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5G technology

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OVERVIEW

5G is the next generation of mobile communications technology. It is expected to offer faster, lower latency (response time) mobile broadband connections and be able to connect a greater number of devices to a mobile network while maintaining good quality connections. Mobile broadband will be the first widespread application of 5G technology, however, in the longer term, it could have applications in a number of other areas.

5G networks are technologically different to previous mobile networks in several ways, including the use of: new radio spectrum frequencies, new and upgraded mobile base stations (which connect devices such as smartphones to the rest of the telecommunications network) and new software techniques to help control and manage telecoms traffic more effectively. 5G mobile broadband will initially be rolled out on existing mobile network infrastructure and sites. However, in the longer term, 5G is likely to use a greater number of small base stations known as 'small cells'.

The government has said it wants the UK to be a global leader in 5G and, in its 2018 Future Telecoms Infrastructure Review, announced its ambition for the "majority of the UK" to have 5G mobile coverage by 2027. Work is ongoing across industry and government in the UK to develop 5G mobile networks and to trial 5G in other sectors. The UK's four mobile network operators have carried out trials of 5G technology and EE and Vodafone have recently launched commercial 5G networks in several UK cities.

There are several challenges associated with 5G rollout, including investment and demand uncertainty, building 5G infrastructure, and the security of 5G networks. There have also been public concerns about the potential health impacts of 5G radio waves. These challenges and ongoing policy developments around 5G are discussed in more detail in Commons Library Briefing CBP-7883, 5G.

This POSTbrief provides a technical overview of 5G technology, including the radio spectrum, infrastructure and software it is expected to use. It discusses the application of 5G in mobile broadband and potential applications in other sectors such as healthcare and transport. It also summarises some of the main challenges for the implementation of 5G and gives a general overview of global developments.

INTRODUCTION

5G is the term used to describe the next generation of mobile communications technologies. It follows on from the previous generations of mobile technology, including 3G and 4G. 5G is expected to improve on these in several ways: [1,2]

- **Increased speed:** 5G is expected to have much faster rates of data transfer, meaning downloading and uploading information will be faster. Estimates for the actual speed of 5G networks varies, but Ofcom states that 5G will have maximum speeds of around 10–20 gigabits per second (around 10–20 times faster than the maximum speeds of 4G networks).[1]
- **Lower latency:** 5G is expected to have much lower latency (the delay time between a command and its corresponding action), meaning the response times experienced when using mobile phones and other devices to access a 5G network will be shorter.
- **Higher capacity:** 5G will have a higher capacity, meaning many more devices will be able to connect to the network simultaneously and still have a high-speed connection.

Improved mobile broadband will be the first widespread application of 5G, with initial deployment happening in densely populated urban areas where there is a high demand for mobile connectivity.[3] In the longer term 5G is expected to support many other applications, in areas including manufacturing and entertainment. 5G is also expected to provide the high capacity data transfer needed for 'Internet of Things' services and applications (whereby everyday objects and devices are connected to a network and can communicate with each other).[4] The type and scale of 5G applications beyond mobile broadband is currently unclear and still developing.

The types of services and applications 5G is expected to support are commonly grouped into three categories:[5,6]

- **Enhanced mobile broadband:** 5G will provide faster and more reliable mobile broadband connections and allow more devices to connect to a network. 5G networks may also be used to provide fixed wireless broadband to homes and businesses.[1]
- **Massive-machine type communications:** 5G is expected to provide the capacity needed to support 'Internet of Things' services and applications, which are forecast to become more widespread over the next 5 years. For example, 5G networks may be used to support remote health monitoring and increased automation of production lines.[5]

- **Ultra-reliable and low latency communications:** Low latency 5G networks are expected to provide 'instant response' (near real-time) communications with high reliability. This could make 5G networks suitable for applications such as the remote control of machinery used in manufacturing processes or supporting the operation of connected and autonomous cars.[5]

The varying demands of these applications are likely to require different network speeds, mobile coverage and reliability, and may require new and upgraded infrastructure and technologies in different parts of the telecoms network (Box 1).

The UK Government has said it aims to be a global leader in 5G and published a 5G strategy in March 2017.[2] As part of this strategy, the government is providing funding for 5G trial projects through its 5G Testbeds and Trials Programme (see Applications and Development Section). All four of the UK's mobile network operators (EE, Vodafone, O2 and Three) have carried out 5G trials and EE and Vodafone have both turned on commercial 5G networks in parts of some UK cities.[7,8] The other mobile network operators (MNOs) have announced plans to launch 5G networks in 2019. A limited number of 5G-enabled mobile devices are now available in the UK.[9] The Department for Digital, Culture, Media & Sport's (DCMS's) July 2018 Future Telecoms Infrastructure Review stated the government's aim for the "majority of the UK" to have 5G mobile coverage by 2027.[10]

Box 1. Structure of the mobile telecommunications network

Mobile networks comprise two main parts: a 'core' and an 'access' network.[11]

A core (or 'backbone') network connects telecoms networks to each other and carries large volumes of communication data across the country. Most of the network control and management functions take place in the core network. The core network consists of exchanges (known as 'mobile switching centres'), normally connected by fibre optic cables, which also connect to the internet. There are several different but interconnected core networks in the UK.

Access networks connect customers in a local area to the core network. They comprise base stations (connected to the exchanges) that communicate with devices wirelessly using radio signals (also known as 'spectrum' – Box 2). Base stations provide access to the network over a limited area, so many of them are required to achieve UK-wide coverage. They are fitted with antennae that transmit and receive radio signals. There are around 40,000 base station sites across the UK.[12] Mobile operators generally use fibre optic cables to connect base stations to the core network. Wireless connections (via radio waves) are also used. This is referred to as 'backhaul'.

Each of the UK's four mobile network operators operate their own core and access networks, but often have agreements in place to share sites and infrastructure.[13-15] Core and access network infrastructure can also be provided by third parties.

TECHNOLOGY

5G networks require both new and upgraded technologies and infrastructure. These include new frequencies in the radio spectrum (Box 2), new core and access network infrastructure (Box 1), and new software to help manage the network.

Spectrum for 5G

The spectrum bands (Box 2) currently used for mobile communications are already heavily used and are limited in the amount of data they can send and receive.[16] 5G is expected to operate using a combination of different frequencies, including high frequency radio waves referred to as 'millimetre waves'.[5] Some of the spectrum for 5G will be new (not previously used for mobile broadband services) and some will be repurposed (previously used for earlier generations of mobile broadband or other services, such as TV or satellite communications).[1,2]

Ofcom has worked with the European Radio Spectrum Policy Group (RSPG) and other European regulators to identify three bands of spectrum that will be used to enable 5G in Europe.[1] These are categorised by Ofcom as low, mid and high frequency spectrum bands. Each band has different characteristics and is suitable for different uses. For example, the mid frequency spectrum is suitable for boosting capacity in certain areas, whereas the low frequency spectrum is suitable for providing wide area coverage.[1]

- **Low frequency spectrum (700 MHz):** This band has the longest range and is expected to support improved mobile broadband coverage. In the UK, this band is currently used for digital terrestrial television (Freeview) and wireless communication at music and sporting events.[17] Ofcom is in the process of clearing this band to make it available for mobile broadband use and plans to auction it by Spring 2020.[18]
- **Mid frequency spectrum (3.4–3.8 GHz):** This band has been recognised as the primary band for 5G across Europe.[19] It is generally perceived as being able to provide good coverage and high data capacity, and can be deployed on existing base stations.[19] Parts of this band were auctioned to UK mobile operators in April 2018, with a further auction planned by Spring 2020.[18,20] The first deployments of 5G mobile broadband are using this band.[5]
- **High frequency spectrum (24.25–27.50 GHz, also referred to as 'millimetre wave' spectrum):** This band has the potential to transmit very high volumes of data at very high speeds, however it has a very short range and cannot penetrate buildings. Many stakeholders suggest it is likely to be used in future 5G applications that require a very high

capacity connection, or to deliver localised services in specific areas.[19] Ofcom has stated that it wants to encourage trials using high frequency spectrum and is currently developing proposals for how to make parts of this band available for 5G in the UK.[5, 21]

In order to incentivise mobile operators to improve mobile coverage across the UK, Ofcom plans to offer MNOs the opportunity to obtain a discount on spectrum prices in the next low and mid frequency spectrum auctions if they commit to meeting certain coverage obligations.[18] More information on spectrum auctions and the spectrum shares currently held by each MNO in the UK (including 5G spectrum) are detailed in Commons Library Briefing CBP-7883, 5G.

Spectrum sharing

Spectrum sharing is when the same spectrum band is accessed by multiple different users.[22] Currently, blocks of spectrum are licenced to MNOs on exclusive UK-wide licences, meaning that the MNO can decide how to utilise that spectrum (Box 2). Some stakeholders have called for Ofcom to adopt a more flexible approach to spectrum licencing in order to allow spectrum sharing.[22,23] This means that spectrum that is not being used by a MNO in a particular area (for example, in rural areas) could be used by other operators for different services. Ofcom has proposed two models for spectrum sharing that it intends to pursue.[24] More information on Ofcom's proposed models for spectrum sharing can be found in Commons Library Briefing CBP-7883, 5G.[25]

Box 2. Radio frequency spectrum

The radio frequency spectrum (referred to as 'spectrum') describes bands of radio frequencies that are used to deliver wireless services, such as broadcast television, mobile broadband and global satellite navigation systems services (such as GPS). Radio waves are usually specified by their frequency, which is measured in Hertz (Hz, where 1 GHz = 1000 MHz = 1,000,000,000 Hz).

Different frequencies of spectrum have different characteristics and are suitable for different uses. Lower frequency radio waves are suitable for providing mobile communications coverage across a wide physical area, as they can travel further, can bend around hills and are better at penetrating physical objects (such as walls). High frequency radio waves can carry more data than low frequency radio waves and are more suitable for providing higher network capacity. However, because higher frequency waves cannot travel as far and find it harder to penetrate physical objects, they require that base stations (Box 1) be deployed closer together.[1]

Only a limited amount of spectrum is available. Access to and use of the spectrum is managed by Ofcom. Ofcom grants spectrum licences to mobile network operators, usually via an auction process, which gives them exclusive rights to transmit signals over a specified range of frequencies in the UK.[26] Only one operator may transmit across a specified frequency to avoid interference.

Infrastructure

5G networks are likely to require a combination of new and upgraded core and access network infrastructure and technologies.[27] This will involve upgrading existing mobile base stations and installing new mobile base stations, including smaller base stations known as 'small cells'.[28] This will require installation of new and upgraded mobile backhaul (Box 1). It is also likely to be combined with technologies designed to utilise the radio frequency spectrum more efficiently, such as Massive MIMO.

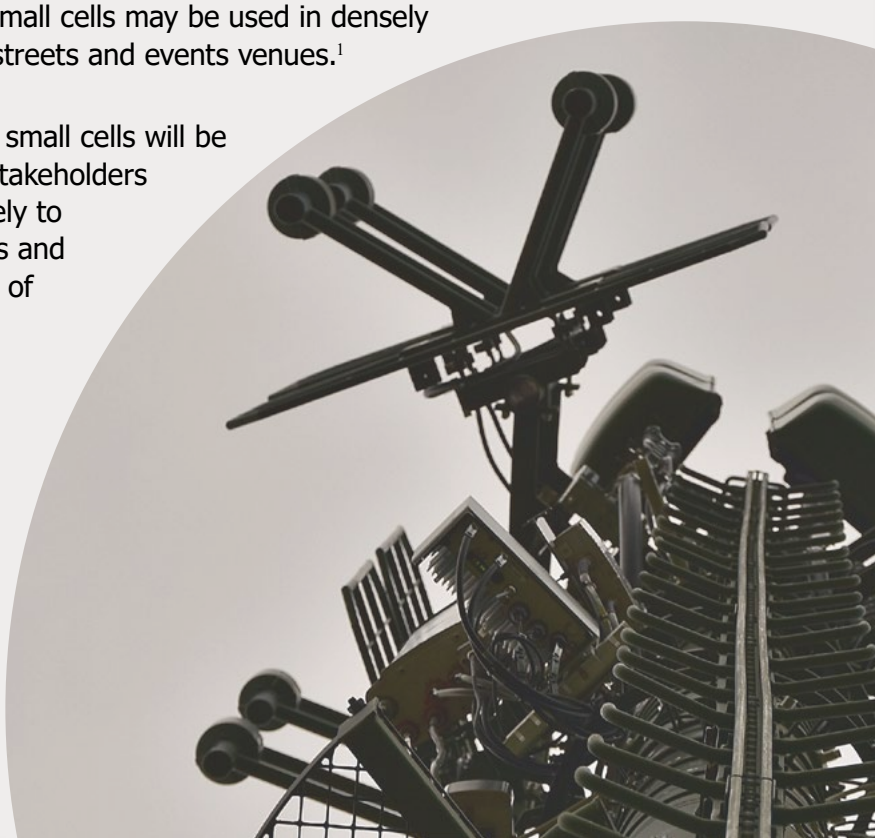
Small cells

Most 3G and 4G networks use base stations known as 'macro cells'.[6] Macro cell antennae are usually mounted on dedicated ground-based towers or masts, or on tall buildings, typically between 10 and 40 metres above the ground.[29] Macro cells provide radio coverage over varying distances (depending on terrain, presence of buildings and other factors), but can be in the range of 1 to 8 kilometres from the base station.[29,30] Initially, 5G will be rolled out on existing macro cell sites used for 3G and 4G, which will be upgraded to operate using the 5G spectrum.[10]

In the longer term, 5G may require a greater deployment of small cells in areas where there is a high demand for mobile coverage.[2] Small cells are low-power base stations that are smaller and more lightweight than macro cells and have a shorter range. Small cells can be mounted on existing street infrastructure, such as bus shelters, lamp-posts or traffic lights. There are different types of small cells that have different coverage areas, but typically they provide radio coverage ranging from ten metres to several hundred metres from the base station.[2] Small cells are already used in 4G networks in some areas, but they may be more widely deployed in future 5G networks to provide increased network capacity in areas of high mobile broadband demand.[1,10] For example, small cells may be used in densely populated urban areas, such as high streets and events venues.[1]

There is uncertainty about how many small cells will be required for 5G networks, but many stakeholders agree that future 5G networks are likely to operate using a mixture of macro cells and small cells to cater for the wide range of potential applications.[31]

In 2018, telecoms infrastructure companies CityFibre and Arqiva announced plans for a small cell pilot project in central London. The project will involve the installation of up to 300 outdoor small cells and is expected to be completed by 2020.[32]



Backhaul

Mobile base station networks require a backhaul connection (usually a fibre optic cable that can transmit information almost instantaneously via light pulses) to connect to the wider telecoms network (Box 1). Some existing backhaul connections for 3G and 4G base stations may not be suitable for the greater volume of network traffic that 5G is expected to support. In addition, newly deployed small cells would, in most cases, require fibreoptic backhaul connections. This means that 5G is likely to require both new and upgraded fibre backhaul infrastructure.

Ofcom has highlighted the importance of backhaul connectivity for the success of 5G, and has committed to ensure appropriate backhaul connectivity is available.[33] The government is supporting the rollout of fibre infrastructure as part of its wider plans to install a UK-wide full-fibre network by 2033 (more information on full-fibre can be found in Commons Library Briefing CBP-8392, Full-fibre networks in the UK). The government expects that its ongoing fibre infrastructure projects will ensure greater availability of the fibre connections required for the future deployment of 5G networks.

Openreach (owned by BT) owns an extensive network of ducts and poles (the infrastructure used to host fibre backhaul). In order to facilitate the rollout of fibre backhaul for fixed line and mobile networks (including 5G), Ofcom recently announced plans to introduce unrestricted access to Openreach's ducts and poles for telecoms infrastructure providers.[34] More information on ducts and poles can be found in Commons Library Briefing CBP-8392, Full Fibre Networks in the UK and POSTbrief 24, Telecommunications Infrastructure: Cabling, Ducts and Poles.

There are several regulatory, financial and practical challenges associated with installing small cells and fibre backhaul, including gaining access to sites where they are needed. These are discussed in the Challenges section of this briefing.

Massive MIMO

Mobile base stations use antennae to transmit and receive radio signals. MIMO (multiple input, multiple output) is a technology that uses multiple antennae to transfer data between a base station and devices. MIMO is used in some 4G networks, and typically uses two or four antennae on a base station.[35,36]

Massive MIMO is an extension of MIMO technology that uses a greater number of antennae.[37] It is likely to play a key role in 5G as it allows for more radio signals to be transmitted and received simultaneously, increasing the overall capacity of the network. The number of antennae used in massive MIMO systems varies, with some trials demonstrating the use of up to 128 antennae on a base station.[31] Massive MIMO is already

used in some 4G networks, including in the UK and abroad, but it is expected to be a key aspect of 5G macro cells and small cells.[30] UK mobile operator Vodafone has installed massive MIMO on several of its 4G base stations across the UK. In November 2018, O2 and Nokia announced plans to trial Massive MIMO at two sites in central London.[38]

Software in 5G networks

5G is expected to be more reliant on software to control and manage the telecoms networks. In many cases, this will replace some dedicated telecoms hardware, such as switches and routers.[6] Using more software in the telecoms network is advantageous because it is easier to install new features and operate different applications simultaneously.[30,39] However, greater reliance on software in 5G networks may give rise to different security requirements (see Challenges Section). Box 3 details some of the types of software that 5G networks may use.

Box 3. Software in 5G networks

Some of the types of software expected to play a key role in 5G include:

Network function virtualisation refers to the replacement of network functions on dedicated components (such as routers and servers), with functions that can operate using off-the-shelf hardware.[40]

Software defined networking is a technique that uses software to control where telecoms data is routed to.[41] It is used in some 4G networks.[42]

Network slicing allows for a mobile network to be separated into multiple 'virtual' sections that can be used to operate different services. Network slicing is expected to be able to support the multiple services and applications envisaged in future 5G networks. Each virtual network (or slice) can be given different characteristics (such as latency, speed and bandwidth) to optimise it for a particular function.[12, 42] For example, a slice of a network that is being used to control a connected vehicle will require a lower latency connection than a slice of a network that is being used to deliver mobile broadband.

Edge computing involves more data being processed closer to the 'edge' of the network (near to the devices that use the network) rather than at hubs in the core of the network. This is expected to improve network latency.[12]

STANDARDS

The International Telecommunications Union (ITU) is the international body responsible for setting formal global standards for 5G, which it plans to publish in 2020. In 2017, the ITU published a set of minimum technical performance requirements that networks must meet in order to qualify as 5G.[43] These requirements, amongst others, include:

- The ability to connect 1 million devices per square kilometre and for all devices to receive a good quality service
- A user experienced download speed of 100 Mbps
- A user experienced upload speed of 50 Mbps
- A maximum user experienced latency of 4 milliseconds for mobile broadband and 1 millisecond for ultra-low latency applications (such as operation of connected and autonomous vehicles)

There are several standards development organisations that are working to develop standards in line with the ITU's overarching 5G technical requirements.[44] They are required to submit technology proposals to the ITU, which it will evaluate to inform its 2020 global standards.[45]

The main standards development organisation for 5G is the 3rd Generation Partnership Project (3GPP).[46] 3GPP is an international consortium made up of regional standards bodies and trade association groups from across Asia, Europe and North America. 3GPP produces standards for telecommunications in 'releases'. 3GPP is developing standards for 5G in two phases, known as 'Release 15' and 'Release 16' (these follow on from previous telecommunications standards). The releases will form part of 3GPP's submission to the ITU:[47]

- **Release 15** outlines standards for 5G mobile broadband. It was published in June 2018. This release is split into standards for both 'non-standalone' 5G mobile broadband (5G which is supported by existing 4G infrastructure) and 'standalone' 5G mobile broadband (which can operate independently of existing 4G infrastructure).
- **Release 16** outlines standards for the applications of 5G beyond mobile broadband, including ultra-reliable low latency, and machine to machine type applications.[48] It is expected to be published in March 2020.[49]

Many manufacturers have produced handsets and other equipment (such as base stations) for 5G mobile broadband according to the existing 3GPP standards, and 5G has already been rolled out in some countries, including the UK (see 5G across the world Section).[50,51]

APPLICATIONS AND DEVELOPMENTS

Improved mobile broadband will be the first widespread application of 5G technology. In the longer term, 5G may have other applications across a variety of different sectors. As they are in early stages of development, the type of 5G applications beyond mobile broadband services is currently unclear. However, there are trials taking place across government and industry to assess the benefits of the technology. The UK Government is supporting 5G trials across a range of sectors under its 5G Testbeds and Trials Programme (5GTT, Box 4).[52] In addition to the 5GTT programme, there is ongoing research into various aspects of 5G technology. For example, the National Physical Laboratory and others are working on a project to validate the performance of antennae that operate using the millimetre wave spectrum.[53]

The following section discusses progress in the development of 5G mobile broadband in the UK, followed by an overview of ongoing research into the applications of 5G in sectors beyond mobile broadband.

Mobile broadband

The rollout of 5G mobile broadband is led by commercial MNOs. All of the UK's four MNOs (EE, Vodafone, O2 and Three) have carried out trials of 5G technology. EE and Vodafone have turned on their 5G networks in parts of some UK cities, and O2 and Three have announced the launch of their 5G networks in some UK locations in 2019:

- **EE** switched on its commercial 5G service in parts of six UK cities in May 2019, including London, Cardiff, Belfast, Edinburgh, Birmingham and Manchester.[7] The networks utilise parts of the mid-frequency spectrum allocated for 5G (see section 'Spectrum for 5G'). EE also has an ongoing 5G trial network at Canary Wharf in London.
- **Vodafone** launched its 5G network in parts of seven UK cities in July 2019, including Birmingham, Bristol, Cardiff, Glasgow, Manchester, Liverpool and London.[8] Vodafone has run 5G trials at Manchester Airport and Birmingham New Street railway station.[54,55]
- **O2** has an ongoing 5G trial at the O2 arena in Greenwich, and in 2018 it worked with Nokia to carry out two trials of Massive MIMO in the King's Cross and Marble Arch areas in London.[56] O2 has confirmed that Belfast, Cardiff, Edinburgh and London will receive its 5G network in 2019.[57]
- **Three** carried out a demonstration of 5G home broadband in 2018 in partnership with Huawei.[58] In 2019 it installed a permanent 5G network at Central Saint Martins – University of the Arts London as part of a

5G demonstration at London Fashion Week. Three plans to launch its commercial 5G network in August 2019.[59]

Beyond mobile broadband

Sectors in which there has been an increasing interest in the application of 5G technology include transport, healthcare, entertainment and manufacturing.[52,60] There is also interest in using 5G networks to provide fixed wireless broadband (whereby internet services are provided to homes and businesses using a local wireless network instead of fixed lines to individual premises).[61] Although the future role of 5G fixed wireless access is unclear, some experts have suggested that it could be used in areas where it is difficult to install infrastructure (such as rural areas),[62,63] with a report by Three saying it could be more cost effective in some cases.[61]

Many potential 5G application areas are being explored as part of the UK Government's 5GTT Programme (Box 4). In some cases, future 5G networks may be used alongside other technologies, such as artificial intelligence and robotics, to deliver certain services. As 5G technologies continue to develop, other applications may also emerge.[64]

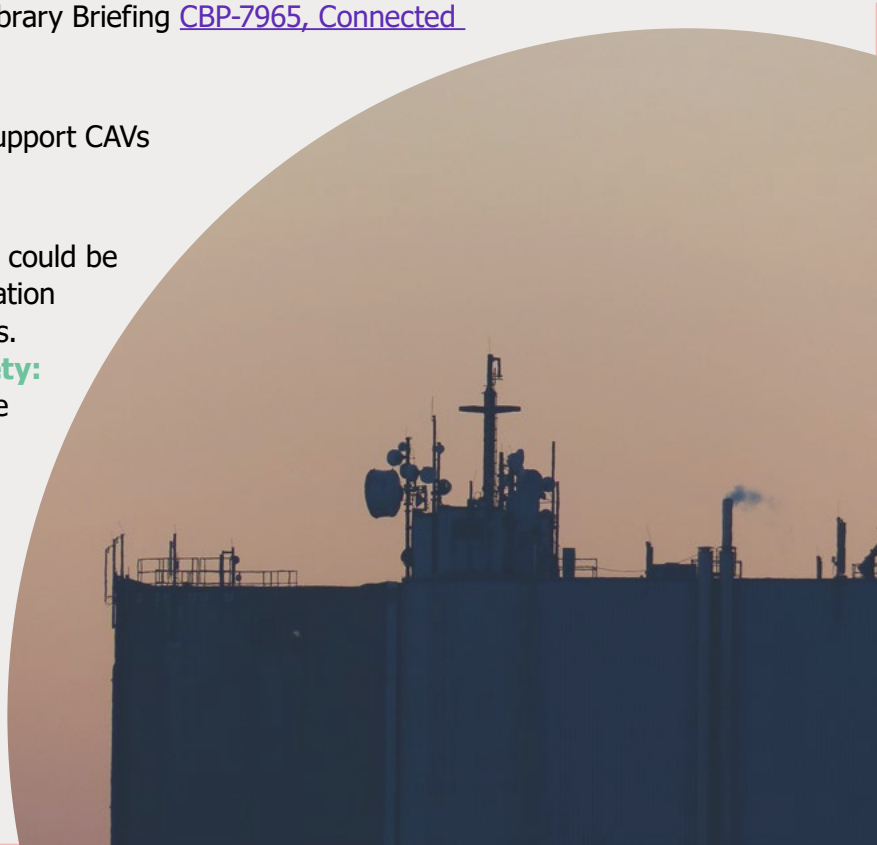
Transport

Many stakeholders agree that 5G could play a role in the transport sector, including in connected and autonomous vehicles and the railways.

Connected and autonomous vehicles (CAVs). Connected vehicles are vehicles that can use communications technologies to send and receive information to and from other vehicles and/or surrounding road infrastructure. They also use sensors and software to operate without human intervention (see Commons Library Briefing CBP-7965, Connected and Autonomous Vehicles).

Some of the ways in which 5G may support CAVs include:[28,65]

- **Driver assistance:** 5G networks could be used to provide CAVs with information about traffic or weather conditions.
- **Vehicle maintenance and safety:** 5G networks could support vehicle maintenance and safety services. For example, 5G networks could be used to send data about a vehicle's performance back to the manufacturer to identify faults more quickly.



- **In-vehicle connectivity:** 5G networks could be used to provide a broadband connection in vehicles, allowing passengers to stream very high-quality video content while travelling.

In the UK there are a number of ongoing trials exploring the use of 5G in CAVs.[66] AutoAir is a government-funded project that aims to explore how CAVs could utilise small cells and the millimetre wave radio spectrum to control autonomous vehicles.[67] Trials will take place at Millbrook Proving Ground, a vehicle testing centre in Millbrook, Bedfordshire.[68] The Urban Connected Communities Project (Box 4) also plans to investigate the use of 5G with CAVs.[69]

Rail. There has been interest in how 5G networks could play a role in improving connectivity on UK railways. For example, it has been suggested that a 5G network could support communications between track-side rail infrastructure and train drivers.[74] The government has provided funding towards the creation of a 5G test facility at Network Rail's Rail Innovation & Development Centre in Melton Mowbray, which opened in Spring 2019.[70]

Box 4. UK Government 5G Testbeds and Trials Programme

The UK Government is supporting 5G development through its 5G Testbeds and Trials (5GTT) Programme. The Programme, led by the Department for Digital, Culture, Media & Sport (DCMS), aims to coordinate 5G trial projects, find new applications for 5G across a range of sectors, and identify potential technical and deployment challenges.[52] The programme has been awarded £200 million of government funding, which forms part of the government's £1 billion investment in digital infrastructure.[52]

In March 2018, £25 million of funding from the 5GTT programme was allocated for six 5G projects across the UK to research potential applications of 5G in a range of sectors, including agriculture, transport, and health and social care. This was followed by a project to develop a city-wide 5G trial network (the Urban Connected Communities Project) in partnership with the West Midlands Combined Authority.[72] In July 2019, the government announced its Industrial 5G Testbeds and Trials competition, which will award funding for projects exploring the use of 5G in the manufacturing and logistics industries.[73]

The 5GTT Programme has also supported the creation of the 5GUK Test Network, and the establishment of the UK5G Innovation Network:

- **5GUK Test Network:** £16 million of funding was awarded to the University of Surrey, the University of Bristol and King's College London to set up a 5G test network. The network was completed in March 2018 and is currently being used to trial further 5G applications and technologies.[74]
- **UK5G Innovation Network:** UK5G is a network of organisations that was set up in March 2018. It aims to promote 5G research and facilitate collaboration between organisations working on 5G development projects to support commercial applications of the technology.[75]

In February 2019, FirstGroup and Blu Wireless, in partnership with Network Rail and the UK Government, announced plans to install track-side 5G infrastructure to deliver on-board Wi-Fi for South Western Railway passengers.[71]

Healthcare

It has been proposed that 5G networks could support the healthcare sector in several ways, including:[76]

- **Health monitoring:** 5G networks could enable the remote monitoring of patients' health via wearable or implanted health devices (such as pacemakers), or via environmental monitors installed in the home.[77,78]
- **Remote consultations:** It has been suggested that 5G could allow medical appointments to take place remotely via high-quality video calls, more reliably than is currently possible.
- **Connected ambulances:** 5G connected ambulances could share patient data with Emergency Department staff before arriving at hospital.[79]

The government is funding a 5G Testbeds and Trials project in Liverpool that is investigating the potential benefits of 5G in health and social care.[80]

Entertainment and media

A 2018 report by Ovum and Intel forecast that the global revenue of the media and entertainment industry could double between 2018 and 2028 as a result of services and applications enabled by 5G.[81] It has been suggested that future 5G networks may be used in this sector to: provide better quality mobile broadband connections for online gaming; allow high-quality video to be downloaded much faster than is currently possible,[82] and offer high-quality live streaming of sporting events. Many stakeholders have also raised the potential for 5G networks to wirelessly deliver virtual and augmented reality content, which typically requires the transfer of large amounts of data and a very low latency connection.[81,83] For example, UK telecoms company Vodafone recently demonstrated the use of a 5G network to deliver a holographic football training session.[84]

As part of the government's 5GTT Programme, the West of England Combined Authority are testing the wireless delivery of visual experiences for tourists via a 5G network, using technologies such as virtual and augmented reality. The trials are taking place at tourist sites around Bristol and Bath.[85]

Manufacturing

Manufacturing processes are predicted to benefit from the low-latency connections provided by 5G networks.[86] It has been suggested that 5G could be used in 'smart' manufacturing to connect different machines

involved in a production line, or to transmit real-time data on machine faults and safety issues from cameras and sensing devices to factory staff.[87] 5G may also be used to support the remote control of production line robotics.[88] For example, Nokia and Bosch have developed a prototype 'pick and place' robot for use on production lines that is controlled using a 5G trial network. The trial is taking place at Bosch's factory in Worcester.[89]

CHALLENGES AND IMPLICATIONS

There are several challenges associated with 5G rollout. These include investment risk, building 5G infrastructure, and security and health concerns.[30] These challenges and ongoing policy developments are discussed in more detail in CBP-7883, 5G.

Investment risk

5G is likely to require significant investment by mobile network operators and others.[10] In the Future Telecoms Infrastructure Review, the government estimated that the initial upgrade of existing 3G and 4G sites to accommodate 5G will require an overall investment of £4–5 billion.[10] While reports suggest that 5G will have significant economic benefits, some stakeholders, including the UK Government and mobile industry, have highlighted that commercial risk is a key challenge in the deployment of 5G, as the demand for (and applications of) 5G remains uncertain and the cost of deploying 5G infrastructure is likely to be high.[10,90,91]

The government and Ofcom have stated that maintaining competition between the UK's four MNOs is the best way to drive investment and innovation in 5G.[10] Mobile UK, the trade association for the UK's four mobile network operators, has called for tax relief on new mobile infrastructure, and additional funding for local councils to support infrastructure planning and development.[92] Mobile network operators have also called for local councils to consider mobile infrastructure requirements in their long-term plans.[93]

Building 5G infrastructure

5G will involve upgrading equipment at existing base station sites and building new infrastructure, such as macro cells, small cells and fibre backhaul (see Infrastructure for 5G Section). In the short-term, 5G will be

rolled out on existing macro cell sites. The government's Future Telecoms Infrastructure Review highlighted that some existing base station masts may need to be strengthened to support new 5G equipment.[10]

A 2018 analysis for the Broadband Stakeholder Group found that some of the challenges faced by small cell deployment include:

- the process of obtaining planning permission for new small cell sites (which tends to vary between local authorities);
- finding suitable base station sites (that are not hindered by urban restrictions);
- accessing power supplies for new base stations; and
- accessing fibre backhaul.[30]

More information on the installation of fibre backhaul for telecoms networks more generally can be found in Commons Library Briefing CBP-8392, Full Fibre Networks in the UK.

Some stakeholders have commented that, due to the greater number of small cells and Massive MIMO antennae, the energy consumption of 5G networks is likely to be higher than previous mobile networks.[94,95] However, there is ongoing research and development to improve the energy efficiency of 5G equipment[96-99] and some experts believe that 5G will improve on the energy efficiency of previous mobile networks.[100,101]

Although it is currently unclear how many small cells will be deployed as part of the 5G rollout, operators have highlighted that the cost of deploying and maintaining small cell sites, including the associated fibre backhaul and power supplies, is likely to be high.[30] The cost of deploying small cells also varies depending on location, and is higher in remote areas.[30]

Security

5G will use more software to control and manage the network (see Software in 5G networks Section). This gives rise to some new security challenges, and may mean that 5G networks are vulnerable to different types of cyber threat.[102] Experts have highlighted the need to ensure that software used in 5G networks is secure and protected from unauthorised access, and that strong anti-virus systems are in place.[103] 5G systems that employ network slicing may need to apply different levels of security to different slices of the network.[103] In addition, the greater number of 5G base stations and 5G connected devices mean that there is a greater number of access points for potential physical and cyber-attacks to occur.

In December 2018, a 5G Testbeds and Trials technical report on 5G network security outlined four security principals that 5G networks should meet:[103]

- **Cross-layer security:** There should be coordination between the security features applied to the different parts of a 5G network (such as the software, physical infrastructure and devices).
- **End-to-end security:** There should be a secure connection between the network user and the core network.
- **Cross-domain security:** There should be coordination between the security features applied to different uses of 5G.
- **Secure-by-design:** Security should be built into the network design process.

The 5G Testbeds and Trials Programme has allocated £10 million of funding to test the security of 5G networks in collaboration with the National Cyber Security Centre.[103]

There have been concerns raised in Parliament and the press about the use of equipment in 5G networks that has been supplied by foreign companies, including the Chinese telecoms supplier Huawei.[104] A full discussion of the security concerns around foreign telecoms suppliers can be found in Commons Briefing Paper CBP-7883, 5G.

Health

There have been some public concerns about the health effects of the radio waves that will be used in 5G mobile networks.[105,106] The International Commission on Non-Ionizing Radiation Protection (ICNIRP) is an independent organisation that provides scientific advice and guidance on the health and environmental effects of non-ionising radiation.[107] It is formally recognised as an official collaborating non-governmental organisation by the World Health Organization (WHO) and the International Labour Organization (ILO). ICNIRP has previously issued international exposure limit guidelines in 1998 (for radio waves up to 300 gigahertz, which includes the radio frequencies allocated for 5G) and carried out a further review of the scientific evidence in 2009, concluding that subsequent research has not identified any evidence of adverse health effects below exposure limits.[108,109] These guidelines are based on the thermal effects of the radio waves (the ability for the radio waves to heat up human body tissue). ICNIRP has concluded that, based on the scientific evidence produced in this area, adverse health effects caused by radio waves are unlikely to occur if exposure is below its guidelines.[109] The WHO's position is that "EMF [electromagnetic field] exposures below the limits recommended in the ICNIRP international guidelines

do not appear to have any known consequence on health" and Public Health England (PHE) has advised that it supports these ICNIRP guidelines.[108]

The UK independent Advisory Group on Non-Ionising Radiation (AGNIR) published a comprehensive review in 2012 of radio frequencies in the range 100 kHz to 300 GHz. It examined evidence of effects on individuals exposed to higher levels of exposure to RF fields (MRI and diathermy) as well as thermal effects from other industrial sources, such as induction heating and welding.[110] In addition, the evidence covered studies on cells *in vitro* and a wide range of biological animal models. These studies found that radio wave levels under current ICNIRP guidelines do not cause heating of cells, nor the initiation and development of cancer, nor any consistent evidence of effects on the brain and nervous system, hearing systems, or fertility. The evidence also suggests that radio wave exposure below guideline levels does not cause acute symptoms, including acute cognitive effects. AGNIR therefore concluded that there is no convincing evidence that radio waves below ICNIRP guidance levels causes health effects in adults or children.[110]

The Health Protection Agency (which merged to become part of Public Health England in 2013)[111] responded to this review by re-stating "a recommendation to follow the ICNIRP guidelines will remain central to HPA's advice on exposures to RF fields".[112] Since then, the government has stated that it anticipates no negative effects on public health associated with the rollout of 5G, and that it is committed to working with PHE to monitor available evidence in this area.[113,114]

In June 2019, the Chief Medical Officer for England confirmed that there is sufficient evidence to demonstrate that 5G rollout does not present a public health risk.[115] European Council Recommendation 1999/519/EC invited the European Commission to keep the scientific evidence under review. The Commission is advised by the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR). SCENIHR examines global studies on radio frequencies and produces Opinions. The most recent SCENIHR Opinion (January 2015) found that epidemiological studies do not indicate an increased risk for cancers and animal model studies were also negative; no effects on DNA were seen below exposure levels; there was a lack of evidence of effects on cognitive function; and they could find no causal link between symptoms and short-term exposure to radio waves. Therefore, SCENIHR concluded that the results of current scientific research show that there are no evident adverse health effects if exposure remains below the levels set by current standards.[116]

The WHO is currently running a long-term project to "assess the health and environmental effects of exposure to static and time varying electric and magnetic fields in the frequency range 0–300 GHz".[117] This has been examining original studies published during the past 25 years and will publish a scientific literature review with conclusions for the clear-cut health outcomes. It will also recommend further systematic analyses for health outcomes for which the evidence does not provide consensus.[117]

Between 2001 and 2012, Ofcom and its predecessor, the DTI Radiocommunications Agency, conducted a programme of measurements that found that emission levels around mobile phone base stations were consistently at a very small fraction of the exposure guideline levels.[118] Of 780 surveys by 2012, the highest measurement was 1/279th of the ICNIRP threshold and no installation tested exceeded 0.005% of the specified radiation safety limit. Ofcom now provides surveys upon request, free to schools and hospitals, and at a charge to other organisations and individuals. All results are available on the Ofcom website,[119] with none of the sites tested since 2012 exceeding 0.2% of ICNIRP levels. In 2017, the International Electrotechnical Commission (a global standards body for electrical, electronic and related technologies) prepared new international standards for measuring electromagnetic fields from mobile base stations, including 5G base stations.[120,121]

In addition, certificates of compliance are provided by mobile network operators or infrastructure providers to local authorities during planning applications for base stations. These take the form of signed declarations of conformity with ICNIRP public exposure guidelines.[122] This process is detailed in Mobile UK's Code of Best Practice on Network Development in England.[123]

5G ACROSS THE WORLD

The main countries that are leading in 5G development and deployment worldwide are the US, China, Japan and South Korea.[124-126] This section gives an overview of some of the main developments in 5G deployment in these countries and in Europe.

United States

US mobile operators have launched 5G mobile networks in some parts of the country. For example, Verizon has a 5G mobile network in some parts of Chicago and Minneapolis, and AT&T has live 5G networks available in 19 US cities.[127] Other major MNOs have carried out trials of 5G technology and have commercial launches planned for 2019.[125] The Federal Communications Commission (the US radio communications regulator) has been making spectrum available for 5G and has plans to accelerate small cell rollout.[128] The FCC recently announced that it will make $20.4 billion available to fund the rollout of 5G mobile networks and rural broadband in the US.[129,130]

China

The Chinese Government is promoting 5G development as part of its 'Made in China 2025' action plan, which includes research, development and deployment strategies.[131] China has not launched any commercial 5G networks yet, however, all of China's mobile network operators have conducted 5G trials and most have plans to deploy commercial networks by 2020. China Mobile is planning to launch its commercial network by the end of 2019.[124,125] In June 2019, the Chinese Government issued commercial deployment licences to three of the country's largest telecoms operators and its state-owned China Broadcasting Network.[132]

Japan

Japan's main mobile operator, NTT DoCoMo, has trialled 5G technology and aims to launch a commercial 5G network by mid-2020. The Japanese Ministry of Internal Affairs and Communications (MIC) and Japanese telecoms companies have indicated that the 2020 Summer Olympics in Tokyo is a target for commercial 5G launch.[124, 133] The MIC has committed around US$300 million to support 5G and future technologies, such as Internet of Things and robotics.[125]

South Korea

5G trials have been taking place in Korea, including a 5G demonstration at the February 2018 Winter Olympics in PyeongChang.[134] Three South Korean mobile operators launched commercial 5G services in April 2019 to a limited group of customers, and it is expected that nationwide deployment of 5G networks will be completed by 2022–2023.[125, 135] A '5G forum' was created in South Korea, that aims to establish national policy, promote research and development and support international collaboration.[136] The UK and South Korean governments recently announced that they will be jointly funding a project to explore how 5G can be used to deliver entertainment services across the Seoul metro system. The project will use wearable devices (such as headsets) to deliver augmented and mixed reality content to passengers, such as travel information, video streaming and gaming.[137]

Europe

In 2016, the European Commission launched its 5G Action Plan to boost 5G deployment efforts across the EU.[125,138] The European Commission has also committed €700 million through the Horizon 2020 programme to support 5G research and development.[139]

Ten EU member states have published 5G action plans, including Austria, Estonia, France, Finland, Netherlands, Spain, Sweden, Germany, Luxembourg and the UK.[125] Some 5G services have been launched across Europe.[125] For example, in March 2019, Magenta Telekom launched a 5G mobile network for a limited group of customers in Austria, which primarily covers rural areas,[140] and in June 2019, Vodafone Spain launched a commercial 5G service in 15 Spanish cities.[141] In Switzerland, Swisscom launched 5G mobile broadband in April 2019 in 54 towns, and plans to roll out 5G to the whole country by the end of 2019.[125,142]

REFERENCES

1. Ofcom (2018). Enabling 5G in the UK
2. HM Government (2017). Next Generation Mobile Technologies: A 5G strategy for the UK.
3. Tobin (May 2018. When Will 5G Launch In The UK And Why Is This Exciting? Forbes. Accessed 31/05/19
4. Government Office for Science. The Internet of Things: making the most of the Second Digital Revolution
5. Ofcom (2017). Update on 5G spectrum in the UK.
6. ITU (2018). Setting the scene for 5G
7. EE [online]. UK 5G Coverage Map. Accessed 16/06/19
8. Vodafone [online]. Vodafone 5G is live. Accessed 03/07/19
9. https://5g.co.uk/phones/
10. DCMS (2018). Future telecoms infrastructure review
11. Electronic Communications Resilience and Response Group. Telecommunications Networks – a vital part of the Critical National Infrastructure
12. NIC (2016). 5G Infrastructure requirements for the UK
13. MBNL [online]. About Us. Accessed 21/06/19
14. Cornerstone [online]. Home. Accessed 21/06/19
15. Jackson (2019). Vodafone and O2 Extend UK Network Sharing to 5G Mobile and Fibre. ISPreview. Accessed 21/06/19
16. Ofcom [online]. Spectrum (international work). Accessed 21/06/19
17. Ofcom [online]. Ongoing projects - UHF: 700 MHz Accessed 21/06/19
18. Ofcom (2019) Award of the 700 MHz and 3.6-3.8 GHz spectrum bands
19. European Commission (2018). Radio Spectrum Policy Group Strategic Spectrum Roadmap Towards 5g For Europe
20. Ofcom (2018). Award of 2.3 and 3.4 GHz spectrum bands
21. Ofcom (2017). 5G spectrum access at 26 GHz and update on bands above 30GHz.
22. Nominet (2018). Spectrum Sharing White Paper
23. Ofcom [online]. Call for Input - A framework for spectrum sharing – Arqiva response. Accessed 21/06/19
24. GSMA (2018). Spectrum Sharing
25. Ofcom [online]. Consultation: Enabling opportunities for innovation. Accessed 21/06/19
26. Ofcom [online]. Spectrum. Accessed 16/07/19
27. Hossain and Hasan (2015). 5G Cellular: Key Enabling Technologies and Research Challenges. IEEE Instrumentation and Measurement Magazine. Vol 18 pgs 11-21
28. NIC (2018). Connected future
29. NIC (2016). 5G Infrastructure requirements for the UK
30. Broadband Stakeholder Group (2018). Lowering Barriers to 5G Deployment
31. Analysis Mason (2019). Global race to 5G Update
32. Arqiva (2017). Rolling out 5G in the UK: What's involved?
33. Ofcom (2018). Enabling 5G in the UK.
34. Ofcom (2019). Promoting competition and investment in fibre networks.
35. University of Bristol [online]. Bristol and Lund set a new world record in 5G wireless spectrum efficiency. Accessed 26/06/19
36. Gupta (2015). A Survey of 5G Network: Architecture and Emerging Technologies. IEEE Access. Vol 3 pgs 1206-1232
37. Bjornson et al. (2016). Massive MIMO: Ten Myths and One Critical Question. IEEE Communications Magazine. Vol 54 pgs 114-123
38. Wray (2018). O2 launches Massive MIMO 5G pilot in London. 5G. Accessed 26/06/19
39. DCMS (2017). Next Generation Mobile Technologies: A 5G strategy for the UK.
40. SDX Central [online]. How 5G NFV Will Enable the 5G Future. Accessed 26/06/19
41. Fulton (2018). What is SDN? How software-defined networking changed everything. ZDNet. Accessed 26.06.19
42. Nencioni et al. (2018). Orchestration and Control in Software-Defined 5G Networks: Research Challenges. Hindawi Wireless Communications and Mobile Computing.

43. ITU (2017). Minimum requirements related to technical performance for IMT-2020 radio interface(s)
44. SDXCentral [online]. 5G Standards: What You Need to Know. Accessed 21/06/19
45. ITU [online]. IMT-2020 submission and evaluation process. Accessed 21/06/19
46. DCMS (2017). Next Generation Mobile Technologies: An update to the 5G strategy for the UK
47. 3GPP [online]. Release 16. Accessed 21/06/19
48. Qualcomm [online]. The first 5G standard is complete — so what's next?. Accessed 21/06/19
49. 3GPP [online]. RAN adjusts schedule for 2nd wave of 5G specifications. Accessed 21/06/19
50. Rogerson (2019). What are the first 5G phones?. TechRadar. Accessed 21/06/19
51. 5G [online]. 5G Phones. Accessed 21/06/19
52. DCMS (2017). UK 5G Testbeds and Trials.
53. NPL [online]. Ensuring the 5G revolution is a success. Accessed 21/06/19
54. Vodafone [online]. UK's first 5G train station connected as Vodafone live tests 5G in Birmingham. Accessed 03/07/19
55. Rogerson (2019). Vodafone has brought fast 5G to Manchester Airport. 5G. Accessed 03/07/19
56. Jackson (2018). O2 UK Lays Groundwork for 5G with London Trial of Massive MIMO. ISPreview. Accessed 26/06/19.
57. O2 [online]. O2 5G to arrive in 2019 as company builds a 5G Economy in partnership with British business. Accessed 03/07/19
58. Jackson (2018). Three UK and Huawei Demo 3-4Gbps 5G Wireless Broadband Link. ISPreview. Accessed 03/07/19.
59. BBC [online]. Three to launch 5G service in August. Accessed 21/06/19
60. Digital Catapult (2018). 5G Nation
61. Ovum (2018). 5G Wireless Home Broadband: A Credible Alternative to Fixed Broadband
62. Plum (2018). High performance wireless broadband: an opportunity for rural and enterprise 5G
63. Analysis Mason (2019). 5G fixed–wireless access: more of a challenge than a complement to fixed broadband.
64. Qualcomm [online]. Landmark Study on Impact of 5G Mobile Technology Released. Accessed 21/06/19
65. 5GPPP (2015). 5G Automotive Vision.
66. Centre for Connected and Autonomous Vehicles (2018). UK Connected & Autonomous Vehicle Research & Development Projects 2018
67. DCMS [online]. AutoAir: 5G Testbed for Connected and Autonomous Vehicles. Accessed 21/06/19
68. Millbrook [online]. Deployment of the UK's First Transport 5G Network. Accessed 21/06/19.
69. West Midlands Combined Authority [online]. West Midlands to become UK's first large-scale 5G testbed. Accessed 21/06/19.
70. DCMS (2019). Trans Pennine Initiative Trial: Call For Information Update and Notification of Discontinuation of Radio Infrastructure Delivery
71. Jackson (2019). FirstGroup and Blu Wireless to Upgrade UK Trains with 5G Broadband. ISPreview. Accessed 21/06/19
72. DCMS [online]. Urban Connected Communities. Accessed 16/06/19
73. DCMS [online]. Industrial 5G Testbeds & Trials: Manufacturing and Logistics Sectors Projects. Accessed 18/07/19
74. DCMS (2018). 5G Testbeds and Trials Programme Update
75. https://uk5g.org/
76. Ericsson [online]. Understanding the opportunities for operators in healthcare. Accessed 21/06/19
77. Latif et al. (2017). How 5G (and concomitant technologies) will revolutionize healthcare. Future Internet. Vol 9.
78. Vodafone [online]. Health plan: When 5G meets IoT. Accessed 21/06/19.
79. TechUK (2019) How 5G could transform care for patients in the hospital and at home
80. http://liverpool5g.org.uk/
81. Ovum (2018). How 5g will transform the business of media & entertainment
82. Deloitte (2019). Media & Entertainment Industry Outlook.
83. Qualcomm (2018). VR and AR pushing connectivity limits
84. Rogerson (2018). Vodafone made a holographic 5G call and accelerated its launch. 5G. Accessed 26/06/19
85. DCMS [online]. 5G smart tourism. Accessed 21/06/19
86. Ericsson (2019). 5G and smart manufacturing.
87. 5GPPP (2015). 5G and the factories of the future.
88. Ericsson (2017). The 5G business potential.
89. Tobin (2019). UK switches on inaugural 5g factory trial marking the start of the fourth industrial revolution. Forbes. Accessed 26/06/19
90. GSMA (2018). Road to 5G

91. IET (2017). 5G networks for policymakers.
92. MobileUK [online]. Mobile UK budget submission: time to prioritise mobile infrastructure. Accessed 26/06/19
93. Turner (2018). UK mobile industry lobbies local councils to support 4G/5G deployment. 5G. Accessed 26/06/19
94. Ge et al. (2017). Energy Efficiency Challenges of 5G Small Cell Networks. IEEE Communications Magazine. Vol. 55 pgs 184–191.
95. Vertiv (2019). A Practical Guide to Enabling 5G Deployments.
96. Monroy (2017). Achieving a 90% reduction in power consumption for 5G. BlueSpace 5GPPP. Accessed 26/06/19
97. Buzzi al. (2016). A Survey of Energy-Efficient Techniques for 5G Networks and Challenges Ahead. IEEE Journal on Selected Areas in Communications. Vol 34 pgs 697 – 709.
98. EU Commission [online]. Project Information: Self-organization towards reduced cost and energy per bit for future emerging radio technologies. Accessed 26/06/19
99. Abrol & Jha (2016). Power optimization in 5G networks: A step towards green communication. IEEE Access. Vol 4 pgs 1355-1374
100. Nokia (2016). 5G network energy efficiency – Nokia white paper.
101. Ericsson [online]. Breaking the energy curve: why service providers should care about 5G energy efficiency. Accessed 26/06/19.
102. SDX Central [online]. Top 5G security challenges. Accessed 26/06/19.
103. DCMS Phase 1 5G Testbeds & Trials Programme (2018). 5G Network Architecture and Security
104. BBC [online]. Huawei: Which countries are blocking its 5G technology?. Accessed 26/06/19
105. Cutlack (2019). Kids pulled from school by anti 5G parents. Gizmodo. Accessed 26/06/19
106. Smith (2018). Questions raised over 5G links to cancer as mobile network is tested in Bristol. Bristol Live. Accessed 26/06/19.
107. https://www.icnirp.org/
108. Public Health England (2019). Mobile phone base stations: radio waves and health.
109. International Commission on Non-Ionizing Radiation Protection [online]. High Frequency. Accessed 26/06/19
110. Health Protection Agency (2012). Health effects from radiofrequency electromagnetic fields: Report of the independent advisory group on non-ionising radiation.
111. Health Protection Agency. Health protection agency has closed.
112. UK Government [online]. HPA response to the 2012 AGNIR report on the health effects from radiofrequency electromagnetic fields. Accessed 16/07/19
113. PQ 176372 [on 5G and human health]. 08/10/18
114. PQ 176373 [on 5G and human health]. 08/10/18
115. S&T Committee (06/06/19). Work of the Chief Medical Officer inquiry. Oral Evidence Dame Sally Davies.
116. European Commission (2015). Scientific committee on emerging and newly identified health risks: Opinion on potential health effects of exposure to electromagnetic fields (EMF)
117. WHO. The international EMF project.
118. Ofcom [online]. Audit of mobile phone base stations - information sheet. Accessed 16/07/19
119. Ofcom [online]. Mobile phone base station audits. Accessed 16/07/19
120. IEC (2017). Determination of RF field strength, power density and SAR in the vicinity of radiocommunication base stations for the purpose of evaluating human exposure.
121. IEC Blog [online]. New IEC Technical Report focuses on 5G base station RF safety assessment. Accessed 19/07/19
122. Ministry of Housing Communities and Local Government (2019). National planning policy framework.
123. Mobile UK (2016). Code of best practice on mobile network development in England.
124. European Parliament (2019). 5G Deployment: State of Play in Europe, USA and Asia
125. EU Commission (2019). 5G Observatory Quarterly Report 3
126. Analysis Mason (2018) Report for CITA. Global Race to 5G Spectrum and Infrastructure Plans and Priorities.
127. AT&T [online]. About. Accessed 26/06/19
128. FCC [online]. The FCC's 5G fast plan. Accessed 26/06/19
129. McCaskill (2019). Trump vows not to nationalise 5G as FCC makes funding and spectrum available. Tech Radar. Accessed 26/06/19
130. Fung (2019). 5G is about to get a big boost. Washington Post. Accessed 26/06/19
131. EY (2018). China is poised to win the 5G race.
132. Tomás (2019). Chinese government issues commercial 5G licenses. RCRWireless. Accessed 26/06/19.
133. Ryall (2018). Games changer: Technology that will innovate the Olympics in 2020. Japan Today. Accessed 26/06/19

134. Fortune [online]. The PyeongChang winter Olympics are testing 5G—to ward off wild boars. Accessed 26/06/19
135. Park (2019). S.Korea first to roll out 5G services, beating U.S. and China. Reuters. Accessed 26/06/19
136. Keysight Technologies [online]. Keysight Technologies joins 5G forum in South Korea. Accessed 26/06/19
137. DCMS [online]. UK and South Korea go underground for innovative new 5G partnership. Accessed 16/07/19
138. EU Commission [online]. 5G for Europe Action Plan. Accessed 26/06/19
139. EU Commission [online]. Towards 5G. Accessed 26/06/19
140. Hardesty (2019). T-Mobile Austria launches 5G network with 25 base stations. FierceWireless. Accessed 26/06/19
141. Vodafone [online]. Vodafone Spain launches the first commercial 5g network on 15 June in 15 cities. Accessed 26/06/19.
142. The Local [online]. Swisscom launches 5G network in 102 locations in Switzerland