CONNECTED FUTURE

NATIONAL
INFRASTRUCTURE
COMMISSION

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CONNECTED FUTURE: IN BRIEF

5G means seamless connectivity. Ultra-fast and ultra-reliable, transmitting massive amounts of data at super low latency. It will support the ever increasing requirements of the existing network and new applications as unknowable today as the 4G services we take for granted would have been a decade ago.

Securing the mobile networks necessary to put the UK at the forefront of this emerging technology will be critical to the growth of our economy. This report makes recommendations to make that happen.

The Commission's central finding is that mobile connectivity has become a necessity. The market has driven great advances since the advent of the mobile phone but government must now play an active role to ensure that basic services are available wherever we live, work and travel, and our roads, railways and city centres must be made 5G ready as quickly as possible.

PART 1: THE MOBILE REVOLUTION

The UK mobile market has transformed from a luxury in the 1980s to an essential today. 93% of adults in the UK own a mobile phone, smartphones have overtaken laptops as internet users' device of choice, and there are more mobile devices than people.

Yet the UK's networks are not complete. There are too many digital deserts across the country and the availability of our 4G network is worse than many countries including Albania, Panama and Peru.

PART 2: GOVERNMENT AS A DIGITAL CHAMPION

The market has driven enormous change – but now government must take responsibility to secure our digital future, starting with the creation of a strong digital champion backed by a dedicated cabinet committee.

Government must ensure we have the infrastructure in place to deliver 5G across our major centres and transport networks.

Major roads: Our motorways must have roadside networks fit for the future. The infrastructure should be in place by 2025.

Key rail routes: The railway network must rapidly improve connectivity. This will be best delivered in future by a trackside network. Government should provide a plan by 2017, and the infrastructure should be in place on main rail routes by 2025.

Towns and cities: Local Authorities and LEPs should work with network providers to develop approaches that enable the deployment of the tens of thousands of small wireless cells we expect to need in our urban centres.

PART 3: ENABLING THE MARKET TO DELIVER WHAT WE NEED

Government and Ofcom must ensure basic outdoor mobile services are available wherever we live, work and travel.

Regulation must keep pace with the rapid evolution of the mobile communications markets, allowing innovative new firms to provide services that the existing market has not delivered.

Greater connectivity is inevitable and essential. The UK cannot be left behind.

CONNECTED FUTURE AT A GLANCE

1G Analogue voice transmission

2G Digital talk and text

3G Data services become a core part of mobile phones

4G High speed internet access

5G Ultra-fast, ultra-reliable, mobile connectivity able to support ever larger data requirements

The market has driven great advances since the advent of mobile technology, but now Government must play a role in securing the more comprehensive coverage required for 5G.

5G City Centres

Local Authorities and LEPs should work with network providers to enable the deployment of the tens of thousands of small cells we will need in our urban centres.

Motorways

It is vital that our motorways have mobile networks fit for the future. Infrastructure should be in place by 2025.

Rail

The railway network must rapidly improve connectivity. Government should provide a plan by 2017, and the infrastructure should be in place on key routes by 2025

A universal service obligation for mobile

Mobile connectivity has become a necessity, consumers should enjoy essential services wherever they live, work and travel.

The UK is currently 54th in the world for 4G availability. Even our city centres are still plagued by 'not spots' - areas without any coverage at all.

EXECUTIVE SUMMARY – 5G AND THE FUTURE OF MOBILE NETWORKS

BACKGROUND

The National Infrastructure Commission (NIC) was asked to advise government on the steps the UK should take in order to become a world leader in the deployment of 5G mobile telecommunications networks, and ensure that the UK can take early advantage of the applications those networks may enable.

Since the spring, the NIC has engaged extensively with a wide range of stakeholders across industry, government and civil society in order to inform an analysis of future mobile telecommunications in the UK.

5G is expected to deliver a step change of ultrafast, low latency, reliable, mobile connectivity, able to support society's ever larger data requirements as well as wide ranging new applications. From connected and autonomous vehicles to an Internet of Things, 5G has the potential to be transformative across a number of sectors including health, transport and education, and will bring new innovations as unknowable today as the mobile apps and services we now take for granted were a decade ago. Securing the mobile networks necessary to put the UK at the forefront of this emerging technology will be critical to the UK's growth and to drive our industrial base into the internet applications and services economy.

The Commission's central finding is that mobile connectivity has become a necessity. The market has driven great advances since the advent of the mobile phone. But Government must now play an active role to ensure that basic services are available wherever we live, work and travel, whilst our roads, railways and city centres must be made 5G ready as quickly as possible.

PART 1: THE MOBILE REVOLUTION IN CONTEXT

In the thirty years since the first mobile cellular network was deployed in the UK, mobile communication has transformed how we live and work. This mobile revolution is widely expected to accelerate over the coming decades, resulting in a step change whereby the primary way we will access our digital lives, control our devices and absorb information will be mobile, wireless, rapid and reliable.

The UK mobile market has grown enormously since the 1980s, and mobile connectivity has been transformed from a luxury to an essential part of peoples lives. Today, 93% of adults in the UK own and use a mobile phone, smartphones have

overtaken laptops as internet users' device of choice, and there are more mobile devices than people. The mobile sector contributes an estimated £4.5 billion per annum to national economic output and is a major British industry in its own right, with the four largest mobile operators providing over 35,000 full-time equivalent jobs, and supporting some 140,000 UK jobs overall.[1]

The development of mobile communications, whilst rapid, has been an evolutionary process, with each mobile generation introducing improvements in quality and functionality. In the early 1980s, the first generation of mobile (1G) allowed for analogue transmission using the electromagnetic spectrum to send 'voice' in essentially the same way as any two-way radio. In the early 1990s, 2G was characterised by the adoption of digital transmission and switching technology, which increased the capacity and efficiency of networks and allowed for text messaging and some early data-based services. Whilst 2G networks resulted in significant growth in subscriber numbers, however, it was only with the advent of 3G in 2003 that data services became a core part of mobile phone use. The smart phone drove the adoption of the mobile internet, with speeds steadily improving, and audio and video streaming becoming feasible over mobile networks, as new technologies have been developed and introduced.

The introduction of 4G services, since 2012, has provided access to considerably faster data speeds and lower latency, and given rise to the various new services and applications we are now accustomed to in the smart phone age. This has resulted in an enormous increase in data rate usage per user, as streaming of services, such as video becomes commonplace. 2014 saw total data demand increased by 53 per cent in the UK (per active mobile SIM), similar to the increase seen in 2013.

As a result of these advances and the ability for increasingly sophisticated mobile devices to reach a mass market, mobile telecommunications and mobile services more broadly, are now established at the heart of our society and economy. They have fundamentally changed how we stay in touch, make purchases, view entertainment and participate in wider networks, and are increasingly important to business, where a digital transformation is underway. Indeed, a basic level of mobile service provision is increasingly regarded as a utility.

However, the UK lacks the level of coverage necessary to offer these basic mobile services ubiquitously. In rural areas 3% of the population do not have any coverage outside their homes (complete not-spots) and 25% do not have coverage offered by all the main mobile networks (partial not-spots). Coverage on our road networks is poor even for voice coverage (2G), 17% of A and B roads are in complete not-spots and an additional 42% have only partial coverage.

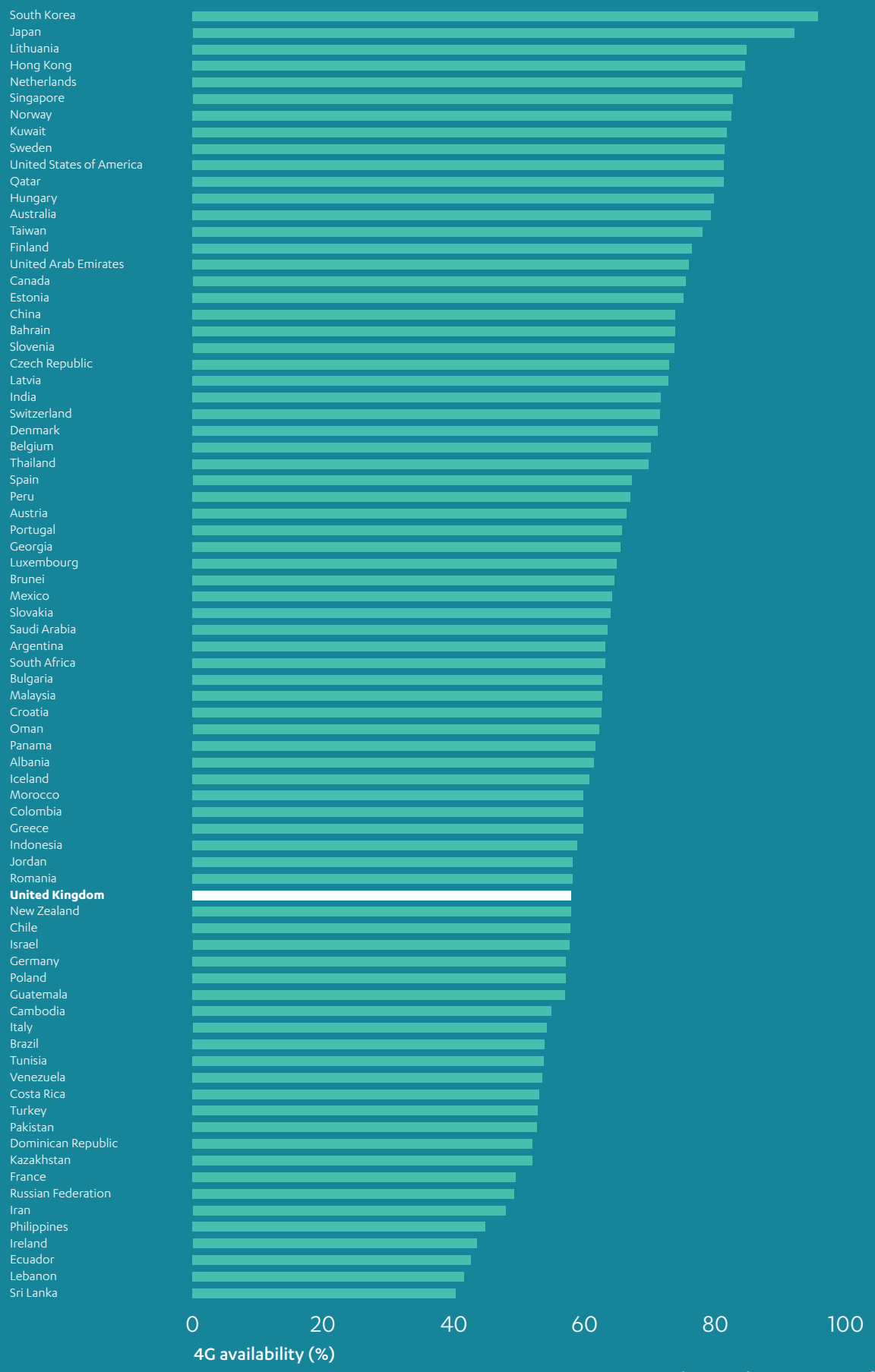
The UK performs poorly in comparison to other countries when looking at the availability of 4G – a metric that captures how much of the time a phone is able to connect to the 4G network (see chart below). This is driven to some extent by the fact the UK was significantly later than other countries in making 4G spectrum available, in part due to delays in the 4G spectrum auction stemming from operators threatening litigation around auction conditions. The first 4G auction in the US took place in 2008, compared with the 4G auction in the UK enabling all operators to deploy being held in 2013, with EE having begun deployment using its existing spectrum in 2012.

This delay means that operators in the UK are still in the process of deploying 4G networks. Although government has agreed with operators that they should deliver 90% geographic coverage for voice and text by 2017, it is not clear that this will meet consumer service expectations. As it stands, gaps in current 4G networks mean that around 20% of urban premises and almost 80% of rural premises are in a not-spot for 4G coverage.

The next generation of mobile connectivity will need to deliver the right type of networks, in the right places, for the services that people and business need. This means that 5G networks cannot be thought of in isolation but must be considered as part of a wider ecosystem of mobile connectivity. Delivering the connectivity we require for the future must start by ensuring that we have the networks we need for today – this will not only provide a basic level of service to consumers now but also the backbone of the network infrastructure we need for the new services of the future.

Only 8% of A and B roads have complete **4G coverage** with 47% having no 4G coverage at all

4G AVAILABILITY



OpenSignal November 2016 State of LTE Report

What is 5G?

5G is the next generation of mobile. Standards are due to be agreed in 2019 followed by gradual introduction from the early 2020s, but with full deployment unlikely until the 2030s. As well as existing spectrum bands, 5G technologies will use very high frequency spectrum, enabling rapid data transfer speeds and making it easier to download/upload on mobile devices. Where 5G networks are deployed, they will build on and add to the foundation created by previous mobile generations. This will be critical as the high frequency 5G technologies will only be able to transmit data across short distances; high quality wide area coverage will therefore continue to be essential.

The emergence of 5G will result in more complex and interconnected networks. Over time, the boundaries between, for example, fixed connectivity such as Wi-Fi and mobile, will become blurred giving users the sense of always on, high quality and rapid connectivity.

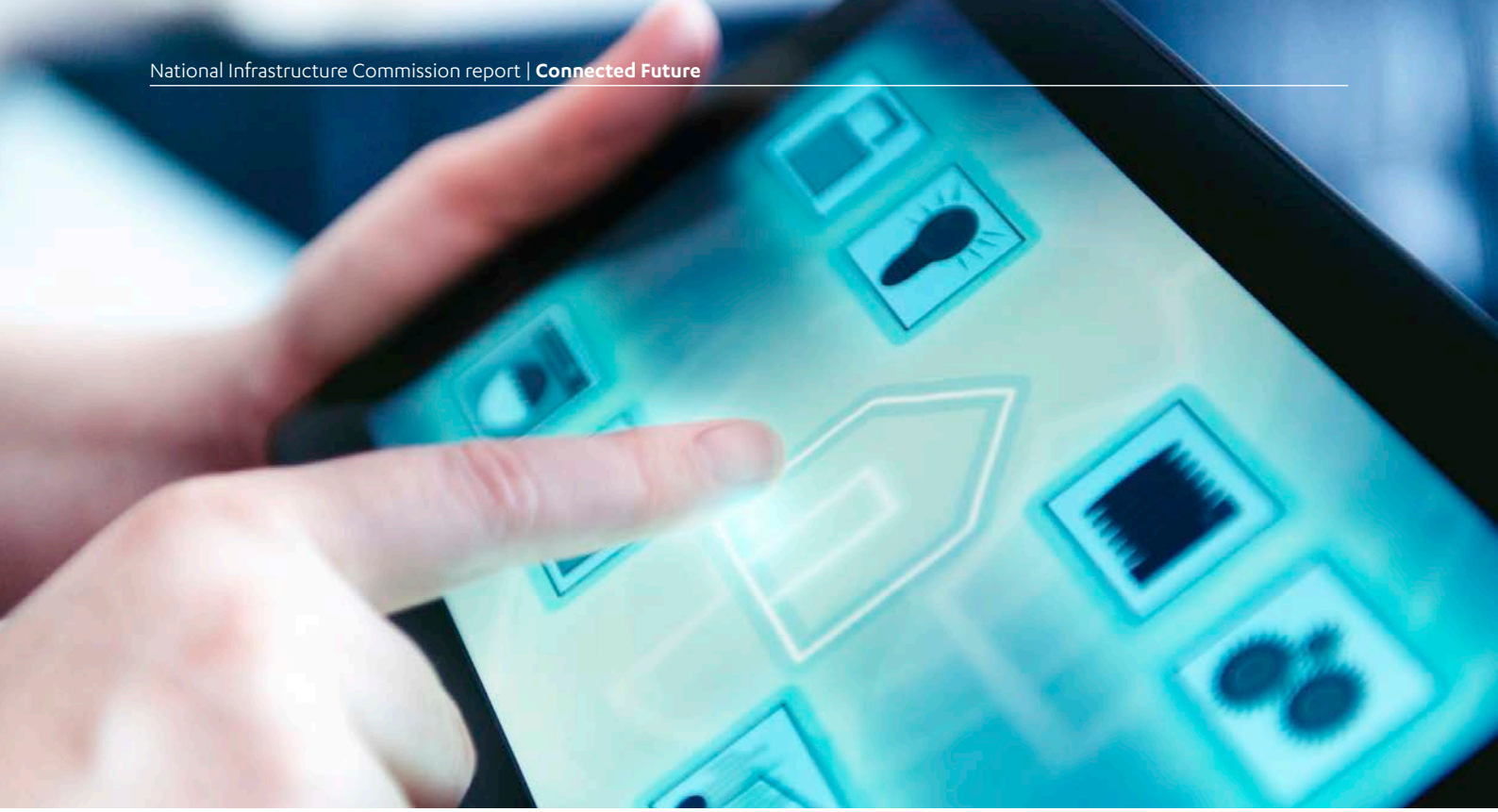
5G will also provide capacity for the many thousands of internet-connected devices, such as wearable health sensors, that are predicted to proliferate and enter our everyday world (known as the Internet of Things) and will underpin a number of new anticipated applications across a variety of sectors.

In the automotive industry, the low latency and high capacity capabilities of 5G will help facilitate the evolution of highly connected and, ultimately, fully autonomous vehicles. And, in sectors as varied as healthcare and gaming, the potential for new services – like real time health monitoring and augmented reality to improve lives and generate growth is enormous.

Realising these benefits will require the deployment of tens of thousands of new small cell mobile base stations connected to fibre optic cables, which will necessitate investment, coordination and removal of a number of regulatory barriers. In order to pave the way towards the vision of an always on, reliable and high speed network, it will be vital to address existing issues, such as areas of poor coverage.

Although all of the services that future mobile networks will enable cannot be known in advance, certain characteristics of future network requirements – such as the need for ever more data, reliability and connectivity across a range of sectors – are clear. Indeed, countries such as the United States and Japan already have data volumes four to five times higher than the UK, and are predicted to carry on growing exponentially.

The potential for mobile networks to enable innovative new services opens up manifold opportunities for the UK to exploit in fields such as connected and autonomous vehicles and the Internet of Things (IoT). Improved connectivity can help the UK get the most from its existing infrastructure, for example through



remote sensors enabling more efficient maintenance and the smart management of energy and water demand. The development of new services to make use of this level of connectivity will also bring UK plc a range of benefits, although as the fabric of our daily lives and our infrastructure becomes increasingly underpinned and reliant on advanced connectivity ensuring robust cybersecurity will also be critical.

Countries such as the United States and Japan already have data volumes four to five times higher than the UK

Other countries already have the advantage in terms of manufacturing the hardware needed for 5G, and the UK will not make up that ground. But the development of new services to make use of the improved connectivity offered by 5G is an area which will build on many of the existing strengths of the UK economy and provide opportunities for British firms both at home and abroad. The UK has the potential to be amongst the leaders in growth industries developing around internet and cloud-based applications and services, and around the Internet of Things, that depend on the widespread deployment of advanced mobile connectivity like 5G. But this potential will only be fully realised if the relatively slow roll-out and availability of 4G networks is not repeated.

The NIC's analysis suggests, however, that Mobile Network Operators (MNOs) will struggle to deliver these networks in the locations and at the speed needed without government assistance, supporting and coordinating the investments made by the private sector. A lack of government action risks the UK finding itself once again near the bottom of the league tables for connectivity as 5G is rolled out.

A lack of government action risks the UK finding itself once again near the bottom of the league tables for connectivity as 5G is rolled out.

Getting 5G deployment right will be critical in a future where connectivity is becoming integral to almost all parts of the economy, and the UK will put its future growth and competitiveness at risk if it falls behind.

PART 2: DIGITAL INFRASTRUCTURE AT THE HEART OF GOVERNMENT

Government as a digital champion

Given the importance of the UK's digital infrastructure – a key component of which is mobile telecommunications – it is notable that there is no single government department with responsibility for it. Instead, the government's interests in digital infrastructure are fragmented and entwined with the wider policy interests of numerous departments and agencies. For example, the Home Office's procurement and delivery of the Emergency Services Network is a major telecoms project and many of the projects for which the Department for Transport has responsibility, such as roads and railways investment and upgrades have a significant digital component. These activities do not have national mobile connectivity as a core objective. This risks the deprioritisation of telecommunications within them, resulting in a patchy, uncoordinated approach and missing the huge opportunity that digital infrastructure offers at a relatively small cost for the country's other infrastructure networks and wider economy.

Given the increasing importance of connectivity across all parts of the economy, digital infrastructure should sit at the core of the government's industrial strategy, ensuring that the UK can take full advantage of technologies such as artificial intelligence and augmented reality, and the needs of new industries, to improve productivity and develop the businesses of the future.

To grasp the inherent opportunities that digital infrastructure offers, there must be a single part of government, with senior ministerial and official leadership and supported by a well-equipped and powerful unit, that is responsible for setting the UK's overarching plan for digital infrastructure and ensuring that it is delivered in a coordinated way. The creation of a Director General lead in the Department for Culture, Media and Sport (DCMS) is a good first step.

Recommendation 1: Digital infrastructure lies at the heart of the UK's industrial strategy and affects every sector of the economy. To reflect its importance, ultimate government responsibility for digital infrastructure should reside in one place under a single cabinet minister with the authority to shape policy and delivery across government, ensuring that it delivers the government's overarching digital strategy. This work should report to the Economy and Industrial Strategy Cabinet Committee. It should:

- Identify the public projects that contain a significant element of digital infrastructure and establish and maintain a plan which sets out how they can help deliver the government's overarching digital strategy and maximise the benefit of better mobile telecommunications for UK citizens and businesses.
- Hold the various parts of government that are delivering digital infrastructure to account, in order to ensure adequate telecoms network provision in the delivery of its infrastructure programmes.
- Ensure that when upgrading existing or delivering new infrastructure, such as that alongside our roads and railways, the long term capacity needs of telecoms networks are considered and met. This could include installing more fibre and additional infrastructure to make sure that networks are future-proof. It will also mean ensuring that the networks are readily accessible to communications providers.
- Be a centre of telecoms expertise within government that supports departments in determining their needs and procuring telecoms infrastructure, and support departments in demonstrating and testing of new, digitally-enabled ways of delivering public services such as education and healthcare.
- Support and challenge local government in their plans to enable the delivery of digital infrastructure; both in terms of ensuring that these plans help the UK to meet its national objectives, and that local authorities develop consistent approaches to support the deployment of mobile infrastructure across the country.

Connectivity on our major roads

4,400 miles of Strategic Road Network (SRN), which are managed by Highways England, form a critical spine for enormous volumes of traffic.[2] Some 1,865 miles of the SRN in England are motorways, which comprise just over 1% of the total length of the entire road network, but carry 21% of all vehicle traffic (miles). Motorways are therefore crucial in linking communities and allowing us to commute to work, transport goods and visit friends and family.[3]

Given the importance of road transport, the impact that technology can have on the sector in the future has the potential to be transformative. A great deal of investment has driven progress in the development of connected and autonomous vehicles, including government support for research and development, but ensuring the necessary digital infrastructure is in place will be critical if the UK is to take advantage of this technology.

Predictions about the pace of mass deployment of fully autonomous vehicles vary, but most in the industry consider it to be inevitable in the longer term. Before that end point is reached, increasingly connected vehicles will be capable of delivering near term capacity, safety, environmental and information/entertainment benefits, as well as helping to pave the way towards full autonomy. In the UK, world leading automotive companies – such as Jaguar Land Rover – are delivering the innovation that will allow for increasingly sophisticated, connected vehicles.

However, without the appropriate underpinning mobile network infrastructure, the development and mass deployment of connected vehicles in the UK will be hindered.

Work commissioned by the NIC has estimated costs for a telecoms network that makes best use of existing roadside infrastructure alongside England's motorways to be in the order of £380 million. This network could be a commercial asset selling connectivity services to drivers, MNOs and the public sector, and the strategy for its deployment should aim to maximise private sector funding.

Recommendation 2: Our motorways must have mobile telecommunication networks fit for the future. It is vital that our motorways are able to meet both the long term operational needs of connected vehicles and the connectivity needs of the passengers. This will necessitate the timely installation of an open and accessible mobile telecommunication and backhaul network that is fit for the future.

The government should set out its plans for how to deliver this by the end of 2017. As part of this work consideration should be given to who is best placed to install, manage, fund and own the network, noting the potential for private sector funding.

Ensuring that best use is made of the existing infrastructure, such as masts, poles, ducts power supplies and the fibre network alongside our motorways, so that it can be used to support the backhaul of mobile data will be essential.

Ultimately, the government should ensure that the necessary infrastructure is in place on motorways by 2025 at the latest if it wants to offer a reasonable level of connectivity on a timescale consistent with the deployment of 5G networks.

Ofcom should set out how a regulatory regime would support these different operating models.

The provision of a robust and forward looking communications network infrastructure on our motorways should inform the process for ensuring that there is adequate coverage and capacity on the rest of the road network to meet future needs, including the partnerships needed between road stakeholders and mobile communications providers.

Connectivity on our main rail routes

There is huge demand for rail travel in the UK and it has seen strong growth with passenger numbers more than doubling since 1996/97 and some 1.7 billion passenger journeys made last year.[4, 5] However, mobile coverage on our rail routes is notoriously poor; making it difficult to carry out tasks taken for granted in many other contexts, such as making a phone call or checking emails. Although unreliable and patchy coverage on the railways is in part a consequence of difficult geographies, such as tunnels and cuttings, these issues are not insuperable.

The current model of delivery through existing mobile networks of towers set some distance from railway lines is enabling some of the most immediate challenges to be addressed but it is unlikely to be a cost effective means for achieving high capacity continuous connectivity to trains in the long term, and will become increasingly substandard as passenger data requirements increase. A different model will be necessary, one which relies on trackside infrastructure to support the deployment of high capacity wireless connectivity.

This will require the upgrade of our existing key mainline and metro rail routes, including the London Underground, and should be built in from the start for any new lines.

Improved trackside communications can also support a resilient and high performance operational network for our railways. Indeed, investment in the operational side of railway telecommunications must in future take full consideration of passenger needs, and vice versa.

Work commissioned by the NIC has estimated costs for such an approach to be in the order of £500-£600 million for the UK's main rail routes. In a similar model to a roadside telecoms network, this network could ultimately be a commercial asset selling connectivity services to train operators, MNOs, and the public sector, and the strategy for its deployment should aim to maximise private sector funding.

Recommendation 3: Rail passengers should have high capacity wireless connectivity. This should be achieved through a delivery model that utilises trackside infrastructure to provide an open and accessible mobile telecommunication and backhaul network that is fit for the future.

The government should set out its plans for how to deliver this by the end of 2017. As part of this work consideration should be given to who is best placed to install, manage, fund and own the network, noting the potential for private sector funding.

Ensuring that best use is made of the existing infrastructure, such as masts, poles, ducts power supplies and the fibre network alongside our railways so that it can be used to support the backhaul of mobile data will be essential.

Ultimately, the government should ensure that the necessary infrastructure is in place on the main rail and key commuter routes by 2025 at the latest if it wants to offer a reasonable level of connectivity on a timescale consistent with the deployment of 5G networks.

Ofcom should set out how a regulatory regime would support these different operating models.

Engaging local government as a partner

Delivering the mobile services envisaged for the future will require dense networks of potentially tens of thousands of new 'small cell' radio antennae in our towns and cities. This will allow for increased capacity requirements resulting from the predicted growth in data use from both people and machines to be met. It will also help to provide the underpinning infrastructure that will be necessary for a number of smart city tools and technologies to be introduced, such as the use of sensors and real time data feeds to tackle traffic congestion. However, there will be a significant challenge both in finding suitable sites and infrastructure to support these cells, and ensuring that telecoms networks meet local needs.

Recent planning changes and an amendment of the Electronic Communications Code have gone a long way to removing existing planning barriers. But Mobile Network Operators (MNOs) will need to bring together their network expertise with that of local authorities, who best understand their area and can provide an accurate picture of local area requirements.

Recommendation 4: Local government should actively facilitate the deployment of mobile telecoms infrastructure:

a) Local authorities should work together and with Local Enterprise Partnerships (LEPs) to develop coordinated local mobile connectivity delivery plans. These plans should:

- set out how local authorities and LEPs will enable the deployment of mobile networks and maximise the opportunities and benefits to residents and businesses;
- be developed in discussion with mobile network operators and infrastructure owners;
- identify a designated individual with lead responsibility for engaging with mobile telecoms infrastructure providers;
- consider the role of local government assets and infrastructure, (e.g. land, buildings, roads, street furniture) and help coordinate the role that other public buildings in an area (e.g. hospitals and universities) can play to facilitate the deployment of mobile telecoms infrastructure; and
- consider how the deployment of digital infrastructure can be established as a priority in local planning policy.

Local authorities and LEPs should report annually to the government department with responsibility for digital infrastructure on their progress delivering against these plans.

b) Local models for facilitating the deployment of these networks should be piloted and evaluated to inform national roll-out. Any pilot programme should allow for the evaluation of deployment models in different types of area (e.g. urban, rural, coastal) and in both single-tier and two-tier local government areas. It should also seek to establish how high quality design can minimise the impact of hosted infrastructure on the built environment. Such pilots would be a good use of a proportion of the funding recently announced in the Autumn Statement to support mobile telecoms infrastructure.

PART 3 – ENABLING THE MARKET TO DELIVER WHAT WE NEED

Meaningful coverage

In February 2015, Ofcom varied the licences of the UK's four MNOs to commit the operators to providing 90% geographic coverage for voice calls by the end of 2017.[6] Additional sites are being deployed in order to meet this commitment and to achieve an improvement in indoor data coverage to 98% of premises. And, as part of the UK government's new Emergency Services Mobile Communications Programme, EE will be building more than 500 additional 4G sites which will have the added benefit of providing increased coverage for their mobile customers.[7]

However, although geographic coverage data offers a good indication of the reach of mobile voice and data services, the picture is incomplete in terms of mobile user experience. For example, a recent study (April 2016) by Which? and independent mobile coverage experts OpenSignal found in their November 2016 'State of LTE' report that mobile customers across the UK's four networks were on average able to access 4G just 53% of the time. This indicates that network availability from a user perspective is lower than that suggested by overall coverage statistics.

Combined with poor coverage on large parts of our transport network, this suggests that improvements are necessary. The urgency of this is highlighted by the CBI's recent finding that 81% of firms see more reliable mobile connectivity as essential. As a minimal level of mobile service becomes more and more important – and increasingly similar to a utility – this patchy network picture will become untenable.

Provision of outdoor mobile services remains a challenge. Government and Ofcom should act to address this now, particularly as the emergence of 5G technology is unlikely to provide a solution but instead will itself require the right basic infrastructure to be in place.

*Independent mobile coverage experts OpenSignal found in their 'State of LTE' report that mobile customers across the UK's four networks were on average able to access 4G just **53%** of the time*

Recommendation 5: Government and Ofcom should develop a meaningful set of metrics that represent the coverage people actually receive and use these to determine a mobile universal service obligation setting out the minimum service level people should expect to receive.

a) Ofcom, government and mobile operators should report their coverage so that they are genuine and meaningful reflections of the services enjoyed by customers. Metrics should be measurable and based on the reality of service and coverage provided to customers, not based on simulated or predicted performance. Ofcom should set out how this is best achieved by the end of 2017.

Ofcom and government should use these metrics as the basis of future interventions such as spectrum licence obligations or voluntary agreements with operators.

Government, Ofcom or the Advertising Standards Authority should take action if operators advertise or report coverage in a way that does not reflect services being delivered to consumers on an everyday basis.

b) Mobile services are increasingly viewed as essential, underpinning our daily lives and the digital economy. Government must deliver a view by the end of 2017 on what aspects of mobile services are considered "essential". It should then establish how this "essential" level of service provision can be made available through a mobile universal service obligation regardless of the network to which a customer is subscribed. Government should engage with Ofcom and industry to establish the best delivery mechanism, whether through spectrum licence obligations, enabling roaming, enabling cross operator Mobile Virtual Network Operators (MVNOs), through government procurement or a mix thereof.

Government with the assistance of Ofcom should deliver this as soon as is practical but no later than 2025.

Regulation that is fit for the connected future

The future of mobile looks different to the past and enabling that future will necessitate regulatory change. Delivering extensive coverage at high data speeds and with robust reliability, with each operator running a separate network, would require vast levels of investment. There must be an increased role for infrastructure sharing, not only to reduce the costs of network deployment where possible but to make best use of the limited supporting infrastructure such as street furniture in our towns and cities. Any regulation of network infrastructure should seek to be supportive of this sharing, whilst ensuring competition and fair access are maintained.

In addition, the paradigm of competition in all areas of the mobile market may break down in coming years, particularly where the business case for the private sector to deploy mobile telecoms infrastructure is weak, such as rural areas. It may be necessary to allow a single set of infrastructure that supplies services to all.

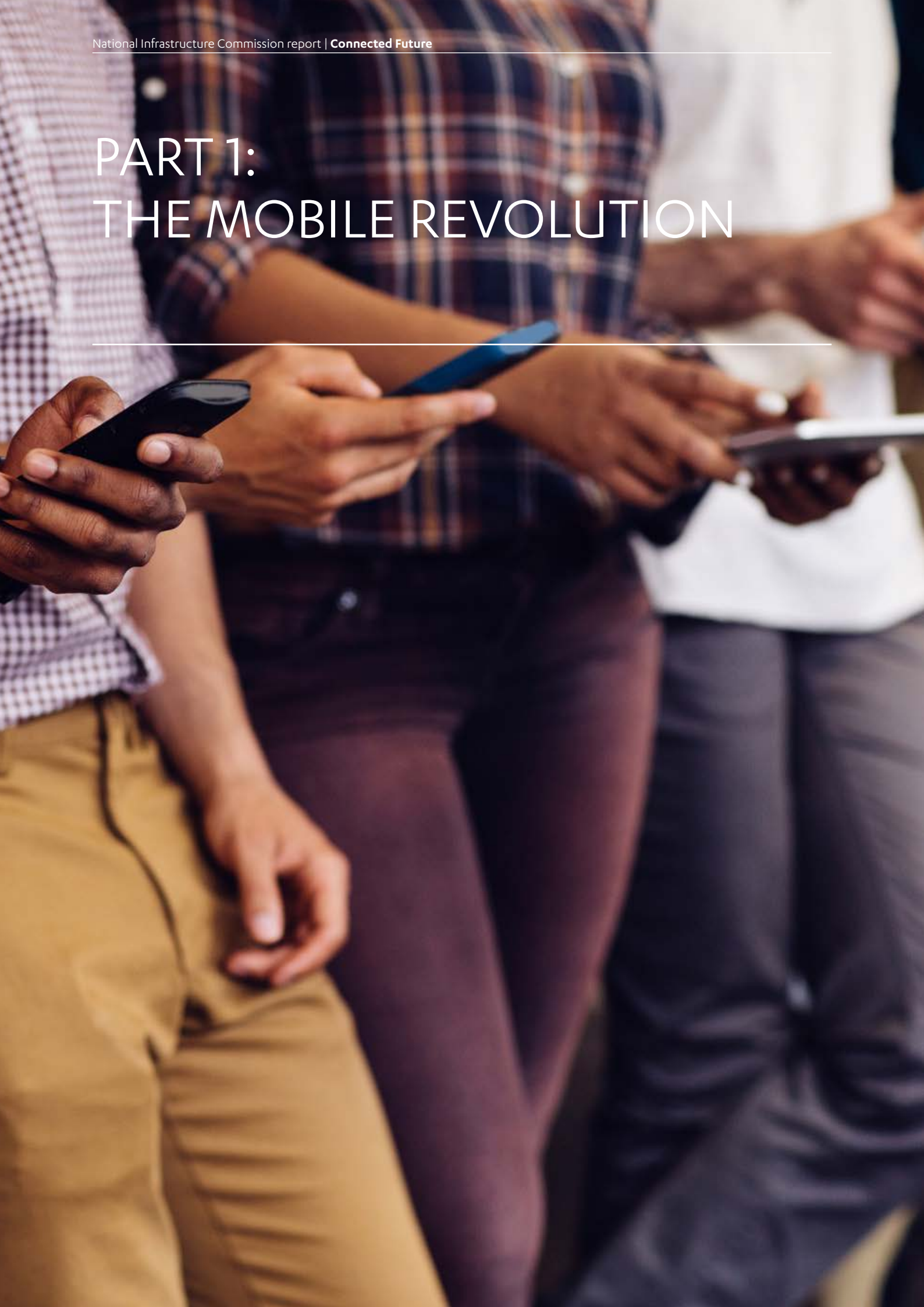
Recommendation 6: By the end of 2017 Ofcom and government must review the existing regulatory regime to ensure that it supports the sharing of telecoms infrastructure. This will be particularly important for areas of the country where competition driven markets have struggled to provide the necessary mobile infrastructure.

As well as lower frequency radio spectrum, 5G expects to make use of very high frequency millimetre wave radio spectrum, provided by dense networks of very small mobile cells. These are not anticipated to be deployed outside of urban centres and other 'hot-spots' by mobile operators. Auctioning spectrum licences in large, national scale blocks, at these very high frequencies, risks a significant share of the radio spectrum lying fallow in large parts of the country, because deploying the dense networks described above may not be profitable for the major operators in these areas, yet the spectrum will still be inaccessible to other users. This could act as a barrier to entry for new firms to compete in the provision in mobile services and may impede the most widespread deployment of 5G high frequency small cells.

Recommendation 7: Ofcom and government must ensure they keep pace with the rapid evolution of the mobile communications market, and that the regulatory regime is fit for purpose. By the end of 2017 Ofcom and government must review the regulatory regime to ensure that spectrum allocation and regulatory decisions support a growth model in a world where technology developments enable greater shared access and interoperability. Government and Ofcom should review how unlicensed, lightly licensed spectrum, spectrum sharing and similar approaches can be utilised for higher frequencies to maximise access to the radio spectrum. Spectrum decisions should where possible enable:

- Community or small provider solutions to meet the needs of local areas if they remain unserved or poorly served.
- Niche entrants or sub-national players to access the higher frequency spectrum anticipated for 5G. Allocation of nationwide spectrum licenses to a small number of operators could leave large areas of the UK fallow.
- Businesses, universities and others to access spectrum where they need to within their factories or buildings, including already licensed spectrum if there are no interference risks. This will unlock multiple wireless service provider options, including self-provision, spurring the innovation in industrial internet of things, wireless automation and robotics.

PART 1: THE MOBILE REVOLUTION



The significance of mobile communications

1.1 In the thirty years since the first mobile network was deployed in the UK, mobile communications have transformed how we live, work and play. Wireless is the principal means of accessing the internet and the services it offers. Today, 93 per cent of adults in the UK own and use a mobile phone, and smartphones have overtaken laptops as internet users' device of choice.[8] The services accessed via mobile devices have fundamentally changed how we stay in touch, make purchases and participate in wider networks, and are increasingly critical to business, creating an ever more connected society. A digital transformation has been described as taking place across various industries, with digital technology acting as an enabler of "fundamental innovation and disruption".[9]

1.2 Mobile communication is a central part of this story, helping create opportunities to increase efficiencies, productivity and income. It has been estimated that the rollout of 4G networks alone will provide a £75bn boost to the UK economy.[10] And recent research by the CBI found that 81 per cent of firms see more reliable mobile connectivity as essential.[11] Mobile telecoms is also a major British industry in its own right, with the four largest mobile network operators providing over 35,000 FTE jobs, and supporting some 140,000 UK jobs overall, contributing £4.5 billion per annum to national economic output.[12]

The evolution of mobile communications

1.3 Given its current prevalence and significance, it can be surprising to reflect on how recently mobile telecoms technology emerged. The first public service for a mobile telephone was in Japan in 1979, which was followed by the introduction of the 'Nordic Mobile Telephone' in Europe. In 1983, the first commercial services were introduced by Motorola in the USA.[13] Cellular networks were first deployed in the UK by Vodafone and BT Cellnet in 1985, inaugurating the first generation of mobile systems.[14]

1.4 The development of mobile communications has, from the beginning, been an evolutionary process, with each generation of mobile standards introducing improvements in quality and functionality. In the early 1980s, the first mobile generation, or 1G, introduced a niche service to a limited number of subscribers, which allowed for analogue transmission using the electromagnetic spectrum to send 'voice' in essentially the same way as any two-way radio.

1.5 The second generation of mobile, 2G, was introduced in the early 1990s and was characterised by adoption of digital transmission and switching technology, which increased the capacity and efficiency of networks and also allowed for the introduction of some early data services, with the first text (SMS) messages sent in sent in Finland in 1993.[15]

1.6 Although 2G networks created a step change in the global number of subscribers, it was not until the advent of 3G in 2003 that data services became a core part of mobile phone use.[16] This drove the adoption of the mobile internet, with data rates and speeds steadily improving through the development of various new technologies (sometimes referred to as 3.5G) and allowing for streaming of audio and video.[17]

What is Machine to Machine and The Internet of Things?

Machine-to-Machine, or M2M, is a connection between devices, often wireless, where human input is not necessarily required. For example, smart electricity and gas meters, which use a SIM to report energy usage data for billing purposes.

The Internet of Things (IoT) is a broader term for the creation of new and innovative services by the interconnection of everyday devices, often using M2M connections. M2M and the IoT are not reliant on a specific mobile generation – in fact 2G technology provides sufficient bandwidth and connection speed in many instances – but connected devices are predicted to grow exponentially across the coming decades, which will place growing demands on the capability of the UK's networks.

1.7 The transition to 4G services, seen in the UK since 2012, has provided users with access to considerably faster data speeds and lower latency (or 'lag'), and given rise to the proliferation of the manifold new applications that are increasingly taken for granted in the smart phone age. This has resulted in an enormous increase in data usage per user as streaming of services such as HD video becomes commonplace. Data demand increased by 53 per cent in the UK in 2014 alone.[18]

1.8 As well as improving the connectivity of individual users, advances in mobile technology have also resulted in the emergence of devices connected over the internet, known as the Internet of Things (IoT). Although still at a nascent stage, there are already some 6 million connected devices in the UK.[19] This figure is predicted to increase rapidly with, for example, energy suppliers committed to installing around 50 million gas and electricity smart meters to all homes and small businesses by the end of 2020.[20]

1.9 The potential for connected devices is vast, and has already led to the emergence of wearable sensors for people with serious health conditions as well as developments in many other sectors, from logistics through to agriculture.[21]

Figure 1: Features of the mobile generations

Generation	Primary Services	Key differentiator	Weakness (addressed by subsequent generation)
1G	Anologue 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	
5G	Enhanced mobile broadband, Massive Machine type communications/IoT, critical communications	Ultra-fast, low latency and reliable connectivity giving the sense of ubiquitous coverage. Enabling numerous new benefits across a range of industrial sectors	

The UK mobile ecosystem

1.10 Over the last decade, the UK mobile market has undergone a number of significant changes reflecting developments in technology, demand for services and market maturation. Since the 2010 merger between T-Mobile and Orange there have been four UK Mobile Network Operators (MNOs) which own and maintain mobile networks and licenced spectrum.

Figure 2: UK Mobile Network Operators and share of subscribers

Operator	Subscribers including MVNOs (%)	Ownership	Network Sharing	Active Infrastructure	Passive Infrastructure
BT/EE	33	BT Group	MBNL	Operator retains ownership. Operational responsibility for 3G network with MBNL.	Operator retains ownership. MBNL manages sites.
Three	11	Hutchison			
O2	33	Telefonica	CTIL	Operator retains ownership. Operational responsibility split geographically. Vodafone West, O2 East.	CTIL owns passive assets. CTIL Manages sites.
Vodafone	23	Vodafone			

Source: Analysis Mason Data (note: "active" describes antenna and related radio equipment, "passive" enables the active infrastructure to operate, e.g., masts and power supply.)

1.11 In recent years network sharing agreements have been established by the MNOs through joint ventures between EE and Three (MBNL), and O2 and Vodafone (CTIL). This marks a departure from the previous model of vertical integration and is widely seen to have reduced the fixed costs of network deployment, operation and upgrade and also to have improved coverage.

1.12 At the network-supply level, access to cell sites is increasingly controlled through third party providers known as Wholesale Infrastructure Providers (WIPs). Both MBNL and CTIL utilise third party sites for locating mobile network equipment. In the UK the largest WIP is Arqiva, which has some 16,000 sites including 8,000 active cellular sites in the UK.[22] Wireless Infrastructure Group are also very active in the wholesale market, owning more than 2,000 shared communication infrastructure assets and providing independent infrastructure aimed at delivering improved, smart city connectivity. Use of WIPs results in cost savings for MNOs through economies of scale in a similar way to network sharing, indeed, industry analysis suggests that use of WIPs can save as much as 50 per cent of costs in some circumstances. As a result the need for increased infrastructure sharing has been highlighted as central to delivering future networks efficiently and effectively.[23]

1.13 An important feature of today's mobile market is that customers are no longer constrained to use only the services provided by their MNO. The internet is an open platform, and access to it via smart phones 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, increasing demand for mobile data. These applications have also enabled the growing substitution of traditional mobile services, including voice calls and SMS texting, by comparable services offered through web-based applications such as WhatsApp and Skype. Taken as a whole, the changes seen in the mobile market have increased complexity considerably.

Mobile Virtual Network Operators

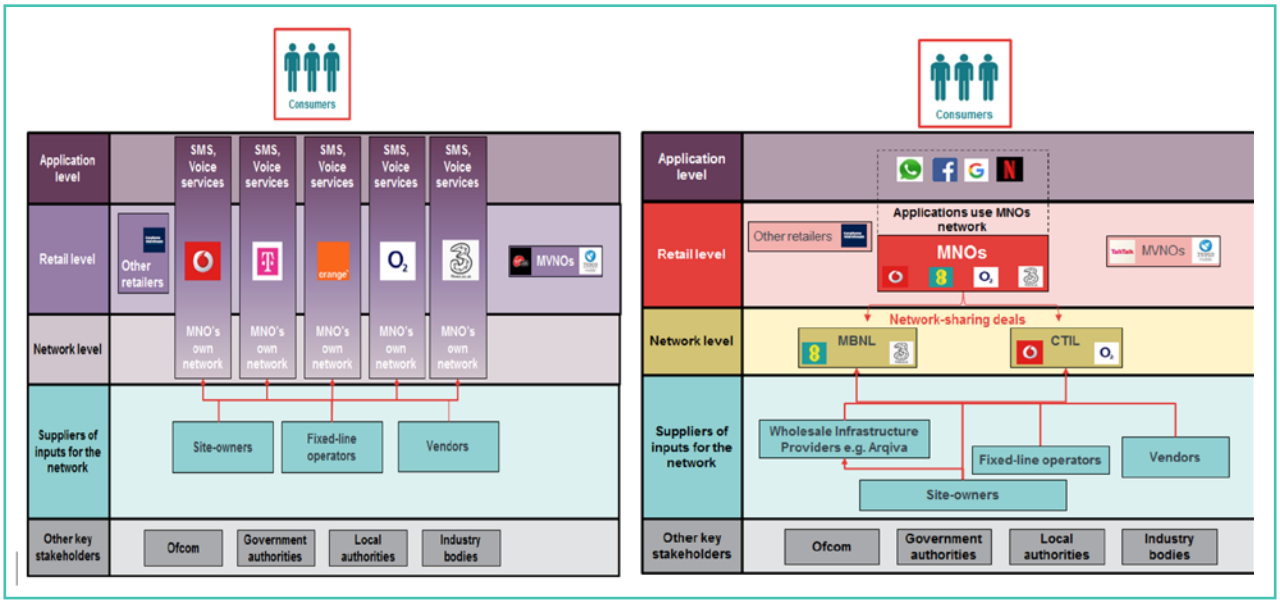
Mobile Virtual Network Operators (MVNOs), offer services similar to a mobile network operator (MNO), but MVNOs do not own the infrastructure or radio frequency spectrum. Instead, MVNOs enter into agreements with MNOs which then provide access to spare infrastructure capacity and spectrum. Depending on the type of MVNO, it will either buy bulk access to the network services from the MNO at discounted rates and then set its own proposition and retail prices, or it will enter into a reseller agreement with the MNO. MVNOs help to foster competition in the market by providing more diverse customer products and services. In the UK, MVNOs hold a combined 15% of total subscribers. The largest UK MVNO is provided by Tesco, which has over 3.5 million customers and runs on O2 infrastructure.

1.14 However, whilst significantly changed, the UK mobile market has remained competitive. Four MNOs still play a central role in network investment and seventeen Mobile Virtual Network Operators (MVNOs) are active,[24] helping foster competition. As a result, consumers have enjoyed innovative services and pricing in recent years, such as unlimited internet data, and UK prices are among the lowest in Europe, with the cost of a typical package falling by two-thirds since 2003.[25]

1.15 Following some years of declining revenues, the UK mobile market appears to have stabilised, with total telecoms revenue growing by £0.2bn (0.5%) to £37.5bn, and UK mobile companies generating some £15bn in revenue.[26] At the end of 2015, UK mobile subscriptions had reached 91.5 million and were continuing to grow.

1.16 Rapid advances in mobile device technology have also impacted the mobile ecosystem profoundly. Smartphones and tablets have been phenomenally popular with consumers, and have transformed how we communicate and consume media. This, in tandem with the launch of 4G, has been a further factor driving the very significant data usage increases seen over recent years. The graph below shows recent and predicted increases in global data usage; a similar pattern of growth has been seen and is forecast in the UK.

Figure 3: Changes to the mobile telecoms market, 2005 – present



1.17 In the UK, MNOs have invested billions in 4G network deployment, and "by the end of 2015, 39.5 million mobile connections could access 4G services, an increase of 15.9 million compared to the previous year, equivalent to 46 per cent of all UK mobile connections (excluding Machine to Machine connections), an 18 percentage point increase".[27]

What is 4G?

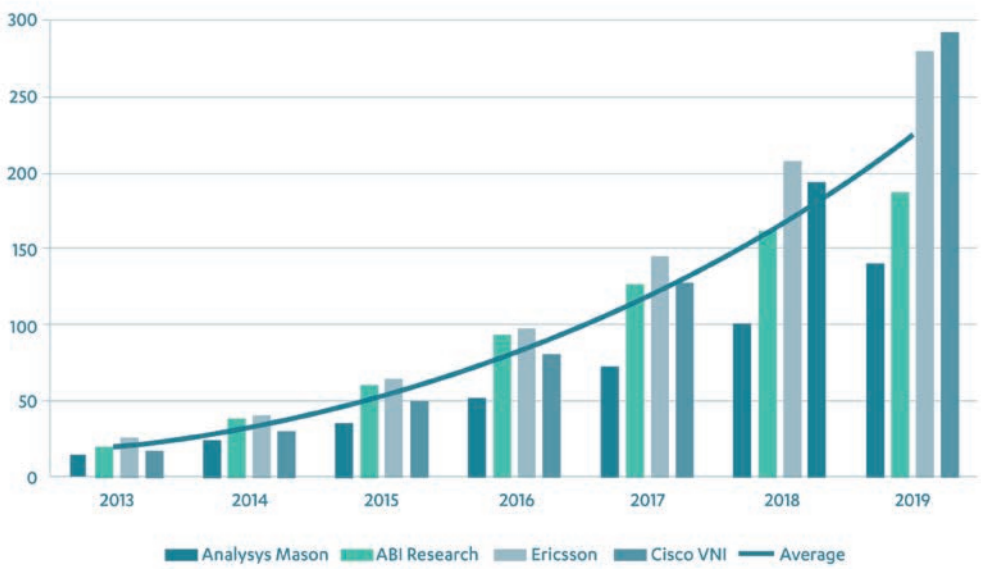
4G stands for the 4th generation mobile communications standard. It allows internet access at higher speeds than previous standards. All premium smartphones can use 4G services, but are still compatible with previous (2G/3G) standards. The first commercial 4G service was launched in the UK in Oct 2012 by EE, and the auction for 4G spectrum ended in Feb 2013, with EE, Telefonica (O2), Vodafone, Three and Niche Spectrum Ventures Ltd (a BT Group subsidiary) receiving licences. Vodafone and Telefonica launched their 4G services in August 2013, and Three followed in 2013 (London) and 2014 (nationwide). Voice over 4G networks is now being deployed across the UK.

1.18 However, it is notable that the majority of traffic to mobile devices is now delivered over fixed line Wi-Fi networks, with this share predicted to grow further.

1.19 As data consumption over mobile devices has increased, there has been a corresponding decline in use of a number of more traditional telecoms services. Fixed home lines and fixed voice call minutes fell by seven billion minutes (9.2%) in 2015.[28] And traditional mobile messaging (SMS/MMS) has declined for three consecutive years due to the rise of substitute services such as WhatsApp and Facebook messenger.

Figure 4: Industry forecasts of global mobile data traffic

Traffic in exabytes



How do mobile networks function?

1.20 In order to allow tens of millions of people across the UK to make calls, send texts and access mobile broadband services, each of the four MNOs divides the UK into thousands of individual geographic areas known as 'cells'. At the heart of each cell is a fixed-location base station. Mobile phones access the mobile network by sending and receiving data from a nearby base station, and switch from one cell to another as the mobile device user travels and reaches what is called the 'cell edge'.

1.21 The UK mobile network is extensive with the four MNOs utilising some 40,000 base station sites to provide mobile coverage, and each utilising their own 'core fibre' fixed network as well as using fibre connectivity from third parties such as BT. The UK's four MNOs operate under a licence which grants them access to specific radio spectrum, although network share agreements and use of third party owned sites play an increasingly important role. How the mobile network functions is outlined below:

Figure 5: A roof mounted macro cell base station, a mast mounted macro cell base station, and an EE small cell mounted on a lamppost.

There are currently 40,000 base station sites across the UK. The denser network required for 5G will require many more.

Mobile network infrastructure

Mobile network infrastructure can be divided into three main elements:

- The **radio access network**: the network of base stations providing cellular coverage across the UK to transmit and receive data from mobile devices such as smart phones.
- The **backhaul network**: the network which relays data from the base stations to the operator's core network. Backhaul can be over physical cabling, such as fibre or over wireless microwave links – often used in more remote areas. MNOs therefore use a combination of microwave and physical backhaul, with fibre now preferred where possible due to its ability to carry high capacity data. In some cases fixed-line operators (e.g. BT and Virgin) provide the links necessary to connect different parts of the MNO's network and in other cases MNOs provide these links themselves.
- The **core network**: the "intelligent" part of the network owned by each MNO, 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.

Base Stations

Base stations send and receive mobile voice or data information. They vary in size and cost, but each requires an appropriate site with a power supply and, generally, a fibre connection. The decision about which type to install on any given site depends on the coverage area required and the service – in terms of data speeds/quality – to be delivered. Mobile networks are essentially comprised of four types of base station, known as:

- **Macrocells**, which provide the main radio coverage for a mobile network. Antennas for macrocells are mounted on ground-based masts, rooftops and other existing structures.
- **Microcells**, which provide infill radio coverage and additional capacity where there are high numbers of users within urban and suburban macrocells. The antennas for microcells are mounted at street level (i.e. below the surrounding buildings and terrain) typically on the external walls of existing structures, lamp-posts and other street furniture.
- **Picocells**, which provide more localised coverage than microcells (e.g., inside buildings) where coverage is poor or there are high numbers of users
- **Femtocells** which are more commonly installed by home or small business owners as opposed to traditional mobile network operators.

Spectrum

The radio spectrum is part of the electromagnetic spectrum, and is widely used for modern day telecommunications, broadcast TV and radio. Information can be transmitted over different frequency bands within the radio spectrum, broader bands enabling more data to be transferred. The radio spectrum is a finite resource and so bands are allocated to users such as the mobile operators by Ofcom to ensure the spectrum is efficiently used and to avoid interference between users. Different frequency bands have different characteristics with lower frequencies providing better wide area coverage and building penetration and higher frequencies offering better capacity, but over shorter distances. A mixture of high and low frequency bands are therefore needed by mobile operators and used at each base station to provide services.

MNOs currently hold spectrum licenses to operate in the 800MHz, 900MHz, 1,800MHz 2,100MHz and 2,600MHz bands, although each operator has different exact spectrum holdings. Not all spectrum is licensed; WiFi networks use shared 2.4GHz and 5GHz frequency bands, with each band offering a trade-off between capacity and coverage.

Coverage

Mobile voice coverage is provided by MNOs using a combination of 2G and 3G technologies with mobile data coverage provided over 3G and 4G. In February 2015, Ofcom varied the licences of the UK's four MNOs to commit them to providing 90% geographic coverage for voice calls by the end of 2017. Ofcom's 4G auction was designed so that one licence – acquired by O2 – has to roll out 4G to cover at least 98% of the UK population by 2017 at the latest, with market forces pushing the other MNOs to follow suit. Additional sites are being deployed to meet these commitments and to achieve an improvement in data coverage to 98% of premises. As part of the UK Government's new Emergency Services Mobile Communications Programme, EE will be building more than 500 additional 4G sites which will have the additional benefit of providing increased coverage for their mobile customers.

UK COVERAGE FOR MOBILE VOICE SERVICES, BASED ON COMBINED 2G AND 3G COVERAGE

	O2	Vodafone	EE	Three
Outdoor coverage				
Premises	98%	98%	99%	98%
Geographic	72%	77%	78%	68%
Indoor/In-car* coverage				
Premises	93%	92%	94%	93%
Motorways	97%	97%	99%	98%
A & B Roads	67%	73%	81%	73%

UK COVERAGE FOR MOBILE DATA SERVICES, BASED ON COMBINED 3G AND 4G COVERAGE

	O2	Vodafone	EE	Three
Outdoor coverage				
Premises	92%	92%	98%	98%
Geographic	47%	49%	75%	68%
Indoor/In-car* coverage				
Premises	86%	83%	94%	93%
Motorways	83%	83%	99%	98%
A & B Roads	49%	48%	79%	73%

*For in-car coverage we assume that the phone is used within the vehicle. Coverage would be better if a car kit with an external antenna were used.

Source: Ofcom analysis of operator data

Although coverage data provides a good indication of the reach of mobile voice and data services, the picture is incomplete in terms of mobile user experience. For example, a study this year by Which? and independent mobile coverage experts OpenSignal found that mobile customers in the UK were able to access 4G just 53% of the time on average. This suggests that network availability from a user perspective is lower than that set out in coverage statistics. Coverage on our transport networks is often poor. The RAC foundation found that c. 4,600 miles of British roads have no 2G mobile phone coverage from any network provider – the minimum coverage required to make a call – and that over half of the entire road network had no 4G coverage. The situation is similarly poor on the railways with rail passengers frequently unable to make voice calls, utilise SMS messaging or send and receive mobile data due to poor coverage across the rail network.

Future mobile networks

1.22 Each successive mobile generation has given rise to an ever larger number of users, uses and applications. The impact has been profound, with mobile connectivity often now described as a utility rather than a luxury. This pattern is set to continue as mobile markets adapt and 5G technologies are introduced. Against this context, it will be vital for mobile networks to be deployed and available in the places and with the capability that people and businesses require.

1.23 In order to help inform a sense of how the UK's mobile networks are likely to evolve across the next decade and beyond, it is instructive to consider the factors which will influence this together with lessons from previous network deployments. A central factor will be the way in which network providers respond to the future demands of society and the economy for mobile services.

Evolution or revolution?

1.24 A common feature across all previous mobile generations – and one which is likely to continue – is the evolutionary nature of both technological improvement and mobile network deployment. The next mobile generation – 5G – is widely predicted to mark a step change in digital communications, but it will take time for business models for new mobile services to develop, for networks to be rolled out and for new technologies to be tested and brought to market. Despite a great deal of speculation and enthusiasm about the possibilities, 5G is still at an early stage with primary research ongoing and standards not yet set. There is not yet a universally agreed definition of what 5G will encompass.

1.25 A number of questions therefore remain to be addressed. For example, there is uncertainty about the extent to which the market will be willing and able to invest at scale in capital intensive 5G networks, particularly in less populated areas.[29] There is also uncertainty about which future mobile services will take off and drive demand for 5G and whether it will be possible to monetise such services.

Potential scale of 5G benefits

Determining the scale of 5G benefits is necessarily speculative. However, a 2016 EU study estimates that in 2025 benefits from the introduction of 5G capabilities could reach €113.1 billion per year in four key sectors which will be the first users of 5G connectivity: automotive, health, transport and energy. Investments of approximately €56.6 billion will be likely to create 2.3 million jobs in Europe.

1.26 Nevertheless, over time 5G is seen as likely to change the way people, institutions and objects interact in a number of ways. This could have profound implications for society. It is expected that, as and where 5G networks are deployed, there will be ultra-fast connectivity and the perception of virtually ubiquitous broadband capacity, not only to individual users but also to connected objects, supporting a wide range of advanced technologies. 5G is expected to facilitate a wide range of new services to diverse sectors, such as: smart cities, eHealth, energy management, cloud computing, augmented and virtual reality, autonomous vehicles, online gaming, and enhanced mobile broadband. It is also considered to be an underpinning technology for the 'Internet of Things'. Taken together, these services and applications are expected over the course of the next two decades to require a combination of higher data download and faster data upload speeds, lower latency (lag) and greater on the move accessibility.

1.27 5G will not be a single network akin to the first 2G deployments in the UK. Instead it is expected that we will see the convergence of existing mobile generations and fixed networks, and see the introduction of evolved versions of 4G, before 5G technologies emerge. As technologies develop further over time, millimetre wave ("MMWaves") cells using extremely high frequency radio spectrum are expected to begin to be utilised, mainly in densely populated areas, in order to provide a response to the low latency and high bandwidth demands predicted of future services. This will require an increased number of macro cells and – if predictions are correct – an order of magnitude increase in small cells, each using a range of mobile technologies. These new cells will require a power supply and, in most cases, a fibre link. Given the large proportion of mobile data consumed over Wi-Fi – some 80% today – it seems highly likely that Wi-Fi will continue to play a significant role in the future, in the home and workplace as well as in many public spaces.

1.28 Mobile infrastructure in the UK is already expanding, driven by market forces and government intervention, in order to try to meet existing user needs. But with demand for ubiquitous coverage and higher data rates set to increase markedly, there are urgent questions to consider about how best the market, regulators and government should respond.

Over time 5G is seen as likely to change the way people, institutions and objects interact in a number of ways.

Factors that will influence future mobile network deployment

1.29 The mobile market has seen significant change over time, from an industry previously dominated by five vertically integrated MNOs, to the current multi player ecosystem which includes bodies such as: MNOs, MVNOs, WIPs, and an increasing number of 'Over the Top' content providers, such as Netflix, Skype and Google.

1.30 Adding to this complex picture are a number of (known) pressures facing the mobile telecoms industry which will continue to provide challenges across the next decade and beyond. How the industry responds will go a long way to determining the nature of the services users can expect to readily access. Key among these challenges are capacity and coverage which are explored below:

Capacity of networks

Mobile networks have evolved to deliver increasingly sophisticated services to growing numbers of subscribers. As smart phones and tablets have proliferated, a phenomenon known as the "capacity crunch" has emerged, which is characterised by a scarcity of spectrum and mobile network infrastructure in areas where demand for mobile services is high. This is a result of significant growth in user data rates, which spiked dramatically following the launch of the iPhone in 2008, and the associated increase in 'media rich' data based applications for mobile devises. This growth trend is predicted to continue with a six fold increase expected on mobile traffic in Western Europe between 2015 – 2020 which poses questions about the ability for existing mobile infrastructure to accommodate anticipated demand. Most additional data is likely be consumed in densely populated areas, although busy transport networks will also see an increased capacity requirement. In the past, data capacity/traffic growth has been served through a combination of greater spectral efficiency and the allocation of increased amounts of prime spectrum for mobile communications. However the ability of technology to carry more data over spectrum bands is becoming limited, as is the availability of evermore suitable spectrum bands for deployment on traditional macro cell networks since this has already been allocated.

The combination of these factors means that additional 'small cell' base stations will be required using higher frequency spectrum, meaning significant new deployments of infrastructure are necessary.

An emerging tension in the UK mobile market – likely to exacerbate the capacity crunch – is limited capital. Data usage has grown exponentially over recent years, but the UK mobile market has been unable to increase revenues by passing on costs of this to consumers, leading to challenges in financing the enhancement and deployment of capital intensive networks. Therefore, whilst competition in the market would be expected to lead to a degree of additional network deployment over the next 10 – 15 years, limited private capital within the market and previous difficulties seen in monetising data usage suggest that this is likely to be limited to the most economic (generally dense urban) areas.

Coverage across the UK

As mobile communications becomes increasingly embedded in everyday life, there is an implicit expectation of ubiquitous coverage, indeed, 100 per cent reliability and ubiquitous coverage have been described as potential features of 5G. However, gaps exist across each mobile generation in terms of coverage today, which demonstrates the limitations of competition to deliver ubiquity. This is due to a combination of factors, including regulatory and planning constraints, together with the costs and dynamics of deploying mobile networks. This has led to government intervention, such as service obligations, through Ofcom. But despite these measures, there are still areas with no mobile coverage from any operators (complete not spots), as well as where only some operators provide coverage (partial not spots). Though many of these coverage gaps are in rural areas, as has been seen, they also exist on our transport networks. Inadequate geographic coverage affects users now and, if allowed to continue, will likely hinder the deployment of a number of innovative applications. Although developments in the medium term – such as the completion of the roll out of 4G networks and NMO licence obligations requiring 90% geographic coverage for voice calls by the end of 2017 – will bring some improvement, it is likely that there will continue to be ongoing coverage issues unless further action is taken.

What will future networks be used for?

1.31 Accurately predicting all of the services and applications that will emerge as a result of improved mobile networks in the future is impossible. The impact that the introduction of smart mobile devices has had on how we function as a society has been unprecedented, but it was not predicted in advance.

1.32 Nevertheless, recent research suggests that there are several possible broad use cases for future mobile networks which appear credible over the near to mid-term.[30] By examining a group of broadly representative potential use cases – which consequently place representative demands on network requirements – it is possible to begin to illustrate how 5G might evolve.

1.33 At the global and European levels, efforts to begin to standardise 5G – due to be finalised in 2019 – have led to the identification of three key, high level service areas. These are:

- **Enhanced mobile broadband** could enable a plethora of media rich services, such as continual, low latency and high speed access to cloud services and applications: real time augmented reality and AI assistance permeating into more and more aspects of our daily work and social lives, as well as nearer term examples such as advanced gaming. Increased demand for mobile broadband has been exponential as mobile subscribers continue consume data hungry services. Demands for adequate quality of experience are already driving the need for the densification of network infrastructure and placing demands on spectrum. Data rates for services are now, and will continue to be, important for mobile broadband services. But, increasingly, the ability to offer a consistent quality of experience will come to the fore.

- **Massive machine type communications** is chiefly concerned with the consolidation of machine to machine communications into a single enabling infrastructure, such as 5G, necessary to enable the rapid increase in numbers of connected devices in coming years. Many of these devices will be low cost, specialised sensors transmitting relatively small data volumes, often intermittently. A number of potential smart city functions are underpinned by massive machine type communication, such as energy usage and transport management. Emerging technologies employing machine to machine type communications have the potential to radically improve the way we manage our infrastructure in the UK.

- **Ultra-reliable and low latency communication** is expected to be required for the control of machinery, for example in highly automated factories and for management of mission critical assets, for example, in the utilities industry. It necessitates mobile cells in close proximity to the end user/devices, for example, at the roadside or within an automated factory, in order to reduce latency.

1.34 Research conducted for the NIC has helped to identify emerging areas of interest within the UK. These are:

- Connected and autonomous vehicles
- Mobile media and cloud
- Railway connectivity
- Healthcare
- Smart utilities
- Supply chain and logistics

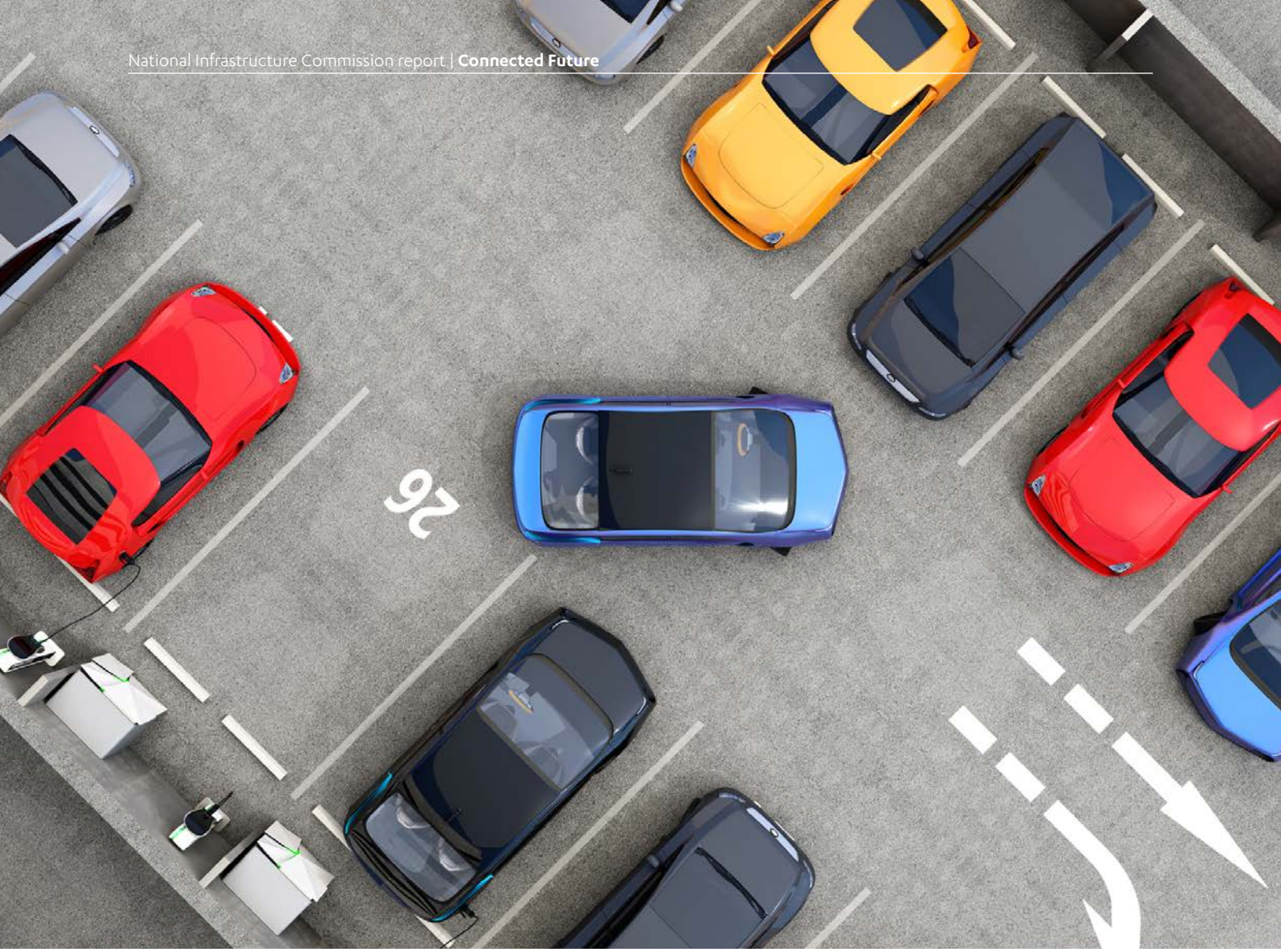
1.35 Whilst there is still uncertainty about how future mobile services will develop over time, the areas identified above – whilst by no means exhaustive – appear credible on the basis of the process of industry liaison undertaken to inform this study. Importantly, they also give broad coverage for a range of other uses that could emerge. By considering the infrastructure implications for these representative nascent and more foreseeable uses, it is also possible to consider future mobile network requirements which are likely to encompass services that will be harder to foresee.[31]

Connected and autonomous vehicles

1.36 Connected and autonomous vehicles (CAVs) have been described as the next 'mobile device' beyond the current generation of smart phones, tablets and emerging wearable devices. Mobile service providers and vehicle and component manufacturers have all identified features which either rely on or benefit from increased connectivity; indeed, the industry has expressed concern that poor existing mobile coverage is slowing the mass market entry of increasingly connected vehicles.

1.37 The potential benefits of CAVs are very significant, with recent research suggesting a value of £51 billion per year to the UK economy by 2030.[32] The enabling infrastructure to support the introduction of sophisticated, highly connected and increasingly autonomous vehicles is, therefore, of real significance to the automotive industry and wider society.

1.38 CAVs are likely to operate through a combination of technologies. On-board intelligence through radar/sensors and processing will be required to take decisions in milliseconds about collision avoidance, for example. Such systems are unlikely to be reliant on external communications networks. However, to achieve the full benefits from these technologies, connectivity that incorporates both vehicle to vehicle and vehicle to infrastructure systems will be needed. Roadside small cell beacons, transmitting and receiving data, will deliver a rapid and reliable data feed, which will enhance operational capability and provide information, for example, about congestion, lane closure and adverse weather, as well as a general internet connection for entertainment and vehicle management purposes.



Connected and autonomous vehicles network needs

Connected and Autonomous Vehicles (CAVs) suggest three distinct, though linked, future network use cases for:

Driver assistance – sometimes known as advanced driver assistance (ADA), this uses on board sensors and connections to other vehicles and back office systems to improve safety as well as reduce congestion. Vehicle to vehicle and vehicle to infrastructure connections provide better control to road operators as well as enhancing on board sensing capabilities, for example receiving data that a vehicle in front is stationary. ADA is time critical and therefore requires low latency and certainty of communication.

In vehicle connectivity – provides access to entertainment as well as general in-car connectivity. Typically, an in built Wi-Fi access point in the vehicle supports several devices and applications simultaneously. This use could place large data demands on networks.

Vehicle management – provides a variety of services, such as data feed to manufacturers regarding the performance of their vehicles and the parts/sub systems in them, as well as identifying vehicle faults in advance. Vehicle management is essentially a machine to machine application with a relatively low data requirement.

1.39 In the near term, roadside connectivity could be provided using a range of technologies, such as Dedicated Short Range Communications (DSRC), a short- to medium-range wireless communication channel. And, as 5G technologies come to market, they are likely to be well suited to rapid, high capacity roadside connectivity.

1.40 There is still uncertainty about precisely how, where and when CAVs will come into mass operation, though full automation is not considered likely until beyond 2030.[33] However, the process is already underway, with features such as on-board Wi-Fi and increasing degrees of driver assistance (such as autonomous parking and braking) included in vehicles already on the market. And the Department for Transport, Transport for London, Kent County Council and Highways England are moving towards deployment of an extensive connected corridor trial on stretches of road including the A2 and M2, which will utilise roadside connectivity infrastructure.

1.41 Before the end point of fully autonomous vehicles is reached, there are significant potential benefits for motorists and wider society to be captured through increasing levels of vehicle connectivity and autonomy. For example, the platooning of vehicles will increase efficiency, advanced driver assistance will reduce error, and real time data connectivity will notify the vehicle and driver of accidents and congestion ahead. As a result, supporting the development of CAVs through provision of enabling infrastructure must be a priority.

1.42 As has been described, there are existing mobile connectivity challenges on UK roads, both strategic and local. Therefore, a critical challenge to be overcome in order to facilitate the entry of CAVs will be the provision of high quality and ubiquitous roadside coverage. To achieve this on UK roads a substantial amount of additional infrastructure will be required. In thinking about deployment of infrastructure to enable communications between cars and infrastructure it is clearly important to consider whether this infrastructure can also be used for passenger communication needs. These issues are explored in more detail in part 2.

Mobile media and cloud Services

1.43 The media and cloud sectors have been transformed in the past 15 years by high speed connectivity and a widening range of smart devices, particularly smart phones.[34] The rising consumption of services such as Netflix and cloud based content, as well as the changing pattern of broadcast TV consumption have created new businesses and opportunities in the UK, as well as challenging established players.

1.44 Media and cloud services are already increasing network demands. For example, there has been significant growth in consumption of video through mobile devices, and the rise in immersive gaming.People are increasingly making use of massive cloud based processing from our smartphones transparently to achieve tasks that were computationally impossible a decade ago – for example through the AI based speech recognition and assistance embedded in many Apple and Android devices. This pattern is set to continue for the foreseeable future as opportunities for entertainment on the move, digital advertising and pay-TV business models are further exploited.

Cloud computing market is predicted to be worth some **£13 billion** *by the end of 2016 and* **84% of UK companies** *used hosted cloud services in 2015.*

1.45 Demand for increased worker and business efficiency will also place increased demands on mobile networks. Cloud services are an area of high growth in the UK; the cloud computing market is predicted to be worth some £13 billion by the end of 2016 and 84% of UK companies used hosted cloud services in 2015. Collaborative working platforms using features such as conferencing, cloud based productivity apps and storage, currently present a relatively low peak rate data demand, partly due to the prevalence for mobile data carried over Wi-Fi (some 80% today). However, across the next decade and beyond, the cumulative device density is likely to have a significant impact on mobile infrastructure capacity in densely populated areas and potentially outside urban centres. Given the importance of business efficiency while travelling, this also poses questions about mobile coverage and capacity on transport networks.

1.46 The use of mobile media and cloud-based services will continue to evolve over time as consumers become accustomed to the new opportunities offered, network capacities increase and users acquire supporting devices. By 2019, video over mobile is expected to account for 80 per cent of worldwide mobile traffic, with the rise of next generation ultra-high resolution video – "4K" – expected to contribute in increasing this further, particularly if mobile users choose to record and share 4K videos in large numbers.

1.47 Taken as a whole, the potential UK benefits through mobile media and cloud services appear very significant due to the size of cloud driven business as well as that of the TV and gaming industries. The UK gaming industry was worth some £4.2 billion in consumer spend in 2015 and the UK TV industry generated £13.2 billion in revenue in 2014. In terms of advertising revenues, mobile is driving the highest levels of growth in the digital sector, with mobile having overtaken desktop for the first time and now accounting for 51% of total ad display. But continuing growth relies on new and improved services, which in turn will rely on improved networks.

Railways

1.48 Demand for rail travel in the UK has shown consistent growth over recent decades, with passenger numbers more than doubling since 1996/97, and some 1.7 billion passenger journeys made by rail last year. However, mobile coverage on the UK's 19,000 miles of railways is notoriously poor. The Government has already made clear its desire to improve mobile connectivity for rail passengers[35] as well as its ambitions for utilising digital services for improved rail operations. And the demand for mobile broadband on trains is evident, with mobile connectivity regarded as a top ten issue by passengers.[36]

1.49 The benefits to be derived through improved trackside connectivity could be very large, potentially increasing passenger efficiency, productivity and recreation and providing the connectivity required to enable a digital railway to function effectively. It could also facilitate the introduction of a number of IoT applications, for example supporting railway and rolling stock maintenance. Currently, however, rail passengers are mostly reliant on cellular coverage. Due to the difficult geography of cuttings, tunnels and rural routes, this often amounts to a very substandard level of connectivity.

1.50 The Government is committed through the franchise process to making Train Operating Companies (TOCs) accountable for the provision of in carriage Wi-Fi. It has set passenger connectivity targets to be met by TOCs, which will incorporated into new franchises as these are renewed (although the renewal process will not be completed until 2028).

1.51 There are questions about whether this approach will provide future-proof connectivity for passengers and meet the potential connectivity requirements of future digital rail operations. These issues are explored in more detail in part 2.

The health sector

1.52 New technologies, enabled by wireless networks, could be transformational to the healthcare sector. Both the Department of Health and NHS have identified the better use of data and technology as priorities with "the power to improve health, transforming the quality and reducing the cost of health and care services".[37]

1.53 A number of trials are underway with the aim of harnessing technology to address some of the most complex issues facing patients and the UK health service,[38] which is under pressure due to an increasing and ageing population as well as a rise in chronic conditions.[39]

1.54 This backdrop has led to high interest and growth in digital healthcare services which can potentially replace or complement physical resources and provide improved efficiencies and cost savings. Broadly, digital healthcare services can be categorised as:

- **Preventative health services** – are based on health monitoring via a connected mobile device, managed by the consumer rather than a healthcare provider. These applications are often smartphone based but in future will likely encompass wearables able to provide more detailed data. Such technologies can, for example, monitor heart rate, blood pressure and sugar levels. Given the increase in lifestyle related health issues in the UK, preventative health represents a central goal in UK health policy, enabling patients to take more control of conditions, lifestyle and fitness. The potential market is large and hence associated benefits in terms of better health outcomes and reducing burdens on the NHS could be very significant. There is also the opportunity to use the data generated for preventative purposes by enabling data-driven analysis of nationwide health trends.

- **Assisted living services** – are a form of health monitoring managed and monitored remotely by a healthcare provider, social care provider or family member. The aim is to decrease the amount of time that individuals with health conditions spend in hospitals and care homes and increase the time they can stay in their home. Sensors around the home can provide information about a person's movements, raising alerts to any unusual behaviour, and wearables (body sensors) can enable health monitoring outside the hospital for those who would not use a smartphone app or where such an app would be insufficiently sophisticated. Given the UK's ageing population, there are clear social and economic benefits from enabling higher levels of assisted living in the home.

- **Remote healthcare services** – includes patients consulting with their GPs remotely via a fixed or mobile internet link, and also the potential for subsequent monitoring on an ongoing basis. This could be achieved through, for example, smartphone apps, wearables or body-based sensors depending on the symptoms to be monitored and could be particularly beneficial to patients in remote areas and/or with limited mobility. The consultation experience could potentially be made more realistic with virtual reality and diagnostics could make use of artificial intelligence engines to improve accuracy. Applications of these kinds could enable a significant area of health service activity to be delivered more effectively, with more convenience and at lower cost.[40]

NHS diabetes digital coach

Diabetes digital coach is a two-year Internet of Things 'test bed' programme led by the West of England Academic Health Science Network.

It will recruit 12,000 people with diabetes across the region to test and evaluate a wide range of innovative technologies to help in the self-management of their condition. Individuals with diabetes will gain a comprehensive, real-time view of their own data, which will inform self-management strategies which they can share with relevant healthcare professionals, who will then be better able to prioritise the needs.

The project subsequently intends to aggregate data, information and knowledge to gain a real-time (as opposed to historic) and population-wide view of the health status of people with diabetes to promote behaviours to improve health.

1.55 Each of these healthcare uses seem likely to be most heavily utilised in indoor environments, for example, home sensors and patient monitoring devices connecting via a local area network or via a broadband access point at the home (e.g. Wi-Fi). Therefore, ensuring all of the population have access to either mobile or fixed line broadband services is likely to be the key near term requirement to support remote health services. But to deliver the fullest benefits over the longer term wider monitoring capability including in external environments will be needed.

1.56 Many monitoring products, such as smart insulin pens and smart inhalers, either currently available or planned, are commonly tethered to mobile devices for data upload back to central servers. This requirement is unlikely to put significant strain on the UK's mobile networks in the near term, because the data throughputs and volume of data from each monitoring device are small and a lot of the data traffic may be offloaded through indoor networks, but it does raise questions about ubiquitous coverage.

1.57 Over time, machine type communications supporting massive densities of patient sensors are seen by many as a key requirement for future 5G mobile networks offering those with long term conditions freedom from hospitals and care centres for longer, and reducing burdens on the NHS as a result. As noted above, although much of the data traffic is likely to be carried on indoor networks (such as Wi-Fi), where connectivity is required on the move or where mobile networks are providing "last mile" broadband connectivity – for example through radio links to rural premises – then high quality, reliable mobile networks become critical.

1.58 This suggests that UK wide coverage is already becoming increasingly necessary in order to avoid regional inequalities in the use of current and future healthcare technologies relying on mobile connectivity, at least in part. Over the next decade or so, as new technologies emerge, the ability to achieve fast and reliable connectivity when on the move could become very significant for a range of 'smart' health devices.

Smart utilities

1.59 Smart metering and smart grids are examples of machine to machine applications designed to produce a reduction in energy consumption and carbon emissions, lower costs for consumers, and – through aligning power generation with consumption in near real time – lead to an overall reduction in the requirement for new generating capacity.

1.60 Smart metering is the connection of utility meters to a central server in order for readings to be automatically uploaded throughout the day. Smart meters are likely to evolve to include demand management functions so that at peak times power could be reduced for short periods to appliances such as fridges and air conditioning units in order to reduce peak energy load.

1.61 The scale of the smart meter programme is very large, peaking at some 14 million meters in 2018, and with some 50 million gas and electricity meters to be fitted across the UK by the end of the decade. The benefits of smart metering include more accurate bills, lower meter reading costs and reduced consumption due to consumer awareness of energy consumption.

1.62 Arqiva and O2 each won contracts in 2013 – worth a total of £2.1 billion – to deploy networks across the UK to enable smart meters. Arqiva will use long-range radio technology, supplementing their existing mast infrastructure where necessary allowing each meter to transmit energy consumption data at frequent intervals.

1.63 Smart grids – which essentially put IT and communications solutions at the heart of generation, transmission and local distribution – will also evolve over time to provide more control at the distribution network and local levels. This will allow automated solutions to be deployed integrating supply, demand and optimal network operation. Smart grid requirements and technologies are at an early stage of development and standardisation, however, it seems clear that networks which exercise control over critical national infrastructure will need to be secure and highly reliable. For this reason, smart grid connectivity is likely to require low latency (at times) and certainty of communications.

1.64 Delivering smart grids will require much of the local power distribution networks to be connected either for sensor readings or for control purposes. The challenge that this presents should not be under-estimated, as there are around 700,000 transformers and sub stations. The remote nature of large parts of these networks increases the challenge further.

Smart water meters

Smart water meter deployment is not a national policy commitment, but could offer a number of potential benefits, including efficiency. Thames Water contracted Arqiva in 2015 to deploy smart water meters, which will connect by wireless, to 3.3 million properties. This is the first UK deployment of smart water meters. The programme of installation is expected to complete by 2030, with 441,000 smart meters expected to be installed by 2020, though some 60,000 are already installed in London. As water becomes an increasingly scarce resource, smart water metering looks set to play a central role in aiding the water industry to better manage consumption and leakage.

Supply chain and logistics

1.65 The UK haulage and logistics industry employs over 2 million people in 190,000 companies, with some 80 per cent of UK freight moved by road There are nearly half a million commercial vehicles over 3.5 tonnes (HGV) on the roads and some 3.3 million commercial vehicles under 3.5 tonnes.

1.66 Competitive pressures and environmental factors are pushing fleet operators to improve efficiency and reduce costs and carbon emissions. Fleet and logistics management systems require a permanent connection to vehicles and drivers to provide real time location and average speed data, which support journey prediction and optimal routing. As a result, reliable wide area coverage on road networks has a number of potential benefits. Additionally, the benefits described above relating to connected and autonomous vehicles also apply to the supply chain and logistics sector where the emergence of vehicle platooning, for example, could result in significant efficiencies, reduced congestion and improved reliability.

PART 2: DIGITAL INFRASTRUCTURE AT THE HEART OF GOVERNMENT

Government as a digital champion

2.1 Connectivity is becoming ever more important across all sectors, not just changing how we live our lives as individuals but also transforming businesses in all parts of the economy. Securing the mobile networks necessary to put the UK at the forefront of this emerging technology will be critical to the UK's economy and to ensuring that British businesses benefit from the major opportunities presented by the growing internet application and services sector.

2.2 Infrastructure is no exception to this ongoing trend. Connectivity and the access to real time information and analytics that it allows can allow the UK to make much better use of existing infrastructure. The National Infrastructure Commission's 'Smart Power' report showed how real time information can improve the utilisation of the power system. Enhanced connectivity can also improve how we use and maintain roads, rail, water and energy networks. Importantly, in comparison to the costs of building and upgrading infrastructure such as power stations, roads and railways, the costs of integrating digital infrastructure are small. This is particularly true when installed at the outset, given that the majority of the costs of deployment relate to the laying of ducts, power supplies and the construction of masts and poles rather than the fibre, radio antennae and supporting technology.

2.3 Given the importance of the UK's digital infrastructure it is notable that there is no single government department with responsibility for it. Instead, digital infrastructure forms just one element within the many infrastructure projects and upgrade programmes that numerous government departments and agencies deliver. For example, the Home Office's procurement and delivery of the Emergency Services Network is a significant telecoms project and many of the projects for which the Department for Transport, has responsibility, such as roads and railways investment and upgrades have a significant digital component. These activities do not have national mobile connectivity as a core objective. This risks a lack of coherence in achieving the digital infrastructure the UK requires and the deprioritisation of digital connectivity as an objective.

2.4 Given the increasing importance of connectivity across all parts of the economy, digital infrastructure should sit at the core of the government's industrial strategy, ensuring that the UK can take full advantage of technologies such as artificial intelligence and augmented reality to improve productivity and develop the businesses of the future.

2.5 To grasp the inherent opportunities that digital infrastructure offers, there must be a single part of government, with senior ministerial and official leadership, supported by a well-equipped and powerful unit, that is responsible for setting the UK's overarching plan for digital infrastructure and ensuring that it is delivered in a coordinated way. The creation of a Director General lead in the Department for Culture, Media and Sport (DCMS) is a good first step.

Recommendation 1: Digital infrastructure lies at the heart of the UK's industrial strategy and affects every sector of the economy. To reflect its importance, ultimate government responsibility for digital infrastructure should reside in one place under a single cabinet minister with the authority to shape policy and delivery across government ensuring that it delivers the government's overarching digital strategy. This work should report to the Economy and Industrial Strategy Cabinet Committee. It should:

- Identify the public projects that contain a significant element of digital infrastructure and establish and maintain a plan which sets out how they can help deliver the government's overarching digital strategy and maximise the benefit of better mobile telecommunications for UK citizens and businesses.
- Hold the various parts of government that are delivering digital infrastructure to account, in order to ensure adequate telecoms network provision in the delivery of its infrastructure programmes.
- Ensure that when upgrading existing or delivering new infrastructure, such as that alongside our roads and railways, the long term capacity needs of telecoms networks are considered and met. This could include installing more fibre and additional infrastructure to make sure that networks are future-proof. It will also mean ensuring that the networks are readily accessible to communications providers.
- Be a centre of telecoms expertise within government that supports departments in determining their needs and procuring telecoms infrastructure, and support departments in demonstrating and testing of new, digitally-enabled ways of delivering public services such as education and healthcare.
- Support and challenge local government in their plans to enable the delivery of digital infrastructure; both in terms of ensuring that these plans help the UK to meet its national objectives, and that local authorities develop consistent approaches to support the deployment of mobile infrastructure across the country.

Connectivity on our major roads

2.6 The provision of consistent, good quality mobile coverage on the UK's strategic and local road networks is challenging for a number of reasons. Transmitting and receiving data to and from vehicles is may be difficult because sections of road network are located in cuttings and tunnels; because access to the road for masts can be hard to obtain, and because mobile reception within vehicles may be poor.

2.7 The UK's roads – and particularly its motorway network – frequently contain very high concentrations of mobile service users, yet the road network is diffuse, passing through extensive areas with low population density which have poor existing cellular coverage as a result.

2.8 These issues are heightened by the fact that the Mobile Network Operators (MNOs) have limited incentives to provide widespread coverage of the road network. In part this is because costs for additional network infrastructure may not outweigh additional revenues from existing or new subscribers (although this may change as new uses for roadside connectivity develop). It is also due to the fact that current coverage obligations imposed on MNOs through spectrum licences have focused on achieving coverage to premises and have not incorporated transport links.[41]

2.9 Ofcom estimates that, in 2015, 17% of A and B roads were not covered by any operator's 2G voice and text services (complete not-spots). And that 42% lacked coverage from all operators (partial-not spots). Even on the motorway network, where coverage is generally better, there remain partial and complete not spots for both mobile voice and data.

2.10 Patterns of poor coverage result in passengers often being unable to make calls and/or connect to online services. Looking to the future we expect this situation to become compounded as demand from passengers and, in particular, connected and autonomous vehicles grows rapidly, requiring roadside mobile networks to supply greater capacity. It is notable that, even if all coverage gaps were addressed on the road network, it is notable that it is doubtful capacity offered by existing networks will be sufficient. Across the next decade and beyond, as we have seen, it is expected that many of the applications envisioned for connected roads and vehicles will require or benefit from a step change in the quality of connectivity. The existing extent and quality of coverage therefore risks slowing or even preventing the deployment of future connected and autonomous vehicles technologies, which will be reliant on reliable, good quality connectivity.

2.11 As 4G networks continue to be rolled out and MNOs look to meet their licence obligations by the end of 2017, overall geographic coverage for mobile is expected to increase. However, concern has recently been expressed about the extent to which MNO efforts to meet licence conditions will lead to meaningful and future ready coverage: "The most recent figures, provided by Ofcom in its annual Connected Nations report, suggest that the MNOs have a long way to go before outdoor voice coverage reaches 90% in geographic areas. On average, the four MNOs each provided 2G and 3G coverage to 73.75% of the geographic area in the UK in 2015."[42] Given the geographic spread of the road network, this suggests that coverage gaps are likely to persist for some time unless further action is taken.

Roads, vehicles and technology

2.12 In recent years, the installation of smart motorways has become a significant programme of work for Highways England, delivering a number of benefits by increasing capacity through hard shoulder running, and improving congestion and reliability through active real time management of speeds and lane use. The smart motorway programme is set to continue improving the links between our largest urban areas: "By the end of the second Road Period, there will be continuous Smart Motorway corridors linking London, Leeds, Manchester and Birmingham".[43]

2.13 However, although smart motorways provide a number of benefits, in many respects they represent a nascent stage in the development of increasingly sophisticated road networks, where the rapid transmission of data to and from vehicles together with advances in automated in-vehicle systems will bring about further benefits.

2.14 The mass introduction and adoption of ever more sophisticated CAVs is predicted to generate benefits worth some £51 billion per year by 2030,[44] which are expected to be derived through improved efficiency, mobility,

productivity, and environmental performance. In terms of safety, it is estimated that some 2,500 lives will be saved on UK roads and 25,000 serious accidents prevented by connected car technology across the next 15 years.

2.15 The take up of CAVs will also allow for a better understanding of network conditions, such as traffic flow and speed, route optimisation and maintenance. For example, a connected vehicle could potentially use on-board technology to examine road surfaces and identify maintenance needs, using connectivity to alert the road infrastructure operator about issues in real time.

It is estimated that some **2,500 lives will be saved** *on UK roads and* **25,000 serious accidents prevented** *by connected car technology across the next 15 years.*

What are connected and autonomous vehicles?

Whilst closely linked, there are a number of distinctions between 'connected' and 'autonomous' vehicles:

Connected vehicles: are those that can communicate with other vehicles or infrastructure on the road network. A good example are freight platoons, where a lead vehicle, within which the driver has full control, is electronically coupled to other vehicles in the platoon allowing drivers of the following vehicles to cede elements of control to the lead vehicle. The connected vehicle concept is about supplying useful information to a driver or a vehicle to help the driver make safer or more informed decisions.

Autonomous vehicles: a fully autonomous vehicle is one that does not require a human to drive, instead it uses a range of systems (sensors, computer processing, etc) to safely navigate the road. This is the end point, not anticipated to be reached until the 2030s. But some vehicles are already being deployed with autonomous functionality, such as self-parking or auto-collision avoidance features.

2.16 Given such predictions, it is welcome that the government has made clear its recognition of the enormous potential for CAVs, as well as the potential for the UK to become a world leader in their development, production and deployment. Ensuring the UK keeps pace with our competitors and partners in Europe, such as Germany – where the government has recently committed to using spectrum licences to enable for provision of 50Mbps by the roadside in the next few years – will be essential.

2.17 Realising the full range of these benefits will rely on continued operational trials and research and development into both vehicle and supporting technologies, as well as work to build public support.[45] Critically, it will also require the timely provision of pervasive mobile connectivity across our road network, as well as high quality (high capacity, speed and reliability) connectivity on the busiest stretches of the network.[46] Given this context, it is unsurprising that technology will form a very significant theme in preparations for the second Roads Investment Period, between 2020 and 2025.

How will CAVs Function?

In-car features such as radar, sensors, and processing will provide for a number of CAV functions, such as lane monitoring and collision avoidance. However, there is also a requirement for significantly increased connectivity on road networks, both between vehicles and between vehicles and infrastructure, in order to secure CAV benefits fully and rapidly.

V2V and V2I

The connected vehicle market primarily consists of two broad types of connectivity providing technology: Vehicle-to-Vehicle (V2V) communications, which takes place directly between vehicles, and; Vehicle-to-Infrastructure (V2I) which takes place between vehicles and a fixed piece of the surrounding infrastructure, such as a roadside small cell. Both technologies generally currently rely on Dedicated Short Range Communications (DSRC) to transmit and receive information.

V2V technologies – many of which are concerned with collision avoidance – require that other vehicles on the road are also connected, otherwise non-communicating vehicles are only visible to connected vehicles through separate features, such radar.

V2I applications tend to be less immediate or safety-critical so have a broader scope. For example, V2I is seen to increase possibilities for more complex data analysis, as well as a more general information feed for entertainment purposes. It can also provide redundancy should on-board systems fail. Unlike V2V, V2I only requires the infrastructure and the vehicle to be connected, allowing for useful applications immediately (once supporting infrastructure is in place) without the need for very significant market penetration. As a result, certain V2I applications may be market ready before those for V2V, which will make V2I a significant force in leading market adoption of connected vehicles.

Where will CAVs operate?

The ultimate end point for CAVs will be the ability to function across the full variety of environments – from congested streets, to residential areas and busy highways – which each offer a range of potential benefits. For example, increased connectivity in cities could allow for smart signal phasing of traffic lights, and real time information being relayed to vehicles about parking space locations. There are also safety gains, such as at busy intersections where connectivity could allow for real time data to be shared about the locations/intentions of vehicles.

On our busiest strategic roads where large traffic volumes travel, often at high speed and in dense formation, similar benefits exist, as well as those opened up through the platooning of vehicles and warnings about congestion and incidents ahead.

The nature of mobile coverage will be an important determinant of where and when CAVs can operate, and with what sorts of features. Roads in suburban areas may, in general, have relatively low data capacity requirements, at least in the near term, due to lower traffic volumes and densities. As a result, cellular coverage may provide sufficient connectivity in such areas for CAVs in the near term. However, in busy areas, where capacity requirements are greater, dedicated coverage (through for e.g. small cell deployments) is likely to be necessary to allow for increased data capacity needs. And, where the reliability and quality of connectivity is important or critical in nature, dedicated networks will be necessary.

Roads – digital infrastructure considerations:

2.18 The speed and nature of CAV uptake will be significantly affected by the telecommunications infrastructure available to provide connectivity to vehicles. As set out above, existing mobile coverage across our road networks can be unreliable, causing difficulties for road users, and also for vehicle manufacturers seeking to enable increasing levels of reliable connectivity in new models. Widespread road coverage should therefore be a matter of priority in the near term.

2.19 On the busiest roads and in busy urban areas mobile capacity will need to grow significantly to meet forecast service quality needs. Similarly on the strategic road network, concentrated numbers of vehicles with sophisticated connectivity needs will result in requirements that existing mobile networks are unlikely to be able to meet. Meeting the demand for higher capacity is likely to require a denser network of much smaller cells, along with improved technology.

2.20 Analysis conducted for the NIC suggests that in dense urban areas where there are likely to be sufficient incentives for the deployment of small cells at scale, to deliver improved coverage and capacity, which should in turn help meet the connectivity needs of CAVs in urban areas. However, on major roads, where improved connectivity can help to realise a range of

A 5G ready roadside network

Future deployments of telecoms networks at the roadside on the Strategic Road Network (SRN) would benefit from being able to take advantage of extensive existing infrastructure. A UK wide network of ducts, poles and in some places high speed and high capacity optical fibre network is in place on all of the UK's motorways and major trunk roads. Fibre and ducting is used for operational purposes, providing connectivity for equipment such as CCTV cameras, information signage and message boards to gantries. Analysis for the NIC has found that there is potentially capacity on the fibre and ducting network that could be used to provide better wireless coverage and to deliver high speed connectivity to vehicles enabling numerous transport related applications.

The analysis found that connecting approximately eighteen thousand wireless sites utilising the existing infrastructure as far as possible along England's motorways would cost approximately £380 million and deliver the necessary underpinning platform for 4G and 5G high capacity connectivity as well as enabling V2V and V2I communications for CAVs.

Liaison with the telecoms sector suggests that there are a number of opportunities for such a network to be funded commercially, for example with the infrastructure provider – potentially a neutral host – able to monetise 'connectivity as a service' through provision of data and connectivity to highways authorities, car manufacturers and to MNOs. Service obligations for future 5G spectrum releases could potentially be employed to commit spectrum holders to delivering roadside services and to provide investment certainty.

benefits, problems with accessibility (for example, for safety reasons). and the more limited incentives on MNOs, mean it is much less certain that current arrangements will deliver the connectivity required. To ensure sufficient connectivity is provided, rather than maintain the status quo and suffer the deployment lag which this would entail, better coordination, investment and efficient utilisation of the significant existing roadside telecoms assets will be necessary.

2.21 The provision of a robust and forward looking communications network infrastructure on our motorways should inform the process for ensuring that there is adequate coverage and capacity on the rest of the road network to meet future needs, including the partnerships needed between road stakeholders and mobile communications providers.

Recommendation 2: Our motorways must have mobile telecommunication networks fit for the future. It is vital that our motorways are able to meet both the long term operational needs of connected vehicles and the connectivity needs of the passengers. This will necessitate the timely installation of an open and accessible mobile telecommunication and backhaul network that is fit for the future.

The government should set out its plans for how to deliver this by the end of 2017. As part of this work consideration should be given to who is best placed to install, manage, fund and own the network, noting the potential for private sector funding.

Ensuring that best use is made of the existing infrastructure, such as masts, poles, ducts power supplies and the fibre network alongside our motorways, so that it can be used to support the backhaul of mobile data will be essential.

Ultimately, the government should ensure that the necessary infrastructure is in place on motorways by 2025 at the latest if it wants to offer a reasonable level of connectivity on a timescale consistent with the deployment of 5G networks.

Ofcom should set out how a regulatory regime would support these different operating models.

Connectivity on our main rail routes

2.22 Mobile coverage on UK railways is reliant on existing MNO cellular networks, which generally utilise base stations located some distance away from railway lines.[47] This has resulted in poor mobile coverage and capacity on rail routes to date. The challenges include:

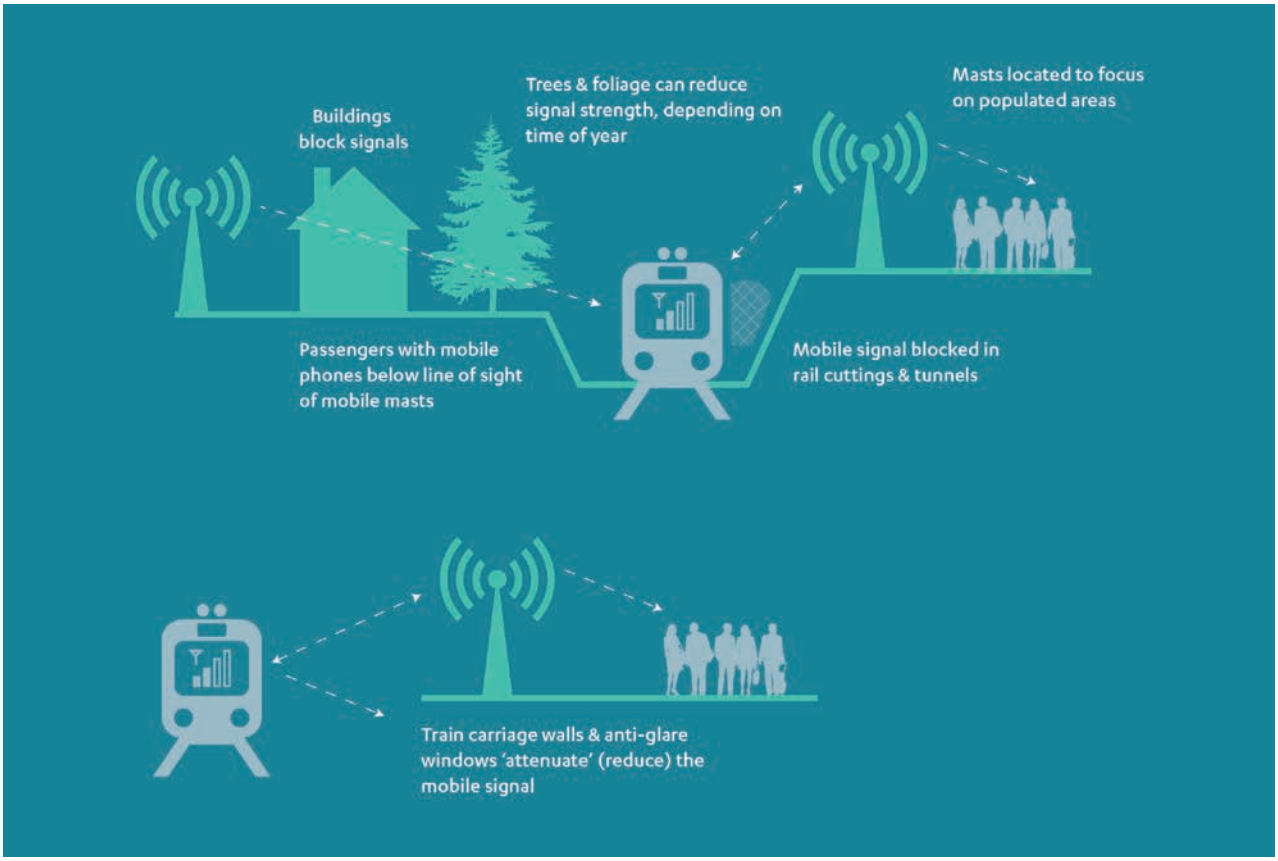
- Around 40 per cent of railways are in tunnels or cuttings, causing base station signals to be blocked. These difficult geographies mean that even with near-ubiquitous geographic coverage MNOs would be unlikely to provide sufficient coverage and capacity to deliver a quality service to passengers without trackside infrastructure;
- Train carriages and windows can strongly attenuate wireless signals, impeding reception further;
- Large numbers of people concentrated in small areas on carriages, often moving at high speeds, and in close proximity to other trains;
- The mobile market provides few incentives for MNOs to invest in improving rail coverage;[48]
- Coordination issues can occur due to the number of stakeholders involved, which can be exacerbated by poorly aligned incentives to roll out mobile networks along the railways.[49]

2.23 As a result of these challenges, passengers are often unable to make or receive phone calls reliably and frequently receive poor data connectivity, reducing satisfaction and productivity. Lack of sufficient rail corridor connectivity also risks impeding the realisation of a number of Digital Railways initiatives because features such as digital in cab signalling, operational improvements as well as real time information for passengers rely on good, reliable trackside coverage.

Project SWIFT

Project SWIFT (Superfast Wi-Fi In-carriage-for Future Travel) is an example of a UK railways Wi-Fi trial between Glasgow and Edinburgh. It is being undertaken by CISCO together with partners including Innovate UK and Network Rail. SWIFT aims to deliver high quality and high speed Wi-Fi broadband to rail carriages running between Glasgow and Edinburgh. It is an 18 month project that will demonstrate high speed connectivity (handover durations of 2ms) that improves passenger experience, enhances commercial opportunities and improves train management through increased operational data. SWIFT will utilise the existing high quality trackside fibre that is in place between Edinburgh and Glasgow and put in place a dedicated track to train infrastructure of small cell devices mounted on masts and connected to the fibre, using unlicensed spectrum.

Figure 6: The challenges of providing train connectivity



2.24 In response to these long standing issues, the Department for Transport announced an 'On-Train Wi-Fi' policy last year, which made clear the government's commitment to improving mobile connectivity for rail passengers.[50] This programme is timely and welcome; passenger demand for on-train broadband services is evident[51], and the benefits of improved trackside connectivity could be very large, for both passengers and rail operations.

2.25 The programme is now under way and will utilise the rolling franchise competition process to make Train Operating Companies (TOCs) responsible for delivering in-train Wi-Fi, which must meet a set of minimum service levels prescribed by the DfT. TOCs will be free to negotiate their own solutions with service providers in order to meet the service level metrics, likely resulting in a variety of approaches.

2.26 An encouraging start has been made; several proof of concept trials have begun in conjunction with Network Rail Telecom, such as project SWIFT in Scotland and the Chiltern Railways/EE deal for Continuous On-Train Wi-Fi Services. The aim of these trials is to allow telecoms service providers to showcase potential solutions, and gain insights into the best ways forward.

2.27 There are broadly two approaches open to TOCs. The first is to work chiefly with MNOs to use their networks to backhaul mobile data from the trains using commercially available spectrum and current 4G technologies with "in fill" coverage (at, or close to, trackside) added where required to overcome connectivity issues, for example in tunnels. This is the approach adopted by EE/Chiltern Railways. The alternative approach is to focus on delivery of dedicated trackside infrastructure, installed along the railways and using either licensed or unlicensed spectrum. This is the approach adopted in the SWIFT trial.

2.28 Over the course of the franchise renewal process (which will run until 2028) it is anticipated that TOCs will negotiate commercial agreements with one or more telecommunication providers to deliver the minimum service level through a range of technological solutions.

2.29 It is important to note that the role of Network Rail Telecom will be central in ensuring the success of solutions chosen by TOCs. Track-side telecommunication assets and infrastructure are located in a hazardous and safety-critical environment. The experience and competence of Network Rail Telecom will, therefore, be essential in any solutions that seek to leverage Network Rail assets.

2.30 Though focus here has been on rail, a similar set of benefits could be realised through improved mobile connectivity on underground/light rail networks. The NIC note that Transport for London (TfL) are working on a plan to consolidate their telecommunications networks including those they run and those they buy in. This is the right approach, and TfL should look to produce their plan as quickly as possible.

Railways – considerations

2.31 Poor mobile coverage on our railways has been a perennial issue, but the provision of good quality connectivity to rail passengers could bring about a range of benefits, indeed, earlier this this year, it was described by the Transport Select Committee as an, "important, and potentially transformative, factor".[52] It is therefore welcome that the government is actively seeking to address longstanding mobile coverage and capacity issues on UK railways.

2.32 Looking to the future, and the capacity demands expected in the 5G era, it will be important to make timely decisions about the nature of the networks to be deployed in order to meet longer term passenger and operational needs. Central to these considerations will be the degree of coverage and capacity considered necessary.

2.33 At present, the minimum service level set by the DfT for on-train Wi-Fi aims to deliver a data speed per passenger equivalent to 100 Mbps backhaul per train for 95 per cent of the route (for 85% of passengers journeys). This level of connectivity is aimed at supporting basic internet services, such as email access, and Wi-Fi voice calls. Analysis produced for the NIC suggests that, whilst delivering a 100Mbps per train is a target that could potentially be met relatively quickly (by using a combination of MNO cellular networks with 'in-fill' where required) it is modest based even on today's user requirements.

2.34 Backhaul of 100Mbps per train equates to an approximate data speed target of 256kbps per passenger. However, these assumptions are not based on fully loaded trains – which may carry in the order of 800 people – and assume only 1 in 4 connected passengers for that figure to be possible. This could lead to passengers in some circumstances, for example on peak loaded trains, experiencing a poor service in the near term. Looking over a 10 – 15 year horizon, this basic connectivity level is unlikely to meet future demand.

2.35 There are requirements on TOCs to accommodate growth of 25 per cent per annum in demand, but this is less than half of the currently observed rate of mobile data growth.[53] Ofcom reported eightfold mobile data growth between 2011 and 2015, substantially exceeding their previous forecasts.[54] The growth assumptions underpinning the current approach may therefore significantly underestimate demand across the next decade and beyond.

2.36 Published analysis of 5G requirements suggests significantly greater demand, as do industry expectations. A widely accepted target for 5G connectivity is 50Mbps per user on an average basis[55], though with much greater peak demand. This suggests that a more realistic, future proof approach would be to target backhaul of tens of gigabits per train, and that this degree of connectivity would in particular be necessary on the busiest mainline and commuter routes.

2.37 Targeting this level of demand necessitates extensive deployment of trackside infrastructure along rail routes. This is likely to be the most viable way to achieve high data rates and enable low latency connections. It also has the potential significant advantage of making use of the existing trackside infrastructure such as ducts and poles, following the SWIFT model. It will also be vital to ensure that the mobile connectivity needs of new railway lines are given full consideration at the earliest stages so that appropriate trackside mobile infrastructure can be deployed efficiently as new railways are constructed.

2.38 Work commissioned by the NIC has estimated costs for such an approach to be in the order of £500-£600 million for the UK's main rail routes. Commercial approaches to funding these infrastructure costs appear likely to be feasible due to opportunities for infrastructure providers to secure revenue streams from improved trackside connectivity.

Recommendation 3: Rail passengers should have high capacity wireless connectivity. This should be achieved through a delivery model that utilises trackside infrastructure to provide an open and accessible mobile telecommunication and backhaul network that is fit for the future.

The government should set out its plans for how to deliver this by the end of 2017. As part of this work consideration should be given to who is best placed to install, manage, fund and own the network, noting the potential for private sector funding.

Ensuring that best use is made of the existing infrastructure, such as masts, poles, ducts power supplies and the fibre network alongside our railways so that it can be used to support the backhaul of mobile data will be essential.

Ultimately, the government should ensure that the necessary infrastructure is in place on the main rail and key commuter routes by 2025 at the latest if it wants to offer a reasonable level of connectivity on a timescale consistent with the deployment of 5G networks.

Ofcom should set out how a regulatory regime would support these different operating models.

Engaging local government as a partner

2.39 The deployment of small cell radio antennae using existing 4G technologies is already being seen in some of the busiest urban areas simply to address existing capacity challenges created by ever increasing mobile data requirements. In order to enable the enhanced mobile services envisaged from 5G, however, a step change in the number and density of such small cell networks is anticipated. This will require the deployment of tens of thousands of small cells in our towns and cities.

2.40 The provision of so many new cells will be a significant challenge in terms of finding suitable sites and providing supporting infrastructure such as backhaul, as well as ensuring that telecoms networks meet local needs.

Why are dense networks necessary in urban areas?

2.41 Mobile infrastructure in dense, urban areas is typically deployed by MNOs on the rooftops of office blocks and residential buildings or on poles in the street. These sites provide the key capacity layer for mobile broadband in our towns and cities, which today delivers mobile broadband speeds averaging 15 Mbps. However, there is growing expectation and demand for this mobile connectivity to grow further. 5G millimetre wave small cells offer the ability to provide ultra-fast speeds (more than 100 Mbps) and high levels of capacity while on the move.

2.42 The benefits of providing this level of connectivity could be very significant and wide ranging, enabling the anticipated proliferation of data rich services, such as mobile augmented reality, to become mainstream in densely populated areas. It will also be needed to support the smart city of the future, which will benefit from a fast, responsive, and stable mobile network, able to handle a vast amount of data.

2.43 5G and millimetre wave Wi-Fi small cells may cover an area just 100m – 200m in radius. This implies significantly more cell sites than are currently available could be needed to deliver the ultra-fast broadband speeds and high levels of capacity that future applications could require.

Analysis for the NIC found that as many as **42,000 small cell sites** *could be needed to deliver the* **ultra-fast broadband speeds expected of future networks** *in an area the size of the City of London.*

Aberdeen– A city with a 5G vision

5G infrastructure deployment in the UK will begin with 4G small cells connected into a future proofed fibre infrastructure which will allow for 5G technologies once released.

Aberdeen City Council has a vision to provide high quality connectivity through world class infrastructure. The Council has shaped its small cell concession to target significant long-term investment in enabling infrastructure which is able to maximise benefits from the most recent mobile generation, 4G, whilst being 5G ready and future proofed for other wireless services.

In order to achieve maximal connectivity in Aberdeen, the Council ensured that new infrastructure would be available to all network providers – indeed, this will be the UK's first multi operator cloud radio access network. Following a competitive tender process, the concession was awarded to Wireless Infrastructure Group (WIG) – an independent provider of wholesale infrastructure to the UK communications sector. After awarding the concession to WIG, the Council formed a steering group comprising representatives from the IT and Transformation, Legal, Intelligent Transport Systems, Street Lighting, Planning, Roads and Digital Economy departments. This group worked in partnership with WIG and played an essential role in developing processes to access street furniture and ducts. Following two years of network planning and ground-work WIG is now ready to launch a network of small cells connected by fibre. Work to date has highlighted a number of lessons learned:

- Long-term enabling infrastructure is key, which means installing fibre connected nodes that support 4G now and 5G in the future.
- It is important to maximise connectivity through infrastructure solutions which support multiple wireless services. A long-term concession approach is likely to incentivise investment in high-quality infrastructure.
- A proactive Council is invaluable in unlocking deployment and the local authority should take an active steering role.
- 5G deployment needs vision – while the standards are not yet defined, but it is clear that fibre connected small cells will be a core element.
- It takes two years of ground work to launch a fibre connected small cell network – if cities want to be early adopters of 5G they need to engage now.

Delivering densification

2.44 A number of challenges will need to be addressed in order to achieve this level of provision. Key amongst these are the enabling fibre necessary to backhaul high capacity data from the base stations to the network core. Fixed telecommunications operators will need to play a central role if dense networks of small cells are to be able to be deployed. BT, Virgin Media and Vodafone already carry significant proportions of data traffic on their fixed fibre networks in the UK. Ofcom's proposals around duct and poles access are likely to be important to enabling the necessary fibre to be provided for small cell deployments.

2.45 Plans recently announced by government to improve access are also a positive step forward in encouraging more fibre provision, as is the funding for fibre deployment announced in the 2016 Autumn Statement. Suitable arrangements amongst operators in terms of fibre and duct access flexibility, maintenance, sharing of contractual obligations and future deployment will also be necessary. In the coming years, a new challenge will be the extension of fibre and connecting cells into non-typical locations, such as street furniture, so that operators can roll out new sites in a cost effective and timely manner.

2.46 Operators will have to be prepared for large scale deployments, and there are signs that they are gearing up. BT, for example has started testing new software and virtualised network technologies in readiness for connecting the numerous wireless sites required to deliver future networks. These will likely become commercially available around 2019 coinciding with the completion of 5G standards and live trials.

2.47 A notable feature of small cell densification will be the need for access to street furniture. This will require collaboration between network operators and landlords (generally local authorities) to handle agreements and issues that might occur due to deploying telecommunications equipment on infrastructure not designed for that purpose. There is currently no common approach to this type of collaboration, though pioneering Smart cities projects such as Bristol is Open and collaborations between forward thinking authorities such as Aberdeen Council and network providers will offer valuable insight into how best to drive network provision (see break out box).

2.48 Early signs from across the UK are that the process tends to be fragmented across different local authorities and negotiations are often legally complex and protracted, making MNOs reluctant so far to get deeply involved. Aspects such as planning policy, legislation for code powers, and guidelines for deployment at street level will need to be addressed before dense site deployment can take place.

2.49 Taken together, these challenges suggest it would be unwise to assume that small radio cells will necessarily be cheaper or quicker to deploy than other types of cell architecture. Significant backhaul requirements together with the sheer volume of sites required will result in the need for significant investment. And urban restrictions such as local authority permits and traffic management needs could prove to be costly obstacles, causing delays and expense.

2.50 Therefore, to make timely 5G deployment possible, and ensure networks can expand to meet future requirements in dense urban areas, active local government engagement and support will be necessary. This should include the development of robust and coordinated plans for the deployment of enhanced mobile networks, drawn up by local authorities in collaboration with the broader Local Enterprise Partnership and incorporating input from network providers. Some Local Authorities and Local Enterprise Partnerships are already starting to develop their thinking in this area and developing policies such as the City of London's Digital Infrastructure Toolkit and the North East LEP's plans for a digital test bed.

2.51 In this context, there is also a role for central government, which should keep under review recent legislative changes impacting the sector: planned changes to the Electronic Communications Code, currently passing through Parliament, as well as amendments to planning regulations appear to be steps in the right direction, which should help encourage both small and macro cell deployments.[16] Government must now monitor how these efforts to stimulate network investment end up working in practice and keep open the possibility of further legislative changes if necessary.

2.52 Whilst it is likely that the precise model of small cell deployment will vary to some extent across local areas, there will be benefits from harmonising the general approach taken, which should increase efficiency and incentivise investment. Ensuring that the optimal approach is identified and implemented should be a priority. Central Government should therefore prioritise the piloting of a range of delivery models across diverse environments.

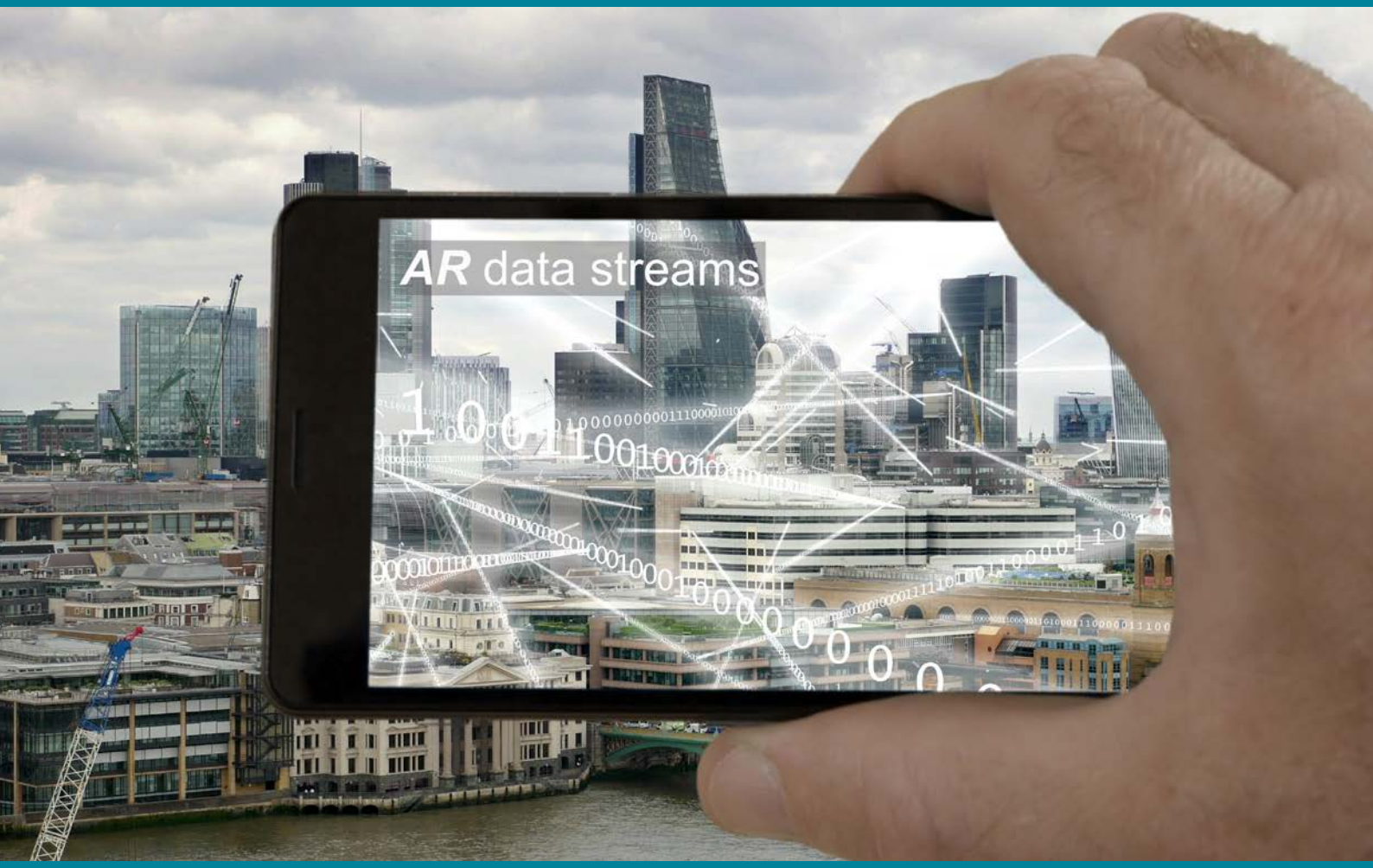
Recommendation 4: Local government should actively facilitate the deployment of mobile telecoms infrastructure:

a) Local authorities should work together and with Local Enterprise Partnerships (LEPs) to develop coordinated local mobile connectivity delivery plans. These plans should:

- set out how local authorities and LEPs will enable the deployment of mobile networks and maximise the opportunities and benefits to residents and businesses;
- be developed in discussion with mobile network operators and infrastructure owners;
- identify a designated individual with lead responsibility for engaging with mobile telecoms infrastructure providers;
- consider the role of local government assets and infrastructure, (e.g. land, buildings, roads, street furniture) and help coordinate the role that other public buildings in an area (e.g. hospitals and universities) can play to facilitate the deployment of mobile telecoms infrastructure; and
- consider how the deployment of digital infrastructure can be established as a priority in local planning policy.

Local authorities and LEPs should report annually to the government department with responsibility for digital infrastructure on their progress delivering against these plans.

b) Local models for facilitating the deployment of these networks should be piloted and evaluated to inform national roll-out. Any pilot programme should allow for the evaluation of deployment models in different types of area (e.g. urban, rural, coastal) and in both single-tier and two-tier local government areas. It should also seek to establish how high quality design can minimise the impact of hosted infrastructure on the built environment. Such pilots would be a good use of a proportion of the funding recently announced in the Autumn Statement to support mobile telecoms infrastructure.



One of the future applications unlocked by 5G is Augmented Reality (AR). AR enriches reality by providing additional information that is relevant to the surrounding environment and context of the user. A very high data rate and low latency (lag) are necessary for enabling AR. This means that, for AR applications outside the home or workplace, high speed and high capacity mobile infrastructure networks will be required.

PART 3: MEANINGFUL COVERAGE

The importance of high quality pervasive coverage

3.1 The services that are delivered over mobile wireless have moved from being a luxury to an essential. This trend is only set to continue into the next decade as our personal lives and businesses rely increasingly on cloud connectivity, and our digital economy is underpinned by it. Having limited access due to poor coverage will be increasingly problematic to people and businesses.

3.2 As a nation, the full range of benefits of mobile services can only be realised when their reach is maximised.[56] Meaningful coverage where people want it is, as was highlighted recently by the British Infrastructure Group, necessary now for mobile phone users.[57] Over the next decade, widespread and high quality mobile coverage could enable transformational change to sectors such as connected health, education, transport and the internet of things. It could also put the UK in a leading position to enable our digitised industries and the digital services sector to flourish. Failure to establish first rate coverage risks missing such opportunities as well as exacerbating the digital divide.

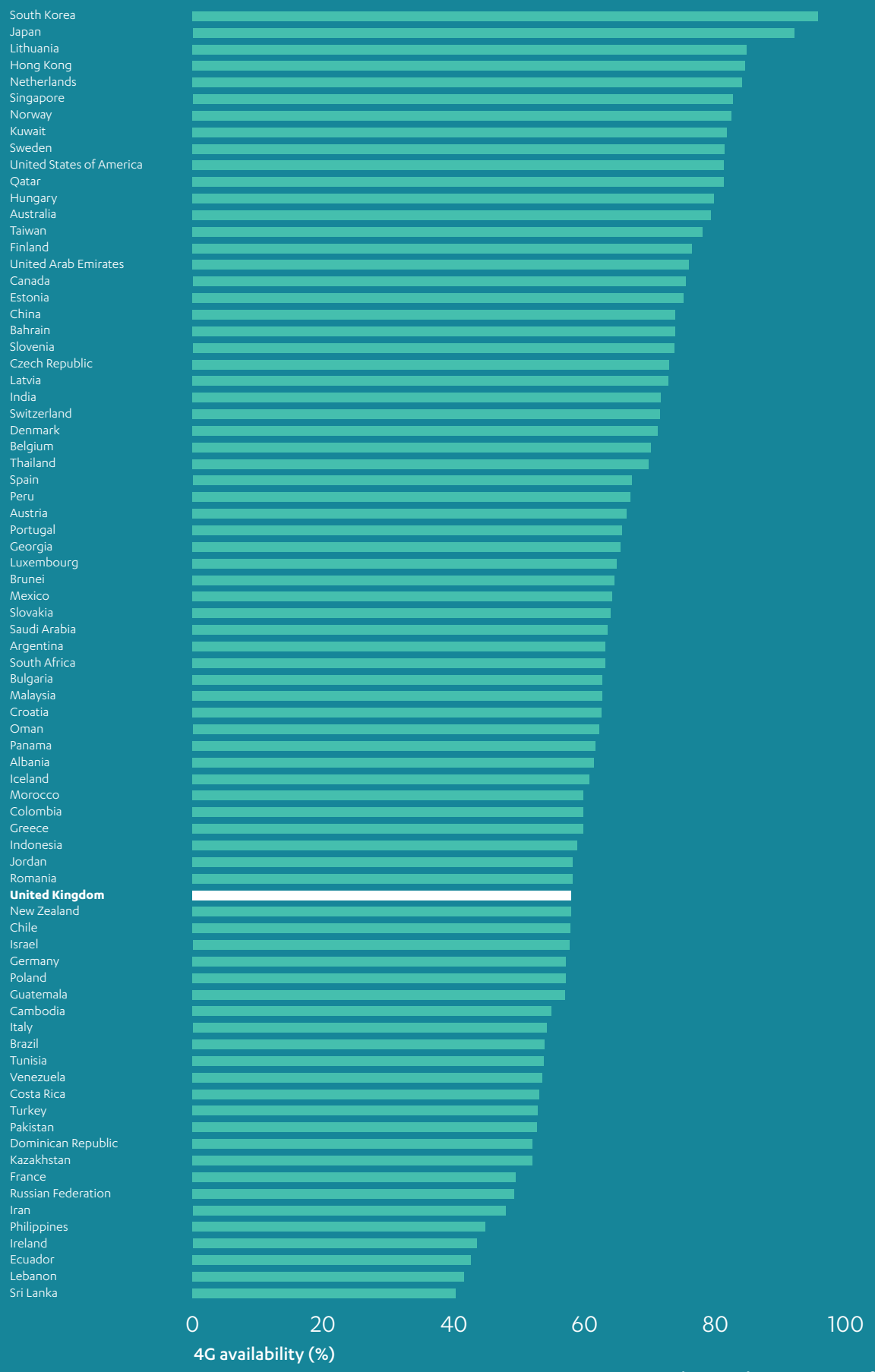
3.3 However, left purely to the market, experience shows we may expect the densest areas of population, our major towns and cities, to receive the best (and first) coverage. Less populated areas, or areas which are more difficult to reach with wireless connectivity, will need to make do with poorer quality or non-existent coverage for some time, and potentially indefinitely. This is of particular concern because in future much of the good brought by mobile networks may increasingly be societal – with citizens benefiting through improvements to health and other public services – but the incentives for network operators to deploy the pervasive networks that will be necessary are not clear.

3.4 These issues need to be addressed to enable widespread provision and adoption of various future services in the UK, with high quality mobile access where people live, work and travel. Addressing coverage issues now will provide the infrastructure platform on which successive generations of mobile technology will sit, be they 5G, 6G or next generation Wi-Fi.

How does the UK benchmark against other nations?

3.5 The UK is currently not in a leading position when it comes to the availability of mobile services. While it benchmarks well within Europe and more widely on having a highly competitive telecommunications sector – leading to benefits such as low prices relative to many countries[58] – the evidence on quality and coverage of mobile telecommunications services shows it as firmly middle of the pack.

4G AVAILABILITY



OpenSignal November 2016 State of LTE Report

3.6 OpenSignal's most recent data[59] from their 'State of LTE' November 2016 report shows the UK is behind the most forward looking technology nations such as South Korea, Japan, Singapore and the US in terms of the nationwide availability of 4G. They suggest it ranks 55th out of just under 80 countries. Within Europe the UK is in a middling position, behind countries such as Sweden, Norway, Switzerland, Spain & Greece; approximately level with Germany, and ahead of France and Ireland.

3.7 Compared to other nations, the UK has been relatively slow to deploy both 3G and 4G technologies widely. To reach the leading edge of mobile developments and to meet demand and stimulate growth in future there will need to be significant and well-targeted investment in both network equipment and infrastructure.

UK coverage

3.8 There is evidence to suggest that there is a gap between consumers' experience of the mobile services they receive and the coverage reported by operators and government. This gap prevents consumers from making informed purchase decisions based on coverage. It also creates expectations around policy interventions that may not be realised – for example expectations around the most recent obligations on 4G and geographic coverage (discussed below) may not be met in terms of real services. This gap must be closed.

3.9 The difference in the coverage reported by operators and the experience of users is in part explained by a lack of clarity around what coverage actually means. "Having coverage" is not as simple as it might sound (see breakout "Define coverage"), and depends on exactly what the user wants to do – send a text, make a call, browse the web, or watch a video. Complicating things further, a user may in theory have coverage in their current location, only for it not to be available because it is not from the provider they are subscribed to.

3.10 UK operators regularly refer to their coverage in advertising and when selling phones and contracts in store and Ofcom also reports regularly on the state of mobile coverage in the UK. Both parties base their coverage estimates on computer predictions by mobile operators, which are difficult to relate to the service levels experienced by consumers and – taken at face value – can paint an overly optimistic picture.

What is 'coverage'

The quality of the connection a mobile handset receives, and therefore the services that can be enjoyed, is dependent upon a number of factors. These include the distance of the user from the base station, the exact location of the user (as buildings & trees can block signals), and also the number of other people who are actively using their handsets nearby (in the same cell).

All of these factors continuously vary; for example the number of active users sharing the capacity of a cell swells at certain peak times during the day, and diminishes at night. Therefore saying with precision what quality of connection a mobile user can expect at an exact location and time across the UK is very difficult. Communicating this in a meaningful and simple way to mobile phone customers even more-so.

For this reason mobile operators and public policy makers have historically used computer predictions of phone signals to estimate the quality of mobile coverage people will receive across the UK. This creates the risk that it fails to reflect the true user experience. Predictions may suggest a good service based on the modelled signal coverage for example, but not account for a busy location or time of day, meaning that a user can't make a call. This explains the sometimes frustrating experience of having signal – indicated by several bars on your phone – but not necessarily being able to do what you want with it.

This situation is further exacerbated by differing definitions of "coverage". Coverage may mean in one circumstance the ability for the phone to simply connect to the network, or in another the ability to make a call, or – in another – the ability to watch a video.

With the advent of smart-phones much richer data is becoming available to establish a true picture of the coverage and quality of service that is experienced. Smart phones can collate detailed statistics on service experience which can be tagged with location and time. This data can be collated from millions of smart phones, making operators and third parties increasingly able to publish richer statistics of phone performance based on actual experience. OpenSignal is one such 3rd party service.

3.11 For example, Ofcom estimates outdoor voice coverage to be greater than 98% of UK premises.[60] Coverage for high speed mobile data is now also predicted to be high – Ofcom reports the availability of 4G mobile services having increased rapidly, with the UK having 97.8% of outside premises (i.e. coverage immediately outside of homes and businesses) covered by at least one operator in May 2016.[61] Figures reported by mobile operators broadly agree with Ofcom data. For example EE reports that their network provides 4G coverage to 97% of the population in the UK.[62]

3.12 These figures contrast with those derived from crowd sourced data from smart phones. For example, OpenSignal's data in their 'State of LTE' November 2016 report suggests that in the UK EE (who performed best in their tests) gave users access to an LTE connection 64% of the time, and the operator '3' gave access figures to the 4G network 44% of the time.[63]

3.13 Although Ofcom report that outdoor voice coverage is available at more than 98% of UK premises, this is concentrated around urban centres (see the box on UK Coverage below). In rural areas, Ofcom data shows users have a starkly different experience to their city dwelling neighbours; 28% of rural premises are in voice not-spots (see the box below on not-spots).

In rural areas **just under 80% of premises** *are in a* **4G not-spot**.

3.14 This picture is exacerbated when 4G mobile broadband is considered. Ofcom's most recent reports suggest that although nearly 98% of UK premises were in areas with some outdoor 4G coverage, in urban areas of the UK around 20% of premises are in a not-spot. In rural areas just under 80% of premises are in a 4G not-spot.

Not-spots

Not-spots are areas where users may not have coverage.

Complete not-spots are areas where there is no mobile coverage. It does not matter which mobile operator you are subscribed to, there is simply no coverage from any mobile network in that area.

Partial not-spots are areas where there is coverage from at least one of the four national mobile network operators (3, EE, O2, Vodafone). However if it is not the operator you are subscribed to (whether directly from EE for example, or through a retail provider such as GiffGaff or Tesco mobile) you will not receive service. Not-spots are more prevalent outside urban centres in the UK.

3.15 Figures which better represent the daily experience of mobile phone users also need to account for coverage on roads, railways, and around towns and businesses rather than simply addressing residential premises. Here, there is further evidence of patchy coverage. Ofcom estimates, for example, that 2G not-spots account for nearly 60% of UK A & B roads. For 4G services, though the last estimate is from data in 2015 and roll-out is still underway, partial not-spots account for around 45% of A & B roads, and complete not-spots account for a further 47%.[64]

3.16 On motorways, OpenSignal UK Roads and Rail Report (2014) report that users failed to get a 3G or 4G signal 24% of the time and on A-roads 33% of the time. On rail, they report that rail passengers were without a 3G or 4G signal 28% of the time.

3.17 In summary, there is a significant gap in the reporting of coverage and the consumers' experience which is not in consumers' interests. This is because:

- Computer predictions of coverage are not representative of real service levels provided to consumers;
- Coverage is not clearly defined – it is not related to a service or package of services;

UK COVERAGE

Voice Coverage: Urban Premises

Voice Coverage: Rural Premises

Figure 7: Urban verus Rural Voice Premises Coverage

4G Coverage: Urban Premises

4G Coverage: Rural Premises

Figure 8: Urban verus Rural 4G Premises Coverage

Voice Coverage A&B Roads

4G Coverage A&B Roads

Figure 9: Voice and 4G Coverage of A & B Roads

All operators *Partial not-spot* *Complete not-spot*

- Quoting coverage to residential properties is not representative of mobile consumption – for example, it ignores roads and railways; and
- Partial not-spots remain an issue of significance. Figures quoting coverage for "at least one mobile operator providing coverage" do not help consumers since they are tied to the coverage provided by the operator to which they subscribe.

The reasons for poor coverage in the UK

3.18 It appears deployment has struggled to keep pace with the transition to a world where ubiquitous good quality connectivity is an expectation.

3.19 While competition, in principle, drives investment in aspects of networks, this has not led to universal coverage. There remain some areas where the benefits to an operator, though not necessarily the societal benefits, from investing in marginal sites appear to be less than investment costs.

3.20 Deployment costs rise quickly when providing mobile infrastructure to inaccessible areas for example on our motorways and in our rail-cuttings where restricted access and other factors such as safety drive costs up. Similarly, deployment in rural areas becomes increasingly expensive as the density of customers per base station deployed decreases and the costs of base station and backhaul infrastructure increase. This makes it more difficult for operators to make a clear profitable business case to deploy. Other factors such as regulation around site acquisition, rental & planning can also impact costs.

3.21 Enhanced coverage by an operator may drive their ability to acquire and retain customers. However as we have seen the ability of competition to drive coverage is limited in part due to the inability of consumers to understand true coverage and network quality and make informed choices. It is further limited as consumers have many other factors to consider in their buying and switching decisions – particularly in the world of quad and triple play phone/broadband/mobile/TV bundling.

3.22 It appears that there are insufficient 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. Again, in these cases, 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, particularly where the costs of deployment may be driven up by factors such as planning issues, poor local coordination or inaccessibility of key sites.

3.23 The potential for societal benefits to outweigh the revenues an operator can capture has been recognised by Ofcom, leading to coverage obligations being imposed both on 3G licences and on one 4G licence. In its statement on the 4G spectrum award Ofcom stated:

"Our 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".

3.24 Coverage obligations on the radio spectrum licenses which Ofcom grants the MNOs have been the principal public mechanism used to drive the market to improve. These obligations are often offset against the cost of licenses – in effect a public subsidy. Looking over the history of UK coverage obligations (See Coverage interventions in the UK) shows how over the last decade these have increased in terms of their stretching nature and ambition, reflecting the increasing importance of widespread mobile access to the public and policy makers.

Coverage interventions 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 (see "Define coverage"), and approaches vary.

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.

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. 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 by end 2017), but it was imposed on one licensee only. It was expected that the other operators would feel commercial pressures to match the coverage levels delivered by the operator with the coverage obligation. Operators later confirmed their plans to achieve this.

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.

Meaningful coverage: looking to the future

3.25 The coverage levels that MNOs advertise, however, and which are discussed in policy terms are often not based on meaningful measures. Only with an honest and understandable picture of service quality can consumers hope to make informed purchase decisions and policy makers target the right issues.

3.26 The UK does not compare well internationally, being firmly middle of the pack on coverage and speed. If the UK is to move into a leading role, where it is recognisably ahead of peers in terms of the quality of mobile connectivity, this must change. Provision of the fundamental wireless infrastructure in hard to reach areas (ducts, fibre, masts & poles) is one useful means to enable widespread and early deployment of new generations of mobile technology. This is a helpful area for government to support and the Commission welcome the 5G enabling measures recently announced in the Autumn Statement. The push for seamless and ubiquitous connectivity must not wait for 5G, instead immediate action is needed to improve mobile coverage for users now and to help build a foundation which will enable widespread access to 5G services in future.

3.27 Although mobile services are increasingly a necessity rather than a luxury, the UK currently operates without a clear definition of the services that should be provided at near ubiquitous levels ("the essentials") versus those which are more discretionary. This makes it difficult for interventions to be targeted around agreed and transparent expectations.

3.28 There are three key areas to address:

- coverage that does 'what it says on the tin' – addressing the gap between modelled and actual coverage;
- identifying defined "essential" services that are expected to be widely available, which will enable clarity and transparency on expectations around mobile coverage quality for the future in the UK; and
- identifying a strategy to tackle partial-not spots.

3.29 There is a strong case for a wholesale shift away from the use of predicted residential coverage as a benchmark for mobile services. This is likely to mislead consumers when so much of their mobile experience is based elsewhere – on transport networks, around businesses, towns and villages. The advent of smart-phone data analytics means vast quantities of data are available, based on real user experience, which can be linked much more accurately to the services used. Widespread adoption of realistic measures of user quality of service and coverage are necessary if consumers are to drive competition through purchasing decisions.

The Commission believe it is time for a wholesale shift away from the use of predicted residential coverage as a benchmark for mobile services.

3.30 In the interim, Ofcom has a strong capability to measure real coverage through its field force, demonstrated in some of its more recent reports, such as Smart Phone Cities.[65] This could well form the basis of enforcing more measurable service based obligations and policy interventions going forwards, and ensuring coverage levels cited in advertising can be validated through spot testing of network performance. This approach should enable valuable progress in the short term, while a longer term plan is developed to use data collected from networked devices such as smartphones.

3.31 The definition of 'essential' mobile communications might cover the ability to be able to make calls, send messages, and access basic internet services – such as web browsing, maps and navigation assistance. This could form the basis of transparent messaging around coverage expectations, advertising, policy interventions and enforcement.

3.32 A fairly basic level of "essential" service is likely to imply a 256kb/s or 500kb/s level of connectivity, though it will almost certainly rise in the future. Establishing this "essential" layer will enable competition in the future to drive service quality based on network speed and capacity, rather than coverage which denies users' further insight into quality of service. Whilst, many consumers may well be satisfied with a level of service provision meeting these 'essential' standards, others will demand more, which the market should be well able to provide.

3.33 The level of "essential" services would need to evolve over time as technology changes and new services are taken up and embedded within society. As well as the current view of "essential" standards, a forward view across the next 5 and 10 years would provide transparency about the government's coverage objectives. Terms like "4G coverage" or "5G coverage" do not help in this regard, as they are technologies, rather than indicators of particular services consumers can use.

3.34 Addressing these points will provide a more honest picture of mobile service quality in the UK, as well as enabling more informed purchase and switching decisions and more informed and targeted policy interventions; and providing transparency about the services that consumers should be able to expect from the mobile operator ecosystem on a widespread basis – wherever we live, work and travel.

Establishing coverage where we live work and travel

3.35 Partial and complete not-spots are persistent and substantial issues in the UK, which are incompatible with long-term expectations for a connected society.

3.36 There are a number of ways this situation can potentially be addressed in areas where the market is not driving an adequate solution. These include:

- enabling roaming between networks;
- enabling multi-operator MVNO's who can aggregate coverage from the wholesale providers;
- procurement of the service level;
- coverage obligations;
- or a combination thereof.

3.37 These approaches, which have been considered previously by others, are covered in more detail in our reported research.[64]

3.38 By the end of 2017, the mobile operators are expected to have delivered their obligations on voice coverage to 90% of the UK geographic landmass and 4G coverage to 98% of homes (O2 only). It is not clear, however, how those obligations relate to the real service level consumers can expect and to what extent this will resolve issues around partial not-spots. It therefore remains to be seen whether the combination of the two existing coverage obligations will, when fully rolled out, be sufficient to meet an "essential" service level across all operators.

3.39 Any future obligation or procurement to address mobile coverage using the approaches mentioned must be coherently thought through by Government and Ofcom and where possible avoid proliferating the patchwork of differing obligations further. This should consider the precise definition of delivering "coverage where we live, work and travel" For example does it mean 95%, 98% or 100% of our road network.

3.40 The Commission call for a coherent review and recommendations on the right approach to deliver ubiquitous essential service coverage from mobile networks, and also the market enables high quality for users of mobile networks. This should take a long term view and make recommendations around 4G and 5G, as well as reflecting the contribution of unlicensed technologies be they Wi-Fi/4G or 5G.

3.41 Establishing near universal mobile coverage now means the foundation for widespread 5G services is laid. The evidence that the Commission has considered suggests that without any intervention we can expect 5G to roll out similarly to 4G in the UK; it will roll out in urban areas first, followed by rural areas later; outside of urban areas we can expect patchy coverage, including on our roads and railways, and with some areas receiving no coverage at all. We should expect 5G services to be delivered in a middle, rather than a leading timescale. To avoid this picture means building the right infrastructure by our motorways, railways and fixing not-spots in rural areas now.

Recommendation 5: Government and Ofcom should develop a meaningful set of metrics that represent the coverage people actually receive and use these to determine a mobile universal service obligation setting out the minimum service level people should expect to receive.

a) **Ofcom, government and mobile operators should report their coverage so that they are genuine and meaningful reflections of the services enjoyed by customers. Metrics should be measurable and based on the reality of service and coverage provided to customers, not based on simulated or predicted performance. Ofcom should set out how this is best achieved by the end of 2017.**

Ofcom and government should use these metrics as the basis of future interventions such as spectrum licence obligations or voluntary agreements with operators.

Government, Ofcom or the Advertising Standards Authority should take action if operators advertise or report coverage in a way that does not reflect services being delivered to consumers on an everyday basis.

b) **Mobile services are increasingly viewed as essential, underpinning our daily lives and the digital economy. Government must deliver a view by the end of 2017 on what aspects of mobile services are considered "essential". It should then establish how this "essential" level of service provision can be made available through a mobile universal service obligation regardless of the network to which a customer is subscribed. Government should engage with Ofcom and industry to establish the best delivery mechanism, whether through spectrum licence obligations, enabling roaming, enabling cross operator Mobile Virtual Network Operators (MVNOs), through government procurement or a mix thereof.**

Government with the assistance of Ofcom should deliver this as soon as is practical but no later than 2025.

Regulation that is fit for the future

3.42 The regulatory framework for mobile telecommunications has helped to deliver good outcomes in the UK. Whilst significant changes have been seen in the UK market across the last decade, it remains highly competitive, with four MNOs and 17 active Mobile Virtual Network Operators (MVNOs), which help to foster competition by establishing agreements to use existing MNO infrastructure in order to provide more diverse customer products and services. As a result, consumers have enjoyed innovative services and pricing in recent years; indeed UK prices are among the lowest in Europe, and the cost of a typical package has fallen by two-thirds since 2003. By the end of 2015, mobile subscriptions had reached 91.5 million and were continuing to grow. And, following some years of decline in revenues, the market has been stable for the last three years.

3.43 As set out previously in this report, the UK remains in the middle of the pack in terms of delivery of world class, high quality mobile services. If we wish to move to a leading position, regulation which looks to the future and also enables the necessary investment in the UK market is critical.

Key developments in the mobile market

3.44 The mobile eco-system has continually evolved to reflect changes in technology, the increasing demands of users, and operational efficiencies in a maturing market. Over the last 15 years, the market structure has evolved from one where MNOs were vertically integrated, controlling 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 such as application providers and wholesale infrastructure providers.

3.45 These trends are set to continue. Looking to the decade ahead there are a number of possible developments that will influence the deployment of future mobile telecoms networks.

- **Ongoing financial pressure on MNO's and investment.** The ability for third parties to create applications for mobile phones has generated an explosion in services and data, demand forecast to continue grow rapidly into the future. This creates the challenge around investing in network infrastructure and technology to meet demand, while revenues from the apps do not necessarily flow to the MNOs. Mobile operators have also seen little willingness to pay more for new generations of mobile technology such as the move from 3G to 4G.
- **A greater pressure to share infrastructure.** This is likely to be necessary to reduce capital and operational costs for establishing coverage in less profitable areas required for ubiquitous coverage, and potentially for providing the ultra-dense 5G network deployments envisaged. Neutral hosting models are one way to facilitate infrastructure sharing.
- **Further reduction of vertical integration and control.** While the MNOs may remain key investors in mobile infrastructure, 5G technology developments such as network virtualisation and cost efficiencies mean 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 this are already being introduced, (such as Google's Project Fi which shifts intelligently between networks to the best available signal) though current technology means that services attempting to stitch together separate networks are sub-optimal, for example not being able to manage a seamless handover when operators move between different networks. Technology is moving rapidly however with seamless handover from Wi-Fi to 4G for example now mainstream.

- **A push to smaller, higher capacity cells and potentially more local network provision.** Very high capacity connectivity pushes to very high frequency small cells in millimetre wave bands. These are unlikely to be deployed on a national coverage basis. However, there may be opportunity for other smaller providers alongside the existing four national wholesale operators to contribute to widespread 5G deployment by adding to the UK's telecom infrastructure.

3.46 The future changes to the mobile telecoms market suggest that mobile operators will be a key part of 5G deployment, but may well not be the only players providing digital infrastructure. For 5G to emerge in a timely manner regulatory options for the future need to enable continued investment to flow into mobile infrastructure through MNOs and other infrastructure providers, as well as enable the market to evolve as it has over the last decade.

3.47 A key consideration for regulation to address therefore is enabling investment by encouraging the maximum amount of infrastructure sharing that is possible while maintaining an appropriate degree of competition. This will minimise capital and operational expenditure for both the infrastructure needed to provide coverage in hard to reach areas and also for highly dense networks. Secondly enabling wide access to the market for new and possibly sub-national infrastructure providers and to enable innovation means looking hard at whether dedicated spectrum licensing is the right option.

Infrastructure Sharing

3.48 When making investment decisions operators must balance costs and benefits, including benefits of that might come from differentiating themselves from their competitors. Reducing the costs of network deployment will increase the operators' incentive to make incremental investments in their networks; whether to extend existing network capacity and coverage or to introduce 5G specific technology.

3.49 A considerable degree of sharing already occurs in UK mobile networks as is clear from the formation of the network sharing companies MBNL and CTIL, as well as through the existence of dedicated wireless infrastructure providers such as Arqiva and WIG. The current network sharing arrangements reduce the cost of coverage for operators, reducing some fixed costs by half (with two operators sharing site infrastructure).

3.50 It has been 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. To date 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.

3.51 Costs could be further reduced if all operators shared sites. While this is encouraged under existing regulation (see breakout), and can be facilitated by Wireless Infrastructure Providers (WIPs) acting as neutral hosts, in many cases co-ordination issues mean that each network sharing agreement (CTIL and MBNL) rolls out duplicate sites. There are difficulties in enabling this co-ordination without providing adequate incentives for the stakeholders to align, for example incentives to roll out increased coverage networks.

Infrastructure sharing in the Electronics Communications Code (ECC)

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 or strategic reasons may deter operators from entering into agreements for individual pieces of infrastructure (compared to network sharing agreements at a national level). A "first mover advantage" would be an example of incentivising investments which are not shared. For example In order to be first to the market with 4G, EE chose to roll out its 4G network independently of Three.

While the reform of the ECC reduces costs for MNOs in a number of areas, a potential stumbling block could be that the revised Code will not regulate the fees charged by Wholesale Infrastructure Providers for their sites. This may need review moving forward as WIPs owned approximately one third of mobile towers/rooftops as of May 2016.

3.52 While further network sharing, in its extreme form through the formation of a single wholesale network, could lead to higher cost-savings still, the element of network competition would be lost and there may be fewer incentives to innovate. The GSMA found[66] 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. Innovation is vital in a rapidly changing hi-tech sector such as telecoms.

3.53 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.

3.54 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.

3.55 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.

3.56 The onus therefore may be on improving incentives for infrastructure sharing to reduce the cost of greater coverage requirements. There are a number of ways this could be achieved – coverage obligations, roaming, enabling multi operator MVNOs, or tendering a universal service obligation. When determining the appropriate approach to deliver a USO, enabling the maximum levels of infrastructure sharing possible should be considered.

3.57 Wholesale only infrastructure providers (sometimes called vertically separated infrastructure providers) have different incentives to vertical MNO infrastructure holders. With appropriate regulation establishing fair, reasonable and non-discriminatory terms for access this model of infrastructure provision could be a valuable means of lowering the friction and cost associated with providing mobile services. There are opportunities for following this approach in the provision of digital infrastructure alongside our motorway network and roads, the trackside infrastructure along our railways, rural areas and potentially for local authorities and others who might choose to invest in 5G.

3.58 The Commission sees independent infrastructure providers as potentially an enabling mechanism for meeting some of the remaining challenges around deployment of 4G and 5G connectivity. Regulation should encourage and enable such provision where possible to maximise the ability for the market to meet some of the challenges around deployments of both dense networks and rural networks.

Recommendation 6: By the end of 2017 Ofcom and government must review the existing regulatory regime to ensure that it supports the sharing of telecoms infrastructure. This will be particularly important for areas of the country where competition driven markets have struggled to provide the necessary mobile infrastructure.

Enabling subnational provision of services: the role of spectrum policy

3.59 Spectrum policy is intimately tied to market economics in mobile communications. Whether you have a license to access parts of the radio spectrum defines in the main whether you can offer services. The small number of licenses granted, governing access to this scarce resource tends to limit the number of market players. Across the world we see mobile operators operating in a national oligopoly market. This in part enables the very large investments required to roll out, operate and upgrade nationwide networks.

3.60 Spectrum auctions have become the most prevalent method for allocating the scarce resource through spectrum licenses to market players such as the MNOs. This is because:

- they are seen to act as an efficient means to allocate a resource to a variety of market players with potentially differing uses. A party who is willing to bid most for the resource is the one who values it most for driving their future business; and
- they raise money for governments.[65]

3.61 There are a number of ways spectrum policy can influence outcomes for 5G deployments in the UK. Costly spectrum licenses can limit the market to major oligopoly players. Most of the spectrum which is usable (either currently or in the near future) for mobile devices such as iPhones and Android phones is valued very highly by existing national mobile operators. Others in the market, for example small scale providers, are unlikely to be able to raise sufficient investment to outbid a national player and thus spectrum access for them becomes a challenge.

3.62 Spectrum auction fees – often hundreds of millions of pounds – and ongoing annual license fees are another cost which makes business cases more of a challenge for operators and investors faced with uncertain decisions such rolling out infrastructure for new technology markets.

3.63 The very high frequency millimetre wave bands proposed for 5G may not need such tight regulation. Alternative licensing approaches such as unlicensed or light licensing (see breakout box below) may be appropriate. These approaches reflect that the need for licensing is reduced by technology managing interference, or reducing it to an extent which operators can manage through a code of practice. This potentially drives much greater spectrum use than allocation of dedicated rights to players who then may make use of spectrum in just a small number of areas. Balancing the availability of unlicensed as well as licensed spectrum in the market enables innovation as well as enabling appropriate investment certainty for established players.

3.64 5G is seen as providing hot spots of super high capacity, not necessarily uniform wide areas coverage, or coverage on a nationwide basis. Unlicensed or light licensed spectrum access could enable smaller scale players to enter the market and contribute to particular localities, or for businesses to self-provide. For example:

- Factory owners may choose to purchase 5G capability for their factories – controlling robots. They may do this either from a mobile operator, or a smaller niche provider, or indeed choose to self-provide. It can be seen that if 5G spectrum is held by and only accessible to mobile operators the latter two cases are not possible.
- Councils, communities or business park owners may choose to deploy 5G hotspots in a locality providing ultrafast wireless broadband or coverage for IoT uses or sensor networks.
- Sub-national fibre companies (alt-nets) rolling out fibre to rural communities may wish to provide 5G services in those areas making maximum use of their deployed fibre assets.

Licensed and Unlicensed Spectrum

Spectrum is a finite natural resource. Historically spectrum licensing has been required to manage the potential for wireless operators to interfere with each other and impact their ability to provide services. Spectrum licenses take slices of the radio spectrum and allocate them to individual operators and uses to eliminate the interference risk.

Technology is moving rapidly in a direction where such regulation is looking archaic. Modern technology is increasingly able to manage interference, and the interference risk itself diminishes as technology pushes to the ever higher frequencies expected to be used for 5G. The very high data rate communications envisaged by 5G and other technologies also requires access to much wider parts of the radio spectrum than can be efficiently licensed to one operator.

Other approaches to licensing are available that allow potential entrants to use the spectrum without making the necessary investments to outbid MNOs in a spectrum auction. They also reduce spectrum costs (as unlicensed spectrum is free of charge) and potentially increase spectrum utilisation as more than one user would can have access to this spectrum.

Wi-Fi is an example of unlicensed spectrum being used successfully to enable global innovation. While MNOs still have a pivotal role in providing wide area coverage when customers are 'out and about'. The majority of traffic to mobile devices is now delivered by Wi-Fi networks rather than traditional mobile networks.

Unlicensed spectrum is also enabling innovation in the IoT space. Sigfox and LoRa are two IoT technologies which use unlicensed spectrum to provide services and have already started rolling out networks in the UK. Sigfox has partnered with Arqiva in the UK to roll-out an IoT network and LoRa installed their first base station in London in early 2016. With the number of connected devices predicted to reach billions, these dedicated networks are likely to expand and benefit from their own economies of scale. These networks in turn drive competition in standards and are likely to incentivise MNOs to upgrade their own M2M/IoT capabilities from 2G and 3G to LTE and ultimately 5G.

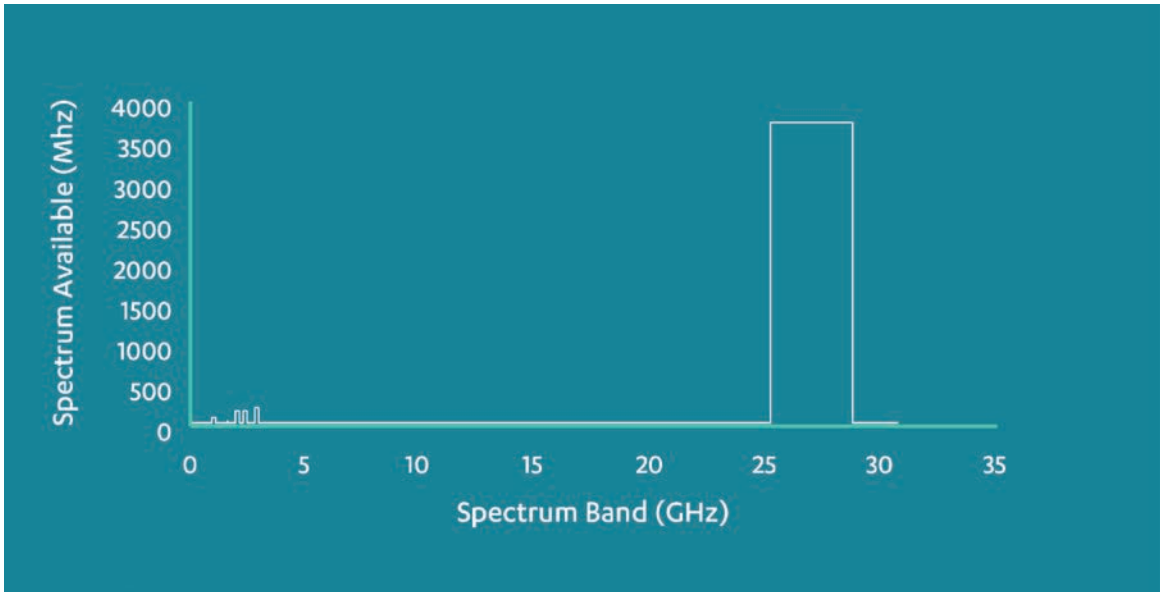
What is millimetre wave spectrum, and why does 5G need it?

5G technology is looking to use both traditional radio spectrum bands currently used in mobile communications and much higher frequency bands – termed millimetre wave bands

The amount of data that can be transmitted wirelessly is proportional to the amount of radio-spectrum you are transmitting over. Historically technology has only been able to operate at low frequencies where there is limited spectrum bandwidth available. As time has moved on, ever higher frequencies of the radio spectrum have become accessible, meaning greater spectrum bandwidth has been able to be exploited by mobile operators for increase data rates.

Technology has now enabled access to the very high frequency millimetre wave bands of the radio spectrum. The components and signal processing required to make efficient radios have moved from the research community into mainstream manufacture. The large amounts of spectrum bandwidth necessary for the high data rates that 5G seeks to supply are only available at these higher parts of the radio spectrum.

In 2016 in the UK the total holdings of the four mobile operators are approximately 600MHz. By comparison just one of the anticipated 5G bands offers potentially 3500MHz of spectrum.



Unfortunately radio waves at such high frequencies do not propagate as well as at lower frequencies, meaning distances over which communications is possible are much more limited – potentially limiting the area mobile cell can cover to just 100m or 200m. Whilst such small cells create an infrastructure a challenge, it does mean the base station data capacity is shared between a small number of users, offering potentially vast data rates.

3.65 This direction of travel is supported by evidence in the UK and abroad. The US has taken the approach of releasing considerable amounts of both licensed and unlicensed spectrum for 5G services. In the UK, Vodafone recently commented on their openness to the possibility of less restrictive licensing approaches to the millimetre wave 5G spectrum bands.[67]

3.66 Where spectrum licensing is considered essential (at lower frequencies) obligations on licensees may be a good thing in terms of driving infrastructure provision and minimising costs to operators. They act as a public subsidy for infrastructure provision – bidders subtract the cost of fulfilling the obligation. In theory they can result in spectrum licenses being awarded for zero cost or negative cost if onerous obligations cost more to fulfil than the value of the spectrum.

3.67 One way of driving early 5G deployment in the UK would be to put an obligation on the 3.4GHz licenses which is the first "5G" spectrum to be released to the market in the UK. An obligation could for example require an operator to deploy 5G equipment on all masts within its current network.[66] This would be a radical departure from technology neutrality which is usual in spectrum policy, but it serves to demonstrate how spectrum licenses can subsidise early rollout if that is the policy objective.

3.68 In summary, as well as lower frequency radio spectrum, 5G expects to make use of very high frequency millimetre wave radio spectrum, resulting in very small mobile cells. These are not anticipated to be deployed outside of urban centres by mobile operators. Auctioning spectrum licences in large, national scale blocks, at these very high frequencies, risks a significant share of the radio spectrum lying fallow in large parts of the country where it is not profitable for operators to deploy networks, yet would be closed off to other uses. This acts as a barrier to entry for new firms to compete in the provision in mobile services and may impede the most widespread deployment of 5G high frequency small cells.

3.69 Spectrum sharing or much less restrictive access to higher frequencies could be a highly efficient way to ensure a number of operators can provide connectivity, making best use of the scarce resource. We think Government and Ofcom should review how unlicensed, light licensed spectrum, sharing and associated approaches can be utilised in high frequencies to maximise access to the radio spectrum beyond the 4 national wholesale operators. This will stimulate maximum innovation and could result in the reach of 5G being maximised.

3.70 Ensuring the right balance of unlicensed, light licensed and sharing with traditional licensed approaches is likely to stimulate maximum innovation and could result in the reach of 5G being maximised.

Recommendation 7: Ofcom and government must ensure they keep pace with the rapid evolution of the mobile communications market, and that the regulatory regime is fit for purpose. By the end of 2017 Ofcom and government must review the regulatory regime to ensure that spectrum allocation and regulatory decisions support a growth model in a world where technology developments enable greater shared access and interoperability. Government and Ofcom should review how unlicensed, lightly licensed spectrum, spectrum sharing and similar approaches can be utilised for higher frequencies to maximise access to the radio spectrum. Spectrum decisions should where possible enable:

- Community or small provider solutions to meet the needs of local areas if they remain unserved or poorly served.
- Niche entrants or sub-national players to access the higher frequency spectrum anticipated for 5G. Allocation of nationwide spectrum licenses to a small number of operators could leave large areas of the UK fallow.
- Businesses, universities and others to access spectrum where they need to within their factories or buildings, including already licensed spectrum if there are no interference risks. This will unlock multiple wireless service provider options, including self-provision, spurring the innovation in industrial internet of things, wireless automation and robotics.

THE NATIONAL INFRASTRUCTURE COMMISSION

Chair

Lord Andrew Adonis

Lord Andrew Adonis was appointed as chairman of the National Infrastructure Commission on 5 October 2015. He was a member of the independent Armitt Commission, which recommended an independent National Infrastructure Commission in 2013.

Andrew Adonis was formerly the Transport Secretary from 2009 to 2010, Minister of State for Transport from 2008 to 2009 and Minister for Schools from 2005 to 2008. He was Head of the No10 Policy Unit from 2001 to 2005.

Deputy Chair

Sir John Armitt

Sir John Armitt is Chairman of the National Express Group and City & Guilds, Deputy Chairman of the Berkeley Group and a member of the Board of Transport for London, Senior Vice President of the Institution of Civil Engineers and a Fellow of the Royal Academy of Engineering, the Institution of Civil Engineers and City & Guilds of London Institute. He has received honorary doctorates from the universities of Portsmouth, Birmingham, Reading and Warwick and was awarded the CBE in 1996 for his contribution to the rail industry and a knighthood in 2012 for services to engineering and construction.

In September 2013 the Armitt Review, his independent review of long term infrastructure planning in the UK, was published. The review is now Labour Party policy.

Commissioners

Tim Besley

Tim Besley is School Professor of Economics and Political Science and W. Arthur Lewis Professor of Development Economics at the LSE. He was a co-chair of the LSE growth commission and a member of the IFS's Mirrlees Review panel, and is currently Chair of the Council of Management of the National Institute of Economic and Social Research.

Demis Hassabis

Demis Hassabis was the co-founder and CEO of DeepMind, a neuroscience-inspired AI company, bought by Google in Jan 2014. He is now Vice President of Engineering at Google DeepMind and leads Google's general AI efforts.

The Rt Hon Lord Michael Heseltine CH

The Rt Hon the Lord Heseltine CH was a Member of Parliament from 1966 to 2001. He was a Cabinet Minister in various departments from 1979 to 1986 and 1990 to 1997 and Deputy Prime Minister from 1995 to 1997. He is founder and Chairman of the Haymarket Group, and most recently was appointed by the government as an advisor to the Secretary of State for Communities and Local Growth.

Sadie Morgan

Sadie Morgan BA (HONS), MA (RCA), FRSA is a co-founding director at the award-winning practice, dRMM Architects. She became the youngest and only third ever-female President of the Architectural Association in 2013. In March 2015, Sadie was appointed as Design Chair for High Speed Two (HS2) reporting directly to the Secretary of State.

Bridget Rosewell

Bridget Rosewell OBE, MA, MPhil, FICE is a UK economist, with a track record in advising public and private sector clients on key strategic issues. She is a founder and Senior Adviser of Volterra Partner and a non-executive director of Network Rail and of Ulster Bank. She was Chief Economic Adviser to the Greater London Authority from 2002 to 2012. She has been a member of several Commissions looking at the future of public services, cities, infrastructure and local finance.

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1 See, for example: Economic Impacts of Mobile Communications in Scotland, Report to the Scottish Government, SQW, January 2014, though there is a counter view that questions the true economic value of features such as increased bandwidth. See: Kenny, R. and C. Kenny (2011). "Superfast broadband: is it really worth a subsidy?" info, 13(4): 3–29.

2 There are a further c.1,900 miles of trunk roads in Scotland and around 1,000 miles of trunk roads in Wales.

3 Road Use Statistics, DfT, 2016 - https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/514912/road-use-statistics.pdf

4 Rail delivery group. "GB rail: better services, better journeys and better value" http://www.raildeliverygroup.com/files/Publications/2015-09_rail_industry_dataset.pdf

5 See http://orr.gov.uk/__data/assets/pdf_file/0015/22056/passenger-rail-usage-2015-16-q4.pdf

6 In December 2014, the UK Government signed a binding agreement with the four network operators to improve mobile coverage. This was aimed, in particular, at reducing 'partial not spots', where coverage is provided by some but not all mobile operators. This agreement guarantees coverage of a mobile voice and text service from each operator to 90% of the UK's land mass by 2017. This is expected to improve with the future availability of voice services over the 4G networks operating in the lower 800MHz band.

7 It should be noted that O2 has a coverage obligation in its licence to roll out 4G to cover at least 98% of the UK population (when indoors) by 2017 at the latest. This results in more than 99% coverage for 4G when outdoors. Other UK mobile operators have indicated they intend to match the 98% coverage.

8 Ofcom, press release, 'UK is now a smartphone society', 2015, https://www.ofcom.org.uk/about-ofcom/latest/media/media-releases/2019/cmr-uk-2015

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11 See: http://www.cbi.org.uk/news/infrastructure-survey-2015/infrastructure-survey-2015/ . Similarly, the Federation of Small Businesses recently found that three quarters of small businesses believe mobile phones are crucial or very important to their business FSB http://www.fsb.org.uk/media-centre/publications?page=13

12 See, for example: Economic Impacts of Mobile Communications in Scotland, Report to the Scottish Government, SQW, January 2014, though there is a counter view that questions the true economic value of features such as increased bandwidth. See: Kenny, R. and C. Kenny (2011). "Superfast broadband: is it really worth a subsidy?" info, 13(4): 3–29.

13 5G Mobile And Wireless Communications Technology, Edited by A. Osseiran, J. Monserrat, P. Marsch, Cambridge 2016, pg 3.

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20 The IoT is predicted to grow enormously, but in the UK a recent survey by Deloitte suggest that connected home devices are yet to take off, with just 2% of adults owning smart lights and smart appliances. See: Global Mobile Consumer Survey 2016, Deloitte

21 Understanding 5G: Perspectives on future technological advancements in mobile, GSMA, December 2014

22 WIPs also include: WIG, which operates a network of over 2,000 shared communication infrastructure assets 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, Shere, which owns approximately 500 sites in the UK with access to 4,150 potential sites on land belonging to United Utilities and Thames Water

23 Frontier for NIC, citing analysis produced by Analysys Mason

24 As of September 2016. Source: Globalcomms

25 Frontier for NIC, 2016

26 Ofcom Market Report, 2016 http://stakeholders.ofcom.org.uk/binaries/research/cmr/cmr16/uk/CMR_UK_2016.pdf

27 Linked to this narrative of increased mobile data usage is an increase in the number of Machine to Machine (M2M) connections, which increased by 7% between 2014-15, to a total of 6.7 million in 2015; whilst still relatively modest, this is a sign that the IoT has arrived. See: Ofcom Market Report, 2016 http://stakeholders.ofcom.org.uk/binaries/research/cmr/cmr16/uk/CMR_UK_2016.pdf

28 Ibid

29 5G networks will be capital intensive due to the need for a significant increase in small cells to realise many of the predicted 5G benefits. High frequency 5G technologies will only propagate across tens to hundreds of metres, which will necessitate 'densification' of small cells.

30 Research by RealWireless for NIC, 2016. See also – 'Identification and quantification of key socio-economic data to support strategic planning for the introduction of 5G in Europe', prepared for the European Commission DG Communications Networks, Content and Technology, 2016, page 9

31 Research by RealWireless for NIC: These areas are taken from a comprehensive long list of potential candidates, and alone illustrate the diversity of potential uses that are envisioned for future mobile services and suggest at the consequent demand that will be placed on future mobile network infrastructure.

32 Connected and Autonomous Vehicles – Opportunity March 2015

33 By 2030, some consider it likely that high degrees of automation will be seen during certain vehicle operations, for example, motorway 'autopilot', but not for the full end to end journey, which is expected at some point beyond 2030. See KPMG: https://www.smmt.co.uk/wp-content/uploads/sites/2/CRT036586F-Connected-and-Autonomous-Vehicles-%E2%80%93-The-UK-Economic-Opportu...1.pdf

34 Research for NIC by RealWireless, 2016

35 See, for example, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/434379/Improving_mobile_communications_to_UK_rail_passengers.pdf

36 Transport Focus – National Rail Passenger Survey: http://www.transportfocus.org.uk/research-publications/research/national-passenger-survey-introduction/

37 See – Personalised health and care 2020: a framework for action, Department for health, 2014

38 Several NHS 'test-beds' for the use of new technologies in healthcare were announced by NHS earlier this year. They include two IoT test-beds which will seek to help diabetes and dementia sufferers through a range of sensors and wearables. See: https://www.england.nhs.uk/2016/01/embracing-innovation/

39 For example, 1. Diabetes UK estimate there are over 4 million people in the UK living with diabetes, an increase of 65% over the past decade. The UK also has the highest obesity level of European with nearly 1 in 4 adults classed as obese in 2008. In addition, mental illness is becoming an increasing issue with more than a quarter of hospital inpatients in 2014-2015 suffering from dementia.

40 A further future envisaged use case for remote healthcare is 'remote surgery' via the Tactile Internet. However, there is considerable uncertainty over what tactile internet applications will emerge and whether they will be taken up in the short to medium term, especially given questions over consumer acceptance. Given that the UK population has good access to medical facilities, the need for remote surgery is unclear.

41 Analysis for NIC by Frontier Economics, 2016

42 See the recent report regarding mobile coverage in the UK by the British Infrastructure Group: http://britishinfrastructuregroup.uk/wp-content/uploads/2016/10/Mobile-Coverage.pdf

43 Roads Investment Period 1, Plan, 2015

44 Analysis by KPMG in 2015. See: https://www.kpmg.com/BR/en/Estudos_Analises/artigosepublicacoes/Documents/Industrias/Connected-Autonomous-Vehicles-Study.pdf

45 A number of trials are underway: The UK Connected Intelligent Transport Environment (CITE) connected vehicle trial by April 2018, which includes Jaguar Land Rover, Coventry City Council, Visteon, Vodafone and others – a project sponsored by Innovate UK; The A2/M2 Connected Corridor, with partners including DfT, Highways England, Transport for London and Kent County Council and supported by the Automotive Electronic Systems Innovation Network; And an HGV platooning, announced in Budget 2016.

46 Where the density and volume of traffic is likely to cause spectrum capacity issues in the near to mid-term and where technology can help realise innovations such as vehicle platooning.

47 MNOs have told the NIC that this is often due to the additional complications, access restrictions and expense of placing base stations on the trackside.

48 All operators are all equally affected by trackside access difficulties and many rail routes travel through areas of low population density with limited existing infrastructure (such as power, fixed networks and access roads) driving the investment required to support mobile networks up.

49 For example, until new Franchise Agreements were introduced recently, TOCs were not incentivised to provide connectivity on trains. Moreover, Network Rail was not incentivised to allow MNOs to place masts close to rail tracks (for personnel safety reasons).

50 The Policy is aimed at implementing the 2015 Conservative Manifesto Commitment of installing Wi-Fi on trains.

51 Ref Passenger Focus Survey, Wi-Fi a top ten passenger Issue

52 TSC, The future of Rail: Improving the rail passenger experience, 2016

53 Ofcom Connected Nations 2015, p.2, https://www.ofcom.org.uk/__data/assets/pdf_file/0028/69634/connected_nations2015.pdf?lang=rsndbjgoyjfdsv

54 Ofcom Mobile Data Strategy, June 2016, https://www.ofcom.org.uk/__data/assets/pdf_file/0033/79584/update-strategy-mobile-spectrum.pdf

55 Next Generation Mobile Networks 5G White Paper, Feb 2015, https://www.ngmn.org/uploads/media/NGMN_5G_White_Paper_V1_0.pdf

56 Amended planning regulations came into force on Thursday 24 November: 'The Town and Country Planning (General Permitted Development) (England) (Amendment) (No. 2) Order 2016' and can be accessed at http://www.legislation.gov.uk/id/uksi/2016/1040

57 Exploring the Cost, Coverage and Rollout Implications of 5G in Britain Edward J Oughton[12] and Zoraida Frias[31] Centre for Risk Studies, Cambridge Judge Business School, University of Cambridge, England

58 Mobile Coverage: A Good Call for Britain, British Infrastructure Group, Oct 2016. http://britishinfrastructuregroup.uk/wp-content/uploads/2016/10/Mobile-Coverage.pdf

59 UK prices are among the lowest in Europe, with the cost of a typical package falling by two-thirds since 2003. Analysis for NIC by Frontier Economics, 2016

60 OpenSignal's state of LTE, November 2016 report. We note caution should be used in inferring coverage from OpenSignal's availability metric. It includes other factors – accounting for indoor connections and times of high congestion. Countries in the earlier stages of their 4G deployments can sometimes have higher availability scores as the numbers of 4G subscribers are typically small and confined to large urban areas where new 4G networks are typically located.

61 Connected Nations 2015, Ofcom

62 The Communications Market Report, 2016, Ofcom

63 EE 4G network summary, EE website, December 2016

64 Connected Nations 2015, Ofcom

65 Smart Phone Cities, Ofcom

66 Frontier Economics, analysis for NIC, 2016

67 Westminster eForum: The UK mobile industry: consolidation, 5G and infrastructure, November 2016. Transcript to be published