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5G

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Contents:

Contents

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Summary

What is 5G?

5G is the next generation of wireless technology, following 2G, 3G and 4G. It is expected to provide faster connections with much higher capacity and very fast response times, which means that many more users and devices can access fast internet connections and large amounts of data at the same time. In addition to faster and higher capacity mobile networks, 5G is expected to support a variety of other uses and applications beyond mobile broadband. Examples include in healthcare, smart cities, transport and manufacturing.

Government 5G policy

The Government's strategy for future digital infrastructure – full-fibre and 5G – is set out in DCMS's Future Telecoms Infrastructure Review (FTIR), published on 23 July 2018. In the FTIR, the Government set a target that the majority of the population will be covered by a 5G signal by 2027.

When will 5G be rolled out?

5G mobile broadband will be the first application of 5G to be rolled out commercially. The roll-out of 5G mobile broadband is led by commercial mobile network operators (MNOs) and roll-out plans are not usually publicly available. Some MNOs have begun 5G trials and announced early network roll-out plans beginning in 2019. Trials for 5G applications and use cases are ongoing, for example, through the Government's 5G Testbeds and Trials programme. The type and scale of 5G applications is still unknown and developing.

5G policy challenges

5G presents some new and different infrastructure challenges compared to 3G and 4G. 5G is expected to see a greater number of small cells (low powered base stations that can be mounted on buildings and street furniture) and will require wider deployment of full-fibre broadband infrastructure. DCMS's Digital Connectivity Portal provides practical guidance for local authorities and commercial providers intending to facilitate deployment of digital infrastructure. Additionally, 5G deployment will require significant investment from mobile operators and other stakeholders, which still presents commercial risks and uncertainties as 5G applications and business cases develop. This paper also covers other 5G policy challenges including security and health concerns.

Spectrum for 5G

5G will require spectrum of different frequencies to suit different applications. Ofcom is working on making spectrum available in three categories:

- Low frequency spectrum (the 700 MHz band) to enable wide coverage;
- Mid-frequency spectrum (the 3.4–3.8 GHz band) for large bandwidths to provide necessary capacity and to enable higher speeds; and
- High-frequency spectrum (26 GHz band) providing ultra-high capacity but with very small coverage ranges.

Some 5G spectrum was auctioned in April 2018 (the 3.4–3.6 GHz band; see the Library paper: Spectrum Auctions 2018 for background). Ofcom plans to auction spectrum in the 700 MHz and 3.6–3.8 GHz bands by Spring 2020. Trial licences are available in the 26 GHz band.

1. 5G in the UK

1.1 What is 5G?

5G is the next generation of wireless network technology. It is expected to support many other uses beyond mobile broadband.

As the fifth generation of mobile technology, 5G follows on from the development of 2G, 3G and 4G mobile technology:[1]

- 2G technology was the first digital mobile technology. It is suitable for making calls, sending text messages and supports very-low speed data connections;
- 3G made it possible to access the internet more effectively through a mobile phone (called mobile broadband), supporting voice, text and data services. 3G provides typical download speeds of over 5 Mbps (in 2014, the UK average was 6 Mbps).[2]
- 4G, launched in 2012, made it much quicker to surf the web on mobile phones, tablets and laptops, supporting faster upload and download speeds and faster response times. 4G supports download speeds over 10 Mbps (in 2014, the UK average was 15 Mbps).[3]

5G technology is expected to bring much faster data speeds, high capacity and much faster responsiveness (low latency):[4]

5G is expected to bring much faster data speeds, high capacity and low latency.

- **Faster data speeds**: means very high data upload/download speeds. Ofcom states that peak speeds of 10–20 gigabits per second will be possible with 5G.
- **High capacity**: means the ability to connect very large numbers of devices. Ofcom states that 5G could support up to one million devices per square kilometre.
- **Low latency**: latency is the delay time for a communications signal, that is, the time between when you click something and when you see a response (such as a website beginning to load). Low latency means fast signal response times. Ofcom states that 5G is expected to have latency in the order of 1 millisecond, which means that 5G response times will feel instantaneous, which is important for real-time communications applications (see below).

The first sets of technology standards for 5G have been agreed by international industry standardisation body 3GPP (3rd Generation Partnership Project) and standards are still developing.[5] Formal

1 Ofcom, Connected Nations 2018, 18 December 2018, Main Report, page 22.
2 Ofcom, Connected Nations 2017, Detailed analysis: mobile voice and data services, 22 December 2017, page 35; Ofcom, Ofcom publishes 4G and 3G mobile broadband speeds research, 13 November 2014 [accessed 7 February 2019].
3 Ofcom, Connected Nations 2017, Detailed analysis: mobile voice and data services, 22 December 2017, page 35; Ofcom, Ofcom publishes 4G and 3G mobile broadband speeds research, 13 November 2014 [accessed 7 February 2019].
4 Ofcom, What is 5G, 9 March 2018; [accessed 7 February 2019]; Ofcom, Enabling 5G in the UK, 9 March 2018, para 2.6.
5 3GPP, RAN adjusts schedule for 2nd wave of 5G specifications, 14 December 2018.

standards are expected to be agreed by the International Telecommunications Union (ITU) by 2020.[6]

5G uses

5G is likely to support many applications beyond mobile broadband.

The above listed features – fast data speeds, high capacity and low latency – mean that 5G is expected to support a variety of uses beyond mobile broadband.

Use cases for 5G can be grouped into three broad categories,[7] which Ofcom summarises as applications that support more data, more devices and instant response times: [8]

- **Enhanced mobile broadband ('more data')**: an evolution of the 4G services already used, encompassing improved consumer experience (such as a more consistent quality of service), more connected devices and faster connection speeds. 5G may also be used for wireless home broadband solutions and could support virtual and augmented reality technology. While 5G is expected to provide faster speeds and extend capacity at existing mobile sites, it is not expected to, of itself, extend the coverage of mobile networks.[9]
- **Massive Machine Type Communications ('more devices')**: this means that 5G is expected to support many internet-connected devices and applications – known as the **Internet of Things** (see Box 1). This could include applications from e-health, transport and logistics, environmental monitoring, smart energy networks and smart agriculture.
- **Ultra-reliable and low latency communications ('instant response'):** this means that 5G will be able to support near real-time communications applications with high reliability. Applications may include driverless vehicles, drone delivery, smart manufacturing, remote healthcare and emergency response and management.

These different use cases and services will have different requirements in terms of speed, coverage, reliability and security, which will demand different network solutions, spectrum bands, infrastructure and roll-out models.[10] Most of these use cases are still developing in terms of technology and businesses cases that would support their deployment.

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6 International Telecommunications Union (ITU), ITU's approach to 5G, 15 October 2018; Futuristic mobile technologies foresee "IMT for 2020 and beyond, [accessed 13 February 2019]. Setting the Scene for 5G: Opportunities & Challenges report; 10 September 2018

7 ITU, Setting the Scene for 5G: Opportunities & Challenges report; 10 September 2018; ITU, IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond, Recommendation ITU-R M.2083-0, September 2015.

8 Ofcom, What is 5G, 9 March 2018; [accessed 7 February 2019]; Ofcom, Enabling 5G in the UK, 9 March 2018, page 12-13.

9 Ofcom, Enabling 5G in the UK, 9 March 2018, para 1.32

10 Ofcom, Update on 5G spectrum in the UK, 8 February 2017; ITU, Setting the Scene for 5G: Opportunities & Challenges report; 10 September 2018. [Accessed 13 February 2019].

Box 1: The Internet of Things

The Internet of Things (IoT) refers to a network of connected devices that talk directly to each other without needing to interact with human beings. 5G is likely to be the networking technology that supports the Internet of Things in the future, due to its low latency and capacity to support many devices at one time. Examples of possible uses are numerous and encompass a vast range of sectors. Some of these technologies already exist or are in development, some are not. Examples suggested to date include smart energy meters, wearable health sensors, driverless cars, smart bins which send warnings when they are full, and smart fridges that can tell you how much food you have left or even order replacement items when you run out.

1.2 When and where will 5G be rolled-out?

5G for mobile broadband

Mobile broadband is expected to be the first commercial use of 5G. The first 5G commercial networks are expected to launch later in 2019 and the first 5G compatible consumer handsets are also expected to become available in 2019.[11]

The first 5G mobile networks are expected to launch in 2019.

The roll-out of 5G mobile broadband is led by commercial mobile network operators (MNOs) who choose when and where they will roll-out services. There are four MNOs in the UK: BT/EE, Three, Vodafone and O2. There are also a number of mobile virtual network operators (MNVOs) (for example, TalkTalk and GiffGaff) which have access to a MNOs network through commercial agreements.

The roll-out plans of private operators are not generally publicly available. Initial pre-commercial trials of 5G by some mobile operators have begun, however, and most operators have made announcements about early roll-out plans for 2019/2020 (see Box 2).

Initially, 5G infrastructure is likely to be deployed on existing 4G mobile sites in busy urban areas to enhance the capacity of existing mobile broadband (that is, the number of people that can use the network at one time and experience a quality service). Section 2 of this briefing paper provides more information about building 5G infrastructure.

[11] Ofcom, What is 5G, 9 March 2018; [accessed 7 February 2019]; EE, EE to be first operator in the world to range OnePlus 5G smartphone, 5 December 2018 [accessed 7 February 2019]; Three, Three UK continues 5G network preparation, 9 July 2018 [accessed 7 February 2019]; Deloitte, Technology, Media & Telecommunications Predictions 2019, 5G: The new network arrives, [accessed 20 February 2019].

Box 2: 5G announcements by Mobile Network Operators

All four MNOs have made announcements about 5G trials and/or network launch plans, for example:

- EE has announced 16 cities in which it would first launch 5G in 2019. The first six cities will be: Edinburgh, Manchester, London, Belfast, Cardiff, Birmingham; 5G will be launched in busy parts of those cities.[12] EE is also carrying out 5G trials including in East London,[13] Canary Wharf,[14] and at Wembley Stadium.[15]
- Vodafone launched a pre-commercial trial of 5G at Salford, Greater Manchester in October 2018.[16] Vodafone has also been reported to have announced plans to have 1000 5G sites by 2020, including in rural areas such as Cornwall and the Lake District.[17]
- Three has been upgrading its network to prepare for 5G and intends to launch 5G mobile and home broadband services in 2019.[18]
- O2 has announced it will launch its first 5G networks in London, Cardiff, Belfast and Edinburgh in 2019, with other areas of the UK to follow in 2020.[19] O2 has also launched a trial 5G testbed at the O2 Arena in Greenwich (which encompasses 5G use cases beyond mobile broadband).[20]

5G trials: developing new 5G applications

5G presents many potential use cases beyond mobile broadband. Most of these use cases are still in development. Commonly cited applications include healthcare, smart cities, transport and manufacturing, as well using 5G technology in rural areas to provide broadband connectivity, agri-tech, precision farming and tourism applications.[21]

Developing these wider 5G applications involves collaborations and input from academia and local Government as well as industry. A report from Digital Catapult (the UK's digital innovation centre)[22] – 5G Nation: the UK 5G Ecosystem 2018 – provides a map of 135 5G-relevant trial projects across the UK, involving 39 academic institutions, 29 local authorities and 57 companies.[23] Further information and examples are available on the Digital Catapult website: 5G mapping.

12 EE, EE announces launch locations for 2019, 13 November 2018 [accessed 7 February 2019]
13 EE, EE switches on 5G trial in East London, 7 November 2018, [accessed 7 February 2019].
14 Canary Wharf Group plc, EE brings 5G to the UK for the first time with switch on of live 5G site in Canary Wharf trial, 5 October 201, [accessed 7 February 2019].
15 EE, EE continues 5G leadership with first live 5G broadcast in partnership with BT Sport, 21 November 2018, [accessed 7 February 2019].
16 Vodafone, Vodafone first to switch on full 5G in the UK, 25 October 2018 [accessed 7 February 2019].
17 Vodafone plans 1,000 5G sites by 2020 in race with rivals, Nic Fields, *Financial Times* [subscription only], 20 September 2018, [accessed 7 February 2019].
18 Three, Three UK Committed to Invest Over £2bn into 5G, 7 November 2018 [accessed 7 February 2019].
19 O2, O2 5G to arrive in 2019 as company builds a 5G Economy in partnership with British business, 21 February 2019, [accessed 22 February 2019].
20 O2, O2 to launch 5G test bed at The O2, 22 February 2019, [accessed 7 February 2019].
21 Digital Catapult report: 5G Nation: the UK 5G Ecosystem 2018, 11 June 2018 [accessed 7 February 2019].
22 Digital Catapult is one of a network of Catapult Centres established by Innovate UK (an executive agency of the Department for Business, Energy and Industrial Strategy) as independent, not-for-profit physical centres to connect businesses with academic researchers by providing facilities and programmes to support collaboration. 5G is one of three core technology programme streams that Digital Catapult focuses on.
23 Digital Catapult report: 5G Nation: the UK 5G Ecosystem 2018, 11 June 2018, Figure 4, pages 18 and 20.

The Government is supporting 5G trials through its 5G testbeds and trials programme (see Box 3) and another large source of 5G trial activity is UK universities (see Box 4).

Box 3: 5G Testbeds and Trials

The Government's 5G Testbeds and Trials programme (led by the Department for Digital Culture Media and Sport (DCMS)) is supporting 5G trial projects across a range of sectors to identify opportunities for 5G, develop business models and improve understanding of potential deployment challenges.[24]

The first phase is funding six trial programmes that were announced in March 2018:[25]

1. 5G Smart Tourism (Bath and Bristol)
2. Liverpool 5G Testbed (Liverpool)
3. AutoAir: 5G Testbed for Connected and Autonomous Vehicles (Millbrook)
4. Worcestershire 5G Consortium - Testbed and Trials (Worcestershire)
5. 5G Rural Integrated Testbed (5GRIT) (Cumbria, Northumberland, North Yorkshire, Inverness-shire, Perthshire and Monmouthshire).[26]
6. 5G RuralFirst: Rural Coverage and Dynamic Spectrum Access Testbed and Trial (first trial to focus on Orkney Islands, Shropshire and Somerset).[27]

In September 2018 the Government announced that the West Midlands Combined Authority (WMCA) will lead a 5G Urban Connected Communities (UCC) project that will trial a large-scale 5G testbed in a UK city.[28]

Box 4: UK Universities and 5G

There are a number of UK universities leading work on 5G technology development.[29] For example:

- The 5GUK project is a collaboration between the University of Surrey, University of Bristol and Kings College London to develop a 5G test network that can then be used to trial other projects. The project funding included £16 million awarded by DCMS in July 2017.[30]
- University of Surrey's 5G Innovation Centre opened in 2015.[31] The centre supports several research groups as well as partners across industry, other universities and local and national government.
- University of Bristol's Smart Internet Lab includes projects on smart city applications of 5G in Bristol.
- Kings College London's Centre for Telecommunications Research has been running 5G trial projects in collaboration with Ericsson at their London campus.

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24 DCMS, 5G Testbeds and Trials Programme, 10 September 2018, [accessed 9 November 2018].
25 DCMS, £25m for 5G projects on the anniversary of the UK's Digital Strategy 10 March 2018, [accessed 7 February 2019].
26 5G rural test integrated bed, [accessed 9 November 2018].
27 5G rural first, [accessed 9 November 2018].
28 DCMS, West Midlands to become UK's first large-scale 5G testbed, 4 September 2018, [accessed 7 February 2019].
29 Digital Catapult report: 5G Nation: the UK 5G Ecosystem 2018, 11 June 2018.
30 DCMS, Three universities to develop £16m 5G test network, 6 July 2019, [accessed 7 February 2019].
31 University of Surrey, 5G Innovation Centre officially opens at the University of Surrey, 15 September 2015, [accessed 7 February 2019].

1.3 Government's 5G strategy and policy

The Government's strategy for future digital infrastructure – 5G and full-fibre networks – is set out in DCMS's Future Telecoms Infrastructure Review (FTIR) published on 23 July 2018.[32] The Government had published two previous 5G strategies prior to the FTIR, in March and December 2017.[33]

The Government has set a target that the majority of the population will be covered by a 5G signal by 2027.

In the FTIR the Government stated an ambition to be a world leader in 5G, noting that 5G has the potential to generate "significant economic benefits from the digital transformation of many sectors".[34] The Government set a target that "the majority" of the population would be covered by a 5G signal by 2027.[35]

The Government's policy focus set out in the FTIR is to support a "market expansion model" for 5G in the UK. This means supporting a competitive market of mobile network operators, which the Government believes is an important driver of investment in 5G, as well as promoting innovation by new providers that could deliver "innovative solutions" to challenges such as rural coverage.[36]

The FTIR identified four priority areas that Government policy for 5G will focus on to support the market expansion model:

1. Make it easier and cheaper to deploy mobile infrastructure and support market expansion, including the implementation of the wide-ranging Electronic Communications Code (ECC) on site access and consideration of further planning reforms;
2. Support the growth of infrastructure models that promote competition and investment in network densification and extension;
3. Fund beneficial use cases through the Government's £200 million 5G Testbeds and Trials Programme that helps de-risk business models for 5G; and
4. Promote new, innovative 5G services from existing and new players, through the release of additional spectrum. We should consider whether more flexible, shared spectrum models can maintain network competition between MNOs while also increasing access to spectrum to support new investment models, spurring innovation in industrial internet of things, wireless automation and robotics, and improving rural coverage.[37]

The Library briefing papers on Mobile Coverage in the UK and Full-fibre networks in the UK provide information about the reforms to the Electronic Communications Code as relevant to mobile and fibre networks, respectively. Box 3 above explains the Testbeds and Trials

32 DCMS, Future Telecoms Infrastructure Review, 23 July 2018.
33 DCMS, Next Generation Mobile Technologies: A 5G Strategy for the UK, 8 March 2017; and Next Generation Mobile Technologies: An Update to the 5G Strategy for the UK, 19 December 2017.
34 DCMS, Future Telecoms Infrastructure Review, 23 July 2018, page 53.
35 DCMS, Future Telecoms Infrastructure Review, 23 July 2018, para 158.
36 DCMS, Future Telecoms Infrastructure Review, 23 July 2018, para 187.
37 DCMS, Future Telecoms Infrastructure Review, 23 July 2018, page 12.

programme (the third listed priority area) and Section 3 of this paper covers spectrum policy (the fourth listed priority area).

The FTIR was broadly welcomed by industry stakeholders as a statement of Government ambition to facilitate digital infrastructure build.[38] The Broadband Stakeholder Group (a stakeholder group encompassing representatives from industry, Government, local government, Ofcom and others) noted that the change in competition models (for example the "market expansion model" for 5G) "marked a significant evolution in the Government's approach".[39] Mobile UK, the trade body for mobile operators, said that the FTIR was a "step in the right direction" but argued that the strategy lacked urgency and clear deadlines for action:

> The publication of the DCMS's Future Telecoms Infrastructure Review is a step in the right direction and begins to provide the mobile industry with a view of the Government's ambitions and how it wants to achieve them. Its recommendations by and large mirror much of what the industry has highlighted is required for the UK to become a world leader in digital connectivity. The problem, however, is that its sense of urgency and emphasis on action needed 'at a pace' is not matched by a solid timetable for reform or firm commitments to reform the planning system which is not yet fit for purpose for the upcoming 5G deployment. Urgency should be the watchword here but without set deadlines and firm commitments it is difficult to see how or even when these recommendations will come about.[40]

The Confederation of British Industry (CBI) commented in a report published in December 2018, that a "step-change" in Government action was required to meet the ambitious coverage targets set in the FTIR.[41]

Government funding for 5G

Government funding support for 5G since 2016 has been allocated through the National Productivity Investment Fund (NPIF).[42] The NPIF, which also covers other areas such as housing and transport, was first announced in the Autumn Budget 2016 and, following extensions every year since then, is now a £37 billion overall fund running to 2023–2024.[43]

In the Autumn Statement 2016, the Government announced £740 million from the NPIF would be set aside for full-fibre networks and 5G. From that funding, the main investment for 5G has been £160 million

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38 Wireless Infrastructure Group, Wireless Infrastructure Group welcomes DCMS Future Telecoms Infrastructure Review (FTIR), July 2018; Mobile UK, Government published its Future Telecoms Infrastructure Review, July 2018; techUK, initial response to Future Telecoms Infrastructure Review, 23 July 2018. [Accessed 11 February 2019].

39 Broadband Stakeholder Group, A long read – Forging our Full-Fibre and 5G Future, 23 July 2018 [accessed 11 February 2019].

40 Mobile UK, Future Telecoms Infrastructure Review is a positive step but it is deadlines that will achieve its goals, Gareth Elliott, July 2018 [accessed 11 February 2019].

41 Confederation of British Industry, Ready, Set, Connect, 7 December 2018 [accessed 11 February 2019].

42 Note this section does not include funding allocated through research grants.

43 The NPIF was first announced in the Autumn Budget 2016 as a £23 million fund to 2020–2021; the Autumn Budget 2017 extended the overall NPIF to £31 billion, which corresponded to an extra £7 billion for 2022-2023. The Autumn Budget 2018 extended the NPIF to 2023-24, and expanded it to £37 billion overall.

for the testbeds and trials programme (see Box 3). That £160 million also included £10 million set aside for testing the security of 5G networks and £5 million to test 5G applications and deployments on roads.[44]

Other funding commitments on 5G have included:

- creating in 2018 the National 5G Innovation Network to trial and demonstrate 5G applications. The first phase was to invest up to £16 million in a 5G testing facility (the 5GUK project, see Box 4);[45]
- £35 million to improve internet connectivity on trains (a combination of mobile and fibre broadband).[46]

Mobile UK and the CBI have both called for further funding support for mobile infrastructure, arguing that the Government should support mobile infrastructure to the same extent as initiatives for fixed-broadband (full-fibre) networks.[47]

44 HM Treasury, Autumn Budget 2017, 22 November 2017, section 5.19.
45 HM Treasury, Spring Budget 2017, 8 March 2017, para 1.4 and 5.5.
46 HM Treasury, Autumn Budget 2017, 22 November 2017, section 5.19.
47 Mobile UK, Budget 2018: Fibre progress welcomed but mobile infrastructure cannot be forgotten, 29 October 2018; Confederation of British Industry, Ready, Set, Connect, 7 December 2018, page 7. [Accessed 11 February 2019]

2. Challenges for 5G

2.1 Building 5G infrastructure

Mobile operators argue that there are 'barriers' holding back the roll-out mobile infrastructure (generally, both 4G and 5G) and have called for further reforms such as to the planning regime, access to public assets, and for better collaboration between local authorities, landowners and industry.[48] 5G infrastructure presents some challenges that make these concerns particularly acute for 5G-roll out compared to mobile coverage generally; some of these challenges are set out below.

In the FTIR the Government reiterated its support for facilitating the roll-out of mobile infrastructure however no legislative reforms specifically related to 5G were proposed. The Library briefing paper on Mobile Coverage in the UK (CBP 7069) provides information about building mobile infrastructure, which also applies to 5G, including information about the planning regime and reforms to the Electronic Communications Code in 2017. DCMS's Digital Connectivity Portal launched in December 2018 provides resources and advice for local authorities and commercial providers and is intended to facilitate deployment of broadband and mobile networks.[49] The Portal has been welcomed by mobile operators.[50]

Box 5 provides an overview of key mobile infrastructure terminology used in this section.

Box 5: Mobile infrastructure explainer

Base stations: mobile base stations contain radio communications equipment that sends and receives mobile voice/data signals over an area surrounding the station and connects them to a mobile operator's network. Mobile masts, macro cells and small cells are all types of base stations. Mobile base stations require access to power and a backhaul connection.

Macro cell: a mobile base station that provides wide-area coverage for a mobile network. The antennas for macro cells can be mounted on ground-based masts, rooftops or other existing structures.

Small cell: a low-powered base station that provides coverage over a smaller area than macro cells. Small cells are used to boost mobile network capacity and coverage in localised areas e.g. dense urban areas where there are large numbers of users. They are smaller and lighter than macro cells so can be mounted in more places, for example on street furniture.[51] There are different types of small cells (e.g. femtocells, picocells, microcells) that operate with different coverage ranges. Small cells are already used for 4G networks in some areas.

Backhaul: the link that connects a mobile base station to the core internet and phone network. Backhaul is usually provided by full-fibre broadband cables or fixed-radio links.

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48 Mobile UK, Building Mobile Britain, [accessed 8 February 2019]; Broadband Stakeholder Group, Forging our 5G Future: Barriers and Solutions to network deployment, 20 July 2018; DCMS, Future Telecoms Infrastructure Review, 23 July 2018, para 194-200; Digital Catapult. 5G Nation: the UK 5G Ecosystem 2018, 11 June 2018, page 44.

49 DCMS, Digital Connectivity Portal, 20 December 2018.

50 Mobile UK, DCMS launches new Digital Connectivity Portal for local authorities and communications network providers, 3 January 2019, [accessed 8 February 2019].

51 GMSA, Improving wireless connectivity through small cell deployment (pdf) December 2016.

What are the challenges to building 5G infrastructure?

5G presents some new and different infrastructure challenges compared to the roll-out of 3G and 4G.[52] Mobile operator EE, following the launch of 5G trial sites in London, listed the following as examples of infrastructure challenges faced by 5G equipment:

- Rooftop sites often need significant strengthening to carry the new 50kg 5G antennas – and some sites house three of these
- The level of upgrade work required can cause delays in obtaining planning permission, and can necessitate repeat visits, which means multiple access requests to landlords
- Location for 5G antennas can be dictated by the need to stay below regulated power output levels.[53]

Backhaul: Backhaul connections to 5G sites present another infrastructure challenge. Backhaul connections at some 3G and 4G base stations are not suitable for 5G, which are likely to require much higher capacity connections.[54] Further, a dense array of 5G small cells is likely to require a dense full-fibre network to support it, which also faces infrastructure challenges. The roll-out of 5G is therefore strongly linked to full-fibre roll-out. The Library briefing paper on Full-fibre networks in the UK provides information about building full-fibre networks.

Small cells: Initially, 5G is first expected to be rolled-out on existing macro sites used for 3G and 4G. In the longer term, 5G networks are also likely to require a greater number of small cells compared to 3G and 4G to provide capacity for the large numbers of users and devices that 5G is expected to support. Also, high-frequency applications of 5G will require base stations to be placed close together because high-frequency signals cannot travel long distances (see Box 6 for information about frequency characteristics). The large-scale deployment of small cells for 5G is a longer-term prospect and there is still uncertainty about the number of small cells that will be required or ultimately deployed.[55]

In the FTIR the Government stated that its analysis indicated that the roll-out of 5G on existing macro sites with some smalls cells in dense urban areas appeared feasible by 2020, but that the larger scale deployment of small cells would likely require new approaches to building infrastructure from operators and local stakeholders to enable more efficient deployment.[56]

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52 Broadband Stakeholder Group, Forging our 5G Future: Barriers and Solutions to network deployment, 20 July 2018; Arqiva, Rolling out 5G in the UK: What's involved?, Jonathan Freeman, 5 December 2017. [Accessed 11 February 2019].
53 EE, EE switches on 5G trial sites in East London, 7 November 2018, accessed 15 January 2018.
54 Digital Catapult. 5G Nation: the UK 5G Ecosystem 2018, 11 June 2018, page 44-45.
55 DCMS, Future Telecoms Infrastructure Review, 23 July 2018, para 181.
56 DCMS, Future Telecoms Infrastructure Review, 23 July 2018, para 184-185.

2.2 Investment and commercial risks

Deployment of 5G will require significant investment from mobile operators and other relevant stakeholders (for example wireless and full-fibre infrastructure providers).[57] In the FTIR the Government estimated that deployment of 5G will require a total of £3–4 billion overall investment. The Government highlighted that the large-scale roll-out of 5G still presents commercial risks for mobile network operators as business cases and demand are still developing, describing this uncertainty as a "policy puzzle":

> On the demand side, there remains uncertainty about exactly where 5G will make the biggest impact and the extent to which demand for new applications and services will emerge. On the supply side, it is not yet clear how and where 5G networks will be deployed. It is likely that their development will be part of a wider ecosystem of wireless connectivity, building on investment in 4G networks and the ongoing development of fixed network infrastructure, with different upgrades required to deliver different use cases in different areas.
>
> This puzzle could mean that 5G deployment may be less extensive than would be optimal for society.[58]

The Broadband Stakeholder Group highlighted "investment uncertainty" as one of the biggest overarching barriers to 5G deployment, stating that this makes removing other barriers to 5G deployment (such as to infrastructure build highlighted above) "all the more important".[59] Mobile operators have called for tax relief for mobile infrastructure and for more funding to local and regional bodies to support mobile infrastructure deployment.[60]

The International Telecommunications Union (ITU) has also identified investment risk and uncertainty as an important policy challenge for 5G deployment and urges policy makers to also focus on boosting 4G networks while 5G investment cases develop.[61] The ITU has also noted that there is a risk that 5G could widen 'digital divide' if rural areas fall behind urban areas on 5G roll-out.[62] Commercial investment cases are more difficult in rural areas which face higher infrastructure build costs and lower demand (due to lower population). Others highlight that 5G offers opportunities for rural areas and could help bridge digital divides if frameworks for encouraging investment and take-up of digital

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57 ITU, Setting the Scene for 5G: Opportunities & Challenges report, 10 September 2018, pages xii and 9 [accessed 14 February 2019].
58 DCMS, Future Telecoms Infrastructure Review, 23 July 2018, page 53.
59 Broadband Stakeholder Group, Forging our 5G Future: Barriers and Solutions to network deployment, 20 July 2018.
60 Mobile UK, Mobile UK Budget Submission: Time to Prioritise Mobile Infrastructure, 29 October 2018, [accessed 7 February 2019].
61 ITU, Setting the Scene for 5G: Opportunities & Challenges report, 10 September 2018, pages xii and 9 [accessed 14 February 2019]. For information about 4G roll-out in the UK, see the Library briefing paper on Mobile Coverage in the UK.
62 ITU, Setting the Scene for 5G: Opportunities & Challenges report, 10 September 2018, pages xii and 9 [accessed 14 February 2019].

technologies are in place.[63] Some of the Government 5G testbed and trial projects are focusing on 5G applications in rural areas (see Box 3).

2.3 5G and security

There have been press reports regarding security concerns in relation to foreign-supplied products for 5G networks, in particular by Chinese telecommunications company Huawei (pronounced "Wah-Way").[64] In addition to manufacturing devices such as smart phones and tablets, Huawei also manufactures equipment used in building mobile networks such as radio access equipment and core network infrastructure. There are not many companies that provide radio access equipment; others include Nokia (Finnish) and Ericsson (Swedish).[65] [66]

Security concerns about telecoms supply chains are not unique to 5G;[67] for background information, see Box 5 in POSTnote 554 on Cyber Security of UK Infrastructure (May 2017). This issue has come to the fore again as new commercial supply agreements for 5G equipment are negotiated worldwide. Additionally, 5G raises some new and different security challenges compared to other mobile and telecoms networks, due to new approaches to network architecture that will be employed. Although incorporating existing security standards and being built on top of existing networks, these new technologies will require new approaches to security and network design.[68] In doing so, 5G also offers opportunities to develop more secure systems. A good discussion of 5G security challenges is provided in a blog post written by the National Cyber Security Centre's (NCSC) technical director, Ian Levy: Security, complexity and Huawei; protecting the UK's telecoms networks (20 February 2019).

Concerns about foreign involvement in telecommunications networks – and Chinese involvement in particular – also touch on broader strategic and geopolitical issues regarding the growing global presence of

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63 O2 blog, UK Cities Face a Digital Divide: 5G is the Answer, Derek McManus, 12 July 2018; Cisco blog, The UK is ready for 5G, Nick Chrissos, 28 March 2018. [Accessed 14 February 2019].

64 Huawei under fire as politicians fret over 5G security, David Bond, James Kynge, *Financial Times*, 2 December 2018 [accessed 29 January 2019, subscription only]; MPs call on Parliament to investigate dangers Huawei poses to the UK's national infrastructure, Joseph Archer and James Cook, The Telegraph, 15 December 2018; Gavin Williamson has 'grave' concerns over Chinese telecom giant Huawei providing UK 5G network, Charles Hymas, *The Telegraph*, 26 December 2018.

65 How 5G Will Shape Innovation and Security: A Primer, James A Lewis, Centre for Strategic and International Studies, December 2018.

66 Intelligence and Security Committee, Foreign involvement in the Critical National Infrastructure: The implications for national security, Cm 8623, June 2013, paragraph 31.

67 See for example the 2013 Intelligence and Security Committee Report: Foreign involvement in the Critical National Infrastructure: The implications for national security, Cm 8623, June 2013.

68 3GPP 5G Security, 6 August 2018; Technical Report on 5G Network Architecture and Security, University of Surrey 5G Innovation Centre and DCMS Phase 1 5G Testbeds and Trials projects, 17 December 2018; 5G Whitepaper: 5G Security Overview, University of Surrey 5G Innovation Centre, March 2018.

Chinese technology companies.[69] Some countries, for example the US,[70] Australia,[71] and New Zealand,[72] have restricted the role that foreign telecommunications providers can play in national 5G and/or telecoms networks.[73] There have been some calls for the UK Government to consider taking a stricter approach on Huawei products in 5G networks in the UK.[74] Other experts, however, such as Robert Hannigan (former head of GCHQ), have commented that an outright ban on Chinese technology companies would not be an effective approach to managing security arguing that decisions should be made based on "technical expertise and rational assessment of risk" rather than geopolitical concerns.[75]

How is Huawei equipment used in existing UK telecoms networks?

In the UK, the Huawei Cyber Security Evaluation Centre (HCSEC, run and funded by Huawei but jointly overseen and staffed by GCHQ) has since 2010 evaluated the security of Huawei products being used in UK telecoms networks. For background, see the Intelligence and Security Committee's 2013 report, Foreign involvement in the Critical National Infrastructure: The implications for national security,[76] and Ian Levy's blog post (February 2019), which provide an overview of the use of Huawei equipment in the UK. Ian Levy states that the model has worked "pretty well for the past 8 years" but notes that although most of the

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69 Joint Committee on the National Security Strategy, Oral evidence: Work of the National Security Adviser, HC 625, 28 January 2019, Q51; The EU needs its own security strategy to confront the digital threat, Julian King, *Financial Times*, 31 January 2019, [subscription only]; Huawei debacle throws spotlight on China's technology ambitions, Nigel Inkster, International Institute for Strategic Studies, 10 December 2018; Huawei, the U.S., and Its Anxious Allies, Edward Alden, Council on Foreign Relations, 31 January 2019. [Accessed 22 February 2019]

70 The US has restricted the use of Huawei and ZTE equipment in federal contracts: US Congress, 'John S. McCain National Defense Authorization Act for Fiscal Year 2019' (2018).

71 The Australian Government did not name any specific companies but stated: "*The Government considers that the involvement of vendors who are likely to be subject to extrajudicial directions from a foreign government that conflict with Australian law, may risk failure by the carrier to adequately protect a 5G network from unauthorised access or interference*"; Australian Ministers for Communications and the Arts, Government Provides 5G Security Guidance To Australian Carriers, 23 August 2018. This has been interpreted as effectively a ban on Huawei and ZTE: Huawei and ZTE handed 5G network ban in Australia, *BBC News*, 23 August 2018.

72 The New Zealand Government rejected one telecoms provider's proposal to use Huawei 5G equipment in November 2018: New Zealand Government Communications Security Bureau, 'GCSB statement', 28 November 2018; Spark NZ, GCSB declines Spark's proposal to use Huawei 5G equipment, 29 November 2018.

73 Council on Foreign Relations, Year in Review: Huawei and the Technology Cold War, Adam Segal, 26 December 2018.

74 China–UK Relations: Where to Draw the Border Between Influence and Interference?, Occasional Paper, Charles Parton, Royal United Services Institute (RUSI), 20 February 2019; Huawei is too great a security gamble for 5G networks, John Gapper, *Financial Times*, 30 January 2019, [subscription only]. [Accessed 22 February 2019]

75 Blanket bans on Chinese tech companies like Huawei make no sense, Robert Hannigan, *Financial Times*, 12 February 2019.

76 Intelligence and Security Committee, Foreign involvement in the Critical National Infrastructure: The implications for national security, Cm 8623, June 2013.

big providers use the HCSEC for information, not all providers do (its use is not mandatory).[77]

Several Parliamentary Committees have asked the Government for assurances regarding foreign-supplied products to UK telecoms networks and the effectiveness of the HCSEC, including the Joint Committee on the National Security Strategy in its November 2018 report on Cyber Security of UK Critical National Infrastructure,[78] and the House of Commons Science and Technology Committee, which wrote to three Ministers and to Huawei about the issue in January 2019; Huawei's response was published on 6 February 2019.[79] [80]

Ciaran Martin, CEO of the NCSC, in a speech in February 2019 explained how Huawei equipment is deployed in UK networks as follows:

> We also have strict controls for how Huawei is deployed. It is not in any sensitive networks – including those of the government. Its kit is part of a balanced supply chain with other suppliers. Our regime is arguably the toughest and most rigorous oversight regime in the world for Huawei.
>
> And it is proving its worth. Last July, our annual Oversight Board downgraded the assurance we could provide to the UK government on mitigating the risks associated with Huawei because of serious problems with their security and engineering processes. As we said then, and repeat today, these problems are about standard of cyber security; they are not indicators of hostile activity by China.
>
> The company have accepted these findings and have pledged to address them, acknowledging that this will be a process of some years. We will monitor and report on progress and we will not declare the problems are on the path to being solved unless and until there is clear evidence that this is the case. We will not compromise on the improvements we need to see from Huawei. And, based on our hard-headed assessment of risk and our detailed knowledge of how networks work, we are putting in place our own plans for helping our operators to manage these risks.[81]

What has the Government said about Huawei products for 5G networks?

The Government states that its position on foreign supplied products in 5G networks will be determined as part of DCMS's cross-government review of UK telecommunications supply chains, which was launched in November 2018 and is expected to conclude in spring 2019.[82] The Government outlined that the review will consider "the full UK market

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77 NCSC, Security, complexity and Huawei: protecting the UK's telecoms networks, 20 February 2019, [accessed 20 February 2019].

78 Joint Committee on the National Security Strategy, Cyber Security of the UK's Critical National Infrastructure, Third Report of Session 2017–19, HL 222, HC1708, 19 November 2018, paragraph 66.

79 House of Commons Science and Technology Committee, MPs seek assurances on security of UK communications infrastructure, 23 January 2019.

80 Letter from Ryan Ding, Huawei to Norman Lamb MP, Chair of Science and Technology Committee, dated 29 January 2019.

81 NCSC, Ciaran Martin's CyberSec speech in Brussels, 20 February 2019.

82 DCMS, Telecoms Supply Chain Review Terms of Reference, 8 November 2018.

position, including economic prosperity, corporate and consumer effects, and the quality, resilience and security standards of equipment with a view to establishing a robust supply chain policy framework that balances security and prosperity".[83] Ciaran Martin (NCSC) in February 2019 said that "everything is on the table" and that no decisions had yet been taken.[84]

In a House of Lords PQ response on 23 January 2019 Lord Young of Cookham, Lords spokesperson for the Cabinet Office, when asked about the Government's approach to Huawei's participation in 5G networks, stated that the Government did not consider it in the national interest to ban Huawei products outright, and that the Government approach is to balance seeking the best available technology and inward investment without compromising national security:

> I am grateful to my noble friend, who has drawn attention to the need to get the balance right. America has banned Huawei from federal networks. We do not plan to go as far as that. I think America has a different approach from this country to international trade and inward investment, particularly under its "America first" policy. Of course, it has particular difficulties with China at the moment. We want to get the balance right and to have the best digital infrastructure we can, with up-to-date equipment to promote growth and inward investment, but we do not want to compromise national security. Huawei is precluded from taking part in certain sensitive parts of our infrastructure—lawful intercept, for example—and in other cases its equipment is interposed between equipment from other firms to mitigate risks.
>
> […]
>
> In the case of Huawei, we have set up unparalleled arrangements in this country. As the noble Lord will know, we have set up at Banbury a centre to evaluate Huawei's strategy and the equipment it is developing. That board is overseen by the chief executive of the National Cyber Security Centre, so we have a deep insight into what Huawei is up to and can take mitigating action in certain circumstances. As I have said, in certain circumstances we can ban it from taking part. But we want to make use of the latest technology and, as my noble friend said, Huawei is a world beater and it would not be in the national interest to ban it totally. We are looking at whether we have the legal structure right for the future in protecting national security, but I think we have the balance about right.[85]

In oral evidence to the Joint Committee on the National Security Strategy in January 2019, the Government's National Security Advisor, Mark Sedwill, stated that the UK is in a different position to other countries due to the "unrivalled insight and scrutiny" provided by the HCSEC arrangements.[86]

The issue continues to be raised in the press, for example:

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83 PQ 209750, 22 January 2019 [Huawei: USA].
84 NCSC, Ciaran Martin's CyberSec speech in Brussels, 20 February 2019.
85 HL Deb 795, 23 January 2019 [Domestic Infrastructure: Chinese Ownership]
86 Joint Committee on the National Security Strategy, Oral evidence: Work of the National Security Adviser, HC 625, 28 January 2019, Q57.

Could Huawei threaten the Five Eyes alliance?, Gordon Corera, *BBC News*, 20 February 2019.

UK cyber security chief says Huawei risk can be managed, David Bond, *Financial Times,* 20 February 2019 [subscription only].

Is Huawei a friend or foe in the battle for 5G dominance?, Jamie Doward, *The Observer*, 3 February 2019.

US files charges against China's Huawei and CFO Meng Wanzhou, *BBC News*, 29 January 2019.

Huawei under fire as politicians fret over 5G security, David Bond, James Kynge, *Financial Times*, 2 December 2018 [subscription only].

2.4 5G and health

Some concerns have been expressed about potential health effects associated with radio frequency spectrum (radio waves) used for 5G.[87] More information about radio frequency spectrum for 5G is provided in Section 3 of this paper.

Public Health England (PHE), an executive agency to the Department of Health and Social Care, provides advice to the Government on public health issues. A 2017 guidance document from PHE on Smart meters, radio waves and health, summarised the research undertaken and the evidence available on radio waves and health in general. PHE stated that, based on the existing research, it considered that there was no convincing evidence of harm from exposure to radio waves within the international guideline levels. These guideline levels are those set by the International Commission on Non-Ionising Radiation Protection (ICNIRP), part of the World Health Organization. PHE also acknowledged that there remain some areas of scientific uncertainty; and have committed to keeping the evidence under review, and to publish further reviews and updated statements as necessary.

An April 2018 PHE document on 5G explains that exposure of the general public to radio waves from existing telecommunications networks are within international guideline levels and that these guidelines will continue to apply to 5G products:

> Mobile telecommunications technology has developed through several generations and there are now many 2G, 3G and 4G base stations installed throughout the environment providing services to users of mobile phones and other devices. Over the decades since the networks were first introduced there has been a general trend towards increasing numbers of smaller transmitters that individually provide services to smaller geographical areas and which have reducing radiated powers. Against this background, many measurements have been made and these continue to show that exposures of the general public to radio waves are well within the international health-related guideline levels that are used in the UK. These guidelines are from the International

[87] See, for example, Written question 176373 and Written Question 176372 [5G: health hazards] 16 October 2018, DCMS,The Future Telecoms Infrastructure Review: Call for Evidence Responses, July 2018.

> Commission on Non-Ionizing Radiation Protection (ICNIRP) and underpin health protection policies at UK and European levels.
>
> In relation to the implementation of 5G user devices and networks, this technology is at an early stage and reflects the latest evolution in mobile communications technology. Current technical standards that draw on the ICNIRP guidelines will apply to the products that are developed and the UK network operators are already committed to complying with the ICNIRP guidelines.[88]

The document goes on to discuss the use of higher frequency spectrum that is being discussed for future use by 5G technology (see Section 3.5 of this paper for technical information):

> With the increase in the volume of information being transferred, more spectrum is being made available and the highest frequencies being discussed for future use by 5G are around ten times higher than those used by current network technologies, up to a few tens of GHz. Their use is not new, and they have been used for point-to-point microwave links and some other types of transmitters that have been present in the environment for many years. ICNIRP guidelines apply up to 300 GHz, well beyond the maximum (few tens of GHz) frequencies under discussion for 5G.
>
> Exposure to radio waves is not new and health-related research has been conducted on this topic over several decades. In particular, a large amount of new scientific evidence has emerged over the past few years through dedicated national and international research programmes that have addressed concerns about rapidly proliferating wireless technologies.
>
> The main focus of recent research studies has been on exposure to the types of radio signals used by current communications technologies and at the frequencies they use, up to a few GHz. Fewer studies have been carried out at higher frequencies but the biophysical mechanisms that govern the interaction between radio waves and body tissues are well understood at higher frequencies and are the basis of the present ICNIRP restrictions. The main change in using higher frequencies is that there is less penetration of radio waves into body tissues and absorption of the radio energy, and any consequent heating, becomes more confined to the body surface.
>
> It is possible that there may be a small increase in overall exposure to radio waves when 5G is added to an existing network or in a new area; however, the overall exposure is expected to remain low relative to guidelines and as such there should be no consequences for public health.[89]

The Government has said it anticipates no negative effects on public health from 5G roll-out and has committed to work with Public Health England's Centre for Radiation, Chemical and Environmental Hazards (CRCE) to monitor available evidence and take action if necessary.[90] The Minister for Digital Policy, Margot James, provided the following response to a Parliamentary Question in October 2018 when asked about health concerns associated with 5G and the representations that have been made to Government on this topic:

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88 PHE, 5G, April 2018
89 PHE, 5G, April 2018
90 Written question 176373 [5G: health hazards] 16 October 2018.

> 5G is the latest evolution of mobile communications technologies and currently in its development stages. 5G is likely to be deployed as part of a patchwork of technologies, including those already in use, such as advanced LTE (4G), Wi-Fi, as well as 5G new radio - forming a 'network of networks' of a heterogeneous nature.
>
> The Department has had a number of open consultations, and calls for evidence over the past year, for the Future Telecoms Infrastructure Review, as well as relating to the 5G Programme. Across these, and with departmental correspondence, we have received 34 representations on the potential health risks of 5G technology.
>
> A considerable amount of research has been carried out on radio waves and we anticipate no negative effects on public health. As 5G continues to develop, the Government is committed to working with Public Health England's Centre for Radiation, Chemical and Environmental Hazards (CRCE) in order to monitor available evidence and will take action if necessary.[91]

[91] Written question 176373 [5G: health hazards] 16 October 2018.

3. Spectrum for 5G

Box 6: Spectrum explainer

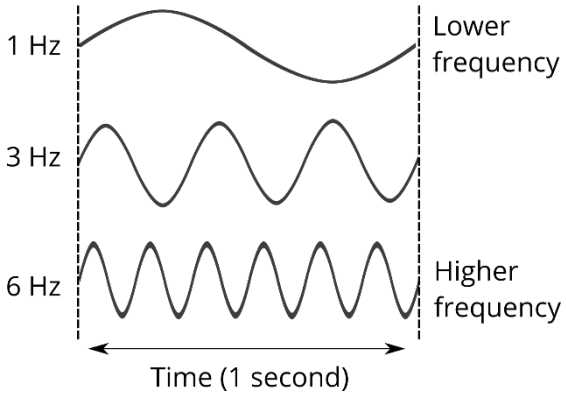
What is spectrum?

Spectrum (sometimes called airwaves) refers to the radio waves that mobile operators use to transmit data. Mobile data is transmitted over the radio frequency spectrum, which is a comparatively small part of the wider electromagnetic spectrum, which also includes light, microwaves, and X-rays. Radio waves cover the frequency range 3 Hz to 300 GHz. Other uses of the radio frequency spectrum include TV and radio broadcasting, Wi-Fi, and satellite communications.

Frequency and Hertz (Hz)

Radio waves are usually specified by frequency. *Frequency* refers to the number of wave cycles that pass a fixed point in a fixed unit of time.

Frequency is measured in Hertz (Hz). 1 Hz means one wave cycle per second. The diagram to the right shows waves with frequencies of 1, 3 and 6 Hz.



1 Megahertz (Mz) means one million waves per second. 1 Gigahertz (GHz) means 1000 MHz (one billion waves per second).

Bands and bandwidth

Bands are ranges of different frequencies; *bandwidth* is the size of the band. For example, the frequency band 700–800 MHz has a bandwidth of 100 MHz; the band 2–3 GHz has a bandwidth of 1 GHz (1000 MHz). The latter band has a wider/larger bandwidth.

The bandwidth determines how much data a portion of spectrum can carry. A wider bandwidth can carry more data.

Different frequencies of spectrum are suited to different applications

Low frequencies (usually less than 1000 MHz) are well suited for providing rural and indoor mobile coverage. This is because lower frequency waves can travel longer distances and are better at penetrating physical objects than higher frequencies.

Higher frequencies are well-suited to support network capacity (the amount of data traffic the network can support) and therefore tend to be used in cities and busy urban areas where lots of people are using the network. This is because at higher frequencies (typically 2–3 GHz) wider bandwidths are available, which can carry more data. However, higher frequencies cannot travel as far as lower frequencies, so require base stations (see Box 5) to be placed closer together.

5G will require a range of different frequency bands to support different applications (see Section 3.1).

How is spectrum allocated?

Spectrum is a finite resource that is managed in the UK by Ofcom. Each mobile network operator transmits signals over separate frequencies to avoid interference. Owning more spectrum often means mobile operators can connect more people, offer faster speeds and provide more stable services.

Ofcom is responsible for allocating spectrum to different mobile operators. To do so it often uses spectrum auctions (also called spectrum awards) to grant licences to transmit radio waves over defined frequency bands.[92] Mobile operators bid to be allocated certain portions of spectrum and the money raised goes to HM Treasury.

There are calls for to Ofcom to take a more flexible approach to spectrum licencing for 5G spectrum in addition to auctions to allow more users in addition to MNOs to access spectrum. This is referred to as spectrum sharing or spectrum efficiency (see Section 3.4 of this paper).

[92] The *Wireless Telegraphy Act 1998* (as amended) enabled the use of auctions to grant spectrum licences, where appropriate.

3.1 Spectrum for 5G: an overview

5G will require access to different spectrum bands with different characteristics (see Box 6) to support the diverse uses, technologies and applications enabled by 5G.

Ofcom is preparing to make more spectrum available for 5G in the UK. It is also working with other European regulators and international spectrum bodies to identify bands that have the potential to be harmonised globally.

Ofcom and European Regulators have identified spectrum bands to enable 5G in Europe; they fall into three classes:[93]

5G will require access to different spectrum bands with different characteristics.

1 **Low frequency spectrum** to enable 4G and 5G mobile coverage to wide areas (the 700 MHz band).

2 **Mid-frequency spectrum**: spectrum with large bandwidths to provide capacity to support many users accessing large amounts of data with high speeds (the 3.4–3.8 GHz band).

3 **High frequency spectrum**: spectrum at very high frequencies (above 25 GHz) and with very large bandwidths, providing ultra-high capacity and very low latency. Spectrum in this region is also sometimes called millimetre wave ("mmWave") spectrum.

3.2 Low frequency spectrum (700 MHz band)

The 700 MHz band has been identified in Europe as the primary band for wide area 5G coverage in Europe. It can also be used for 4G coverage and is compatible with existing 4G handsets but is not currently licenced for mobile use. The release of the 700 MHz spectrum for mobile is a key part of Ofcom and the Government's proposals to improve rural mobile coverage generally. Ofcom has proposed coverage obligations to be included on some licences for the 700 MHz band, which is directed towards improving rural mobile coverage. For more information, see the Library briefing paper on Mobile Coverage in the UK.

The first 5G spectrum was awarded in 2018 (3.4–3.6 GHz).

The next spectrum auction will be held by Spring 2020 (700 MHz and 3.6-3.8 GHz bands).

Ofcom intends to auction spectrum in the 700 MHz band in the UK by Spring 2020 as part of a combined auction with spectrum in the 3.6–3.8 GHz band (see below).

3.3 Mid-frequency spectrum (3.4–3.8 GHz band)

The 3.4 to 3.8 GHz band has been identified as the primary 5G band across Europe.[94] This band can provide the large bandwidths necessary for new 5G mobile services. The first deployments of 5G mobile services are likely to use this band. It is likely to be used first in populated areas to increase network capacity using existing base stations.

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93 Ofcom, Update on 5G spectrum in the UK, 8 February 2017, [accessed 6 February 2019].

94 Ofcom, Enabling 5G in the UK, 9 March 2018, para 4.11.

In the UK, access to this band is being made available by Ofcom in two stages:

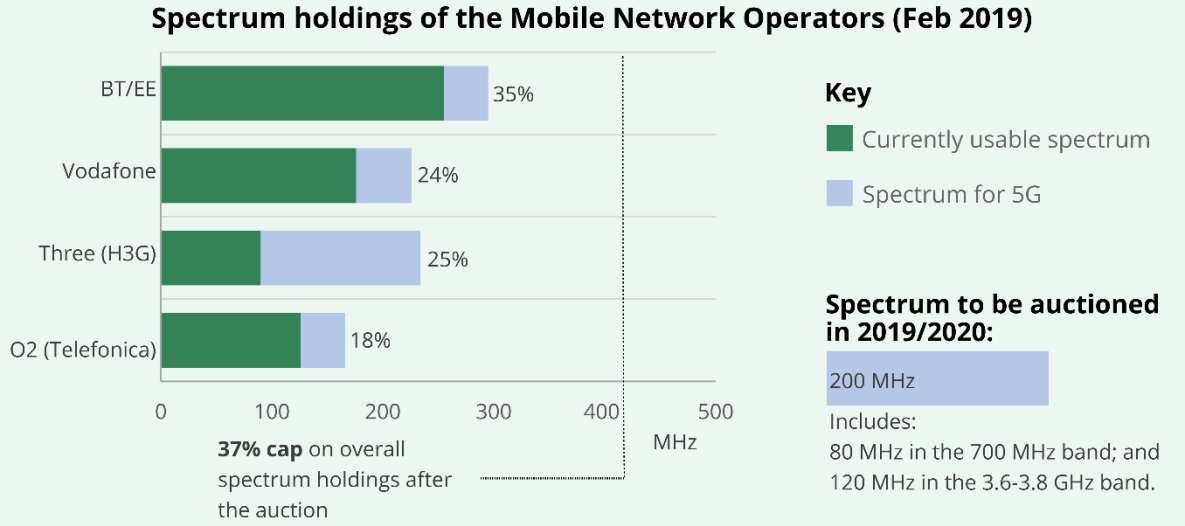
1 **The lower part of the band (3.4–3.6 GHz)** was auctioned in 2018. All four UK MNOs (BT/EE, Vodafone, O2 and Three) acquired spectrum in this band (see Box 7).[95] The Library briefing paper Spectrum Auctions 2018 provides background information about the auction.

The upper part of the band (3.6–3.8 GHz) will be auctioned with the 700 MHz spectrum; the auction is expected to be held by Spring 2020.[96] Ofcom is consulting on proposed auction rules until 19 March 2019. Ofcom has proposed to include a 37% cap on the spectrum shares that operators can hold after the auction (as it did for the 2018 auction).[97] This is intended to ensure that the mobile market remains competitive (see Box 7).

Box 7: Spectrum holdings by MNOs

The diagram below shows the spectrum shares held by each mobile operator for all mobile spectrum currently allocated, including spectrum suitable for 5G.[98] It also shows the spectrum to be auctioned in the 700 MHz and 3.6–3.8 GHz bands and the effect of the proposed 37% spectrum cap. Ofcom considers that asymmetry in the amount of spectrum held by mobile network operators could pose a risk to competition because providers with more spectrum are better placed to respond to increased consumer demand for mobile data than others; the cap is intended to address this concern.[99]

The effect of the spectrum cap is that BT/EE will be restricted to acquiring up to 120 MHz of the 200 MHz available, Vodafone up to 190 MHz, Three up to 185 MHz, with no restriction on the amount that O2 could acquire.[100]



Source: Ofcom, *Award of the 700 MHz and 3.6-3.8 GHz spectrum bands*, 18 December 2018.

95 Ofcom Results of principal stage of auction for mobile airwaves, 5 April 2018.
96 Ofcom, Consultation: Award of the 700 MHz and 3.6-3.8 GHz spectrum bands, 18 December 2018.
97 Ofcom, Consultation: Award of the 700 MHz and 3.6-3.8 GHz spectrum bands, 18 December 2018.
98 The currently useable spectrum includes the 800, 900, 1400, 1800, 2.1, 2.3 and 2.6 GHz bands. Spectrum for 5G includes the 3.4 GHz band (auctioned in 2018) and the 3.6–3.7 GHz band (in which Three already owns 84 MHz and is included in the total percentage calculation).
99 Ofcom, Ofcom sets rules for mobile spectrum auction, 11 July 2017.
100 Ofcom, Consultation: Award of the 700 MHz and 3.6-3.8 GHz spectrum bands, 18 December 2018. The 37% spectrum cap is set at 416 MHz (37.2%). Values are rounded due to the minimum lot size for the auction (5 MHz). See page 77.

3.4 Spectrum sharing for 5G

Spectrum sharing is when the same spectrum band is accessed by multiple users. There are several different approaches to spectrum sharing that could be taken (see Box 8).

Currently spectrum mobile is licenced by Ofcom to mobile network operators (MNOs) on an exclusive national licence. This model leaves the utilisation of that spectrum—a finite national resource—to the MNO. There have been calls for Ofcom to move to a more flexible approach to licensing for 5G spectrum to allow spectrum that is not being used by the major MNOs, for example in rural areas, to be used by other parties. This is also sometimes called spectrum efficiency, to ensure that spectrum is being used to its maximum capacity.

The National Infrastructure Commission in 2016 called for the Government and Ofcom to review the regulatory regime for spectrum management and consider how approaches to spectrum sharing could be utilised to maximise access to the radio spectrum for 5G.[101] It explained:

> 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.[102]

The Government identified spectrum efficiency as one of its strategic priorities for 5G in the FTIR and asked Ofcom to consider flexible licencing models as part of the release of 3.6-3.8 GHz spectrum. This forms part of the Government's 'market expansion model' for 5G (see Section 1.3 of this paper) to support smaller, new providers – which generally cannot acquire spectrum rights at national auctions due to the high price paid by MNOs. The Government has also asked Ofcom to include a 'use it or lose it' condition as part of the licence conditions for the 3.6–3.8 GHz auction (see Box 8),[103] and included an expectation that such provisions be used when granting spectrum rights in its draft Statement of Strategic Priorities to Ofcom.[104]

The Government supports spectrum sharing as part of its strategic priority to ensure efficient use of spectrum for 5G.

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101 National Infrastructure Commission, Connected Future, 14 December 2016, Recommendation 7.

102 National Infrastructure Commission, Connected Future, 14 December 2016, page 20.

103 Letter from James Heath, Director of Telecoms, DCMS to Katie Pettifer (Government and Parliament Director, Ofcom) dated 22 October 2018. The letter was published on Ofcom's webpage: Consultation: Award of the 700 MHz and 3.6-3.8 GHz spectrum bands, 18 December 2019 [accessed 8 February 2019].

104 DCMS, Statement of Strategic Priorities for telecommunications, the management of radio spectrum and postal services, 15 February 2019, para 38. Sections 2A-2C of the *Communications Act 2003* (as amended) contains powers, (introduced through the *Digital Economy Act 2017*) for the Government to make a Statement of Strategic Priorities (SSP) to which Ofcom must have regard when carrying out its functions. This will be the Government's first SSP to Ofcom.

The Institution of Engineering and Technology (IET) has formed an industry campaign group called "5G Further Faster" which has been calling for flexible spectrum licencing for the 3.6–3.8 GHz band; it is supported by a number of industry partners including Nominet, Google, TalkTalk and the Wireless Infrastructure Group.[105] Other industry stakeholders that have made similar calls include the UK Wireless Internet Service Providers Association (WISPA)[106] and the Independent Networks Co-operative Association (INCA).[107]

Advantages of spectrum sharing articulated by these stakeholders, the Government and Ofcom, include:[108]

- Improving rural mobile coverage by opening up opportunities for new entrants to access spectrum in specific locations not covered by the main MNOs;[109]
- Increasing spectrum available for rural broadband connectivity through fixed wireless technology. This could improve rural broadband in areas where fixed line broadband connections (e.g. full-fibre) are not commercially viable;[110]
- Providing opportunities for private networks to develop new use cases for 5G, for example industrial automation and robotics;[111]
- Speeding up the development and roll-out of 5G nationwide by increasing the number of companies and innovators able to participate and allowing new business models to be tested.[112]

Challenges for spectrum sharing models include protecting the existing rights of MNOs, protecting existing and future investment by MNOs in mobile networks, determining the value of spectrum that is shared, establishing commercial incentives for sharing, and technological challenges to protect against interference.[113]

Mobile network operators generally argue for exclusive national licences and wish to ensure access to wide bandwidths that are necessary to provide high quality 5G services.[114] The GSM Association (the global trade body for mobile operators) states that mobile operators typically

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105 Institute of Engineering and Technology (IET), 5G Further Faster, [accessed 8 February 2019].
106 UK WISPA, The UK's wireless spectrum management is no longer fit for purpose, [accessed 8 February 2019].
107 INCA, INCA calls for shared 5G spectrum following new report, [accessed 8 February 2019].
108 DCMS, Future Telecoms Infrastructure Review, 23 July 2018, para 219.
109 Ofcom, Consultation: Enabling opportunities for innovation, 18 December 2018, para 1.3.
110 Ofcom, Consultation: Enabling opportunities for innovation, 18 December 2018, para 1.3; Plum consulting (commissioned by WIPSA and INCA), High performance wireless broadband: an opportunity for rural and enterprise 5G, Ian Corden, Tony Lavender, Laura Wilkinson, 14 June 2016;
111 Ofcom, Consultation: Enabling opportunities for innovation, 18 December 2018, para 1.3; Plum consulting (commissioned by WIPSA and INCA), High performance wireless broadband: an opportunity for rural and enterprise 5G, Ian Corden, Tony Lavender, Laura Wilkinson, 14 June 2016.
112 Institute of Engineering and Technology (IET), 5G Further Faster White Paper (pdf), [accessed 8 February 2019]; Nominet, 5G Spectrum Sharing, September 2018.
113 Ofcom, Framework for Spectrum Sharing, 31 July 2015.
114 DCMS, Future Telecoms Infrastructure Review, 23 July 2018, para 222.

favour simple sharing frameworks that are investment-friendly and support reliable, high quality mobile services.[115]

Box 8: Spectrum sharing

Spectrum is shared when the same spectrum frequency band is accessed by multiple users and/or for different uses.[116] This might mean different users operating in different places, at different times and/or at different frequencies within one spectrum band. Spectrum sharing needs to be coordinated in some way to ensure avoid interference.

There are different potential models for coordinating spectrum sharing, for example:

- **Licensed Shared Access (LSA)**: a form of priority licensing where a MNO may have an exclusive national licence but secondary users can be granted licences for specific uses at a specific frequency, place and/or time where spectrum is not being used by the MNO.[117]
- **Light licensing** means coordinated use of spectrum by multiple parties such as through localised licences for geographic areas, but without a priority licence holder. Access could be controlled by a registration process and a database with access allocated, for example, on a first-come, first-served basis.[118]
- **Dynamic spectrum access (DSA)** uses a database to monitor where, when and how spectrum is being used and to predict interference. Unused spectrum can then be licensed to users on a dynamic basis reflecting changes in use over time. DSA could be used to coordinate either of the above two models. A dynamic spectrum access model is already used in the UK for TV White Space (unused TV spectrum).[119]
- Other examples of spectrum sharing include: *licence-exempt access* (a common example is spectrum used for Wi-Fi),[120] *voluntary commercial agreements* between parties (for example, wholesale spectrum leasing and spectrum trading) and *rural roaming agreements* (where an MNOs allows customers of another network to access ('roam') onto their network).

Other policy mechanisms available to enforce efficient spectrum use by MNOs include:

- **Coverage obligations**, which require MNOs to deliver coverage to a defined minimum geographic area as a condition of their spectrum licence. Coverage obligations are expected for the 700 MHz spectrum auction, see the Library briefing paper on Mobile Coverage in the UK.
- **'Use it or lose it'** requirements would require MNOs to make use of the spectrum allocated to them in a timely way or risk having it taken away. The new European Union Electronic Communications Code (EECC) includes a 'use it or lose it' principle.[121] The UK Government supports the new EECC and has stated that it intends to transpose it, including the 'use it or lose it' principle, into UK law "subject to the ongoing Brexit negotiations".[122]

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115 GMSA, Spectrum Sharing: public policy opinion, November 2018 [accessed 8 February 2019].
116 Ofcom, Framework for Spectrum Sharing, 31 July 2015.
117 European Commission Radio Spectrum Policy Group, RSPG Opinion on Licensed Shared Access, 12 November 2013.
118 DCMS, Future Telecoms Infrastructure Review, 23 July 2018, para 221.
119 Nominet, TV White Space Deployment, [accessed 13 February 2019].
120 Some spectrum is set aside by Ofcom on a licence-exempt basis, which means that users do not use a licence to use the spectrum but equipment must meet certain criteria and operate according to specified rules to avoid interference. Wi-Fi is a common example of wireless technology, using licence-exempt spectrum in 2.4 GHz, 5.8 GHz bands. Ofcom, Supporting the expanding role of wireless innovation in UK industry: a discussion paper, 1 February 2019, page 6.
121 Directive (EU) 2018/1972 of the European Parliament and of the Council of 11 December 2018 establishing the European Electronic Communications Code (Recast)Text with EEA relevance, Recital 122 and Article 47; European Council press release, Better connectivity: EU adopts telecoms reform, 4 December 2018 [accessed 8 February 2019].
122 DCMS, Future Telecoms Infrastructure Review, 23 July 2018, page 13; Letter

Ofcom's proposals for spectrum sharing

Ofcom has not proposed to set aside specific spectrum for sharing as part of the 3.6–3.8 GHz auction and proposes to award national licences as for previous auctions – detailed reasoning is given in Ofcom's consultation document published in December 2018 (and open for consultation until March 2019).[123] Ofcom also decided not to include a 'use it or lose it' clause in the licence conditions for the 3.6–3.8 GHz spectrum for the following reasons:

- Such conditions are very difficult to make workable in practice because of the problem of defining what constitutes 'use' and therefore what the trigger for an enforced trade or revocation would be;
- There may be entirely legitimate reasons for spectrum remaining unused – the licensee may be holding back until it sees a suitable commercial opportunity or until the technology it wishes to use is ready; and
- Imposing such an obligation also has the potential to distort and/or chill the incentives to invest in the spectrum, and so reduce the benefits for consumers and citizens which the award would otherwise create.[124]

Instead, in December 2018, Ofcom set out proposals for two models of spectrum sharing that it intends to pursue in 2019–2020.[125] Ofcom believes these proposals would provide the quickest route to allow new users to access spectrum.

1 Enable spectrum sharing in three "shared access bands":

Ofcom proposes to introduce managed spectrum sharing in three shared access bands: 3.8–4.2 GHz, 1800 MHz, and 2300 MHz bands. (This would be a form of light licencing – see Box 8 – although Ofcom does not use that term.)

Ofcom states that the 3.8–4.2 GHz band is included in 5G technology standards and could also be used for rural broadband services through fixed wireless technology; the 1800 and 2300 MHz bands are supported by 4G handsets.[126]

Ofcom proposes to manage the licencing process in all three shared access bands on a first come first served basis. Potential users would be able to make an application to Ofcom specifying the bands and locations in which they wish to operate. Ofcom would then assess interference with regards to other licensees. Ofcom indicated an

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123 Letter from James Heath, Director of Telecoms, DCMS to Katie Pettifer (Government and Parliament Director, Ofcom) dated 22 October 2018. The letter was published on Ofcom's webpage: Consultation: Award of the 700 MHz and 3.6-3.8 GHz spectrum bands, 18 December 2019 [accessed 8 February 2019].

124 Letter from Katie Pettifer (Government and Parliament Director, Ofcom) to James Heath (Director of Telecoms, DCMS), dated 13 December 2018; Ofcom, Consultation: Award of the 700 MHz and 3.6-3.8 GHz spectrum bands, 18 December 2019, para 10.19 [accessed 8 February 2019].

125 Ofcom, Enabling opportunities for innovation, 18 December 2018 [accessed 8 February 2019].

126 Ofcom, Enabling opportunities for innovation, 18 December 2018, pages 2-3 [accessed 8 February 2019].

intention "explore the potential" for Dynamic Spectrum Access (Box 8) in these bands in the future.[127]

2 ***Facilitate licenced access to spectrum already awarded to mobile operators***

Under this approach, new users wishing to access spectrum that is licenced to MNOs could apply to Ofcom for a local access licence to use specific frequencies at a particular location and Ofcom would engage with the MNO to facilitate access:

> Under this approach, a third party would apply to us for a local access licence to use specific frequencies at a particular location (this can be in any of the mobile bands licensed to MNOs as set out in the Mobile Trading Regulations).[128] We would engage with the relevant MNO(s). If they raise a reasonable objection, then the application would be declined. If they agree this does not adversely impact their planned use of the spectrum, then a local licence would be issued.[129]

(This would be a form of Licensed Shared Access – see Box 8 – although Ofcom does not use that term.)

Ofcom's proposals for spectrum sharing are open for consultation until 12 March 2019.[130]

3.5 High frequency spectrum: 26 GHz band

High frequency spectrum (above 25 GHz) offers high data capacity and low latency but with a limited coverage range. Frequencies in this region are sometimes referred to as **millimetre wave ("mmWave")** spectrum.[131] This high frequency spectrum is most likely to enable new 'revolutionary' use cases of 5G beyond mobile broadband.[132] It is likely be used in small, specific areas for services requiring high bandwidth.

The 26 GHz band is being prioritised across Europe as the first high frequency band for 5G.[133] Ofcom has stated that devices compatible with the 26 GHz band are likely to be available from early 2019.[134] Other high frequency spectrum bands that are being considered in

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127 Ofcom, Enabling opportunities for innovation, 18 December 2018, para 1.25 [accessed 8 February 2019]

128 This can be in any of the mobile bands licensed to MNOs as set out in the Mobile Trading Regulations; those bands are currently the 800 MHz, 900 MHz, 1400 MHz, 1800 MHz, 1900 MHz, 2100 MHz, 2.3 GHz, 2.6 GHz and 3.4 GHz bands.

129 Ofcom, Enabling opportunities for innovation, 18 December 2018, para 1.17.

130 Ofcom, Consultation: Award of the 700 MHz and 3.6-3.8 GHz spectrum bands, 18 December 2019.

131 Strictly speaking "mmWave" means waves with frequencies of 30–300GHz, which have wavelengths 1–10 millimetres (mm).

132 Ofcom, Enabling 5G in the UK, 9 March 2018, para 4.21.

133 The 26 GHz band ranges from 24.25–27.5 GHz. Ofcom, Enabling 5G in the UK, 9 March 2018, para 4.22. The European Electronic Communications Code (Directive (EU) 2018/1972, Article 54) contains a requirement that Member States allow the use of at least 1 GHz of spectrum in the 24.25–27.5 GHz band by 31 December 2020 "provided that there is clear evidence of market demand and of the absence of significant constraints for migration of existing users or band clearance".

134 Ofcom, Enabling 5G in the UK, 9 March 2018. para 4.27.

Europe for 5G include the 66-71 GHz band and the 40.5-43.5 GHz band.[135]

In July 2017, Ofcom launched a call for inputs to inform its work to make spectrum in the 26 GHz band available for 5G networks in the UK.[136] In March 2018, Ofcom explained that the responses to the consultation indicated that the band is likely to become important for 5G but many were of the view that it is too early to say how the band will be used, by whom and for what purposes.[137]

Ofcom grants innovation and trial licences in the 26 GHz band.

Ofcom provides short-term trial licences for spectrum in the 26 GHz band for research and development purposes. Ofcom launched an Innovation and Trial web-portal in March 2018 to provide guidance on obtaining trial licences. The aim is to promote the research, development and trialling of innovative uses of the spectrum.

In November 2018, Ofcom expanded access to spectrum in the 60 GHz band (57–71 GHz) on a licence-exempt basis.[138] This means that companies can use the spectrum without a licence (as long as the equipment meets specific conditions). The conditions are such that it could be used for 5G technology or for fixed-wireless access, which could be used for home broadband, for example.

135 Ofcom, Enabling 5G in the UK, 9 March 2018. para 4.22-4.23.
136 Ofcom, 5G spectrum access at 26 GHz and update on bands above 30 GHz, 28 July 2017.
137 Ofcom, Enabling 5G in the UK, 9 March 2018, para 4.26.
138 Ofcom, Making it easier to launch new wireless services and 5G technology and Statement: Decision to implement technical and regulatory changes to the 57 – 71 GHz band, 8 November 2018. [Accessed 14 February 2019]

4. Glossary

Backhaul: the link that connects a mobile site (either a mast, macro or small cell) to the core internet and phone network, usually by full-fibre broadband or a radio link.

Bandwidth: the term bandwidth is used differently in different contexts. In a spectrum context, bandwidth refers to the size of a band of spectrum, measured in Hertz (Hz). For example, a band of spectrum from 700–800 MHz has a bandwidth of 100 MHz. Bandwidth is also used to refer to broadband upload and download speeds (see below).

Base station: mobile network access points that send and receive mobile voice or data signals and connects them to the main network via a backhaul connection. Mobile masts, macro cells and small cells are all types of base stations.

Broadband upload/download speed: the amount of data that can be downloaded or uploaded per second on a broadband connection, usually in megabits per second (Mbps). This is also called the bandwidth of a connection. Most internet connections have higher bandwidth for downloading (data going from the internet a device) than for uploading (data going from a device, to the internet).

> *Difference between bandwidth and latency*: both bandwidth and latency (see below) affect the broadband 'speed' experienced by a user. Bandwidth refers to how fast a website is able load and latency is the time it takes to start the download process. A common analogy is a highway – bandwidth is like the number of lanes on the highway, and latency is like the speed the cars are travelling.

Full-Fibre: a fixed-line broadband technology where fibre optic cables run from the exchange directly to the premises. It is also called Fibre-to-the-Premises (FTTP) or Fibre-to-the-Home (FTTH). See the Library paper on Full-fibre networks in the UK (CBP 8293) for more information.

Hertz (Hz): a unit of measurement for frequency, one hertz means one wave cycle per second. Megaherts (MHz) = 1 million Hz; 1 Gigahertz (GHz) = 1000 MHz.

Latency: is the delay time for a communications signal. It is the amount of time it takes for a packet of data to travel from a device, to a third-party server and back to the device. In practical terms it is the time it takes from clicking something to when you see a response, such as a website beginning to load. Low latency (i.e. fast signal response times) is important for applications that require real-time response, for example, live-streaming, gaming, video calls, virtual reality applications and driverless vehicles.

Macro cell: a mobile base station that provides wide-area coverage, usually mounted on ground-based masts or on rooftops.

Megabits (Mb) and megabytes (MB): units for expressing a quantity or amount of data. 8 megabits (Mb) is equal to 1 megabyte (MB); 8

gigabits is equal to 1 gigabyte (GB). Broadband speeds are usually expressed in megabits uploaded/downloaded per second (see above).

Mobile Network Operator (MNO): a provider of wireless communications services that owns or controls all the elements necessary to sell and deliver services to an end user, including spectrum allocation, infrastructure, and customer services. There are four MNOs in the UK: EE (owned by BT), Vodafone, O2 (owned by Telefonica) and Three (owned by Hutchinson 3G). Contact details and spectrum allocations for each of the MNOs are provided on Ofcom's webpage: Mobile and Wireless Broadband below 5 GHz.

Mobile Virtual Network Operator (MVNO): a mobile service provider that does not own the infrastructure which is uses to deliver services. MVNOs have agreements with the MNOs to deliver services using the MNOs infrastructure.

Mobile broadband, WiFi and fixed-wireless are all ways of connecting wirelessly to the internet. They use different spectrum frequencies, different signalling and receiver technology and infrastructure, are suited to different purposes/uses and are operated by different providers.

> **Mobile broadband:** usually means internet access provided wirelessly through a mobile network operated by a Mobile Network Operator (MNO). Mobile base stations are arranged in a 'cellular' format so that a user can move between different base stations and remain connected to a single network.
>
> **Wi-Fi**: short-range wireless broadband usually used in home or localised settings. A Wi-Fi router converts a fixed/wired broadband connection into a wireless signal so that Wi-Fi enabled devices (laptops, tablets, mobiles) can connect to. Wi-Fi uses specific licence-exempt spectrum bands.
>
> **Fixed wireless broadband:** wireless broadband networks can be used as a solution for rural broadband in areas where cables are difficult to build. There are a variety of different technologies available for delivering fixed wireless access, including mobile broadband technology.[139] Fixed wireless networks are usually operated in a localised area by a specific provider. Fixed wireless networks for rural broadband is one potential application of 5G technology.

mmWave: radio waves with frequencies between 30–300 GHz. In a 5G context, this term is often used to refer generically to the very high frequency bands discussed for 5G (above 25 GHz in Europe).

Small cell: low-powered mobile base stations that provide coverage to a small localised area.

Radio frequency spectrum: electromagnetic waves in the frequency range 3 Hz to 300 GHz over which wireless communication systems are delivered.

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[139] Ofcom, Mobile and wireless broadband, accessed 20 February 2019.

Spectrum sharing or spectrum efficiency: refers to having more than one user in the same frequency band. See Box 8.

TV White Space: unused spectrum in frequencies ranges used for TV e.g. gaps left between TV channels. There is technology available that can deliver home broadband networks using TV White Space.[140]

[140] Nominet, TV White Space Deployment, [accessed 13 February 2019].

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