frontier economics

INCENTIVES TO INVEST IN 5G

Final report for the NIC

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EXECUTIVE SUMMARY

The mobile industry has delivered huge benefits to the economy over the last 30 years, following the roll out of four 'generations' of mobile network technology. These generations have supported the introduction and mass take up of mobile voice (1G and 2G respectively) and the introduction and mass take up of mobile Internet (3G and 4G).

The mobile market continues to evolve, with 4G networks expanding to offer both extended coverage and more capacity to users. There is an expectation that mobile networks will increasingly be used to connect machines (the 'Internet of Things') as well as people. Technologists are also working on technologies which will be included in the fifth generation of mobile networks.

The mobile ecosystem continues to evolve and now consists of a large number of companies competing at a retail level, but also co-operating on infrastructure and equipment to efficiently deliver innovative services at ever lower costs. This includes operators and end users providing Wi-Fi networks, which now deliver the majority of traffic to smartphones and which are not under the control of traditional mobile networks. The trend towards a more complex eco-system is likely to continue, with further concentration at the infrastructure level and the scope for providers serving specific types of end users, with traditional mobile operators increasingly focussing on a small number of core functions.

In this report, we examine how investors make decisions about investing in new technologies and the expansion of existing networks. For new technologies, if demand uncertainty is high, investment may be deferred until there is more certainty. This was the case for 3G services, where despite the UK being at the forefront of licencing spectrum in 2000, investment in 3G networks was limited until data demand began to increase rapidly following widespread take up of smartphones by end users. In contrast, for 4G networks, demand was well established but the availability of spectrum was the limiting factor for investments, with the UK being relatively late in making additional spectrum available.

Currently, there is considerable uncertainty on both the nature of 5G technologies and the demand for the use cases potentially supported by candidate technologies (e.g. driverless cars). If this uncertainty is not resolved by the time 5G technologies are introduced, operators will have an incentive to defer investment until there is clear demand for 5G services. Policy intervention to encourage innovation and to lower the cost of network deployment may be needed to break the cycle of low demand and low investment.

Incentives to invest in the UK mobile market are also affected by the nature of the market, with high fixed costs and other barriers to entry (e.g. licensed spectrum). In order to recover these fixed costs, operators need to maintain a degree of market power, which they achieve through product differentiation (with the operators differentiating themselves from their competitors in terms of price, coverage, speed, brand, handsets' availability, etc.) Given these market characteristics, the operators are more likely to make investments which deliver clear benefits in terms of product differentiation. For example, they aim to introduce new capabilities ahead of their competitors in order to gain competitive advantage and to maintain this advantage as long as possible. This is well illustrated by EE's rapid roll out of the 4G network ahead of its competitors in 2012-13.

While competition between operators can lead to them expanding the capabilities of their networks in order to compete (even where such investments do not increase overall industry revenues), this may not deliver all policy objectives. One such example is the provision of coverage in rural areas, where the market may not be delivering a socially-desirable outcome (ubiquitous coverage). Government can play an important role in creating an environment which encourages investment, both by reducing barriers to investment and providing incentives for socially important investments to be made.

In this report, we have identified a number of challenges for the mobile industry in the future:

1. Delivering coverage - in rural areas, on strategic roads and on rail – where coverage is currently insufficient for supporting new applications (such as automotive and the Internet of Things) and even for traditional applications, such as mobile voice and broadband;
2. Delivering increased capacity in densely populated areas - this would require a wide-spread deployment of 'small cells' at street level, which present challenges with respect to planning; and
3. Efficiently delivering varying quality of service for a wide range of applications from very high bandwidth services in urban areas to support for large numbers of lower power, low bandwidth machines. Technologies introduced in 5G, such as network virtualisation and network 'slicing', should enable such differentiation. While such arrangements may be delivered effectively by competition, virtualisation may lead to regulatory challenges and the need to update regulations designed for legacy networks, for example, existing net neutrality rules.

In light of these challenges, a key question for policy makers is how to incentivise the rapid deployment of infrastructure and equipment required to support future mobile services and applications. Potential policies may include:

- Flexible spectrum policy which balances the need to provide investors with certainty when making investments tied to spectrum holdings with the need to support emerging technologies and players.
- Fit for purpose planning regulation which fully recognises the benefits that current and future mobile networks bring to users and the wider economy, including the infrastructure needed to provide ubiquitous coverage and high capacity networks.
- Coverage obligations placed on mobile operators that are focussed on ensuring real improvements in mobile coverage and are not tied to (infrequent) spectrum auctions but can be regularly updated to take account of the developing market.

- Improving future coverage of transport networks by giving stakeholders in transport networks incentives to work with investors in mobile networks to deliver competitive efficient networks which can serve future applications.
- Where necessary, regulating to ensure all mobile operators have access to fibre networks at competitive prices or access to the infrastructure needed to install their own fibre networks.
- Better coordination of publicly-funded infrastructure projects to identify and evaluate synergies between publicly-funded projects and policy objectives with respect to mobile networks.
- Keeping mobile sector specific regulations up to date, removing outdated regulation where necessary to reduce constraints on the development of new technologies and business models.

1 INTRODUCTION

On 16 March 2016, the (then) Chancellor asked the National Infrastructure Commission (NIC) to:

“consider what the UK needs to do to become a world leader in 5G deployment, and to ensure that the UK can take early advantage of the potential applications of 5G services.”

The Commission’s assessment and recommendations, which will be reported back to government by the end of 2016, will underpin the government’s 5G strategy, which will be announced in spring 2017.

As part of this work, the NIC has commissioned Frontier Economics to deliver a report on incentives to invest in 5G telecoms network, identifying key barriers that might limit roll out of 5G under the existing market structure and regulatory regime. We also need to consider “*alternative approaches for incentivising investment in future mobile networks*”[1] and their potential costs.

In order to understand the context for 5G development, in the remainder of this section we consider the evolution of mobile technologies from 1G to 4G.

The evolution of mobile technologies: from 1G to 4G

The mobile industry has delivered huge benefits to consumers and the wider UK economy over the last 30 years, since the first mobile phone call was made in the UK in 1985[2].

While there has been constant technological innovation during these 30 years, the need to maintain compatibility between handsets and the network means that the underlying mobile network technology remains fixed for a number of years[3]. However, new technologies are introduced on a regular basis, a new ‘generation’ which are incompatible with the previous generation of technologies.

Four generations of mobile technology have been introduced over the past 30 years. These generations are broadly defined as follows:

- **1G**: the first generation of ‘cellular’ mobile phone systems (1G) used analogue radio transmission. They were developed in the late 1970s and used in the UK from 1985, with the networks being switched off in 2000 and 2001. This technology supported voice calls.
- **2G**: “second-generation mobile communications” used digital transmission, providing greater capacity and security and allowing for users to ‘roam’ between countries. The first UK networks using the GSM standard were launched in 1991. While GSM was primarily designed to offer voice services it

1 Statement of Requirements, para 6.1.3

2 http://www.vodafone.com/content/index/media/vodafone-group-releases/2014/thirtieth_anniversary_uk_mobile_call.html

3 All handsets for a given generation should be supported by network equipment from that generation, so for example, a 2G handset from the 1990s will remain supported by 2G network equipment installed today and vice versa,

also offers text messages (SMS) and was later extended to offer data services.

- **3G**: the third generation of mobile communications (3G) was designed from the beginning to offer packet data services in addition to voice, using spectrum with much greater efficiency than 2G services. It enabled faster (‘broadband’) data services than available on 2G networks although true broadband was only delivered with later versions of the technology. Spectrum specifically for 3G services was auctioned in 2000, with the first services being introduced in 2003.
- **4G**: the fourth generation of mobile communications (4G) is a data oriented network based on internet protocol (IP) standards, with voice being transported as an IP service. From the user perspective, the main advantage of 4G services are faster download speeds and faster response times (latency). 4G services were launched in 2012 by EE using spectrum previously used for 2G services (‘re-farmed’ spectrum) with other operators launching services in 2013 based on a mixture of new spectrum acquired at auction and re-farmed spectrum.

Exhibit 1 below summarises how each generation of technology built upon previous generations, addressing the identified weaknesses of the previous generation.

Exhibit 1: The evolution of mobile technologies

Generation	Primary services	Key differentiator	Weakness (addressed by subsequent generation)
1G	Analogue phone calls	Mobility	Poor spectral efficiency, major security issues
2G	Digital phone calls and messaging	Secure, mass adoption	Limited data rates - difficult to support demand for internet/e-mail
3G	Phone calls, messaging, data	Better internet experience	Real performance failed to match hype, failure of WAP for internet access
3.5G	Phone calls, messaging, broadband data	Broadband internet, applications	Tied to legacy, mobile specific architecture and protocols
4G	All-IP services (including voice, messaging)	Faster broadband internet, lower latency	?

Table 1: Evolution of technology generations in terms of services and performance
Source: GSMA Intelligence

Source: https://www.gsmaintelligence.com/research/?file=141208-5g.pdf&download

The generations can be broadly split into the voice centric 1G and 2G and the data–centric 3G and 4G technologies. 2G technology did not adequately support the clearly identified need for mobile Internet access which was partially addressed with 3G and then fully addressed with 4G networks. The evolution of 4G networks will continue to offer increasing speeds and capacity for these use cases. This will be achieved by a combination of technology changes, such as the ability to 'aggregate' an increasing number of spectrum bands to offer increased speeds, and infrastructure changes such as increased use of 'small cells' to offer additional capacity in hot spots.

Future evolution of mobile networks

The critical question for policy makers and technologists is then what are the critical use cases that are not currently supported by current mobile networks. This may cover two broad areas:

- Uses which could be supported by existing 4G technologies and their evolution but which are not currently delivered; and
- Uses which could be supported by the technologies which are likely to be introduced as 5G technologies.

There are three main areas where current 4G networks, once they have fully completed their roll outs, will not fully meet users' needs in the UK:

- coverage in rural areas, including transport links (roads and rail) running through urban areas;
- coverage indoors; and
- capacity in dense urban areas.

5G technologies

While previous generations introduced new radio technologies which could substitute for previous generations (albeit with a long period of parallel running to provide backwards compatibility), there appear to be no candidate technologies which would replace 4G networks in providing wide area coverage.

Potential new radio technologies concentrate on much high frequencies ('millimetre waves') which could support very high capacities and speeds over relatively short distances. This could provide greater capabilities in urban areas and potentially provide a lower cost alternative to fibre access networks in the 'last mile' connection to end users.

Another potential focus of 5G technologies will be in the core network, with the potential for software defined networks (SDNs) to provide greater flexibility allowing for a range of benefits:

- The potential for lower costs by moving network functionality from specialised hardware to commodity hardware in the cloud; and
- The ability to virtualise networks allowing:
  - Different users to access common network infrastructure with each user having defined capabilities – a 'network slice'; and
  - The ability to combine different access networks to provide a seamless experience across the networks.

A potential further development in the core network would be to bring storage and processing closer to the end user to reduce latency – 'edge computing' – in order to deliver services reliant on very low latency, such as augmented/virtual reality.

The potential use cases which are not currently met are explored in the report by Real Wireless commissioned by the NIC.

The use cases are likely to translate into requirements for additional cell sites which in turn will require additional infrastructure, over and above that currently used for mobile networks. This is explored in the report by LS telcom commissioned by the NIC.

Rolling out 5G networks, including access to new infrastructure will require significant investments. If the UK is be a “world leader’ in 5G deployment, this investment needs to be incentivised in order to ensure it takes place before it does in other countries.

The rest of the report is structured as follows:

- Section 2 describes the existing mobile market, how its various stakeholders interact with each other as part of this “mobile eco-system” in order to understand how the supply chain and business models have evolved over time.
- In Section 3 we review how government affects mobile investment through the existing regulation.
- Section 4 discusses how operators make investment decisions in the mobile market taking account of the impact of uncertainty and competitive dynamics. We use case studies of the introduction of 3G and 4G in the UK as an illustration.
- Section 5 sets out potential policy measures that could incentivise 5G network investment and their impact on the relevant stakeholders.
- Section 6 presents our conclusions

2 THE MOBILE ECOSYSTEM

Mobile services are delivered using inputs from a wide range of companies. These inputs and mobile services themselves are subject to a range of sector specific and general regulation. In this section, we discuss the stakeholders and regulations that make up this mobile ‘eco-system’. This section is structured as follows:

- We first provide an overview of the mobile eco-system, showing how this has evolved over time;
- We then discuss the role of each stakeholder in the eco-system and their part in the development of new technologies; and
- Finally, we discuss possible changes to the mobile eco-system in the future.

2.1 An overview of the mobile eco-system

The mobile value chain can be broadly divided into the mobile network (i.e. providing a connection to mobile users and transport of information from these users) and retail service provision, maintaining the customer relationship and providing services to end users. The key components in mobile networks are described below.

WHAT INPUTS DO MOBILE NETWORKS NEED?

At the network level, MNOs require the following inputs:

- **Sites** – Base stations can be sited on private land, on public highways or on existing buildings (i.e. on rooftops in urban areas). In the roll out of new technologies such as 5G, lampposts or street furniture may also be used as sites.
- **Infrastructure** – These consist of towers and masts to site antennae and buildings or cabinets to accommodate electronic equipment.
- **Radio access network (RAN) equipment** – This is used to send and receive radio transmissions from the user equipment, i.e. mobile devices. The access network is made up of overlapping "cells" of different sizes, ranging from macro cells which provide the widest coverage to small cells which provide the least.
- **Backhaul** – This is the transmission used to transmit data from the RAN to the core networks which may be based on radio links or more frequently on fibre optic networks.
- **Core network** – The core network is the "intelligent" part of the network which identifies where the network's subscribers are and ensures that data is sent to the correct user. It also provides the link to other networks, such as the other mobile networks and fixed networks for calls or the Internet.
- In addition to the tangible assets described above, mobile networks require access to **spectrum**.

At a retail level, operators need to acquire and care for customers, provide them with services and bill them. In addition, end users need to acquire terminals (such as handsets) to use with the network.

The mobile eco-system has continually evolved to reflect a combination of changes in technology and the need to increase efficiency as the demands by users increase while revenues in a mature market remain stable. Over the last 15 years, the market structure has evolved from one where Mobile Network Operators (MNOs) were vertically integrated (i.e. each MNO controlled a large part of the value chain from owning and operating the network to retailing services and handsets to consumers), to a more complex structure with a number of players operating in parts of the value chain (e.g. application providers, wholesale infrastructure providers, etc.)

Exhibit 2 below provides a high-level illustration of the key stakeholders and relationships that existed within the mobile ecosystem in the early 2000s.

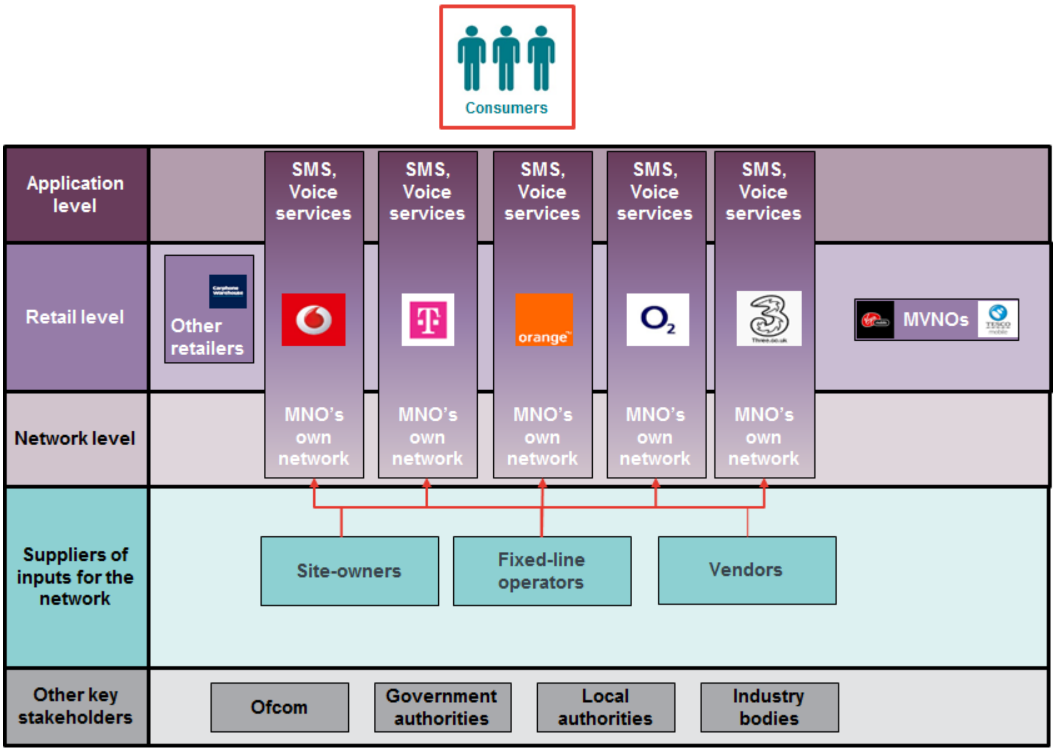
At the network or wholesale level, MNOs relied on critical inputs provided by other stakeholders in order to build and operate their networks. For instance:

- site landlords provided access to the land and rooftops on which MNOs built towers and masts;

- vendors (e.g. Nokia, Ericsson) provided the RAN equipment needed to run the network; and
- for backhaul, in some cases fixed-line operators (e.g. BT and Virgin) provided the links necessary to connect different parts of the MNO's network and in other cases MNOs self-provided these links, for example using microwave spectrum transmission.

At the retail level, MNOs sold mobile subscriptions/pre-paid services and handsets through a mixture of their own retail outlets and third party retail shops (e.g. Carphone Warehouse). They had exclusive relationships with customers for the provision of mobile services as they were the only providers of the dominant mobile applications (voice calls and SMS) available at the time. This strong customer relationship gave MNOs clear incentives to invest in customer acquisition and in maintaining these customer relationships (by providing customer care, billing and investing in customer retention). Given that each MNO had its own independent network and that switching behaviour between MNOs was influenced by aspects of network quality (such as coverage and quality of service), the MNOs had a strong incentive to invest in the network to remain competitive.

Exhibit 2. The mobile eco-system at the time of the traditional, vertically integrated MNO



Source: Frontier Economics

Note: This is the structure prior to 2005, which was before Arqiva entered the market and the network sharing agreements were struck.

Over the last decade, the mobile market has undergone significant changes reflecting developments in technology, the demand for services and the maturation of the market (in terms of penetration).

The rest of the eco-system has undergone a number of changes:

- There are now four MNOs instead of five, with T-Mobile and Orange having merged to form EE in 2010, with the merging parties arguing that this would deliver cost efficiencies and allow investment in a network with high coverage and quality.[4] The merger appears to have delivered efficiencies and increased capability (with the introduction of 4G using existing spectrum) and, in the long run, coverage following the consolidation of the two networks. However, the literature on the impact of mergers on industry investment is ambiguous[5];
- The MNOs increasingly sell network services on a wholesale basis to mobile virtual network operators (MVNOs) who then sell to retail customers; TeleGeography estimate that UK MVNOs' market share has increased from around 12% in 2012 to 15% in June 2016;
- At the network level, there are now network sharing agreements, with each MNO pairing with another operator in order to achieve better network quality, in particular in terms of coverage, while saving costs on network deployment, operations and upgrades, by sharing some of the fixed costs. As a result, at a network level, there are arguably two networks;
- At the network-supply level, access to sites is often through Wholesale Infrastructure Providers (WIPs). WIPs act as intermediaries between landlords and MNOs (leasing land for sites and renting those sites to MNOs). They also build common infrastructure on sites which can then be shared between MNOs and other providers of radio based services; and
- Given that the Internet is an open platform, the mobile customers are no longer constrained in their choice of applications to those provided by the MNOs. At the application level, this has led to the development of parallel customer relationships between end-users and new (over-the-top) application providers, such as Facebook, Google and Netflix, who serve customers independently of the access technology (fixed or mobile). These new applications have encouraged consumer demand for mobile data. At the same time, applications such as WhatsApp and Skype have partially substituted traditional mobile services such as SMS and voice calls.

As can be seen in Exhibit 3 below, key stakeholders such as government bodies remain relevant in the mobile eco-system. The regulations they set shape the behaviour of stakeholders in the mobile market and influence the incentives to invest in new technologies.

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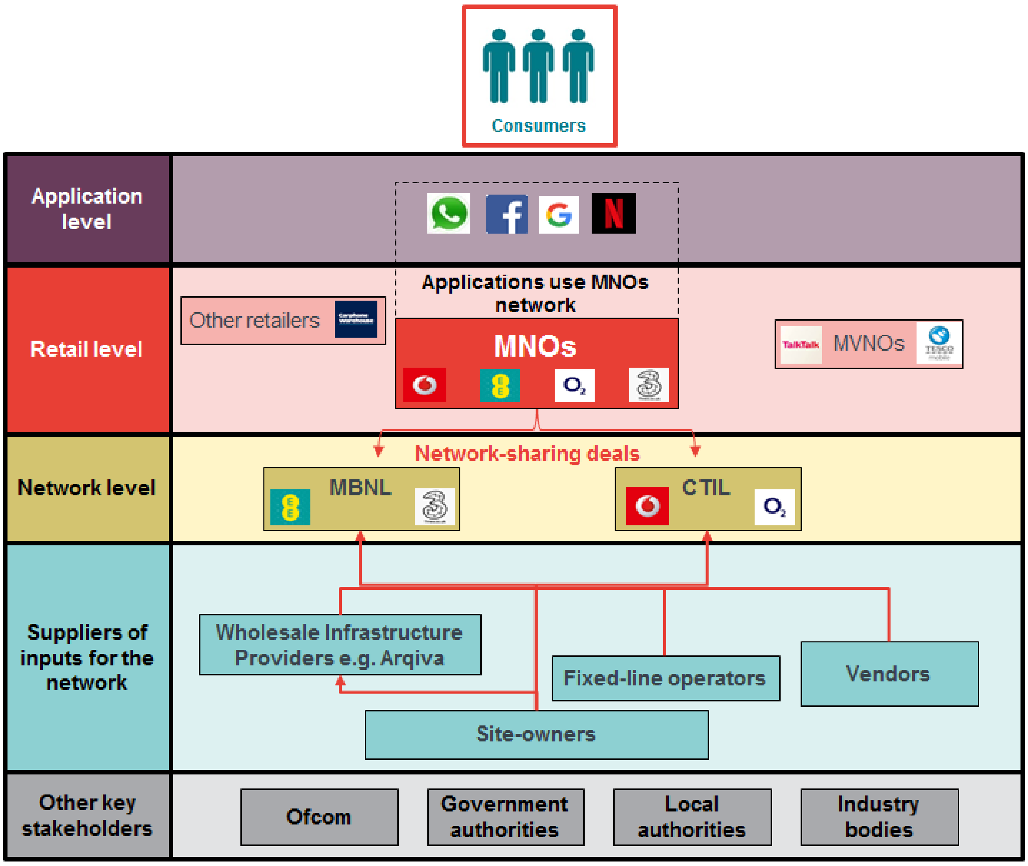
[4] http://explore.ee.co.uk/our-company/newsroom/deutsche-telekom-and-france-telecom-plan-merge-t-mobile-uk-and-orange-uk-create/

[5] For example, Genakos at al. find that in markets with 5 operators, capex per operator is 7% lower than in markets with 4 operators, but no clear (statistically significant) result for capex overall :http://cerre.eu/sites/cerre/files/150915_CERRE_Mobile_Consolidation_Report_Final.pdf

Exhibit 3. The mobile eco-system now



These changes have made the relationships in the eco-system more complex.

So for example:

- a subscriber to TalkTalk;
- who are hosted by O2 as an MVNO;
- could make a call using Skype;
- with the data making up the call being transmitted to a base station operated by Vodafone (as part of Vodafone and O2's network sharing deal);
- with the base station on the site operated by Arqiva; and
- with the fibre backhaul being provided by BT Wholesale.

MNOs' have, to date, still had a central role in investment in traditional mobile infrastructure, with this central role reinforced by their control of most of the spectrum suitable for current mobile technologies.

In addition, while MNOs still have a pivotal role in providing wide area coverage when customers are 'out and about', increasingly the majority of traffic to mobile devices is delivered by Wi-Fi networks rather than traditional mobile networks. The Digital Communications Review by Ofcom found that 89% of smartphone users accessed the internet via Wi-Fi in their homes. Ofcom also quoted a study by Cisco which found that 54% of all mobile data traffic in the UK was accessed by Wi-Fi in 2015, and that this will increase to 65% by 2020.[6]

Wi-Fi is a set of technologies that provide short range data access using unlicensed 2.4GHz and 5GHz spectrum. Coupled with broadband Internet access provided over fixed line networks, this provides an Internet service with a degree of mobility.

The unlicensed nature of the spectrum allows a range of stakeholders to offer Wi-Fi access either to closed user groups or to the public:

- End users to extend the reach of their fixed broadband Internet services using self-provided equipment or equipment provided by their broadband provider;
- Telecoms operators, including BT, O2 and Virgin, offer their consumers use of multiple Wi-Fi hotspots when they are 'out and about' with, for example, Virgin providing services on the London Underground; and
- Businesses such as airports and shopping malls, providing Wi-Fi access within their premises.

Wi-Fi networks are not managed to the same extent as traditional mobile networks, e.g. there is no centralised control of access and usage of the spectrum. The unlicensed nature of the spectrum used means that it is subject to interference both from other Wi-Fi users and other devices such as microwave ovens. Despite this, from an end user perspective, the quality of service may be indistinguishable from, or in some cases preferable to, a mobile service within the area served.

From the MNOs' perspective, Wi-Fi can be seen as a complement to traditional mobile services rather than a substitute. Wi-Fi 'offloads' traffic from their networks, providing more capacity for customers. Wi-Fi also provides coverage in areas, particularly indoors, where MNOs coverage may be poor[7]. The MNOs may then be effectively seen as providing wide area coverage between deeper pools of capacity provided by Wi-Fi.

Some candidate 5G technologies provide much greater capacity than current mobile networks but over much shorter distances. If these technologies are taken up, this could address the need for increased capacity in densely populated urban areas, but there would still be a need for a separate coverage layer to provide ubiquitous service. Such high capacity services could either be provided by the MNOs or by other players, for example using unlicensed spectrum in a similar way to WiFi.

2.2 The impact of stakeholders

In this section, we discuss in more detail the role of each set of stakeholders in the development and deployment of new technologies. We have grouped them by the "layers" used in Exhibit 2 and Exhibit 3:

[6] See http://stakeholders.ofcom.org.uk/binaries/consultations/5-GHz-Wi-Fi/summary/improving-spectrum-access-consumers-5GHz.pdf

[7] With operators offering 'Wi-Fi calling' to allow subscribers to make voice calls over the Wi-Fi infrastructure rather than their networks

- Those involved at the retail/ application level;
- Those involved at the network level;
- Those that supply inputs for the network; and
- Other stakeholders.

2.2.1 Stakeholders at the retail/application level

Mobile Virtual Network Operators (MVNOs)

MVNOs retail mobile services but do not have their own network infrastructure or spectrum. Instead, they buy wholesale access to MNOs' networks in bulk and resell this to end users. There is no obligation on MNOs to provide wholesale access under sector specific regulation, as the existence of competition between network operators means that they are not considered to have 'significant market power' in the relevant market.

MVNOs can benefit consumers by increasing competition at the retail level. MVNO deals are commercially negotiated, with MNOs seeing MVNOs as another channel to market for their services where the MVNOs have either lower costs or some other competitive advantage so that any market share loss to the MVNO in the retail market is offset by increased wholesale margins. For example:

- Some MVNOs primarily offer 'SIM cards only' plans (i.e. contracts sold without a phone), which tend to be cheaper; and
- Some cater to more niche demand in the market, such as the demand for cheap international calls (offers by Lebara or Lycamobile).

Another driver for MNOs to offer services via an MVNO has been to offer bundled products. For example, Virgin Mobile was acquired by NTL-Telewest (a cable operator) allowing the renamed Virgin Media to offer quadruple play bundles which combine broadband, TV, fixed line and mobile. Sky will be able to offer quad-play bundles, which will include broadband, TV, fixed phone lines and mobile after it launches its MVNO.

However MNOs still rely on direct sales to customers as their main channel to market. TeleGeography estimate that UK MVNOs' market share as of June 2016 was approximately 15%, having increased from around 12% in 2012. Tesco Mobile (a joint venture between Tesco and O2) is the largest MVNO, with a market share of approximately 5%.

Typically MVNOs have an exclusive agreement with one MNO[8]. When this exclusive deal is coming to an end, the MVNO would either renegotiate with its current host or choose a different one. Google in the US has managed to negotiate an agreement where purchasers of its handsets have access to several mobile networks and Wi-Fi (project Fi). This new model allows these customers to benefit from better overall coverage by combining the coverage of a number of networks. However, the commercial barriers to widespread roll out of such arrangements are likely to be considerable as MNOs would see that such

[8] This is a standard MVNO model both in the UK and in other markets.

MVNOs would be able to differentiate in the retail market by offering greater coverage thus threatening the MNOs retail margins, while providing no certainty of the level of offsetting wholesale revenues.

MVNOs are, compared to MNOs, ‘asset light’ and will have lower margins than MNOs (who need to recover the cost of network investments from their margins). While MVNOs invest in retail assets (customer care and billing systems) and may invest in some network assets such as location registers and switching, they do not invest in radio access or spectrum holdings, and do not generally drive usage and innovation in the access network (for example, MVNOs did not necessarily have access to 4G at the same time as the host MNOs launch 4G services).

MVNO-like arrangements to access MNOs wide area networks could also form the basis for new business models, allowing operators who wish to deploy their own networks with limited coverage to also gain wide area coverage. For example, TalkTalk in the UK deploys an inside-out network, relying on its own assets (for coverage and capacity in urban areas) and on an MVNO access to provide nationwide geographic coverage (both models are discussed in detail in Section 2.3 below).

In this context, MVNO agreements can be seen less as a simple resale of MNOs services but more of an agreement which provides access to the MNO’s network to complement other networks.

If 5G results in new entry, either in the form of vertical application providers such as automotive connectivity or through networks without full national coverage, then MVNO-like access to MNOs networks could allow these entrants to provide full national coverage. The ability of 5G networks to provide network ‘slices’, i.e. logically separate networks operating over common network equipment, could enable such an access agreement.

Other retailers

Third party retailers (e.g. Carphone Warehouse) sell mobile phones and mobile packages to consumers in return for a commission from the MNOs and MVNOs. They therefore offer an alternative to the MNOs’ own retail outlets. They also carry out some ongoing customer-management, providing a point for customer care.

Their key role is to help customers compare offers from different MNOs and MVNOs. They operate at the retail level only, without any investment in the network. Therefore, they are unlikely to influence investment in future technologies.

Application providers

In traditional telephony networks, there was little or no separation of networks from services, so a telephone network provided telephone calls with the network unable to provide other services and it being impossible to provide calls without operating networks. Digitalisation and the move to open IP-based networks along with more advanced user-equipment such as smartphones has meant that the network transport and the applications using this transport can be separated.

This means that application providers do not need to own and operate networks, and networks and applications can be provided by different stakeholders. For example, calls can now be made through Skype, Viber and many other applications. These 'calls' are transported as packets of data by the mobile networks.

As noted above, mobile networks lagged behind fixed networks in providing viable Internet services, with broadband services only being widely available from the mid-2000s onwards with the widespread roll out of 3G networks. Application providers include those who initially developed their business models on the fixed Internet, e.g. Google, and those who developed applications specific to mobile such as WhatsApp. The scope offered by mobile Internet has allowed application providers to offer applications reflecting mobile-specific functionality (e.g. location based services) and has enabled new business models.

New application providers are a diverse set

Application providers are often called 'over-the-top' (OTT) providers because traditionally, they have not invested in their own networks[9] but use MNOs' networks to deliver their services to customers. Efforts by MNOs to control the applications provided on their networks – so called 'walled gardens' – proved to be of little interest to consumers used to the open nature of the Internet and have failed.

The ability of MNOs to control the applications over their networks has been further constrained by the current net neutrality rules (wherein MNOs cannot prioritise traffic and charge application providers for this service, see Section 3 for "Net Neutrality"). While this model has allowed new applications to flourish, the operators' ARPUs remain largely stable. Therefore, they might not have sufficient incentives to invest *further* to support applications which cannot be served by current open access 'best effort' networks (for example to provide high quality networks on roads for automotive use), unless there are additional revenues streams, which would make this investment worthwhile.

There are a large number of application providers in the market and they have changed the way consumers use mobile services. Some examples of application providers are the following:

- Players which provide substitutes for MNOs traditional narrowband services - WhatsApp and Skype are examples of such applications. This has led to a decline in the revenues MNOs earned from voice and SMS due to the pricing pressure imposed by these providers, who can provide services at minimal marginal cost to the user, and the substitution of traffic. Operators have managed to maintain ARPUs by selling bundles of calls, messages and data access rather than the traditional 'per minute' and 'per message' pricing models. MNOs ability to maintain ARPUs then becomes a function of the ability to maintain market power by differentiating themselves on the overall package of services provided to customers rather than the willingness to pay for any individual element of this package.

9 Google launched Google Fibre to provide fibre to the premises in 2010 in a small number of cities in the US. However, in August 2016, it was announced that Google would focus on wireless technologies instead because it was expensive and time-consuming to roll-out fibre.

- Content providers - examples are Netflix and YouTube. Cisco estimates that 75% of the world's mobile data traffic will be video by 2020, emphasising the role such players have played in driving data demand. For example, 3 UK has seen average data usage grow from 500MB in 2010 to 3.3GB in 2014, and then further to 5GB in 2016.[10] As a large proportion of mobile data traffic is generated by video content, it is one of the key drivers of MNOs revenues, (with subscribers buying larger data bundles in order to be able to watch online videos) and of costs (as growing data traffic leads to capacity constraints in urban areas and the need for the networks' densification).
- 'Platform' providers - who aim to build strong customer relationships through bundles of applications and other products and services e.g. Apple, Google and Amazon:
  - Google provides a range of applications (including search) which are generally provided free of charge and are bundled with its smartphone operating system Android, which is used on the majority of smartphones. While Google does not charge customers for its applications or handset manufacturers for its operating system, it accumulates huge amounts of information about its customers. This information allows Google to sell targeted advertising. It therefore has developed a business model in a two-sided market which interacts with the mobile business model. On the one side, it offers it services to advertisers. On the other side, it provides its services over the MNO's network and interacts with customers, forming strong relationships with them.
  - Apple offers integrated hardware, an operating system and applications. The introduction of the iPhone was seen as the inflection point in the growth of mobile data. When the iPhone was first launched in the UK, it was offered exclusively through O2. This led to a number of customers switching from other networks to O2; Apple claimed that two thirds of customers buying the iPhone had switched from other networks.[11] This strong customer preference for one handset over another compared to the degree of preference for one MNO over another, and allowed Apple to extract larger margins from customers than that enjoyed by the MNOs.

While application providers vary hugely in type, there are a number of shared characteristics:

- Application providers are generally technology neutral – providing similar applications[12] over traditional mobile networks, fixed networks or Wi-Fi. Providers are able to monetise their strong customer relationships either directly, by charging for handsets, applications or content, or through two sided markets, e.g. advertising. For a comparison, MNOs can only charge their customers for connectivity, but are limited in their ability to charge content providers (due to relatively weak bargaining power vis-à-vis Facebook and Google, and due to the net neutrality rules).

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[10] See http://www.ispreview.co.uk/index.php/2016/03/three-uk-see-mobile-broadband-data-usage-surge-5gb-per-user.html

[11] See http://www.thetimes.co.uk/tto/business/industries/telecoms/article2192863.ece

[12] With notable exceptions such as location based services

- This suggests that while some of these players may be very large profitable companies, it is not clear that these profits can be channelled into network investment, although they may provide demand for network services, unless they require specific functionality which cannot be met by existing networks.
- Current applications are designed to work effectively over current 'best effort' mobile data networks, for example being, to a degree, delay tolerant and adapting to the available bandwidth. Application providers requiring a better quality of service may be induced to invest in the network infrastructure required. For example, niche applications, such as emergency services, are currently served by separate networks as they require better quality of service in some dimensions than offered by the MNOs existing networks. However, on 5G networks, such applications could be provided using separate network 'slices', with the applications provider funding any incremental investment in infrastructure or equipment required to deliver the required quality of service. This ability to offer differentiated quality of service whilst benefiting from economies of scope is already happening to some extent, with a mobile operator (EE) winning the contract to provide the Emergency Services Network based on its 4G network by prioritising this traffic on the network. With new 5G technologies, the process of allocating network resources to different applications will be more dynamic and cost-effective.

2.2.2 Stakeholders in the network level

At the network level, a key change in the last 10 years is a shift from operators' building and operating their own independent networks to a greater or lesser degree of network sharing.

Network sharing

Building a mobile coverage network involves high fixed costs, i.e. costs which are independent of the level of demand. For example, in order to provide coverage throughout the UK, a large number of base stations need to be deployed, even in the absence of customers. Sharing network components enables these costs to be shared, thereby lowering the costs of expanding the network and rolling out new technologies. The network components that are shared can vary:

- **Passive sharing**: This involves MNOs sharing infrastructure (sites, towers and masts only). MNOs deploy their own active equipment on these towers and masts. This allows MNOs to differentiate in terms of network technology and capacity.
- **Active sharing**: This is a deeper level of sharing, wherein MNOs also share the radio access equipment on the towers and masts. However, MNOs have distinct core networks, which is where the intelligence of the network sits. This provides some ability to differentiate the quality of their retail products.
- **Spectrum pooling**: This goes another step further, with the MNOs also sharing spectrum. This will limit their ability to offer differentiated products. The operators in the UK do not currently share spectrum. However, there are

examples of spectrum sharing in other countries, e.g. in Australia and Denmark[13].

There are currently two network sharing agreements in the UK:

- **MBNL** was created in 2007 as a joint venture between Three and T-Mobile (which went on to merge with Orange to form EE) to jointly roll out their 3G radio access networks. At the time, it represented a network sharing agreement between the two smallest MNOs in the UK in terms of subscribers, enabling them to benefit from the sharing of fixed costs in the 3G network and allowing them to roll out 3G coverage faster than they would have been able to independently. The sharing agreement involves both passive sharing, wherein the two parties have access to common sites, and active sharing of 3G equipment, where a single base station broadcasts both Three and EE's 3G spectrum (while T-Mobile had a 2G network, Three did not and so 2G equipment was not shared). While continuation of the MBNL joint venture was a remedy offered to gain approval for the T-Mobile/Orange merger, the agreement at that time (2010) did not foresee 4G roll out. With the ability to roll out 4G in advance of the other MNOs, EE rolled out its 4G network independently, with Three rolling out its equipment later. Therefore, 4G RAN equipment is not shared between EE and Three.
- **CTIL** was created in 2012 as a joint venture between Vodafone and O2. The aim was to create efficiencies in cell site deployment and operation of the network in order to roll out a competitive coverage network. CTIL involves both active and passive sharing:
  - Passive sharing takes place through CTIL, wherein Vodafone and O2's sites have been transferred to this entity, with the 'best' sites retained for rolling out the new network. The two MNOs therefore have a common 'grid' of masts, towers and sites through this arrangement.
  - Active sharing takes place through Project Beacon: Vodafone and O2 share equipment for 2G, 3G and 4G.The United Kingdom is split between O2 and Vodafone on an East/West basis. Each is responsible for installing and operating RAN equipment (which broadcasts spectrum of both parties) in their half of the country. Each then acts as a reciprocal service provider to the other in their part of the country, hence providing national coverage. CTIL allowed Vodafone and O2 to access a wider range of sites and thus achieve higher coverage at lower cost and quicker than they could have individually. Project Beacon also allows them to benefit from cost-savings, as each operator only needs to invest in and operate RAN equipment for one half of the country.

There are trade-offs to further network sharing

As mentioned above, the benefit of network-sharing is that it delivers cost savings, allowing operators to offer wider coverage at a lower cost. It has been

[13] https://www.itu.int/en/ITU-D/Regulatory-Market/Documents/CostaRica/Presentations/Session8_Daniel%20Leza%20-%20Mobile%20Infrastructure%20Sharing%20-%2012%20March%202014.pdf

estimated that network-sharing could potentially lead to overall cost savings for an MNO of up to 15% through mast-sharing and 30% through RAN-sharing.[14]

The network sharing agreements have been approved by competition regulators as they still provide scope for operators to differentiate in terms of different dimensions of network quality and thus provide incentives for investment.

Further network sharing, in its extreme form through the formation of a single wholesale network, could lead to higher cost-savings. However, since the element of network competition would be lost, there may be fewer incentives to innovate. For example, Frontier's report for the GSMA finds that countries with network competition were much faster in introducing new technologies than countries with single networks, with major network upgrades coming 1 to 2 years later in single network countries[15]. We also see this in other regulated industries such as Energy and Water, wherein Outcome Delivery Incentives are used to incentivise operators to outperform the targets set by regulators. We further discuss the impact of competition on incentives to innovate in Section 4.2 below.

Both the cost savings and the potential loss in competition at the wholesale level would therefore need to be considered if a decision of deeper sharing is to be made.

It is possible that in meeting the need to increase the number of sites under 5G networks, whether to increase capacity in urban areas or to increase coverage in particular areas, rolling out a number of parallel infrastructures may not be efficient, or even physically possible (e.g. rolling out tens of thousands of small cells in densely populated areas). Thus there may be a role for increased network sharing in specific areas, even if operators maintain the existing level of network competition in general.

Similarly, in areas with no mobile coverage (which operators consider uneconomic to serve), a common set of infrastructure for the four MNOs would, in principle, minimise costs of network roll out. However, these cost savings might still not be sufficient to incentivise the operators to serve these areas. Tendering a Universal Service obligation that can be delivered in a technology-neutral way might be a potential solution for those areas (see Section 5.3 for more details).

2.2.3 Stakeholders in the input-supply layer

Site landlords

These are the owners of the land or buildings which MNOs use to build towers and masts. Urban sites are often located on rooftops of buildings, whereas outside urban areas sites tend to be located on open land or on public highways ('street works'). Sites and masts are a necessary input for any mobile network and therefore regulations governing the access to sites are important for the roll-out of future technologies. This is discussed in more detail in Section 3.1.2.

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14 See http://www.gsma.com/publicpolicy/wp-content/uploads/2012/09/Mobile-Infrastructure-sharing.pdf

15 See http://www.gsma.com/publicpolicy/wp-content/uploads/2014/09/Assessing_the_case_for_Single_Wholesale_Networks_in_mobile_communications.pdf

Wholesale Infrastructure Providers (WIPs)

WIPs lease sites from landlords and rent these out to MNOs, acting as an intermediary. They also build infrastructure such as towers and masts on the sites, which can be shared by MNOs. This enables cost savings through economies of scale in a similar way to network sharing, especially for smaller MNOs. For instance, Analysys Mason estimated that the total cost of site ownership is £242,000, whereas a licence from a WIP is £126,000: almost half the cost[16].

Analysys Mason further estimates that as of May 2016, there were approximately 33,000 physical mobile towers/rooftops in the UK. Of these, about two thirds are owned by the MNOs and the remainder owned by WIPs. Arqiva (the largest WIP) grew out of the broadcast transmission network, with broadcast masts also being suitable for mobile services. It is also the UK's largest public Wi-Fi provider and is currently building a national Internet of Things (IoT) network for smart metering.

Although WIPs have enabled cost-savings, this could be offset to the degree that they have market power, i.e. they control a portfolio of sites for which there is no competitive alternative, for example because a lack of available sites or because planning regulations prevent operators from building or contracting alternative infrastructure. However, if significant concerns regarding WIPs market power arise, these can be addressed through ex post competition rules.

Backhaul providers

When the primary mobile services were narrowband voice services, MNOs relied on a combination of microwave links and low bandwidth physical links (using copper or fibre) for their backhaul needs. However, as the volume of data carried over the networks has increased, fibre based Ethernet backhaul has become the preferred option as fibre costs are generally lower for high bandwidths. Due to the economies of scope with fibre based fixed broadband products, fixed line operators have lower costs for the provision of fibre links than self-provision by (standalone) mobile operators.

There are currently two main fibre backhaul providers:

- BT - BT is the incumbent fixed-line operator in the UK[17]. It is obliged to provide access to fibre based services throughout the UK as part of the remedies imposed by Ofcom in its review of the business connectivity market. This is discussed in more detail in Section 3.1.2.
- Virgin Media - Virgin Media is the cable operator in the UK covering 45% of premises in the country using hybrid fibre co-axial network.[18] Virgin also offers a fibre backhaul product exploiting economies of scope where it has rolled out a fibre network (but does not provide UK wide coverage). For instance, Three

[16] See https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/523787/Analysys_Mason_-_Financial_impact_of_ECC_changes_-_Final_report__3_.pdf

[17] Excluding Kingston-upon-Hull

[18] See http://stakeholders.ofcom.org.uk/binaries/telecoms/policy/digital-comms-review/DCR-statement.pdf

and EE, through their network sharing agreement[19] MBNL, use Virgin's backhaul product in some areas. The price of this product is determined commercially, i.e. it is not regulated by Ofcom.

If the amount of traffic carried over the 5G mobile network increases significantly or the number of cells required increases, backhaul requirements may also increase, subject to the network architecture remaining similar to that of previous generations. In Section 5.2 below, we discuss how investment in backhaul could be incentivised to ensure that backhaul does not constrain the deployment of 5G networks.

Network equipment vendors

Vendors tend to be large international companies which provide network equipment. Vendors have moved up the value chain by offering network-management services in addition to equipment sales. For instance, Ericsson provides network equipment and also manages MBNL's network.[20]

While vendors used to be nationally based, the move to standardised equipment regionally and globally has led to consolidation within the industry.

Given that the UK MNOs are part of international groups with operations in several countries[21], they typically procure equipment at a group level to benefit from economies of scale. For example, Huawei established a Strategic Alliance with Vodafone to develop communication services for the enterprise market in Europe, Asia Pacific and Africa. In the UK, Huawei provides Vodafone with single RAN equipment which enables 2G, 3G, and 4G to operate on a single network infrastructure.[22,23]

Vendors also have a role to play in the standardisation and roll-out of new technologies. The standards for any new technology are defined in general terms by the ITU (International Telecommunications Union), following which a committee/collaboration between various groups of international telecommunications stakeholders determine the technical specifications for technology[24]. Vendors have a role to play in this process:

- They carry out research and development to determine the standards which can be achieved; and then
- They build and sell equipment which meets the set standards.

19 See Section 2.2.2 for more detail on Network Sharing.

20 http://telecoms.com/23360/merger-of-3uk-and-t-mobile-uk-networks-complete/

21 For example, Vodafone Group has MNO operations in 26 countries. See http://www.vodafone.co.uk/about-us/company-history/

22 http://www.huawei.com/en/news/2016/3/Huawei-and-Vodafone-Extend-Strategic-Alliance

23 http://www.4g.co.uk/4g-news/news-features/huawei-joins-forces-vodafone-project-spring_30018210.html

24 The IMT-2020 group at the ITU set out the scope for 5G. Following this, the 3rd Generation Partnership Project will set the specifications as part of Release-15, which will be the first release of the 5G specifications.

2.2.4 Other stakeholders

Industry bodies

Supra-national bodies such as the ITU (International Telecommunication Union) provide forums which ensure that decisions related to mobile sector issues are co-ordinated at a global level. They have a role to play in co-ordinating and harmonising the release of spectrum. Different frequencies of spectrum are assigned particular uses at a regional and global level by the ITU through the World Radiocommuncations Conferences (WRC) of the ITU. This is to ensure that spectrum use is harmonised across countries, wherein approximately similar frequencies are globally allocated for the same uses. This enables interoperability between different countries and continents, which can lead to the following advantages:

- Handset manufacturers, vendors, etc. can benefit from economies of scale as they can produce output to meet global rather than regional demand; and
- Harmonisation enables international roaming so that handsets can function over similar frequencies even when the user travels outside their home country.

The ITU also has a role in ensuring that new technologies are standardised globally (see “Vendors” in Section 2.2.3 above).

This standardisation was successful in driving down cost in 2G, 3G and 4G networks and handsets by enabling economies of scale. A corollary is that ultimately 5G standards and the availability of equipment and handsets will be determined by international industry bodies, in cooperation with equipment manufacturers, not by individual countries.

Users

End users include both personal customers and businesses. Many businesses have specific use case. Where business previously relied on specialised networks, the increased capabilities of cellular networks (and Wi-Fi) have seen usage migrate to these networks, taking advantage of the scale and scope of economies available. For example, while taxi companies previously used private radio, they can now rely on mobile voice and data solutions (and applications such as Uber). Content delivery has begun to migrate from specialist broadcast networks (e.g. DTT or DTH satellite) onto mobile networks.

While mass market users have little direct impact on network investment, large users with specialist requirements can influence MNOs’ investments. While previously such specialist requirements would have been met with separate networks, developing network technology allows similar capabilities to be delivered over a converged network. For instance, the Emergency Services Network tender states that it will require a mobile network based on 4G technology with extensive coverage, high resilience, appropriate security and public safety functionality. This will be used to provide voice and broadband services for three emergency services. EE, as the winner of the tender, will need to make significant investments in additional infrastructure and equipment to deliver the quality of service required. This will have positive implications for other mobile users, partially addressing some of the coverage challenges faced by the mobile industry (e.g. coverage of roads and geographic coverage)[25].

Regulatory bodies

Finally, central government, Ofcom, local governments and councils play an important role in regulating the sector. We discuss these stakeholders in more detail below in the context of the regulations which govern the eco-system, in Section 3.

2.3 Potential changes to the mobile eco-system in the future

The trends in the evolution of the mobile eco-system described above are likely to continue. In particular, while the MNOs are likely to remain the key investors in the mobile infrastructure, as has been the case over the last 20 years, the scope for network virtualisation means that the level of vertical integration could fall further:

- MNOs could outsource elements of the core network to cloud computing providers;
- Application providers and retail providers could offer services over their own ‘network slices’, having greater control over quality of service than under existing wholesale (MVNO) agreements; and
- Retail providers could combine services from several networks to provide seamless services.

Examples of the latter approach are already being introduced. However, the lack of virtualisation means that services that attempt to stitch together separate networks are sub-optimal, for example not being able to manage a seamless handover when operators move between different networks.

One such example is an ‘inside-out’ network, which is currently being tested by TalkTalk (see the textbox below). It relies on TalkTalk’s existing assets (which provide fixed access) that could be used for backhaul and a low-power spectrum licence. If successful, this model is likely to lead to more competition in the sector and to deliver increased capacity in densely-populated urban areas.

[25] The ESN is discussed in more detail in Section 5.3.

'INSIDE OUT' NETWORKS: TALKTALK[26]

TalkTalk is a nationwide fixed network broadband supplier with over 4 million customers (which relies on local loop unbundling). It also has an MVNO deal with Telefonica.

In 2006, TalkTalk acquired one of the 12 licences for 3.3MHz FDD spectrum in the guard band between GSM and DECT at 1880MHz. Intended for low power use, it is mostly relevant for indoor use, but there is no restriction against short range outdoor service. It can also be deployed nationwide.

TalkTalk has developed its own prototype femtocell, which works as an "all-in-one" ADSL/VDSL modem, Wi-Fi router and LTE femtocell that supports high speed LTE voice and data. These femtocells can achieve coverage up to 60m from the residence. The LTE signal is more effective than Wi-Fi and does not have to compete with other uses on the unlicensed spectrum bands. It is also at a lower frequency of 1.8GHz (rather than 2.4 or 5GHz), which has better propagation characteristics.

Qualcomm estimates that adequate street coverage can be achieved from a random distribution of 20 homes out of 320 houses, which is equivalent to 7% penetration. As TalkTalk is already present in c. 20% of UK homes, it could potentially achieve good coverage of residential areas.

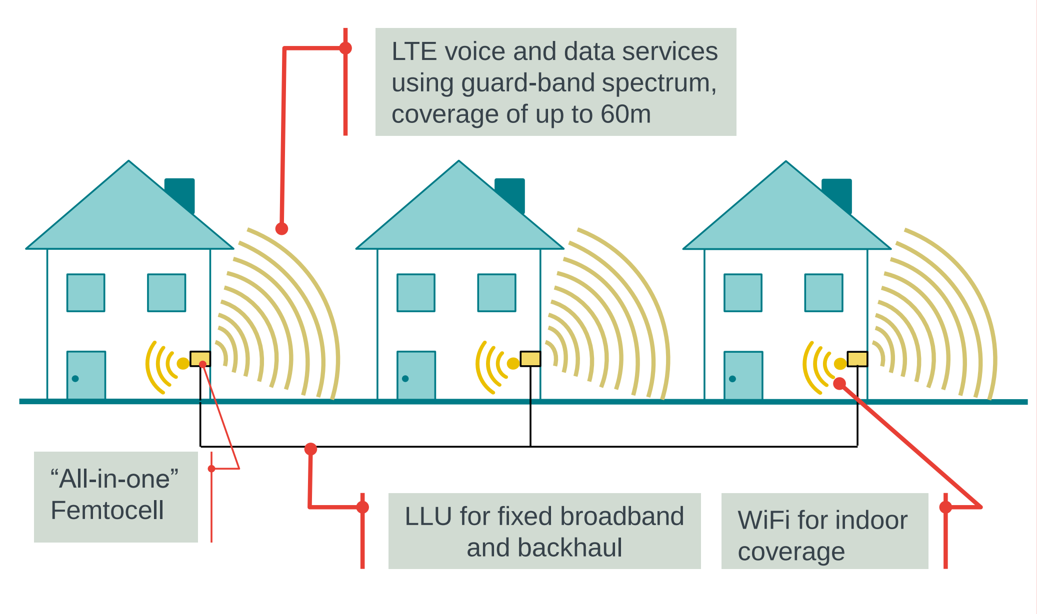
Overall, TalkTalk is expected to be in a position to build an "inside out" network using residential femtocells. This would allow TalkTalk to expand its scope by capturing the majority of traffic when at or near the homes of any of their subscribers, reducing the costs paid to the host mobile network and potentially making their quadruple-play offer more attractive to customers.

Millimetre wave radio, which is one of the candidate 5G technologies, could potentially be deployed in a similar way, providing very high speeds within specific locations, with wide area coverage provided by evolution of 4G technologies.

Having its own fixed assets and spectrum puts TalkTalk in a stronger position compared to a traditional MVNO and allows it to innovate and compete for customers (offering higher speeds, larger data packages, etc.).

[26] https://www.thinksmallcell.com/Residential/talktalk-s-inside-out-lte-femtocell.html

Exhibit 4 Schematic representation of an 'inside out' model



Source: Frontier Economics

Another example of innovation in the sector is Project Fi, currently piloted by Google in the US (discussed in the text box below). Google also has an MVNO-type arrangement, but with two mobile operators (rather than one). By having access to two mobile networks and Wi-Fi hotspots, Google achieves better coverage and greater capacity than each of the MNOs on its own by using its control of smartphone software to manage transitions between networks.

PROJECT FI[27]

Project Fi was introduced by Google in the US in April 2015 on a small range of compatible Google Android smartphones.

The connectivity behind Project Fi is sourced from two mobile networks (Sprint and T-Mobile), along with a collection of shared public Wi-Fi access points. The service moves seamlessly between them "*intelligently connecting users to the fastest network*". The customers benefit from unlimited voice and texts, a flat fee per GB of data, with no additional roaming charges for mobile data. Moreover, data consumed while connected to public Wi-Fi is free of charge.

This project is innovative as (i) it allows Google (effectively an MVNO) to rely on several mobile networks for coverage (thereby improving user experience) and (ii) employs Wi-Fi for capacity (to reduce costs and offer consumers more competitive tariffs).

As well as addressing partial not-spots (areas where some mobile networks have coverage, while others do not), Project Fi also addresses capacity constraints, by utilising public Wi-Fi and distributing traffic over two mobile networks (subject to required Quality of Service).

[27] https://fi.google.com/about/network/, http://telecoms.com/opinion/project-fi-googles-mobile-master-plan/

From the MNOs perspective, the wholesale agreements with the network operators provide a stream of revenues for the MNOs. The MNOs who have signed up (Sprint and T-Mobile) are relatively small and so the offsetting potential loss of market share at a retail level may be relatively small. To the extent that software will choose between networks based on quality of service, incentives to invest in the networks are likely to be preserved.

Project Fi is effectively a test multi-operator MVNO. It remains to be seen whether it is successful, i.e. whether it can balance offering lower prices and good quality to consumers with providing the host MNOs with sufficient incentives to invest in their networks. However, even if it is successful in the US, it is not guaranteed that it will be replicated in other markets. Indeed, in the US, the two smaller national operators (T-Mobile and Sprint) agreed to sign a deal with Google, while two larger national operators (Verizon and AT&T) have not. This suggests that incentives to provide wholesale access on non-exclusive basis might vary depending on the market structure and the operators' position in the market.

Similar approaches could be used by entrants using new technology such a millimetre wave radio. This technology is unsuitable for building networks with national coverage but entrants could either use access to MNOs' networks to provide wide area coverage or alternatively sell access to their networks on a wholesale basis to third parties (such a Google) to combine with other networks.

2.3.1 Vertical applications

The majority of demand on mobile networks can be characterised as personal communications. However, this market is largely saturated. One potential source of growth is machine to machine communications (M2M) or the Internet of Things.

The evolution of these markets could lead to a number of changes in the eco-system:

- Entry into the mobile market of players from other industries which rely on the IoT to enhance their products, for example, players from healthcare or the automotive industry becoming niche MVNOs;
- Changes in the retail relationship, either because the products are largely business to business or because the connectivity will be sold embedded into a physical product (e.g. the 3G capability built into some versions of Amazon Kindle e-readers); and
- Development of network technologies to support the IoT, potentially separate from mobile technologies designed for personal communications.

It is possible that virtualisation (so called network 'slicing') could be used to support future vertical mobile applications, e.g. in the automotive segment, with car manufacturers (e.g. BMW) seeking access and striking commercial agreements with the MNOs to achieve the best possible mobile coverage on motorways. These new models should be encouraged by the regulator though flexible spectrum policy and fit-for-purpose regulation (see Section 5 for more details on our recommendations).

2.3.2 Changes at the network level

Although MNOs have driven the roll out of new technologies so far, this need not continue to be the case. Application-specific networks, such as Sigfox and LoRa, are examples of companies that have built their own Low-Power Wide-Area Networks for the Internet of Things. These networks serve devices that require low power and transmit small quantities of data, such as smart meters and smoke alarms.

Both Sigfox and LoRa use unlicensed spectrum and have already started rolling out networks in the UK. Sigfox has partnered with Arqiva in the UK to roll-out an IoT network[28] and LoRa installed their first base station in London in early 2016.[29]

While the general assumption is that to benefit from the economies of scale, most future applications would be delivered on the same networks, applications with unique requirements (low power, small quantities of data) might be delivered by entirely separate networks more efficiently and cost-effectively. With the number of connected devices predicted to reach billions[30], these dedicated networks (such as Sigfox and LoRa) are likely to expand and benefit from their own economies of scale. To the extent that these networks are able to stimulate demand for the IoT applications and generate some additional revenues for the operators providing the IoT connectivity, it might also incentivise MNOs to upgrade their own M2M / IoT capabilities from 2G and 3G to LTE[31] and ultimately 5G.

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[28] https://www.arqiva.com/overviews/internet-of-things/internet-of-things-network/

[29] https://iotuk.org.uk/londons-first-lora-base-station/

[30] http://www.techweekeurope.co.uk/networks/m2m/juniper-internet-of-things-devices-173468

[31] For example, LTE-Cat NB1

3 THE IMPACT OF REGULATION

Regulation, both sector-specific and general, shapes the behaviour of stakeholders in the mobile market and will influence incentives to invest in future technologies. As new technologies have been introduced, regulation has also had to evolve.

The framework for sector-specific regulation governing telecommunications networks, including the use of spectrum by these networks, are set at an EU level and then adopted by its member states into their national laws and regulations.

Other laws and legislation which impact on investment in networks, in particular planning restriction, is determined at a country level.

In this section, we first provide an overview of the EU regulatory framework. The rest of the section is focussed on the national legal framework relevant to mobile networks and infrastructure in the UK.

3.1.1 Overview of the electronic communications regulatory framework in the EU

The framework for regulating the electronic communications sector, including the mobile market, is currently based on the EU framework.

The EU framework aims to create a single digital market for the countries in the EU. Regulation aims to achieve a competitive and efficient market which is harmonised to the greatest extent possible.

Much of the EU framework focusses on fixed operators, reflecting the fact that incumbent fixed network operators have SMP and universal service obligations, while mobile networks were developed in a competitive environment without universal service obligations. As such, for the most part EU regulation of the mobile sector has been designed to facilitate entry and competition in the sector.

From the perspective of mobile operators, much of the key EU regulation has been around mobile frequencies and technology, with the EC promoting early and harmonised adoption of GSM[32] and 3G[33] technologies, albeit with the allocation of frequencies being made at a national level.

3.1.2 Overview of the regulatory framework in the UK

The framework for regulating the mobile market in the UK is based on this EU framework, and the directives discussed above have been transposed in UK laws and regulations.

There are a number of acts of Parliament which govern the functioning of mobile telecommunications in the UK: the Communications Act 2003, the Wireless

[32] Council Directive 87/372/EEC of 25 June 1987 on the frequency bands to be reserved for the coordinated introduction of public pan-European cellular digital land-based mobile communications in the Community

[33] Decision No 128/1999/EC of the European Parliament and of the Council of 14 December 1998 on the coordinated introduction of a third-generation mobile and wireless communications system (UMTS) in the Community

Telegraphy Act 2006, the Office of Communications Act 2002 and the Digital Economy Act 2010.

Ofcom is the NRA in the UK and its statutory duties and functions stem from these acts (and other legislation, such as acts relating to broadcasting and the postal sector). The Communications Act and the Wireless Telegraphy Act (WT Act) are particularly important in specifying Ofcom's duties relating to the mobile market.

THE COMMUNICATIONS ACT AND THE WIRELESS TELEGRAPHY ACT

- The Communications Act 2003 is one of the key pieces of legislation for telecoms, transposing the key EU directives from the 2002 package. To ensure that it remained consistent with the EU framework, it was amended in 2009 to reflect amendments to the Directives.

  Ofcom is responsible for ex-ante regulation in the UK. This involves carrying out periodic market reviews, establishing if any operator has market power and imposing the necessary obligations on them to ensure that the market functions in a manner which simulates competition. These activities are in line with the Access Directive. For mobile operators, the only 'relevant market' is the market for call termination (i.e. calls made to mobile phone users) where Ofcom sets the regulated wholesale price charged by the MNOs for terminating these calls.

- The WT Act requires Ofcom to issue licenses for the operation of wireless telegraphy apparatus and for the use of certain frequencies. Ofcom is responsible for the number of wireless telegraphy licences granted, their purposes and the frequencies on which they operate. WT Act also outlines Ofcom's spectrum management duties including those related to the publication of spectrum plans, licensing of spectrum, setting charges for license, etc. Ofcom's powers under the WT Act set out how it can allocate spectrum between uses, for example between broadcasting and mobile communications and how it can licence spectrum to individual operators, for example through spectrum auctions.

There are also other government bodies that are involved in the regulation of the mobile ecosystem, such as the Department for Culture, Media and Sport (DCMS), local governments and councils. For instance, the DCMS is responsible for the Electronic Communications Code which governs the operators' ability to access sites and build mobile infrastructure. Local governments implement the planning regulations by rejecting/accepting planning permissions to build towers or masts in their jurisdiction.

Finally, there are competition authorities dealing with 'ex post' competition issues (Ofcom's powers under the EU framework allow it to intervene 'ex ante' to regulate to prevent anti-competitive behaviour). The relevant competition authorities for telecommunications are Ofcom and the CMA in the UK (who have concurrent powers with respect to the sectors regulated by Ofcom under the

Enterprise and Regulatory Reform Act 2013) and the European Commission at the EU level. The competition powers cover:

- Article 101 of the EU treaty, which prohibits restrictive agreements;
- Article 102, which prohibits the abuse of a dominant position; and
- Merger control and potential market investigations.

These powers apply to the mobile eco-system through oversight of network sharing agreements, merger control (for example, the prohibition of the proposed merger between Three and O2 in the UK) and investigations into the abuse of a dominant position. They ensure that competition in the UK and other European mobile markets is protected. Below, in Section 4.2, we discuss the link between competition and the operators' incentives to invest in new technologies in more detail.

The remainder of this section focusses on UK laws and regulations which are relevant to the mobile ecosystem and in particular investment in networks. We have grouped them as follows:

- Relating to non-physical assets, i.e. spectrum;
- Regulation relating to physical infrastructure;
- Regulation governing wholesale relationships; and
- Those governing retail relationships.

Regulation relating to spectrum

As spectrum is a 'scarce resource', i.e. there is a finite amount of resources and potential demand exceeds supply in certain bands, there is a need to allocate rights to use spectrum for efficiency purposes. At a high level, Ofcom in its role as spectrum manager (as per the WT Act) determines the uses to which particular frequencies are assigned. It does so in a way that ensures that:

- Interference between uses is minimised; and
- It is consistent with the ITU's regional/global assignment of spectrum to particular uses (e.g. to mobile, satellite, etc).

As an example, the 800MHz is allocated to mobile, while 1.6106 - 1.6138GHz is allocated to radio astronomy.

Once this assignment is determined, Ofcom manages the allocation of spectrum rights to users. This centrally planned management of uses and users is known as the Command and Control approach.

There are a number of methods to assign spectrum rights to users, as described in the box below.

HOW IS SPECTRUM ALLOCATED AND PAID FOR?

Spectrum rights are typically allocated to users for a fixed ‘block’ of spectrum (which may include ‘paired’ spectrum allocations for two way communications) for a given geographic area (e.g. nationwide or for a limited geographic area) for a given period of time (which may be extended, on either an exclusive basis or shared with other users).

Spectrum used by MNOs has been allocated generally on a paired basis (reflecting the two way nature of voice communications), for exclusive nationwide use with licence terms of 20 years (to allow operators to recover investments related to the spectrum).

There are a number of potential methods of allocation:

- “First-come-first-served” – this method of allocation is used if there is no excess demand for spectrum (i.e. supply exceeds or is equal to demand). For example, some spectrum for wireless fixed links is allocated on a link by link basis on a ‘first-come-first-served’ basis.
- Auction – this is the preferred method of allocating spectrum for mobile use in the UK. Auctions are favoured because they are transparent and, if designed well, they deliver efficient outcomes (i.e. the auction allocates spectrum to the operators that would use it in the most efficient way). Depending on the auction design, they can be used as a policy tool to influence market structure (through spectrum caps or reserved blocks). Auctioned licences can include obligations such as coverage obligations in theory allowing these obligations to be met efficiently as operators will reflect the cost of meeting these obligations in their bids.
- Comparative evaluation (‘Beauty contests’) – spectrum licences are allocated based on a set of criteria (e.g. roll out plans, future coverage, business viability, etc.). Beauty contests were used for the initial allocation of 1G and 2G spectrum to mobile operators but since 2000 auctions have been used in the UK.

The EC Framework Directive sets out the limited conditions under which spectrum licences can be charged for, generally in order to ensure an efficient allocation of spectrum[34]. There are a number of potential charging mechanisms:

- Auctions – Well designed auctions allow the market to determine the price for spectrum with the market price in theory leading to an efficient allocation of spectrum.
- Administered Incentive Pricing - Under this mechanism, Ofcom sets annual licence fees to reflect an estimate of the market price of the spectrum. Market pricing can encourage spectrum to be used efficiently as inefficient users would not be willing to pay the market price and will relinquish spectrum to be allocated to users with a high value.
- “Cost-based” pricing - Where Ofcom considers that AIP is not justified, for example if spectrum is not scarce in a band, it sets the fees to recover its costs of management of the licence.
- Below cost fees - Ofcom can also set below-cost fees or not charge a fee at all if it wishes to encourage certain uses. For example “non-operational licences" are used for development and academic research and fees are set at a level low enough to encourage innovation.

Most mobile spectrum has been auctioned. Auctioned licenses generally have a 25 year term during which no fees need to be paid over and above the price paid at the auction. After the initial term of the licence, operators are expected to have right of first refusal for spectrum they currently hold with fees from this point charged under AIP.

The 900MHz and 1800MHz bands were initially allocated to the MNOs through a process of comparative evaluation and have annual license fees applied.

Ofcom is looking to liberalise spectrum-use by moving away from the command and control approach. Under this state of the world, there would be more license exempt uses and license trading, which we discuss next.

[34] Member States are prohibited from applying fees solely to raise revenues.

Licence exemption

As mentioned above, the WT Act requires Ofcom to issue Wireless Telegraphy licences for the operation of wireless telegraphy apparatus and for the use of certain frequencies. However, the Act allows Ofcom to exempt some types of radio equipment from requiring licences depending on:

- The purpose for which the equipment will be used;
- The frequency that it will be used;
- The strength with which the equipment will send and receive signals; and
- Whether the equipment is compliant with national/international standards.

Licence exempt equipment can operate only on specific “licence exempt” frequency bands. Wi-Fi, for instance, operates in the licence exempt band of 2400 - 2483.5MHz. Commonly used licence exempt devices are electric car keys, microwave ovens, wireless microphones, etc. Uses that operate in unlicensed frequency bands therefore share the band and onus is on them to minimise interference.

Depending on the use cases for new technologies such as 5G, licence exemptions could be a model to aid roll-out. For example, 870-876MHz and 915-921MHz were made available on a licence exempt basis for Short Range Devices such as smart meters, among other uses. In Section 5.1 below, we discuss the role of unlicensed spectrum in 5G roll out in more detail.

Spectrum trading

Spectrum trading allows holders of certain wireless telegraphy licences to transfer some or all of their rights to another party on commercially negotiated terms. This could lead to more efficient outcomes, with spectrum being used by those that value it most. Ofcom introduced regulations allowing for spectrum trading in 2004, for certain bands subject to certain conditions. These were updated and simplified in 2011.

Few spectrum trades have taken place so far in the UK. In 2012, in order to satisfy the commitments given when the European Commission approved the merger of Orange and T-Mobile[35], EE divested 2x15MHz of 1800MHz spectrum by transferring it to Three. In 2015, Qualcomm (a technology company) transferred 20MHz of its 1400MHz spectrum to Vodafone and 20MHz to Three[36]. All these sales have been approved by Ofcom.

Although infrequent, spectrum trading is a useful tool to ensure better spectrum utilisation. However, on its own, it might not prevent inefficient use of spectrum if asymmetric information prevents trades or operators prefer not to trade spectrum with competitors for strategic reasons. As such, most spectrum for mobile communications has been made available through clearing existing users under a ‘command and control’ approach and then allocating the resulting spectrum through auctions, rather than by trading between users.

[35] Commission press release IP/10/208

[36] https://www.ofcom.org.uk/__data/assets/pdf_file/0022/81670/trade-of-frequencies-statement.pdf

Regulation relating to physical infrastructure

Physical infrastructure is essential for the roll out and upgrade of mobile networks. Constraints on deployment of this infrastructure will also constrain the deployment and upgrade of mobile networks.

There are different types of infrastructure and activities which are regulated:

- Laying fibre lines for fibre backhaul;
- Building/placing equipment for the core-network;
- Accessing sites to be able to build infrastructure;
- Building towers and masts at mobile sites;
- Installing RAN equipment at the sites e.g. installing antennae on towers; and
- Replacement, upgrade and maintenance of installed equipment.

These activities are regulated by a combination of national planning regulations and the Electronic Communications Code (ECC), which confers specific powers on communications operators.

Planning regulations

Planning regulations are a key factor influencing an operator's ability to expand its network as they govern where sites can be built and the physical appearance of the equipment that can be installed on these sites.

Both the location of the site and the specifications, such as height of towers and masts, determine the coverage and capacity that can be offered by a mobile network. Constraints resulting from planning regulations can restrict the benefits from new investment.

For example, one of the respondents to the NIC 5G call for evidence estimates that a typical 50 metre mast provides a coverage area of up to 116km², in comparison to 58km² for a typical 15 metre mast, so only half the number of 50 metre masts would be required to coverage a given area. The average ground-based mobile mast in the UK is only 18 metres tall, compared with between 72 and 100 metres in Sweden. This suggests that more than twice as many masts need to be deployed in the UK than in Sweden to provide a comparable level of coverage. This results in higher costs for the UK consumers, as well as slower speed of upgrading the infrastructure.

The complexity of planning regulations (discussed below) could also potentially significantly increase the required time to make new investments and the resulting costs. As such planning regulations could have a significant impact on the financial viability of new investments in coverage, capacity or technology.

Planning in the UK is governed by separate acts of Parliament for England and Wales, Scotland, and Northern Ireland[37], as well as secondary legislation. This

[37] Therefore, the relevant acts which govern planning in the nations are Town and Country Planning Act 1990 for England and Wales, Town and Country Planning (Scotland) Act 1997 in Scotland and the Planning Act (Northern Ireland) 2011 in Northern Ireland.

secondary legislation consists of General Permitted Development Orders or GPDOs.[38]

WHY ARE PLANNING PERMISSIONS NECESSARY?

Planning regulation is necessary to balance the benefits of development, which in the case of mobile networks may accrue to a wide range of users, with negative "externalities" associated with development, which may impact on people in a specific area. These externalities are negative consequences of the operators' decisions to build, which do not impact on the operator itself. For instance, an operator might find it beneficial to build a tower in a national park as it will increase its coverage. However, the tower may spoil the view and reduce visitors' enjoyment of the area. Thus, the purpose of the planning permission becomes to ensure that these externalities are minimised and/or properly balanced against the benefits. For example, planning authorities might allow the tower to be built if mobile coverage is considered a priority, but its height restricted to reduce its impact.

GPDOs recognise that the benefits of the development of mobile networks are wide in scope and cannot be assessed at a local level and that there are benefits to a harmonized approach at a national level.

The GPDOs provide descriptions of "permitted developments" and "developments not permitted". The permissions necessary for telecommunications developments will therefore depend on the category the development falls under:

- Permitted development – For mobile operators, permitted developments are defined by the GPDOs to be developments on land owned by the operator or changes which are in accordance with the ECC. This allows operators to make certain changes to their installations; for example adding a second small antenna to existing masts. For such "permitted developments", the operators may only need to notify the Local Planning Authority of the changes they intend to make.
- Development that requires prior approval or full planning permission – The GPDO in England draws a distinction between developments which are permitted but require prior approval (the operator has to apply to the local planning authority to seek approval) and those which are not permitted and require an application to the Council, who can then choose to accept or reject the application. The Welsh, Scottish and Irish legislation also have similar specifications for developments which are not permitted.

A number of changes have been made to the list of developments in the English GPDO 2015, as has been confirmed in the latest version of the GPDO 2016. [39] These changes expand the list of permitted developments, allowing taller masts

[38] The secondary legislation applicable is The Town and Country Planning (General Permitted Development) (England) Order 2015, The Town and Country Planning (General Permitted Development) (Scotland) Order 2011, Town and Country Planning (General Permitted Development) Order 1995 and The Planning (General Permitted Development) Order (Northern Ireland) 2015.

[39] See 2016 The Town and Country Planning (General Permitted Development) (England) (Amendment) (No. 2) Order 2016, , available at http://www.legislation.gov.uk/uksi/2016/1040/pdfs/uksi_20161040_en.pdf

and towers to be built without seeking full planning permission. Another change is that there are fewer restrictions on the installation of small cell systems.

The latter change could make it easier to roll out a network of small cells and also increase coverage. Allowing operators to increase the height of masts or to build taller masts in protected areas will enable them to increase coverage while incurring fewer costs. Similar changes to the legislation in Scotland, Wales and Northern Ireland could therefore be considered to aid consistent UK-wide coverage and roll-out.

These recent and further proposed changes and their implications for the small cell deployment are discussed in more detail in Section 5.

Electronic Communications Code (ECC)

The Electronic Communications Code ('the Code') gives network providers certain rights which are not available otherwise, in order to allow them to construct networks. The Code enables these providers to construct infrastructure on public land (streets), to take rights over private land, either by agreement with the landowner or applying to the County Court or the Sheriff in Scotland. It also conveys certain immunities from the Town and Country Planning legislation in the form of Permitted Development.

The Code is granted to network providers by a direction made following a public consultation and consideration of the responses to that consultation. The Code has been granted to a wide range of operators include all of the MNOs.

In addition to the rights conferred on operators, the Code provides conditions for the installation of telecommunications lines, equipment and apparatus. These range from physical specifications (such as requiring certain apparatus to be installed underground or the use of conduits for line installation) to specifications of when planning permission should be sought. For certain installations, it extends the list of permitted developments beyond those allowed for in the Town and Country Planning legislation. [40]

The Code is thus important as the powers it confers can ease the rollout out of networks but it can inhibit the rolling out of new technologies if, for instance, it is overly-restrictive on the developments that are permitted.

The code that currently applies is the ECC 2003. It was found to be complex and outdated[41] and the DCMS proposed to reform it[42]. The updated ECC has been included in the Digital Economy Bill[43], which is currently making its way through the House of Commons.

The changes being proposed to the ECC address a number of problems that existed with the previous Code. For instance, site rentals will be regulated and

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40 See http://licensing.ofcom.org.uk/radiocommunication-licences/mobile-wireless-broadband/cellular-wireless-broadband/policy-and-licensing-information/electronic-communications-code/

41 These findings formed part of the Law Commission's review of the ECC, which was conducted at the request of the DCMS. Available at http://www.lawcom.gov.uk/wp-content/uploads/2015/03/lc336_electronic_communications_code.pdf

42 Outcomes from the consultation available at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/523788/Electronic_Communications_Code_160516_CLEAN_NO_WATERMARK.pdf

43 Information relating to the Bill available at http://services.parliament.uk/bills/2016-17/digitaleconomy.html

should be set up on a "no scheme" basis (defined below) and MNOs can have automatic rights to upgrade their apparatus on the site.

WHAT ARE THE CHANGES TO THE ECC AND THEIR IMPLICATIONS?

The new ECC is likely to have a number of changes:

- Regulation of site-rents – An issue that existed with the previous Code was a lack of regulation of the site-rentals. Since sites may not always be substitutable, there were instances of landlords using their market power to charge high rents. The new Code sets out that rents be valued on a "no scheme" basis, wherein the rent is set to equal the opportunity cost of land.[44] The switch to a "no scheme" basis for setting site-rents will likely have two effects:
  - Cost-savings on the existing sites: The Law Commission estimated that this could lead to yearly savings of £8.6 million on site renewals.[45] Some of these cost savings are likely to be passed on to consumers, and some are likely to be used to fund future innovation/ investment. To the extent that complete coverage will be a requirement for 5G, lower roll-out costs will help to achieve it.
  - Increase in incentives to add more sites: The cost-savings can also be used to add more sites to MNOs' networks which will also help achieve higher coverage.
- Automatic rights to upgrade and share apparatus: Another issue under the previous code was that operators could not upgrade or share apparatus with other MNOs automatically and therefore, could require approval from the site-landlord. This had been an obstacle to the upgrades necessary for 3G and 4G. It is likely that more upgrades will be necessary in the move to 5G. This change will be instrumental in upgrades taking place quickly as additional negotiations with site-owners will not be required.
- Prohibition of "contracting out" of the code: The new Code prohibits landlords and MNOs from striking up contracts which can circumvent the code. This should reduce the ability of landlords to negotiate terms which could hinder speedy roll-out of new technologies.

While these changes reduce costs for MNOs, a potential stumbling block could be that the revised Code will not regulate the fees charged by Wholesale Infrastructure Providers for their sites. This could be problematic moving forward

[44] The opportunity cost refers to the value of the second-best option. In the context of sites, it therefore implies the value of the land in the event that the MNOs did not use the site, i.e. the value assigned by the second-best user. Consequently, the rent is set to reflect the value of the land as is, rather taking into account any appreciation that may occur as a result of the use the land currently serves.

[45] See Financial Impact of ECC Changes, Analysys Mason, May 2016. Available at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/523787/Analysys_Mason_-_Financial_impact_of_ECC_changes_-_Final_report__3_.pdf

as WIPs owned approximately one third of mobile towers/rooftops as of May 2016.[46]

INFRASTRUCTURE SHARING

The ECC states that operators should share infrastructure where practicable. This can involve sites, towers, masts or radio access equipment. Ofcom therefore requires applicants applying to be Electronic Communications Code operators to show that they are willing to share their apparatus with other operators. The objective is to minimise both the inefficient duplication of network infrastructure and the visual impact of telecommunications equipment. Sharing can also be attractive to operators as the fixed-costs of network deployment can be shared. However, practical difficulties in sharing infrastructure[47] or strategic reasons may deter operators from entering into agreements for individual pieces of infrastructure (compared to the network sharing agreements described above on a national level). In Section 4.2.1, we discuss the role of "first mover advantage" in incentivising investments in the mobile sector. In order to be first to the market with 4G, EE chose to roll out its 4G network independently of Three.

Depending on the use-cases for new technologies, sharing infrastructure could lower the cost of deployment subject to sharing being feasible.

Access

There are a number of wholesale relationships which are important to the functioning of mobile networks. The 'Access Directive' as transposed into UK law sets out the framework in which access and interconnection arrangements are regulated, where an operator has been determined to have significant market power. This impacts on mobile operators in two ways:

- Regulation of mobile call termination where all of the MNOs are determined to have SMP in the relevant market; and
- Access to fixed networks for backhaul, where BT is determined to have Significant Market Power in a number of relevant markets.

While call termination rates have declined significantly in the last 10 years and are unlikely to affect incentives to invest in future mobile technologies in any material way, the role of access to backhaul is likely to become more critical. As described above (in Section 2.2.3), backhaul is used to transmit data from the radio access network to the core network. MNOs can self-supply backhaul by using point to point radio links, typically sites on the towers used for cell sites. In this case, the planning and spectrum-related regulations are relevant (and have been discussed above).

However, MNOs are increasingly moving to fibre based backhaul as this can reliably deliver the high bandwidths required to deliver data capacity at a lower

[46] See Financial Impact of ECC Changes, Analysys Mason, May 2016. Available at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/523787/Analysys_Mason_-_Financial_impact_of_ECC_changes_-_Final_report__3_.pdf

[47] For example, given that MNOs have spectrum at different frequencies (with different propagation characteristics), they might prefer to position their masts differently.

cost than radio links. MNOs are therefore using a combination of microwave and fibre backhaul[48]. There are different channels to acquire fibre backhaul for this:

- Commercial solutions where MNOs buy transmission services from a fixed operator. These services may be simple links from point to point or a managed service which provides greater functionality such as increased resilience or more flexibility in use of capacity;
- Regulated access to wholesale inputs[49] – Backhaul services form part of the business connectivity market review in 2016 (BCMR). BT was found to have significant market power and was obliged to provide two types of product at regulated prices through BT Openreach[50]:
  - Dark fibre - This is a passive product wherein BT provides the MNO with raw fibre input but the MNO has to install its own equipment for the fibre to function; and
  - Leased lines - This is an active product wherein BT provides a functioning fibre line as it also includes equipment. Because the MNO does not install its own equipment, it has less control over the quality of the product.
- Duct and pole access - BT owns a network of ducts and poles in the UK. If MNOs have access to these, they can lay their own fibre lines and self-supply backhaul. However, Ofcom did not include duct and pole access as a remedy in the BCMR as it could lead to the risk of inefficient entry (i.e. inefficient duplication of infrastructure). However, the EU directive on measures to reduce the cost of deploying high-speed communication networks obliges network operators (which also include electricity, gas and water providers) to meet all reasonable requests for access to its physical infrastructure[51]. This would therefore include BT's ducts and poles. Once implemented, MNOs may use this directive to gain access to BT's ducts and poles, but on commercial terms because it will not be a regulated product; and
- Commercial offers by BT Wholesale and Virgin Media – BT's wholesale division and Virgin offer complete backhaul solutions. This would involve outsourcing backhaul provision entirely.

Given the current mobile technologies, Ofcom considers that BT's provision of dark fibre and leased lines at regulated prices are sufficient remedies to meet MNOs' needs. This, however, may require reconsideration when the network architecture and needs of new technologies become clearer, especially if thousands of small cells get deployed and need to be connected to the core

48 According to Analysys Mason, historically, mobile operators used a different mix of physical backhaul and microwave for mobile backhaul. For example, Orange (now part of EE) relied predominantly on self-provided microwave; Vodafone used the leased lines and self-provided microwave in equal proportions, while O2 relied predominantly on regulated and commercial leased lines. https://www.vodafone.com/content/dam/group/policy/downloads/analysys-mason-final-report-vodafone-phase2.pdf

More recently, the trend has been to rely predominantly on regulated leased lines.

49 See http://stakeholders.ofcom.org.uk/telecoms/telecoms-competiton-regulation/ethernet-and-leased-lines/2016-bcmr/

50 Openreach is a subsidiary of the BT Group and owns the physical infrastructure including ducts, cables and poles in the UK.

51 Including pipes, masts, ducts, inspection chambers, manholes, cabinets, buildings or entries to buildings, antenna installations, towers and poles; cables, including dark fibre, as well as elements of networks used for the provision of water intended for human consumption.

network. Our proposals for future regulation of backhaul are discussed in Section 5.2 below.

Regulations governing retail relationships

The regulations governing retail relationships have an impact on the revenue earned by MNOs and so, their ability to invest in new technologies. We explore them in turn.

Net neutrality

The rules on net neutrality determine how traffic carried over the internet is treated. The aspect of this that has the greatest impact on MNOs is that it can restrict them from offering paid prioritisation (and zero rated services). With paid prioritisation, an MNO can offer dedicated capacity to an OTT service (e.g. Netflix) for a fee. This runs contrary to the current "best effort" delivery system wherein all data is treated equally.

Ofcom's rules on net neutrality date back to 2011.[52] Then Ofcom found that best effort and prioritisation should co-exist as both have their merits. The former lowers the barrier for entry for potential new OTTs and therefore allows room for innovation. The latter, on the other hand, can lead to a more efficient allocation of capacity. However, Ofcom emphasised that one should not come at the expense of the other, i.e. prioritised services should not lead to a degradation of quality of the 'best-efforts' access. Ofcom further considered that the market would be able to determine if any prioritisation methods were anti-competitive and required redressing, as long as consumers had the information necessary to make purchasing decisions. Therefore, Ofcom's rules emphasise the need to make consumers aware of the MNOs' traffic management practices.

The most recent EC regulation[53] on net neutrality is more prescriptive. It prohibits traffic management other than in a few exceptional circumstances (such as to protect the network from cyber-attacks). While specialised services (with specific quality requirements) are allowed, they can only be provided if there is sufficient network capacity to provide them in addition to any internet access service and must not be to the detriment of the availability or general quality of internet access services for end-users. The National Regulatory Authorities (NRAs) are also required to verify whether and to what extent optimisation for specialised services is necessary.

Given the UK's decision to leave the EU, it is unclear if this regulation will be adopted by Ofcom.

Strict net neutrality rules could lower the operators' ability to invest in new technologies. More specifically, it is expected that 5G applications would vary greatly in terms of the requirements they would place on the networks (some would require high bandwidth and low latency, others low latency but ubiquitous coverage and so on). With such a wide range of underlying requirements, it would not be efficient to meet the requirements by delivering all traffic to meet the most stringent quality of service requirement in all dimensions, i.e. to provide

[52] Available at http://stakeholders.ofcom.org.uk/binaries/consultations/net-neutrality/statement/statement.pdf

[53] Available at http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015R2120&from=en

each application with exactly the same Quality of Service. Therefore, it is important to ensure that net neutrality rules address these new requirements. A failure to update the regulation might slow down the transition to 5G (i.e. the operators might choose to delay investment if the regulatory position is not clear). This is discussed in more detail in Section 5.

In the next section, we consider the operators' incentives to invest in new technologies.

4 AN ASSESSMENT OF THE INVESTMENT DRIVERS FOR THE DEPLOYMENT OF 5G NETWORKS

In this section, we analyse how operators make investment decisions in the mobile market in practice. This will impact on both strategic investment decisions, such as whether or not to implement a new technology or compete for a new type of customer, and ongoing decisions about investments in incremental capacity or coverage.

Classical financial theory postulates that investments are made if net present value of future cash flows generated from assets exceeds costs of investment. However, this only holds under certain conditions which, in most cases, do not hold for mobile operators facing strategic decisions given the significant uncertainty on the future level of cash flows faced by mobile operators. More recent theories of investment under uncertainty appear to better model the operators' behaviour, as they predict that if demand uncertainty is high, investments are made incrementally rather than as a single project. We illustrate the dynamics of investment under uncertainty through a case study looking into the evolution of the 3G market in the UK.

Another feature which determines investment in the UK mobile market is the oligopolistic nature of the market, reflecting the large barriers to entry such as high fixed costs and access to spectrum. Given the high fixed costs of mobile networks, operators need to price above marginal cost in order to fully recover their investments, which necessitates a degree of market power, i.e. the ability to set prices somewhat independently of other players. In order to develop and maintain this market power, operators try to differentiate themselves from their competitors in terms of price, coverage, speed, brand, handset availability, etc.

This dynamic also informs the incentives for investment as operators will make investments which deliver clear benefits in terms of differentiation. For example, introducing new capabilities ahead of one's competitors (so called 'first mover advantage') and maintaining this advantage is particularly desirable. We illustrate this with a case study of the evolution of 4G market in the UK.

However, there may be investments which neither deliver sufficient cash flows on their own to justify the initial investment nor clearly differentiate the operator from the customers' perspective, but which are socially important. For example, investment in coverage in remote rural areas might not deliver sufficient additional revenues to justify high roll-out costs from the operators' perspective. However, this kind of investment is important as it improves economic and social prospects of individuals living in those remote areas.

Historically, it was accepted that different mobile operators had different coverage footprints, reflecting a combination of differences in frequency used and the order of entry[54]. Coverage was seen as one of the differentiating factors, with customers being able to choose operators with better coverage and consequently higher prices, or lower prices but with less coverage. However, differences in coverage are smaller as all operators have been in the market for a considerable period of time and now have access to low frequency spectrum. In addition, there is now an expectation of ubiquitous coverage by consumers. However, from the operators' perspective, the financial case of making the additional investment needed to deliver ubiquitous mobile coverage might not be sufficiently strong. Marginal increases in coverage, where costs are relatively high and demand low are unlikely to either generate significant additional revenues or have a sufficient impact on consumer acquisition and retention to justify the investment.

We conclude this section by discussing potential challenges to the adoption of 5G in the UK, such as the lack of ubiquitous geographic coverage, coverage on roads and rail, as well as insufficient capacity in urban areas and challenges to designing products with differentiated Quality of Service.

4.1 Investment under uncertainty

4.1.1 Investment theory

Classical investment theory and its limitations

Classical investment theory suggests that companies will invest in all 'projects' where the resulting cash flows have a higher net present value (NPV) than the investments required. Therefore, if expected future revenues over the lifetime of a new technology have higher NPV than the roll out costs (capital expenditure) and the costs of serving the customers (operating expenditure), the MNOs would invest in this new technology. There is a large body of academic literature developing this theory, see for example Jorgenson (1963) and Tobin (1969).

However, implicit in the classical theory are some necessary conditions, which typically do not apply to the mobile sector. More specifically, it is assumed that:

- Either there is no uncertainty involved in future revenues and profits; or
- If there is uncertainty:
  - either the investment is reversible (i.e. it can be recovered if the market conditions turn out to be worse than initially anticipated); or
  - if the investment is irreversible, it is a 'now or never' decision – that is if the firm does not invest now, it will not be able to do so later.

These are clearly conditions which do not apply to the mobile industry in general, in particular with respect to new technologies. More specifically:

- Demand, and hence revenues, from new technology tends to be highly uncertain;

[54] First two entrants, Vodafone and O2, were able to roll out national networks before later entrants and had the benefit of access to lower frequency spectrum (900 MHz)

- Investments in networks are largely ‘sunk’, i.e. the recoverable value of assets is far less than their acquisition cost and so cannot be considered ‘reversible’; and
- There is typically scope to defer investments.

There may be some cases where one or other of these conditions do hold:

- Allocation of spectrum rights are generally a ‘now or never’ investment decision (given that spectrum auctions in a given band take place infrequently); and
- Incremental investment, for example for capacity, in existing networks.

In these two cases, operators can (and do) use classical financial tools such as NPV calculations (or IRR) and ‘pay back’ periods to make investment decisions.

For other sunk assets where demand is uncertain, investment can be delayed or carried out incrementally. By doing so, the mobile operators preserve flexibility. If demand for new services grows rapidly, the operators expand coverage and/or capacity of their networks. If, on the other hand, demand for new services remains low, the operators defer or do not make incremental investments. This approach is best described by a theory of investment under uncertainty developed by A. Dixit and R. Pindyck.

Investment under uncertainty: the real option theory

In the book “Investment under uncertainty”, Dixit and Pindyck argue that

“*a firm with an opportunity to invest is holding an “option” analogous to a financial call option – it has the right but not the obligation to buy an asset at some future time of its choosing*”. [55]

When a company makes an investment, it exercises this option, i.e. it gives up the possibility of waiting for new information that might affect the desirability and timing of this investment. This lost option value is an opportunity cost that should be considered as part of the cost of the investment when it is made. Shareholder value is likely to be enhanced by deferring investments or accelerating investment in the light of new information, such as consumers’ willingness to pay or demand from new customer segments.

This theory has empirical support. For example, Summers (1987)[56] shows that “hurdle rates” required from the investment projects he studied when assessed on an IIR basis (i.e. excluding ‘option value’) tended to be 3-4 times higher than the cost of capital, which is at odds with classical investment theory, but is consistent with the real option theory once the opportunity cost of making an investment now in an uncertain world is included.

The theory of investment under uncertainty appears to better describe mobile operators’ approaches to investment for new technologies, where there is significant demand uncertainty. As such, there is value in making incremental investment decisions on capacity and/or coverage rather than fully rolling out new

[55] A. Dixit and R. Pindyck (1994) “Investment under uncertainty”, Princeton University press, page 6

[56] L. Summers (1987) “Investment incentives and the discounting of depreciation allowances”, in the *Effects of Taxation on Capital Accumulation,* ed. M. Feldstein, Chicago University Press

generation technology as a single program. This is particularly well illustrated by investment in 3G in the UK (which is discussed in detail in a case study in Section 4.1.2 below).

In summary, this case study shows that facing uncertain demand for mobile data, the operators delayed making investments in 3G networks as these investments could be made incrementally. This is in contrast with the operators' approach to buying 3G spectrum - a 'now or never' type of investment, which had to be made regardless of demand uncertainty and for which an NPV approach was appropriate.

Another useful lesson from the 3G case study is that demand for mobile data only took off with the arrival of handsets which made effective use of data networks (smartphones). This shows that the whole eco-system needs to be sufficiently developed for the new services to be taken up by consumers.

This appears to be an important lesson for future mobile technologies, especially for new applications, such as driverless cars or wide area coverage for the Internet of Things, where demand is not yet proven. Given that these applications place unique demands on the infrastructure and require significant investments, mobile operators might wait for demand for these applications to be more predictable and invest incrementally. On the other hand, consumers might be slow adopting driverless cars if there are geographic limitations on where these cars could be used. In Section 5, we look at alternative models that could be used to stimulate investment in this and other 5G applications, depending on the infrastructure requirements specific to each use-case.

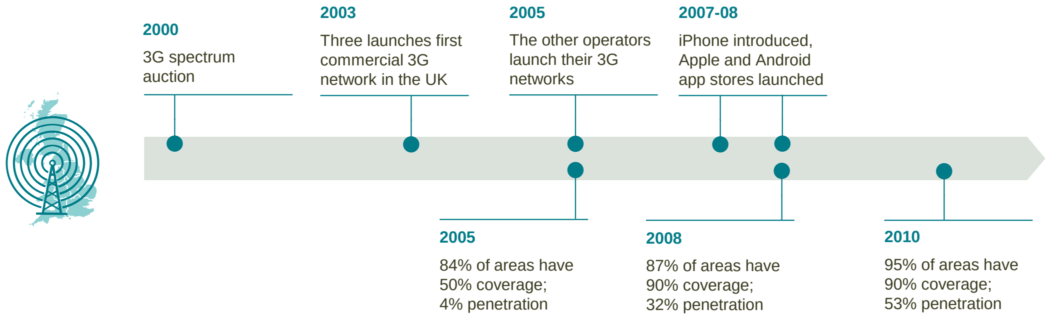
4.1.2 The evolution of 3G in the UK as a case study of investment made under uncertainty

INTRODUCTION OF 3G IN THE UK: KEY POINTS

- Despite paying high prices for 3G spectrum in 2000 (£22.5bn - around four times the media predictions), operators were slow to roll out 3G networks.
- This was driven by a lack of consumer demand, rooted in the scarcity of compelling applications and in the poor choice of 3G handsets at the time.
- 3G roll-out and take up started growing between 2006 and 2008, with improving handsets and the advent of smartphones.
- The slow development of the market illustrates that even after committing billions in a spectrum auction (seen as a "do-or-die" decision), investors can be cautious in committing to further infrastructure development without proven demand.
- The massive investment in 3G after 2006 did not quite pay off in terms of revenues in the following years, suggesting that high immediate profits might not be a necessary condition to drive investment in the sector.

Exhibit 5 provides a timeline highlighting the main events affecting the evolution of 3G in the UK. Below, we discuss this sequence of events in more detail.

Exhibit 5. Timeline of 3G development in the UK



UK's 3G auction

In 2000, the UK held the world's first auction for 3G spectrum. While the first release of the 3G family of standards (IMT-2000) ('release 99') had been standardised, standard compliant equipment and handsets were not widely available at this point. The government auctioned off five spectrum licences in the 2.1GHz spectrum band, with one of these licences being reserved for a new entrant[57].

Initially, media outlets predicted that the licences would sell for a combined sum of up to £5 billion, but the final prices were substantially higher, with the winning bids totalling £22.5 billion.[58] Four licences were acquired by the then-incumbents in the market,[59] and the fifth was acquired by Hutchison-Whampoa - which would later start operating in the UK under the brand name "Three".

Due to the timing of the auction, UK operators were among the first in the world to gain access to 3G spectrum[60]. In most other European auctions, prices (in per capita terms) were substantially lower, except in Germany (see Exhibit 6).

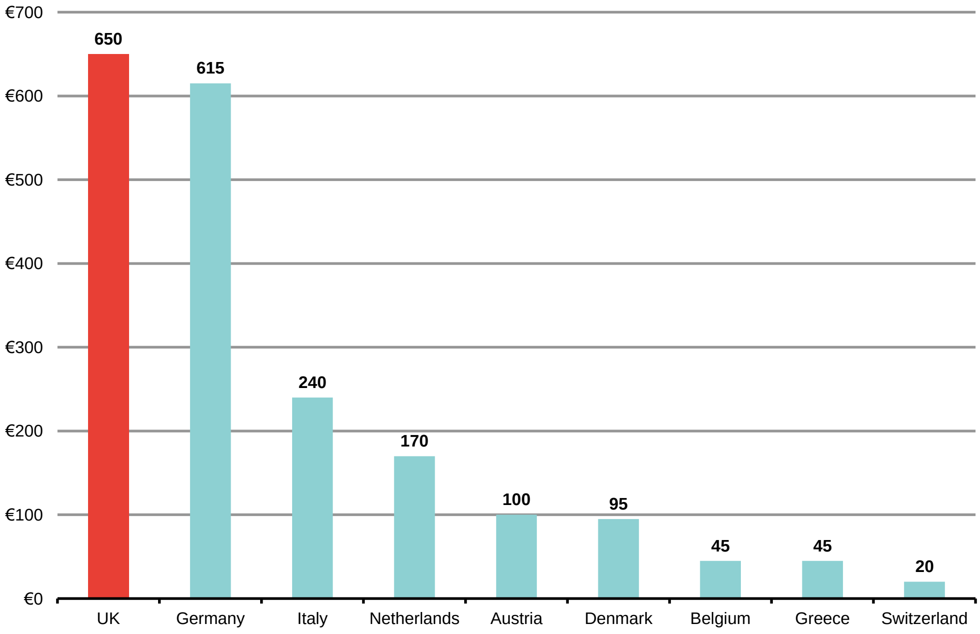
[57] The licences varied slightly in terms of the spectrum available, with the 'new entrant' licence having more spectrum than some of the other licences.

[58] Klemperer, 2002

[59] BT Cellnet, Orange, One2One and Vodafone

[60] Eight other European countries also held 3G spectrum auctions in 2000 and 2001: Austria, Germany, Italy, The Netherlands, Switzerland, Belgium, Denmark and Greece.

Exhibit 6. Revenues from European 3G spectrum auctions in 2000-01 (€ per capita)



Source: Klemperer 2002

The high prices that operators were willing to pay were driven at the time by:

- The auction being the first of its kind in Europe, with bidders potentially seeing this as their first best chance to enter the wider European market (assuming there were economies of scale in having a large 3G 'footprint') and not allowing bidders to learn from previous experience;
- The fact one licence was reserved for a new entrant, attracting a large number of bidders and intensifying competition for the available licences;
- An optimistic view of the business potential of 3G, reflecting the 2000 tech bubble; and
- The size and attractiveness of the UK market meant that it provided a potential foothold for operators seeking to build a pan-European mobile business[61].

After the UK auction, it appears that the lower prices paid in other auctions reflected reduced valuations, with the Nasdaq composite falling from a peak in March 2000, a level not reached again for 15 years. In addition, losing bidders in the UK auction did not generally attempt to bid to enter other markets[62].

It is clear that, at least in the UK and Germany[63], the bidders approached the 3G auction as a 'now or never' opportunity:

[61] See Klemperer, 2002 and Cramton, 2001

[62] In the UK, 13 bidders competed for five licences, but there were no more than seven bidders in any other country in 2000 or 2001. In some of those auctions, there were no competitive bids by new entrants at all, which drove down competition drastically.

[63] In Germany, six operators won 3G licences. However, two operators never rolled out mobile networks and subsequently returned their licences,

- The incumbent operators felt that they needed to bid whatever it takes to defend their existing mobile business; and
- Potential new entrants felt this was their only chance to enter a lucrative market and also gain an option to roll out in further complementary markets.

This behaviour and these assumptions were implicit in the high valuations of spectrum (about the rate at which 3G networks would be rolled out and what 3G revenues would be generated) contrasted with what followed with respect to 3G network roll out, which was slow and incremental, due to the slow take up of 3G services.

Slow initial roll-out

Despite the forecasts of fast roll out reflected in the valuations of spectrum for the new technology, actual roll out was slow and gradual (illustrated by Exhibit 7).

- The first 3G network in the UK was launched by Three in 2003 on a small scale, with a choice of three handsets[64] which were less attractive than 2G handsets, being bulkier and having lower battery life. By 2004, 3G technology had low penetration in all markets (except Japan), and Three only had around 600,000 subscribers in the UK at the time.[65]
- The other operators (Vodafone, Orange, T-Mobile, O2) only rolled out their 3G networks on a small scale in 2004, providing mobile broadband services to businesses using ‘dongles’, and did not provide support for mobile handsets until 2005[66]. At the end of 2005, Three was the largest player in the still-small market - but even Three failed to attract many new 3G customers during the course of 2005. This partially reflected customers’ dissatisfaction with Three’s limited network coverage compared to 2G, but also the limited benefits of 3G services compared to the still considerable disadvantages in terms of handset choice and battery life.

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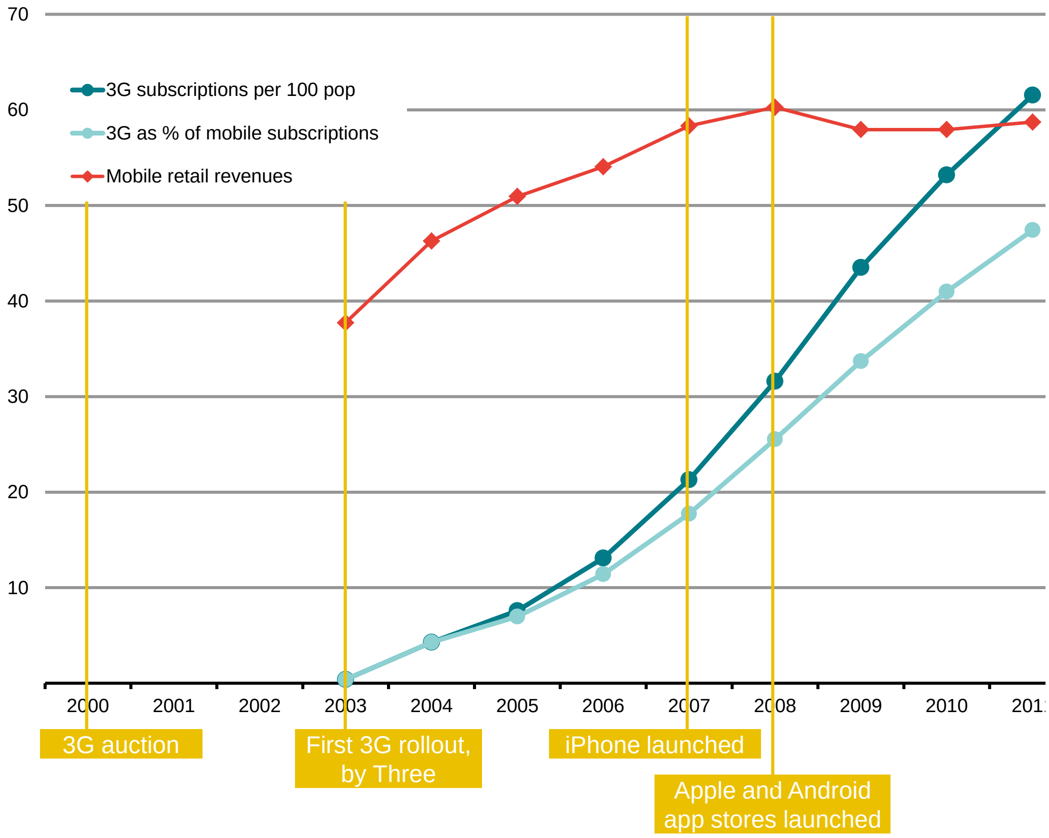
[64] http://www.mobilephonehistory.co.uk/history/3g.php

[65] Ofcom, in 2004 CMR: “3G is still a considerable way off from being regarded as mass market…3G has yet to catch fully the imagination of existing mobile phone subscribers… 3G is more likely to be sold as a high end user experience which consumers will recognise as a utility benefit rather than a specific technology.”

[66] Another reason why the four larger MNOs did not try to accelerate the transition from 2G to 3G was because they did not want to cannibalise their existing 2G revenues. Three, on the other hand, did not have a 2G network, so did not face the same issue.

Exhibit 7. 3G penetration and mobile retail revenue, 2000 to 2011



Source: Frontier analysis based on Ofcom Communications Market Reviews, 2004-12

The slow take-up of 3G at the time can be attributed to:

- Low overall demand for data-enabled mobile services, stemming from a lack of compelling applications and uses for the technology and relatively high prices;
- Poor choice of 3G-enabled handsets, which were generally larger, heavier, more expensive and had a shorter battery life than 2G-only devices; and
- Low levels of coverage, due to operators' slow and cautious roll-out, focusing mostly on existing sites in high-traffic urban areas.

The lack of suitable applications and the poor choice of handsets were outside the control of operators. However, the limited demand and limited coverage of 3G networks were interconnected and reinforced each other, causing somewhat of a vicious circle of low demand and low investment. As seen in Exhibit 7, in 2006 only 11% of mobile subscriptions had 3G network access.

The behaviour of the operators in the 3G auction, where they were willing to invest large sums of money on the 3G spectrum licences, contrasts with their later behaviour in rolling out networks where they did not seek to roll out complete networks in the absence of proven demand and well-developed eco-systems (including 3G handsets) but instead chose to roll out networks incrementally (which is consistent with the theory of investment under uncertainty). We consider this to be an important learning point for the deployment of 5G networks. To the extent that demand for new applications (e.g. driverless cars) is likely to be uncertain, the traditional MNOs might be slow to invest in new networks and wait for demand for these applications to pick up. Regulatory interventions, which would lower the cost of new networks and encourage new business models, are needed to break the cycle of low demand and low investment. These interventions are discussed in Section 5.

Post-2006 market evolution

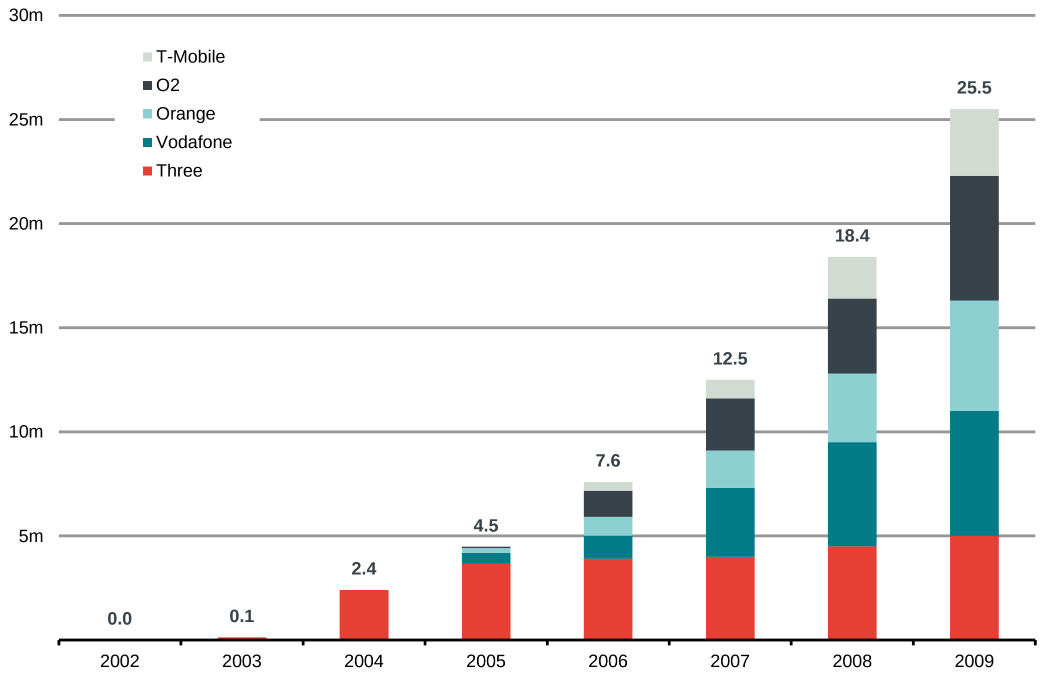
The barriers to take up of 3G services were gradually overcome between 2006 and 2008, and 3G finally began to mature into a substantial, established market.[67] This was driven by several trends:

- **Handsets**: handset and application choice and quality increased substantially, with a variety of cheaper, smaller handsets entering the market, led at the time by Nokia. The vast majority (80%) of handsets sold in 2006 already had some 3G capabilities, although smartphones had limited capabilities at this time. Despite the first iPhone being released in 2007[68] and the Apple and Android app stores launching in 2008, smartphones still remained a relatively small part of the market until the end of the decade. Only 13% of handsets sold in Q4 2008 were smartphones, and that share didn't exceed 25% until early 2010.
- **Roll out**: While operators other then Three (who had no 2G network) had focussed on maintaining their 2G networks which carried most of their traffic in the first half of the decade, from 2006 onwards the other operators joined Three in increasing their 3G network coverage significantly. Faster roll out was aided by a significant decline in equipment costs and standardisation of new technologies which provided significant increases in capability (such as HSPA and HSPA+).

67 Ofcom wrote in the 2009 CMR about the "*maturing*" of the mobile broadband market, which "*emerged as a viable consumer proposition*", although the market was described as still focussing mostly on mobile dongles. In 2012, Ofcom's take on 3G was around levelling off of use of mobile broadband on PCs (after doubling in the two years prior); and around the dramatic rise in mobile data use, "*driven largely by more subscribers choosing to own a smartphone*".

68 A 3G-enabled version appeared in 2008.

Exhibit 8. 3G subscribers by operator, 2002-2009 (m)



Source: Ofcom

- **Coverage**: it is difficult to obtain consistent data on population coverage of 3G, as measuring standards and indicators used by Ofcom changed often over time. However, it is clear that a significant jump in coverage occurred between 2006 and 2008-09. According to Ofcom's data (based on provider reports):
    - In 2006, only 70% of UK postcodes had 3G coverage of 75% by at least one operator.
    - In 2008, 87% of postcodes had 90% coverage by at least one operator, showing that both the number of areas covered (to some extent) and the level of coverage within these areas had increased significantly. This put the UK roughly in line with other OECD countries.[69]

The growth in 3G take-up and in corresponding data use meant that mobile data revenues rose significantly in this time period (though not as quickly as data usage due to price reductions). In the five years between 2005 and 2010, total mobile data revenues rose by 61% (10% annually), but still accounted for less than a third of operators' revenue.[70]

However, when looked at as a whole, total mobile revenues have remained almost flat throughout the increase in 3G penetration and investment, (see Exhibit 7). This suggests that increases in profitability are not a necessary condition to drive investment in the sector (even if operators were forecasting increases in revenues at the time licences were acquired).

[69] See item 3.7 in http://www.oecd.org/internet/broadband/oecdbroadbandportal.htm

[70] Source: 2011 Ofcom CMR, based on Ofcom figures and operator data

Even where revenues do not increase, to the degree that customers value the capabilities generated by investments, operators may find it necessary to make investments in order to attract and retain customers, a dynamic explained further below.

4.2 Oligopolistic competition and its implications for investment

Much of the discussion of technology roll out focusses on an industry perspective, i.e. whether the potential margins from a technology exceed the costs of rolling out the networks. However, investment is not made in a co-ordinated way across the industry, with each operator making decisions on investment depending on the impact of the investment on their business. This can result in all operators choosing to make investments in a new technology, even if industry revenues as a whole do not increase. As example of this is the roll out of 4G, which did not increase overall industry revenues (despite initial attempts to charge a premium for 4G speeds) but which is now being rolled out by all operators.

This section focuses on how operators make investment decisions in a competitive market and the potential implications both for investment in new technologies and in incremental investments in capacity and coverage.

4.2.1 Theory of oligopolistic competition and ‘first mover advantage’

The market for mobile network services in the UK is an example of oligopolistic competition, i.e. there are a small number of players in the market. This reflects the fact that there are significant barriers to entry (in the form of spectrum licences and high costs of network roll out).

The existence of high barriers to entry and large fixed costs means that the operators are not pure ‘price takers’, with no influence over the market price or total output (as would be the case if the market was perfectly competitive). This also implies that individual operators’ decisions affect the market as a whole (e.g. in terms of prices and product choices).

There are different theoretical models of oligopolistic competition, which vary in terms of the assumptions they are based on and their predictions for the market outcomes.[71] One commonly used model of competition in the mobile markets is an oligopolistic model with product differentiation (e.g. differentiated Bertrand model)[72].

The key features of this model are:

- There is product differentiation in the market, i.e. customers make their choices based on a combination of price and other product characteristics (e.g. coverage, speed, availability of specific handsets, quality of customer

[71] Cournot, Bertrand and Stackleberg models to name a few [include references].

[72] For example this ’differentiated Bertrand’ assumption has been used by the EC when assessing the impact of mergers in mobile markets.

service, brand, etc.). Different customers might have different preferences (e.g. some prefer inexpensive plans with large data bundles; while others might care mostly about coverage and customer service).

- Operators invest in different aspects of quality (coverage, new technologies, brand) and compete for different customer groups.

This model has been used by the European Commission in its assessment of several recent telecoms mergers, as it is considered to adequately capture the salient features of the telecommunication markets[73].

The implication of this model is that it is in the operators' interest to make their products sufficiently different to appeal to different groups of consumers and hence preserve a degree of market power (even if there are several competitors in the market)[74]. If certain groups of customers attached a higher value to some qualities while others are willing to trade off this aspect of quality for a lower price, for example a lower level of coverage for a lower subscription charge, then operators can seek to differentiate by some offering higher levels of coverage at higher prices, with others offering lower coverage and lower prices. However, if there are certain dimensions of quality that are valued by most groups of customers, then all operators may choose to invest in these areas.

This explains why 'first mover advantage' is considered to be so valuable in oligopolistic markets, especially if the benefits can be sustained for a period of time, either through maintaining the objective advantage or due to the reputational effect of enhancing the brand. It allows the leader to distinguish itself from the rest of the competition, to gain market share and/or charge a price premium for the new product or service. Assuming that the new capability proves to be popular across a wide range of customers, the other competitors will aim to close the gap as soon as possible. This can then result in investments being made across the industry which, overall do not necessarily increase free cash flow (i.e. producer surplus) but may increase economic welfare (i.e. a significant consumer surplus).

Investing in order to achieve a 'first mover advantage' is generally a now or never decision, meaning that it cannot be deferred and investments may be made even if demand is uncertain.

This dynamic is illustrated by the introduction of 4G in the UK and this is discussed in the 4G case study below. In summary, due to the auction of spectrum suitable for 4G taking place relatively late in the UK, EE applied and was granted permission by Ofcom to launch 4G services using its existing 1800MHz spectrum which had been previously allocated for the use of 2G services[75]. Given the likelihood of demand for 4G services from consumers and the availability of 4G handsets which used this band, EE rapidly rolled out a 4G

[73] See, for example, http://www.competitioneconomics.org/dyn/files/basic_items/566-file/Motta-Mobile%20mergers%20What%20have%20we%20learned%20[Compatibility%20Mode].pdf

[74] In an extreme (somewhat theoretical) case, if the products are very similar, competition becomes primarily about prices (as all other product aspect of quality are the same), driving prices down to marginal costs and preventing operators from recovering their fixed costs.

[75] While O2 and Vodafone also had 1800MHz spectrum, they did not have sufficient spectrum to launch a viable 4G network at the same time as supporting their 2G user base. Three gained access to 1800MHz spectrum divested by EE as part of the remedies for the Orange/T-Mobile merger but did not gain access to this spectrum until later.

network in order to differentiate itself. The remaining three operators who had later access to sufficient spectrum to launch 4G services have subsequently made significant efforts to close the coverage gap. Despite being late to auction spectrum for 4G, the UK is now ahead of a number of other Western economies in terms of 4G service availability.

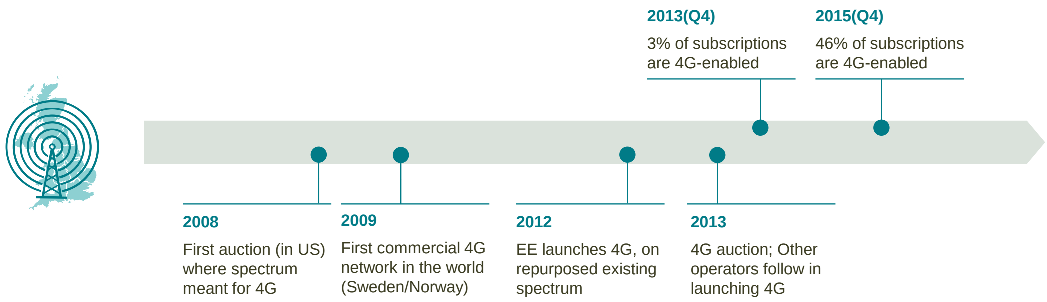
4.2.2 The evolution of 4G in the UK as a case study of the impact of competition on investment

SUMMARY OF THE KEY POINTS

- The UK was somewhat late to begin 4G/LTE rollout compared to the rest of Europe. This was mostly due to delays in the 4G spectrum auction stemming from operators' threatening litigation around the auction's conditions.
- A number of measures were taken in the 4G auction to preserve and strengthen competition in the mobile market (e.g. spectrum caps and spectrum reservations).
- Once the UK started rolling out 4G, customer take-up and operator roll-out were quick to pick up, with penetration of 4G handsets reaching 46% of all mobile subscriptions in 2016 (compared to an average of 32% in Western Europe as a whole).
- EE had a 10-month 'first mover advantage' in terms of 4G roll out, with the other operators making efforts catch up.

Exhibit 9 provides the timeline of the main events (discussed in detail below).

Exhibit 9. Timeline of 4G development in the UK



The UK was several years behind other developed markets in launching 4G[76]

Soon after 3G was being rolled out around the world, engineers began to develop the next generation of mobile communication to address some of the shortcomings in 3G technology, in particular the legacy of circuit switched technology which had largely been replaced by packet switching, relatively high latency and the poor performance of 3G networks at the edge of cells. Grouped under the umbrella term "4G", this most commonly refers to the LTE (Long-Term

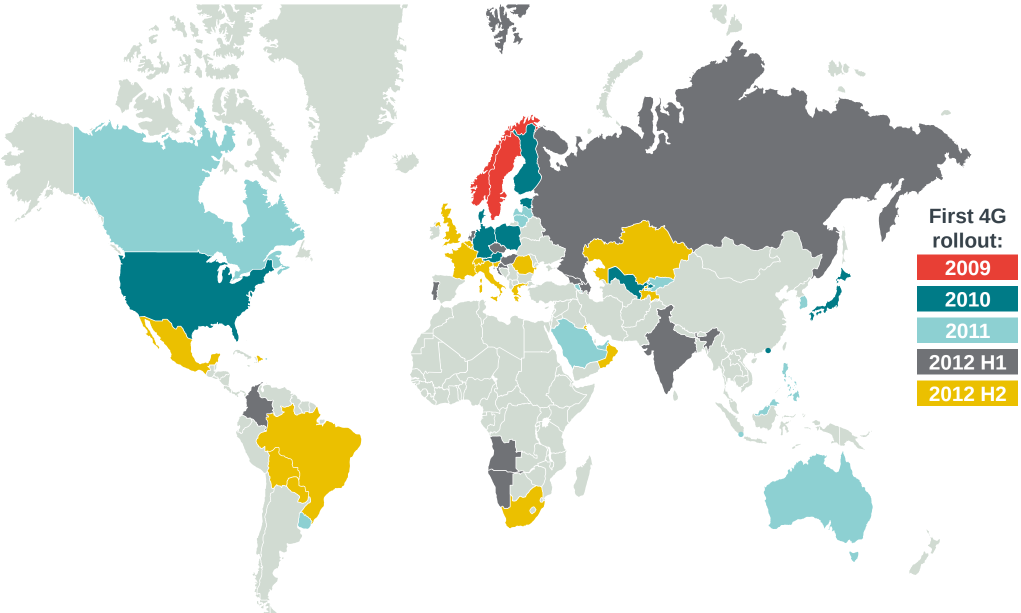
[76] This subsection is based on data from GlobalComms.

Evolution) family of standards, allowing for much higher data speeds and improved functionality such as high-definition video and carrying voice over the data network.

As demand for higher speeds and better mobile connectivity grew, 4G started to be introduced in the most advanced markers.

The first commercial network was launched in 2009 in Stockholm and Oslo, and in 2010, further networks were rolled out elsewhere in Europe, as well as in other countries like the US, Hong Kong and Japan (see Exhibit 10 below).

Exhibit 10. Map of worldwide 4G rollout up to and including the UK

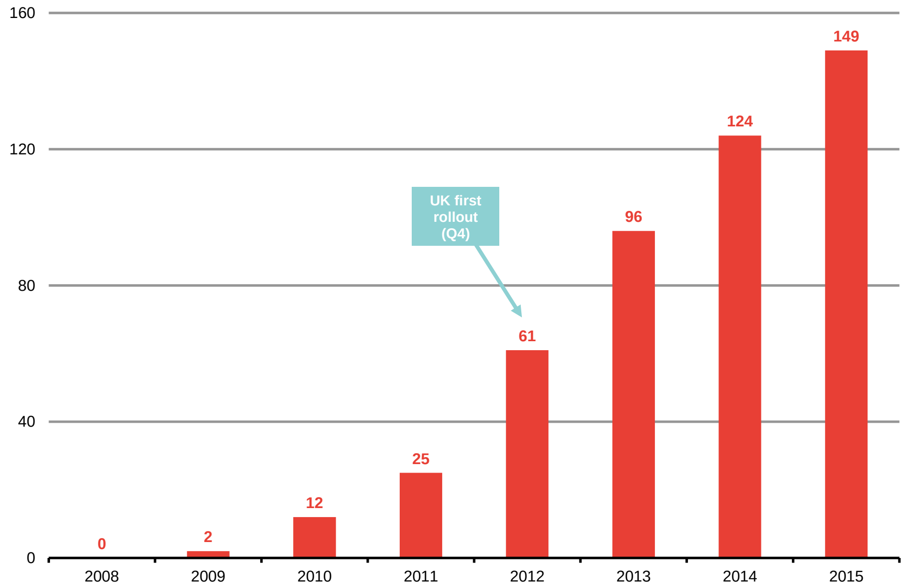


Source: Frontier analysis of TeleGeography data

- Roll out and take up accelerated after 2011, with the number of countries with 4G networks more than doubling in 12 months.
- By the end of 2012, when the first 4G network was launched in the UK by EE, 61 countries already had at least one LTE provider (see Exhibit 11).[77]

[77] At the end of the previous quarter, before UK introduction, the count of countries was 44. So the UK was somewhere between 45th and 61st to introduce 4G.

Exhibit 11. Number of countries with at least one 4G provider



Source: Frontier analysis of TeleGeography data

What caused the delay?

Ofcom started considering issues of Digital Dividend (spectrum used for analogue television broadcasting, which was about to be released after digital switchover) in 2003, with a statement published in 2007.[78] In 2009, Ofcom appointed an independent spectrum broker to start developing the transition to 4G. The broker recommended that the new 800MHz spectrum band was auctioned together with 2.6GHz spectrum to allow for a comprehensive allocation process, and also proposed setting limitations on the ability of existing providers to buy spectrum.[79] These limitations were disputed by the MNOs, and the ensuing consultation, together with the 2010 UK election, caused a delay in the spectrum auction.[80]

After the auction was delayed to 2013, a new concern arose – EE's possible first mover advantage. Unlike other operators, EE already had access to a sufficient quantity of 1800MHz spectrum, which had been standardised internationally for

[78] http://stakeholders.ofcom.org.uk/consultations/ddr/statement/

[79] Low-frequency and high-frequency spectrum are complementary: the low bands, like 800MHz or 900MHz, are used for coverage and the high bands, like 1800MHz or 2600MHz, for capacity. The proposal was to limit the ability of operators who have access to a specific type of spectrum (low/high frequency) to buy additional spectrum of a similar type, in effect placing restrictions on almost all of the players in the market. See http://webarchive.nationalarchives.gov.uk/; http:/www.culture.gov.uk/images/publications/ISB_final_report.pdf

[80] See http://stakeholders.ofcom.org.uk/consultations/800mhz/, http://www.gsma.com/spectrum/wp-content/uploads/2012/07/700MHz-800MHz-band-UK.pdf, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/238653/7548.pdf

4G[81]. EE could potentially repurpose it for 4G before the auction and gain a significant head start in the market.

However, it required an approval of 1800MHz 'liberalisation' (lifting the requirement that 1800MHz can only be used for 2G) by Ofcom. After a consultation, Ofcom decided to grant this approval in October 2012.[82] Therefore, EE's 4G first mover advantage was limited to 10 months: it launched its 4G network by the end of October 2012, while Vodafone and O2 followed in August 2013, and Three launched its own 4G offer in December 2013[83]).

The UK 4G auction

As a result of these consultations and the desire to ensure that the auction is well-designed, the 4G auction in the UK was delayed until February 2013. Spectrum was won by the four MNOs as well as by BT. By that time, 4G network were roll out in most countries in Western Europe[84] and 4G coverage in Germany reached 75%.[85]

The auction had several mechanisms to preserve and strengthen competition incorporated in it:

- Some spectrum was reserved for a 4th national operator – Ofcom made it clear that it was important to preserve competition in the UK mobile market and that having four independent national mobile network operators was key;
- Caps on total and low frequency spectrum holdings – Ofcom also introduced caps for low frequency (800MHz) and total spectrum holdings, which took into account the operators' existing spectrum[86];
- Low-power concurrent licences – an additional unusual feature of the UK 4G auction was to allow low-power users to bid alongside high power users (i.e. MNOs), with bids from low-power users being aggregated and compared against the individual MNO bids. This, at least in theory, could allow alternative uses to emerge, i.e. some spectrum could be allocated to provide in-building coverage on a regional basis. Being low power, these potential users could share the spectrum without causing interference. While there were a few bidders bidding for low-power licences in the auction, they collectively failed to outbid high-power users (MNOs). The UK 4G auction can be seen as an attempt to take a less prescriptive approach to spectrum allocation, allowing the market to identify the most valuable spectrum uses.

[81] Finland allowed 1800MHz spectrum to be used for 4G as early as 2009. The first commercial deployments of 4G over similar spectrum was in 2010 in Poland, followed closely by Hong Kong, Singapore and Denmark (see http://gsacom.com/wp-content/uploads/2015/10/151013-Evolution_to_LTE_report.pdf, https://www.gsmaintelligence.com/research/2010/10/hong-kong-and-singapore-lead-lte-charge-in-asia-pacific/228/, https://www.telegeography.com/products/commsupdate/articles/2010/09/08/duo-launch-lte-network/). By 2014, 1800MHz was the most commonly used band for 4G worldwide (GSA 2015).

[82] See http://stakeholders.ofcom.org.uk/consultations/variation-1800mhz-lte-wimax/statement

[83] TeleGeography

[84] See Exhibit 10

[85] http://www.zdnet.com/article/4g-in-europe-how-far-how-fast-and-how-much-is-lte-in-germany/

[86] The low frequency cap was binding for Vodafone and O2, i.e. these two operators could only buy 2x10MHz of 800MHz spectrum. The total cap was binding for EE (which could only acquire 2x40MHz of additional spectrum).

In addition to these competition measures, one 4G licence (won by O2) had a coverage obligation attached to it, which required the licence holder to deliver mobile broadband service for indoor reception to at least 98% of the UK population (expected to cover at least 99% when outdoors) and at least 95% of the population of each of the UK nations – England, Northern Ireland, Scotland and Wales - by the end of 2017[87]. It appears that this coverage target was not overly ambitious, as O2 announced its intent to meet the target two years earlier than required.[88] Other countries (e.g. Germany and Sweden) took a stricter approach to similar coverage obligations, requiring roll out to rural areas first or meeting speed targets in specified areas with poor coverage ("not spots")[89] However, there is likely to be a trade-off between stricter coverage obligations and the general speed of roll out of new technologies. While the specified rural areas in Germany have seen coverage with 4G, the overall 4G coverage level in Germany is lower than in the UK. (See Section 5.3 and Annex A for more details).

Post-auction roll-out

Since acquiring 4G spectrum, the MNOs have rapidly deployed 4G networks, in most cases combining roll out with a network refresh as EE consolidated the separate networks of Orange and T-Mobile and Vodafone and O2 implements project Beacon. This introduced new technology such as 'single RAN' and fibre backhaul to deliver increased capabilities at lower cost. While 4G coverage is still lower than 2G/3G coverage reflecting resource constraints which prevent the whole network being refreshed quickly, for example the availability of engineering staff to visit each site to upgrade it,[90] it has been growing steadily across the UK, with EE holding on to its first mover advantage (see Exhibit 12). Despite exact population coverage figures being somewhat elusive, Ofcom has estimated that by May 2016, nearly 98% of UK premises were in areas with outdoor 4G coverage, with over 70% having outdoor coverage from all four operators.[91]

87 http://media.ofcom.org.uk/news/2013/winners-of-the-4g-mobile-auction/

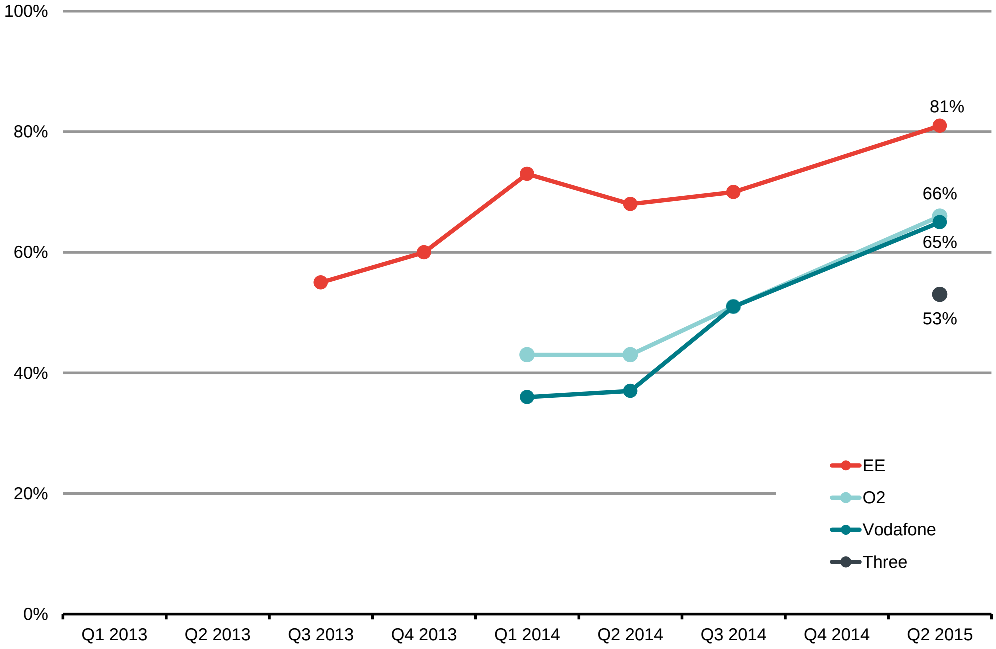
88 Ofcom (2014), "4G radio spectrum auction: lessons learned". Available at: http://www.nao.org.uk/wp-content/uploads/2015/03/4G-radio-spectrum-auction-lessons-learned.pdf

89 See more details on coverage obligations in Germany and Sweden in Section 5.3.

90 Stats on coverage by technology are available at http://researchbriefings.files.parliament.uk/documents/SN07069/SN07069.pdf

91 See Ofcom Communications Market Review 2016

Exhibit 12. Estimated 4G premises coverage by operator



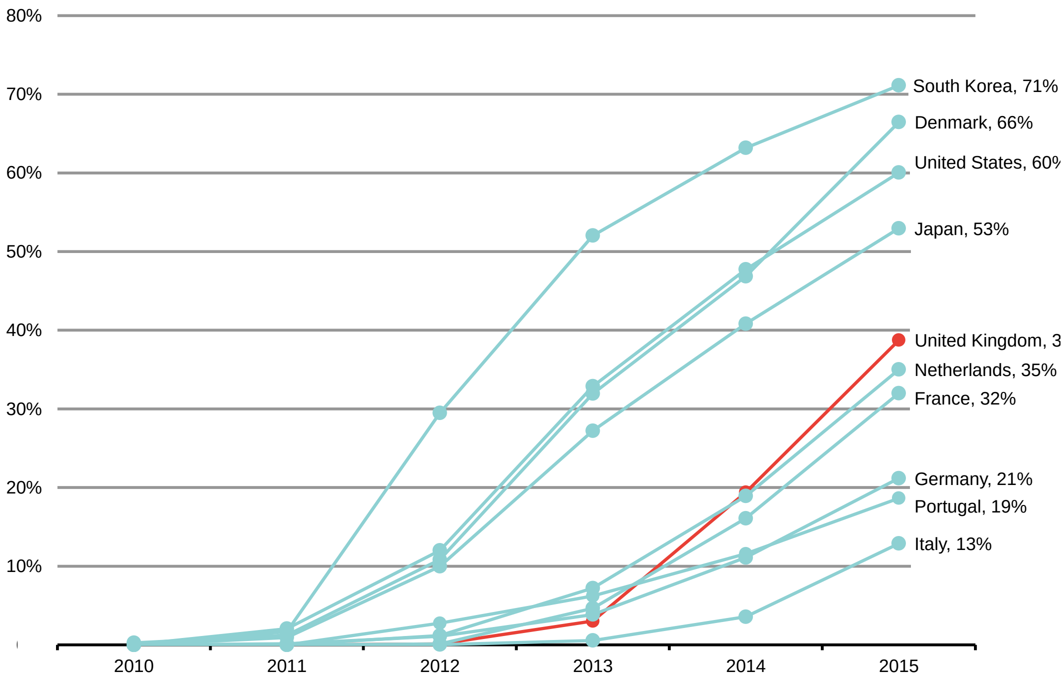
Source: Ofcom, EE press releases

Note: Three data not available prior to Q2 2015

Despite the UK starting to roll out 4G relatively late, take up was fast and quickly overtook earlier adopters such as Germany, France, Portugal and the Netherlands (see Exhibit 13). This appears to have been driven by relatively higher demand for mobile data and for smartphones.[92]

[92] In a 2013 Ofcom survey (see 2013 CMR), speed was stated by customers as the top reason for wanting to switch to 4G, while cost was mentioned as the biggest reason to postpone such a switch. This was corroborated in later surveys - for instance Ofcom CMR 2015, where it was reported that people switching from 3G to 4G were mostly satisfied with speed and mostly dissatisfied with the cost of service.

Exhibit 13. 4G as share of all mobile subscriptions, selected countries



Source: TeleGeography

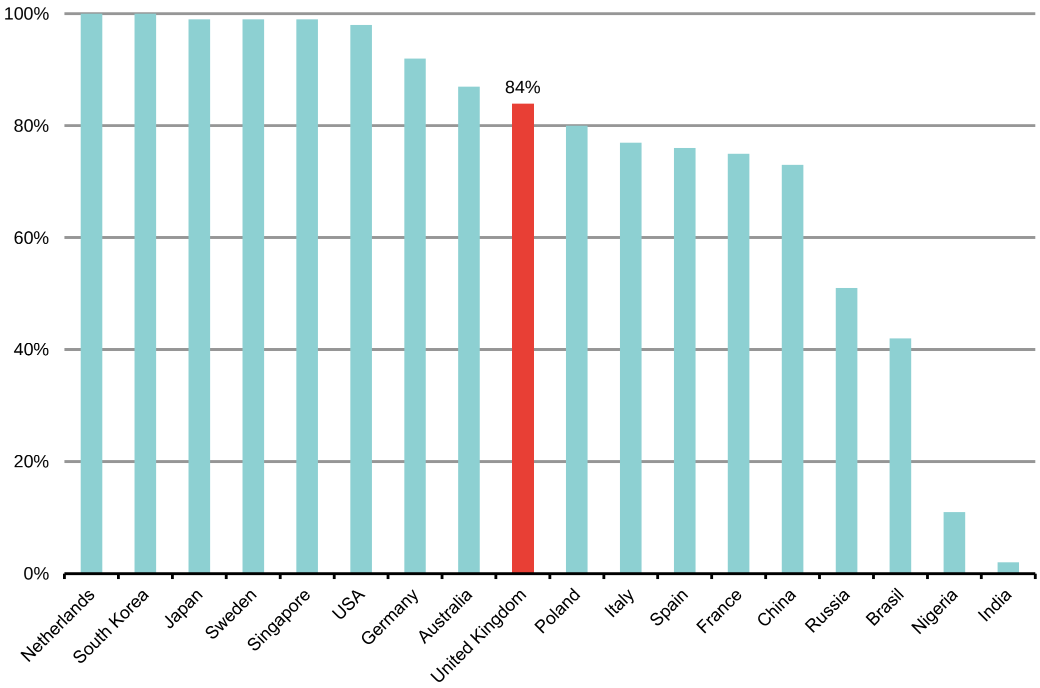
Coverage in the UK has also seemed to improve when compared internationally. According to Ofcom, in 2014 the UK was in the middle of a set of comparator countries (see Exhibit 13). This, however, is not entirely consistent with other international coverage comparisons. For example, according to OpenSignal, the UK was 50th out of 69 countries in terms of 4G coverage[93]. While OpenSignal's approach is likely to have its limitations, this apparent discrepancy between Ofcom and OpenSignal's rankings highlights difficulties in agreeing on one universally accepted definition of coverage.[94]

A comparison of a range of outcomes (price, coverage, speed, etc,) in the UK and several comparator countries (France, Germany, US and Japan) are presented in Annex A.

93 http://opensignal.com/reports/2016/02/state-of-lte-q4-2015/

94 OpenSignal, a telecoms analytics company, estimated the UK as of September 2015 to be 54th out of 69 countries in terms of 4G "time coverage" (percentage of time users get a 4G signal) and 36th out of 69 countries in terms of average 4G speed (see *State of LTE September 2015*). Their methodology has its flaws (not least of which the small sample sizes in some countries), but it does place a question mark on Ofcom's claim of high population coverage in the UK.

Exhibit 14. 4G network availability in 2014 (measured as % of population coverage of at least one operator)



Source: Ofcom International Communications Market Review, 2015

4.3 Challenges to future mobile investment in the UK

As noted in the introduction, future mobile investment can support new use cases either by increasing investment in:

- Existing 4G technologies and their evolution to meet demand which is not currently served; and
- Those technologies which are likely to be introduced as 5G technologies.

In the first case, the MNOs are likely to continue to play a key role given their control over the radio access networks and the spectrum that has been assigned to date.

In the second case, there may be more scope for new entry if there are limited economies of scope between 5G technologies and the MNOs' existing businesses.

Moreover, some potential new applications might have very specific requirements, which may or may not be satisfied by the existing networks and infrastructure. For example, automotive applications would require uninterrupted coverage along motorways, which currently is not provided. Below, we consider potential challenges to investment in future mobile networks, which can be broadly separated into:

1. Delivering coverage (geographic, roads, rail) – in particular, we would consider whether the market is likely to deliver expected levels of coverage or whether there are strong grounds for government/regulators to intervene;
2. Delivering increased capacity in densely populated areas - some applications would require significant increases in capacity in densely populated urban areas, which can only be delivered with a wide-spread deployment of small cells and potentially the use of higher frequency spectrum. This is likely to present unique regulatory challenges with respect to planning. While the operators might have strong incentives to invest in additional capacity, it is not clear that the existing planning regulations correctly balance the costs and benefits of widespread deployment of small cells; and
3. Using network virtualisation to deliver differentiated Quality of Service - it is expected that 5G applications would vary greatly in terms of the requirements they would place on the networks (some would require high bandwidth and low latency, others low latency, but ubiquitous coverage and so on). It is envisaged that these applications would be served by different 'network slices', which would satisfy the requirements specific to these applications. While such arrangements may be delivered effectively by competition, virtualisation may lead to regulatory challenges and the need to update regulations designed for legacy networks. For example, existing net neutrality rules may not be appropriate.

We discuss these challenges in turn below.

4.3.1 Challenges to achieving universal mobile coverage

As mobile communications become increasingly embedded in everyday life, there is an implicit expectation of ubiquitous coverage, which current networks do not meet.

"100% reliability and availability" and "ubiquitous coverage" are considered to be among the main requirements of '5G' and of mobile networks in general. These features are especially critical for some applications, such as Health. A recent business survey by CBI shows that 80% of businesses consider reliability and geographic availability of mobile services to be crucial for their business[95].

While competition, in principle, drives investment in coverage and in other aspects of quality, this has not led to universal coverage, i.e. there remain some areas where the benefits to an operator from investment in marginal sites appear to be less than investment costs. The benefits of an incremental site will come from two sources:

- The incremental revenues generated from traffic on this site; and
- The impact of enhanced coverage on the ability to acquire and retain customers more generally (i.e. by differentiation).

In areas with few people, the incremental revenues are likely to be very low as there are fewer people to make calls or use data (particularly as a proportion of potential calls or data usage outside coverage areas may simply be deferred until

[95] http://www.cbi.org.uk/news/speed-up-pace-of-infrastructure-action-say-two-thirds-of-businesses-cbi-aecom/2015-cbi-aecom-infrastructure-survey/,

the subscriber is in a coverage area). Even so, it may be commercially viable to cover these areas if doing so would enhance the operator's brand and it would be able to acquire more customers in aggregate. This second factor leads operators to invest in marginal sites which do not appear to generate sufficient traffic, to cover the costs of investing in and operating the site.

However, it appears that there is not a sufficient number of customers in very rural areas to justify ubiquitous coverage. More surprisingly, operators do not appear to have sufficient commercial incentives to ensure good coverage even in some built up areas[96].

In this case, private benefits (expressed in terms of customers' willingness to pay or the value they assign to ubiquitous coverage) may not reflect full social benefits from ensuring universal coverage (e.g. bridging a 'digital divide' between urban and rural areas)., making government's case for intervention stronger.

That was recognised by Ofcom and coverage obligations were imposed both on the 3G licences and on one 4G licence. In its statement on "Assessment of future mobile competition and award of 800MHz and 2.6GHz", Ofcom stated:

"O*ur proposals to promote competition were likely to drive wide availability but felt that they should be underpinned by a minimum coverage obligation to ensure that a future mobile broadband service would be provided to a significant proportion of citizens and consumers on a reasonable timescale*".[97]

The text box below provides more details on the use of coverage obligations in the UK.

[96] Geographic differentiation in prices could, in theory, address some of the coverage gaps, with customers in high-cost areas paying a higher price for mobile services. This, however, would be contrary to how the market has developed so far. National pricing is preferred for its simplicity. Moreover, charging consumers different prices based on their geographic locations is likely to be very unpopular.

[97] Ofcom, Auction Statement, p.5, https://www.ofcom.org.uk/__data/assets/pdf_file/0031/46489/statement.pdf

COVERAGE OBLIGATIONS IN THE UK

Coverage obligations are a major part of telecoms regulation and are imposed by governments in many countries. However, measuring coverage and monitoring compliance can prove difficult and approaches vary.[98]

The 3G auction in 2000 imposed an 80% coverage obligation by the end of 2007, which was met by four of the five operators at the time. O2 failed to meet the target by nearly five percentage points, and Ofcom threatened to shorten O2's licence as a result. After a few months of increased investment, O2 improved the coverage to meet the obligation by June 2008, and Ofcom confirmed that at the end of 2008, all operators have met the 80% threshold.[99]

The coverage obligation was later raised to 90% in 2011, and Ofcom announced that the new obligation was met in June 2013 by all operators except Vodafone, which reached it six months later.[100] The two cases in which an operator failed to reach the threshold (but was forced to do so quickly afterwards) imply that coverage obligations have indeed been an effective policy tool. This is reinforced by Ofcom's view that the original obligations could have been higher to begin with and it would have benefitted consumers.

The 4G auction obligations were set at a higher level to reflect this lesson (98% population coverage), but it was imposed on one licensee only.[101] It was expected that the other operators would feel commercial pressures to match the coverage levels delivered by the operator with the coverage obligation.

While at the time of the 4G auction the coverage obligation appeared to be stretching, there was a continuing concern that the coverage levels delivered by the MNOs fell short of consumers' expectations, especially in relation to geographic coverage (although networks had not at this point fully rolled out their 4G networks). This led to an agreement between Government and the operators to raise geographic coverage to 90% by area (which implies a much greater coverage by population) by 2017. It is unclear whether the combination of this agreement and the full roll out of 4G networks will be sufficient to meet consumers' expectations with respect to coverage.

In addition to imposing a coverage obligation on one 4G licence (effectively an indirect subsidy), the government also provided a direct subsidy (£150m) for delivering mobile coverage in remote rural areas through the Mobile Infrastructure Project (MIP). The effectiveness of the MIP is discussed in detail in Section 5 below.

The UK government also proposed enforcing national roaming as a potential solution to partial not-spots, i.e. in areas where some but not all mobile networks provide coverage[102]. The idea behind national roaming is that when a customer

98 For an overview, see Díaz-Pinés, A. (2009), "Indicators of Broadband Coverage", OECD Digital Economy Papers, No. 165

99 See http://uk.practicallaw.com/7-380-8246, http://uk.practicallaw.com/0-381-4175, http://licensing.ofcom.org.uk/binaries/spectrum/mobile-wireless-broadband/cellular/coverage_maps.pdf

100 See http://media.ofcom.org.uk/news/2013/3g-coverage-compliance/

101 http://www.bbc.co.uk/news/technology-24367672

finds that they are in an area not covered by their mobile provider (e.g. Vodafone) but covered by another operator (e.g. EE), their phone would automatically connect to EE's network.

This proposal was rejected by the MNOs due to:

- technical difficulties in its implementation – MNOs argued that roaming between different networks would result in more dropped calls, that transition would not be seamless and that overall customers would have a poorer experience.
- undermining incentives to invest – arguments were also made that such a solution, if mandated by the government, would undermine the operators' incentives to invest, as they would not be able to use coverage to differentiate their service from that of a competitor, leading to 'free riding'.

To illustrate the latter point, let us assume that there are two operators (A and B). A currently covers 80% of country, B covers 60% of the country, and together they cover 95% of the country. This suggests that there are partial not-spots: 15% of the population are covered only by operator B, while 30% of the population are covered only by operator A. The operator A has invested more in coverage and expects that it would enhance its brand and increase its market share.

A national roaming deal, if imposed on these two operators, would ensure that both operators could achieve 95% population coverage, by having access to each other's networks. However, in that case, customers would not know that operator A has invested more in coverage and its efforts would not be rewarded. Indeed, from the customer's perspective, coverage provided by both operators is indistinguishable. Therefore, the operators' incentives to invest and expand coverage unilaterally would be significantly reduced. They would rely on each other to provide coverage (i.e. they will free-ride). National roaming would be particularly detrimental for incentives to invest if it applies to all technologies (not just legacy technologies, e.g. 2G voice), as it would reduce the operators' incentives to upgrade their sites to new technologies.

Rather than implementing national roaming, the operators agreed to increase geographic coverage to 90% by 2017. Operators should have both the incentive and the ability to significantly increase coverage over this timescale due to a combination of: the availability to all operators of low frequency spectrum (800 MHz) suitable to provide coverage for both data and voice (using voice over LTE); O2 and Vodafone completing their joint Project Beacon roll out; O2 aiming to meet the coverage target attached to their 800 MHz spectrum licence; and the additional infrastructure being roll out by EE for the ESN becoming available.

Even if the 2017 target is met, it is likely that there will continue to be some 'not spots' in geographic coverage in areas of very low population density.

An additional problem is seamless coverage indoors – while Wi-Fi networks increasingly provide indoor coverage where signals from mobile networks cannot easily penetrate, these networks do not necessarily provide seamless coverage, for example 'hand over' of calls from Wi-Fi to mobile networks and vice versa.

5G technologies may provide the additional capabilities ability to enable such seamless handover.

Inadequate geographic coverage might prevent a number of future applications from developing, such as e-health and various IoT applications requiring ubiquitous geographic coverage.

Coverage on rail

The government identified coverage along railway lines as an issue in February 2015[103], with both voice and data coverage along rail lines being incomplete.

This can be partly attributed to technical challenges:

- Passenger trains contain very high numbers of people concentrated in a small areas moving potentially at very high speeds between stations and in close proximity to other trains when stationary at stations;
- Intercity routes may travel through areas of low population density and through areas where there is limited infrastructure (such as power, fixed networks and access roads) to support networks;
- Around 40% of rail tracks are in cuttings, i.e. tracks below the general ground level.[104] The signal emitted by base-stations set up to provide wide coverage to the area (rather than rail-specific coverage) may therefore be blocked as the track is in a signal shadow. Infrastructure specifically targeted at linear track-coverage may need to be built to ensure continuous coverage. This would include base-stations, access-equipment, as well as backhaul.
- Furthermore, the metal body of train carriages weakens the signal being transmitted into the carriage (it acts as a ‘Faraday cage’). This means the challenge is similar to achieving indoor coverage in steel framed buildings.

These characteristics mean that current mobile networks, even with near-ubiquitous geographic coverage are unlikely to provide sufficient coverage and capacity to deliver a good quality of service to passengers on trains on a commercial basis.

Some of these issues could be addressed by lowering the cost of covering rail networks. One obvious approach would be to leverage the rail infrastructure such as power, fibre transmission and overhead infrastructure to support mobile networks. However, MNOs are not allowed by Network Rail to install their base stations on Network Rail land adjacent to the tracks due to safety risks associated with giving access to non-Network Rail staff.

Even if MNOs were able to provide good coverage of rail tracks, their ability to provide sufficient data capacity within train carriages would be limited due to limited signal strength. This means that the efficient provision of adequate data capacity requires two components:

- A mobile service providing a high capacity link from the network to the moving train (i.e. backhaul); and

[103] https://www.gov.uk/government/news/free-wi-fi-to-help-rail-commuters-stay-connected

[104] http://stakeholders.ofcom.org.uk/binaries/research/telecoms-research/not-spots/rail-not-spots.pdf

- A service to distribute this capacity to users within carriages, either using Wi-Fi or mobile technology (femtocells).

A further complication is the number of stakeholders required to provide such a service. The textbox below describe the main stakeholders involved in the provision of rail coverage.

KEY STAKEHOLDERS IN THE PROVISION OF RAIL COVERAGE

There are four types of stakeholders whose participation can aid consistent mobile coverage and capacity in trains:

- **Network Rail** - Network Rail Telecoms (NRT) owns and manages Network Rail's telecommunications assets. These assets include:
  - Base-stations and mobile devices necessary for GSM-R radio, which is the communications standard used between trains and the control centres. We understand that these base-stations are used exclusively for GSM-R, and MNOs' towers and masts cannot be located in close proximity to them.[105] This imposes a constraint on the sites MNOs can access.
  - A fibre network that runs alongside its tracks. The fibre network (FTNx) has recently been upgraded and is used to provide high bandwidth services to Network Rail, including voice, broadband, video and data. An example of FTNx's use is CCTV. NRT received Electronics Communications Code powers in 2014, enabling it to expand its fibre network outside its existing land and infrastructure. NRT had said in its application that it would use its fibre network to improve mobile connectivity along the rail corridor.[106] It has also suggested that it would provide wholesale access to the spare capacity on its network, but these plans have not yet materialised.
- **Rolling-stock companies** - These companies own the rolling-stock which is leased by the Train Operating Companies (TOCs). They would be responsible for installing the equipment necessary to receive mobile signals and transmit them within the carriages.
- **Train Operating Companies (TOCs)** - For mobile coverage to be provided in trains, TOCs would need to ensure that their trains are fitted with the necessary equipment (repeaters, femtocells, picocells, etc.) and therefore order such trains from the Rolling Stock Companies. Some TOCs[107] have started requiring such equipment to be installed on their trains. However, for this equipment to work, access to mobile backhaul is needed.
- **MNOs** would deploy masts and sites in the vicinity of rail tracks to transmit mobile signals into the trains. Network Rail does not allow MNOs to place sites close to rail tracks for personnel safety reasons. This makes the provision of mobile coverage on rail challenging.

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[105] ibid

[106] http://stakeholders.ofcom.org.uk/binaries/consultations/network-rail-infastructure/summary/Network_Rail_Infastructure_Limited.pdf

To deliver coverage and capacity efficiently requires the commercial incentives of all four parties to be aligned.

These incentives have recently being changed by government requirements for TOCs to provide Wi-Fi on the trains as part of their Franchise Agreements. Furthermore, the Department for Transport set aside £50 million to fund the provision of Wi-Fi by 2017 for TOCs whose franchise agreements are not up for imminent renewal.[108] This has led to TOCs signing agreements with MNOs to provide the backhaul services required to offer Wi-Fi on trains. For example, EE and Chiltern have formed a partnership where EE will add network capacity and coverage through a wireless trackside network.[109]

While new Franchise Agreements provide incentives for implementing Wi-Fi, the implicit subsidy required may be higher than necessary due to the elevated costs for MNOs of providing coverage, as Network Rail' has little incentive to facilitate rolling out mobile networks along rail tracks. Facilitating mobile coverage using existing rail infrastructure could reduce the overall cost to the government of delivering Wi-Fi access on trains.

In Section 5 below, we discuss how the existing incentives could be altered to improve the outcome.

Coverage on the road network

The challenges to providing coverage on the road network are similar to that of providing coverage on the rail network: roads can contain high concentrations of users; roads may be in cuttings or tunnels and cars themselves may attenuate the signals.

Inadequate coverage along roads might prevent certain future use cases (e.g. infotainment) Ofcom estimates that in 2015, 17% of A and B roads were not covered by any operator i.e. were complete not-spots. It also found that 42% were partial-not spots.[110]

As with geographic coverage, MNOs have had limited incentives to ensure complete coverage of the road network as the costs of rolling out additional network infrastructure are likely to outweigh the benefits of additional revenues from attracting new subscribers or from existing subscribers.[111]

Furthermore, the coverage obligations imposed on MNOs in their spectrum licences relate to population coverage or land area coverage rather than coverage of roads. Hence, there has been little additional incentive for the MNOs to invest specifically in road coverage. However, the geographic spread of the road network means that in most cases, increasing overall geographic coverage

[107] Thameslink, Southern and Great Northern (TSGN), Southeastern, Chiltern, Arriva Trains Wales.

[108] https://www.gov.uk/government/news/free-wi-fi-to-help-rail-commuters-stay-connected

[109] https://www.chilternrailways.co.uk/news/chiltern-railways-and-ee-set-transform-onboard-wi-fi-experience-for-thousands-commuters

[110] http://stakeholders.ofcom.org.uk/binaries/research/infrastructure/2015/downloads/connected_nations2015.pdf

[111] Assuming that the existing subscribers would not migrate to more expensive bundles as a result of road coverage improvement

should provide increased road coverage. In addition, on most roads the density of demand should be relatively low enabling capacity requirements in most scenarios to be met with a coverage network.

However, motorways, with higher concentrations of (data) traffic, may not have sufficient capacity provided by a minimal coverage network. In addition any automotive applications which require uninterrupted connectivity are likely to deliver greater benefits on roads with higher levels of traffic. In the absence of predictable demand for the new services that would require uninterrupted road coverage and a well-developed supply chain, the operators are unlikely to invest in ubiquitous high capacity coverage on motorways. However, this investment may be needed to ensure that the UK is well placed to reap the benefits of these new applications. In Section 5 below, we look at alternative business models that might help improve road coverage (from a user perspective) and at potential government interventions which would improve incentives to invest in road coverage.

4.3.2 Delivering increased capacity in urban areas

Mobile data traffic is predicted to grow 6-fold in Western Europe between 2015 and 2020[112]. While in the past data traffic growth has been served by a combination of greater spectral efficiency and the allocation of increased amounts of prime spectrum to mobile communications, growth in capacity on existing networks through these mechanisms is limited:

- Much of the spectrum suitable for deployment on traditional ‘macro-cell’ networks has already been allocated; and
- The rate at which spectral efficiency can increase in the future is limited by physical constraints (‘Shannon’s law’).

The combination of these two factors means that additional capacity will require addition base stations using higher frequency spectrum and hence with lower range than traditional macro-cells. This will be particularly important in densely populated urban areas due to the higher density of traffic in these areas and constraints on finding additional macro-cell sites. The MNOs are already making efforts to densify their networks by deploying small cells in these urban areas. The LS telcom report estimates that tens of thousands of small cells would need to be deployed to support new applications[113].

In Section 5 below, we focus in more detail on the changes to the planning system and look at complementary forms of increasing capacity, e.g. deploying more spectrum at higher frequencies.

4.3.3 Achieving differentiated Quality of Service through virtualisation

Operators are likely to introduce a degree of network virtualisation through software defined networks as this should provide significant savings in capital

[112] http://www.cisco.com/assets/sol/sp/vni/forecast_highlights_mobile/

[113] LS telcom, “5G Infrastructure Requirements in the UK”, 2016

expenditure and ongoing operating costs through using commodity hardware and potentially outsourcing to cloud based providers. However, as well as enabling cost savings, network virtualisation could also enable providers to offer different levels of quality of service to different users or for different applications.

Currently, mobile subscribers are not generally given any guarantees that they can either get a mobile connection in any given geographic area or that a connection will meet any particular threshold for quality. In the large part, this reflects the nature of current mobile networks, where capacity, and to a degree coverage, is affected by a wide number of factors, some of which are outside the control of the MNOs (e.g. the usage and position of users at any given point in time, weather conditions, etc.).

As a result of this, most mobile applications are currently designed to run on ‘best effort’ Internet while delivering a reasonable quality of user experience with varying bandwidth and latency. While certain applications (e.g. video streaming of live sports) could benefit from having access to higher bandwidth (being prioritised), and users may potentially be willing to pay a premium for this, such traffic prioritisation is not allowed by the EC net neutrality rules.

Potential 5G applications will cover a wider range than which currently exists. It is expected that 5G applications would vary greatly in terms of the requirements they would place on the networks (some would require high bandwidth and low latency, others low latency but ubiquitous coverage and so on). With such a wide range of underlying requirements, it would not be efficient to meet the requirements by delivering all traffic to meet the most stringent quality of service requirement in all dimensions, i.e. to provide each application with exactly the same Quality of Service.

Similarly, there is likely to be greater diversity in network infrastructure with, for example, high capacity urban networks based on millimetre waves combined with traditional mobile networks offering ubiquitous coverage but relatively low bandwidth. Users may be better served by a range of different network technologies working together (HetNets) rather than the ‘one size fits all’ approach of current mobile networks. This in turn could lead to increased requirements for interworking between different networks. While this may be enabled by commercial agreements between operators, there may need to be oversight by competition authorities to ensure innovation is not frustrated.

5 APPROACHES TO FACILITATE INVESTMENT IN 5G NETWORKS

With demand for new applications uncertain, it is not clear whether there are strong incentives for the MNOs to invest in new technologies in the near future, either because new applications could increase overall industry revenues or investing will enable operators to differentiate. This suggests that the additional investments required may not be delivered in a timely manner under the existing mobile eco-system. This may require changes in three dimensions:

- Providing incentives for investors to make investments which would not be made under current business models;
- Lowering the costs of mobile infrastructure to strengthen the business case for incremental investment; and
- Providing sufficient flexibility to allow investors to try a range of potential business models to deliver 5G services.

In this section, we look at potential solutions for the challenges described above across these three dimensions. We have identified a number of potential policy measures that could be used; some of them might cut across all these problems, while others are likely to be more targeted and specific to particular problems.

These policy measures can be split into the following broad categories:

- Enabling innovation through more flexible spectrum policy;
- Lowering network costs by modifying the existing regulations;
- Addressing potential market failures in delivering public goods through direct government interventions; and
- Allowing innovation through alternative business models.

For each of these broad categories, we discuss specific polices/initiatives that could be used and the challenges these initiatives are likely to address, e.g. flexible spectrum policy is likely to address capacity issues and facilitate innovation. Some of the proposed solutions are market-based, i.e. they do not require active government intervention. The government's role is to enable these solutions through flexible policy and regulation.

5.1 Spectrum policy

Spectrum policy for mobile communications has had a number of objectives, the relative importance of which has changed over time as the market has developed. These have included:

- Facilitating market entry;
- Promoting specific technologies;
- Providing additional spectrum for mobile use; and

- Providing investors with long term certainty.

However, recent developments, in particular the success of Wi-Fi in providing significant capacity using a relatively small amount of unlicensed spectrum, suggest ‘flexibility’ should be another objective.

Flexible spectrum policy should be able to balance the needs of traditional network operators for sufficient spectrum and investment certainty, with the flexibility to allow other players/new entrants to offer innovative business models. This can be achieved through, for example, unlicensed or shared spectrum models.

Making more spectrum available to mobile

More spectrum will need to be reallocated to mobile use to support the additional data usage that will arise from continued traffic growth from existing applications and potential new 5G applications. Given the limited amount of additional spectrum available at lower frequencies, this spectrum will most likely mainly come from bands above 6GHz, specifically from a number of bands in the range of 24GHz to 86GHz, as included in the WRC-19 agenda. The propagation characteristics at these higher frequencies are limited compared to the traditional mobile spectrum bands (in the 700MHz – 2.6GHz range). However, higher frequency bands could be used indoors or for hotspots, with ranges of up to around 200m.[114]

In the UK, the government recently published a report identifying a number of bands used by the public sector (e.g. aeronautical, emergency services) that could either be released to the market or identified for sharing. In the report, the government proposes to identify 750MHz of spectrum for release or sharing below 10GHz by 2022[115].

In light of the government’s proposals, Ofcom has updated its long-term spectrum strategy[116]. Ofcom is committing to make available an additional 446MHz below millimetre wave (below 24GHz) frequencies to mobile[117]. Ofcom also considers that millimetre wave frequencies may provide around 1 to 5GHz, but does not provide any clear timeframe for making these frequencies available.

In contrast, the FCC has recently announced plans to make nearly 11GHz of high-frequency spectrum available for mobile and fixed wireless broadband, which includes 3.85GHz of currently licensed spectrum and 7GHz of unlicensed spectrum.

Large quantities of millimetre wave spectrum could enable new applications, such as ultra-high definition video, augmented reality and virtual reality. It also allows remote driving of vehicles and other IoT applications requiring high data rate and low latency.

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114 RealWireless, “Identification and quantification of key socio-economic data to support strategic planning for the introduction of 5G in Europe”, 2016

115 “Enabling UK growth: Public Sector Spectrum Release Programme”, UK Government Investments, April 2016
https://www.gov.uk/government/publications/enabling-uk-growth-public-sector-spectrum-release-programme

116 Ofcom “Mobile Data Strategy: Update on our strategy for mobile spectrum”, 30 June 2016

117 Including 700MHz, 2.3GHz and3.4GHz spectrum.

The FCC Chairman Tom Wheeler stated:

> *"With today's order, we are repeating the proven formula that made the United States the world leader in 4G: one, make spectrum available quickly and in sufficient amounts; two, encourage and protect innovation-driving competition; and three, stay out of the way of market-driven, private sector technological development"*.
>
> *"By becoming the first nation to identify high band spectrum, the United States is ushering in the 5G era of high capacity, high speed, low latency wireless networks."*[118]

This illustrates a significant difference of approaches between the US and the UK in terms of spectrum allocation for 5G. While there is considerable uncertainty over the development of millimetre wave technology, the FCC takes a bolder approach, making large quantities of spectrum available before it is being standardised for 5G.

This would arguably allow the US mobile operators and other players to start testing potential 5G technologies, business models and applications earlier than it would be done in other countries (where spectrum has not been made available). It would help the US firms to establish themselves or to strengthen their position as global leaders in the mobile sector, and to influence 5G technology in a way that will be beneficial to the US mobile market. To the degree that these technologies are successful, it would also allow US consumers to benefit earlier from these new technologies.

Ofcom should consider whether it's more cautious approach is appropriate and whether it could follow the US lead in making more spectrum available for 5G sooner rather than later.

Flexible approach to allocating spectrum

Most of the spectrum currently used by the telecoms sector is subject to exclusive licencing (exceptions being 2.4GHz and 5GHz bands used by Wi-Fi) for long time periods (the licences issued for 3G and 4G spectrum had initial terms of 20 years). The reason for using exclusive licensing is that it provides security of tenure and protection of assets for the licensees, and limits interference. However, this model can be criticised as inflexible. For example, operators cannot easily change the amount of spectrum they use between auctions. While spectrum can in theory be 'traded' between users, information asymmetries mean trades which could increase both sides' values may not take place. Assigning spectrum on a national basis may also be inefficient as spectrum that is used by the MNO in some areas, such as dense urban areas, might be underutilised in other areas, even though there are applications which would use it.

Non-exclusive use, i.e. spectrum sharing, could help realise the 5G vision and incentivise investment in its roll-out. A common approach to spectrum sharing is access to spectrum on a licence-exempt basis, in which devices can freely access the spectrum and coexist in the same spectrum band at the same time in the same location. Given the uncertainty over the business case for the use of

[118] https://bol.bna.com/fcc-votes-to-open-spectrum-for-5g-internet-of-things/

millimetre wave technology, it is not clear that demand for this frequency exceeds supply. However, if the spectrum is auctioned, MNOs are likely to try and acquire the spectrum for strategic reasons.

Attempts have already been made by Ofcom to introduce some elements of spectrum sharing in the UK. In the 4G auction, for example, Ofcom relied on market mechanisms to assign 2.6GHz spectrum either to high power exclusive use or to low-power concurrent users. Although low-power users failed to outbid high-power users, this was clearly a step in the right direction as it introduced some flexibility into the process of spectrum allocations (away from technology-specific to more technology-neutral approach).

A degree of flexibility would allow potential entrants to use the spectrum without making the necessary investments to outbid MNOs in a spectrum auction. It would also reduce spectrum costs (as unlicensed spectrum is free of charge) and potentially increase spectrum utilisation as more than one user would be able to have access to this spectrum. On the other hand, unlicensed spectrum is more likely to be affected by interference from other users.

Wi-Fi is an example of unlicensed spectrum being used successfully, with a majority of data on tablets being delivered over Wi-Fi. More recently, technical specifications have been produced for operating LTE-U base stations and consumer devices on unlicensed frequencies in the 5 GHz band.[119]

While the unlicensed spectrum would not entirely replace licensed spectrum (due to interference issues), making more unlicensed spectrum available would give new entrants and alternative operators the opportunity to innovate.

There are also a number of alternative approaches for spectrum sharing including:

- Concurrent shared access – multiple operators share access to the same portion of spectrum in a coordinated and managed way (e.g. different users in different regions);
- Licensed shared access – licensed users permitting access to their spectrum by way of a sub-licence and
- Authorised shared access – dynamic use of spectrum at any time and any location where it is unused by the incumbent (as long as it does not cause interference). [120] If the incumbent continues to have priority when using shared spectrum and if shared access does not cause interference, the incumbent's incentives to invest should be preserved.

All these models could be successfully used depending on circumstances. Concurrent shared access and licensed shared access are less dynamic and arguably less efficient that authorised shared access. The latter, however, would require an advanced technology to manage spectrum sharing without causing interference.

[119] The specifications support LTE operation in the 5 GHz UNII-1 and UNII-3 bands as Supplemental Downlink (SDL) carriers, in conjunction with an LTE deployment in licensed bands, based on 3GPP already published Release 10 and later specifications. https://www.qualcomm.com/invention/technologies/lte/unlicensed

[120] More details in RealWireless, "Identification and quantification of key socio-economic data to support strategic planning for the introduction of 5G in Europe", 2016

For licenced spectrum, Ofcom might also consider whether some spectrum should be explicitly reserved for alternative (non-MNO) users. It is broadly accepted that without special protective measures (e.g. spectrum reservation), new entrants are typically outbid by the incumbents. While the UK mobile market is unlikely to see another 'traditional' new entrant which would roll out a national mobile network, alternative providers might want to acquire spectrum to test alternative business models and compete with the established MNOs. In order for these alternative providers to succeed, Ofcom might need to introduce special measures to enable their entry, including some post – entry remedies.

Overall, Ofcom should aim to make more spectrum available for future mobile uses (licenced, unlicensed and shared spectrum) – comparable with the amount of spectrum made available by other leading nations. When allocating spectrum, Ofcom should consider reserving some spectrum for non-MNOs to allow new innovative models to emerge.

A flexible spectrum policy is likely to enable innovation, reduce costs and address the sector's capacity needs.

5.2 Lowering infrastructure costs

When making investment decisions of a strategic nature or for incremental deployment, operators must balance costs and benefits, including benefits of differentiation. Operators should make investments up to the point where benefits are marginally greater than costs. Reducing the costs of network deployment will increase the operators' incentive to invest in incremental networks, whether that is required to extend existing networks in terms of capacity and coverage or to introduce 5G specific technology. In this section, we focus on specific types of regulation that affect the operators' costs. These are:

- Planning regulations;
- Access to land for installing infrastructure; and
- Regulations ensuring access to infrastructure bottlenecks (e.g. the regulation of backhaul).

These were mentioned by a number of respondents to the NIC's 5G call for evidence, and raised in our interviews with industry stakeholders as potentially not fit for purpose for future (5G) networks.

Planning regulations

As discussed above, mobile operators and other stakeholders predict that large numbers of small cells need to be deployed in urban areas in the near future to cope with increased demand for data. They considered the planning rules (as per the 2015 GPDO)[121] as a key constraint in the small cell, antenna and mast deployment (see the text box below).

[121] Available at http://www.legislation.gov.uk/uksi/2015/596/pdfs/uksi_20150596_en.pdf.

STAKEHOLDER RECOMMENDATIONS IN RELATION TO DEPLOYMENT OF SMALL CELLS[122]

Many stakeholders responded to the NIC's call for evidence to inform its 5G recommendations. Several submissions suggested that changes should be made to planning restrictions. Some of the changes they suggested were:

- The current planning rules only allow two small cell antennae on a building or other structure and full planning permission is necessary if more are to be installed. The stakeholders consider two antennae insufficient as more may be needed for backhaul, for example. It was suggested that a "small cell system" should be permitted with more than two antennae and associated equipment.
- The current rules do not allow antennae facing highways to be built on structures that are within 20 metres of the highway without obtaining full planning permission. This rule makes delivering mobile coverage and capacity on roads more costly for the MNOs.
- Prior approval is currently needed for the deployment of small cells on buildings and other structures in conservation areas. The procedure for prior approval is considered cumbersome, especially taking into account the number and size of conservation areas (including in urban areas).
- In relation to macro sites, taller masts were proposed in order to reduce the cost of mobile coverage. One MNO in its response to the NIC stated that "the average ground-based mobile mast in the UK is only 18m tall, compared with between 72-100m in Sweden. This has resulted in poorer coverage at more cost <in the UK> than elsewhere."

A new GPDO has come into force (as of November 11, 2016), after the NIC's call for evidence.[123] This GPDO appears to address some of the above concerns. For example, small cell antenna and small cell systems are not affected by the limitations on building-based apparatus that applied previously. It also appears that the height limitation on masts has been raised from 15 metres to 25 metres on unprotected land.[124]

These changes may facilitate the roll-out of 5G networks. However, given that the GPDO has come into force only recently, it is too early to judge if it:

- goes far enough in addressing operators' concerns; and
- will have a significant impact on the speed of 5G roll-out.

In any case, it remains vital that the planning framework for mobile in the UK keeps pace with technological change and consumer demand, and enables the deployment of the most efficient and effective infrastructure.

Access to land on fair and reasonable terms

Another means to incentivise the roll-out of 5G is to ensure that access to land is available to all parties on a fair and reasonable basis. Access to suitable sites is

122 These recommendation are largely based on submissions from Arqiva, Three and Ericsson, in response to the NIC's 5G call for evidence

123 See http://www.legislation.gov.uk/uksi/2016/1040/pdfs/uksi_20161040_en.pdf

124 Ibid.

particularly important for delivering coverage in remote rural areas, along railway lines and roads.

The Electronic Communications Code (ECC)

Access to sites was highlighted as one of the challenges faced by the mobile industry, with landowners charging excessive site rents and imposing additional charges for infrastructure upgrades and network sharing. This was considered a major problem for upgrading to 4G and future technologies. These problems have been addressed by recent amendments to the ECC (discussed in Section 3.1.2).

The site rents are set on fair terms (in line with the opportunity cost of land) and infrastructure upgrades are allowed (with no extra charges). These are positive changes as they are likely to reduce the operators' costs of deploying and upgrading the infrastructure.

Shared infrastructure

The current network sharing arrangements reduce the cost of coverage for operators, reducing some fixed costs by half (with two operators sharing site infrastructure).

Costs could be further reduced if all operators shared sites. While this is encouraged under existing regulation, and can be facilitated by WIPs, in many cases co-ordination issues mean that each network sharing agreement (CTIL and MBNL) rolls out duplicate sites. The MIP project, discussed below, shows the difficulty of enabling this co-ordination without adequate incentives for the stakeholders to roll out increased coverage networks.

As such, the onus may be on improving the incentive to increase coverage while encouraging increased network sharing in order to reduce the cost of greater coverage requirements.

Regulation of backhaul

As discussed in Section 1, backhaul products are available on commercial terms from operators such as BT Wholesale, Virgin Media and Cable & Wireless, as well as on a regulated basis from Openreach for some inputs.

However, the mobile industry's requirements for backhaul links are likely to grow by an order of magnitude (in line with demand for mobile data and hence sites) which may mean that the current level of pricing are unsustainable.

There may be ways to lower the cost barriers by:

- ***Backhaul regulation*** – Currently Openreach's products which can be used for mobile backhaul, such as Ethernet Access and dark fibre are regulated as part of the 'Business Connectivity' market. The prices of these services include a much greater contribution per link to Openreach's fixed costs than the mass market broadband services, which is sustainable due to a much higher willingness to pay from corporate customers and to backhaul traffic from mobile sites potentially serving many thousands of customers. However, the resulting prices are likely to be too high for small cells serving hundreds of customers in a much smaller area. Ofcom should ensure forward looking regulation of these inputs does not result in backhaul being a barrier to deployment of small cells. For example, Ofcom might consider conducting a separate market review of mobile backhaul products (separately from leased lines and other business connectivity products);

- ***Allowing duct access for the provision of mobile backhaul*** - Physical Infrastructure Access (introduced by Ofcom in 2010), which includes access to BT's ducts, does not allow them to be used for deploying services other than mass market broadband, e.g. mobile backhaul. This restriction enables BT to maintain price discrimination between 'Business Connectivity' and mass market broadband services. However, as noted above the degree of discrimination may prevent the use of fibre backhaul for small cells. If this restriction was lifted, it could significantly reduce the cost of mobile backhaul, and make the business case for investment in 5G more attractive.

These proposals, reflecting the new demand on fixed networks resulting from the expansion in the number of mobile sites, are likely to lead to significant reductions in network costs and to address a number of challenges faced by the industry, i.e. to improve coverage, increase capacity and lower the overall network costs.

5.3 Addressing the market failures through direct government interventions

There are a number of different ways in which government can incentivise investors to roll out future mobile networks if competition alone cannot deliver public goods. While there are a number of existing market based initiatives which aim to increase the level of coverage, such as the enhanced coverage obligations and changes to the ECC, it is possible that further intervention by government will be necessary.

Interventions could include:

- Imposing obligations – government could impose further coverage and rollout obligations, to ensure that specific policies are achieved (e.g. ubiquitous coverage and fast rollout of new technologies);
- Coordinating directly or indirectly with publicly-funded infrastructure projects – government can play a coordinating role to ensure that, if there are synergies between infrastructure projects funded by the government and the government's objectives in terms of mobile networks, that the funding is contingent on these synergies being realised; and
- Direct government subsidy - government can provide money to fund specific interventions where there are public goods involved and whether the market on its own would not deliver socially optimal outcomes.

We discuss each in turn below.

Coverage obligations

To date mobile coverage obligations have been attached to spectrum licences for specific technologies. Coverage obligations have been attached to 3G and 4G spectrum licences for 2100MHz and 800MHz spectrum respectively. The coverage obligations were implicitly subsidised as operators would have paid a higher price for equivalent spectrum without the coverage obligations[125].

In the 4G auction, the coverage obligation was imposed on only one operator as this was expected to stimulate a competitive response from the others. Despite these obligations being applied, coverage is not ubiquitous and there is widespread dissatisfaction with the level of coverage both in rural areas and on certain key infrastructure, such as strategic roads. Recognising this problem, the government negotiated a voluntary coverage obligation with all of the MNOs to increase geographic coverage from 69% to 90% by 2017[126].

In future spectrum auctions, Ofcom might consider alternative approaches to defining coverage obligations, which were used, for example, in Germany and in Sweden:

- To roll out new networks in rural areas first before they could be rolled out in urban areas (used to promote 4G rural coverage in Germany - see the text box below);
- An obligation to cover specific postcodes that lack mobile coverage (used in Sweden); and
- To consider imposing coverage obligations on all, rather than some licences. This would ensure that the required level of coverage will be achieved by all operators within a given timeframe.

125 The amount of subsidy in the 4G auction, for example, can be inferred by comparing prices paid for 800MHz spectrum with and without the coverage obligation.

126 http://www.publications.parliament.uk/pa/cm201617/cmselect/cmcumeds/147/147.pdf

COVERAGE OBLIGATION IN GERMANY[127]

Within each Bundesland, the winners of the 800MHz spectrum were required to build-out their networks in listed communities in four stages in areas with no or very low broadband coverage, before deploying in more populated areas. The so-called “Weiße Flecken-Listen” (white spot lists) had been defined by the administrations of the Bundesländer. The four stages were:

- smaller towns and districts with 5,000 or fewer inhabitants (priority stage 1)
- towns and districts with between 5,000 and 20,000 inhabitants (priority stage 2)
- towns and districts with between 20,000 and 50,000 inhabitants (priority stage 3)
- towns and districts with more than 50,000 inhabitants (priority stage 4).

Deployment in each stage in each Bundesland could only begin once 90% of the population in the towns and districts specified in the previous stage had been provided with access by one or more of the 800MHz licensees. All of the coverage obligations had to be met by 2016. Licensees were allowed to co-operate with each other in respect of sharing of infrastructure and leasing frequencies to meet these coverage obligations.

While the approach in Germany has contributed to improving rural coverage (by design), it has also slowed down 4G roll out overall, with Germany being behind the UK in terms of overall 4G coverage (see Annex A for more details). Therefore, it is important to recognise that this type of coverage obligation presents a trade-off between achieving better rural coverage, but at a cost of slower deployment of 4G networks overall.

An alternative mechanism to linking coverage with spectrum auctions could be to tender for Universal Service Providers (USP), i.e. operators who would be subsidised to provide a high level of coverage in a given area. The advantage of breaking the link with specific spectrum licences would be:

- The obligation could be met in a technology neutral way, rather than relying on a given spectrum band/technology;
- The obligation could be applied in a more flexible way, i.e. tenders for different regions or coverage obligations could also be required to deliver coverage on strategic motorways and along rail tracks;
- The obligation could be updated on a periodic basis rather than tied to the allocation of new spectrum, allowing new coverage requirements to be introduced as the market develops.

More generally, where further coverage and roll out obligations are introduced (either as part of spectrum licensing or through other mechanisms such as tendering), it is important to ensure that the obligations are closely aligned with the policy objectives, whether this is to ensure the rapid roll out of technology or ensuring universal availability of services.

[127] http://www.gsma.com/spectrum/wp-content/uploads/2011/11/700MHz-800MHz-band-Germany.pdf

Rail coverage: an example of Franchise Agreements as a coverage obligation on non-MNOs

In Section 4.3.1 above, we have identified multiple challenges with delivering mobile connectivity on train:

- Technical challenges – rail tracks being in cuttings below the general ground level, the metal body of train carriages weakening the mobile signal, and intercity routes passing areas of low population density with limited infrastructure to support mobile networks; and
- Coordination issues – With multiple stakeholders involved (Network Rail, Rolling Stock companies, Train Operating companies (TOCs) and MNOs, incentives to roll out mobile networks along rail track were poorly aligned.[128] Until new Franchise Agreements were introduced recently, TOCs were not incentivised to provide connectivity on the trains. Moreover, Network Rail was not incentivised to allow MNOs to place masts close to rail tracks (for personnel safety reasons).

While new Franchise Agreements have removed some of the incentive problems (i.e. TOCs are now incentivised to provide Wi-Fi on trains), the implicit subsidy required may be higher than necessary due to the elevated costs for MNOs of providing coverage.

While there are clearly technical and safety challenges to be resolved, there may be scope for Network Rail to provide some form of access to its infrastructure, for example through a subsidiary, to improve efficient mobile coverage of rail lines and surrounding areas. Therefore, obligations could be placed on Network Rail to facilitate mobile infrastructure deployment and infrastructure sharing along rail tracks.

Coverage on motorways: the role for the Highway Agency

Our assessment in Section 4.3.1 above suggests that increasing overall geographic coverage should provide increased road coverage, which should also be sufficient to satisfy capacity requirements on most roads (where the density of demand is sufficiently low).

However, the situation may be different on motorways, where a minimal coverage network might not provide sufficient capacity for certain applications (e.g. infotainment). In the absence of predictable demand for the new automotive applications (that would require uninterrupted road coverage and a well-developed supply chain), the operators are unlikely to invest in ubiquitous high capacity coverage on motorways. This suggests that there may be scope for public intervention. For example, the Highway Agency may be required to cooperate with MNOs to facilitate roll out of mobile infrastructure capable of delivering automotive applications along the Strategic Road Network.

Ensuring that infrastructure projects take account of 5G

Another important policy tool to increase coverage/speed of roll out of new technologies is to ensure that publicly-funded infrastructure projects (for example

[128] See more details in Section 4.3.1

building rail infrastructure or motorways) take account of the needs of 5G networks, to the greatest extent possible.

The best practice approach to coordinating infrastructure projects with interdependencies is formulated in a supplement to the Treasury's Green Book[129](see the textbox below).

ASSESSING INTERDEPENDENCIES BETWEEN DIFFERENT PUBLIC INFRASTRUCTURE PROJECTS

Best practice in terms of assessing, planning and coordinating public infrastructure projects with interdependencies is presented in a supplementary guidance to the Treasury's Green Book. The key principle of the joined up approach are as follows:

- When appraising infrastructure, it is important to recognise that infrastructure networks are increasingly interdependent. This offers opportunities to create value and reduce costs through sharing (but might also increase risks of a multiple-networks' failure).
- Join delivery of interdependent infrastructure projects is likely to result in (1) cost sharing in delivery; (2) cost sharing in operation; and (3) improved use of redundant land.
- Many existing infrastructure assets could also be used for additional infrastructure networks or systems. Using existing infrastructure rather than building entirely new networks could significantly lower the cost of delivering infrastructure.
- Implementing passive provision - Passive provision allows for flexibility of future uses of infrastructure components. It can help to avoid irreversible decisions, which may rule out later investment opportunities or alternative use of resources.
    - For example, the Bill for HS2 Phase One included clauses for the laying of a communications network along the route of the railway in the future.
- For every publicly-funded infrastructure project, it is important that the feasibility and appropriateness of delivering shared infrastructure alongside it is considered at an early stage of the project development cycle. This requires a policy appraiser to work across organisational (departmental) boundaries in order to identify opportunities to add value.

The approach advocated by the Treasury's Green Book, if applied consistently, would help to encourage investment in new services and applications even if the operators face demand uncertainty. By lowering the cost of investment in new technologies (achieved through joint delivery of independent infrastructure projects) and by future-proofing the infrastructure built (achieved through implementing passive provision), government can stimulate the roll out of new technologies earlier.

One of the key practical challenges is to be able to identify and evaluate synergies between various publicly-funded projects. If investing into a particular project (e.g. delivering high-speed fixed broadband in rural areas) might help achieving government's other objectives (e.g. to improve mobile coverage), it would make sense to ensure that these synergies are identified, assessed and explicitly taken into account when the project's objectives are formulated.

[129] "Valuing infrastructure spend: supplementary guidance to the Green Book"

Below, we consider two examples of recent publicly-funded projects, with significant potential spill-over effects for the mobile sector. In one case (procurement of ESN), these spill-over effects are likely to be realised, while in the other case (BDUK), an opportunity to make a positive change has been missed.

Awarding a contract to upgrade the emergency services network (ESN) to a mobile operator (EE) represents an example of a publicly-funded project that is likely to create significant positive spill-over effects for the mobile sector (including improved mobile coverage - see the textbox below).

GOVERNMENT AS A PROCURER OF NEW SERVICES: EMERGENCY SERVICES NETWORK (ESN)

The emergency services mobile communications programme (ESMCP) was set up by the Home Office in 2013 to upgrade and replace the technology currently used by Emergency Services which does not provide broadband services.

The objective was to provide next generation communication, including voice and broadband services, to the three emergency services through the "Emergency Services Network".

Procurement was completed in December 2015, with Motorola responsible for installing the operating infrastructure and applications, and EE responsible for providing the mobile network over which the ESN will operate[130]. EE will have the option of using sites built in remote areas to increase its commercial 4G coverage, while other operators have the right under a European State Aid agreement to also deploy their own equipment on masts paid for by the programme[131]. ESN is expected to be launched in 2017 with a three-year transition period, with the current system being switched-off in 2020.

As part of its role as the network provider, EE will need to expand its coverage to 97% of land.[132] This is likely to lead to a positive externality of extended LTE coverage for mobile voice and data and will deal with some of the challenges identified above (e.g. ubiquitous coverage). This, however, might not solve all coverage issues this level of coverage may only be available using specialist equipment for the ESN.

Although some expressed concerns as to whether the move to LTE for emergency services was premature (as current technology would still be needed for mission critical services)[133], awarding the ESN contract to a mobile operator is likely to both save public money and achieve wider benefits, in the form of improved coverage of EE's mobile network.

This example shows that there could be significant synergies between different publicly-funded projects. Identifying these synergies explicitly and making decisions based on maximising overall benefits (rather than benefits to a specific use group) would allow government both to save public money, but also to tackle

[130] A number of bidders dropped out of the procurement process. For example, HP and O2's withdrawal from the lots they were participating in left Motorola and EE as the only bidders. HP cited concerns regarding the requirements and the timelines of the project. O2 stated that it withdrew because of the uncertainty related to its potential acquisition by Three.

[131] http://ec.europa.eu/competition/state_aid/cases/258318/258318_1718437_89_2.pdf

[132] See http://bluelightinnovation.co.uk/wp-content/uploads/2015/11/11.30-Gordon-Shipley.pdf

[133] See https://www.ft.com/content/ee2eef92-0df8-11e5-8ce9-00144feabdc0

challenges (such as mobile coverage in rural areas) more effectively and efficiently.

There are also examples where interests of the mobile sector have not been incorporated in recent publicly-funded infrastructure projects. For example, the BDUK project that aims to increase availability of high-speed broadband in the UK and to reduce ‘digital divide’ between urban and rural areas has explicitly excluded mobile backhaul from its scope[134]. This represents a missed opportunity in terms of maximising benefits across the two sectors (fixed and mobile telecommunications).

In addition to new infrastructure projects, wider sharing of the existing infrastructure should also be encouraged. DCMS is currently implementing the Broadband Cost Reduction Directive[135], which requires infrastructure owners to give high speed Internet providers access to and information about physical infrastructure at a ’fair and reasonable price’ and to provide information about and co-ordinate planned civil works[136]. While the main objective of this regulation is to reduce the costs of fibre deployment, it can also create additional benefits for the mobile operators, especially with respect to mobile backhaul.

Government subsidy

Another way to correct a perceived market failure is for Government to provide a subsidy[137] in order to achieve a particular desired outcome, e.g. to improve geographic coverage. This has been recently attempted in the UK though the Mobile Infrastructure Project.

As explained below[138], the MIP was not considered a success: it failed to achieve its objectives and only a fraction of the allocated subsidy was spent (see the text box below for more details). There are numerous lessons that could be learned from this project – some are specific to a particular objective (extending mobile coverage), while others more general about the project design.

It is important that future projects involving a direct subsidy from government learn from the MIP’s experience:

1) Government needs to ensure that all stakeholders’ incentives are aligned. In this case, the operators had weak incentives to participate as the government subsidy only covered the roll out costs, but not the operation and management costs (making the sites unprofitable for MNOs to operate).

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[134] European Commission, SA. 40720 (2016/N) – National Broadband Scheme for the UK for 2016-2020, 26 May 2016

[135] http://eur-lex.europa.eu/legal-content/en/TXT/?uri=celex%3A32014L0061

[136] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/534187/2016-6-13-RPC-3056_2_-DCMS-Broadband_cost_reduction_directive_final.pdf

[137] Subject to State Aid rules

[138] Sources: https://www.gov.uk/government/consultations/mobile-infrastructure-project-industry-stakeholder-engagement, https://www.gov.uk/government/news/mobile-reception-around-uk-to-get-massive-boost, https://www.gov.uk/government/publications/2010-to-2015-government-policy-communications-and-telecomms/2010-to-2015-government-policy-communications-and-telecomms, researchbriefings.files.parliament.uk/documents/SN07069/SN07069.pdf

2) Local authorities should also be more engaged in facilitating publicly-funded infrastructure projects, bringing communities on board and helping to coordinate various publicly-funded projects in their areas (e.g. MIP and BDUK).

THE MOBILE INFRASTRUCTURE PROJECT, 2011-16

In October 2011, the UK government allocated £150milion in capital expenses to improve the coverage and quality of mobile access in remote and rural areas – known as the "Mobile Infrastructure Project" (MIP). The project was run by the Department for Culture, Media & Sport (DCMS), and its goals were two-fold:

- to connect to the mobile grid the 5-10% of consumers and businesses that live in areas with poor or no coverage ("not-spots"); and
- to extend overall mobile coverage to 99% of the UK population.

The project was meant to begin with procurement in 2012 and be completed by 2015, with some 600 mobile mast locations identified in the original plan. It gained EU clearance under State Aid rules in December 2012 and Arqiva was chosen in May 2013 to deliver the masts. However, the project then encountered numerous obstacles, and was closed in March 2016 with just 75 masts completed, most of these not being live a few months before the project's end.[139] The MIP project was widely regarded to have failed to meet its goals, with only £9.1m out of the allocated £150m spent by the government.

Several reasons for the project's failure were identified by the DCMS and Arqiva, mostly revolving around the planning process.

- Discovering the precise location of the "not-spots" proved more technically challenging than expected.
- Finding suitable mast locations proved difficult, in that they had to be accessible to roads and to power lines. These requirements also increased the capital costs of constructing the sites.
- At many locations, there were difficulties with receiving planning permissions. This was partially due to push-back from the local authorities and partially due to somewhat ineffective engagement between Arqiva and some of the local authorities (according to a survey conducted by the Local Government Association).
- Due to the nature of the "not-spots", many of the proposed locations were in National Parks or Areas of Outstanding Natural Beauty, raising special conservation and aesthetic concerns. This was further complicated by the fact that many masts needed a height of 20-30 metres, above the limit allowed for reduced planning restrictions.
- According to the Minister in charge of DCMS at the time, planning was made more difficult by a lack of cooperation from the MNOs, who were being forced to operate masts in unprofitable areas and would have to incur the operating costs, including the (often high) land rental fees.

Other than the specific barriers around rural planning and community management (some of which were addressed in the 2016 budget[140]), this project offers a valuable lesson in infrastructure development. Namely, that a capital injection in itself is not sufficient to overcome investment barriers in cases where:

a) the continued running and management of the infrastructure is not profitable for the asset's operators; and
b) the specific placement of the assets might encounter push-back from the local community.

[139] In November 2015 there were only 15 live MIP masts, according to the Minister for Culture and the Digital Economy. http://researchbriefings.files.parliament.uk/documents/SN07069/SN07069.pdf

[140] For instance, raising the height of masts which can be built without special planning permission.

5.4 Further innovation in business models

In Section 2 of this report, we discussed how the eco-system has evolved so far from a number of vertically integrated companies both controlling the networks and providing a limited number of applications to end users, to a more complex model, with a wider range of players and applications. Consumers clearly benefit from this trend, as they can get access to a wider range of new services and applications.

This trend is likely to continue, with application providers and new players further expanding their role. The use of SDNs should further enable innovative business model.

In Section 2.3, we have considered a few examples of such innovation – Project Fi and TalkTalk’s inside out network.

Ensuring that the net neutrality rules do not prevent delivering differentiated services

As discussed in Section 1, the EC net neutrality rules[141] require that all traffic has to be treated equally, with no prioritisation of traffic in the internet access service.

While specialised services (with specific quality requirements) are allowed, they can only be provided if there is sufficient network capacity to provide them in addition to any internet access service and must not be to the detriment of the availability or general quality of internet access services for end-users. The National Regulatory Authorities (NRAs) are also required to verify whether and to what extent optimisation for specialised services is necessary.

This approach is likely to come into conflict with new applications requiring guaranteed QoS and technical solutions underpinning 5G technology (e.g. network slicing).

It will be important for regulators to be flexible in their approach to regulating mobile networks to ensure that applications with different QoS could be delivered by the same networks in the most cost-effective way. A rigid requirement that ‘all traffic should be treated equally’ is likely to undermine the development of 5G.

We recommend considering specialised services and internet access services as two different unrelated types of services (rather than specialised services being delivered in addition to internet access services). It would be reasonable to preserve net neutrality rules for the internet access services. This, however, should not place restrictions on specialised services.

Agreements between players

Unlike fixed telecommunications, where the market power of former incumbents has required a high degree of regulation of agreements, for the most part, the existence of a number of similarly sized vertically integrated network operators means that agreements could generally be agreed commercially.

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[141] https://ec.europa.eu/digital-single-market/en/open-internet-net-neutrality

However, the market has evolved into a market structure where the number of players varies depending on the part of the value chain, for example:

- There are numerous players serving end users, both the four MNOs and a large number of MVNOs;
- There are numerous alternatives for key applications such as messaging and voice communications;
- The vast majority of smartphones use one of two operating systems;
- There are two network sharing deals underlying the four MNOs; and
- In some areas, there may be one potential infrastructure provider (for example BT for fibre backhaul or Network Rail for sites serving).

New partnerships may be based on exclusive agreements and while these do provide a first mover advantage, they can also incentivise investment by competitors. There have been examples in the recent past of exclusivity agreements between handset manufacturers and MNOs, which led to an increase in competition in the market.

For example, an agreement with Apple made O2 the exclusive carrier for Apple's iPhone handsets for a two-year period (2007-2009) in the UK.[142] During this two-year period, O2 was able to attract a number of high-value subscribers away from rivals increasing its market share and strengthening its brand. Over the same period, churn at Vodafone UK rose from 2.8% to 3.4% and from 2.2% to 2.4% at Orange.[143]

At the same time, in France, the exclusivity agreement between Orange (the largest mobile operator) and Apple, which was signed for a 5 year period, was challenged by the French Competition Council as anti-competitive.[144]

Similarly, in the UK, Network Rail's plans to have an exclusivity agreement with Vodafone to deliver Wi-Fi connectivity on trains (project Quicksilver) raised competition concerns and the project has been terminated by Network Rail[145].

This shows that while exclusivity agreements may encourage investment and innovation, these benefits need to be balanced against potential anti-competitive risks. More generally, the regulator in the UK should continue assessing competitive conditions at all levels of the mobile value chain and intervene if competition at any level is undermined.

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[142] http://www.apple.com/uk/pr/library/2007/09/18Apple-Chooses-O2-as-Exclusive-Carrier-for-iPhone-in-UK.html

[143] https://www.gsmaintelligence.com/research/2011/04/o2-records-lowest-churn-rates-in-uk/277/

[144] http://www.pocket-lint.com/news/139057-google-pixel-and-pixel-xl-when-and-where-can-i-get-them

[145] http://www.parliament.uk/business/publications/written-questions-answers-statements/written-question/Commons/2015-11-24/17427/

6 CONCLUSIONS

The mobile industry has delivered huge benefits to the economy over the last 30 years, following the roll out of four ‘generations’ of mobile network technology. These generations have supported the introduction and mass take up of mobile voice (1G and 2G respectively) and the introduction and mass take up of mobile Internet (3G and 4G).

The mobile market continues to evolve, with 4G networks expanding to offer both extended coverage and more capacity to users. There is an expectation that mobile networks will increasingly be used to connect machines (the ‘Internet of Things’) as well as people. Technologists are also working on technologies which will be included in the fifth generation of mobile networks.

The mobile ecosystem continues to evolve and now consists of a large number of companies competing at a retail level, but also co-operating on infrastructure and equipment to efficiently deliver innovative services at ever lower costs. This includes operators and end users providing Wi-Fi networks, which now deliver the majority of traffic to smartphones and which are not under the control of traditional mobile networks. The trend towards a more complex eco-system is likely to continue, with further concentration at the infrastructure level and the scope for providers serving specific types of end users, with traditional mobile operators increasingly focussing on a small number of core functions.

In this report, we examine how investors make decisions about investing in new technologies and the expansion of existing networks. For new technologies, if demand uncertainty is high, investment may be deferred until there is more certainty. This was the case for 3G services, where despite the UK being at the forefront of licencing spectrum in 2000, investment in 3G networks was limited until data demand began to increase rapidly following widespread take up of smartphones by end users. In contrast, for 4G networks, demand was well established but the availability of spectrum was the limiting factor for investments, with the UK being relatively late in making additional spectrum available.

Currently, there is considerable uncertainty on both the nature of 5G technologies and the demand for the use cases potentially supported by candidate technologies (e.g. driverless cars). If this uncertainty is not resolved by the time 5G technologies are introduced, operators will have an incentive to defer investment until there is clear demand for 5G services. Policy intervention to encourage innovation and to lower the cost of network deployment may be needed to break the cycle of low demand and low investment.

Incentives to invest in the UK mobile market are also affected by the nature of the market, with high fixed costs and other barriers to entry (e.g. licensed spectrum). In order to recover these fixed costs, operators need to maintain a degree of market power, which they achieve through product differentiation (with the operators differentiating themselves from their competitors in terms of price, coverage, speed, brand, handsets’ availability, etc.) Given these market characteristics, the operators are more likely to make investments which deliver clear benefits in terms of product differentiation. For example, they aim to introduce new capabilities ahead of their competitors in order to gain competitive advantage and to maintain this advantage as long as possible. This is well illustrated by EE's rapid roll out of the 4G network ahead of its competitors in 2012-13.

While competition between operators can lead to them expanding the capabilities of their networks in order to compete (even where such investments do not increase overall industry revenues), this may not deliver all policy objectives. One such example is the provision of coverage in rural areas, where the market may not be delivering a socially-desirable outcome (ubiquitous coverage). Government can play an important role in creating an environment which encourages investment, both by reducing barriers to investment and providing incentives for socially important investments to be made.

In this report, we have identified a number of challenges for the mobile industry in the future:

1. Delivering coverage - in rural areas, on strategic roads and on rail – where coverage is currently insufficient for supporting new applications (such as automotive and the Internet of Things) and even for traditional applications, such as mobile voice and broadband;
2. Delivering increased capacity in densely populated areas - this would require a wide-spread deployment of 'small cells' at street level, which present challenges with respect to planning; and
3. Efficiently delivering varying quality of service for a wide range of applications from very high bandwidth services in urban areas to support for large numbers of lower power, low bandwidth machines. Technologies introduced in 5G, such as network virtualisation and network 'slicing', should enable such differentiation. While such arrangements may be delivered effectively by competition, virtualisation may lead to regulatory challenges and the need to update regulations designed for legacy networks, for example, existing net neutrality rules.

In light of these challenges, a key question for policy makers is how to incentivise the rapid deployment of infrastructure and equipment required to support future mobile services and applications. Potential policies may include:

- Flexible spectrum policy which balances the need to provide investors with certainty when making investments tied to spectrum holdings with the need to support emerging technologies and players.
- Fit for purpose planning regulation which fully recognises the benefits that current and future mobile networks bring to users and the wider economy, including the infrastructure needed to provide ubiquitous coverage and high capacity networks.
- Coverage obligations placed on mobile operators that are focussed on ensuring real improvements in mobile coverage and are not tied to (infrequent) spectrum auctions but can be regularly updated to take account of the developing market.

- Improving future coverage of transport networks by giving stakeholders in transport networks incentives to work with investors in mobile networks to deliver competitive efficient networks which can serve future applications.
- Where necessary, regulating to ensure all mobile operators have access to fibre networks at competitive prices or access to the infrastructure needed to install their own fibre networks.
- Better coordination of publicly-funded infrastructure projects to identify and evaluate synergies between publicly-funded projects and policy objectives with respect to mobile networks.
- Keeping mobile sector specific regulations up to date, removing outdated regulation where necessary to reduce constraints on the development of new technologies and business models.

ANNEX A MOBILE MARKET OUTCOMES: UK VS. A SET OF COMPARATOR COUNTRIES

In this annex, we compare the mobile market outcomes (take up, coverage, speed, ARPU, data usage) against those in selected comparator countries (the US, Germany, France and Japan). We find that out of five countries, the UK is:

- the leader (together with France) in mobile connections per capita (although in all countries mobile connections exceed 100%), but in the 3rd position in mobile data take up (behind Japan and the US);
- in the 4th position in terms of 4G coverage (behind the US, Japan and Germany);
- in the 5th position in terms of mobile data consumption per user, with just 24% of the US data consumption and 20% of data consumption in Japan (but not far behind France and Germany);
- in the 2nd position in terms of mobile download speed (significantly behind Japan), but closely followed by Germany, France and the US.

In terms of average revenue per user (ARPU), revenues in the UK are c. 70% of mobile revenue in the US and 80% of mobile revenue in Japan (70-80%), but higher than in Germany or France.

Overall, it appears that the outcomes in the mobile market in the UK are inferior to those in the US and Japan, but are broadly comparable to those in France and Germany.

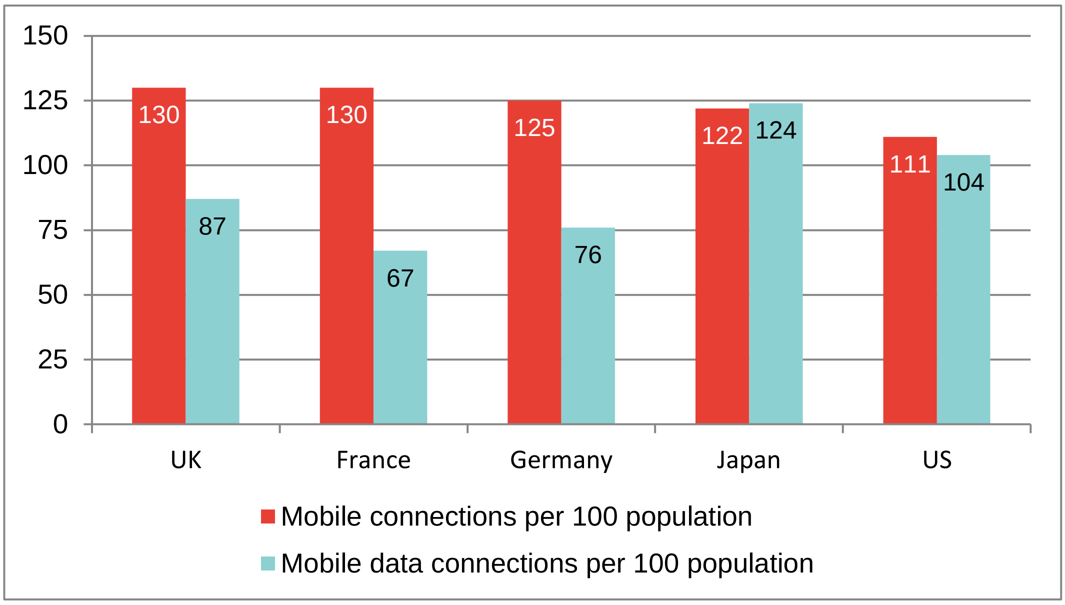
It appears that these outcomes are driven by a variety of different social and economic reasons, and cannot be easily explained by differences in market structure or any particular policy tool (such as coverage obligations).

Market outcomes

Mobile take up and coverage

While the UK leads the comparator countries (tied with France) in mobile connections per capita, this is not the case for data connections. In fact, the US and Japan are far ahead of the UK in terms of mobile data connections per capita, but France and Germany are substantially behind.

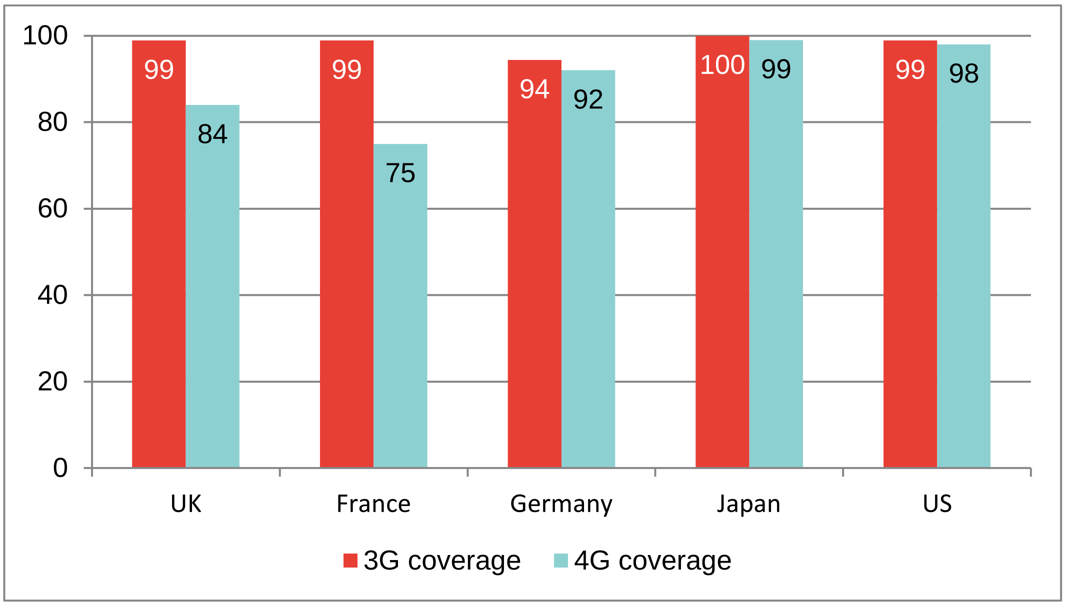
Exhibit 15 Mobile and data connections



Source: Ofcom, International Communications Market Review 2015

3G coverage is similar in the comparator countries, with all but Germany having 99%+ population coverage. For 4G the situation is quite different, with coverage ranging from 75% (in France) to 99% (in Japan), with the UK in the 4th place at 84%.

Exhibit 16 3G and 4G coverage by at least one operator, % of population



Source: 3G: GSMA; 4G: Ofcom

Note: Coverage measured as % of population with access to at least one 3G/4G provider

Data usage, speed and ARPU

The US and Japan have mobile data volumes four to five times higher than the European comparator countries.

Average monthly telecoms revenues in the UK (£37) are lower than in the US (£52) and Japan (£45), but higher than in France and Germany (£25).[146]

Exhibit 17 Average monthly mobile data volume per person (MB) and average monthly telecoms revenues per capita (£)

	UK	France	Germany	US	Japan
Volume	362	397	398	1,495	1,771
Revenue	37	25	25	52	45

Source: Ofcom, International Communications Market Review 2015

In terms of mobile speed[147], Opensignal reports Japan as the leader among the 5 comparator countries with c. 21 Mbps, with the four countries with similar speeds of 12-14Mbps (the UK being slightly ahead the remaining three countries).

Potentially explanatory factors

It is not clear whether these somewhat inferior outcomes in the UK (compared to those in Japan and the US) can be attributed to any particular factor. Most likely, they are driven by a mix of social and economic factors, some of which may not be easily observable.

Below, we look at differences in market structure, timing of 4G launch and coverage obligations. None of these differences (if exist) seem to play an obvious role.

Market structure

Market structure in all 5 countries appears to be broadly similar – with 3-4 national MNOs and a range of MVNOs (with the exception of Germany, where MVNOs appear to play a much more prominent role than in the other countries).

- There are three or four national mobile operators in each country (in the US, there are other regional operators, but they collectively represent only 2% of the market)
- The market leader in each country has 33-45% of market share. The lowest (33%) – in the US; 45% - in Japan. In the UK, the market leader EE has 35%.

The bigger differences are observed in the place of MVNOs in the market - whereas the UK's 17 active MVNOs[148] hold a combined 15% of subscribers, some of the comparator countries have a much stronger presence. In France, 35 active MVNOs have a combined market share of 23%, and in Germany there are more than 100 such entities (including the MNOs' discount sub-brands), accounting for about 50% of subscriptions in the markets. Japan and the US appear to be similar to the UK, in terms of the number of MVNOs and the market share they achieve.

[146] This does not necessarily reflect prices per minute, message or MB of data, but only total average revenue.

[147] Opensignal makes an adjustment for availability. Therefore, overall speed is defined as the average mobile data connection a user experiences based on both the speeds and availability of 3G and 4G networks.

[148] As of September 2016. Source: Globalcomms.

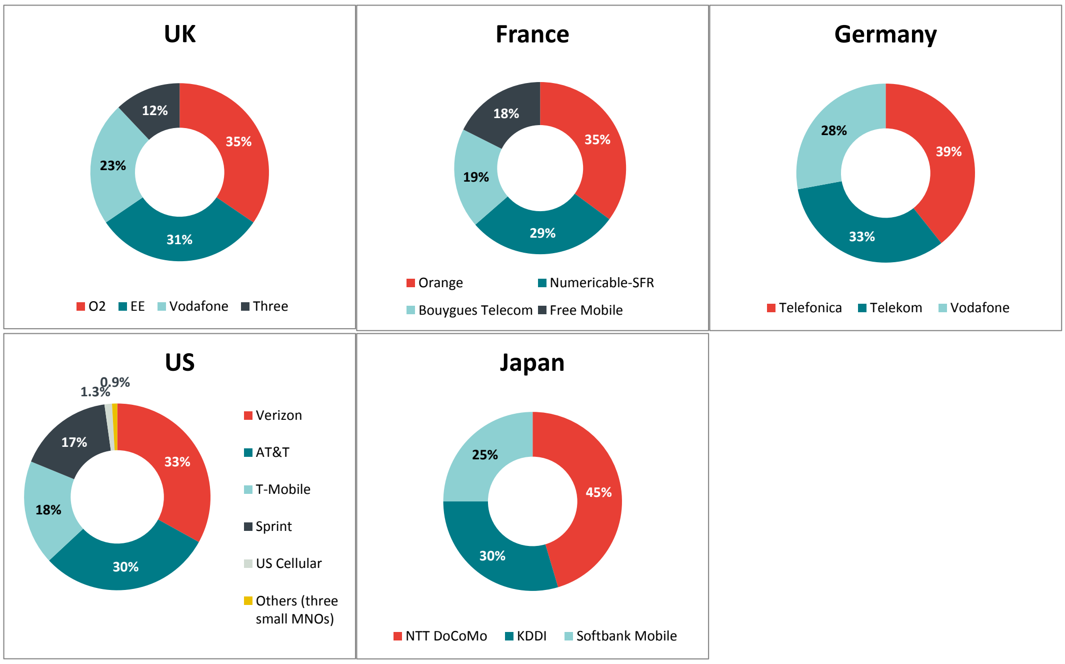
Exhibit 18 Market structures in comparator countries

Metrics	UK	France	Germany	US	Japan
# of mobile networks	4	4	3	8*	3
Market share of largest network	35%	35%	39%	33%	45%
# of active MVNOs	17	36	100+	9	16
Combined MVNO market share	15%	23%	50%	13%	8%

Source: Telegeography 2016

*Note: * 4 MNOs account for 98% of the US market*

Exhibit 19 Network market shares in comparator countries



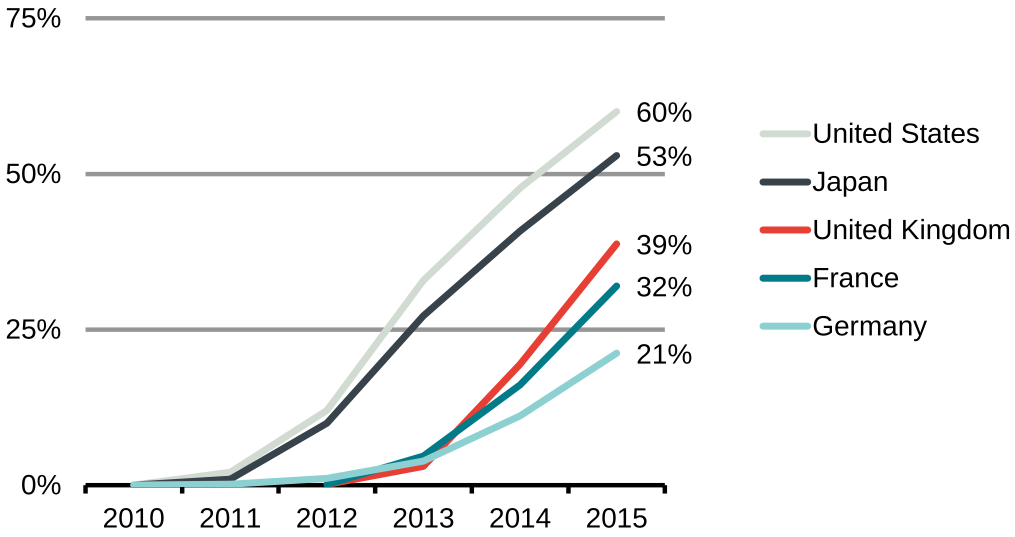
Source: TeleGeography, 2016

It is possible that stronger presence of MVNOs in Germany and France contributes to more competition and lower ARPUs than in the other three countries.

Timing of 4G entry

Japan, the United States and Germany all saw their first 4G services being launched in 2010, but the growth rate in Japan and the US was much faster than in Germany. The UK and France had their first roll-outs two years later, and quickly overtook Germany in 4G penetration rate, while remaining significantly behind the US and Japan.

Exhibit 20 4G as a share of all mobile subscriptions



Source: TeleGeography

Coverage obligations

Coverage obligations have been used in some countries, to varying degrees of success.

- The coverage obligations in the US (40% within 4 years and 75% within 10 years) was imposed on AWS (1.9GHz) spectrum licensees;
- In the UK, 98% population coverage by 2017 on one licence holder (O2).
- In Germany 4G operators were required to roll out in rural areas before entering urban areas, and they all met their rural coverage obligations within two years.[149]
- We are not aware of coverage obligations being imposed in Japan.

Overall, based on 5 observations, it is not clear whether coverage obligations result in better mobile coverage. Two countries with best 4G coverage (Japan and the US) had either no coverage obligation or an obligation which was not particularly demanding.

[149] See section [X] for more details.

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