UK MOBILE MARKET DYNAMICS

A report for DCMS

July 2018

CONTENTS

1 EXECUTIVE SUMMARY

1.1 Context

Cellular mobile services were first launched in the UK in 1985. Since then, a combination of competition between the four network operators and technical advances over four generations of technology have delivered large benefits to users and to the wider economy. Users now take for granted the ability to make calls and benefit from an increasing number of applications delivered over smartphones when on the move.

5G, the fifth generation of mobile services, aims to extend the applications delivered by mobile networks, with an increased emphasis on machine to machine communication and applications, such as augmented reality, that cannot be supported by existing networks. A number of necessary conditions for the launch of 5G services, including initial technology standards and award of spectrum, will likely be in place by the end of the year. To support further investment by operators, there have also been a number of recent policy changes to reduce the cost of rolling out networks.

The UK government has an ambition to be a world leader in the deployment and use of 5G, due to the economic and social benefits that widespread uptake of 5G-based applications are likely to bring.

Operators have strong incentives to continue investing in new technologies in order to deliver current services. This will allow them to compete to acquire and retain customers. However, the business case for novel applications based on 5G technology is uncertain. While the mobile operators plan roll-out of 5G networks to support existing business cases, such as mobile broadband, delivery of the full capabilities of the technology could require a significant increase in investment over and above the level that the mobile network operators currently incur. With uncertainty over the rate at which new applications will be taken up, operators may delay investment until there is more clarity of the demand for these services.

The current market structure consists of four mobile network operators, reliant on two infrastructure sharing joint ventures (JVs) and with further mobile virtual network operators (MVNOs) competing for end users. New technologies for voice and mobile broadband have been introduced and there has been significant growth in mobile broadband speeds and data consumption. However, in light of the potentially significant investment required to roll-out 5G, and the different use cases that this may support, DCMS has commissioned Frontier to consider the likely outcomes under the current market structure, and to consider alternative market models that may be required to deliver the full capabilities of 5G.

In this report we consider three market models and consider their potential to deliver improved outcomes relative to the existing market structure (the ‘status quo’):

- Single Wholesale Network – as full roll-out of 5G may involve significant investment in network equipment, one policy option is to move to a market with only one network which operates at the wholesale level allowing multiple retail players access to the network in order to deliver services to consumers.
- Market expansion – a continuation of the existing competitive market with entry into the market by a wider range of players, alongside the existing MNOs, at a network or infrastructure level. This model could involve neutral hosts for provision in some areas – effectively localised versions of single wholesale networks; and flexible spectrum policy.
- Market consolidation – a move to a market with a smaller number of MNOs through consolidation of existing MNOs i.e. through mergers of MNOs.

We note that in this report we do not discuss in detail the specific policies that could be put in place to achieve these models, nor the implementation, as this is beyond the scope of our engagement.

1.2 The market models

Single wholesale networks

While network competition has benefits in terms of providing strong incentives to reduce costs and to innovate in order to profitably compete for customers, it also imposes additional costs as fixed network costs are replicated. To some extent this can be mitigated by operators choosing to share network infrastructure commercially, although such network sharing agreements cannot completely remove duplicate costs. A number of jurisdictions have considered, or are in the process of implementing, so-called single wholesale networks (SWNs) which, in the long run, aim to reduce or remove the need to duplicate equipment and infrastructure. However, there is little evidence yet to suggest that implementing an SWN in the UK would deliver overall net benefits, taking into account the loss of competition as an incentive to innovate. In addition setting up an SWN would take a considerable amount of time, leading to potential delays in the roll-out of new technologies.

Market expansion model

The structure of vertically integrated competing networks has, in general, proven to be effective. However, this structure may not be optimal for all use cases and geographies. In some circumstances the provision of duplicate infrastructure may increase costs substantially or may not be physically possible because of space limitations. In such cases a ‘neutral host’ model could allow the four operators to deliver services over a single infrastructure in areas where the competitive model would not reach. There may also be circumstances where players other than the existing MNOs may be in better positions to invest in infrastructure to support 5G and/or develop applications based on 5G technology. Where non-MNO users may want to deliver innovative 5G use cases over a smaller area, for example on an industrial site, they cannot currently do so without cooperation from an MNO who holds a share of the available spectrum. Due to information asymmetries about the expected demand for use cases and/or different business models, MNOs may have less incentive to make some investments than potential 5G users. Neutral host models could lead to greater competition at the service level and attract new forms of capital to the market.

Consolidation

In the last decade there has been a global tendency for consolidation in mobile markets, with the number of network operators being reduced from 5 to 4 in the UK following the merger of Orange and T-Mobile to form EE (later acquired by BT). It was argued by the parties involved that this merger allowed faster roll-out of 4G technology. Rolling out 5G is expected to involve a different scale and type of investment to 4G, hence we consider whether further consolidation would lead to increased investment and faster roll-out of 5G. We conclude that any potential future cases will need to be assessed on its merits as a particular case.

1.3 Assessment

We have evaluated each market model against the status quo, according to six assessment criteria agreed with DCMS. Our assessment based on the analysis in the report is shown in the figure below.

Figure 1 Evaluation of market models

	Status quo	Single wholesale network (SWN)	Market expansion	Consolidation permitted
Pace of rollout	Market models are evaluated relative to the Status quo	⊗	✓	⊖ ✓
Total cost (capex)		✓	⊖ ✓	✓
Coverage (rural)		✓	✓	⊖ ✓
Coverage (indoor)		✓	✓	⊖ ✓
Innovation/service differentiation		⊗	✓	⊖
Feasibility		⊗	⊖*	⊖

✓ **Positive** = expected to lead to improved outcomes relative to the Status quo

⊖ **Neutral** = outcomes expected to be largely the same as under Status quo

⊗ **Negative** = expected to lead to worse outcomes relative to the Status quo

Source: Frontier

*Note: We have placed a * in the feasibility category for the market expansion model as the feasibility would depend on the precise policies which would be implemented under this model.*

2 INTRODUCTION

2.1 Purpose of the report

Analysis of the mobile sector in the UK suggests that the market has performed well in the delivery of mobile voice and data services to end users to date.[1] The market operates with four Mobile Network Operators (MNOs) delivering mobile services using a range of technologies across most of the country (but with some coverage gaps). These competing networks result in differentiation in services and coverage, whilst retail competition is enhanced by commercially negotiated Mobile Virtual Network Operator (MVNO) access. There is a degree of network sharing (two network sharing agreements) which reduces costs without significantly reducing competition at the retail level.

The Government is considering whether “additional policy interventions” could be used to facilitate the deployment of 5G networks as part of its Future Telecoms Infrastructure Review (FTIR):

“*The cross-government Review, led by DCMS, will assess whether any additional policy interventions are needed to create the conditions for long term investment in world-class digital connectivity that is seamless, reliable, long-lasting and widely available”*.[2]

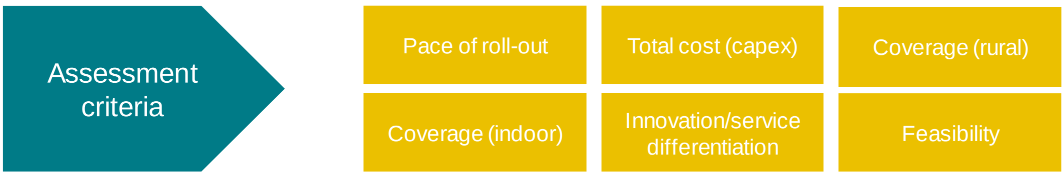
To assist the Government’s work in this area, DCMS has asked Frontier to assess how investment into 5G infrastructure is likely to evolve under:

1. The ‘status quo’ scenario in which the current market model and regulatory framework remains broadly unchanged; and

2. a range of alternative market models, which could be underpinned by a range of policy interventions, compared to the status quo.

Our assessment of the merits of these alternative models for the deployment of 5G networks has been undertaken based on six assessment criteria agreed with DCMS set out in the figure below.

Figure 2 Assessment criteria for market models



Source: Frontier

[1] The UK has high levels of population coverage including high coverage with the latest generation of technology 4G. Geographic coverage is not as extensive as population coverage with gaps affecting some rural areas. User satisfaction is generally high. This can be seen from Ofcom’s analysis in the ICMR 2017 version available here: https://www.ofcom.org.uk/__data/assets/pdf_file/0026/108908/icmr-2017-telecoms-networks.pdf

[2] FTIR, Call for Evidence, https://www.gov.uk/government/consultations/future-telecoms-infrastructure-review-call-for-evidence

This report summarises our findings based on:

- Theoretical and empirical literature: we have reviewed existing theoretical and empirical evidence relating to the potential market models.
- International experience: we have considered evidence relating to experience from other countries, in particular we have drawn on international examples of market consolidation and Single Wholesale Networks.
- Responses to DCMS call for evidence for the FTIR: we have reviewed responses to a 6-week call for evidence that DCMS launched in December 2017, to understand what market or policy interventions might support long term investment in the next generation of telecoms infrastructure.
- Frontier modelling: we have conducted our own modelling work, using data from a range of sources including 5G Norma, LS Telcom and mobile operator data to estimate the likely costs of roll-out of 5G networks, undertaking a range of sensitivities.

2.2 Parallel report on fixed sector

As part of its Future Telecoms Infrastructure Review, the Government is also considering “additional policy interventions” that could be used to facilitate the deployment of Fibre to the Premise (FTTP).

To assist the Government’s work in this area, DCMS has also asked Frontier to assess how investment in FTTP infrastructure will evolve over the next 25 years. As such a parallel report has been prepared by Frontier[3], which focuses on FTTP.

While there continue to be significant differences between fixed and mobile telecoms markets on both the supply and demand side, there is increasing convergence between the markets.

On the demand side mobile voice has increasingly substituted for fixed voice and for some users, mobile broadband provides an effective substitute for fixed broadband. However, the reliance of mobile networks on spectrum as a scarce resource means that unit costs are still higher for mobile services than fixed services and the bandwidth available per user is lower, leading mobile users to often choose to offload traffic to fixed networks via WiFi.[4] While improved technology and increased spectrum will continue to reduce the unit cost and increase the bandwidth of mobile networks the capability of fixed networks will also increase.

On the supply side there is increasing commonality in the infrastructure and technologies used for fixed and mobile networks outside the last mile. Mobile network base stations are increasingly connected (backhauled) to the core network over fibre infrastructure while fixed operators are increasing fibre in the access network to serve fixed subscribers. Economies of scope and scale means that it will be efficient for fibre rolled out for fixed networks to also be used to serve mobile base stations in the coverage area.

[3] See Frontier Economics report on UK Telecoms Market Dynamics for the fixed sector

[4] See page 131-134 of Ofcom’s Communications Market report 2017 https://www.ofcom.org.uk/data/assets/pdf_file/0017/105074/cmr-2017-uk.pdf

As such, whilst each report stands independently, we do at points refer to areas of convergence where relevant and to differences between the mobile market and the fixed telecoms market throughout the report.

2.3 Remainder of the report

In the remainder of the report we:

- Set out the key features of the current UK mobile market;
- Review 5G developments so far;
- Assess the expected level of investment into 5G under the baseline scenario;
- Present evidence on the potential impact of three alternative models on outcomes:
  - a single wholesale network;
  - market expansion; and
  - market consolidation.
- Assess the performance of the different models, based on DCMS's main criteria set out above.

3 KEY FEATURES OF UK MOBILE MARKET

In this section we set out the key features of the UK mobile market at present, considering the factors that have influenced the status quo to date, including the competitive dynamics and investment incentives. We then present the market outcomes across a range of indicators.

3.1 The UK mobile market differs from the fixed market

The mobile telecoms sector has been characterised by a rapid rate of innovation and relatively high level of network based competition, with four mobile network operators and a significant number of MVNOs providing services across the UK. This has translated into significant gains to consumers with almost universal uptake of mobile services (from a subscriber base of less the 2 million in 1990[5]) and continuous increases in the range and quality of service (across a number of dimensions), without significant increases in average customer spend in recent years.[6]

There are a number of features of the UK mobile market that differ from the corresponding features of the fixed market:

- Network competition has been a factor in the UK mobile market since the very first cellular networks were introduced in the 1980s, with further entry in the 1990s and in 2000 meaning that the need to intervene to address market failures has been limited;
- The rate of innovation has been high, with new 'generations' of technology being introduced every decade bringing both new use cases (such as data services introduced by the third generation) and improvements in efficiency, leading to ongoing reductions in unit costs which have been passed through to consumers; and
- Key inputs such as handsets, spectrum and equipment are now standardised at a global level, limiting the scope for individual countries to introduce technology in advance of other countries or differentiate in terms of the technology used.

3.2 Network competition has been favoured

The first licences for cellular networks were issued to Vodafone and Cellnet (the predecessor to O2) in 1983, at the same time that the statutory monopoly in fixed networks enjoyed by BT[7] began to be removed through a process of liberalisation which carried on until the mid-1990s. A further three 2G network licences were issued in 1989 (although only two networks were launched following a merger of

5 International Telecommunication Union, World Telecommunication/ICT Development Report and database

6 See Ofcom Communications Market Report 2017 e.g. Figure 4.18, 4.25, 4.26 https://www.ofcom.org.uk/data/assets/pdf_file/0017/105074/cmr-2017-uk.pdf

7 Kingston had the statutory monopoly in the Kingston-upon-Hull area

two of the licensees) with a further 3G entrant licensed in 2000. Following the merger between T-Mobile and Orange in 2010[8] there are now four network operators providing services throughout the UK. A further proposed merger between Three and O2 was blocked by the European Commission (EC) in 2016 on competition grounds.[9]

Network competition has proven sustainable and efficient in mobile services for a number of reasons:

- In a competitive market, operators have strong incentives to mitigate any increase in costs due to network duplication, for example through sharing of infrastructure where this does not impinge on operators' ability to compete[10], reducing the potentially increased fixed costs due to competition; and
- The dynamic nature of the market with rapid technological improvements, means the potential dynamic efficiency losses through lack of competition are large compared to the relatively small static efficiency losses due to duplication of fixed costs.[11]

The competitive nature of mobile networks means that they have not been subject to regulation to the same extent as fixed networks. For example, MNOs are not subject to regulated access obligations. MNOs provide access to their networks to MVNOs on commercial terms, increasing the degree of competition in retail mobile markets and providing an additional revenue stream for MNOs to recover fixed costs.

In addition in recent years there has been growth in connections for machine to machine (M2M) communications which are not provided through the retail channels used for traditional mobile phone services.[12]

3.3 Investment incentives

The relationship between investment and demand in mobile networks is complex. This contrasts to investments in fixed access networks where capital and operating costs are broadly proportional to the addressable market, in terms of the number of premises (homes in residential access networks) passed. For mobile networks a greater proportion of costs are variable capacity-related costs, making managing capacity a more significant issue for mobile networks compared to fixed networks. This is demonstrated in the type of offers available for fixed and mobile broadband access – whilst fixed broadband offers typically

[8] EC Case No COMP/M.5650 - T-MOBILE/ ORANGE

[9] EC Case No. M.7612 - HUTCHISON 3G UK /TELEFONICA UK

[10] We return to discussion of network sharing in the following sections.

[11] This is discussed in Section 5 of the Frontier Economics report for the GSMA (2014) https://www.gsma.com/publicpolicy/wp-content/uploads/2014/09/Assessing_the_case_for_Single_Wholesale_Networks_in_mobile_communications.pdf

[12] 7.6 million M2M subscribers by 2016 based on Ofcom 2017 Communications Market Report https://www.ofcom.org.uk/__data/assets/pdf_file/0017/105074/cmr-2017-uk.pdf

have unlimited data allowances, mobile broadband offers still typically include data limits.[13]

This complexity in capacity management in mobile networks is both on (a) the demand side, where demand for traffic varies both in terms of the time of day but also location, and (b) on the supply side, with network planners having a wide range of options including use of more spectrum or densification to improve network performance in order to better attract and retain customers. As a result the user experience delivered by a given network to a potential customer varies significantly depending on the time and location in which they try to access services.

Financing of infrastructure projects

Generally investment in the mobile sector is financed by the MNOs.[14] All four MNOs are subsidiaries or divisions of much larger groups and are dependent on these groups for funding. Capex budgets will be set through a process of negotiation between the MNOs management and the Group finance function. Investment requirements may combine strategic investments, for example multi-year programmes to roll-out new technologies or upgrade infrastructure, with tactical investments for example to address localised network congestion or to react to marketing initiatives from other MNOs.

Investment into new technologies tends to happen on a gradual roll-out basis, with investment cycles approximately every decade in line with each generation of mobile technology. Such investment has been largely brownfield after the original roll-out of 2G networks[15], as it mainly involves upgrades or the addition of new equipment to existing mobile masts which have already been built. The MNOs also have an established customer base and are already generating a steady stream of positive cash flows.

All four MNOs now generate positive operating cash flow and so can fund investment without, in general, needing recourse to external funding. They also can be expected to have incentives to invest in order to defend their competitive position. In the fixed sector, with the exception of BT and Virgin Media (in its existing footprint), investors need to raise capital to invest in new fibre build in the expectation that they will get a return on this investment by acquiring customers.[16]

The MNOs have also engaged in network sharing for roll-out in specific areas or technologies in order to reduce the capital and operating costs required. Network sharing is possible in areas where MNOs view the cost savings as greater than any competitive advantage they would achieve through differentiation or first mover advantage if they rolled out on their own network in a particular area.

[13] "Tariff data collected by PurePricing in May 2017 show that just over half (55%) of pay-monthly plans offer a data allowance of 5GB or less, while most fixed broadband plans (94%) offered 'unlimited' data." Ofcom 2017 CMR https://www.ofcom.org.uk/__data/assets/pdf_file/0017/105074/cmr-2017-uk.pdf

[14] See Figure 18 in Section 5.

[15] Or a 3G network in the case of Three.

[16] Planned FTTP investment in the UK involves also investors entering into 'co-investment' agreements with existing retail fixed broadband providers – see Frontier Economics report UK Telecoms Market Dynamics for the fixed sector.

Nature of demand

The majority of UK mobile customers purchase mobile services on a post-pay contract basis[17], with the monthly payment including a contribution to the cost of a handset and a bundle of calls, messaging and data. A typical contract length is 24 months. At the end of the contractual period customers have a choice of continuing on their current contract, choosing a new contract from their current provider or choosing a new contract (the very high penetration of mobile services indicates that most customers choose to remain subscribers and most purchasing decisions are made by existing subscribers rather than new subscribers).

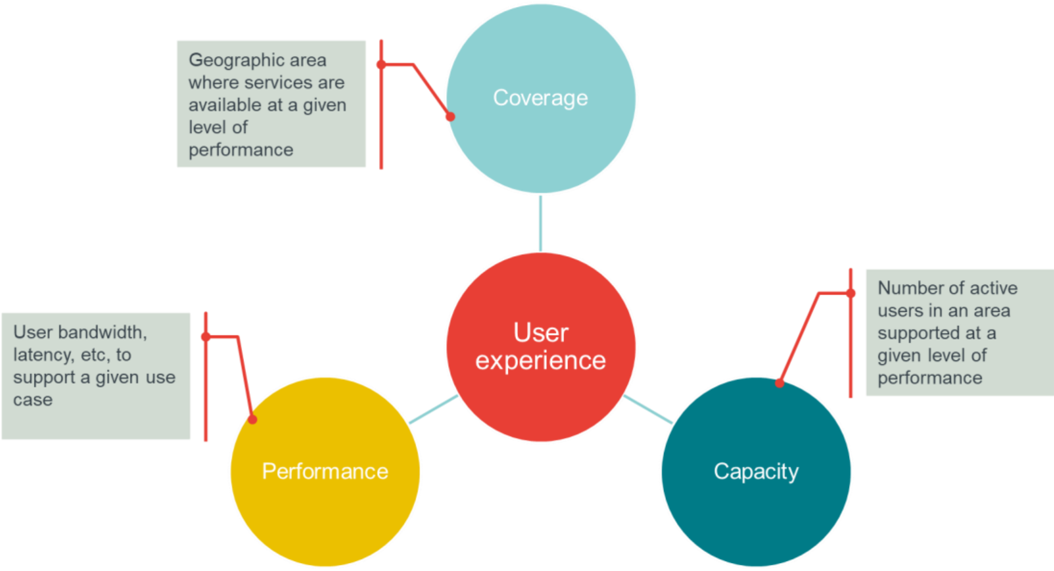
When making purchasing decisions, consumers take account of a number of factors including: the handsets available (when they wish to purchase a new handset), the overall price and network quality.

Given that price is a significant factor in customers' purchasing decisions, operators have a strong incentive to compete on price. However, in addition there is scope to differentiate from other operators by improving the network. There are three dimensions of the network that may impact on the user experience:

- Performance - The ability of the network to support a given application (for example the user bandwidth that the network could support) and use cases (in the absence of congestion);
- Coverage - The set of locations where the network is able to support a given application/use case. The level of performance on networks is a function of distance (from the base station site) meaning that the closer the user is to the base station, the higher the mobile broadband speed they are likely to receive, all else equal;
- Capacity - Networks have finite capacity and if the 'offered' demand from users is too high in a given area, then some traffic will not be carried. In voice networks this generally resulted in calls being 'blocked', however on a packet switched network, this may result in a traffic being delayed and ultimately a proportion of traffic being discarded, with customers receiving a lower data rate than requested.

[17] 67.5% in 2016 – Ofcom 2017 CMR https://www.ofcom.org.uk/__data/assets/pdf_file/0017/105074/cmr-2017-uk.pdf

Figure 3 Factors used to differentiate network quality



Source: Frontier

However, it is difficult for users to assess mobile network quality and differences between networks in an objective fashion. While marketing communications and information published by third parties or regulators such as Ofcom[18] may influence some users, the experience of individual users of coverage and performance of their networks, and 'word of mouth' from users of other networks, may also have a significant influence. This will provide an incentive for operators to improve and maintain the quality of their networks as there is less likelihood that a customer will seek to change their provider if they are happy with the network's quality (or at least perceive it to be equivalent to other networks).

As such, consumers may take into account both the absolute performance of their network, for example the degree of congestion or lack of coverage and the relative performance of their network, i.e. whether the network is significantly worse than competing networks. For example, new entrants had a strong incentive to roll-out coverage networks to the point where they were broadly comparable with established operators as customers prefer operators with higher coverage networks.[19]

Supply side issues

Competing network operators will seek to offer the optimal balance between the user experience they offer and the cost of the network. In order to improve the network performance, or maintain it given increases in traffic over time, network planners have a number of investment levers they can use:

- Additional base stations can offer improvements in coverage (when deployed in areas where coverage is not complete) and/or increased capacity.

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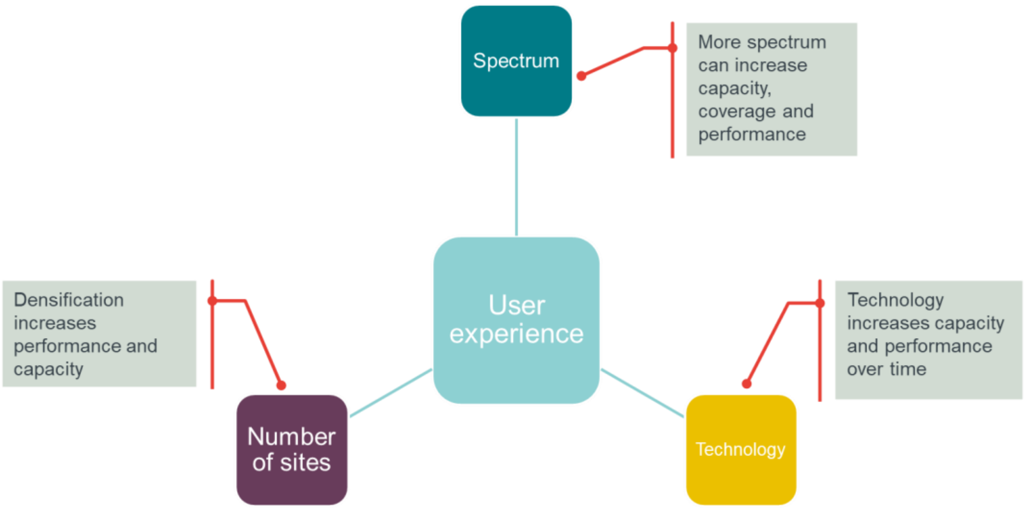
[18] See for example Ofcom's mobile and broadband checker https://www.ofcom.org.uk/about-ofcom/latest/features-and-news/broadband-checker

[19] Some customers may exclude operators with limited coverage from their purchasing choices and others require discounts to reflect this difference in quality.

Additional base stations can also increasingly improve performance which is a function of the distance from the nearest base station;

- Additional spectrum deployment, with lower frequency spectrum offering greater coverage and higher frequency incremental spectrum offering increased capacity and performance (for example through carrier aggregation); and
- Technology improvements due to equipment upgrades can bring increases in performance and capacity (in large part through increased spectral efficiency) over time, and in some cases coverage. Successive 'generations' of mobile technology have focussed on increasing performance and capacity of mobile networks both in terms of the 'core' and 'radio access' networks:
  - 1G networks provided a basic voice service with low capacity and low security;
  - 2G networks significantly increased voice capacity of mobile networks while introducing additional applications – packet data and SMS;
  - 3G networks offered significantly more capacity for packet data services with increased performance in terms of user bandwidth;
  - 4G networks offered increased capacity and performance for packet data services with an IP based core.

Figure 4 Levers for improving network performance



Source: Frontier

Network planners will use a combination of these levers, both reactively, for example to address congestion in a given area, and proactively. For example, operators may decide on the overall structure of the network infrastructure and spectrum/technology mix in order to be consistent with the long-term commercial strategy of the operator.

The structure of pricing, with most customers now being on a relatively fixed subscription (at least for the period of contract length – typically 24months) and with prices being geographically averaged, means that it may be difficult for operators to directly extract incremental revenues from network upgrades such as increases in coverage. However, within investment decisions, implicit or explicitly there will be a trade-off between investment (and the related cost) and the operator's ability to attract and retain customers, taking into account the performance of other networks.

Restrictions on network supply

There are some operational and technical restrictions on the effectiveness of the levers that operators can use to increase supply:

- Licensed spectrum holdings are fixed between licence awards which limit the spectrum available to each operator that can be deployed on any one base station;
- Densification of networks to deliver increased capacity has technical limitations (on the minimum inter-site distance) and operational limits on the availability of sites in high traffic areas;
- Increasing coverage may lead to increasing unit costs per base station due to increased remoteness of sites; and
- Technology requires standardisation before products are created (both in terms of network equipment and terminal equipment).

These issues may imply it becomes increasingly expensive to carry on increasing capacity in the highest traffic density areas (absent technological improvements) or increasing coverage in very rural areas. This, in combination with the relatively indirect link between customer experience and investment and the inability to generate incremental revenues directly from those particular customers who benefit from specific investments, may lead to individual network operators choosing not to deploy incremental investments in geographies with very low traffic densities and being unable to deploy additional capacity in high traffic areas. As a result the user experience may be degraded both in very high traffic areas (for example transport hubs) and very low traffic areas (highly rural areas).

3.4 Market outcomes

Current delivery of mobile services

Competition has encouraged operators to deliver networks with increasing performance, coverage and capacity, by deploying more sites, spectrum and better technology, while controlling costs in order to offer competitive pricing. In some cases this has been through co-operation between operators in network deployment. However, competition has not necessarily delivered ubiquitous coverage as the benefits to operators, through increased profits, has been lower than the costs of extending coverage. As such, policy intervention has been required to achieve a level of coverage above that which would be achieved otherwise.

The predominant service provided over current mobile networks (in terms of traffic and revenues) is mobile broadband (MBB) delivered to smartphones.[20]

[20] See Ofcom CMR – https://www.ofcom.org.uk/__data/assets/pdf_file/0017/105074/cmr-2017-uk.pdf

MBB supports a wide range of applications including email, messaging, social media and music and video streaming. The predominant application in terms of traffic over mobile networks is currently video streaming[21], due to the relatively high bandwidths required and the long duration of video streaming sessions. The majority of data delivered to smartphones is delivered over WiFi connections (e.g. at home, at work or from public hotspots), rather than the mobile networks.[22] Ofcom suggests that this may be due to users having unlimited fixed data allowances (compared to limited data allowances in mobile bundles) and potentially due to fixed broadband offering a more reliable connection.

MBB is delivered on a ‘best effort’ basis with no explicit or implicit guarantees of performance in terms of bandwidth and latency, with large variations over time and location. Service quality tends to be poorer both in dense urban environments, due to congestion and in rural areas, due to gaps in coverage. The best effort nature of 4G MBB services limits the use cases that can be delivered to those which are not ‘mission critical’.

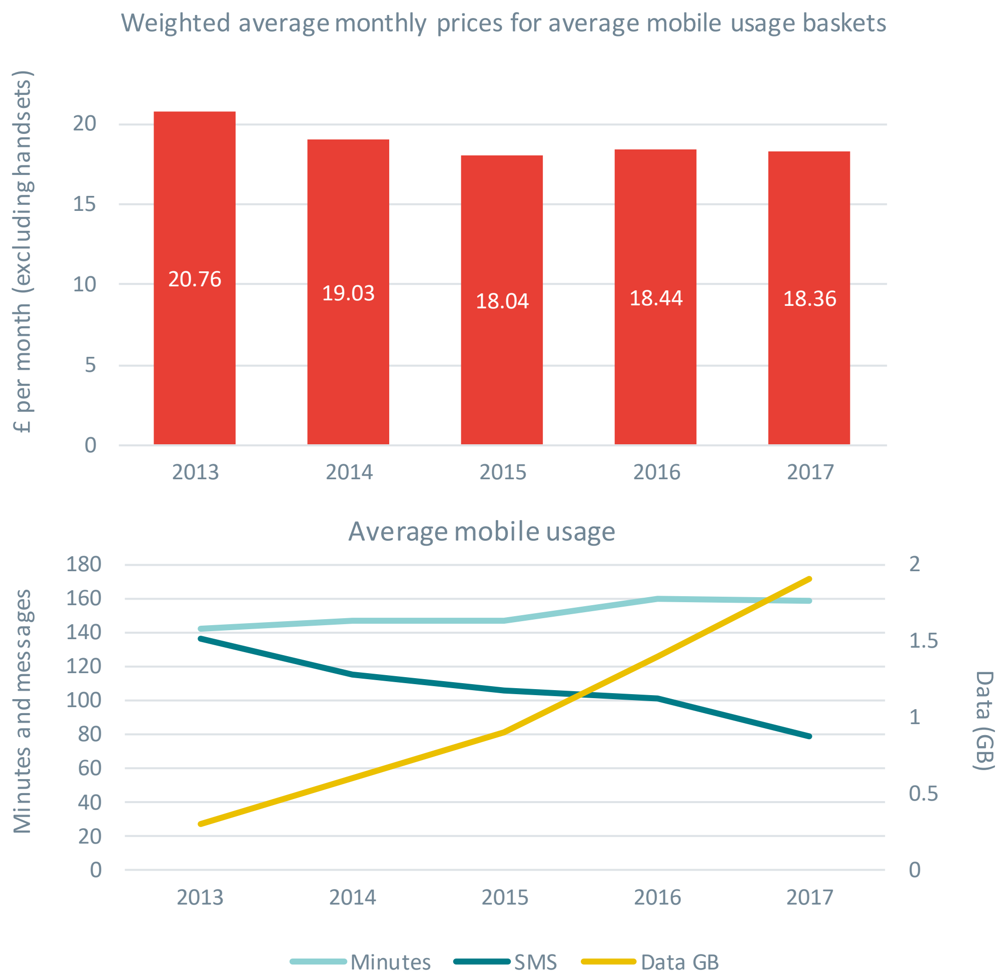
Outcomes for consumers

Competition combined with the rapid rate of innovation in mobile networks has resulted in significant gains for consumers with rapid increases in penetration, initially of mobile voice and latterly of mobile broadband, and significant increases in data traffic and user download (and upload) speeds.

[21] See Ofcom CMR - https://www.ofcom.org.uk/research-and-data/multi-sector-research/cmr/cmr-2017/interactive/mobile-research-app

[22] See Ofcom CMR – 59.9% of apps sessions delivered over WiFi - https://www.ofcom.org.uk/research-and-data/multi-sector-research/cmr/cmr-2017/interactive/mobile-research-app

Figure 5 Mobile ARPU and usage

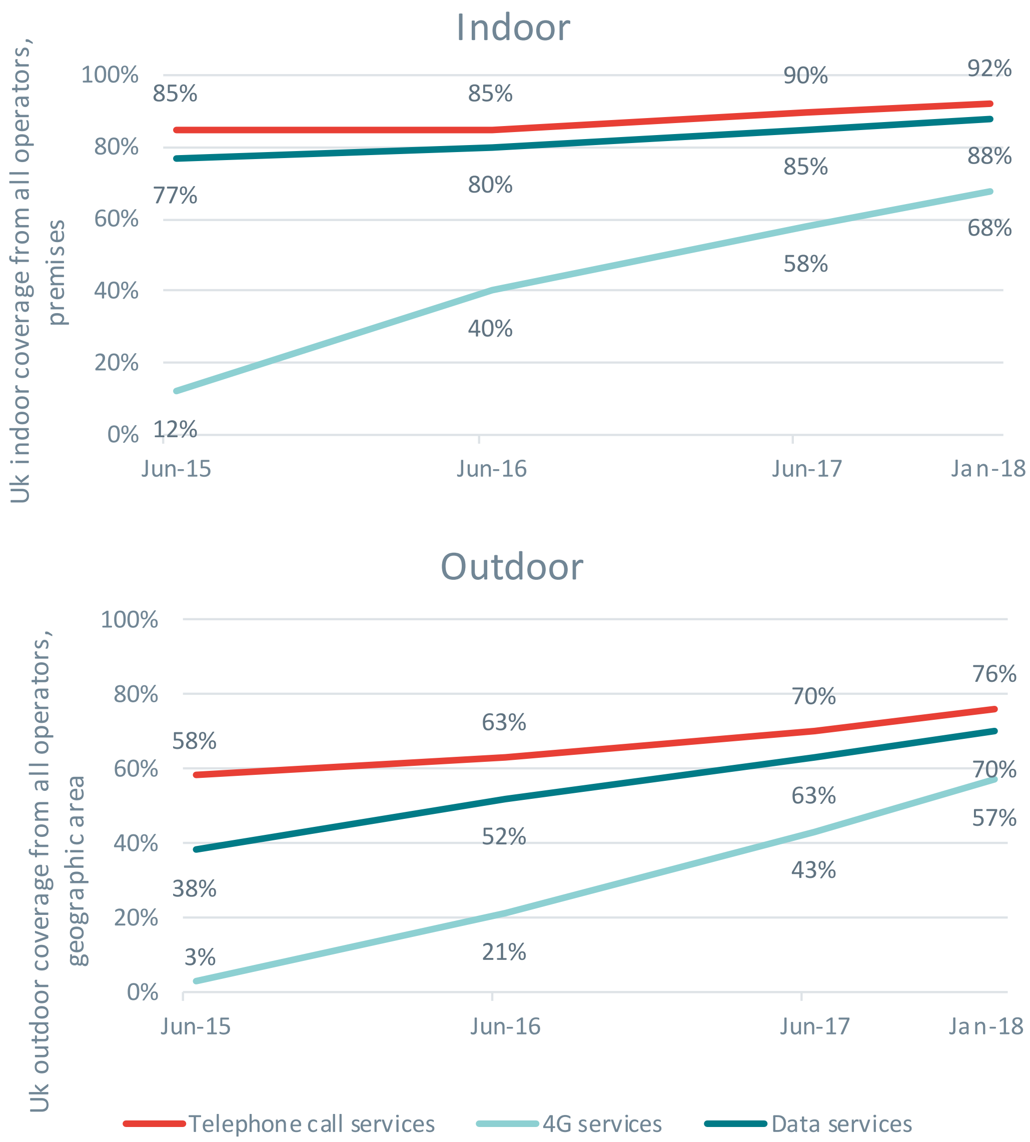


Source: Frontier based on Ofcom - Pricing trends for communications services in the UK (Figure 4)

As shown in Figure 5 above, the significant increases in usage (made possible by the increases in penetration and speeds) has occurred despite mobile average revenue per subscriber remaining largely static, implying that unit costs (per traffic) have been falling.

However, national regulatory authorities (NRAs) as well as governments have recognised that commercial incentives alone may not lead to a level of coverage consistent with public policy objectives and have used coverage obligations, typically tied to spectrum licence awards, to increase coverage above that which operators would have built otherwise. Figure 6 below illustrates that coverage of all mobile services (both indoor and outdoor) has been increasing meaning consumers have benefitted from greater access to mobile services. However, coverage of some mobile services, particularly 4G services which offer higher speeds, is below other services and coverage is not universal. Whilst the majority of premises are covered by mobile services, full geographic coverage, which is costly to achieve, remains behind indoor coverage.

Figure 6 Coverage of mobile services

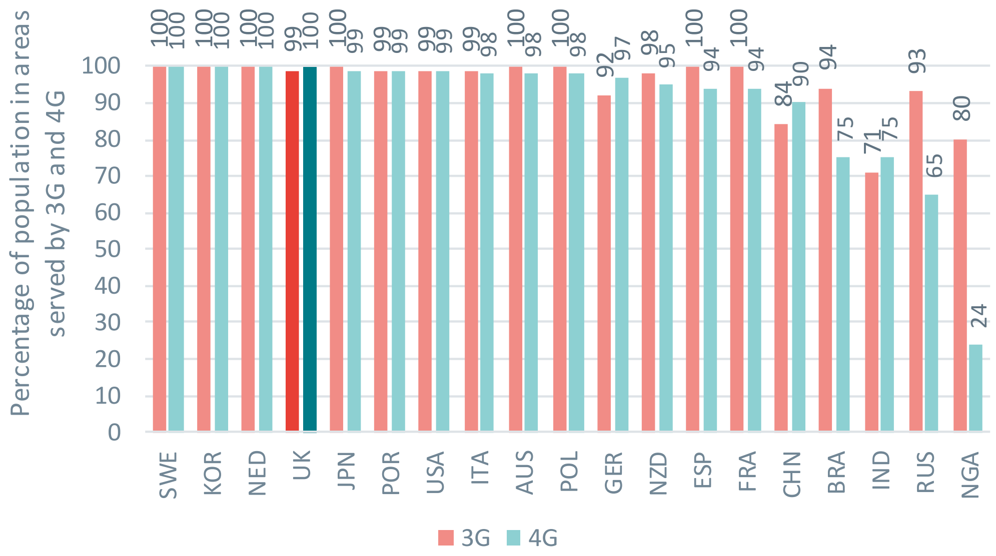


Source: Frontier based on Ofcom – Connected nations update – Spring 2018 (Figures 2 and 3)

Performance compared to other countries

Whilst UK consumers appear to have benefitted from improving outcomes in the mobile market, it is also relevant to consider how the UK performs relative to other countries. Ofcom considers the performance of the UK mobile market relative to a wide range of comparator countries in its International Communications Market Review (ICMR). The latest available data (Figure 7 below) shows that the UK performs better than other European countries in the sample in terms of population coverage of 3G and 4G networks, and of the countries in the sample, is only outperformed by three countries, matching them in terms of 4G population coverage and only 1% behind in terms of 3G population coverage.

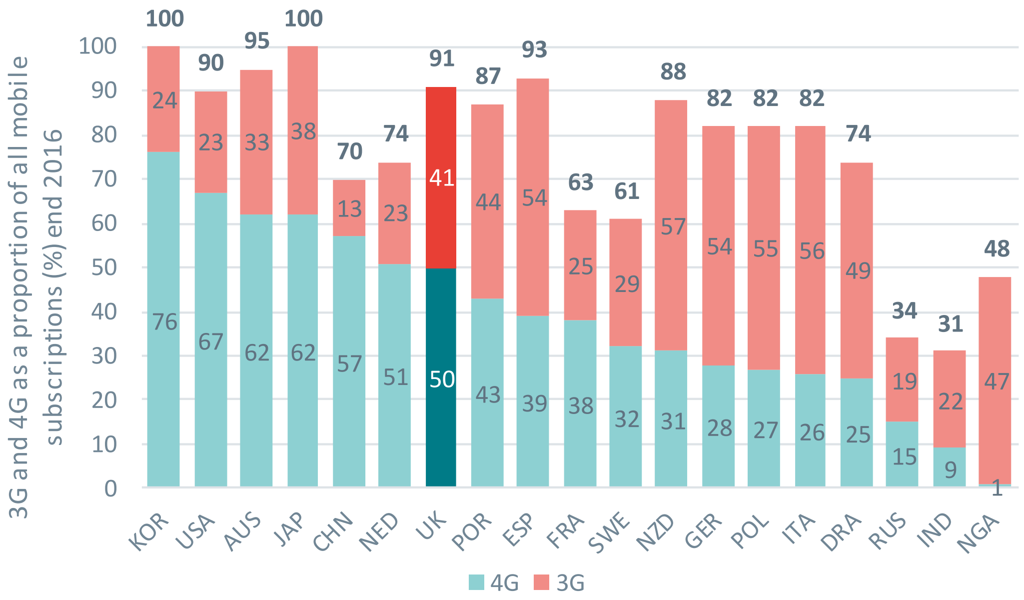
Figure 7 3G/4G population coverage (end 2016)



Source: Frontier based on Ofcom ICMR 2017 (Figure 33)

UK performance is slightly weaker in terms of 4G take up (as a proportion of mobile subscriptions), ranking 7th out of the comparator countries, this is shown in Figure 8 below. However, in terms of combined 3G and 4G, the UK ranks 5th out of the comparator countries with 91% of subscriptions with access to these technologies.

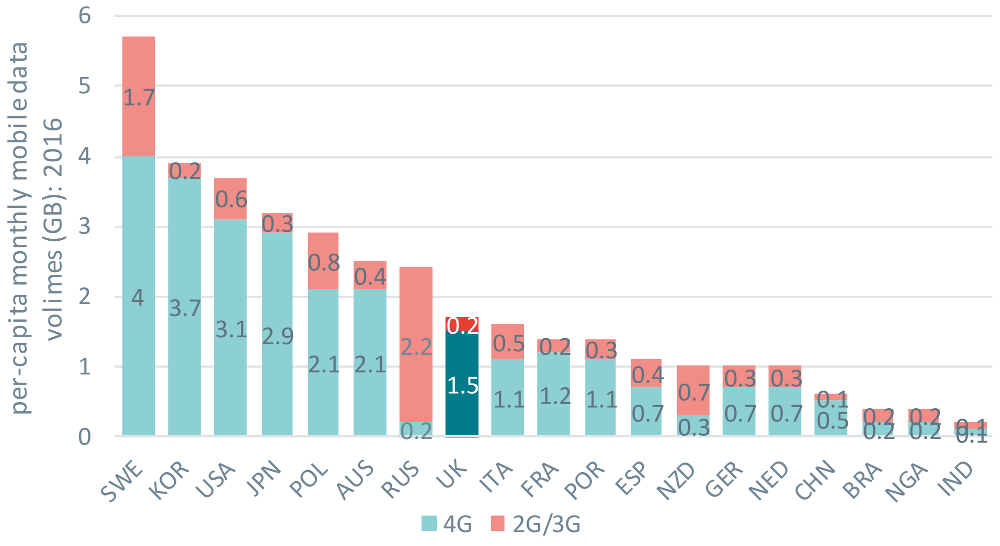
Figure 8 3G and 4G as a proportion of mobile subscriptions (end 2016)



Source: Frontier based on Ofcom ICMR 2017 (Figure 37)

Figure 9 illustrates that whilst UK consumers currently consume around 1.7GB of data a month, predominantly on 4G networks, this is significantly lower than a number of other countries such as Sweden, South Korea and the USA where consumption is more than double that of the UK.

Figure 9 Monthly data per capita (GB) 2016



Source: Frontier based on Ofcom ICMR 2017 (Figure 44)

The UK government recognises that whilst the UK has performed well on mobile market outcomes so far, further interventions may be necessary for the UK to take a leading position in terms of 5G developments due to the different or increased challenges deployment will present. This is described in the following sections.

4 5G DEVELOPMENTS

In this section we discuss the development of 5G and how this differs to past technologies. We consider the necessary spectrum and network architecture that will be required for 5G networks.

4.1 Past technology developments

The nature of mobile networks means that, for users to take full advantage of mobility, a common set of standards need to be supported across a wide geographic scope, to allow users to use services over a wide area.

Technologies have been developed in ‘generations’ to ensure a common baseline for interoperability between network and device equipment. While both network equipment and terminals will evolve within generations to allow for increased functionality, all terminals and equipment within a generation should be interoperable (so current GSM networks will in theory support handsets from the 1990s). The use of multi-mode handsets since the introduction of 3G, with devices being able to fall back to previous generations, has meant that coverage in new generations can be built up slowly or be geographically limited.

First generation networks

The initial generation of analogue cellular networks included a range of incompatible technologies which were deployed on a national (or in some cases regional) basis. This approach had a number of disadvantages, as the lack of economies of scale increased the cost of network and terminal equipment; and users were not able to use their handsets on networks outside their home country/region (‘roaming’).

The use of analogue technology also restricted the capacity of networks, due to lack of compression of the voice signal, with each conversation using a dedicated radio channel. In addition security was limited, with ‘cloning’ of handsets allowing unauthorised access to the network and interception of calls being straightforward.

2G networks

Second generation networks were designed to address the shortcomings of the first generation of cellular networks, using digital technology and compression to multiplex different calls on a single carrier. 2G networks also included strong encryption to prevent cloning and interception.

In the EU, the GSM Directive imposed a single standard, by reserving key spectrum for use with the European developed GSM standard. This approach proved effective with the resulting economies of scale leading to GSM becoming a de-facto global standard, with other 2G technologies having uptake limited to specific regions, such as the Americas and Japan.

GSM also allowed for limited data services in the form of short messaging services (SMS) and circuit switched data (CSD). The GSM standards were later developed to provide higher speed data services (so called 2.5G technology).

3G networks

While 2G technologies were primarily designed to offer voice services, the increasing uptake of fixed data services meant that it was logical to move to mobile technologies that gave greater weight to data services. The IMTS-2000 initiative by the ITU set out objectives to enable innovative applications and services (e.g. multimedia entertainment, infotainment and location-based services, among others). In addition new spectrum bands became available at high frequencies (2.1GHz) to support these networks.

3G standards in Europe were based on evolutions of GSM technologies (e.g. a common core network) by the 3rd Generation Partnership Project (3GPP). While the first network in the UK was launched in 2003 by Three, widespread uptake began around 2007 driven by improvements in the technology (high speed packet access), increases in coverage and the widespread availability of smartphones.

This led to a rapid take up of data services which in turn led to issues of congestion. In addition the coverage of 3G networks was more limited than 2G networks due to the relatively high frequency used and the fact that user bandwidths fell off sharply towards the edge of cells.

4G networks

The 4G technology developed by the 3GPP, LTE, has become a single de-facto global standard implemented across the globe. LTE provides a number of advantages over 3G technologies:

a. An all IP packet switched network;

b. Increase spectral efficiency, leading to greater capacity;

c. Higher user bandwidth available; and

d. Ability to use a wide range of frequency bands to provide both high levels of coverage (using low frequency) and high capacity (using high frequency spectrum).

In the UK, the initial launch of 4G networks was delayed due to legal challenges to the auction of new spectrum and the ability of existing operators to ‘re-farm' existing spectrum. EE eventually launched in Autumn 2012, with the remaining operators launching in 2013 having acquired spectrum in an auction that year. However, once launched, the roll-out and take up of 4G (as shown in Figure 8) has been far more rapid than 3G.

Other technologies

The standards used for mass market mobile services have increasingly been used to deliver specific vertical applications such as railway communication (GSM-R), communications for emergency services (e.g. the UK ESN based on

4G LTE technology), taking advantage of economies of scope and replacing other specialised networks such as TETRA for emergency services.

However, other wireless technologies have operated in parallel with cellular networks. For indoor wireless broadband coverage, WiFi is predominantly used rather than mobile networks. Even for smartphones, WiFi networks carry the majority of traffic.

4.2 5G developments

IMT-2020 initiative

As noted above, mobile network technologies are introduced in a series of generations at intervals of around a decade. The ITU has set out a series of objectives and use cases for 5G technologies (IMT-2020).

The use cases are split into three main groups:

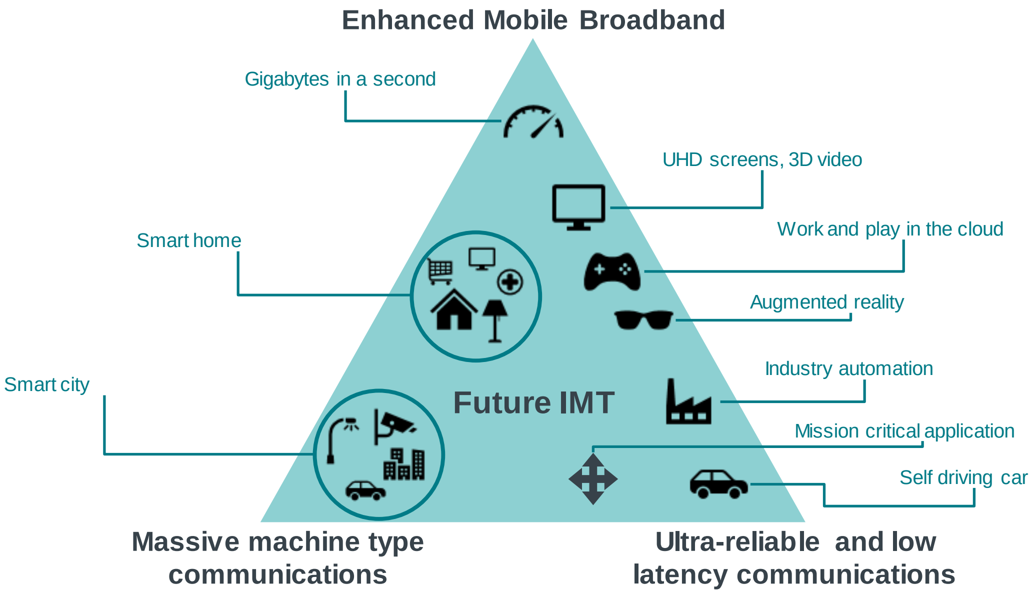
a. Enhanced mobile broadband (eMBB);

b. Massive machine type communications (mMTC) (Internet of things); and

c. Ultra-reliable low latency services (URLLC) for industrial uses and VR/AR.

The figure below illustrates some of the wider range of use cases that sit under these groups.

Figure 10 Proposed 5G use cases



Source: Frontier based on ITU

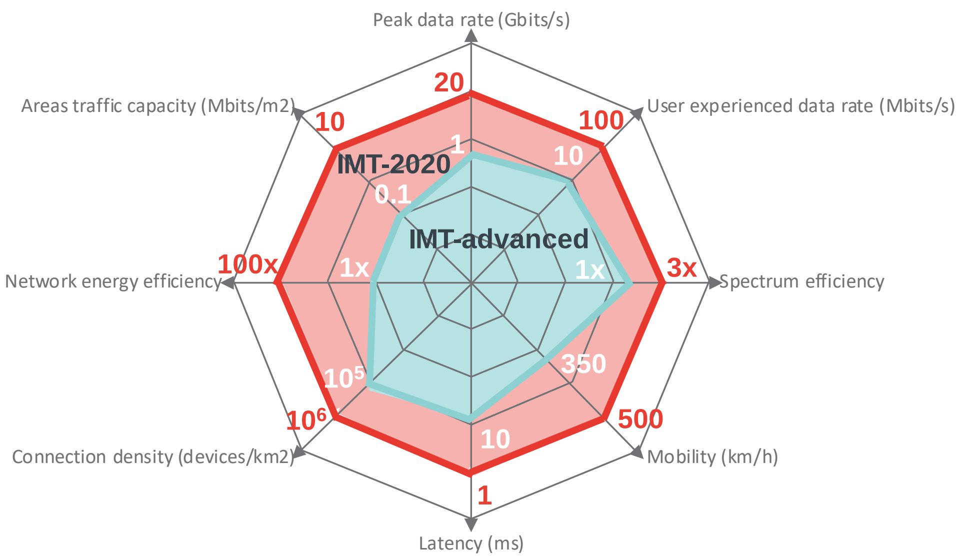
Increasing the use cases that can be supported by 5G networks should in theory bring economic and commercial benefits due to economies of scope (with a single network serving a number of uses) and scale (as an increased volume of equipment will be needed reducing unit costs). As such the aim of 5G technology is not only to improve existing service offerings in terms of quality and cost, but also to allow additional use cases to be served using 5G networks.

A relevant parallel is the transition from 2G to 3G technology which allowed the mobile broadband use case to be added to the mobile voice and messaging use case supported by 2G networks. In the same way that some of these 5G use cases can be partially supported by developments of 4G technology (such as IoT), MBB was also partially supported by 2.5G networks.

One significant difference compared to the transition from 2G to 3G is that while MBB has been largely sold to the same customers who purchase voice services (with voice and data services generally sold in a single bundle), the use cases supported by 5G services are likely to be purchased by different customer groups. For example IoT may be largely purchased by industrial users rather than individuals. While this provides potential opportunities, in that mobile services will not be subject to the budget constraints of households, it may require different business models.

In order to meet all of these use cases with a single technology requires improvements in a number of dimensions of network performance. This is illustrated in the figure below, which shows the manifold areas in which 5G (IMT-2020) should outperform 4G (IMT-advanced).

Figure 11 5G performance improvements compared to 4G



Source: Frontier based on ITU

5G standardisation

While the ITU has set out the high level objectives for 3G, 4G and 5G networks, the ITU does not develop the technical standard(s) which will meet these objectives. For 3G services there were a number of competing technical standards, but for 5G there appears to be a single candidate technology being developed by 3GPP. These standards will cover both the air interface and core network developments, which will build on the networks developed for previous generations.

Key elements of the 5G standards will be:

- 5G New Radio (NR) for the air interface which should provide benefits in terms of spectral efficiency and potentially coverage compared to 4G;
- Network function virtualisation (NFV) which will allow network functionality to be delivered using commodity hardware rather than specialised equipment; and
- Network slicing, which will provide virtually separate logical networks over a single physical network allowing use cases with differing quality of service to be deployed.

The 3GPP issues standards in 'Releases' which package together a number of standards. The key releases are:

- **Release 15**, which includes 5G phase 1, focussed on the eMBB use case and was 'frozen' in June 2018[23];
- **Release 16**, which will include 5G phase 2 aiming to meet all of the IMT-2020 requirements and which will be 'frozen' in 2020.

In parallel with the development of 5G standards, 3GPP will also further develop 4G standards, which will overlap to a degree with the functionality provided by 5G. In particular 4G developments share techniques such as massive MIMO or small cells which could increase spectral efficiency and hence capacity. Given these developments, the fact that existing 4G networks deliver a quality of service which is sufficient for many existing use cases and the fact that there are considerable sunk costs both in 4G network equipment and 4G terminal equipment, mean it is likely that 4G networks and 5G networks will co-exist for a period of time.

The first partial standards were frozen in December 2017 which defined the air interface, 5G NR, but not the core network and only allowed for the 5G air interface to be deployed alongside an existing 4G network ('non standalone' – NSA) to provide additional capacity. Release 15 includes the full specification for core network and allows for standalone 5G operation.

On a forward looking basis new equipment (antenna and RAN equipment) should allow both 5G and 4G technologies to be used simultaneously and in the same band.

Once the specification is frozen, equipment manufacturers can start to develop and produce standards compliant network equipment and terminal equipment. There will be a lead time (approximately 18 months) associated between the standard being frozen and network equipment (or software upgrades in some cases) being available on the market.

Mass market smartphone availability may lag behind network deployments due to the need to miniaturise components for a smartphone form factor and ensure power consumption is consistent with a reasonable battery life. While Huawei

23 http://www.3gpp.org/news-events/3gpp-news/1965-rel-15_news

announced the first 5G smartphone will be available at the end of 2018, some analysts are forecasting that 4G phones will be the norm for at least the next 5 years.[24]

Spectrum for 5G

The main bands identified by Ofcom to be allocated for 5G in the medium term are 700 MHz, 3.4-3.8 GHz and 26 GHz. These are the bands promoted by the Radio Spectrum Policy Group of the European Commission as part of their strategic roadmap towards 5G for Europe.[25] The characteristics of these bands differ significantly:

e. **700 MHz** spectrum, previously used for Digital Terrestrial Television (DTT), is a lower frequency range than existing mobile communications bands, which can provide wide coverage from existing (macro) sites. However the limited amount of spectrum available and the limited spectral efficiency due to the inability to use massive MIMO means that it provides limited additional capacity or user bandwidth;

f. **26 GHz** is a much higher frequency than existing mobile spectrum which limits the effective coverage of sites using this frequency, however the large amount of spectrum available and its suitability for massive MIMO and the resulting gain in spectral efficiency could allow it to deliver high bandwidths and traffic density using small cells.

g. **3.4 - 3.8 GHz** lies between these two frequencies and offers relatively large amounts of new spectrum, high spectral efficiency albeit with lower effective range.

Cells for 5G

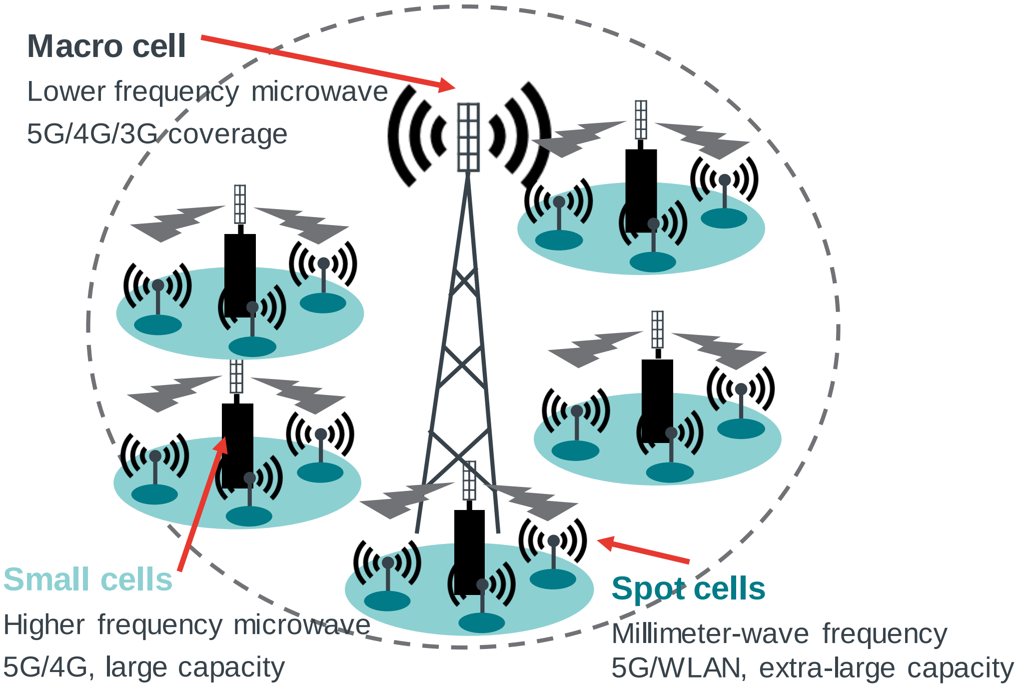
Given the spectrum available, 5G is likely to be delivered through a combination of different cells:

- Macro cells – which will deliver 5G coverage alongside previous technologies relying on low frequency spectrum (mainly 700MHz) potentially in combination with high frequency spectrum (3.4-3.8GHz);
- Small cells – which will sit within the cell radii of Macro cells and provide additional capacity through high frequency spectrum (3.6GHz spectrum); and
- Spot/Pico cells – which will provide extra large capacity in high traffic areas based on 26GHz spectrum.

[24] https://www.strategyanalytics.com/strategy-analytics/blogs/devices/emerging-devices/emerging-devices/2018/03/22/5g-handsets-are-just-around-the-corner-but-4g-2g-still-have-a-long-run-ahead-of-them#.WyYxS8anGUk

[25] https://circabc.europa.eu/sd/a/fe1a3338-b751-43e3-9ed8-a5632f051d1f/RSPG18-005final-2nd_opinion_on_5G.pdf

Figure 12 5G network cell types



Source: Frontier based on ITU

We focus on the delivery of 5G through macro cells and small cells in this report. We use the term ‘small cells’ to capture a variety of different cell types including all cell sizes below macros.

5 EXPECTED LEVEL OF INVESTMENT INTO 5G UNDER THE STATUS QUO

In this section we discuss the expected development of 5G under the status quo. This is the baseline scenario against which we consider the other potential market models in the following sections of this report. We first consider the investment into 5G we expect to happen under the status quo and the drivers of this. We then consider *how* this investment is expected to take place and potential gaps in deployment.

5.1 Expected drivers of initial roll-out of 5G

The business case for 5G is likely to evolve over time, with different use cases developing at different rates depending on:

a. The point at which the necessary network technology is standardised and then becomes commercialised in network equipment and terminals;
b. The rate at which the ‘ecosystem’ around the use cases develops (particularly for ‘vertical’ apps aimed at industrial uses); and
c. The relative advantages of 5G compared to any existing technologies used to deliver the use case.

Widespread roll-out of 5G technology appears very likely in the long term from 2020 onwards when standards providing for the full set of 5G capabilities are agreed, as network equipment is refreshed. There will be consumer demand for the ‘next generation’ almost irrespective of whether consumers will utilise the enhancements offered by 5G compared to 4G, and this will drive MNOs to invest in order to compete with rivals and protect market share/ attract new customers as described in Section 3.3.

In addition, after standards are finalised, new network equipment will support both 4G and 5G technologies allowing both 4G and 5G terminals to be supported simultaneously in the same frequency bands with dynamic allocation of resources between the two. Price differentials for 5G-capable equipment are likely to rapidly narrow to the point where it is unlikely to be sufficient to encourage operators to roll-out 4G-only equipment on a forward looking basis, in the knowledge that 5G equipment will be the norm sooner or later.

However, as with the initial roll-out of 3G networks, the scope of 5G roll-out could be more limited in the short term due to the high sunk costs associated with 4G networks. 4G networks provide an acceptable quality of service for many customers much of the time in terms of coverage and in cells which are not congested, i.e. in cells where there are relatively few active customers at the busiest time of day.

For example, many users may currently find existing networks sufficient to meet their needs, i.e. sufficient throughput to allow good quality video streaming. Vodafone reports a KPI of the proportion of user sessions with a throughput greater than 3 Mbit/s (broadly a level which would allow good quality video streaming) and this is achieved across much of the Vodafone network.[26]

Therefore the drivers of investment in the short term may be:

a. The need for congestion relief on existing 4G networks;
b. New 5G-specific use cases driving consumer demand; and
c. Competitive interactions between MNOs.

Given the spectrum bands available, and investment costs, operators may seek to deploy the technology on existing mobile infrastructure and new infrastructure such as small cells. This is explored in further detail in the remainder of this section.

In this section we explore the benefits and potential costs of deploying 5G technology in the medium term (until around 2025) and draw conclusions on the potential level of investment in the status quo (i.e. absent any additional policy interventions from those currently foreseen).

5.2 MBB Congestion relief

Over time, traffic and what customers perceive as an acceptable level of user bandwidth will continue to increase. For example, the usage and quality of mobile video continued to increase since it initially became available with 3G and following the launch of 4G. To some degree this continued growth in demand can be met through the deployment of additional spectrum where not all spectrum is currently deployed, densification of the network, continued re-farming of spectrum from 2G and 3G technologies to 4G and technology advances in 4G.

However, in areas where 4G networks are currently heavily congested, these approaches are unlikely to provide sufficient capacity to fully remove congestion. In these areas, a number of techniques may be required to add capacity relying on 5G technology, such as:

- Additional spectrum licences acquired;
- Use of massive MIMO to increase the capacity (and coverage) associated with higher frequency spectrum; and
- Roll-out of small cells to densify the network in high traffic areas.

New spectrum

The main trigger for roll-out of new equipment in the short term will be the availability of new bands for mobile. Spectrum for 5G technologies can come from two sources:

- Spectrum cleared of other uses, such as spectrum previously used for television broadcast;
- Spectrum ‘refarmed’ from previous generations of mobile technology.

[26] 92% of sessions across Western Europe report in Vodafone Group Results: for the year ended 31 March 2018 15 May 2018

Initially 5G capable equipment is likely to be deployed on cleared new spectrum, rather than replacing equipment on existing bands as:

a. The costs of deploying spectrum for previous generations have already been incurred, i.e. there are sunk costs; and
b. The benefits of 5G compared to 4G are not sufficient to write off the investment in 4G networks at present.

However, the 5G standards allow for the use of almost all existing mobile bands and as the network is refreshed or when the capabilities of new equipment make it worthwhile to upgrade networks, 5G capable equipment will increasingly be deployed on existing bands.

As described above, three main spectrum bands have been identified to be allocated in the medium term; 700MHz, 3.4-3.8GHz and 26GHz. The characteristics of these bands differ significantly with low frequency capable of providing wide coverage but limited additional capacity, 3.4-3.8GHz spectrum providing higher capacity but lower coverage, and 26GHz providing very high capacity but with very weak propagation.

Spectrum in the 3.4-3.8GHz band (3.4-3.6GHz) was auctioned in April 2018 with all four MNOs acquiring spectrum. 700MHz spectrum is planned to be auctioned in 2019 alongside additional spectrum in the 3.4-3.8GHz band (3.6-3.8GHz).

As they currently do with 2G, 3G and 4G, network operators can use different bands in different geographies to deliver the optimal trade-off between user experience and cost:

a. Using low frequency spectrum with high inter-site distance (ISD) in areas with lower traffic density to lower the costs of coverage; and
b. Using higher frequency spectrum with low ISD in areas with high traffic density.

Massive MIMO

Massive Multiple-input multiple-output (MIMO) is a technology that will be supported by 5G technology (and can also be used in the 4G context with high frequency spectrum), with a high number of antenna transmitting and receiving more than one data stream simultaneously, allowing greater capacity with a given amount of spectrum. Through the use of beamforming technology, spectrum can be used efficiently to target users, allowing improved data rates and coverage.

Massive MIMO will be important for delivering the desired outcomes of 5G as it allows significant improvements in data rates and link reliability, meaning more users in a dense area can consume data without using more spectrum or suffering from interference.

Small cells

As noted in the previous section, 5G is likely to be delivered through a combination of macro cells and small cells. A network of small cells will be necessary to provide sufficient capacity in high traffic areas where low frequency spectrum deployed on macro sites will be insufficient (and coverage would be insufficient with high frequency deployed on macros, utilising MIMO).

5.3 New use cases

While there is likely to be a good business case for using newly acquired spectrum to provide improved eMBB services over 5G (where networks are currently congested or are likely to be congested in the near future) this is unlikely to lead to significant overall increases in revenues as data allowances are likely to increase in line with capacity.

A relevant question is whether it is commercially feasible to offer high user bandwidths ubiquitously by extending the network of 5G small cells to areas which are not congested. Over and above the roll-out to congested areas, an accelerated rate of 5G deployment will depend on demand for 5G-specific use cases:

- For evolutions of existing use cases, including eMBB, the extent of roll-out will depend on whether there are expected to be sufficient benefits specific to 5G. The incremental benefits brought by 5G compared to 4G must be sufficient, or be perceived by customers to be sufficient, to justify roll-out of 5G to complement or replace existing 4G investments in areas where congestion or coverage is not an issue; and
- Whether there is sufficient demand from new use cases such as IoT and URLLC which cannot be supported by existing networks to justify roll-out of incremental 5G equipment.

eMBB

Currently MBB performance is more limited by congestion and capacity than any fundamental shortcoming of 4G technology, which can offer theoretical data rates far in excess of those generally used on smartphones. For example, EE offer theoretical maximum speeds of 60Mbps to over 35 million customers and 90Mbps in central London. Later releases of 4G technology will increase the peak bandwidth available for 4G.

However, more ubiquitous 5G roll-out may be necessary if there are use cases that require significantly higher user bandwidth or generate more traffic when users are outside of the home or office (where WiFi networks are likely to continue to provide most capacity). While developments such as ultra-high quality video (e.g. 4K video) could provide a requirement for greater bandwidth, the likely limited additional perceived utility of such services on a smartphone compared to HD video means this improvement may not drive incremental revenues and hence incentives for roll-out.[27]

The existing MBB market is saturated, with high penetration. ARPUs have been flat in recent years, even as usage has increased dramatically, suggesting that

[27] For example to be able to perceive any benefits from a move from HD to UHD, BT estimate that the viewer would need to view the screen from a distance less than 3 times the height of the screen (http://www.mediaandbroadcast.bt.com/wp-content/uploads/Research-paper-UHDTV-final-v1.01-.pdf) which for an iPhone X would require the viewer to be around 7 inches from the screen.

consumer behaviour could be characterised more as consumers setting their budget for mobile (including the cost of a smartphone) and adjusting their consumption with the resulting data cap (using WiFi where available). Previous differences in performance, e.g. the early introduction of 4G or the introduction of carrier aggregation (which allows higher speeds for 4G services), do not appear to have allowed operators with an advantage to charge a significant premium or attract/retain a significantly greater proportion of customers. Unless there is a 'killer app' for eMBB it may be unlikely that operators will find it profitable to roll-out a denser small cell network for 5G outside of congested areas, only to support eMBB with consistently much higher user bandwidths.

Whilst the business case for investing in an extensive small cell 5G network to support consumer eMBB services is currently unclear, such a network could offer the potential of new B2B applications and drive new sources of revenue.

Internet of Things

The Internet of Things (IoT) captures a wide range of use cases involving machine to machine connectivity - where devices communicate with each other. This includes many devices under the bracket of 'smart homes' – allowing efficient and remote control of household appliances, heating and electricity, and 'smart cities' with connected traffic signals and sensors.

While IoT can clearly lead to significant benefits for users in the long term, a degree of process re-engineering will be required to deliver these benefits along with integration of connectivity into devices.

IoT use cases may require communication either within a defined area (e.g. smart home, smart cities) or near ubiquitous access. The need to provide good coverage, including indoor, means that IoT applications would benefit from the use of low frequency spectrum (e.g. sub-1GHz spectrum). The typically low bandwidth required means that performance is less of an issue, meaning that IoT services can be delivered using low frequency bands and large cells.

One of the most significant cases of mobile networks to support IoT uses is smart metering. O2 won the contracts to provide connectivity over 15 years for the South and Central parts of the UK with the total contract value worth £1.5 billion[28] based on GPRS (2G).

There are a number of competing technologies for IoT wide area coverage including Narrowband IoT (NB-IoT) which is based on 4G technology. 5G IoT services will not be standardised until 2020. This suggests NB-IoT will play a key role for a number of years and there could be a more gradual to migration to 5G based IoT services.

The need to ensure low cost device connectivity through economies of scale is likely to mean that mass adoption of 5G for IoT will be dependent on 5G being adopted as the global de facto standard in the same way that WiFi is currently the de facto standard for home automation (where neither range nor power consumption are significant constraints).

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[28] https://news.o2.co.uk/press-release/telefonica-uk-signs-1-5bn-smart-meter-deal/

At this point it is unclear what incremental revenues will accrue to network operators providing the wide area connectivity for IoT services and to what degree operators will be able to use 5G technology to differentiate from other competing technologies.

Ultra-Reliable and Low Latency Communications

URLLC services are those that require secure data communications with ultra-high reliability and very low latency requirements such as those that require time-sensitive responses. Examples include industrial automation, unmanned and autonomous vehicles and remote control of sensitive equipment involving tactile feedback.

URLLC will also be standardised in 2020. URLLC will require a good level of underlying network coverage and performance which is likely to restrict its use initially to limited geographic areas where such a level of coverage can be guaranteed, for example industrial parks, campuses, etc. Again the need to build an eco-system around these use cases may limit take up initially.

If such localised use cases prove successful then this could be a signal for a wider roll-out of the network infrastructure required to support these use cases.

Fixed wireless access

Ironically a fixed use case has been posited as one of the first applications of 5G technology i.e. using mobile networks to also provide services within customers' homes. The use of high frequencies can result in bandwidths competitive with copper based access technologies such as VDSL and potentially even fibre technologies, for the provision of broadband services. As such 5G networks could provide an alternative to rolling out new fixed infrastructure in some circumstances.

FWA does have some advantages over traditional fixed line services, in particular the ability to self-install the service with no need for work in the network. In addition, without the constraints of power consumption and miniaturisation of smartphones, 5G terminal equipment for FWA may be available before 5G smartphones. However, the user bandwidths available for FWA appear uncompetitive with those available on a forward-looking basis from UFBB networks such as full fibre networks.[29] This is the case even in the best case scenarios, with significant variation in user bandwidths depending on location relative to the base station.[30] While this can be mitigated to some extent by using roof base aerials, this effectively negates any self-install advantages.

However, given the ability to provide FWA in addition to MBB services over a common network, FWA may be a profitable niche service prior to the roll-out of full fibre networks for a subset of customers who do not find current broadband services meet their needs. It may also be able to provide services in areas where fibre roll-out is not economically viable.

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29 Full fibre networks can deliver gigabit speeds uniformly across the user base currently, with technologies to deliver much higher speeds (XG-PON and NGPON2) already standardised and beginning to be rolled out.

30 https://www.ericsson.com/en/ericsson-technology-review/archive/2016/fixed-wireless-access-on-a-massive-scale-with-5g

5.4 5G Deployment on existing sites

Given the above, the short-term drivers of investment are likely to initially be the need for congestion relief for 4G networks, followed by the potential for wider use-cases. Therefore operators will seek to first deploy 700MHz or 3.4-3.8GHz spectrum on existing sites as the spectrum becomes available. The operators currently have networks of around 18,000 sites each[31] with a large degree of sharing of sites within the two network sharing arrangements.[32] Our assumptions on the incremental cost for deployment is set out below:

Figure 13 Incremental Unit cost for deployment on existing macro sites

Band	Capex (£/site)	Opex (£/site/year)
700MHz	35,073	2,625
3.4-3.8GHz	36,450	2,925

Source: Frontier based on 5G Norma

These costs are based on the assumption that the underlying infrastructure can support the additional equipment. To some extent the space requirements on towers and roof top sites can be reduced by installing equipment and antennae which consolidates both existing and new bands/technologies, albeit at additional cost. However, massive MIMO antennae are significantly heavier than existing antennae and there may be a need to strengthen a significant proportion of masts. As such the unit costs above may be a lower bound.

3.4-3.6GHz spectrum is available now and offers significant potential increases in capacity and performance but, being a higher frequency, it has significantly worse propagation characteristics than the spectrum currently used in mobile networks, all else being equal. Deploying on the existing 'grid' of macro-cells which has been rolled out to provide coverage using lower frequency spectrum for existing technologies (typically 1800MHz for 4G – LTE1800 and 2100MHz for 3G – UMTS2100) could leave parts of built up areas not covered by the 3.4-3.8GHz spectrum. However, this can be mitigated to some extent by three factors:

a. 5G beam forming, through Massive MIMO (as described above), can provide increased range.

b. Technologies are in development that could allow 5G networks to use different bands ('decoupling') for the uplink from downlink, again providing increased range as the uplink range is lower than the downlink range for 3.4-3.8GHz.[33]

c. The overall capacity will be increased, even where higher frequencies do not cover the full coverage area served by a site. Operators can use the additional capacity offered by 3.4-3.8GHz close to cell sites to offload traffic for other lower frequency bands. This would result in more available capacity

[31] See Ofcom Mobile call termination market review 2015-18 Annexe 9 https://www.ofcom.org.uk/__data/assets/pdf_file/0019/72109/annexes_7-13.pdf

[32] There will also be a degree of sharing between the two network sharing arrangements either due to both JVs using sites from 3rd party infrastructure providers or because one JV accesses a site of the other JV.

[33] https://www.huawei.com/en/press-events/news/2017/11/Huawei-EE-5G-Uplink-Downlink-London

in those other bands which would improve consumer outcomes over a wider area than that directly covered by 3.4-3.8GHz spectrum.

However, given the characteristics of 3.4-3.8GHz spectrum, the inter-site distance[34] in rural areas will to make roll-out of this spectrum outside built-up areas less likely. We assume that this spectrum will be rolled out to sites in built up areas only – approximately 13,000 sites per operator.[35] The remaining approximately 5,000 sites per operator would primarily provide 5G coverage using low frequency spectrum - likely the 700MHz spectrum. The benefits of rolling out 3.4GHz spectrum to macro sites in rural areas is likely to be small as the increased capacity would only be available in a small area around the macro site.

Given the two network sharing JVs, the number of physical sites where equipment will need to be installed would be approximately double this number. As 5G is likely to be outside the scope of existing network equipment sharing agreements and operators are likely to seek to differentiate from each other in the roll-out of 5G equipment we assume both operators will install their own active equipment at each site, i.e. two sets of active equipment installed at each physical site.

Even among the sites in built up areas, the distribution of traffic is likely to vary significantly. Cells in the most densely trafficked areas are likely to still be congested even where all the 3.4-3.8GHz spectrum is deployed. Meanwhile, cells at the margins of built up areas could potentially offer more than acceptable levels of throughput without using 3.4-3.8GHz spectrum. As such the assumption that the 3.4-3.8GHz spectrum is deployed on all cells in built up areas is likely to be an upper bound (offset to a degree by the exclusion of infrastructure upgrade costs).

700MHz spectrum could be deployed to most existing sites.[36] For rural sites, low frequency spectrum is required to provide coverage. Installing equipment to deliver 5G using 700MHz spectrum would bring benefits both in terms of additional capacity and also enable 5G specific capabilities (such as MMC and URLLC) where these are not available from the existing equipment.[37] In built up areas low frequency spectrum helps provide in-building coverage, due to the ability to better penetrate buildings. As noted above, the operators currently have networks of around 18,000 sites each with a large degree of sharing of sites within the two network sharing arrangements.[38] As above, we assume that 5G roll-out would be outside the scope of any existing arrangements to share active equipment and so all 4 MNOs would install equipment independently.

[34] See RealWireless assumptions in Annex D.

[35] Source Ofcom : Annexes to Advice to Government on the consumer and competition issues relating to liberalisation of 900MHz and 1800MHz spectrum for UMTS

[36] In dense urban areas, it may not be efficient to deploy low frequency spectrum on all sites.

[37] Current equipment typically delivering LTE at 800 MHz and GSM and UMTS at 900 MHz.

[38] There will also be a degree of sharing between the two network sharing arrangements either due to both JVs using sites from 3rd party infrastructure providers or because one JV accesses a site of the other JV.

Figure 14 Total capex and opex across all 4 operators

Band	Number of sites per operator	Total Capex (£billion)	Total Opex (£billion/year)
3.4 GHz upgrade to urban and suburban macro sites	13,000	1.90	0.15
700 MHz upgrade to all macro sites	18,000	2.53	0.19

Source: Frontier

Note: Costs based on an assumption of no network sharing of active equipment

5.5 Small cells deployment

Rolling out new spectrum on existing sites is not likely to provide all of the potential performance requirements of 5G networks (if all eMBB, IoT and URLLC use cases materialise). This is due to the range of 3.4-3.8GHz being too low to provide seamless coverage at the high level of performance set out in the ITU's IMT-2020 specifications from existing macro sites alone.

In addition, even after the deployment of all spectrum on macro-sites, highly trafficked areas may still face congestion from continued growth in MBB uses, with Cisco forecasting 47% growth in mobile data traffic per annum in the period from 2017 to 2021.[39]

Densifying the network further is best achieved through the use of a network of smaller cells rather than additional macro cells, which could operate within coverage of macros to provide both higher capacity and higher performance to a wider area than is possible through relying on deployment of high and low frequency spectrum on macros alone.

Given the current uncertainty about the demand for 5G networks and when the use cases which demand high performance may materialise, it is not clear that such seamless networks will be necessary immediately. However, if a 5G network that provides seamless high performance connectivity is required, the large number of cells needed will mean that the forward looking investment necessary to deliver this is significant. Offsetting this is a reduced unit cost for small cells compared to macro-sites. Our estimate of the unit cost of small cells is shown below.

Figure 15 Small cell unit costs per site

	Capex (£/site)	Opex (£/site/year)
3.4-3.8GHz small cell	16,023	5,384

Source: Frontier based on 5G Norma

While the investment cost per small cell site is around a tenth of that of a full macro-site[40], Opex remains a significant cost as there is still a need to provide

[39] Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2016–2021 White Paper

[40] With a new 5G macro site estimated to have capex costs of around £150,000 (based on 5G Norma) depending on the amount of spectrum and active equipment deployed on the site.

power, rent the site and provide high capacity backhaul in addition to maintaining the active equipment.

As small cells with 3.4-3.8GHz spectrum will typically provide more limited coverage, they are unlikely to be deployed extensively outside built up/populated areas. We have used information on ‘’clutter types” to define four areas in order to model the cost of providing seamless coverage to populated areas. These clutter types broadly corresponding to the 80% of the population that is defined as living in populated areas.

In order to estimate the number of small cell sites required we have used assumptions on the inter-site distance required assuming that cells can be deployed uniformly across the territory shown below.

Figure 16 Number of small cells required for coverage

Clutter type	Land area (Km square)	Cell radii (Km)	Number of cell sites
Dense urban	176	0.09	9,296
Urban	3,686	0.09	194,635
Suburban	6,309	0.17	93,359
Villages	4,955	0.62	5,514

Source: Frontier based on Real Wireless and LS Telcom

The assumptions on the number of sites required has been cross checked against work carried out by LS Telcom looking at infrastructure requirements for a small sample of areas.

Combining the number of sites required with the unit costs above gives the following estimates of total costs for the 4 operators (assuming no sharing of equipment). There is however some uncertainty and lack of industry consensus on the number of small cells required for 5G and the extent to which infrastructure will be shared. The cost estimate for a single set for small cells serving dense urban and urban areas is c. £3bn Note, this does not include core network upgrades or the cost of spectrum.

Figure 17 Total cost of small cell networks across all 4 operators

	Capex (£bn)	Opex (£/bn/year)
Dense urban small cells	0.60	0.20
Urban small cells	12.47	4.19
Suburban small cells	5.98	2.01
Village small cells	0.35	0.12
Total	19.40	6.52

Source: Frontier

Note: Costs based on an assumption of no network sharing of active equipment

Specialised networks

Some use cases reliant on 5G-specific features such as URLLC may only require coverage of a localised area, for example an industrial site or office campus. In these cases the end user may be able to internalise the investment required by installing their own infrastructure, rather than relying on an operator to provide coverage, subject to the availability of spectrum. We touch on this point further, later in the report.

5.6 Viability of required investment

As noted above, the link between demand and investment is less clear than in fixed telecommunications networks. As such it is difficult to determine whether a given investment is profitable, in that the resulting cash flows cover the costs of the investment including the cost of capital. Instead we use two benchmarks to assess the degree to which incremental investment in 5G networks is viable:

a. Comparison of the incremental capital expenditure required for different 5G deployment scenarios with the historical level of capex by UK MNOs; and

b. Comparison of the incremental cost of ownership of the new network compared to the current level of revenues of the industry.

These comparisons do not indicate whether a given type of investment will provide positive returns for a given operator compared to the counter-factual where the investment is not made. However, the analysis will provide some indication of whether investment by the industry is achievable at current levels of revenue and profitability. If the investment appears to be too high to be delivered at the currently level of profitability and revenues this could mean:

a. The investment is unlikely to be made;

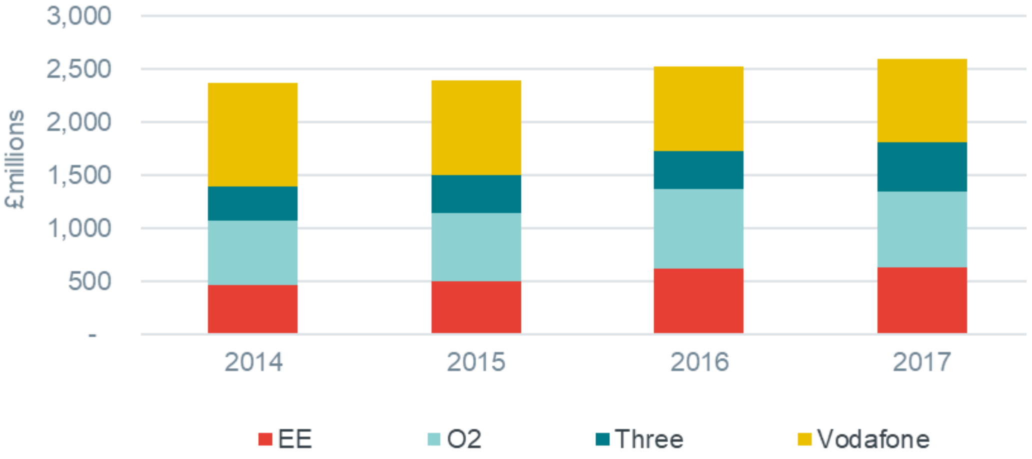
b. The investment could be made at current levels of profitability, conditional on additional revenues (margins) being generated, for example through increases in ARPU for existing subscribers or from new business to business revenues; or

c. Competition between the operators will result in the investment being made, even though this will reduce the overall level of industry profitability.

Current level of investment by the industry

The UK MNOs (or the groups that own the UK MNOs) publish data on capital expenditure on an annual basis. This shows the level of investment incurred by the MNOs. This shows that overall capital expenditure has increased slightly over the past four years despite the slight declines in ARPU over the period.

Figure 18 UK MNO Capex



Source: Company annual reports

Note: For EE and Vodafone year is FY starting April each year

However, overall capital expenditure will cover a wide range of investments including refreshing and replacing existing assets, adding new capacity as well as introducing new capabilities. In addition, the expenditure will have to cover not just the RAN but also the aggregation and core network and a range of non-network systems.

The proportion of capital expenditure for different uses will vary over time and between operators. Vodafone estimated in 2017/18 for their operations in major European markets (which includes the UK) that only 18% of capital expenditure was incurred for new mobile capabilities.[41] Recognising that this figure reflects a range of different spending and investment profiles across Vodafone's European activities, this may give some indication of forward capex in the UK. If the fraction of capex spent on new mobile capabilities was similar across the UK industry this would suggest that the envelope for expenditure on 5G RAN upgrades is likely to be around a quarter of the total capital expenditure for the operators or of the order of £625 million a year. Other industry analysis suggests that the amount spent per operator could be significantly higher at around 50% of the total annual capex and we also present an assumption based on an incremental annual spend of £1,250 million a year.[42]

We compare this with the total investment required to estimate how many years would be required to complete the investment within the current capital expenditure envelope.

Roll-out of 3.4 GHz spectrum on 13,000 sites would require approximately 3 years (18 months assuming the spend equating to 50% of current capex run rate) of this capex spend with rolling out 700 MHz on all sites requiring a further 4 years (2 years under the higher capex assumption) once the spectrum became

[41] Vodafone 2018 results presentation, Page 18 https://www.vodafone.com/content/dam/vodafone/investors/financial_results_feeds/year-ended-31-march-2018/FY_2018_Presentation_DOWNLOAD.pdf

[42] HSBC (2018), '5G: What's the use…?'
https://www.gbm.hsbc.com/insights/technology/does-5g-have-a-use

available. Thus upgrading existing sites would be feasible even within current capex budgets.[43]

However, rolling out a network of small cells across the country would require a significantly longer period of capital investment.

Current level of revenues

The vast majority of MNOs revenues are currently from voice and MBB usage by individuals.[44]

Ofcom publishes both ARPU and subscriber numbers, with the number of subscribers being greater than the population in the UK. This can be used to derive the total retail revenues of the mobile industry which can then be compared to the total cost of 5G upgrades.

Capital investment is only one component of the total cost of the network, as new infrastructure and equipment will incur incremental operational expenditure for operations and maintenance (or may reduce operational expenditure due to efficiency gains). To maintain profitability, revenues will have to be sufficient to cover:

- The recovery of the initial investment over time;
- A return on the initial investment; and
- The operating expenditure.

The standard approach to determining the viability of investments is to forecast future cash flows resulting from the investment, both capital and operating costs and future margins, and calculate the internal rate of return. However, given the uncertainties attached to the revenue side, such an approach cannot be easily applied to 5G investments. Instead, as a benchmark we have estimated an equivalent total annualised cost by applying a simple economic depreciation[45] calculation to the capital expenditure and adding the estimated operational expenditure.

A scenario based on roll-out of 5G equipment on existing sites plus small cells in dense urban areas would likely lead to an increase of costs equivalent to around 10% of revenues, which appears to be sustainable. However a scenario which also has a full small cell roll-out over built up areas would lead to an increase in costs equivalent to c. 70% of revenues (assuming no infrastructure sharing) which does not appear plausible without a significant increase in revenues. While new use cases could drive increased revenues, there is considerable uncertainty on the timing and level of such incremental revenues. MNOs are unlikely to make speculative investments in advance of more certainty on the potential revenues from these new use cases.

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43 This may only provide 5G coverage in a relatively small geographic area of the country with more than 75% of the population in built up areas making up 6% of the UK land mass.

44 Although in many cases this usage will be paid for by businesses.

45 Economic depreciation also includes the cost of capital, compared to accounting depreciation which only includes the recovery of the initial investment. We have used a simple annuity formula, which assumes that recovery is constant (in real terms) over the life of the asset. We have used an asset lifetime of 10 years and a real post tax cost of capital of 7.0%.

5.7 The current market model may not deliver in some areas/use cases

Based on the expected deployment of 5G described above, there appear to a number of areas where the current model may not be able to fully meet demand for connectivity from all users at least in the short term:

- Rural areas, where incremental revenue from consumer mobile services does not cover the cost of deployment;
- Inside office buildings, hotels and shops, where physical and economic constraints can prevent operators from installing In-Building Systems;
- Road and Rail corridors, where again physical and access limitations can prevent roll-out by mobile network operators, or render it prohibitively expensive; and
- Industrial premises and campuses, which may require bespoke networks and use cases utilising 5G features (such as URLLC or mMTC).

Below we discuss each of these in turn.

Rural coverage

In rural areas, where demand for mobile broadband is less likely to lead to congestion on existing networks, the benefits of roll-out using spectrum in the 3.4-3.8GHz band may be limited because of a lack of demand for such connectivity. Further, due to the limited propagation characteristics of this spectrum it would likely be expensive for all MNOs to cover all rural areas with 3.4-3.8Ghz spectrum, due to the requirement for a large amount of investment into new cell sites. Whilst this investment may be feasible for areas of high demand, the land area it would be necessary to cover in order to deliver full 5G coverage with high frequency spectrum would likely make this economically infeasible. Therefore there seems to be limited commercial rationale for MNOs to roll-out to all areas with higher frequencies such as 3.4-3.8Ghz spectrum, even where they have existing coverage.

Whilst 5G networks based on 3.4-3.8GHz spectrum may not be economically feasible in all areas, there is still likely to be user demand for 5G technology in rural areas and for the benefits in terms of higher speeds and potential use cases in these areas to be accessible. Operators may therefore be expected to cover certain areas with lower frequency spectrum, including 700MHz spectrum. This might largely be sufficient for the needs of consumers in these areas, and could deliver 5G at a lower cost. This is likely to be achieved mainly through refreshing equipment on existing sites and increased site sharing, rather than building new sites.

In some cases, the provision of fixed wireless access services may generate additional revenues which could support increased roll-out of 5G technology. For example, a network rolled out for rural mobile coverage may provide better broadband services than current copper based networks. However, as fixed networks are upgraded to deliver the 10 Mbit/s universal service obligation (USO), the MNOs’ 5G networks based on sub 1GHz spectrum alone are unlikely to provide consistently better performance than the fixed network. This differential will further increase when FTTP is rolled out in rural areas. While supplementing sub 1GHz spectrum with higher frequencies to narrow the performance gap with fixed could be an option, the effectiveness of this would depend on the costs of providing more capacity (including the cost of backhaul) compared to the potential revenue generated from FWA customers within the coverage area of higher frequency spectrum.

Ofcom has consulted on rural coverage obligations[46] attached to up to three[47] spectrum licenses for the 700MHz spectrum auction in 2019/20, which do not have to be met using 5G technology (or even the spectrum to which the coverage is attached).

Indoor coverage

Providing high capacity/high performance networks will require the use of higher frequency spectrum, such as the 3.4-3.6GHz band recently auctioned. MNOs in general provide coverage in-building with an “outside-in” model. i.e. reliant on signals from a site outside the building penetrating inside the building to serve users indoors. Whilst the “outside-in” approach is generally sufficient with sub-1GHz spectrum, it may not ensure sufficient coverage for deep inside larger buildings and when buildings are made of certain materials, particularly with higher frequency spectrum. Given the propagation characteristics of 3.4-3.8GHz spectrum, an “outside-in” approach may therefore not provide sufficient indoor coverage; it will be necessary to install equipment directly inside buildings to ensure mobile coverage is available within the buildings themselves. This presents additional challenges which were not present to the same extent with previous generations of technology operating on lower spectrum frequency bands.

In-building mobile coverage in large, multi-occupancy buildings, airports and shopping centres has tended to be delivered through Distributed Antenna Systems (DAS) where the MNOs’ mobile signal is distributed to a network of antenna nodes which are placed throughout the building to ensure the best coverage throughout the building as less power is wasted overcoming penetration losses because line of sight is present in most cases. This has been used in specific areas for existing mobile technologies such as delivering mobile services through the Channel tunnel, where the use of DAS is more efficient than alternatives.

Installing in-building systems requires agreements for access by landlords in order for the DAS systems to be installed and maintained. This has generally been found to be uneconomic for all but the largest buildings and campuses. This creates a significant barrier to delivering in-building coverage using higher frequency spectrum. If all MNOs attempt to provide in-building coverage independently, this would require four bilateral agreements with landlords for every in-building installation and a large amount of equipment. Further, physical

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[46] Ofcom, Proposals for coverage obligations in the award of the 700MHz spectrum, Section 3 https://www.ofcom.org.uk/__data/assets/pdf_file/0022/111937/consultation-700mhz-coverage-obligations.pdf

[47] A third licence would have obligations in terms of the provision of in building coverage.

constraints on space may limit the amount of equipment that can be installed in buildings and this may limit the number of operators that can provide in-building coverage in a given location.[48] Although there may be an incentive for self-provision by landlords, without access to spectrum, landlords will rely on MNOs to deliver indoor coverage. Given the costs of addressing administrative barriers, all MNOs are unlikely to find it commercially attractive to deliver full in-building coverage, without further intervention.

As such in-building coverage could be limited to the most important strategic areas in the short term or only available on certain mobile networks and consumers would be expected to rely on other technologies such as WiFi for connectivity indoors.

Transport infrastructure

Given the nature of the challenges in delivering connectivity on transport networks, it is not clear that the current market structure is optimal. It is not self-evident that mobile networks or an SWN using MNO's spectrum bands would be an optimal solution to improving connectivity on roads and railways. The National Infrastructure Commission envisages dedicated roadside or trackside infrastructure to provide connectivity[49] which could require an alternative commercial model. This might be delivered over a non-MNO SWN in future, however, MNO connectivity is the current default option.

As with in-building systems, for certain transport infrastructure such as rail networks, the delivery of 5G mobile services may need to rely on specific systems such as DAS or networks designed to deliver sufficient coverage given the nature of the transport infrastructure, e.g. where rail networks go through tunnels or in deep cutting. As described above, DAS has been used for delivery of existing mobile services for the Channel tunnel.

On transport infrastructure there may be significant physical limitations to the amount of equipment that can be installed onto transport infrastructure and restrictions on site access due to safety issues. For this reason, sharing of DAS systems may be necessary, for example the DAS system in the Channel tunnel is shared by all network providers on the French side and the UK side, and MNOs are expected to share equipment on the network currently being planned by TfL to deliver mobile services on the London Underground. These physical constraints are likely to be present across many transport networks, limiting the ability of all four existing MNOs to provide independent coverage across transport networks.

Even if the physical constraints on infrastructure deployment can be overcome, the costs of doing so could make investment in sufficient capacity for transport users uneconomic. This is a particular risk where there are peaks of high demand (e.g. at rush hour) against a background of generally much lower demand. The two examples above demonstrate that these systems have typically only been installed where there is guaranteed high demand, and with some delay.

[48] This would be the case taking into account network sharing arrangements as well, as (a) in some cases it may not be feasible to have more than one set of equipment and (b) network sharing agreements may not cover such roll-out, to allow MNOs to develop differentiated retail offers.

[49] NIC 'Connected Future' report.

Although network sharing arrangements may be negotiated in some cases it is possible that in the short term, some areas of transport networks will remain uncovered by all MNOs under the status quo.[50] We note that DCMS has an on-going programme of work focused on transport connectivity issues, including specific interventions on road and rail.

Innovative use cases and Industrial premises

As described in Section 3, there are a wide range of potential use cases for 5G, many of which extend beyond the existing mobile broadband ecosystem. Indeed, a significant number of existing 'smart technologies' have developed on the basis of WiFi, rather than relying on mobile technologies. Future smart use cases under the IoT category may need stable connectivity inside and outside of homes and therefore may need to rely on mobile networks, including 5G.

A wide range of proposed use cases under the URLLC bracket relate to industrial applications for automation, which may need to rely on high performance networks and require the low latency characteristics of 5G. MNOs are likely to focus on the development and delivery of 5G services where there is certainty that there are a large number of customers who will benefit from the technology, as this gives them the greatest chance of recovering the fixed costs of the investment. Therefore they may prioritise the development of networks in highly populated dense urban areas which can provide eMBB services. This may not be sufficient for a large number of enterprise users who may require a high performance 5G network and networks in areas outside of the dense-urban hotspots in order to utilise features of 5G relating to URLLC for automation for example, or mMTC. Although industrial companies or MVNOs serving these customers could aim to negotiate with MNOs to incentivise them to develop networks in specific areas, it may be difficult to reach agreement with MNOs who have largely focused on delivering mobile services to consumers.

Even where there is likely to be strong demand from a particular vertical use case, information asymmetries between potential users and the MNOs could prevent investment. For example, a particular use case may require an upfront investment which is sunk in nature – cannot be recovered if the demand for the use case turns out to be low. In such cases, the user (or a provider of a service to meet the use case demand) has an incentive to present a strong business case to the MNO, as they know that once the MNO invests, the MNO will face a significant part of the downside risk. The MNO itself knows this, and hence discounts the strength of the business case presented, in the absence of information to confirm it. This then leads to either the investment not being made, or being postponed until more information becomes available. These barriers to investment could be overcome by the users themselves, who have better knowledge and/or increased certainty on the level of demand, making the investment. As such self-provision may be attractive to a range of industrial companies in industries such as manufacturing – however, in 5G use cases this is not possible without access to spectrum.

[50] For example, although TfL is now planning a 4G network on the London Underground, this has come at a significant delay compared to the availability of other mobile services elsewhere in the country.

As a result, whilst limiting spectrum to a small number of licensees has ensured MNOs had sufficient spectrum to deliver consumer mobile services, with 5G, this approach could delay the development of a wider range of service providers and use cases. In addition the increased amount of spectrum available for mobile operators and technological advances may mitigate the potential impact of more flexible spectrum licensing on the MNOs incentives to continue investing.

5.8 Conclusion

In this section we have presented what we expect 5G development to look like under the status quo. The roll-out of 5G based on deploying new spectrum on existing macro-sites and some densification of the network using small cells in capacity hot spots looks achievable in the medium term (c. 2025) within operators' current capex budgets. This is likely to deliver nationwide 5G to the majority of the population. This approach would also appear to be consistent with the competitive dynamics between operators:

a. It would allow the operators' to advertise widespread coverage of 5G services, which is likely to become necessary to attract and maintain customers when 5G handsets become the norm;

b. It will reduce congestion in urban areas, providing a noticeable improvement in MBB performance in these areas which would enable them to attract and maintain customers who live, work or travel through these areas; and

c. It would enable them to advertise higher peak speeds in built up areas (although this performance would not be available uniformly).

These networks would also offer wide area coverage to support delivery of IoT over 5G but might not provide the high performance required for some of the eMBB, mMTC and URLLC use cases envisaged by the ITU outside of dense, urban areas. The widespread network of small cells that is likely to be required to deliver these use cases will require significantly greater investment and will take longer to deploy. In addition the additional costs of maintaining a dense network of small cells might require a significant increase in revenues in order to maintain profitability.

It is unclear at present what the business model is for some of the suggested 5G use cases, particularly those relating to URLLC and mMTC where concepts have been discussed but the products are not yet developed. Even under a 'first mover' business model, the MNOs are unlikely to consider that the investment required is justified as:

- Demand certainty would be a barrier to making investment even where there is a potential premium for the first mover; and
- The time taken to roll-out a network of small cells in order to deliver ubiquitous and/or bespoke high performance services would make it possible for other operators to react if a significant advantage was apparent in the first areas of deployment. This would reduce the period over which a first mover advantage would be enjoyed in the case that the effect was significant.

We also explained that due mainly to the costs of achieving widespread geographic coverage, indoor coverage, and transport infrastructure coverage, the status quo might not meet the demand for related 5G services, at least in the short term.

In the following sections we therefore consider three alternative market models and the extent to which outcomes for 5G might differ under these models, to the expected outcomes we have described in this section.

The three models are:

- **Single Wholesale Network** – a move to a market with only one network which operates at the wholesale level, allowing multiple retail players access to the network in order to deliver services to consumers. This is an option that has been considered and implemented for the delivery of 4G services as it removes the duplication of network investment.
- **Market expansion model** – a continuation of the existing competitive market with policies to allow further entry into the market by a wider range of players alongside the existing MNOs. This model could include neutral hosts for provision in some areas – effectively localised versions of single wholesale networks; and flexible access to spectrum. This model is being considered by DCMS following the call for evidence for the FTIR as a model that at minimum maintains the existing level of competition between MNOs in combination with policy measures to expand the market.
- **Market consolidation** – a move to a market with a smaller number of MNOs due to consolidation of existing MNOs through a merger. This is an option that has been presented by the industry as a means of reducing investment costs through reducing some duplication of networks.

6 SINGLE WHOLESALE NETWORK

In this section we discuss Single Wholesale Networks, the first of the alternative market models we consider in this report. We consider the rationale for this market model, comparing this to the status quo of network competition where relevant. We then discuss the potential options for implementation and summarise the evidence on Single Wholesale Networks.

6.1 Rationale for SWN

In some jurisdictions, regulators and/or governments have considered whether a Single Wholesale Network (SWN) (or Wholesale Open Access Network) might better deliver mobile services than the existing model of competing network infrastructures.

Those who support SWNs argue that they can remedy issues which arise when applying the traditional model of network competition. The most important of these concerns is that competing operators may lack the incentives to maximise coverage, resulting in inadequate or slow coverage in rural areas (where the roll-out of multiple networks would be unprofitable or where the competitive benefits of increased roll-out are limited). An expected advantage of SWNs is that it avoids the inefficient duplication of fixed infrastructure, reducing total costs, whilst allowing competition at the retail level of the market, with access available to any companies wishing to offer retail services. At the same time, relying on a monopoly such as an SWN network will likely result in worse outcomes in terms of innovation and speed of roll-out compared to competitive markets, even where regulation attempts to proxy competitive market outcomes.

Coverage and duplication of infrastructure

An SWN could deliver benefits where there is a concern that under network competition, the high costs of coverage may mean it is not profitable for operators to roll-out networks to all areas.

In theory an SWN may solve these issues in a number of ways. A single network removes the additional costs of duplication of network infrastructure which occur when multiple operators roll-out their own networks. This leads to cost savings and the smaller total costs can be recovered from the entire customer base (rather than each network operator needing to recover the costs of its own network from its own customer base).

Secondly, a government or regulator can impose coverage targets/obligations on the SWN and may provide a subsidy for the SWN to deliver this (either directly or indirectly through lower spectrum fees). Whilst they could also do this for competing operators, the costs of applying coverage targets for all operators would be higher given duplication, meaning that either coverage targets would be more limited or coverage targets would only be imposed on some operators and therefore not all customers would benefit from the full coverage.

Under both SWN and network competition, coverage without external policy intervention may be less desirable from a public policy perspective:

Therefore the main difference is that under an SWN scenario the cost of extending coverage should be lower, as duplicate investments can be avoided. However, the increased cost of competitive roll-out may be mitigated by two factors:

a. Under network competition, operators can avoid duplication of costs through network sharing arrangements, or by one operator moving first to cover the territory.
b. Network competition tends to incentivise cost reductions through innovation and by negotiating competitive prices from suppliers.

Innovation and speed of roll-out

Policymakers are concerned with a range of policy objectives in addition to maximising network coverage. For example, the costs and benefits of mobile services in any national market are heavily dependent on the rate at which new services are introduced. Even though mobile technologies are typically developed at an international level, the speed at which they become available to consumers depends crucially on investment which is dependent on both the policy environment and market structures.

Competitive markets are generally better at promoting innovation than monopolies, as competitors have incentives to innovate and to differentiate and thus gain market share. In addition while wholesale only networks will typically still allow competition in the retail market, innovation in mobile services often requires co-ordination between the retail and the network activities of an operator. New data services require new handsets and new networks to be introduced at the same time and to work together. As a result, vertically integrated network operators can be expected to be more efficient at co-ordinating these activities than a wholesale only network, where the wholesale network is a separate entity.

6.2 Potential models for introduction of SWNs

International examples give rise to two distinct models of SWNs that could be used for the roll-out of new technologies such as 5G.

The first is an SWN that is active only in the provision of wholesale services for a new technology (e.g. 5G), while current MNOs remain vertically integrated in other areas of mobile services such as voice and mobile broadband based on existing technologies. The existing MNOs would use their own networks, supplemented by purchasing 5G capacity from the SWN. The SWN might be set up entirely by the government, a new entrant or as a joint venture between the government and/or existing MNOs.

The other model entails establishing an SWN that delivers all mobile services including voice and all legacy forms of mobile broadband. Under this model the government would need to consolidate all currently allocated spectrum and asset ownership under a monopoly SWN.

We outline these two approaches below.

SWN dedicated to a single technology

In the past few years, attempts have been made to set up an SWN that is dedicated to 4G services only, including by Rwanda and Russia. These examples are discussed in more detail in Annex B. Such a model is more simple to implement than the alternative set out above, in terms of spectrum and asset ownership, as current MNOs can retain their existing spectrum and assets, and the SWN can be allocated dedicated spectrum for delivery of the specific network technology (e.g. 4G or 5G). However, coexistence of MNOs and an SWN causes potential inefficiencies which may outweigh the benefits; as MNOs will still have incentives to maintain traffic on their existing networks and the SWN cannot benefit from the existing network infrastructure to reduce costs unless access agreements are formed.

In a scenario of co-existence, there are three possible long term outcomes:

- The SWN is successful and legacy network operators fail to compete, meaning the SWN becomes a monopoly in the long run;
- The SWN is successful and legacy network operators differentiate, meaning continued network competition with an increased number of players; or
- The SWN fails and existing operators continue to provide mobile services on their existing networks.

The first scenario could occur if the SWN is given significant advantages such as preferential access to spectrum or exclusive rights to deliver 5G. Although the existing operators may be able to use their existing networks to compete with the SWN for some time, in the long term, the advantages of the SWN network could be sufficient to imply existing operators cannot continue to offer their ‘old generation’ services competitively, making legacy networks redundant. To the extent that the legacy technology remains attractive to end consumers, this may be as a complement rather than substitute for the services offered by the SWN, implying high costs for MNOs to deliver both legacy networks and purchase a large degree of capacity from the SWN. Therefore existing network operators may have limited incentive to continue to enhance their existing networks after the SWN has been established, as the costs may be difficult to recover in addition to 5G wholesale charges. In the long run, therefore, it is possible that the existing operators could decommission their own networks and migrate their remaining traffic to the SWN, or that there would be a move for consolidation so that the existing networks would effectively form part of the SWN. Whatever the exact scenario, it is likely that the situation could evolve over time into a full SWN, with no (or limited) network competition.

At the other extreme, an alternative outcome is that the SWN fails: if the existing network operators are able to meet their future retail demand using their existing networks and without relying upon the SWN at all, the SWN may not have sufficient economies of scale to be sustainable. Alternatively, the regulator may set access prices at a level which encourage the existing network operators to use the SWN to support their traffic in ‘uneconomic’ areas but to retain traffic on their own networks as far as possible. This will in part reflect the asymmetry in costs faced by existing operators when deciding whether to 'build' their own network capacity or 'buy' from the SWN:

a. On their own network, operators will only face the incremental cost of delivering additional traffic (i.e. sunk fixed costs will not be taken into account);
b. For traffic on the SWN, access prices must be set to recover a proportion of fixed and common costs for the SWN to be sustainable (i.e. for the SWN to recover all its incurred costs including fixed and sunk costs).

The MNOs will only divert traffic to the SWN if the average costs of the SWN are below the incremental costs of the serving traffic on their existing networks (for example if the SWN is given significant advantages in technology or spectrum). However, in the case of 5G in the UK, the existing MNOs have large spectrum holdings and for existing use cases such as MBB and IoT, the performance of 4G is likely to be similar to 5G for the foreseeable future. As such a 5G-only SWN could find it difficult to attract traffic from the MNOs.

A final potential outcome is that a 5G SWN runs in parallel to the existing MNOs. This outcome could occur if it attracted sufficient MVNO customers to be sustainable or it differentiated sufficiently from the existing networks, for example offering performance and coverage that could not be matched by the existing networks. However, in this case the SWN is effectively an additional nationwide operator, negating the cost advantages of avoiding duplicate networks.

SWN covering all mobile services

The other model entails establishing an SWN that incorporates all mobile services including voice and all legacy forms of mobile broadband.

Under this model the government would need to consolidate all currently allocated spectrum and asset ownership under a monopoly SWN. In order to do this, they would have to recall spectrum licences from existing operators and presumably compensate the operators for the value of the spectrum and any stranded assets.

If the government wished to benefit from the infrastructure or equipment of the existing mobile networks in the UK and combine these into the SWN, they would also need to acquire these assets from the MNOs. Given the existence of multiple networks in the UK, this would likely lead to a large amount of stranded assets. The system of consolidating spectrum and assets would therefore involve significant difficulties as existing operators would have to be compensated sufficiently and would be likely to strongly object to the forced closure of their network businesses, meaning the negotiation would be expected to take a long time. The closest example is the Australian fixed NBN, which has had a very long gestation period.

There would also be an issue of ensuring mobile services would be delivered during the transition phase and negotiation. This process would be expected to take a long time and risk significantly delay to the roll-out of new technologies.

6.3 Evidence on SWNs

In Annex B we present further evidence on SWNs:

- In B.1 we present information on the international experience where SWNs have been implemented or attempted. There are some attempts internationally at establishing SWNs for the roll-out of 4G services which have faced a number of issues, however none of these seem a relevant comparator for the UK, in terms of objectives or market conditions. The countries where this has been attempted include:
  - Kenya – where a plan for a 4G SWN was abandoned after failure to negotiate.
  - Mexico – where a 4G SWN network has now been launched in 2018 after a series of delays and is not expected to be completed (reaching 92.2% population coverage) before 2024.
  - Rwanda – where a 4G SWN network was launched in 2014 and has met its coverage targets but take up has been limited.
  - Russia – where a planned 4G SWN was abandoned after failure to negotiate.
- We also present empirical evidence on the role of competition for driving investment. Empirical work undertaken to assess the benefits of mobile network competition[51] shows 3G population coverage to be 36% higher in countries with network competition compared to countries served by a single network. Overall coverage also increased three times faster. [52] Other studies[53] also found a positive relationship between competition and investment.
- In B.2 we present some of the challenges of implementing SWNs. These include:
  - **Challenges establishing the SWN** - building SWNs will typically involve major investments over a period of years, with positive cash flows a number of years after initial investments have been incurred. Providing the appropriate structure and returns to attract the required funding in SWNs will also likely raise complexities.
  - **Issues relating to co-existence** - the SWN is also likely to require government support to be viable which will lead to potential distortions of competition during a period of co-existence of the SWN with existing network operators.

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51 https://www.gsma.com/publicpolicy/wp-content/uploads/2014/09/Assessing_the_case_for_Single_Wholesale_Networks_in_mobile_communications.pdf

52 Given the limited number of countries with a single mobile network today, our analysis compares the performance of single network countries and multiple network countries in 2001 (and 2005), to ensure a sufficient variation in our data set. In particular, we have identified countries that had below 50% 2G coverage in 2001 and calculated by how much 2G coverage had increased by 2005. While we recognise the limits of our empirical analysis, in the absence of real world examples of SWNs in mobile, analysing the performance of countries with a single mobile network provides a useful indication of how the SWN is likely to perform in practice.

53 See for example Alesina et al. (2005) , Li (2008) and Wallsten (2001).

- **The need for regulation** - The SWN will finally require regulation to protect consumers from high prices – this will need to balance, amongst other, the objective of encouraging the use of the SWN and providing a return to investors in the SWN that reflect appropriately the associated risks.

6.4 Conclusion

The main advantage of SWNs is that for a given cost, it could help achieve both improved rural and indoor coverage all else being equal. Furthermore, it can deliver overall capex savings by avoiding duplication of infrastructure.

The potential advantages could be relevant to 5G networks, as the total cost of rolling out these networks are expected to be high.

In principle, an SWN can ensure that coverage targets are met in all service areas. An SWN might also perform better in terms of indoor coverage, as it may be better placed to negotiate with building owners than if multiple independent MNOs negotiated separately.

At the same time, network competition would likely perform better than an SWN in terms of innovation and differentiation of service. Competition between MNOs generally helps speed up the roll-out of new technologies and increase efficiency. Vertically integrated operators can also be expected to be better at introducing new services, as the capabilities of handsets and the network have to be coordinated, and vertically integrated network operators can better respond to signals from consumers.

Establishing an SWN is likely however to involve long and difficult negotiations due to the wide range of stakeholders involved and the uncertainties surrounding future costs and demand. Extensive regulation is also required to ensure that a monopoly created through the SWN has adequate incentives to invest, reduce costs and improve the quality of its services. This is especially challenging in a complex and fast innovating sector. The time required to set up an SWN in the UK could risk a delayed introduction of 5G leading to delays in the delivery of the benefits of 5G use cases.

7 MARKET EXPANSION MODEL

In this section we discuss the market expansion model as the second potential alternative market model. This model involves a combination of arrangements that seek to reduce roll-out costs, and potentially introduce a higher number of network operators in the market with a more focussed and bespoke scope. We first introduce this market model and then consider the two features of this model and the expected outcomes for 5G deployment under this model compared to the status quo.

7.1 Introduction to the market expansion model

Under the current market model, roll-out of competing 5G networks by the MNOs that unlocks the full potential of 5G may be challenging for a range of reasons:

- because of the demand uncertainty associated with new 5G use cases;
- where the costs of roll-out exceed the margin that can be generated;
- because it is practically difficult for all operators to roll-out due to physical constraints; or
- because other players in the digital ecosystem may have incentives to introduce innovative applications which rely on 5G connectivity, but there is a coordination issue with the MNOs.

The market expansion model draws on evidence received by DCMS during the FTIR process as well as international developments, industry reports and papers. This is discussed in more detail in Annex C. It involves a continuation of the existing competitive market complemented with new entrants providing targeted solutions to address the challenges set out above.

First, the model would see the introduction of neutral hosts for provision of connectivity in specific areas – effectively localised versions of single wholesale networks. Second, it would facilitate bespoke entry into the market by a wider range of different types of players alongside the existing MNOs – this is to support the evolution and development of more innovative and use case specific 5G solutions; including through a more flexible approach to access to spectrum.

Given the benefits derived to date from the current market structure, this model would need to maintain competition in the UK mobile market and complement it with new entrants. As such, the interventions described in this model are intended, as far as possible, to retain the MNOs incentives to compete and innovate where competition between the MNOs can deliver effective outcomes.

In the following sections we discuss the aspects of the Market Expansion model which would be intended to improve outcomes in the areas where demand may not be met under the status quo. These fall into two categories discussed in turn:

- Neutral host models; and
- Reducing barriers to the provision of innovative use cases.

7.2 Neutral host models

In Section 6, we discussed the potential benefits and limitations of national SWNs. Given the difficulties in setting up an effective national SWN, and the loss of dynamic efficiencies in the market associated with national SWNs, there is significant risk that it would not deliver improvements compared with the status quo.

However, as set out in section 3.4, competition is not currently delivering the same level of connectivity for all users, particularly:

- In rural areas, where the incremental revenues from consumer mobile services do not cover the high cost of deployment; and
- Indoor settings, due in part to physical limitations and practicalities of delivering multi-operator solutions.

Based on the expected deployment of 5G, as described in section 5, these issues may be compounded as new connectivity challenges emerge:

- The 'outside in' approach that MNOs have taken to provide connectivity indoors is unlikely to deliver optimal solutions for indoor 5G coverage, given the propagation characteristics of 5G using spectrum frequencies above 1GHz.
- In urban areas, where operators are most likely to densify their networks, sites suitable for hosting 5G infrastructure - likely small cells - will be at a premium. This raises access issues and it could be a costly exercise to deploy multiple networks.

With supportive Government policy, neutral hosts (which are effectively localised SWNs) could help address these challenges without undermining the main competitive dynamics between the national MNOs in areas where this could be expected to deliver good outcomes for 5G.[54] Neutral Host models also have the potential to change the financing model for network infrastructure and encourage further competition in the provision of services at the retail level.

A neutral host could take any one of a number of different forms, covering areas where MNOs may not have a commercial incentive to roll-out their own 5G networks (at least in the short term) or areas where deploying multiple networks could raise issues (such as indoors). For example:

1. Neutral hosts that provide the underlying passive infrastructure (such as masts and power) on which operators install their own active equipment. This model is already prevalent in the UK, particularly for macro sites.
2. By also providing shared access to active electronic a neutral host can further reduce MNOs costs, but equipment duplication is required to allow each operator to transmit using its own radio spectrum.
3. A neutral host that also has access to suitable radio spectrum could host operators through roaming or wholesale access agreements. Such an

[54] Assuming the neutral host networks were in areas where they would not directly compete with existing MNOs, this should largely avoid coordination issues that may arise in the case of national SWNs, as discussed in Section 6.

approach would minimise equipment duplication and could deliver benefits in terms of efficient use of spectrum and peak speeds.

As well as improving the business case for rural areas and addressing the difficulties with deploying indoors and dense urban settings, neutral hosts could also play a role in providing connectivity along transport networks.

Neutral host models could lead to greater competition at the retail level by making it easier for new entrants and smaller network players to deploy equipment on a neutral host network and/or offer retail services. A neutral host should have incentives to maximise the return on their assets by minimising costs and maximising the number of wholesale customers. However, depending on the specific neutral host model, there could be a need for regulatory oversight and/or competition safeguards to ensure consumers benefit from the lower costs under this model.[55]

Evidence submitted to DCMS as part of its review suggests that neutral host models could attract new forms of longer term, lower cost capital to the market. In turn, this could reduce upfront capex required by wireless providers, incentivising deployment. Deployments inside buildings, such as hotels and offices could attract funding from landlords.

Neutral host models also lend themselves well to areas where a public subsidy could be required - for example if the government was to tender for connectivity to be provided in an area where there may be limited commercial incentives for the roll-out of networks. Such an approach has been proposed by Transport for London in order to provide connectivity on the London Underground.[56] Under this approach, the wholesale access framework can be set ex-ante as part of the tendering process and commitments sought from operators to reduce demand uncertainty.

7.3 Reducing barriers to the development of innovative 5G use cases

While spectrum licences awarded to a small number of MNOs have provided the necessary certainty to enable investment in national mobile networks, significant innovation has also occurred using shared spectrum technologies such as WiFi.[57] If a wider range of players had access to spectrum, 5G use cases and innovation may not be limited by the MNOs investment decisions. The potential for self-provision of services, if wider access to spectrum is available, could unlock further new investment. To date, self-provision has been mostly limited to licence-exempt spectrum, such as that used by Wi-Fi. While this is adequate for some, there are limitations to the types of services that can be offered over licence-exempt spectrum. New approaches to sharing spectrum have recently been

[55] For example, without regulatory oversight, if the host is a monopoly in a given area, it may have an incentive to charge higher (monopoly) prices to access seekers.

[56] https://tfl.gov.uk/info-for/media/press-releases/2017/november/4g-mobile-coverage-on-tube-on-track-to-begin-from-2019

[57] For example, a significant range of smart home devices which rely on WiFi have become available in recent years. These include personal assistant devices such as Amazon Alexa and Google Home, along with other devices such as WiFi based home security systems and remote heating controls such as the Nest.

developed which allow dynamic sharing of spectrum owned by a national operator in those locations where it is not being used, and where alternative use would not lead to interference. These have been pioneered by Ofcom in the so-called TV white space.

However, certainty for MNOs about spectrum access, and ensuring that national operators have sufficient spectrum to deliver 5G across the country is also important. There are a number of potential approaches already used in practice in a number of markets to allow innovation using 5G technologies[58], including spectrum leasing and dynamic spectrum access which would appear not to restrict the MNOs access to spectrum for the provision of 5G services and could also support the growth of neutral host models.

Flexible access to spectrum

Providing access to spectrum for self-provision could be achieved through specific allocations of spectrum being made available on an ‘licence exempt' basis, in the same way as the spectrum used for WiFi networks. This would allow any users to deploy equipment subject to restrictions to prevent harmful interference. Alternatively licences could be granted to allow spectrum not being used by the ‘primary' licensee in a given geography to be made available for other users. With flexible access to spectrum, a broad range of users including industrial companies and other businesses may have the ability and incentives for self-provision of localised networks. This is likely to be increasingly required as industry digitises its processes. As such, flexible access to spectrum may support the growth of innovative use cases whilst potentially improving some of the potential coverage gaps for rural areas, industrial sites and indoor coverage by giving a wider range of providers the option to develop localised networks.

Spectrum sharing policies could also increase the geographic usage of spectrum by allowing a wider range of potential users to access spectrum in areas where MNOs may not have strong incentives to use it for the provision of services. For example, in rural areas where MNOs may have limited incentive for investment in equipment using 3.4-3.8GHz spectrum, given its propagation characteristics (as discussed further above) this could be used by other potential users, such as on industrial sites, in rural locations, or for the provision of other valuable services such as broadband access through FWA networks. This approach is being taken by in the USA via the CBRS (Citizens Broadband Radio Service) in the 3.5 GHz band. Some existing use is protected but the aim is to have a tiered approach to licensing where some users have bid for “priority access” licences and others for “general authorised access”.[59] The FCC is proposing to make the 3550MHz to 3700MHz bands available for small cell mobile broadband services on tiered basis, providing a dedicated block of spectrum via regional licences, and making available unused spectrum on a dynamic shared basis.

Given the broad range of potential use cases for 5G technology, and the benefits that the use of high frequency spectrum such as the 3.4-3.8GHz spectrum implies – less interference for different users of the same bands due to weaker propagation – there could be benefit from allowing flexible access to this

58 For example the CBRS approach in the USA.

59 https://ocadotechnology.com/press-releases/ocado-teaches-robots-to-talk-over-4g/index.html

spectrum (as well as a potential case for mmWave spectrum) which could allow self-provision of a range of innovative 5G use cases.

7.4 Conclusion

The market expansion model may lead to improvements in outcomes compared to the status quo, without compromising the benefits that arise from the existing competition between MNOs. There could be benefits in terms of the pace of roll-out and coverage of 5G services to the extent that neutral hosts and self-supply may remove some barriers in the short term. More flexible access to spectrum may allow a wider range of innovation and service differentiation.

The precise implementation of the policy interventions to deliver the market expansion model would need to be carefully designed however to achieve these benefits.

8 MARKET CONSOLIDATION

In this section we consider market consolidation, the final market model we assess in this report. Like the SWN, this involves a reduction in the number of network operators, however it does not involve significant changes to the status quo beyond those caused by a merger between network operators. It is therefore less extreme than the SWN model. This model would be expected to be an industry led model and is therefore evaluated with a hypothetical scenario where a merger proposed as the starting premise, rather than a scenario of government policies being introduced. In this section we consider first the link between the number of players and consumer outcomes which is crucial for the evaluation of mergers in the context of 5G and former generations of mobile technology, followed by a presentation of the evidence to date.

8.1 Link between number of players and consumer outcomes

As described in Section 3, the mobile market is characterised by frequent investment cycles resulting in high capital intensity and a degree of fixed costs which investors would expect to recover. This results in a trade-off between the minimisation of total costs through avoiding duplication of network investment (static efficiencies), and the benefits of competition which may drive down prices and lead to innovation (dynamic efficiencies).

A very fragmented market with a large number of operators would be unlikely to lead to an optimal outcome for consumers. This is because a combination of high fixed costs associated with rolling out networks and fragmented spectrum holdings would mean many investments would not be feasible for a smaller operator, as they would have difficulty recovering costs from a small customer base and may be less able to deploy spectrum efficiently to minimise costs.[60]

However, while there are benefits from consolidation in terms of efficient use of scarce resources such as spectrum, a market with too few operators risks higher prices and potentially lower incentives to innovate. MNOs enforce competitive constraints on one another, encouraging faster innovation and better quality in attempts to win customers from rivals. This means consumers can potentially access the latest technology earlier, or receive the same service at a better price, as well as better coverage. In addition to these risks relating to prices and innovation, a market with too few players also increases the risk of operators coordinating behaviour to the detriment of consumers.

Therefore, a trade-off exists between higher costs and limited capacity with a very large number of players against the loss in the benefits of competition if there are too few players in the market.

[60] Operators with access to sufficient low frequency spectrum for example, can provide coverage at a lower cost given the need for fewer sites – there is some substitutability between spectrum and sites to deliver coverage.

From an operator's perspective, the potential fixed cost savings from network consolidation are valuable as these can be expected to be passed through to investors or support further profitable investment. As a result, there has been a significant push for consolidation in mobile markets, particularly across the EU in recent years. MNOs have argued that in light of declining revenues and the continued need for investment into new network technologies, consolidation would support the delivery of benefits in terms of ability and incentive to invest and hence improve consumer outcomes.

Network sharing between MNOs can result in lower fixed costs and increased coverage; however, if two networks share, the fixed cost saving from network sharing will be less extensive than the fixed costs savings achieved by having one vertically integrated player rather than two. This is because network sharing agreements tend to be restricted to specific areas of the network where there is clear common interest between the two (or more) parties to reduce costs. This may exclude parts of the network from the sharing agreement where the interests of the parties may diverge - either currently or in the future. Thus, some potential fixed cost savings and network expansion will be foregone by network sharing parties as they seek to differentiate or, due to asymmetric information or uncertainty cannot negotiate a mutually acceptable division of any benefits.

8.2 Evidence on consolidation

There has been significant research and applied cases of mobile consolidation. Further details of the experience of mobile consolidation are presented in Annex D.

- In D.1, we first examine the experiences of mobile consolidation in recent years which highlights the concerns and potential advantages of consolidation in a number of European markets. The majority of recent mobile mergers have been cleared by the EC; however, the EC expressed concerns in a number of cases that the merger could lead to upward pricing pressure due to the removal of competitive pressure. In a number of cases these concerns were addressed through remedies which aimed to promote retail competition (through MVNO access) and in some cases to allow the creation of a new network player.
- In D.2, we consider the two cases of proposed consolidation in the UK over the last decade and the arguments specific to the UK markets applied in these cases. The first case of the T-Mobile and Orange merger was cleared and led to the creation of EE. The merger was cleared on the condition of the divestment of spectrum and that the merged entity had sufficient spectrum to get a head-start on competitors in the roll-out of a 4G network. The second case was a proposed merger between O2 and Hutchison 3G. This merger was blocked, despite the parties proposing a number of remedies. The EC's main concerns with Hutchison 3G (H3G) acquiring O2 were based on higher post-merger prices, reduced investment in mobile infrastructure and potentially reduced wholesale access.
- In D.3, we present some of the literature on the impact of consolidation on market outcomes. The literature shows mixed results. One study (Genakos,

Valletti and Verboven, 2015) showed that hypothetical mergers would increase prices but also potentially have a positive effect on investment/innovation through the impact on investment incentives. Another study (Frontier Economics for the GSMA, 2015) found limited evidence of a relationship between the number of players and prices or investment whilst another study (Ofcom, 2016) found a relationship based on the presence of a 'disruptor' firm.

8.3 Conclusion

The outcomes of consolidation may vary depending on a variety of factors relating to both the merging parties themselves and the remaining competitors, which in general will require a case by case assessment. If either of the merging parties exert significant competitive pressure on the market as a whole then a merger could be detrimental for aspects such as pricing if the incentive to compete is reduced. On the other hand, a large number of mergers were cleared by the EC, suggesting some recognition that potential benefits may offset the costs in terms of loss of competition, subject to appropriate remedies.

It is difficult to predict exactly how 5G will affect the relative costs and benefits of consolidation. Substantial investment is likely to be required for 5G networks, with an increased number of sites leading to an increasing proportion of fixed costs. Therefore cost savings from consolidation may be significant and could put the remaining operators in a better financial position to cover wider areas or invest in other use cases beyond mobile broadband. Some degree of savings could also be achieved through network sharing agreement; however, uncertainties in future demand or the value of first mover advantage may make it more difficult to negotiate network sharing arrangements for 5G.

The impact of consolidation on innovation is mixed. Consolidation may reduce the competitive pressure across operators and hence the incentive to innovate to differentiate. However, consolidation may put operators in a better position to deliver innovations due to the greater proportion of scarce resources available to a larger operator.

For example in the case of Orange and T-Mobile in the UK, the merger resulted in combined spectrum holdings which allowed the merged entity to invest in 4G at a time when it may not have been possible for the individual operators absent the merger. As a merged entity, EE had sufficient spectrum and capital to invest £1.5bn in LTE roll-out.[61] As a result, EE introduced 4G earlier than it could have done pre-merger, and before the remaining UK competitors.

As a result of these factors, the impact of any consolidation in the market of 5G outcomes compared to the status quo will depend on the specific circumstances of the proposed merger.

[61] GSMA, p.15 https://www.gsma.com/publicpolicy/wp-content/uploads/2014/12/European_mobile_network_operator_mergers-A_regulatory_assessment-WEB_FINAL.pdf

9 EVALUATION OF THE MARKET MODELS

9.1 Assessing the market models

In the previous sections we have discussed the potential advantages and disadvantages of each of the market models, in comparison to the status quo, for delivering the government's 5G ambitions. On the basis of the discussion and evidence above, in this section we summarise the conclusions on each market model, then compare each of the models against the assessment criteria agreed with DCMS. These criteria include:

- Pace of Roll-out;
- Total Cost (Capex);
- Coverage (Rural);
- Coverage (Indoor);
- Innovation/Service Differentiation;
- Feasibility.

9.2 Summary for each market model

Moving to a single wholesale network would be complicated and would risk the benefits of competition

Moving to a structure with a single national wholesale only network, with competing retail operators buying from this network, is a more drastic approach to reducing costs than market consolidation. This approach has been introduced or proposed in a small number of jurisdictions, generally in an attempt to improve coverage. As discussed in Annex D, there would be a large number of challenges in setting up an SWN. These include having a process to consolidate existing networks into the SWN and compensate existing investors and determining a regulatory regime which achieved an appropriate balance between the need to incentivise investors, protect consumers and encourage service and application innovation. Countries which have moved towards an SWN, such as Rwanda and Mexico, have set up a new entrant wholesale only operator. While such an approach is somewhat simpler than a rapid transition to an SWN the potential benefits are smaller in the medium term (as introducing a new network increases the level of fixed costs in the short term), it increases the commercial risk for the SWN and does not fully remove the difficulties of tendering for the network and setting up an adequate regulatory regime.

A Market Expansion model could increase the scope of roll-out while encouraging innovation and competition

Under the current market model, roll-out of competing 5G networks by the MNOs that unlocks the full potential of 5G may be challenging for a range of reasons:

- because of the demand uncertainty associated with new 5G use cases;

- where the costs of roll-out exceed the margin that can be generated;
- because it is practically difficult for all operators to roll-out due to physical constraints; or
- because other players in the digital ecosystem may have incentives to introduce innovative applications which rely on 5G connectivity, but there is a coordination issue with the MNOs.

In order to balance the benefits of MNO competition whilst encouraging new investment models to extend coverage and boost innovation in services, a market expansion approach could be applied with policies introduced to supplement MNO networks with localised neutral hosts and self-provision of infrastructure.

The first policy area that forms part of market expansion is the encouragement of neutral hosts – where a host would roll-out a single network in potentially underserved areas and allow existing MNOs and third parties access to the network to deliver services to consumers. As discussed in Section 7.2, there are a range of ways neutral hosts could be established - the precise implementation of such a neutral host model may depend on the particular case. If effectively implemented, a neutral host model could ensure wider access to 5G services in areas that might otherwise go uncovered in the short term by minimising the costs of delivery without affecting competition in other areas.

The second policy area under a market expansion model is to reduce the barriers to provision of innovative use cases. The obvious barrier that could prevent innovative use cases from being developed outside of the MNOs, is spectrum availability. While spectrum licences awarded to a small group of MNOs have provided the necessary certainty to enable investment in national mobile networks, much innovation has occurred using shared spectrum technologies, WiFi being an obvious example. As described in Section 0, there are a range of potential approaches to allowing more flexible access to spectrum which may allow for more innovation using 5G technologies than might be seen under the status quo.

The market expansion model may lead to improvements in outcomes compared to the status quo, without compromising the benefits that arise from the existing competition between MNOs. This would be dependent on the precise implementation of the policy interventions to deliver the market expansion model. The design and implementation of policies to achieve market expansion is likely to be more feasible than an SWN.

Consolidation may increase investment at the expense of competition

One suggested approach to increase the level of investment is to allow further consolidation from 4 to 3 or even 2 network operators. As discussed in Section 8, this could reduce future costs of 5G roll-out, even compared to existing network sharing arrangements, by reducing the duplication of fixed costs in areas that are not covered by the network sharing agreements. Pooling of spectrum could provide additional benefits in delivering high performance services.[62] In addition a reduction in competition could provide more certainty on returns and increase the potential returns on risky investments. However, a reduction in competition could lead to increases in prices and a reduction in the incentives to innovate in the longer term. As discussed in Section 8 and Annex C, this has been a key concern of the EC when evaluating past mergers, and depends heavily on the specifics of the case in question. It is unclear whether remedies, such as an improved wholesale access to networks, could fully offset the loss of competition at the network level.

This market model is dependent on concrete proposals from industry players to consolidate and should be assessed on a case-by-case basis by the relevant authorities. It is difficult to predict exactly how 5G will affect the relative costs and benefits of consolidation. Additionally, the impact of any consolidation in the market on 5G outcomes compared to the status quo will depend on the specific circumstances of any proposed merger.

9.3 Evaluation against each assessment criterion

In this section we consider each of the assessment criteria in turn and evaluate each market model against the status quo, on the basis of the evidence and discussion of the previous sections of the report.

Pace of roll-out

The key barriers to roll-out under the existing market structure relate to the high costs of coverage with high frequency spectrum in rural areas, including 3.4-3.8 GHz and the uncertainty about the extent of demand. Uncertainty about demand means that in the short run at least, roll-out of 5G may be limited to upgrades to existing sites and dense urban areas to alleviate capacity constraints.

Under:

- **SWN:** although roll-out targets can be set, uncertainty and the complexities involved in designing and setting-up a SWN would likely lead to a significant delay to the start of roll-out compared to the status quo. This is supported by the (limited) international experience.
- **Market expansion:** the option for neutral hosts to roll-out in localised areas may increase the pace of roll-out to certain areas compared to a model relying solely on competitive network provision by the MNOs. A more flexible spectrum policy may also enable self-provision of localised 5G networks that seek to prioritise deployment of networks for particular customer groups or locations in advance of the MNOs.
- **Market consolidation:** a merger could increase the ability to roll-out due to efficiencies and pooled resources (assets, capital and operational ability). However it may also weaken competitive pressure to roll-out and the effect would have to be evaluated on a case by case basis.

[62] Ofcom did not apply specific spectrum caps on the 3.4 GHz spectrum in the recent auction reflecting the potential benefits due to large contiguous spectrum holdings (although it did place caps on the overall amount of spectrum that could be held).

Total capital cost

If all MNOs roll-out individual competing networks the total costs will be high, particularly in a scenario where a large number of new small cells are required to provide ubiquitous coverage. Sharing arrangements to reduce costs may be possible but would have to be negotiated.

Under:

- **SWN:** A national SWN removes duplication and hence would lead to significantly lower costs. However, in the short run there may be costs of parallel running/consolidation and in the long run a SWN may not have as strong incentives to minimise costs in the absence of competitive pressure.
- **Market expansion:** neutral host models may reduce costs in certain areas by avoiding duplication and improving opportunities for sharing, complemented by national networks provided by the MNOs.
- **Market consolidation:** there would be fewer operators reducing total costs and full mergers would be more comprehensive than network sharing agreements. However there could be a loss of dynamic efficiencies brought about by effective competition.

Rural coverage

Under the existing market model there may be limited commercial benefit from improving coverage further with 5G, even to match other operators. Ofcom proposes coverage obligations to be attached to a subset of 700Mhz spectrum licences which will mean customers of those networks will benefit from improved rural coverage. Under:

- **SWN:** Higher coverage targets can be placed on a national SWN on the assumption that it can recover the costs across all customers. However, if the SWN operates in parallel to existing MNOs it may not be financially viable to increase coverage to the degree required.
- **Market expansion:** a neutral host model may enable rural coverage through localised SWNs. Spectrum flexibility could allow for self-deployment in some areas and could also lead to greater utilisation of spectrum in areas where national MNOs may not be incentivised to deploy.
- **Market consolidation:** it is unclear whether rural coverage would improve as larger players may have a greater ability to serve rural areas, however weakened competitive pressure may mean operators have limited incentives to extend coverage.

Indoor coverage

Under the existing market model there may be barriers to all MNOs providing indoor coverage due to the need for all MNOs to negotiate access and physical restrictions. Dedicated indoor networks such as those required for industrial applications may not be a priority for MNOs. Under:

- **SWN:** Barriers relating to duplication would be removed, however a single monopoly provider may have lower incentives to negotiate access with landlords in order to differentiate from potential rivals.
- **Market expansion:** flexible spectrum policy allowing self-provision and the possibility of designated neutral hosts for indoor coverage, along with competing national MNOs, may improve outcomes compared to the status quo, as discussed above.
- **Market consolidation:** fewer operators may reduce the number of negotiations required and physical limitations (although not remove them); however, weaker competitive pressure may reduce incentives to provide high quality indoor coverage.

Innovation / service differentiation

Under the existing market model there is a risk that the more innovative use cases may not evolve if MNOs have weaker incentives to introduce more bespoke/niche use cases that require risky investment beyond the provision of existing mobile broadband services. However, competing MNOs will still have incentives to differentiate themselves. Under:

- **SWN:** competitive pressures to differentiate would be removed under a SWN and regulation is unlikely to be effective in encouraging innovation.
- **Market expansion:** flexible spectrum policy allowing for self-provision in certain settings (e.g. factories), along with national competing MNOs makes innovation and differentiation more likely.
- **Market consolidation:** fewer operators may reduce the competitive pressure to differentiate but efficiencies could increase MNOs ability to invest in new innovations/areas.

Feasibility

The continuation of the existing market model would be the most feasible market model.

The administrative requirements and coordination required to set up and regulate a SWN would be significant and complex. Many international examples of proposals have failed and issues of overhauling the market model entirely would likely lead to significant objections from interested parties (i.e. existing MNOs). As such a SWN is likely to be the least feasible option.

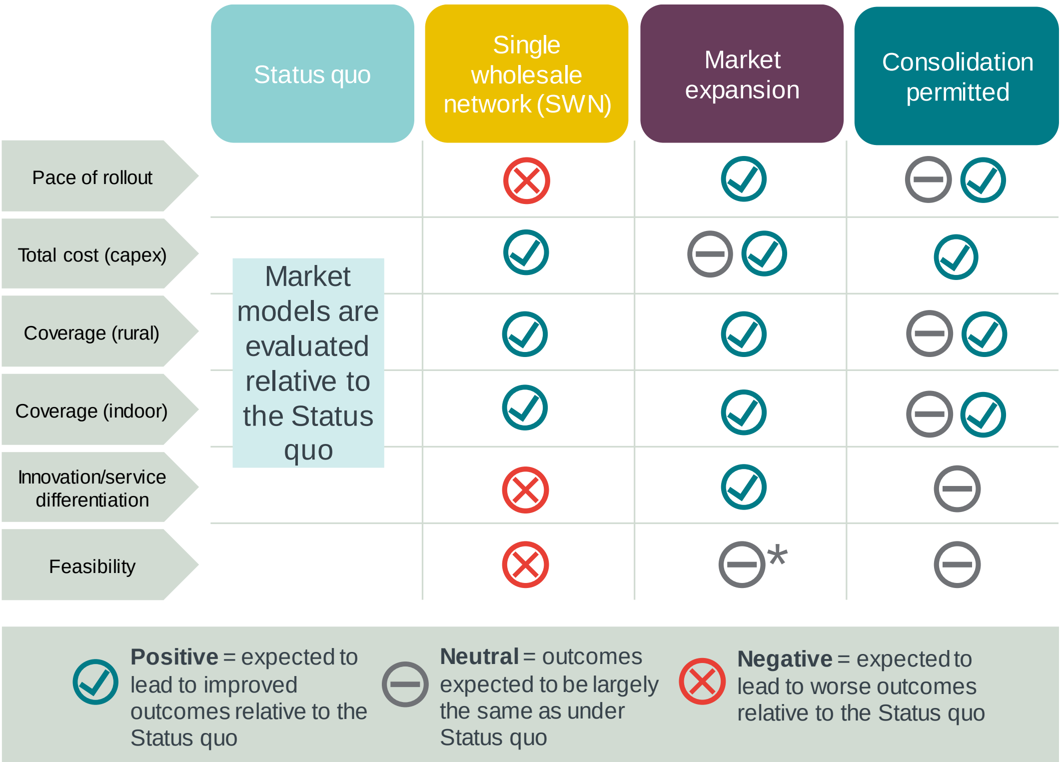
The Market Expansion model would require the design of policies relating to neutral hosts and spectrum policy, however it would not require changes to many of the existing market structures. The feasibility would depend on the precise policies in question.

Market consolidation has occurred in the past and MNOs are likely to continue to have an incentive to consolidate, however this would depend on the clearance of any merger by the relevant competition authorities based on the particular circumstances of the merger.

Summary

The figure below summarises the evaluation of the market models relative to the status quo, based on the analysis in this report. The symbols attempt to indicate the extent to which each market model would be expected to lead to improved, equivalent or worsened outcomes for the delivery of 5G relative to the status quo. Where there is more uncertainty two symbols have been used.

Figure 19 Evaluation of market models



Source: Frontier

*Note: We have placed a * in the feasibility category for the market expansion model as the feasibility would depend on the precise policies which would be implemented under this model.*

ANNEX A GLOSSARY

Figure 20 Glossary of key terms

Term	Description
MNOs	Mobile Network Operators – in the UK these are EE, O2, Vodafone and Three
MVNOs	Mobile Virtual Network Operators – retail providers of mobile services who rely on MNOs networks
5G	The next generation of mobile technology following 4G, 3G, 2G and 1G.
FTTP	Fibre to the Premises - A network architecture in which optical fibres run all the way between the exchange and the premises. Capable of offering download speeds in excess of 300Mbps.
Spectrum/cellular licences	A right to use a given frequency of spectrum
EC	European Commission
Macro cells	A macrocell is a cell in a mobile phone network that provides radio coverage.
Small cells	In this context Small cells describe all cells which are smaller than macros. They complement macro cells and will typically sit within the coverage of a macro cell providing increased capacity for a smaller range than a macro.
Carrier aggregation	Allows different carriers to be combined meaning spectrum in different bands can be used together.
MBB	Mobile broadband
WiFI	Technology for wireless local area networks
Bandwidth	the capacity of a wired or wireless network communications link to transmit the maximum amount of data from one point to another
latency	The time interval (delay) between transmission and receipt of data
ITU	International Telecommunication Union - ITU is the United Nations specialized agency for information and communication technologies responsible for allocating global radio spectrum and developing the technical standards that ensure networks and technologies seamlessly interconnect.
ISD	Inter-site distance – the distance between cell sites which depends on the spectrum frequencies used.

Term	Description
eMBB	Enhanced mobile broadband - provides greater data-bandwidth complemented by latency improvements compared to existing mobile broadband performance
IoT	The Internet of Things captures a wide range of use cases involving machine to machine connectivity: devices communicating with each other.
URLLC	Ultra-reliable and low latency communications services are those that require secure data communications with ultra-high reliability and very low latency requirement such as those that require time-sensitive responses.
FWA	Fixed Wireless access – a means of providing internet access to homes using wireless mobile network technology rather than fixed lines
Capex	Capital expenditure
Opex	Operating expenditure
Massive MIMO	Massive Multiple-input multiple-output - a system that will be possible with 5G technology (but can also be used in the 4G context with high frequency spectrum) with a high number of antenna transmitting and receiving more than one data signal simultaneously, allowing greater capacity without using more spectrum.
Beamforming	A technology which means spectrum can be used efficiently to target users and allows improved data rates and to some extent coverage.
ARPU	Average Revenue per user
Beacon	The joint undertaking between Vodafone and Telefónica UK (parent company of O2).
MBNL	The joint undertaking between EE and Three UK.
HHI	Herfindahl-Hirschman Index - a measure of market concentration that is used to determine market competitiveness
Hedonic pricing	A technique which evaluates price based on the value of characteristics of a good
Disruptor/maverick	disruptive players that do not follow the crowd and actively disturb existing market dynamics
SWN	Single Wholesale Network
Neutral host	A neutral provider of a network allowing access to operators

Term	Description
DAS	Distributed Antenna Systems - where the MNOs' mobile signal is distributed to a network of antenna nodes which are placed throughout the building to ensure the best coverage throughout the building as less power is wasted overcoming penetration losses because line of sight is present in most cases.

Source: Frontier

ANNEX B FURTHER INFORMATION ON SWNS

B.1 International experience and empirical evidence

International experience

There have been a number of attempts internationally at establishing SWNs for the roll-out of 4G services. This international evidence provides examples of the issues raised in seeking to create an SWN for 5G services.

Kenya

In Kenya, the wholesale open access wireless broadband network was planned to be built via a Public Private Partnership approach. The Government and private partners' were to build, own and operate the network which would offer wholesale capacity to new and existing service providers.

The proposed objectives of the policy were to avoid duplication of infrastructure, provide countrywide broadband connectivity and high quality, affordable services throughout the country, as well as economic growth as a result of increased penetration.

However, the roll-out of the SWN stalled due to a complicated negotiation process with a number of stakeholders. The original development plan seems to have since been abandoned. The 800MHz spectrum, which was intended to be used by the SWN, has been assigned to existing mobile operators who have begun establishing their own networks to provide mobile broadband services on this frequency band.[63]

Mexico

The main rationale for establishing an SWN in Mexico was to promote competition and increase investment. The SWN was planned to provide only wholesale services in unbundled form, providing non-discriminatory access and competitive pricing to MNOs. The government intended to impose an obligation on the SWN to reach 98% of population coverage.

The roll-out was intended to begin in 2014 using both private and public investment, and be operational by 2018. However, attracting private investors based on the initial requirements took time, despite 21 qualified bidders. In May 2015, the government announced the investment target had been reduced from $10 billion to $7 billion and the estimated number of cell towers will be closer to 12,000 instead of 20,000. [64]

[63] https://www.gsma.com/spectrum/wp-content/uploads/2017/07/GSMA_SWN-8-pager_R3_Web_Singles.pdf

[64] ibid

In March 2018, “Red Compartida” went live. Altán Redes, a private consortium that won the right to build the network, will incur the network costs whilst the government is providing spectrum in the 700MHz band and access to the fibre-optic network.[65] The network currently covers 30% of the population aiming to cover 50% by 2020 and 92% by 2024.

Rwanda

In a joint venture with the South Korean operator KT, the Rwandan Government began roll-out of a new LTE network in 2014.[66] The rationale for a national network was to enhance broadband coverage and speed. The Government argued that the national network would allow Rwanda to achieve affordability and adoption of broadband by reducing costs to end users and supporting innovation that would drive increased usage through better content and applications. It was also suggested that the single network would promote availability of broadband services especially in the rural and remote areas.[67]

in January 2018, KT announced that it had reached its coverage target of 95% population coverage on schedule.[68] However, the evidence suggests that the government intervention did not result in reduced mobile broadband prices, according to data from the regulator's website. This contrasts with the cost of voice services, which has fallen over the same period. Over the lifetime of the network there have been several significant reductions in wholesale prices (which are set via commercial negotiations), but they have not consistently translated into lower retail prices.[69]

In order to provide 4G services the MNOs must rely on wholesale access (as they have no 4G licensed spectrum themselves). However, the MNOs appear to have limited inclination to migrate customers currently using the existing 3G networks. The additional cost of 4G capable smartphones may be another barrier. Take up of 4G services, appears to have been limited.

Russia

In Russia, Scartel (branded as Yota) was allocated 40 MHz of spectrum in the 2.6 GHz band and given the first licence to offer LTE services in Russia with the condition that wholesale access must be provided to other mobile operators with the existing MNOs being able to invest in Yota. However, this initiative failed as carriers were not able to reach an agreement with Yota and launched their own LTE networks , after reportedly insisting on choosing their own vendors. A further

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65 https://www.economist.com/business/2018/03/28/mexico-switches-on-its-government-run-wholesale-mobile-network

66 http://www.myict.gov.rw/fileadmin/Documents/DRAFT_NATIONAL_BROADBAND_POLICY_FOR_RWANDA_7.22.13.doc

67 ibid

68 https://www.telegeography.com/products/commsupdate/articles/2018/01/05/rwandan-4g-network-hits-95-coverage/

69 https://www.gsma.com/spectrum/wp-content/uploads/2017/07/GSMA_SWN-8-pager_R3_Web_Singles.pdf

issue was that the government allowed Yota to act as both a wholesaler and retailer distorting Yota's incentives to offer wholesale terms attractive to other operators with which it would compete at the retail level. It appears that a revised plan for a LTE only SWN (similar to Rwanda or Mexico) also has been rejected following the roll-out of LTE services by the Russian mobile operators.

Empirical evidence

In addition to the evidence from the case-studies above demonstrating the range of potential barriers to speedy deployment, empirical work undertaken by Frontier economics for the GSMA[70] analysing data from more than 200 countries over a 15 year period shows that network competition has driven mobile network coverage for 1, 2 and 3G networks further and faster than has been achieved by single networks. After taking into account other factors such as differences in GDP/capita, 3G population coverage was found to be 36% higher in countries with network competition compared to countries served by a single network. Overall coverage also increased three times faster. [71]

This slower transition to new technologies also contributes to lower take-up of new services. In fact, markets with monopolistic provision of mobile services were estimated to lead to, on average, a 17 percentage points lower 3G take up than under network competition, after controlling for other factors driving 3G take up.

A number of academic studies have also demonstrated the key role that the opening up of markets to competition has had on driving investment. These include Alesina et al. (2005) , Li (2008) and Wallsten (2001).

B.2 Challenges with implementing SWNs

In this section we discuss the challenges of implementation of SWNs. These include:

a. Building SWNs will typically involve major investments over a period of years, with positive cash flows a number of years after initial investments have been incurred. Providing the appropriate structure and returns to attract the required funding in SWNs will also likely raise complexities.

b. The SWN is also likely to require government support to be viable which will lead to potential distortions of competition during a period of co-existence of the SWN with existing network operators.

c. The SWN will finally require regulation to protect consumers from high prices – this will need to balance, amongst other, the objective of

70 https://www.gsma.com/publicpolicy/wp-content/uploads/2014/09/Assessing_the_case_for_Single_Wholesale_Networks_in_mobile_communications.pdf

71 Given the limited number of countries with a single mobile network today, our analysis compares the performance of single network countries and multiple network countries in 2001 (and 2005), to ensure a sufficient variation in our data set. In particular, we have identified countries that had below 50% 2G coverage in 2001 and calculated by how much 2G coverage had increased by 2005. While we recognise the limits of our empirical analysis, in the absence of real world examples of SWNs in mobile, analysing the performance of countries with a single mobile network provides a useful indication of how the SWN is likely to perform in practice.

encouraging the use of the SWN and providing a return to investors in the SWN that reflect appropriately the associated risks.

Establishing the network

SWNs for the provision of mobile broadband services are largely unproven, as existing mobile cases have not yet demonstrated clear benefits. Even the countries that implemented an SWN to deliver fixed broadband services (e.g. Australia, New Zealand and Singapore) are relying on network competition to deploy next generation mobile networks. Nevertheless, the experience from the fixed segment suggests that the design, financing and implementation of any SWN are likely to pose a significant challenge. The Australian Government required at least 5 years to partially implement a fixed network SWN. A mobile SWN will be even more complex because technology changes more frequently and typically there are likely to be more existing operators to negotiate with.

Negotiations for the establishment of an SWN are complicated by a number of factors. Any private investor in the SWN will want to understand how the SWN is to be regulated in advance, since this will determine both the costs incurred by the SWN (to meet coverage and other targets) and the revenues the SWN can expect to earn (from wholesale access charges which are likely to be set or influenced by Government). It is, however, very difficult for policy makers to guarantee returns for a network that has yet to be built, and is even more challenging when forecasting costs and revenues many years ahead in the face of highly uncertain demand. Furthermore, both the regulator and the SWN will need to engage in negotiations about commitments which the other side requires. This is essentially an example of the 'hold up problem' as the contract between the government and SWN will be incomplete (i.e. cannot foresee all potential changes in the market).

Establishing an SWN is therefore likely to involve long and difficult negotiations amongst a wide range of parties. Whilst this happens, existing operators may stop/'chill' further investments until the outcome is clear. In contrast, in a competitive setting, the operators have a strong incentive to move as quickly as possible to build networks and exploit new spectrum holdings.

Co-existence of the SWN and MNOs when the SWN covers all mobile services

In the short term, the SWN will represent an additional network in the market and this would be expected to increase, rather than reduce, the overall network costs. The new SWN network will need to attract traffic to its network in order to achieve scale and reduce costs, but as described above, it is not clear that the SWN will be able to generate sufficient demand for its services to reach efficient scale.

Governments and regulators are also likely to try to ensure that the SWN will succeed in attracting traffic to its network. This 'assistance' could take several forms, including

a. assigning a high proportion of available spectrum to the SWN so as to force the existing operators to use the SWN to meet demand;

b. subsidising the wholesale prices which the SWN charges its users, so as to make them sufficiently attractive; or

c. restricting what the existing operators can do with their existing networks.

These measures would distort competition and would involve costs for consumers, potentially over and above the additional costs of parallel running of the SWN and existing networks.

Regulation

Many of the issues identified in connection with SWNs arise from the fact that it is a monopoly. There is widespread evidence that monopolies have weak incentives to invest, to seek to expand output, to reduce costs or to improve the quality of the services they provide. Those who support SWNs therefore recognise that extensive regulation will be required in an attempt to address these issues. Regulators can, for example, set wholesale prices which are intended to encourage the monopolist to improve the efficiency of its operations (e.g. through RPI-X type wholesale price controls/caps), or to encourage retailers to expand their output (e.g. through 'two part' charges). They can also set coverage targets for the SWN in an attempt to accelerate or extend roll-out, or require the SWN to upgrade its network at specified dates (e.g. by benchmarking against other countries). They can also define the speeds of the services, or other aspects of the quality of the services to be provided. Regulation in this context could take the form of clear rules or targets included in the licence granted to the SWN or in subsequent directions from the regulator, or it could involve the Government influencing the conduct of the SWN through its ownership position.

Such measures could, if implemented well, go some way towards reducing the concerns of a SWN operating as a monopoly. However, the key question policymakers must consider is whether we could reasonably expect the SWN to be regulated effectively and, even if we could, whether it would outperform network competition.

As with any monopoly regulatory regime regulators will have asymmetric information on which to set targets for the SWN, and the SWN itself may have little incentive to co-operate. Often, the 'right' regulatory answer will be unclear. For example, a regulator may find that trying to set wholesale access prices too low will threaten the capacity of the SWN to attract investors, whilst setting them too high may mean that the SWN is unable to attract traffic to the network. Enforcement may also be difficult, since the Government may have no alternative to the SWN in meeting its objectives and the investors in the SWN will realise this. To the extent that the Government has a significant influence in the ownership of the SWN, regulation of the SWN may also raise conflicting objectives: for example, the interests of the Government as owner of the SWN may be to opt for relatively higher wholesale prices to try and maximise the chances of the SWN's commercial success, which may differ from its interests as regulator, to primarily protect consumers from too high prices.

The performance of the SWN will be decisively affected by how well it is regulated, and there are good reasons to believe that effective regulation will face a number of challenges. The performance of network competition is not influenced by regulation to the same extent due to the absence of the regulatory risks set out above.

ANNEX C FURTHER INFORMATION MARKET EXPANSION

C.1 Current mobile coverage gaps in the UK

Evidence from Ofcom shows the extent of existing coverage gaps in the UK. This evidence forms part of the basis for the market expansion model considered by DCMS.

Ofcom data shows that currently 87% of UK landmass has a 4G signal from at least one operator (compared to 78% in 2017). However, as shown in the table below, whilst headline coverage figures are improving, these figures are lower when we consider coverage from all four Mobile Network Operators in specific locations. For example, 4G geographic coverage is only available from all four MNOs in roughly half of all rural areas. Even in urban areas, a quarter of indoor premises do not have 4G coverage from all four MNOs.

Figure 21 4G coverage from all four Mobile Network Operators as at Jan 2018

	UK Total			UK Urban			UK Rural		
	Jan 2018	Jun 2017	Jun 2016	Jan 2018	Jun 2017	Jun 2016	Jan 2018	Jun 2017	Jun 2016
Indoor premises	68%	58%	40%	74%	64%	45%	29%	18%	6%
Geographic coverage	57%	43%	21%	94%	87%	67%	52%	38%	16%
A&B roads	45%	33%	16%	72%	61%		33%	20%	

Source: Ofcom Connected Nations Report - spring 2018 update

Sub 1GHz spectrum is expected to make a significant contribution to the levels of 4G coverage achieved, particularly in rural areas. Given the propagation characteristics of the 3.4-3.8GHz spectrum and the deployment incentives for MNOs (as discussed in Section 5.6 of this report), coverage of 5G deployed in this spectrum band is likely to be lower than current coverage of 4G.

C.2 Evidence gathered during the DCMS Call for Evidence

During the course of the FTIR, DCMS has reviewed evidence from a number of stakeholders regarding the potential for innovative, new solutions to connectivity problems which could be unlocked with a more flexible policy towards spectrum, particularly in the 3.4-3.8GHz band. Alongside the evidence from Ofcom on coverage gaps described above, this evidence forms part of the basis for the Market expansion model considered by DCMS and assessed in this report. The relevant evidence is summarised in this section.

Dense Air

Dense Air, which unsuccessfully bid for spectrum in the auction which concluded in April 2018, expressed the view that neutral host providers will be key to ensuring that 5G networks do not suffer from gaps in coverage on road and rail networks, inside buildings and in industrial environments.

"… national MNOs are focused on different ways to address their commercial challenges – increasing their bundling of services in quad play offerings; reducing costs drastically; investing in content and other non-connectivity assets; and consolidating to achieve economies of scale. Therefore, if these are the only companies implementing 5G, it raises the risk that the UK will be slow to see new services materialise....

The UK has the chance to introduce a different approach when the next auctions are held. These are likely to be in 700 MHz and 3.6-3.8 GHz. The latter, because of its plentiful capacity (which could be extended to 4.2 GHz in future) is the most interesting for supporting an additional, neutral host operator."[72]

Confidential respondent to call for evidence

Another confidential respondent called for spectrum to be made available on a lightly licensed basis, for neutral host providers to provide indoor coverage and serve the enterprise market. This correspondent expressed a particular interest in that part of the 3.6-3.8 GHz band which overlaps with the CBRS band in America, because it the availability of devices in that band.

King's College London's Faculty of Natural & Mathematical Sciences, Department of Informatics and Policy Institute

King's College London's Faculty of Natural & Mathematical Sciences, Department of Informatics and Policy Institute have spoken of the need for spectrum policy to become more nuanced in order to foster a culture of innovation.

"There needs to be a legal and policy framework in place to allow enterprises such as manufacturing sites, shopping malls, cultural institutions, and wider private sector organisations to build their own networks for their own clients – in conjunction with traditional operators."[73]

KCL recommends a framework for alternative spectrum licensing models to provide access to spectrum by new types of users and service providers, such as wholesale infrastructure service providers.

Google

In their presentation to the Dynamic Spectrum Alliance Global Summit in 2018, Google expressed the following view:

[72] Dense Air and the case for 'Neutral Host Networks' in the UK, 2018

[73] King's College London, "How government can drive 5G innovation", 2018

"Dense 5G deployments will take more than traditional carriers to get into dense areas, such as venues, buildings, enterprises."[74]

Google highlighted new models emerging, such as private LTE networks; Industrial IoT; and neutral host networks.

Broadway Partners

Broadway Partners believe that current mobile spectrum authorisation methods have the effect of stifling investment in innovation and coverage, suppressing economic activity and raising barriers to market entry.

"Given 5G's requirement for large swathes of new spectrum, and the continuing economic and opportunity cost represented by the gaps in 4G geographic coverage, there is a clear case for a more efficient and market- and needs-responsive approach to spectrum allocation. Broadway believes that the technology exists ... to allow a more efficient allocation and sharing of spectrum in rural areas."[75]

Plum Consulting for INCA and WISPA

In its report for INCA and WISPA, Plum Consulting highlights the opportunity for innovative and flexible use of spectrum in the 3.6 - 3.8 GHz and 3.8 - 4.2 GHz bands in order to meet demand from Fixed Wireless Access ("FWA") Internet Service Providers in rural areas.

"Access to 3.6-3.8GHz spectrum will be essential, as FWA equipment is readily available in this band at attractive pricing levels – due to international markets and economies of scale in the supply chain. Technical standards and commercial equipment have not as yet been developed in the 3.8-4.2 GHz band, and supply is not expected to be available until c. 2023, if at all.

Whilst the 3GHz bands are being considered for deployment of 5G mobile services, new innovative methods for spectrum management, such as dynamic shared access and geographic licensing, can be contemplated. ... These could support mixed fixed and mobile usage and new 5G business models – such as 'service neutral' enterprise networks.

Development of regulation, recognising the emerging 5G ecosystem as a whole, facilitating operation of both mobile and fixed radio links in the 3.6-3.8 and 3.8-4.2 GHz bands, will support essential and widespread high quality service access for a varied mix of users across the UK. 5G should not be considered as a mobile technology only, but should be leveraged to meet varied market demands including mobile service, static broadband access, and emerging private enterprise requirements."[76]

[74] Challenges with the Current Spectrum Approach, Dr. Preston Marshall, Principal Wireless Architect, Google, LLC, presentation to DSA Global Summit, 2018

[75] Broadway Partners, Response to Future Telecoms Infrastructure Review, 2018

[76] High Performance Wireless Broadband: an opportunity for rural and enterprise 5G, Plum Consulting, 2018

The 5G Innovation Centre at the University of Surrey

The 5G Innovation Centre at the University of Surrey has estimated that a traditional licensing route for 3.6-3.8GHz spectrum is likely to lead to a low geographic spectrum efficiency outcome, perhaps even as low as 10%.[77]

Vodafone

In its response to Ofcom's consultation on improving access to mobile services at 3.6-3.8GHz, Vodafone expressed the view that satellite stations in rural areas could continue to enjoy protection from interference because earth stations located in "*Cornwall, Herefordshire, Oxfordshire and the Western Isles are clearly rural*".[78] This is consistent with MNOs not deploying this spectrum in rural areas at the same speed and/or to the same extent as in urban areas.

[77] University of Surrey 5G Innovation Centre, Response to Ofcom Consultation - Improving consumer access to mobile services at 3.6 GHz to 3.8 GHz, 2017

[78] Vodafone response to Ofcom Consultation: Improving consumer access to mobile services at 3.6 to 3.8 GHz, December 2016

ANNEX D FURTHER INFORMATION MOBILE CONSOLIDATION

D.1 Experience in other jurisdictions

There have been a number of cases of market consolidation from 4 to 3 MNOs including within the EU, over recent years. Whilst the European Commission (EC), has cleared a significant number of these mergers with remedies, the remedies agreed with merging parties have become more stringent over time. These remedies have focussed on the promotion of future retail competition. The more recent UK O2/H3G merger was blocked, and the Telia-Sonera Telenor proposed merger in Denmark dropped, due to an inability to agree appropriate remedies. This section looks at previous experience of mobile consolidation and considers what this might mean for any future consolidation in the context of 5G.

The Netherlands

In 2007, the EC cleared the 4 to 3 merger between T-Mobile and Orange unconditionally citing a variety of reasons. The Dutch market was characterised by a large number of MVNOs which put competitive pressure on the MNOs. The EC concluded that this would likely still be the case post-merger and that the market share of MVNOs would be unaffected by the merger. The EC saw post-merger price rises as unlikely, and whilst the merged entity would strengthen its position in terms of spectrum holdings, it did not consider any of the competing MNOs to be at a disadvantage as a result.[79]

The EC subsequently published a study on the impact of the merger. This suggested prices in the Netherlands did increase following the merger compared with other countries, however this effect cannot be isolated to the T-Mobile/Orange merger and the study also showed that the MVNOs managed to increase their overall market share[80]. The role of MVNOs was an important factor in this merger being cleared. The EC's view in this case acknowledged the potential fixed cost savings resulting from a smaller number of networks, and concerns about the potential reduction in competitive pressure was mitigated by the presence of MVNOs. The EC's view at the time suggested that if network access for MVNOs is unaffected by the merger, then this can ensure the effects of competition remain at the retail level.

Ireland, Germany and Austria

Between 2012 and 2014 three instances of 4 to 3 player mergers were brought before the EC. The mergers, which were all cleared with remedies, were Orange and H3G in Austria, H3G and O2 in Ireland and E-Plus and Telefonica in Germany.

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[79] EC http://ec.europa.eu/competition/mergers/cases/decisions/m4748_20070820_20310_en.pdf

[80] EC, pp.77-78 https://www.acm.nl/sites/default/files/old_publication/publicaties/15067_effectenonderzoek-telecom.pdf

In all three cases, the EC anticipated some post-merger price rises and reduced levels of competition, due to losing the competitive effects driven by H3G (which was viewed as an 'important competitive force'), and the loss of the competitive pressure between the merging firms. Commitments to divesting spectrum and access for new MVNOs were required in order for the mergers to clear.

In the case of Germany for example, due to E-Plus and Telefonica both having strong positions in the wholesale market, the EC expected the merging of these operators to reduce the availability of new technologies to MVNOs. The EC argued that reduced competitive pressure would make the merged entity less inclined to provide wholesale partners access to the most advanced technologies, such as 4G networks.[81]

The Irish market is a similar example, but the market is characterised by low population density, spread across rural areas, adding further expense to rural coverage. The merger provided access to spectrum allowing H3G to continue providing coverage to rural areas and enabling the roll-out of 4G technology[82].

Although all three cases were cleared, the remedies put in place by the EC were designed with a strong emphasis on promoting further retail competition through MVNO access, and to allow for potential further network competition in the future through spectrum divestment to potential new players.

Italy

The merger in Italy between Hutchison H3G and VimpelCom WIND was cleared by the EC in 2016. Absent remedies this would have seen the market move from 4 operators to 3. However, in order for the proposal to be cleared remedies were applied which required the entry of a fourth operator, Iliad.

This was achieved through H3G and WIND divesting multiple frequencies of spectrum, network sharing agreements for base stations and agreements on the transition to new technologies. The EC's analysis suggested that without the introduction of more competition, prices could be expected to rise[83]; this is due to the loss of H3G's competitive pressure as a maverick MNO and the loss of constraints imposed on each other by H3G and WIND as competitors.

The remedies imposed in Italy went further than those required for Germany, Austria and Ireland, actually requiring a new market entrant in order to counter the potential effects of consolidation of major MNOs, rather than just making conditions more favourable for potential entry.[84]

D.2 UK mergers

Two mobile mergers were proposed in the UK telecoms sector in recent history; T-Mobile and Orange in 2010 and O2 and H3G in 2015. The EC's decision on

[81] EC, p.183 http://ec.europa.eu/competition/mergers/cases/decisions/m7018_6053_3.pdf

[82] EC, pp.205-206 http://ec.europa.eu/competition/mergers/cases/decisions/m6992_20140528_20600_4004267_EN.pdf

[83] EC, p.180 http://ec.europa.eu/competition/mergers/cases/decisions/m7758_2937_3.pdf

[84] This was described as a 'fix it first' remedy in that the remedy ensured an increase in competition to offset the loss of competition following the merger.

these demonstrates the feasibility of using consolidation to facilitate the rollout of new technologies, as well as some of the issues associated with capex and innovation.

T-Mobile and Orange

The proposed between T-Mobile and Orange was cleared in 2010. The EC approved the move from 5 to 4 operators on the basis that neither firm was a driver of competition in the market and the operators were not close competitors. Their evidence for this was that both T-Mobile and Orange had been seeing falling market shares and were some of the more expensive providers.[85] Remedies were required however, due to concerns over network sharing agreements between H3G and T-Mobile and H3G and Orange. Without additional agreements, there was a concern that there could have been a negative impact on the development of 3G networks and ultimately H3G's ability to drive competition.[86] Additional concerns existed around spectrum holdings; the merged party would have held 1800 MHz spectrum, providing an unmatchable advantage in rolling out LTE technology in future. Divesting 2x15 MHz of this spectrum was considered sufficient to solve the problem.

Despite the divestment of some spectrum, the merger still allowed the combined entity EE, to begin roll-out of LTE before other operators who had to wait until the 2012 4G spectrum auction in the UK to begin roll-out.[87] Arguably this was a positive outcome of the merger as EE's first mover advantage in 4G rollout may have driven the other operators to more rapidly roll-out 4G once spectrum became available in order to compete with EE.

O2 and H3G

The EC blocked the proposed merger between Telefonica O2 and Hutchison 3G in 2016, despite the parties proposing MVNO remedies. The EC's main concerns with H3G acquiring O2 were based on higher post-merger prices and concerns about the implications of the merger for network sharing agreements.

H3G was considered to have a strong influence on competition as a maverick operator[88], consistently growing its market share and subscribers[89], whilst O2 already had significant market share. The EC considered that the merged entity would have a lower incentive to compete on price and quality with the remaining two operators, Vodafone and EE.

Concerns also arose based on H3G and O2's role in different network sharing agreements. The merged party would have been required to initially operate across both of the UK's network sharing agreements, Beacon and MBNL, but could ultimately withdraw from one of these. It was argued that the lack of long-term commitment and changing interests within the network sharing agreements

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85 EC p. 13 http://ec.europa.eu/competition/mergers/cases/decisions/m5650_1469_2.pdf

86 EC pp. 16-20 http://ec.europa.eu/competition/mergers/cases/decisions/m5650_1469_2.pdf

87 Or in the case of Three having access to the 1800 MHz spectrum divested by EE.

88 EC, p.13 http://ec.europa.eu/competition/mergers/cases/decisions/m5650_1469_2.pdf

89 EC, p.120 http://ec.europa.eu/competition/mergers/cases/decisions/m7612_6555_3.pdf

would cause a variety of effects: a reduced incentive to invest in one network could harm the development of mobile infrastructure and could increase long term running costs, whilst the merging parties would also have had an information advantage from being involved in both networks.[90] The parties argued that uncertainty and changing interests were intrinsic to network sharing agreements and having access to sites from both agreements would enable them to build a denser higher capacity network.

D.3 Analysis of impact of consolidation/market structure

A number of studies consider the impact of market consolidation on prices[91], whilst some also look at the effect on investment (Genakos, Valletti and Verboven, 2015; Frontier Economics for the GSMA, 2015). Using 33 countries over a 12 year period, Genakos, Valletti and Verboven find mixed outcomes from market consolidation[92]. The main results showed that a hypothetical *symmetric* merger, moving from 4 to 3 players could be expected to increase prices compared to the case where no merger occurs. They also predicted that investment per operator would also increase.

Similarly to Genakos, Valletti and Verboven, Frontier Economics consider the effect of market structure on prices and investment using both the number of MNOs in a market and the HHI. Prices were measured using average revenue per minute (with other services converted to voice minute equivalents) and investment by capex per subscriber.[93] The results show that the intensity of competition does not have a significant effect on investment or prices.

Despite the concerns in Austria pre-merger, the GSMA have argued that the effects of consolidation in the Austrian market have been beneficial to the pace of roll-out and coverage of newer technologies. Analysis by the GSMA suggested that the pace of roll-out for 4G coverage increased by 20-30% as a result of the merger, whilst download and upload speeds also increased earlier than they would have done had the merger not occurred.[94] The GSMA also found evidence of positive market wide effects on network quality as a result of the merger.

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90 Ibid, pp.268-270

91 We focus here on studies that have considered empirically both prices and investment – there are a number of studies that have focussed on the relationship between consolidation and prices, for a summary see BEREC Report on Post-Merger Market Developments - Price Effects of Mobile Mergers in Austria, Ireland and Germany.

92 The authors measure the effect on price (the bill for a particular basket of calls, data etc.) of changing the market structure. Market structure is measured using two variables, the number of operators and Herfindahl-Hirschman Index (HHI). Using the HHI allows for the true size of consolidation to be reflected and measured, as well as just the number of firms merging. Investment is also measured using either the capex of a given operator or total capex across all operators in a given country. Time and country fixed effects are included in both estimations. Robustness tests were carried out by varying the sample, which involved only including certain countries and extending the time period, and by using different baskets. This looked at whether the results were robust to changing consumer habits such as increased data consumption.

93 The study considers EU markets with 3 and 4 MNOs over a 14 year period, also using fixed effects to control for operator and country differences.

94 GSMA, p.31 https://www.gsma.com/publicpolicy/wp-content/uploads/2017/07/GSMA_Assessing-the-impact-of-mobile-consolidation-on-innovation-and-quality_36pp_WEB.pdf

Contrary to some of the findings above, Ofcom (2016) suggest that greater competition does lead to lower prices. Ofcom estimate the impact on price based on the presence of a “disruptor” firm using time and country fixed effects.[95]

A less recent study by Li and Lyons (2011) looks at the effect of market structure on the speed of market penetration, effectively the pace of roll-out. The study covers 30 countries over a 15 year period up to 2006. The effect is estimated by measuring the impact of the number of MNOs on mobile network penetration, defined as the number of mobile users per 100 citizens. The results show that a market with 3 operators, relative to a monopoly, has the fastest rate of mobile penetration. Markets with 2 or 5 players, again relative to a monopoly, provided the next best rate of penetration. It is important to note however, that the findings of this are likely to be somewhat outdated.

[95] The same price data source as in Genakos, Valletti and Verboven’s study is used, Teligen, with supplementary data from Tarifica. Hedonic prices (prices taking account of quality and other characteristics) are calculated based on mobile service characteristics such as handset, data allowance and technology. The independent variable is a dummy variable for a disruptor firm. Ofcom consider a firm to be a disruptor if it introduces new services before competitors or competes aggressively and acts as a competitive constraint to larger MNOs. This introduces a certain degree of circularity in the analysis as the definition of ‘disruption’ is dependent on the operator’s pricing behaviour.

ANNEX E INPUT DATA FOR 5G DEPLOYMENT ANALYSIS

E.1 Land area to be covered

Estimates of the land are that would need to be covered under a small cell roll-out was based on a classification of the UK land area into 'clutter types' which were used by LS Telcom in its work for the NIC.[96]

The assumptions of the land to be covered in each area type is based on Morphodata from selected geotypes in the UK, collected by LS Telcom as shown below.

Figure 22 Classification of land area

Geotype	Clutter types included	Total area (km squared)
Dense urban	Dense urban Building Block building	176
Urban	Mean urban Industrial	3,686
Suburban	High suburban Suburban	6,309
Rural/Village	Village Single low houses Open in urban Park	4,955
Other	Open Forest Inland water	237,422
Total		**252,549**

Source: Frontier analysis of LS Telcom data

E.2 Cell radii and spectrum assumptions

Small cell radii were based on Real Wireless assumptions for the NIC[97] for an eMBB service using 3.4-3.8 GHz.

[96] 5G Infrastructure requirements for the UK – LS Telcom report for the NIC

[97] Source Real Wireless for the National Infrastructure Commission: Future Use Cases for Mobile Telecoms in the UK

Figure 23 Small cell radii used

	Cell radii (km)
Dense urban	0.09
Urban	0.09
Suburban	0.17
Rural/village	0.62

Source: Real Wireless

These cell radii we then converted to area per site on the assumption that site coverage areas were 90% of the theoretical area if sites were perfectly tessellated (i.e. regular hexagons) to take account of imperfect site location.

E.3 Cost assumptions

The below cost assumptions have been based on cost information provided in 5G Norma 2017 with additional assumptions on backhaul based on Openreach's indicative dark fibre access pricing.[98]

Figure 24 Unit capex cost assumptions (£ per site)

	Cost assumptions
3.4 GHz upgrade to urban and suburban macro sites	36,450
700 MHz upgrade to all macro sites	35,073
Dense urban small cells	16,023
Urban small cells	16,023
Suburban small cells	16,023
Village small cells	16,023
Road small cells	16,023

Source: Based on 5G Norma 2017 minus RAN costs plus Backhaul

Figure 25 Breakdown of Capex costs (£ per site)

	Site acquisition and civils	Antenna cost	Feeder, install and test and commission	Backhaul	Active	Total
Macro 700MHz upgrade	N/A	2,400	4,400	2,023	26,250	**35,073**
Macro 3.4GHz upgrade	N/A	7,200	4,400	2,023	29,250	**36,450**
Small cell	4,800	1,000	700	2,023	7,500	**16,023**

Source: Based on 5G Norma 2017 and Openreach (Backhaul)

98 Following BT's successful appeal of the 2016 Business Connectivity Market Review decision, the dark fibre service was not introduced by Openreach.

Figure 26 Unit Opex per year assumptions

	£/per site/year
3.4 GHz upgrade to urban and suburban macro sites	2,925
700 MHz upgrade to all macro sites	2,625
Dense urban small cells	5,384
Urban small cells	5,384
Suburban small cells	5,384
Village small cells	5,384
Road small cells	5,384

Source: Based on 5G Norma (Licencing and Maintenance only for macro cells)

Figure 27 Small cell breakdown of Opex (£/site/year)

	Site rental	Rates and utilities	Licensing and maintenance	Backhaul	Total
Small cell	1,000	540	1,875	1,969	5,384

Source: Based on 5G Norma and Openreach (Backhaul) frontier economics

www.frontier-economics.com