making communications work
for everyone

Spectrum Roadmap

Delivering Ofcom's Spectrum Management Strategy

Welsh version available

Discussion document

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Contents

1. Summary

The radio spectrum (the invisible waves that enable wireless technology) is a finite resource crucial to delivering a wide range of wireless applications benefiting different users, and Ofcom has the job of ensuring it is used in the best interests of all in the UK. This approach sits at the heart of Ofcom's mission to make communications work for everyone.

Wireless communication is playing an increasingly significant role across many sectors of the economy, delivering our news, connecting us to friends and family, automating factories, supporting public services and monitoring the natural environment.

Technological developments are enabling new and innovative applications and business models, meaning more people and organisations are making use of wireless technology. In the face of this growing and, in many cases, competing demand for spectrum, Ofcom set out a new **Spectrum Management Strategy** in July 2021.

In this **Spectrum Roadmap** we outline the work we are planning to deliver on this strategy, both through our current projects (as outlined in the Plan of Work 2022/23) and proposed future areas of work. Our proposed future areas of work sit under three broad themes:

Network evolution and convergence

We will review the long term impact of technology and network convergence on spectrum use, in light of the roll-out of full fibre across the UK, the development of 6G and Wi-Fi, and the growth in the number and capabilities of satellite networks, to ensure continued efficient use of the spectrum for existing and new uses.

Accelerating innovation and sharing with spectrum sandboxes

We will explore the use of spectrum 'sandboxes' in specific geographic locations and specific bands, to enable industry to collaboratively experiment with new ways to enable greater spectrum sharing, working directly with stakeholders to accelerate the process of specifying and agreeing coexistence and sharing conditions

Better data for better spectrum management

We will look to obtain more real world data in a variety of ways and leverage this to support more efficient use of the spectrum, laying the foundation for greater spectrum sharing in the future

These activities will provide the data, market insight and operational capabilities we will need to prepare us for the coming decade and inform future policy. We do not expect the full benefits to be seen straight away – but they will provide an important foundation on which we can build in future years.

We will continue to review and update the work areas identified in this roadmap in light of progress and market and technology developments.

About this document

This document first outlines the wider context of **spectrum use in the UK**, including what the radio spectrum is, how Ofcom manages it and how it is used in the UK today. We then provide an overview of our **current spectrum projects and the spectrum bands under review,** including showing how this work aligns with our spectrum management strategy.

Demand for spectrum is continuously evolving, technological developments are opening up opportunities to better utilise this finite resource, and wider market developments may affect the use of wireless technologies. We set out some of the key **market and technological trends** that Ofcom will need to consider in planning our future work. We also outline the challenges and opportunities these may present for our spectrum management work.

Finally, in light of these challenges and opportunities, and leveraging innovation in spectrum use, we have considered **future work areas** which will be important in building on our current work and in delivering our spectrum management strategy.

As we go about delivering our strategy to maximise the value of spectrum to the UK, we will work collaboratively with the Government, including having regard to their work to deliver a Wireless Infrastructure Strategy for the UK.

We welcome feedback from stakeholders and interested parties on this Roadmap. Our current projects are already underway and will be the subject of separate consultation processes. We are therefore interested in receiving comments on:

- Our future work areas, including views on which are most important (the highest priority) and whether there are other areas which we have not mentioned but which stakeholders think are important.
- Whether there are additional spectrum bands that we have not covered in this roadmap but which stakeholders consider will be important over the next 5 years.

If you would like to provide feedback on the Roadmap please do so by 20 May. You can contact the team at spectrum.roadmap@ofcom.org.uk.

Spectrum roadmap summary

Key:

- Continued improvements in the wireless communications used by everyone
- Access for businesses, public sector and other organisations with specialised requirements
- Increased flexibility to support innovation, with assurances for continued use
- Sustained improvements in the efficiency of spectrum use

Ofcom '22/'23 Plan of Work *(Current projects)*				
Mobile Spectrum Demand	✓			✓
Future use of the 1.4GHz band for wireless broadband	✓			✓
Opening access to mmWave for mobile	✓	✓		✓
Space spectrum strategy	✓	✓		✓
Increasing access to the 14GHz band	✓	✓		✓
Preparation for WRC23	✓	✓		✓
Planning small scale DAB radio	✓			
Increasing spectrum access for Restricted Service Licences	✓			
Spectrum for Utilities		✓		✓
Understanding industry demand for spectrum		✓		✓
Enabling growing demand for the use of drones		✓	✓	✓
Local indoor access in the upper 6GHz band		✓	✓	✓
Terahertz	✓		✓	✓
Improving propagation models				✓
Noise floor measurements				✓
Database approach to spectrum management			✓	✓
Future use of unpaired 2100MHz spectrum				✓
Annual licence fees				✓
Delivering a single online licensing platform				✓

Future proposed programme of work				
Network Evolution and Convergence				
Monitoring and influencing the development of next generation network technologies	✓	✓	✓	✓
Assessing the implications of new technologies on how we manage spectrum use		✓	✓	✓
Review potential for migration from 'dedicated' to 'general purpose' networks		✓		✓
Impact of fibre roll-out on use of wireless fixed links		✓		✓
Developing a cross sectoral understanding of evolving spectrum demand at 6GHz	✓	✓	✓	✓
Accelerating innovation and sharing with spectrum sandboxes				
Spectrum sandboxes: working with industry to test new spectrum sharing scenarios			✓	✓
Better data for better spectrum management				
Measuring utilisation of selected bands			✓	✓
Using real world data to improve propagation models				✓
Using real world data to improve spectrum assurance				✓
Improve our understanding of active antenna systems				✓
Improving receiver resilience				✓

2. Spectrum use in the UK

2.1 The radio spectrum is an important resource and needs to be carefully managed to ensure that it can continue to deliver the services we need – benefiting individuals, industries, scientific research, public services and defence. This is Ofcom's role - we manage the UK's radio spectrum for the benefit of everyone in the UK.

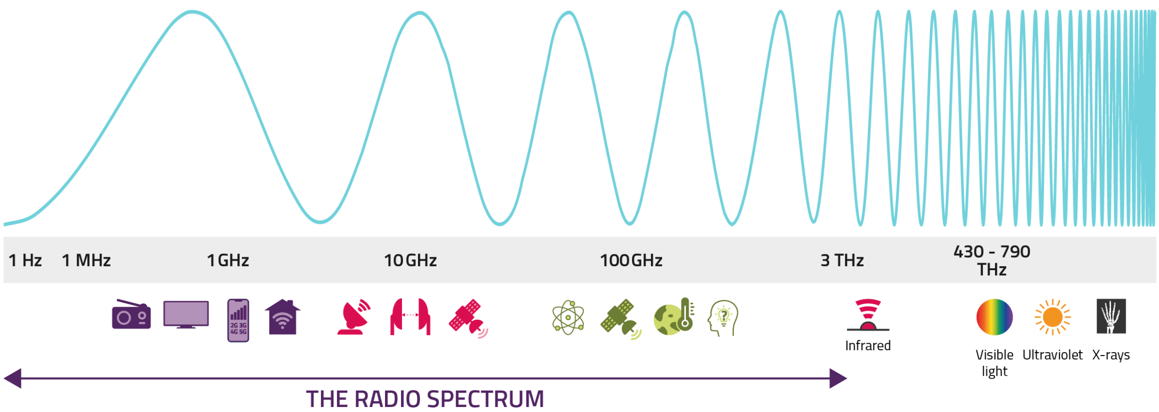
2.2 Before we set out our current and forward-looking programme of spectrum management work to deliver our vision, we provide an overview of the radio spectrum: what it is, how it is used, and the work Ofcom has been doing to ensure its efficient use.

2.3 The decisions Ofcom makes in managing spectrum impact everyone in the UK. It's therefore important that everyone who wishes to, has the opportunity to understand and engage with the work we do, irrespective of their current understanding of spectrum and our role in managing it. **To ensure we are as inclusive as possible, and as this is our first Spectrum Roadmap, this section has been written for the reader who is less familiar with radio spectrum and how we manage it.** It introduces some of the basic concepts of spectrum use and management as well as some statistics on access to spectrum for different users/uses.

What is radio spectrum?

2.4 Radio spectrum, also known as radio waves, forms the lower part of the wider electromagnetic spectrum, just below infrared and visible light.

Figure 1: The electromagnetic spectrum



2.5 The ability of radio waves to travel through the air, space and solid materials means that they can be used for radiocommunication. Using these waves is how television is broadcast into your home, or how you can have a conversation with a distant friend using mobile phones. But there are many more uses for these waves.

2.6 At the most basic level, a radiocommunications system involves a transmitter taking information (typically data) and converting it into a radio signal at a particular frequency, and a receiver taking the radio signal and extracting the information. However, sometimes this communication between transmitter and receiver can be disrupted by interference, such as signals from other transmitters, degrading or in some cases, preventing communications altogether.

2.7 For this reason, radio spectrum cannot be used in an uncontrolled way. To prevent interference between users, the transmission of radio waves is regulated by national laws, some of which is codified as a result of international coordination via the International Telecommunications Union (ITU) and the European Conference of Postal and Telecommunications Administrations (CEPT). International coordination is important because radio waves, particularly at low frequencies, can travel over international borders and may cause interference in other countries. Ofcom is responsible for authorising and managing use of radio spectrum in the UK and represents the UK in international forums.

2.8 The radio spectrum is a finite resource – we cannot 'make' new frequencies. Demand for access to the spectrum has continually grown and will continue to grow in the future. As a result, we and industry need to find ways to squeeze more users in without causing harmful interference. Although we cannot create new spectrum, new technologies can enable it to be used more effectively, so it can serve more users and uses, and help transform the way we live and work.

How is spectrum used in the UK?

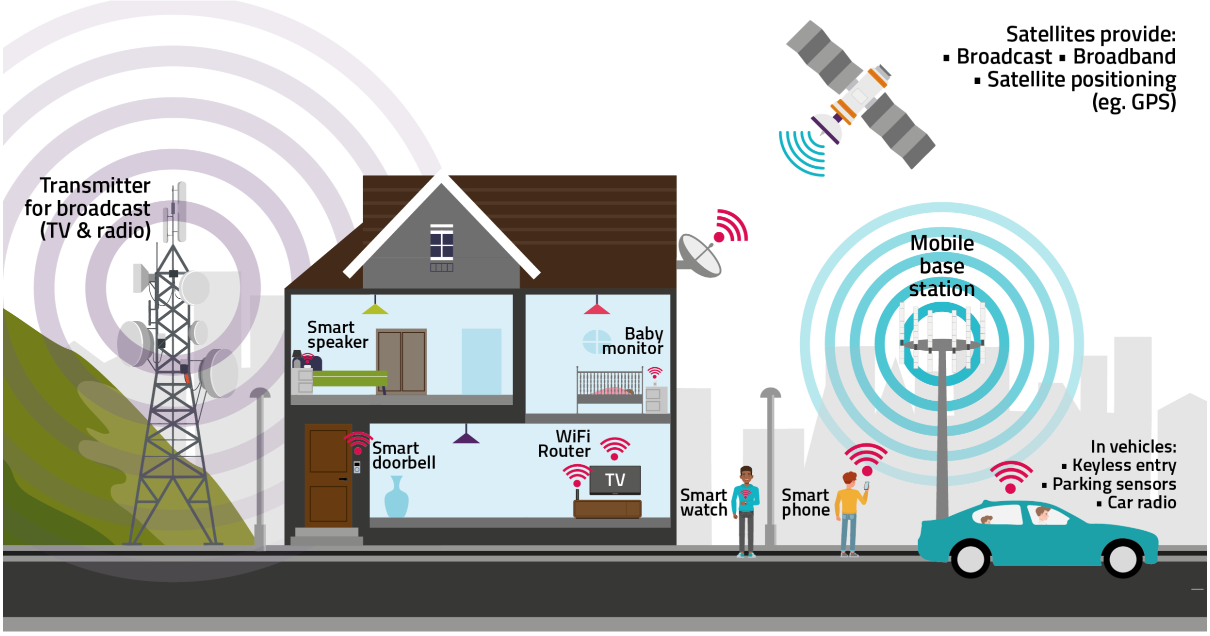
2.9 Everyone in the UK – people, businesses and public organisations – uses or relies on a range of wireless services and technologies on a daily basis.

2.10 Some of the most prevalent consumer uses of spectrum include:

- Browsing the internet at home or on the go using a **mobile** network and/or a **Wi-Fi** connection.
- Making a mobile phone call or sending a text message using a **mobile** network.
- Watching **television** or listening to the **radio**, via an aerial or satellite dish.
- Using a **Bluetooth** connection to connect a wide range of personal and home devices.
- Accessing navigation services on a smartphone or in-car SatNav using a **GPS**[1] signal provided by satellite.
- **Satellite & Wireless broadband** for homes that are not connected to a reliable fixed network, for example those in remote areas.

[1] Global Positioning System

Figure 2: Examples of spectrum uses



2.11 In addition to consumer uses, many businesses and organisations make specialised use of spectrum to help them effectively manage their business and provide services. Some of the main commercial uses of spectrum include:

- Ships use a wide range of **maritime radio** equipment for general communications, for navigation, to keep track of other vessels and to ensure the safety of people on board.
- A typical commercial aircraft may have over twenty **aeronautical radio** systems on board for communication, navigation and surveillance functions.
- **Business radio** users range from taxi companies and factories, to hospitals, care homes, industrial sites, utilities networks and transport operators.
- Radio astronomy and other **space science** activities contribute to our knowledge of the universe. For example, earth observation satellites collect data about the earth and its atmosphere that is used for weather forecasting, environmental monitoring, climate change research and many other applications.
- Broadcasters and event organisers use **programme making and special events (PMSE)** equipment (such as wireless microphones, wireless cameras, in-ear monitors) for news gathering, sports events, live concerts, films, theatre, religious and educational activities.
- Mobile operators, broadcasters and others use **fixed links** (also known as microwave links) to send large amounts of data wirelessly between two or more points, such as connecting a mobile base station to the core network.

2.12 Spectrum is also significantly used by the **public sector**, with the majority of this spectrum being available for defence use.

How spectrum is accessed and authorised in the UK

2.13 In the remainder of this section we discuss spectrum access by different sectors, the different ways Ofcom authorises its use, and how this process has evolved over time. We summarise the recent work Ofcom has been doing to drive more efficient and effective use of the spectrum in line with our strategic vision, by supporting innovation, introducing local licensing where appropriate and promoting spectrum sharing.

2.14 Our analysis focuses on the spectrum up to 275 GHz and is based on information from our spectrum map. Whilst Ofcom is responsible for managing radio spectrum up to 3 THz, international spectrum allocations are currently only defined up to 275 GHz.

2.15 To provide a structure for this discussion, and to better explore developments across different spectrum bands and ranges, we have divided the radio spectrum into four blocks or sub ranges and describe the main uses of each block and the changes to spectrum access we have made in the last two to three years:

- Below 1 GHz
- 1-10 GHz
- 10-100 GHz
- 100-275 GHz

2.16 Our analysis of the different spectrum blocks focuses on the sectors that have seen the greatest changes over recent years and where we have introduced new authorisation approaches to enable innovative and efficient use of the spectrum.

2.17 We then provide a summary view of the spectrum by sector up to 100 GHz.

2.18 Readers will note that the sum of all sectors' access, across all ranges analysed, adds up to much more than 100%. This is due to the high levels of **spectrum sharing** between sectors. For the analysis presented within this section we have considered spectrum as shared when the same band is accessed by *more than one sector*. However, in many cases users within the same sector are also sharing spectrum, for example thousands of Business Radio licensees operating in the same band.

2.19 Spectrum can be shared by separating users in one or more of:

i) frequency - different users accessing different channels within the same band;

ii) geography - different users accessing the same channel but in different areas; or

iii) time - different users accessing the same channel in the same area but at different times to other users.

2.20 An example of sharing using the time dimension (and without direct coordination) is 'listen before talk', where a device 'listens' for transmissions and only transmits if it won't cause interference. Wi-Fi is an example of a technology that uses 'listen before talk' protocols to manage sharing between devices.

2.21 We can also use a database approach, where a device queries a database which stores information on the location of certain (typically 'higher tier') users and whether they are transmitting. Where and/or when these users aren't transmitting, the device can access the spectrum.

2.22 Alternatively, in some cases we authorise multiple users to share channels in the same area where the probability that users will want to access the channel simultaneously is acceptably low. For example, Ofcom's Business Radio Technically Assigned licences offer 'shared assignments' which operate on this basis.

Ofcom's toolbox of spectrum authorisation approaches

Ofcom authorises access to spectrum using two main approaches – licensing and licence exemption:

Licence exemption: Ofcom is required to exempt radio equipment if its installation or use is not likely to result in undue interference to other radio equipment.[2] Under this approach, a user does not need a licence as long as their device complies with specified technical parameters. This approach tends to be used for low power equipment where the risk of interference from uncoordinated use is low. Most mass-market consumer devices are licence exempt.

Where we license spectrum use, access is provided through the following licence types:

Technically Assigned: For this licence type, we coordinate the individual assignment of frequencies within the band. This authorisation approach is appropriate where different users are applying to use the same spectrum, where a high quality of service (QOS) is desired and where the absence of coordination between licensed users may result in harmful interference.

Light licensed and self-coordinated: Light licences generally require no specific assignment or co-ordination by Ofcom and are available on request. This authorisation approach is appropriate where there is limited risk of interference between different users or where a high quality of service (QoS) is not essential, but still allows Ofcom to manage any problems arising from high densities of devices interfering with each other.

Block Assigned: We issue a licence that provides access to a block of spectrum within a given geographic area and licensees can manage their own deployments within the block. The geographic area could be nationwide (as in the case of existing mobile licences), but can also be regional (such as in the 28GHz band). Block assigned licences have generally been awarded by auction to help ensure efficient use of the spectrum. While there are conditions that users must meet to avoid causing interference to others, block assigned licences give users a higher degree of flexibility over how they use the spectrum.

[2] Section 8(4) and (5) of the Wireless Telegraphy Act 2006 set out the full list of conditions that, if satisfied, would lead to Ofcom exempting equipment from the need for a licence.

Below 1 GHz

Figure 3: Spectrum access by sector below 1 GHz (excludes sectors with access to less than 1% of spectrum, figures rounded to nearest 1%)

Aeronautical	Amateur	Broadcasting	Business radio	Licence exempt	Maritime	Mobile	PMSE	Public sector	Space science
9%	2%	26%	12%	31%	5%	21%	30%	40%	3%

2.23 The spectrum below 1 GHz supports a great variety of services, from TV, radio and mobile to maritime and aeronautical uses. The figure above shows the proportion of spectrum available to different sectors in the 0-1 GHz range.

2.24 Terrestrial **broadcasting** includes TV and Radio. Broadcast radio (AM, FM and DAB) has access to 41 MHz of spectrum below 1 GHz and terrestrial television has access to 216 MHz. This is both for historical reasons (as an early user of radio spectrum) and because its transmissions need to cover wide areas in order to reach almost everyone in the UK

2.25 **Mobile phone networks** also use frequencies below 1 GHz and have done since the earliest 2G networks.

2.26 The growth in mobile data use, accelerated in recent years by the advent of smartphones, has driven demand for radio spectrum. In response to this growing demand, Ofcom has twice replanned broadcast frequencies to enable mobile data growth. First, we cleared the 800MHz band (as part of the move from analogue to digital TV) and awarded this to mobile networks in 2013 to enable the deployment of 4G. More recently, we cleared and awarded the 700MHz band which has paved the way for 5G roll out in more rural areas. Between them, the mobile network operators now have access to 209.6 MHz of the spectrum below 1 GHz.

700MHz band clearance and award

Ofcom awarded 80 MHz of spectrum in the 700MHz band in March 2021 through an auction. This award marked the culmination of an eight year programme of work to move terrestrial TV and other existing uses out of the band and replan them in other frequencies. The spectrum was acquired by the mobile operators EE, Three and O2 to meet the growing demand for mobile data.

2.27 The **programme making and special events (PMSE)** sector is also a significant user of spectrum below 1 GHz. Although PMSE has access to around a third of the spectrum, the majority of this is shared with other services. For example, low power PMSE applications such as wireless microphones and in ear monitors can use TV broadcasting spectrum in areas where it is not being used for TV so does not cause interference to TV reception.

2.28 The spectrum in the gaps between broadcast transmitters has also been used by some network operators for delivering wireless broadband in rural areas.

2.29 **Business radio (BR),** which provides voice and low speed data services, is another long-time user of this spectrum and there are over 20,000 licensed users across the UK. In the past, users could enjoy near exclusive access to their Ofcom assigned channel(s) but, as the number of users increased, greater sharing of channels was required. In 2017, Ofcom increased the sharing factor from two to three which allowed more users to get access to spectrum.

2.30 **Amateur radio**, sometimes known as ham radio, is a hobby that enables participants to experiment with and learn about radio and to communicate with other radio amateurs around the world. Amateur users have access to a wide range of spectrum from the very lowest to the very highest frequencies. However, the most popular amateur bands are in the below 1 GHz range.

1 – 10 GHz

Figure 4: Spectrum access by sector between 1 – 10 GHz (figures rounded to nearest 1%)

Aeronautical	Amateur	Fixed links	Licence exempt	Maritime	Mobile	PMSE	Public sector	Satellite	Space science	Wireless broadband
19%	5%	25%	47%	9%	10%	12%	81%	26%	48%	7%

2.31 With advances in radio and antenna technology and increasing demand, this spectrum range is being used by a large number of sectors. While signals in frequencies above 1 GHz do not generally travel as far as in lower frequencies, the larger bandwidth (and larger channel sizes) available means that more information or data can be carried in these frequencies.

2.32 Figure 4 shows the proportion of spectrum accessed by each sector in the 1-10 GHz range.

2.33 **Fixed links**, also known as microwave links, have for many years accessed this range, often providing 'backhaul' connectivity from mobile phone masts back to the core networks and offering different types of data links to a wide range of companies. Over time and as technologies have improved, fixed links have used ever higher frequencies within this block to take advantage of wider channel bandwidths for delivering higher data rates. Fixed links now have access to around one quarter of the spectrum between 1 and 10 GHz and there are currently c.2800 licensed fixed links in this spectrum block.

2.34 **Satellite** uses in the 1-10 GHz range include satellite broadband, global positioning services (GPS) and communications in emergency situations, e.g. for maritime and aeronautical emergency comms. Typically, satellite communications systems comprise of satellite earth stations on the ground communicating with satellites orbiting the Earth in space. Earth stations vary in size from the small dishes installed on houses to dishes tens of metres in diameter. The frequencies and orbital positions for satellites are coordinated internationally, while the earth station frequencies are authorised by Ofcom. As with other uses, satellite spectrum use has shifted up in frequency over time.

2.35 Fixed links and satellite earth stations often share spectrum; of 2 GHz of spectrum available for fixed links use in the 1-10 GHz range, over two thirds is shared with satellite.

2.36 The massive growth in demand for mobile data, and the technology developments underpinning new generations of mobile technology, have led to an increasing demand for spectrum for **mobile phone networks** in the 1-10 GHz range. The 3G auction in 2001 saw mobile phones gain access to the 2100MHz band. Further awards of spectrum between 1-10 GHz have followed (2.6GHz, 2.3GHz, 3.4-3.6GHz), with the most recent award of 3.6-3.8GHz being completed last year. Mobile operators also have access to 40 MHz of spectrum at 1.4GHz and 143.2 MHz at 1.8GHz.

2.37 1152 MHz of spectrum is currently accessed by the four Mobile Networks Operators (MNOs) across all bands – of this, 390 MHz has been awarded since 2018. The majority of this increase was in bands above 1 GHz (see box below). Spectrum has been awarded to mobile network operators on a nationwide basis – giving them the flexibility to build masts without having to coordinate each one with Ofcom.

Awards of 2.3, 3.4-3.6 and 3.6-3.8GHz spectrum to mobile operators

Ofcom awarded 190 MHz of spectrum in the 2.3 and 3.4-3.6GHz bands to mobile operators in April 2018 following a spectrum auction.

A further 120 MHz of spectrum in the 3.6-3.8GHz band was awarded to mobile operators in our March 2021 auction (which also awarded 80 MHz in the 700MHz band). This was made possible by clearing the band of fixed links and satellite uses.

Details of all the spectrum bands awarded to the national mobile network operators are available on our website.

2.38 As mobile technology has evolved, there has been growing interest in the use of mobile technology for wireless applications beyond consumer mobile broadband, such as provision of local private networks for manufacturing, enterprise, logistics, mining and agriculture. In recent years Ofcom has looked to make spectrum available to enable these emerging uses and support wireless innovation – this spectrum is captured under our **wireless broadband**[3] category in this document.

[3] The Wireless Broadband category includes a number of bands which are licensed on a technology neutral basis. The category includes the spectrum accessible through our Shared Access and EHF licences, as well as various block assigned bands at 10, 28, 32 and 40GHz . All the bands in this category can be seen on our spectrum map.

Enabling wireless innovation through local licensing

In July 2019, Ofcom opened up spectrum bands for local licensing. Our objective was to support innovation by enabling more people to access spectrum in a choice of bands that support mobile technology. This included:

Introducing ***Shared Access licences*** in the 3.8-4.2GHz band and the 1800MHz & 2300MHz shared spectrum bands, a total of over 400 MHz in the 1-10 GHz range and a further 2.25 GHz in the lower 26GHz band (for indoor use only). These bands typically sit adjacent to bands used by the national mobile networks and so benefit from equipment ecosystems.

Introducing ***Local Access licences*** in existing mobile spectrum bands, available in geographic areas where mobile operators have not yet utilised it and have no immediate plans to do so.

Ofcom authorises the Shared Access licences on a first come, first served basis; we liaise with MNOs to provide access to licensed mobile spectrum in areas where the mobile licensees have not deployed/aren't using a band through a Local Access licence.

2.39 Another significant user of spectrum in the 1-10 GHz range is **Wi-Fi**,[4] which is mainly authorised to operate on a **licence exempt** basis. Wi-Fi was designed from the outset to fit around, and share with, existing users of spectrum. Multiple Wi-Fi devices (as well as similar devices such as Bluetooth) can operate on the same radio channel by employing "listen before talk" polite protocols.

2.40 The first Wi-Fi devices in the UK used 83.5 MHz of spectrum in the 2.4GHz band and later 605 MHz in the 5GHz band. As the penetration of devices and the quantity of traffic per device has increased, the spectrum used by Wi-Fi devices has become more congested and, as fixed broadband speeds have increased, limited spectrum bandwidth can be a speed bottleneck for users. In response to this growing demand, in 2020 we made 500 MHz of additional spectrum available for Wi-Fi and other RLAN devices that meet the necessary technical conditions. This means that Wi-Fi now has access to 1.2 GHz of spectrum in the 1-10 GHz frequency range.

Opening spectrum for Wi-Fi in the lower 6GHz band

In July 2020, Ofcom made an additional 500 MHz (5925-6425 MHz) of spectrum available to Wi-Fi (and other RLAN technologies) and removed some technical constraints on spectrum in the 5GHz band to help reduce congestion. Wi-Fi devices now have access to 1189 MHz of spectrum in the 1-10 GHz range.

[4] Wi-Fi is an industry interoperability standard for RLANs (radio local access networks). It represents by far the most common type of RLAN equipment available on the marketplace today and is widely used by consumers and industry. In this section, for simplicity, we use "Wi-Fi" to refer to all RLAN technologies.

2.41 Overall, 4.2 GHz of spectrum is available for licence exempt use in the 1-10 GHz range. This includes a variety of mass market uses (such as Wi-Fi) and many industrial/niche applications. Some examples of licence exempt uses include baby monitors, social alarms for vulnerable people, assisted listening devices (ALDs) and Bluetooth devices. In commercial or industrial settings, licence exempt users include Radio Frequency Identification (RFID), which can be used to track and identify assets or goods during manufacture, and radar sensors used in vehicles and industrial processes.

2.42 7.3 GHz of spectrum in the 1-10 GHz range is available for use by the **public sector**. This spectrum is used by government departments and other public bodies to deliver a wide range of public services. However, the large majority of this spectrum is already shared with other uses.

2.43 Ofcom has worked with Government to encourage efficient use of spectrum by the public sector, including more sharing with other users. In a similar way to the work done to replan the TV bands to allow access to mobile, public sector uses have been moved and replanned to make additional spectrum available for other services. This includes the upper 2.3GHz and 3.4GHz bands, which have been awarded for mobile. We have also opened up part of the 8GHz band for fixed services, made additional spectrum available for shared use at 2390 MHz and made the 5.8GHz band available for low power licence exempt use.

2.44 **Space Science** has access to a significant amount of spectrum in the 1-10 GHz frequency range – almost half. However, almost all (99%) of the spectrum that Space Science has access to is shared with other services. Space science includes several types of use which help us understand our planet and contribute to our knowledge of the universe. Earth observation satellites collect data for a range of purposes including weather forecasting, environmental monitoring and climate change research. Radio telescopes and radars (located on the earth or in space) are used to monitor naturally occurring radio emissions from celestial bodies and outer space, or study objects in space. Spectrum in this frequency range is also allocated for communication concerned with the operation of spacecraft, including space tracking and telemetry, as well as for the collection and distribution of meteorological data.

2.45 Some space science use does not involve transmitting, but only receiving natural signals. A licence is not required for receive-only radio equipment but a grant of 'Recognised Spectrum Access' (RSA) gives formal recognition to this equipment, enabling Ofcom to take account of it on a comparable basis to licensed use.

10 – 100 GHz

Figure 5: Spectrum access by sector between 10 – 100 GHz (figures rounded to nearest 1%)

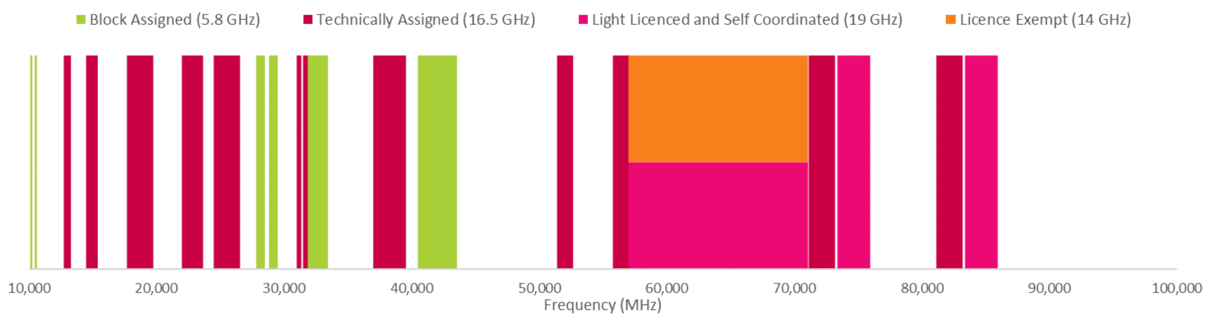
Aeronautical	Amateur	Fixed links	Licence exempt	PMSE	Public sector	Satellite	Space science	Wireless broadband
1%	7%	26%	35%	1%	37%	10%	62%	24%

2.46 Frequencies above 10 GHz are attractive as they allow larger channel bandwidths to be used to meet the demand for very high data rates. New antenna technologies, such as massive MIMO and improvements in radio signal amplifiers are helping to overcome some of the coverage challenges and allow these frequencies to be used for new applications.

2.47 As noted earlier, network operators have gradually been deploying fixed links in higher and higher frequencies and have used the wider channel bandwidths to deliver higher speed connections.

2.48 Fixed links in the 10-100 GHz range have been authorised using all four of the authorisation approaches discussed earlier: block assigned, technically assigned, light licensed and licence exempt. This is illustrated in Figure 6 below[5].

Figure 6: Authorisation approaches for deploying fixed links in 10-100 GHz range[6]



2.49 **Satellite services** have already used this spectrum for some years (e.g. satellite television uses frequencies just above 10 GHz) and satellite use of these frequencies will continue to grow. In recent years there has been growth in the use of non-geostationary (NGSO) satellite systems for communications services, with companies such as OneWeb and SpaceX deploying large numbers of new satellites. Satellite broadband services have traditionally been delivered using satellites in geostationary orbit, around 36,000 km above the earth's equator. NGSO satellites can orbit the earth at much lower altitudes (sometimes a few hundred kilometres, known as Low Earth Orbit or LEO) and offer lower latency and greater capacity compared to traditional geostationary satellites. Expected use cases include residential broadband, connectivity to aircraft and ships and backhaul to remote mobile base station sites. However, they may also create additional spectrum management challenges because, unlike geo-stationary satellites, they move across the sky and are made of constellations of thousands of satellites – making coordinating spectrum use more complicated.

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[6] The figure shows bands from our Fixed links, Wireless broadband and Licence Exempt categories in the 10-100 GHz range that are suitable for deploying fixed link equipment.

Update to NGSO licensing approach

In December 2021 Ofcom updated the licensing application process and conditions for non-geostationary satellites (NGSO) operating in parts of the Ku band (10.7-12.7 GHz and 14.0-14.5 GHz) and Ka band (18-20 GHz and 27.5-30 GHz) to include checks that ensure NGSO systems can coexist with each other. Further details can be found on our website.

2.50 To date, commercial use of spectrum in this range has primarily been for fixed links and satellite. More recently, the development of 5G technologies has enabled the use of spectrum in the 10-100 GHz range for mobile, with the 26GHz band having been harmonised globally for 5G services. In addition, the 40GHz band (40.5-43.5 GHz) was also identified for mobile and as a future 5G band in Europe, with work ongoing to develop harmonised technical standards for 5G.

Preparing the 26GHz band for new mobile use

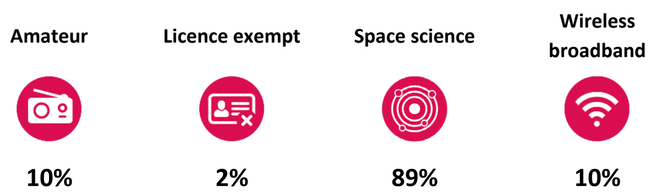
Work to make this band available for mobile services is ongoing. Ofcom made 24.25 – 26.5 GHz available in December 2019 for Shared Access licensing on an indoor, low power basis. In January 2022 Ofcom announced the closure of the 26GHz band to new fixed link applications to make space for future 5G usage. Our wider work on opening access to these frequencies (often referred to as mmWave spectrum) for mobile is discussed in the next section.

2.51 A range of radio equipment has also been permitted to make **licence exempt** use of frequencies in this range. For example, the 24GHz and 79GHz bands are used for vehicle radars, like parking sensors, and various short-range devices operate between 57 – 71 GHz. The nature of radar technology is such that very wide bandwidths are required to improve the accuracy and resolution of the radar images.

2.52 **Space science** uses have access to a large amount of spectrum in the 10-100 GHz range but, as is the case for 1-10 GHz, most (almost three quarters) is shared with other users. Some space science uses have special requirements for spectrum, due to the need to monitor very faint and/or distant natural radio emissions, or because they sometimes need to use very specific frequencies dictated by the physical properties of the matter being studied. In the spectrum above 10 GHz are several bands of particular importance in which all man-made emissions are prohibited to avoid interference with these natural measurements, with further bands also protected above 100 GHz.

100 - 275 GHz

Figure 7: Spectrum access by sector between 100 – 275 GHz (figures rounded to nearest 1%)



2.53 Until now, limitations in technology have meant that most practical uses of spectrum have been restricted to frequencies below 100 GHz. Use of frequencies above 100 GHz, often referred to as Terahertz spectrum, has been minimal to date and confined to scientific measurements of earth from satellites by the **space science** sector. Only c. 20% of spectrum used by space science above 100 GHz is shared because current technology limitations mean that other sectors are not currently able to use it.

2.54 More recently there has been interest in using the lower end of the range for very high capacity fixed links and researchers are looking at the possibility of using the spectrum for the next generation of mobile technology, 6G. To facilitate innovation in this spectrum we have made 18 GHz of spectrum available for use under a light licence authorisation and published a discussion paper on future uses of Terahertz spectrum and how to manage.

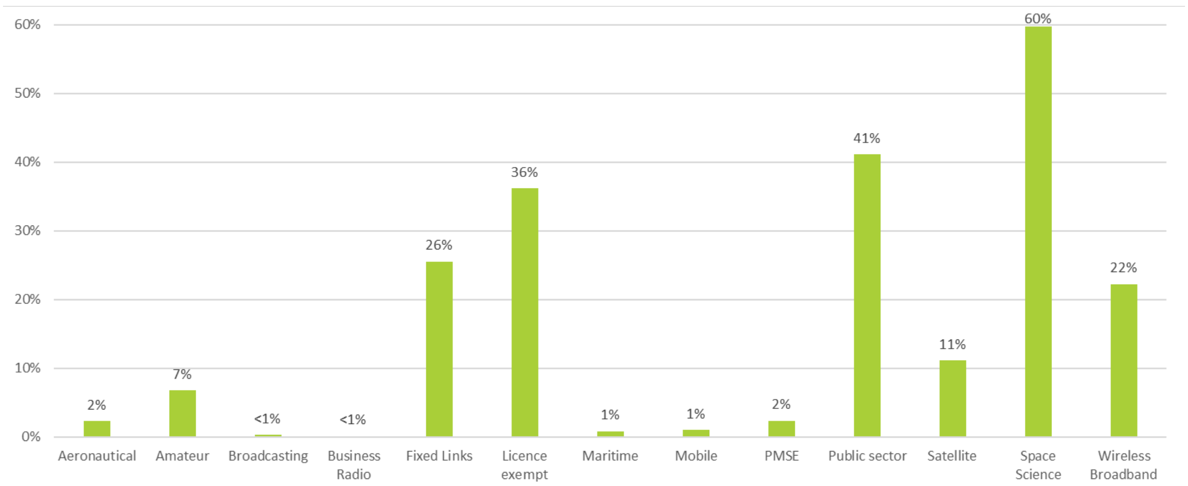
Supporting Innovation in the 100 – 200 GHz Range

In October 2020, Ofcom released 18 GHz of radio spectrum across three bands in this range: 116-122 GHz, 174.8-192 GHz and 185-190 GHz. Although technologies are at an early developmental stage, there is a range of envisaged applications that may use this spectrum. Our objective is to foster innovation by enabling easier, long-term, cheaper, and more flexible access to these spectrum bands. Further details are available on our website.

Summary of spectrum access by sector

2.55 The chart below provides a summary of the proportion of spectrum that is accessed by each sector. Further details of how spectrum is being accessed by different users can be found in our spectrum map. The data on which the map is built is also available as open data on the Ofcom website as a json file.

Figure 8: Summary of spectrum access by sector up to 100 GHz



2.56 Our summary analysis, covering all sectors, focuses on spectrum up to 100 GHz. This is because spectrum above 100 GHz is dominated by a small number of sectors and the inclusion of such large bandwidths would skew the analysis of relative spectrum access by sector.

2.57 As previously explained, whilst space science has access to the most spectrum, a large proportion is shared with other user and where the spectrum is not shared it is generally in the very highest frequencies where there is currently limited demand from other sectors. Similarly, virtually all spectrum accessible to a wide range of licence exempt devices is also accessible by one or more other sectors.

2.58 The public sector also has access to significant proportion of spectrum (over 40 GHz); of this, around 80% is shared with other sectors.

2.59 Fixed link operators have access to the most spectrum of all the commercial sectors. Across the range of bands and authorisation types available, around 40 GHz of spectrum is accessible for the deployment of fixed links.

2.60 As we work to deliver our spectrum vision we can expect to see shifts in the amount of spectrum accessible to different sectors as well as the spectrum authorisation methods we use and the nature of spectrum sharing. We will use future updates of the Roadmap to track progress.

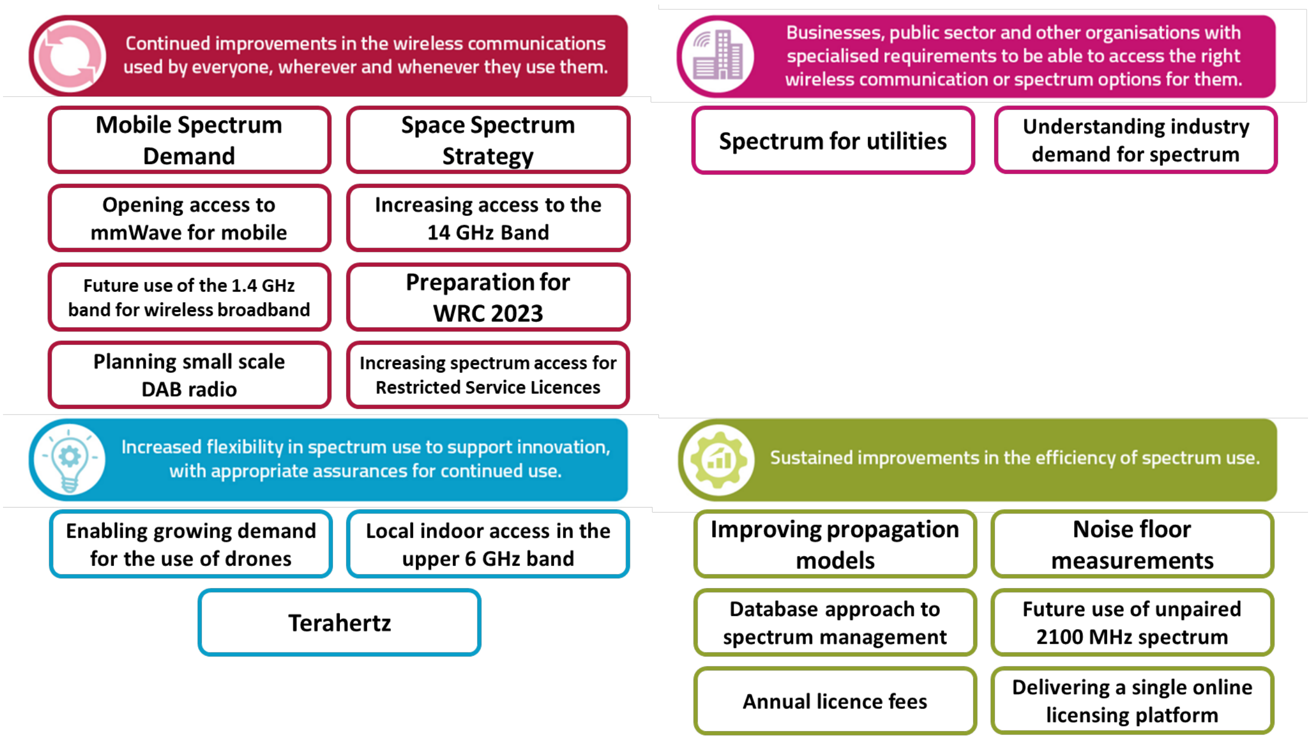
2.61 Having discussed how spectrum is used today, the next section provides an overview of the work we are already doing to progress toward our spectrum vision.

3. Ofcom’s current priority projects

3.1 We have described above how demand for spectrum has evolved over time and the actions Ofcom has taken as a result, including by authorising spectrum access in higher frequencies, promoting innovation, licensing to fit local and national services and, where possible, enabling more sharing.

3.2 Our Roadmap focuses both on current projects included in Ofcom’s Plan of Work 2022/23 and future areas of work which will enable us to deliver against our spectrum vision. In this section we present information on our current spectrum projects and explain how they fit with our spectrum vision. In many cases, these projects will contribute to achieving more than one of the objectives but, for simplicity, we have listed projects under the objective with which they most closely align.

Figure 9: Current spectrum activities and projects



Continued improvements in the wireless communications used by everyone

3.3 There is a core set of wireless services and technologies that nearly everyone uses and depends on in their everyday lives and to support businesses and public services. These currently include mobile, Wi-Fi, wireless connections (like Bluetooth) between a growing range of devices, broadcast radio and television services, and satellite navigation. We want to enable these services to continue to improve, wherever and whenever people use them, to meet increasing and changing needs.

Mobile Spectrum Demand Our Mobile Spectrum Demand work sits alongside our future approach to mobile markets, and looks at how the UK's mobile networks may evolve in the period to 2035. It sets out our initial thinking on how mobile networks could meet future demand taking account of spectrum, technology developments and potential deployment strategies. The aim of this work is to encourage longer-term thinking about spectrum for mobile networks, beyond what is already in the pipeline (1.4GHz and mmWave), and within the wider context of increasing demand for spectrum from other users.	***Next steps*** We plan to set out our initial conclusions on mobile networks and spectrum by the end of 2022.
Future use of the 1.4GHz band for wireless broadband We plan to release more spectrum in the 1.4GHz band for supplementary downlink only wireless broadband (SDL). The spectrum between 1492-1517 MHz is internationally harmonised for SDL.	***Next steps*** We plan to consult in 2023.
Opening access to mmWave for mobile The 26GHz band was globally identified for mobile services in 2019 and is a pioneer 5G band in Europe with harmonised technical conditions. The 40GHz band was also identified for mobile and as a future 5G band in Europe, with work ongoing to develop harmonised technical standards for 5G. We are considering how to make these mmWave bands available for innovative services, including 5G.	***Next steps*** We plan to consult in Q1 2022/23.
Space spectrum strategy Our Spectrum Space Strategy outlines our proposals in response to changes in the space sector. It covers actions in three areas: 1) Satellite communications; 2) Earth observation and navigation and 3) Understanding and enabling access to space. It has a particular focus on the challenges raised by the growth in non-geostationary orbit (NGSO) satellite communication systems. Our strategy identifies a number of areas where we will consider providing greater access to spectrum bands, including 14.25 – 14.5 GHz and Q / V bands (37.5 – 42.5, 47.2 – 50.2, 50.4 – 51.4 GHz).	***Next steps*** We plan to publish a statement in Q2 2022/23.

Increasing access to the 14GHz band As highlighted in our Space Spectrum Strategy document, we are currently exploring demand for additional access to 14.25 – 14.5 GHz and examining options for its future use. The potential benefits for satellite services from greater access to this band would be a doubling of uplink capacity of Ku band user terminals. This could enable improved services for a range of applications provided by both GSO and NGSO systems, such as inflight broadband and consumer satellite broadband services. As part of this work we may consider extending existing licences to allow aeronautical and maritime earth stations in motion (ESIMs) in this band.	***Next steps*** We plan to consult in Spring 2022.
Preparation for WRC 2023 Ofcom represents the UK at World Radiocommunications Conferences (WRCs) which are held approximately every 4 years and leads the preparatory work for the Conference. The next WRC is scheduled for late 2023 and will touch on a number of issues covered in this roadmap.	***Next steps*** We plan to consult in Q2 2022/23.
Planning small scale DAB radio We will continue our work to plan (and license) small-scale DAB radio.	***Next steps*** We expect to enable around 50 new multiplexes (which can carry around 1000 new digital radio stations) in 2022/23.
Increasing spectrum access for Restricted Service Licences We have proposed to introduce an innovative new method of spectrum planning that enables us to identify small gaps in spectrum use between existing broadcast radio services in the FM band.	***Next steps*** We aim to publish a statement in Summer 2022.

Meeting the needs of businesses, public sector and other organisations with specialised requirements

3.4 Growing and innovative use of wireless communications can support the continued transformation of a wide variety of sectors; from managing electricity networks, to controlling robots in warehouses and air traffic control. Some organisations also have specialised scientific requirements that can only be met by using specific frequencies, e.g. to monitor our climate. We want to meet the spectrum needs of potential and future users with specialised requirements.

Spectrum for utilities The operational communication requirements for utilities (electricity, gas, and water) are changing as a result of UK government policy objectives to deliver net zero (by reducing greenhouse gases through increased renewable energy generation and electrification of heat and transport, and environmental policies to address challenges around water supplies). We are undertaking a review of the role of spectrum in supporting utilities networks, with the goal of developing a strategy to support the changing wireless operational communication needs of the Energy (Electricity and Gas) and Water sectors as they look to meet government objectives.	***Next steps*** We will continue to work with BEIS, DCMS and Ofgem, and engage with stakeholders to complete our review of the role of spectrum in supporting utilities networks.
Understanding industry demand for spectrum In this work we are seeking to understand the specific spectrum needs of key industries, in particular whether existing Ofcom licences, such as Local and Shared Access licences, are meeting these needs. We are doing this through a range of channels, including hosting virtual events, inviting stakeholder input, attending, and participating in a range of industry conferences, and running a programme of engagement with dozens of organisations, including industry bodies, consultancies, and Government.	***Next steps*** We will continue to engage with these industries to inform our policies.

Increased flexibility in spectrum use to support innovation

3.5 We aim to provide flexibility in spectrum use that enables innovation to flourish, as we cannot accurately predict what new wireless services will emerge in coming years or which ones will bring most benefit to people in the UK. Complementing this, we will continue to ensure there are appropriate assurances for continued use of spectrum, both to support existing benefits from wireless services and to provide conditions for future investment.

Enabling growing demand for the use of drones We are exploring spectrum and authorisation options to support the growing demand for use of drones beyond visual line of sight (BVLOS) for a range of potential applications such as delivering medical supplies and monitoring traffic systems. We will collaborate with the Civil Aviation Authority (CAA) to ensure a joined up regulatory framework.	***Next steps*** We plan to publish a consultation on authorisation in April 2022, followed by a statement later this year.
Local indoor access in the upper 6GHz band We published a consultation in February 2022 setting out our proposals to make the upper 6GHz band available for low power indoor-only use, under a Shared Access licence. These proposals would not preclude future uses, either for licence-exempt WiFi or mobile applications.	***Next steps*** We plan to publish a statement in Q2 2022/23.
Terahertz Ofcom's objective for this spectrum is to enable growth by existing services whilst keeping options open for innovative new services. It is therefore important that the spectrum management approach we adopt for this spectrum is as flexible and efficient as possible to ensure that incumbent uses are afforded protection from interference without creating a barrier for potential new uses. We published a discussion document in December 2021 with the intention of starting a discussion around the potential of Terahertz spectrum, the challenges we think need to be overcome to unlock the benefits and why we believe spectrum sharing is key.	***Next steps*** Potential demand for the lower Terahertz frequencies (W & D Bands) will be explored in our proposed new work areas (see section 4).

Sustained improvements in the efficiency of spectrum use

3.6 The radio spectrum is a finite natural resource, so ultimately all new and improved wireless services for people in the UK depend on making more efficient use of this resource. We aim to create the conditions where efficiency of spectrum use can continue to increase over time, for example as a result of greater sharing of spectrum, deployment of new technologies and 'recycling' of spectrum from lower to higher value uses.

Improving propagation models Current trends in changing climate and weather patterns have the potential to impact spectrum users through their influence on the way radio waves propagate. In 2021, we initiated a long-term propagation measurements campaign to capture, understand and model the impact of infrequent weather patterns that can lead to outages of broadcast and fixed links services. Additionally, as we look to share bands at frequencies above 5 GHz, the quality of the topography data used by our models becomes increasingly important. We are bringing in the use of most recent and high-resolution datasets to further improve the accuracy of our predictions.	***Next steps*** The results of our research work and data will be made available under Ofcom's open data policy, with data starting to be published in 2023. We will continue contributing to international work on propagation undertaken by ITU.
Noise floor measurements Radio noise derives from natural (e.g. lightning discharges) and man-made sources (e.g. electronic devices) and constitutes a baseline level above which wireless signals must rise to be detected. We are undertaking a long-term radio noise monitoring campaign in the UK to better understand its impact and how the background noise levels, in particular man-made noise, may change over time. This will help to ensure that we are using appropriate safety margins in spectrum assignments. We aim to extend our campaign in distinct locations across the UK which will help provide a better view of the impact of man-made noise in different environments. In line with our Spectrum Strategy, we will be working to include the new evidence in our spectrum sharing framework.	***Next steps*** The results of our research work and data will be made available under Ofcom's open data policy, with data starting to be published in 2023. Internationally, this work will feed into the ITU-R Study Group 3 to refine models on man-made radio noise.

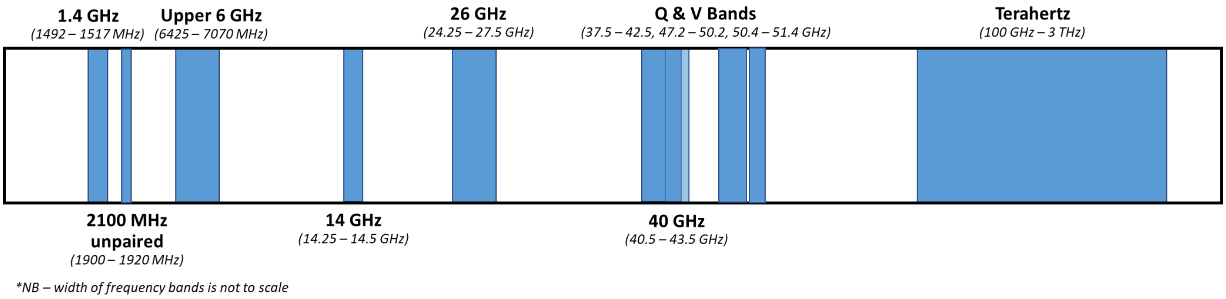
Database approach to spectrum management This work is looking at the potential role that an automated assignment process via database could play in meeting future spectrum management challenges, in particular by optimising use of spectrum resources and enabling more efficient use overall. We will seek input on the range of solutions, enabled by technology developments, and consider the challenges and benefits our approach might encounter alongside traditional spectrum management authorisation options.	***Next steps*** We plan to publish an update in Q4 2022.
Future use of unpaired 2100MHz (1900-1920 MHz) spectrum We plan to consult on the future use of the band, including on a proposal to revoke existing licences in the band.	***Next steps*** We plan to consult in Q2 2022/23.
Annual licence fees Several bands will reach the end of their initial terms in 2023. These bands are: 1.4GHz, 10GHz, 28GHz, 32GHz and 40GHz.	***Next steps*** We will develop our fee proposals for these bands during 2022.
Delivering a single online licensing platform We have a transformational change programme which will be delivered incrementally over several years and which aims to provide a single licensing platform to replace our legacy licensing systems. Our objective is to create a robust, upgradeable, and configurable licensing system to enable us to respond to changes more rapidly regarding the ongoing development of licence types. It will provide many benefits to stakeholders including online 'end-to-end' licensing for many licence types, account management features and greater overall efficiencies in the licensing process.	***Next steps*** We are currently working on replacing the legacy system for aeronautical licences, and licensees should start to see the benefits of this work from mid-2022.

3.7 The projects outlined above reflect our immediate priorities and are set out in Ofcom's wider annual plan of work for 2022/23. The draft plan of work was published in December 2021 and the final plan was published 25 March 2022. Where necessary, we will be engaging with stakeholders and consulting on proposals.

Summary of bands covered by current projects

3.8 As a number of our current projects focus on opening spectrum bands for new uses. We provide an overview of all the spectrum bands covered by current projects in figure 10 below.

Figure 10: **Spectrum bands covered by current projects**



3.9 One of the purposes of the Roadmap is to look at a longer time horizon than is considered by our annual planning process to ensure our approach to spectrum management takes into account possible future, longer-term market and technology trends. It also aims to provide a cross-sectoral approach taking account of the growing demand for spectrum across a variety of sectors. The following section sets out our assessment of these longer-term trends and the final section proposes areas of work that we believe will best equip us to meet future spectrum management challenges and exploit new technology and market developments.

4. Key market and technological trends

4.1 Our spectrum work programme, in the short and long term, is driven by our duties, aimed at delivering our strategic vision and informed by external trends and developments. In this section we explore the trends and developments that are likely to have implications for spectrum. This section is structured as follows:

1. **The wider external context,** including political and socio-economic developments.
2. **Increasing demand for spectrum** as wireless technologies support a growing range of applications and new connectivity technologies and services emerge.
3. **Improvements and developments in spectrum use,** exploring how technological developments are opening up opportunities to better utilise this finite resource.

4.2 We have already reviewed some of these trends in our Spectrum Management Strategy, published in July 2021. However, we revisit these trends here and explore additional ones to highlight the factors we have considered in developing our future programme of work.

4.3 In some cases, these trends may have direct implications for Ofcom's spectrum management work, for example raising a specific challenge or opportunity. Some of these are already being addressed through our current work programme. In addition, our **proposed future work areas** have been designed in light of these trends and their implications for spectrum.

The wider external context

4.4 A range of geopolitical and socio-economic trends may affect the use of wireless technologies and in some cases spectrum management directly. Ofcom will need to consider a range of factors when planning and going about our Spectrum work, including but not limited to:

- General economic conditions
- Availability of components for wireless technologies and devices, including changes in supply chains
- The geopolitical context, including the spectrum needs of the MoD and NATO and the threat of malicious action impacting wireless networks
- International shifts in market leaders for specific technologies and standards, and the impact on international spectrum fora negotiations

4.5 We note particular implications for spectrum in the below trends and discuss them in more detail.

A changing climate

4.6 Environmental concerns and the effects of climate change will increasingly affect people, businesses and the UK more widely. The technologies which the availability of spectrum can enable may help support the fight against climate change. This may be indirect; for example, a smart, wirelessly connected factory may be more energy efficient and produce less waste. In other areas, spectrum may directly reduce energy waste through smart utilities management or improve our understanding of the environment through climate monitoring. Demand for these applications will influence demand for spectrum.

4.7 We expect stakeholders to increasingly consider the environmental impact of their operations. As a result, there may be greater focus on energy-efficient communication services and the need for durable and/or recyclable and upgradeable equipment. A focus on equipment energy efficiency may not be aligned with spectral efficiency. More complex radio technologies or network topologies that maximise spectral efficiency may use more electricity than simpler, less spectrally efficient technologies.

4.8 Additionally, climate change is impacting how signals propagate (e.g. heavy rainfall and even variations in the size of raindrops can impact radio signals), affecting the risk of interference between spectrum users.

An increased need for network resilience

4.9 Wireless technologies are becoming more and more crucial to the economy and people's lives. As more industries, organisations and public sector functions rely on wireless services, the importance of Ofcom quickly and efficiently responding to or investigating reports of harmful interference issues will grow, particularly if these issues impact critical services or supply chains.

4.10 In addition, wireless technology may increasingly act as a connectivity back up to ensure resilience. Hybrid networks, in which seamless connectivity to an end user can be provided across different technologies (for example, 4G and 5G networks being used to provide resilience to fibre broadband) are becoming more common. In some cases, access to spectrum may only be required when there is an issue with the primary physical connectivity solution, which may result in more ad-hoc demand for spectrum.

Increasing demand for spectrum

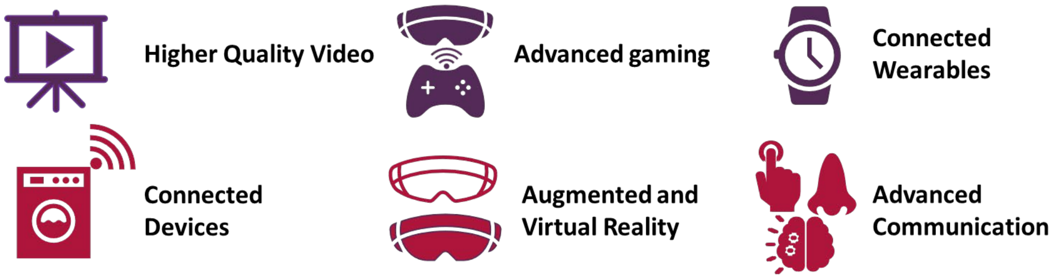
4.11 Spectrum supports a wide variety of applications and technologies, and we can expect new uses to emerge in the future, increasing demand for spectrum. It is a finite resource and growing demand from different industries will in many cases conflict with demand from other areas, and the needs of incumbents. Growing demand will also impact Ofcom's ongoing operational work, including those areas that cover compliance and licensing.

4.12 Below we outline specific trends that may drive demand for spectrum as a result of evolving consumer behaviours, digital transformation, and technology developments opening up opportunities for new applications and services.

Growing demand for consumer wireless broadband

4.13 Consumers are increasingly relying on wireless connectivity either at home via Wi-Fi, or on the move using mobile networks. Wi-Fi provides the final link between broadband routers and Wi-Fi enabled devices; data usage on fixed networks, a portion of which will travel over Wi-Fi, continues to grow. Average monthly data traffic per fixed connection was 453 GB in 2021, up from 429 GB and 315 GB in 2020 and 2019 respectively.[7] Total mobile data traffic has also continued to grow in recent years, at a rate of around 40% year on year.

4.14 We expect consumers' appetite for data to continue to grow, in large part driven by new and more data-intensive applications, including:



4.15 Our recent discussion paper, 'Mobile networks and spectrum: Meeting future demand for mobile data' set out our initial thinking on future demand for mobile services and how mobile networks may need to evolve to meet that demand.[8] There are a number of ways in which they might do this including using technology upgrades to increase the efficiency of the spectrum they use, network densification, and more extensive deployment of existing spectrum holdings and planned future spectrum for mobile e.g. in the millimetre wave (mmWave) bands. We will consult on our approach to making mmWave spectrum available for mobile and other new uses shortly.

4.16 Large amounts of spectrum have been made available for mobile; between them, the UK mobile network operators (MNOs) currently hold 1152 MHz of spectrum below 3.8 GHz. The mobile industry has suggested that more spectrum, in addition to the bands already in the pipeline, will be needed. Their focus is on the upper 6GHz band (6425-7125 MHz), currently used by a number of sectors including fixed links and satellite, and the 600MHz band, which is currently used for digital terrestrial broadcasting. Over the longer term, we anticipate the mobile industry will likely turn their attention to an even wider range of bands to enable mobile connectivity (including for 6G), such as the 7-20 GHz range and 'Terahertz' bands above 100 GHz. All of these bands are already being accessed by a variety of existing users delivering services to UK citizens and consumers.

4.17 Wi-Fi already operates across a range of bands; in the UK, Wi-Fi can operate in the 2.4GHz, 5GHz and lower part of the 6GHz bands, with access to a total of 1189 MHz. Access to more spectrum may often offer faster speeds and greater reliability, by increasing the number of possible non-overlapping channels a Wi-Fi router can operate in, reducing the risk of interference and enabling a greenfield space for the new generation of Wi-Fi technologies. The Wi-Fi industry is also targeting the upper 6GHz band to enable growth.

[7] See Ofcom's Connected Nations 2021 UK Report

[8] Further work is ongoing, we will take into account stakeholder input and will set out our initial conclusions by the end of 2022.

4.18 Any decisions Ofcom takes on making additional bands available for mobile or for Wi-Fi will need to take into account the needs of the existing users of the bands, as well as the growing demands from other sectors.

The growing role of satellite networks in delivering terrestrial services[9]

4.19 The development of small Low Earth Orbit (LEO) satellites, which are smaller in size and cheaper to launch, is opening up a wide variety of opportunities to use non-terrestrial networks (NTNs) to deliver greater capacity and lower latency. As discussed in 'Spectrum use in the UK', the growth in NGSO satellites prompted Ofcom to introduce a new licensing approach. However, international coordination is also required to manage the interference risks between an increasing number of NGSO networks.

4.20 A range of companies are looking to expand the role of satellites in providing broadband. For example, SpaceX's Starlink is rolling out direct-to-home broadband services using LEO satellites.[10] It has already launched more than 2,000 satellites, with plans to launch tens of thousands more.[11]

4.21 Additionally, LEO satellites can provide cost effective backhaul services, extending mobile coverage into areas where traditional terrestrial backhaul like fibre might not be economic. For example, BT is exploring how it might use OneWeb services to extend its services into rural areas in the UK and overseas.[12]

4.22 There is also work being done, including through 3GPP, to explore how non-terrestrial networks can be integrated into terrestrial 5G networks. Several companies, including Vodafone, are exploring how satellites can deliver direct-to-phone mobile communication services for ordinary mobile phones.[13] This could enhance the resilience of mobile services in emergencies and possibly extend mobile services in less populated areas.

4.23 All of this means that additional spectrum, in frequencies that are already allocated, may be needed to support satellite services. The potential role of direct-to-phone satellite connectivity raises coexistence challenges if the same frequencies are used by terrestrial and non-terrestrial networks.

A shifting role for fixed terrestrial links

4.24 Fixed terrestrial links refer to terrestrial based wireless systems, operating between two ('point to point') or more ('point to multi-point') fixed locations, that enable data transmission between those points.

4.25 Typical uses of point to point fixed terrestrial links include providing backhaul data from mobile cells, to transmit data across borders, to connect a range of businesses, and to

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[9] Our Space Spectrum Strategy provides further detail on our work in this area and market developments, including the key areas where Ofcom proposes to focus our spectrum management efforts.
[10] See https://www.starlink.com/
[11] See, for example, https://www.businessinsider.com/how-elon-musk-42000-starlink-satellites-earth-effects-stars-2020-10?r=US&IR=T; https://www.space.com/spacex-launch-48-starlink-satellites-march-2022
[12] https://oneweb.net/media-center/oneweb-and-bt-sign-agreement-to-explore-rural-connectivity-solutions-in-the-uk-and-beyond
[13] https://www.vodafone.com/news/technology/vodafone-ast-space-mobile-collaboration

enable faster financial transactions. However, the rollout of alternative networks like fibre and lower latency satellite networks might impact the nature of demand for fixed terrestrial links. For example, in mobile networks, physical cables may connect an increasing proportion of the network infrastructure, with wireless fixed links playing a more focused role at the edges of the network.

4.26 As technology develops, we may also see a shift towards higher frequencies, enabling very high-capacity but short range wireless links in areas ranging from harder to reach remote locations to complex urban areas to enable network densification and edge connectivity. It is possible, given the increased focus on the need for resilience, that fixed terrestrial links will also be used to provide back-ups to physical connections.

4.27 Overall, demand for spectrum to enable fixed terrestrial links may evolve as alternatives such as fibre or satellite increasingly become available and higher frequency wireless links are used more.

A growing role for wireless connectivity in the digital transformation of industry

4.28 Industry is increasingly on a journey of digital transformation. Exactly what this entails, and the speed of transformation may vary from sector to sector. However, it is clear that wireless connectivity is playing a key role in this wide-ranging transformation. Industrial wireless applications will range from automation of production and logistics, to the tracking of assets across the country. Wireless connectivity is also enabling changes beyond business, impacting our cities, infrastructure and public services like healthcare.

4.29 We expect that digital transformation will continue to be enabled by a wide range of wireless technologies, such as Wi-Fi, public mobile networks and technologies, like NB-IoT, Sigfox and LoRaWAN, that can connect devices over wide areas. Digital transformation may contribute to growing demand across all of these networks.

4.30 Private mobile networks may enable many of these changes. Private mobile networks are networks accessible by a closed group of people and devices that use mobile technologies. The current private mobile network market is fairly small,[14] but many analysts expect the overall market to grow significantly in the coming years,[15] particularly if prices come down and the device ecosystem grows.

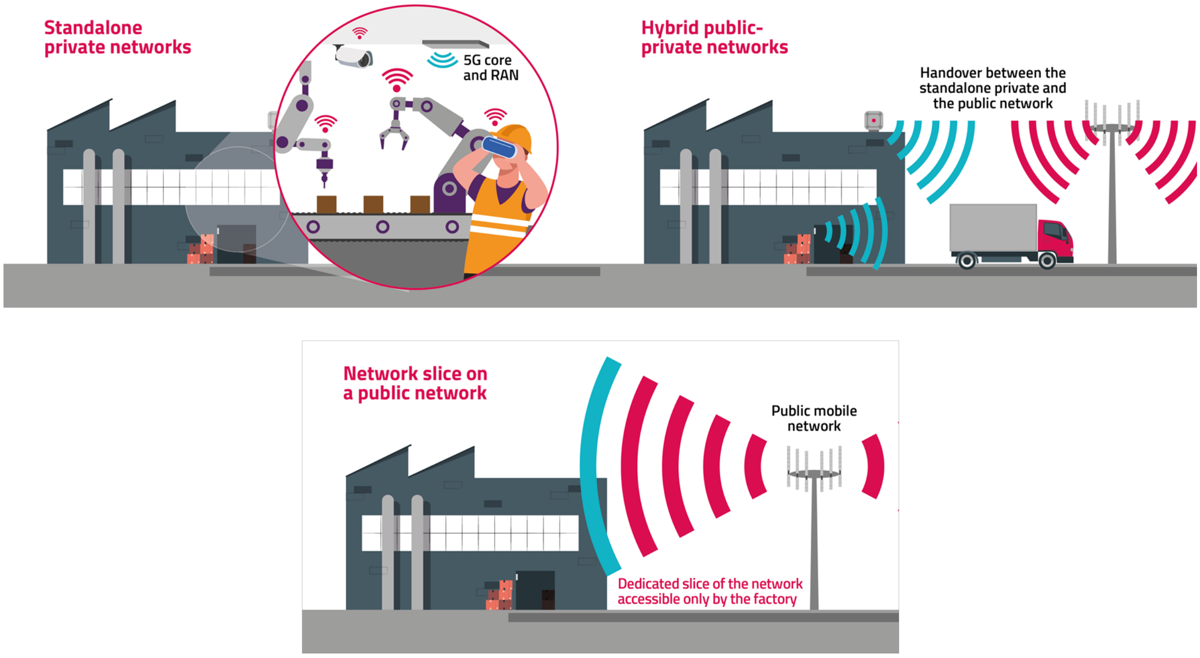
4.31 Private network solutions may be offered by a range of different market players. For example, some MNOs, vendors and solution providers/system integrators are targeting the provision of private networks. New players are also entering the market, including big tech firms such as Amazon Web Services[16] and infrastructure providers such as Cellnex. [17]

4.32 There are also different spectrum access models that can be used to support private mobile networks. First, MNO mobile spectrum can be used, either in partnership with an

[14] Analysys Mason estimates that there were only 1,000 private LTE/5G network deployments worldwide in 2021.
[15] See, for example, Analysys Mason, Private LTE/5G networks: worldwide trends and forecasts 2021-2026, March 2021.
[16] See https://aws.amazon.com/private5g/; note not yet launched in the UK
[17] See https://www.cellnextelecom.co.uk/cellnexuk5gprivatenetworkbasingview/

MNO, or through a Local Access licence. When partnering with an MNO, the private mobile network infrastructure may be integrated into a public mobile network to some degree. In the future, MNOs may also be able to offer a 'network slice' of their public network.[18] Second, shared access spectrum, for example 3.8-4.2GHz, can be accessed through a Shared Access licence to enable standalone private networks. Figure 11 below outlines the different types of private networks.[19]

Figure 11: Different types of private mobile networks



4.33 As the market grows, the demand for shared access licences is likely to increase and Ofcom is already looking to develop an easier and quicker solution to access this spectrum, including through automation. There could also be demand for additional shared access bands, with flexibility around licence location and power levels, all whilst avoiding interference.

A potential shift towards 'general purpose' network technologies

4.34 A number of network technologies, such as mobile, Wi-Fi, satellite and fibre, are becoming more versatile and capable of supporting a wide range of uses. For example, a private 5G network can support a variety of applications and services across different industries.

4.35 As these technologies develop, prices fall, and the device ecosystem grows, organisations may move away from dedicated networks and services towards these more versatile network technologies. For example, an organisation using a business radio solution may instead use a private 5G network, which could also support voice across a campus, in

[18] These are virtual networks relying on the public 5G standalone network infrastructure. These virtual networks (slices) can then be customised to operate with specific quality of service and meet the specific needs of applications, services, devices, customers or operators

[19] See Ofcom's discussion paper 'Ofcom's future approach to mobile markets', pg 48 – 50, for a more detailed discussion on private mobile networks.

addition to enabling other higher bandwidth applications, supporting wider operational efficiencies.

4.36 This shift may impact demand for different types of spectrum licences, which could have implications for Ofcom's spectrum management approach.

Supply of spectrum & opportunities for improved spectrum management

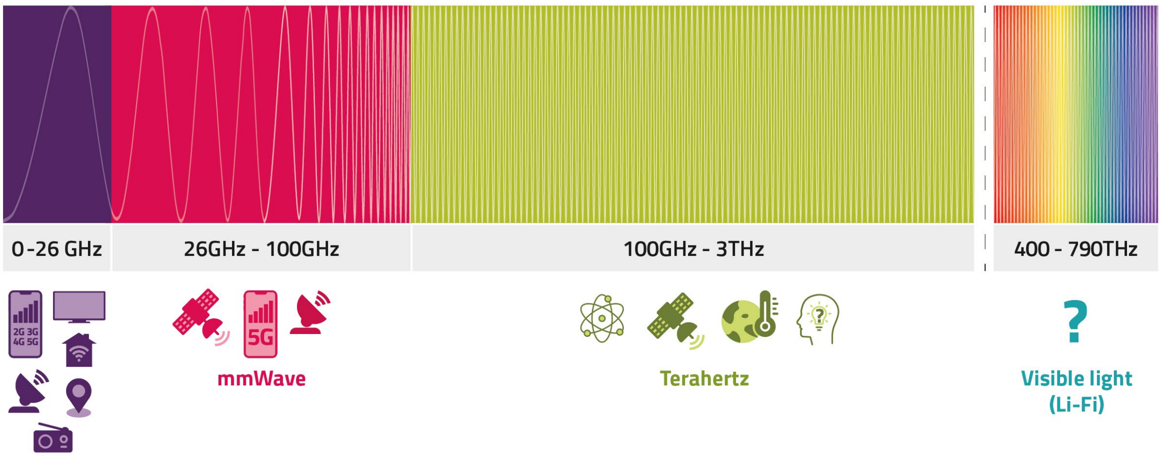
4.37 Technological developments are offering ways to better utilise spectrum, including opening up higher frequency bands to a wider range of applications and facilitating more efficient use of spectrum through sharing. These trends are discussed below.

A shift towards higher frequencies

4.38 As outlined in 'Spectrum use in the UK', almost all spectrum up to around 100 GHz is allocated for use across a wide range of applications and services, with the greatest congestion in lower frequencies.

4.39 In many industries however, higher capacity is becoming increasingly important. Higher frequency spectrum has fewer incumbents, which may allow wide bandwidths to be made available to support high bandwidth/capacity applications. Using higher frequencies is becoming more feasible, supported by improvements in technology that (i) are improving the effective range of high frequency spectrum,[20] and (ii) are increasingly delivering cost-effective devices able to operate on higher frequency spectrum.

Figure 12: A shift towards higher frequencies



4.40 As an example, Ofcom has already identified a large amount of additional spectrum for mobile in the mmWave frequencies (above 24 GHz). This high frequency spectrum may offer a sizeable boost to MNO network capacity in localised areas, supporting the use of high bandwidth applications.

[20] See for example https://www.ericsson.com/en/reports-and-papers/further-insights/leveraging-the-potential-of-5g-millimeter-wave

4.41 Looking still higher up in the spectrum, advances in technology across a range of fields are starting to open up opportunities to use Terahertz spectrum (between around 100 GHz and 3 THz) for new applications, such as high-speed wireless links, high-resolution imaging and sensing and to support future mobile technologies.

4.42 As outlined in our discussion paper 'Unlocking the potential of Terahertz radio spectrum: the role of spectrum management', Terahertz spectrum could offer the opportunity to explore new approaches to spectrum management, for example spectrum sharing by default, supported by the shorter range of Terahertz spectrum reducing the risk of interference. However, there are existing users in Terahertz bands, including for scientific applications. Ofcom's spectrum management approach will need to ensure the needs of incumbents are taken into account whilst setting conditions for future users that do not stymie innovation.

4.43 Looking further up the frequency range, it is possible that even higher frequencies might support communication. Visible Light[21] (Li-Fi) could support a range of applications, making use of the ability to deliver very high speeds due to very large bandwidths.

Spectrum sharing and interference management technologies[22]

4.44 Our Spectrum Management Strategy highlighted an increased focus on localised spectrum access and spectrum sharing. A range of techniques and technologies make using spectrum on a localised or shared basis possible. Spectrum sharing is not new and has been used for years, including via geographical separation and sharing in time.

4.45 In the future, a range of additional technologies and techniques may supplement or improve existing spectrum sharing methods, including by reducing the risk of interference. Ofcom is keen to explore different ways of accessing and sharing spectrum, including:

a) **Automatic coordination:** Today, Wi-Fi devices access and operate on wireless channels by 'listening' first before transmitting, reducing the risk of interference. In the future, different Wi-Fi access points may directly coordinate and agree when to transmit to deliver more predictable quality of service and better manage congestion.

b) **Learning algorithms and artificial intelligence (AI):** Learning algorithms enabled by AI may support reductions in spectrum consumption, which may make sharing easier. The AI engines may operate on measurement data collected by the device itself or data collected by other devices or sensors in the vicinity – an approach known as 'cognitive radio'. Additionally, by applying learning on top of an existing 'listening' protocol to access a spectrum channel, devices can detect the best options to transmit in a quicker fashion and potentially with less risk of interference. Future software, supported by AI, may also enable advanced signal processing to identify and mitigate interference even once a signal has been received.

[21] Visible light is far higher up the frequency range, sitting around 400 – 790 THz. We note that Ofcom does not manage spectrum at this frequency.
[22] See Ofcom's Technology Futures paper for a wider discussion on future mobile and wireless technologies

c) **Intelligent Reflecting Surfaces (IRSs):** An IRS is a programmable structure that can be used to control the propagation of electromagnetic waves by changing the electric and magnetic properties of the surface. This could help to improve the reach of wireless networks by reflecting signals into places that they would not otherwise reach.

4.46 These technologies, and others, may enable the more efficient use of spectrum, but may raise new spectrum management questions that Ofcom will need to consider in developing and future proofing authorisation approaches.

Developments in antenna technology

4.47 Antenna technology continues to develop and 'active' antenna systems that can be dynamically configured to optimise connectivity to end users are in common use. By combining and coordinating many individual antennas elements in one system, it is possible to send and receive multiple radio signals to an end user by exploiting reflections off buildings and other obstacles. This technique, known as Multiple Input Multiple Output (MIMO) helps to improve capacity, speeds and reliability.

4.48 At higher frequencies, antenna elements become smaller and more can be packed into an antenna system. With high numbers of elements, and by carefully coordinating the signals from each one, narrow radio beams can be formed and electronically steered. By concentrating radio energy in this way, capacity and coverage can be increased and interference between users reduced.

4.49 'Beam steering' to many users inherently creates a large number of beams being directed to different positions and that move as they follow users. The real-world impact on the probability of interference depends on the number and location of users and traffic profiles. The statistical probabilities associated with the modelling of these systems increases the complexity of radio coexistence analysis.

4.50 We explore other potential developments in antenna technologies in our Technology Futures Report, such as the move to "cell free" mobile architectures.

Greater access to real-world data and improvements in modelling capabilities

4.51 Ofcom uses propagation and coexistence modelling to support areas like our spectrum authorisation work. There is already work underway to improve our modelling, and a range of developments may allow Ofcom to further enhance these models using real-world data, which would enable them to be less conservative and risk averse. This may support Ofcom's aim of promoting spectrum sharing through the use of better data and more sophisticated analysis, as set out in our Spectrum Management Strategy.

4.52 First, the shift towards software-based devices and network function virtualisation is making capturing of data easier and cheaper. Additionally, spectrum monitoring, data capturing and processing technologies, alongside data storage, are improving and becoming more affordable. Second, harmonised spectrum and 3GPP equipment standards now support data collection and promote the use of real-world spectrum data. Third, the range of data sources on spectrum quality and performance is growing, including data generated by connected devices, like crowd-sourced data from mobile phones, on spectrum quality and performance.

4.53 All of this may make it easier for our stakeholders, and in some cases Ofcom, to gather real-world data. Greater access to real-world data via our stakeholders could support Ofcom's understanding of the real-world impacts of various antenna technologies, enable improvements in our assurance work and could support enhancements in propagation modelling and the selection of realistic parameters in coexistence modelling. Ofcom's modelling capability may also be improved by developments in AI and interference analysis software.

4.54 Taken together, this may enable a more realistic approach to considerations of how users may use spectrum without causing harmful interference to each other, enabling more users to gain access to spectrum.

5. Proposed future work areas

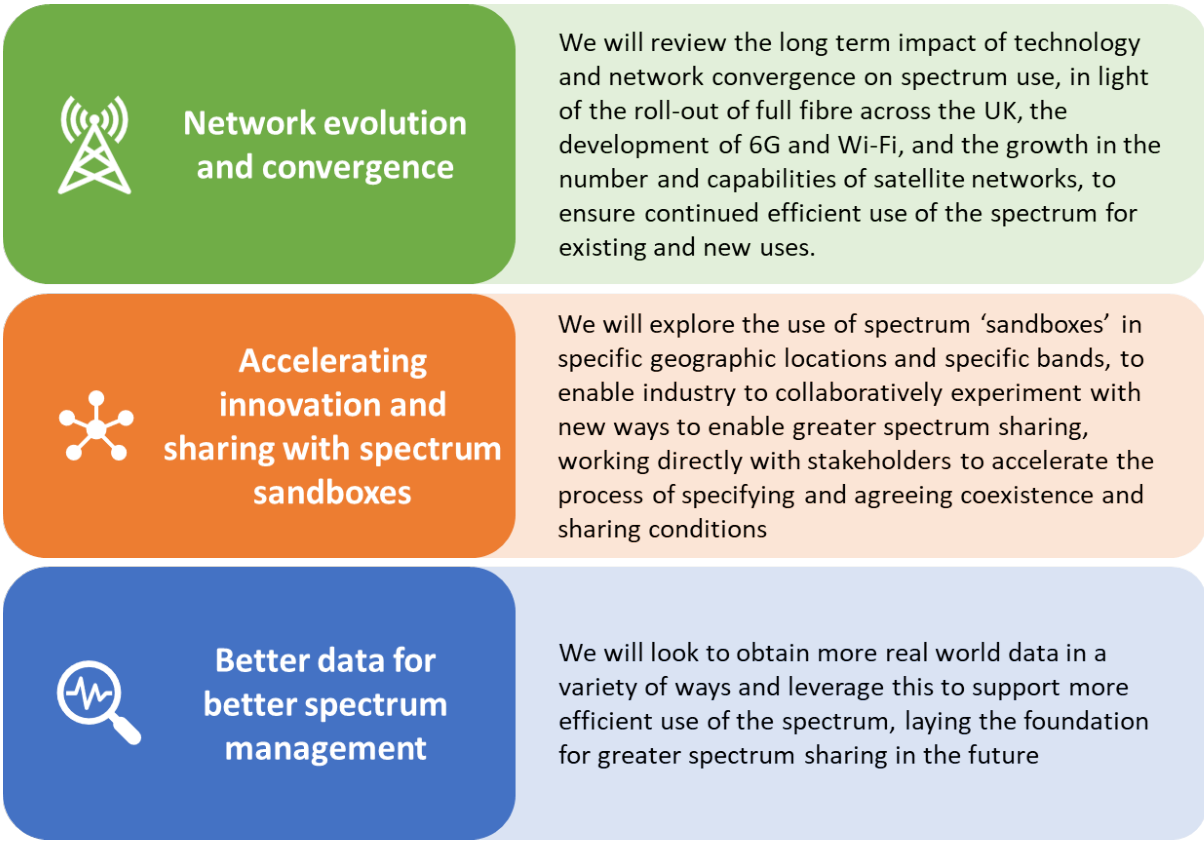
5.1 In light of the trends set out in the previous section, and the implications for spectrum use and management, we have identified a set of proposed future work areas that we consider instrumental to delivering our spectrum vision. We have paid particular attention to activities which relate to our three areas of increased focus: supporting wireless innovation; licensing to fit local and national services; and promoting spectrum sharing.

5.2 Some of these activities will become ongoing, programmatic work that will inform our future policy development and we will review and refine them when we update the Roadmap. Other activities will focus on more specific challenges and opportunities and trigger specific projects.

5.3 Our current work is already taking account of some of the trends identified in the previous section; for example, our work to improve the propagation models is taking into account some aspects of the impact of climate change on signal propagation.

5.4 The proposed new activities will enable us to deliver on our duties against the backdrop of growing and competing demand, and will provide the data, market insight and operational capabilities we will need to prepare us for the coming decade.

Figure 13: Themes of future work areas



Network evolution and convergence

5.5 There are a number of technology developments that we expect will bring increased spectrum efficiency, improved functionality and enable different deployment models. We can expect these new developments to be incorporated in future networks such as 6G and next-generation Wi-Fi and satellite. As standards bodies work toward closer integration of 5G/6G with Wi-Fi and satellite systems, the coverage, capacity and capabilities of the combined, hybrid networks could be further enhanced.

5.6 Additionally, the demand for certain wireless technology solutions may also be impacted by wider market developments. Of particular interest is the potential impact of nationwide fibre roll out on the demand for fixed links.

5.7 These developments may impact spectrum demand for both new and existing bands. The activities we have identified will provide the information and evidence we require to take a cross-sectoral, long-term view of future spectrum demand, help ensure we manage spectrum effectively and enable innovation and competition.

5.8 We plan to undertake the initial research work in the next 12-18 months and will then assess whether we need to review existing spectrum policies. The projects we are proposing under this theme include:

Monitoring and influencing the development of next-generation network technologies

We will expand our current programmatic work on monitoring and influencing the development of next-generation wireless network technologies:

6G: We will continue to engage in ITU work to develop a 'vision document for 6G' and monitor emerging demand for spectrum, particularly in the 7-20 GHz range where there has been interest expressed by some in the mobile industry for 6G. This will inform our position on any 6G-related agenda items being proposed for the ITU World Radiocommunications Conference (WRC) meetings in 2023 and 2027.

Wi-Fi: We will engage with the Wi-Fi community and standardisation process to better understand future capabilities, spectrum needs and timelines for Wi-Fi7 and beyond. This work will also inform our contribution to WRC 23.

Satellite: Given our duty to make services widely available across the UK, one area of particular focus is the development of solutions over the coming years that could enable voice and data services to be delivered to standard mobile devices directly from satellites, with the potential to extend coverage of terrestrial mobile networks and improve access to emergency services. This will include monitoring developments in 3GPP (Release 18) and proprietary solutions. This is a longer-term area of work for Ofcom.

Hybrid networks: We will develop our understanding of the activities within standards bodies and operators to develop closer integration of mobile, Wi-Fi, satellite and other network technologies as well as the potential commercial & partnership models.

Developing a cross-sectoral understanding of evolving spectrum demand at 6GHz

A key objective of the work areas set out above is to gain insight into how existing spectrum demand might change and new demand emerge.

We will have a particular focus on the long-term demand for the upper 6GHz band (6425 – 7125 MHz) where there is interest from both the mobile and Wi-Fi communities and existing use by fixed links. Our work in this area will inform our position going into WRC23.

Impact of fibre roll-out on future use of wireless fixed links

Ofcom carried out a review of spectrum used by fixed wireless services in 2017/18, which set out a 5-year plan for this spectrum. Since then, there have been significant developments in relation to investment and roll-out of fibre to the premises by a large number of companies offering a range of commercial models. The UK Government has a target that at least 85% of premises should have access to gigabit broadband by 2025, rising to 99% by 2030.

In addition, growth in mobile traffic is increasing demand for wireless mobile backhaul links and a move to centralised radio signal processing in datacentres, rather than mast sites, could increase demand further. Densification of mobile networks using small cells could also lead to a large increase in the need for short range fronthaul/backhaul connectivity to street furniture and rooftops. Beyond mobile backhaul, fixed links continue to be used for a wide range of connectivity solutions including connecting CCTV cameras, linking office buildings, providing links across the sea and redundancy for fixed line connections.

Given these changes, we plan to undertake a new review of how spectrum demand for fixed links in existing and new higher frequency bands (including W&D bands[23] at sub Terahertz range) may evolve in the coming decade in light of future fibre roll-out, new emerging wireless technologies such as 5G/6G and LEO satellite and as well as the role of wireless connectivity in providing redundancy for fibre connectivity. The review will inform our short and longer term work on enabling access to spectrum for fixed links. We propose to start this work in the coming months.

Assessing the implications of new technologies on how we manage spectrum use

We will monitor the technology advances that might lead to new, innovative ways to manage spectrum. For example, Intelligent Reflective Surfaces could improve the reach of wireless networks by reflecting signals into places that they would not otherwise reach, but may require us to consider new ways to authorise their use in order to avoid interference.

[23] W Band is 92–114.5 GHz, D Band is 130-174.8 GHz

Review potential for migration from ‘dedicated’ to ‘general purpose’ networks

Building on our work to understand the future capabilities and availability of general purpose network technologies such as 5G/6G, Wi-Fi, satellites and fibre, this activity will seek to model future scenario of possible migration away from dedicated networks and services and to identify drivers and barriers to migration. For example, an organisation using a business radio solution for a campus or industrial site may plan to migrate its users onto a private 5G network if they are building one to drive wider operational efficiency.

The work will involve market research of end users and suppliers and analysis of the service features they require and how these might evolve through to 2030, and compare these against the evolving capabilities of general purpose network technologies.

Using the future scenarios we will explore the potential future spectrum demand and the extent to which we may need to make changes to how we manage spectrum in order to ensure spectrum continues to be used efficiently, whilst helping deliver higher quality services and promoting competition.

How these activities deliver our spectrum vision

Our proposed work on network evolution and convergence should ensure businesses and other organisations are aware of potential wireless technology and spectrum options and can gain access to the services they need. Our work will also aim to ensure efficient use of spectrum, including by facilitating migration to newer technologies where this would result in more efficient use of spectrum.

Accelerating innovation and spectrum sharing with spectrum sandboxes

5.9 The process for defining sharing conditions between different users/uses is a complex one and can take many years due to conflicting requirements. The process can often lead to conservative assumptions that limit network deployments and utilisation of a band.

5.10 We want to encourage and enable ‘spectrum sandboxes’ to accelerate innovation and develop new ways to share spectrum. This type of collaborative, iterative development in a field trial environment has become more viable with the move to software defined radios and network function virtualisation. These software centric systems allow faster and more flexible iterations than is possible with hardware based radios and performance data collected from the systems themselves can reduce the cost of performing field measurements with specialist, high-cost equipment.

Spectrum Sandboxes

We will work with industry and academia, in a defined geographic area, to explore how equipment can coexist in the real world. Participants would be given scope to experiment with different approaches and algorithms for sharing spectrum, laying the basis for a quicker and more innovative approach to agreeing sharing conditions.

We think the sandbox model could be beneficial for exploring solutions in a number of different bands:

- There is currently interest for higher power, outdoor use in the lower 6GHz band and the band is already used by several hundred fixed links. A sandbox would provide the opportunity for interested parties to explore the possibility of sharing the band. Equipment and database standards already used in the US to support sharing (Wi-Fi 6E with AFC) could provide a useful starting point for trials – allowing participants to develop new and improved algorithms for sharing spectrum that could run on top of the pre-existing solution.
- We are already developing a more automated solution to issue Shared Access licences to meet growing demand, particularly for the 3.8-4.2GHz band. A sandbox trial could provide an opportunity to overlay an option to enable more dynamic access to this band – allowing greater flexibility of access by time, place and frequency. For example, the sandbox could explore whether less restrictive technical conditions could be enabled, such as higher power transmission, in an environment where there is more intelligent coordination between users.
- Whilst the technologies are still largely in the academic research phase, there may be opportunities to use a sandbox environment to explore the sharing of Terahertz spectrum between different users. These bands are already used by passive earth observation satellites and there is potential demand in the mid-term for high capacity fixed links and in the longer term, 6G mobile communications and sensing applications. A controlled, sandbox environment could provide some early insight into how these applications might be designed to share spectrum. Given the nascent state of technologies in this band, a 'virtual sandbox' conducted within a software simulation that creates a digital twin of a real world environment may be more viable in the short term.

5.11 The success of a sandbox approach is very dependent on the engagement of industry and the quality of collaboration. We would seek to take a facilitating role, looking to industry and academia to drive the process. We will draw on lessons learnt from relevant international initiatives, such as the Spectrum Collaboration Challenge run by DARPA in the USA (which used virtual sandboxes).

5.12 We will aim to start our engagement with industry in the coming months to explore how best to establish the first sandbox and which bands to target.

5.13 Subject to the success of our initial work in this area, we will also consider what other bands may be suitable candidates for future spectrum sandboxes. The sandboxes initiatives would run in parallel with, and inform our work on, database driven and more dynamic approaches to managing spectrum.

How these activities deliver our spectrum vision

In addition to potentially accelerating the process for agreeing conditions for shared use of spectrum, our proposed spectrum sandbox activities could also help to deliver improvements in spectrum efficiency by allowing spectrum users to see 'real world' evidence that radio systems can coexist without suffering harmful interference.

This approach should also provide opportunities for innovation, with spectrum users able to try out innovative sharing approaches and make iterative improvements to sharing algorithms in the field with the involvement of potential future sharers.

If successful, these sandboxes could enable accelerated access to additional spectrum for wireless services used by consumers, businesses and the public sector.

Better data for better spectrum management

5.14 A number of the challenges we have identified relate to demand for additional spectrum from a range of services and industry sectors.

5.15 Current spectrum authorisations tend to be based on conservative assumptions and do not always take into account the latest technology developments. This can limit the number of existing users that can gain access to a particular spectrum band and act as a barrier to entry for new types of use. In many cases this is because there is insufficient data on the real-world performance of radios and the propagation of radio waves.

5.16 The latest radio technologies and network management systems are able to generate rich data on the technical performance of radio systems, including system parameters, radio propagation, capacity and quality of service. Many of the system parameters and measurements will reflect equivalent parameters used in propagation models and so provide the opportunity to compare models with the real world.

5.17 Access to real world data will provide an opportunity to refine the models we use to authorise spectrum, more easily identify causes of interference and identify opportunities to use spectrum more efficiently.

5.18 We are therefore proposing a number of new activities to access and use better data and help to pave the way towards more spectrum sharing:

Using real-world data to improve propagation and coexistence modelling

We propose to use information requests to collect real world systems parameters and performance metrics from spectrum users. Due to the static location of transmitters and receivers and widespread deployment across different parts of the UK and across frequency bands, we are likely to prioritise fixed links.

We will engage with spectrum licensees in defined band(s) to discuss what data is readily available from their network management systems and optimal sampling approaches. The data may be complemented and calibrated with measurements made via our own monitoring stations and field engineers. We expect the analysis of the data to help us to test and optimise existing coexistence and propagation models. We will feed the relevant results into the international working groups and standards bodies.

Improving our understanding of the real-world performance of active antenna systems (AAS)

As wireless technologies have moved up to higher frequencies, vendors and operators have started to make more use of active (phased array) antennas. These antennas can focus radio beams to wireless devices and exploit the 'multi-path' signals that result from radio waves bouncing off buildings and other obstacles as they travel from the transmitter to the receiver. These techniques may provide high data rates simultaneously to more users than traditional passive antennas. However, this also adds new complexity and uncertainty to coexistence analysis and there may be opportunities to improve how these systems are modelled.

We will consider the differing characteristics of new AAS antennas versus older passive antennas and how these factor into coexistence analysis and technical parameters for licence conditions.

We note that real-world measurements of AAS emissions are the next logical step for improving and refining our existing theoretical models. We will engage internationally with global suppliers to work towards a repeatable measurement methodology, and would welcome the opportunity to work collaboratively with industry to collate metrics for real-world deployments.

Improving receiver resilience

Where adjacent frequency bands are proposed for different applications, technical studies are conducted to assess whether a new service will impede the operation of incumbent users of the radio spectrum. A previous example was where the introduction of mobile services in 2.3GHz was preceded by significant testing of Assisted Listening Devices (ALDs) operating at 2.4GHz.

Currently such assessments are developed on a case by case basis using assumptions about receiver performance that are not necessarily representative, and lead to overly conservative protection requirements. The technical European CEPT SE21 group is developing a framework on resilience of receivers to transmission in adjacent frequency ranges. This aims to establish baseline norms for receiver resilience across a range of frequencies and receiver types, which would allow for better advance planning, and more robust and consistent testing to facilitate future spectrum band evolution.

Ofcom is an active contributor to this programme and we plan to conduct sample testing to validate the proposed methodology and compile real-life data on receiver performance for a range of devices which will complement our modelling work.

Using real-world data to improve the efficiency and effectiveness of our spectrum assurance work

Currently our Spectrum Assurance team make use of a range of monitoring equipment, including at fixed sites and in vehicles, to investigate cases of radio interference. This works well for traditional radio technology which transmits in a predictable way and over a relatively large area.

The shift to using higher frequencies, active antennas and more localised access to spectrum will make finding the source of interference more challenging.

Gathering technical performance data directly from licensees' radio equipment could be helpful in identifying the cause of interference issues and even highlighting potential interference issues before they impact services.

We will therefore explore the introduction of a 'proof of concept' API (application programming interface) to allow spectrum users to log interference events. In exploring this we will engage with stakeholders to discuss what data is available and how it could be submitted. We envisage that access to this API would be provided on an 'opt in' basis, i.e. spectrum users could decide whether they wished to submit data. This could bring benefits to users in that it could allow Ofcom to more accurately identify potential or actual instances of interference on a real-time basis and allow more effective and proportionate targeting of interference investigations.

Such an approach could generate large volumes of complex, unstructured data. Through our internal Data Hub team we would plan to use the latest Big Data and AI techniques to efficiently process the data and identify trends and insights that would not previously have been possible.

Analysis of our historic records of reported interference will help us identify and prioritise our engagement with stakeholders to explore the potential interest in this work. We are also considering engaging with the developers of new wireless systems and equipment to encourage them to support reporting to the API as a core feature of their products.

Measuring utilisation in selected spectrum bands

Better understanding of the use of existing spectrum bands is critical to deliver against our vision and enable innovation and growth via sharing.

Where Ofcom authorises individual radio networks, such as business radio and shared access licences, we already hold data on infrastructure deployed. However, for bands that have been awarded, particularly those used for fixed links, we do not have full visibility of infrastructure deployment. Similarly, we do not hold data on the number and location of devices that are exempt from needing a spectrum licence – such as Wi-Fi routers or 'passive' devices that only receive radio signals (and require protection from interference) but do not transmit.

Ofcom has a range of monitoring sites and equipment which can help understand actual use of bands. However there is a limit to what monitoring can do and in some cases it may be necessary, or more cost effective, to seek information from spectrum users on their use of spectrum.

We are therefore proposing to collect data on radio deployments and spectrum use from stakeholders in spectrum bands where we currently have limited information. We are keen to engage with ISPs on Wi-Fi router deployments and spectrum utilisation by band, with fixed links operators to better understand deployments in awarded bands and with passive band users (such as Earth Observation satellites) to identify actual use and confirm protection requirements.

Collection of data on Wi-Fi router deployments will be important as we consider the evolving demand for Wi-Fi spectrum and the future uses of the upper 6GHz band.

How these activities deliver our spectrum vision

Our proposed activities around better data should all help with our objective to deliver sustained improvements in the efficiency of spectrum use.

Use of real-world data for our propagation and coexistence modelling, and a better understanding of active antennas, should enable the use of less conservative protection distances between users and allow more users in a given amount of spectrum.

Our proposed approach to allowing users to log interference events using an API should help to improve our ability to identify, resolve and even pre-emptively manage interference issues. This should bring benefits to all users of spectrum, providing greater assurance to businesses that rely on spectrum for business critical communications.

Gaining a better understanding of the real utilisation of spectrum should help us to better target future spectrum management activities, including by identifying potential new spectrum sharing opportunities and whether there may be opportunities for more local access in certain geographical areas.

These activities could also pave the way towards a more dynamic approach to spectrum management, where more intelligent radios will enable the collection and use of more data, and spectrum sharing will rely on flows of data between users and databases or each other.

Next steps

5.19 All of the work areas we have outlined above will rely on active engagement by spectrum users and the equipment supply chain if we are to successfully deliver on our spectrum vision. We welcome feedback from all stakeholders on our proposals and suggestions on how we can refine or add to them. Over the coming months we plan to hold a number of events and workshops to give stakeholders the opportunity to participate and contribute to the activities proposed in this Roadmap.

5.20 As noted above, we welcome feedback from stakeholders on these potential projects, and suggestions on other additional projects which stakeholders think could be helpful in delivering our spectrum vision.

5.21 If you would like to provide feedback on the Roadmap please do so by 20 May. You can contact the team at spectrum.roadmap@ofcom.org.uk.