ENSURING OPTIMAL VALUE FROM SPECTRUM

A report for DSIT

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1 EXECUTIVE SUMMARY

Spectrum now pervades almost all aspects of our economic and social lives. It is the resource used to communicate wirelessly: data or information encoded into radio waves can be transmitted and received, and decoded by reception technologies. It is versatile: it can transmit over many thousands of miles (for example, to enable satellite communications to and from the earth) or over very short distances (for example, between a payment card and a card reader).

Spectrum is a finite but infinitely reusable resource. Being finite means that more cannot be created. One person's use of spectrum can affect another's. If different users attempt to use spectrum to transmit data in the same band (or similar bands) in close geographic proximity, the spectrum transmissions may create interference with each other, which will disrupt the signal that is received. Being infinitely reusable means that one user’s use of a certain frequency does not reduce the amount future users are able to use.

Given that the spectrum resource needs to be managed (both on a national and international basis), policymakers have a keen interest in understanding how spectrum is used across the different bands. Allocating a spectrum band exclusively to one user can restrict its use for other purposes. Therefore, to maximise the benefits of the use of spectrum to society, it is important that the different spectrum bands are allocated efficiently to ensure maximum benefits.

The Digital Infrastructure team, Department for Digital, Culture, Media and Sport (DCMS), now within the Department for Science, Innovation and Technology (DSIT), commissioned Frontier Economics and LS telcom to provide analysis which will help it better understand how the UK Government can improve efficiency in the way the UK uses its spectrum. This study examines:

- the value derived from spectrum use to different sectors and applications, e.g. mobile, satellite, broadcasting, etc.;
- future demand for radio spectrum by sector over the next 5 to 15 years;
- the future challenges for ensuring spectrum in the UK is optimally used and allocated; and
- alternative policies which could be implemented in the UK to improve the optimal value and use of spectrum.

1.1 SPECTRUM VALUATION

Radio spectrum is integral to the UK economy in terms of the direct delivery of valuable services and broader societal benefits. This report has analysed the value (both in terms of direct contribution to the UK economy[1] and broader benefits) created in the key sectors that use spectrum as a direct input[2]. Below we set out the key trends in each sector.

Mobile services

[1] This value is measured as the Gross Value Added (GVA), and is the contribution that the firm or sector makes to the economic output of the economy (measured by Gross Domestic Product (GDP)).

[2] This approach captures the value of current economic activity in a given sector. However, a high value associated with a given sector is not necessarily informative of the incremental value of assigning more spectrum to that use, relative to other possible uses.

We estimate that the use of spectrum in mobile services enabled the sector to contribute **£8.7 billion**[3] in GVA in 2019, as well as enabling productivity benefits, emissions reductions, and better health and inclusion outcomes.

In recent years, advances in mobile broadband have also enabled significant value to be created in downstream sectors such as digital advertising, e-commerce and the app economy. Market, technical and commercial trends that will be brought about by the development of 5G and 6G point towards continued growth in demand for services reliant on mobile data, suggesting that the value it enables to the UK economy will continue to increase.

Broadcasting

TV and Radio Broadcasting services that rely on spectrum are consumed by large proportions of the population and are an important source of cultural and wellbeing benefits. We find that TV and radio broadcasting using spectrum-enabled technologies contributed **£2.5 billion** in GVA in 2019[4]. Looking forward, changes to the way in which people consume TV and radio mean that the value created by broadcasting using technologies enabled by spectrum is unlikely to grow further but will remain significant.

Commercial satellite operations

The use of spectrum in the commercial satellite sector enabled the sector to contribute over **£700 million** in GVA in 2019, a figure which has increased steadily in recent years. This is consistent with growth and increased investment globally in the commercial satellite sector, particularly satellite communications, where a large number of new entrants have entered the market. Looking forward, it is likely that developments in the capacity of satellite broadband networks mean that the value created by this sector will continue to grow in the near future.

Fixed links, PMSE and PMR sectors

The Programme Making and Special Events (PMSE) sector, Private Mobile Radio (PMR) and fixed links are sectors that play a crucial role in enabling significant activity in other sectors of the economy[5]. For instance:

- the use of spectrum in **fixed links** as a backhaul solution enables operators to rollout networks in areas where they otherwise would not have been able to reach, leading to higher levels of connectivity;
- the use of **PMSE** spectrum enables journalists to broadcast from a wider range of areas and significantly enhances the quality of production in the broadcasting and the live events sectors; and
- the use of spectrum by the **PMR** sector ensures the smooth and safe running of a range of vital services such as the utilities, construction, transport and security services.

Given these clear benefits that accrue to a wide range of industries, it is important to ensure that these three sectors are able to continue to operate effectively.

[3] The methodology used to calculate GVA estimates is set out in **Annex A**.

[4] This includes GVA enabled by DTH satellite broadcasting.

[5] It has not been possible to estimate the GVA of these three sectors as all three goods are used as an input to the production process of other products and services. This means that it is not possible to reliably separate GVA associated with the use of these goods from GVA associated with other activities.

Wi-Fi and the licence-exempt sector

The use of licence-exempt spectrum - bands used by certain applications without prior individual authorisation - enables an increasingly diverse range of devices and applications, most notably Wi-Fi and IoT networks. Although we are unable to accurately estimate GVA attributable to Wi-Fi alone, we estimate that fixed networks contributed **£11.7 billion** in GVA in 2019. For many use-cases, Wi-Fi provides the final link between broadband delivered over these networks and Wi-Fi enabled devices, however there will also be use-cases where the final link is through a wired connection and therefore it would be incorrect to state that the entirety of this GVA is enabled by Wi-Fi networks.

Looking ahead, demand for data traffic is set to increase substantially, a proportion of which is expected to be carried by Wi-Fi, meaning that the importance of Wi-Fi will increase. Alongside this, developments in smart devices and applications mean that the value created through the use of licence-exempt spectrum by IoT devices will also increase.

Public sectors

The public sector's use of spectrum creates a significant amount of direct economic value as well as a range of non-quantifiable benefits.

- The usage of spectrum for navigation and communication in the maritime and aviation sectors enables those sectors to make a significant contribution to the UK economy (contributing **£9.2 billion** and **£10.7 billion** in GVA in 2019).

- The usage of spectrum enables the delivery of key public services such as the defence and emergency services. These sectors create significant benefits in terms of national security and emergency mitigation and prevention. These benefits, however, are difficult to quantify.

- The use of spectrum in the space and earth science sectors enables valuable activities such as weather forecasting, climate monitoring and earth observation.

Public sectors, particularly defence, have also made a significant contribution to ensuring a more optimal allocation of spectrum in the UK by freeing up under-utilised spectrum. Given the growing demands for spectrum from other sectors, there will likely be further interest from commercial users in spectrum currently used by the public sector. A key objective for Government should be ensuring that any reallocation preserves the public sector's ability to create value.

1.2 SPECTRUM DEMAND

This section of the report summarises our findings in relation to future demand for spectrum across several sectors that use spectrum in the UK. We have considered forward-looking trends in each market and changes in the technology to examine how demand for spectrum will change over a 5-to-15-year time frame. We examine how sector trends are driving spectrum demand, and using the information gathered, including feedback from stakeholders, we reach conclusions on future spectrum demand.

Shifts in consumer and business trends over the last 10 years have helped drive an increase in public and private data traffic across a range of sectors that rely on access to spectrum. The most notable and consistent growth has been for both mobile data traffic and Wi-Fi traffic. However, it is anticipated that sectors such as satellite, PMR and other public sectors will increasingly utilise high-speed wideband data to fulfil operational requirements.

Through our analysis, we place future spectrum demand for each sector into one of the following categories:

- Sectors in which there is increased demand for spectrum, which leads to a requirement for additional spectrum. These sectors include mobile, Wi-Fi, utilities and rail.

- Sectors in which there is growing demand, but the current spectrum allocation is sufficient to address this. These are sectors where it is expected that increased demand can be met through technology developments in the existing spectrum with no change to the required amount of spectrum. These sectors include satellite communications, fixed links, PMSE, PMR, space science, emergency services, defence, aeronautical and maritime.

- Sectors where spectrum need/use is declining, which implies that spectrum could be used for a different service in the long term. These sectors include broadcasting Direct Terrestrial Television (DTT) and FM radio.

Figure 1 below summarises our findings, which we discuss in more detail in the sub-sections below.

FIGURE 1 SUMMARY OF UK SPECTRUM DEMAND 2022-30

SECTOR	MAIN DRIVERS		SPECTRUM DEMAND 2022- 30
Broadcasting	Reduction in linear TV viewing increase on demand IP	↘	Steady decline
Fixed Links	More mobile backhaul/WAN	→	Steady increase
Mobile Service	More mobile broadband and FWA usage	↗	Increase resulting in demand outstripping supply
PMSE	More/better production/events	→	Steady increase/needs protection
PMR	More voice and data for businesses	→	Steady increase
Satellite Communications	Connected cars/LEO	→	Steady increase
Wi-Fi	Congestion and wider bandwidth apps	↗	Rapid increase
Energy/Utilities	Energy network expansion and address govt net zero mandate	→	Steady increase
Defence	Enhanced capabilities UAVs	→	Steady increase
Emergency services – Police/health	Wideband data capabilities	→	Steady increase
Space science & Radio Astronomy	EO developments, research UK Space sector growth	→	No change/needs protection
Aviation	Dependent on full use of Beyond visual line of sight for UAVs	→	Steady increase
Maritime	Dependent on full use of autonomous vessels	→	Steady increase
Rail	Wideband data and FRMCS	→	Steady increase
Roads	ITS and connected cars	→	Steady increase

Source: LS telcom
Note: In this table spectrum demand is referring to demand for services that use the spectrum

1.2.1 SECTORS IN WHICH THERE IS A CONTINUED INCREASE IN DEMAND FOR SPECTRUM OVER THE NEXT 10 YEARS OR MORE

Mobile services

We observed, both from the analysis and wider global market trends, that **there will continue to be increased demand for mobile spectrum** at around 40% year-on-year growth for at least the next 5 years.

Our demand model has found that, depending on the assumed demand growth rate, there are scenarios where dense urban networks become congested in the next 5 to 6 years. **In the mid-case scenario, the most likely traffic growth scenario (35% year-on-year growth for the next 5 years), urban networks could run out of capacity in the sub-1 GHz by 2027 and in the 1-5 GHz range by 2025.**

Access to more spectrum within these timescales would be the most cost-effective option to ease congestion arising across the network for urban areas.

Wi-Fi

One of the major drivers for Wi-Fi connectivity is the increased rollout of fibre. Market indicators and demand studies have shown that if homes and offices demand speeds above 1 Gbit/s, from fixed broadband, in the next 5 years, then the available Wi-Fi bandwidth will need to align and support those speeds. The current spectrum and technologies will be able to support this up to a point. It is expected that the new Wi-Fi technologies (e.g. Wi-Fi 6E/7) will be able to support wider bandwidth applications, such as Augmented Reality (AR), Virtual Reality (VR) and higher resolution Ultra High Definition (UHD) video streaming applications. However, these new technologies can only be supported in 5 GHz and 6 GHz bands. There is also growth in Wi-Fi roaming around large public spaces that requires sufficient spectrum to limit congestion and deliver ever-increasing bit rates to a high density of users.

Over the 15-year time frame of this study, more spectrum will need to become available for Wi-Fi to avoid localised congestion (notably in dense residential locations). A lack of spectrum will limit the ability to introduce new wideband applications. New Wi-Fi technologies will emerge, with greater use of Multiple Input Multiple Output (MIMO), for example, which will help to ease any short-term congestion that may arise within the time frame.

Energy utilities

The **steady increase in demand for spectrum for energy utilities** is being driven by the Government mandate to support Net Zero 2050, which means significant upgrades to the Electronic Communications Networks (ECNs), which will be carrying more traffic from more devices.

We would expect a solution for meeting the utilities spectrum demand requirements to arise, in the short term, within the next five years, recognising there are other commercial and regulatory pressures to take a decision sooner. This is not only due to increasing needs of energy utilities, but also the risks posed by Public Switched Telephone Network (PSTN) and 2G/3G switch off[6] within this time frame. There are specific

[6] Note that BT is planning to switch off PSTN in 2025 (See: https://business.bt.com/why-choose-bt/insights/digital-transformation/uk-pstn-switch-off/) and some mobile operators (Vodafone/Three) are planning to switch off 3G as early as 2023 and switch off 2G by 2033 to support continued operation of smart meters. https://www.ispreview.co.uk/index.php/2021/12/all-public-2g-and-3g-uk-mobile-services-switched-off-by-2033.html

resilience implications of losing access to PSTN and some 3G services which means it is important this decision is made as soon as possible.

Rail

The use of 2G technology (GSM-R) designed specifically for railway operational communications by Network Rail, is likely to continue for the next 8 years (as the network was only introduced in 2013).

The need for wideband data from trackside to train connectivity and support of new modern requirements for automatic train control and monitoring will be the driver for a **steady increase in demand for spectrum**. An additional 2x1.6 MHz of spectrum is set to be added to the existing allocation to support the transition to Future Railway Mobile Communication System (FRMCS). However, we expect that the transition will place greater data demands than this available spectrum, and additional capacity may be required in congested areas.

1.2.2 SECTORS IN WHICH THERE IS INCREASED DEMAND BUT SUFFICIENT ACCESS TO EXISTING SPECTRUM

Satellite Communications

Whilst **demand for satellite communications services continues to grow steadily**, modern techniques such as multi-beam antennas and enhanced frequency reuse are enabling this growth to be handled within existing spectrum bands. This is true for satellite communications, navigation and earth exploration. This was supported during stakeholder engagement with the UK Space Agency. The issue is therefore, not one of identifying significant new amounts of spectrum for satellite services but **ensuring that access to spectrum that is already available is suitably protected and that this spectrum can be used flexibly for fixed, mobile, geostationary and non-geostationary constellations**.

Fixed links

The main driver for a continuous **steady increase in demand** for fixed links is expected to be backhaul for public mobile networks and wide-area connectivity for at least the next 5 years as 5G coverage continues to be rolled out. However, given that fibre connectivity is improving and that Ofcom expects higher frequencies to be made available to serve the increased backhaul demand arising from 5G, it is expected that current spectrum assignments for fixed links will be sufficient until such a point as Ofcom makes additional spectrum available, which has not yet been published. This does not rule out the possibility of localised shortages in the availability of spectrum for fixed links.

PMSE

Demand for existing PMSE spectrum is very high, especially in some locations, and any further reductions in PMSE spectrum would materially impact the ability of the creative industries to innovate or even continue to run existing events on the current basis. Though PMSE users have, in the past, been able to be somewhat nomadic in their spectrum use, as with other industries, regulatory certainty over access to spectrum remains paramount and ensuring that there is sufficient spectrum available for all applications is important to protect the UK's creative industries.

PMR

The operation of private mobile voice networks remains vital to many of the business radio users that rely on these networks. There will be a **steady increase in demand for PMR spectrum** largely driven by the continued need for critical voice/'push to talk' services such as for safety and security applications but also a growing need for private data networks and adoption of digital technologies. This means there will be continued pressure on access to Very High Frequency (VHF) and Ultra High Frequency (UHF) frequencies, as the bands are already squeezed due to extensive narrowband assignments, which is the predominant use for PMR spectrum. Trends in shared access demand for wideband assignments are discussed in the mobile section.

Space science

There is **an increased utilisation of spectrum for Earth observation, space science, space exploration and radio astronomy areas**, which will continue to increase over the next 5 years. This does not necessarily mean that increased spectrum is required, as the current spectrum allocation for space services allows for the expansion of such activities with greater utilisation of the existing spectrum as the space economy grows. However, the increased utilisation has implications for sharing between space services and between space and other services and applies to spectrum used by sensors and to spectrum used for data downloads. Therefore the challenge is to ensure the spectrum that is used for such sensitive monitoring is protected to ensure the continued integrity of the critical information that such monitoring provides.

Emergency services

The use of spectrum by the emergency services has changed, predominantly driven by **the increase in demand for wideband data services** to support the growing need for more capable and bandwidth-intensive communications. The transition from Airwave to the Emergency Services Network (ESN) by 2026 indicates how this need is being addressed by public mobile networks. The increase in demand will be accommodated within the EE 4G network. Solutions for short term access to spectrum may be needed for the emergency services, particularly around areas where coverage is challenging or where there could be significant demand during an incident. Any review of the ESN implementation, once complete, will need to include an assessment of the impact on spectrum and future spectrum requirements.

Defence

The Ministry of Defence (MOD) **will have a long-term steady increase in demand for spectrum** that will be needed to meet the requirements for future defence capabilities as outlined in the Integrated Review of Security, Defence, Development and Foreign Policy[7]. New Unmanned Aerial Vehicles (UAV) capabilities, space radars and the introduction of space launches in the UK will all need access to spectrum in future. The demand will need to be met by the existing spectrum available to the MOD.

Transport including aeronautical, maritime and roads

There is a common trend in the transport sector linked to the use of autonomous vehicles, aircraft or vessels, and the use of technology for safety-related systems. These new unmanned autonomous vehicles/vessels will require access to spectrum in the future, **indicating long term additional demand**.

1.2.3 SECTORS WHERE SPECTRUM NEED/USE IS DECLINING IN THE LONG TERM

DTT broadcasting

Demand for Free To View (FTV) content over the DTT broadcast network is slowly decreasing, but continued access to the UHF spectrum for terrestrial broadcasting will remain for the next 10-to-15 years

[7] See: https://www.gov.uk/government/publications/global-britain-in-a-competitive-age-the-integrated-review-of-security-defence-development-and-foreign-policy [Accessed 13th April 2022].

due to licensing commitments until 2034 (noting there is also a break point in the licences at 2030). From 2034 onwards, demand for UHF spectrum from broadcasters is likely to decline as DTT viewers choose alternative platforms, opening the way for some broadcasting spectrum to be made available for other services, such as mobile.

A reduction in demand for the DTT spectrum in the 470–694 MHz band would enable parts of, or potentially the entire band, to become available for other uses, notably for 5G or 6G. Fixed and mobile broadband are the potential alternatives to DTT and are currently widely used by viewers. However, the ability of these networks to cater to the significant increase in traffic that a full replacement of DTT would bring remains unproven. It is recommended that a comprehensive cost-benefit analysis is undertaken on the use of the DTT spectrum relative to alternative platforms, which includes quantifying the amount of data that would shift from DTT to other platforms.

Given the nature of the services (both existing and candidate new ones) making amendments to usage involves long lead times which should be factored into the decision making process. An assessment will be needed to determine the extent to which the DTT spectrum is re-allocated to mobile. This aligns with the Government's white paper[8] recommending a comprehensive analysis to be undertaken in 2025 as part of its planned review of DTT, to examine capability of alternative platforms as long-term replacement for DTT. The review should also consider the long-term implications for the PMSE sector, which shares frequencies with DTT.

1.3 THE UK'S CURRENT SPECTRUM MANAGEMENT FRAMEWORK AND STAKEHOLDER VIEWS ON HOW IT COULD BE IMPROVED

The aim of the current spectrum management framework in the UK is to support a wide range of spectrum-enabled services and ensure that spectrum is used optimally. 'Optimal use of spectrum' implies that spectrum is used in a way that maximises the benefits that individuals, businesses and other organisations derive from its use (including the wider social value of spectrum use).

We have discussed the current spectrum management framework with a range of stakeholders. These discussions focused on a number of topics, including the extent to which the UK's current spectrum management framework ensures the optimal allocation and use of spectrum, challenges stakeholders are likely to face in future with respect to obtaining needed spectrum and whether stakeholders foresee any need for government intervention with regard to spectrum availability in the future.

Stakeholders, on the whole, consider that the current spectrum management framework is broadly suitable to meet spectrum needs of current and future wireless networks. However, a number of issues have also been identified that need to be considered in order to ensure that spectrum management framework continues to be fit for purpose going forward. These issues relate to the following policy areas: **spectrum sharing**, **spectrum reassignment**, **spectrum pricing and annual licence fees**, and **forward-looking international harmonisation**.

1.3.1 SPECTRUM SHARING

Stakeholders note that the introduction of spectrum sharing schemes for Local Access and Shared Access licences (introduced in 2019) supports innovation and improves spectrum utilisation. However, there are

[8] The government asked Ofcom to conduct a review of demand and market changes that may affect the future of content distribution before the end of 2025. See government publication April 2022: https://www.gov.uk/government/publications/up-next-the-governments-vision-for-the-broadcasting-sector/up-next-the-governments-vision-for-the-broadcasting-sector

concerns that the current approach is too slow and not sufficiently agile. Some stakeholders have suggested changes to the existing framework that could address these concerns, such as requiring operators to respond to a Local Access licensing request within a fixed time window or providing operators who refuse a request with a time limit for executing their own deployment.[9] These issues are discussed in more detail in **Section 5.1.4** below.

Furthermore, several stakeholders recommend implementing an automated spectrum sharing tool, which will provide access to the shared spectrum dynamically and on a real-time basis. In its recently published Spectrum Roadmap Ofcom has noted plans for developing a more automated solution to issue Shared Access licences (particularly for the 3.8-4.2 GHz band).[10] An automated dynamic system has already been implemented in the US: the Citizens Broadband Radio Service (CBRS). As there is an expectation that spectrum sharing will become increasingly important, addressing these issues should be prioritised. We provide more details on the CBRS in **Section 6.3** below.

1.3.2 SPECTRUM REASSIGNMENT

In order to come to a view on whether a particular spectrum band should be reassigned from its current user (or use case) to a new use case, Ofcom carries out a cost-benefit analysis to establish whether additional benefits to consumers from the new use case would outweigh the costs and/or reduction in benefits from the loss of spectrum to its current users. This is typically a long and complex process that involves several consultations with relevant stakeholders.

In their responses, some stakeholders voiced concerns over the perceived prioritisation of the mobile sector over other use cases. In particular, stakeholders that have already released spectrum (e.g. MOD and broadcasting) argue that they have increased their spectrum efficiency and may not be in a position to clear more spectrum without it having a detrimental impact on the services they provide. Some incumbent users (e.g. MOD) also emphasised the role of spectrum sharing as the most appropriate way forward, which is preferable – from their perspective – to spectrum reassignment.

We consider that any issues related to spectrum reassignment need to be addressed on a case-by-case basis as this allows all relevant costs and benefits, including in relation to the transition from one use case to another, to be considered and, where necessary, evaluated. We consider Ofcom's current approach to spectrum reassignment to be broadly appropriate: the approach aims to ensure that all benefits and costs to all parties are taken into account, including wider social benefits. The approach can be complex and resource-intensive, but this reflects the complexity of the issues that often need to be addressed, including evaluating costs and benefits of spectrum for a range of different uses, issues related to interference, and the need to also ensure international coordination. In relation to wider social benefits, in particular, it is important to understand how they would change if a given band was reassigned from one use case to another. If the change is expected to be significant, a more detailed quantification may be needed.

1.3.3 SPECTRUM PRICING AND ANNUAL LICENCE FEES

Where there is excess demand for spectrum, Ofcom uses market-based mechanisms – auctions and incentive-based pricing – to ensure that spectrum is allocated to the most efficient users. After initial spectrum licences expire, spectrum fees are set to reflect the opportunity cost of spectrum, i.e., the value that alternative use

[9] These changes would also address feedback raised as part of the DCMS 5G Testbeds and Trials Programme, in which stakeholders similarly raised concerns regarding the time and resource intensive nature of application processes for Local and Shared Access licences.

[10] Ofcom, 2022. Spectrum Roadmap: Delivering Ofcom's Spectrum Management Strategy, pg. 42.

of spectrum would deliver, but which is forgone due to its current use. These fees are known as Administered Incentive Pricing (AIP) and, in the context of mobile, Annual Licence Fees (ALFs). Ofcom considers AIP and ALFs to be instrumental in ensuring that spectrum is allocated efficiently: if the current spectrum user is no longer the most efficient (i.e. if it values spectrum below its opportunity cost), the current user would return the spectrum to Ofcom or would sell it to another user, which would be a more efficient outcome.

Several industry stakeholders disagree with Ofcom. They are of the view that ALFs, in their current form, are a tax on the mobile sector that does not contribute to the allocative efficiency of the market (in other words, it does not create additional incentives to allocate spectrum to those users who value it the most). They argue that ALFs should be set more conservatively, based on a forward-looking view of spectrum value rather than based on historical spectrum benchmarks. Furthermore, some stakeholders recommend to ringfence ALF proceeds and reinvest them in the sector, for example, in 5G infrastructure or to extend rural coverage.

According to Ofcom, industry profits in the mobile sector are falling, with two out of four operators currently being unable to cover their cost of capital. However, Ofcom notes that falling returns are a common trend across Europe, suggesting that declining profitability in mobile markets is not a UK-specific issue.[11] In the UK context, MNOs have argued that their costs have been affected by factors including High-Risk-Vendor equipment replacements, the methodology used for setting ALFs, and stringent consumer regulation.[12] When setting ALFs, Ofcom relies on historical auction prices paid for similar spectrum in the UK and Europe (including auction prices paid 8-10 years ago). However, this may not be appropriate given that the market conditions have changed, i.e., evidence from earlier auctions may not be informative of current trends.

We consider that this may be a suitable point in time to review Ofcom's approach to setting ALFs and to investigate whether there are any alternatives available, including greater reliance on spectrum trading.

1.3.4 INTERNATIONAL HARMONISATION

Stakeholders highlighted that it is important for Ofcom to continue to engage with the international harmonisation bodies: International Telecommunication Union (ITU), European Conference of Postal and Telecommunications Administrations (CEPT), European Telecommunications Standards Institute (ETSI), etc., given the benefits of international harmonisation of spectrum, both for the UK and globally. They particularly encourage Ofcom, as a highly-respected regulator, to achieve a clear UK position through consultation and to lead on coordinating a common approach across Europe in relation to 600 MHz, 3.8-4.2 GHz and other bands where there are competing spectrum demands. Some stakeholders are concerned that if the UK does not take a clear position and lead in the debate, the resulting decision may be sub-optimal for the UK.

1.4 ALTERNATIVE POLICY OPTIONS

We have reviewed international precedent in order to explore whether there are alternative approaches that could be used to address the issues raised by stakeholders in the course of our interviews.

1.4.1 SPECTRUM SHARING

A number of stakeholders have advocated the CBRS as a dynamic and more agile spectrum allocation system (compared to Ofcom's current approaches to spectrum sharing). We also note that Ofcom's Spectrum Roadmap outlines plans to support development of more dynamic solutions to spectrum sharing,

[11] Ofcom, 2022. Ofcom's future approach to mobile markets, para. 6.14.

[12] See, for example, Ofcom, 2022. Ofcom's future approach to mobile markets, para. 7.3.

particularly in the context of issuing Shared Access licences where Ofcom is looking at ways to develop an easier and quicker solution to accessing this spectrum, including through automation.[13]

In the US, the CBRS approach appears to have been successful.[14] The infrastructure for spectrum sharing appears to be working as intended; sensing networks have been successfully deployed around the country, and no interference issues have been reported so far. We note that the CBRS is the first system of its kind and was complex and time-consuming to implement – with Ofcom previously opting against pursuing this approach on this basis. However, we understand that the solution is now more commoditised and could be adapted to the UK context. We recommend that DSIT and Ofcom explore further with the developers of the CBRS and potential users of the system practical steps that would need to be taken to implement a version of this system in the UK. We further recommend that DSIT monitor the progress of the US's SpectrumX program, which aims to provide further tools designed to promote dynamic and agile spectrum management.[15]

1.4.2 SPECTRUM REASSIGNMENT

A number of stakeholders (in particular, broadcasting, PMSE and satellite) have voiced concerns over a perceived prioritisation of the mobile sector over other use cases and sectors. Nevertheless, as the mobile sector is growing and requires more spectrum to meet demand, we anticipate more spectrum bands might be considered for reassignment to mobile. We note that if an efficient spectrum-sharing system is implemented, it would, at least to some extent, address the issue of the growing demand for spectrum, as different use-cases would be able to co-exist within the same spectrum band (for instance, we understand that certain MOD-used bands could in principle be shared with mobile, e.g. 2.3 GHz).

Our review of international precedents has not identified a better alternative to the current reassignment process. Although the decision-making process to reassign spectrum is time-consuming, it ensures that all relevant stakeholders have been consulted. Moreover, Ofcom's consultations and analyses are open and transparent.

In the US, an alternative approach was used to reassign the 600 MHz spectrum – a reverse two-sided auction - with both mobile operators and broadcasters participating in the auction. Ofcom consulted previously on the use of an incentive auction in the UK, but this approach was not supported by stakeholders and deemed to be too complex. Our assessment takes a similar view: we observe that the incentive auction in the US lasted for over a year and was complex to implement. Furthermore, the auction required that a significant share of the auction proceeds (upwards of 60%) be distributed to broadcasters and not retained by the Treasury.[16]

Moreover, the use of incentive auctions (or any auction mechanism) may limit opportunities for spectrum reassignment to particular sectors or users. Consider, for example, a scenario in which a decision needs to be made whether to assign spectrum for licensed use (e.g. in mobile) or licence-exempt use (e.g. by Wi-Fi users). Wi-Fi users are unlikely to be in a position to join forces in order to bid for spectrum, preventing their involvement in an auction intended to determine how spectrum should be reassigned. Instead,

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[13] Ofcom, 2022. Spectrum Roadmap: Delivering Ofcom's Spectrum Management Strategy, para. 4.33.

[14] More details on the CBRS are provided in the main body of the report.

[15] SpectrumX is a Spectrum Innovation Centre funded by the US National Science Foundation through a partnership with the FCC. Objectives of the funding program include the development of new mechanisms for sharing and managing the radio spectrum, as well as providing a hub for collaboration between academics, private enterprises and public bodies.

[16] In contrast, costs incurred by the UK Government in clearing the 700MHz spectrum band for use by UK mobile operators (approx. £350 million) were less than 30% of the eventual proceeds raised through the auction of the cleared spectrum (approx. £1.4 billion).

administrative decision-making on the part of regulators is required if spectrum is to be reassigned for licence-exempt use.

Overall, the current approach used in the UK (i.e. an administrative decision-making process that takes into consideration all costs and benefits associated with the spectrum reassignment) remains appropriate. This process critically depends on the quality of information and evidence provided by stakeholders. Therefore, we recommend that stakeholders continue to provide high-quality evidence and information to Ofcom and DSIT in order to support decision-making in relation to spectrum reassignment.

1.4.3 SPECTRUM PRICING AND ANNUAL LICENCE FEES

As discussed above, some stakeholders raised concerns in relation to ALFs and their impact on efficiency. We observe that in the US, no additional fees apply to the mobile spectrum after the initial spectrum licences expire, with spectrum typically awarded on an indefinite basis. At the same time, spectrum trading (i.e. spectrum reallocation) is common through secondary markets, which implies that market participants have incentives to trade even in the absence of annual licence fees.[17]

We also consider that France provides an interesting example of spectrum licence renewal processes being used as an opportunity to achieve welfare-enhancing policy objectives. The French telecoms regulator (ARCEP) renewed 900 MHz and 1800 MHz spectrum licences, with no additional fees, in exchange for stricter coverage obligations and a commitment to cover “white spots” in rural areas.[18] In effect, spectrum fees were being “reinvested” in the industry to the benefit of consumers through operators’ commitments to deploy networks in areas where these networks would not have been deployed otherwise.

In the UK, rural not-spots are currently being addressed via the Shared Rural Network (SRN), with mobile operators committed to invest £532 million to increase coverage to 95% of the UK landmass by the end of 2025.[19] At the same time, ALFs for the legacy spectrum appear to be set independently of this process. For example, the Ofcom 2021 consultation on 2.1 GHz ALFs did not discuss issues of low sector profitability or significant investments required to improve rural coverage. We consider this to be a drawback of the current system. Indeed, significant coverage obligations and other costs imposed on the sector imply lower future profitability (and therefore imply lower spectrum valuation), which should be reflected in forward-looking spectrum fees. If coverage obligations are imposed as part of the auction process, bidders are able to reflect the lower valuation in their bids, which results in lower spectrum prices. In the same way, administrative prices set by the regulator (i.e., ALFs) should also take these costs into account. To the extent that Ofcom relies on historical auction prices to set forward-looking ALFs, these historical prices need to be adjusted to reflect the new coverage obligations and other costs that impact operators’ profitability – and therefore operators’ spectrum valuations.

1.4.4 INTERNATIONAL HARMONISATION AND SPECTRUM RELEASE

In recent years, cross-country efforts to support international harmonisation of spectrum have focused on ensuring that sufficient spectrum is available to support sectors where there is growing demand while ensuring that other sectors are not unduly affected. Harmonisation is also important to prevent or minimise

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[17] Some trades in the UK have involved spectrum which was not subject to ALFs; for instance, the sale of 2.6 GHz spectrum by EE to O2 in 2020.

[18] ARCEP has also proposed to adopt a similar approach for renewal of licences for 2.1GHz spectrum, which are set to expire in 2024. This approach had not been implemented for other bands of spectrum prior to use in the renewal of 900MHz and 1800MHz spectrum, as the initial licence terms for other spectrum bands for mobile use have yet to expire.

[19] See: https://www.gov.uk/government/news/shared-rural-network [Accessed 28th April 2022].

harmful cross-border interference while also enabling global interoperability. Furthermore, harmonisation provides opportunities for economies of scale in the manufacturing of equipment - a vital means by which to drive down costs.

Stakeholders highlighted that it is important for Ofcom to continue to engage with international harmonisation bodies given the benefits both for the UK and globally of international harmonisation of spectrum. We understand that Ofcom participates in all these harmonisation bodies and will continue to do so going forward.

With regards to releasing a new spectrum for growing sectors, we note that Ofcom acted proactively when releasing key bands for 5G. However, one area where the UK is lagging behind is in relation to the mmWave spectrum, with countries, such as the US, having already allocated mmWave spectrum in the 28 GHz, 37 GHz, 39 GHz and 47 GHz bands. Ofcom has now published a consultation on the award of mmWave spectrum in the 26 GHz and 40 GHz band and, given the fact that some UK stakeholders have expressed demand for that spectrum, we recommend that Ofcom should consider allocating mmWave spectrum as soon as practical – following this consultation.

2 INTRODUCTION AND BACKGROUND

DCMS is responsible for UK spectrum policy and strategy. In the UK, while spectrum is managed by Ofcom[20], DCMS's role is to ensure the spectrum management framework continues to be fit for purpose, delivers wider Government objectives and maximises the economic and social value of spectrum use. This involves, but is not limited to, ensuring the efficient use of spectrum for the diverse range of commercial and societal applications that rely on it.

In this regard, Digital Infrastructure, DCMS (now within DSIT) has commissioned Frontier Economics and LS telcom to provide analysis which will help it better understand how the UK Government can improve efficiency in the way the UK uses its spectrum. This encompasses an assessment of:

- how spectrum is used and identifying the trends in spectrum use;
- how spectrum delivers societal value by sector - including for public sector uses - and supports not just economic activity but the creation of social value; and
- what trends will determine the demand for different spectrum bands and future challenges in supporting optimal allocations.

In this report, we:

- consider the value derived from spectrum use to different sectors and applications, e.g. mobile, satellite, broadcasting, etc. (**Section 3**);
- assess demand for radio spectrum over the next 5 to 15 years by sector and application (**Section 4**);
- assess the future challenges for ensuring spectrum in the UK is optimally used and allocated (**Section 5**); and
- consider alternative policies which could be implemented in the UK to improve the optimal value and use of spectrum (**Section 6**).

The remainder of this section explains the importance of spectrum and why it is important that spectrum is managed carefully.

2.1 SPECTRUM IS AN ESSENTIAL NATURAL RESOURCE

Spectrum now pervades almost all aspects of our economic and social lives. Spectrum technology is used to communicate wirelessly: data or information encoded into radio waves can be transmitted, received and decoded by reception technologies. It is versatile: it can be used to transmit over thousands of miles (for example, to enable satellite communications to and from the earth) or over very short distances (for example, between a payment card and a card reader).

It plays a role in our communications, the media we consume, and how we travel and interact. Our consumer communications devices, whether mobile handsets, tablets or gaming devices, all use spectrum to transmit data. Even fixed communications networks rely on spectrum to connect devices in the home to our broadband routers. Spectrum also allows different devices to wirelessly connect, whether for connecting printers and computers or gaming keypads with consoles. This means it is an important input shaping how we use and consume internet-based services. It is also used to broadcast audio-visual content, and although the amount of content streamed or downloaded using the internet has increased in recent years, the majority

[20] Ofcom manages spectrum which is "non-Crown use". Crown bodies currently use spectrum without individual authorisation from Ofcom.

of households continue to use a traditional broadcast transmission from terrestrial broadcasts or satellite broadcasts to receive TV and radio services. Spectrum is an essential input into the maritime and aviation sectors to support navigation, positioning and safety features; the public sector uses spectrum, for example, to coordinate and communicate with emergency services. The Internet of Things (IoT) revolution means that spectrum is increasingly embedded in consumer devices we use around the home, used to manage the environments where we live, and is essential in many production and supply processes. Technological advances have increased computing power, reduced the size and cost of devices, and increased battery power in wireless devices. As technology evolves and user demand changes, it is necessary to ensure that the framework for managing spectrum meets our changing needs.

2.2 SPECTRUM RIGHTS ARE CAREFULLY MANAGED

Spectrum has to be managed carefully. It is a finite natural resource which means that more cannot be created. However, it is divisible such that it can be subdivided and, with limitations, allocated to different users. It is a non-exhaustible resource in that the use of spectrum today does not reduce the supply of spectrum in the future. However, one person's use of spectrum can affect another's. If different users attempt to use spectrum to transmit data in the same band (or similar bands) in close geographic proximity, the spectrum transmissions will create interference with each other which will disrupt the signal that is received. In this way, spectrum shares some economic characteristics with other natural resources, such as land rights. Land is a divisible finite resource that is non-exhaustible: the use of land today does not prevent its use in the future. As with spectrum, one person's use of land can affect the ability of near neighbours to enjoy their land: hence property rights can define restrictions on how the land can be used so as not to interfere with others.

For these reasons, the rights to use spectrum are clearly defined and allocated. Users can be granted rights to use a specific part of the radio frequency (broadly 3 kHz to 300 GHz), for a specific purpose, with constraints on the power of transmission, for a particular geographic area, or for a specific time period. These rights may be granted to specific users or categories of users, and can be revoked in certain circumstances.[21]

These rights are "intangible assets" in that they create value but are not physical in nature. These intangible assets are used as inputs in the production of goods and services across our economy.

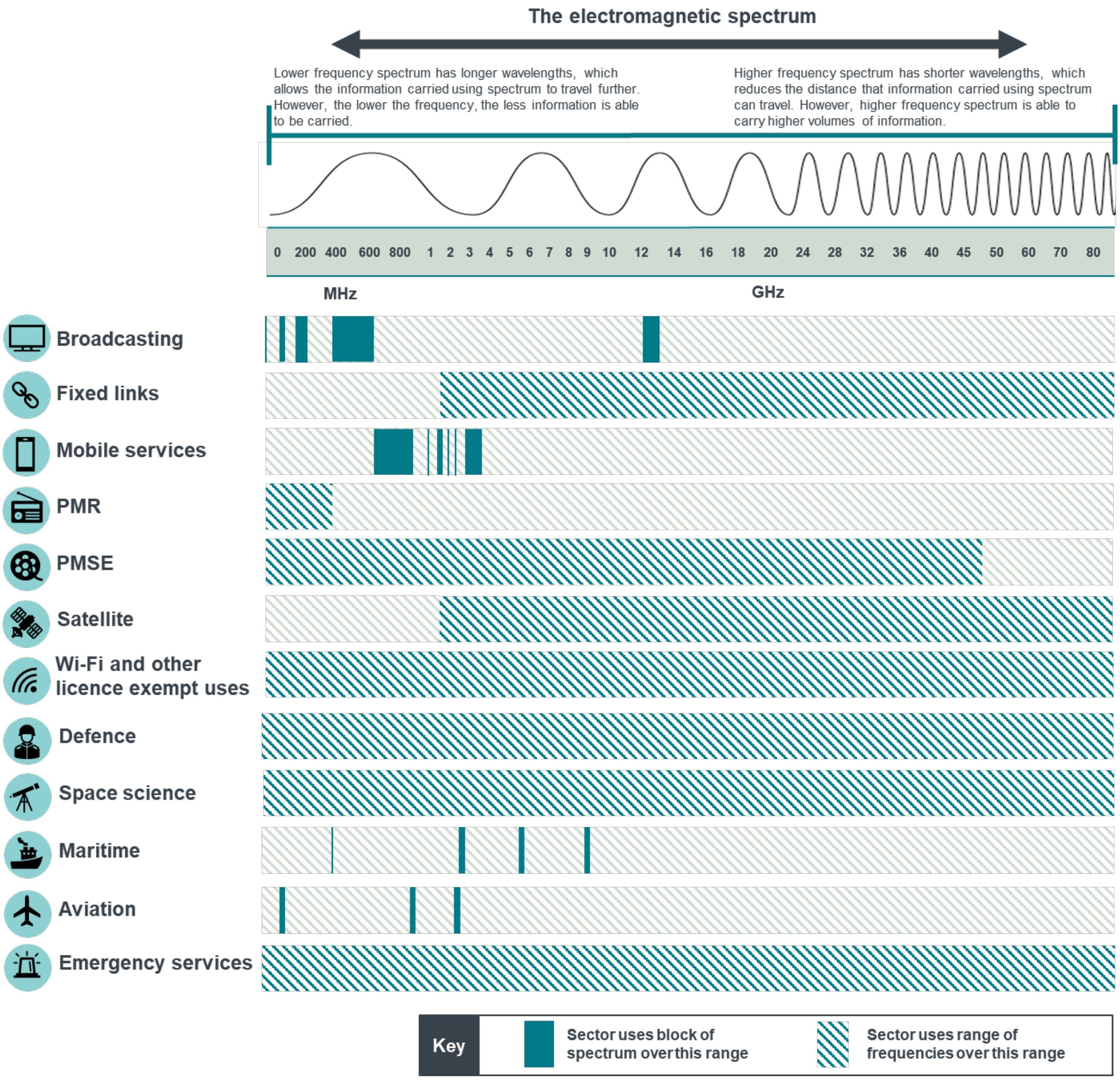
Spectrum is not uniform. Different spectrum bands have different characteristics in terms of how far it can travel between a transmitter and receiver (i.e. its propagation characteristics): lower frequency spectrum (below 1 GHz) will travel further (at a given power of transmission) and be less disrupted by obstacles than higher frequency bands. There is variation in scarcity of spectrum in different bands, with spectrum in higher bands, broadly, being more abundant than in lower bands. Spectrum will vary in how it is managed: with different technical restrictions on its use (whether use case or the power constraints) depending on the band.

2.3 THE FRAMEWORK FOR MANAGING SPECTRUM

Given that the spectrum resource needs to be managed, policymakers have a keen interest in understanding how spectrum is used across the different bands. Allocating the use of a spectrum band to one use can deprive other users. Therefore, in order to maximise the benefits of the use of spectrum to society, it is important that the different spectrum bands are allocated in a way that can maximise the value to society.

[21] We discuss different types of spectrum licences in more detail in **Section 5.**

FIGURE 2 ALLOCATIONS OF SPECTRUM BANDS BY USE



Source: Frontier Economics and LS telcom

Spectrum creates value beyond the suppliers of goods or services that directly rely on spectrum. It generates value in upstream markets that supply inputs to suppliers of goods and services that use spectrum and in downstream markets for complementary goods and services. For example, the app economy or internet advertising are partly driven by the rise in consumption of content over wireless networks powered by spectrum. Spectrum is also used in the supply of public goods where there is no market price, such as for emergency services or national defence.

The use of spectrum (whether for privately or publicly supplied goods) can generate non-monetary values to end users (consumer surplus). However, societal value also includes wider benefits that can accrue not just to users of goods and services that rely on spectrum: such as social, environmental or productivity benefits (externalities).

Spectrum management authorities will use a number of different mechanisms to allocate spectrum in order to maximise the value to society. These can range from pure market mechanisms, which identify the user with the highest value of the rights using auctions, to beauty contests where spectrum rights are allocated according to a number of quantitative or qualitative criteria, or on a “first come, first serve” basis. In practice, there can be a blend of different approaches. Allocation of spectrum across different uses is often managed and coordinated internationally to minimise cross border interference and realise supply chain benefits enabled by allocating certain spectrum to specific uses.

Different approaches to spectrum allocation are consistent with the objective of maximising societal value in different ways. Market mechanisms can help identify the private user with the highest value and hence the allocatively efficient allocation of spectrum. However, market mechanisms will not readily consider social externalities that may also need to be taken into account when allocating spectrum. Therefore, they cannot be universally applied. In other cases, it is not efficient to award spectrum on a market basis, for example, where spectrum rights are granted to many users simultaneously on a licence-exempt basis.

2.4 SPECTRUM IS USED BY A RANGE OF SECTORS

Given that almost all sectors of the economy use spectrum to some degree, either directly or indirectly, it is necessary to be proportional in identifying and defining a set of sectors for a sector-level analysis.

This report assesses the value and future demand for spectrum from sectors that directly use spectrum and that are listed in Ofcom’s UK spectrum map[22]. However, as this report also considers future demand for spectrum, **Section 4** contains additional sections on future demand from sectors that may directly use spectrum in the future: private mobile networks, utilities, rail and roads. In addition, in a limited number of cases, the definition of a sector used in this report may differ from the definition in the spectrum map. Where this is the case, this is noted in a footnote.

[22] Ofcom’s spectrum map is a resource created by Ofcom that maps access to spectrum against specific sectors to provide a high-level indication of how different spectrum bands are used. See Ofcom, UK spectrum map. Available at: http://static.ofcom.org.uk/static/spectrum/map.html [Accessed 8th April 2022].

3 SPECTRUM VALUATION

The rights to use spectrum create value for the suppliers of services, end-users and, more widely, the economy. However, the value created varies across different sectors. In order to ensure that spectrum is allocated appropriately and efficiently, it can be helpful to understand the value that it generates across different sectors.

This section describes the economic value created in different sectors of the economy that rely on spectrum. It is structured as follows.

- **Section 3.1** sets out the approach we have used to value the sectors of the UK economy that use spectrum.
- **Section 3.2** sets out the economic value of spectrum for the range of private and public sectors and services that use spectrum.
- **Section 3.3** summarises our findings and provides recommendations for future work.

3.1 METHODOLOGY

This section provides further context on how this report assesses the value of sectors that use spectrum in the UK. It explains:

- challenges in measuring the value of spectrum;
- the range of potential approaches to estimating the value created by a sector;
- the approach used by this report; and
- how this compares to previous work.

3.1.1 CHALLENGES IN MEASURING THE VALUE OF SPECTRUM

There are a number of reasons why measuring the value of spectrum is complex. These challenges are set out below.

Spectrum is used in a number of goods and services, which are themselves, in turn, inputs in a complex supply chain downstream, meaning the value of spectrum is felt in a wide set of markets

Spectrum is a direct input in a number of communication, transport, and public goods and services. Through those goods and services, it is indirectly used in a much wider set of economic activities, which reach all aspects of the economy. For example, content providers derive economic value from broadcasters that distribute content using spectrum, and the app economy is enabled through the provision of mobile broadband by mobile providers.

Spectrum is only one of several inputs in the goods and services that use it, and different sectors rely on spectrum to different degrees

Spectrum is but one input used in the supply of goods and services. Therefore, the economic output associated with goods and services that use spectrum should not all be attributable to spectrum. This is because other inputs such as components, research and development, and intellectual property rights will all contribute to the economic value of the good or service.

In addition, different sectors rely on spectrum to different degrees. We highlight two important considerations below.

- **Some sectors use spectrum for all activities, whereas other sectors only use spectrum for a subset of activities.** For instance, spectrum is used in some broadcasting transmission technologies, but not all. Similarly, some users of fixed communications services will connect wirelessly using Wi-Fi, but others will connect using a wired connection, which does not require spectrum. On the contrary, in sectors such as mobile services or Private Mobile Radio (PMR), spectrum is a necessary input to all of the sector's activities.

- **In some sectors, there is an alternative, albeit often inferior input, to spectrum, whereas in other sectors, there is no such substitute**. For instance, PMSE spectrum is used in a range of production equipment (such as wireless microphones, wireless cameras and in-ear monitors). In some cases, it would be possible for wired alternatives to be used, although this would lead to an inferior level of service. In other sectors, no such wired alternative exists. For instance, if spectrum was unavailable, it would not be possible for the vast majority of activities in the space and earth sciences or commercial satellite sector to go ahead as there is no alternative input.

A counterfactual analysis, in theory, would identify the economic value, which was solely attributable to spectrum, by comparing economic outputs today to a counterfactual where spectrum was unavailable. However, in practice, it is difficult to reliably estimate the incremental value created by spectrum compared to a counterfactual where the amount of spectrum used by the sector is reduced or where spectrum is not available at all.

The use of spectrum may have wider "spillover" economic impacts

The use of spectrum can have wider impacts which do not relate to the specific suppliers or users of goods or services that use spectrum. In this sense, they are termed "externalities" (i.e., the value accrues to those who are not suppliers or consumers). These impacts can accrue to specific groups[23] or to the population or economy more generally.

Externalities can be positive (bringing benefits) or negative (causing costs). For instance:

- one sector's use of spectrum can enable economy-wide productivity improvements, which benefit all sectors of the economy; whereas
- pollution created by sectors that use spectrum has a negative impact on society (including those who do not produce or consume the good).

There is, however, increasing pressure for firms to recognise and mitigate the negative *social* and *environmental* impacts of their activities. Where a firm undertakes mitigation activities, such negative impacts would not (fully) be considered an *externality* since the firm has (at least partially) "internalised" the impact. For example, firms might pay to offset CO_2 emissions or to directly capture carbon emissions, leading to lower negative externalities.

In many cases spectrum is allocated for public use

Much of spectrum that is currently managed is used for services provided by the state, which are distinct from services provided in the commercial economy (for example, defence or emergency services). These applications strongly rely on spectrum and have a clear economic value. However, this value can be hard to measure as these goods are not commercially traded.

[23] For instance, noise pollution from airports only affects those that live in the close surrounding area.

3.1.2 POTENTIAL APPROACHES TO ESTIMATING THE VALUE OF A SECTOR

The "value" of a sector can be considered from a number of different perspectives, with different approaches capturing different types of value. Therefore, the preferred approach depends on the purpose of the valuation exercise and the availability of the necessary data.

Direct economic impacts

The direct economic value created in the supply of services and products in a given sector that uses spectrum is a broad measure of value that can be compared consistently across sectors. This value is measured as the Gross Value Added (GVA) and is the contribution that the firm or sector makes to the economic output of the economy (measured by Gross Domestic Product (GDP)).[24] At the sector level, the value created in sectors that use spectrum can be estimated using national accounting data, whilst at the firm level, it can be estimated using information from a firm's annual financial statements.

Estimating the economic value using GVA is a standard approach used to value different sectors in the economy and is used by DCMS and DSIT to monitor the economic contribution of sectors within its remit, e.g. creative industries.[25]

Spectrum is also used in a variety of public goods and services[26] (such as emergency services and defence). In theory, the direct economic value of these goods can be measured in the same way: by estimating the contribution that the public sectors that use spectrum make to the economy as measured by the GVA. However, in practice, data on GVA may not be available to the same degree for public sector outputs since public bodies are not required to produce data from which GVA can be measured.

Economic welfare effects

The welfare created as a result of economic activity represents the net benefits that suppliers and users (privately) receive from consuming or supplying goods or services. The sum of the producer and consumer surplus is termed economic welfare (or social surplus) and is maximised at allocatively efficient levels of production.

The private producer surplus created by suppliers that use spectrum relates to the gross profit that is generated as a result of supplying services that use spectrum. The producer surplus is a component part of the direct value (measured by GVA) and could be estimated using firms' annual accounting data where this is available. However, the producer surplus of publicly provided goods would be zero where the goods are not supplied for profit, and hence this measure cannot be used to compare the value across public and private uses.

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[24] Gross value added is the difference between production value and intermediate consumption and represents the value added by the firm. It can be estimated by summing the gross operating profit earned by suppliers in the sector of interest with the compensation of employees and self-employed earnings.

[25] DCMS, DCMS Sectors Economic Estimates. Available at: https://www.gov.uk/government/collections/dcms-sectors-economic-estimates [Accessed 28th April 2022].

[26] Public goods, from an economic perspective, are goods that are non-rivalrous (in that one person's consumption of the good does not preclude another from consuming the good) and non-excludable (in that providers cannot exclude consumers from consuming the good). Goods with such characteristics are typically undersupplied in competitive markets and hence, supplied by the government, e.g. defence.

The consumer surplus is the private value that consumers enjoy from consuming goods and services that rely on spectrum. In a given market, it relates to the difference between consumers' maximum willingness to pay and the price paid.

In practice, the consumer surplus is not easy to accurately estimate since it requires a good understanding of the consumer demand across all potential prices. Typically, information on the relationship between prices and demand is only observable in a narrow range around existing prices. Nonetheless, through using assumptions on the shape of consumer demand, it is possible to estimate the value of consumer surplus associated with products and services that use spectrum, though inevitably, there will be some uncertainty over such estimates. Estimates of consumer surplus are harder to make in markets where products are provided for free (such as for public goods) or where there is no price benchmark to anchor consumer views on their use and value of the goods and services.

Economic externality impacts

As set out above, the use of spectrum can have wider impacts which do not relate to the specific suppliers or users of goods or services that use spectrum. These impacts are termed "externalities”.

Estimating the scale of externality impacts is complex for several reasons. These are:

- Externalities, by definition, do not have a "price";
- while it is possible to use techniques to measure the value of externalities, it may be hard in some cases to ascribe specific benefits to spectrum; and
- in a practical sense, typical techniques to measure externality impacts (such as consumer surveys on willingness to pay/willingness to accept) need to be interpreted with caution, given the standard biases which can affect consumer surveys.

3.1.3 METHODOLOGY USED IN THIS REPORT

In this report, we adopt the following approach to assess the value created in the range of public and private uses (as identified by Ofcom’s Spectrum Map). It assesses:

- The **direct private economic contribution of sectors** that use spectrum, as measured by their contribution to economic output in 2019[27] **(measured by GVA[28])**. This approach provides an assessment of the value created by a sector that can be consistently measured across different sectors. Where the data needed to calculate GVA is not available, we provide a **qualitative assessment of the direct economic contribution.** We also highlight **non-monetary direct benefits** in cases where that is the direct purpose of the service provided by the supplier. For instance, this is the case with national security (in the case of the defence sector) or forecasting and resilience (in the case of meteorological services).

- **Qualitatively: the externalities** in the sectors that rely on spectrum. Externalities create value which extends beyond the supplier and user of the good or service.

When interpreting the results of this analysis and reflecting the fact that different sectors rely on spectrum to different degrees, we aim to consider: (i) the degree to which the value created through a sector’s activities

[27] For some sectors, data from the ONS is used to estimate GVA, which is only available until 2019. Therefore, for consistency purposes, we use 2019 for all sectors. Using 2019 has the benefit of avoiding capturing any temporary effects of the Covid-19 pandemic.

[28] The methodology used to calculate sector level GVA is set out in **Annex A.**

is enabled by spectrum and (ii) the degree to which the value created in a sector would be lost absent spectrum.

3.1.4 COMPARISON TO PREVIOUS METHODOLOGIES USED TO VALUE SPECTRUM IN THE UK

The approach described above incorporates two of the three approaches to valuation set out in **Section 3.1.2**. Previous spectrum valuations studies commissioned by DCMS[29] have used the third approach, which is based on estimating the economic welfare created in each sector rather than the sector's GVA. The conclusions and recommendations of the DCMS's most recent study are set out in the box below.

[29] The most recent study was conducted by Analysys Mason in 2012. See Analysys Mason, 2012. Impact of radio spectrum on the UK economy and factors influencing future spectrum demand.

IMPACT OF RADIO SPECTRUM ON THE UK ECONOMY AND FACTORS INFLUENCING FUTURE SPECTRUM DEMAND

In 2012, DCMS commissioned a study of the value of spectrum use (measured by economic welfare) to the UK economy. This was an update of a similar study, which used the same approach, conducted in 2006.

The previous study calculated that, in 2011, the economic welfare in the UK (i.e. the sum of the producer and consumer surplus) created by the use of spectrum was £52 billion. The majority of this value (58%) was created by the public mobile communications, with a significant proportion of value in this sector (80% of the sector's value) coming from the consumer surplus. The second-largest contributor was TV broadcasting, accounting for 15% of value, with Wi-Fi, radio broadcasting, microwave links, satellite links and PMR collectively accounting for the remaining 27% of value.

Whilst it recognised the important role that spectrum has to play in the delivery of public services, the previous study did not attempt to quantify the value of spectrum in public use.

The study made the following recommendations.

- Further spectrum should be released for mobile usage, given that it found that this sector created the most value. It noted that the benefits of such a programme would be maximised if the bands released were harmonised internationally.
- There should be support for the sectors that would be affected by increases in demand for mobile data. For instance, in this context, the report referred to Wi-Fi (which it noted was being increasingly used to offload data traffic from public mobile networks) and TV broadcasting (which it noted was witnessing the increasing use of mobile devices, most often connected via Wi-Fi, for TV viewing in the home and elsewhere).
- The rest of the Digital Terrestrial Television (DTT) multiplexes should be upgraded to the Digital Video Broadcasting – Second Generation Terrestrial (DVB-T2) standards (which would create capacity for additional high-definition channels), with the Digital Audio Broadcasting (DAB) platform being upgraded to DAB+ or another alternative (which would improve sound quality and reception in weak signal areas).
- There should be better sharing of under-utilised spectrum, for instance, by exploring technologies that enable more dynamic access to spectrum.
- Some public-sector spectrum should be released, with the report noting that the benefits would be maximised if spectrum that was released was harmonised on an international basis and was released in contiguous blocks.

Following discussions with DCMS, we concluded that we were unable to employ the valuation method used in the 2012 study. This is because:

- Estimating consumer surplus requires information on the shape of the demand curve, i.e., the quantities of goods and services demanded at different price points. This is typically informed by studies on consumers' willingness to pay. Since the 2012 study, there has been no new willingness-to-pay research, meaning that it is not possible to estimate consumer surplus reliably.

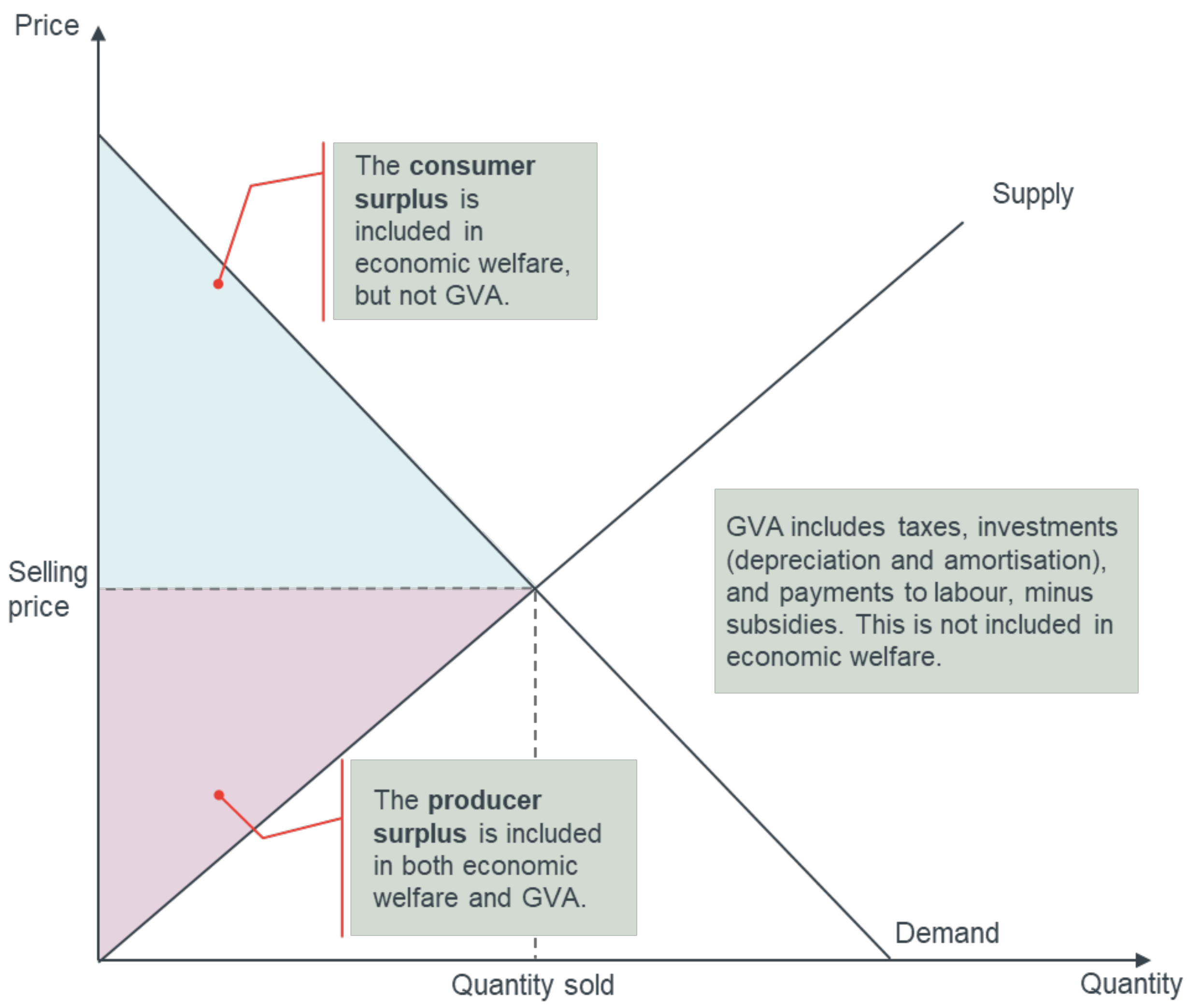
- As noted in **Section 3.1.2**, it is particularly difficult to estimate the consumer and producer surplus for public goods that are provided for free.

There are a number of differences between the value estimated using economic welfare and using GVA.

- The consumer surplus is the private value that consumers enjoy from consuming goods and services that rely on spectrum. It is included in economic welfare but is not part of GVA.
- The producer surplus is the gross profit that is generated as a result of supplying services that use spectrum. As gross profit contributes to GDP, the producer surplus is also captured as part of GVA.
- GVA captures the other channels through which firms in the industry contribute to GDP (namely taxes, fewer subsidies, investment and payments to labour). These are not captured in economic welfare.

These are shown in the figure below.

FIGURE 3 COMPARISON OF ECONOMIC WELFARE TO GVA



Source: Frontier Economics

Given the differences in the approaches used, the estimates of spectrum value in this report are not directly comparable with the estimates in the studies that estimate consumer surplus. **However, it is likely that estimates of value based on economic welfare will exceed those calculated using GVA.** This is because the consumer surplus, which is included in economic welfare but not GVA, is potentially infinite (depending on the shape of the product's demand curve) and, for many products, exceeds the producer surplus and other components of GVA by many orders of magnitude. For instance, the 2011 report found that the consumer surplus of mobile services was four times the size of the producer surplus of mobile services.

However, as explained above, we are unable to replicate the 2011 analysis due to the lack of recent consumer willingness-to-pay research, which is needed to reliably estimate the consumer surplus.

DCMS has also commissioned work that investigates the ways of incorporating social value (both to the user and producer and to society at large) when valuing the use of spectrum[30]. The authors of that study assess the pros and cons of three different approaches to assessing value: stated preference research, deliberative research and subjective wellbeing data, and provide a recommendation on how they can be incorporated when making allocation decisions. As these approaches require bespoke primary research, it has not been possible to implement them in this report. Instead, the approach used in this report is to qualitatively discuss the non-monetary benefits and economic externalities created through each sector's use of spectrum.

3.2 ECONOMIC VALUE OF SPECTRUM BY SECTOR

This section describes the direct economic contribution and the externalities generated by the private and public goods and services that use spectrum.

- **Sections 3.2.1 - 3.2.7** set out the value of private goods and services that use spectrum, namely: broadcasting, commercial satellite operators, fixed links, mobile services, PMSE, PMR, and Wi-Fi and other licence-exempt uses of spectrum.
- **Sections 3.2.8 - 3.2.12** set out the value of public goods and services that use spectrum, namely: aviation, defence, emergency services, maritime, and space and earth sciences.[31]

3.2.1 BROADCASTING

The broadcasting sector in the UK provides free-to-view nationwide coverage of radio and television services via various wireless technology platforms. This sub-section considers recent trends in each of the TV broadcasting (including both satellite and terrestrial technologies) and radio broadcasting sectors separately, then sets out the overall direct economic contribution and the externalities created in the sector.

RECENT TRENDS IN THE TV BROADCASTING SECTOR

The TV broadcasting sector transmits hundreds of channels across a number of different transmission technologies. Spectrum is an essential input for certain transmission technologies: digital terrestrial television (DTT) and direct-to-home (DTH) satellite television broadcasting. It does not play a central role in transmission via internet protocol (IPTV) or cable television broadcasting.[32] Furthermore, there is an increasingly blurred line between broadcasters and online video providers (otherwise known as Over The Top (OTT) services). This includes providers of video content which is available via broadband, such as BBC iPlayer, Netflix or Britbox.

In the UK, DTT broadcasters use 224 MHz of spectrum between 470 and 694 MHz, while DTH broadcasters make use of the Ku-band (approx. 12 GHz). In 2012, the UK switched from the old analogue to digital television. This resulted in improved spectrum efficiency, squeezing more channels into a reduced amount

[30] Cave et al., 2015. Incorporating Social Value into Spectrum Allocation Decisions.

[31] The use of spectrum by the maritime and aviation sector enables a significant amount of value from private goods and services. We consider these as public sector uses as spectrum is administered by public bodies (the MCA and CAA, respectively).

[32] Although IPTV does not use spectrum directly in the same broadcasting context as DTT and DTH, this report recognises that IPTV can indirectly rely on Wi-Fi (discussed in **Section 3.2.7**) or mobile services (discussed in **Section 3.2.4**).

of available UHF spectrum and, in turn, creating a 'digital dividend' by freeing up spectrum for other uses. The digital dividend spectrum (800 MHz) was auctioned by Ofcom in 2012 and assigned to the mobile operators. This process was repeated in 2018 when Ofcom identified that it would be possible to re-farm the 700 MHz band from the television broadcasters to mobile operators. The 700 MHz band was awarded via auction to mobile operators in mid-2021.[33]

DTT uses a network of 1,156 transmitters (approximately 80 main transmitters and a series of over 1,000 relay transmitters) to broadcast channels. In the UK, Freeview (a free-to-view service managed by Digital UK Ltd and DTV Services Ltd) is the sole DTT platform, carrying over 70 channels.[34] The digital television services on the DTT network are carried by six national 'multiplexes' plus a number of local multiplexes. Each multiplex compresses and bundles several television services into a single frequency and transmits it digitally before it is decoded by TV equipment in consumer households. These key features of the six DTT multiplexes are summarised in the table below.

TABLE 1 SUMMARY OF UK DTT MULTIPLEXES

NATIONAL MULTIPLEX	LICENSEE	REGULATED UNDER	SERVICES CARRIED
1	BBC	BBC Charter and Agreement	All BBC SD channels.
2	Digital 3 & 4 Ltd (ITV/Channel 4 subsidiary)	Ofcom	PSB (Public Sector Broadcasting) main channels ITV, C4, C5 and S4C, and some PSB portfolio channels including ITV 2, E4, Film 4.
A	SDN Ltd (ITV subsidiary)	Ofcom	Commercial services including some of the commercial PSBs portfolio channels (e.g. ITVBe and 5 USA) and other third party commercial channels.
B	BBC Free to View Ltd (BBC subsidiary)	Ofcom	High Definition PSB channels (e.g. BBC One HD; ITV HD; C5 HD) and some commercial channels.
C	Arqiva Muxco Limited (Arqiva)	Ofcom	Commercial channels.
D	Arqiva Muxco Limited (Arqiva)	Ofcom	Commercial channels.

Source: DCMS, 2021. Consultation on the renewal of Digital Terrestrial Television (DTT) multiplex licences expiring in 2022 and 2026.

There are two DTH satellite television services in the UK: Sky TV and Freesat.

[33] See https://www.ofcom.org.uk/spectrum/spectrum-management/spectrum-awards/awards-archive/700-mhz-and-3.6-3.8-ghz-auction [Accessed 7th March 2022].

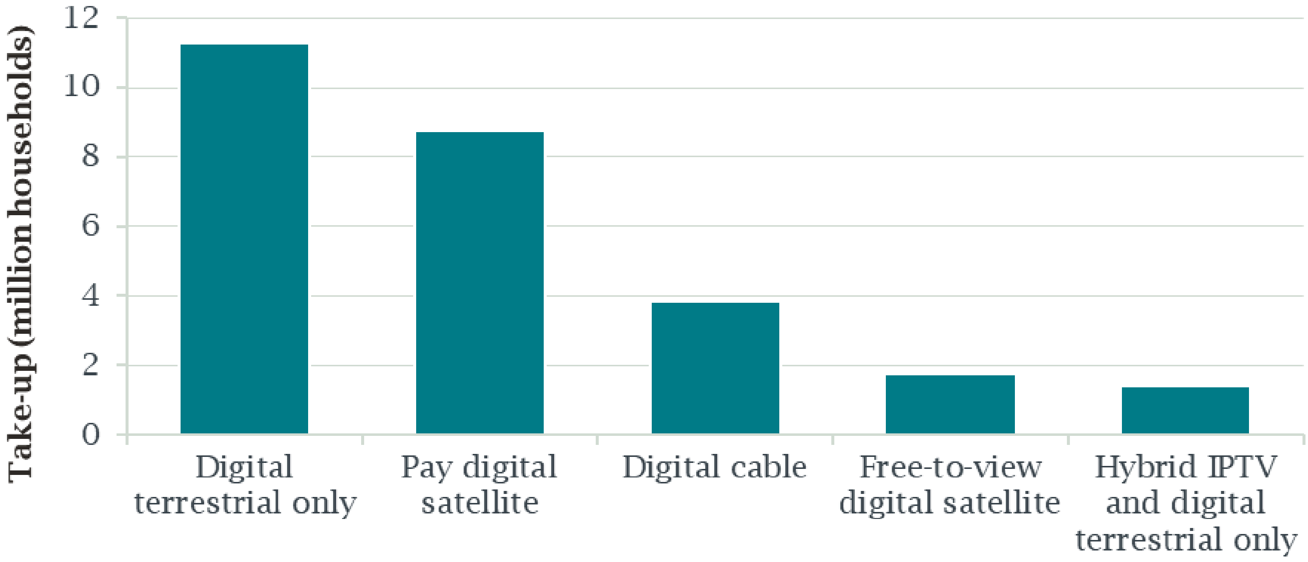
[34] The companies have three common shareholders: BBC, ITV and Channel 4. Note: Sky is also a shareholder in DTV Services Ltd. See: https://www.freeview.co.uk/about-freeview [Accessed 7th March 2022].

- Sky TV is a subscription-based platform operated by Sky Ltd (owned by Comcast), offering over 350 channels, depending on the package a customer subscribes to.[35]

- Freesat is a free-to-view service operated as a joint venture between BBC, ITV, Channel 4, and Channel 5, carrying over 170 channels.[36] The signals for both Sky TV and Freesat are transmitted via the same Astra 2E, 2F and 2G satellites owned by SES, a satellite network provider based in Luxembourg.[37,38]

In 2019, DTT-only households made up the largest share of UK homes (approximately 40% of all homes), followed by pay-satellite (DTH) homes (31%), homes using digital cable services (14%) and free-to-view satellite (DTH) homes (6%).[39] **Figure 4** shows how this platform take-up across UK households changed between 2000 and 2019.

FIGURE 4 TV PLATFORM TAKE-UP BY HOUSEHOLD (MILLIONS)



Source: Frontier Economics based on Ofcom's 2019 Media Nations report.

Note: Digital terrestrial TV only = receives digital TV via aerial and not through satellite, cable or other platforms. Hybrid IPTV digital terrestrial only = receives digital terrestrial TV through any IPTV platform.

However, the relative stability of platform shares over the last decade masks a structural shift in how TV is consumed. The proliferation of online video means that users rely less on TV broadcasting. In 2020, individuals aged four and older, on average, viewed 192 minutes of television per day, down from 240 in 2012.[40] As described by Ofcom in 2019, traditional broadcast TV services are *"no longer* the *dominant way*

[35] See https://www.sky.com/tv [Accessed 7th March 2022].

[36] See https://www.freesat.co.uk/about [Accessed 7th March 2022].

[37] RX: TV, 2021. SES secures ongoing carriage of key free-to-air channels. Available at: https://rxtvinfo.com/2021/ses-secures-ongoing-carriage-of-key-free-to-air-channels [Accessed 7th March 2022].

[38] RX: TV, 2021. Sky stays on satellite until at least 2027. Available at: https://rxtvinfo.com/2021/sky-stays-on-satellite-until-at-least-2027 [Accessed 7th March 2022].

[39] Ofcom, 2019. Media Nations. Available at: https://www.ofcom.org.uk/__data/assets/pdf_file/0019/160714/media-nations-2019-uk-report.pdf [Accessed 7th March 2022].

[40] Ofcom, 2021. Communications Market Report – Interactive Data. Available at: https://www.ofcom.org.uk/research-and-data/multi-sector-research/cmr/cmr-2021/interactive-data [Accessed 7th March 2022].

to watch audio-visual content in all households", with significant increases in online video services viewership.[41] Over the same period, there has been a small decline in the number of households that have a TV set: in 2020, 92% of UK households owned a TV set, down from 96% in 2012.[42]

Despite these trends, it is likely that DTT and DTH transmission will remain important ways for a proportion of end-users to receive their TV services. This is demonstrated by the UK government's decision to renew, until 2034, the licences of five DTT multiplexes expiring in 2022 and 2026.[43]

RECENT TRENDS IN THE RADIO BROADCASTING SECTOR

The radio broadcasting sector uses spectrum to transmit radio stations across analogue and digital transmission technologies. The radio sector distributes 333 analogue (AM/FM/MW) services and 574 digital (DAB) services[44]. It also transmits via digital television services (see above) and internet protocol (see **Section 3.2.7**).

Broadcasters of analogue and digital stations include the BBC, commercial radio groups such as Global, Bauer Media and Wireless, and a range of local commercial and community stations. **Table 2** shows the distribution of AM/FM services, as of March 2021, across these station types.

TABLE 2 NUMBER OF UK AM/FM SERVICES

	AM	FM	AM/FM TOTAL
Local commercial	43	236	279
UK-wide commercial	2	1	3
BBC UK-wide networks	1	4	5
BBC local and nations	19	46	46
Community radio stations	24	282	306

Source: BBC/Ofcom in Ofcom, 2021. Media Nations. Available at: https://www.ofcom.org.uk/__data/assets/pdf_file/0023/222890/media-nations-report-2021.pdf [Accessed 7th March 2022].
Note: Figures are as of March 2021. AM figure excludes Radio 4 LW and MW.

The radio broadcasting sector uses approximately 78 MHz of spectrum, all in frequency ranges below 350 MHz. This is shown in **Table 3** below.

[41] Ofcom, 2019. Media Nations. Available at: https://www.ofcom.org.uk/__data/assets/pdf_file/0019/160714/media-nations-2019-uk-report.pdf [Accessed 7th March 2022].

[42] Ofcom, 2021. Communications Market Report – Interactive Data. Available at: https://www.ofcom.org.uk/research-and-data/multi-sector-research/cmr/cmr-2021/interactive-data [Accessed 7th March 2022].

[43] See: https://www.gov.uk/government/consultations/consultation-on-the-renewal-of-digital-terrestrial-television-dtt-multiplex-licences-expiring-in-2022-and-2026 [Accessed 7th March 2022].

[44] Ofcom, 2021. Media Nations. Available at: https://www.ofcom.org.uk/__data/assets/pdf_file/0023/222890/media-nations-report-2021.pdf [Accessed 7th March 2022].

TABLE 3 SPECTRUM USED BY THE RADIO BROADCASTING SECTOR

	FREQUENCY BAND (MHZ)	AVAILABLE SPECTRUM (MHZ)
DAB	174 – 230	56
FM	88 – 108	20
MW	0.531 – 1.7	1.169

Source: Frontier Economics and LS telecom using data from Ofcom.
Note: The Government has recommended that the BBC, Wireless, and Bauer should develop a plan for the migration from MW and LW services to take place at some point in the mid-2020s. The BBC has announced plans to migrate all stations away from MW and LW by 2027.[45]

DAB radio services, like DTT TV services, are broadcast via multiplexes. In the UK, there are three national DAB multiplexes, summarised in Table 4, as well as a number of local and small-scale[46] multiplexes, broadcasting over 500 services.[47]

TABLE 4 UK NATIONAL DAB MULTIPLEXES

MULTIPLEX	OWNER	COVERAGE (% HOUSEHOLDS)	NUMBER OF SERVICES	EXAMPLES OF SERVICES
BBC National DAB	BBC	98%	11	BBC national radio stations
Digital One	Arqiva	92%	23	Absolute Radio, Heart, Classic FM, Capital, LBC
Sound Digital	Arqiva, Bauer Media, Wireless	83%	21	Virgin Radio, talkRADIO, Planet Rock

Sources: BBC/Ofcom in Ofcom, 2021. Media Nations. Available at: https://www.ofcom.org.uk/__data/assets/pdf_file/0023/222890/media-nations-report-2021.pdf [Accessed 7th March 2022]. Arqiva, National DAB. Available at https://www.arqiva.com/media/radio/national-dab [Accessed 7th March 2022].

[45] DCMS, 2022. Digital radio and audio review. And, BBC, 2022. A digital-first BBC.

[46] Following successful trials, Ofcom has recently begun to license “small-scale multiplexes”. These cover smaller geographics areas and allow smaller commercial and community radio stations to broadcast on DAB. By the end of July 2021, Ofcom had awarded 25 small scale multiplex licences, with plans to roll out many new areas over the next 3-4 years. See: DCMS, 2022. Digital radio and audio review.

[47] Ofcom, 2021. Media Nations. Available at: https://www.ofcom.org.uk/__data/assets/pdf_file/0023/222890/media-nations-report-2021.pdf [Accessed 7th March 2022]. Note: the figure for the number of services on local commercial multiplexes includes all commercial services carried on each multiplex, meaning that a service may be counted more than once. BBC local and nations services are also carried on local commercial multiplexes

In Q4 2021, 49.5 million people in the UK, or 89% of those aged 15 and older, tuned into the radio each week. The average listener tuned in to 20.3 hours of live radio per week. 42% of those listening hours were via DAB broadcasts and 36% via AM/FM. [48]

ECONOMIC OUTPUT OF THE BROADCASTING SECTOR

As shown in **Table 5**, the GVA of the broadcasting sector in the UK was £4.1 billion in 2019. Of this, £3.5 billion was contributed by the TV broadcasting sector and £600 million by the radio broadcasting sector.

However, only a proportion of the GVA created in the broadcasting sector will have been enabled by technologies that use spectrum (DTT, DTH, DAB, and AM/FM radio). To estimate this proportion, we have apportioned the GVA of the broadcasting sector based on the viewership of each type of technology. Based on this, we estimate that the GVA of the sector attributable to technologies that use spectrum was, in 2019, around £2.5 billion. Of this, £2 billion is from TV broadcasting technologies that use spectrum (DTT and DTH broadcasting), and £480 million is from radio broadcasting technologies that use spectrum (DAB and AM/FM radio).

TABLE 5 GVA OF BROADCASTING SERVICES

	GVA IN 2019
TV broadcasting	£3.5bn
Radio broadcasting	£600m
Total broadcasting	**£4.1bn**
TV broadcasting enabled by spectrum	£2.0bn
Radio broadcasting enabled by spectrum	£480m
Total broadcasting enabled by spectrum	**£2.5bn**

Source: Frontier Economics based on data from ONS, RAJAR and Ofcom's Technology Tracker.

Note: In recent years, there has been a decline in the GVA of the TV broadcasting sector (captured by ONS code 60.1), while at the same time, there has been an increase in the GVA of the TV production sector (SIC code: 59). This is suggestive of a trend toward TV broadcasters outsourcing the production of content to third parties (which would be captured in the production sector) rather than producing content in-house (which would be captured in the broadcasting sector).

As noted in the introduction to this chapter, when assessing the value created in a sector, we consider the degree to which the value created in a sector would be lost absent spectrum. In the case of broadcasting, as there are direct substitutes for spectrum related technologies, it is likely that not all of this £2.5 billion in GVA would be lost absent spectrum, as some usage could shift to other technologies (e.g. cable TV, IPTV and internet radio). At the same time, there would likely be some GVA lost due to the increased inconvenience of accessing these services, potentially reducing demand. Alongside this, there will be a small but significant proportion of the population who would be unable to access these alternative services.

[48] RAJAR, 2022. Q4 2021 Infographic. Available at: https://www.rajar.co.uk/docs/news/RAJAR_DataRelease_InfographicQ42021.pdf [Accessed 7th March 2022].

ECONOMIC EXTERNALITIES GENERATED BY BROADCASTING

Broadcasting also creates wider value beyond that which is captured in the direct contribution to the economy. These externalities are primarily social benefits (in terms of education, health and culture) as well as the sector's impact on the environment. When assessing these externalities, we consider the degree to which these positive and negative externalities created in the sector would be lost absent spectrum.

Education

Studies have suggested that early-age exposure to certain television programmes can increase later educational outcomes.[49] Given this, the positive educational impacts of television viewing can be considered to benefit the wider economy through the creation of a more educated and productive workforce.[50] These education externalities are not necessarily spectrum-dependent as the same content could be viewed using non-spectrum-dependent technologies (for example, streaming via fixed networks or cable television broadcasts).

Health

There is evidence that certain types of broadcasting exposure can have a positive impact on health outcomes, for instance, through public health broadcasts or educational content. For example, a study found that tobacco control television mass media campaigns in Scotland were effective in triggering calls to smoking cessation hotlines.[51] Furthermore, during Covid-19, many community radio stations increased emergency programming and broadcast public service health announcements to their communities in multiple languages.[52] This may have increased the likelihood of listeners engaging in social distancing or taking up vaccines.

However, broadcasting could also have a negative impact on health outcomes. For example, time spent watching television can contribute to health-related concerns over sedentary lifestyles, with some studies noting decreased health markers among children, which are associated with increased TV viewing.[53][54]

As with education externalities, these externalities are not necessarily spectrum-dependent as the same content could be viewed using non-spectrum-dependent technologies.

Social cohesion and inclusion

Broadcasting can contribute to overall societal cohesion. For TV, this comes through improved relationships between those with shared cultural experiences, a phenomenon which has been termed the 'water cooler' effect. Radio broadcasts can also help improve social cohesion and inclusion within local communities. In

[49] Gentzkow & Shapiro, 2008. Preschool television viewing and adolescent test scores: Historical evidence from the Coleman study.

[50] Seabright & von Hagen, 2007. The Economic Regulation of Broadcasting Markets: Evolving Technology and Challenges for Policy

[51] Haghpanahan et al., 2017. The impact of TV mass media campaigns on calls to a National Quitline and the use of prescribed nicotine replacement therapy: a structural vector autoregression analysis.

[52] DCMS, 2021. Digital Radio and Audio Review. Available at: https://www.gov.uk/government/publications/digital-radio-and-audio-review/digital-radio-and-audio-review#chapter-1----background-and-scope-of-the-review [Accessed 7th March 2022].

[53] Seabright & von Hagen, 2007. The Economic Regulation of Broadcasting Markets: Evolving Technology and Challenges for Policy.

[54] Nieto & Suhrcke, 2021. The effect of TV viewing on children's obesity risk and mental well-being: Evidence from the UK digital switchover.

the UK, there are over 300 analogue community radio stations, reaching over 1 million listeners per week.[55] Survey evidence suggests that UK radio listeners value the community service and the connection to the local area that community radio services provide via localised news, traffic and weather updates, diversity of music and relatable presenters.[56] However, broadcasting could also have negative wider impacts on social cohesion. For example, it has also been theorised that television viewing can hinder social capital and cohesion as individuals substitute TV time for time previously used for social interaction.

The extent to which spectrum is necessary for enabling these social externalities is difficult to determine but most likely varies. For example, the positive social cohesion effects from shared cultural experiences could still be achieved, to some extent, absent spectrum, by viewers consuming content via cable television broadcasting or fixed network streaming. However, other effects, such as those from community radio, may be more difficult to reproduce. As noted by Radiocentre and GfK, in some areas, the absence of local newspapers makes community radio the only source of regular news updates.[57] While the same content could be streamed on internet radio via fixed networks, the potentially reduced listenership caused by the reduction in ways of accessing the content could diminish the overall social cohesion benefit.

Environmental

Broadcasting content which disseminates information on environmental issues can generate positive environmental externalities, for instance, by encouraging viewers to reduce their waste and energy usage or buy more sustainable goods.[58] However, broadcasting also generates negative environmental externalities through energy usage and carbon emissions. For both TV and radio, this occurs through two main channels.

- Through the emissions associated with the energy required for broadcasters to prepare and transmit television and radio services. For example, 114 GWh/year of energy is used by the UK radio industry to transmit AM, FM and DAB services (representing 0.03% of total UK energy use).[59]

- Through the emissions associated with the energy used during the consumption of content (i.e., TV and radio set usage).

Studies by the BBC have found that the energy usage during consumption is significantly more substantial than usage by broadcasters during preparation and transmission.[60][61] The studies estimated that, when considering BBC content, consumption represents 94% of the energy usage associated with TV broadcasting and 73% for radio broadcasting. Furthermore, a number of UK broadcasters have made pledges to reduce

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[55] RAJAR, Ipsos, RSMB, 2021, Audience Estimates for UK Community Radio Stations. Available at: https://getdigitalradio.com/wp-content/uploads/2021/10/RAJARIpsosRSMB-Audience-Estimates-for-UK-Community-Radio-Stations-April-2021.pdf [Accessed 8th March 2022].

[56] Radiocentre & GfK, 2021. Community Radio Audiences and Values. Available at: https://getdigitalradio.com/wp-content/uploads/2021/10/Community-Radio-Audiences-and-Values-February-2021.pdf [Accessed 7th March 2022].

[57] Radiocentre & GfK, 2021. Community Radio Audiences and Values. Available at: https://getdigitalradio.com/wp-content/uploads/2021/10/Community-Radio-Audiences-and-Values-February-2021.pdf [Accessed 7th March 2022].

[58] Behavioural Insights Team, 2021. The Power of TV: Nudging viewers to decarbonise their lifestyles. Available at: https://www.bi.team/wp-content/uploads/2021/10/Broadcasters-Report.pdf [Accessed 7th March 2022].

[59] DCMS, 2021. Digital Radio and Audio Review. Available at: https://www.gov.uk/government/publications/digital-radio-and-audio-review/digital-radio-and-audio-review#chapter-1----background-and-scope-of-the-review [Accessed 7th March 2022]

[60] BBC, 2021. The carbon impact of streaming: an update on BBC TV's energy footprint. Available at: https://www.bbc.co.uk/rd/blog/2021-06-bbc-carbon-footprint-energy-envrionment-sustainability [Accessed 7th March 2022].

[61] Chandaria & Fletcher, 2020. The energy footprint of BBC radio services: now and in the future.

carbon emissions from their activities (see **Annex B** for more details), suggesting that the ratio of energy usage and emissions from the broadcasting sector will continue to be dominated by consumption rather than transmission.

The extent to which the overall amount of pollution created by the broadcasting sector would change absent spectrum would depend on a number of factors. These include:

- The degree to which consumption of broadcasting would decrease.
- For consumption that switched to alternative technology, the type of platform it switched to (as some platforms are more energy-efficient than others). For instance:
  - The BBC study found that digital terrestrial broadcasting was the least energy-intensive platform compared to cable, satellite and internet streaming (which can use up to 2.5 times more energy per device-hour). [62]
  - On a per radio station basis, DAB radio transmission is more efficient than AM or FM.[63]

3.2.2 COMMERCIAL SATELLITE OPERATIONS

This section assesses the value created in the commercial satellite sector. This includes communications (both voice and broadband) and navigation.[64]

- **Communications** - includes one-way and two-way connections to a fixed location or mobile users. This communication may be civil or military. For instance, satellite broadband or mobile connections in remote locations; or on boats and aircraft where no terrestrial infrastructure exists.
- **Navigation** - refers to the use of satellites to help track the position of people (or aircraft/boats/vehicles).

Below we discuss the range of operators in the sector and the frequency bands used.

Key operators in the commercial satellite sector

There are a number of operators of commercial satellite services in the UK.

- Inmarsat operates a global network of geostationary communication satellites. Originally intended for maritime voice communication, the network now provides voice and data connectivity to many mobile users, as well as to remote areas or those with poor communications infrastructure.

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[62] BBC, 2021. The carbon impact of streaming: an update on BBC TV's energy footprint. Available at: https://www.bbc.co.uk/rd/blog/2021-06-bbc-carbon-footprint-energy-envrionment-sustainability [Accessed 7th March 2022].

[63] DCMS, 2021. Digital Radio and Audio Review. Available at: https://www.gov.uk/government/publications/digital-radio-and-audio-review/digital-radio-and-audio-review#chapter-1----background-and-scope-of-the-review [Accessed 7th March 2022].

[64] Although satellite broadcasting is a commercial satellite activity, for the purposes of this report, DTH satellite broadcasting is considered as part of broadcasting in S**ection 3.2.1**. The use of satellites for other purposes, such as meteorology or earth observation, is considered in S**ection 3.2.12**.

- Avanti operates a regional network of geostationary communication satellites covering the Americas, Europe, Africa, and the Middle East. Avanti aims to provide high bandwidth connectivity to areas where, for example, internet speeds are slow.

- OneWeb, now part-owned by the UK government, operates a network of Low Earth Orbit (LEO) satellites providing high bandwidth connectivity to areas with poor terrestrial infrastructure.

- Airbus Defence and Space operate the UK government's military SkyNet satellite network for communications amongst UK defence forces.

- SpaceX has introduced services in the UK[65], and other non-geostationary orbit NGSO operators, such as Amazon Kuiper, are planning to introduce similar services[66].

In addition to the above, there are several academic, scientific and commercial satellites which have been launched by UK organisations.

Frequency bands used by the commercial satellite sector

The sector uses a wide range of frequency bands to provide its services. **Table 6** below sets out the key bands used by the sector.

TABLE 6 FREQUENCY BANDS USED BY THE COMMERCIAL SATELLITE SECTOR

BANDS	USES
VHF and UHF bands	Typically used for low bandwidth applications, including Internet of Things (IoT) applications, as well as some weather, academic and scientific satellites.
L-band (approx. 1.5 GHz) and S-band (approx.. 2.5 GHz)	Used by a range of mobile satellite constellations, including Inmarsat, for relatively low bandwidth (i.e. voice and slow-speed data) connections as well as relatively low bit rate broadband connections (i.e. up to 1 Mbps). In addition, this frequency range is used by satellite navigation systems.
C-band (approx. 4 GHz)	The first range of satellite frequencies which have sufficient bandwidth to provide high-capacity connections. This band is used for satellite communications around the world, particularly in areas with heavy rainfall, as well as services required over whole continents (such as air traffic information), as it is possible to have a 'global beam' which covers around a third of the planet in one go.
X-band (approx. 8 GHz)	Used for military communications. It is also used for high-resolution synthetic-aperture radar (SAR).

[65] See: https://www.independent.co.uk/tech/spacex-starlink-premium-internet-elon-musk-b2006196.html [Accessed 17th May 2022].

[66] See: https://www.aboutamazon.com/news/innovation-at-amazon/amazon-makes-historic-launch-investment-to-advance-project-kuiper [Accessed 17th May 2022].

BANDS	USES
Ku-band (approx. 12 GHz)	The band is primarily used in the UK for satellite television broadcasting.[67] It is also used for; satellite broadband from both geostationary and low earth orbit constellations; and fixed (i.e. home or business) or mobile (i.e. aircraft or ship) connections.
Ka-band (approx. 24 GHz)	Increasingly being used for satellite broadband connectivity as Ku-band is becoming increasingly congested. At these frequencies, attenuation due to heavy rainfall can become an issue, reducing the reliability of connections.
Q/V bands (approx. 40 GHz)	The next frontier for satellite connectivity. The higher frequency brings even larger difficulties for rain attenuation. However, there is more bandwidth available at these frequencies, bringing opportunities for even higher capacity connections.
W band (approx. 80 GHz)	Being considered for additional capacity, especially for satellite feeder links, where professional equipment can be used to help mitigate the problems of rain and atmospheric attenuation.

Source: Frontier and LS Telcom based on data from Ofcom.

ECONOMIC OUTPUT OF THE COMMERCIAL SATELLITE SECTOR

The commercial satellite sector contributed **£724 million of GVA** to the economy in 2019.[68, 69] This activity was directly enabled by spectrum; without spectrum as an input, this activity could not take place.

The GVA of the sector has increased steadily in recent years, increasing by 18% between 2018 and 2019. This is consistent with growth and increased investment globally in the satellite sector, where a large number of new entrants have entered the market. £4.3 billion has been invested in the broader satellite sector by UK based companies between 2013 and 2020, of which over £3 billion was invested in OneWeb and Inmarsat.[70]

Although it is not possible to accurately quantify the direct contribution of satellite navigation services, they are a key input to a wide range of products and services, including critical national infrastructures as well as private sectors such as logistics, transport and finance. It was estimated that these services indirectly supported £314 billion, or 14.7%) of UK GDP in 2020.[71]

ECONOMIC EXTERNALITIES GENERATED BY THE COMMERCIAL SATELLITE SECTOR

Satellite telecoms services also create wider value beyond that which is captured in the direct contribution to the economy. These externalities are summarised below.

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[67] Discussed in Section **3.2.1** above.

[68] Based on Frontier Economics' analysis of ONS data.

[69] This figure includes GVA representing the contribution from operating and maintaining facilities for the transmission of voice, data, text, sound and video using a satellite telecoms infrastructure. It does not include GVA related to specialised telecoms applications, including satellite tracking, communications telemetry and radar station operations. This activity is captured in the ONS's estimate for the 'other telecoms' sector alongside non-satellite activity such as VOIP provision or the provision of dial-up internet access. It is not possible to reliably separate out these activities.

[70] Know.space for the UKSA, 2020. Size & Health of the UK Space Industry 2020.

[71] Ibid.

Productivity

Satellite networks provide connectivity which enables innovation and growth of a wide range of devices, such as machine-to-machine (M2M) and IoT applications, particularly in sparsely populated areas.[72] Innovation in satellite communications can enable millions of IoT devices to be connected resource-efficiently, which in turn can lead to increases in economy-wide productivity. In a no-spectrum-counterfactual scenario, many of these connections would not be possible or potentially less efficient, reducing these productivity benefits.

Environmental

Like mobile networks, satellite technologies can be used to enable a range of devices, including smart IoT devices, which can reduce economy-wide emissions. For instance, satellite navigation services can enable more efficient journeys and therefore reduce the emissions created by road vehicles.[73]

On the other hand, satellite launches burn solid rocket fuels and release trace gases which can contribute to ozone depletion. However, satellite launches are relatively infrequent, meaning their total impact is unlikely to be significant.

3.2.3 FIXED LINKS

Fixed links are radio links that facilitate the wireless transmission of data between two or more fixed locations. Their use is typical in areas where existing fibre connectivity is poor, for example, in rural areas, and where the cost, difficulty or timescales associated with installing fixed connectivity may be prohibitive. Fixed links have a range of use cases, including:

- backhaul provision for mobile network base stations;
- distributing TV signals from studios to broadcast transmitter sites;
- connecting nodes within private or corporate communication networks;
- enabling point-to-point connectivity between nodes for utility networks;
- emergency services communications backhaul; and
- provision of fixed wireless broadband for last-mile connectivity (commonly known as fixed wireless access).

Fixed links tend to use highly directional antennas, at least in the case of point-to-point links. As such, despite sometimes requiring significant transmission powers, the highly directional nature of antennas limits the areas over which interference can be caused. This means that, in fixed link bands, careful planning can allow for high geographical reuse of frequencies.[74]

In 2017, there were around 45,000 fixed wireless links in the UK,[75] with these making use of a range of Ofcom managed and licence-exempt frequencies between 1.3 GHz to 86 GHz. The choice of frequency band

[72] IoT UK, 2017. Satellite technologies for IoT applications.

[73] Thai, Laurent-Brouty and Bayen, 2016. Negative Externalities of GPS-Enabled Routing Applications: A Game Theoretical approach.

[74] In bands shared with other services, for example, in the 3.8–4.2 GHz band, there is potential for interference from other services such as fixed satellite systems. In these bands, geographical separation or careful specification of operation parameters are required to ensure interference-free operation of the two services. This can result in a reduced availability or geographic usability of fixed links.

[75] Most of these were bi-directional.

is dependent on various factors, including link length, the required data throughput and the required rain fade resilience. The bands are also, in most cases, harmonised across Europe and shared with other services.[76] The key bands used by the sector are set out in the table below.

TABLE 7 FREQUENCY BANDS USED BY THE FIXED LINKS SECTOR

FREQUENCY BAND	FREQUENCY RANGE	AVAILABLE SPECTRUM (MHZ)
1.4 GHz	1.350–1.375 GHz 1.492–1.517 GHz	50
4 GHz	3.815–3.875 GHz 4.135–4.195 GHz	120
5.8 GHz	5.725–5.850 GHz	125
Lower 6 GHz	5.925–6.425 GHz	500
Upper 6 GHz	6.425–7.125 GHz	700
7.5 GHz	7.425–7.900 GHz	475
13 GHz	12.75-13.25 GHz	500
14 GHz	14–14.5 GHz	500
15 GHz	14.5-15.35 GHz	850
18 GHz	17.7-19.7 GHz	2000
23 GHz	22-23.6 GHz	1600
26 GHz	24.5-26.5 GHz	2000
31 GHz	31.0-31.3 GHz 31.5-31.8 GHz	600
38 GHz	37-39.5 GHz	2500
52 GHz	51.4-52.6 GHz	1200
55 GHZ	55.78–57 GHZ	1220
60 GHz (“V” band)	57-64 GHz	7000
65 GHz (“V” band)	64-66 GHz	2000
70/80 GHz (“E” band)	71-76 GHz 81-86 GHz	10000

Source: Frontier Economics and LS telcom based on data from Ofcom.

While fixed links use approximately 33 GHz of spectrum in bands that are managed by Ofcom, approximately 2 GHz of this spectrum is not available to new entrants. This is because:

[76] Ofcom, 2017. Fixed wireless spectrum strategy.

- the 1.492–1.517 GHz range has closed to new applicants as the spectrum has been identified for mobile broadband;[77]
- the 26 GHz range has also been identified for 5G, and Ofcom has announced the closure of the band to new applicants as of July 2022;[78]
- fixed link licences in the 3.6–3.8GHz range have been migrated to other spectrum, primarily in the 3.8-4.2 GHz range - to enable usage of spectrum for 5G; and
- the 14.25–14.5 GHz band is closed to new fixed link applicants due to increased usage from satellite earth stations.[79]

Ofcom made the lower 6 GHz band available for Wi-Fi and other Radio Local Area Network (RLAN) technologies on a licence-exempt basis in 2020[80] and is currently consulting on adding the upper 6 GHz band (6.425-7.070 GHz) to its Shared Access licence framework, potentially for Wi-Fi or 5G, with a limitation for indoor and low power use only.[81, 82]

In addition, usage in the 31 GHz band may also, in due course, be reviewed by Ofcom due to limited usage by the fixed service. Ofcom additionally has plans to investigate making spectrum available at higher frequencies above 92 GHz in the W and D bands. It expects this could be used to provide backhaul for 5G networks, noting that the high frequency will limit the range of any links. As such, spectrum will likely only be useful for shorter hops, likely in urban areas.

VALUE CREATED BY THE FIXED LINKS SECTOR[83]

Fixed links create value by acting as a suitable backhaul solution where there is a need to bridge the gap between a base station and the nearest fibre point, particularly in areas where bridging the gap is challenging using other solutions (e.g. in rural areas). For example:

- Cellular operators can often use towers which are already in use to provide fixed links. This can lower the overall cost of provision.
- Fixed links are a lower cost, albeit lower capacity, alternative to the laying of fibre. This allows the links to be used as an alternative in situations where a network only carries a low volume of traffic and/or is difficult to reach.

The net result of the cost-saving created by the use of fixed links is that operators are able to rollout their networks into areas where they otherwise would not (due to the additional cost they would need to incur).

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[77] See: https://www.ofcom.org.uk/__data/assets/pdf_file/0017/115631/statement-fixed-wireless-spectrum-strategy.pdf [Accessed 7th March 2022].

[78] Ofcom, 2022. Closure of 26 GHz band to new fixed link licence applications and technical variations.

[79] Ofcom, 2018. Review of spectrum used by fixed wireless services.

[80] Ofcom, 2020. Improving spectrum access for Wi-Fi.

[81] Ofcom, 2022. Enabling spectrum sharing in the upper 6 GHz band.

[82] Ofcom, 2020. Improving spectrum access for Wi-Fi.

[83] Fixed links are used as an input to the production process for a wide range of products and services. This means that it is not possible to separate GVA associated with the use of fixed links from GVA associated with other activities, and therefore it is not possible to reliably estimate the GVA of the fixed links sector.

3.2.4 MOBILE SERVICES

Mobile cellular services ("mobile services") rely on spectrum to transmit and receive data between a network of transmitters and receivers and end users' handsets or smart devices. Originally conceived as voice networks, they now largely carry data alongside voice and SMS communication. These networks support a wide range of data services, such as streaming audio-visual content, using messaging apps, internet access, and gaming.

There has been significant growth in demand for mobile services

Over ten years ago, Ofcom reported that the UK is a nation addicted to smartphones.[84] At that time, a quarter of adults and nearly half of all teens owned a smartphone. In 2020/21, it was reported that 85% of adults and nine in ten of those aged 16-54 used a smartphone and that smartphone penetration in the UK was almost 80%.[85]

This increased usage and data consumption is largely driven by improved accessibility, better networks, larger data packages and the continued evolution of handsets (for increase, improvements in screen resolution or in the quality of cameras). Likewise, viewing high-quality video on smartphones is a major driver of use. As networks have improved, migrating from predominantly 2G voice traffic in the early 1990s to intensive data-driven 5G traffic today, the device mix on networks has evolved. User devices do not just comprise a mix of individual smartphones but include other connected devices (or machines), with the major growth now being seen in IoT devices.[86] This can range from MiFi devices (providing hotspots via Wi-Fi), drones, sensors and vending machines, among a wide range of other connected devices. Additionally, mobile operators have begun to provide Fixed Wireless Access (FWA) services, which is an alternative to fixed broadband with the aim to offer equivalent broadband speeds to households.

Increased mobile handset usage has led to increased consumption of mobile data. Recent years have seen approximately a 40% year-on-year growth in aggregate monthly mobile data traffic over UK public mobile networks – between 2011 and 2021, monthly mobile data traffic rose by a multiple of 20, from 9 million GB to 571 million GB.[87] The launch of 5G in 2019 by mobile operators has meant further increases in traffic as average user speeds have increased relative to 4G, leading to higher mobile data consumption. For instance, OpenSignal found that users of 5G networks consumed over twice as much traffic compared to users of 4G networks.[88]

The mobile sector has catalysed activity in downstream markets

The advances in the speed and coverage of mobile broadband networks have help to catalyse economic activity in downstream markets. This has affected a significant number of markets and can, for example, be

[84] Ofcom, 2011. A nation addicted to smartphones.

[85] 30+ Smartphone Usage Statistics for the UK [2022], Cybercrew, Jan 2022. Available at https://cybercrew.uk/blog/smartphone-usage-statistics-uk/ [Accessed 23rd March 2022].

[86] State of the IoT 2020: 12 billion IoT connections, surpassing non-IoT for the first time, IoT analytics, Sept 2021. Available at: https://iot-analytics.com/state-of-the-iot-2020-12-billion-iot-connections-surpassing-non-iot-for-the-first-time/ [Accessed 23rd March 2022].

[87] Ofcom, 2022. Discussion paper: Ofcom's future approach to mobile markets, based on data from Ofcom's annual Connected Nations reports.

[88] OpenSignal, 2020. 5G users, on average, consume up to 2.7x more mobile data compared to 4G users.

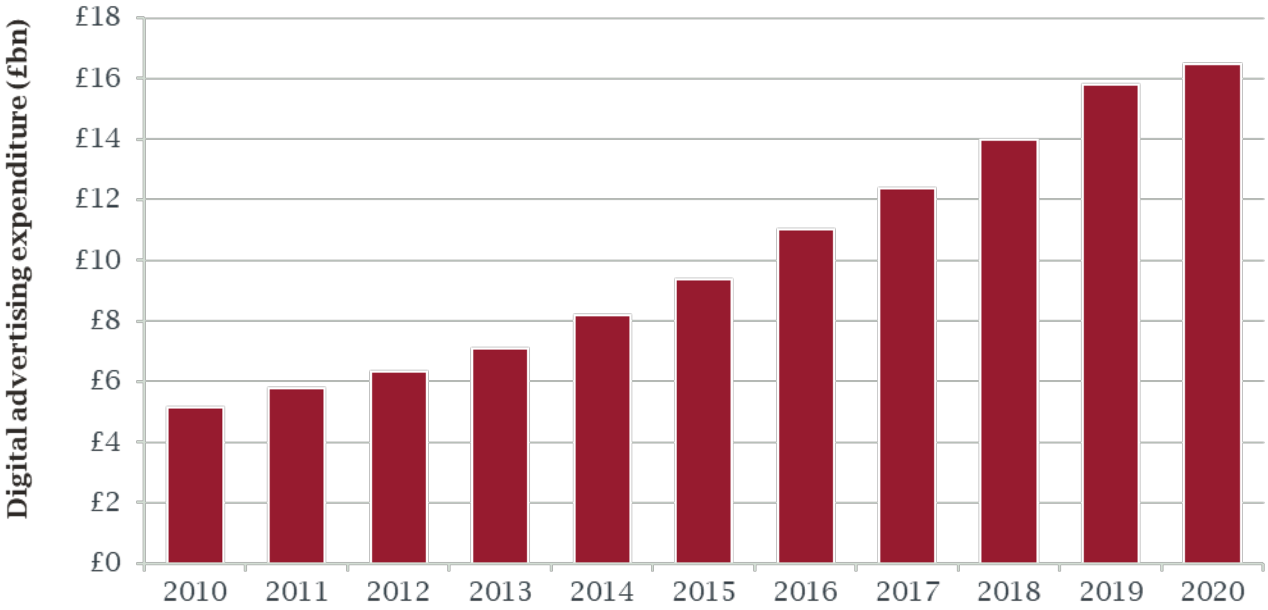
observed in the significant growth in the UK's online advertising, e-commerce and app economy sectors which rely to a degree on mobile broadband networks. Key trends in these sectors are set out below.

- Expenditure on digital advertising in the UK has grown at a compound annual growth rate (CAGR) of 12% between 2010 and 2020, equivalent to a three-fold increase. This is shown in **Figure 5**.

- The amount spent on online retail sales in Great Britain has grown at a CAGR of 18% between 2010 and 2020, equivalent to a five-fold increase. This is shown in **Figure 6**.

- Third-party estimates place the annual rate of growth in the UK app economy at between 16% and 23% in recent years, implying a doubling every 4-5 years.[89]

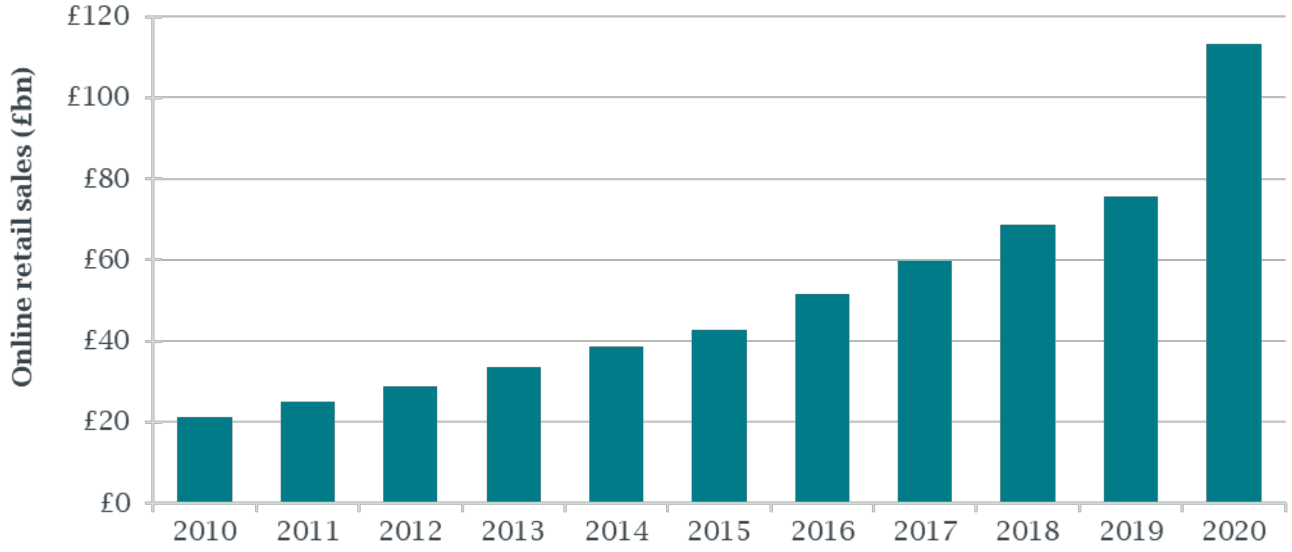
FIGURE 5 UK DIGITAL ADVERTISING EXPENDITURE, 2010-2020



Source: Ofcom, 2021. Media Nations Report 2021, Figure 3.2.

[89] In 2014, Statista, using data from VisionMobile, forecasted that the annual growth rate of the UK app economy would be 22% between 2013 and 2025 (see: https://www.statista.com/chart/2414/britains-app-industry-is-ready-for-takeoff/ [Accessed 7th March 2022]). IBISWorld estimates that the app development in the UK grew by 18.6% between 2017 and 2022 (see: https://www.ibisworld.com/united-kingdom/market-size/app-development/ [Accessed 7th March 2022]). Apple estimate that the earnings of app developers using its App store grew by 22% between 2019 and 2020 (see: https://www.apple.com/uk/newsroom/2021/03/uk-ios-app-economy-has-a-breakthrough-year-grows-to-support-330000-jobs/ [Accessed 7th March 2022]).

FIGURE 6 GREAT BRITAIN ONLINE RETAIL SALES, 2010-2020



Source: ONS. Online and instore retail sales, Great Britain. Available at: https://www.ons.gov.uk/businessindustryandtrade/retailindustry/bulletins/retailsales/latest [Accessed 7th March 2022].
Note: Does not include data on Northern Ireland, which is published separately.

Mobile operators hold approximately 30% of spectrum below 3.8 GHz

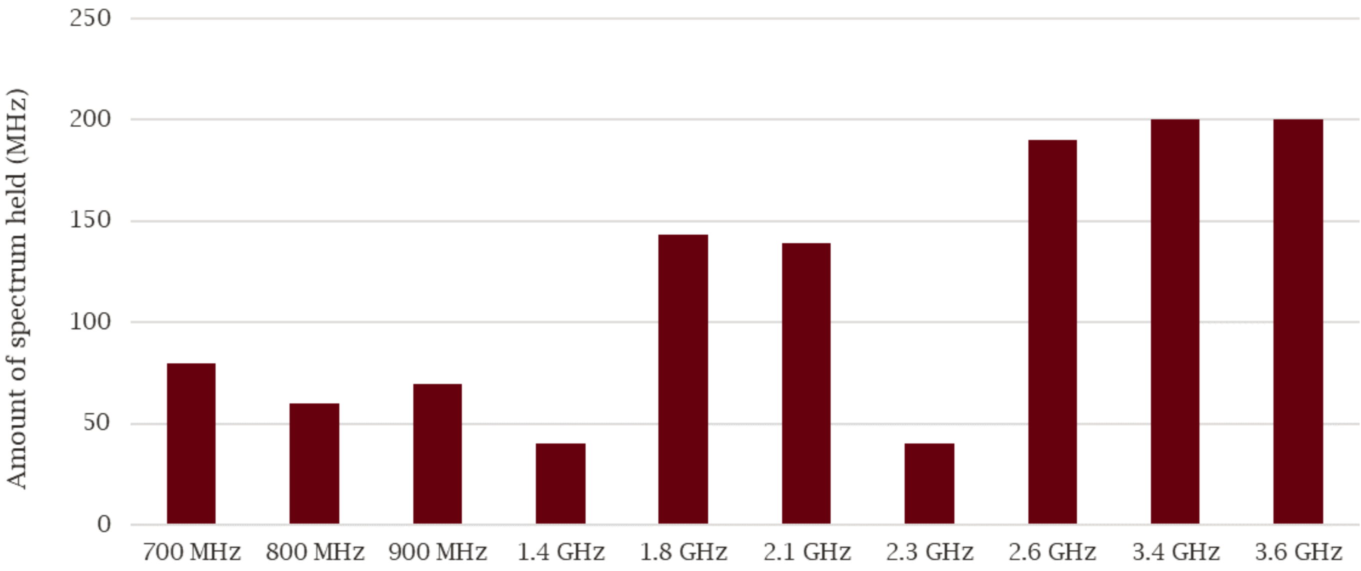
In the UK, mobile services are delivered by four Mobile Network Operators (MNOs): Vodafone, Virgin Media O2, Three, and EE. These MNOs also provide wholesale services to a number of Mobile Virtual Network Operators (MVNOs), who, in turn, supply retail services to their customers. These MVNOs include giffgaff, Tesco Mobile, Sky Mobile, Virgin Mobile, Lycamobile, and others.

The MNOs currently hold 1,152 MHz of spectrum between them in the 700 MHz, 800 MHz, 900 MHz, 1.4 GHz, 1.8 GHz, 2.1 GHz, 2.3 GHz, 2.6 GHz, 3.4 GHz, and 3.8 GHz bands. Most recently, in 2021, Ofcom completed an auction for 60 MHz of spectrum at 700 MHz and 200 MHz in the 3.6–3.8 GHz range, enabling mobile operators to extend their 5G coverage across the UK. Over the next 2-3 years, mobile operators will be focusing on building out their 5G networks to make optimal use of the newly acquired spectrum.

The spectrum held by MNOs accounts for approximately 30% of all spectrum below 3.8 GHz, with MNOs holding 21% of all sub 1 GHz spectrum and 34% of all 1–3.8 GHz spectrum.[90] **Figure 7** presents the holdings of mobile operators by band.

[90] Ofcom, 2021. Ofcom's future approach to mobile markets.

FIGURE 7 SPECTRUM HELD BY MOBILE OPERATORS, BY BAND



Source: Frontier Economics and LS telcom based on data from Ofcom.

ECONOMIC OUTPUT OF THE MOBILE SECTOR

Table 8 below presents the estimated GVA of the mobile sector in 2019, split between MNOs and MVNOs. As this shows, we calculate that mobile services contributed £8.7 billion in GVA in 2019, mostly driven by the contribution of MNOs, who are responsible for large investments in managing their respective networks.

TABLE 8 GVA OF MOBILE SECTOR, 2019

	GVA
GVA	**£8.7bn**
GVA from MNOs	£7.8bn
GVA from MVNOs	£0.9bn

Source: Frontier Economics, based on data from operators' financial statements.

Note: Figures may not sum due to rounding.

These figures capture the value created from major mobile operators' public networks and the activities of MVNOs. As the rollout of private mobile networks is still at a nascent stage, these activities are not included in these figures.

VALUE OF LOW AND MID BAND SPECTRUM USED IN THE MOBILE SECTOR

This section compares mobile operators' valuations for low (sub 1 GHz) and mid-band (1-3.8 GHz) spectrum based on the amount paid in auctions or annual licence fees.

As noted in earlier sub-sections, mobile operators in the UK make use of a range of frequencies between 700 and 3.8 GHz.

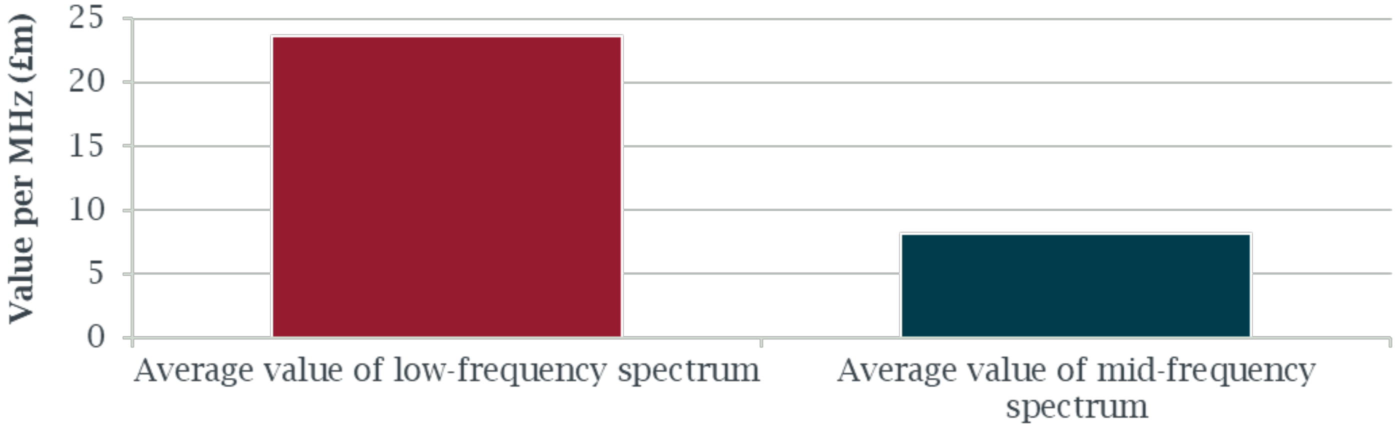
- **Sub-1 GHz spectrum (i.e. low-frequency spectrum).** This spectrum can efficiently provide wide coverage in sparsely populated areas at a lower cost as fewer base stations are required to achieve greater geographic coverage. It is also used to improve indoor coverage in urban areas.

- **1–15 GHz spectrum (i.e. mid-frequency spectrum).** This spectrum is used to increase network capacity in more densely populated urban and suburban areas where demand for network capacity is high. In practice, the mobile sector currently only uses spectrum up to the 3.8 GHz band in the UK.

- **Supra-15 GHz spectrum (i.e. high-frequency spectrum).** At present, this type of spectrum is not used for mobile services in the UK. However, its high bandwidth means that in the future, it may be possible to use bands such as 26 GHz and 40 GHz to provide ultra-high-speed mobile broadband in urban areas.

Using data on prices paid for spectrum by mobile operators in awards in the UK, **Figure 8** compares estimates of the average value operators attribute to a MHz of low- and mid-frequency spectrum. It shows that operators placed a significant premium (291%) on low-frequency spectrum compared to mid-frequency spectrum. The average value in the 700-900 MHz bands is £23.6 million per MHz per annum compared to £8.1 million per MHz per annum across the 1.8–3.6 GHz bands. [91]

FIGURE 8 AVERAGE VALUE PER MHZ OF LOW AND MID FREQUENCY SPECTRUM USED BY MOBILE SECTOR



Source: Frontier Economics based on data from Ofcom.

Note: Ofcom's "lump-sum" values account for differences in the timings of the award, licence duration and the amount of spectrum in each band in order to express the amount paid per MHz on a comparable basis (standardised to a 20-year licence duration). Caution should be exercised in interpreting data on outcomes of auctions since the prices paid by operators for spectrum, particularly those determined through an auction, can be affected by a range of factors (such as coverage obligations or spectrum caps). Although averaging prices across bands reduces the effect of any single auction/assignment, this analysis is still subject to outlier effects and therefore needs to be interpreted with caution.
Does not include the 1.4 GHz or unpaired 2.1 GHz spectrum.

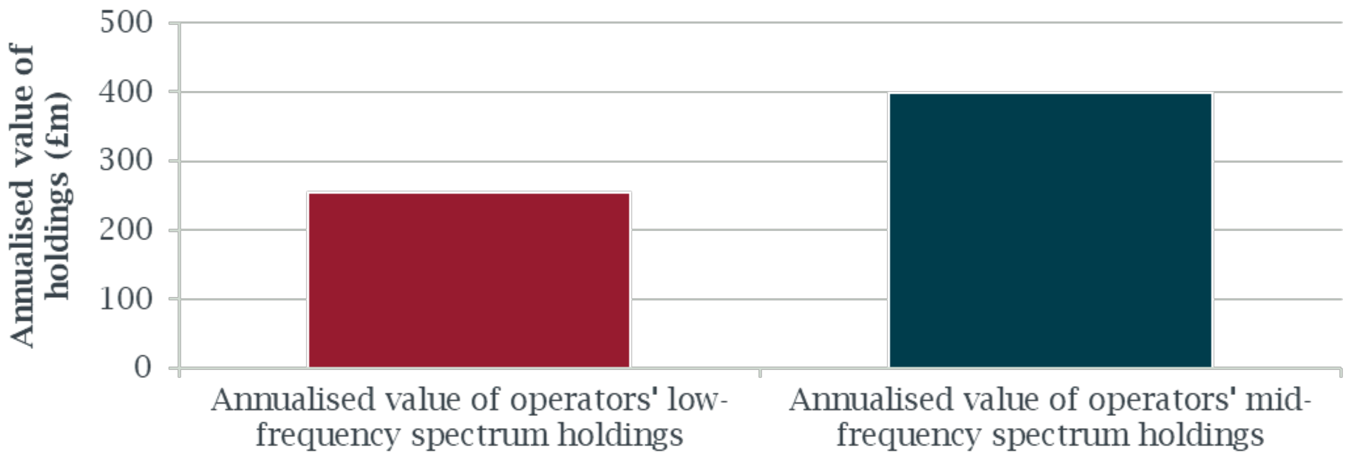
Figure 9, below, compares the annualised value of operators' holdings of low-frequency (sub 1GHz) and mid-frequency (1.8–3.6 GHz) spectrum. It shows that the annualised value of operators' mid-frequency spectrum holdings is 56% higher than their low-frequency holdings.

[91] In April 2021 prices.

This analysis demonstrates the following.

- On a per MHz basis, operators are willing to pay more for low-frequency spectrum than mid-band spectrum. This is driven by the fact that low-band spectrum is scarcer.
- However, even though the price per MHz of low-frequency spectrum is higher, operators spend more, in total, on mid-band spectrum as they hold more (over four times as much) mid-band than low-frequency spectrum.

FIGURE 9 ANNUALISED VALUE OF OPERATORS' LOW- AND MID-BAND FREQUENCY SPECTRUM HOLDINGS



Source: Frontier Economics based on data from Ofcom

Note: These estimates are based on multiplying lump-sum prices by the amount of spectrum held by operators in each band. The prices used adjust for differences in the timings of the award and the amount of spectrum in each band in order to express the amount paid per MHz on a comparable basis. Caution should be exercised in interpreting data on outcomes of auctions since the prices paid by operators for spectrum, particularly those determined through an auction, can be affected by a range of factors (such as coverage obligations or spectrum caps). Although averaging prices across bands reduces the effect of any single auction/assignment, this analysis is still subject to outlier effects and, therefore, cannot assess the precise relativity of operators' private values.
Annualised using the same methodology as employed by Ofcom when setting ALFs in the 2100 MHz band.
Does not include the 1.4 GHz or unpaired 2.1 GHz spectrum.

ECONOMIC EXTERNALITIES GENERATED BY MOBILE SERVICES

Mobile services also create wider value beyond that which is captured in the direct contribution to the economy. These externalities can be hard to measure; however, they are nonetheless important sources of value. They are summarised below.

Productivity benefits

The use of spectrum in mobile services creates substantial value through positive effects on productivity, increasing the effectiveness of both labour and capital beyond what would be possible absent spectrum. Labour productivity increases are driven by factors including the ability to communicate and access information remotely, the use of mobile-based collaboration and productivity tools, and reduced search and information costs.[92] Capital productivity improvements can also be realised by reducing the need for computers, office space or other capital-intensive processes.

Research has found that mobile telecommunications contributed 0.37% annually to productivity growth in the UK between 1990 and 2008.[93] And a separate study has found that across the period 1995–2010, if a country had a 10% higher mobile penetration, in the long run, and all else equal, it would, on average, experience a total factor productivity (TFP) increase of 4.2 percentage points.[94, 95] Other studies have considered the impact of mobile services on labour productivity specifically. A 2016 paper estimated that a one percentage point increase in the number of employees with mobile internet access is causally associated with 0.2% higher labour productivity.[96] Another found that a 10% increase in broadband speeds in one year is associated with a 0.2% increase in labour productivity the following year.[97]

Social cohesion, inclusion and well-being

For a proportion of users, mobile services bring positive externalities relating to social cohesion and connection. The reduction in social isolation and increased access to services can improve well-being and civic participation through several channels.

For example, for some users, mobile services provide the ability to easily create and maintain social relationships through mobile messaging or social media apps, which can increase interpersonal communication and connectivity. In the context of workplace inclusion, mobile technology can remove locational barriers to employment, enable flexible working arrangements and allow for mobile job searching.[98] These factors can increase labour participation and foster workplace inclusion. This not only benefits the individual but the wider economy. Mobile technology can also foster social inclusion and wellbeing for certain communities. For example, mobile-based technology has been shown to reduce social isolation for the elderly, improve physical and mental well-being outcomes, as well as increase social inclusion among adults with learning disabilities.[99, 100]

The extent to which mobile spectrum specifically is necessary for enabling these social externalities is difficult to determine but most likely varies. For example, in a no spectrum scenario, while some of the social connectivity enabled through the use of mobile messaging and social media apps could be achieved via the use of fixed networks, it is likely to be greatly diminished. On the other hand, it is less clear that the increased use and availability of fixed networks would not be able to recreate the workplace inclusion benefits generated by the use of mobile spectrum.

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[92] See, for instance: Gruber & Koutroumpis, 2011. Mobile telecommunications and the impact on economic development and Kretschmer, 2012. Information and communication technologies and productivity growth: a survey of the literature.

[93] Gruber & Koutroumpis, 2011. Mobile telecommunications and the impact on economic development.

[94] Total Factor Productivity (TFP) refers to the ratio of aggregate output (GDP) to aggregate inputs. In the cited paper, TFP is defined by the equation *GDP = TFP x f(Capital, Labour,...).*

[95] Deloitte, 2012. What is the impact of mobile telephony on economic growth?

[96] Bertschek & Niebel, 2016. Mobile and more productive? Firm-level evidence on the productivity effects of mobile internet use.

[97] Edquist, 2021. The Economic Impact of Mobile Broadband Speed.

[98] For example, in 2019, research by Glassdoor estimated that 58% of users searched for jobs via mobile devices, see https://www.glassdoor.com/research/app/uploads/sites/2/2019/06/Mobile-Job-Search-1.pdf [Accessed 7th March 2022].

[99] Sen et al., 2021. The use of digital technology for social wellbeing reduces social isolation in older adults: A systematic review.

[100] Martin et al., 2021. The role of mobile technology in promoting social inclusion among adults with intellectual disabilities.

Environmental impact

Mobile services generate both positive and negative environmental impacts. There are two predominant channels via which mobile services generate negative impacts through carbon emissions:

through the emissions associated with the equipment and processes used to deliver mobile spectrum (i.e. emissions generated by mobile network operators themselves); and

through emissions associated with the (downstream) activities enabled by mobile spectrum use (e.g. the manufacture and use of mobile phones to, for example, stream videos).

Globally, in 2019, the mobile sector, through these channels, was estimated to be responsible for 0.4% of emissions.[101] However, mobile services also play a significant role in reducing emissions. For example, this can be through the behavioural changes enabled by the use of smartphones (such as reduced travel) and through the use of smart technologies that reduce emissions (see **Annex B** for more detail on such smart technology use cases). It has been estimated that globally, in 2019, the annual reduction in emissions through the use of mobile services was 10 times higher than the emissions produced by the mobile sector.[102] Additionally, in the UK, all operators have made pledges to reduce carbon emissions in their network and their supply chain (see **Annex B** for more details on actions already taken by UK MNOs).

3.2.5 PROGRAMME MAKING AND SPECIAL EVENTS (PMSE)

The term PMSE describes radio applications used for Services Ancillary to Programme Making (SAP), Services Ancillary to Broadcasting (SAB), Electronic News Gathering (ENG), and Outside Broadcasting (OB). The equipment that makes use of PMSE applications includes wireless microphones, walkie-talkies, in-ear monitors and talkback systems, and production services for radio, TV, theatre, live music or sports events, and corporate events. This equipment requires spectrum to transmit and receive data, usually over relatively short distances and is used in a variety of different events: film and television programme-making, outdoor events, and theatre productions. PMSE spectrum is used by different types of providers to support their programme-making and events, from large broadcasters to local community organisations.[103]

PMSE spectrum is licensed on a temporary, localised basis. Equipment tends to operate at low power so as not to cause interference to other users, and licences are approved using an online licensing portal facilitated by Ofcom, where users can book short-term or long-term frequencies for their events or usage within studios and other venues. [104]

There are approximately 100 frequency bands available to support the different equipment uses. **Table 9** below sets out the frequency bands used for some of the sector's key use cases. Specific details on each frequency allocation can be found in Ofcom's Interface Requirement document IR2038.[105]

[101] GSMA, 2019. The Enablement Effect. Available at https://www.gsma.com/betterfuture/wp-content/uploads/2019/12/GSMA_Enablement_Effect.pdf [Accessed 7th March 2022].

[102] GSMA, 2019. The Enablement Effect. Available at https://www.gsma.com/betterfuture/wp-content/uploads/2019/12/GSMA_Enablement_Effect.pdf [Accessed 7th March 2022].

[103] Some wireless microphones and video equipment are classified as licence-exempt where their use is not likely to involve any undue interference to other legitimate use of radio spectrum. See: https://www.ofcom.org.uk/spectrum/radio-spectrum-and-the-law/licence-exempt-radio-use [Accessed 9th March].

[104] See: https://www.ofcom.org.uk/manage-your-licence/radiocommunication-licences/pmse [Accessed 12th April].

[105] UK Interface Requirement 2038 PMSE, Ofcom. Available at https://www.ofcom.org.uk/__data/assets/pdf_file/0017/10781/ir2038.pdf [Accessed 12th April 2022].

TABLE 9 FREQUENCY BANDS USED BY THE PMSE SECTOR

USE	APPROX. FREQUENCY WITHIN THE RANGE (MHZ)	CHANNEL BANDWIDTH (KHZ)	COMMENT
Radio microphones and in-ear monitors	175-210	200	
	470-698		
	823-832		
	961-1154		
	1785-1805		
Talkback	47–86	12.5	Numerous sub-band ranges identified
	139–189	12.5	
	427–470	12.5 & 50	
	470–694	25	
Audio links and Audio distribution	48–62	50/75/200	Numerous sub-band ranges identified
	191–200	200	
	425–469	50	
	467–469		
	470–698	200	
	1517–1525	500	
Wireless cameras and video links	2000–3400	10000	Numerous sub-band ranges identified
	5472-5925	20000	
	7110-10360	10000/20000	
	12200-12475	20000	
	24250–24500	25000	
	48000-48400	100000	
Telemetry and Telecommand links	181–189	12.5	Numerous sub-band ranges identified
	462	12.5	
	470–478	25	

Source: Frontier Economics and LS Telcom based on data from Ofcom.

VALUE CREATED BY THE PMSE SECTOR[106]

PMSE equipment is used as an input in the production process of broadcasters and journalists and in the events industry. These sectors contribute substantial amounts to the UK economy.

- As set out above, we calculate that the broadcasting sector contributed £4.1 billion in GVA in 2019.

- Third-party research has estimated that the UK events industry generated around £31 billion in 'direct spend' for business-related events and around £39 billion in leisure events.[107] Over 30 million fans attended gigs and music festivals in 2019, contributing £4.5 billion to the UK economy. 34 million theatre tickets were sold in 2018. Since then, the use of live-streams and recordings has opened up the sector to new audiences.[108] These estimates of value are not comparable to GVA and will include a number of events that do not utilise any PMSE equipment but do serve to demonstrate the importance of the sector to the UK economy.

The use of spectrum by the PMSE sector enables value in a number of ways.

- It reduces cost and logistical challenges at major events by removing the need for expensive and intrusive cabling.

- It allows journalists to broadcast from difficult locations. Absent PMSE spectrum, it would be significantly more cumbersome to broadcast from these locations.

- It enhances the quality of both the broadcasting of live events and the events themselves. For instance, PMSE spectrum enables viewers to see angles they would not otherwise have seen and enables performers to move around more freely.

3.2.6 PRIVATE MOBILE RADIO (PMR)

PMR, or business radio, systems are used by organisations to operate their own private mobile communication networks. Private-sector use cases for PMR include utilities, logistics, construction, transport, chemicals, and entertainment sectors. PMR can be used over a local area (for instance, over a construction site or warehouse) or over a wide area (for instance, to coordinate across a local train network). For this reason, Ofcom offers five licence types. These licences permit a range of uses from mobile-to-mobile communication anywhere in the UK without the use of a base station (Simple Site licence) to an Area Defined licence, which allows exclusive use of a frequency within a defined area.[109]

PMR users have historically used narrowband channels for wide area and local voice networks and data networks. However, in recent years, some services delivered using PMR spectrum (e.g. Digital Mobile Radio) have been transferred to using cellular technology and services provided by cellular operators. This change

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[106] Although there are some dedicated suppliers of PMSE equipment and services, it is not possible to accurately calculate the GVA of firms in the PMSE sector since many large broadcasters and event organisers self-supply PMSE. Therefore, it is not possible to differentiate between GVA from PMSE activities from other activities.

[107] BVEP, 2020. The UK Events Report. How Events Delivers the UK's Industrial Strategy.

[108] SHURE presentation to the European Commission's Workshop on the Sub-700 MHz band. Available at: https://digital-strategy.ec.europa.eu/en/library/presentations-workshop-sub-700-mhz-band [Accessed 12th April 2022].

[109] Ofcom, 2022. Business Radio Technical Frequency Assignment Criteria.

has occurred due to the reduction in the cost of provision of cellular services and as increased data rates on 4G have unlocked access to new services across an all-IP platform.

The PMR bands are traditionally in the VHF and UHF frequency ranges, and licences are assigned by Ofcom in the bands shown in the table below. More detail on the different types of usage, notably at UHF, can be found in Ofcom's Strategic Review of UHF 1 and UHF 2.[110]

TABLE 10 FREQUENCY BANDS USED BY THE PMR SECTOR

BAND	FREQUENCY FROM (MHZ)	FREQUENCY TO (MHZ)	BANDWIDTH (MHZ)	NOTE
Band I	56	68	12	
VHF-Low	68	87.5	19.5	
VHF-Mid	138	165	24	(Excludes 144 - 147 MHz)
VHF-High	165	173	8	
Band III	177.2	191.5	14.3	
	380	399.9	19.9	2x5 MHz used for Tetra services (such as Airwave), the rest remains MoD
UHF I	410	450	15	(Excludes 430-440 MHz - except in London)
UHF II	450	470	20	

Source: Frontier and LS Telcom based on data from Ofcom.

VALUE CREATED BY THE PMR SECTOR

While it is not possible to accurately calculate the GVA of firms in the Private Mobile Radio (PMR) sector, work from the industry highlights the range of benefits that the sector enables.[111, 112] These are described in more detail below and include logistical, safety, resilience, environmental and productivity benefits.

- **Logistics.** PMR is needed to ensure the smooth running of key services such as underground trains, ports, tower cranes on building sites, traffic services, and utilities. These services use private radio

[110] Ofcom, 2017. Statement: Strategic Review of UHF1 and UHF2. Available at: https://www.ofcom.org.uk/__data/assets/pdf_file/0017/102185/Statement-on-strategic-review-of-UHF-Band-1-and-Band-2.pdf [Accessed 11th April 2022].

[111] It is not possible to accurately calculate the GVA of firms in the PMR sector since it is an input to the production process for a wide range of products and services (ranging from large utility companies to small local organisations such as the Scouts).

[112] See https://www.fcs.org.uk/business-radio/business-radio-group/ [Accessed 8th March 2022] and Joint Radio Company, 2012. Radio Spectrum is used by Utilities in support of their operations.

networks to coordinate between units, for example, between utility maintenance workers or taxi drivers, so that they can be used most efficiently.

- **Safety.** PMR is used to ensure safety in a range of contexts. For example, PMR enables security services to communicate effectively and operate efficiently. Without PMR, it would not be possible for security workers to work alone and instead would require crews of at least 2 staff members rather than 1 member with a radio set, increasing response times and costs. Another example is in overground rail networks, where PMR is used as a safety system to prevent collisions and deal with obstacles on the tracks.

- **Resilience.** The use of PMR to enable critical services (such as utilities or transport) provides resilience benefits beyond the direct improvements in logistics and safety for users. For example, in the utilities sector, PMR is used during critical incidents, such as electricity network outages, to monitor, manage and restore services in a timely and effective way. This contributes to resilience through greater security of supply in the network, benefitting all users and the wider economy. Using US and UK data, the Joint Radio Company (JRC) estimated that the socio-economic value of reliable electricity supplies, which PMR enables, provides a societal benefit of 50 to 100 times the value of the electricity itself.[113]

- **Environmental and productivity externalities.** PMR use also enables wider externality benefits beyond those listed above. For example, the JRC highlights that the use of PMR in the utilities sector is required to enable greener “smart grids”, where communications to monitor network load is needed for the network to function. In this way, PMR generates a positive environmental externality by enabling reductions in carbon emissions. Also, by enabling the efficient operation of transport networks (e.g. trains or taxis), PMR helps reduce journey times for workers, contributing to societal productivity.

It is clear that the quality of services that rely on PMR would be vastly reduced in the absence of spectrum.[114][115] The impact would be most apparent in cases where critical services are needed or PMR is required to ensure safety, and availability must be in the order of 99.999%. This is the case for the utilities and transport sectors. The JRC state that for these sectors, *“business radio is either non-substitutable, or only at such a cost that it is not realistically possible for them to offer the same services”.*[116]

3.2.7 WI-FI AND OTHER LICENCE-EXEMPT USES OF RADIO SPECTRUM

‘Wi-Fi’ describes a family of wireless local area networking (WLAN) technology standards developed by the Institute of Electrical and Electronics Engineers (IEEE). It uses licence-exempt spectrum to connect devices wirelessly in a small area, usually indoors. It provides the final link between broadband routers and Wi-Fi enabled devices. Wi-Fi devices operate across a range of bands. At present, in the UK, Wi-Fi most commonly operates in the licence-exempt Industrial, Scientific and Medical (ISM) spectrum bands at 2.4 GHz (most commonly used by home Wi-Fi routers) and 5 GHz. However, there is an ongoing debate around whether it could also operate in the upper 6 GHz band.

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[113] Joint Radio Company, 2012. Radio Spectrum used by Utilities in support of their operations.

[114] FCS, 2010. The Strategic Review of Business Radio.

[115] Joint Radio Company, 2012. Radio Spectrum used by Utilities in support of their operations.

[116] Joint Radio Company, 2012. Radio Spectrum used by Utilities in support of their operations.

Alongside Wi-Fi, there are a large number of other devices that currently use licence-exempt spectrum to provide connectivity over a variety of standards. This includes some IoT networks, as well as a wide range of high- and low-power devices such as wireless headsets and hands-free devices based on the Bluetooth standard; baby monitors; remote locking/opening devices for cars, gates and garages; radio-controlled models; and medical devices with remote monitoring.

Given the wide range of devices and sectors that rely on licence-exempt spectrum, it is not possible to identify and define a “licence-exempt sector”. Instead, this section sets out the direct economic contribution of the fixed telecoms sector (which relies on the use of Wi-Fi for connections between devices and networks). Although we are not able to quantify the benefits created by other licence-exempt uses of spectrum, it is clear that the opportunities for businesses to innovate without having to purchase a licence to access the necessary spectrum are significant.

Recent trends in the Wi-Fi sector

There have been increases in traffic carried over Wi-Fi networks, driven by increases in the use of data-hungry applications like movies and gaming, particularly at home. In the last decade, the average volume of data traffic consumed per fixed connection rose from 17 GB a month in 2011 to 453 GB a month in 2021.[117] By comparison, the average monthly mobile data use per data user over public mobile networks was 5.3 GB a month in H1 2021.[118]

Wi-Fi is also becoming increasingly important for smart device connectivity. For instance, the number of installed smart home Wi-Fi devices is forecast to reach 17 billion globally by 2030.[119]

There is uncertainty as to what impact increases in the usage of mobile data will have on the usage of Wi-Fi. Increases in unlimited data plans may mean that more traffic moves to mobile networks. For example, Ofcom found that people using the Three network used a higher proportion of data over mobile than customers using other networks, which may be driven by higher take-up of high and unlimited data tariffs amongst Three customers. On the other hand, despite recent advances in mobile networks, Wi-Fi remains by far the most common way of connecting to the internet. In 2021, 73% of data connections were made over Wi-Fi networks. This was an eight-percentage point increase relative to 2019 levels; however, this was likely driven by the impact of Covid-19 restrictions.[120]

ECONOMIC OUTPUT CREATED BY WI-FI

Fixed telecoms networks contributed £11.7 billion of GVA in 2019. This figure captures the value created from major fixed operators’ fixed networks as well as their business networks. Wi-Fi only provides the final link between broadband routers and Wi-Fi enabled devices, and there will be many use-cases where the final link is through a wired connection. Given this, it would be incorrect to state that this GVA is enabled by Wi-Fi networks.

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[117] Ofcom, 2021. Connected Nations 2021: UK report.

[118] Ofcom, 2022. Discussion paper: Meeting future demand for mobile data.

[119] Strategy Analytics, 2022. 2022 Global Smart Home Devices Forecast - January 2022. Available at: https://www.strategyanalytics.com/access-services/devices/connected-home/smart-home/market-data/report-detail/2022-global-smart-home-devices-forecast---january-2022 [Accessed 7th March 2022].

[120] Ofcom, 2021. Mobile Matters.

It is not possible to accurately quantify how much the GVA from the fixed sector would be reduced in the absence of spectrum. While, in many cases, wired connection provides a direct substitute for Wi-Fi, it provides a convenient way of accessing fixed networks and allows users to connect devices that would not otherwise be able to be connected using fixed ports (e.g. mobile devices).[121] Absent spectrum, it is likely that replicating the connectivity benefits of Wi-Fi using fixed ports would require significant investment and space and - in many cases - be impractical, leading to significant reductions in the value the sector is able to create.

ECONOMIC EXTERNALITIES CREATED BY WI-FI

Wi-Fi networks and other licence-exempt uses also create wider value beyond that which is captured in the direct contribution to the economy. These externalities are summarised below.

Productivity

There is evidence to suggest that access to high-speed broadband can lead to improvements in wider economic outcomes.[122][123][124] For example, in a sample of high- and medium-income countries (including the UK), one study estimated, using data from 1980-2007, that for every 1 per cent increase in broadband penetration, productivity grew by 0.13 per cent.[125] These benefits are achieved through a number of channels.

- Reducing labour and capital costs for businesses through improvements such as cloud computing, which allow for faster access to data and require less investment in physical storage.
- Improved output, either through making workers more productive or by allowing for the creation of new products or services (or improving existing services).

While many of the productivity benefits from broadband are realised through the use of Wi-Fi networks, there is relatively little evidence of the specific impact of Wi-Fi on productivity. One exception to this is a study which used Finnish firm-level data to estimate the labour productivity effects of ICT technology using different types of connectivity.[126] The authors found that computers with wireless connectivity (WLAN) boosted labour productivity by 6%.[127]

Academic work has also found that IoT networks have a positive but relatively small impact on labour productivity in the US and the EU. The small impact is likely due to IoT networks being at a relatively nascent stage in development, with projections suggesting that IoT will contribute more to productivity growth in the future.[128]

[121] Previous research from 2012 has estimated that 15% of households would disconnect if Wi-Fi was unavailable. However, this research is now 10 years old and may not account for recent trends in the type of devices that use Wi-Fi and consumer preferences for how they use Wi-Fi. R Thanki, 2012. The economic significance of the licence-exempt spectrum to the future of the Internet.

[122] Gruber et al., 2014. Broadband access in the EU: an assessment of future economic benefits.

[123] Koutoumpis, 2009. The economic impact of broadband on growth: a simultaneous approach.

[124] Kongaut and Bohlin, 2014. Impact of broadband speed on economic outputs: An empirical study of OECD countries.

[125] Waverman, 2009. Economic Impact of Broadband: An Empirical Study.

[126] Labour productivity is defined as output per worker.

[127] Maliranta and Rouvinen, 2006. Informational Mobility and Productivity – Finnish Evidence.

[128] Espinoza et al., 2020. Estimating the impact of the Internet of Things on productivity in Europe.

As noted above, in the absence of spectrum, Wi-Fi could, in some instances, be substituted with fixed connections. However, it is likely that these connections would require significant investment and space and, in many cases, be impractical. This could result in a reduction in the overall level and efficiency of devices currently using Wi-Fi networks, reducing the level of productivity benefits they enable. Similarly, IoT networks are, by their nature, entirely reliant on spectrum. In a no spectrum counterfactual, all the value generated by IoT networks, and the accompanying productivity externalities, would be eliminated.

Environmental

While very little work has looked into the emissions of Wi-Fi and IoT networks, both the networks and the users will create pollution, as seen in mobile and satellite networks. This is through, for example, the energy required for the production and use of equipment, such as Wi-Fi routers and Wi-Fi enabled and IoT devices.

At the same time, the use of these Wi-Fi and IoT networks, as described in the case of mobile networks previously, can act as an enabler for smart devices that can aid in reducing emissions, and in the absence of spectrum, many of the devices currently using these networks would cease to be practical. In addition to this, the use of Wi-Fi and IoT networks enabled by fixed connections could provide a more energy-efficient alternative to using mobile networks, particularly in rural areas. For instance, work from the German Federal Ministry for Environment, Nature Conservation, Nuclear Safety and Consumer Protection noted that fixed networks are, in the set of circumstances that were assessed, more energy-efficient than mobile networks for streaming HD video.[129]

3.2.8 AVIATION

Spectrum is essential for the operation of the aviation industry. Spectrum enables flight, airline and air traffic management operations by enabling air traffic control's use of ground-based radars, airborne systems (e.g. measuring altitude), navigation systems, communication from the aircraft to traffic control, and navigation aids which are essential for landing systems.

The spectrum allocation for the aviation industry is determined internationally by the International Telecommunications Union (ITU), the UN agency responsible for telecommunications. Due to the need for international alignment, large amounts of spectrum used by the aviation sector are internationally harmonised.

In the UK, the Civil Aviation Authority (CAA) is responsible for managing aviation spectrum on behalf of Ofcom and the Ministry of Defence (MOD). It also ensures that users of the band meet safety requirements and coordinates the use of spectrum bands in the UK with military users. The frequencies they manage include:

- 117.975–137.000 MHz (used for aviation communications);
- 960-1164 MHz (used for distance measuring equipment and secondary surveillance radar); and
- 2.7-2.9 GHz (used primary for surveillance radar).

In 2018, following efforts from the CAA, Ofcom and the PMSE sector to ensure that safety requirements could be met, the UK aviation industry was able to share spectrum in the 960-1164 MHz band with the PMSE sector. Sharing with cellular services has been explored in other bands, such as the 2.7-2.9 GHz primary

[129] Federal Ministry for Environment, Nature, Conservation, Nuclear Safety and Consumer Protection, 2020. Video streaming: data transmission technology crucial for climate footprint. Available at: https://www.bmuv.de/en/pressrelease/video-streaming-data-transmission-technology-crucial-for-climate-footprint/ [Accessed 9th March 2022].

surveillance band. However, it was deemed that sharing would not be possible without the closure of radars. This exercise also found that many radars have poorly designed receivers, which do not help spectrum sharing. The CAA confirmed it is working to resolve this issue.

ECONOMIC OUTPUT OF THE AVIATION SECTOR

There are over 60 airports in the UK,[130] with London Heathrow being recognised as a European Hub airport.[131] A report commissioned by Airlines UK estimated that in the UK in 2021, 74,000 people were employed in the airlines sector, and 66,000 more were employed at airports or in other support activities.[132] We estimate that the GVA of the aviation sector in 2019 was **£10.7 billion.**[133]

Although spectrum will only account for a small proportion of the sector's expenditure, it is a critical input without which it would be impossible to ensure safety in the sector. This means that absent spectrum, the vast majority of activity would not be able to take place.

ECONOMIC EXTERNALITIES GENERATED BY THE AVIATION SECTOR

The aviation sector has a wider impact beyond that which is captured in the direct contribution to the economy. This impact can be hard to measure but is nonetheless important to capture. The externalities created by the sector are summarised below.

- **Productivity benefits**. The aviation industry increases a country's connectivity, raising productivity through more investment, innovation and higher quality employees, which, in turn, improves the productivity of an economy.[134]

- **Environmental impact.** The aviation industry is a carbon-intensive form of transport, accounting for 7% of UK GHGs.[135]

In the absence of spectrum, potential reductions in trade volumes could lessen both the magnitude of the negative environmental externality and the positive productivity benefit created by the sector.

3.2.9 DEFENCE

The defence sector is the largest public-sector user of spectrum in the UK.[136] Spectrum allocated for defence use in the UK is assigned and managed by the MOD and is used for military purposes for a diverse range of uses, such as; narrowband telemetry, military radar, aeronautical mobile systems for surveillance, tactical relay links, and air operations.

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[130] See: https://www.caa.co.uk/data-and-analysis/uk-aviation-market/airports/ [Accessed 9th March, 2022].

[131] See, for instance, paragraph 14 of House of Commons Committee on Exiting the European Union, 2017. Aviation Sector Report.

[132] YorkAviation, 2021. Aviation jobs in Great Britain.

[133] This estimate includes the value-added created from all activities related to the transport of passengers or freight over the air as well as service activities incidental to air transportation (such as the operation of airport facilities and navigation, pilotage and landing activities).

[134] Sustainable aviation, 2016. UK Aviation industry socio-economic report.

[135] Climate Change Committee, 2020. The Sixth Carbon Budget, Aviation. Sector summary.

[136] MOD, 2019. Electromagnetic Spectrum Blueprint.

Spectrum reserved for military use covers a wide range of frequencies from very low frequencies (sub 1 MHz) to very high frequencies (supra-90 GHz). It is allocated in the UK Frequency Allocation Table (FAT) in accordance with various allocations, with the main service categories being radio-location, radio-navigation and radio-navigation satellite. Many of these allocations are not specific to the UK and are designated for similar purposes, either across NATO countries (of which the UK is a part) or internationally.

While the MOD and the armed forces (Royal Navy, Royal Marines, British Army, and Royal Air Force) are the direct users of spectrum licenced by the MOD, the UK has a significant private defence sector that also benefits from the armed forces' use of spectrum.

In March 2021, the UK Government published its Integrated Review of Security, Defence, Development and Foreign Policy. To enable the objectives set out in the Integrated Review, the Government announced it would increase defence spending by £24.1billion over the following four years. This included £6.6 billion on new research and development, some of which would involve investment in technologies that rely on spectrum.[137]

Public Sector Spectrum Release Programme

The UK Government set out a plan to release, between 2011 and 2022, 750 MHz of spectrum used by the public sector.[138] The MOD has contributed to meeting the Public Sector Spectrum Release Programme target, sharing approximately 85% of the frequency bands it manages with other users, including other government departments and the civil sector. As of 2019, it had already released or shared 572 MHz of spectrum across a range of low and medium frequencies. This is shown in **Table 11** below.

TABLE 11 SPECTRUM RELEASED BY THE DEFENCE SECTOR AS OF 2019

BAND	QUANTITY	YEAR	RELEASED OR SHARED?
870 - 872 MHz 915 - 917 MHz	4 MHz	2014	Released
2.025 – 2.070 GHz	45 MHz	2015	Shared
Upper 2.3 GHz (2.350-2.390 GHz)	40 MHz	2015	Released
3.4 GHz (3.410-3.600 GHz)	190 MHz	2015	Released
5.7 GHz (5.725-5.850 GHz)	125 MHz	2017	Shared
7.9 - 8.4 GHz	168 MHz	2019	Shared
Total	**572 MHz**		

Source: MOD, 2019. Electromagnetic Spectrum Blueprint.

[137] UK Gov, 2021. Global Britain in a Competitive Age: the Integrated Review of Security, Defence, Development and Foreign Policy.

[138] In March 2011, the Defence Minister endorsed the DCMS paper 'Enabling UK growth – releasing public spectrum', agreeing to make 500 MHz of spectrum available by 2020 as part of the Public Sector Spectrum Release Programme. In the Budget statement of 2016, it was announced that the target would be increased to 750 MHz by 2022.

Since 2019, the MOD has continued to free up spectrum for sharing or release and has played a key role in the freeing up of 687 MHz of spectrum throughout the course of the Public Sector Spectrum Release Programme (i.e. 63 MHz less than the target for the end of 2022).

ECONOMIC OUTPUT OF THE DEFENCE SECTOR

Below we discuss the direct economic contribution made by the defence sector to the UK in terms of investment, GVA, employment and exports, and the direct non-monetary benefits created by the sector.

It has not been possible to assess and list the wide range of activities for which the military uses spectrum. However, in general, it is clear that the needs of the defence sector around communication and navigation mean that spectrum is core to its activities. It is likely that absent spectrum, the direct economic contribution and the non-quantifiable direct benefits created by the defence sector would be greatly diminished.

- **Investment.** The defence sector spent over £20 billion in the UK economy in 2019/20.[139] This expenditure supports a range of UK jobs and businesses. The 2020 Spending Review announced a further investment of over £24 billion over the next four years, with at least £6.6 billion of funding in "advanced and next-generation R&D to deliver an enduring military edge in areas including space, directed energy weapons, and advanced high-speed missiles".[140]

- **GVA.** One study estimated that the Army directly contributed £5.5 billion to UK GDP in GVA in 2019, based solely on its employee compensation and taxes on production (based on its business rates bill).[141] The same study estimated that the indirect impact of the Army's supply chain purchases supported a further 66,000 jobs and a £3.7 billion contribution to UK GDP in 2019.[142]

- **Employment.** As of October 2021, the Armed Forces employed 149,000 full-time regular staff, 4,000 Gurkhas and 37,000 volunteer reservists.[143] It also supports a large number of jobs in the wider supply chain. For example, in 2017, it was estimated that the defence sector contributed to the indirect employment of a further 120,000 people.[144]

- **Exports.** The UK is a significant exporter of defence goods and services. On a rolling 10-year basis, the UK remains the second largest global defence exporter after the USA. In 2020, the value of UK security export sales was £7.9 billion, accounting for 6% of the global market.[145]

Alongside positive economic benefits to the UK, the sector’s primary direct contribution to is through its core purpose of protecting the country, dealing with disasters and preventing future conflict.

[139] Ministry of Defence, 2021. MOD regional expenditure with UK industry and commerce and supported employment 2019/20. Available at: https://www.gov.uk/government/statistics/mod-regional-expenditure-with-uk-industry-and-supported-employment-201920/mod-regional-expenditure-with-uk-industry-and-commerce-and-supported-employment-201920 [Accessed 12th April 2022].

[140] UK Gov, 2021. Global Britain in a Competitive Age: the Integrated Review of Security, Defence, Development and Foreign Policy.

[141] Oxford Economics, 2019. The wider value of the British army.

[142] Oxford Economics, 2019. The wider value of the British army.

[143] Quarterly service personnel statistics 1 October 2021.

[144] ADS, 2017. UK Defence Outlook 2017.

[145] UK Defence and security exports, 2021. UK defence and security export statistics: 2020.

- **National security.** Protecting against domestic and international security threats is seen as the primary role of defence. Defence does not only provide security in times of crisis but also seeks to deter and prevent conflict, thus making the UK a safer place.

- **Contribution to Britain's role in the international community.** The UK's armed forces enable soft power levers that create the ability for it to shape the behaviours of allies, partners and potential adversaries. For instance, the MOD's International Defence Engagement Strategy outlines examples of the range of mechanisms through which defence helps the UK to cultivate and exert influence globally. These include treaties and alliances, senior-level visits, the UK's Defence Attaché network, civilian defence advisors, loan service personnel, overseas exchange and liaison officers, overseas training teams, security sector reform, international defence training, conventional deterrence and reassurance, overseas joint exercises, ship, unit and aircraft visits, and support to UK defence sales and international defence industry cooperation.[146]

- **Contribution to community.** The defence sector plays an important social role within UK public life. One aspect of this role involves enhancing the resilience of the UK government and wider society against shock or crisis. This can involve a wide range of tasks and includes providing military aid to civil authorities (MACA) in times of emergency, contributing search-and-rescue (SAR) assets by air or sea, deploying troops to address flooding or support to the National Health Service during a pandemic such as Covid-19.[147]

ECONOMIC EXTERNALITIES CREATED BY THE DEFENCE SECTOR

The defence sector also creates several economic externalities. These are effects that are not the intended for public good but rather occur alongside the main benefit and accrue to society at large. These are set out below.

Productivity

The defence sector makes significant investments in research and development in order to overcome technological challenges, create better equipment, yield cost savings, and enhance operational effectiveness. These innovations also generate benefits for the wider economy, as knowledge and know-how disperse through the economy. Ultimately, innovation enhances productivity and is a key driver of the UK's long-run prosperity. Oxford Economics estimated that at the end of 2019/2020, the cumulative stock of the army's R&D assets was worth £1.2 billion. It used this figure to estimate that this stock of R&D raises UK productivity and hence the overall size of the economy by 0.03% per year, equivalent to £730 million in GDP in 2019/20.[148] As with the direct impacts created by the sector, it is likely that these externalities would be reduced significantly absent spectrum.

Environmental impact

The defence sector causes negative environmental externalities as it is responsible for a substantial amount of pollution, accounting for approximately 50% of the UK central Government's emissions.[149] A third-party estimated that the MOD directly emitted 3.03 million tonnes of carbon in 2017-18, while the broader military

[146] UK Ministry of Defence, 2017. International Defence Engagement Strategy.

[147] See, for instance: RAND, 2021. Understanding the Value of Defence.

[148] Oxford Economics, 2019. The wider value of the British army.

[149] MOD, 2021. Climate Change and Sustainability Strategic Approach.

sector (including the private sector and MOD suppliers) emitted 6.46 million tonnes of carbon in the same period, or 1.4% of UK emissions.[150]

The MOD has stated publicly that it is committed to the target of Net Zero emissions by 2020 and has reduced emissions across its estate by 50% over the last 10 years. In March 2021, it launched the Defence Climate Change and Sustainability Strategic Approach, which sets out *"the ambition, principles and the methods needed for UK Defence to meet the challenge of climate change, enhance our sustainably activities and lower our emissions"*.[151]

It is not possible to quantify the change in this externality absent spectrum. A no spectrum scenario would likely render a lot of technology useless, which may decrease emissions, but could also increase emissions if it leads to less efficient use of resources.

3.2.10 EMERGENCY SERVICES

The emergency services rely on several radio technologies and frequency ranges to provide the communication capabilities required by the police, ambulance and fire services. The use of these low, medium and high frequencies enables a variety of fixed wireless and wireless video communication systems that are essential to effective policing, fire and ambulance operations.[152] In England, Wales and Northern Ireland, Ofcom is responsible for licensing frequencies and administering their use. In Scotland, this function is carried out by the Scottish Government.

At present, all of Great Britain's emergency services, as well as over 300 public safety organisations, communicate using the "Airwave" network.[153] Forming part of the nation's Critical National Infrastructure, this network is designed to withstand major incidents, and it covers 99% of Great Britain's landmass.[154] However, this network will be switched off by the end of 2026 as it reaches the end of its lifespan. Traffic will then move over to the Emergency Services Network (ESN), which will begin to be used from 2026, although the majority of the work needed to upgrade the existing sites/build new ones is already completed.[155]

Switching over to the ESN will ensure that the network used by the UK emergency services is fast, safe and secure. However, alongside this, investment in the ESN will also mean improvements to 4G network coverage to ensure that emergency calls are able to be made from previously hard to reach areas. Once it is rolled out, 300,000 frontline emergency service users will depend on the ESN, using handheld devices or operating equipment in 45,000 vehicles, 66 aircraft and more than 100 control rooms.[156]

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[150] Scientists for Global Responsibility, 2020. The Environmental Impacts of the UK Military Sector.

[151] UK Parliament. Ministry of Defence: Greenhouse Gas Emissions. Question for Ministry of Defence tabled on 15 July 2021 (UIN 34007).

[152] Ofcom, 2020. Frequencies for Emergency services in the UK.

[153] Northern Ireland has its own TETRA based communication system, and while it is considering moving to an LTE-based system, this is still in the early stages of development.

[154] Airwave, Emergency Services Network. Available at: airwavesolutions.co.uk/the-service/emergency-services-network [Accessed 9th March].

[155] Matthew Rycroft, 2021. Update on the Emergency Services Mobile Communication Programme (ESMCP).

[156] Home Office, 2021. Emergency Services Network: overview.

VALUE CREATED BY THE EMERGENCY SERVICES SECTOR

As a public good, the main benefit of the emergency services comes from the prevention, reduction and mitigation of emergency events. All emergency services use the radio spectrum to communicate between units and central command centres. For example, police services use radio to coordinate responses to incidents and call for assistance. Radio is used by ambulance services to communicate between units of care, ensuring that patients receive help as efficiently as possible, while fire services use radio to ensure the safety of firefighters.[157] Given the importance of reliable and secure communication to the activities of the emergency services, spectrum can be thought of as a vital input to its activities. The Federation of Communication Services state that the "*entire operation of emergency services is facilitated by professional radio communications*".[158] Without dedicated radio networks, the speed and efficiency of emergency service responses would be greatly diminished, worsening outcomes associated with emergency situations.

3.2.11 MARITIME

Spectrum is used by the maritime sector in routine operations and for safety purposes. The spectrum used by the maritime sector is primarily used for both 'ship to ship' and 'ship to shore' communications, as well as navigation systems.

Frequency usage in the UK is managed by Ofcom and reflected back into International Maritime Organisation (IMO) documentation. Due to the need for extensive international coordination on frequencies, many of the bands used by the maritime sector are harmonised. The key bands used by the sector are shown in the table below, along with their uses.

TABLE 12 KEY BANDS USED BY THE MARITIME SECTOR

FREQUENCY	USE
415 kHz-27500 kHz	Maritime mobile – Coastal station radio including navtex service
156 MHz-163 MHz	Maritime mobile - Communications
409-409.1 MHz	Emergency Position Indicating Radio Beacons (EPIRBs).
2.9–3.1 GHz	Radio navigation, where it is a requirement for ships over 300 tonnes to carry this equipment.
5.470–5.650 GHz	Maritime radio navigation.
9.2–9.3 GHz	Maritime radio navigation search and rescue transponders.
9.3–9.5 GHz	Radio navigation X-band radars used for close proximity positioning. This is mandatory on ships over 300 tonnes but is also used by smaller vessels.

Source: Frontier Economics and LS Telcom based on data from Ofcom.

[157] Joint Radio Company, 2012. Radio Spectrum is used by Utilities in support of their operations.

[158] See https://www.fcs.org.uk/business-radio/business-radio-group/ [Accessed 8th March 2022].

ECONOMIC OUTPUT OF THE MARITIME SECTOR

Traffic in the UK maritime sector is significant, with 428,994 tonnes of inward and outward port traffic in 2020 and over 89,000 ship arrivals.[159] The UK has the 24th largest fleet in the world, and on a deadweight tonnage basis, the UK registered trading fleet accounted, in 2020, for 0.5% of the world fleet. Indeed, this increases to 4% if including all ships owned, parent-owned or managed in the UK.[160]

We calculate that the GVA of the maritime sector in 2019 was £9.2 billion.[161] The maritime sector also acts as a catalyst for downstream economic activity, with over 95% of UK trade being transported via maritime freight.

While spectrum only accounts for a small part of the sector's production process, it is a key input needed to ensure safety. Without spectrum, it is likely that the sector would be significantly less efficient and that the overall volume of activity would decrease significantly.

ECONOMIC EXTERNALITIES GENERATED BY THE MARITIME SECTOR

The maritime sector has a wider impact beyond that which is captured in the direct contribution to the economy. This impact can be hard to measure but is nonetheless important to capture. The externalities created by the sector are summarised below.

- **Productivity.** The increase in global trade has allowed companies to specialise. Specialisation leads to greater efficiency because each company can use the latest technology for their sector and reach economies of scale for their product or service. Specialisation also leads to countries gaining comparative advantage. This has allowed many countries to become more efficient and competitive in a global market. Finally, greater dispersion of technologies increases competition and investment, eventually leading to a further increase in productivity.[162] Analysis from the Organisation for Economic Cooperation and Development (OECD) indicates that a 10% increase in openness is associated with a 4% increase in income per head.[163]

- **Environmental.** According to the Department for Transport, in 2016, the shipping sector accounted for 3.4% of all of the UK's Green House Gas (GHG) emissions. However, the UK government has set targets for emissions reductions in the sector. For instance, by 2025, it expects all vessels in UK waters to be maximising the use of energy-efficient options.[164]

In the absence of spectrum, potential reductions in trade volumes could lessen the magnitude of the negative environmental externality and the positive productivity benefit created by the sector. However, it is possible that the sector could become more inefficient, meaning that per journey emissions could increase (for

[159] Department for Transport, 2021. Port and domestic waterborne freight statistics: data tables (PORT). Specific data tables: PORT0503 and PORT0601.

[160] House of Commons Library, 2021. The UK's Maritime sector.

[161] This estimate includes all activities related to the transport of passengers or freight over water as well as service activities incidental to water transportation (such as the operation of port and harbour facilities, navigation, pilotage and berthing activities).

[162] Department for International Trade, 2018. International trade: The economic benefits.

[163] OECD, 2012. Economic Globalisation Indicators and OECD, 2002. Intra Industry and Intra Firm Trade and the Internationalisation of Production.

[164] Department for Transport, 2019. Maritime 2050. Navigating the future.

example, in the absence of satellite navigation, shipping journeys took longer). This would increase the magnitude of the negative environmental impact on a per journey basis.

3.2.12 SPACE AND EARTH SCIENCES

The Met Office, UK Space Agency and the scientific community use a broad range of spectrum bands across a wide range of use cases. These include earth observations, radio astronomy, space research, space operations, meteorological services, radiolocation services, and standard frequency and time signal services. These services can be grouped under two categories:

- **Passive services** that measure naturally occurring radiation, often at very low power levels. This information provides useful data to help understand and monitor the earth and the universe. Examples of such services are the Earth Exploration Satellite Service (EESS) and the Radio Astronomy Service (RAS).

- **Active services.** These services use technology to carry out measurements, provide signals, make observations or transfer the collected data.

Many of these use cases have specific requirements. Examples of these are included below.

- Radio astronomy and space research both seek to receive signals from radio sources, which are incredibly weak, and thus require access to a very 'radio quiet' spectrum that is as free as possible from interference from terrestrial sources. Registered Radio Astronomy sites in the UK are located at Cambridge, Darnhall, Defford, Jodrell Bank, Knockin and Pickmere.

- Space research and space operations services support sensing and communications links between the Earth and various destinations in space (such as devices in orbit, on the Moon and Mars, on other bodies in the solar system and space probes). By necessity of the large distances involved, these transmissions are often high power and thus have the potential to cause interference to terrestrial services over a relatively wide area. Similarly, receivers on earth are extremely sensitive and vulnerable to interference from terrestrial services.

- The frequencies used for radio astronomy are often dictated by the physical properties of matter (such as the Hydroxyl spectrum lines around 1.6 GHz).

It is for these reasons that reception (and transmission) sites tend to be situated in areas which are physically distant from sources of terrestrial radio emissions. It is also why it is the duty of Ofcom (as dictated in Articles 4.6 and 4.7 of the ITU radio regulations) to protect these services' use of spectrum to the same degree as it would for other radio services.

However, there is nothing stopping individuals from participating in Radio Astronomy (or from receiving signals from spacecraft in deep space), and there are many amateur observers around the country. In the UK, Goonhilly Earth Station has recently been adapted to operate deep space communications links. NASA uses a network of stations in Madrid (Spain), Canberra (Australia) and Goldstone (California), which between them provide continuous coverage as the Earth rotates. The European Space Agency (ESA), of which the UK is a member state, maintains a network of ESA stations in Australia, Spain, Argentina, Sweden, France, Guiana, Belgium and the Azores. Russia, China, Japan and India also operate deep space networks.

The space and earth science sector makes use of a wide range of frequencies from 2.5 MHz to 275 GHz. Some of the frequency bands used by these services for deep space and radio-astronomy are set out in the table below.

TABLE 13 KEY SPACE AND EARTH SCIENCE FREQUENCY BANDS

FREQUENCY RANGE	SERVICE	NOTES
Approx. 327 MHz	Radio astronomy	Deuterium line observations
Approx. 1.4 GHz	Radio astronomy	Hydrogen line observations
Approx. 1.6 GHz	Radio astronomy	Hydroxyl line observations
2.120 – 2.120 GHz 2.290 – 2.300 GHz	Space research	
Approx. 3.3 GHz	Radio astronomy	Methyladine line observations
Approx. 4.8 GHz	Radio astronomy	Formaldehyde line observations
Approx. 6.66 GHz	Radio astronomy	Methanol line observations
7.145–7.190 GHz 8.450–8.500 GHz	Space Research	Used for connections with deep space probes. Frequencies immediately adjacent to these are used for connections to other space research craft (i.e. in Earth orbit).
31.8–32.3 GHz		
34.2–34.7 GHz	Space Research	Used for connections with deep space probes.

Source: Frontier Economics and LS telcom based on data from Ofcom.

ECONOMIC OUTPUT OF THE SPACE SCIENCE SECTOR

Know.space, on behalf of the UK Space Agency, estimated that the GVA of the space manufacturing sector (which includes activities such as scientific and engineering support, and fundamental and applied research), space operations (which includes activities such as launch services) and ancillary services, was approximately £2 billion in 2020 (shown in **Table 14**).[165] This is not a precise estimate of the GVA of the narrower space science sector, as the definition of these categories includes some activities not related to space science research. Nevertheless, it gives an indication of the overall value created by the sector at large.

[165] On a biennial basis, the UK Space Agency ("UKSA") commissions a report on the size and health of the UK space industry. The UKSA report includes broadcasting and telecommunications (which this report considers separate categories) as well as downstream and upstream sectors that rely on the space science sector, such as space manufacturing and consulting, and is not directly comparable to the definition of the sector in this report. Nevertheless, it is a helpful source in understanding trends in both the space science as well as the broader 'space' sector.

TABLE 14 GVA AND EMPLOYMENT OF UK SPACE INDUSTRY SECTORS, 2020

	GVA (£M)	EMPLOYMENT
Space manufacturing	1,090	8,924
Space operations	690	3,360
Ancillary services	225	2,752
Total	**2,005**	**15,036**

Source: Know.space for the UKSA, 2020. Size & Health of the UK Space Industry 2020.

Note:
- Space manufacturing activities include: launch vehicles and subsystems, satellites/payloads/spacecraft and subsystems, scientific instruments, ground segments systems and equipment, suppliers of materials and components, scientific engineering support, fundamental and applied research, and space testing facilities.
- Space operations activities include: launch services, launch brokerage services, proprietary satellite operation, third-party ground segment operation, ground-station networks, in-orbit servicing, debris removal, space surveillance & tracking, space tourism, in-space manufacturing, and spaceports Ancillary services activities include: launch and satellite insurance services, legal and financial services, software and IT services, market research and consultancy services, business incubation and development, and policymaking, regulation and oversight.
- Know.space also estimates GVA and employment for the space operations appliances sector. This sector is excluded from the table above as it includes DTH broadcasting as well as fixed and mobile satellite communication, which are discussed elsewhere in this report.

The same report estimates that the income of the broader space sector has almost quadrupled since 2000 (a CAGR of 5.5%) and increased by 62% since 2010. The UK's share of the global space economy is estimated to be 5.1%.[166]

UK space science is an important subject for academic research in UK universities, with over 2,000 researchers across over 50 universities involved in space science research.[167] In particular, the sector plays a crucial role in climate monitoring and earth observation, both of which are essential for understanding and combatting climate change.[168]

Another key channel through which the space science sector directly benefits the UK is meteorological services, which mitigate the impacts of weather events and, therefore, avoid costs that would otherwise be incurred.[169] As shown in the table below, the cumulative value of the Met Office services was valued to the public sector at over £1 billion per annum in 2015.

TABLE 15 ANNUAL VALUE OF WEATHER-RELATED ACTIVITY

SECTOR	DESCRIPTION	VALUE (£ MILLION)
Flood damage avoidance	The Met Office inputs into the Environment Agencies Flood Warning Service to protect people and property.	64
Storm damage avoidance	The Met Office provides the Cabinet Office with warnings of strong winds.	80

[166] Know.space for UKSA, 2020. Size & Health of the UK Space Industry.

[167] Know.space for SPAN, 2021. UK Space Science: a summary of the research community and its benefits.

[168] ITU, 2019. Monitoring our changing planet. Available at: 2019_ITUNews01-en.pdf [Accessed 24th March 2022].

[169] Met Office, 2007. The Public Weather Service's contribution to the UK economy.

SECTOR	DESCRIPTION	VALUE (£ MILLION)
Public	The Government's Heatwave plan relies on Met Office forecasts, and the Met Office provides emergency services with their National Severe Weather Warnings.	480
Aviation	The Civil Aviation Authority can avoid turbulence and ice using Met Office data. The Met office data allow the aviation industry to plan more cost-efficient routes. This reduces delays and reduces environmental externalities of aviation.	400

Source: Met Office, 2007 The Public Weather Services contribution to the UK economy and Met Office, 2015, The Latest Public Weather Service Value for Money Review.

Spectrum acts as a core input to space science, without which the vast majority of the productive activities described above could not take place. The importance of ensuring that space science has a suitable spectrum is demonstrated by the considerable efforts national and international regulators make to protect the spectrum it uses and ensure that it is free from interference.[170]

ECONOMIC EXTERNALITIES CREATED BY THE SPACE SCIENCE SECTOR

Space science also generates productivity, cultural, and environmental externalities, which, absent spectrum, would not occur (or be greatly reduced). These are set out below.

Productivity

Research has found that for each £1 of public investment, UK space science and innovation returned £2-7 of direct benefits, plus £4-14 of spill-over benefits (defined as the impact on output or productivity or other, non-investing organisations as a consequence of the leveraged private investment).[171]

Cultural and education

In its report for the Space Academic Network (SPAN), know.space highlights the social and cultural benefits that space research creates. It highlights that advances in space-related knowledge inspire artistic and creative endeavours, enhance well-being and generate cultural capital.[172]

Environmental

The space science sector generates both negative and positive environmental impacts. Space science, and the associated satellite sector, create a number of negative environmental externalities. For example:

- the manufacture, launch and operation of satellites create carbon emissions at each stage of the supply chain;

[170] See, for instance, Ofcom, 2021. Protecting passive services at 23.6-24 GHz from future 26 GHz uses.

[171] London Economics, 2015. Return from Public Space Investments.

[172] Know.space for SPAN, 2021. UK Space Science: a summary of the research community and its benefits.

- the increased proliferation of satellites in space can lead to congestion and increases the chances of collisions; [173] and
- satellites create light pollution, which can affect astronomers' view of the night sky.[174]

However, the sector also plays an important role in understanding and mitigating the effects of climate change. For example, it does this by detecting changes in the atmospheric concentration and monitoring sea temperatures and ice sheets.[175] Furthermore, the government's National Space Strategy, published in September 2021, set out an ambition for the UK to be a leader in using space for climate action, with fighting climate change with space technology being one of the government's ten initial focus areas.[176]

3.3 CONCLUSIONS AND RECOMMENDATIONS

This chapter of the report has demonstrated the significant impact that radio spectrum has on the UK economy, both in terms of direct benefit created in the sectors themselves that use spectrum but also through the creation of economic externalities that benefit society as a whole.

In this sub-section we:

- compare the findings in this report to previous work commissioned by DCMS in 2012 and assess recent progress against the recommendations of this previous work; and then
- comment on the implications that our findings and future developments could have for future spectrum allocations.

3.3.1 COMPARISON TO PREVIOUS WORK

Below we compare the results of our work with the results of the previous study commissioned by DCMS in 2012[177] and then assess the progress made against the recommendations of the previous report.

COMPARISON OF RESULTS

A number of methodological differences between the approach taken in this report and the previous DCMS study mean that it is only possible to make a limited comparison of the results of the two studies. These differences are set out below.

- As noted in the methodology section of this chapter, the previous study used a fundamentally different approach to the one used in this study. This study has assessed the value of spectrum to the UK by analysing the direct contribution of sectors that use spectrum to the UK economy, as measured by their GVA. The previous study assessed the value of spectrum to the UK by analysing the economic welfare created in each sector that uses spectrum. This means the estimates of the

[173] NASA, 2021. Space station. Available at: https://www.nasa.gov/mission_pages/station/news/orbital_debris.html [Accessed 9th March 2022].

[174] See https://www.astro.princeton.edu/~gbakos/satellites/ [Accessed 9th March 2022].

[175] ESA. Climate Change: The evidence from Space. Available at: https://climate.esa.int/en/evidence/observations-change/#:~:text=By%20accurately%20detecting%20these%20small,greenhouse%20gases%20in%20the%20atmosphere [Accessed 9th March 2022].

[176] HM Government, 2021. National Space Strategy.

[177] Analysys Mason, 2012. Impact of radio spectrum on the UK economy and factors influencing future spectrum demand.

"value" of each sector are not comparable across the two reports, nor is it possible to quantitatively assess the growth in the value of sectors since the previous report.

- As the two reports use different methodologies, there are some differences in the sectors that they are able to value:
  - the previous study estimated welfare in the PMR and fixed links sectors, which this report does not do;
  - this report estimated the value of the maritime and aviation sectors, which the previous study did not do; and
  - the previous study estimated the value of the Wi-Fi sector, whereas this report estimates the value of the fixed sector, whilst noting that only a portion of this is attributable to Wi-Fi.

Despite the differences in approach, there are a number of similarities in the conclusions across the two studies.

- **Large amounts of the value created through spectrum are created by mobile services.** The previous study estimated that over 50% of the total value created across the sectors assessed in the report was created by the mobile sector. This report has valued other large sectors, such as the transport sector and fixed networks, and therefore mobile services account for a smaller proportion of overall value. Nevertheless, this report finds that the mobile sector continues to be a significant source of value, accounting for £8.7 billion in GVA in 2019, approximately 40% of the value created in communication sectors (mobile, fixed and commercial satellite networks and broadcasting).

- **The broadcasting sector is a second important source of value.** Both reports found that the TV and radio broadcasting sectors generate a large amount of value. The previous study found that the TV and radio broadcasting sector generated economic welfare equivalent to 36% of the economic welfare created in the mobile sector. Although it used a different methodology, this report found a similar result, with the economic contribution of TV and radio broadcasting being equivalent to 29% of the economic contribution created by mobile services.

- **While mobile services and broadcasting are two of the largest sectors, other private sectors continue to contribute significant value.** Both reports noted the significant value created in the fixed links, PMR, PMSE and commercial satellite sectors. The previous study estimated that the fixed links, PMR and commercial satellite sectors collectively contributed 18% of the total economic welfare. This report has only been able to quantify the direct contribution of the commercial satellite sector. However, it notes that this sector, alongside PMR, fixed links, and PMSE, is an important source of value.

As above and for the reasons explained in **Section 3.1.4,** it is not possible to quantitively assess the growth in the value of sectors that use spectrum since the previous report. However, improvements in what can be delivered using spectrum mean that it is likely that the value of spectrum has increased significantly since 2011. This is for the following reasons.

- The amount of traffic carried over communication networks that rely on spectrum has increased dramatically. This has led to drastic increases in the usage of mobile and Wi-Fi networks as well as newer use cases such as NGSO satellite networks and industrial IOT networks. Indeed, demand for spectrum is greater than ever, reflecting the increasing amount of productive activity that relies on spectrum.

- Increases in the speed and latency of fixed and mobile broadband networks have led to significant growth in a number of downstream sectors that rely on these networks. For instance, in **Section 3.2.4,** we note that there has been significant growth in sectors such as the app economy, e-commerce, and digital advertising sector. These sectors, along with sectors such as OTT messaging, do not directly rely on spectrum but benefit from the use of spectrum in upstream sectors.

PROGRESS AGAINST RECOMMENDATIONS OF PREVIOUS WORK

Alongside the valuations set out above, the previous study made a number of recommendations (described in **Section 3.1.4**) around spectrum for mobile services, support for the Wi-Fi and broadcasting sectors, improvements to infrastructure, spectrum sharing, and public sector spectrum release. Since the publication of that report, the UK has made varying amounts of progress against all of these recommendations. We expand on this below.

1. Supporting the future growth of the public-mobile sector

Since the publication of the previous study, Ofcom has successfully freed up spectrum in the 700 MHz and 3.4–3.8 GHz bands for mobile use. The freeing up of the 700 MHz band was done in conjunction with stakeholders in the TV broadcasting and PMSE sectors, and it represents a significant achievement.

Ofcom successfully auctioned spectrum in the 3.4–3.6 GHz bands in 2018 (putting the UK among the first countries in the world to do so).[178] And it successfully auctioned the 700 MHz and 3.6–3.8 GHz spectrum in early 2021[179].

2. Supporting growth in other sectors that will be influenced by the growth in mobile data

As predicted in the previous study and noted in **Section 3.2.7** above, there has been significant growth in the traffic carried over Wi-Fi networks. In 2020, Ofcom authorised access to the lower 6 GHz band for indoor and very low power outdoor uses, which enabled these frequencies to be used by Wi-Fi and IoT networks[180]. The UK was one of the first countries in the world to do this[181].

3. DTT and DAB technology upgrades

Currently, only one of the UK's seven DTT broadcast multiplexes supports DVB-T2[182]. Services using DVB-T2 enabled by this multiplex were launched in 2013, and it is used to support the broadcasting of HD channels[183].

The UK's first national DAB+ stations launched in 2016. As of March 2022, there are over 180 stations broadcasting on DAB+ in the UK, including 25 national stations[184]. The majority of new radios are DAB+ compatible; however, in 2021, the industry estimated that only 30-40% of DAB radios in homes received

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[178] Ofcom, 2020. Supporting the UK's wireless future.

[179] See: https://www.ofcom.org.uk/spectrum/spectrum-management/spectrum-awards/awards-archive/700-mhz-and-3.6-3.8-ghz-auction [Accessed 14th April 2022].

[180] Ofcom, 2020. Improving spectrum access for Wi-Fi.

[181] Ofcom, 2020. Supporting the UK's wireless future.

[182] See: https://www.ofcom.org.uk/spectrum/information/transmitter-frequency [Accessed 14th April 2022].

[183] See: https://www.ofcom.org.uk/tv-radio-and-on-demand/advice-for-consumers/television/dvb-t2-and-freeview-hd [Accessed 14th April 2022].

[184] See: https://getdigitalradio.com/faqs/what-is-dab/ [Accessed 14th April 2022].

DAB+ stations.[185] Ofcom has recently made spectrum available for small scale DAB radio, which will provide an affordable route to broadcasting via terrestrial digital radio for small commercial and community radio stations.[186]

4. Better sharing of under-utilised spectrum

In 2019, Ofcom introduced a revised licensing approach. This aims to provide localised access to spectrum for businesses across a range of sectors and to facilitate spectrum sharing.[187] This included Shared Access licences in key frequency bands, permitting access to unused spectrum held by mobile operators (through Local Access licences) and permitting sharing of spectrum in the 26 GHz band for indoor deployment. Ofcom plans to continue looking for opportunities to promote spectrum sharing, including, where appropriate, developing the use of automated spectrum management tools.[188]

A discussion of Ofcom's approach to spectrum sharing and stakeholders' views on this is set out in **Section 5** of this report.

5. Release of public-sector spectrum

In 2011, the Government announced plans to release 500 MHz of spectrum under 10 GHz held by the public sector[189]. This target was extended by a further 250 MHZ in the 2016 budget.[190]

The programme is on track to be successful, and by the end of 2022, this programme will have released 750 MHz of spectrum (either by releasing the spectrum entirely or making the spectrum available for sharing).

3.3.2 RECOMMENDATIONS

This chapter of the report has highlighted the significant benefits radio spectrum brings to the UK economy. Below we comment on the implications that our findings on the economic value of spectrum and future developments could have for future spectrum allocations.

Allocation decisions should consider the marginal benefits of each option

This report finds that there are likely to be further opportunities for a range of sectors to increase their value to the UK economy. Given this potential, it will be important to ensure that each sector has adequate spectrum. While this report has assessed the value created by each sector's current usage of spectrum, this is not equivalent to the additional value created if a sector was allocated more or less spectrum.

When making reassignment decisions, it is important to take into account all relevant incremental costs and benefits associated with that spectrum. This may present options to employ methodologies to assess the value of non-monetary direct benefits and externalities, such as those set out in Cave et al. (2015). A more

[185] See: https://radiotoday.co.uk/2021/06/digital-radio-uk-starts-to-promote-dab-radio-upgrade/ [Accessed 14th April 2022].

[186] See: https://www.ofcom.org.uk/__data/assets/pdf_file/0027/193662/statement-licensing-small-scale-dab.pdf and https://www.ofcom.org.uk/news-centre/2021/digital-technology-switch-on-brings-new-radio-choices

[187] Ofcom, 2019. Enabling wireless innovation through local licensing: Shared access to spectrum supporting mobile technology.

[188] Ofcom, 2020. Supporting the UK's Wireless Future: Our Spectrum Management Strategy for the 2020s (Consultation), para. 1.13.

[189] DCMS, 2011. Enabling UK growth – Releasing public spectrum.

[190] HM Treasury, 2016. Budget 2016.

detailed discussion of the approaches to spectrum reassignments is provided in **Section 5.2.5** and **Section 6.4**.

Understanding the economic externalities and non-monetary direct benefits of spectrum requires bespoke research on each category of benefits

Spectrum is a central input in a range of sectors, which enables a range of non-monetary direct benefits and economic externalities. These benefits are inherently difficult to assign monetary valuations to, and there is currently limited information on the nature of these benefits. To the extent there are particular externalities that DCMS, DSIT and Ofcom are interested in understanding and monitoring (for instance, on the net environmental impact of the ICT industry), they may wish to consider developing an approach for collecting and tracking this data.

Furthermore, it was not possible for this report to build on the approaches proposed in Cave et al. (2015). If DCMS or DSIT wishes to quantify the value of non-monetary direct benefits or externalities, it may wish to commission new willingness-to-pay research.

Understanding the role of spectrum policy in achieving net zero

We find significant evidence to suggest that sectors that use spectrum can play a major role in helping the UK achieve the target of being a net-zero emitter by 2050. DSIT may wish to consider or commission further work that explores the range of policy options that it could implement to ensure that the UK makes the most of the potential in these sectors. For instance, the National Infrastructure Commission (NIC) recommended that Ofcom (along with Ofgem and Ofwat) should have new duties to promote the achievement of net zero by 2050[191]. In a similar vein, it may also wish to consider the range of policy options it could use to encourage further and faster decarbonisation in the industry. For example, this could include imposing incentives in spectrum auctions. Recent work by Plum for the UK Spectrum Policy Forum has set out a range of spectrum policy options and recommendations that regulators and governments could use to be more environmentally responsible[192].

Future opportunities for public sector sharing

We find that the public sector's use of spectrum makes a significant contribution to the UK economy and that public sectors have played a significant role in ensuring an optimal allocation of spectrum by facilitating the release of valuable radio spectrum. As the PSSR programme is close to coming to an end, it may be worthwhile to conduct further work to further understand how the public sector uses spectrum and identify any opportunities for further sharing or release. Mechanisms for spectrum sharing are discussed further in **Section 5.**

[191] NIC, 2019. Utility regulators must have new powers if the UK is to tackle climate change. Available at: https://nic.org.uk/news/utility-regulators-must-have-new-powers-if-uk-is-to-tackle-climate-change/ [Accessed 22nd March 2022].

[192] Plum, 2021. The role of spectrum policy in tackling the climate change issue.

4 SPECTRUM DEMAND

This section of the report provides an assessment of demand for radio spectrum over the next 5 to 15 years by sector and by application, as required by the project terms of reference. In order to fully understand the role of spectrum in the UK, it is necessary to understand what the demands for spectrum are and how these demands are projected to change across different sectors over time. Modelling spectrum demand is challenging, especially for periods extending beyond 5 to 10 years. This is because the level of certainty diminishes as the period of time increases. The analysis provided in this chapter aims to minimize the uncertainty by generating plausible and reasonable assumptions for such an extended time frame. Ultimately, the only way to credibly derive such long-term demand is through a range of scenarios and to apply different probabilities in which these scenarios will be realised. These assumptions on likelihood have then been verified through stakeholder engagement.

For each sector, this section:

- re-visits the sector's trends discussed in **Section 1.2**, specifically focusing on how these drive spectrum demand;
- looks at the technologies that will be used to examine how demand for spectrum will manifest over a 5-to-15-year time frame;
- focuses on long term demand and efficient use of spectrum for the sectors of interest; and
- identifies the risks for excess demand for spectrum in certain sectors and optimal use of spectrum across all sectors.

4.1 BROADCASTING

4.1.1 CURRENT DEMAND FOR BROADCAST SPECTRUM

Spectrum is an essential input for DTT and DTH broadcasting transmission. As noted in **Section 3.2.1**, DTT broadcasters use 224 MHz of spectrum between 470 and 694 MHz, while DTH broadcasters make use of the Ku-band (approx. 12 GHz). Through this spectrum, viewers receive Free to View (FTV) broadcast channels on television sets across the UK.

Demand for this broadcast spectrum is driven by consumption habits. These are changing for both radio and television broadcasting with a move away from traditional linear consumption where shows are viewed/listened to at a set time determined by the broadcaster's schedule. This is due to the increase in on-demand platforms for streaming content. The introduction and popularity of streaming services have meant a shift in viewing behaviour. Whilst the growth of on-demand platforms is expected to continue, there are signs that it is slowing down[193]. With UK household budgets being challenged by the increasing cost of living[194], on-demand platforms are beginning to find it harder to attract new subscribers.

[193] This article from The Guardian is just one example of how the sector is cooling - with a slowdown in membership subscriptions https://www.theguardian.com/media/2022/feb/19/investors-alarmed-as-streaming-services-lose-their-magic-touch. [Accessed April 2022].

[194] House of Commons Library research briefing published in April 2022, 83% of adults in the UK reported an increase in their cost of living in March 2022, and with inflation reaching its highest recorded level since 1992, this has affected the affordability of goods and services https://researchbriefings.files.parliament.uk/documents/CBP-9428/CBP-9428.pdf [Accessed 28 April 2022].

Alongside newer methods of accessing audio and visual content, there is still continued popularity, and reliance, on DTT from a large proportion of the population, with some 40% of households[195] relying on DTT for FTV linear content. Furthermore, 2% of households do not have access to fixed broadband sufficiently fast for video streaming (10 Mbit/s)[196]. Alongside the reliance on DTT by some, there is also the draw of popular events viewed live by millions across the UK.[197]

Currently, there is a requirement in the UK for the continued use of DTT for public service broadcasting with free access to live news, events and entertainment. The Covid-19 pandemic demonstrated the vital and continued importance of FTV access to content.

"…the Covid-19 pandemic has reinforced the special importance of public service broadcasting. People sought out high-quality, trusted and accurate news, entertainment programmes and educational content to support home schooling. Its contribution to the creative economy across our four nations has never been more vital."[198]

The fire at the Bilsdale tower in August 2021 further highlights the reliance on public service broadcasting. The outage affected an estimated 600,000 households[199] and received widespread coverage in both local and national news. The exact numbers of households covered by the support scheme set up to handle those left without a DTT signal have not been published; however, the outcry that this event caused highlights the importance of DTT services to those affected.

Whilst viewing habits have changed, the use of broadcast spectrum has been confirmed (in its current assignments) by the extension of 2 national multiplex licences that were due to expire in 2022 for another 12 years. The other national multiplexes (MUX) due to expire in 2026 (3 MUXs) and 2027 (1 MUXs) have also been extended to 2034. These licenses do have a break clause enabling Ofcom to revoke them for spectrum management reasons, with the consent of the Secretary of State, with a five-year notice period, but this clause cannot take effect before the end of 2030[200].

4.1.2 FUTURE DEMAND FOR BROADCAST SPECTRUM

Future demand trends

There will continue to be a dependence on access to DTT from a significant proportion of the population across the time frame of this study. Viewing linear television in this fashion will likely remain stable, coexisting with time-shifted viewing enabled using Personal Video Recorders (PVRs) within set-top boxes. PVRs allow for live off-air content to be recorded for later consumption, accounting for approximately 10%

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[195] DCMS, December 2021 Consultation on the renewal of Digital Terrestrial Television (DTT) multiplex licences expiring in 2022 and 2026 (page7) [Accessed March 2022]. See: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/945915/DTT_Mux_Consultation_Document.pdf

[196] Ofcom, 2021 Connected Nations Report 2021.

[197] For instance, viewing figures for the Eurovision 2022 final peaked at 10.6 million people. See: https://www.bbc.co.uk/news/entertainment-arts-61457573 [Accessed 18 May 2022].

[198] Ofcom, 2021 Small Screen: Big Debate Recommendations to Government on the future of Public Service Media, p2.

[199] BBC News, 6 October 2021 Bilsdale transmitter: Fire-damaged TV mast demolished.

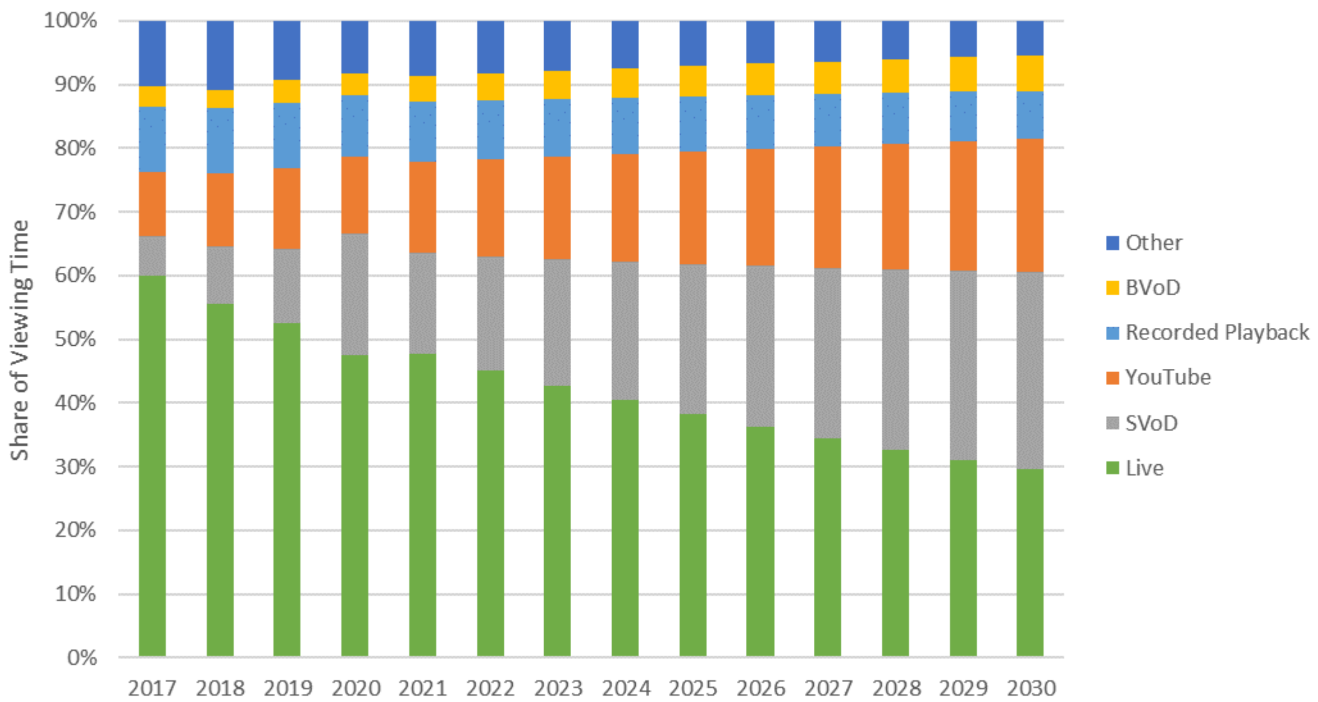
[200] UK Government, 2022, Consultation Outcome: Consultation on the renewal of digital terrestrial television (DTT) multiplex licences: full government response. See: https://www.gov.uk/government/consultations/consultation-on-the-renewal-of-digital-terrestrial-television-dtt-multiplex-licences-expiring-in-2022-and-2026/outcome/consultation-on-the-renewal-of-digital-terrestrial-television-dtt-multiplex-licences-full-government-response#next-steps

of all viewing minutes in 2017-21[201]. It is also anticipated that FTV consumption will continue to be complemented by additional over-the-top (OTT) streaming services. Hybrid TV[202] is also proving to gain market traction, as demonstrated by Freeview Play, and we anticipate that this trend will continue. Freeview Play offers a mix of linear viewing alongside on-demand services such as individual public service media (PSM) on-demand offerings and services such as Brit Box. This does require a fixed broadband connection, but current trends[203] indicate that broadband rollout continues to expand to more rural and remote areas.

In the 5-to-15-year period of this study, it is anticipated that:

- the UK broadcast sector will continue to be characterised by patterns of viewing that blend live linear consumption with on-demand content, as presented in **Figure 10** (below)[204]; and
- there will be a continued need from the broadcast sector to access DTT spectrum in the 470–694 MHz frequency range due to the licensing obligations until 2034.

FIGURE 10 PREDICTED CHANGES IN SHARE OF VIEWING TIME PER TECHNOLOGY UP TO 2030



Source: LS telcom based on data from Ofcom Media Nations 2021 (Figure 2.10: Average minutes of viewing per day on all devices, by type (2017-20)) and 2018 (Figure 7: Average daily minutes, per person, of total TV screen time) reports.

Note: assumes linear growth for YouTube, Broadcaster Video on Demand (BVoD) and Subscription Video on Demand (SVoD), linear decline for Other, no change for Recorded Playback, and an inverted sigmoid (inverted S curve) for Live.

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201 Media Nations Report 2021, Ofcom.

202 Connected Nations Report 2021, Ofcom.

203 Ramping up the rollout of full-fibre broadband, Ofcom March 2021, https://www.ofcom.org.uk/about-ofcom/latest/features-and-news/rollout-full-fibre-broadband

204 Figure 10 is a prediction of change in demand per technology, taking the figures that are currently available from the Ofcom Media Nations report and continuing the current trend to provide an estimation of what the situation may be by 2030. A full analysis would be needed to provide an exact figure on the percentage of reduction in linear viewing over the time frame of this study.

The trends in viewing habits present an opportunity to consider a reduction in broadcast spectrum. It is not simply a case of reducing the amount of spectrum. A change in spectrum use and a re-allocation of some of the spectrum away from broadcasting within the 470-694 MHz band would have consequences for FTV broadcasting.

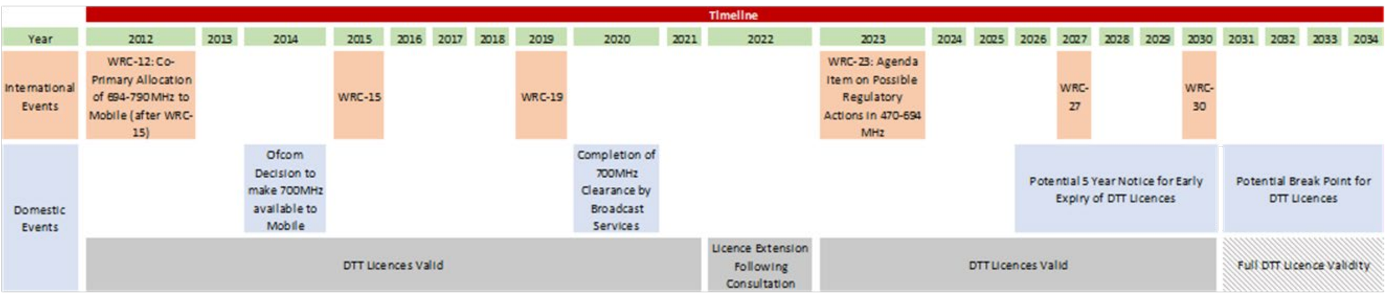
Due to a decline in linear FTV consumption DTT spectrum could be reduced once the current licence commitments have expired

However, a reduction in spectrum can only be achieved if:

- the broadcast networks would need to be replanned to support the release of a contiguous block of spectrum;
- receiving equipment (TVs and set-top boxes) would need to be upgraded to more spectrally efficiency standards;
- there is a reduction in the number of FTV channels, i.e. fewer channels, which would in turn require less spectrum; and
- there is a transition from DTT platforms to alternative platforms.

The decisions made at future World Radio Congress meetings will also influence the UK decision making process on the future of 470-694 MHz. The timeline in **Figure 11** shows some of the key events that will shape the future use of DTT spectrum in the UK.

FIGURE 11 TIMELINE OF KEY EVENTS FOR BROADCAST SPECTRUM 2012-34



Source: LS telcom

WRC 23 agenda item 1.5 will review spectrum use and spectrum needs of existing services in the 470-694 MHz frequency band in Region 1, in particular focusing on the spectrum needs of broadcasting and mobile. A decision on the allocation of the band could be taken as early as WRC-23, and the UK needs to be prepared for this.

This is an extremely complex environment and cannot simply be viewed from the perspective of spectrum. Whilst reducing the number of channels may seem like a simple option to make more spectrum available, this would reduce the revenues broadcaster receive from advertising. A reduction in revenue then starts to challenge the economic viability of the network itself. Reducing the number of channels also impacts the costs of running the platform. Currently, the running costs are split between the TV channels carried on it. Reducing the spectrum will result in a reduction in TV channels and the numbers of players contributing to the fixed costs of running the platform, further challenging its ongoing viability.

Furthermore, a reduction in the number of channels risks placing these channels out of reach of a material proportion of the population, particularly households for whom a broadband subscription is not desired or prohibitively expensive. The alternative FTV platform, Freesat, is less widely used than Freeview, and hence the usage of this platform would, in many cases, require households to invest in additional reception equipment.

Improving spectral efficiency also comes with its challenges for broadcasters. Depending on the speed of technology evolution and user adoption, it is possible that the DTT network could continue to support the same level of service and quality, including greater support of HD services, in reduced amounts of spectrum. This is dependent on the speed of adoption of the new technologies.[205] If more efficient use of the DTT spectrum were required, a mandated change of transmission standards could be considered as one of the mechanisms through which to achieve a reduction in broadcast spectrum. Whilst technically feasible, a full cost-benefit analysis of any such reassignment is essential and outside the scope of this study. Spectrum reassignment is discussed in detail in **Sections 5 and 6** of this report.

We also note that UK decisions regarding the UHF band cannot be made in isolation from the rest of Europe, particularly the neighbouring countries for whom the UK's use of spectrum may present an issue (due to cross-border interference). Broadcasting and mobile services have been shown (both theoretically and practically) not to be suitable to coexist in neighbouring countries within the same spectrum. Examples of this are interference cases in the 800MHz band that were observed between Italy and its neighbours[206]. The same could be true of any further clearance of broadcast spectrum: if the UK takes a decision that is at odds with the rest of Europe, difficult discussions will likely ensue as a result of both the land border shared with the Republic of Ireland, and also the sea path borders shared with, for example, France, Belgium and the Netherlands. Whilst this, of course, does not preclude the allocation of a portion of the band to mobile services, it certainly has the potential to introduce obstacles associated with doing so.

Broadcast spectrum cannot simply be reassigned without consideration of where that traffic might go and the potential alternatives for content distribution

Viewing via fixed and mobile broadband: Fixed and mobile broadband have demonstrated they have a role to play in content distribution. Households currently make use of these services to view live and on-demand content, both at home and on the move. The capabilities of fixed and mobile networks to cope with an increase in traffic resulting from increased content consumption are considered within S**ections 4.4 and 4.9** of this report. It is not unreasonable to assume that the immediate transfer of all broadcast traffic to either a mobile or fixed network would cause a significant jump in traffic loading of these networks, which could result in reduced quality of service. Wi-Fi and mobile standards are both improving, allowing for greater throughput and a better user experience. There is work ongoing within 3GPP, the mobile standardisation body, to define a multicast system (eMBMS) for mobile networks. This will enable a broadcast mode within existing mobile networks, which, if implemented, will improve spectrum efficiency. The result of this would be to lessen the load on mobile networks during periods of high levels of simultaneous consumption of the same content. However, the adoption of these standards will take time, limiting the extent to which either network would be expected to offer a widespread alternative to DTT in the next 5 years. The impact of increased traffic loading - in a scenario where broadcast spectrum is reduced - needs to be fully quantified and analysed. Even under the assumption that these networks can cope, there are additional considerations.

[205] The interim multiplexes COM7 and COM8 were originally launched to drive uptake of DVB-T2 and HD. COM8 has since been switched off, with no corresponding migration of HD services or increased usage of DVB-T2 on the rest of the platform.

[206] Aegis, 2009. , Interference from Italian DTT stations into mobile networks on channels 66-69, for GSMA 9th July 2009 https://www.gsma.com/spectrum/wp-content/uploads/DigitalDividend/DDtoolkit/uploads/assets/downloads/06/aegis-report-on-interference-from-italian-dtt-stations-into-mobile.pdf [Accessed March 2022].

- The use of mobile and fixed networks to individually deliver the same content to multiple users is inefficient and artificially loads networks, thereby decreasing users' experience.

- An important factor, particularly for any public service broadcaster, is the requirement for end-users to have payment free access to its content. The requirement for fixed and mobile broadband subscribers to pay a fee to access the internet likely means that this FTV requirement is not met. Further, there are considerations on the DTT platform with regards to the prominence of content, for example, the allocation of low logical channel numbers (LCNs) in the electronic programme guide (EPG) to the BBC[207], ITV, and Channels 4 and 5. Without a dedicated platform bringing content from various broadcasters together, ensuring such prominence would likely be difficult. These issues were discussed in detail during the Ofcom Small screen: Big Debate in 2021, with recommendations made to the Government on the future of Public Service Media.[208]

5G broadcasting: 5G Broadcast aims to combat the inefficiency of fixed and mobile networks delivering the same content to multiple users. This is by utilising a broadcast mode within the 5G standard in an approach that is more consistent with DTT networks. A further benefit of this approach is the potential for broadcast content, traditionally only available through TVs, to be accessible via mobile devices without the use of OTT apps. There are two primary topographies envisaged for 5G Broadcast: replication of a DTT type network delivering all content to users via 5G Broadcast or the use of 5G Broadcast to alleviate mobile traffic in hotspots.

Considering first the DTT type approach, various trials have been conducted, including one by the BBC[209], looking at the delivery of radio content through mobile broadcast. A recent trial focused on the use of 5G Broadcast for delivery of more traditional broadcast content took place in Vienna, Austria. The trial found that 5G Broadcast could be used to extend the reach of terrestrial broadcasting to mobile devices, achieving comparable performance to existing DTT networks and enabling innovation and new business models[210]. The spectral efficiency of the two systems was similar, although the reception requirements for the 5G Broadcast were more stringent.

There are two main options for the provision of a 5G Broadcast signal: use of existing broadcast networks or use of mobile networks (existing or yet to be deployed).

- **Use of broadcast networks**: The UK's current DTT network is designed to achieve fixed rooftop reception. Mobile reception, e.g. on a mobile phone, requires greater field strengths due to both a smaller receive antenna and a less favourable reception location, i.e., on the ground surrounded by 'clutter' rather than on a rooftop. As such, if existing broadcast networks were to be used for the provision of a 5G broadcast signal, it is likely that densification of the network would be required.

- **Use of mobile networks**: If mobile networks were to be used for the provision of a 5G Broadcast signal, the geographical coverage would need to match, or exceed, that of DTT. DTT networks are subject to strict service level agreements (SLAs) requiring, for example, the use of diverse power supplies and uninterrupted power supplies (UPSs) to ensure high levels of availability. Given the much larger number of mobile sites, it is unclear how practical these sorts of SLAs would be.

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[207] Ofcom, 2019, Review of prominence for public service broadcasting [Accessed March 2022].

[208] Ofcom, 2021 Small Screen: Big Debate Recommendations to Government on the future of Public Service Media, [Accessed March 2022].

[209] BBC, 2019, 5G for Broadcasters – New Opportunities for Distribution and Content, BBC, 2019 [Accessed March 2022].

[210] ORS Input to CEPT, 2021, Technical implementation status of 5G Broadcast: Vienna Field Trial.

Further issues that would need to be clarified prior to any widespread replacement of DTT by 5G Broadcasting would be:

- **Support equipment that receives the 5G broadcast signal** - there is no support currently in equipment, e.g. mobile phones or other reception equipment, for a 'receive only mode', that is to say, one which is SIM-free. Without this, 5G Broadcast would not be expected to meet the free to view requirements placed on broadcasters. Inclusion of this functionality would take time, investment, design and support from the handset vendors. In addition, if 5G were to be a DTT replacement, then it would also need to connect to other viewing devices in the home if there is no phone or fixed broadband, such as Smart TVs and set-top boxes.

- **Whether existing DTT spectrum could be used to support 5G broadcast.** At present, the use of mobile networks to deliver an equivalent broadcast service (to the DTT network) would require the use of the existing mobile spectrum. There is currently uncertainty as to the most suitable business model and technical approach to achieve the most efficient use of DTT spectrum compared to current broadcast networks.

Considering the second approach, looking to relieve traffic on mobile networks in areas or at times of high congestion, this could potentially alleviate the need for a full dedicated 5G Broadcast network. Instead, this approach could present an opportunity for operators to improve the experience for users in heavy traffic areas, for example, in a sports stadium, by broadcasting certain content to multiple users. When deployed alongside a normal mobile network, this approach has the benefit of reducing congestion for both broadcast users and those connected via unicast.

A trial[211] conducted in the UK in February 2022 investigated using 5G as a platform for delivering broadcast content to mobile handsets. The trial was supported by Virgin Media O2, Rohde & Schwarz, DTG, GWS, Digital Catapult, and the University of Surrey's 5G/6G Innovation Centre and used 5G broadcast at a football match to investigate the way fans interact with live sport. It used a specially designed app that allowed six high-quality live streams of different perspectives of the game to be viewed. Particular findings of the trial were proof of the ability of 5G Broadcast to take live inputs, i.e., cameras onsite, and distribute them to viewers in a way that did not cause excess traffic on the local mobile networks.

Whilst this approach may help to moderate the levels of traffic over mobile networks, it likely represents a niche feature to a certain market segment (e.g. live sports viewers). As such, it is likely to be limited compared to the choice available across the DTT platform or a wider 5G Broadcast implementation. If such a service gained popularity, it would be expected to increase in parallel with DTT, a replacement of DTT with mobile/fixed broadband, or a wider 5G Broadcast implementation.

4.1.3 FUTURE OF RADIO

There remains a relatively strong demand for FM services received at home and in-car[212] in the UK. There has been a steady increase in listening via the DAB platform, with 60% of all listening via DAB or other digital platforms. In 2020, the Government issued a report[213] indicating the need for protection of FM services, predominantly for the elderly, vulnerable and those in remote places, to be able to continue listening to their

[211] TVB Europe article, Feb 2022 UK-first 5G broadcast trials take place at MK Dons football stadium. See: https://www.tvbeurope.com/media-delivery/uk-first-5g-broadcast-trails-take-place-at-mk-dons-football-stadium

[212] Ofcom 2021 Media National: UK 2021, https://www.ofcom.org.uk/__data/assets/pdf_file/0023/222890/media-nations-report-2021.pdf

[213] The Digital Audio Review, 2020.

favourite radio services. By 2030, it is expected that listening via FM services will be between 12% and 14% of all radio listening but will likely remain important for the elderly and those with limited DAB reception.

It is recognised that there is growth in audio demand via new technology platforms, such as smart speakers, but this relies on a fixed broadband connection and Wi-Fi in the home. There are still many households in the UK which do not have fixed broadband and completely rely on (largely) analogue sound broadcasting. However, by 2030, with the continued rollout of fixed networks, it is likely that more access to digital (on-demand) audio platforms will be possible, reducing the reliance on FM services at home for remote listeners[214].

4.1.4 SUMMARY AND RECOMMENDATIONS

Demand for Free To View (FTV) content over the DTT broadcast network is slowly decreasing, but continued access to the UHF spectrum for terrestrial broadcasting will remain for the next 10-to-15 years due to licensing commitments until 2034 (noting there is also a break point in the licences at 2030). From 2034 onwards, demand for UHF spectrum from broadcasters is likely to decline as DTT viewers choose alternative platforms, opening the way for some broadcasting spectrum to be made available for other services, such as mobile.

A reduction in demand for the DTT spectrum in the 470–694 MHz band would enable parts of, or potentially the entire band, to become available for other uses, notably for 5G or 6G. Fixed and mobile broadband are the potential alternatives to DTT and are currently widely used by viewers. However, the ability of these networks to cater to the significant increase in traffic that a full replacement of DTT would bring remains unproven. It is recommended that a comprehensive cost-benefit analysis is undertaken on the use of the DTT spectrum relative to alternative platforms, which includes quantifying the amount of data that would shift from DTT to other platforms.

Given the nature of the services (both existing and candidate new ones) making amendments to usage involves long lead times which should be factored into the decision making process. An assessment will be needed to determine the extent to which the DTT spectrum is re-allocated to mobile. This aligns with the Government's white paper[215] recommending a comprehensive analysis to be undertaken in 2025 as part of its planned review of DTT, to examine capability of alternative platforms as long-term replacement for DTT. The review should also consider the long-term implications for the PMSE sector, which shares frequencies with DTT.

Although demand remains steady today and in the short to medium term, the move from FM to DAB and other digital services may make more spectrum available in the VHF band after 10 years.

[214] The Government will be undertaking a further review of radio and audio planned to take place in 2026. https://www.gov.uk/government/publications/digital-radio-and-audio-review/government-response-to-the-digital-radio-and-audio-review

[215] The government asked Ofcom to conduct a review of demand and market changes that may affect the future of content distribution before the end of 2025. See government publication April 2022 https://www.gov.uk/government/publications/up-next-the-governments-vision-for-the-broadcasting-sector/up-next-the-governments-vision-for-the-broadcasting-sector

4.2 COMMERCIAL SATELLITE OPERATIONS

4.2.1 CURRENT DEMAND FOR COMMERCIAL SATELLITE SPECTRUM

Satellites enable a wide range of commercial applications in the UK, including[216] communications and navigation. As noted by Ofcom in their Space Spectrum Strategy consultation, the size of the satellite communications sector is growing[217] based on an increasing number of satellites (with some NGSO systems deploying hundreds of thousands of satellites). This is being driven by an increase in the number of entrants (mainly driven by new LEO operators) into the satellite communications market. In addition, Ofcom has revised its NGSO licensing process to ensure that the regulatory framework is both competitive and attractive to service providers. Ofcom's Space Spectrum Strategy and Future Approach to Mobile Markets paper[218] also notes the trend towards greater integration between terrestrial and satellite networks for broadband, mobile and IoT.

As noted in **Section 3.2.2**, there are a number of new entrants to the commercial satellite market including, OneWeb and SpaceX leading the way with NGSO networks, but also Telesat Lightspeed and Amazon Project Kuiper, joining longer-term market participants such as SES and Intelsat. These satellite communications networks all need spectrum, and this is presenting new spectrum management challenges, not just in the UK but globally. This growth in demand for satellite spectrum has seen an associated increase in agenda items at the ITU focused on addressing the need for greater supply to meet the demand.

There are several ongoing activities at an ITU level and anticipated for discussion and decision at WRC-23 and within the UK, which could directly impact spectrum use for satellite communications:

- Agenda Item 1.18 at WRC-23 is considering a range of frequencies in the S-band (2010–2025 MHz), which were previously set aside for mobile services (but which were never taken up in the UK). This band is used by PMSE wireless cameras in the UK which would make it difficult to use for narrowband mobile satellite services (i.e. IoT type connectivity).

- The frequency range 3.6–3.8 GHz is part of the C-band fixed satellite downlink spectrum. However, in the UK, this is licensed to EE, Three and O2 for mobile services. At present, access to this band for mobile services is on a co-primary basis at a European level, but at an ITU level (and therefore in other parts of Region 1), it is a secondary user. WRC-23 Agenda Item 1.3 is considering raising the status of mobile services in this frequency range to primary. This would provide equal priority for mobile and satellite services. Whilst the UK was still part of the European Union, this band was identified for mobile services[219] meaning that it was harmonised for mobile services in advance of any decision at the WRC. Nevertheless, a decision internationally to make this band co-primary for satellite and mobile services could affect the use of the band for those in the UK who rely on it nationally and internationally (i.e. Inmarsat). Across the whole of the region (i.e. for delivery of connectivity between the UK and Africa).

- The frequency range 3.8–4.2 GHz represents the remaining part of the C-band downlink spectrum that is not currently used in the UK for national public mobile services. Ofcom has made this

[216] This section does not consider DTH satellite broadcasting (see **section 4.1**) or the use of satellites for other purposes, such as meteorology and Earth observation (see **section 4.12**).

[217] Ofcom, March 2022, Ofcom Space Spectrum Strategy Consultation [Accessed April 2022].

[218] Ofcom, March 2022, Ofcom's future approach to mobile markets, A discussion paper [Accessed April 2022].

[219] Commission Implementing Decision (EU) 2019/235 of 24 January 2019 on amending Decision 2008/411/EC with regards to an update of relevant technical conditions applicable to the 3400-3800 MHz frequency band.

spectrum available for local licensing for small scale private mobile networks and for fixed wireless access uses. Whilst the proposed licensing framework will allow Ofcom to protect existing UK-based C-band downlinks, a wider international take-up of this approach could leave the C-band largely unusable for UK satellite operators with downlinks in other countries.

- The 6 GHz band is the frequency range used for C-band satellite uplinks. Ofcom currently permits the use of the lower part of this band (5925–6425 MHz) for low-power (250 mW indoor and 25 mW outdoor) licence-exempt Wi-Fi. At the time of this study, Ofcom published a consultation (February 2022) on permitting similar access to the upper part of the band (6425–7070 MHz) on a lightly licensed basis (i.e. where the licensee pays a small fee and must register their usage)[220]. As this is an uplink band, any increase in signals in this band could cause interference to UK satellites and those of other countries. This band is also being studied at the ITU for WRC-23 (Agenda Item 1.2) with the goal of potentially identifying the band for IMT/5G use. A change in focus of the band towards higher-powered terrestrial services could cause significant difficulties for satellite use of the band.

- WRC-23 Agenda Item 1.15 seeks to harmonise the use of the frequency range 12.75–13.25 GHz to uplink Ku-band satellites from aircraft and water-going vessels. This would provide additional connectivity for these purposes and would support UK operators who provide services (such as Intelsat), and as such, usage is primarily at high altitudes or in coastal waters meaning that the impact on terrestrial users of the band (such as fixed point-to-point links) is minimal.

- WRC-23 Agenda Item 1.16 aims to provide the necessary technical restrictions to allow communication from moving satellite Earth stations (e.g. on aircraft and vessels) to non-geostationary (i.e. low and medium Earth orbit) satellites in the Ka-band. This would provide the certainty necessary to allow these services to be permitted and would support, but is not limited to, companies like OneWeb.

- WRC-23 Agenda Item 1.14 is looking at re-arranging the use of spectrum in the 230 GHz range to try and better reflect the use of the spectrum for Earth observation. The UK Space Agency indicated that this was necessary in order to regularise usage.

Another issue which was raised by the UK Space Agency was the need for a regulatory framework to be established for sub-orbital vehicles (such as Virgin Galactic), which is an agenda item (1.6) at WRC ‘23. At present, the height these vehicles reach is above that normally regarded as being aeronautical but below that which might be regarded as space. It is, therefore, not clear which regulatory regime applies to their use of spectrum. With an increasing number of Unmanned Aerial Systems (UAS) also reaching these kinds of altitudes, defining how they should be dealt with from a regulatory perspective would be a positive step. Whether the final decision is to extend the height of aeronautical spectrum use or classify their heights as space, a harmonised global decision would provide much-needed certainty to the space sector.

4.2.2 FUTURE DEMAND FOR COMMERCIAL SATELLITE SPECTRUM

The cost of fixed satellite connectivity has been steadily declining both for professional and domestic users[221]. Similar trends exist for mobile satellite connectivity. These trends are driven by competition but

[220] Ofcom, 2022 https://www.ofcom.org.uk/__data/assets/pdf_file/0022/233194/spectrum-sharing-6ghz.pdf [Accessed 13th April 2022].

[221] NSR FSS Regional Mean Price Index Satellite Capacity Pricing Index, 6th Edition (2020).

also by the increasing amount of capacity, which can be delivered by more sophisticated satellites and constellations.

Whilst demand for satellite television broadcasting remains strong, according to the UK Satellite Applications Catapult, the primary driver of increased demand for satellite communications is broadband connectivity. This may be in the form of professional demands for backhaul from remote sites or from domestic users whose terrestrial internet connectivity is poor. Companies such as Space X, with its Starlink satellite network, are making inroads in delivering domestic satellite broadband capacity with high enough connectivity speeds (100–200 Mbits/s)[222] and low enough costs to make the network attractive to consumers.

Increased capacity in satellite networks can be delivered in several ways.

- Improved spectrum efficiency means that each MHz of spectrum can deliver increasing amounts of connectivity. High throughput and very high throughput satellites (HTS and VHTS, respectively) can deliver Terabits of connectivity, but there are limits to how far this can be taken due to restrictions on the total amount of power that satellites can transmit towards the Earth.
- Smaller satellite beams (spot beams) allow frequencies to be re-used in neighbouring areas, in much the same way that mobile networks re-use frequencies on neighbouring cell sites, and this improves spectrum efficiency.
- Low and medium earth orbit (LEO and MEO) constellations can also re-use spectrum by providing connections that are at different look-angles to GEO satellites (i.e. pointing away from the geostationary arc) and also provide smaller footprints being closer to the Earth. According to the UK Satellite Applications Catapult, the additional capacity this provides is in the order of 3 to 4 times that of GEO systems.
- By using higher frequency bands, where more spectrum is available.

Together, these developments are allowing satellite communication companies to significantly increase the amount of capacity they can deliver whilst re-using the same spectrum. Whilst Ku-band is slowly becoming congested, Ka-band is taking up the strain, and the availability of Q, V and W bands should provide sufficient spectrum to allow expansion to continue (for example, Space X have filed an application to the FCC in the USA for 7000 Starlink satellites using Q/V band).

There is continued growth in the use of satellite navigation applications with an expected 2.5x market growth over the next 10 years, according to a report[223] by EU Agency for the Space Programme (EUSPA). The use of satellite navigation across different sectors, primarily in transport with integration into vehicles, aircraft, trains and ships but also in mobile devices, is being driven by growth into new markets (such as emerging markets and further penetration into the three main segments of consumer solutions, tourism, health, road and automotive). Satellite navigation is also used for timing signals which are used by other electronic communications network operators to provide synchronisation and timing, which is vital for the precise operation.

The growth in demand is coming from shipments of Global Navigation Satellite System (GNSS) devices rather than deployment of new satellite navigation networks and thus, is not placing additional demands directly

[222] SpaceX Starlink just got faster: Price, speed, release window for premium tier https://www.inverse.com/innovation/starlink-premium

[223] EUSPA publishes EO and GNSS Market Report 2022, EUSPA, Feb 2022 https://space-economy.esa.int/article/126/euspa-publishes-eo-and-gnss-market-report-2022

on spectrum. There are a few challenges with the deployment of satellite navigation network deployments, namely long development lifecycle and launch time frames (e.g. Galileo, the European satellite navigation network, has taken 18 years from European agreement to full deployment), high cost of constructing and launching the necessary constellation (this can run up to billions of pounds). There are already satellite navigation networks launched by the USA (GPS), the EU (Galileo), China (Beidu) and Russia (Glonass) providing a mix of commercial and government services, some of which are free to consumers and businesses and some are paid for.

4.2.3 SUMMARY AND RECOMMENDATIONS

Whilst **demand for satellite communications services continues to grow steadily**, modern techniques are enabling this growth to be handled within existing spectrum bands. This is true for satellite communications, navigation and earth exploration. This was supported during stakeholder engagement with the UK Space Agency. The issue is, therefore, not one of identifying significant new amounts of spectrum for satellite services but **of ensuring that access to spectrum that is already available is suitably protected and that this spectrum can be used flexibly for fixed, mobile, geostationary and non-geostationary constellations**.

For satellite communication, bands which are just coming into use (Q, V, W bands) and are currently lightly used, may provide the future backbone for satellite communications, in particular as feeder links and, as stakeholders told us, potentially for consumer connections too. These frequency ranges are also being examined for 5G use which means that a balanced approach needs to be taken to ensure both industries can continue to grow.

The growth in demand for satellite communication needs to be handled alongside the sensitive monitoring requirements of other satellite uses, such as meteorology. **Growth in satellite communications can be expected, but there is a risk that this demand will compromise the protection of critical spectrum bands currently used for earth observation.**

The UK Government should continue to support access to spectrum for satellite use, ensuring alignment with space sector growth and future requirements for NGSOs, and continue working to ensure that the spectrum regulatory environment is attractive to service providers and supports a competitive market. There is also a need for the Government to be supportive of the sector's other requirements, such as the protection of frequencies in relation to interference from other services balanced with the wider market needs of spectrum sharing.

4.3 FIXED LINKS

4.3.1 CURRENT DEMAND FOR FIXED POINT-TO-POINT LINKS SPECTRUM

As noted in **Section 3.2.3**, fixed links provide wireless connectivity between two or more points. This could be between communications masts (on a point-to-point basis), between buildings (point to multipoint basis) or a mix of the two.

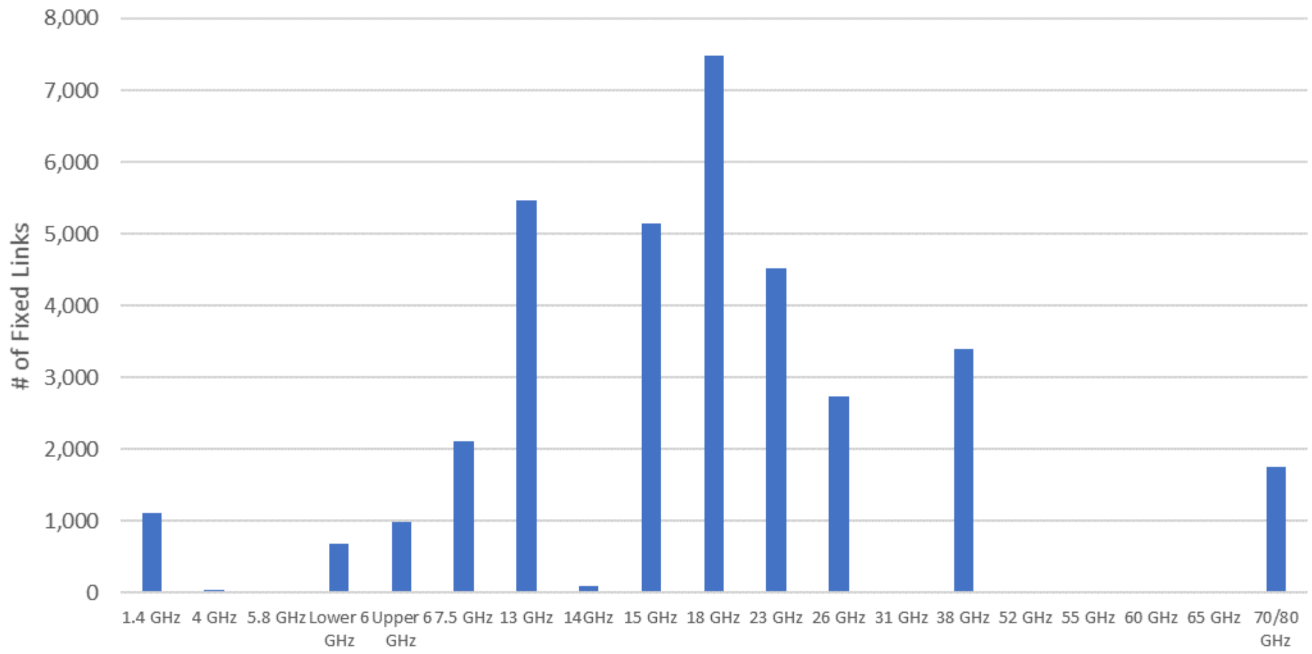
There are currently approximately 45,000 fixed links in operation in the UK[224], with approximately 35,000 bidirectional links in the spectrum that are managed by Ofcom[225] and 10,000 within a set of the so-called

[224] Ofcom 2018, Fixed Wireless Spectrum Strategy Consultation on proposed next steps to enable future uses of fixed wireless links https://www.ofcom.org.uk/__data/assets/pdf_file/0027/108594/Fixed-Wireless-Spectrum-Strategy.pdf [Accessed March 2022].

[225] See: https://www.ofcom.org.uk/spectrum/information/spectrum-info-faq/wtr

block assigned frequencies which are privately owned blocks of spectrum held by telecommunications operators.

FIGURE 12 USAGE OF FIXED LINK BANDS



Source: LS telcom based on data from Ofcom, 2022. Wireless Telegraphy Register [Accessed December 2021].

Ofcom notes that the total number of fixed links within the UK has remained broadly similar between its most recent reviews (in 2012 and 2017) but that the number of fixed links authorised in the Ofcom managed bands has decreased, with a corresponding increase in the number of links using block assigned spectrum.

The block assigned spectrum is licensed to mobile network operators, broadcasting and utility network operators, and commercial connectivity providers. No data is publicly available on the number of links authorised in block assigned spectrum, but Ofcom notes that the numbers of fixed links within these bands has increased.

It is expected that this trend will continue so long as there is sufficient bandwidth within the blocks to support the capacity requirements. This is because it is more convenient for licensees to use block assigned spectrum (which is delivered as a service to operators) than to apply for additional licences in Ofcom's managed spectrum, although, overall, the total number of links has remained broadly stable. Block assigned spectrum also gives the licence holders the control and ease of spectrum access they require thereby encouraging greater efficiency.

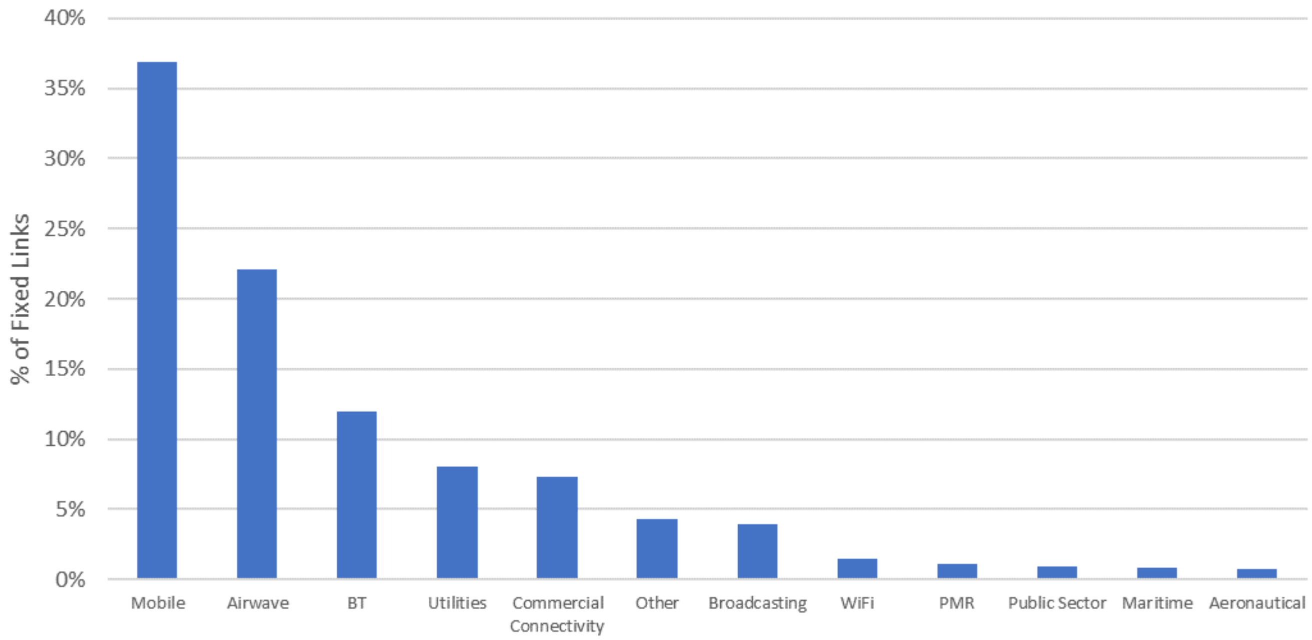
Within the Ofcom's managed spectrum, approximately 65% of licensed fixed links operate in the sub 23 GHz range (as illustrated by **Figure 12** above), with the remaining proportion of fixed links above 26 GHz operating in the 38 GHz bands, but these are for a limited number of applications[226].

[226] Ofcom does not hold data on the 60 and 65GHz bands, as these are licence-exempt and holds limited information on the usage of the 5.8GHz as it is lightly licensed and typically used by wireless internet service providers.

As shown in **Figure 13**, 80% of the fixed links within the Ofcom managed spectrum are operated by 9 companies: Airwave, Vodafone, BT, Telefonica, MBNL, Arqiva, JRC, WPD Telecoms and EE, noting that a number of these companies also have access to block assigned spectrum. These can be grouped by sector, with each sector holding the following share of fixed link licences within spectrum managed by Ofcom.[227]

- Mobile – 37%
- Airwave – 22%
- BT – 12%
- Utilities - 8%

FIGURE 13 FIXED LINKS BY ORGANISATION



Source: LS telcom based on data from Ofcom, 2022. Wireless Telegraphy Register [Accessed December 2021].

4.3.2 FUTURE DEMAND FOR FIXED POINT TO POINT LINKS SPECTRUM

Going forward, Ofcom expects that demand for fixed link spectrum will be dominated by the following applications[228]:

- 5G backhaul requirements;
- increased capacity requirements for fixed wireless access and broadband backhaul; and
- changes to electricity distribution.

5G backhaul requirements

Growth in mobile data demand, as explored in the mobile section of this report (**Section 3.2.4**), is expected to be the key driver of changes in the demand for fixed links. It is unclear the extent to which the existing

[227] Note, links licensed to EE are categorised under mobile rather than under BT.

[228] Ofcom 2018, Fixed Wireless Spectrum Strategy Consultation on proposed next steps to enable future uses of fixed wireless links https://www.ofcom.org.uk/__data/assets/pdf_file/0027/108594/Fixed-Wireless-Spectrum-Strategy.pdf

fixed links spectrum can satisfy these requirements. A number of frequency bands, for example, 1.4 GHz, 6 GHz, 15 GHz and 26 GHz, have closed to new applicants, which potentially limits the extent to which the existing spectrum is able to meet demand. As Ofcom expects to make more spectrum available in the higher frequency ranges (70 GHz, 80 GHz, 92 GHz-114.25 GHz, and 130-174.8 GHz) for 5G urban backhaul, it is expected that this will be sufficient to meet the increased requirements of MNOs going forward. However, this does not necessarily preclude the potential for localised shortages of spectrum, mainly due to congested use in urban areas.

In the case of widespread usage of autonomous cars or mMTC (massive machine-type communications), data requirements over mobile networks will increase. Given the locations of these use cases, however, such as along roads and within workplaces, fibre connectivity is expected to be sufficient, which will remove the need for wireless fixed links. For example, 50% of the strategic road network (which is most of Britain's motorways) is covered by National Roads Telecommunications Service's fibre network[229]. Similarly, 98% of UK urban households and 95-96% of business premises in each of the nations have access to superfast broadband[230], suggesting that connectivity is already in place in the locations where people live and work. As such, for significant increases in the capacity required along roads and in urban areas, existing and planned fibre developments in these areas could replace the need for fixed links.

In addition, as the current Airwave system is to be retired in 2024, it can be expected that there may be an increase in the available fixed link spectrum. This is because the replacement, ESN, which will be operated by EE, utilises its existing 4G offering[231] with its own existing fixed links. The fixed link spectrum capacity from Airwave should be available (i.e. returned to Ofcom for reassignment) to accommodate at least some of the wider mobile sector's future demand for fixed links.

Fixed links in the utilities sector

The utilities sector is becoming ever more dependent on connectivity, driven in part by the adoption of smart grid approaches, allowing for near real-time balancing of demand and energy generation[232]. This requires connectivity to provide both; telemetry for generation and distribution and domestic metering. It is expected that this will increase the demand for fixed links, as investigated within the PMR and Utilities section of this report (See **Sections 4.7 and 4.8**).

Whilst the demand for fixed links is expected to increase in certain sectors, technological developments in fixed link technology can support higher throughput across links. Adoption of newer, more spectrally efficient technology may help to reduce the number of licences required, although it is unclear the extent to which these developments have already been deployed.

4.3.3 SUMMARY AND RECOMMENDATIONS

The main driver for a continuous **steady increase in demand** for fixed links is expected to be backhaul for public mobile networks as 5G networks continue to be deployed and other wide-area connectivity (e.g. Fixed

[229] NIC, 2016, 5G Infrastructure requirements for the UK, LS telcom, https://nic.org.uk/app/uploads/5G-Infrastructure-requirements-for-the-UK-LS-Telcom-report-for-the-NIC.pdf [Accessed March 2022].

[230] Ofcom, 2021, Connected Nations report, https://www.ofcom.org.uk/__data/assets/pdf_file/0035/229688/connected-nations-2021-uk.pdf [Accessed March 2022].

[231] UK Government Emergency Services Network Overview website, 2022, https://www.gov.uk/government/publications/the-emergency-services-mobile-communications-programme/emergency-services-network [Accessed March 2022].

[232] British Consulate General website https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/321852/Policy_Factsheet_-_Smart_Grid_Final__BCG_.pdf [Accessed March 2022].

Wireless Access) throughout the time frame of this study. However, given that fibre connectivity is improving and that Ofcom expects higher frequencies to be made available to serve the increased backhaul demand arising from 5G, it is expected that current spectrum assignments for fixed links will be sufficient until such a point as Ofcom makes additional spectrum available which has not yet been published. This does not rule out the possibility of localised shortages in the availability of spectrum for fixed links.

For other services, the freeing up of spectrum caused by mobile operators moving fixed links into block assigned spectrum provided by the likes of Arqiva and MLL Telecom and the retirement of Airwave is expected to ensure there is sufficient spectrum available to meet demand. Furthermore, we do not expect any spare capacity in the fixed link spectrum to be refarmed for other uses.

It is recommended that Ofcom maintains a continued review of demand for fixed links based on the potential risk of localised shortages and ensures that operators can access spectrum in the higher frequency bands in a timely manner.

4.4 MOBILE SERVICE

In this section, we discuss the demand for public mobile network traffic (voice and data), covering specific mobile demand forecasts that, in turn, drive the demand for more mobile spectrum. We also conduct a high-level spectrum demand modelling exercise to understand how much spectrum may be needed within the 5-to-15-year time frame of the study. This section is structured as follows:

- Public mobile network traffic demand forecasts
- Near term demand growth for mobile
- Medium to long term demand growth for mobile
- Mobile spectrum demand model (2020–35): When will mobile operators require additional spectrum to meet demand?
- Summary and recommendations

4.4.1 PUBLIC MOBILE NETWORK TRAFFIC DEMAND FORECASTS

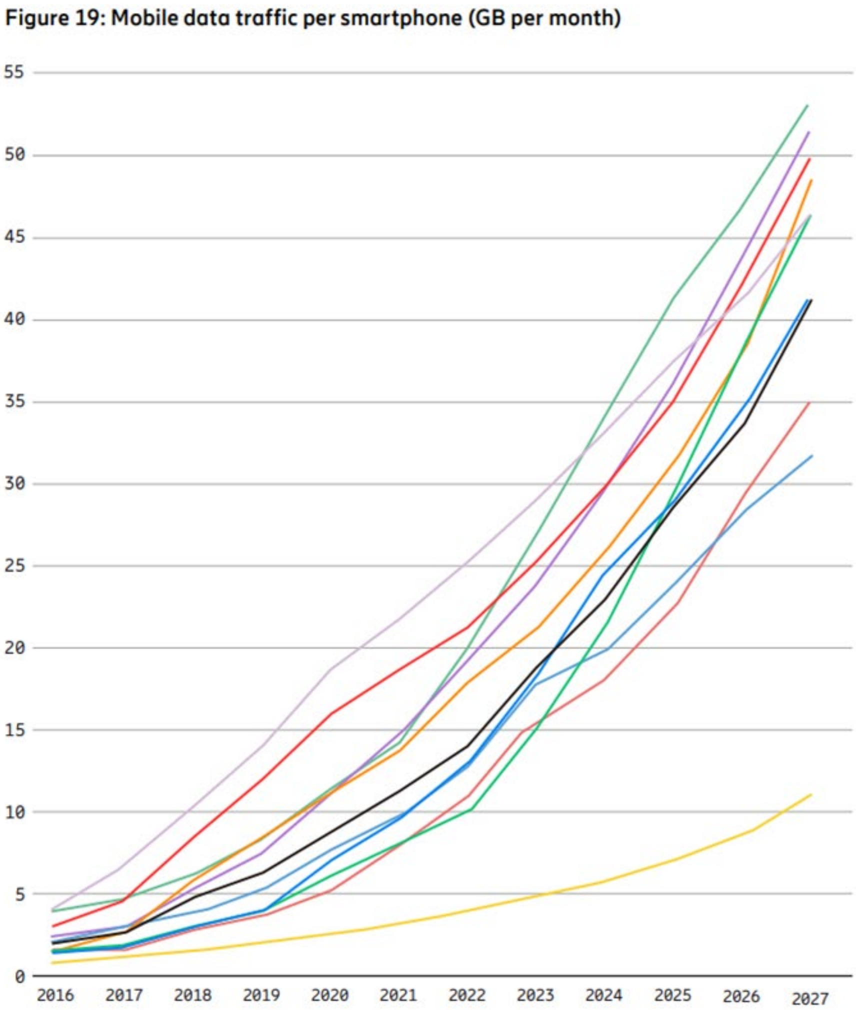
Predicting future public mobile network traffic demand has become common practice amongst vendors and analysts who try to project mobile data growth, typically over a five-year period. These forecasts try to estimate how much traffic demand there is likely to be in the future so that operators, vendors and regulators have information to use and help prepare business plans or network rollouts and ensure networks do not become congested. Examining forecast trends is therefore useful in gauging potential future outcomes. This study considers mobile demand trends over a 10-to-15-year time frame. As discussed earlier, forecasting over longer periods is more uncertain as it becomes increasingly difficult to predict what the potential growth rates would be. To mitigate this uncertainty, we have provided a range of growth rate assumptions. The input assumptions for mobile traffic demand and capacity are available in **Annex C**.

Fundamentally, since the release of the first smartphone, mobile traffic has continued on a steadily increasing trajectory. This has largely been driven by increasing user consumption as technologies improve over time. **Figure 14** from the Ericsson Mobility report[233] shows growth in mobile data traffic per smartphone in GB/month for different regions around the world. The chart shows observed historical consumption and

[233] Ericsson, Nov 2021 Ericsson Mobility Report, https://www.ericsson.com/en/reports-and-papers/mobility-report/dataforecasts [Accessed March 2022].

future projected growth (2016 to 2027) in most of the regions (except for sub-Saharan Africa) with similar trajectories but varying total volumes.

FIGURE 14 GLOBAL AND REGIONAL TRAFFIC DEMAND FORECASTS



Regions	2021	2027	CAGR 2021–2027
North America	14.6	52	24%
Western Europe	15.2	51	23%
India	18.4	50	18%
North East Asia	13.9	48	23%
South East Asia and Oceania	8.0	46	34%
GCC	22	46	13%
Middle East and North Africa	9.6	41	27%
Global average	11.4	41	24%
Latin America	7.9	35	28%
Central and Eastern Europe	9.9	32	22%
Sub-Saharan Africa	2.9	11	25%

Source: Ericsson, 2021. Ericsson Mobility Report November 2021.

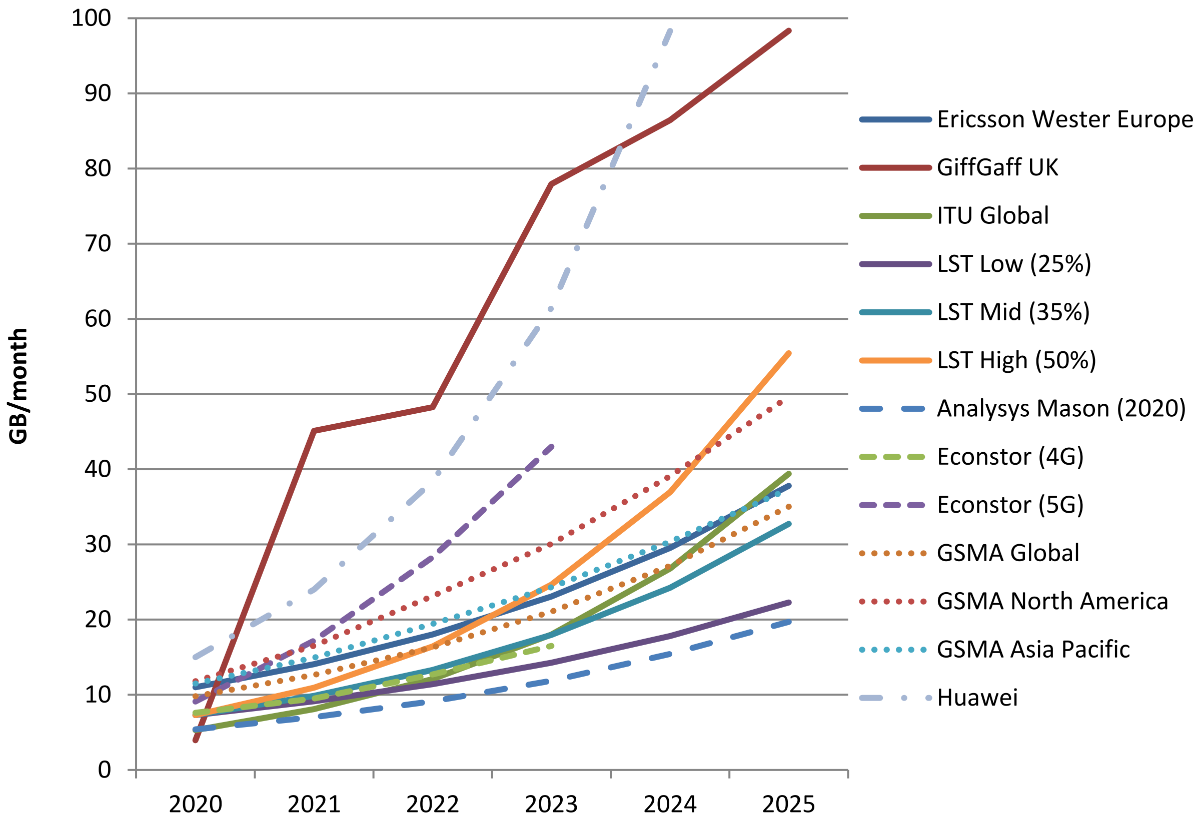
The small uplifts in the rate of growth that appear around 2019-21 correspond to the introduction of 5G across most developed economies around the world, demonstrating the impact on mobile traffic of introducing new technology. The continued growth rates are affected by the continued take-up and rollout of 5G across the world.

In the next section, we examine some of the more specific forecasts for mobile data demand and provide our assumptions on-demand growth estimates to determine a likely future outcome of mobile traffic in the UK. The traffic considered for these forecast estimates is mainly based on smartphone user traffic. This is because smartphone usage is currently the main driver of traffic on mobile networks. We acknowledge that other traffic types are served on mobile networks (e.g. FWA and IoT). These are also discussed below.

4.4.2 NEAR TERM DEMAND GROWTH FOR MOBILE

In order to estimate traffic growth trends, we have researched a range of forecasts across different sources that publish near term (five-year) charts. These are set out in **Figure 15** and provide a reasonable level of certainty of how mobile data traffic will grow over this period.

FIGURE 15 GLOBAL AND REGIONAL MOBILE DATA TRAFFIC GROWTH OVER 5 YEARS



Source: LS telcom.

The chart above shows that, across a range of sources, there is a general trend of steady growth between 20-30% year-on-year, with one or two extreme cases of very high growth per year. Giffgaff [234], for example, was based on a prediction from 2016, which showed an 11-fold jump in 2020/21 due to the introduction of 5G. Huawei has projected strong mobile data growth out to 2030[235]. The chart also shows our assumed growth lines - low (25%), mid (35%) and high (50%) - developed for this study which broadly align with the majority of forecasts (discussed in more detail in the next section). We use these forecasts to estimate mobile traffic demand and impact on available spectrum in the 10-to-15-year time frame.

[234] Giffgaff website See: https://www.giffgaff.com/sim-only-plans/campaign [Accessed 29th April 2022].

[235] Huawei, 2021 Communications Network 2030, https://www-file.huawei.com/-/media/CORP2020/pdf/giv/industry-reports/Communications_Network_2030_en.pdf [Accessed March 2022].

Besides smartphones, traffic is also generated by IoT (comprising applications such as connected cars, CCTV, drones and sensors, e.g. smart meters) and FWA.

- FWA traffic has a much larger volume per unit compared to smartphones (and most IoT devices) because it is a fixed-line replacement for (mainly) homes and offices. Typical traffic volume today on FWA networks ranges from 150-250 GB/month, according to a 2019 Analysys Mason study[236]. This is compared to the average usage of 453 GB/month for fixed broadband in the UK[237]. However, the number of FWA customers is relatively small, estimated at just 110,000[238].

- Mobile network IoT (e.g. NB-IoT) still represents a small proportion of all IoT traffic, with one forecast by Ofcom in 2016[239] of 156 million devices by 2024. Assuming mobile IoT represents around 8-10%[240] of the total IoT device base, this means around 12-15 million mobile-connected devices in 2024. Furthermore, these devices will typically carry very low volumes of traffic - circa 10 MB/month[241] - yielding a total traffic contribution of 150 TB/month. This is compared to smartphones, whose traffic volumes are measured in Petabytes (an order of magnitude higher).

- In contrast, connected cars, which are considered IoT devices, will consume greater volumes of traffic (GSMA indicated in one report[242] figures up to 6-9 Gbit/s) compared to other mobile IoT devices such as smart meters or other sensors. Connected cars are considered broadband IoT devices and can consume multi GB/month traffic volumes adding to the demand on mobile networks. We consider this to be a high-end estimation that may arise in the 2030 time frame, given that most cars on the road will not need to stream onboard video but rather record and store it for transfer later on. The greatest demand in the near term will most likely be from passenger data within vehicles for in-car entertainment including, live video streaming.

4.4.3 MEDIUM TO LONG TERM DEMAND GROWTH FOR MOBILE

The long term forecast of mobile data traffic is shown in **Figure 16** below and, as already mentioned, is a lot more uncertain. It shows the high scenarios until 2035, reaching a maximum of nearly 700 GB/month on average per smartphone user.

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[236] Analysys Mason December 2019, Discussion on the 6 GHz opportunity for IMT, https://www.analysysmason.com/contentassets/2a36d000895f4700a2273d3bfee449bf/discussion-on-the-6-ghz-opportunity-for-imt.pdf [Accessed March 2022].

[237] Ofcom, 2021, Connected Nations 2021, Ofcom https://www.ofcom.org.uk/__data/assets/pdf_file/0035/229688/connected-nations-2021-uk.pdf [Accessed March 2022].

[238] Metrics for the UK independent network sector Including results from Spring 2021 survey, Point Topic May 2021 https://www.inca.coop/sites/default/files/inca-point-topic-report-2021.pdf [Accessed March 2022].

[239] Ofcom, 2016 Connected Nations 2016, https://www.ofcom.org.uk/__data/assets/pdf_file/0020/108515/connected-nations-internet-things-2017.pdf [Accessed March 2022].

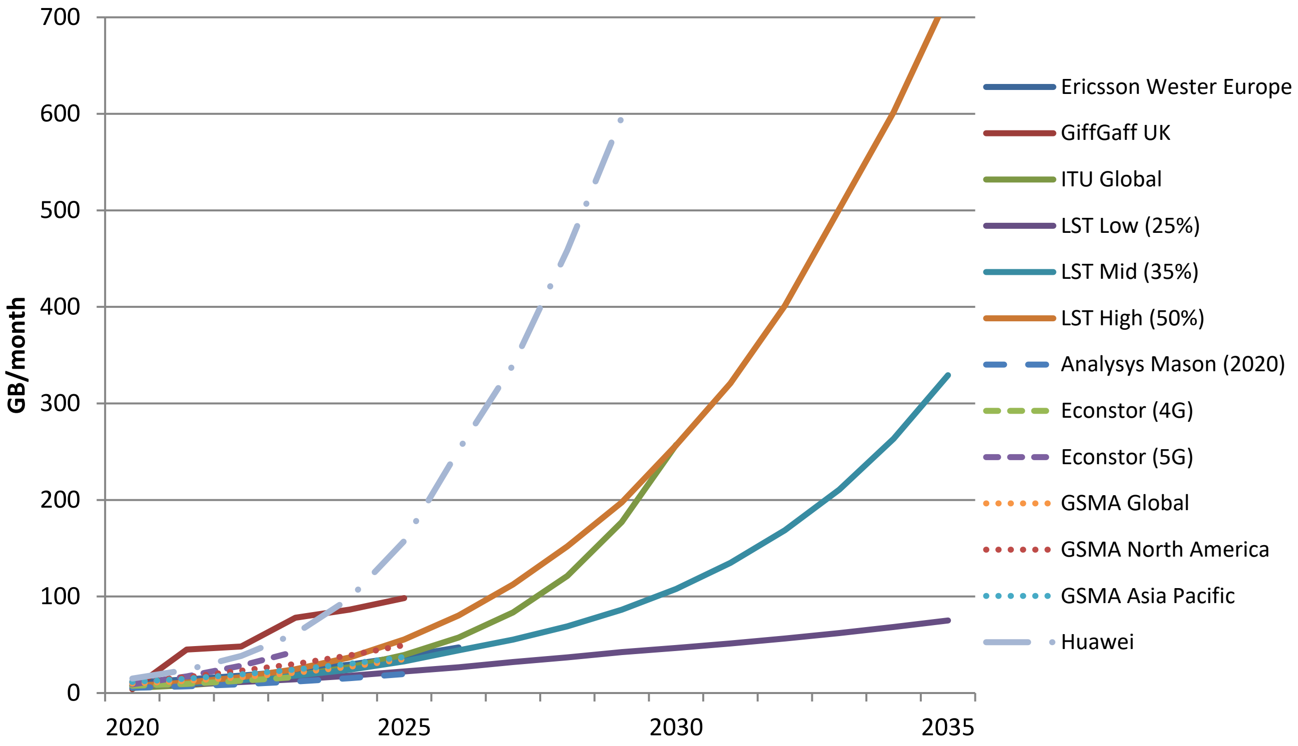
[240] By 2026, Cellular IoT Devices Will Hit a Global Total of 5.7 billion. See: https://iotbusinessnews.com/2020/11/18/80310-by-2026-cellular-iot-devices-will-hit-a-global-total-of-5-7-billion/ [Accessed March 2022].

[241] Cellular IOT roaming data traffic forecast to reach 274 petabytes in 2024: Kaleido intelligence. See: https://roaming.kaleidointelligence.com/cellular-iot-roaming-data-traffic-forecast-to-reach-274-petabytes-in-2024/ [Accessed March 2022].

[242] Coleago on behalf of GSMA, December 2021 Estimating the mid-band spectrum needs in the 2025-30 time frame, https://www.gsma.com/spectrum/wp-content/uploads/2021/07/Estimating-Mid-Band-Spectrum-Needs.pdf [Accessed March 2022].

The basis for these assumptions can be found in **Annex C**, which explains the potential scenarios and the likelihood of each scenario occurring. In essence, we consider the mid scenario as the most plausible based on a reasonable continuation of mobile consumption by smartphone users.

FIGURE 16 GLOBAL AND REGIONAL MOBILE DATA TRAFFIC GROWTH OVER 15 YEARS



Source: LS telcom.

There is a range of typical applications used on smartphones that drive traffic, the most data-intensive is video (as a proportion of all smartphone traffic). Many forecasters indicate that video traffic (and evolving resolutions, e.g. SD to HD to UHD) will continue to generate the highest proportion of traffic for years to come. Ericsson, in their latest mobility report,[243] indicates that "*video traffic is estimated to account for 69 per cent of all mobile data traffic, a share that is forecast to increase to 79 per cent in 2027*". Similarly, in the 2019 Virtual Networking Index report, Cisco forecast that video would account for 79% of global mobile data traffic by 2022. Other applications, such as web browsing, email or other downloading, make up the remaining proportion of smartphone traffic[244].

In the period beyond 2030, traffic demand forecasts become more uncertain mainly due to the challenges of predicting certain outcomes arising so far into the future. However, we note that 6G technology will likely be launched by the early 2030s, which aligns with the (roughly) ten-year mobile generation technology cycle

[243] Ericsson, Nov 21 Ericsson Mobility Report, https://www.ericsson.com/en/reports-and-papers/mobility-report/dataforecasts [Accessed March 2022].

[244] Smartphone apps such as email or social media apps soften work in the background, synchronising and downloading updates, which continue to consume data.

(4G launched in the UK in 2012 and 5G in 2019). We discuss the introduction of 6G in more detail in **Annex C**.

4.4.4 MOBILE SPECTRUM DEMAND MODEL (2020–35): WHEN WILL MOBILE OPERATORS REQUIRE ADDITIONAL SPECTRUM TO MEET DEMAND?

In this section, we provide the results of modelling for mobile spectrum demand. The aim of the model is to identify in which band ranges (sub 1 GHz, 1- 5 GHz and mmWave) there will be excess demand, the drivers of this excess demand and when it will occur for a theoretical operator (explained further in **Annex C**).

We present the results as charts which show the different traffic demand scenarios overlaid with the capacity available in each case - across the different frequency ranges. The bar charts represent the *traffic* growth for the low, mid and high growth scenarios[245]. The lines represent the low, mid and high *capacity* available over the 2020 to 2035 time frame (the capacity assumptions are further explained in **Annex C**). Where demand for the available capacity in a particular band is exceeded, this traffic is forced to use a higher frequency band: for example, if all the available capacity in the sub-1 GHz spectrum is utilised, any traffic which would normally be carried on this layer is forced to the mid-band spectrum. Similarly, excess demand using mid-band spectrum is forced to mmWave bands where this is available on sites deployed within the operators' network.

Results for sub-1 GHz

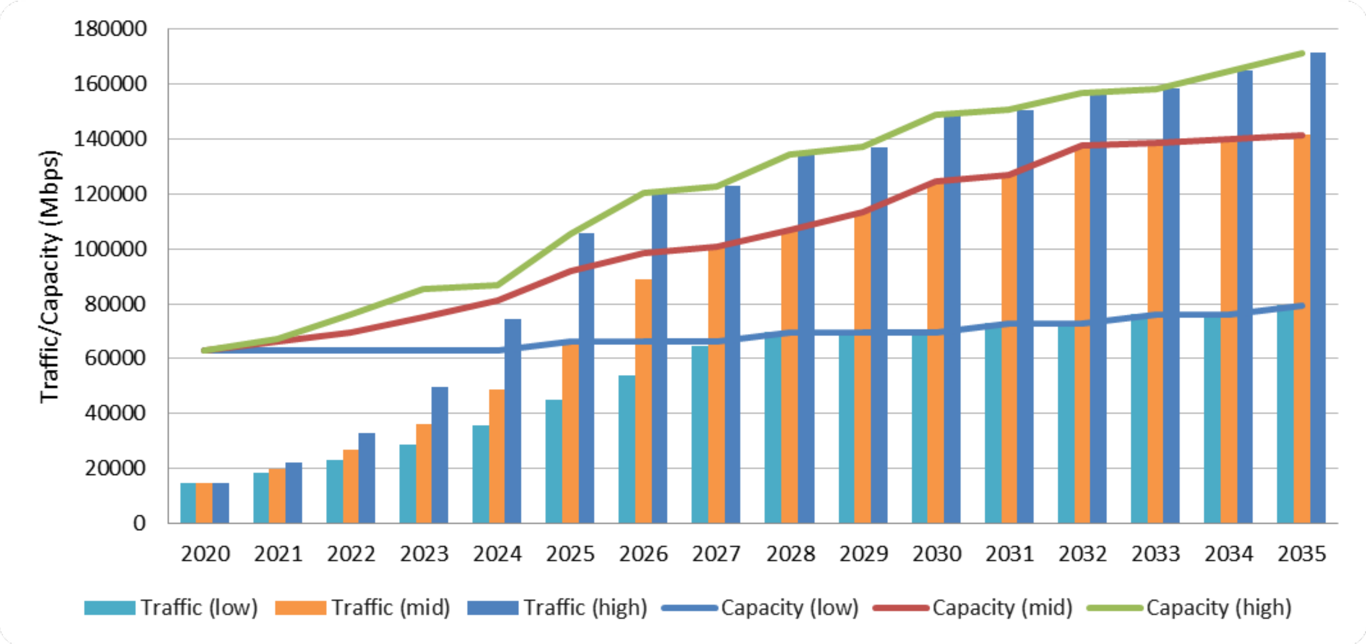
Figure 17 below shows the traffic demand (vertical bars) versus available capacity (horizontal lines) in the sub-1 GHz frequency range. It shows that:

- in the low traffic growth scenario, the low-capacity becomes saturated by 2027;
- in the case of the mid traffic demand growth scenario, the low-capacity is exceeded by 2025 and the mid-capacity scenario is exceeded by 2027; and
- in the high traffic demand case, low-capacity is exceeded from 2024, and the mid- and high-capacities are exceeded from 2025.

It is noted that in the case of excess traffic in sub-1 GHz, the traffic is served by higher frequencies available on the network.

[245] The mobile traffic growth scenarios are presented in Annex C Table 23. A low scenario with an initial growth of 25%, a mid scenario with a growth of 35% and a high with a growth of 50%.

FIGURE 17 MOBILE TRAFFIC DEMAND VS CAPACITY SUB 1 GHZ



Source: LS telcom.

Table 16 shows the points in time when the traffic demand exceeds each of the capacity scenarios for each frequency range.

TABLE 16 SUMMARY RESULTS TABLE: YEARS WHEN DEMAND EXCEEDS SUPPLY

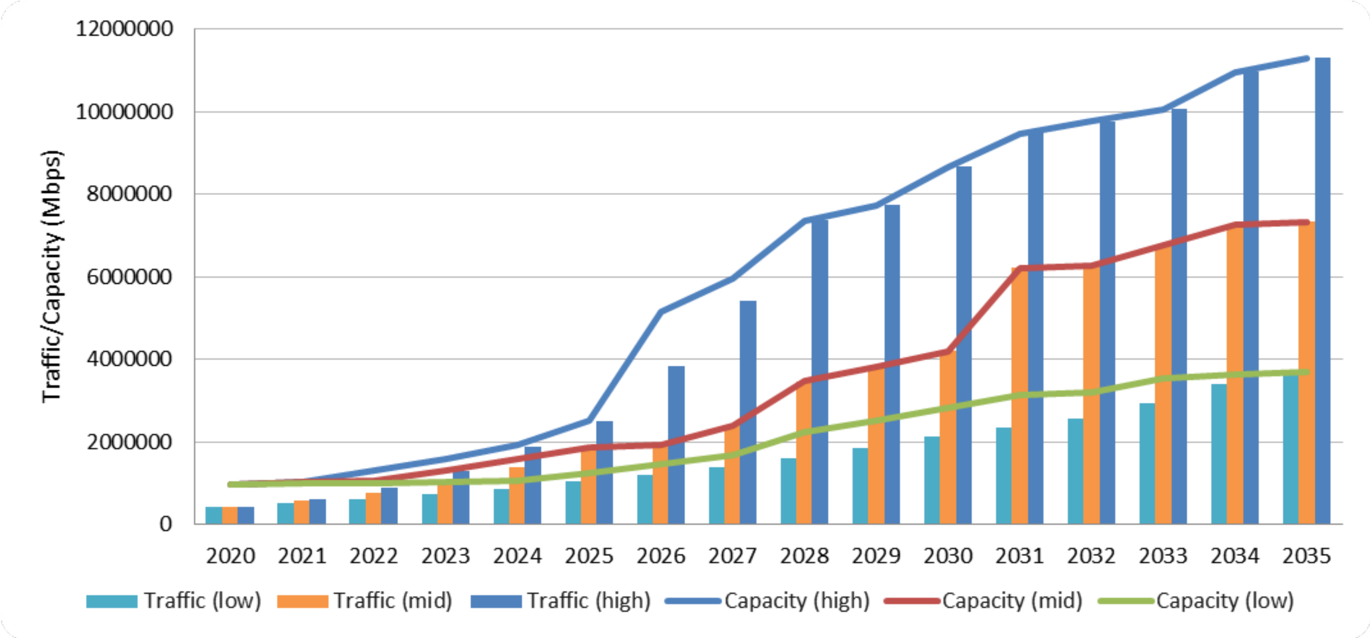
	LOW TRAFFIC GROWTH EXCEEDED?	MID TRAFFIC GROWTH EXCEEDED?	HIGH TRAFFIC GROWTH EXCEEDED?
Low-capacity scenario	2027–35	2025-35	2024-35
Mid-capacity scenario	No	2027-35	2025-35
High-capacity scenario	No	No	2026-35

Source: LS telcom.

Results for 1–5GHz band

Figure 18 below shows the traffic demand versus available capacity in the 1-5 GHz frequency range. We have assumed that, for each capacity scenario, a range of different frequency band options become available, providing different quantities of spectrum at different times (as shown in **Annex C**). We also assume that fixed wireless access traffic is carried in this band range.

FIGURE 18 MOBILE TRAFFIC DEMAND VS CAPACITY 1-5 GHZ



Source: LS telcom

Table 17 shows the points in time when the traffic demand exceeds each of the capacity scenarios for each frequency range.

TABLE 17 SUMMARY RESULTS TABLE: YEARS WHEN DEMAND EXCEEDS SUPPLY – 1-5 GHZ

	LOW TRAFFIC GROWTH EXCEEDED?	MID TRAFFIC GROWTH EXCEEDED?	HIGH TRAFFIC GROWTH EXCEEDED?
Low-capacity scenario	Does not exceed capacity	2023-35	2022-35
Mid-capacity scenario	Does not exceed capacity	2025-35	2023-35
High-capacity scenario	Does not exceed capacity	Does not exceed capacity	2025 and 2028-35

Source: LS telcom

For the low traffic growth/low-capacity scenario, the capacity does not reach saturation across the time frame. This is because the assumed capacity is sufficient to serve the low demand traffic.

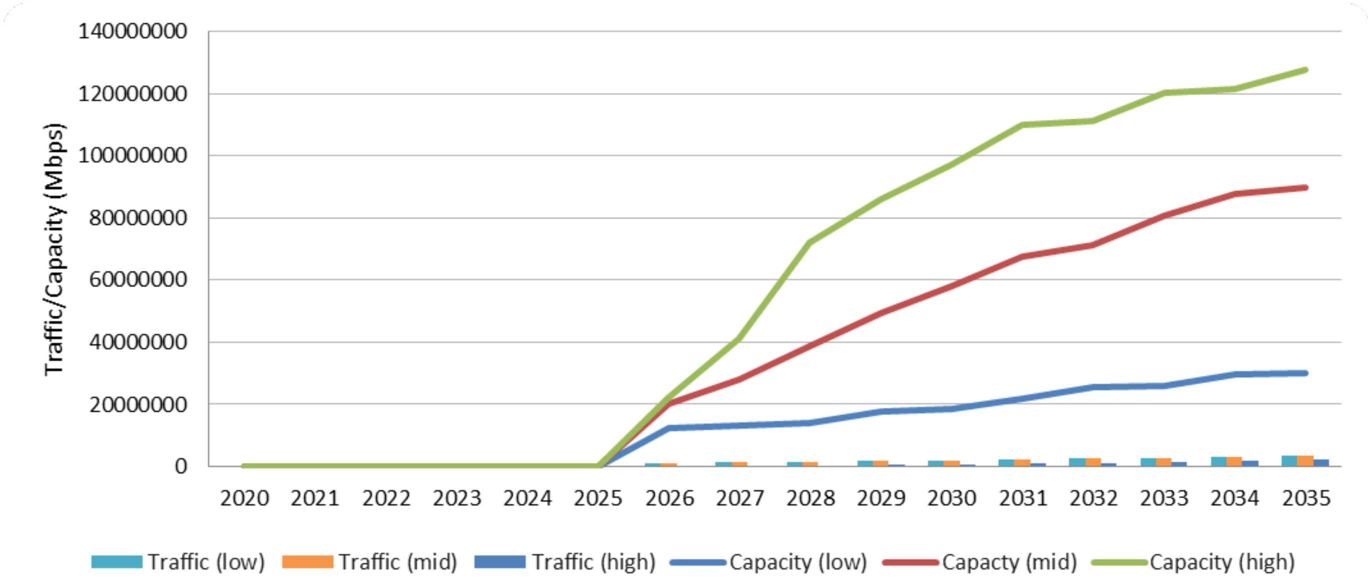
In the mid-case scenario, there is a long period in which there is excess demand: between 2026 and 2035. The evolved spectral efficiency and additional spectrum that becomes available in the mid-case are not enough to alleviate congestion in this spectrum layer.

In the high demand growth scenario, the available high capacity is exceeded for all but two occasions over the time frame. In the 2020 to 2024 period and then short 1-year period 2026-27. This is because there is enough spectrum available from 2020, but traffic demand growth catches up by 2025. For this scenario, it can be seen that rapid demand growth is not satisfied for long, even by adding a portion of spectrum once the network reaches congestion. It only offers a short-term easing since demand exceeds supply again within 2 years.

Results for mmWave band

Figure 19 below shows the traffic demand versus available capacity in the mmWave band range (i.e. 25–27.5 GHz) and 40.5 – 43.5 GHz. We have assumed that our theoretical operator will be able to offer 375 MHz of downlink spectrum in the 26 GHz band 450 MHz of downlink spectrum in the 40 GHz band (not all the 26 GHz band can be used outdoors – see **Annex C** for details) as a proportion of all the total available spectrum**.**

FIGURE 19 MOBILE TRAFFIC DEMAND VS CAPACITY MMWAVE



Source: LS telcom.

Table 18 shows the points in time when the traffic demand exceeds each of the capacity scenarios for each frequency range.

TABLE 18 SUMMARY RESULTS TABLE: YEARS WHEN DEMAND EXCEEDS SUPPLY – MMWAVE

	LOW TRAFFIC GROWTH EXCEEDED?	MID TRAFFIC GROWTH EXCEEDED?	HIGH TRAFFIC GROWTH EXCEEDED?
Low-capacity scenario	Does not exceed capacity	Does not exceed capacity	Does not exceed capacity
Mid-capacity scenario	Does not exceed capacity	Does not exceed capacity	Does not exceed capacity
High-capacity scenario	Does not exceed capacity	Does not exceed capacity	Does not exceed capacity

Source: LS telcom

Due to the combination of spectral efficiency and wide available bandwidths, the capacity available far exceeds demand across all scenarios. This is because the mmWave bands will be used for the extreme, highly localised demand cases in very densely populated areas and not be used to serve demand across the network.

Therefore, we would expect this result to occur based on the demand growth and capacity assumptions that have been made for this theoretical network.

The global mobile industry and research institutions are still in the early phases of defining the requirements and technology solutions for 6G. It is anticipated that 6G will become available commercially from 2030 onwards, similar to the developments of previous mobile generations, which broadly evolve over a 10-year time frame - from early conception through to commercial rollout. The introduction of 6G and the potential spectrum demand impacts are available in **Annex C**.

4.4.5 SUMMARY AND RECOMMENDATIONS

We observed, from both the above analysis and wider global market trends, that **there will continue to be increased demand for mobile spectrum** at around 40% year-on-year growth for at least the next 5 years. Our demand model has found that, depending on the assumed demand growth rate, there are scenarios where dense urban networks are congested in the next 5-6 years for both sub-1 GHz and mid-band frequency ranges

In the mid-case scenario, the most likely traffic growth scenario (35% year-on-year growth for the next 5 years), urban networks could run out of capacity in the sub-1 GHz by 2027 and in the 1-5 GHz range by 2025.

In this scenario, more mid-band spectrum would help to ease congestion in that spectrum layer, in addition to the bands[246] we assumed may become available in the time frame. There are limited options for additional mid-band spectrum over the next decade that could become available. However, mobile operators have identified (globally) the upper 6 GHz (6425-7125 MHz) range as a useful band to help ease congestion and add capacity, but access to this band is dependent on an IMT designation being made at the next WRC in 2023 and thus remains uncertain. However, if this band became available, it would mean an additional 700 MHz for mobile use, and in practice, this represents around 175 MHz of additional spectrum for our theoretical operator in the mid to late-2020s time frame. Furthermore, we note that mmWave does not really offer the same amount of coverage as 6 GHz, so would be better suited for those hotspot areas that 3.5 GHz cannot deal with.

These findings assume that operators have invested in infrastructure upgrades (enhancing spectral efficiency) and budgeted for building a fixed number of sites over the time frame. Therefore, access to more spectrum within these timescales would be the most cost-effective option to ease congestion arising across the whole network.

The alternative to assigning more spectrum is to upgrade mobile networks with enhanced technology capability and increase the number of sites (not yet budgeted for or, in some cases, not feasible due to reaching capacity on rooftop sites in Central London). This could include small cells (cheaper to deploy than rooftop macro sites). This could deliver up to 20% improvement in spectral efficiency and, although both require additional investment, could offer sufficient capacity, thus delaying the need for more spectrum towards the end of the decade. However, it should be noted the investment requirements of the high-capacity case may exceed MNOs' available budget and may be too expensive (i.e. this incremental cost may be higher than the resulting incremental revenue generated by MNOs). Therefore, this investment is unlikely to be made

[246] 1.4 GHz, 2.3 GHz and 4.8 GHz.

Ofcom has not identified any additional mobile bands to enter the market within the next 5 years. However, beyond 5 years, the UK Government and Ofcom may need to work together with stakeholders to identify whether there is a need for specific bands entering the market, noting there is the possibility of the potential for an IMT allocation in the upper 6 GHz band but is dependent on a decision being made at WRC-23. Pending such an outcome from WRC-23 a decision by Ofcom can take 2 to 3 years including an impact assessment of the costs, benefit and risks and consultations. Once a decision is made it can take 6 to 8 years to clear incumbent services from the band. Therefore, the earliest that spectrum in the upper 6 GHz band could become available for mobile use is 2030.

4.5 PRIVATE MOBILE NETWORKS

4.5.1 CURRENT DEMAND FOR PRIVATE MOBILE NETWORKS SPECTRUM

In this section, we discuss the demand for spectrum by private mobile networks which do not fit entirely into either the public mobile sector or the PMR sector. This is mainly because they are a hybrid of the two. Private mobile networks can use a mix of either licensed mobile spectrum by way of local access licensing or shared access licensing. This is further contrasted by other private IoT type networks such as Sigfox and LoRa, which use licence-exempt spectrum.

Private mobile networks are also referred to as non-public mobile networks, or private cellular networks, and more recently, private 5G networks, which exclusively use 5G technology. The users of private mobile networks are typically businesses/enterprises/verticals that require a dedicated wireless network serving a local area which could be a factory, industrial plant, port, airport, campus or business/leisure park. These private networks would need to be reliable and robust with minimal impact from interference to support business-critical applications.

The localised nature of these private networks has driven the spectrum options, demonstrating that sharing of frequency bands is possible if limited to relatively small areas and hence the creation by Ofcom of the two licensing approaches.

In terms of current demand, private mobile networks are still in the early stages of rollout and development. The current commercial cellular private networks in place are 4G, and most of the 5G private network deployments in the UK are government-funded trials and testbeds. The Port of Felixstowe[247] recently deployed a 5G private network, and it is expected, based on recent market forecasts[248], that private 5G network growth will ramp up with a suggested CAGR of 40-48% from 2022 to 2030.

Major telecommunications vendors Nokia, Ericsson and Samsung, are key players in the private network market; however, other players such as Mavenir, Federated Wireless, Parallel Wireless and Athonet are supporting the market. The EU 5G Observatory[249] summarises the private 5G network deployments across the EU and globally, showing regular increases in the number of networks deployed on a quarterly basis. The GSA estimates that from February 2022, around 656 organisations have deployed/are deploying LTE or 5G private networks globally.

[247] Hutchison Ports, March 2022 5G Goes Live at the Port of Felixstowe, https://www.portoffelixstowe.co.uk/press/news-archive/5g-goes-live-at-the-port-of-felixstowe/ [Accessed May 2022].

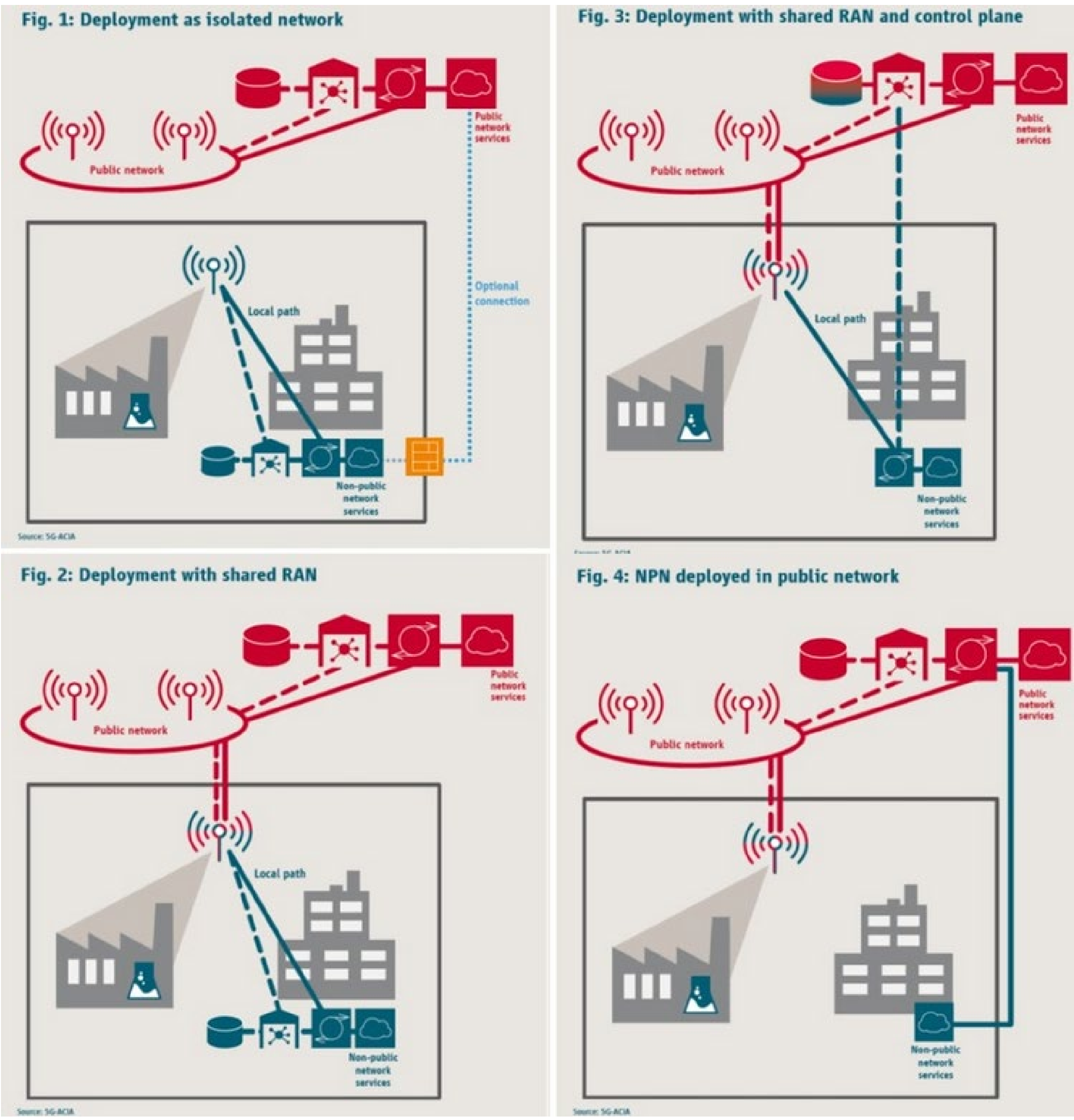
[248] UK5G website article, Feb 2022 5G Private Networks: Driving Digital Transformation and Business Growth, https://uk5g.org/5g-updates/research/5g-private-networks-driving-digital-transformation/ [Accessed May 2022].

[249] 5G Observatory website https://5gobservatory.eu/5g-private-networks/ [Accessed May 2022].

Private network investments are made based on decisions that will improve business operations or cut costs and do not follow trends equivalent to that of the public mobile market. Therefore, the trends do not follow a particular growth cycle in the same way as public mobile does for consumer demand. However, introducing innovation, modernisation, and other similar factors may drive a trend towards an uptake in private networks.

There are several private network architecture models that are being used by operators and suppliers. These options vary in terms of cost and complexity but are also flexible to meet the needs of enterprises. The deployment models are summarised in the figure below from the 5G Alliance for Connected Industries and Automation[250] (5G-ACIA).

FIGURE 20 OVERVIEW OF THE PRIVATE 5G NETWORK DEPLOYMENTS



Source: 5G-ACIA.

[250] 5G-ACIA, July 2019, 5G Non-Public Networks for Industrial Scenarios White Paper, https://5g-acia.org/wp-content/uploads/2021/04/WP_5G_NPN_2019_01.pdf

In the case of private networks in which the enterprise will deploy and own the entire network (or use third party system integrators) access to spectrum on a local or shared basis is required (see **Figure 20** above). Ofcom recognised the potential demand for spectrum in this area and has identified the following bands/categories.

TABLE 19 PRIVATE SPECTRUM USE

	LOCAL ACCESS LICENCE	SHARED ACCESS LICENCE
Spectrum options	Suitable MNO spectrum	1781.7-1785 MHz paired with 1876.7-1880 MHz; 2390-2400 MHz; 3800-4200 MHz band; and 24.25-26.5 GHz. This band is only available for indoor low power licences

Source: LS telcom extracted from Ofcom data.

Currently, there are:

- 27 local access licences issued across 9 licensees, according to Ofcom;[251]
- 1051 low power shared access licences issued across 23 licensees;[252] and
- 386 medium power shared access licences issued across 33 licensees.

The spectrum through the different licences has been available for around 3 years. This suggests there is interest in private networks, but there is potential for further growth.

4.5.2 SUMMARY AND RECOMMENDATIONS

In summary, private mobile networks are still in their infancy, with forecast growth of around 40% for the next 8 years. It is not clear from which sectors demand is arising or how this can be determined without more granular detail; however, an increase in rollouts globally may demonstrate the realisation from businesses of the benefits that private mobile networks can offer. We recommend that the Government should monitor the progress of private network rollout and investment by the different sectors. In turn, this will determine if the relatively new licensing approaches are proving useful to encourage increased use of the spectrum or whether uptake is slow and the spectrum is not being used efficiently.

4.6 PROGRAMME MAKING AND SPECIAL EVENTS (PMSE)

4.6.1 CURRENT DEMAND FOR PMSE SPECTRUM

General demand for PMSE spectrum is largely driven by a regular ongoing requirement for usage at television/film production studios, theatres, churches and large offices/venues that use a mix of radio microphones, audio talkback units and in-ear monitors, and also possibly wireless cameras for some

[251] Ofcom April 2022, Local Access Licences web page [Accessed May 2022]. https://www.ofcom.org.uk/__data/assets/pdf_file/0021/222591/local-access-licences.pdf

[252] Data extracted from Ofcom spectrum information system [Accessed May 2022]. https://www.ofcom.org.uk/spectrum/information/spectrum-information-system-sis/spectrum-information-portal

locations. The usage tends to be largely fixed in terms of the number of devices or can vary according to the type of production; however, the demand (including peak) is predictable.

The other major use for PMSE is for live events, which can range from small outdoor festivals using a few dozen radio microphones to the Formula 1 Grand Prix at Silverstone and the Glastonbury festival, both occurring over 3-4 days.

A study by Cambridge Consultants conducted for Ofcom in 2014[253] predicted growth in the use of audio PMSE for TV studios over a 10-year period (2014-24) at approximately 30%, but no growth in any PMSE usage at outdoor music events, using Glastonbury as the baseline. They also predicted slow growth of PMSE usage in major theatre productions with 74 radio microphones in 2014 and 94 in 2024 (around 2-3% per year) due to the increasing sophistication of productions.

In the case of increasing demand in the likes of TV studios and theatre productions, there is a limit to the number of users in the studio or on the stage, meaning there is an upper limit to demand. However, some locations have dual microphones or multiple channels for resilience and interference management. The Cambridge Consultants report also indicated that the dense use of radio microphones in the West End might cause interference, so careful planning and coordination are needed.

Although the 2014 study forecast no growth in demand for PMSE spectrum from live events, recent data from Ofcom demonstrates that peak demand at the largest events continues to grow. Between 2016 and 2019[254] assignments increased by 28% and 19% for Glastonbury and Reading Festivals, respectively, and early reports for 2022 are that assignment counts are up another 19% approximately on 2019.[255] The drivers for increased demand for spectrum at these events include the need for greater resilience (more talkback units) and higher video resolution. Wireless cameras migrating to 4K UHD video will require a move from the current 10 MHz channel bandwidth to 20 MHz[256], effectively doubling spectrum requirements.

Other potential impacts on demand have been the introduction of digital PMSE equipment[257], especially radio microphones and talkback systems. The benefits of migrating to digital equipment are to improve audio quality, improve resilience to interference and increase spectral efficiency through improvements in the design of transmitters and receivers. Initially, there were issues with the latency of digital microphones, but with more modern designs (and slightly more expensive), this has been resolved[258]. Digital devices also tend to have higher battery consumption, and in some cases, this may hamper their use due to the need for frequent recharging. Overall, both analogue and digital have their balance of advantages and disadvantages and will both likely continue to be used for events and productions. As the density of PMSE usage increases, the benefits of using digital radio microphones may become more apparent.

[253] Cambridge Consultants, July 2014, Technology Evolution in the PMSE Sector, https://www.ofcom.org.uk/__data/assets/pdf_file/0024/59163/cambridge-main-report.pdf

[254] 2020 and 2021 excluded because of COVID and cancellation of events.

[255] Data provided by Ofcom.

[256] CEPT, Feb 2021, ECC Report 323 Spectrum use and future spectrum requirements for PMSE, https://docdb.cept.org/download/3470

[257] Shure, 2018, Why the Future of Wireless Is Digital, https://www.shure.com/en-US/performance-production/louder/future-wireless-digital

[258] RF Venue website: Seriously, What Are Digital Wireless Microphones, and Why Should You Use One? 2014 [Access March 2022]. https://www.rfvenue.com/blog/2014/12/15/digital-wiireless-explored

4.6.2 LONG TERM FUTURE DEMAND FOR PMSE SPECTRUM

Over the longer time frame of this study (10-to-15 years), we expect demand for PMSE spectrum to continue in a similar vein as in the short term (i.e. moderate growth), with any changes being as a result of more sophisticated productions and the introduction of higher resolution video. Usage is relatively predictable, and we anticipate it will remain reasonably consistent, albeit with a slight potential upturn in demand.

Given there has been growth in the events sector in the last 10 years, we foresee moderate, but not dramatic, increases in demand for PMSE equipment and, therefore, spectrum, with steady growth and potential for very high demand in dense locations such as theatre districts (e.g. London's West End), with a high concentration of theatres or at the British Formula 1 Grand Prix (high concentration of similar users) or other major live outdoor music event (a large number of users with varying demands). However, no additional spectrum has been identified for PMSE use.

A number of technology developments may assist PMSE users in making more efficient use of the spectrum available to them. Examples of these technologies are set out below, however it should be noted that, at present, these technologies are not commercially proven to meet the specific high quality of service and very low latency requirements of the sector.

- **5G for PMSE.** Event organisers and broadcasters often use 4G for some of the data links between equipment and control rooms or broadcast rooms/trailers. However, for major live events with large audiences, the capacity can be limited, and there is a risk to consistent throughput speeds that are needed. These applications could be supported by 5G (either public or private networks) as the throughput speeds will be greater, and there will be higher capacity available during events to ease capacity concerns[259].

- **Wireless Multichannel Audio System (WMAS).** This approach to audio PMSE system deployment adopts the use of a single wideband radio frequency (RF) channel (e.g. 20 MHz) to deploy multiple audio channels to support radio microphones and in-ear applications. This approach can improve spectral efficiency by up to 50% but is still being standardised and so has attracted limited commercial interest so far.

- **C-PMSE.** Cognitive PMSE has been developed to mitigate interference and improve the overall performance of the deployed system by dynamically sensing interference and channel availability and automatically assigning frequencies to PMSE devices[260].

4.6.3 SUMMARY AND RECOMMENDATIONS

We foresee a continuing demand for PMSE spectrum based on the time frame of this study. This is driven by more events and requirements for high-quality productions. Increases can be accommodated through; the current spectrum allocations and innovations, adoption of new technologies such as 5G, improvements in equipment performance and dynamic sharing. There will be continued challenges and costs facing the

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[259] The use of 5G technology for PMSE equipment/solutions is being researched by a project coordinated in Germany PMSE xG, which is a collaboration of the mobile industry and PMSE industry to 'consider future-oriented use of mobile broadband radio technology and network infrastructure for PMSE applications with the aim to develop new products and services through innovation'. A primary aim of the project is to address the continued diminishing availability of dedicated spectrum.

[260] The ETSI technical report ETSI TR 102 801 provides details of the solution and demonstrates how enhancements in the reliability and stability of the equipment can lead to improvements in spectral efficiency.

industry over the longer term as new technologies are adopted or if the sector needs to switch to new bands not supported by existing equipment.

Demand for the existing PMSE spectrum is very high, especially in some locations, and any further reductions in PMSE spectrum would materially impact the ability of the creative industries to innovate or even to continue to run existing events on the basis that they currently are. Though PMSE users have, in the past, been able to be somewhat nomadic in their spectrum use, as with other industries, regulatory certainty over access to spectrum remains paramount and ensuring that there is sufficient spectrum available for all applications is important to protect the UK's creative industries.

PMSE coexists in complex radio environments and has done so for the last 30 years. PMSE users have demonstrated the ability to share with critical use cases, such as aeronautical systems. PMSE users could be deemed a 'good sharer' and an example of what wider adoption of sharing principles could potentially achieve.

There are no obvious candidate bands for additional spectrum becoming available to PMSE in the next 5-to-10 years, whilst spectrum may be lost. It is not inconceivable, however, that there could be further opportunities for identifying spectrum bands that could be shared with PMSE over the longer 10-to-15 year timeframe. There is some certainty of continued access for audio PMSE applications in the 470-694 MHz band for at least the next 12 years now that the DTT will remain operational due to the MUX licence extension. This gives the PMSE industry time to continue utilising its existing equipment and recoup its investment but also to plan should a further portion of the band be allocated to the public mobile service. This future planning could include the adoption of more efficient and frequency-agile technologies and wider adoption of audio PMSE equipment that supports the 960–1164 MHz band.

It is recommended that DCMS, DSIT and Ofcom should consider the long-term future of PMSE given the possible expiry of the DTT MUX licence in 2034. This includes a more detailed understanding of the impact on PMSE users if access to the 470–694 MHz band is reduced further and what bands/ primary services could be identified for sharing with audio PMSE below 2 GHz. This analysis should be undertaken at the same time as the analysis recommended for broadcasting in **Section 4.1**, given the forthcoming decisions on the 470-694 MHz band at WRC-23.

4.7 PRIVATE MOBILE RADIO (PMR)

4.7.1 CURRENT DEMAND FOR PMR SPECTRUM

PMR, or business radio, systems are used by organisations to operate their own private mobile communication networks. These networks use dedicated portions of allocated spectrum in a range of sub-bands below 470 MHz in either wide-area (town/cities/nationwide) or local areas such as part of a town/city or large site (e.g. construction or stadium).

The number of PMR licences has steadily increased over the last 10 years. At present, there are approximately 27,000 business radio licences on issue in total[261]. However, despite this increased demand, the available spectrum has not increased. In addition, the continued growth in demand for business radio licences together with other temporary assignments in similar bands causes congestion in some parts of the UK.

[261] Ofcom, 2021. The Office of Communications Annual Report and Accounts For the period 1 April 2020 to 31 March 2021 (A.6 Spectrum licensing). See: https://www.ofcom.org.uk/__data/assets/pdf_file/0025/221686/annual-report-2020-21.pdf

Industry stakeholders confirmed that demand for voice communications will remain strong for the foreseeable future (this includes the use of licence-exempt PMR 446 walkie-talkie radios, which can be used and take some of the less critical demand from the main PMR frequencies) but will not necessarily grow as fast as the introduction of private data-driven communications networks.

The PMR industry expects the continued development of technology features and facilities demanded by customers today to be implemented into equipment, with the transfer of data expected to be a major driving factor for technological changes in the PMR sector. This means not just continued access to existing VHF and UHF PMR bands but ensuring enough bandwidth is available in the future to support the wider bandwidth needs of data transfer combined with high-resilience, mission-critical voice requirements. This could come from either public or private mobile networks.

However, currently, in the case of non-critical applications that require wider channels/higher data rates, business radio users tend to use public networks (e.g. 3G and 4G).

4.7.2 LONG TERM DEMAND FOR PMR SPECTRUM

It is anticipated that the current trends in customers' requirements will continue. However, it is expected there will be market disruption in the coming years to some parts of the industry (e.g. Water industry) being driven by switching off the legacy fixed copper public communications network (Public Switched Telephone Network). The water industry (including the Environment Agency) has relied on the copper public communications network for access to remote monitoring locations such as water quality sites. Once the copper network is switched off, it is unlikely there will be physical line replacement and will therefore have to rely on wireless technologies, potentially placing increased demand on PMR spectrum. In addition, remote connectivity using the public mobile networks will also be impacted in the future by the switch-off of 2G and 3G networks.

The current PMR allocations will continue to be needed for the foreseeable future. This is because they support vital services within major sectors (e.g. transport sector, utilities and security) that rely on access to the spectrum using band-specific equipment that would be costly and time-consuming to replace.

There is some uncertainty about the long-term future of private mobile radio. The demand for PMR bands will continue to grow steadily as the requirement for critical and resilient private mobile voice networks will remain necessary (and relevant) for different sectors. For PMR, data resilience is a critical requirement: Businesses require data provision that reflects the resilience required by their operations, which cannot always be provided by public mobile networks. Therefore, private data provision is required, to which private 4G or 5G networks might be the solution since public networks cannot offer the same level of resilience or support the type of Service Level Agreements for some of the critical applications. For extreme resilience needs, such as wide-area energy industry distribution network communications, a private LTE/5G network with access to a dedicated spectrum may be the solution.

The critical communications industry[262] has also indicated that TETRA technology will be needed well into the 2030s and beyond, thus further supporting the need to retain access to PMR spectrum. The TETRA, DMR and dPMR standards will support the increasing need for critical communication broadband services offering an alternative to public mobile with security and resilience built into its foundation.

It is less clear what will emerge from the demand for increased data provision on wide-area private networks, and it becomes more uncertain over the longer 15-year time frame. There are currently no planned solutions

[262] TCCA turns 25, article on Critical Communications Today website, 2019, https://www.criticalcomms.com/news/tcca-turns-25 [Accessed March 2022].

for a nationwide private mobile network (similar to Airwave) that could support non-critical users for nationwide coverage (e.g. haulage firms). These businesses rely on current public mobile networks, but this may not necessarily (currently) offer the extent of coverage or specific localised provisions (e.g. providing connectivity into depots). For this to happen, the public mobile networks would need to greatly extend their geographical coverage to match the customer's usage area, which may be very remote. However, the deployment of extended coverage from the Shared Rural Network infrastructure may go some way toward addressing these specific business needs.

Depending on the level of migration from current narrowband frequency assignments to public networks, more spectrum may become available in the 450–470 MHz range. The band is used by a wide mix of different users with slightly different requirements, largely based on the criticality of usage. For example, in the case of security and safety personnel at sports arenas around the country, such as Wembley stadium, a fast response via voice is needed with very low levels of delay. This is compared to some narrowband data/control systems that communicate every few minutes and thus are not so time-critical. London and some other urban areas are 'congested' in as much as it is difficult to obtain a licence. This could be resolved with a re-planning of the band in the future in several ways. For instance, by re-aligning with the European band plans to minimise continental interference (as the UK is currently reverse to that of Europe), or by re-organising allocations within the band to increase frequency assignment efficiency.

Although unlikely, even in the long term, if enough PMR licensees could migrate to public networks, this would potentially free up large portions of PMR spectrum, and, in turn, could potentially provide a sufficient quantity of spectrum to create an appropriately sized block assignment[263]. For example, if 2x5 MHz could be made available, it could support a range of private network applications and, in turn, provide secure and resilient private mobile services using the latest mobile technology. However, Ofcom, in its last UHF band strategic review in 2017, concluded there was: "No evidence to support such a requirement" relating to a UK wide LTE network, largely due to the cost and disruption to incumbent users. Ofcom has indicated that a review of the licensing regime, its approach to spectrum pricing in the band, user migration, and further spectrum sharing opportunities would address the challenges set by the demand for growth in PMR usage.

Stakeholder feedback indicated that there would be benefits to PMR users if a nationwide business-critical private LTE network were to be deployed. This type of private network could support a wide range of users and sectors that could utilise a suitable portion of 450 MHz spectrum in a potentially more efficient way.

4.7.3 SUMMARY AND RECCOMENDATIONS

The operation of private mobile voice networks remains vital to many of the business radio users that rely on these networks. There will be a **steady increase in demand for PMR spectrum** largely driven by the continued need for critical voice/'push to talk' services but also a growing need for private data networks and the adoption of digital technologies. This means there will be continued pressure on access to VHF and UHF frequencies, as the bands are already squeezed due to extensive narrowband assignments.

We consider, on balance, that there is a low risk that there will be limits to PMR spectrum access on a national scale. We recognise there will be pockets of congestion persisting in urban areas; as the likely upward trend in usage continues over the time frame. This is because as operational requirements change, technologies (DMR, TETRA, 4G/5G) evolve and levels of resilience improve. This will mean some demand will be satisfied from a variety of technology and network solutions available on the market. This will result in a neutral

[263] This approach is similar to Dolphin Telecom, which held a licence for a private TETRA network in the 400 MHz band.

impact on spectrum demand from PMR users over the longer time frame, coupled with regular improvements in frequency assignments and radio system designs that will continue to evolve with demand.

As discussed in the previous section, there may be benefits to the implementation of a nationwide private 4G network. Full consideration should be given to the viability of making a suitable quantity of UHF spectrum available for such a purpose, such as 2x5 MHz for harmonised access within the 410-470 MHz range.

4.8 UTILITIES

4.8.1 CURRENT DEMAND FOR UTILITIES SPECTRUM

The use of PMR within the utilities sector is a specific use case of PMR that, given its role in Critical National Infrastructure, justifies a section solely focused on this. Electronic Communications Networks (ECNs) providing connectivity for the utilities sector are considered a critical national infrastructure according to Civil Contingencies Secretariat[264]. The ECNs used by utilities networks are self-provided using individual licensed assignments in the PMR bands in Band I (52-87 MHz), VHF (138-160 MHz) and UHF2 (450–470 MHz) and are self-managed, with licences administered and/or held by the Joint Radio Company (JRC) and the Telecommunications Association of the UK Water Industry (TAUWI) or held outright by individual companies. Together, these organisations manage 80 UHF channels (licensed nationally by JRC and TAUWI) and approximately 160 VHF channels (each with a channel bandwidth of 12.5 kHz - duplex) which are utilised through the UK. In total, there are over 50,000 critical utility systems in use, according to utilities stakeholders.

Utilities are made up of the gas, electricity and water distribution networks and the electronic communications networks that are used for control and management. The utilities ECN comprises a mix of narrowband Supervisory Control And Data Acquisition (SCADA) and voice systems based largely on analogue and digital mobile radio standards. The majority of the VHF and UHF channels are allocated on the basis of national mobile plans, which maximise frequency re-use whilst simultaneously providing a high degree of protection to adjacent users.

The requirement for critical voice remains, although the number of voice systems has not increased for several decades. The disruption to public networks caused by severe storms, such as Storm Arwen, means there is renewed interest across the utilities sector for dedicated, highly resilient voice systems for emergency situations. The demand for SCADA/data only connectivity is continuing to increase significantly. Existing narrowband systems based on Ofcom's technical frequency assignment criteria and principles do not scale well, and there is already a saturation of the SCADA band (450/460 MHz), driving some utilities to offload less critical systems to public network provision. VHF SCADA systems based on digital mobile radio standards are less congested but also less universally adopted and currently suitable for rural automation rather than critical SCADA.

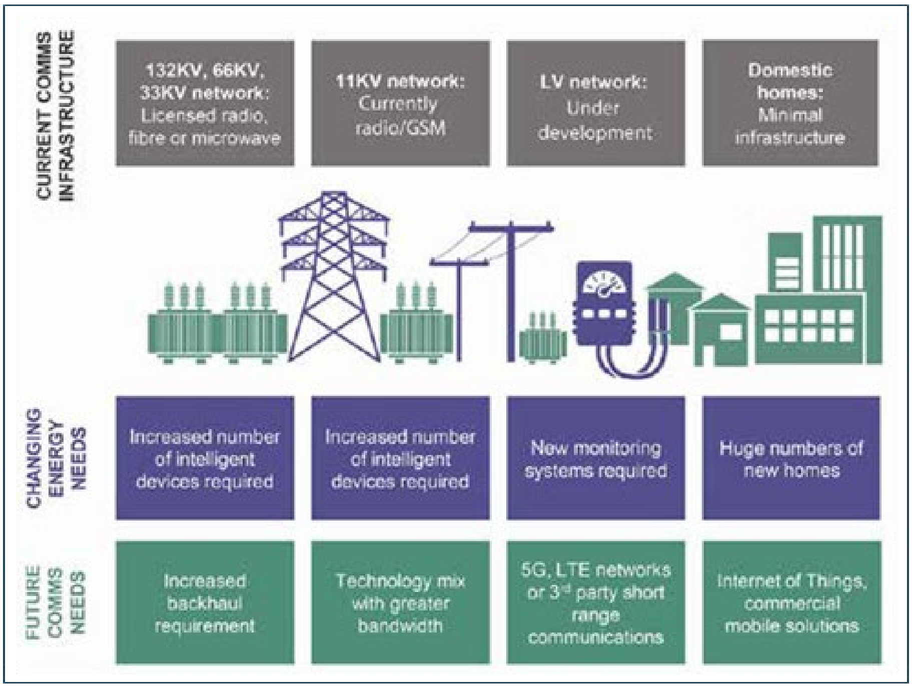
The UK Government's commitment to reach net zero emissions by 2050[265] means there will need to be a major change in the way energy is generated and distributed across the network. This will necessitate the implementation of a smart grid which uses wireless communications technologies and thus access to spectrum. According to the Energy Network Association (ENA), current utility ECNs are not fit to support

[264] Cabinet Office, 2017, Public Summary of Sector Security and Resilience Plans, Civil Contingencies Secretariat, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/678927/Public_Summary_of_Sector_Security_and_Resilience_Plans_2017__FINAL_pdf___002_.pdf [Accessed March 2022].

[265] UK Government, Net Zero Strategy: Build Back Greener (October 2021).

this.[266] The ENA makes a case for increased spectrum allocation in Operational Telecommunications to enable electricity networks to facilitate the Net Zero transition. The Operational Telecommunications elements are made up of a mix of private networks and other communication providers networks. It is the private networks, owned and operated by the electricity companies, which support the critical operations. All other applications, such as for monitoring, are largely provided by public electronic communication network providers.

FIGURE 21 OVERVIEW OF THE UK'S ENERGY NETWORK INFRASTRUCTURE AND CONNECTIVITY NEEDS



Source: Energy Networks Association, 2019. Position Statement of Strategic Telecommunications Group.

The steady increase in demand for utilities private networks is mainly from the increase of newly required control and monitoring equipment. This equipment will need to be deployed across as many as 200,000 assets (for a single Distribution Network Operator (DNO)) which could potentially equate to a million or more devices for all DNOs, according to the Energy stakeholders. More touchpoints and control points in the network are needed to maintain network stability; however, these are typically also found at the periphery of the network, where there is limited connectivity.

Additional assets include growth in charging points for electric vehicles, with Deloitte[267] indicating around 280,000 additional charge points are needed by 2020. There is also the introduction and potential growth in the use of heat pumps to replace traditional gas boilers, supported by the ambitions of the Heat and Buildings Strategy with the aim to have a UK market with the capacity and capability to deploy at least 600,000 hydronic heat pump systems per year by 2028[268].

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[266] Need for Increased Spectrum Allocation and Investment in Operational Telecommunications (OT) to enable the Electricity Networks to facilitate the 'Net Zero' transition Position Statement of Strategic Telecommunications Group, 2022.

[267] Deloitte, 2019, UK EV charging infrastructure update (part 2): Show me the money. https://www2.deloitte.com/uk/en/pages/energy-and-resources/articles/uk-ev-charging-infrastructure-update-show-me-the-money.html

[268] HM Government, October 2021, Heat and Buildings Strategy.

The type of traffic consumed on these devices is typically quite low, in the order of 10 kbit/s on average for data and even less for voice. The move to a smarter grid will require increased data rates, in the order of 64-100 kbit/s, which will need to scale to the increased number of assets, greatly increasing the demand on the ECNs, which will not be possible with the current frequency assignments.

4.8.2 PLAN AND PROPOSAL FOR SPECTRUM FOR UTILITIES

The utilities industry has identified a requirement for an additional 2x3 MHz of spectrum,[269] ideally in the sub 1 GHz range (to support all the critical service needs), which should provide enough bandwidth to deliver both the scale of additional devices on the network, but also higher capacity required by some of these devices.

There is an ongoing collaboration between BEIS, Ofcom, DCMS and Ofgem to identify the spectrum needs of the utilities and identify an appropriate approach to meet these needs in a timely way. The utilities industry has hosted workshops with the regulators and government to articulate these needs. In addition, the JRC, as the relevant industry body representing the energy networks, has provided responses to Ofcom consultations outlining these needs. However, a spectrum band still needs to be identified that can support all the needs of the industry.

Ofcom has made it clear there are highly utilised bands in sub-1 GHz and other frequencies that could potentially be used by utilities (see **Figure 22** below). It identifies the potential LTE bands that could be used, including a comment on the existing usage and/or challenges that would face the industry to gain future access.

FIGURE 22 OFCOM CHART ON UHF BANDS FOR PRIVATE LTE NETWORKS FOR UTILITIES

Band	Uplink (MHz)	Downlink (MHz)	Comment
28	703 - 748	758 - 803	2 x 3 MHz available in 700 MHz band, but high risk of harmful interference from 700 MHz mobile use (SDL) >9km separation needed
31	452.5 - 457.5	462.5 – 467.5	BR use: ~15k licensees & 28k licences (incl Light Licences) PMSE: ~14k freq assignments Emergency Services: 110 Licensees & 135 assignments
72	451 - 456	461 - 466	
73	450 - 455	460 - 465	
87	410 - 415	420 - 425	RAF Fylingdales needs >230 km separation from LTE (ECC Report 240) Arqiva Smart Meters (Scotland and Northern England)
88	412 - 417	422 - 427	
40	2300 – 2400 (TDD)		2300-2350 MHz used by MOD and HO 2350-2390 MHz awarded
5G (C-Band)	TDD 3300 - 4200 (TDD)		Limited transmit power available

Source: Ofcom, 2021. Wireless Communications for the UK Utility Industry.

[269] EUTC, 2021, https://eutc.org/media/2021/08/EUTC-Response-to-Ofcom-412-MHz-Consultation.pdf

There is limited availability in the bands identified by Ofcom, as shown above, and finding sufficient available bandwidth will be a challenge.

There is the option for shared spectrum if the dedicated spectrum cannot be made available. However, this may impose restrictions on the deployment of the sector's requirements for secure, highly available access. Lastly, there is a consideration of utilising commercial networks, but this presents a mix of challenges from insufficient coverage to limited security and resilience that is required by the Civil Contingencies Act.

4.8.3 SUMMARY AND RECOMMENDATIONS

The **steady increase in demand for spectrum for energy utilities** is being driven by the Government mandate to support Net Zero 2050, which means significant upgrades to the network carrying more traffic from more devices.

We would expect a solution for meeting the utilities spectrum demand requirements to arise in the short term within the next five years recognising there are other commercial and regulatory pressures to take a decision sooner. This is not only due to the increasing needs of energy utilities but also the risks posed by the Public Switched Telephone Network and 2G/3G switch off[270] within this time frame. There are specific resilience implications of losing access to PSTN and some 3G services, which means it is important this decision is made as soon as possible.

In the 10-to-15-year time frame, we would expect a private LTE network to be deployed and be up and running in a suitable spectrum band supporting at least 2 x 3 MHz of spectrum. However, regulators and government will need to identify the frequency band soon and determine whether the spectrum accessed would be to be shared or not.

A prioritised set of strategic actions over the 5-to-15-year time frame is required, if it is not already in place, together with timescales and responsible departments taking into account industry developments/demands, challenges (2G/3G/PSTN switch off) to be able to make the final decision on identifying the suitable spectrum band for use by the sector.

4.9 WI-FI

4.9.1 CURRENT DEMAND FOR WI-FI SPECTRUM

There is continued growth in demand for Wi-Fi and, in turn, demand for spectrum[271]. Wi-Fi technology, through the evolution of the IEEE 802.11 standards, provides a mix of connectivity options and architectures. It mainly provides the wireless interface from a home or office router (access point) to client devices as part of a fixed broadband service. The performance of the latest Wi-Fi technologies (See **Annex C)** needs to be considered when assessing spectrum demand, as the speeds that can be achieved from the latest technologies are approaching 10 Gbit/s.

The other type of connectivity includes device-to-device, such as smartphone to headset or printer. More recently, Wi-Fi technology has enabled mesh networks, which extend the Wi-Fi coverage in the home, office (or other indoor/outdoor local areas) by wirelessly connecting the access points (AP). This enables users to seamlessly roam between access points (without continually having to re-connect each time the user moves

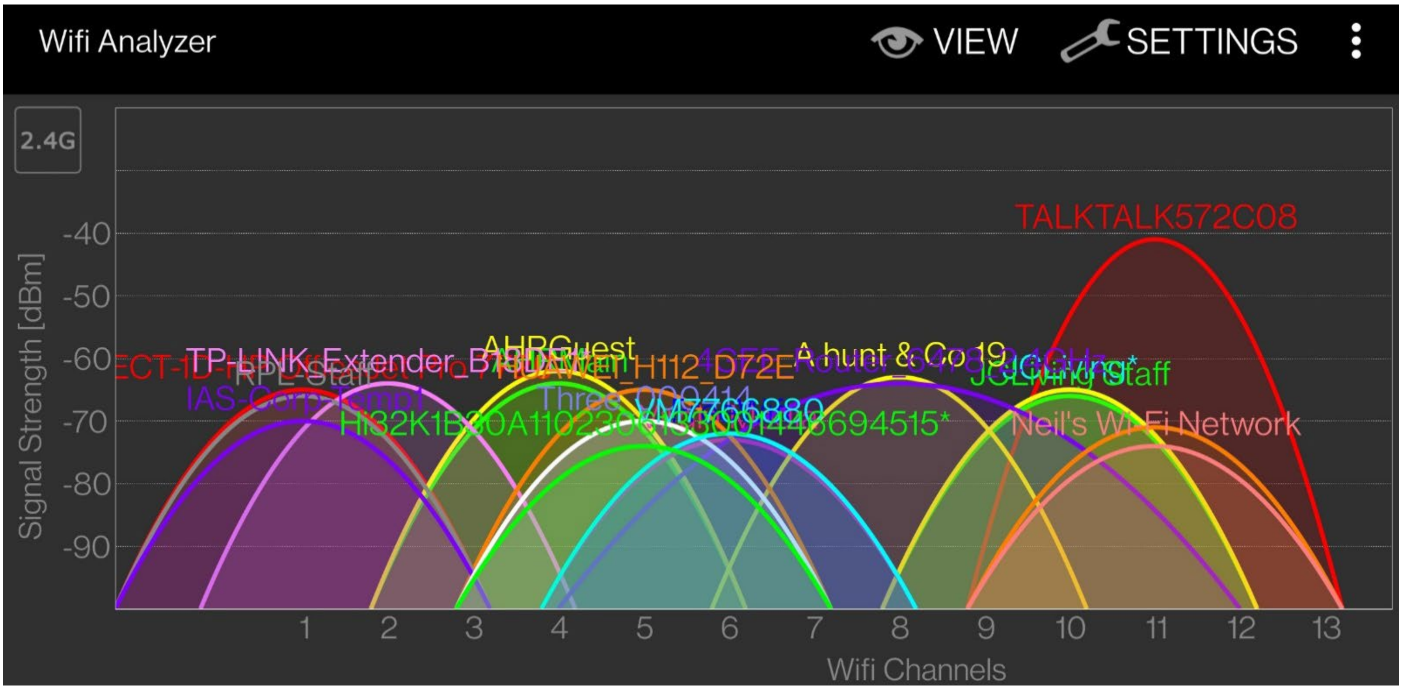
[270] Note that BT is planning to switch off PSTN in 2025, and mobile operators planning to switch off 3G by some (Vodafone/Three) as early as 2023 and switch off 2G by 2033 to support the continued operation of smart meters.

[271] Ofcom March 2020: Improving spectrum access for wifi – spectrum use in the 5 and 6 GHz bands.

to a new hotspot), typically in large venues (e.g. railway stations, shopping malls). This seamless connectivity has also allowed the likes of wide-scale public Wi-Fi networks to be deployed by local authorities.

This scaling-up of Wi-Fi has led to congestion in both public and private Wi-Fi networks. It is worth noting that in busy, densely populated areas, there can be tens, sometimes hundreds, of Access Points broadcasting their SSID (Wi-Fi network name), indicating the level of congestion for a particular area. This is exemplified in the chart in **Figure 23,** which shows a plot of the numerous overlapping Wi-Fi networks (using different channels and their signal strength) broadcasting their ID in the 2.4 GHz band.

FIGURE 23 CONGESTION IN WI-FI NETWORKS



Source: LS telcom

This is most critical in apartment blocks or offices where interference from neighbouring Wi-Fi access points can cause degradation to each apartment's/office services. As shown in **Figure 23**, Wi-Fi congestion is the reason why more spectrum was needed for Wi-Fi, and the 5 GHz band was identified for Wi-Fi use. However, parts of the band have certain restrictions attached, e.g. not to cause interference to some incumbent services. This means that some Wi-Fi use is limited to indoor-only in parts of the 5 GHz band.

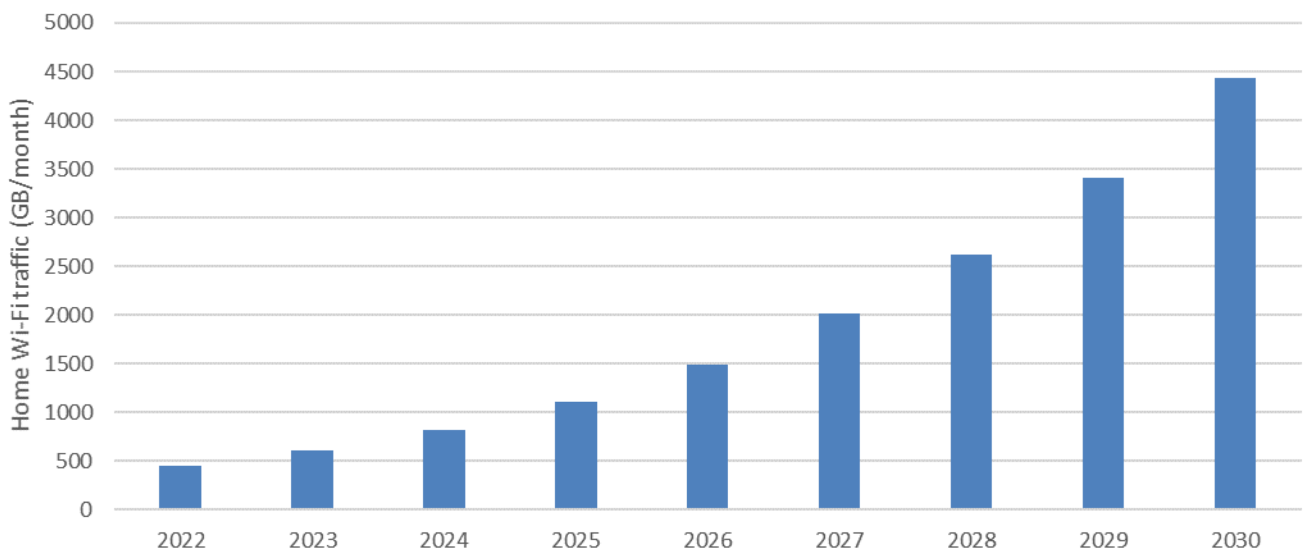
4.9.2 WI-FI TRAFFIC DEMAND GROWTH

There has been continued growth of Wi-Fi traffic for many years, most notably as smartphones, tablets and laptops were starting to generate large volumes of traffic on Wi-Fi networks. Forecast estimates predicting growth in Wi-Fi traffic typically cover a five-year period. The traffic estimates are based on per-user average bitrates (Mbps) or monthly consumption (e.g. GB/month). However, the device mix connected to a home AP or public Wi-Fi connection means the quantity of traffic can vary depending on the device type. For example, a laptop consumes more traffic (as a unit of volume) compared to a smartphone because of the type of usage and time spent by the user on each device. Furthermore, a Wi-Fi-connected smart TV will likely consume more data than multiple laptops due to the higher bit rate requirement and increased length of time spent viewing, potentially on more than one screen. With video being the predominant driver for internet traffic[272], a smart TV can consume between 200-300 GB/month alone.

The figures published by Ofcom in the 2021 Connected Nations report indicate that the average fixed home broadband monthly consumption was 454 GB/month for 2020. As the speed of the latest Wi-Fi technology typically exceeds the capability of most home broadband connections, it is fixed home broadband that enables (or limits) the speed of the Wi-Fi connection.

We also note predictions of traffic growth from Cisco and, in the UK, the website "Increase Broadband Speed", who have estimated monthly internet usage to reach beyond 1 TB by 2025[273]. This assumes an average year-on-year growth rate of approximately 30% for the first three years reducing, gradually to 20% growth in the last two years. Based on this trend, we have forecast growth out to 2030 for home broadband and, in turn, the impact on Wi-Fi traffic. According to this growth trend, by 2030, home broadband traffic could reach nearly 4.5 Terabytes (TB)/month.

FIGURE 24 ASSUMED TRAFFIC GROWTH ESTIMATES TO 2030



Source: LS telcom based on data from Ofcom and Increase Your Broadband Speed website [Accessed March 2022].

Wi-Fi, as an access technology, needs to match the access line technology in the home or office. This can be copper-based such as Asynchronous Digital Subscriber Line (ADSL) to the home (achieving 15-20 Mbit/s) or fibre to the cabinet (FTTC), or cable (DOCSIS) (achieving 80 Mbit/s or more) or fibre to the premise (FTTP) which can deliver up to 1 Gbit/s. This means that customers expect to receive these kinds of speeds within their premises over Wi-Fi.

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[272] InterDigital/Futuresource Report, Dec 2020, Video Will Grow to 82% of Internet Traffic by 2022: Streaming Media website [Accessed April 2022].

[273] Increase Your Broadband website July 2020, TV and Video Will Triple Average Home Monthly Internet Usage to Beyond 1 TB By 2025, Dr Mark Heath. [Accessed March 2022].

The need for Wi-Fi became more apparent during the Covid-19 pandemic when working and learning from home were mandated. Although Ofcom reported an increase in traffic demand[274], networks were not overloaded and were able to support the increased demand. However, the impact on the Wi-Fi spectrum was not clear. Most home routers available today can handle 4-6 concurrent users with average speeds of 30 Mbits/s, but in practice, with continuous use and in densely populated areas, the Wi-Fi quality can be degraded.

Two studies, in particular, demonstrate demand for additional Wi-Fi spectrum that examine both the congestion issue and also overall increase in the expected quality of service. The Wi-Fi Alliance commissioned a study[275] by Quotient Associates to calculate how much spectrum would be needed for a range of scenarios in the 2020–25 and 2025–30 time frames. The study found that:

- in the year 2025, across multiple regions (Europe, USA, China), there will be a need for 500 MHz to 1 GHz more spectrum (see below paragraph on baseline assumptions) than currently available to satisfy the Busy Hour scenario; and
- in the high demand, upper bound scenario[276], an estimated maximum of 1.3 and 1.8 GHz more spectrum may be needed.

The study found from the three locations analysed (residential, office and shopping mall) that the residential had the greatest requirement for spectrum, predominantly because a single access point is deployed compared to larger venues which typically deploy multiple access points. It should be noted that the baseline traffic and utilisation were based on a cumulative distribution approach[277].

The findings from the Wi-Fi Alliance study are further supported by a study[278] from Qualcomm, which examined the spectrum needs of 5 GHz unlicensed spectrum. The aim of the study was to "*provide numerical input into future spectrum requirement discussions and submissions".* It was conducted in 2016 and was forward-looking as it set a target of 1 Gbps coverage to be sustainable to end-users. The sensitivity analysis also considered how much spectrum would be needed for a sustainable 100 Mbps, 500 Mbps and 2.5 Gbps Wi-Fi throughput. To put these speeds into context, Ofcom[279] reported the average actual download speed is 50.4 Mbit/s which is the speed to the router. The Wi-Fi performance will vary depending on several factors *including in-house wiring, in-house contention when more than one device is using the broadband connection, device limitations and the performance of servers delivering content over the connection".* We assume that the average speed measured by Ofcom can be expected by residential consumers over their Wi-Fi networks when connecting to one device in the home.

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[274] UK's internet use surges to record levels, Ofcom article June 2020 https://www.ofcom.org.uk/about-ofcom/latest/media/media-releases/2020/uk-internet-use-surges

[275] Quotient Associates on behalf of the Wi-Fi Alliance, February 2017, Wi-Fi Spectrum Needs Study.

[276] The justification for the upper bound scenario assumes "*unexpected novel applications of a further concentration of the busy hour traffic into fewer than the assumed four hours per day*". This suggests that in practice, the busy hour scenario is the most likely to occur compared to the upper bound scenario.

[277] "*…where at least 95% of the offered traffic is carried, and the 95th percentile of AP utilisation is below 70%. We vary the spectrum available at 5GHz to try to satisfy these targets".* This means the Wi-Fi spectrum at 5 GHz was included in the baseline noting the total quantity available is 455 MHz.

[278] Qualcomm 2016, A quantification of the 5 GHz Unlicensed band spectrum needs.

[279] Ofcom, September 2021, UK Home Broadband Performance The performance of fixed-line broadband delivered to UK residential consumers, https://www.ofcom.org.uk/__data/assets/pdf_file/0020/224192/uk-home-broadband-performance-technical-report-march-2021-data.pdf

The key findings from the study indicated the following.

- There was a huge impact on spectrum demand from high density and overlapping networks, the comparison being an apartment block versus a bungalow located in a rural area. The bungalow required 80 MHz total spectrum for 1 Gbps in every room (assuming no interference), compared to 320 MHz for the apartment block, which assumed densely deployed access points.

- The study concluded that to meet the required throughput speeds, multiple access points would be needed per dwelling in the dense scenario, including some using 60 GHz connectivity for the last hop (which means the connectivity between the access point and the end-user device is provided by the 60 GHz band only).

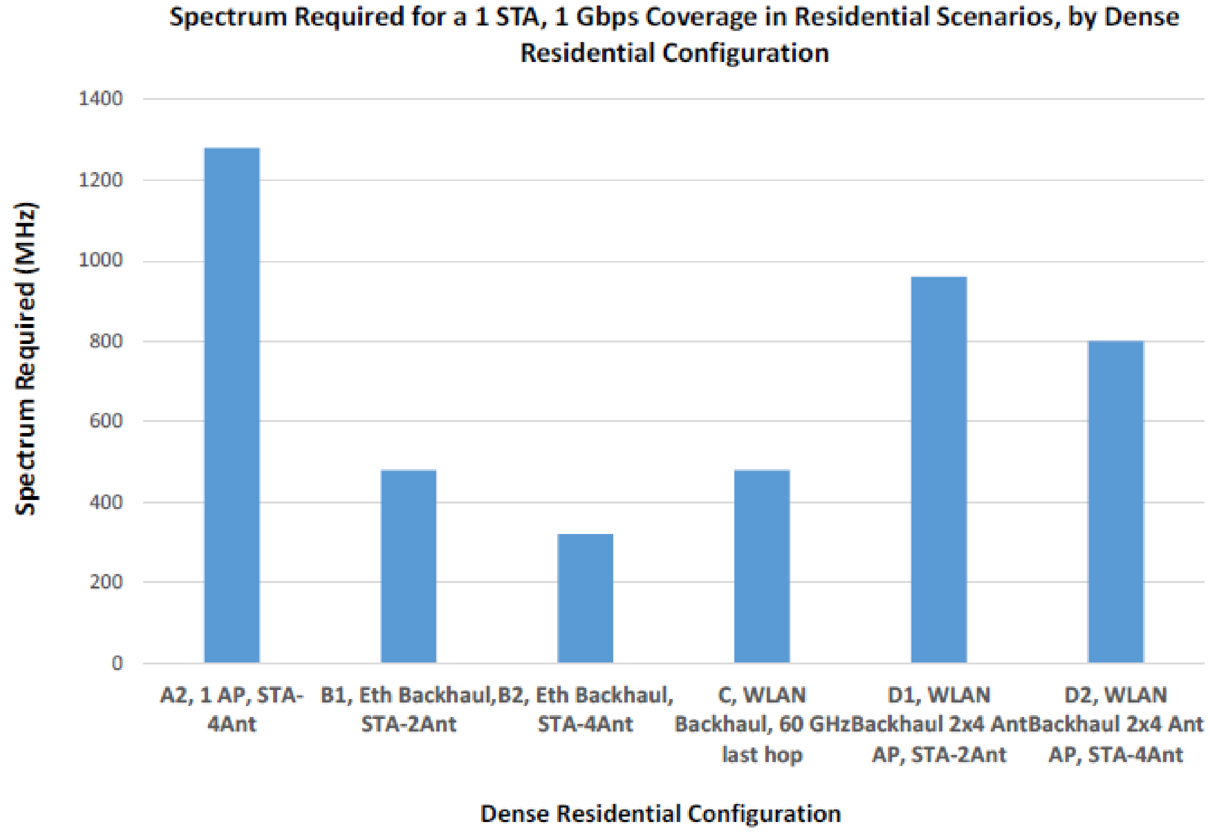
- Equipment would need to be upgraded to the latest technology using multiple antennas so that Multiple Input Multiple Output (MIMO) and Multi-User Multiple Input Multiple Output (MU-MIMO) could be used to support the high-capacity requirements in the dense scenario.

Figure 25 below presents the overall spectrum requirement values across the different dense residential scenarios noting that there is a range of different equipment and network architecture configurations that all drive a wide range of spectrum needs. There are two extreme cases, one which shows highest demand with a configuration of a single access point with the end-user device having 4 antennas requiring 1280 MHz to achieve 1 Gbps. This is the worst-case scenario. The best-case scenario is the configuration of 4 access points per dwelling (one per room), each AP (with four antennas) connected by ethernet with a single device (with 4 antennas) connected to one AP requires 320 MHz to achieve 1 Gbps.

The study also considers each of the scenarios and configurations to achieve slower speeds, such as 100 Mbps for the same best-case scenario requires 40 MHz (if there is interference) or 20 MHz (if there is no interference). These latter figures we would consider more realistic in today's deployments as the bit rates are more typical to what residential users experience.

The Qualcomm study provides some insight into the future demands for spectrum where 1 Gbps is the norm, which, based on the earlier demand growth forecasts, could be within the next 3-5 years.

FIGURE 25 EXTRACT FROM QUALCOMM STUDY ON RESIDENTIAL SPECTRUM DEMAND FOR WI-FI



Source: Qualcomm, 2016.

The results shown in **Figure 25** (above) note the total spectrum required per residential configuration from an analysis done in 2016. We compare these scenarios with the total available spectrum in the UK of 1038.5 MHz below 6 GHz and 14000 MHz at 60 GHz. There is only one scenario, as highlighted with the red rectangle (total 1280 MHz), that could not be served by a combination of the most popular bands (2.4 GHz, 5 GHz and 6 GHz) in use today by most devices (i.e. 60 GHz is not currently widely deployed in smartphones, smart TVs and laptops). This means that better equipment is needed (i.e. the next generation of Wi-Fi technology), or more access points or the use of ethernet to reduce the amount of spectrum needed.

We lastly consider the work done by Ofcom in its 2020 consultation for Improving spectrum access for Wi-Fi[280]. In the consultation, Ofcom identified the need for more Wi-Fi spectrum based on addressing existing problems of 'slow speeds and congestion' and, in turn, enabling new and innovative applications. Ofcom recognised the increasing use of Wi-Fi for everyday activity and new applications. As technology evolves the need for wireless connectivity, particularly for local area connectivity, is driving the demand for Wi-Fi spectrum. There are also new applications starting to increase in usages, such as Augmented Reality (AR) and Virtual Reality (VR), in addition to Ultra High-Definition video. All these applications require high throughput speeds and access to wider bandwidths within the licence-exempt spectrum, hence the need for more Wi-Fi spectrum. The growth in Wi-Fi enabled devices is shown in a chart below (**Figure 26**) produced by Ofcom collected by their Technology Tracker[281]. It shows a range of different devices, some of which can

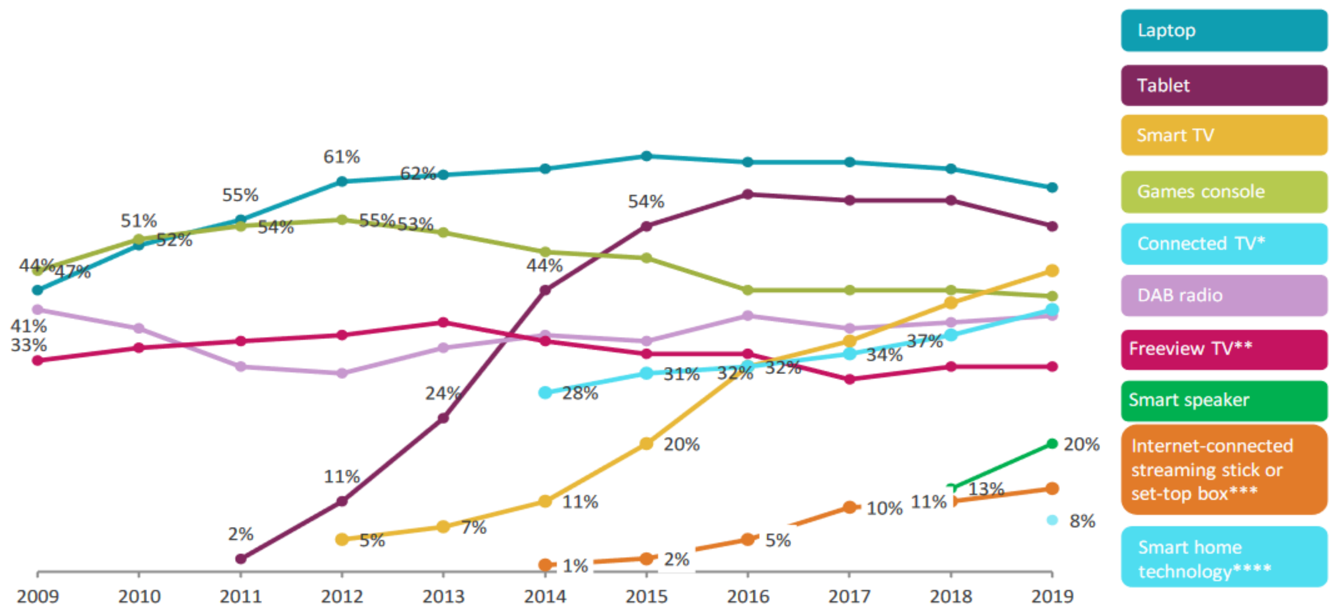
[280] Ofcom, 2020, https://www.ofcom.org.uk/__data/assets/pdf_file/0038/189848/consultation-spectrum-access-wifi.pdf [Accessed 13th April 2022].

[281] Ofcom, 2020, Ofcom technology tracker 2020, https://www.ofcom.org.uk/__data/assets/pdf_file/0037/194878/technology-tracker-2020-uk-data-tables.pdf.

connect to Wi-Fi at home and some that do not (e.g. DAB radio), but mainly it shows the trend of the types of devices connecting to Wi-Fi with the likes of smart speakers, smart TVs and internet-connected streaming stick or set-top box increasing. This will/has impacted the use of Wi-Fi at home by adding more devices this increases demand, putting pressure on the existing 2.4 GHz and 5 GHz bands.

It should be noted that AR and VR are not specifically mentioned and not implied within the games console either, as the games console appears to be in slow decline. One forecast by IDC[282] indicates that by 2022 there will be 15 million global shipments of AR and VR headsets and almost 45 million shipments by 2025 indicating rising demand. This also suggests that AR/VR is still in the very early stages of growth.

FIGURE 26 EXTRACT FROM OFCOM'S TECHNOLOGY TRACKER OF GROWING AND DECLINING WI-FI CONNECTED DEVICES



*Source: Ofcom Technology Tracker. *Includes games console, PC, set-top box, streaming stick, internet-connected set-top box; ** Refers to Freeview as the main TV platform; ***Includes NOW TV box, Roku, Chromecast, Fire TV and Apple TV; **** Ability to control or monitor your home remotely, such as heating, lighting or seeing who is at the door, using a smartphone or other device.*

Source: Ofcom

Ofcom also indicates that with faster broadband being provided to customers through full-fibre rollout and ultrafast broadband, in turn, they are expecting higher capacity, faster speeds and greater reliability from their Wi-Fi. There is also a growing expectation of a consistent and seamless experience, especially when gaming but also with online video calls, which has seen a significant increase in the last two years.

[282] IDC, December 2021, AR & VR Headsets Market Share, article by, https://www.idc.com/promo/arvr.

Following consultation, Ofcom decided[283] to open up access to the lower portion of the 6 GHz band (5925–6425 MHz) in a way that was flexible[284] and that could support the new Wi-Fi standards being developed, such as Wi-Fi 6E. The latest smartphones, such as the Galaxy S21 Ultra and Google Pixel 6, now support this band along with a wide range of modules, routers and smart TVs[285].

Ofcom made a further decision to improve access to spectrum for Wi-Fi in the 5725–5850 MHz band proposing the removal of the need for Dynamic Frequency Selection (DFS) limits (which is needed to protect radars from interference from Wi-Fi users), which is used to protect radars. This decision has helped improve access to the Wi-Fi spectrum in a number of ways, namely:

- removing the DFS requirement will widen the vendor equipment pool for the UK; and
- improve the quality of connection by reducing the overall delay imposed by having to have DFS enabled.

4.9.3 SUMMARY AND RECOMMENDATIONS

The reports and studies examined are predict **that global Wi-Fi traffic growth will continue to increase** at a similar pace to today (20-30%) for at least the next 5 years. Our analysis suggests that there will continue to be strong demand for Wi-Fi connectivity for the next 5 to 10 years. This is being driven by a mix of increased per device traffic (more time spent by users on increasingly capable devices) but also new innovations and applications that will demand access to wider bandwidths, as indicated by Ofcom.

One of the major drivers for increased Wi-Fi connectivity will be the increased rollout of fibre. Market indicators and the demand studies we assessed have shown that if homes and offices will be demanding speeds above 1 Gbit/s from fixed broadband in the next 5 years, then the available Wi-Fi bandwidth at home and in the office will need to align and support those speeds.

Therefore, the recent introduction of Wi-Fi 6E and its use of the lower 6 GHz band will be used by consumers, private enterprises and public organisations to provide additional capacity. Over time as the usage of the new lower 6 GHz band increases, it can be determined how much more demand there will be for Wi-Fi more generally. This will be done in addition to measuring the trend in congestion in the 2.4 GHz and 5 GHz bands, as this may decline as more devices move to 6 GHz.

However, the spectrum will be able to support this demand up to a point. It will be the new Wi-Fi technologies (e.g. Wi-Fi 6E/7) which provide the much wider bandwidths for applications such as AR, VR and higher resolution (UHD) video streaming applications. These new Wi-Fi technologies will also help ease congestion in public Wi-Fi networks (where users can seamlessly connect to different access points as they move around large public spaces, this adds to congestion) and will deliver ever-increasing bit rates to a high density of users.

Over the longer 10-15-year time frame and based on a sustained 5-10 Gbit/s throughput (assuming fixed broadband will reach this level) over an entire household, we would consider that the spectrum available for Wi-Fi today can meet these demands for a single household with low surrounding interference. However, in locations of congestion, such as apartment blocks, dense urban areas and high footfall areas, we consider

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[283] Ofcom, 2020, https://www.ofcom.org.uk/__data/assets/pdf_file/0036/198927/6ghz-statement.pdf [Accessed April 2022].

[284] The restrictions that have been applied to this band include low power indoor access at 250 mW EIRP and very low power outdoor use at 25 mW in order to protect incumbent services such as fixed links and satellites.

[285] Wi-Fi Alliance website, April 2021, Quarterly update: Wi-Fi 6E devices driving technology innovation, https://www.wi-fi.org/beacon/the-beacon/quarterly-update-wi-fi-6e-devices-driving-technology-innovation [Accessed March 2022].

that additional spectrum would be needed to ease that congestion ensuring all users can receive a sufficiently high degree of quality. In the 2030 time frame and beyond, users should be able to receive 200–300 Mbit/s even in congested areas (i.e. more than 4-6 times today's average). The amount of additional spectrum that may be needed depends on the situation. However, according to the demand analysis studies, in situations where there is interference and congestion, at least 6–7 times more bandwidth is needed relative to a single (20 MHz) channel.

The options, benefits and regulatory challenges of assigning additional Wi-Fi spectrum in the upper 6 GHz range specifically within the UK needs to be explored further to determine whether:

- there is a risk of further congestion on the existing 2.4 GHz and 5 GHz spectrum considering developments of Wi-Fi usage in lower 6 GHz; and
- there is sufficient demand for Wi-Fi over the entire 6 GHz range.

DCMS, DSIT and Ofcom should work collaboratively to identify and validate any specific national and international pressures on potentially less restrictive access to the upper 6 GHz band for Wi-Fi in areas that go beyond Ofcom's recent consultation[286].

4.10 DEFENCE

4.10.1 CURRENT DEMAND FOR SPECTRUM BY THE MOD

In this section, we consider the current usage of spectrum by the MOD with a particular focus on the sub 6GHz bands. We examine MOD's near-term (within the next 5 years) spectrum needs across a range of specific bands that can be utilised for a mix of defence purposes but also the potential to share with other civil users. The specific bands from the 2017 CMU report[287] are listed below, with details of these and other bands provided in **Annex C:**

- 380–400MHz;
- 406–430MHz;
- 1427–1452MHz;
- 2.3–2.35GHz;
- 2.7–2.9GHz;
- 2.9–3.1GHz;
- 3.3–3.4GHz;
- 4.4–5GHz; and
- 5.35–5.47GHz.

[286] Ofcom Consultation, Feb 2022, Enabling spectrum sharing in the upper 6 GHz band Shared licences for local, low-power indoor use of the upper 6 GHz band (6425-7070 MHz) https://www.ofcom.org.uk/__data/assets/pdf_file/0022/233194/spectrum-sharing-6ghz.pdf

[287] UKGI CMU, Aug 2017, Public Sector Spectrum Release Programme 2nd Annual Report by UKGI Spectrum Central Management Unit https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/643037/CMU_2017_Annual_Report.pdf

4.10.2 FUTURE DEMAND FOR SPECTRUM BY THE MOD

The Integrated Review[288] (IR) represents an investment in new technology, with innovations needed because of the modernisation of the battlefield with the likes of drones being deployed and fewer soldiers needed on the ground.

The IR focuses on the increased use of automation, notably for the UAVs (unmanned aerial vehicles) and UAS (unmanned air systems). There are also various naval systems being developed in specific frequencies used by the MOD, and MOD expect this will increase in future.

An example of UAV systems is the Protector, which is a new drone with a multitude of capabilities. Before the integrated review, there would have been 8 UAVs, this is increasing to 16 by 2024, indicating the growing need for the MOD UAV capabilities. Since there are more UAVs, this helps MOD and the wider defence community with certain missions to combat illegal immigration and anti-drug work. Other examples are the ‘loyal wingman’ concept, which is an aircraft surrounded by drones, which can then be tasked to do different missions. In addition, the new fighter jet is F35, which uses spectrum bands previously unused in aircraft. It can be flown with or without a pilot, but this requires new technology to be achieved.

There are new naval ships being developed, including two aircraft carriers, which will need access to more spectrum. Examples of innovation, in this case, are the use of 5G networks onboard ships instead of fixed wires and investment in anti-mine warfare. These initiatives are likely to be used in UK waters, which puts pressure on the bands that are already being shared.

The army also needs new ways of training and new ways of connecting. These include autonomous vehicles and convoys, all of which need spectrum. However, due to the sometimes localised or time-specific requirements for MOD spectrum use, there are opportunities for sharing spectrum (which are discussed further in **Sections 5 and 6** of this report).

During the longer time frame of this study, it will be critical for Ofcom and the MOD to agree on a mutual understanding of the definition of ‘sharing’, which enables the MOD to continue planning and supporting the UK’s defence needs in parallel with DCMS, DSIT and Ofcom meeting market demand for spectrum.

4.10.3 SUMMARY AND RECOMMENDATIONS

The MOD **will have a long-term steady increase in demand for spectrum** that will be needed to meet the requirements for future defence capabilities as outlined in the Integrated Review of Security, Defence, Development and Foreign Policy[289]. New UAV capabilities, space radars and the introduction of space launches in the UK will all need access to spectrum in future.

The demand will not solely be met by the existing spectrum available to the MOD but also use of civil bands where sharing is possible. It is anticipated that by the end of 2022, the MOD will be close to meeting its spectrum release/sharing target (at the time of writing is 63 MHz short of the target) as part of the conclusion of the PSSRP. In the next phase of making spectrum available to other users, spectrum sharing presents a balance between the MOD’s demands and capability requirements and the need for spectrum for other services to continue to support national prosperity and productivity. The MOD, DCMS, DSIT, Ofcom and

[288] Government UK, 2021, https://www.gov.uk/government/publications/global-britain-in-a-competitive-age-the-integrated-review-of-security-defence-development-and-foreign-policy [Accessed 13 April 2022].

[289] The UK Government, 2021 https://www.gov.uk/government/publications/global-britain-in-a-competitive-age-the-integrated-review-of-security-defence-development-and-foreign-policy [Accessed 13 April 2022].

other government departments need to work collaboratively to develop and refine the approach to sharing (or indeed any release) in the future, and this needs to be addressed in the short term (next 5 years). A critical aspect will be to settle on a definition of sharing that enables the MOD to continue planning and supporting defence needs in parallel with DCMS, DSIT and Ofcom, meeting market demand for spectrum.

A review of the last PSSRP needs to identify lessons learned from that process and what improvements could have been made to inform future public sector sharing and/or release of spectrum from MOD use. There needs to be the timely publication of information on what spectrum will be shared or released, and to what timescales to enable the market to make future investment plans.

4.11 EMERGENCY SERVICES

4.11.1 GROWTH IN DEMAND FOR EMERGENCY SERVICE APPLICATIONS

As noted in **Section 3.2.10**, the emergency services will be moving away from Airwave to the ESN, in 2024 with the transition due to be complete by 2026. ESN is expected to deliver the required voice and wideband data services in locations across the UK where all emergency service vehicles could travel to. The coverage of ESN is expected to replicate that of Airwave, which includes strategic areas such as the London Underground[290] and inside major event venues such as Wembley Stadium. This transition will move emergency service applications off of the legacy PMR Airwave network and onto a 4G network. The spectrum used by the Airwave TETRA network (in the 380–400MHz range) is harmonized for NATO use and defence purposes in the UK. Once the Airwave network is closed this spectrum will move back to MOD use. This will increase the amount of spectrum available to the MOD.

The move from Airwave to ESN also presents a change in EE's spectrum use, as indicated by the EE application to Ofcom for licence variations, which were accepted by Ofcom in 2017[291].

Through stakeholder engagement, the Home Office informed the project team that spectrum was needed to support standardised 3GPP Device to Device applications. Discussions were ongoing with Ofcom for access to the centre guard band in 700MHz. Future options that may be explored include access to the DTT band for PPDR, but this will be subject to discussions at WRC 23.

It will be critical for the emergency services to have long-term access to the required harmonised bands and bandwidths in order to support many of the new wideband data applications, such as live video streaming from aircraft or live video feeds from body-worn cameras by emergency service personnel.

One specific example of where the demand for spectrum will come from is the 'Connected Ambulance', which currently incorporates electronic patient care reporting using tablets and remote vehicle monitoring and dispatch capabilities via its mobile data terminal using both the Airwave SDS service and GPRS networks. The Ambulance Radio Programme is working with the Emergency Services Mobile Communication Programme (ESCMP) to ensure its remit of future connectivity for the ambulance service and wider health service is delivered.

[290] See Critical Communications website https://www.criticalcomms.com/news/esn-testing-on-the-london-underground [Accessed March 2022].

[291] Ofcom, 2017, Ofcom decision in response to EE application for licence variations in support of enhanced mobile communications for the emergency services (10 January 2017) [Accessed April 2022].

4.11.2 SUMMARY AND RECOMMENDATIONS

The use of spectrum by the emergency services has changed, predominantly driven by **the increase in demand for wideband data services** to support the growing need for more capable and bandwidth-intensive communications. The transition from Airwave to the Emergency Services Network by 2026 indicates how this need is being addressed by public mobile networks. The increase in demand will be accommodated within the EE 4G network.

Solutions for short term access to spectrum may be needed for the emergency services, particularly around areas where coverage is challenging or where there could be significant demand during an incident. Any review of the ESN implementation, once complete, will need to include an assessment of the impact on spectrum and future spectrum requirements.

4.12 SPACE AND EARTH SCIENCES

4.12.1 DEMAND FOR SPACE AND EARTH SCIENCES SPECTRUM

There is **an increased utilisation of spectrum for earth observation, space science, space exploration and radio astronomy areas**. This does not necessarily mean that more spectrum is required, in general, there is more utilisation of existing spectrum as the space economy grows. However, in term of the total quantity of spectrum, the increased amount is minimal, and although there is broadly sufficient capacity within the current spectrum allocation to accommodate this increase, from time-to-time identification of new allocations is needed to introduce new types of services. This has implications for sharing both between space services and between space and other services and applies to spectrum used by sensors and to spectrum used for data downloads.

In the space operations service, used to control spacecraft, an increase in the number of science missions, including commercial earth observation, has already created considerable spectrum congestion in the S-band allocations around 2.1 GHz. The X-band spectrum is also under pressure, particularly the 8-8.4 GHz band which is mainly used for data downloads from space missions. Active remote sensing spectrum is also seeing greater utilisation, with growth in synthetic aperture radars at 0.45, 3.2, 5.4 and 10 GHz and is seeking a new secondary allocation for spaceborne radar sounders around the 45 MHz range. Lower frequency bands can penetrate ice fields and tree canopies, whereas the higher bandwidth that is now available, around 10 GHz, allows greater resolution earth imagery. Furthermore, the UK Space Agency suggested there should be a revision of the allocations above 100 GHz to better reflect actual use for earth observation. The UK may wish to support this as a future agenda item.

Stakeholders confirmed that there is growing interest in space scientific applications which in turn aligns with the UK's National Space Strategy, published by the UK Government in September 2021. The strategy focuses on four pillars which will be acted upon to achieve its stated goals. Pillar three focuses on growing the UK as a science and technology superpower with an ambition to grow UK participation[292] and benefits gained from space science activities. Earth observation is encompassed within this as a priority activity along with the data collected by passive and active space monitoring from the UK.

In parallel with this growth, the radio environment is also becoming more congested due to the increasing use of spectrum by other services (e.g. satellite communications or mobile services) in frequency bands close to where radio astronomy and other scientific research are conducted. This presents an ever-increasing risk of interference to radio astronomy and space science. This means at some point the flexibility of use of

[292] Government UK, HM Government National Space Strategy, September 2021 p36.

spectrum in the location of receive stations may begin to be restricted, potentially making it harder for the research to be conducted. This is not just a problem for the UK but internationally, as frequency bands adjacent to radio astronomy are becoming increasingly utilised, thus demonstrating the need for continued support from the UK at an international level at World Radio Conferences to ensure these frequencies continue to be sufficiently protected from interference now and in future.

Much of the use of spectrum for space research is fixed either by the need to support space missions over the long term (the Voyager missions, for example, were launched in 1977) or the fact that the frequency of use is determined by physics and chemistry.

4.12.2 SUMMARY AND RECOMMENDATIONS

Protection of existing spectrum is especially necessary for earth observation where any interference into the spectrum they use could lead to a significant and harmful degradation to the service they provide. It was noted by the UK Space Agency that EO satellites use a number of frequency bands simultaneously and that disruption to *any* of the bands in use could render the measurements they take unusable, thus it is not a case of protecting some bands but not others but ensuring that all spectrum used for this purpose remains as clear as possible from interference.

There **is no significant change in demand *per se* for spectrum** for space science and radio astronomy services, nor has there been a significant change in usage over recent years. The challenge is to ensure the spectrum that is used for such sensitive monitoring and earth observation (Ofcom identify 8 GHz and 26 GHz bands) is protected to ensure the continued integrity of the critical information that such monitoring provides. The priorities for the space sector need to give due recognition to the vital importance of this spectrum to radio astronomy and space sciences and ensure that sufficient measures are in place to protect the frequencies from interference as the utilisation of spectrum increases.

4.13 TRANSPORT: AVIATION, MARITIME, RAIL, AND ROAD

4.13.1 AVIATION

CURRENT DEMAND FOR AVIATION SPECTRUM

The demand for aviation spectrum has remained stable over recent years with no additional requirements for spectrum that were not able to be met from within existing allocations. The focus of the industry is on increased spectrum efficiency. This would usually mean better use of spectrum by aeronautical equipment with technology improvements and designs. However, the UK aviation sector has demonstrated cross-industry spectrum efficiency with its willingness and ability to share critical aeronautical spectrum (as discussed in **Section 3.2.8**) with the PMSE sector. This is a step-change in approach to spectrum management for the aeronautical industry setting a precedent for other sectors.

Stakeholders confirmed that near term demand (within 5 years) for spectrum for the UK aeronautical sector will come from the following areas:

- increased use of Unmanned Aerial Vehicles (UAV) particularly in non-aero bands; and
- business as usual with an increase in air traffic after Covid-19 with a likely 3-4% growth per annum

UAV: The CAA is tackling the various challenges of introducing drones into Unmanned Traffic Management (UTM) airspace. This space is at 400m above ground typically but requires spectrum to manage the various drone applications as well as for the amount of weight it can safely carry (payload) of some vehicles. There is an ongoing discussion on which spectrum bands should be used, either an aeronautical spectrum (such as 960–1164 MHz used for Automatic Dependent Surveillance–Broadcast[293]) or a commercial mobile spectrum for both UAV control and data communications. The proposed UTM airspace aims to allow the use of drones Beyond Visual Line of Sight (BVLOS) which will unlock the likes of drone deliveries, such as that being developed by Amazon[294] but also a whole range of other applications that can utilise data transfer, which could use mobile network frequencies. There may also be new methods of autonomous air transport (Urban air mobility) using drones with companies such as Volocopter[295] and Airbus[296]. There are also new concepts for swarms of drones[297] which can fly in formation and make deliveries, conduct surveillance and undertake other tasks.

Business as usual and increase in air traffic: The CAA expected (pre-Covid-19) that there would be a 3-4% growth in air travel but this would have no incremental impact on spectrum. The CAA also foresee continued use of existing spectrum allocations with no need for additional spectrum. We also note that the lead time on any new aeronautical systems is very long (up to 30 years) so there will need to be plenty of notice when making any changes to the requirements.

FUTURE DEMAND FOR AVIATION SPECTRUM

Longer-term demand (within 10-to-15 years) for spectrum for the UK aviation sector will come from the following areas:

- The introduction of space planes, which travel at altitudes above 100 km
- Use of autonomy to bring gaps between aircraft closer together and implications on spectrum requirements, which will help with increasing air traffic and reduction in CO2

Space planes[298]: These aircraft will be able to travel at altitudes of 100 km or more and are a hybrid of a normal jet aircraft and a spacecraft and can travel sub-orbital or orbital. They require the use of rocket-propelled engines to travel at such altitudes. The CAA is developing approaches for spectrum management and the use of frequencies for Air Traffic control, and other airspace management requirements. Due to the large investment required in spaceplanes, there has not been a great deal of development in the UK but could be operational within the 10-to-15-year time frame.

Autonomous manned aviation: This concept considers autonomy from an air traffic management perspective in which the aircraft itself is autonomous and communicates with other aircraft in the surrounding environment. The aim would be to improve and optimise traffic routing live, and avoidance of severe weather or headwinds which can reduce fuel consumption and CO2 emissions. Also flying in closer formations with one aircraft in the vortex of the other can also reduce fuel consumption and contribute to reductions in CO2 emissions. This would require an interactive communications system and would unlikely

[293] Automatic Dependent Surveillance–Broadcast used for aircraft surveillance and positioning.

[294] See Amazon website https://www.amazon.com/Amazon-Prime-Air/b?ie=UTF8&node=8037720011 [Accessed March 2022].

[295] See Volocopter website https://www.volocopter.com/ [Accessed March 2022].

[296] See Airbus website https://www.airbus.com/en/innovation/zero-emission/urban-air-mobility/cityairbus-nextgen [Accessed March 2022].

[297] Aerial Swarms: Recent Applications and Challenges. M Abdelkader et al. See: https://link.springer.com/article/10.1007/s43154-021-00063-4

[298] Definition of spaceplane from the CAA website https://publicapps.caa.co.uk/docs/33/CAP1189_UK_Government_Review_of_commercial_spaceplane_certification_and_operations_technical_report.pdf

use existing solutions such as ADS-B. Options include satellite communications or public mobile communications, but both would have their challenges for interference management.

ICAO and Eurocontrol have been exploring improvements in spectral efficiency and where improvements can be made in Communications, Navigation and Surveillance (CNS). For example, on aircraft, there are individual units for each radio system. This can be combined into a single box, or solution, which would mean developing new technologies that can support the different communications, navigation and surveillance systems. However, the time frame being proposed is around 30 years (to 2050). This is because aircraft procurements are so long with the airframe expected to last for 30-35 years. In future, there is an opportunity to remove unnecessary redundancy within aircraft which could reduce the number of radios (boxes) on the aircraft. Although there is uncertainty as to what spectrum will be required in future to support such changes, a move to a single solution for CNS may reduce the spectrum requirements for air traffic control which could be used for other aviation services.

SUMMARY

There is sufficient bandwidth to meet future demand which mainly considers continued business as usual (including an increase in air traffic). We do not foresee any changes in the spectrum needed. In the longer 15-year time frame the introduction of Unmanned Aerial Vehicles and Spaceplanes could require access to additional bandwidth or use of public networks but it remains uncertain which bands they could use or the quantity of spectrum that will be required.

4.13.2 MARITIME

CURRENT DEMAND FOR MARITIME SPECTRUM

Near term demand (within 5 years) for spectrum for the UK maritime sector will come from the following areas:

- digital transformation of ports;
- business as usual with increased maritime traffic and shipping after Covid-19; and
- faster and better internet onboard ship.

Digital transformation of ports: Increasing shipping traffic at the UK's ports (notwithstanding the impact of Covid-19– see below) requires additional communications capabilities. A private 5G network has recently been deployed at the port of Felixstowe[299] to help improve logistics and performance when unloading container ships and support predictive maintenance to maximise operations. The demand for spectrum, in this case, comes from the use of either shared spectrum such as 3.8–4.2 GHz or from the mobile operators. We would anticipate a growth in this trend over the next 3-5 years as private 5G networks become a popular solution for the maritime/port sector

Business as usual with an overall gradual increase in maritime traffic: There was a decline in tonnage handled by UK ports of 9% in 2020[300]. Since 2010 the number of cargo vessels arriving at UK major ports has

[299] IT Pro website March 2022, UK's largest port to deploy 5G and IoT tech, article on https://www.itpro.co.uk/mobile/5g/364569/uks-largest-port-to-deploy-5g-and-iot-tech [Accessed March 2022].

[300] DfT, 2021, UK Port Freight Statistics: 2020, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1014546/port-freight-annual-statistics-2020.pdf [Accessed March 2022].

fallen overall. Figures from the 2019 Department for Transport UK Port Freight Statistics state that whilst the number of cargo vessels arriving has fallen overall, the total deadweight tonnage and gross tonnage have remained broadly stable. This reflects an increase in average vessel size.[301] The Department for Transport, in the Maritime 2050 strategy, anticipates that the historical growth in the volume of goods transported by sea will continue and that by 2050 the volume of cargo will be far greater than it is now.[302]

As the density of ships starts to increase, this can place extra demands on the use of spectrum but are unlikely to exceed the available supply predominantly due to ship traffic management and the way in which ship communications traffic including the Global Maritime Distress and Safety System (GMDSS)[303] and MDSS and Safety of Life at Sea (SOLAS) operate. The most important issue for maritime spectrum is to ensure the bands, which are globally harmonised, remain protected from interference but also are not re-allocated for other uses. It is likely that there will be more sharing in some bands used by the maritime sector in future. This is discussed earlier in the MOD section.

Faster and better internet onboard ships: One area that will continue to grow and evolve in the next few years is improved connectivity for passengers onboard ships. Most international ferry service providers and cruise operators that operate beyond the reach of shore-based networks already offer onboard Wi-Fi. Apart from international ferries, at-sea internet connections are predominantly provided by onboard satellite infrastructure complemented with cheaper land-based links, where available. There is an increasing demand on behalf of crew members to have full internet connectivity throughout the voyage, thus driving the provision of onboard Wi-Fi in the commercial non-passenger segment. Although there is no public data available on this trend, demand is likely to increase over the next 5 to10 years.

On-board connectivity has continued to improve over the years with higher throughput satellites connecting to ships whilst out at sea. There are also coastal and in-port communications which can be provided by terrestrial mobile systems for both operational and passenger communications. Passengers can use Wi-Fi or mobile to connect to the internet with the devices that they bring onboard. With UK maritime passenger numbers marginally declining between 2018-2019[304] the primary driver of spectrum demand in the maritime sector is likely to be caused by users' demand for increasing personal data speed and volume as well as the increasing provision of on-board Wi-Fi. This is a trend that will continue in the same way for passengers at sea as with the expectations of users for higher mobile broadband speeds on land.

FUTURE DEMAND FOR MARITIME SPECTRUM

In the near future (up to 5 years), spectrum demand in the maritime sector is likely to be predominantly determined by the increasing data volume as well as by an increase in the provision of onboard Wi-Fi. However, this is primarily delivered by satellite communications and therefore does not impact maritime spectrum demands. As commercial SOLAS vessels are only rarely refitted more than once during their lifespan, any rapid increase in the number of spectrum-relevant equipment used by these ships is unlikely.

[301] Department for Transport UK Port Freight Statistics: 2019 (12 August 2020) https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/908558/port-freight-statistics-2019.pdf [Accessed March 2022].

[302] Department for Transport Maritime 2050: navigating the Future (January 2019) [Accessed March 2022].

[303] Global Maritime Distress and Safety System (GMDSS) is the internally agreed-upon set of safety procedures, types of equipment and communication protocols to increase the safety of life communications at sea making it easier to rescue ships and aircraft in distress

[304] Department for Transport Sea Passenger Statistics: All routes 2019 (11th November 2020) https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/934144/sea-passenger-statistics-all-routes-2019.pdf [Accessed March 2022].

Key drivers of maritime demand for spectrum are rooted in the transition from voice-centric VHF terminals to VHF data exchange systems (VDES), and the emergence of vessel-to-vessel and vessel-to-port applications.

Longer-term demand (within 10-15 years) for spectrum for the UK maritime sector will come from the following areas:

- increased use of Unmanned surface (and undersea) Vehicles, i.e. autonomous ships; and
- e-navigation.

USV: These are autonomous maritime surface (or undersea) vehicles that can be used by the Navy or border control organisations. They require wide-area control communications which can come from a mix of satellite and terrestrial systems. There are also opportunities for merchant shipping and the leisure/cruise sector for such capabilities, but the systems are in the research phase. In the next 10 years, we can expect unmanned ships that are equipped with sophisticated technologies including tracking systems, and advanced sensor and positioning systems. This would also include AI for dynamic route changes and live remote-control systems in case of emergency. The benefits being suggested[305] include reduced onboard resources, minimising human error and reduced/removed risk to life.

e-Navigation: This has some impact on spectrum as the aim is to enhance the processes and approach for the provision of navigation and other information for ship-to-ship communications and ship-to-shore communications. The IMO introduced the E-Navigation concept in 2006[306] and is an ongoing strategy as user requirements and technologies evolve. It incorporates five e-navigation solutions which include:

- improved, harmonised, and user-friendly bridge design;
- means for standardised and automated reporting;
- improved reliability, resilience and integrity of bridge equipment and navigation information;
- integration and presentation of the available information in graphical displays received via communication equipment; and
- improved communication of Vessel Traffic Services (VTS) Service portfolio (not limited to VTS stations).

An example of the systems that will be updated from the e-Navigation strategy, that has been developed by the IMO includes:

- automatic Identification Systems (AIS);
- GMDSS; and
- long Range Identification and Tracking Systems.

In coastal waters, the use of VHF provides sufficient coverage for the likes of VDE (VHF Data Exchange). It is when out at sea far away from any coast this could require the use of other technology solutions such as satellites to provide additional higher rate information that would be needed to support the features of e-Navigation.

[305] SHM Group blog website Feb 2019, Future trends in maritime communication, https://www.shmgroup.com/blog/future-trends-maritime-communication/ [Accessed March 2022].

[306] See the International Maritime Organisation website https://www.imo.org/en/OurWork/Safety/Pages/eNavigation.aspx [Accessed March 2022].

SUMMARY

Against the backdrop of reduced seaborne passenger transport, a decreasing number of fishing vessels and stagnating numbers of maritime freight transport, **we expect longer-term demand for spectrum** is likely to be triggered and dominated by increasing use for continuous vessel-to-vessel and vessel-to-shore connectivity in addition to increased use of autonomous vessels. We also expect an increase in onboard mobile and Wi-Fi provision on international ferries and cruise ships.

Overall, we do not expect there to be demand for more spectrum from applications (e.g. ship communications and navigation) within the maritime sector itself. Instead, we expect there will be better provision of connectivity from both terrestrial and satellite networks to satisfy the significant increase in digital communication applications and the requirement for ships to be continuously connected to shore-based internet. As noted in **Section 3.2.11,** many of the maritime spectrum bands are harmonised internationally and any changes would need to be driven forward at an international level. As there is no indication of a desire to amend or change the use of these harmonized maritime bands, we do not anticipate that the maritime bands will provide any immediate opportunities for a change in use.

4.13.3 RAIL

CURRENT DEMAND FOR SPECTRUM BY RAIL

The railway network is a vitally important critical national infrastructure that is utilised for the transport of freight and passengers across Britain. Notwithstanding the impact on passenger and freight numbers due to the COVID-19 pandemic, there were 1.77 billion passenger journeys[307] in the 12 months up to the end of June 2019 according to the ORR[308]. The efficient and safe running of trains on the network is reliant on fixed and wireless communications networks. These communications are comprised of:

- The GSM-R network operates on licensed spectrum in the 876-880/921-925 MHz. The band is licensed by Ofcom and held by Network Rail as is a European harmonised band (and was) protected by Commission Decision 999/569/EC of 28 July 1999[309] but this no longer applies since Britain left the EU. It is used for cab radio voice communications between the signaller and train driver. It is also the bearer platform for signalling information between the signals and the train. It is this system that enables safe train movements across the national network.
- Fixed Telephone Network (more recently FTNx) which provides the fixed communications over fibre between predominantly stations, signals, and GSM-R masts. This provides the backhaul from GSM-R traffic and connectivity for the Wide Area Network from control rooms, signalling sites and other fixed assets on the network

The other type of connectivity that has been steadily increasing on the rail network is the use of remote sensors both on the trackside and on the train using public mobile network connectivity. There has been an increase in IoT for Network Rail but also the train operating companies (TOC) to undertake remote condition monitoring, provision of sensor data to TOC control rooms and live positioning information. In addition, the

[307] Passenger Rail Usage 2019-20 Q1, ORR statistics October 2019 https://dataportal.orr.gov.uk/media/1481/passenger-rail-usage-2019-20-q1.pdf

[308] Figures have been used for 2019 as representative of 'business as usual' pre-Covid-19 pandemic levels and what it could be anticipated levels will return to.

[309] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:01999D0569-19990729&qid=1519396120758&from=EN

TOCs were mandated by the Government[310] to provide free Wi-Fi on board trains. This required the deployment of mobile gateways onboard that would connect to the public mobile networks and provide Wi-Fi onboard to passengers.

The GSM-R network was introduced in 2013 and fully deployed in 2015. Although based on 2G technology, it provides the required voice and data capabilities needed for the operation of the railways. The propagation characteristics at 900 MHz allow for very wide area coverage along the railway corridors and inside tunnels, except for those with dedicated infrastructure (e.g. Severn tunnel). There are 2500 GSM-R masts deployed covering around 15000 km of track.

In the near term (up to 5 years), the GSM-R network will continue to function without the need for more spectrum as the existing voice and data communications requirements for the safe running of the railways are satisfactorily met. There is work ongoing within the International Union of Railways (UIC) and technical standards bodies to develop the new Future Railway Mobile Communications System (FRMCS) that will need access to more spectrum and is discussed further in the next section.

FUTURE DEMAND FOR SPECTRUM BY RAIL

As mentioned above, the new FRMCS system being proposed by the international rail industry intends to support a much wider range of applications including automatic train operation, remote control and monitoring of engines and other onboard equipment, emergency communications and interoperability, multiple voice operations and the need for transfer of wideband data, such as onboard CCTV to name a few. This means more spectrum is needed (wider bandwidths) for the system to support current and new mobile technologies such as 5G. The industry has identified a requirement for spectrum in the 1900–1920 MHz band, noting this is designated as a public mobile band, and 10 MHz within this band has been identified internationally for railway communications. In addition to this, a further 2x1.6 MHz (2x5.6 MHz in total) has been identified for the existing harmonised band for railways, which was agreed across Europe[311].

However, in the UK, the 1900 MHz band is assigned to EE[312] with a recent variation made to its licence by Ofcom for use by the Emergency Services Network as an enhancement for the capacity of the band in remote locations. Network Rail has indicated an interest in sharing access to this band with ESN to support additional capacity in areas of the network where there is likely to be congestion, such as busy junctions and entrances to mainline stations.

This access would be required whilst transitioning the GSM-R network to FRMCS and help Network Rail cope with any congestion on the network, which without access to another band such as 1900 MHz, could make this quite challenging. Otherwise, the current allocation of spectrum for railways at 900 MHz is sufficient to support FRMCS.

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[310] DfT, Feb 2015, Free wi-fi to help rail commuters stay connected, https://www.gov.uk/government/news/free-wi-fi-to-help-rail-commuters-stay-connected [Accessed March 2022].

[311] CEPT, 2020 ECC Decision 20(02) harmonised the unpaired spectrum 1900-1910 MHz (including the paired frequency bands 874.4-880.0 MHz and 919.4-925.0 MHz) for Railway Mobile Radio (RMR):, Nov 2020, https://docdb.cept.org/download/1446[Accessed March 2022].

[312] Ofcom, 2017, EE application for licence variations in support of enhanced mobile communications for the emergency services, Ofcom statement 2017 https://www.ofcom.org.uk/__data/assets/pdf_file/0032/96566/Statement-EE-application-for-licence-variations-in-support-of-enhanced-mobile-communications-for-the-emergency-services.pdf [Accessed March 2022].

In the case of delivering connectivity to rail passengers, there have been attempts[313] by Network Rail to procure a solution that will enable the deployment of additional trackside infrastructure and fibre to provide wideband data connectivity onboard. The architectural approach has typically been to have as many base stations on the trackside as possible to connect to a rooftop antenna on the train to maximise the signal strength and deliver optimum coverage. The continued challenge has not necessarily been a technical one (albeit there is still work to overcome the mobile coverage challenge in tunnels and cuttings) but a commercial one with the need for close collaboration between government, Network Rail and telecommunication service providers. A breakthrough was made and in 2021, Cellnex was awarded a 25-year contract[314] to deploy communications infrastructure (masts and fibre) along the Brighton Mainline route for continuous mobile connectivity. This connectivity will also help Network Rail with coverage for trackside workers and support other connectivity applications. The next challenge is to extend this model across more routes on the network.

Another area that has been explored within the rail environment is the potential for sharing spectrum with other users, including CAA in the 2.7–2.9 GHz band and aeronautical radar (see aeronautical section). Furthermore, Network Rail could utilise spectrum in the recently created shared bands such as 1800 MHz, 2300 MHz, 3.8-4.2 GHz and 26 GHz. However, these are more appropriate for local area solutions.

SUMMARY AND RECOMMENDATIONS

The use of 2G technology (GSM-R) designed specifically for railway operational communications by Network Rail, is likely to continue for the next 8 years (as the network was only introduced in 2013).

However, the need for wideband data from trackside to train connectivity and support of new modern requirements for automatic train control and monitoring will be the driver for a **steady increase in demand for spectrum**. Given the limited amount of spectrum for rail currently (2x4 MHz) within the 900 MHz range, there is a risk that there may not be enough bandwidth for the transition from GSM-R to FRMCS, without access to some additional capacity in congested areas (not including the additional 2x1.6 MHz of spectrum to be added to the existing allocation to support the transition). Network Rail has identified the possibility of sharing access to a 10 MHz portion in the 1900 MHz band with the Emergency Services Network (ESN) in areas of the rail network that could become congested during the transition period. We do not anticipate that the transition to FRMCS will commence before 2027/28 but imminent action is required to identify whether Network Rail could access the ESN spectrum on a shared basis.

4.13.4 ROADS

The communication systems that are used for road safety, road traffic management and general information to drivers and other road users, are called Vehicle to Everything or V2X. There are different subsets of V2X including:

- Vehicle-to-Vehicle (V2V)
- Vehicle-to-Infrastructure (V2I)
- Vehicle-to-Network (V2N)

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[313] Railways: Telecommunications systems, Nov 2015 https://questions-statements.parliament.uk/written-questions/detail/2015-11-24/17427 [Accessed March 2022].

[314] Cellnex website, March 2021, Cellnex UK awarded a 25-year Network Rail contract to provide continuous connectivity along the Brighton Mainline route, article on https://www.cellnextelecom.com/content/uploads/2021/03/20210316-PR-Cellnex-UK-awarded-25-year-Network-Rail-contract-to-provide-connectivity-along-the-Brighton-Mainline-route_EN.pdf [Accessed March 2022].

- Vehicle-to-Pedestrian (V2P)

Applications of V2X fall into two broad categories of Intelligent Transport Systems (ITS), they are either; safety ITS, or non-safety related ITS. The spectrum band that has been identified internationally and by Ofcom for use by ITS is the 5875–5925 MHz band. The DfT has been working with the industries, both telecoms and the automotive sector, on how the regulations and technology choices could impact how ITS systems can be deployed including for embedded modules in vehicles.

The 5875–5925 MHz band is a European harmonised band which means that an equipment ecosystem can be developed (in some cases there is already equipment available) to support these frequencies for both roadside transmitting equipment and vehicle-mounted equipment.

The spectrum is intended specifically to be deployed for road safety and traffic efficiency applications from a propagation as well as from a technology availability point of view. CEPT/ECC studies regarding the necessary spectrum requirements for road safety and traffic efficiency within the 5.9 GHz band based on accepted traffic scenarios with both Inter-Vehicle Communications (IVC) and Roadside-to-Vehicles (R2V) communications have confirmed that a realistic estimate of the needed bandwidth is between 30-50 MHz including 20 MHz of bandwidth for time-critical road safety applications.

However, in Europe, there was a vote by the Member States to reject the Delegated Act[315] which proposed the Cooperative Intelligent Transport Systems (C-ITS). By voting against this Act, they rejected the European Commission's proposal for the implementation of direct communication between vehicles using primarily ITS-G5 as the default method. According to the European Member States, the choice for this existing technology, which is based on Wi-Fi, has come too early and they want more time to consider alternatives based on the upcoming 5G network rollout.

The automotive industry is grappling with a choice of technology between a Wi-Fi-based technology ITS-G5 and mobile technology C-V2X, which can use 4G or 5G. A study[316] was carried out by the 5G Automotive Association (5GAA) on the spectrum needs of so-called day-1 and advanced use cases for intelligent transport systems (ITS) as implemented by vehicle-related mobile technologies. The study estimates the amount of bandwidth required for the introduction of use cases for direct communications (via the cellular V2X PC5 interface in the 5.9 GHz) and network-based communications (via spectrum already assigned to public mobile communication networks). The results of the 5GAA studies of the spectrum needs of C-V2X direct communications drew the following conclusions:

- It is expected that the delivery of day-1 use cases via LTE-V2X for the support of basic safety ITS services will require between 10 and 20 MHz of spectrum at 5.9 GHz for V2V/I communications; and
- The delivery of advanced use cases via LTE-V2X and NR-V2X for the support of advanced driving services will require an additional 40 MHz or more of spectrum at 5.9 GHz for V2V/I/P communications.

[315] EU Council rejects European Commission's Wi-Fi plans for connected and autonomous vehicles, Herbert Smith Freehills, Jul 2019 https://hsfnotes.com/cav/tag/delegated-act/

[316] Updated study of spectrum needs for safety-related intelligent transportation systems – day-1 and advanced use cases, 5GAA, October 2021 https://5gaa.org/news/study-of-spectrum-needs-for-safety-related-intelligent-transportation-systems-day-1-and-advanced-use-cases/

SUMMARY

In the UK, the introduction of ITS is the driver for a **steady increase in demand for spectrum** which is still in the early stages of development and rollout. The demand for spectrum is already being addressed by current regulations and identification of the band 5875–5905 MHz for V2X connectivity. The spectrum is authorised by way of licence exemption and is set out in Ofcom's Interface Requirement IR 2086[317] (although the actual provisions are set out in the appropriate SI[318]). Ofcom has yet to extend the provision to 5925 MHz and will announce a decision in due course.

It should be noted that there is military, various short-range devices, satellite earth stations and PMSE also using the 5850-5925 MHz band according to Ofcom's spectrum map[319] but this should not adversely affect the use of the band for ITS.

5 THE UK'S CURRENT SPECTRUM MANAGEMENT FRAMEWORK AND STAKEHOLDER VIEWS ON HOW IT COULD BE IMPROVED

In this section, we discuss the UK's current spectrum management framework and stakeholder views on how it could be improved. This analysis is informed by in-depth interviews with a range of stakeholders across a range of sectors and government departments. In these interviews, we sought views of spectrum users on the UK's spectrum management, current and future demand, and challenges to accessing required spectrum.

We examine different elements of the UK spectrum management framework, such as:

- the rationale for spectrum management and the relevant stakeholders responsible for the UK's spectrum management framework (discussed in **Section 5.1**);
- spectrum authorisation, including spectrum auctions, administrative pricing, spectrum sharing and spectrum reassignments (discussed in **Section 5.2**);
- Ofcom's role in international representation (discussed in **Section 5.3**); and
- our understanding of the delineation of roles between Ofcom and the UK Government in relation to spectrum management (in **Section 5.4**).

After setting out the key elements of the spectrum management framework, we summarise stakeholder comments and provide our assessment in relation to each of these elements.

5.1 RATIONALE FOR SPECTRUM MANAGEMENT AND RELEVANT STAKEHOLDERS

Access to and use of spectrum has the potential to deliver significant economic benefits to a range of private and public users, as shown in previous sections of this report (see, for instance, Section 3.2). However, delivering these benefits requires that spectrum use is carefully managed. Given the number of spectrum users (and use cases) in the UK, uncontrolled use of spectrum is highly likely to generate interference, impacting the ability of affected users to use their spectrum effectively. As a result, it is typical for the use of spectrum to be coordinated centrally by a spectrum management authority.

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[317] Ofcom IR 2086. See: https://www.ofcom.org.uk/__data/assets/pdf_file/0033/84948/IR_2086.pdf

[318] See: https://www.legislation.gov.uk/uksi/2011/2949/made/data.pdf

[319] Ofcom spectrum map web page. See: http://static.ofcom.org.uk/static/spectrum/map.html [Accessed March 2022].

In the UK, Ofcom is the authority responsible for the effective management of spectrum. This role requires Ofcom to ensure that spectrum resources support a range of electronic communication services across the UK and that the use of this spectrum is optimised.[320] Ofcom defines the 'optimal' use of spectrum as use that "maximises the benefits that people, businesses and other organisations derive from its use, including the wider value of spectrum use".[321] Ofcom is therefore responsible for authorising access to spectrum and establishing – and enforcing – the rules users of spectrum must follow (such as frequency or power limits). These rules aim to reduce the likelihood of harmful interference and help to ensure the efficient use of spectrum across the vast ecosystem of spectrum users.[322]

Ofcom is supported in its duties by the DCMS, the department of government responsible for telecommunications policy and the sponsor department for Ofcom. In this role, DCMS is responsible for setting the UK's overarching domestic and international policy framework for the use of radio spectrum with the key aim to maximise the economic and social value of spectrum for the UK into the future. Further discussion of the relevant responsibilities of Ofcom and DCMS is provided in **Section 5.4.**

5.2 AUTHORISING SPECTRUM USE

Ofcom confers rights to use spectrum in a number of ways depending on the type of application and type of user.[323] These include licensed products, block-assigned licences[324] and licence-exempt spectrum.

In the case of licensed spectrum rights, there are several approaches that Ofcom may use to determine the allocation of licences.[325] These include issuing licences on a first-come, first-served basis (if it is deemed that an additional user can co-exist with existing licenced users without causing interference) or issuing licences via auction. Ofcom will typically use an auction in cases where the demand for spectrum exceeds the available supply of spectrum.

Licences are defined by an initial term, during which time Ofcom's power to revoke the licence is limited.[326,327] For mobile spectrum licences, this initial term usually lasts between 15 to 20 years; although the licence period can be shorter in other instances.[328] In cases where an indefinite licence is issued, a licensee's rights

[320] Communications Act 2003, Section 3.

[321] Ofcom, 2020. Supporting the UK's Wireless Future: Our Spectrum Management Strategy for the 2020s (Consultation), para. 2.9.

[322] Ofcom is also responsible for representing the UK's interests in international forums on spectrum use, as discussed in more detail in **Section 5.2**.

[323] Ofcom, 2020. Supporting the UK's Wireless Future: Our Spectrum Management Strategy for the 2020s (Consultation), para. 3.6.

[324] Under this approach, Ofcom issues licences that enable the licensee to manage their own deployments within the relevant spectrum band.

[325] Ofcom, 2020. Supporting the UK's Wireless Future: Our Spectrum Management Strategy for the 2020s (Consultation), para. 3.8.

[326] Licences may be revoked during the initial period in exceptional circumstances due to a breach of licence terms by the holder, or with consent from the holder. See Ofcom, 2017. The award of 2.3 and 3.4GHz spectrum bands: Information Memorandum, para. 5.10.

[327] Licences with an initial term are typically used when allocating mobile spectrum. However, there are examples of Ofcom issuing licences with an initial term in non-mobile sectors. For instance, in 2006, Ofcom awarded a national, indefinite licence with a 15-year initial licence to Arqiva – a radio services provider – for use of spectrum in the 412 MHz band in 2006.

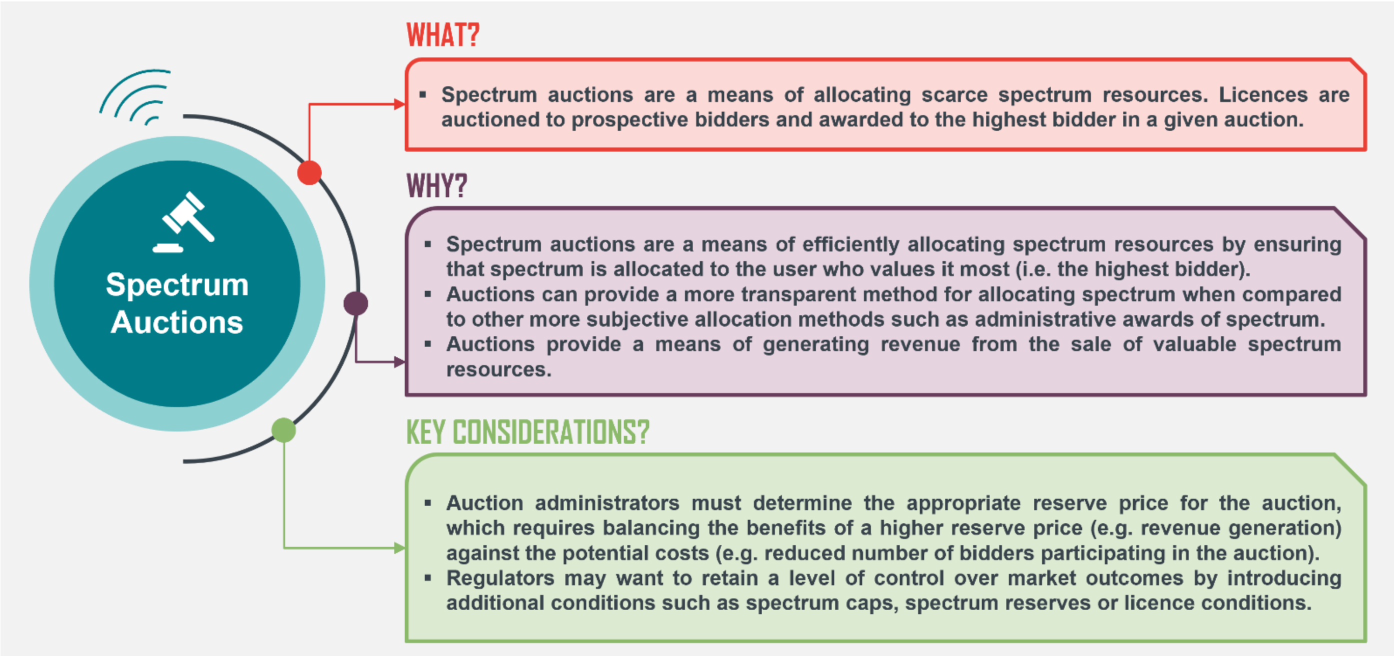
[328] For instance, the default licence period is three years for Local Access licences, though Ofcom does consider applications for periods shorter (or longer) than the default period.

to the licence continue indefinitely beyond the initial term. However, after the initial term, Ofcom is able to revoke the licence for spectrum management reasons, provided sufficient notice (usually 5 years) is given.[329]

Ofcom is also required, under Section 4 of the Communications Act 2003 (the 'Community Requirements'), "to act in a manner which, so far as practicable, is technology-neutral"[330] (i.e. without specifying the technology that should be deployed as a condition of the licence).

5.2.1 SPECTRUM AUCTIONS

AT A GLANCE



Where there is excess demand for spectrum, Ofcom aims, where possible, to use market-based mechanisms to allocate spectrum, with spectrum auctions being used to allocate spectrum to mobile operators and also to some other uses.[331] Ofcom does, however, retain an ability to influence market outcomes and achieve policy objectives through a range of tools at its disposal. These include spectrum caps, spectrum reservations and technical and non-technical licence conditions. We explore these in more detail below in the context of recent mobile spectrum auctions (2.3 GHz and 3.4-3.6 GHz in 2018; 700 MHz and 3.6-3.8 GHz in 2021).

- **Spectrum caps.** Ofcom may use spectrum caps to limit, in justified circumstances, the amount of spectrum that can be held by a single licensee, in particular in cases where Ofcom has concerns about asymmetries in the spectrum holdings of different licensees. These concerns primarily arise

[329] Ofcom, 2010. Strategic Review of Spectrum Pricing: The revised Framework for Spectrum Pricing, para 4.105.

[330] Ofcom, 2020. Supporting the UK's Wireless Future: Our Spectrum Management Strategy for the 2020s (Consultation), para. A5.5.

[331] E.g., the 412 MHz spectrum, which is currently used for smart metering, was allocated using an auction. For a summary of recent spectrum awards by auction, see the Ofcom website. Available at: https://www.ofcom.org.uk/spectrum/spectrum-management/spectrum-awards/awards-archive [Accessed 22nd March 2022].

in the context of mobile markets.[332] For example, Ofcom used spectrum caps in the 2.3 and 3.4 GHz spectrum auction, due to concerns about asymmetry in the spectrum holdings of different mobile operators.[333,334] Ofcom also implemented a spectrum cap in its more recent award of licences for spectrum in the 700 MHz and 3.6-3.8 GHz bands that limited the amount of spectrum that bidders could purchase across the two bands.[335,336]

- **Spectrum reservations.** Ofcom may seek to encourage competition by reserving spectrum for smaller operators and/or new entrants in order to maintain or increase competition in the relevant market. For example, Ofcom's 3G auction in 2000 reserved one licence for a new entrant, while in the 4G auction, some spectrum was reserved for the smallest player. However, recent spectrum auctions have not involved the use of spectrum reservations, as Ofcom considered that all four MNOs had sufficient spectrum to remain credible, even if they were not to win any spectrum in these awards.[337]

- **Licence conditions.** Ofcom may attach conditions to the spectrum licences it awards that must be complied with by the licence holders. These are typically comprised of technical conditions and non-technical conditions:

  - **Technical conditions.** Technical constraints are placed on new services (or users) in order to take account of existing users and to manage the risk of harmful interference.[338] This can include limits on the maximum power that can be transmitted or conditions on coordination between neighbouring users.

  - **Non-technical conditions.** Non-technical constraints are placed on new services (or users) such as obligations relating to coverage (for providers of mobile services).[339] Recent auctions for mobile spectrum have not included coverage obligations, with Ofcom considering MNOs' commitments to provide rural coverage under the Shared Rural Network programme as sufficient.[340] We note that Ofcom does not typically impose a "speed of rollout" obligation on spectrum licence holders. This is in contrast to the approaches taken to 5G spectrum awards in other jurisdictions (e.g. in South Korea, France and Germany), where MNOs are

[332] Asymmetries in the allocation of spectrum can potentially weaken competition in markets with a limited number of players (mobile markets typically have 3 to 4 players). Spectrum asymmetries appear to be less of an issue in other sectors. In broadcasting, for example, there are multiple users of spectrum, with each user having a dedicated narrow channel. In other sectors, such as Wi-Fi, spectrum is shared.

[333] Ofcom, 2017. Award of the 2.3 and 3.4 GHz spectrum bands: Competition issues and Auction Regulations, paras. 1.37-1.38.

[334] Ofcom implemented two spectrum caps in the auction of 2.3 and 3.4 GHz spectrum. The first cap limited operators' holdings of immediately useable spectrum at 255 MHz (where immediately useable spectrum was defined as: spectrum useable now, and in the period before 3.4 GHz frequencies were brought into use, for the provision of mobile services). The second cap limited operators' overall holdings of spectrum at 340 MHz (37% of total spectrum designated for mobile services).

[335] Ofcom, 2020. Award of the 700 MHz and 3.6-3.8 GHz spectrum bands, para. 1.6.

[336] This capped holdings of spectrum for mobile services held by any winner in the auction at 416 MHz (37% of total spectrum designated for mobile services).

[337] See, for example, Ofcom, 2020. Award of the 700 MHz and 3.6-3.8 GHz spectrum bands, para. 4.303.

[338] Ofcom, 2020. Supporting the UK's Wireless Future: Our Spectrum Management Strategy for the 2020s (Consultation), para. 6.33.

[339] Ofcom, 2017. Award of the 2.3 and 3.4 GHz spectrum bands: Competition issues and Auction Regulations, para. 3.1.

[340] Ofcom, 2020. Award of the 700 MHz and 3.6-3.8 GHz spectrum bands, para. 1.5.

required to deploy a certain number of 5G sites over a specified period as a condition of award.[341]

STAKEHOLDER COMMENTS

- There is a difference of opinion between stakeholders as to whether the current spectrum management framework works well or not. Some argue that the market-based approach to allocating spectrum has generally worked well. They further argue that "*the current spectrum management framework is suitable to meet the spectrum needs of current and future wireless networks*", promotes innovation and is supportive of new competitive business models. One stakeholder added that this is particularly the case "*post the introduction of local/shared access bands*".

- Other stakeholders are more critical and argue that the current regulatory framework requires change. A common theme is a need for a new approach to address the issue of spectrum availability. In particular, stakeholders argue for a more dynamic spectrum sharing system and cite the CBRS system in the US as a means of promoting extensive sharing of reusable spectrum. We discuss this topic in more detail in subsequent sections.

- Mobile stakeholders also raised concerns as to how well Ofcom's wider regulatory framework promotes investment, citing the need for regulators to put "*appropriate weight on investment objective[s] and longer-term benefits*". In particular, MNOs commented on rules that apply to consolidation, network sharing and net neutrality, arguing that "*benefits that come with scale, consolidation, collaboration should be weighed against potential harm to competition*".

We discuss stakeholder comments on spectrum sharing in more detail in **Section 6.3**.

With regards to mobile stakeholder comments on the wider regulatory framework not being conducive to investment, we consider these issues to be important. Indeed, Ofcom's latest analysis of the mobile market shows that returns on capital employed for two out of four operators are below their cost of capital.[342] Ofcom is currently consulting with the industry on issues of mobile consolidation and is separately carrying out a review of how the net neutrality framework is functioning.[343] While we recognise the importance of these issues, we note that they are outside the scope of this report as they are not directly related to spectrum.

5.2.2 SPECTRUM PRICING

If spectrum is not allocated using an auction or if the initial licence period has expired, Ofcom would typically impose an annual spectrum fee. Ofcom's approach to setting these fees depends on whether (i) demand for spectrum exceeds the available supply of spectrum or (ii) there is no excess demand for spectrum.[344] In the former case, spectrum fees are set to reflect the opportunity cost of spectrum, i.e. the value that an alternative use of spectrum would deliver, but which is forgone due to its current use. These fees are known as Administered Incentive Pricing (AIP) and, in the context of spectrum for mobile, Annual Licence Fees

[341] A more detailed international comparison is provided in **Section 6**.

[342] Ofcom, 2022. Ofcom's future approach to mobile markets, para. 6.14.

[343] Ofcom, 2021. Call for evidence: Net neutrality review.

[344] Ofcom, 2020. Supporting the UK's Wireless Future: Our Spectrum Management Strategy for the 2020s (Consultation), para. 7.21.

(ALFs).[345] In the latter case, spectrum fees reflect Ofcom's costs associated with managing spectrum (cost-recovery fees).

If spectrum is allocated via auction, licence holders pay an upfront fee, which reflects the auction price for that spectrum. However, when the initial licence expires, Ofcom will apply an AIP fee (subject to excess demand for that spectrum). It is expected that if the current spectrum user continues to have the highest valuation, that user would be willing to pay the AIP (which is set at the opportunity cost, i.e., below the current user's valuation). However, if the current user is no longer the highest value user, that user would sell the spectrum to those who value it the most, as a result of which, the spectrum would be used more efficiently.

STAKEHOLDER COMMENTS

- Mobile operators argue that ALFs are a tax on the industry that harms investment and present a barrier to spectrum trading. They consider that "*a fundamental review of the impact of spectrum costs on investment is needed, including changes to the obligation to deliver full market value and amending outdated statutory instruments*". They argue that Ofcom should either; reduce ALFs, for instance, through a more conservative approach to price setting that focuses on the forward-looking value of spectrum, or ensure that ALF proceeds are ringfenced for reinvestment in the sector, in particular in new 5G infrastructure.
- Furthermore, another stakeholder argued that "*spectrum pricing as a policy instrument is too blunt, and has served rural regions very poorly*" as it does not create incentives for improving rural coverage. That is the stakeholder considers that the current framework does not deliver good outcomes for consumers in rural areas.

These are indeed important concerns. According to Ofcom, industry profits in the mobile sector are falling, with two out of four operators currently being unable to cover their cost of capital (however, Ofcom notes that falling returns are a common trend across Europe, suggesting that declining profitability in mobile markets is not a UK-specific issue).[346] In the UK context, MNOs have argued that their costs have been affected by factors including High-Risk-Vendor equipment replacements, the methodology used for setting ALFs, and stringent consumer regulation.[347]

We consider that these additional costs and reduced profitability need to be taken into account when setting forward-looking ALFs. Indeed, MNOs' spectrum valuation critically depends on operators' profitability on a forward-looking basis – the lower the profits, the lower the operators' willingness to pay for spectrum. We recognise that auction prices are affected by a number of factors specific to a particular award (such as market developments and timing of awards). However, other things being equal, we expect that a reduction in MNOs' profitability is likely to be reflected in lower spectrum valuation and lower auction prices. This effect appears to have been realised in recent spectrum auctions, with the prices paid by operators recently being lower compared to auction prices paid historically. For example, the price of 800 MHz spectrum paid

[345] Ofcom, 2020. Supporting the UK's Wireless Future: Our Spectrum Management Strategy for the 2020s (Consultation), para. 7.22-23.

[346] Ofcom, 2022. Ofcom's future approach to mobile markets, para. 6.14.

[347] See, for example, Ofcom, 2022. Ofcom's future approach to mobile markets, para. 7.3.

in 2013 was £37 million per MHz (April 2021 prices, adjusted for inflation), while the price paid for 700 MHz spectrum in 2021 was £14 million per MHz.[348]

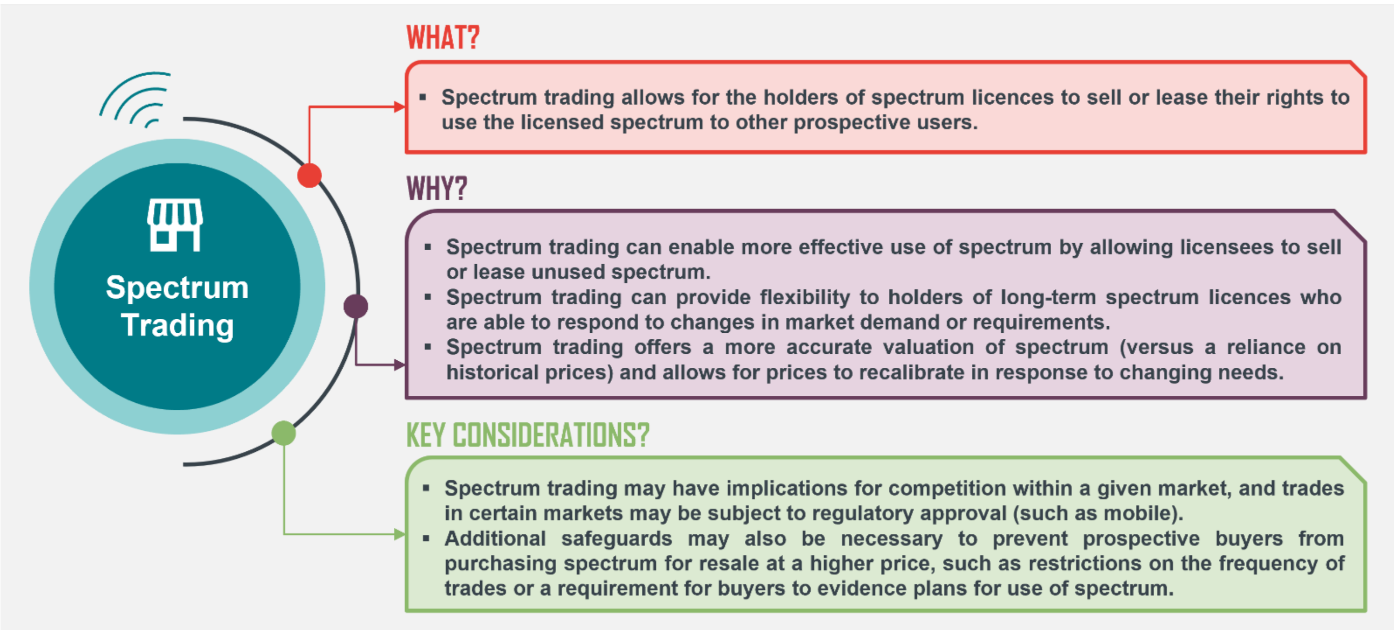
When setting ALFs, Ofcom's methodology includes the use of historical auction prices as relevant benchmarks, including auction prices paid 8-10 years ago, as well as historical auction evidence from other European countries.[349] We are of the view that this may not be appropriate given that the market conditions have changed, i.e. evidence from earlier auctions is unlikely to be informative of current trends. We consider that Ofcom should investigate, in the calculation of ALFs, how current and evolving market conditions can be taken into account.

The effectiveness of ALFs as an instrument to support efficient allocation of spectrum would also be expected to be reduced if spectrum trading is allowed. Indeed, if the current spectrum user is no longer the most efficient, the user would have incentives to sell the spectrum and benefit from the trade, irrespective of whether this spectrum block is subject to the ALF or not. As discussed below, such trades have occurred in the UK.

In relation to spectrum pricing and rural coverage, we observe that in some markets (e.g. France), emphasis is placed on expanding the scope of obligations placed on licensees (such as rural coverage obligations on holders of mobile spectrum) and linking these obligations explicitly to reduced spectrum fees. We discuss this example in more detail in **Section 6.2**.

5.2.3 SPECTRUM TRADING

AT A GLANCE



[348] Ofcom, 2021. Annual licence fees for 2100 MHz spectrum, Table 4.1.

[349] See, for example, Ofcom's decision on setting ALF for 2.1GHz spectrum. In its benchmarking, Ofcom continues to rely on auction prices from 2013.

Ofcom relies on the use of market mechanisms where possible, with spectrum trading one of the market mechanisms that Ofcom has implemented.[350] Most licences that Ofcom issues are tradeable, allowing licensees to sell or lease their spectrum rights and obligations.[351] Recent examples of the traded spectrum include a sale of 25 MHz of 2.6 GHz spectrum by EE to O2[352] (2020) and a sale of 1.4 GHz spectrum by Qualcomm to Three and Vodafone (2015).[353]

There are several differences between a sale of spectrum rights and a lease of spectrum rights. These include differences in who holds the rights to the spectrum licence and the level of involvement required by Ofcom in the trading process. In both cases, however, the terms of the agreement (including the transfer or lease price) are determined through negotiations between the relevant parties.

Most spectrum licences are tradeable and for Wireless Telegraphy (WT) licences, Ofcom does not need to give consent to a trade, with transfers automatically approved subject to certain prespecified conditions being met.[354] This is similar to the approach taken in countries such as the US, where spectrum transfer applications are also approved automatically provided certain criteria are met; in cases where criteria for immediate approval are not met, a regulatory review is triggered.[355] We note that in the UK, however, licences covered by the Mobile Spectrum Trading Regulations do require Ofcom's consent for a trade to occur.[356]

Overall, spectrum trading is critical for ensuring that the spectrum is allocated and used optimally. Ofcom itself previously cited the benefits of spectrum trading as a factor in its decision to simplify the spectrum trading framework back in 2011, noting that its proposals were aimed at "*benefitting society by enabling a wider range of market transactions and institutions, including commercial band managers, to secure more productive use of spectrum*".[357] Ofcom has also emphasised the particular benefits of spectrum leasing (introduced through trading), which it has noted provides additional flexibility (versus trading) that "*can be expected to benefit citizens and consumers by reducing transaction costs and execution times and so making spectrum available faster for new services*".[358]

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[350] See The Wireless Telegraphy (Spectrum Trading) Regulations 2012.

[351] Ofcom, 2020. Supporting the UK's Wireless Future: Our Spectrum Management Strategy for the 2020s (Consultation), para. 7.13.

[352] CommsUpdate, 2020. EE seeks Ofcom permission to trade a portion of the 2.6 GHz spectrum to O2. Available at: https://www.commsupdate.com/articles/2020/10/19/ee-seeks-ofcom-permission-to-trade-portion-of-2-6ghz-spectrum-to-o2/ [Accessed 4th April 2022].

[353] Fierce Wireless, 2015. Available at: https://www.fiercewireless.com/europe/qualcomm-agrees-eu139m-l-band-spectrum-deal-vodafone-uk-and-three-uk [Accessed 4th April 2022].

[354] See the Wireless Telegraphy (Spectrum Trading) Regulations 2012.

[355] FCC, 2003. Secondary Markets Order, para. 150.

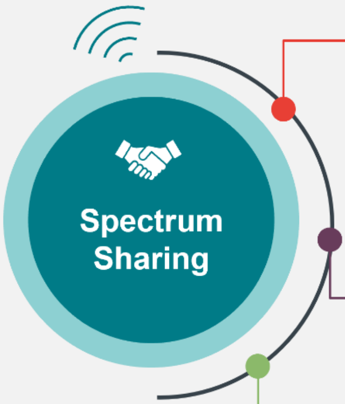
[356] See the Wireless Telegraphy (Mobile Spectrum Trading) Regulations 2011.

[357] Ofcom, 2011. Simplifying Spectrum Trading: Spectrum leasing and other market enhancements, para. 3.3.

[358] Ofcom, 2011. Simplifying Spectrum Trading: Spectrum leasing and other market enhancements, para. 6.5.

5.2.4 SPECTRUM SHARING

AT A GLANCE



WHAT?

- Spectrum sharing is the use of radio spectrum resources or a set of frequencies by several users at the same time and/or in the same place (e.g. by multiple MNOs, service providers).

WHY?

- Spectrum sharing can help to address the growing demand for spectrum resources by allowing a wider group of users to access underused or otherwise available spectrum.
- By doing so, spectrum sharing can also promote more efficient spectrum use by ensuring that resources are used according to needs (versus a fixed allocation).
- Spectrum sharing can promote innovation and support new competitive business models by providing access to spectrum resources to wider groups of market participants.

KEY CONSIDERATIONS?

- Spectrum sharing can occur either on a licensed or unlicensed basis.
- Under licensed access, spectrum sharing is authorised by licence holders under conditions set out in the licence to avoid harmful interference between competing users.
- Under an unlicensed or licence-exempt sharing framework, shared access is permitted without a licence but users are often required to adhere to strict technical restrictions (such as power limits) to again protect against interference.

Ofcom's most recent spectrum management strategy proposed to promote spectrum sharing as a means of enabling new services to be introduced whilst protecting existing services already available.[359] Ofcom coordinates spectrum use via spectrum management tools, which involves a spectrum management database. Ofcom plans to continue the development and use of automated spectrum management tools, where appropriate.[360]

In 2019, Ofcom introduced a licensing approach that aims to provide localised access to spectrum for businesses across a range of sectors and facilitates spectrum sharing.[361] This includes:

- **Permitting access to unused spectrum held by mobile operators through Local Access licences (LALs).** Enables access to spectrum that has been licensed to mobile operators on a national basis, but which is not currently being used by operators in every location. Ofcom considers that the spectrum could be used to support the deployment of private networks or rural wireless broadband connectivity.[362] Ofcom will agree to grant a licence if, after discussing with the incumbent licensee, it is agreed that a new user is unlikely to interfere with the incumbent's network or constrain plans for use of the spectrum.[363] Licences are issued on a time-limited basis (the default period is three years, but other durations are available).

[359] Ofcom, 2020. Supporting the UK's Wireless Future: Our Spectrum Management Strategy for the 2020s (Consultation), para. 1.12.

[360] Ofcom, 2020. Supporting the UK's Wireless Future: Our Spectrum Management Strategy for the 2020s (Consultation), para. 1.13.

[361] Ofcom, 2019. Enabling wireless innovation through local licensing: Shared access to spectrum supporting mobile technology.

[362] Licences are awarded subject to the availability of excess spectrum and confirmation that new users would not interfere with mobile operators' existing or planned use of the spectrum band.

[363] Ofcom, 2019. Local Access Licence Guidance document, para. 1.8.

- **Issuing Shared Access licences (SALs) in the 3.8-4.2 GHz, 1.8 GHz and 2.3 GHz spectrum bands.** Access to relevant bands is granted on a first-come, first-served basis, with Ofcom coordinating the issuance of SALs to avoid interference.[364]

- **Permitting sharing of spectrum in the 26 GHz band for indoor deployment.** SALs for indoor use have also been made available in portions of the 26 GHz spectrum band on a per-location, first-come-first-served basis. This is expected to support the deployment of new indoor 5G applications such as industrial use cases (e.g. smart industry), with SAL holders permitted to deploy their own indoor base station equipment under the terms of the licence.

STAKEHOLDER COMMENTS

- A number of stakeholders argue that the allocation of the 3.8-4.2 GHz band to private 5G networks is playing a key role in supporting new competitive models and that more spectrum should be made available on a shared basis.

- Others have also noted that LALs are an important step forward in facilitating better use of spectrum, but note that primary licence holders (e.g. MNOs) have not been accommodating and/or willing to share their spectrum in areas where the spectrum has not been used. They believe that more needs to be done "*to ensure that MNOs play fair with requests for spectrum sharing or sub-licensing*". While it is not possible to assess the level of unsatisfied demand, we understand that this issue has been raised by multiple stakeholders.

- Recommendations have been made to introduce a 'use it or lease it' model, whereby a spectrum owner would be required to make unused spectrum available to a third party. Alternatively, it was suggested that operators refusing access should have a limited time frame to execute their own deployment.

- Others have pointed to the fact that the current licensing approach for SALs and LALs is "*manually intensive, slow, expensive and not in [a] predictable time frame*", with one stakeholder commenting on what it saw as little progress in improving the speed of the application process.

- Some stakeholders argue in favour of spectrum sharing using automated tools and platforms, similar to those used in the United States for Citizens Broadband Radio Service (CBRS), where spectrum is allocated dynamically and is made available in real-time. They believe that this will ensure that spectrum is managed and used as efficiently as possible.

- Further, stakeholders argue that more mechanisms should be put in place to encourage the deployment of neutral host network schemes, both indoors and outdoors.

All of these comments require serious consideration. We understand that DSIT is reviewing the feedback from the 5G Testbeds and Trials Programme, which will provide recommendations on how to improve the current spectrum sharing system (complementing recommendations put forward in the Spectrum Policy Forum's recent spectrum sharing report). Furthermore, given that several stakeholders recommend

[364] Ofcom, 2019. Shared Access Licence Guidance document, para. 5.1.

implementing a dynamic spectrum sharing tool similar to the CBRS in the US, we review the CBRS in detail in **Section 6.3** below.

5.2.5 SPECTRUM REASSIGNMENT

Spectrum reassignment is another aspect of Ofcom's overall spectrum management strategy which helps to ensure that sufficient spectrum is available to support and enable new technologies and use cases. The decision to reassign spectrum from one sector (or use case) to another is driven by the aim of ensuring that scarce spectrum resources are allocated to users who value them most highly. An efficient reallocation of spectrum, therefore, has the potential to lead to welfare improvements, in particular, if it allows for the provision of new (or additional) services that consumers value, without a loss in access to existing services.[365]

To illustrate this, consider Ofcom's recent clearance of spectrum in the 700MHz band for use in mobile.[366] Spectrum in the 700MHz band is particularly well suited for meeting the growing demand for mobile data: it is low frequency, with technical characteristics that make it suitable for providing coverage over wide areas.[367] Moreover, Ofcom considered that the incumbent users of the 700MHz band would have access to sufficient (and suitable) spectrum in other bands, as a result of which the clearance plan would not result in a loss to consumers of existing benefits. Prior to reallocation, the 700MHz band was used to deliver Digital Terrestrial Television (DTT) services; Ofcom considered it would be possible to continue to deliver these services through access to spectrum in the 470-694 MHz range.[368]

The decision to reassign spectrum in the band was supported by a cost-benefit analysis conducted by Ofcom that assessed the case for making the 700 MHz band available for mobile which suggested that clearance would lead to a welfare improvement.

This analysis estimated significant **benefits of between £900 million and £1.3 billion (NPV, 2014)** as a result of improved mobile network performance and network cost savings.[369] For instance:

- release of the 700 MHz band was expected to enable MNOs to improve mobile data speeds indoors and in rural areas;
- MNOs were expected to benefit from a reduction in costs of meeting increased demand for mobile data capacity through having to build and operate fewer network sites; and
- cost savings were expected to be passed on to consumers in the form of lower prices and better quality mobile data services.

These benefits were compared to the costs of the reallocation, incorporating both costs of making the change, and the opportunity cost of existing users losing access to the band. The plan was estimated to incur **costs of between £550 and £660 million (NPV, 2014)**.[370] This included:

[365] In economic theory, this is a concept known as Pareto efficiency. It describes a situation in which no set of individuals can be made better off (as a result of a reallocation of resources) without making at least one individual worse off as a result of the change.

[366] Ofcom, 2014. The decision to make the 700 MHz band available for mobile data: Statement.

[367] Ofcom, 2016. Maximising the benefits of 700 MHz clearance, para. 1.14.

[368] Ofcom, 2016. Maximising the benefits of 700 MHz clearance, para. 1.15.3.

[369] Ofcom, 2014. The decision to make the 700 MHz band available for mobile data: Statement, Table 6.

[370] Ofcom, 2014. The decision to make the 700 MHz band available for mobile data: Statement, Table 6.

- the cost of modifications to DTT transmission infrastructure (including programme management costs and local TV replanning); and
- the opportunity cost of the change of use of the 700 MHz band, equivalent to the value that DTT and PMSE use cases could have delivered in a no-clearance scenario, over and above the services they are able to provide without access to the band.

Results of Ofcom's cost-benefit analysis supported the decision to reassign the 700 MHz band to mobile. However, implementing the clearance programme was nevertheless complex and time-consuming.[371] As a result, the clearance programme took over four years to complete, having started in 2016 and finishing in mid-2020.

In other instances, spectrum has been reassigned as part of the Government's Public Sector Spectrum Release (PSSR) programme. The PSSR was announced in the 2010 Spending Review and targeted releasing 500 MHz of public sector spectrum below 5 GHz by 2020.[372] At the time of launch, around half of the most useful spectrum in the UK was held by the public sector for use across services such as defence, emergency and transport. However, the program aimed to address the growing demand for spectrum from private and commercial users and sought to determine bands that would help meet this demand, provide value to new users, and could be feasibly released from existing use cases. In discussing the program at the time of launch, DCMS noted that any decision on the release of spectrum was to be supported by a cost-benefit analysis.[373]

Under the PSSR, 190 MHz of spectrum was released by MOD, comprising 40 MHz in the 2.3 GHz band and 150 MHz in the 3.4 GHz band. Ofcom subsequently allocated this spectrum via auction to the UK's four mobile network operators in 2018, again on the basis that mobile operators required access to additional spectrum to increase network capacity in response to the growing demand for mobile data services.[374]

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[371] Clearing the band for mobile use required Ofcom to plan the new frequencies to be used by TV transmitters after moving to a different band; a difficult process, given the need to ensure that a range of users could coexist in the new band without causing interference. This subsequently meant that viewers of Freeview TV would have to retune television sets to continue receiving service, with Ofcom choosing to stagger the work to reduce disruption to consumers. For more details see Ofcom, 2020. The biggest Ofcom project you've probably never heard of. Available at: https://www.ofcom.org.uk/about-ofcom/latest/features-and-news/completion-of-the-700-mhz-clearance-programme [Accessed 23rd March 2022].

[372] For more information, see Ofcom, 2016. Review of Public Sector Spectrum Release (PSSR).

[373] DCMS, 2011. Enabling UK growth – Releasing public spectrum, para 1.9.

[374] Ofcom, 2017. Award of the 2.3 GHz and 3.4 GHz spectrum bands, para. 1.7.

STAKEHOLDER COMMENTS

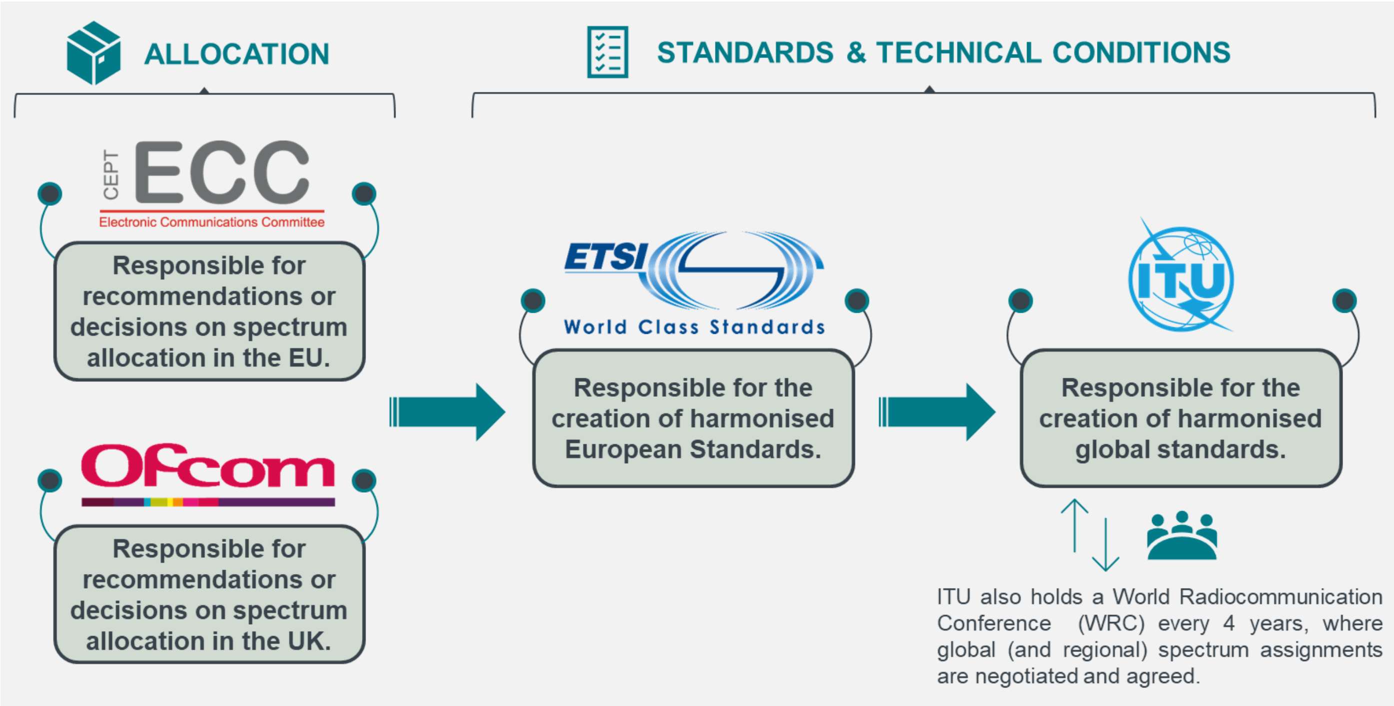
- In our interviews, the current users of spectrum voiced concerns over the perceived prioritisation of the mobile sector over other use cases. In particular, stakeholders that have already released spectrum argue that they have increased their spectrum efficiency and may not be in a position to be able to clear more spectrum without a detrimental impact on the services they provide.
- Some public users also emphasised that they now pay AIPs, which are set by Ofcom in line with the market value of spectrum. They argue that this implies that they are efficient users of the spectrum. Some stakeholders (e.g. MOD) consider that while they are not in a position to release more spectrum without a loss in their capabilities, they are prepared to share spectrum with other users, based on a CBRS-type sharing model used in the US.
- Stakeholders from the satellite sector have also emphasised that they are in favour of spectrum sharing, as long as "*sharing does not mean exclusive access to one technology over the other*", meaning that new use cases should not create interference that would affect the incumbent use case. This particularly applies to the 3.8-4.2 GHz band. Satellite stakeholders argue that this band should continue to be used on a localised/lower power basis (or indoor), as this would allow satellites to co-exist in the same band. If this band is reassigned to mobile high-power users, satellite users will no longer be able to co-exist in this band due to interference.

As discussed above, spectrum reassignment decisions in the UK take place based on a detailed, evidence-based analysis of the incremental costs and benefits. We consider this approach to be broadly appropriate; although complex and resource-intensive, it aims to ensure that all benefits and costs to all parties are taken into account, including wider social benefits. While it may be difficult to quantify wider social benefits precisely, the key issue is to understand how these would change if a given band was reassigned from one use case to another. If the change is expected to be significant, a detailed quantification may be needed.

We further note that the quality of this analysis critically depends on the quality of information and evidence provided by the stakeholders to Ofcom. Therefore, we recommend that stakeholders continue engaging with Ofcom, DCMS and DSIT to support their decision-making in relation to spectrum reassignment.

5.3 INTERNATIONAL REPRESENTATION AND HARMONISATION

AT A GLANCE



Ofcom is responsible for representing the UK in international spectrum fora, acting under the direction of the DCMS Secretary of State.[375] This includes working with other institutions to develop international recommendations and spectrum standards, as well as rules for managing interference between countries. These include:

- the International Telecommunication Union (ITU), a body responsible for allocating global radio spectrum and developing technical standards and regulations;
- the Electronic Communications Committee (ECC), a committee of the European Conference of Postal and Telecommunications Administrations (CEPT) responsible for harmonised and efficient use of spectrum across Europe;[376] and
- the European Telecommunications Standards Institute (ETSI), which supports European regulations and legislation through the creation of harmonised European Standards.

Prior to the UK's departure from the EU, Ofcom was also a member of the EU's Radio Spectrum Policy Group (RSPG). The RSPG is responsible for developing an EU-wide spectrum policy, as well as for considering the various needs of spectrum users. Following the UK's exit from the EU, the UK no longer has a formal role in the RSPG, but Ofcom does continue to cooperate with the RSPG on relevant initiatives.[377] Furthermore, Ofcom

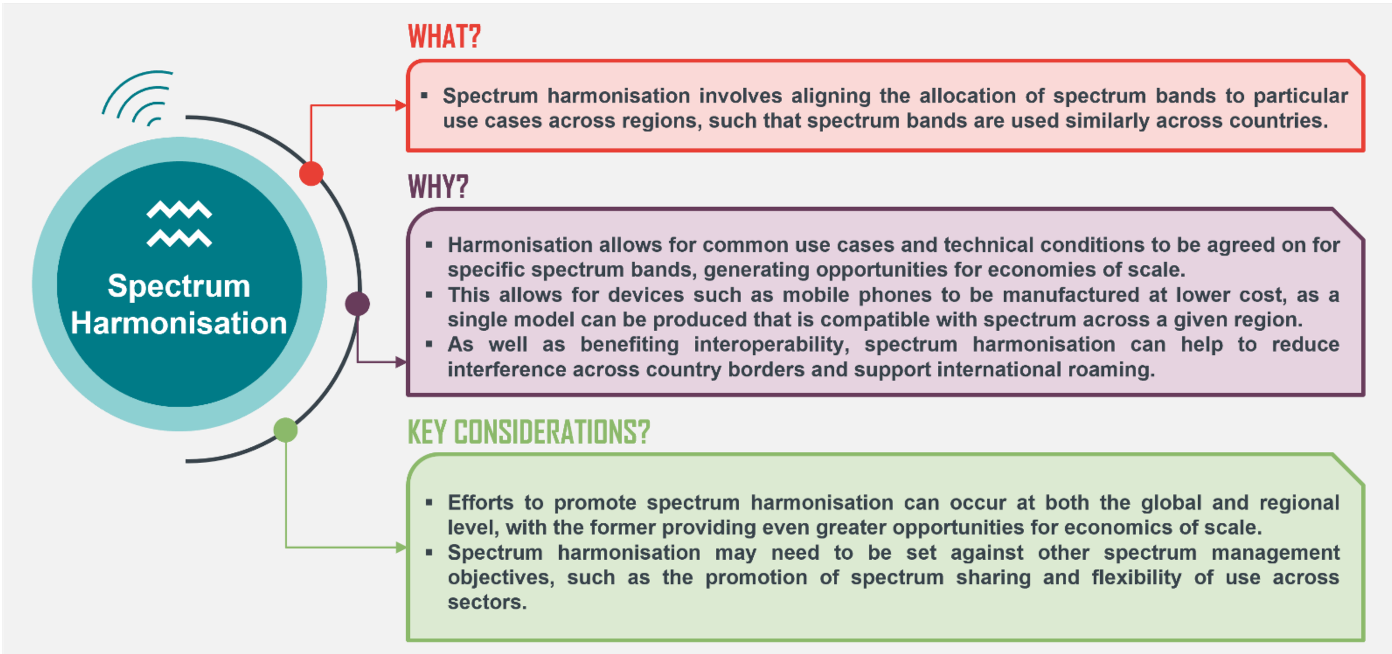
[375] Communications Act 2003, Chapter 21, Part 1, Section 9.

[376] CEPT is comprised of 48 member states and includes all EU member states.

[377] Ofcom, 2020. Supporting the UK's Wireless Future: Our Spectrum Management Strategy for the 2020s (Consultation), para. 3.20.

collaborates with the Government and representatives of the UK industry to best ensure that its contribution to international spectrum fora assists in the development of positions that benefit UK stakeholders.[378]

AT A GLANCE



Coordinated decision-making by international institutions is crucial for harmonising spectrum use across countries. Harmonisation allows for common use cases and technical conditions to be agreed on for specific spectrum bands, generating opportunities for economies of scale (and subsequent cost reductions) in the deployment of wireless equipment and infrastructure. Coordination also enables the wider provision of cross-border services (such as satellite communication) and reduces the potential for interference from high-power transmissions that spill across borders (such as television transmissions in regions of the UK in close proximity to France).

[378] Ofcom, 2020. Supporting the UK's Wireless Future: Our Spectrum Management Strategy for the 2020s (Consultation), para. 3.22.

STAKEHOLDER COMMENTS

- A number of stakeholders commented on the importance of engaging with international harmonisation bodies – ITU, CEPT and ETSI. They state that international harmonisation of spectrum has had huge benefits both for the UK and globally, and urge the UK Government and Ofcom to continue to participate in this work (particularly post-Brexit). They state:
  - "*All Ofcom strategic and forward-looking work should be done in a manner consistent with ITU/international standards*".
  - "*CEPT and ETSI harmonisation work on spectrum usage are essential – the UK must continue to participate in these and monitor EU decision making post Brexit*".
  - "*Ofcom must act in a manner consistent with ITU standards*".
- They particularly encourage Ofcom to achieve a clear position and to lead on coordinating a common approach across Europe in relation to 600 MHz, 3.8-4.2 GHz spectrum and other bands with competing spectrum demands. More specifically, broadcasters highlighted the importance of the UK's position on 600 MHz spectrum in the World Radio Conference 2023 (WRC23) debate. They consider that there is a risk that broadcasters may lose 600 MHz spectrum if a decision is made to move to a co-primary allocation "*because Ofcom/DCMS have not given it enough thought*". They urge DCMS to adopt a stronger position on this band. In their view, WRC-23 is too early to discuss the 600 MHz band, and the decision should be postponed until 2027 or 2031.

Ofcom is a highly-respected regulator, and therefore, the UK's position is likely to influence other countries and stakeholders. In light of that, it makes sense to consult with the industry and come up with a clear position on some of these bands prior to the WRC23 engagement. This would allow Ofcom to take a more active stance and to lead in the WRC debate, especially in relation to critical bands, such as 600 MHz.

5.4 DELINEATION OF ROLES BETWEEN OFCOM AND DCMS

As discussed in Section 5.1, DCMS is the lead government department responsible for telecommunications policy (including wireless communications) and is the sponsor for Ofcom, with this responsibility extending to include control over the UK's overarching domestic and international policy framework for the use of radio spectrum. The DCMS also aims to promote collaboration across Government, Ofcom and industry to enable the effectiveness of its policies.

Ofcom operates under a number of Acts of Parliament and other legislation as set out in the Framework Document signed by DCMS and Ofcom.[379] These include the Communications Act 2003; Wireless Telegraphy Act 2006; Broadcasting Acts 1990 and 1996; Digital Economy Act 2010; Postal Services Act 2011; Competition Act 1998; and Enterprise Act 2002.[380]

Under the Communications Act 2003, Ofcom's principal duty is to "*further the interest of citizens in relation to communications matters and to further the interests of consumers in relevant markets, where appropriate*

[379] Department for Culture, Media and Sport and The Office of Communications (Ofcom) Framework Document, para. 2.3.

[380] Department for Culture, Media and Sport and The Office of Communications (Ofcom) Framework Document, para. 2.3.

by promoting competition".[381] As part of this, Ofcom has to ensure that a wide range of electronic communications services is available across the UK. Ofcom's objectives with regard to spectrum management are set out in the 2006 Wireless Telegraphy Act (the "WT Act"). According to this, Ofcom is obliged to ensure that spectrum is used optimally, i.e., "*in a way that maximises the value that citizens and consumers derive from it, including the wider social value of spectrum use*".[382]

Furthermore, under the Communications Act 2003, the role of the DCMS is to direct Ofcom "*in relation to its functions in respect of communications networks and services and the management of radio spectrum*".[383] DCMS is further responsible for the development of the UK's Wireless Infrastructure Strategy, which will set out a strategic framework for the development, deployment and adoption of wireless networks in the UK out to 2030.[384]

STAKEHOLDER COMMENTS

- Some stakeholders commented on the delineation of roles between government and Ofcom in relation to spectrum matters. In their view, the government should lead and drive policy, particularly in relation to the international spectrum harmonisation, while Ofcom has an important role to advise and review. They consider that "there is too much of a disconnect" between DCMS and Ofcom.

- Stakeholders also commented that Ofcom's duties are primarily in relation to consumers of fixed/mobile services, while enterprises, especially those that support critical infrastructure, get overlooked. They would like to see a more joined-up approach between DCMS, Ofcom, Ofgem, and BEIS in relation to the issues of resilient networks and the availability of spectrum to serve critical infrastructure in the UK.

We understand that DCMS and Ofcom are working to ensure a more joined-up approach to spectrum management. In particular, in its latest Spectrum Roadmap, Ofcom refers to working closely with DCMS, Ofgem and BEIS to identify new spectrum to support the utility networks.[385]

In summary, this section has discussed the concerns raised by stakeholders in relation to the UK's current spectrum management framework. In the section that follows, we consider potential alternative approaches to addressing these concerns and provide our recommendations.

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[381] Department for Culture, Media and Sport And The Office of Communications (Ofcom) Framework Document, para. 2.5.

[382] Ofcom, 2010. Strategic Review of Spectrum Pricing: The revised Framework for Spectrum Pricing, para 1.4.

[383] Ofcom, 2010. Strategic Review of Spectrum Pricing: The revised Framework for Spectrum Pricing, para 1.4.

[384] See Wireless Infrastructure Strategy: Call for Evidence. Available at: https://www.gov.uk/government/consultations/wireless-infrastructure-strategy-call-for-evidence/wireless-infrastructure-strategy-call-for-evidence [Accessed 10th March 2022].

[385] Ofcom, 2022. Spectrum Roadmap: Delivering Ofcom's Spectrum Management Strategy, pg. 23.

6 A REVIEW OF POTENTIAL ALTERNATIVE APPROACHES TO SPECTRUM MANAGEMENT BASED ON THE EXPERIENCE OF SELECT ADVANCED ECONOMIES

As discussed in **Section 5** above, spectrum users in the UK consider that Ofcom's spectrum management framework is broadly suitable to meet the spectrum needs of current and future wireless networks. However, they have identified a number of issues which may require potential changes to improve outcomes and encourage more efficient spectrum use. These issues relate to spectrum sharing, spectrum reassignment, spectrum pricing and Ofcom's role in the international harmonisation process.

In order to understand whether there are alternative approaches to spectrum management, we have reviewed the approaches used to manage spectrum in other advanced economies – the US, Germany, France, and South Korea. Our choice of comparator countries is motivated by relative similarities in key sectors that rely on spectrum and the maturity of spectrum management in these countries.

In line with stakeholder feedback, we have focused this review on the following key areas of spectrum management:

- allocation mechanisms for valuable spectrum (**Section 6.1**);
- spectrum pricing and annual licence fees (**Section 6.2**);
- spectrum sharing (**Section 6.3**);
- spectrum reassignment **(Section 6.4**); and
- international harmonisation and spectrum release (**Section 6.5**).

Our overall conclusions and recommendations are provided in **Section 6.6**.

6.1 ALLOCATION MECHANISMS FOR VALUABLE SPECTRUM

The mechanisms used across comparator countries to allocate spectrum resources are similar to those currently used by Ofcom: on a first-come, first-served basis (if there is no spectrum shortage); on a licensed and unlicensed basis; and via auctions, if there is excess demand.

The design of these mechanisms also appears comparable across countries. As in the UK, regulators in the US, Germany, France, and South Korea use spectrum caps and other tools (such as bidding credits) in order to achieve certain policy objectives. Modifications are intended to maintain a level playing field between small and large operators and to help ensure that the resulting spectrum allocation supports a competitive market structure. For example:

- In the US, **bidding credits** are issued to small businesses or rural service providers and afford recipients a discount on their final winning bid in an auction.[386]
- The US also implements **spectrum caps** that limit the amount of spectrum that can be acquired by a single bidder through a competitive bidding process, as well as (in some cases) thresholds on secondary market transactions for spectrum.[387]

[386] FCC, 2017. Fact Sheet DOC-334420A1, para. 70.

[387] For example, in 2016, the FCC imposed an aggregation limit of 1250 MHz in the 28 GHz, 37 GHz and 39 GHz bands for licensees acquiring spectrum through auction (equivalent to approximately 33 % of total available spectrum in the mmWave bands) (FCC, 2016.

- In South Korea, the Ministry of Science and ICT (MSIT) has implemented **spectrum caps that differ by the band,** agreeing on a cap of 100 MHz per operator for 3.5 GHz spectrum (approximately 36% of available spectrum in the band) and 1,000 MHz per operator for 28 GHz spectrum (approximately 42% of available spectrum in the band).[388] MSIT argued that caps would help to promote competition, protect consumer interests and facilitate faster 5G deployment.[389]

Regulators have also used additional licence conditions to achieve certain policy objectives, including the **coverage and rollout obligations**, when awarding spectrum licences through auction.

- In the US, the FCC has previously awarded spectrum on the condition that operators meet certain performance requirements that include minimum coverage targets within the geographic area covered by the licence.[390] These targets will often include a minimum level of coverage that must be achieved by some point during the licence term (e.g. within four years of award) and a minimum level of coverage that must be met by the end of the licence term.[391] Failure to meet these targets can result in the duration of the licence term being reduced (in the event of failing to meet the in-term target) or automatic termination of the licence (in the event of failing to meet the end-of-term target).[392]

- In South Korea, the MSIT has required spectrum holders to meet minimum deployment targets for base-station equipment as a condition of award, with obligations differentiated across spectrum bands to account for differences in their characteristics.[393]

- Regulators in France and Germany may also choose to attach so-called 'use it or lose it' conditions to the award of spectrum as a means of promoting competition and (subsequently) network deployment. This follows from directives issued in the EU's European Electronic Communications Code (EECC) – which member states are in the process of transposing into national law – that provide national regulatory authorities with the right to take actions that can be expected to "promote effective competition and avoid distortions of competition".[394]

While auctions are prevalent across the jurisdictions we have considered, the French regulator ARCEP has also recently used a **hybrid approach** when allocating 3.4-3.8 GHz spectrum, involving both a (conditional) direct provision of spectrum and a spectrum auction. More specifically, a fixed amount of spectrum (50 MHz) was allocated to each operator at the reserve price in exchange for certain rollout commitments, with operators able to compete for the remaining 110 MHz of spectrum through the auction. This approach allowed ARCEP to achieve a number of objectives, including:

Report and Order FCC-16-89–A91). In addition, a threshold of 1250 MHz was proposed for secondary market transactions in these three bands (FCC, 2016. Report and Order FCC-16-89–A91).

[388] World Bank Group, 2021. Entering the 5G era: Lessons from Korea, pg. 19.

[389] World Bank Group, 2021. Entering the 5G era: Lessons from Korea, pg. 19.

[390] The geography of spectrum licences awarded in the US can vary, but licences are typically awarded on a county-by-county basis. In these instances, the relevant geographic area over which a licensee must meet its coverage obligations is the county. A licensee holding multiple county-based licences would therefore have to meet these obligations in each of the areas covered by its licences.

[391] Code of Federal Regulations, Title 47, Chapter 1, Subchapter B, para. 27.14(g).

[392] Code of Federal Regulations, Title 47, Chapter 1, Subchapter B, para. 27.14(g).

[393] World Bank Group, 2021. Entering the 5G era: Lessons from Korea, pg. 19. By including small cell base stations in operators' network deployment obligations, MSIT intended to enable opportunities for SMEs to grow in the 5G market.

[394] European Electronic Communications Code, 2018. Article 52, para. 1.

- to incentivise MNOs to rollout 5G services and deliver 5G coverage where it is needed (rural areas, transport corridors);
- to ensure that all four MNOs gained access to a certain amount of spectrum at a reasonable price; and
- to allow MNOs to compete for additional spectrum if required. Spectrum was allocated in contiguous blocks, with contiguity being achieved via an assignment stage.

ARCEP'S HYBRID APPROACH TO ALLOCATING SPECTRUM (FRANCE)

All existing operators were offered 50 MHz of spectrum in the 3.4-3.8 GHz band for a fixed sum of €350 million in exchange for the following commitments:

- To deploy 5G using 3.4-3.8 GHz spectrum in at least two cities per operator before the end of 2020 and then to achieve the following rollout targets: 3,000 sites in 2022, 8,000 sites in 2024 and 10,500 sites in 2025. Eventually, all sites will have to provide 5G-type services, which may use frequencies in the 3.4-3.8 GHz band or other bands.
- To deploy 25% of sites in the 3.4-3.8 GHz band required under rollout targets for 2024 and 2025 in areas that include municipalities in low-density areas and those in industrial areas outside main conurbations.
- From 2022, at least 75% of sites will have to have a speed of at least 240 Mbit/s at each site. This obligation will be gradually extended to include all sites until 2030. There are also road coverage obligations imposed on operators.
- Operators are to activate the most innovative features of 5G – including network "slicing" or "differentiated services" capability – by 2023 at the latest.

All four operators took up ARCEP's proposal to acquire 50 MHz of spectrum at the reserve price (€350 million). The remaining 11 blocks of 10 MHz were then sold via auction. All four operators acquired some additional spectrum through this auction, between 20 MHz and 40 MHz each. The price paid for the additional spectrum was €126 million per 10 MHz block (vs. a reserve price of €70 million per 10 MHz block).

We also observe different approaches being taken across countries in relation to the process for renewing spectrum licences that have previously been allocated.

- In the US, an **expedited renewal process is offered to certain types of licence holders** that meet relevant rollout or performance obligations and remain operational at or above that level over the course of their licence term.[395] These so-called "safe harbours" intend to reduce the filing burdens on qualifying licence holders and provide certainty to licence holders on the requirements for licence renewal.[396] If a licence is not renewed, the associated spectrum is returned to the FCC and can subsequently be re-auctioned.[397]

- In Germany, on the other hand, up until recently **spectrum frequencies were re-auctioned after the initial licences expired.** The regulator, Bundesnetzagentur (BNetzA), is currently reviewing its approach to spectrum licence renewals and consulting with the industry on alternatives to its current

[395] FCC, 2017. Fact Sheet DOC-345790A1, para. 16.

[396] The FCC has adopted four safe harbours. These licence renewal safe harbours are for: site-based licenses, wireless providers using geographic licenses, private systems using geographic licenses, and partitioned or disaggregated licenses without a performance requirement.

[397] FCC, 2017. Fact Sheet DOC-345790A1, para. 46.

approach. BNetzA is considering a number of potential alternative approaches: ranging from approaches similar to those used in the US (automatic renewal) to alternative allocation methods (such as administrative allocations or hybrid approaches).[398]

Overall, the UK approach to spectrum allocation using auctions (if there is excess demand for spectrum) is a common approach that is used across all the comparator markets. While there may be differences in details of each auction design, there is a consensus that well-designed auctions are well-suited to ensure that spectrum is allocated efficiently.

6.2 SPECTRUM PRICING AND ANNUAL LICENCE FEES

As discussed in **Section 5.1.2** above, in the UK, spectrum pricing is typically implemented in the form of a fee that the licenced spectrum users pay to Ofcom,[399] which is either a cost-recovery fee or an opportunity cost-based Administered Incentive Price (AIP) fee.

Our benchmarking shows that Ofcom's use of opportunity-cost-based pricing when setting administrative spectrum fees appears to be relatively unique. We understand that Australia and Singapore are considering introducing opportunity-cost-based pricing;[400] however, this is currently a work in progress. Accordingly, the UK's approach differs from the approach taken in most other jurisdictions. For example, in France and Germany, administrative fees for non-mobile spectrum are set based on technical formulae,[401] while mobile spectrum may be re-auctioned after initial spectrum licences expire (as is the case in Germany). The approach to mobile spectrum renewal in France is discussed in more detail below.

The UK also differs from the US and France in its decision to impose annual licence fees on mobile spectrum holders upon renewal of a licence. In the US, the FCC does not require any additional licence fee payments from licensees following renewal.[402, 403] In France, ARCEP renewed spectrum licences for a number of bands (900 MHz, 1800 MHz and 2.1 GHz) with no additional fees, but in exchange for extensive additional commitments from licence holders (mobile operators in this case).[404]

[398] BNetzA, 2021. Orientierungspunkte und Bedarfsabfrage zur Bereitstellung von Frequenzen in den Bereichen 800 MHz, 1.800 MHz und 2,6GHz für den Ausbau digitaler Infrastrukturen. Available at: https://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Sachgebiete/Telekommunikation/Unternehmen_Institutionen/Frequenzen/OffentlicheNetze/Mobilfunk/Orientierungspunkte2022.pdf?__blob=publicationFile&v=1 [Accessed 10th March 2022].

[399] Annual spectrum fees apply if spectrum was not allocated via auction or if the initial licence has expired.

[400] For more details see Australian Government (2018) "Spectrum pricing review" (page 9) and IDA Singapore "Consultation on the Proposed amendments to the Telecommunications Regulations" (page 7). Available at: https://www.imda.gov.sg/~/media/imda/files/inner/pcdg/consultations/20141217_telcomregulations/consultationpaper.pdf [Accessed 10th March 2022].

[401] See, for example, Décret n°2007-1532 du 24 octobre 2007 relatif aux redevances d'utilisation des fréquences radioélectriques dues par les titulaires d'autorisations d'utilisation de fréquences délivrées par l'Autorité de régulation des communications électroniques et des postes, Article 4 Available at: https://www.legifrance.gouv.fr/loda/id/LEGIARTI000038581059/2019-05-31 [Accessed 10th March 2022].

[402] GSMA, 2017. Effective Spectrum Pricing: Supporting better quality and more affordable mobile services, Figure 11.

[403] Although the FCC does not charge annual licence fees for spectrum, it does charge recurring regulatory fees to various groups likely to own spectrum licence holders; including wireless services and broadcasting services. For these groups, the FCC charges annual regulatory fees on a per-subscriber basis (i.e. based on the size of the relevant subscriber base).

[404] ARCEP, 2018. Description of Operator Commitments. Available at: https://www.arcep.fr/uploads/tx_gspublication/description-dispositif-couverture-mobile-220118.pdf [Accessed 8th March 2022].

In doing so, ARCEP aimed to encourage operators to expand 4G mobile coverage as a trade-off for forgoing new payments on renewed spectrum licences. Commitments from licence holders included pledges to expand 4G coverage in key areas such as roads and transport corridors, improve indoor coverage, and promote the efficient use of infrastructure, in particular through RAN and/or passive infrastructure sharing in areas where mobile coverage needed to be expanded.[405]

The ARCEP approach appears to be more in line with the approach recommended by stakeholders interviewed for this report, with MNOs extending mobile coverage and upgrading their networks in exchange for lower and/or more modest spectrum renewal fees.

6.3 SPECTRUM SHARING

Several stakeholders have argued that spectrum sharing in the UK needs to be supported by an automated dynamic spectrum allocation system. We have reviewed approaches to spectrum sharing in other jurisdictions to establish whether there are better alternatives to the current UK approach.

In Europe, approaches to spectrum sharing resemble those currently in place in the UK. Both France and Germany have piloted programs aimed at sharing spectrum using a Licensed Shared Access (LSA) model. Similar to the SALs in the UK, Europe's LSA model provides users with shared spectrum access rights that are guaranteed by a regulator, giving LSA licensees a predictable quality of service.[406] Each user requires an individual, non-exclusive licence to access a particular spectrum band, with authorisation dependent on the specific sharing conditions imposed on a given band. As in the UK, responsibility for managing potential interference between users is the responsibility of the spectrum management authority.[407]

Europe's LSA model is evolving, with a concept called evolved LSA (eLSA) currently under development. eLSA is intended to be a more dynamic version of LSA (versus the current static framework for long-term licensing) that uses spectrum sensing to enable more advanced methods of spectrum sharing, including short-term licensing, local spectrum allocation and supporting the sharing of spectrum between co-primary users.[408] Successful development of an eLSA model would shift Europe's approach to spectrum sharing closer to the approach currently taken in the US, where sharing is carried out dynamically in real-time.[409]

In the US, an example of dynamic spectrum sharing is the Citizens Broadband Radio Service (CBRS), a 150 MHz block of spectrum in the 3.5 GHz.[410] Prior to introducing spectrum sharing in this band, the 3.5 GHz

[405] ARCEP, 2018. Description of Operator Commitments. Available at: https://www.arcep.fr/uploads/tx_gspublication/description-dispositif-couverture-mobile-220118.pdf [Accessed 8th March 2022].

[406] European Commission, 2021. Promoting the shared use of Europe's radio spectrum. Available at: https://digital-strategy.ec.europa.eu/en/policies/shared-use-spectrum [Accessed 24th March 2022].

[407] European Commission, 2021. Promoting the shared use of Europe's radio spectrum. Available at: https://digital-strategy.ec.europa.eu/en/policies/shared-use-spectrum [Accessed 24th March 2022].

[408] Kalliovaara, J. et al., 2018. Licensed Shared Access Evolution to Provide Exclusive and Dynamic Shared Spectrum Access for Novel 5G Use Cases.

[409] In Europe, the European Commission is also currently exploring spectrum sharing in the 3.8-4.2 GHz band for use by both private and public networks, with the Commission mandating CEPT to study the potential deployment of broadband systems for the provision of local-area network connectivity for verticals. For more information, see the European Commission's website. Available at: https://digital-strategy.ec.europa.eu/en/policies/uses-radio-spectrum [Accessed 16th May 2022].

[410] This reflects a wider push by the FCC to make additional spectrum available for 5G services to increase the speed of deployment of 5G services. More information is available at: https://www.fcc.gov/5G [Accessed 10th March 2022].

band was used exclusively by the US Navy and commercial satellite operators.[411] To accommodate shared use of the band (for instance between incumbent military and commercial users and non-incumbent commercial users), a three-tiered access authorisation framework was established (see **Figure 28)**. The three tiers of access are defined as follows:

- **Tier 1: Incumbent Access.** Includes authorised federal users (e.g. Navy, Coastguard) and fixed satellite services. Incumbent Access users receive protection against harmful interference from Priority Access Licences and General Authorised Access users (see below).

- **Tier 2: Priority Access Licences (PAL).** Consists of 7 x 10 MHz channels within the band which are auctioned as 10-year renewable licences on a county-by-county basis.[412] PALs must ensure that Incumbent Access users are protected from interference, and they receive protection from interference from General Authorised Access users (discussed below).[413] The majority of PALs have been acquired at auction (FCC Auction 105) by mobile operators, with a number of cable providers and utilities companies also acquiring licences.[414]

- **Tier 3: General Authorised Access (GAA).** Consists of users permitted open, flexible access to the band but who must not cause harmful interference to Incumbent Access users or Priority Access Licensees. GAA users must accept interference from these users, as well as coordinate to minimise interference with other GAA users.[415] GAA users include private networks, which, for example, serve sports stadiums (e.g. for the provision of reliable connectivity), manufacturing (e.g. to support IoT and smart industry), hospitals, etc.

[411] Specifically, spectrum in the 3.5 GHz band supports critical Department of Defence radar operations, including high-powered defence radar systems on fixed, mobile, shipborne and airborne platforms.

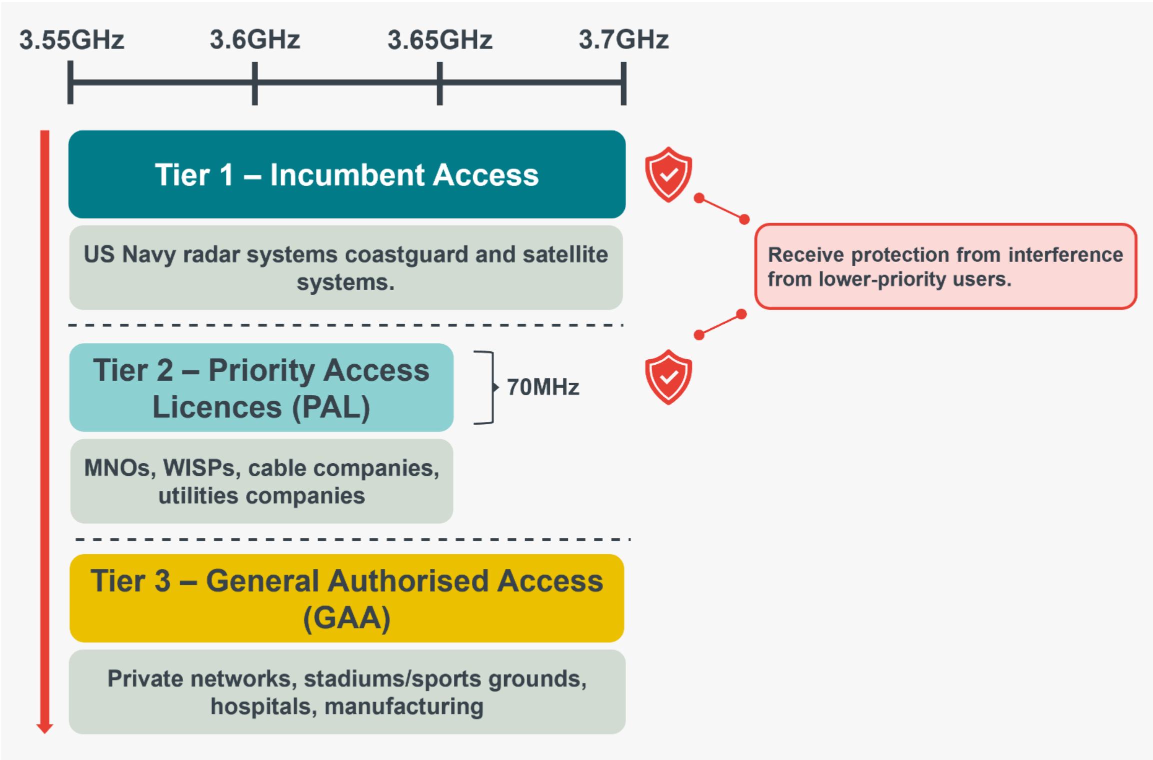
[412] Unlike in the UK, all mobile spectrum in the US is allocated on a regional basis through the assignment of area-based licences (e.g. country-specific licences, partial economic area (PEA) licences).

[413] Furthermore, PAL users are permitted to lease or transfer licences, creating a secondary market for PALs.

[414] LightReading, 2020. CBRS spectrum auction maps: Who won what, and where. Available at: https://www.lightreading.com/5g/cbrs-spectrum-auction-maps-who-won-what-and-where/d/d-id/763837 [Accessed 10th March 2022].

[415] FCC. 3.5GHz band overview. Available at: https://www.fcc.gov/35-ghz-band-overview [Accessed 10th March 2022].

FIGURE 27 ILLUSTRATION OF ACCESS TIERS IN THE CBRS



Source: Frontier Economics.

The CBRS spectrum sharing is implemented using Spectrum Access Systems (SAS).[416] These systems rely on input from Environmental Sensing Capability (ESC) sensors, which signal when incumbent users require access to the band by detecting transmissions from incumbent users (e.g. Department of Defence radar systems). In the event incumbent activity is detected, the ESC alerts the SAS, which then directs PAL and GAA users on frequency and power level to avoid interference with higher-priority (incumbent) users.[417]

For PAL and GAA users that want to access the CBRS, a request to reserve an unused channel (in a given geographic area) must be submitted to a SAS. The request will be granted if the channel is free, ensuring there is no interruption to incumbent users. Once a given user's reservation of a channel ends, this channel once again becomes available for allocation to other PAL and GAA users.[418] **Figure 29** provides an illustration of the spectrum sensing and coordination process in CBRS. Management of channel assignment across tiers of users occurs in real-time, with SAS administrators maintaining a database of all CBRS-connected devices (CBSDs). Real-time sensor data allows for dynamic adjustments to spectrum availability and power assignments as and when requests from devices are received by the relevant SAS administrator.[419]

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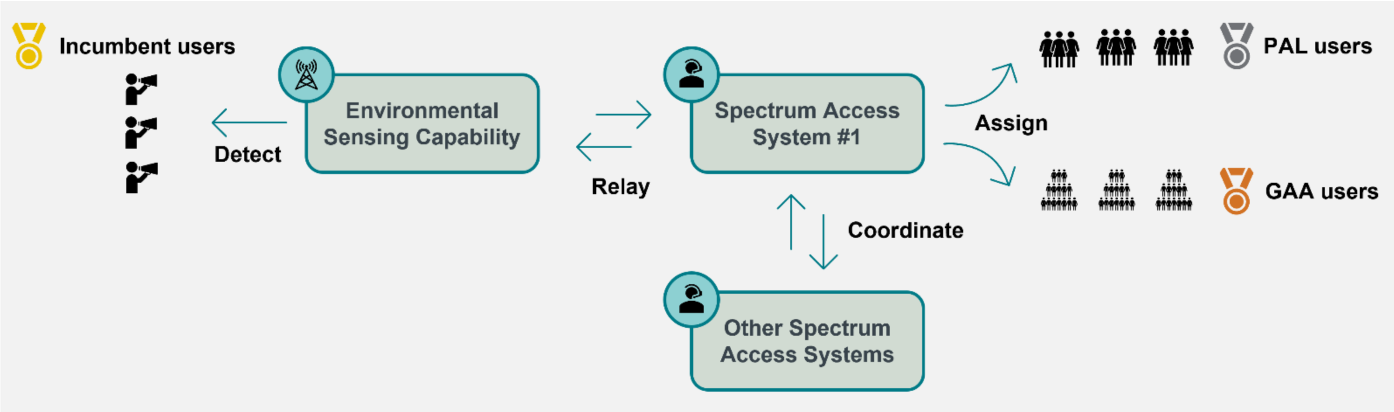
[416] There are five SASs that the FCC has certified for use in managing tiered access to the 3.5 GHz CBRS band: these are run by Federated Wireless; CommScope; Google; Sony; and Amdocs. For more details, see Federated Wireless, 2019. Response to DCMS Statement, pg. 1.

[417] OnGo, 2020. OnGo Private LTE Deployment Guide. Available at: https://ongoalliance.org/wp-content/uploads/2021/05/OnGo-Private-LTE-Deployment-Guide-2.0.pdf [Accessed 10th March 2022].

[418] Blinq Networks, 2020. CBRS, SAS and Spectrum Sharing: The Complete Guide. Available at: https://blinqnetworks.com/cbrs-sas-spectrum-sharing-guide/ [Accessed 10th March 2022].

[419] Specifically, SASs operate on a 60-second 'heartbeat' that defines the rate at which CBSDs check-in with the SAS. If a CBSD does not receive authorisation to continue using a particular channel, it must stop transmitting on that channel within 300 seconds.

FIGURE 28 ILLUSTRATION OF SPECTRUM SENSING AND COORDINATION IN CBRS



Source: Frontier Economics.

Dynamic spectrum sharing systems such as CBRS have the potential to unlock a number of benefits. These include (but are not limited to):

- **Enabling efficient and effective co-existence of spectrum users.** The system allows for a range of eligible users to identify available spectrum at any given point in time and to submit a request for use of this spectrum. These eligible users are able to use the spectrum as long as higher priority users are not using it. The utilisation of ESC sensors alerts administrators to instances when the CBRS spectrum is in use by higher priority users, minimising the risk of interference with other users.

- **Providing spectrum users with flexible capacity.** The availability of Priority Access Licences and General Authorised Access provides users with flexible capacity. For example, telecoms operators may choose to meet their capacity needs through a combination of PALs (perhaps targeting locations where a certain level of protection from interference is required) and GAAs (in areas where unlicensed and opportunistic access to capacity is sufficient).[420]

- **Safeguarding priority access (incumbent) users.** The utilisation of ESC sensors (e.g. along coastlines) alerts SAS administrators to instances when the CBRS spectrum is in use by priority users (e.g. Navy, Coastguard), helping to ensure that no conflicts ensue with lower-priority users and enable coexistence within the band between different users.

- **Allowing CBRS PAL holders to lease (or trade) under-utilised spectrum.** The CBRS is supported by a secondary market for Priority Access Licences following the creation of the Spectrum Exchange by Federated Wireless.[421]

Furthermore, CBRS may help unlock a number of further benefits which are not CBRS-specific. These include:

[420] Federated Wireless, 2019. Response to DCMS Statement, pg. 9.

[421] The Spectrum Exchange is intended to operate like other peer-to-peer services (e.g. Airbnb): PAL owners are able to set and publish prices, terms and location options and view and engage with potential lessees, with transactions (and payment) executed instantly – all without the need to directly engage with the FCC. Secondary markets are expected to particularly benefit local and regional service providers who require additional spectrum to increase availability (but who otherwise do not have sufficient need for full ownership of PALs), such as universities and municipalities wishing to deploy private networks.

- **Protecting investment incentives while promoting innovation.** Access to licensed spectrum through PAL auctions provides regulatory certainty to spectrum users, which should help to protect long-term investment incentives. At the same time, opportunities for unlicensed access to spectrum (i.e. for GAA users) can help to promote innovation and enable new business models.[422]

- **Enabling businesses to build private 4G and 5G networks.** CBRS allows a range of businesses to access reliable 4G and 5G connectivity through small-scale deployment of indoor and outdoor access points.[423]

Meanwhile, there are costs associated with the implementation of dynamic shared access systems such as CBRS, most notably the **time-intensity, cost and complexity of development**. The CBRS system took several years to develop, with the time required to develop the necessary infrastructure to support the system and to coordinate across a large number of stakeholders – in particular on the necessary protection criteria for incumbent and higher-priority users. Estimates for the capital cost of this infrastructure are not publicly available, but we would expect this to be significant, given the requirement for a number of different infrastructure inputs including SASs and ESCs.

Beyond CBRS, the FCC has supported further efforts to innovate through partnerships with organisations that support innovation and R&D in spectrum management. This includes partnering with the US National Science Foundation (NSF), a research body that has recently announced a five-year, $25 million investment in SpectrumX, a Spectrum Innovation Centre.[424] Objectives of the program include the development of new mechanisms for sharing and managing radio spectrum, as well as providing a hub for collaboration between academics, private enterprises and public bodies.[425] The NSF's funding announcement for SpectrumX was only made in 2021, and the project is still in its early phases. However, through the partnership between the FCC and the NSF, SpectrumX has the potential to fuel innovation that supports more effective spectrum management and regulation, ultimately enabling the FCC to better meet its policy objectives.

Overall, we consider that the approach used for spectrum sharing in the US is worth considering in more detail. Therefore, we recommend that DCMS and DSIT further explores, with the developers of the CBRS and potential users, the practical steps that would need to be taken to implement a version of this system in the UK. It is important to note that the version of this system implemented in the UK need not be an exact replica of the CBRS. More specifically, CBRS' three-tiered access authorisation framework comprises a solution to the specific task of enabling spectrum sharing in a band where an incumbent user exists and for whom access to spectrum must be safeguarded and prioritised (e.g. the US Navy as the incumbent user of 3.5 GHz spectrum). In the UK context, a similar system could be used to facilitate sharing spectrum in bands without an incumbent user that requires priority access, and could instead be simplified to include two tiers of access (for instance, PAL and GAA users only).

[422] Federated Wireless, 2019. Response to DCMS Statement, pg. 2.

[423] We note, however, that these benefits are not CBRS-specific as alternative approaches to spectrum management may similarly help to unlock these benefits. For instance, the duration of spectrum licence ownership permitted by Ofcom – and options for renewal – can similarly help to protect users' investment incentives while promoting innovation. Similarly, Ofcom's spectrum sharing and Local Access licensing arrangements for 5G verticals and private networks can help to enable businesses to build their own private networks.

[424] SpectrumX comprises 29 organisations led by the University of Notre Dame and is the first publicly-funded research centre to focus on innovation in spectrum management.

[425] National Science Foundation, 2021. NSF announces the launch of SpectrumX, an NSF Spectrum Innovation Center. Available at: https://www.nsf.gov/news/news_summ.jsp?cntn_id=303454 [Accessed 24th March 2022].

We would also recommend that DCMS and DSIT monitor progress of the US' SpectrumX program, which aims to provide further tools designed to promote dynamic and agile spectrum management.

6.4 SPECTRUM REASSIGNMENT

A number of stakeholders in the UK have voiced concerns over the perceived prioritisation of the mobile sector over other use cases and sectors in issues of spectrum reassignment. They considered that Ofcom does not fully take into account the social value generated by sectors, such as broadcasting and PMSE. Below we consider approaches taken to spectrum reassignment in other jurisdictions to come to a view on whether there is a better alternative to the approach used by Ofcom.

We understand that the approach to spectrum reassignment in Germany and France is similar to that in the UK: in most cases, national regulators assess and make recommendations on whether spectrum bands should be repurposed from one use case to another. This applied to the 800 MHz and 700 MHz spectrum bands, which were reallocated from broadcasting to mobile.

However, the approach taken to spectrum reassignment in the US has, in some instances, been different: instead of determining reassignment on the basis of an administrative decision, the FCC used a market-based approach (an auction) to reassign spectrum for new use cases. This auction, known as the "Broadcast Incentive Auction", aimed to make valuable "low-band" spectrum (600 MHz) available for use by mobile and wireless broadband providers by encouraging the band's incumbent users – broadcasters – to relinquish their spectrum usage rights.[426]

The auction comprised two separate but interdependent auctions – a **forward auction** and a **reverse (or 'backward') auction** (see **Figure 30**).

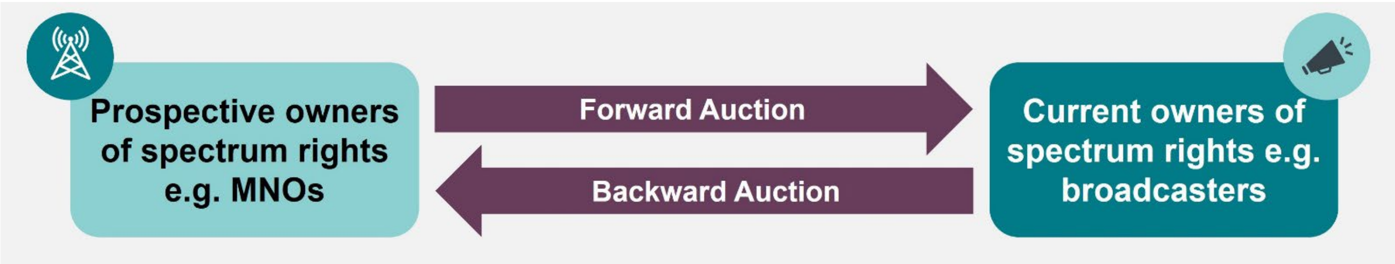
- The **forward auction** determines the price prospective new spectrum holders (e.g. MNOs) are willing to pay for the spectrum reassigned. Through the forward auction, the FCC aims to sell the spectrum it conditionally purchased from broadcasters via the reverse (backward) auction.
- The **reverse (backward) auction** determines the price that current spectrum holders (e.g. broadcasters) are willing to accept to relinquish their spectrum usage rights. Through the backward auction, the FCC conditionally purchased spectrum from broadcasters for sale to MNOs (and other interested bidders) in the forward auction.

The two auctions were linked by a so-called "**repacking**" process that involved reorganising and reassigning channels to the remaining broadcasters (who did not relinquish their spectrum usage rights) in order to create contiguous blocks of cleared spectrum suitable for flexible use by new licence holders.[427]

[426] FCC, 2017. Incentive Auctions. Available at: https://www.fcc.gov/about-fcc/fcc-initiatives/incentive-auctions [Accessed 10th March 2022].

[427] Through the forward and reverse auctions, the FCC determined the amount of spectrum that broadcasters were willing to relinquish and operators willing to purchase. In each stage of the auction, if the FCC could not sell the spectrum to operators for at least as much as it conditionally 'acquired' it from broadcasters, it reduced the amount of spectrum secured from broadcasters – subsequently restarting the backward and forward auctions. As a result of this process, the amount of spectrum that was reassigned from broadcasting to mobile was determined dynamically by the market rather than determined administratively.

FIGURE 29 ILLUSTRATION OF A SPECTRUM INCENTIVE AUCTION



Source: Frontier Economics.

The FCC used an incentive auction to successfully reallocate spectrum from broadcasters to mobile services in the 600 MHz band, helping to meet growing demand from operators for low-frequency spectrum and demonstrating that incentive auctions can promote efficient use of spectrum without relying on government intervention.[428] However, there appear to be several issues with this approach. In particular:

- **The auction process was complex and time-consuming.** In the US context, the FCC had to coordinate the participation of hundreds of broadcasters across multiple rounds of bidding, each of whom was provided with a range of bidding options (to keep their spectrum or to relinquish their spectrum in part or in full). As a result, the auction – which opened for applications for the reverse auction in January 2016 – took over 15 months to close.[429]

- **Broadcasters received a significant share of the auction proceeds.** Given the compensation structure of the auction, a significant share of the auction proceeds – over 60% – was paid to broadcasters (either as direct compensation or via contributions to the reallocation fund).[430] In contrast, costs incurred by the UK Government in clearing the 700 MHz spectrum band for use by UK mobile operators (approx. £350 million) were less than 30% of the eventual proceeds raised through the auction of the cleared spectrum (approx. £1.4 billion).[431]

These issues suggest to us that this approach is unlikely to be appropriate in the UK context. We also further note the use of incentive auctions (or any auction mechanism, for that matter) may limit opportunities for spectrum reassignment to particular sectors or users. Consider, for example, a scenario in which a decision needs to be made whether to assign spectrum for licensed use (e.g. in mobile) or for licence-exempt use (e.g. by Wi-Fi users). In this scenario, Wi-Fi users are unlikely to be in a position to join forces in order to bid for spectrum, preventing their involvement in an auction intended to determine how spectrum should be reassigned. Instead, administrative decision-making on the part of regulators is required if spectrum is to be reassigned for licence-exempt use. This can be seen in the context of the FCC's recent decision to free 1.2 GHz of spectrum in the 6 GHz band for unlicensed use in an attempt to increase available spectrum capacity

[428] International Institute of Communications, 2018. Lessons from the US Incentive Auction, pg. 29.

[429] International Institute of Communications, 2018. Lessons from the US Incentive Auction, pg. 26.

[430] International Institute of Communications, 2018. Lessons from the US Incentive Auction, pg. 25.

[431] UK Gov, 2020. Press Release: Big step forward in digital infrastructure revolution brings benefits of 5G closer. Available at: https://www.gov.uk/government/news/big-step-forward-in-digital-infrastructure-revolution-brings-benefits-of-5g-closer [Accessed 10th March 2022].

for Wi-Fi users. Here, the FCC made an administrative decision to make this spectrum available for unlicensed use, published in a 2020 Report and Order.[432, 433]

Overall, our review of international precedents has not identified a better alternative to the current reassignment process used in the UK. Although the decision-making process to reassign spectrum is time-consuming, it ensures that all relevant stakeholders have been consulted. Moreover, Ofcom's consultations and analyses are open and transparent.

6.5 INTERNATIONAL HARMONISATION AND SPECTRUM RELEASE

In recent years, cross-country efforts to support international harmonisation of spectrum have focused on ensuring that sufficient spectrum is available to support the deployment of use cases in key sectors such as radiocommunication, satellite, aviation, maritime, etc. Below, we provide a brief overview of approaches to harmonising spectrum across these sectors, which is followed by a more detailed overview of current approaches to harmonisation of spectrum for 5G deployment.

6.5.1 INTERNATIONAL HARMONISATION OF SPECTRUM IN KEY SECTORS

With regards to radiocommunication services, harmonisation may be coordinated at either the global level or the regional level, with the ITU responsible for recommending relevant globally or regionally harmonised frequency arrangements.[434]

In contrast to the potential regional approaches to harmonisation of spectrum for radiocommunication, services in sectors such as satellite communications, aviation and maritime require a global approach, with limited scope for national deviation. This is necessary given the nature of services provided by these sectors, in particular, the role that satellite communication services play in supporting aviation and maritime travel; here, global interoperability of spectrum and equipment is crucial for minimising the risks from harmful interference and ensuring safety.

6.5.2 INTERNATIONAL HARMONISATION AND SPECTRUM RELEASE FOR MOBILE

As discussed in **Section 4** above, demand for mobile services is growing and the mobile operators might need more spectrum going forward to be able to serve this demand. In this section, we compare mobile spectrum allocations in the UK with those in other markets to understand whether the UK's approach is consistent with that in other leading economies.

We observe that countries have committed to harmonise a number of 'pioneer spectrum bands' for 5G use and ensure these bands are made available on a sufficient and timely basis. As shown in **Figure 31**, countries have therefore been able to coordinate on spectrum bands awarded for 5G. In particular, we observe that the UK has allocated the 5G spectrum broadly within the same time frames as the comparator economies.

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[432] FCC, 2020. Statement of Chairman Pai, DOC-363945A2.

[433] We further note that from this decision, it is not obvious that the FCC conducted a detailed cost-benefit analysis of potential reassignment options; or, at least, this analysis is not in the public domain. Following the decision, the FCC was challenged by wireless services provider AT&T, who argued that the FCC's decision failed to identify and address issues relating to possible interference between users. This challenge was subsequently overruled by a US Court of Appeals judge, paving the way for the FCC's decision to be implemented.

[434] When considering regional arrangements, the ITU distinguishes between three regions: Region 1 (Europe, Africa, the former Soviet Union, Mongolia, and the Middle East (west of the Persian Gulf, including Iraq)); Region 2 (the Americas, Greenland, and some of the eastern Pacific Islands); and Region 3 (most of non-former Soviet Union Asia (east of and including Iran), and most of Oceania).

However, one area where the UK is currently lagging is in relation to mmWave spectrum, with Ofcom only recently releasing a consultation on the award of mmWave spectrum in the 26 GHz and 40 GHz bands.[435] The US has already allocated mmWave spectrum in a number of bands, including awards of 28 GHz spectrum (2019) and subsequent awards of mmWave spectrum in the 37, 39 and 47 GHz bands (2020). In doing so, the FCC has pointed to the potential for MNOs to deploy these bands alongside the mid-band spectrum.[436] US mobile operators have since deployed mmWave networks in dense urban areas.[437]

In stakeholder interviews, at least one mobile operator raised the issue of mmWave spectrum and indicated there is demand for this spectrum in the UK. Furthermore, our own modelling (see **Section 4**) indicates that mmWave spectrum can be used to address (at least to some extent) congestion issues in high-demand areas.

Overall, the UK's current approach to international harmonisation appears to be aligned with countries in Europe, in particular with regard to the harmonisation of low-band (700 MHz) and mid-band (3.4-3.8 GHz) spectrum. However, there could be further benefits in the UK from awarding mmWave spectrum, especially from the adoption of use cases that will rely on high-capacity, low-latency transmission (e.g. smart industry, next-gen healthcare, etc.).[438]

We note that very large markets (e.g. China and the US) are able to move unilaterally and allocate certain bands for mobile, without these bands being internationally harmonised. This approach, however, would not work in the UK, as the market is not big enough to allow a market-specific ecosystem to develop at a low cost. Indeed, vendors would not produce bespoke cost-effective equipment just for the UK. However, if large markets have moved ahead and started using certain bands for 5G, it would imply that the 5G ecosystem has been developed in those bands. Therefore, it should be possible to follow the "first-movers" and to use the same bands for 5G, even before they were internationally harmonised. For example, given that South Korea uses 4.7 GHz and China uses 4.9 GHz for mobile, smaller markets could also consider using these bands for mobile (as long as it does not cause interference with other users domestically or across the border).

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[435] See Ofcom, 2022. Enabling mmWave spectrum for new use cases: Making the 26 GHz and 40 GHz bands available for mobile technology.

[436] FCC, 2019. Auction 103 Fact Sheet. Available at: https://www.fcc.gov/auction/103/factsheet [Accessed 10th March 2022].

[437] Qualcomm, 2021. 5G mmWave network advantage – How to measure it right. Available at: https://www.qualcomm.com/news/onq/2021/12/15/5g-mmwave-network-advantage-how-measure-it-right [Accessed 10th March 2022].

[438] See, for example, GSMA, 2019. Regional Spotlights: Impact of mmWave 5G.

FIGURE 30 PLANNED OR COMPLETED AWARDS FOR 5G SPECTRUM

	Low-Band		Mid-Band		High-Band	
	600MHz	700MHz	3.4–3.6GHz	3.6–3.8GHz	> 24GHz	Other frequencies
United Kingdom	✗	✓ 2021	✓ 2018	✓ 2021	— 26GHz (TBC) *	2.3GHz (2018)
France	✗	✓ 2015	✓ 2020	✓ 2020	— 26GHz (trial platforms)	
Germany	✗	✓ 2015	✓ 2019	100MHz (mobile) 100MHz (MPNs)	✓ 26GHz (2019) **	2000MHz (2019)
South Korea	✗	✓ 2015	✓ 2018, 2022	✓ 2018	✓ 28GHz (2018)	4.7GHz (2022)
United States	✓ 2017	✗	✓ 2019	✓ 2021	✓ 24, 28GHz (2019); 37, 39, 47GHz (2020)	600MHz (2017)
China	✗	✓ 2019	✓ 2019	✗	— 26, 37GHz (consultation)	4.9GHz (2019)

Source: European 5G Observatory (France, Germany, United Kingdom), ITU (South Korea), FCC (United States), MIIT (China).

Note: (*) Ofcom have made spectrum in the 24.25-26.5 GHz band (the lower 26 GHz band) available for indoor use as part of our Shared Access licence framework. (**) 26 GHz has been awarded in Germany via an application procedure since year-end 2019.

6.6 CONCLUSIONS

Spectrum users in the UK have identified a number of issues which need to be addressed in order to ensure that the framework continues to be fit for purpose going forward. These issues relate to spectrum sharing, spectrum reassignment, spectrum pricing and Ofcom's role in the international harmonisation process. We have reviewed international precedent in order to understand whether there are alternative approaches that could be used to address these issues.

6.6.1 ALLOCATION MECHANISMS FOR VALUABLE SPECTRUM

Based on our review, Ofcom's current approach to allocating spectrum resources is largely consistent with those used in our comparator countries, i.e., market-based mechanisms tend to be used where there is excess demand for spectrum. However, we also note the hybrid approach taken by the French regulator ARCEP when allocating 3.4-3.8 GHz spectrum, which has potential benefits of providing MNOs with access to a certain amount of spectrum at a reasonable price and incentivising additional network deployment. Given the feedback from stakeholders regarding the extent to which Ofcom's current regulatory framework incentives investment, we consider this hybrid approach to spectrum allocation may warrant further consideration by DCMS, DSIT and Ofcom.

6.6.2 SPECTRUM PRICING AND ANNUAL LICENCE FEES

In relation to Annual Licence Fees (ALFs), we observe that in the US, no additional fees apply to mobile spectrum after the initial spectrum licences expire, with spectrum typically awarded on an indefinite basis. At the same time, spectrum trading (i.e. spectrum re-allocation) is common through secondary markets, which implies that market participants have incentives to trade even in the absence of annual licence fees. If spectrum is tradable, the case for ALFs appears to be weaker. Regarding the prevalence of spectrum trades in the UK, with and without ALFs, we note that some trades in the UK have involved spectrum which was not subject to ALFs; for instance, the sale of 2.6 GHz spectrum by EE to O_2 in 2020. This supports the argument that ALFs are not a necessary condition for spectrum trading to occur.

We also consider that France provides an interesting example of spectrum licence renewal processes being used as an opportunity to achieve welfare-enhancing policy objectives. ARCEP renewed 900 MHz and 1800 MHz spectrum licences, with no additional fees, in exchange for stricter coverage obligations and a commitment to cover "white spots" in rural areas. In effect, spectrum fees were effectively being "reinvested" in the industry to the benefit of consumers through operators' commitments to deploy.

In the UK, rural not-spots are currently being addressed via the Shared Rural Network (SRN), with mobile operators committed to investing £532 million to increase coverage to 95% of the UK landmass by the end of 2025. At the same time, ALFs for legacy spectrum appear to be set independently of this process. For example, the Ofcom 2021 consultation on 2.1 GHz ALFs did not discuss issues of low sector profitability or significant investments required to improve rural coverage. We consider this to be a drawback of the current system. Indeed, significant coverage obligations and other costs imposed on the sector imply lower future profitability (and therefore imply lower spectrum valuation), which should be reflected in forward-looking spectrum fees. If these obligations are imposed as part of the auction process, bidders are able to reflect the lower valuation in their bids, which results in lower spectrum prices. In the same way,, administrative prices set by the regulator (i.e., ALFs) should also take these costs into account. **To the extent that Ofcom relies on historical auction prices to set forward-looking ALFs, these historical prices need to be adjusted to reflect the new coverage obligations and other costs that impact operators' profitability – and therefore operators' spectrum valuations..**

6.6.3 SPECTRUM SHARING

Several stakeholders have advocated the CBRS as a dynamic and more agile spectrum allocation system (compared to Ofcom's current approaches to spectrum sharing). We agree that the CBRS has a number of benefits. It has enabled efficient and effective co-existence of spectrum users, provided spectrum users with flexible spectrum capacity and safeguarded incumbent users and priority services.

In the US, the CBRS approach appears (to date) to have been successful. The infrastructure for spectrum sharing appears to be working as intended: ESC networks have been successfully deployed around the country, and SAS software has been developed, with a number of companies now responsible for the operation.

Initial data from Federated Wireless – one of the US' five certified SAS administrators – suggests system administrators have not received reports of interference from Incumbent Access users (and there is confidence this will not increase as deployments increase).[439] LTE private network use cases have successfully

[439] LightReading, 2020. Available at: https://www.lightreading.com/aiautomation/no-news-is-good-news-cbrs-players-report-no-interference/d/d-id/765000 [Accessed 10th March 2022].

been deployed, enabling connectivity in a number of high-demand areas.[440] Furthermore, the secondary market for Priority Access Licences is also now active following the creation of the Spectrum Exchange, enabling CBRS PAL holders to lease (or trade) under-utilised spectrum to third parties to supplement GAA spectrum access.[441]

The CBRS is a first-of-its-kind system and was complex and time-consuming to implement – with Ofcom previously opting against pursuing this approach on this basis.[442] However, we understand that the solution is now more commoditised and could be adapted to the UK context.[443] We are also not aware of any legal barriers to the implementation of such a system in the UK. **Therefore, we recommend that DSIT explore further with the developers of the CBRS and potential users of the system practical steps that would need to be taken to implement a version of this system in the UK.** This would include determining which bands and/or contexts would be most appropriate for such a system: given stakeholder feedback, one option could be spectrum in the 2.3 GHz band, where MOD and mobile use cases could coexist, potentially together with other general and/or lower-priority users. We would further recommend that the DSIT monitor progress of the US' SpectrumX program, which aims to provide further tools designed to promote dynamic and agile spectrum management.

6.6.4 SPECTRUM REASSIGNMENT

Our review of international precedents has not identified a better alternative to the current reassignment process than the one currently used by Ofcom. Although the decision-making process to reassign spectrum is time-consuming, it ensures that all relevant stakeholders have been consulted. Moreover, Ofcom's consultations and analyses are open and transparent.

In the US, an alternative approach was used to reassign 600 MHz spectrum – a reverse two-sided auction, with both mobile operators and broadcasters participating in the auction. Ofcom consulted previously on the use of an incentive auction in the UK, but this approach was not supported by stakeholders and was deemed to be too complex. Our assessment takes a similar view.

Overall, the current approach used in the UK (i.e. an administrative decision-making process that takes into consideration all costs and benefits associated with the spectrum reassignment) remains appropriate. This process critically depends on the quality of information and evidence provided by stakeholders. Therefore, **we recommend that stakeholders continue to provide evidence and information to Ofcom and DCMS in order to support decision-making in relation to spectrum reassignment.**

6.6.5 INTERNATIONAL HARMONISATION AND SPECTRUM RELEASE

In recent years, cross-country efforts to support international harmonisation of spectrum have focused on ensuring that sufficient spectrum is available to support sectors where there is growing demand while ensuring that the other sectors are not unduly affected. Harmonisation is important to ensure that harmful cross-border interference in the provision of key services is prevented or minimised, while also enabling

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[440] Stadium Tech Report, 2021. Available at: https://stadiumtechreport.com/news/padres-boingo-team-on-small-cbrs-network-for-petco-park/ [Accessed 10th March 2022].

[441] Federated Wireless, 2021. Available at: https://federatedwireless.com/news/new-federated-wireless-spectrum-exchange-to-connect-pal-licensees-with-other-carriers-and-businesses-to-accelerate-nationwide-wireless-5g-expansion/ [Accessed 10th March 2022].

[442] Federated Wireless, 2019. Response to DCMS Statement, pg. 4.

[443] For instance, existing SAS administrators have estimated that the development of an SAS for the CBRS band in the UK would take between 3-6 months once Ofcom had established protection criteria for incumbent and/or high-priority users.

global interoperability. Harmonisation also provides opportunities for economies of scale in the manufacturing of equipment - a vital means by which to drive down costs.

Stakeholders highlighted that it is important for Ofcom to continue to engage with international harmonisation bodies given the benefits both for the UK and globally of international harmonisation of spectrum, with DCMS and DSIT continuing to support Ofcom in these international efforts. We understand that Ofcom participates in all these harmonisation bodies and will continue to do so going forward.

With regards to releasing new spectrum for mobile, we note that Ofcom acted proactively when releasing key bands for 5G. The only area where the UK is lagging is in relation to mmWave spectrum, with countries, such as the US, having already allocated mmWave spectrum in the 28 GHz, 37 GHz, 39 GHz and 47 GHz bands via auction.[444] As noted previously, Ofcom has now published a consultation on the award of mmWave spectrum in the 26 GHz and 40 GHz band and, given the fact that some UK stakeholders have expressed demand for that spectrum, **we recommend that Ofcom should consider allocating mmWave spectrum as soon as practical following this consultation.**

[444] As noted previously, Ofcom has now published a consultation on the award of mmWave spectrum in the 26 GHz and 40 GHz band. Responses to this consultation should be closely monitored so as to gauge interest from relevant stakeholders in access to mmWave spectrum, with a closing date for responses set for 18th July 2022.

Annex A - METHODOLOGY USED TO CALCULATE GROSS VALUE ADDED (GVA)

This Annex describes the methodology used to calculate the estimates of Gross Value Added (GVA) presented in **Section 3** of this report. It sets out: (i) the definition of GVA, (ii) the methodology for estimating GVA, (iii) the data sources used in this report, and (iv) the approach taken in specific sectors.

A.1 - DEFINITION OF GVA

GVA measures individual suppliers, areas or sectors' contribution to the economy. Specifically, it is defined as output (at basic prices) minus intermediate consumption (at purchaser prices). It can measure economic activity in a given sector, and GVA plus net taxes on products is equivalent to GDP.

A.2 - METHODOLOGY FOR ESTIMATING GVA

GVA can be calculated through the income, expenditure or production approach. All three approaches lead to equivalent results and are outlined below:

- the production approach estimates GVA by summing the value of the final goods and services minus the value of the inputs to the production process;
- the income approach estimates GVA by summing the income earned by individuals and corporations producing the good or the service; and
- the expenditure approach estimates GVA by summing the expenditure on the good or the service.

Where it is necessary to calculate GVA using raw data, this report uses the income approach to estimate sector level GVA. This involves summing the gross operating surplus, the compensation of employees and taxes on the production of firms in the sector, and then subtracting any subsidies received by firms in the sector.

A.3 - DATA SOURCES

The methodology used in this report relies on financial data from companies' financial statements and macroeconomic data (from the ONS).

- The ONS publishes the data needed to calculate sector level GVA in its Annual Business Survey (ABS) and Supply and Use Tables (SUT).[445][446] Where possible, we use this data.
- For some sectors, it was not possible to use data from the ONS as the ONS's definitions of a sector did not align with the definition of the sector used in this report. For these sectors, we estimate GVA by collecting the relevant data from companies' annual reporting available from Companies House.

Below we describe the approach used to calculate GVA using the two data sources set out above.

[445] The Annual Business Survey (ABS) is a business survey conducted by the ONS. The sample is approximately 62,000 firms, and it is collected annually. Firms included in the sample are UK companies registered for VAT or PAYE or with Companies House. See: https://www.ons.gov.uk/surveys/informationforbusinesses/businesssurveys/annualbusinesssurvey [Accessed 27th April 2022].

[446] The Supply and Use Tables (SUTs) calculate the flow of products and services in the economy for a single year and are the source of the data underlying national GDP. See: https://www.ons.gov.uk/economy/nationalaccounts/supplyandusetables [Accessed 27th April 2022].

A.3.1 - CALCULATING GVA USING ONS DATA

Sector level data published by the ONS is published at different levels of granularity. For instance:

- the most reliable estimate of GVA comes from the SUT, which is published at the two-digit SIC code level (e.g. SIC 60 is broadcasting); and
- data in the ABS is published at the four-digit SIC code level (e.g. SIC 60.10 is radio broadcasting and SIC 60.20 is TV broadcasting); however, the ABS only contains data on Approximate GVA (aGVA).

For the purposes of this report, it would be preferable to calculate GVA at a four-digit Standard Industrial Classification (SIC) code level to allow a richer level of granularity. To calculate GVA at a four-digit level we employed the same methodology used by DCMS to calculate its sector-level estimates.[447] This involves:

- extracting aGVA from the ABS at the industry level (e.g. SIC 60.10);
- calculating aGVA from the ABS at the division level (e.g. SIC 60, by aggregating industries in the division);
- calculating the proportion of the division aGVA that each industry accounts for (e.g. aGVA for SIC 60.10 as a proportion of SIC 60); and
- applying the proportion for each industry to the division GVA in the SUT to get a National Accounts consistent estimate of GVA for each industry.

The output is GVA in current prices in 2019 for each sector at a four-digit SIC code disaggregation.

A.3.2 - CALCULATING GVA USING COMPANY LEVEL DATA

As noted above, where it is necessary to calculate GVA using raw data, this report uses the income approach to estimate sector level GVA This involves collecting the relevant information on each measure listed below from each company’s financial statements.

- **gross operating surplus and taxes on production**, measured by operating profit plus depreciation and amortisation (i.e. EBITDA);
- **total compensation of employees**, measured by total staff costs (including pension and national insurance contributions); and
- any **other taxes on production**, this includes spectrum fees (for instance, annual licence fees).

Using company accounts allows for an estimate of GVA that more closely aligns with the definition of the sector used in this report. However, it may underestimate the GVA of a sector as it may exclude some small providers.

A.4 - APPROACH TAKEN IN SPECIFIC SECTORS

This section sets out the approach used in each sector where we estimate GVA.

A.4.1 - BROADCASTING

447 DCMS, 2021. DCMS Economic Estimates 2019: Gross Value Added – Technical and quality assurance report.

Using the approach set out in **Section A.3.1** we use data from the ONS to calculate GVA from the broadcasting sector (using the SIC codes 60, 60.10 and 60.20).

As explained in the main body, we use data on listening/viewership to calculate the proportion of radio and TV broadcasting GVA attributable to spectrum. This uses the following methodology.

- For radio broadcasting, we use data from RAJAR to:
  - calculate the split of radio listenership between live and listen again; and
  - calculate the proportion of live radio listenership attributable to AM, FM and DAB radio.

  This leads to an estimate of the proportion of radio listening that is attributable to spectrum related technologies, which we then apply to the estimate of the GVA of the radio broadcasting sector.

- For TV broadcasting we use data from Ofcom to:
  - calculate the split of TV revenues between advertising and subscription revenues using data from Ofcom's Media Nations report; we then
  - apportion subscription revenues between Sky (spectrum enabled) and cable providers (non-spectrum enabled) based on data on viewership from Ofcom's Technology Tracker; and
  - apportion advertising revenues between DTH satellite and DTT providers (spectrum enabled) and cable providers (non-spectrum enabled) based on the same data on viewership from Ofcom's Technology Tracker.

  This leads to an estimate of the proportion of TV broadcasting revenues attributable to spectrum related technologies, which we apply to the estimate of the GVA of the TV broadcasting sector.

A.4.2 - COMMERCIAL SATELLITE OPERATORS

Using the approach set out in **Section A.3.1**, we use data from the ONS to calculate GVA from the commercial satellite sector (using the SIC code 61.30 Satellite Telecommunication Activities).

A.4.3 - MOBILE SERVICES

It was not possible to use ONS data to calculate GVA for mobile services. This is because ONS records GVA from activities related to mobile services in SIC code 61.20 wireless telecommunication activities and 61.90 other telecommunication activities. It is not possible to separate mobile services activity in 61.90 from other non-mobile activities. We, therefore, used the approach set out in **Section A.3.2** to calculate GVA from the mobile services.

We did this as follows.

- We collected data on operating profit, depreciation, amortisation, spectrum fees[448] and payments to labour for all MNOs and a selection of the largest MVNOs[449] from financial statements, then

[448] Vodafone and Hutchinson 3G do not report their Annual Licence Fee payments. We estimated their Annual Licence Fee payments using Vodafone and EE's Annual Licence Fee payments adjusted for differences in spectrum holdings.

[449] These were Tesco Mobile, Lycamobile, Virgin Mobile and Giffgaff. We were unable to collect data on Sky Mobile as its financial statements did not report the information necessary to separate GVA from mobile from GVA from broadcasting and fixed services.

aggregated them to collect total GVA.[450] Some companies (Vodafone, EE and Virgin Mobile) are involved in multiple sectors. For these companies, we estimated the proportion of GVA attributable to mobile services based on the proportion of revenue attributable to mobile services.

- As we were unable to gather information for all MVNOs, we applied an uplift to the GVA from MVNOs based on the market share of the MVNOs that were not included in our analysis.

A.4.4 - FIXED SERVICES

As explained in the report, we are unable to calculate GVA attributable to Wi-Fi, and therefore, we calculate the GVA attributable to fixed telecom services (noting that only a proportion of this is enabled by Wi-Fi connectivity).

Like with mobile services, it was not possible to use ONS data to calculate GVA for fixed services. This is because ONS records GVA from activities related to fixed services in SIC code 61.10 wired telecommunication activities and 61.90 other telecommunication activities. It is not possible to separate fixed services activity in 61.90 from other non-fixed activities. We, therefore, used the approach set out in **Section A.3.2** to calculate GVA from fixed services.

We did this as follows.

- We collected data on operating profit, depreciation, amortisation, and payments to labour for all fixed operators from financial statements, [451] then aggregated them to collect total GVA.[452] Some companies (BT, Virgin Mobile and Vodafone) are involved in multiple sectors. For these companies, we estimated the proportion of GVA attributable to fixed services based on the proportion of revenue attributable to fixed services.
- We were unable to gather information for all providers. To account for this, we applied an uplift to GVA based on the market of the providers that were not included in our analysis. This involved calculating the estimated GVA of operators excluded from the analysis based on TalkTalk's GVA relative to its market share. [453]

A.4.5 - AVIATION

[450] Operators reported results using different financial year ends (either March or December). To calculate GVA in 2019, we used the companies' reports up to 31st Dec 2019 (if it reported to a December year-end) or 31st March 2020 (if it reported to a March year-end).

[451] These were BT, Virgin, TalkTalk, Vodafone, Gigaclear and KCOM. We were unable to collect data on Sky's fixed activities as its financial statements did not report the information necessary to separate GVA from fixed services from GVA from broadcasting and mobile services.

[452] Operators reported results using different financial year ends (either March or December). To calculate GVA in 2019, we used the companies' reports up to 31st Dec 2019 (if it reported to a December year-end) or 31st March 2020 (if it reported to a March year-end).

[453] TalkTalk was used as the majority of operators missing from the analysis are access seekers.

Using the approach set out in **Section A.3.1**, we use data from the ONS to calculate GVA from the commercial satellite sector (using the SIC code 51 air transport and 52.23 service activities incidental to air transportation)[454].

A.4.6 - MARITIME

Using the approach set out in **Section A.3.1**, we use data from the ONS to calculate GVA from the commercial satellite sector (using the SIC code 50 water transport and 52.22 service activities incidental to water transportation)[455].

[454] SIC code 51 includes the “transport of passengers or freight by air or via space”. SIC code 52.23 includes the operation of terminal facilities, airport and air traffic control activities and ground service activities on airfields.

[455] SIC code 50 includes the “transport of passengers or freight over water”. SIC code 52.22 includes the operation of terminal facilities such as harbours or piers, navigation, pilotage and berthing activities, salvage activities and lighthouse activities.

Annex B - FURTHER EVIDENCE ON ENVIRONMENTAL EXTERNALITIES

This Annex sets out further information on the environmental impact of the mobile services and broadcasting sectors.

B.1 - MOBILE SERVICES

As is set out in the main body of the report, mobile services can generate positive environmental externalities. The GSMA and the Carbon Trust studied two mechanisms by which mobile technologies can enable emissions reductions, set out below.

- Behaviour changes from the use of smartphones (such as reduced travel and greater switching from higher emission transport to public transport).
- Through the use of smart technologies, such as:
  - Buildings – the automation of building management systems, smart meters and HVAC control systems;
  - Energy – mobile allows for the functioning of smart grids by using machine-to-machine (M2M) communication to monitor and regulate energy demand and transmission.
  - Transport and Cities – the incorporation of traffic monitoring and management technologies help prevent traffic delays and allows drivers to maintain consistent speeds, saving fuel and reducing emissions. Vehicle monitoring telematics can influence fleet driver behaviour, further driving down emissions.
  - Manufacturing – emissions can be avoided by using mobile-enabled inventory management systems, which drive efficiencies through monitoring and automation. This can reduce the need for storage space, requiring less energy for lighting and cooling.
  - Agriculture – precision farming, for example through the use of drones or monitoring equipment using mobile spectrum, can help farmers reduce resource wastage and increase yields.[456]

Despite the significant positive environmental externalities that mobile services enable, they also generate negative environmental externalities in the form of emissions. There are two predominant channels via which mobile spectrum generates carbon emissions:

- through the emissions associated with the equipment and processes used to deliver mobile spectrum (i.e. emissions generated by mobile network operators themselves); and
- through emissions associated with the (downstream) activities enabled by mobile spectrum use (e.g. the manufacture and use of mobile phones to, for example, stream videos).

[456] Mckinsey & company, 2020. Agriculture's connected future: How technology can yield new growth. Available at https://www.mckinsey.com/industries/agriculture/our-insights/agricultures-connected-future-how-technology-can-yield-new-growth [Accessed 7th March 2022].

In 2019, the GSMA and the Carbon Trust attempted to quantify both the positive and negative externalities generated by mobile services worldwide.[457] They estimated that annually, the mobile sector emitted 220 MtCO2e per year (approximately 0.4% of global emissions). This included both emissions by network operators and from the manufacture and use of mobile phones. However, they also estimated that mobile services, through the emission saving channels described above, enabled 2,135 MtCO2e of avoided emissions. These results imply a 10:1 "enablement ratio" of positive to negative environmental externalities. While this study was done at a global level, and UK specific conclusions cannot be drawn with certainty, the outcome does suggest that mobile services can play an important role in the country's climate goals.

Focusing on the UK specifically, there is further evidence to suggest that any "enablement effect" could increase over time. Each of the four UK MNOs has, to varying degrees, announced Net Zero commitments which may effectively eliminate or drastically reduce the portion of the negative externality created by mobile services (see **Table 20** below).

TABLE 20 UK MNO NET ZERO COMMITMENTS

MNO	Net Zero Commitment
Vodafone	Own operations by 2030. Full carbon footprint by 2040.
O2	Own operations by 2025. Reduce supply chain emissions by 30% by 2025.
BT	Own operations by 2030. Supply chain and customer emissions by 2040.
Three	In the process of setting a Net Zero target year in collaboration with the Carbon Trust.

Source: O2, see: https://news.o2.co.uk/press-release/o2-set-to-become-uks-first-net-zero-mobile-network/; BT, see: https://newsroom.bt.com/bt-group-accelerates-net-zero-targets-and-launches-campaign-to-get-the-nation-talking-about-climate-change/; Vodafone, see: https://www.vodafone.com/sustainable-business/our-purpose-pillars/planet/net-zero-by-2040; Three, see: http://www.three.co.uk/social-commitment/environment [Accessed 7th March 2022].

Furthermore, UK MNOs have already taken action to internalise parts of their contribution to the negative environmental externality. For example, in 2021, Vodafone reached its target for every area of its UK business (network, data centres, retail stores and offices) to be 100% powered by electricity from renewable sources, a move which has also been made by BT/EE.[458][459] Similarly, since 2020, 94% of Three's network and buildings have used renewable energy, and 15% of deliveries were completed using electric vehicles.[460]

Alongside these reductions in MNO emissions, studies have suggested that, through the adoption of 5G and IoT technologies, there is further potential for mobile services to deliver positive environmental externalities

[457] GSMA, 2019. The Enablement Effect. Available at https://www.gsma.com/betterfuture/wp-content/uploads/2019/12/GSMA_Enablement_Effect.pdf [Accessed 7th March 2022].

[458] Vodafone, 2021. Vodafone hits a renewable milestone in the UK achieving an important next step in its 'net zero' ambitions. Available at: https://newscentre.vodafone.co.uk/press-release/vodafone-hits-uk-renewable-milestone-on-road-to-net-zero-carbon-emissions/ [Accessed 7th March 2022].

[459] EE, The Environment. Available at: https://ee.co.uk/our-company/corporate-responsibility/being-responsible/the-environment [Accessed 7th March 2022].

[460] Three, Reducing our footprint. Available at: https://www.three.co.uk/social-commitment/environment [Accessed 7th March 2022].

in the UK over time. An analysis in 2020 by WPI Economics, commissioned by Vodafone, estimated there is potential to reduce annual UK emissions by 2.7-4% through the use of 5G and IoT technologies in smart manufacturing, agriculture and transport.[461] A separate WPI paper estimated that smart building technology could reduce emissions from UK buildings by 5-10%.[462]

B.2 - BROADCASTING

This section describes the environmental impact of the TV and radio broadcasting sectors.

B.2.1.1 - TV BROADCASTING

The energy required to distribute and view TV content can be substantial and generates a negative externality in the of form carbon emissions. This energy usage varies by platform and occurs at all stages of the broadcasting value chain, from the preparation of content (e.g., encoding and multiplexing), to distribution by broadcasters (e.g., the use of transmitters) and TV set usage by consumers.

A study estimated the BBC's total TV broadcasting energy usage in the 2019/20 financial year across each of its platforms – terrestrial (DTT), satellite (DTH), cable, IPTV and iPlayer.[463] This showed that satellite viewing was the largest contributor to the BBC's environmental footprint (40%) and the vast majority of all energy usage (94%) came from the consumption of content (i.e. power for TV sets and set-top boxes) rather than preparation and distribution.[464] As audience sizes across platforms (and broadcasters) are not equal, the study also estimated the energy intensity of each TV platform (measured using the average energy consumption per device-hour of each platform), *"allowing for a better comparison of their relative environmental impacts"*. The results, displayed in **Figure 32**, show that digital terrestrial broadcasting is the least energy-intensive broadcasting platform when compared to cable, satellite and streaming, which can use up to 2.5 times more energy per-device-hour.

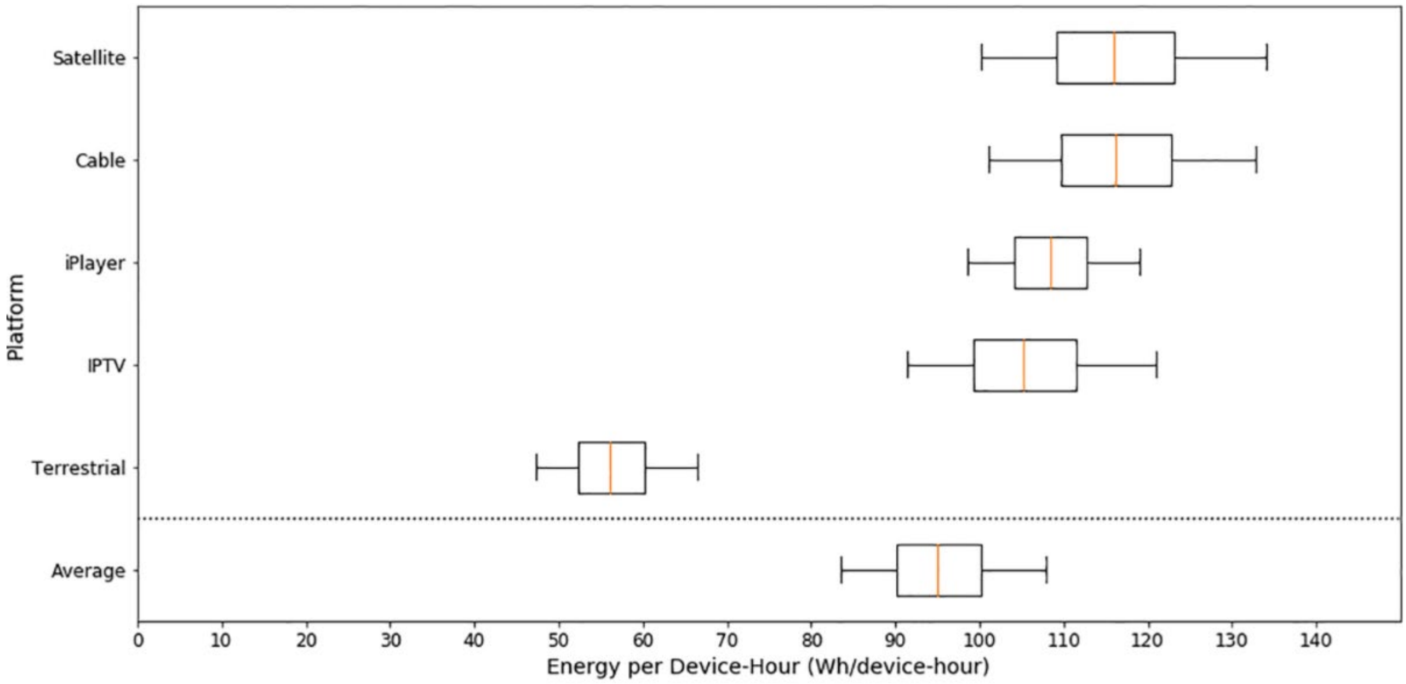
[461] WPI & Vodafone, 2021. Connecting for Net Zero: Addressing the climate crisis through digital technology. Available at: https://newscentre.vodafone.co.uk/app/uploads/2021/09/Connecting-Net-Zero-090921-Pages-1.pdf [Accessed 7th March 2022].

[462] WPI & Vodafone, 2020. Digital Buildings: How smart technology can decarbonise buildings and combat climate change. Available at: https://newscentre.vodafone.co.uk/app/uploads/2020/11/Vodafone-Digital-Buildings-Report-201123-Pages.pdf [Accessed 7th March 2022].

[463] Total energy usage was estimated to be 1,789 GWh, comparable to 0.6% of UK electricity use and equating to 0.1% of UK carbon emissions in 2019. See BBC, 2021. The carbon impact of streaming: an update on BBC TV's energy footprint. Available at: https://www.bbc.co.uk/rd/blog/2021-06-bbc-carbon-footprint-energy-envrionment-sustainability [Accessed 7th March 2022].

[464] Satellite viewing was followed by terrestrial viewing (19%), IPTV viewing (17%), cable viewing (16%) and iPlayer viewing (8%).

FIGURE 31 AVERAGE ENERGY CONSUMPTION PER DEVICE-HOUR BY TELEVISION PLATFORM (2019-20)



Source: BBC, 2021. The carbon impact of streaming: an update on BBC TV's energy footprint. Available at: https://www.bbc.co.uk/rd/blog/2021-06-bbc-carbon-footprint-energy-envrionment-sustainability [Accessed 7th March 2022].

Despite the emissions produced by the sector, broadcasters have already made attempts to mitigate their environmental impact. For example, the BBC's *"Greener Broadcasting"* strategy committed to reducing energy consumption by 10% and carbon emissions by 24% between 2015 and 2022, after it had already reduced both measures by 40% between 2008 and 2016/17.[465] Other examples include ITV, reducing its operational emissions by 27% between 2019 and 2020, and Sky by 22% between 2018 and 2020.[466][467] Finally, a number of broadcasters have announced Net Zero commitments, suggesting that broadcaster-related emissions will continue to fall. This group includes the BBC, Sky, ITV and Channel 4 each of whom has committed to reaching Net Zero emissions by 2030.[468][469][470][471]

[465] BBC, 2017. Greener Broadcasting. Available at: https://downloads.bbc.co.uk/outreach/Greener_Broadcasting_2018_ENG-FINAL.pdf. [Accessed 7th March 2022].

[466] ITV, 2020. Social Purpose Report. Available at: https://www.itvplc.com/~/media/Files/I/ITV-PLC/download/itv-social-purpose-impact-report-2020.pdf [Accessed 7th March 2022].

[467]Sky, 2020. Impact Report. Available at: https://static.skyassets.com/contentstack/assets/bltdc2476c7b6b194dd/blt413353949e85b2cd/Sky_Impact_Report_2020_Seeing_the_Bigger_Picture.pdf [accessed 7th March 2022].

[468] ITV, 2020. ITV commits to net zero carbon emissions. Available at: https://www.itvplc.com/socialpurpose/news/2020/itv-commits-to-net-zero-carbon-emissions [Accessed 7th March 2022].

[469] Channel 4, Environment, Available at: https://www.channel4.com/corporate/about-4/operating-responsibly/environment [accessed 7th March 2022].

[470] Sky, 2020. Sky commits to becoming net zero carbon by 2030. Available at: https://www.skygroup.sky/article/sky-commits-to-be-net-zero-carbon-by-2030 [Accessed 7th March 2022].

[471] BBC, 2020. BBC sets out the path to Net Zero by 2030. Available at: https://www.bbc.co.uk/mediacentre/2021/bbc-path-to-net-zero [Accessed 7th March 2022].

B.2.1.2 - RADIO BROADCASTING

Radio broadcasting can create negative environmental externalities in the form of carbon emissions. This occurs in two ways. Firstly, from the energy required for broadcasters to transmit radio services and secondly, from the energy required to consume services on user devices.

In terms of the energy required to transmit radio services by broadcasters, **Table 21** shows that of the 114GWh/year of energy used by the UK radio industry (representing 0.03% of total UK energy use), roughly three quarters are used by analogue broadcasts (FM/AM) and one quarter by digital broadcasts (DAB). This is in part due to the use of multiplexing in digital broadcasts, which compresses and bundles a number of radio services into a single frequency before transmitting it digitally, making DAB broadcasts on a per-station basis more energy-efficient than AM/FM.

TABLE 21 ENERGY USAGE BY RADIO TRANSMISSION PLATFORM

Platform	Energy Use (GWh/year)
National FM	31.3
National AM	30.2
National DAB	19.1
Local & Nations FM	14.3
Local & Nations AM	10.2
Local DAB	9.1
Total	**114.3**

Source: DCMS, 2021. Digital Radio and Audio Review. Available at: https://www.gov.uk/government/publications/digital-radio-and-audio-review/digital-radio-and-audio-review#chapter-1----background-and-scope-of-the-review [Accessed 7th March 2022].

While broadcasters' energy use does generate negative externalities, many are taking steps to reduce their emissions. As discussed previously, the BBC's *"Greener Broadcasting"* strategy committed to reducing energy consumption by 10% and carbon emissions by 24% between 2015 and 2022, and the BBC has set a Net Zero target for 2030.[472][473]

The second part of the emissions generated from radio broadcasting is those generated by user devices during the consumption of radio services. A paper evaluating the energy footprint of BBC radio services in 2018, estimated this was the most energy-intensive part of the end-to-end chain, representing 73.4% of energy usage. Transmission by broadcasters, on the other hand, represented only 26.5%.[474]

The devices used across different radio broadcasting platforms (AM/FM/DAB, digital television or internet protocol) can vary, from radio sets to television sets. These devices all have different energy-use intensities. As such, the energy used from consuming radio services on a specific platform depends on the specific

[472] BBC, 2017. Greener Broadcasting. Available at: https://downloads.bbc.co.uk/outreach/Greener_Broadcasting_2018_ENG-FINAL.pdf [Accessed 9th March 2022].

[473] BBC, 2021. BBC sets out the path to Net Zero by 2030, 2021. Available at: https://www.bbc.co.uk/mediacentre/2021/bbc-path-to-net-zero [Accessed 9th March 2022].

[474] Chandaria & Fletcher, 2020. The energy footprint of BBC radio services: now and in the future.

devices being used. Per-device-hour, the BBC paper estimated that DAB was the least energy-intensive platform (9.3 Wh/device-hour), followed by FM (13.0 Wh/device-hour), internet protocol (22.5 Wh/device-hour), AM (29.3 Wh/device-hour) and digital terrestrial television (80.6 Wh/device-hour).

The sum of this evidence points to the relative energy efficiency of DAB and FM in the transmission and, more importantly, the consumption of radio services compared to AM or DTT broadcasts. The importance of device energy use has been noted by DCMS in the context of the transition of radio from analogue to digital technologies: *"In conclusion, switching off analogue radio platforms would produce a useful, albeit relatively modest, reduction in carbon emissions, but is only a part of the overall carbon footprint of radio listening. Listening device energy consumption is more significant and the choice of digital listening device in any migration to digital may offset a large part of the analogue transmission energy savings".*

Annex C - ASSUMPTIONS FOR MOBILE SPECTRUM DEMAND MODEL AND TECHNICAL CHARACTERISTICS OF WI-FI

This section sets out the underlying assumptions used for the mobile spectrum demand model, including growth forecast assumptions, spectral efficiency assumptions and spectrum quantity assumptions. It also provides the technical performance characteristics of Wi-Fi technologies.

C.1 - MOBILE DEMAND MODEL ASSUMPTIONS

Input assumptions for mobile traffic demand and capacity

In 2022, there is approximately 1100 MHz of spectrum available across the MNOs in the UK. In order to illustrate how excess mobile traffic impacts demand on spectrum, we have developed a simplified spectrum demand model based on a range of assumptions. We have assumed a theoretical mobile operator with access to one-quarter of the available (1100 MHz) spectrum[475] that has deployed a macro network in Central London, which could be shared with one other operator[476]. The cell sites can support all spectrum bands up to 5 GHz. Small cells will support mmWave bands and are built separately to the macro network.

In this theoretical model, we have assumed the operator can invest in new spectrum bands and also can upgrade its network to support additional spectrum and increase spectral efficiency. This further assumes revenue trends remain steady, i.e., increase with inflation over the whole time frame, and thus that the operators have sufficient income to support any upgrades necessary.

The table below provides a list of other input assumptions used for the model. The rationale for using Central London as the location is based on the following:

- the majority of mobile network traffic congestion arises in urban and dense urban areas, with Central London as one example - the same would apply to other major UK cities; and
- central London is representative of a dense urban area, with high population density, with a well-established network deployment of sites, which can only grow at a relatively slow rate due to many rooftop sites already being fully occupied by operators and limited additional access.

TABLE 22 INPUT ASSUMPTIONS FOR CENTRAL LONDON TRAFFIC DEMAND

PARAMETER	VALUE	UNIT	COMMENT
Number of smartphone users	332,515	Subscribers	We assumed a day time/rush hour adult population 1.3 million[477] in Central London all of them having a mobile subscription and assumed one quarter of these are subscribers to our theoretical operator.

[475] This assumption has been used to simplify the split of available spectrum to make the demand estimations in the model straightforward, however it is acknowledged that MNOs acquire spectrum based on commercial and strategic decisions. In practice each MNO has a wide variety of spectrum holdings in different bands, which they use and flex to provide their service.

[476] This assumes a similar situation in the UK, where four MNOs largely share access across two national cellular networks.

[477] ONS Crown Copyright Reserved [from Nomis on 14 April 2022] https://www.nomisweb.co.uk/query/construct/summary.asp?menuopt=200&subcomp=

PARAMETER	VALUE	UNIT	COMMENT
FWA households	62,500	Households	Based on 1 million total FWA connections[478] in the UK in 2021, assuming one quarter of the 250,000 households are in Central London.
Area	129	km2	Office of National Statistics
Number of macro sites	Variable	Sites	Assume slow growth of macro sites in Central London due to the significant difficulties in finding new macro sites on buildings in Central London as site locations are full.
Mobile data traffic	Variable (Low 25% p.a.) (Mid 35% p.a.) (High 50% p.a.)	GB/month	We assume 7.3 GB/month average traffic per smartphone in 2020 based on it being the mid-range from across the different sources, such as Ericsson Mobility report, GSMA and ITU. We assume 250 GB/month per household for FWA based on Ofcom Connected Nation report. The low, mid and high growth start with the different percentages and slows every 5 years to represent saturation in demand.
Spectrum	275 (starting in 2020 then increasing over time)	MHz	We assume one quarter of the total 1100 MHz available spectrum to MNOs in 2020. This increases over time as more spectrum becomes available to MNOs.
Spectral Efficiency	Variable	Bit/s/Hz	The spectral efficiency assumed varies for different band ranges and takes into account the technology evolution expected per year (e.g. increasing amount of MIMO).
Wi-Fi offload	0%	%	The value of data traffic per user we have used as the base-line constitutes the average of current mobile network traffic, and thus already takes account of Wi-Fi offload. Though the amount of offload may change we have decided not to account for the variations, which may take place, as these are unknown and likely to be relatively small.
mmWave offload	Variable	%	The model will only put traffic on mmWave when mid-band is congested.

Source: LS telecom.

We also provide more details on the mobile traffic demand growth scenarios for low, mid and high below. We assume the mobile traffic growth follows an S-curve, this is because the trend is over a 15-year period and assumes continued growth at the same rate is not sustainable over such a long period of time. This is

[478] Metrics for the UK independent network sector, INCA, May 2021 https://www.inca.coop/sites/default/files/inca-point-topic-report-2021.pdf

due to a range of factors but mainly the uncertainty of the continued rate of growth impacted by economic and social factors (i.e. economic slowdown, wide-scale adoption). We assumed an initial growth period over five years of 25% year-on-year growth for the low scenario, 35% year-on-year growth for five years for the mid scenario and 50% year-on-year growth for five years for the high scenario. Following the S-curve, this growth rate declines steadily over time as demand for mobile connectivity begins to move towards saturation with users maximising their usage.

The amount of available spectrum will increase over time, noting specifically the availability of mmWave spectrum in the 25–26.5 GHz range[479] and 40.5–43.5 GHz range. In addition, based on feedback from stakeholders, other spectrum bands were identified for mobile including in the upper 6 GHz range (6425–7125 MHz). This band has been identified for potential allocation to mobile services (IMT) and will be discussed at the next World Radio Conference in 2023. In addition, Ofcom has published a consultation[480] on shared licences for local, low-power indoor use of the upper 6 GHz band (6425-7070 MHz). The proposal is to add the band to Ofcom's Shared Access licence framework for low-power indoor use, which means enabling access to almost 650 MHz of spectrum in a controlled indoor environment under a lightly licensed framework.

We assume for future mobile spectrum, that a range of new bands could become available (mainly on a shared basis) predominantly in the mid-band range[481]. These include:

- 1400 MHz - total amount 25 MHz, this becomes available by way of sharing with MOD in our time frame;
- 2300 MHz – total amount 40 MHz, this becomes available by way of sharing with MOD in our time frame; and
- 4800–4990 MHz – total amount 100 MHz, this becomes available by way of sharing with MOD much later in the time frame.

In our analysis, we determine whether additional spectrum would be needed in the mid traffic demand scenario. The spectrum could be made available from the upper 6 GHz (6425–7125 MHz) portion – a total of 700 MHz. The earliest it would possibly become available is around 2030 based on WRC-23 making an IMT designation of the band and Ofcom making the spectrum available to MNOs within 7 years after WRC-23. In turn, this would mean in practice (if it is needed) that the band would be shared between licensed outdoor users and lightly licensed indoor users.

TABLE 23 MOBILE TRAFFIC GROWTH SCENARIOS

SCENARIO	INITIAL GROWTH RATE	OVERVIEW
Low	25%	4G networks are becoming congested, and there is limited investment in networks by MNOs, 5G rollout slows down, and the 5G uptake is limited due to tightened

[479] The full 26 GHz band (24.25–27.5 GHz) is not available for outdoor use to ensure the protection of satellite systems.

[480] Enabling spectrum sharing in the upper 6 GHz band Shared licences for local, low-power indoor use of the upper 6 GHz band (6425-7070 MHz), Ofcom, Feb 2022.

[481] It is noted that there currently remains some uncertainty how much spectrum could become available on a shared basis for 1400 MHz, 2300 MHz and 4800 MHz bands and therefore, the assumption is based on the optimistic view that sharing with these MOD-used bands will be possible within the study timeframe.

SCENARIO	INITIAL GROWTH RATE	OVERVIEW
		consumer spending. Low/slow uptake in new devices and chip shortage have impact on the development of new devices also resulting in technology evolution slowing down. Mobile network consumption flattens out due to increased tariffs and the removal of unlimited plans/caps on data plans.
Mid	35%	MNOs are continuing to invest in networks to ensure consumers have a good quality experience. Steady growth in 5G rollout and uptake of 5G services by consumers. This leads to greater consumption of 5G networks and rising demand. Availability of more bandwidth in the mid-2020s results in the easing of network congestion and the opportunity for MNOs to continue evolving network speeds and capacity. Continued steady growth and confidence in consumer spending with the continued upgrade of devices every 2-3 years, but initially, this is limited to tech adopters.
High	50%	MNOs conclude the 5G network rollout early, resulting in a rapid uptake of 5G services. Technology evolution and uptake are in lockstep, with consumers eagerly demanding richer (high quality) services. This results in a rapid increase in spectrum demand that puts networks in temporary congestion. More spectrum soon becomes available but does not diminish demand. Only the most sophisticated networks minimise congestion ensuring networks operate at or near peak speeds well into the late 2020s and early 2030s. There is high confidence in consumer spending leading to wide adoption of the latest technology (chip shortage resolved by mid-2020s), and mobile network usage remains high. By late the 2020s, the majority of users are on 50-100 GB+ per month on a wide range of 5G tariffs or unlimited packages.

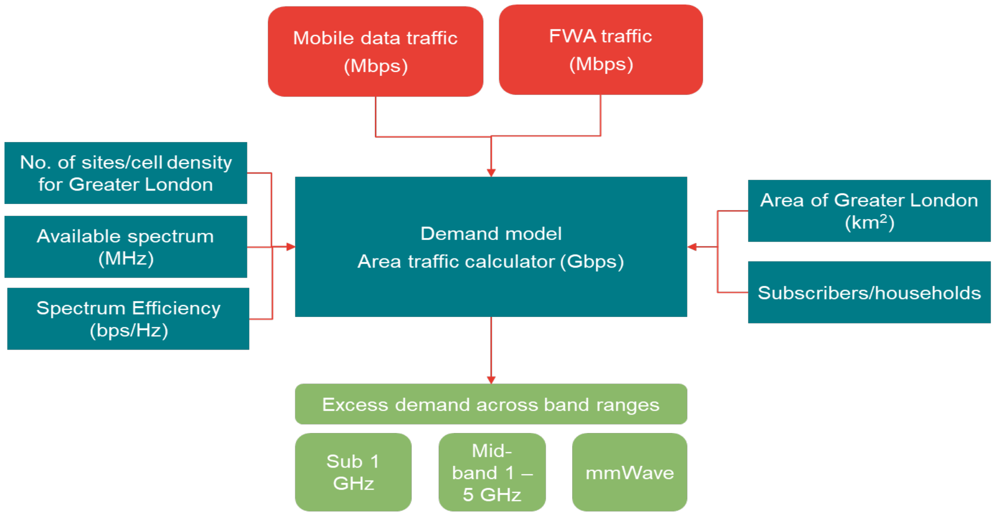
Source: LS telcom Frontier Economics.

We describe the likelihood of each of the three mobile traffic demand forecast scenarios occurring in **Section C.4**. We determine the most probable is the mid traffic demand case. This is because it is most aligned with the growth assumptions given the uncertainty over the 10-15-year time frame. We highlight below our high-level description of the rate at which mobile traffic growth will evolve over time over low, mid and high growth rates.

Structure of the model

The structure of the demand model is shown in the diagram below.

FIGURE 32 STRUCTURE OF MOBILE DEMAND MODEL



Source: LS telcom.

We utilise the mobile data traffic from smartphone users and FWA traffic as the main traffic demand inputs to the model. We then use the number of subscribers and households to calculate the total traffic for the whole Central London area, considering the subscriber population who live, travel and work in the area during the Busy Hour period.

It is noted that the model takes into account both average and peak traffic distributed over the whole network. The model is not able to take into account specific locations of high congestion, which in practice would represent less than 5% of the urban network. As such, the model represents a reasonable level of peak demand without trying to handle the small number of sites which may be overloaded. We believe that this approach allows us to consider the spectrum demand across the majority of the network rather than addressing only the very highest of high peak demand situations.

We calculate the capacity available by multiplying the total quantity of downlink spectrum available in each of the bands (sub-1 GHz, 1-5 GHz and above 5 GHz) over the time frame with the Spectral Efficiency associated with each band range and multiply by the total number of sites for the area. We have used downlink spectrum only in this analysis because a majority of the traffic driving congestion is in the downlink, such as video streaming both on smartphones whilst at home using FWA broadband.

An example of the capacity input scenario is shown in the table below.

TABLE 24 EXAMPLE CAPACITY INPUT SCENARIO

	SUB 1 GHZ	1–5 GHZ	MMWAVE
Spectrum	No increase over time	Gradual increase over time	No increase over time
Spectral Efficiency (gradual increase over time)	1.9-3.5	6-18	7-21

	SUB 1 GHZ	1–5 GHZ	MMWAVE
Sites (gradual increase over time)	2% yearly growth	5% yearly growth	7% yearly growth

Source: LS telcom.

The spectral efficiency (bit/s/Hz) is derived from the technology capability for a particular frequency range which, in turn, provides increasing network capacity over the time frame. For example, we assume a fixed spectral efficiency of 2 bit/s/Hz for the mid-case scenario over the initial five-year period. This will gradually increase to 3 bits/s/Hz over the following five-year period as the operator upgrades its network by adding more MIMO (e.g. 4x4 to 8x8). It should be noted that the gradual evolution of spectral efficiency is based on the gradual upgrade of the network by operators. There can be up to a three-year lag for the whole network to benefit from technology upgrades.

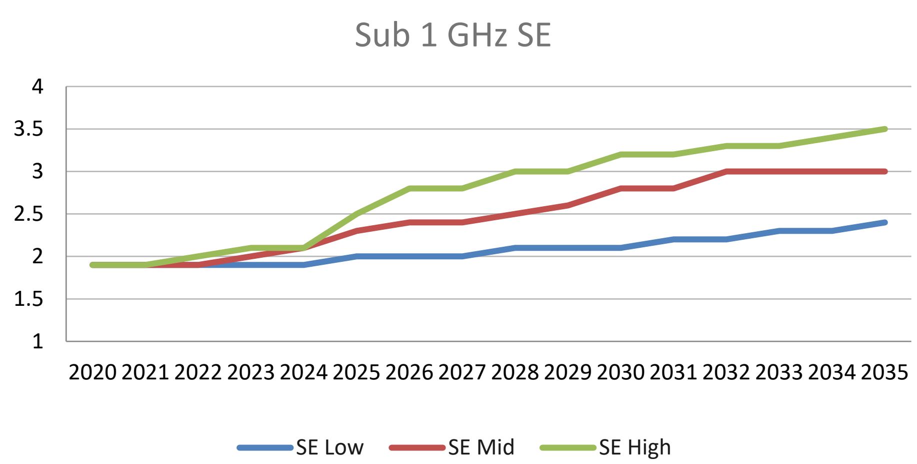
We use the calculated area demand (in Mbits/s) and compare it against the calculated capacity (in Mbits/s) for each band range to determine whether there is excess demand in each year. We show in the results the amount of traffic growth for low, mid and high scenarios overlaid with the increasing capacity for each scenario.

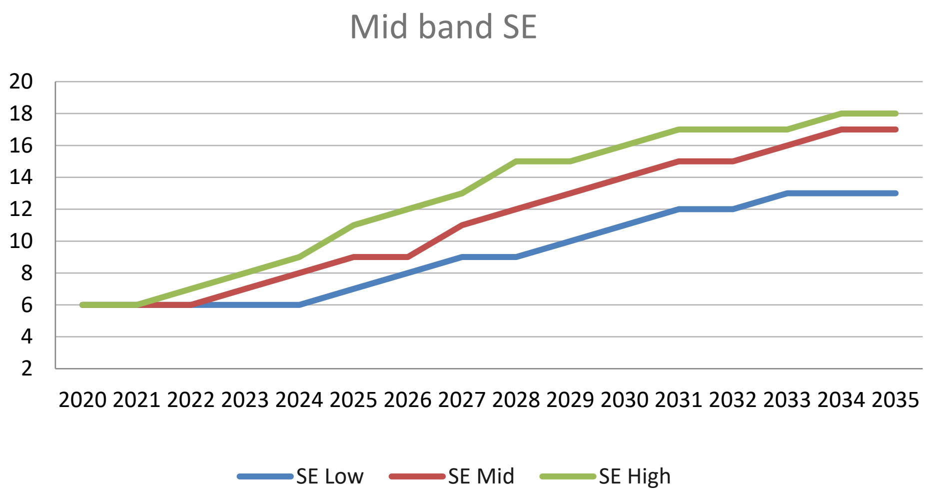
This output identifies frequency ranges in which there is likely to be excess demand, and this is where the focus for the identification of new spectrum bands should be.

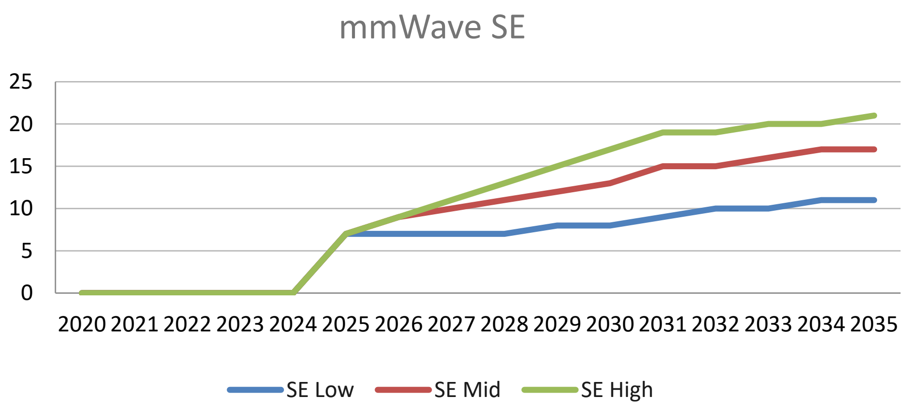
C.2 - SPECTRUM EFFICIENCY

We assumed a gradual evolution of spectral efficiency for the low, mid and high case scenarios. The intention is to demonstrate that network performance and capacity increase evolves gradually over time and on a per-year basis. The charts below show how the spectral efficiency evolves for each scenario and each of the spectrum ranges, sub 1 GHz, Mid-band (1–5 GHz) and mmWave.

FIGURE 33 SPECTRAL EFFICIENCY EVOLUTION OVER A 10-TO-15-YEAR TIME FRAME







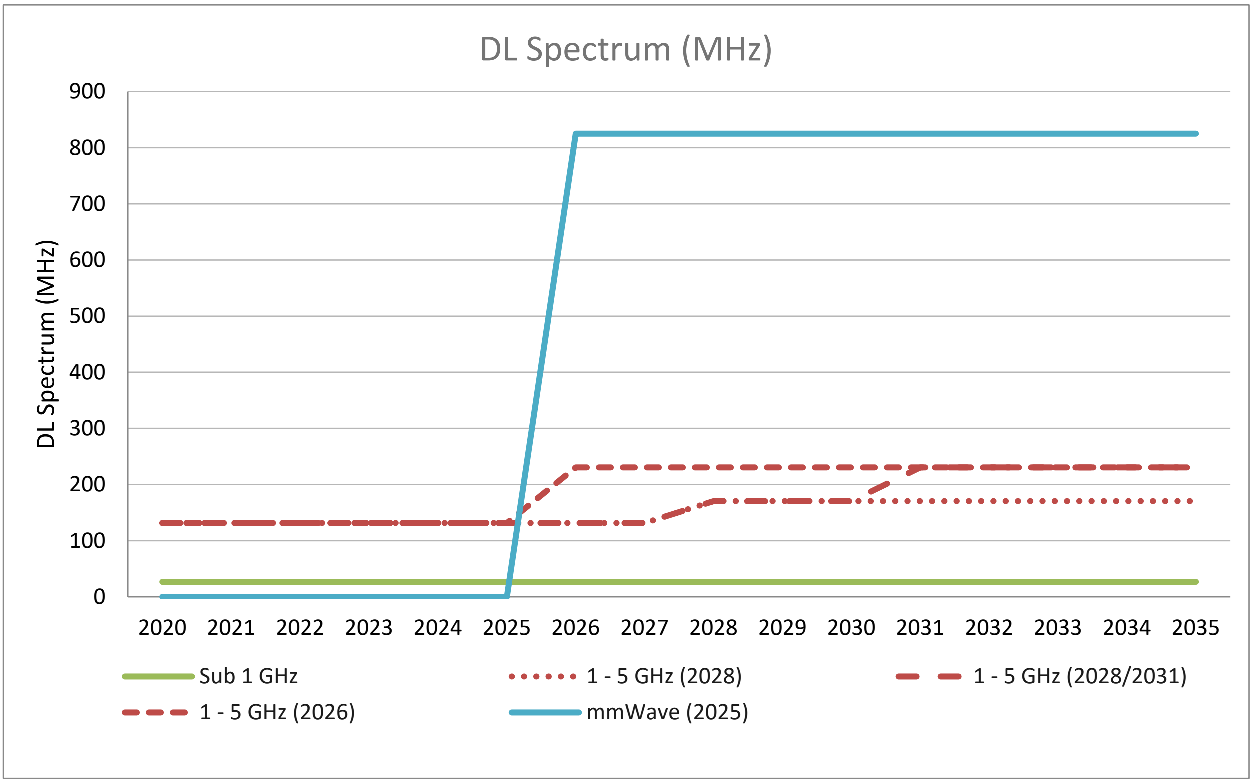
Source: LS telcom.

The spectral efficiency is driven by improved technology evolution, so this could include a new 3GPP technology release, for example, from Release 15 to Release 16, which will improve the technology's performance. In addition, spectral efficiency improvements are also made by adding MIMO to base station deployments. For example, moving from 4x4 MIMO to 8x8 MIMO or 16x16 MIMO can improve gains in spectral efficiency by factors of 2-3 times.

C.3 - SPECTRUM BAND EVOLUTION

We assumed a gradual evolution of the available spectrum for the low-, mid-and high-case scenarios. The intention is to demonstrate that spectrum becomes available either from sharing or release by Ofcom but at certain points over the study time frame. The chart below shows the timescales assumed for when particular bands would become available.

FIGURE 34 SPECTRAL BAND RELEASE OVER A 10-TO-15-YEAR TIME FRAME



Source: LS telcom.

We have assumed in the above charts the following spectrum releases over the 15-year time frame:

- Sub 1 GHz[482]: No additional spectrum released over the time frame. This is because we assumed 600 MHz (currently assigned to DTT) will not be available until 2034 and, therefore, not available for mobile use until after 2035.
- Mid-band (1-5 GHz): There are several bands released in this time frame representing three spectrum options (in terms of quantity and timescale of availability) across the 1-5 GHz range. In each case we assume there are 65 MHz of spectrum at 1400 MHz and 2300 MHz available based on either sharing or release from the MOD, with over half available to our theoretical operator. In addition, we assume a further 100 MHz is available in the 4.8–4.99 GHz range to our operator, most likely shared with the MoD, which arises at different times across the time frame as shown in the chart above.
- mmWave (24.25–27.5 GHz and 40.5 – 43.5 GHz): In practice, the available quantity that can be used for outdoor mobile deployments to soak up maximum capacity in the 26 GHz band is actually 25–27.5 GHz, this is because the lower 750 MHz portion has technical constraints applied to protect adjacent satellite services. This leaves 2500 MHz to use across four operators. We, therefore, assumed our theoretical operator has access to 625 MHz in the band[483]. We further dedicate 60% of the band to downlink traffic. In the 40.5 – 43.5 GHz band Ofcom announced in its

[482] We note that deploying sub 1 GHz spectrum in dense urban areas can be difficult due potential interference, but we assume the band serves users outside high capacity band coverage and indoor users predominantly

[483] We note that the amount of mmWave spectrum that could be held by each MNO could vary widely depending on a range of commercial and market factors but for simplicity assumed our theoretical operator obtains one quarter of the available mmWave spectrum

consultation[484] that operators already hold nationwide licences, though the terms of the licences do not permit mobile use. Ofcom is consulting on options to enable the 40 GHz band for new uses, including varying existing licences and revoking and re-assigning licences. Similar to the 26 GHz band, we have assumed our theoretical operator could access 750 MHz with 60% dedicated to downlink traffic.

C.4 - MOBILE DATA TRAFFIC GROWTH ASSUMPTIONS

We have assumed a range of mobile data traffic growth assumptions so that we can model the different capacity cases, which in turn determines a capacity crunch over the 15-year time frame.

We have assumed three growth scenarios, Low, Mid and High each representing a possible scenario with regards to the rate of increased mobile data consumption. In the main report, we describe the scenario and the drivers and certain possible outcomes occurring. We provide below a high-level analysis of the likelihood of each scenario occurring based on assumptions and justification criteria.

The likelihood rating is scored out of five for each assumption, and a total score of 30 is possible with the scenario achieving the highest score. For example, if the score for investment potential in ‘low’ is 2 and in ‘mid’ is 3, then ‘high’ is 0 - as the maximum points available are five.

TABLE 25 TRAFFIC GROWTH ASSUMPTIONS

ASSUMPTION	LIKELIHOOD (1-5)	JUSTIFICATION
LOW TRAFFIC GROWTH		
Investment potential	2	MNOs have limited funding for investment in networks due to the recent costs of spectrum. In addition, revenues are insufficient to provide enough funding for wide-scale investments in the next 2-3 years.
Rollout of 5G	2	MNOs may slow down their rollout networks due to a lack of investment. There is limited site availability in some cities with challenges to access locations.
5G uptake rate	1	This would be driven by an economic slowdown and a reduction in affordability by consumers. Inflation and other pricing pressures on utilities may divert spending away from high tech adoption.
Tech evolution	1	The pace of tech evolution could be impacted due to limited investment and attention by vendors and R&D departments turning to other non-mobile solutions.
Mobile network consumption	1	General network consumption would reach a plateau if no new interesting content were to emerge. Linked to a slowdown in tech evolution, handsets and other device capabilities would not support higher resolutions.

[484] Ofcom, 2022 enabling mmWave spectrum for new uses, Making the 26 GHz and 40 GHz bands available for mobile technology. See: https://www.ofcom.org.uk/__data/assets/pdf_file/0027/237258/mmwave-spectrum-condoc.pdf

ASSUMPTION	LIKELIHOOD (1-5)	JUSTIFICATION
Data plans changes	1	Removal of unlimited caps would arise if congestion on networks becomes excessive as operators would not be able to cope with the volume of traffic and therefore impose tighter caps and throttling back speeds of intensive users of the network.
MEDIUM TRAFFIC GROWTH		
Investment potential	2	MNOs would continue to invest in their networks to rollout 5G to meet their coverage commitments, minimise network congestion and minimise churn, but maximise the quality of service. For example, Three UK proposed to spend £2 billion on infrastructure investment for its 5G roll out.[485]
Rollout of 5G	2	MNOs will continue to rollout 5G networks to cover as many towns in the UK as possible and realise a return on investment as soon as possible. 1.5 billion has already been spent on network rollout, with plans published by MNOs to continue extending 5G coverage.
5G uptake rate	3	5G uptake is growing, as demonstrated by MNOs and global growth in 5G subscribers. This will fall in line with the expansion of coverage into smaller towns and villages.
Tech evolution	3	The pace of tech evolution is not likely to change in the next 10-15 years; R&D departments are still investing billions on new technologies and contributing to standards.[486] Covid-19 did impact the ability to develop standards, but this is considered a small blip by the industry.[487]
Mobile network consumption	3	5G speeds will result in higher mobile network consumption, as proven by MNOs and Ofcom. Uptake is likely to continue to increase, this is based on MNOs expanding their networks to wider populated areas beyond major towns and cities. Users of 5G will likely continue to watch/stream video whilst on the move, and as quality improves, consumption will steadily increase.
Data plans changes	3	Evidence suggests that unlimited data plans lead to increasing usage of mobile networks.[488]
HIGH TRAFFIC GROWTH		
Investment potential	1	MNOs would seek investment from the capital markets to accelerate network rollout to a stage of early completion on the basis they can prepare for a surge in network usage.

[485] Tech radar, 2018. Three reveals £2bn UK 5G investment. See: https://www.techradar.com/news/three-reveals-pound2bn-uk-5g-investment

[486] Nasdaq, 2021. Which Companies Spend the Most in Research and Development (R&D)? See: https://www.nasdaq.com/articles/which-companies-spend-the-most-in-research-and-development-rd-2021-06-21

[487] RCR Wireless, Mar 2020. 3GPP delays 5G standard updates due to COVID-19. See: https://rcrwireless.com/20200326/5g/3gpp-delays-5g-updates-covid-19.

[488] Ofcom, 2022, Mobile networks and spectrum. Meeting future demand for mobile data. See: https://www.ofcom.org.uk/__data/assets/pdf_file/0017/232082/mobile-spectrum-demand-discussion-paper.pdf

ASSUMPTION	LIKELIHOOD (1-5)	JUSTIFICATION
Rollout of 5G	1	All of the UK's populated areas are served with 5G by the end of 2022/early 2023.
5G uptake rate	1	Consumers seek to adopt the latest technology and quality that is delivered by 5G and, given the early completion of the networks, a rapid surge in 5G uptake. This is also driven by special offerings and partnerships by MNOs such as access to sporting events or free channels such as Netflix. This assumes a healthy economic climate with extra disposable incomes for consumers to spend on luxury tech items.
Tech evolution	1	Innovation in mobile technology, both within handsets and networks, sees a rapid acceleration in technology evolution, meaning higher data rates per user and improved features such as gaming experience, AI, AR/VR.
Mobile network consumption	1	As more users take up 5G, all with greater speeds leading to huge growth in mobile consumption, the knock-on effect is a rapid increase in traffic on mobile networks.
Data plans changes	1	Unlimited plans are the norm, with most operators now having few limited or capped plans available. This is due to highly capable networks, with minimal congestion supporting all possible traffic usage, including intensive users who are supported and separately treated by the evolved networks.

Source: LS telcom.

C.5 - MOD-USED BANDS

The following frequency bands are used by the MOD and have been identified for future sharing or release as explained in **section 4.10.1**. The details include current usage and where decisions have already been made on whether sharing is possible or not.

380–400 MHz: This was added to PSSRP because the Airwave network is being shut down by the Home Office, and emergency services will be transitioned to the ESN (provided by EE). However, NATO coordinates the military use in this frequency band, not MOD and it was NATO that agreed to allow 2x5 MHz to be used by emergency services, as in many European nations. In NATO's view, if emergency service use is no longer required, it should be handed back for military use. An additional agreement has been made with NATO whereby when ESN kicks in and usage of Airwave concludes, the gap can be filled by like for like narrowband services. However, when ESN is launched, there will be 7 other sharers (TFL and 3 or 4 different NATO air users – training networks) using the network, so the spectrum will not be empty. The decision for this band is currently on hold, and Ofcom is not actively seeking any work.

406–430 MHz: The situation with this band is similar to 380–400MHz, but includes some important MOD assets. The band plan used is opposite to what is in use in Europe, which makes it difficult for Ofcom to do much else with the spectrum. The option for access to civil users has been opened many times and then closed because it is too difficult to find a suitable solution.

1427–1452 MHz: This band is currently under review within PSSRP with a likelihood of release (or sharing) in the short term. However, it is also part of the modernisation programme within MOD's 'Integrated Review'.

One of the capabilities that use the band will be replaced in 2028/29, and until the decision is made as to what the replacement will be and whether it can use another spectrum, this band is also on hold by agreement with DCMS and Ofcom.

2.3–2.35 GHz: This band is actively being utilised by MOD, and it is the only bit of the 4G spectrum to which MOD has access. It is also used by aeronautical, maritime and land systems. If the MOD were to move out of this band, it would limit their access to the other 4G spectrum. The impact would mean a costly relocation and retuning of equipment.

2.7–2.9 GHz: This band is used for air traffic control for both MOD and CAA and has been explored for the possibility of sharing with mobile users, specifically to try and improve passenger connectivity on trains. Although ,air traffic radars are not used everywhere, and military ones have been rationalised into NATS, Ofcom found[489] the band is not suitable for sharing with track to train communications.

2.9–3.1 GHz: This is a radar band used for maritime, civil and military, as well as some other military users. It would be difficult to achieve sharing in this band because radars do not interact well with other services. It should also be noted that this band has not been included in the 3GPP mobile standards.

3.1-3.3 GHz: The band is of interest to new applications, for example, the joint US, UK and Australia space radar

3.3–3.4 GHz: This band is used for aeronautical services, some of which are going out of service, but NATO will be using the band for another 10 years and conducts missions over the UK. It is also of interest to space radar.

4.4–5 GHz: MOD confirmed that this is an important band for defence, NATO, and NATO partners. It is also where the police are looking to put their drone capabilities, so MoD are looking to share with them. The band also supports MoD drones and is a harmonised drone band for NATO. However, it is also identified as a 3GPP band with limited assignments in Asia Pacific countries[490].

5.35–5.47 GHz: This band has not been actively looked at in PSSRP. The only band in the whole 5 GHz range that has been considered is the 5.725-5.875GHz, to allow more civil FWA.

C.6 - INTRODUCTION OF 6G AND THE POTENTIAL SPECTRUM DEMAND IMPACTS

The global mobile industry and research institutions are still in the early phases of defining the requirements and technology solutions for 6G. It is anticipated that 6G will become available commercially from 2030 onwards, similar to the developments of previous mobile generations, which broadly evolve over a 10-year time frame from early conception through to commercial rollout.

The global research institutions and industry bodies are publishing white papers and articles on the potential enhanced performance characteristics of 6G, the applications that will be enabled and the further improvements this will bring to what is already available. The Institution of Engineering and Technology published a white paper[491] as a guide on 6G for policymakers to shape the direction of the evolution of

[489] Ofcom, Nov 2020, Advice to Government on improving rail passenger access to data services. See: https://www.ofcom.org.uk/spectrum/information/rail-passenger-data-access

[490] Spectrum Positions 4400 MHz–5000 MHz: June 2021, GSA

[491] 6G for Policymakers, The IET, Feb 2021 https://www.theiet.org/media/8766/6g-for-policy-makers.pdf

wireless-based services, networks and technology over the coming 20 years. It presents a range of new 6G services that aim to fuse the virtual, physical and non-physical worlds. These include applications such as 3D extended reality, dynamic 3D digital twinning[492], immersive digital world experiences and fibre-like fixed wireless access. These applications require an ultra-flexible network that can deliver extremely high bit rates and ultra-low latencies to meet the expected seamless and ubiquitous experiences being proposed.

6G aims to be multifaceted and support the next major leap in innovation for connectivity and address a range of social and economic challenges. In the UK, work has been done within the UK Spectrum Policy Forum (SPF) through its Cluster 2, chaired by Professor Stephen Temple, to determine the UK's research capabilities to deliver worthwhile 6G research efforts. A report was published for DCMS by Cluster 2 on the 6G wireless R&D initiative[493], which assessed a range of research programmes across several universities to explore the 'research excellence' that can address five key goals for 6G. These include:

- widespread coverage;
- innovation in spectrum management;
- economic viability;
- net zero targets; and
- seamless connectivity.

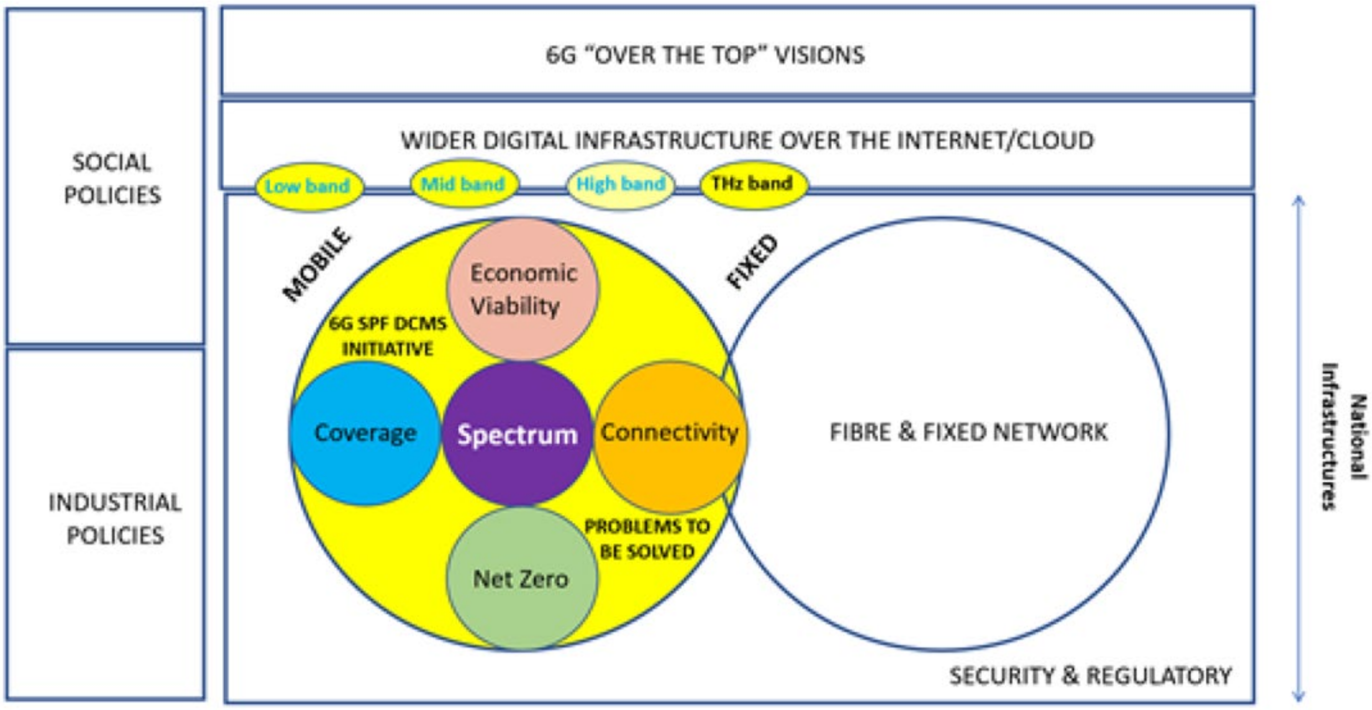
The initiative has helped to establish a wireless research community and bridge the gap between researchers and spectrum policymakers so that spectrum requirements can be identified early in the development of 6G.

There will be significant demands on spectrum for 6G connectivity to support the wide range of requirements and applications being proposed. Research to date has identified priorities across low, mid and high band spectrum and is starting to understand the spectrum needs for 6G and how this can be addressed based on current regulations and also internationally at future WRCs (2023 and 2027). The graphic below (**Figure 35**), developed by UK SPF Cluster 2, shows the boundary of the research initiative and where it sits relative to other contributing factors from spectrum, fixed networks, and other digital infrastructure, mainly from IT/Cloud but also commercial and social policy.

[492] A digital twin is a complete electronic/virtual representation that serves as the real-time digital counterpart of a physical object or process

[493] SPF 6G wireless R&D initiative: A report for DCMS A compilation edited by the Chair of the SPF Cluster 2, Cluster 2 UK Spectrum Policy Forum, 2021

FIGURE 35 OVERVIEW OF UK SPF CLUSTER 2 6G VISION



Source: UK SPF Cluster 2

In relation to this particular study, the central spectrum element (purple circle) is critical for identifying how much spectrum might be needed and in which bands. This will also need to consider which bands can be used for trials of the next generation of integrated systems and technology, such as bands above 100 GHz as identified by Ofcom[494]. Furthermore, shared spectrum access will likely play a key role in supporting 6G, particularly in the very-high-frequency Terahertz bands. New ways of sharing will need to be explored, and the introduction of spectrum sharing between operators in a dynamic way could emerge as an approach to facilitate increased spectrum efficiency. As this would require regulatory intervention action by Ofcom should take place now to explore the range of spectrum management approaches and the bands that will be needed (and expected quantities) to address the different 6G demand requirements.

C.7 - WI-FI TECHNOLOGY CHARACTERISTICS

The table below shows, for evolving Wi-Fi generations, the technical characteristics that can deliver the peak data rates for the varying parameters such as bandwidths, MIMO and modulation scheme. It can be seen as Wi-Fi has evolved from Wi-Fi 4 to Wi-Fi 7, the channel sizes have increased along with the MIMO capabilities and modulation, which has significantly increased the peak data rates.

[494] Supporting innovation in the 100-200 GHz range Increasing access to Extremely High Frequency (EHF) spectrum, Ofcom October 2020 https://www.ofcom.org.uk/__data/assets/pdf_file/0024/203829/100-ghz-statement.pdf

TABLE 26 WI-FI GENERATION

	WI-FI 4	WI-FI 5	WI-FI 6	WI-FI 6E	WI-FI 7
Launch date	2007	2013	2019	2021	2024
IEEE Standard	802.11n	802.11ac	802.11ax		802.11be
Max data rate	1.2 Gbit/s	3.5 Gbit/s	9.6 Gbit/s		46 Gbit/s
Bands	2.4 GHz and 5 GHz	5 GHz	2.4 and 5 GHz	6 GHz	1-7.25 GHz (incl. 2.4, 5, 6 GHz bands)
Channel size	20, 40 MHz	20, 40, 80, 80+ 80, 160 MHz	20, 40, 80, 80+ 80, 160 MHz	20, 40, 80, 80+ 80, 160 MHz	Up to 320 MHz
Modulation	64 QAM OFDM	256-QAM OFDM	1024-QAM OFDMA		4096-QAM OFDMA(with extensions
MIMO	4 x 4 MIMO	4x4 MIMO, DL MU-MIMO	8x8 UL/DL MU-MIMO		16x16 MU-MIMO

Source: LS telcom.

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