# Mobile Data Strategy

Consultation

Publication date: 21 November 2013

Closing Date for Responses: 30 January 2014

# Contents

**Section 1**

# Summary

## Overview

1.1 The objective of our mobile data strategy is to identify and prioritise actions which Ofcom could undertake to facilitate the continued long term growth in consumer and citizen benefits from increasing use of mobile data services. In doing so we recognise that increases in the efficiency of delivering mobile data services, particularly through technology and network improvements, will be important for minimising the impact of this growth on other services.

1.2 This document considers the challenges that rapidly growing demand for these services could raise and what this may imply for Ofcom's work over the coming years. In particular, we identify a number of spectrum bands where we think further work should be carried out to consider their potential future availability for mobile data use, whilst recognising the many other competing demands for spectrum.

## Background

1.3 Mobile data services, and the applications they support, already deliver substantial benefits to UK citizens and consumers. These services include provision of mobile broadband to consumer devices such as smart phones and laptops as well as emerging machine-to-machine (M2M) communications, for example to cars. At the same time, the demand for mobile data is growing rapidly and there are reasons to believe that it could continue to grow materially in the future.

1.4 Meeting this growing demand could substantially increase the benefits of mobile data services to consumers, and the UK economy more generally. Sustaining mobile data growth, in particular the delivery of high-capacity services to rural areas, could also make a significant contribution to citizen benefits, contributing to digital inclusion and facilitating social participation.

1.5 However, meeting this demand also presents a range of challenges including:

- The need for **continuing technology improvements** to increase the capacity and performance of mobile and Wi-Fi networks.

- **Deploying networks** which make even more effective use of existing spectrum, for example through use of smaller cells and Wi-Fi. These in turn may be dependent on having access to appropriate sites and backhaul connectivity.

- **Ensuring competition** in the provision of mobile data to end users.

- **Taking account of other demands for spectrum -** our spectrum management strategy has identified that growing competing demands for spectrum, not just for mobile data, will lead to increasingly difficult choices associated with changing spectrum use, especially at lower frequencies.

- **Improving Coverage -** in future there may be increasing expectations and potential demand for ubiquitous coverage of mobile data services, including, for example, to enable new M2M applications.

## Ofcom's role

1.6 Industry is leading on some of the challenges, particularly technology and network improvements, but we will need to keep closely abreast of these developments – for example through our Infrastructure Report[1] and our involvement in the UK's 5G Innovation Centre[2]. For others we have an important role in helping to address the challenges and already have an active programme of work on many of these. For example:

- In relation to backhaul we have imposed ex-ante rules on BT and KCOM to address their significant market power in the wholesale provision of Ethernet leased lines.

- We recently published a five point plan for improving mobile coverage, including ensuring operators meet their coverage obligations and driving up quality of service through better consumer information.

- In relation to spectrum, we are progressing work on a number of bands, beyond those awarded for 4G services earlier this year, which could support even better mobile data services over the coming years: the award of 2.3 and 3.4 GHz spectrum bands; enabling the use of TV 'white spaces' and considering the future use of the 700 MHz band.

1.7 However, for spectrum we also need to look even further ahead, perhaps as far as 2030, at the longer term spectrum challenges. This is because major changes in spectrum use can take many years to bring about and because important decisions in relation to future bands for mobile data use will be taken in an upcoming international conference, the World Radiocommunication Conference 2015 (WRC-15) and in the EU[3].

## Spectrum prioritisation

1.8 To this end we are proposing to undertake further work in the coming years on the potential for mobile data use of a number of additional bands, based on our current assessment of the relative priority for potential release of these bands (see Table 1). This proposed work includes, for example, better understanding the options for future mobile use and potential costs of any change, and, where appropriate, taking action to create or maintain the opportunity for change of use or sharing. Our final prioritisation of these bands will also serve to inform the UK's engagement in forthcoming international discussions on future mobile bands, for example in the run up to WRC-15. Some of these bands are in public sector use; hence the importance of the Government's ongoing Public Sector Spectrum Release (PSSR) programme.

1.9 In undertaking this prioritisation we have identified key drivers of change that could influence future spectrum demands for mobile data, for example the likely growth in use of small cells and Wi-Fi for carrying mobile data traffic, and the potential demands of emerging machine-to-machine communications that might particularly benefit from a relatively low capacity but reliable and ubiquitous coverage layer. One

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[1] http://stakeholders.ofcom.org.uk/market-data-research/other/telecoms-research/broadband-speeds/infrastructure-report-2013/
[2] http://consumers.ofcom.org.uk/2013/11/ofcom-to-help-develop-5g-innovation-centre/
[3] For example see the Radio Spectrum Policy Group *Opinion on Strategic Challenges facing Europe in addressing the Growing Spectrum Demand for Wireless Broadband*

implication is that a mix of different types of spectrum will continue to be important for use in different situations, ie both high and low frequencies, high and lower power, and shared as well as cleared spectrum.

**Table 1: Proposed prioritisation of bands for potential future release**

| Relative priority for potential release | Bands for consideration |
|---|---|
| Current priorities | • 700 MHz<br>• 2.3, 3.4 GHz<br>• UHF white space |
| High | • 1452-1492 MHz<br>• 1980-2010 / 2170-2200 MHz (2 GHz MSS)<br>• 3.6-3.8 GHz<br>• 5350-5470 MHz, 5725-5925 MHz |
| Medium-High | • 2.7-2.9 GHz<br>• 3.8-4.2 GHz |
| Medium | • 450-470 MHz[4]<br>• 470-694 MHz<br>• 1350-1518 MHz |

1.10 Whilst our focus to date has been on bands up to around 6 GHz, we also recognise that access to spectrum at much higher frequencies might be relevant in the longer term depending on technology developments.

1.11 In addition to continuing to progress our existing priorities (700 MHz, 2.3 GHz, 3.4 GHz and UHF white spaces), the next steps we propose as a result of the above prioritisation are as follows:

- We will continue to support the following bands as potential candidate bands for consideration at WRC-15: 1427-1452 MHz and 1452-1492 MHz (IMT designation), 2.7-2.9 GHz (Mobile allocation and IMT designation) and 3.6-3.8 GHz (Mobile allocation and IMT designation). Adding a mobile allocation (if not already present) and IMT designation at WRC-15 would create the option for future harmonised use of the band for mobile data, but would not require or commit a change of use.

- We will consider sharing opportunities identified in response to our spectrum sharing consultation, including further studying the potential for Wi-Fi to coexist with existing users in the proposed extension bands at 5 GHz. We will also further consider the longer term possibilities for mobile data services to share with existing users in the 3.6-4.2 GHz bands..

- In relation to the 1980-2010 / 2170-2200 MHz (2 GHz MSS) bands, we are in the process of assessing compliance with the common conditions[5] to determine whether it would be appropriate for us to take any further action. We will continue

[4] Consideration of the wider issues for this band (ie beyond potential use for mobile data) is already identified as priority in our spectrum management strategy
[5] As set out in Article 7(2) of Decision 626/2008/EC

to engage with the European Commission and other Member States to secure the efficient use of this spectrum.

- As regards the 470-694 MHz band, we will continue to engage in international discussions on the long term future of this band, and seek to ensure that consumers and citizens can continue to enjoy benefits delivered by Digital Terrestrial Television (DTT) and related Programme Making and Special Event (PMSE) use of the band. However we also recognise that there may come a point, in the longer term future, when more of this band might be used for mobile data.

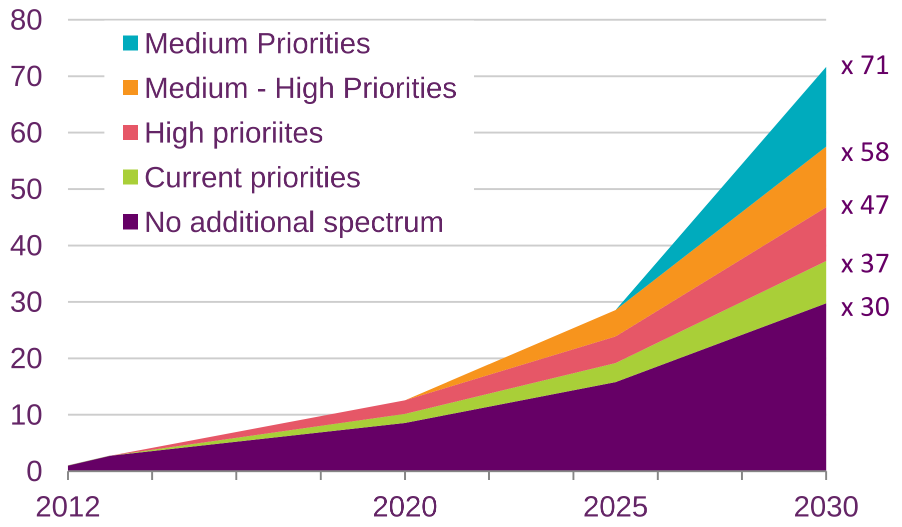
- As indicated in our spectrum management strategy, our priority work area on potential competing demands at 450-470 MHz will include consideration of the potential use of the band for mobile data in the UK recognising that there is already global harmonisation of the band for this use but also recognising the significant level of existing use for a variety of purposes.

1.12 The UK's next steps in international arena will be informed by a number of factors in addition to the band prioritisation we have proposed, including the Government's position and the degree of support (or opposition) to particular bands from other countries, noting the need to maintain a degree of flexibility in negotiations in relation to specific bands.

1.13 We also note that the Government's spectrum release programme is continuing to study the options for release of spectrum in 2.7-2.9 GHz and the possibilities for sharing in 1427-1452 MHz amongst other bands.

1.14 To illustrate what our proposed prioritisation might mean for consumers we have estimated the capacity boost that might result from using these bands for mobile data services in the years to 2030, taking account of future improvements in technology and greater roll out of networks (see Figure 1). This illustration assumes that high priorities are available by 2020, medium-high priorities by 2025 and medium priorities by 2030.

**Figure 1: Potential increase in mobile data capacity relative to 2012 (excluding offload onto fixed networks)**




1.15 In addition, consumers are likely to benefit from greater indoor use of Wi-Fi to 'offload' more mobile data onto fixed networks. Taken together, this additional capacity could enable more people to use mobile data services, more of the time; they will be able to use it at faster speeds and utilise more data hungry applications. For example a tenfold increase in network capacity could allow the delivery of data to be five times faster to twice as many users.

## Next steps

1.16 Following consideration of responses to this consultation, we expect to publish a statement in Q2 2014. This will establish our overall prioritisation of bands as well as our next steps with respect to them. In the mean time we will continue our active engagement in relevant international discussions, including preparatory work in the lead up to WRC-15.

1.17 We also recognise that these priorities will not remain static and will need to respond to market and international developments. Consequently, following our statement we expect to review these priorities periodically and/or to respond to major external developments, including in the international arena.

## Section 2

# Introduction

## Overview

2.1 The objective of our mobile data strategy is to identify and prioritise actions which Ofcom could undertake to facilitate the continued long term growth in consumer and citizen benefits from increasing use of mobile data services. In doing so we recognise that increases in the efficiency of delivering mobile data services, particularly through technology and network improvements, will be important for minimising the impact of this growth on other services.

## Background

2.2 Mobile data services, and the applications they support, already deliver substantial benefits to UK citizens and consumers. These services include provision of mobile broadband to consumer devices such as smart phones and laptops as well as emerging machine-to-machine data communications, for example to cars. At the same time, the demand for mobile data is growing rapidly and there are reasons to believe that this could continue to grow significantly in the future. Meeting this demand will present a range of challenges - including technical, economic and regulatory issues. The resulting need to develop a forward looking strategy in relation to mobile data was identified both in our 2013/14 Annual Plan and in our Spectrum Management Strategy consultation

2.3 The provision of mobile data services is closely related to the provision of wireless data services and, in particular, the use of Wi-Fi to connect to the Internet both at home and when out and about. Earlier this year we published a consultation[6] on the future role of spectrum sharing in delivering mobile and wireless data services (including Wi-Fi). Spectrum sharing could be an important element of future mobile data services both in terms of Wi-Fi provision and for increasing spectrum supply and better managing its use. Therefore the findings of that consultation will complement those of this document.

2.4 We are also developing this strategy in the context of a number of specific initiatives underway or recently completed that could support continued growth in mobile data over the coming years. These include, for example:

- the award of 2.3 GHz and 3.4 GHz spectrum;
- our UHF strategy on the potential future use of 700 MHz for mobile data services;
- our work on enabling the use of TV white space devices;
- preparing for Agenda Item 1.1 at WRC-15 (which is considering spectrum for mobile broadband services); and

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[6] Ofcom, The future role of spectrum sharing for mobile and wireless data services - Licensed sharing, Wi-Fi, and dynamic spectrum access, 2013, http://stakeholders.ofcom.org.uk/consultations/spectrum-sharing/

- our review of business connectivity markets (relevant for the provision of backhaul to mobile base stations).

2.5 Our mobile data strategy builds upon this existing work to identify priorities for additional future work.

## Structure of this document

2.6 The rest of this document is structured as follows:

- In section 3 we consider the growing demand for mobile data services, the challenges that this raises and why we think early preparation in relation to longer term *spectrum* options is the most important aspect for us to progress at present in addition to our existing priorities.
- In section 4 we set out our relevant powers and duties, the role of regulatory intervention in spectrum management, and the international context.
- In section 5 we outline changes to technology and network topology; we consider the possible future trends in these areas and their potential implications.
- In section 6 we set out our methodology for identifying and prioritising potential bands for mobile data use and set out a high level review of a number of bands before proposing an initial prioritisation of these bands.
- In section 7 we set out a range of spectrum scenarios based on our proposed priorities and illustrate the potential capacity implications of those scenarios.
- Section 8 identifies the next steps we are intending to take.

2.7 We invite stakeholders' comments on our analysis and proposals.

## Impact assessment

2.8 The analysis presented in this document constitutes an impact assessment (especially in Sections 3, 5, 6 and 7) as defined in section 7 of the Communications Act 2003.

2.9 Impact assessments provide a valuable way of assessing different options for regulation and showing why the preferred option was chosen. They form part of best practice policy-making.

2.10 We are required to carry out an impact assessment where our proposals would be likely to have a significant effect on businesses or the general public, or when there is a major change in Ofcom's activities. However, as a matter of policy, we are committed to carrying out impact assessments in relation to the great majority of our policy decisions. For further information about our approach to impact assessments, see the guidelines, '*Better policy-making: Ofcom's approach to impact assessment*', which are on our website.[7]

[7] http://stakeholders.ofcom.org.uk/binaries/consultations/ia_guidelines/summary/condoc.pdf

## Equality Impact Assessment

2.11 Ofcom is required by statute to assess the potential impact of all our functions, policies, projects and practices on the following equality groups: age, disability, gender, gender reassignment, pregnancy and maternity, race, religion or belief and sexual orientation. Equality Impact Assessments (EIAs) also assist us in making sure that we are meeting our principal duty of furthering the interests of citizens and consumers regardless of their background or identity.

2.12 We have not identified any particular impact of our proposals in relation to the identified equality groups. Specifically, we do not envisage the impact of any outcome to be to the detriment of any particular group of society.

2.13 Nor have we seen the need to carry out separate EIAs in relation to the additional equality groups in Northern Ireland: religious belief, political opinion and dependants. This is because we anticipate that our proposals will not have a differential impact in Northern Ireland compared to consumers in general.

## Section 3

# The mobile data challenge

## Overview

3.1 This section covers:

- The growth in demand for mobile data services;
- The challenges in meeting that demand, in particular recognising the competing demands for spectrum from others services, and hence in realising the potential for continued citizen and consumer benefits from that growth in the future;
- Ofcom's role in relation to addressing these challenges; and
- The focus of the rest of this document.

## Growing demand for mobile data

3.2 Mobile data services include the provision of mobile broadband to consumer devices such as smart phones and laptops as well as emerging machine-to-machine data communications, for example to cars. These services are typically delivered using wide area mobile networks as well as Wi-Fi access points. We most recently set out the growing demand for these services in our spectrum management strategy.

3.3 Over the past few years, the volumes of data carried over mobile networks have materially increased. The 2013 update of our Infrastructure Report[8] showed that data traffic carried by UK mobile networks went up by approximately 50% between June 2012 and June 2013 and more than doubled between March 2011 and June 2012 (see Figure 2 below).

3.4 Estimating the volume of data carried over Wi-Fi networks is more difficult, as the majority of use is likely to be over private networks, for which measurements are unavailable. However, it is possible to gauge the extent of Wi-Fi use more generally by looking at the volumes of data delivered over public Wi-Fi hotspots. The Infrastructure Report update noted that the total volume of data delivered by public Wi-Fi hotspots in June 2013 had risen by 188% compared with the same month in 2012, to almost 2,000,000GB.

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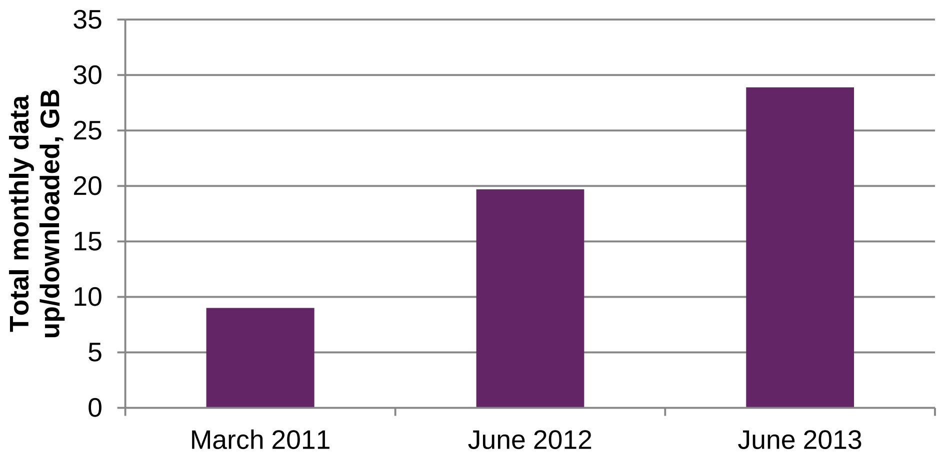
[8] Infrastructure Report: 2013 update, October 2013, http://stakeholders.ofcom.org.uk/market-data-research/other/telecoms-research/broadband-speeds/infrastructure-report-2013/

**Figure 2: Increase in data use on mobile networks**




3.5 Looking forward, data consumption by mobile devices over mobile and Wi-Fi networks might, according to one study, be as much as 80 times higher in 2030 than it was in 2012[9]. Whilst long term forecasts are inherently uncertain, they highlight potential developments that could have very important implications for Ofcom's future work.

## End user mobile broadband

3.6 The most significant factors driving demand for mobile data network capacity are the growth of demand for mobile data from end users, driven by the related trends of increasing adoption of data-enabled devices, and increasing usage of data-hungry applications. Our consumer research shows that, between Q1 2012 and Q1 2013, smartphone adoption grew from 39% to 51% of UK adults, and tablet adoption from 11% to 24%. UK households now have access to, on average, three different types of internet-enabled device[10]. These trends are expected to continue over the long term, with the vast majority of mobile phones becoming smartphones, and multiple device ownership also common.

3.7 Thus a growing proportion of the population is expected to demand data connectivity and typically the level of connectivity they demand is expected to grow. As the penetration of smartphones and tablets increases in future, the emergence of new types of data-capable devices (which could be linked, for example, to emerging trends around wearable technology) could give rise to further increases in demand for mobile data over the long term.

3.8 The increasing sophistication of devices will also mean that they are likely to support more data-hungry applications. Video traffic in particular is predicted to grow significantly (Cisco forecasts that two thirds of total global mobile data traffic will be video by 2017).

3.9 Although growing demands for mobile data capacity are likely to remain concentrated in densely populated areas, end-users' expectations could also evolve towards an increasingly widespread and homogenous coverage of high-speed wireless data

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[9] http://www.ofcom.org.uk/static/uhf/real-wireless-report.pdf
[10] *The Communications Market 2013* http://stakeholders.ofcom.org.uk/market-data-research/market-data/communications-market-reports/cmr13/

services. This may also imply that near-ubiquitous coverage, including the coverage of locations beyond commercial and residential premises, becomes increasingly important. The emergence of M2M applications (see below) could also increase the demand for ubiquitous coverage.

## Machine to Machine (M2M) communications

3.10 M2M communications involves connectivity to machines whose primary purpose does not require connectivity. For example, utility meters, vending machines and cars. Data transfer between these machines is usually initiated without human intervention.

3.11 M2M is often seen as a precursor to the Internet of Things (IoT), which involves adding connectivity to passive objects (e.g. a sensor in a dustbin that sends a message to the council when it is full) and the deployment of connected environmental sensors (e.g. remote temperature or pollution sensors). The IoT also presumes that data from all the connected objects is readily accessible by many different users (e.g. devices are connected to and accessible from the internet).

3.12 M2M applications are currently used in sectors such as utilities (smart meters), automotive (car parking recommendations), health (heartbeat or blood sugar monitoring) and security (alarms or CCTV). Some of these devices will be physically mobile (e.g. cars), whilst some will be stationary ("fixed"). Although both mobile and fixed M2M devices could place demands on the networks used to provide mobile data services, fixed devices could also use wired networks or fixed wireless communications (including short range devices), depending on practicability, performance and cost.

3.13 Compared to mobile broadband consumption, projected per-connection M2M data volumes, possibly with the exception of video surveillance, are likely to be low and can sometimes be scheduled off peak..

3.14 The machines involved in M2M communications may be in locations that are harder to cover by conventional mobile networks. For example, devices may be buried underground (water meters) or in unpopulated areas (for farming applications), compared to the places where consumer applications would typically be used. New automotive M2M applications, for example providing automated calls to the nearest emergency centre in case of car crash[11] and live traffic updates to navigation systems, could be dependent on the provision of reliable mobile data coverage across the road network. This means that many M2M applications might particularly benefit from a relatively low capacity but ubiquitous coverage layer hence relatively low frequencies.

## Indoor fixed wireless (Wi-Fi)

3.15 Wi-Fi plays an important role as an alternative way to deliver data to and from mobile devices, known as offloading. However, as Figure 3 illustrates, Wi-Fi is also increasingly used for in-building wireless networking between a range of fixed and mobile devices, including laptops, wireless speakers, games consoles, smart TVs and printers, as well as servers in an office environment. Much of the data

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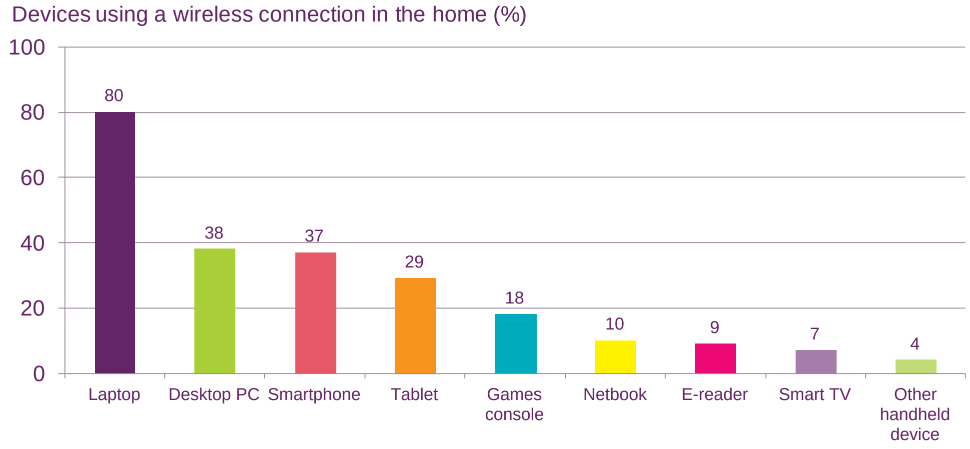
[11] For example eCall, a new service endorsed by the European Commission (see http://ec.europa.eu/information_society/activities/esafety/ecall/index_en.htm), live traffic updates to navigation systems, or longer term prospects for intelligent traffic systems interacting with automated cars.

communication between these devices is inherently intra-building in nature, for example a tablet streaming video to a TV or a laptop backing up large files to a local server. The volume of data demanded by these local area, intra-building uses is estimated to be much higher than that for mobile data offload. This suggests that in assessing overall demand for Wi-Fi, the data that these local area uses exchange should be the primary consideration with offloaded data of mobile devices secondary.

**Figure 3: Consumer use of wireless devices in the home, 2013**




Source: Ofcom Technology Tracker, Q1 2013

3.16 Historically, almost all Wi-Fi devices have operated at 2.4 GHz, leading to the potential for congestion in that band. A recent study conducted on our behalf measured utilisation of the 2.4 and 5 GHz bands by Wi-Fi equipment at various locations and found evidence of congestion in the 2.4 GHz band[12]. However, newer devices support operation at the less congested 5 GHz band and the emerging 802.11ac standard, which offers data rates in excess of 500 Mbps, will operate only in the 5 GHz band.

3.17 Given the likely future demand for data delivered over Wi-Fi it is important to assess whether additional spectrum will be necessary for Wi-Fi. A recent study conducted for Ofcom[13] indicated that the current allocation of spectrum for Wi-Fi may be under pressure by 2020 and that additional spectrum at 5 GHz may be required.

3.18 Our recent consultation on spectrum sharing[14] sought views on (amongst other things) whether additional spectrum for Wi-Fi at 5 GHz would be required, given the expected increase in demand and evolution of technology.

## Fixed broadband

3.19 Finally, there is a potential for greater use of wireless data services to provide an alternative to fixed broadband services. This is because it is challenging to provide

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12 Technical report, Utilisation of Key Licence Exempt Bands and the Effects on WLAN Performance, August 2013, http://stakeholders.ofcom.org.uk/market-data-research/other/technology-research/2013/key-licence-exempt-bands/

13 Technical report, Study on the Future UK Spectrum Demand for Terrestrial Mobile Broadband Applications, June 2013, http://stakeholders.ofcom.org.uk/binaries/consultations/cfi-mobile-bb/annexes/RW_report.pdf

14 Ofcom consultation, The Future Role of Spectrum Sharing for Mobile and Wireless Data Services – Licensed sharing, Wi-Fi and Dynamic Spectrum Access, August 2013, http://stakeholders.ofcom.org.uk/consultations/spectrum-sharing/

superfast broadband to some areas of the UK, where low population density combined with challenging topography means that fixed broadband deployment costs can be relatively high. Wireless data networks may offer an alternative in these areas in some cases. One recent example is EE's trial of 4G services in the Northern Fells, using LTE as an alternative to fixed-line services to provide superfast broadband to rural communities.

### Summary

3.20 In summary, it seems likely that demand for mobile broadband services will remain the most significant driver for mobile data capacity. Addition, coverage, in particular demand for increasingly widespread and homogenous coverage of high-speed services, will continue to be important for consumers and citizens. The importance for improved coverage could also be reinforced by the demands of emerging M2M applications.

*Question 1: Have we correctly identified the future characteristics of mobile data demand?*

*Question 2: Do you agree that there is a prospect of significant continuing growth in demand for mobile data services?*

## Challenges in realising citizen and consumer benefits

3.21 Meeting this growing demand could substantially increase the benefits from mobile services to consumers, and the UK economy more generally. Sustaining mobile broadband growth, including the delivery of high-capacity services to rural areas, could also make a significant contribution to citizen benefits, contributing to digital inclusion and facilitating social participation. Conversely, if the supply of mobile data services falls behind levels demanded, this could lead to a relative scarcity, resulting in higher prices and a loss of consumer benefit.

3.22 Realising these potential benefits is likely to depend on a range of factors, each of which has its own challenges.

### Continuing technology improvements

3.23 Large increases in the capacity and performance of mobile and Wi-Fi networks have been achieved to date through new technical standards that offer greater spectral efficiency than their predecessors. The challenge will be in sustaining the rate of innovation in the long term, with one study suggesting improvements in transmission technology could provide between 3 and 10 times more mobile broadband capacity between 2012 and 2030[15]. Industry led initiatives such as the 5G Innovation Centre (5GIC) are likely to be particularly important in addressing this challenge. Other technology innovations may be dependent on regulatory changes. For example we are working to enable access to TV white spaces and future work on spectrum sharing is a proposed cross-cutting theme in our spectrum management strategy.

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[15] Real Wireless, 2012, "Techniques for increasing the capacity of mobile networks 2012-2030", http://www.ofcom.org.uk/static/uhf/real-wireless-report.pdf

## Network deployments

3.24 The increasing use of small cells in mobile networks and offloading data onto fixed networks via Wi-Fi in areas of high demand may also be relevant to meeting growing mobile capacity needs. Challenges associated with growth of these could include:

- Availability of and access to suitable small cell sites including achieving the necessary planning consents for these sites[16]

- Backhaul from small cell sites to the core network, either using fixed wireless or wired (leased lines) connectivity. In relation to wireless backhaul, deployment of small cells may involve growing demand for quasi-line-of-sight and non-line-of-sight backhaul links. Our current thinking, outlined in our spectrum management strategy and drawing on an earlier review[17] is that there may not be urgent or significant constraints on future growth for these links although there is a question whether the growth of small cells might introduce new challenges. In relation to leased lines, the economics of providing high capacity fibre backhaul to remote mobile sites is likely to be a key challenge.

- The scope for offloading mobile data via Wi-Fi is dependent on availability of fixed broadband. First generation broadband networks are available to close to 100% of premises in the UK, and superfast broadband (speeds of over 30 Mbit/s) is now available to almost three-quarters of UK premises although there may remain challenges in extending superfast broadband to some hard-to-reach areas[18].

## Competing demands for spectrum

3.25 Our spectrum management strategy has identified a number of trends that point towards a significant increase in competing demands for key spectrum bands. At the same time as growing demand for mobile broadband capacity, spectrum requirements for other services are also likely to grow or, at the very least, remain stable. This is likely to lead to increasingly difficult choices associated with changing spectrum use, especially at lower frequencies;

3.26 That strategy also notes that growing demand for mobile broadband capacity could drive significant changes in spectrum use over the next 10 years. Key challenges in enabling additional spectrum to be made available for mobile data services, in the event that doing so would be beneficial for citizens and consumers, are:

- Achieving the necessary international agreements. Important international decisions will be taken at World Radiocommunication Conference 2015 (WRC-15) on bands suitable for future mobile use (specifically Agenda Item 1.1 at that conference) and preparations for this are already well underway. In addition, the

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[16] Similar concerns are addressed by the European Commission's proposal for a regulation of the European Parliament and the Council laying down measures for electronic communications and to achieve a connected continent (see, in particular, Article 15): https://ec.europa.eu/digital-agenda/en/news/regulation-european-parliament-and-council-laying-down-measures-concerning-european-single

[17] *Frequency Band Review for Fixed Wireless Service*, Aegis, November 2011, http://stakeholders.ofcom.org.uk/binaries/consultations/spectrum-review/annexes/report.pdf

[18] 2013 UK Communications Infrastructure Report http://stakeholders.ofcom.org.uk/binaries/research/telecoms-research/infrastructure-report/IRU_2013.pdf

Radio Spectrum Policy Group has recently published an Opinion[19] on the growing spectrum demand for wireless broadband and this might result in the European Commission adopting further binding decisions to make additional spectrum available for wireless broadband within the EU.

- Re-purposing from existing uses. Major changes in use of spectrum typically involve a number of complex steps, involving a combination of regulatory action and market mechanisms[20]. Where there is intensive existing use then clearing that use can take a number of years to plan and implement and can potentially be less disruptive to existing users if planned with sufficiently long lead times. For example, improvements in equipment standards for uses in neighbouring bands could reduce the impact of introducing mobile services but may take several years to permeate through the installed base of equipment.

- Sharing with existing users may take less time but still involves developing and implementing appropriate sharing mechanisms, some of which might be relatively novel, for example use of a 'white space' database or the development of 'sensing' techniques. In addition, effective sharing may depend on upgraded equipment with improved radio performance, which may take many years to be widely adopted by users.

3.27 Overall, the implication is that potential major changes in spectrum use often need to be considered many years in advance in order to secure appropriate international agreements and facilitate a smooth transition.

## Competitive markets

3.28 We consider that ensuring competition in mobile markets in the UK, to the benefit of UK citizens and consumers, continues to be an important objective. In our view, following the 4G auction there are four mobile network operators with sufficient spectrum to be credible national wholesalers in the UK, and we consider that this will help to ensure that the level of competitive intensity in the provision of mobile services is sustained.

3.29 We are also aware, however, that there is ongoing debate about the issue of further consolidation. Our view on the importance of competition does not mean that we are not open to considering proposals for further sharing of networks or even spectrum in future, as we have been in the past. However, we would need to be persuaded that any impact on downstream competition is the minimum necessary and consumers benefit as a result.

3.30 In addition, mobile data services are not only provided by traditional mobile networks using licensed spectrum. For example Wi-Fi, spectrum sharing, the use of white spaces and other innovative services may also have a significant role to play. Therefore there may well be scope for innovative and pro-competitive market entry in the provision of mobile data services and fostering these opportunities could be important.

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[19] *Strategic Challenges facing Europe in addressing the Growing Spectrum Demand for Wireless Broadband* https://circabc.europa.eu/d/a/workspace/SpacesStore/c7597ba6-f00b-44e8-b54d-f6f5d069b097/RSPG13-521_RSPG%20Opinion_on_WBB.pdf

[20] See section 4 of our Spectrum Management Strategy.

### Improving coverage

3.31 As a consequence of the 4G coverage obligation[21] we expect that high-speed mobile data coverage of UK premises will improve materially. That said, in future there may be increasing expectations and potential demand for ubiquitous coverage of mobile data services, extending to geographies other than population premises. For example, the benefits potentially offered by new automotive M2M applications could be dependent on the provision of reliable mobile data coverage across almost the entire road network. The commercial incentives to extend provision of mobile coverage are however likely to remain limited by the challenging economics associated with network rollouts in areas with low population densities and other hard to serve areas like roads and trains lines.

*Question 3: Have we identified all the challenges in realising future growth in citizen and consumer benefits from use of mobile data services and do you have any comments on the nature or the scale of the challenges we have identified?*

## Ofcom's role

3.32 Our principal duties under the Communications Act 2003 are to further the interests of citizens, and the interests of consumers, where appropriate by promoting competition. In doing so, we are also required (amongst other things) to secure the optimal use of spectrum, as well as to have regard to the desirability of securing the availability and use of high speed data transfer services through the United Kingdom, the desirability of encouraging investment and innovation, and the interests of consumers in respect of choice, price, quality of services and value for money.

3.33 This means that Ofcom has a potential role to play in relation to several, although not all of the challenges identified above. In many cases these are the subject of recent or ongoing work that we are undertaking. For others, any specific actions that may be appropriate will need to be considered in the future based on the facts of the specific case. Therefore, what is most important for developing our strategy is to identify the area(s) where additional work by us, beyond our current priorities, could be most effective over the coming years in helping to address the challenges associated with the future growth in mobile data services.

### Continuing technology improvements

3.34 Although technology improvements are likely to be largely driven by industry, one role for Ofcom is to understand future technology evolution so as to inform its policy in other areas. For example, we have recently joined the 5G Innovation Centre (5GIC) at the University of Surrey with this in mind. It may also be important for us to identify where there are enabling regulatory mechanisms necessary for example to support dynamic spectrum access. One example is our current work on UHF white space devices and in our spectrum management strategy we have proposed a cross-cutting priority for future work on spectrum sharing.

[21] The 4G coverage obligation on the 800 MHz spectrum lot acquired by O2 requires the provision of indoor coverage to 98% of UK households (corresponding to about 99.5% outdoor coverage). Competitive pressures and the effects of network sharing agreements could, in fact, result in increased voice and data mobile coverage offered by operators other than O2.

## Network deployments

3.35 Ofcom has existing roles in relation to backhaul – both in wireless and wired backhaul:

- In relation to wireless backhaul, we manage the licensing of wireless fixed links in a number of bands. A review of the management of these bands was undertaken in 2012[22]. One specific change we are currently considering[23] is in relation to the management and authorisation approach within the 71 - 76 GHz and 81 - 86 GHz (70 / 80GHz) bands, recognising the demand for high availability backhaul for 4G services.

- In relation to fixed (wired) backhaul, our role involves reviewing competition in the relevant markets and applying appropriate regulatory remedies to address any competition issues we find. Under the European regulatory framework we need to undertake these reviews every three years.

## Competing demands for spectrum

3.36 Ofcom has specific duties and powers related to spectrum management (see section 4) and we have an important role in supporting major changes in use of spectrum and international negotiations. Current major initiatives include: the award of 2.3 GHz and 3.4 GHz spectrum, taking forward our UHF strategy in relation to 700 MHz spectrum, enabling white spaces in UHF spectrum. Beyond these bands, making other bands available is likely to require a considerable amount of preparation as well as relevant international agreements. Hence there is need to develop our view on which bands should be considered in more detail and to inform our engagement in international discussions. This is a major component of the rest of this document.

## Competitive markets

3.37 Ofcom has a primary duty to further the interests of consumers in communication markets, where appropriate by promoting competition. We do so through different regulatory measures, including the adoption of appropriate rules on the acquisition of spectrum rights (for example the rules in the 4G auction to promote competition).

3.38 Looking forward, in the event that additional bands suitable for the provision of mobile services were to be awarded by Ofcom, we would consider whether there was a case for introducing measures in the award in light of our duties. For example, these could include measures to promote competition, such as reserved spectrum for entrants or smaller firms, or spectrum caps. Any such decisions would be based on an assessment of the specific circumstances of the award, and of the sector at the time of the award.

## Improving coverage

3.39 Ofcom has a role in supporting the delivery of wider social benefits from widespread mobile broadband coverage, for example through the 4G coverage obligation. However, conditions attached to spectrum licences are not the only tool for extending

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[22] *Review of the management of the spectrum currently used for point to point fixed links and other services that share this spectrum* http://stakeholders.ofcom.org.uk/consultations/spectrum-review/

[23] Review of the Spectrum Management Approach in the 71-76 GHz and 81-86 GHz bands http://stakeholders.ofcom.org.uk/consultations/70-80ghz-review/?a=0

coverage of mobile data services, and there may be a number of complementary actions. As set out in our spectrum management strategy, over the next few years our work on mobile coverage will include:

- continuing to monitor effective progress in UK premises coverage;
- considering ways to make sure information is available to consumers on coverage levels and the effective quality of experience offered by operators;
- exploring options to support improvements in geographical coverage of mobile voice and data services, including road and rail coverage; and
- considering the potential demand for near ubiquitous availability of mobile voice wireless data services, the role that public mobile networks might play in delivering this and whether any enabling action by us may be required.

### Summary

3.40 Ofcom already has an active programme of work relevant to many, if not all, of the challenges identified. However, given the potential magnitude of the challenges and the connections between them (which span a number of facets of our work - from ex ante competition policy to spectrum management to consumer information), it is important to ensure that the overall scope and balance of our activities remains appropriate to the task.

3.41 One area in particular where we have identified a need to develop a longer term strategy, above and beyond existing initiatives, is in relation to potential future spectrum options for mobile data services. This is because major changes in spectrum use often need to be considered many years in advance in order to secure appropriate international agreements and facilitate a smooth transition. In particular, at present we need to prepare for the forthcoming conference (WRC-15) which will take important decisions in relation to future bands for mobile use.

*Question 4: Have we correctly identified all the areas where Ofcom has a role in addressing the challenges of growing demand for mobile data services?*

*Question 5: Do you agree that the main additional area that our mobile data strategy needs to address is in relation to potential future spectrum options?*

*Question 6: Is Ofcom doing all that it needs to do in other areas identified as being relevant to the mobile data challenge?*

## Focus of the rest of the document

3.42 In the rest of this document we consider and prioritise the spectrum bands where it could be beneficial to undertake preparatory work, to better understand the options for future mobile use and, where appropriate, take action to create or maintain those options. Consistent with the long lead times often to bring about major changes of use of spectrum, it is important that this work looks to the long term – perhaps as far as 2030 - and beyond those bands that are already a priority for our current work (ie 2.3 GHz, 3.4 GHz, 700 MHz and UHF white spaces).

3.43 However, this document is not seeking to make final decisions about what spectrum will be released and when. This is a fast-changing sector, in which future demand and technological developments are subject to considerable uncertainty. The release of specific bands for mobile data use will depend in each case on an assessment, closer to the time of a possible release, of whether doing so is consistent with our duties. However, given the sometimes long lead times in changing the use of spectrum bands, it is important for us to plan ahead.

3.44 Of course given such long timeframes priorities will almost certainly change over time. Consequently in taking forward our strategy in relation to future spectrum options, we will continue to monitor the affected markets and international developments to ensure that our priorities remain appropriate in the future.

3.45 The next section sets out the context for our spectrum management considerations.

## Section 4

# Spectrum management context

## Overview

4.1 In section 2 we identified that the relevant focus for our mobile data strategy at this point should be in preparing for the possibility of additional future changes in spectrum use, if these turn out to be in the best interests of citizens and consumers.

4.2 In this section we set out the relevant context for considering potential future spectrum options for mobile data. The important pieces of context are:

- Our powers and duties in relation to spectrum management;
- The role of regulatory intervention and the implications for specific actions Ofcom may need to take;
- The international context, in particular WRC-15 and EU initiatives;
- Public sector spectrum.

## Ofcom's specific duties and powers related to spectrum management

4.3 Radio spectrum is a major asset to the UK and a key input to the mobile communications sector amongst many others. A recent study undertaken for Government indicated that spectrum contributes more than £50bn to the economy each year, and much of this value (£30bn) comes from public mobile communications.[24] As such, how spectrum is managed and made available for mobile data use is of critical importance.

4.4 The European Common Regulatory Framework for electronic communications,[25] in particular the Framework Directive and the Authorisation Directive, sets the broad framework for how spectrum use should be authorised and managed in the UK and aims to harmonise the regulation of electronic communications networks and services throughout the European Union. The UK's responsibilities for spectrum management under these Directives are given effect in UK law primarily through two Acts of Parliament:

- The Communications Act 2003 (the "2003 Act"); and
- The Wireless Telegraphy Act 2006 (the "WT Act").

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[24] https://www.gov.uk/government/publications/impact-of-radio-spectrum-on-the-uk-economy-and-factors-influencing-future-spectrum-demand

[25] The Common Regulatory Framework comprises the Framework Directive (Directive 2002/21/EC), the Authorisation Directive (Directive 2002/20/EC), the Access Directive (Directive 2002/19/EC), the Universal Service Directive (Directive 2002/22/EC) and the Directive on privacy and electronic communications (Directive 2002/58/EC), as amended by the Better Regulation Directive (Directive 2009/140/EC), www.ec.europa.eu/information_society/policy/ecomm/doc/140framework.pdf.

4.5 These Acts confer on Ofcom specific duties and powers in respect of spectrum (and the other sectors we regulate).

4.6 The 2003 Act and WT Acts set out a broad range of duties and powers, as well as a wide range of factors that we need to consider when making decisions on how to exercise our powers. Of particular relevance to the exercise of our spectrum functions, the 2003 Act sets out our principal duty to further the interests of citizens in relation to communications matters and of consumers in relevant markets, where appropriate by promoting competition. It also requires us to secure in the carrying out of our functions the optimal use for wireless telegraphy of the electro-magnetic spectrum. In performing our duty of furthering the interests of consumers, we must have regard, in particular, to the interests of those consumers in respect of choice, price, quality of service and value for money.

4.7 In carrying out our spectrum functions, we have a duty under section 3 of the WT Act to have regard in particular to: (i) the extent to which the spectrum is available for use or further use for wireless telegraphy, (ii) the demand for use of that spectrum for wireless telegraphy and (iii) the demand that is likely to arise in future for the use of that spectrum for wireless telegraphy. We also have a duty to have regard, in particular, to the desirability of promoting: (i) the efficient management and use of the spectrum for wireless telegraphy, (ii) the economic and other benefits that may arise from the use of wireless telegraphy, (iii) the development of innovative services and (iv) competition in the provision of electronic communications services.

4.8 We consider that, in general, the optimal use of spectrum is most likely to be secured for society if spectrum is used efficiently, i.e. it is used to produce the maximum benefits (or value) for society. We consider the benefits from efficient use to include those enjoyed by providers and consumers of services as well as the wider social benefits, or the indirect benefits, of services provided using spectrum.

4.9 In addition to our spectrum related duties, we have a wide range of other duties that can be impacted by, or delivered through, spectrum decisions. These include, amongst others, promoting competition and securing the availability throughout the UK of a wide range of communications services, including high speed data transfer services.

4.10 The WT Act and the 2003 Act specifically recognise that on occasion we will need to exercise our discretion in terms of the weight we give to different considerations in making spectrum policy decisions. As such we exercise a considerable degree of discretion in terms of the activities we undertake and the specific decisions that we take. The Acts also provide for Government to direct us to act where it has a specific view on how we should discharge our duties and exercise our powers, including in relation to our spectrum functions.

4.11 In addition to our functions under the Common Regulatory Framework, we have also been directed by Government to represent UK interests in negotiations within the main spectrum related international institutions, including the International Telecommunications Union (ITU), the European Conference of Postal and Telecommunications Administrations (CEPT), and spectrum committees of the European Union (also see below for the relevance of these institutions).

## Our spectrum management strategy and the role of regulatory intervention

4.12 In exercising our discretion regarding how we can best fulfil our duties as they relate to spectrum, it is important that we take a strategic approach to managing this scarce and valuable resource. We have set out our general spectrum management strategy in our October consultation.[26]

4.13 In applying this strategy to mobile data services, it is useful to consider what might happen if demand for mobile data (including demand for high speeds and good coverage) grows quickly, but supply (whether by traditional networks or innovative services) were constrained to grow more slowly. There is a risk that such an outcome could lead to higher prices for mobile data services, weaker competition in the provision of these services, and lower growth in consumption than might have occurred in the absence of this constraint. Higher prices, reduced competition, and slower-than-predicted growth in mobile data traffic would not be in the interests of consumers of mobile data services.

4.14 However, we recognise that, at least in principle, such an outcome might reflect that there are higher-value alternative uses for spectrum in the bands we are considering i.e. for spectrum which might otherwise have relieved this capacity constraint. A change in the use of a band from its existing use to mobile use will not necessarily be in the best interests of citizens and consumers. There are competing demands for spectrum, and most of the spectrum bands which we will go on to consider are currently in use. Releasing a band exclusively for use by mobile networks therefore entails an opportunity cost in that it is no longer available for other uses (shared use of spectrum for different purposes, including mobile data, may be possible but will not always be practical or optimal.) In addition, changing the use of a spectrum band can entail significant transitional costs to the private sector, government, or consumers. This is because such a change can involve moving the existing users out of a spectrum band and mitigating the impact of interference from the introduction of new services into the band.

4.15 Our recent Spectrum Management Strategy consultation confirms that "once the conditions required for the use of market mechanisms are in place, they are generally considered the most effective method of allocating scarce resources to ensure they are used efficiently." The consultation lists these market mechanisms: auctions; incentive-based spectrum pricing (i.e. prices which reflect the potential value of spectrum to alternative users); trading and leasing; and liberalisation to allow change of spectrum use without requiring Ofcom to vary licences.

4.16 Ideally, we would allow market forces to determine the optimal allocation of spectrum between uses. For example, higher prices for mobile data services, as described above, could act as a signal that there was more value in using spectrum to provide such services than in other applications. Companies wishing to provide new or additional mobile data services could respond to this by acquiring spectrum from other (non-mobile) users. The difficulty, however, is that bringing about a major change of use of spectrum is not a straightforward process and, without Ofcom's involvement, might not occur even if it is in the interests of citizens and consumers,

[26] Spectrum management strategy: Ofcom's approach to and priorities for spectrum management over the next ten years, 2 October 2013 http://stakeholders.ofcom.org.uk/consultations/spectrum-management-strategy/

or might be subject to unnecessary costs or delays. Some of the reasons for this are discussed in our Spectrum Management Strategy consultation (paragraph 1.14):

- A major change of use typically requires international coordination, because internationally-harmonised spectrum use enables economies of scale, e.g. in the production of handsets and other devices;
- New high power uses need to be coordinated across borders to avoid harmful interference;
- A major change of use will normally involve vacation of the band by incumbent users, and changes to the interference environment that could have negative effects on users of adjacent spectrum. These processes can be complex, making it hard for the market to reach a coordinated solution.

4.17 For these reasons, there may be situations in which market mechanisms alone are unlikely to deliver the greatest value to society from spectrum use. Therefore failure to plan ahead in this way would create a risk that optimal changes of use will not occur in a timely fashion, leading to higher prices for mobile data services than would otherwise occur, and lower growth in mobile data traffic, with the UK potentially falling behind other countries.

4.18 In practice the type of actions Ofcom may take to better understand or enable a possible change of use include:

- Initial research to better understand the feasibility and potential cost of any changes. This may include investigating coexistence between mobile services and the incumbent users (in the case of sharing) and the adjacent users (in the case of clearance or sharing);
- Developing a high level view on the range of options for use of the band and a high level strategy on how change might come about;
- International engagement to support appropriate international agreements at ITU and European level (see below);
- In some cases we may also help to develop mitigation solutions to limit the impact on existing and/or adjacent users;
- Providing appropriate incentives or conditions for the market to lead to a change of use e.g. through spectrum pricing, clarification of existing rights, liberalisation or possibly through the use of overlay or incentive auctions.

4.19 One of the purposes of this consultation is to help prioritise where, i.e. which specific bands, we should focus our efforts with respect to these types of actions in the future.

4.20 In some cases enabling actions such as these may be sufficient for the market to reach a socially optimal outcome. However in other situations it may be necessary for Ofcom to take further action. The additional actions we may take, sometimes in combination with Government, could include making a decision to clear spectrum of existing users (with any decisions on funding the costs of clearance ahead of an award being a matter for Government); an assessment of the economic viability of change; implementing the clearance of incumbent users and managing mitigation of coexistence issues.

## International context

4.21 The UK's use of spectrum is determined within an international context. This is particularly the case in relation to mobile services, which exhibit very large economies of scale in equipment, with mass market mobile handsets typically being produced at the largest global scale possible and the number of regional variants kept as small as possible. In addition, harmonisation can allow people to use their mobile devices in many other countries without modification. Below we set out the international institutions and processes that are most relevant to the development of our mobile data strategy in the UK.

### ITU World Radiocommunication Conference 2015

4.22 The ITU is a specialised agency of the United Nations, which harmonises the allocation of spectrum internationally. It does so through the ITU Radio Regulations, which are amended approximately every four years by World Radiocommunication Conferences (WRCs). Ofcom takes the lead for the United Kingdom (UK) in WRC negotiations under direction from the Government. We are therefore actively engaged in UK, European and international preparations for the next WRC in 2015 (WRC-15).

4.23 WRC-15 Agenda Item 1.1 concerns the availability of spectrum for mobile broadband applications over the next 10 to 15 years. It will therefore consider options for new frequency allocations suitable for mobile broadband (including Wi-Fi) and identification of frequency ranges as suitable for International Mobile Telecommunications (IMT), the ITU term that encompasses 3G, 4G and 5G wireless broadband systems.

4.24 The ITU's Radio Regulations contain a Table of Frequency Allocations. The Table sets out the status of the radiocommunication services (such as Fixed, Mobile, Broadcasting and Satellite) in each frequency band with respect to neighbouring countries. Within a frequency band, uses with a 'primary' allocation may claim protection from interference from uses in neighbouring countries which have a 'secondary' allocation or no allocation at all. Throughout this document we use the term 'mobile allocation' as shorthand for a primary allocation to the mobile service in ITU Region 1

4.25 Mobile data applications fall within the scope of the mobile service. The service definitions can cover a variety of applications and systems, and so 'identification' is an additional measure that has been used to indicate the bands that are suitable for use for a particular system. Although identification for IMT does not elevate its regulatory status, there is merit in this process as the frequency bands so identified become the bands that administrations around the world are most likely (but not compelled) to make available for that purpose. These are the bands where high volumes of equipment are developed and the benefits of economies of scale flow from this, as well as the benefits of inter-operability within and across different countries.

4.26 Preparatory work for WRC-15 agenda item 1.1 is taking place in Joint Task Group 4-5-6-7 (JTG 4-5-6-7) of the ITU and in Conference Preparatory Group Project Team D (CPG PTD) of CEPT. The CEPT consists of 48 member countries, including all EU Member States. It undertakes technical analysis to facilitate spectrum harmonisation in Europe and is also responsible for developing European positions for WRCs. Ofcom is closely engaged in discussions in the ITU-R and CEPT groups.

4.27 If WRC-15 identifies spectrum for IMT this does not necessarily mean that it will be used for that purpose in the future in the UK. Ofcom would need to consider such policy decisions at a later point, taking account of any relevant harmonisation measures, such as non-binding CEPT ECC Decisions or legally binding European Commission decisions (see below); Ofcom's statutory duties; and applicable EU law. On the other hand, if WRC-15 does not identify a spectrum band for IMT then it is somewhat unlikely that it will be used for that purpose in the UK.

## European Union

4.28 Within the European Union, the Radio Spectrum Policy Programme (RSPP) has set out a series of policy objectives, including an obligation on member states to make every effort to identify at least 1200 MHz of spectrum for wireless data traffic (to consumer devices) by 2015. European member states and the Commission are currently implementing the provisions set out in the RSPP.

4.29 The European Radio Spectrum Policy Group (RSPG) – which provides strategic advice to the European Commission (EC) on matters of spectrum policy – is also undertaking work in this area. Of most relevance is the RSPG Opinion on strategic challenges facing Europe in addressing the growing spectrum demand for wireless broadband[27], which was adopted in June 2013. This includes an analysis of bands between 400 MHz and 6 GHz which are currently available, or more significantly could become available in future, for wireless broadband.

4.30 This analysis has some clear parallels with the preparations for WRC-15 and it is likely that the Opinion will influence the European Common Proposals that will be developed in advance of the Conference. Nonetheless the RSPG Opinion is at this stage distinct and different from the work being undertaken for Agenda Item 1.1, not least in that the RSPG work includes those bands which are already identified for IMT in the ITU Radio Regulations. In addition, while the ITU and work in CEPT is focused around technical aspects relating to the WRC Agenda, the RSPG work and in particular the interests of the EC tend to be more focused around broader political and strategic discussions. It seems likely that the EC may seek to engage more closely in some key policy aspects of the WRC agenda, especially the agenda Items on wireless broadband, as we get closer to the start of the Conference.

4.31 The Commission also has at its disposal the option to propose binding regulatory measures upon member states where related to spectrum use. Established by the 2002 Radio Spectrum Decision (676/2002/EC), the Radio Spectrum Committee (RSC) assists the Commission in the development of technical implementing decisions to ensure harmonised conditions across Europe for the availability and efficient use of radio spectrum. EC harmonisation conditions, in the form of EC Decisions, exist for a number of the bands mentioned in this consultation. These technical conditions are normally drawn from the outputs discussed in CEPT, ITU and the appropriate standardisation bodies. In fact the Commission mandates CEPT to undertake technical work to determine these technical conditions which are then used in the development of the EC harmonisation measure. These conditions, where within a harmonisation measure, directly inform the technical conditions that will ultimately be licensed in the UK.

[27] https://circabc.europa.eu/d/a/workspace/SpacesStore/c7597ba6-f00b-44e8-b54d-f6f5d069b097/RSPG13-521_RSPG%20Opinion_on_WBB.pdf

4.32 The Commission has also recently published a draft regulation laying down measures aiming to promote the single European market for electronic communications. This includes spectrum provisions covering the bands which have been harmonised through EC Decisions for wireless broadband communications. The proposals include measures which, if adopted, would have the effect of imposing greater harmonisation around the timing and form of spectrum auctions and assignments; and would determine criteria that Regulatory Authorities would need to take into account in developing authorisation conditions. However the proposals, which are much wider than just spectrum and cover other important aspects of telecoms regulation, are currently the subject of debate in the European Parliament and Council and it remains unclear at this stage if they will be adopted in their current form.

## Public sector spectrum

4.33 The release of public sector holdings could make a significant contribution to future spectrum availability for mobile broadband. The Government plans to release 500 MHz of public sector spectrum into civil use by 2020. This will begin in 2015/16 with the award by Ofcom of 190 MHz of spectrum previously used by the Ministry of Defence (MoD) in the 2.3 GHz and 3.4 GHz spectrum bands. In addition, a number of the bands discussed in this document are used by the public sector and therefore it will be important to take a coordinated approach across civil and public sector holdings. Government is leading on this issue through its plans for an overarching UK Spectrum Strategy to be published in early 2014.

## Section 5

# Technology drivers of change and implications for spectrum

## Overview

5.1 This section considers relevant trends in technology and network topology affecting the long term demand for spectrum for mobile data services, which, together with the analysis in preceding chapters, provides the context for our prioritisation of bands in section 6.

5.2 In considering these trends, our aim is to understand what the long term picture might eventually look like. Therefore, even where we identify developments that could happen relatively soon, we do not need to consider exactly when and how they might play out over the next few years, only the direction of travel and where they might end up in the long term.

5.3 The rest of this section covers:

- Trends in mobile technology and network topology that may help to address the demand for more mobile data and may have implications for the relative demand for different types of spectrum.

- The most important trends are then brought together to outline the spectrum implications for different types of mobile data use.

## Technology and network topology trends and their implications

5.4 There are two key trends that can help satisfy the increasing demand for mobile data services and influence the future demand for different types of spectrum. They are:

- Deploying networks and devices based on technologies that are more efficient; and

- Deploying network architectures, or topologies, that use spectrum more efficiently or facilitate access to a broader set of access networks.

5.5 An overriding objective in both cases is to improve the use of spectrum, and there are inevitably some links between them. For example, the use of a technology operating in a particular frequency band may require the adoption of a different network topology. In reviewing these trends we have taken a holistic view that looks across all types of networks. and that does not presuppose either licensed or licence exempt spectrum use.

5.6 To date, use of spectrum to provide mobile services has largely been under individual licences which allow high power use of spectrum from outdoor base stations covering a wide area. Lower frequency spectrum, below 1 or 2 GHz, has been particularly valuable because of its superior propagation characteristics. This has started to be augmented by offload onto Wi-Fi.

5.7 While this is likely to remain a significant, if not predominant, model for network design, the technological changes identified below have the potential to change it in a number of ways. Overall these seem to suggest that *higher frequency* spectrum and *shared use* of *spectrum* may have a larger role to play in the future than to date, relative to low frequency spectrum and individual use. However, some developments such as small cells and use of very high frequencies may be limited to more densely populated areas, implying that the model of high power macro cells is likely to remain the dominant model in less densely populated areas.

5.8 In general, the demand for spectrum is driven by coverage, capacity and performance (e.g. improved user data rate) requirements. For coverage, lower frequencies are important due to their propagation advantages. For capacity, large bandwidths are important to enable the support of multiple users simultaneously. For performance, the availability of wide, preferably, contiguous blocks of spectrum in order to support wide channel bandwidths to deliver high data rate services are important. Larger bandwidths in contiguous frequency blocks tend to be more readily available at higher frequencies. Trends in technology are often only relatively weakly related to frequency. Technology adapts to make the most efficient use of the available frequency resource. Certain advances enable use of frequencies that were previously un-usable from a practical point of view.

5.9 Below we summarise a number of key technology and network topology trends and, as far as possible, we outline the potential spectrum implications of these trends. More detail is provided in Annex 5.

## Improvements in spectral efficiency

5.10 Many of the individual technology trends outlined in the sub-sections below lead to a overall improvement in the spectral efficiency of mobile networks. Specific techniques such as higher order modulation schemes, interference cancellation and equalisation are also important.

5.11 Previous research undertaken for us by Real Wireless[28] [29] has reviewed the potential for increases in spectral efficiency over the period to 2030 and the technologies that might enable that. For example, they estimate that between 2015 and 2020 spectral efficiency will increase by 1.6 times, with a further 1.7 times increase between 2020 and 2025.

5.12 Improvement in spectral efficiency mitigates the demand for additional spectrum as it enables more data to be carried for a given bandwidth.

## Support for wider channel bandwidths

5.13 As the demand for mobile data grows the need for networks to support wider channel bandwidths has also grown. Wider channel bandwidths allow data to be transmitted at higher data rates and mobile technology has evolved to utilise wider and wider channels. For instance legacy 2G technology utilises 200 kHz channels whereas today's 4G technologies based on LTE-Advanced utilise carriers up to 20 MHz wide

[28] Technical report, Study on the Future UK Spectrum Demand for Terrestrial Mobile Broadband Applications, June 2013, http://stakeholders.ofcom.org.uk/binaries/consultations/cfi-mobile-bb/annexes/RW_report.pdf
[29] Technical report, Techniques for Increasing the Capacity of Wireless Broadband Networks: UK 2012-2030, April 2012, http://www.ofcom.org.uk/static/uhf/real-wireless-report.pdf

which can be aggregated to make a combined carrier of 100 MHz and offer headline data rates in excess of 1 Gbps.

5.14 Demand for spectrum where wider channel bandwidths can be supported is likely to increase. This may need to be at higher frequencies where wider bandwidths in contiguous frequency blocks tend to be more readily available.

5.15 Techniques, such as carrier aggregation across multiple bands, may mitigate this demand somewhat though this is likely to be at the price of more complex equipment and relatively poorer device performance.

### Advanced antenna techniques

5.16 Multiple Input Multiple Output (MIMO) antenna techniques are commonly deployed by current 3G, 4G and Wi-Fi networks. They improve link performance by allowing multiple steams of data to be sent concurrently. Present systems are typically 2x2 (i.e. 2 antennas at the base station and 2 antennas at the terminal) or 4x4 but the latest LTE-Advanced specification allows up to 8x8 antenna systems.

5.17 Such systems allow improved link performance but at the cost of equipment complexity and potentially reduced battery life. Deploying multiple antennas on both bases stations and handsets can also be subject to practical constraints. For mobile terminals in particular, incorporating the necessary multiple antennas can be a real challenge. Use of higher frequencies may help as antenna size is smaller for higher frequencies. For spectrum below about 2 GHz only 2x2 or 4x4 MIMO may be practical, whereas for frequencies above about 3 GHz 8x8 MIMO becomes a much more practical proposition.

5.18 Recent advances have seen the emergence of more sophisticated multiple antenna techniques such as beam-forming based on so-called massive MIMO systems. These systems may allow the exploitation of higher frequency bands so far un-used by current mobile broadband technologies by overcoming some of the associated propagation constraints. These systems require a very large number of antennas (many 10s or even a 100 or more) and thus are only practical at relatively high frequencies (e.g. above about 10 GHz).

### Development of technologies that can deal with traffic asymmetry (between uplink and downlink)

5.19 Mobile data demand in the future is likely to be driven strongly by services which are predominantly downlink oriented, e.g. video. The delivery of these services using paired spectrum with equal quantities of uplink and downlink spectrum (as is the case with the majority of commercial networks today) may no longer be the most optimal approach. Technologies based on time division duplex (TDD) rather than frequency division duplex (FDD) may help to address this as the amount of uplink and downlink capacity can be more easily adjusted to better match demand. Other technology developments such as supplementary downlink (SDL) may also help by adding additional downlink spectrum capacity to existing paired FDD arrangements.

5.20 Demand may increase for unpaired spectrum suitable for the deployment of technologies such as supplementary downlink (SDL) and TDD.

## Co-ordination between base stations

5.21 The move towards heterogeneous networks with different cell types potentially operating in the same frequency bands (e.g. macro cells and pico/femto cells all operating on the same carrier) requires careful management of interference between the different network layers. This has led to development of advanced coordination techniques between the different cell types and base stations. This coordination allows the efficient utilisation of network resources and a reduction of interference in the network. This improves spectral efficiency thus mitigating demand in the access network. However, such coordination requires fast links between base stations either via fibre or fixed wireless links, hence demand for spectrum suitable for fixed wireless links may increase.

## Spectrum sharing

5.22 There are a number of instances where spectrum assigned for a particular use is not in use all the time and/or in all places. Examples include TV broadcast spectrum and much of the military use of spectrum. This un-used spectrum (sometimes referred to as ‘white space’) could potentially be used for other purposes on a shared basis. There are a number of technology developments that can facilitate this sharing by providing accurate information about how spectrum is actually used at a particular location and time. Two emerging approaches are *geolocation databases* and *spectrum sensing*.

5.23 Access to spectrum on a shared basis may provide a useful source to meet the growing demand for mobile data.

## Development of broadcast capability for mobile terminals

5.24 There is growing demand for the delivery of broadcast content via mobile networks; this may be in the form of linear or non-linear content driven by services such as the BBC’s iPlayer. In addition, there is currently a debate about the future delivery of broadcast content to conventional TVs using LTE services such as Evolved Multimedia Broadcast Multicast Service (eMBMS) and the potential development of a converged mobile/broadcast platform.

5.25 This may lead to the same spectrum being used to deliver broadcast TV to homes and mobile devices thus reducing the overall demand for spectrum for the delivery of these services.

## Mobile device support for multiple bands

5.26 As mobile technology has evolved from generation to generation and the demand for mobile data has increased, the number of frequency bands mobile handsets are required to supports has increased. In the UK there are 6 or 7 spectrum bands in widespread use for mobile services which need to support up to 3 mobile technology generations (2G, 3G and 4G) and Wi-Fi. And the number of bands is expected to increase still further.

5.27 In general, the more bands that a handset is required to support, the more complex the handset need to be, the greater the challenge in integrating this in to a device This inevitably leads to relatively poorer device performance than would otherwise be the case.

5.28 It is likely to be easier and less expensive to integrate new bands in a device if they are closer in frequency to bands already in use as it is more likely that components can be shared. This may be reflected in the relative demand for new bands that are close in frequency to existing ones.

### Other developments that might influence demand

5.29 The development of greater storage capacity in mobile devices allows users to locally store data that they might otherwise have to access over the network, e.g. videos, music, photos, maps, etc. Other developments might also reduce the amount of data needing to be sent across the network e.g. improvements in data compression techniques.

5.30 Such developments mitigate the demand for additional mobile spectrum as they reduce the amount of data needing to be carried.

### Smaller cells

5.31 Demand in a mobile network can be very localised with traffic hotspots developing in predictable locations. It can be more efficient and cheaper to cover these areas with small (micro and pico) cells than by a traditional large (macro) base station. There is a general trend to deploy more and more small cells and we expect their number to proliferate significantly in the future. These small cells can utilise much lower powers and hence the propagation constraints of higher frequencies are less important than they are for the provision of a contiguous coverage area from macros base stations. Other developments such as greater coordination between base stations enable traffic to be managed more efficiently in a network comprising a mix of small and large cells and reduce the overall level of interference.

5.32 Though small cells can be deployed in any frequency band, the lower power and coverage requirements of small cells mean that they can take advantage of higher frequencies that otherwise are challenging to use for the provision of more ubiquitous coverage from macro sites.

### Automatic switching between cellular and Wi-Fi networks

5.33 Wi-Fi offload is playing an increasingly important role in the delivery of services to mobile devices. However, one of the current impediments to greater use of Wi-Fi, especially outdoors, is the inability of mobile devices to seamlessly and efficiently move between cellular and Wi-Fi networks. There are a number of initiatives currently looking to address this issue including Hotspot 2.0 from the Wi-Fi Alliance, Access Network Discovery and Selection Function (ANDSF) from 3GPP and Next Generation Hotspot (NGH) from the Wireless Broadband Alliance.

5.34 Automatic switching to Wi-Fi networks will mitigate demand for spectrum for cellular networks but will place additional demands on Wi-Fi spectrum, although the demands on that spectrum from fixed applications, such as video distribution in the home, may be significantly higher than offload traffic requirements.

### Load balancing

5.35 Load balancing refers to traffic management at the network level aimed at optimally distributing traffic across different network layers and different frequencies. Load balancing can for instance reduce congestion by appropriately managing traffic between different type of base station (e.g. between macros cells and small cells). It can also allow better utilisation of different frequencies by for instance reserving lower frequencies for users in harder to serve locations.

5.36 Load balancing increases the effective spectral efficiency of the network thus mitigating the overall demand for spectrum. It may also help to reduce overall demand for additional low frequency spectrum as this can be more efficiently targeted on users in harder to serve locations.

*Question 7: Do you agree with our high-level assessment of likely technology and topology trends and their implications for future spectrum use? We are particularly interested in views on:*
*a) the potential demand for spectrum above 10 GHz;*
*b) the potential impact of integrating broadcast capability into mobile networks;*
*c) whether the technical and commercial challenges of supporting additional frequency bands in mobile devices drives interest towards bands close in frequency to existing bands;*
*d) the relative importance of large contiguous blocks of spectrum versus aggregation of smaller blocks*

*Question 8: Are there any additional technology or topology trends that we need to consider that could have an effect on spectrum use?*

## Implications for spectrum demand for different uses

5.37 In this sub-section we bring together the trends in demand (discussed in section 3), with the technology and topology trends identified above to consider what the most important spectrum implications are for different types of mobile data use. These are summarised in Table 2.

### Implications for indoor use

5.38 Historically, a particular challenge for mobile networks has been to provide good quality indoor service. This is because services are generally provided from outdoor base stations and therefore signals have had to penetrate building walls. However, a number of longer term developments are could shift that picture somewhat, including:

- Support for Wi-Fi in all mobile devices;
- Seamless authentication and handover for Wi-Fi traffic;
- Greater use of femtocells; and
- Greater penetration of superfast broadband.

5.39 Together these could mean that more indoor mobile data traffic will be offloaded onto fixed networks via indoor access points, whether these are Wi-Fi routers or femtocells. There remains a question over how commercial models and consumer use will evolve to enable this – today not all access points, certainly not residential ones, are open. However it seems plausible that in the long term a model that supports open access could emerge and become widespread. Initiatives like BT FON might be seen as an early step towards this.

5.40 This shift might have a number of implications for spectrum use.

- First, it enables a much higher degree of spectrum re-use (i.e. a much denser network with access points, potentially in every building, with walls helping limit inference to neighbouring users), so delivering more capacity per MHz than traditional networks.

- Second, the spectrum used for providing indoor services can be lower power and/or higher frequency compared to that used for coverage from outdoor base stations

- Thirdly, if the use is constrained to be indoors, there may be some potential for sharing spectrum with other (incumbent) outdoor uses of the spectrum.

5.41 In addition, increasing the proportion of traffic offloaded also benefits users even when they are not covered by a Wi-Fi hotspot or femtocell. This is because it makes more capacity available on the ‘mobile’ network.

5.42 Therefore, actions that could support increased use of offload in the future could be particularly beneficial. Continuation of our work to promote competition in the supply of fixed broadband will also be important to enable the fixed network part of the story.

5.43 Nonetheless, we expect provision of indoor coverage from outdoor base stations will still be needed as indoor offload is unlikely to be completely ubiquitous. However, it is possible that this capacity may be targeted at a lower proportion of traffic than before.

### Implications for capacity in easier to serve environments (outdoors and more densely populated areas)

5.44 A key development relevant here is the likely greater deployment of small cells. These would be aimed at boosting capacity in traffic hotspots and typically have smaller radius and use lower powers. Use of higher frequencies and/or lower powers, but with relatively large bandwidth, will be important to support small cell use. These frequencies might also be important for backhaul from these small cell sites. The other implication is that access to higher frequencies for small cells may be less important in less densely populated areas where larger cells are typically deployed. An idea already floated in our spectrum sharing consultation is that this might create the possibility for geographic sharing with other users of the spectrum who operate in the less densely populated areas.

5.45 In the shorter term, the release of public sector bands 2.3 GHz and 3.4 GHz is likely to be an important source of additional capacity. In the longer term, other bands around 2-6 GHz could be important for boosting capacity and also potentially at much higher frequencies (e.g. 10 GHz or higher), especially if advanced antenna techniques become viable.

### Implications for coverage and capacity in harder to serve environments (including less densely populated areas)

5.46 Despite a range of technical and deployment innovation our proposition is that the mobile data user experience at the ‘edge’ of the network, in the hardest to serve places, is likely to continue to depend on sub 1 GHz, or possibly sub 2 GHz spectrum. This is not simply an issue for less densely populated areas as it also affects transport routes, some parts of towns and cities, and those indoor areas not adequately served by Wi-Fi or femtocells.

5.47 In addition, there is an argument that future innovation in machine-to-machine (M2M) applications could particularly benefit from a relatively low capacity but *ubiquitous* coverage layer. This is because such applications probably will demand significantly less in capacity per device than consumer driven content, but could benefit from having access to very reliable data communications wherever they are (e.g. for mobile payment applications). We have commissioned a technical study on M2M and its findings will inform any additional work in this area.

5.48 Consequently, lower frequency spectrum will be important for improving the minimum throughput that can be reliably and consistently delivered in the areas where there is already coverage today, and possibly for extending mobile data service to currently uncovered areas, to give a (near) ubiquitous service.

5.49 The proposed harmonisation and release of the 700 MHz band could make an important contribution, to improving performance within current mobile network coverage areas. For M2M applications, relatively narrow bandwidth at even lower frequencies, say below 500 MHz bands might also be relevant.

**Table 2: Summary of drivers of change and spectrum implications**

| Environment / use | Most important drivers of change | Potential spectrum implications |
|---|---|---|
| ***All environments*** | • The efficiency of technologies used to deliver mobile and wireless services is continuing to improve, meaning that more data is able to be delivered in the same bandwidth<br>• The move towards the support of wider channel bandwidths is driving the support of higher peak data rates | • In principle, increases in efficiency could lead to a reduction in the rate at which demand for spectrum increases<br>• Demand may increase for spectrum at higher frequencies, where it is easier to support wider channel bandwidths. |
| ***Indoor use both at home and away from home.*** *(around 75% of data use is indoor today and may increase)* | • In the future seamless authentication / handover for Wi-Fi traffic and greater penetration of superfast broadband could result in ‘offload’ via Wi-Fi (and possibly femtocells) becoming a more important, but not exclusive, way of providing indoor service. | • Additional spectrum for indoor use from indoor access points can be mainly at higher frequencies and/or used at lower power compared to that used for coverage from outdoor base stations |
| ***Easier to serve environments*** *(outdoors and more densely populated areas)* | • Expect greater deployment of small cells which are aimed at boosting capacity in traffic hotspots. These typically cover smaller areas and use lower powers than traditional macro cells<br>• In the longer term much higher frequencies could be usable in these environments | • Spectrum operating at higher frequencies and/or lower powers can be used to support small cells.<br>• Sharing may have a role as additional spectrum will be most important in more densely populated areas where small cells deployed<br>• Similar spectrum might be used for backhaul from small cell sites. |

| | | |
|---|---|---|
| ***Harder to serve environments*** *(less densely populated and other harder to serve environments. incl roads, parts of towns & buildings without 'offload')* | • The user experience in these areas is likely to continue to depend on lower frequency (below 1 GHz, or possibly below 2 GHz) spectrum | • Lower frequency spectrum will continue to be important for improving data rates within today's footprint. |
| ***Machine-to-machine*** *(M2M) use* | • Growth in machine-to-machine (M2M) applications might particularly benefit from a relatively low capacity but ubiquitous coverage layer. | • A relatively small amount of spectrum below about 500 MHz may be important for a (near) ubiquitous M2M service. |

## Section 6

# Review and prioritisation of bands

## Overview

6.1 This section reviews a number of specific bands to consider their long term potential for mobile data use and sets out proposals on the relative prioritisation for further work on these bands. Specifically it:

- Briefly reviews the bands that are currently available for mobile data use and the prospective bands which are a focus of our current work;
- Sets out our initial screening of spectrum between 400 MHz and 6 GHz, in order to produce a short-list of bands for further consideration;
- Sets out our prioritisation criteria;
- Provides a summary of the current use and potential issues associated with each short listed band for a change of use and/or sharing;
- Sets out our proposed prioritisation of these bands for potential release.

## Current and prospective spectrum for mobile data

6.2 The main bands that are currently available in the UK for mobile data services are:

- 900 MHz and 1800 MHz bands, which were originally used for 2G mobile services and which have been partly re-farmed for 3G or 4G mobile broadband services. Over future years we anticipate that these bands will be further re-farmed for mobile broadband use.
- 2.1 GHz band, which is currently used for 3G services. Unpaired spectrum at 1900 to 1920 MHz was awarded at the same time but is currently unused.
- 800 MHz and 2.6 GHz bands, recently awarded in the 4G auction.
- 3.6 GHz spectrum (and 20 MHz of 3.4 GHz spectrum) licensed to UK Broadband, currently in limited use for LTE and Ethernet point-to-point and point-to-multipoint networks.
- Wi-Fi spectrum at 2.4 GHz and 5 GHz.

6.3 The bands which are a particular focus of current work are:

- **2.3 & 3.4 GHz**: Ofcom is managing the release of 190 MHz of spectrum formerly used by the Ministry of Defence for military purposes. There is 40 MHz located in the 2.3 GHz band and another 150 MHz above 3.4 GHz, both of which are suitable for mobile data use[30].

[30] See http://stakeholders.ofcom.org.uk/spectrum/public-sector-spectrum-release/ for more details.

- **TV white spaces:** We are working to allow white space devices to access the UHF TV band (470 MHz to 790 MHz) (the UHF TV band) subject to ensuring that there is a low probability of harmful interference to other services in and adjacent to the UHF TV band. Planning is now underway for a pilot of this technology[31].

- **700 MHz:** Following our UHF Strategy Statement we are now considering how to implement the strategy and are undertaking a range of activities to prepare for the potential future change of use of the 700 MHz band (694-790 MHz)[32].

## Initial screening of bands for consideration

6.4 Our initial screening of bands considered all spectrum between 400 MHz and 6 GHz in order to produce a short-list of bands for further consideration. In doing this we had regard to:

- The current UK use and related challenges of a change of use in the long term;

- The level of international interest in future mobile use of the band. This was informed by our involvement in preparation for WRC-15 Agenda Item 1.1 and the RSPG Opinion on Wireless Broadband.

6.5 Our review of the bands is summarised in Annex 6 and is necessarily very high level. In particular, the list is not intended as a complete inventory of every sub-band and every use within the range. For manageability some sub-bands have been combined into a single range and only brief details of current use are noted.

6.6 Our approach for this initial review was that bands with limited prospect (and/or significant challenges) of changes in UK use *and* very limited international support, were not good candidates for the shortlist for more detailed review at present. However, it is possible that these considerations could change in the future and additional bands might subsequently warrant further review. Two factors that could trigger such a change are:

- International interest in certain bands could increase. For example, the Russian Federation has proposed 5925-6425 MHz for an IMT designation at WRC-15 but this proposal currently has no other support.

- Technical advances could make additional bands more attractive for mobile use. For example, South Korea has suggested that bands in the range 20-40 GHz be considered for mobile data use at the subsequent WRC in 2018, based on potential long term technical developments that could make these bands more attractive (see advanced antenna techniques in Section 5 and Annex 5) and ITU-R Working Party 5D has embarked on a study of the technical feasibility of IMT in the bands above 6 GHz[33]. Whilst we have not reviewed the prospects for these bands in detail we will keep these bands under review in the future as technical work progresses.

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[31] http://stakeholders.ofcom.org.uk/spectrum/tv-white-spaces/
[32] http://stakeholders.ofcom.org.uk/spectrum/uhf700mhz/
[33] Chairman's Report of Working Party 5D (Geneva, 9 -16 October 2013): Chapter 5, Attachment 5.8, available at http://www.itu.int/md/R12-WP5D-C-0532/en

6.7 Table 3 below provides the short-list of bands we have identified for more detailed consideration as a result of this initial screening along with their current international status.

**Table 3: Short list of bands for consideration and their international status**

| Band (MHz) | Current UK use | Existing Primary Mobile Allocation (in ITU-R Region 1)? | Existing IMT designa-tion? | Likely to be considered as part of preparatory work for WRC-15? | Does RSPG Opinion view as possible candidate band for wireless broadband? |
|---|---|---|---|---|---|
| **450-470** | Private Mobile Radio (PMR), Emergency Safety Services, Programme Making & Special Events (PMSE) Short Range Devices (SRDs) and Maritime radio | Yes | Yes | Already allocated for mobile use | Limited potential |
| **470-694** | Broadcasting, PMSE, future White Space devices | No | No | Yes | Possibly in very long time frame |
| **1350-1400 / 1427-1518** | Aeronautical navigation, radiolocation, fixed links, NATO military operations | Yes | No | Yes | Yes (1375–1400; 1427–1452 & 1452–1492. Not in rest of the band) |
| **1980 - 2010 / 2170-2200** | Mobile Satellite Service (MSS) (planned) | Yes | Yes | Yes. Already allocated but not for standalone terrestrial mobile use | Yes (Satellite) |
| **2700-2900** | Aeronautical, military, maritime & meteorological radar. | No | No | Yes | No |
| **3600-3800** | Fixed satellite earth stations (downlink) and fixed links. Wireless broadband (2 x 84 MHz) | No | No | Yes | Yes |

| | | | | | |
|---|---|---|---|---|---|
| **3800-4200** | As above | No | No | Yes | Yes |
| **5350-5470; 5725-5925** | Wi-Fi, Science services, aeronautical radar & radionavigation. Radiolocation, amateur, PMSE & SRD. | No<br><br>(Yes for 5850-5925 MHz) | No | Yes | Yes |

## Prioritisation approach

6.8 We have identified a set of assessment criteria to inform our prioritisation and applied this to each of the short-listed bands. In each case we have considered:

- the **benefits** of using the band for mobile services;
- the **costs** of clearing and/or sharing the band;
- domestic or international **constraints/challenges** to a change of use

6.9 These assessment criteria are discussed in more detail below. We then review the short-listed bands and apply the criteria set out in Table 5 later in this section.

6.10 Whilst this gives us a prioritisation of individual bands, in practice a combination of different types of spectrum will continue to be important (as discussed in section 5). For example, if only high frequency, lower power bands were identified as 'high' priority then this might not lead to the optimal balance of spectrum (if all those bands were released, but no others). Consequently, in section 7, we look at which combinations of bands might potentially become available for different uses (e.g. for coverage indoors or in less densely populated areas).

### Benefits

6.11 We have considered the benefits that could in principle be realised from mobile use of each band, assuming the band was fully cleared (or in some cases shared) and internationally harmonised. In considering these potential benefits we have regard to the assessment in section 3 on drivers of future demand for mobile data and the technical trends identified in section 5. In summary, our proposed assumptions are that:

- There will be continuing demand for more spectrum for improving both capacity and coverage of mobile networks. Although lower frequency spectrum will continue to be in demand, particularly for hard to serve areas, demand for higher frequency spectrum may increase (relative to lower frequency spectrum) due to some technical developments that may be more relevant to higher frequencies (see section 5).
- We expect that, as demand for wireless data grows, Wi-Fi is likely to remain an important means of supplying wireless data capacity.

- Although cleared spectrum will continue to be in demand, spectrum that is available on a shared basis (particularly if the incumbent use is in limited geographic areas) may also be in greater demand than it has been in the past.

- Challenges in adding new bands into handsets means that bands that are ‘easier’ to incorporate into handheld devices, e.g. close in frequency to an existing widely used band, may be in greater demand than those that are ‘harder’ to incorporate, everything being equal. Nonetheless there could also be demand for bands which are not widely used in handsets and are mainly used in larger devices (e.g. tablets and laptops).

6.12 The two main criteria on which we have assessed the potential demand for a band are:

- **Capacity** the band can provide. A band where further contiguous spectrum can be made available is likely to be more useful. Generally more contiguous spectrum can be made available at higher frequencies. However, capacity delivered using lower frequencies provides higher average throughputs than higher frequency spectrum making, for example, 50 MHz of spectrum at 700 MHz relatively more useful, under this criterion, than 50 MHz of spectrum at 3 GHz (although this effect is likely to be less important for small cell site use). We have attempted to estimate the capacity that a band can deliver based on technical modelling. This is explained in more detail in Annex 7 (See Figure 18: Increase in capacity in 2020 relative to 2012 as a result of a 50 MHz increase in spectrum availability at different frequencies

- **Coverage** and whether the propagation characteristics of the band will be beneficial in either extending coverage, or boosting performance in hard to cover areas. We have estimated the coverage a band can provide. This is explained in more detail in Annex 7.

6.13 We also qualitatively identify other aspects of the band that may affect the benefits it can deliver, for example its potential geographic availability and the potential for sharing with the incumbent user, and the potential ease or difficulty of incorporating it into mobile devices.

## Costs

6.14 In general it is challenging to quantify accurately the costs of clearing and/or sharing particular bands. A relatively detailed analysis of costs can be appropriate in some circumstances, for example in the context of a regulatory decision to mandate clearance. However, in order to inform our initial prioritisation proposals, we have sought to understand costs at a high level from a qualitative perspective, whilst noting any indicative cost information that may be available.

6.15 When considering the costs of clearing a band, potentially relevant costs to consider are those that stem from:

- Moving the incumbent users to other frequency ranges. This can incur a number of costs including:

    - Modifying physical networks;

    - Replacing or modifying end-user equipment;

  - o Mitigating coexistence issues with adjacent users in the new frequency range;
  - o Providing information and support to end users.

- The opportunity cost of losing services currently provided using the released spectrum;
- Mitigating coexistence issues with incumbent spectrum users in adjacent bands, for example protecting them from interference by fitting filters to equipment, improving existing terminals etc.

6.16 The costs of sharing a band could stem from:

- Mitigating coexistence issues with incumbent spectrum users in the same or adjacent bands, for example protecting them from interference by fitting filters to equipment, improving existing terminals etc
- Relocating some users to different geographic locations to maximise the spectrum available for sharing. This may involve replacing equipment;
- The impact of any increased interference to the incumbent users.

## Constraints/challenges

6.17 Under this criterion we have sought to make an assessment of the extent of non-cost constraints, i.e. practical, technical or regulatory factors that may present challenges or obstacles to realising the potential benefits from use of the band for mobile data. This includes constraints or challenges at the domestic UK level and internationally:

6.17.1 **Domestic constraints.** A practical constraint to a change of use could arise, for example, if there are many licence-exempt incumbent users of the band who could be difficult to locate and identify. This is because there might be a requirement to ensure they stopped using the band, or upgraded their equipment to avoid interference. A regulatory constraint may arise, for example, from the need to meet other policy objectives which are currently delivered through use of the band, such as the delivery of Public Service Broadcasting (PSB).

6.17.2 **International constraints.** In practice, only bands that are internationally harmonised for mobile and/or wireless broadband use are likely to be economically viable for the delivery of mass market mobile data services. As we are looking at a long term strategy, the fact that a band is not yet internationally harmonised for mobile use is not necessarily a constraint. This is because there may be opportunities over the coming years to build international consensus over harmonising additional bands (e.g. at WRC-15). However, some bands may have very limited support internationally for mobile use and/or have other barriers to mobile use. For example some uses of spectrum involve movement between countries (such as maritime or aeronautical use), and agreements which impose obligations or grant access rights in relation to such bands are not easily changed.

## Review of spectrum bands

6.18 In the following paragraphs we set out a summary account of each of the frequency bands from the short-list above (Table 3) before presenting our proposed assessment of each band against the identified criteria.

### 450–470 MHz

6.19 Around one third of the capacity available in the 450–470 MHz band is currently heavily used by business radio users. There are over 25,000 business radio licence assignments in this spectrum which sustain applications that in many cases are of critical importance to a large variety of end users, ranging from utilities and transport operators, to hospitals, care homes, industrial sites and taxi firms. Other users of spectrum in this frequency range include Emergency Services, Scanning Telemetry used by the utilities, PMSE 'talk-back', and licence-exempt devices.

6.20 Technical standardisation work to define a variant of LTE for use in the 450 – 470 MHz band is currently underway in international bodies[34]. A potential long-term use of this band for LTE in the UK could prove beneficial to improving coverage of mobile data services in remote and hard-to-reach areas, given the favourable propagation characteristics of these frequencies.

6.21 This band is already harmonised globally for mobile data, and LTE450 technology is being developed and tested in some countries internationally, most notably Brazil as a useful option to extend the geographical reach of wireless broadband.

6.22 However, the band offers a limited amount of capacity (potentially up to 20 MHz, although the variant of LTE being standardized for this band offers 2 x 5 MHz) and the use of larger antennae sizes at this relatively low frequency may pose challenges for integration into mobile handsets, possibly limiting benefits to consumers.

6.23 Any change in use of this band is likely to be relatively costly (previous estimates of 'band reversal[35]' costs, over £200m, may be a relevant proxy) with no obvious migration path for some key users. There are also a number of other competing possibilities for the band including the next generation of PMR type use and the Emergency and Public Safety services. There may also be adjacent band issues with other services including the early warning radar at RAF Fylingdales. However, given that the benefits of this band for mobile data may be mostly for its use in more rural areas, less costly geographic sharing options may be possible as incumbent use (PMR) is to some extent concentrated in urban areas.

6.24 As well as the potential high costs associated with re-planning of the band, implementation of any clearance and re-assignment programme would also be challenging due to the large and diverse incumbent UK stakeholder group. There is also no consensus in Europe on the re-purposing of this band for mobile services.

6.25 In order to better understand the prospects and options for use of this band, and recognising that changes in patterns of use in neighbouring countries will also impact the interference environment in the UK, we have instigated a new priority work item

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[34] 3GPP expected to ratify the LTE450 standard proposed by Brazil in Nov 2013.

[35] UK PMR *transmissions* are currently at the frequencies that Europe uses for *receiving,* and vice-versa, which limits how efficiently the band can be used in the UK for PMR. There have been previous studies on how much it would cost to reverse UK usage to align with Europe

as identified in our spectrum management strategy, focusing on this band. This will analyse competing demands from current and future uses for spectrum at 450–470 MHz and examine possibilities for the future use of this band. This work will also assess the costs involved in changing use, exploring the wider long term demands and develop an overall strategy for this spectrum.

### 470 – 694 MHz

6.26 The spectrum in this band is widely used for broadcasting television services in many countries. In the UK the spectrum, and the adjacent 694–790 MHz band, is currently shared between digital terrestrial television (DTT) and the programme making and special events (PMSE) sector. From November 2013 the band will also carry local TV services using the interleaved spectrum. From 2014, it is expected that the band will also be used by white-space devices (See Figure 4 below).

**Figure 4: Illustration of spectrum use 400 – 790 MHz**


| Use | Description |
|---|---|
| ❶ | PMR (extensive and diverse civil and military use) |
| ❷ | PMR (most intensive use) also ESS, SRD, PMSE and maritime radio on board ships |
| ❸ | DTT, PMSE, Local TV (from November 2013) and WSD (from 2014) |
| ❹ | DTT & PMSE (700 MHz proposed release) |

6.27 As a sub-1 GHz band, the favourable propagation characteristics of low frequency spectrum are potentially attractive for providing suburban/rural coverage and in-building coverage from outdoor macro-cells. The large quantity of spectrum in this band (up to 224 MHz) has the potential to provide significant data capacity for mobile data services.

6.28 At the same time, in our UHF Strategy statement we noted the significant consumer and citizen benefits arising from the DTT platform, and stated our intention to secure ongoing delivery of those benefits alongside any harmonised release of 700 MHz spectrum for mobile broadband. Any further release of UHF spectrum for mobile data in the short to medium term therefore seems very unlikely given the impact that any such release would be likely to have on the delivery of benefits through DTT.

6.29 However, internationally there may be strong support at WRC-15 for adding a co-primary mobile allocation and identification for IMT to all or some parts of the 470-964 MHz band. Some other European countries make less use of the DTT platform for TV delivery than the UK, and may argue for a greater release of UHF spectrum to mobile than the 700 MHz band.

6.30 As noted in our Spectrum Management Strategy consultation we have initiated wider thinking on the longer-term future of DTT in the UK. We believe that DTT is currently the most appropriate method of meeting the objective of delivering universal free-to-view access to PSB channels, as well as other objectives – we also believe this is likely to remain the case for some time. Consequently, whilst engaging in international discussions on the future use of this band, we will continue to seek to ensure that consumers and citizens can continue to enjoy benefits delivered by DTT (and PMSE) use of the band in the UK.

6.31 However a wider debate over the longer-term role and future of DTT is emerging beyond the likely timescales for a potential release of the 700 MHz band. This debate is likely to focus on the potential for alternative distribution technologies to DTT, including IPTV (especially as superfast broadband availability increases) and satellite to enable a DTT switch off at some point in the long term.

6.32 A relevant scenario in the context of growing demand for mobile data, particularly if a material part of that demand were for broadcast video content, might also be the use of a hybrid platform in this band to deliver TV to mobile devices as well as homes. The technology drivers that lie behind this scenario are described in Annex 5 (section Development of Broadcast Capability for Mobile Networks) and summarised in Section 5. All of these options would need to be tested against current public policy objectives for free to view television, including promoting the reach and impact of PSB and supporting choice and competition amongst TV platforms.

6.33 This band is also very important for a range of PMSE applications including wireless microphones. Changes to the band could have a significant impact on that use. White space device use in this band could also be affected. However, assuming that these uses continue to have significant value in the future, then it is conceivable that some spectrum could remain available for their continuing use. The cost and impact of many of the above scenarios is very hard to assess at the moment and, as discussed in our UHF Strategy work, there is potentially a wide range of consequences resulting from changes to use of this band, some of which would be difficult to quantify. However there are two scenarios where it is possible to illustrate the scale of the potential cost, at least in relation to DTT. The two high level scenarios are if mobile services had access the whole band, or only part of the band:

- **Mobile data access to the whole band.** This would mean losing the provision of DTT in its current form and the important role it now plays in the UK television market. This includes providing free to view access to PSB channels, although as noted above Freesat or other new platforms (e.g. IPTV) could potentially fulfil these roles in time. As such, an illustration of the costs of mobile services gaining access to the whole band might consider the cost of transitioning all DTT homes to Freesat. Analysys Mason estimated this cost as part of a recent study as £1.7 billion.[36]

- **Mobile data access to part of the band** (in addition to the 700 MHz band) would involve re-planning DTT so that a more limited DTT service could continue to be provided. This option would incur significant cost in re-planning the network and related costs. The exact costs of re-planning the network would depend on the extent of the re-plan. A re-plan could affect the whole network - similar to the program that occurred as part of Digital Switchover, where the infrastructure

[36] Analysys Mason, March 2013, “Opportunity cost of the spectrum used by digital terrestrial TV and digital audio broadcasting” http://stakeholders.ofcom.org.uk/binaries/consultations/aip13/annexes/report.pdf

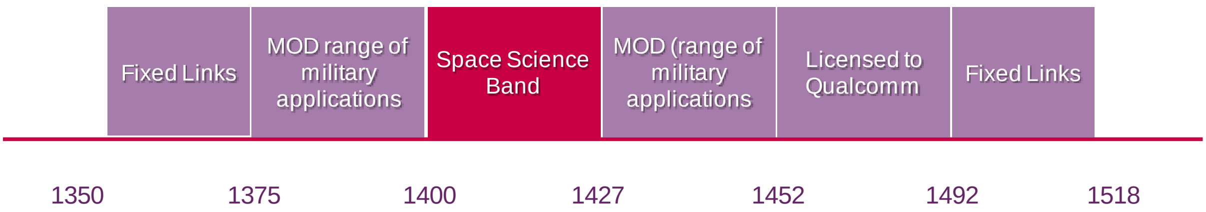
costs were approximately £630 million[37]. A less substantial re-plan might affect only a small number of sites, similar to the program that happened as part of channel 61 and 62 clearance, where the costs were significantly less than for Digital Switchover. In addition, reducing the scope of DTT services could have very significant impact on long-term competitiveness and sustainability of platforms that are underpinned by DTT. These impacts are inherently more difficult to quantify but would be significant considerations.

6.34 Clearly the overall cost of these scenarios could be significantly higher than the estimates above once the wider impacts on consumers, PMSE users and white space devices users are taken into account.

### 1350-1518 MHz

6.35 This frequency range comprises a number of different sub-bands with several different types of use. Its overall configuration is set out in Figure 5 and each of the sub-bands is considered in more detail below. However, the individual bands within this range cannot be considered in isolation. This is because the value of making additional spectrum available is likely to depend on having a sufficiently large contiguous block, or pair of blocks of spectrum.

**Figure 5: Illustration of spectrum use 1350 – 1518 MHz**




6.36 One important restriction within the band is the requirement to limit interference into the space science band at 1400-1427 MHz. This band is used for radio astronomy (RA) studies and earth exploration satellite sensing (EESS) applications. This includes collection of satellite data on soil moisture and ocean salinity used in research for understanding and predicting drought, floods and climate change. In addition to this sub-band itself being unavailable for mobile data use, this imposes some constraints on the use of the adjacent bands, for example the use of guard bands and/or power limits. Given this, two potential scenarios for use of spectrum in this range for mobile data might be:

- To provide a supplementary downlink (SDL) service, based around 1452-1492 MHz and potentially widening this by extending partly or fully into the 1427-1452 MHz and/or 1492-1518 MHz sub bands.

- A paired configuration using some spectrum above the space science (1400-1427 MHz) band paired with spectrum below that band. This would be suitable for Frequency Division Duplex (FDD) use.

6.37 In principle spectrum in this range could offer up to about 100 MHz of spectrum for mobile data services, if all existing users were cleared, plus the 40 MHz in the 1452-

[37] Digital UK Switchover Final Report: http://www.digitaluk.co.uk/__data/assets/pdf_file/0019/82324/DigitalUK_Switchoverfinal_report_Nov2012.pdf

1492 MHz band already licensed to Qualcomm. However in practice, taking account of the configuration of the spectrum and the restrictions for limiting emissions into the space science band, the usable amount of additional spectrum might be considerably less, perhaps around 50 MHz (plus the 40 MHz in 1452-1492 MHz).

6.38 The best way to proceed with these bands will be dependent on the outcome of the technical studies which have been proposed into the feasibility of compatibility and shared use of the band. As well as addressing coexistence issues, these studies will also inform the level of protection required in order to keep the space science band appropriately free from interference.

## 1452-1492 MHz (40 MHz)

6.39 This band was licensed to Qualcomm in the UK in 2008 as a single block of 40 MHz. The spectrum is not currently being used; however Qualcomm is promoting this band for use as a supplementary downlink (SDL) service. SDL is a mobile data service which provides additional downlink to enhance the capacity of paired spectrum in another frequency band, recognising the growing demand for downlink capacity for mobile data in particular.

6.40 There is already some international support for this use. ECC Decision (13)03[38] supporting this use has recently been adopted and WRC-15 is likely to consider adding an IMT identification to this band (it already has a primary mobile allocation).

6.41 We expect to deal with a licence variation request from the existing licensee to reflect the recent ECC Decision.

## 1350 –1375 MHz and 1492–1518 MHz (~2 x 25 MHz)

6.42 This spectrum is in a paired configuration and is used to provide fixed link wireless services. Although the band is harmonised for fixed links use across Europe, it is the UK that is the main user with over 800 licensed fixed links, widely distributed across both rural and urban areas.

6.43 Fixed wireless links also operate in higher frequency bands, including 6 GHz and 7.5 GHz. However, use of this lower frequency band means that fixed link sites can be established using smaller antennas, which are mounted onto smaller masts - hence lower cost and more durability in poor weather conditions. This means that while it might be possible to relocate users to higher frequencies, a number would likely experience a reduced level of service and/or face significant upgrade costs.

6.44 Further work is needed to understand the costs and feasibility of moving links to higher frequency bands, for example upgrading antennas and masts as well as the cost of potential reductions in service.

## 1375–1400 MHz and 1427-1452 MHz (~ 2 x 25 MHz)

6.45 In the UK this spectrum is used for a wide range of military applications including NATO military operations. The existing military use means that clearing sufficient spectrum to be attractive for mass market mobile broadband services on a wide area basis may be costly and challenging, particularly for the lower band (1375-1400

[38] http://www.erodocdb.dk/Docs/doc98/official/Word/ECCDEC1303.DOCX

MHz). At present there are no Government plans to release or share 1375-1400 MHz for that reason.

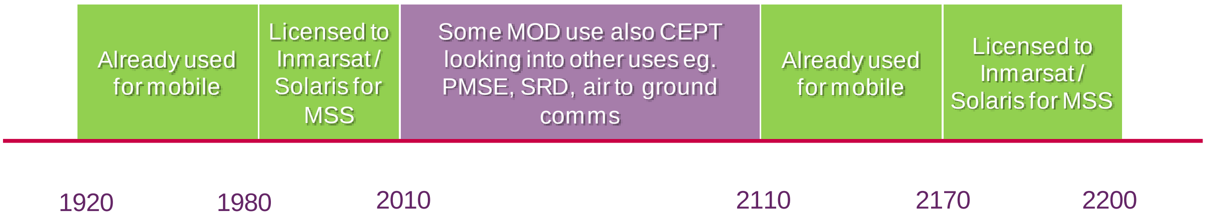
6.46 In relation to 1427-1452 MHz, the MOD has advertised shared access to this band and is currently assessing the details of what spectrum could be shared, and where, based on it potentially being used as backhaul for wireless broadband applications. There is also some European interest developing under WRC-15 Agenda Item 1.1 in the future possibility of mobile use in this band.

6.47 Government's further work on its spectrum release programme will take account of the potential value that these bands could have for future mobile data services.

## 1980–2010 MHz; 2170–2200 MHz

6.48 This band comprises 2 x 30 MHz of spectrum and is adjacent to bands which are already in use for mobile services at 1920–1980 MHz and 2110–2170 MHz. The potential here would be to create a 2 x 90 MHz spectrum pairing which is relatively easy to incorporate into handsets (see Figure 6 below).

**Figure 6 Illustration of spectrum use 1920 – 2200 MHz**




6.49 In 2009, following a European selection and authorisation process, this band of spectrum was allocated to Inmarsat and Solaris for the purpose of providing mobile satellite services (MSS) on a pan European basis. Decision 626/2008/EC requires Member States to ensure that the operators have the right to use the specified radio frequencies and the right to operate a mobile satellite system within their jurisdiction. Such rights are subject to the common conditions as set out in Article 7(2) of that decision. The UK duly granted authorisation to each of Inmarsat and Solaris for use of their specified frequencies in the UK for 18 years with effect from 14 May 2009.

6.50 In its Opinion of 13 June 2013, the RSPG contends that these mobile satellite services have not been a commercial success. It recommends that the Commission should consider re-allocation of the bands to terrestrial mobile services if future actions taken by Member States result in the withdrawal of licences.

6.51 The future availability of this spectrum for (terrestrial) mobile data services will therefore depend on:

- First, the outcome of any enforcement action by individual Member States against the authorised operators if they consider that they have not complied with the terms of their authorisation; and

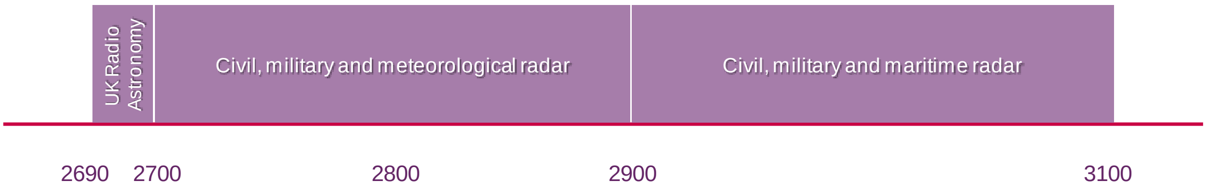
- Second, if the actions above result in the withdrawal of the relevant authorisations, whether the Commission re-allocates the bands to terrestrial mobile services as recommended by the RSPG.

## 2.7–2.9 GHz

6.52 In the UK the spectrum in this band is used to provide primary radar services for both civil and military purposes. Internationally there is also some meteorological activity in the band. Radar use is regulated by the Civil Aviation Authority (CAA) to meet safety and operational requirements, which are provided by the Air Navigation Service Providers to meet their individual requirements. The radar stations are licensed under the Wireless Telegraphy Act (WTA). Radars in this band are also operated by the MoD and coordinated with the CAA.

6.53 There is a low acceptance of interference into radar services. In support of the release of the 2.6 GHz band (which was part of the 4G auction) the radars in the band recently underwent a successful remediation programme. All UK radar systems were upgraded to resolve identified adjacent band coexistence issues.

**Figure 7: Illustration of spectrum use 2.7 GHz – 3.1 GHz**




6.54 The UK Government has initiated work to look into the possibility of re-planning the radar systems in this band and potentially releasing spectrum from the band for other uses, which could include mobile broadband. The programme will look at the following options to release spectrum:

a) Identifying the minimum amount of spectrum required in order to accommodate radar services in this band;

b) The potential spectral capacity that could be made available for other radio systems interleaved with radars within the frequency band 2700–2900 MHz;

c) The potential for moving radar to the 2.9–3.1 GHz band;

d) Making use of alternative technology in this or a different frequency band.

6.55 The Government update[39] *Enabling growth: releasing public spectrum* indicated that up to 100 MHz might potentially be released from the 2.7–2.9 GHz band, although this is subject to the outcome of the above studies.

6.56 At present there is limited international support for consideration of a primary mobile allocation in this band at WRC-15, although this could change going forward.

## 3.6–3.8 GHz and 3.8-4.2 GHz

6.57 Spectrum in these bands is potentially attractive for mobile data services as it offers a very large amount of bandwidth and is adjacent to spectrum at 3.4–3.6 GHz, part of

[39] https://www.gov.uk/government/publications/enabling-uk-growth-releasing-public-spectrum-update-on-progress-to-december-2011

which Ofcom is currently preparing to award. Its higher frequency means that it is likely to provide greatest benefits in more densely populated areas.

6.58 At present, these bands are allocated on a primary basis to the fixed service (FS) and the fixed satellite services (FSS). In the UK the bands are currently used for:

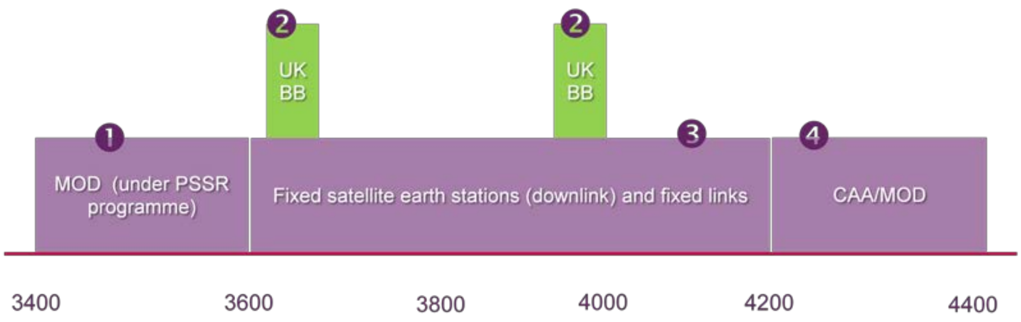
- Around 120 permanent earth stations (PES) at 35 sites providing downlinks from commercial satellites (using the uplink band between 5950 and 6425 MHz) for a range of commercial operators, as well as some governments departments. The upper, 3.8-4.2 GHz, band is more intensively used by these earth stations than 3.6-3.8 GHz.

- fixed wireless links (32) deployed mainly in remote locations; and

- 2 x 84 MHz currently allocated to UK Broadband and used on a limited geographic basis for LTE (3605–3689MHz and 3925–4009 MHz)

6.59 These uses are illustrated in Figure 8 below:

**Figure 8: Illustration of spectrum use 3.4 – 4.4 GHz**




| Use | Description |
|---|---|
| 1 | MOD spectrum under PSSR programme |
| 2 | UK Broadband - 2 x 84 MHz blocks allocated to (3605 – 3689 / 3925 – 4009 MHz) |
| 3 | Fixed Satellite Service & Fixed Service band used by permanent earth stations & fixed links |
| 4 | CAA / MOD use for aircraft (radio altimeters) |

6.60 The remote location of many of the fixed wireless links means that they may not act as a significant constraint on mobile data use in more densely populated areas, and the spectrum currently allocated to UK Broadband is already available for mobile data use. However, it is important to consider further the satellite use of the bands.

6.61 Globally there are hundreds of geo-stationary orbiting (GSO) satellites using the 3400-4200 MHz frequency range. Launched satellite systems have a long lifetime (in orbit for around 15–20 years) resulting in a high investment into the service by the satellite users and operators. A geo-stationary satellite, including launch costs, can cost up to several hundreds of millions of pounds. The band is particularly useful for communication to countries in tropical regions because these frequencies are resilient to rain fade compared to higher frequencies available to satellites.

6.62 One scenario would be if satellite earth station use of this band ceased altogether in the UK (and probably a number of other developed markets in order to achieve necessary economies of scale). This would make the bands available throughout the UK for mobile data services. This need not prevent the bands from continuing to be used for satellite communications between other countries where demand for mobile data were lower and/or particularly benefited from use of this band compared to higher frequencies (i.e. in tropical in regions). However, it would mean the existing communications services would be lost in the UK or need to be replaced by an alternative means of communication, for example using fibre if that were feasible.

6.63 An alternative scenario may be for mobile services to use the band on a geographically shared basis with the existing satellite users, as UK Broadband does at present, i.e. via geographical coordination with PESs. However, if a geographic sharing mechanism was used, mobile broadband services would not be able to use the same spectrum within a certain distance of these Permanent Earth Station sites. This distance may be large (from tens of km to over 100 km) and therefore could significantly impact the area within which mobile data services could be provided, particularly for the more intensively used upper band. Consequently, the re-location of PES sites to less densely populated areas might enable mobile data services to be used by a greater proportion of the population.

6.64 Whilst this scenario would not directly impact the use of launched satellites, there are still likely to be costs incurred. For a PES installation, the costs of moving might range from a few hundred thousand pounds to several millions. Further work is needed to understand the feasibility of relocation, and/or possible shielding of PES installations, and the likely costs. We will also need to consider what additional population coverage could be achieved for mobile data services using these bands if such re-locations were to happen. For example, if coverage of the main UK population centres could be achieved by re-locating 20 PES installations (at say £5m each) then the cost might be in the region of £100m. In contrast, the costs might run to several hundreds of millions of pounds to move all existing PES installations.

6.65 At present there are significant differences in the international status of the two bands

- The 3.6–3.8 GHz band has been harmonised by European Commission Decision 2008/411/EC and there is an unpaired channelling arrangement in CEPT ECC Decision (11)06, as well as a primary mobile allocation in the European Common Allocation Table[40]. There is also support in CEPT Conference Preparatory Group for consideration of a primary mobile allocation in the Radio Regulations at WRC-15.

- The 3.8–4.2 GHz spectrum is not currently harmonised for mobile use, and there is no mobile allocation in Region 1 in the Radio Regulations or in the European Common Allocation Table. The RSPG Opinion identifies this band as having some potential for wireless broadband capacity in limited geographic areas. However, there is currently no support for consideration of a primary mobile allocation in this band at WRC-15 (indeed there is opposition from a number of countries). This may reflect the more intense use of this upper band for satellite links than 3.6-3.8 GHz.

[40] http://www.erodocdb.dk/Docs/doc98/official/pdf/ERCREP025.PDF

## 5 GHz bands (5350–5470 MHz; 5725–5925 MHz)

6.66 Over the past 10 years, the speed of Wi-Fi has evolved in line with the data rates offered by home broadband services. Consumers reasonably expect that Wi-Fi continues to be capable of extending internet connectivity throughout their homes, delivering superfast broadband speeds to a range of wireless devices.

6.67 The latest version of the Wi-Fi standard, known as 802.11ac, operates exclusively at 5 GHz and is capable of a theoretical headline speed in excess of 1Gbps. Actual speeds achievable inside a typical building and with several users accessing the network simultaneously will be lower - but 802.11ac is still capable of delivering a speed similar to current superfast broadband services throughout the home or office.

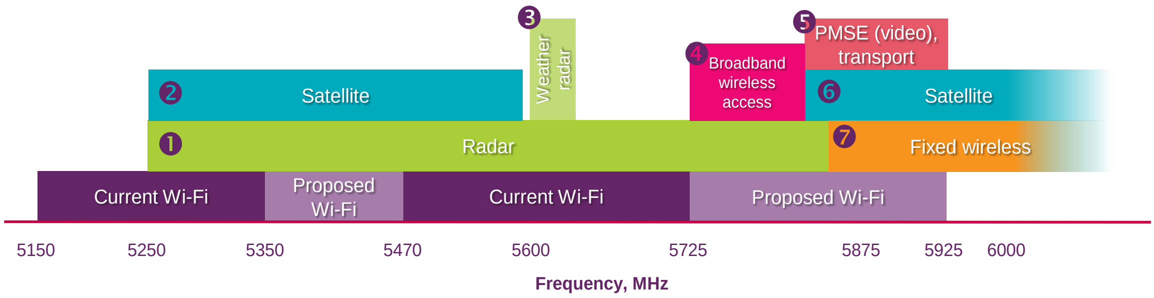
6.68 The main factor contributing to the high data rates achievable by 802.11ac is its use of wide channel bandwidths – 80 and 160 MHz, compared to the maximum of 40 MHz for the previous generation of Wi-Fi products. These wider channels could be particularly important for delivering high data rates throughout a building.

6.69 As discussed in our recent spectrum sharing consultation, the use of spectrum at 5 GHz is likely to become increasingly important for Wi-Fi, as the limited allocation at 2.4 GHz becomes more congested. The proposal at WRC-15 is to designate additional spectrum for Wi-Fi at 5350–5470 MHz and 5725–5925 MHz, effectively creating a contiguous block usable for Wi-Fi between 5150 and 5925 MHz. This would provide an additional 320 MHz on top of the existing allocation of 455 MHz, making a contiguous allocation of 775 MHz.

6.70 In addition, the removal of the current gap in the Wi-Fi band would increase the number of wider bandwidth channels (i.e. 80 and 160 MHz) that can be supported, facilitating the delivery of higher data rates to a larger number of users.

6.71 Much of the 5 GHz band has a primary military designation but, in practice, it is shared by a number of users and applications, as shown in the illustration below:

### Figure 9: Illustration of spectrum use 5-6 GHz




| Use | Description |
|---|---|
| ❶ | MOD radar band |
| ❷ | Satellite-based transmission to measure ground-level (or below) features for mapping or scientific purposes |
| ❸ | Radar to predict heavy rainfall and flooding |
| ❹ | Light licensed use for CCTV or broadband access networks |
| ❺ | Licence exempt for video applications and intelligent transport systems |
| ❻ | Ground-to-satellite uplinks |
| ❼ | Wireless fixed links |

6.72 Wi-Fi access to the 5 GHz extension bands would be on the basis of protecting the incumbent services and will need to take account of the results of sharing and compatibility studies including how practical and enforceable any associated technical and regulatory constraints are likely to be.

6.73 There are already ongoing sharing and compatibility studies on these bands as part of the WRC-15 Agenda Item 1.1 process. The purpose of these studies is to understand under what conditions Wi-Fi sharing with incumbent services would be feasible, including what mitigating actions might need to be taken by new Wi-Fi services

6.74 The technical cost of implementation depends on the sharing mechanism that is put in place. While detailed coexistence studies are still ongoing, there is a good chance that the new bands, if agreed, will utilise Dynamic Frequency Selection (DFS) which is used in the existing shared part of the 5 GHz band (5250–5350 MHz and 5470–5725 MHz). An alternative sharing mechanism would be the use of a geo-location database, in which devices are dynamically assigned frequencies which will not cause interference to incumbent users.

6.75 It is difficult to estimate the cost of either mechanism until the technical details have been finalised. However the cost of implementing sharing would be very low if the new capability were introduced as part of a natural replacement cycle for Wi-Fi equipment. In addition to these mechanisms, Wi-Fi usage in the new bands would almost certainly be restricted to indoor-only deployments and there would be power limits to manage coexistence.

## Proposed prioritisation

6.76 Our proposed prioritisation of these bands by applying the criteria discussed above is set out in Table 5. The categorisation of capacity, coverage and costs used in the prioritisation table is given in Table 4 below. The basis for the relative downlink capacity and coverage estimates used in the table are given in Annex 7. As noted in our discussion of costs above, in many cases the costs of making a band available are uncertain or very uncertain at this stage.

**Table 4: Relative ranking of capacity, coverage and costs for assessment**

| **Rank** | **Capacity** (relative capacity adjusted for frequency) | **Coverage** (% population served indoor) | **Cost** (indicative) |
|---|---|---|---|
| **High** | 75+ | 90%+ | £500m+ |
| **Medium** | 25-75 | 70-89% | £100-499m |
| **Low** | < 25 | <70% | <£100m |

## Table 5: Proposed prioritisation of bands for potential future release

| Band (MHz) | Potential MHz available | Incumbent use / user | Benefit for mobile data use if band was cleared and harmonised | | | | Indicative costs | Constraints on realisation of mobile data benefits | | Proposed priority of band |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Relative downlink capacity | Illustrative Coverage | Other Benefits | Overall benefit | | Domestic | International | |
| **450-470** | 2 x 5 MHz | PMR use, Emergency and Safety Services, PMSE, SRD and Maritime | **Low**<br>10 | **High**<br>100% | Extending coverage into unpopulated areas, although some difficulty incorporating into handsets | **Medium** | **Medium - High**<br>Previous estimates of 'band reversal' costs, over £200m, may be a relevant proxy, but could be higher | **High**<br>Large and diverse stakeholder group in the UK. | **Medium**<br>International standardisation for LTE underway, but currently limited support in Europe. | **Medium** |
| **470-694** | Up to 224 MHz | DTT & PMSE | **High**<br>Up to 112 | **High**<br>99% | Potential 'ubiquitous' benefit as above at lower end of frequency range (although handset issue as above). | **V. High** | **High**<br>Could be in excess of £1bn if need to transition millions of DTT users to another platform, range of other potential impacts incl. on PMSE. | **Medium - High**<br>Relevance of DTT to provision of Public Service Broadcasting and other policy objectives | **Medium - High**<br>Widely used for DTT but likely to attract interest from countries where DTT use is less than UK. | **Medium** |

| Band (MHz) | Potential MHz available | Incumbent use / user | Benefit for mobile data use if band was cleared and harmonised | | | | Indicative costs | Constraints on realisation of mobile data benefits | | Proposed priority of band |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Relative downlink capacity | Illustrative Coverage | Other Benefits | Overall benefit | | Domestic | International | |
| **1452-1492** | 40 MHz | Licensed to Qualcomm with technology neutral conditions, i.e. potentially suitable for mobile broadband. | **Medium**<br>33 | **Med-High**<br>87% | | **Medium** | **Low**<br>Unused, so no costs | **Low**<br>Already available | **Med-Low**<br>Supportive CEPT Decision recently adopted. WRC-15 likely to consider IMT identification | **High** |
| **1350 - 1518 (ex 1400-1427)** | ~ 50 MHz (on top of 1452-1492) | CAA, MOD (aeronautical & radar) Fixed links for Utilities, Public Safety, Fixed Networks, Broadcasters, LAs, MNOs | **Low**<br>21 | **Med-High**<br>88% | Aggregating with existing 1452-1492 MHz band could increase the benefit from that band | **Medium** | **High**<br>Remediation costs for military systems would be significant. Difficulty replacing some fixed links. | **High**<br>Large and diverse stakeholder group. | **Medium - High**<br>CAA & MOD international agreements and military obligations (NATO) | **Medium** |
| **1980 - 2010 / 2170 - 2200** | 2 x 30 MHz | Inmarsat and Solaris for Mobile Satellite Service | **Low - Medium**<br>25 | **Medium**<br>80% | Easy to implement in terminals (adjacent to existing 2.1 GHz 3G bands, with same duplex) | **Medium** | **Low**<br>Implementation cost of making available for mobile will be zero if unused by MSS. | **Low**<br>Availability depends on MSS use and any enforcement action. Any subsequent re-allocation would require agreement at EU level. | **Medium**<br>Availability depends on MSS use and any enforcement action. Any subsequent re-allocation would require agreement at EU level. | **High** |

| Band (MHz) | Potential MHz available | Incumbent use / user | Benefit for mobile data use if band was cleared and harmonised | | | | Indicative costs | Constraints on realisation of mobile data benefits | | Proposed priority of band |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | **Relative downlink capacity** | **Illustrative Coverage** | **Other Benefits** | **Overall benefit** | | **Domestic** | **International** | |
| **2700-2900** | Up to 100 MHz | Radars for air traffic control, defence and meteorology (CAA/NATS, MOD and Met Office) | **Medium**<br>Up to 37 | **Medium**<br>72% | (nearly) adjacent to existing 2.6GHz band | **Medium** | **(Medium)**<br>Subject to ongoing studies. | **Low**<br>Already being considered by Government release programme. | **High**<br>Limited international support at present | **Medium-High** |
| **3600-3800 shared** | Up to 200 MHz | Permanent Earth Stations (PES) and fixed wireless links | **Medium - High**<br>Up to 72 | **Medium - Low**<br>63% | Potentially additional benefits if combined with 3800-4200 if large contiguous bandwidth important | **Medium-High** | **Medium-Low**<br>Re-location of earth stations. Costs for further study, might be low £100m's | **Medium**<br>Depends on feasibility of sharing with relocation / shielding of earth stations. | **Low**<br>Harmonised by European Commission & CEPT Decisions. Some support for mobile allocation | **High** |
| **3800-4200 shared** | Up to 400 MHz | Permanent Earth Stations (PES) and fixed wireless links | **High**<br>Up to 143 | **Medium - Low**<br>60% | Potentially additional benefits if combined with 3600-3800 – large contiguous bandwidth. | **High** | **Medium-Low**<br>As above. | **Medium**<br>As above | **High**<br>Limited international support at present | **Medium-High** |

| Band (MHz) | Potential MHz available | Incumbent use / user | Benefit for mobile data use if band was cleared and harmonised | | | | Indicative costs | Constraints on realisation of mobile data benefits | | Proposed priority of band |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Relative downlink capacity | Illustrative Coverage | Other Benefits | Overall benefit | | Domestic | International | |
| **5350-5470, 5725-5925** | Up to 220 MHz | Aeronautical radar (including MOD) & Earth observation satellite in 5350-5470 MHz; EESS, MOD radar, FWS, satellite uplinks, PMSE in 5725-5925 MHz | **High** | n/a<br><br>Potential use for Wi-Fi (indoors) | Fills in the gaps between existing 5 GHz Wi-Fi bands, increasing the contiguous bandwidth available | **High** | **Low**<br><br>Could be zero, depending on findings of sharing studies | **High**<br><br>UK interests in incumbent uses of the band inc MOD radar, space use. | **Medium**<br><br>The European Space Agency, France and Germany are not supportive. Constraints on the upper band are higher than on the lower band. | **High** |

## Summary

6.77 After completing the full assessment of each band against each assessment criteria, the table below summarises the provisional results of the frequency band prioritisation exercise.

**Table 6: Summary of provisional results of prioritisation exercise**

| Relative priority for further work | Bands for consideration |
|---|---|
| High | • 1452-1492 MHz<br>• 1980-2010/2170-2200 MHz*<br>• 3.6-3.8 GHz<br>• 5 GHz (5350-5470 MHz, 5725-5925 MHz) |
| Medium-High | • 2.7-2.9 GHz<br>• 3.8-4.2 GHz |
| Medium | • 450-470 MHz<br>• 470-694 MHz<br>• 1350-1518 MHz |
| Low | • Other bands that did not make our shortlist for analysis are low priority |

* Depends on MSS use and any enforcement action. Any subsequent re-allocation would require agreement at EU level.

6.78 There are four bands where we think the potential benefits are high and there may be relatively clear - although still far from straightforward - path to create the option for mobile data or wireless broadband use – 1452-1492 MHz, 1980-2010/2170-2200 MHz, 3.6-3.8 GHz and 5 GHz (5350–5470 MHz; 5725–5925 MHz).

6.79 Beyond this there are two bands, 2.7–2.9 GHz and 3.8- –4.2 GHz, which could offer material benefits, and where UK costs or constraints might not be exceptionally high, but where the current international position is a significant constraint on realising that potential value for the UK. In addition, although the constraints for the sub-bands 3.8–4.2 GHz are higher than for the 3.6–3.8 GHz frequencies, there could be additional benefits from combining these bands due to the large (600 MHz) contiguous bandwidth that would be available and which might enable additional innovation.

6.80 Finally there are bands below 2 GHz, i.e. 450–470 MHz, 470–694 MHz and possibly 1300–1518 MHz, which would be beneficial for improving services in harder to serve areas, but where the costs and constraints are likely to be high or very high and the timescales for change of use could be very long.

- **450 MHz** – this offers very limited capacity (perhaps only 2 x 5 MHz) but could be beneficial for extending coverage to areas without any at present e.g. to enable the provision of a ubiquitous coverage layer for machine-to-machine communications.

- **470-694 MHz** – if this entire band were available it would be hugely valuable, offering good capacity and coverage. However, the costs of doing so in the short to medium term would be very significant indeed given its current use for DTT and PMSE (and potential future use for White Space Devices). The lower part of the band could offer similar benefits to 450-470 MHz in extending coverage.

- **1300-1518 MHz** – whilst not quite as attractive as sub 1 GHz spectrum, this band might still be important in the longer term given that there are few other options for additional spectrum below 2 GHz.

6.81 As discussed earlier in this section, in addition to the relative prioritisation of specific bands it is also important to consider how different types of spectrum complement each other, i.e. what spectrum might be usable in different kinds of environments (e.g. indoors or in less densely populated areas).

6.82 In the next section we consider a number of scenarios where some or all of these bands are available for mobile data use in the future. We also consider which bands might be used in different types of environment, and estimate what the implications might be in terms of the available capacity for mobile data services.

*Question 9: Do you agree with the short list of bands we have identified for more detailed consideration?*

*Question 10: Do you agree with our methodology for prioritising potential bands for mobile data use?*

*Question 11: Do you agree with our provisional assessment and the results of our band prioritisation?*

## Section 7

# Spectrum scenarios

## Overview

7.1 Section 6 identified a number of bands which could be considered for future mobile data use, and set out our proposed views on the relative priority of those bands. In this section, we set out how much spectrum, in total, could be available for mobile services if different combinations of the bands we have identified became available. We consider the implications for consumers in terms of the potential capacity available on mobile networks and for Wi-Fi offload, and also the potential implications for other applications such as M2M. These scenarios do not pre-suppose that a band *will* be available nor make a judgement over how likely that will be.

7.2 The rest of this section is structured as follows:

- The first step is to consider roughly *when* each band might become available for mobile data use, *if* it were available for that use in the future, and what that would mean for the quantity of spectrum available for mobile data at different points in time.
- We then set out what spectrum might be available for different types of use by mapping the spectrum availability scenarios against the different environments for mobile data use identified in section 5.
- Finally we illustrate the potential implications for consumers in terms of the capacity available for mobile data services that might be available in different scenarios, including considering the differences between indoor, outdoor and hard to serve environments.

## Timing

7.3 Table 7 below sets out some potential scenarios for when spectrum bands may become available for mobile data use. Some bands are relatively close to being available, and in these cases we can estimate a plausible date of availability with some confidence; the dates, if any, at which other bands will be available are more uncertain (in some cases highly uncertain).

7.4 An additional factor is whether and when user equipment will be available that supports the band. As discussed in section 3 there are challenges associated with incorporating many new bands into mobile handsets. However for the purpose of this analysis we assume that if there is sufficient demand for mobile data then devices will be made that support the available bands. That does not mean that every device will support every band, only that a sufficient number of devices – whether smart-phones, laptops, tablets or dongles – will support a band to enable it to be effectively used.

**Table 7: Potential timing if bands are made available for mobile data**

| Relative priority | Bands | Potential timing of availability *if* made available |
|---|---|---|
| **Existing bands (re-farm)** | 900 MHz, 1800 MHz | These bands are already being partially re-farmed; by 2020 we expect them to be almost completely re-farmed for mobile data use.[41] |
| **Current priorities** | 2.3 GHz, 3.4 GHz, 700 MHz | The 2.3 GHz and 3.4 GHz bands are planned for release in 2015 – 2016. Timing of 700 MHz release is still uncertain; however if released it might be available around 2020. |
| **High** | 1452-1492 MHz | Currently going through CEPT process, devices may be available from 2015. |
| | 1980-2010/2170-2200 MHz | Currently subject to enforcement process coordinated at EU level and therefore difficult to assess timing at this stage. |
| | 3.6-3.8 GHz (adjacent to release of MOD spectrum at 3.4 GHz) | Currently subject to harmonisation activity in EU. Might be available for use on shared basis by 2017-2020 |
| | 5 GHz Wi-Fi extension | Potentially supported in devices from 2016-2018 |
| **Medium-High** | 2.7-2.9 GHz | Potentially by 2020 - 2025 depending on how much and how spectrum is released. |
| | 3.8-4.2 GHz | Potentially 2020 onwards – depending on extent of relocation of existing earth stations (if any) |
| **Medium** | 450-470 MHz, 470-694 MHz and 1350-1518 MHz | These are more likely to be longer term prospects and the timing is highly uncertain at present. Potentially around 2030. |

We have further simplified the timings indentified in Table 7 to allow easy comparison of different scenarios. For our scenarios analysis we have assumed that the proposed high priority bands are all available from 2020; our medium – high priorities - by 2025; and our medium priorities by 2030. We recognise there is significant uncertainty over the potential future timings of release.

7.5 Figure 10 below shows the availability of downlink spectrum up to 2020 based on the availability of existing bands (including re-farming) and the release of different combinations of our current priorities. We have also shown the availability of downlink spectrum if:

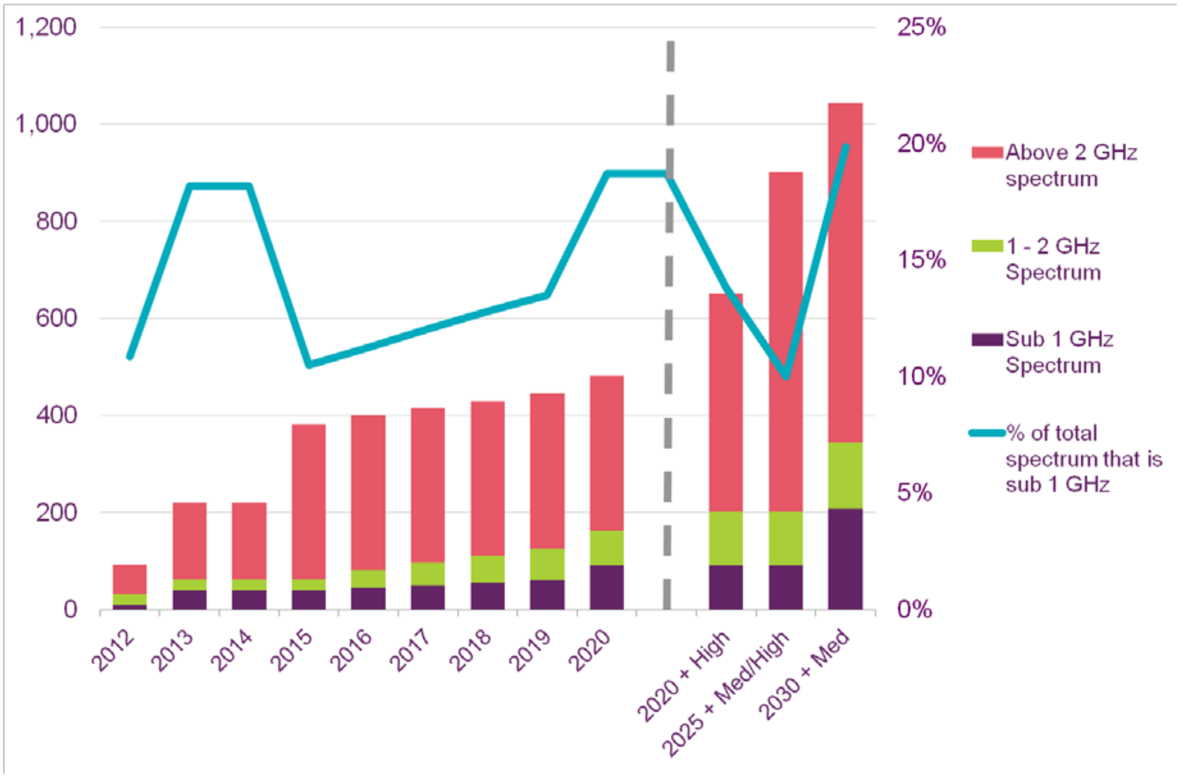
7.5.1 Our high priority bands are available by 2020; plus

7.5.2 Our medium – high priority bands are available by 2025; plus

[41] A small amount of spectrum may continue to be used to provide 2G services. For the purposes of our capacity illustrations we assume that 2 x 5 MHz is used for 2G services out to 2030.

7.5.3 Our medium priority bands are available by 2030

**Figure 10: Downlink spectrum (MHz) available for mobile data use**




## Potential availability for different uses

7.6 Next we bring together the analysis in Section 5 about what sort of spectrum is likely to be important for different types of use in the future and map this against our scenarios for potential future availability.

**Table 8: Potentially relevant bands for different types of use and illustrative timing**

| Type of use | Potentially relevant additional bands in future | Illustrative timing if available |
|---|---|---|
| ***Indoor use both at home and away from home.*** | • 5 GHz Wi-Fi extension bands (5350-5470 and 5725-5925 MHz) | • From perhaps 2016-2018 |
| | • TV white spaces could also be important for larger buildings and/or difficult to cover rooms | • From 2014 |
| ***Easier to serve environments*** *(outdoors and more densely populated areas)* | • 2.3 GHz and 3.4 GHz | • 2015 - 2016 |
| | • 1452–1492 MHz | • Potentially from 2015 |
| | • 2 GHz MSS bands | • Timing difficult to assess |
| | • 2.7-2.9 GHz and 3.6-4.2 GHz. | • Potential 2020 onwards |
| | • Even higher frequencies (e.g. around 14,28 or 38 GHz) might be relevant in the longer term | • Beyond 2020 |

| | | |
|---|---|---|
| ***Harder to serve environments (**less densely populated and other harder to serve environments. incl roads, parts of towns & buildings without 'offload')* | • 700 MHz | • Timing uncertain, around 2020 if released |
| | • Other potential bands to consider are 450-470 MHz, 470-694 MHz, possibly 1.3-1.5 GHz. | • Around 2030 |
| *Machine-to-machine (M2M) use* | • 450-470 MHz may be particularly useful for ubiquitous coverage<br>• Other bands potentially useful depending on application | • Around 2030 |

## Potential implications for consumers of mobile services

7.7 In this section we set out the possible implications for consumers of mobile services arising from the release of the spectrum bands we identified in the previous section. At this stage we are not undertaking a detailed review of the impact of potential future change of use on consumers of incumbent services, however this will be necessary before any decision on change of use is ultimately taken.

7.8 Additional capacity will enable more people to use mobile data services more of the time. They will be able to use it at faster speeds and utilise more data hungry applications – for example a tenfold increase in network capacity could allow the delivery of data to be five times faster to twice as many users.

7.9 The following estimates of capacity are based on a model developed for this consultation; this is explained in more detail in Annex 7.

7.10 Making additional spectrum available is just one way in which capacity on mobile networks can be increased. In order to model the effect of making more spectrum available, we need to make assumptions about other aspects of mobile networks that affect their capacity and coverage. In particular, service can be improved through technological improvements, and through deployment of additional mobile sites (both macro and small cell sites).

7.11 However forecasts of the level of site deployment are highly uncertain and depend on the level of spectrum available – if more spectrum is released, it is possible that fewer additional mobile sites will be deployed.

7.12 In the following analysis, our base case uses the assumptions on improvements in technology and growth in mobile sites set out in Table 9.This results in 21,500 macro sites and 34,000 small cell sites by 2030.

**Table 9: Assumptions on spectral efficiency and site growth**

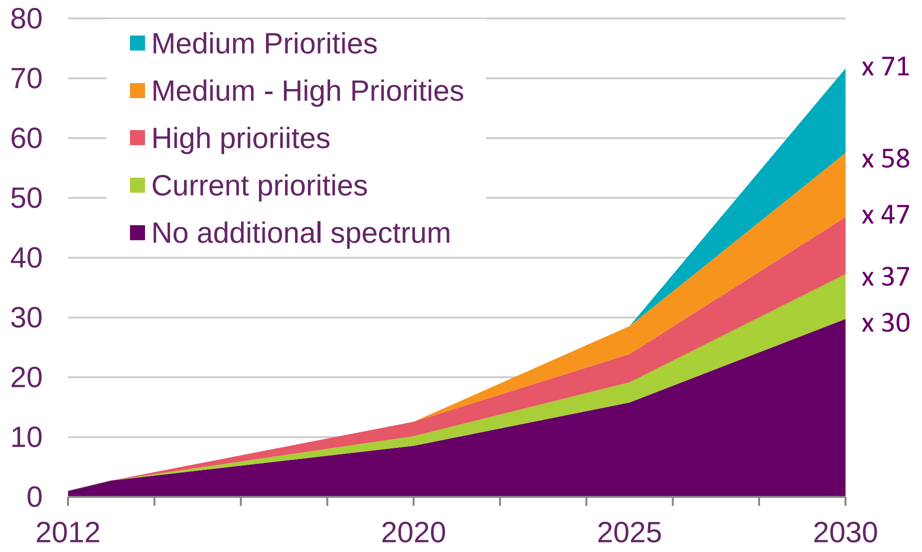
| | Annual growth, 2012 - 2030 |
|---|---|
| Spectral efficiency[42] | 10.7% |
| Macro site numbers | 1% |
| Small cell site numbers | 10% |

7.13 These assumptions are explained in more detail in Annex 7.[43] In the following, we consider first total capacity; this breaks down into indoor capacity and outdoor capacity. Finally we consider capacity in locations which are hardest to serve.

## Total capacity

7.14 We have estimated the total capacity that can be delivered by mobile networks. We have considered the future increase in capacity for a scenario where no additional spectrum is made available (other than re-farming existing bands) and the impact of releasing our proposed current high; medium to high; and medium priority bands.

**Figure 11: Potential increase in total mobile data capacity relative to 2012 (excluding Wi-Fi)**




7.15 Table 10 summarises the potential implications for consumers, expressed as the total mobile network capacity in various spectrum scenarios. Taken together, this additional capacity will enable more people to use mobile data services, more of the time, at faster speeds and for more data-hungry applications.

[42] Spectral efficiency is measured in Bps/Hz. This is the peak throughput that can be delivered using 1 Hz of spectrum.
[43] We present results for two different site growth scenarios in Annex 7.

**Table 10: Illustrative implications for potential mobile data capacity[44]**

| Scenario | Bands used for mobile data | Total MHz for mobile data (downlink) | % of total spectrum < 1 GHz | Spectrum increase over 2012 (downlink) | Total potential capacity increase over 2012 |
|---|---|---|---|---|---|
| **2012** | 2.1GHz, part 900, part 1800MHz | 92 MHz | 11% | - | - |
| **2013**<br>*post 4G award* | • 800 & 2600MHz<br>• Part 900MHz re-farm | 220 MHz | 18% | x 2.4<br>(+128 MHz) | ***x 3*** |
| **2020**<br>*with addition of current priorities only* | • 2.3, 3.4 GHz<br>• 700 MHz (TBC)<br>• Further re-farming | 481 MHz | 19% | x 5.2<br>(+389 MHz) | ***x 10*** |
| **2020 boost**<br>*as above plus high priories* | • 1452–1492 MHz<br>• 2 GHz MSS<br>• 3.6-3.8 GHz<br>• 5 GHz (Wi-Fi) | 651 MHz | 14% | x 7.1<br>(+559 MHz)<br>(+320 MHz for Wi-Fi) | ***x 13*** |
| **2030** *as above plus medium – high priorities* | • 2.7-2.9 GHz<br>• 3.8-4.2 GHz | 901 MHz | 10% | x 9.8<br>(+809 MHz) | ***x 58*** |
| **2030 All**<br>*as above plus medium priorities* | • 450-470 MHz<br>• 470-694 MHz<br>• 1.3-1.5 GHz | 1043 MHz | 20% | x 11.3<br>(+951 MHz) | ***x 71*** |

7.16 Our modelling and results are focussed on relative values compared to 2012. We have not modelled absolute capacity available on mobile networks due to the complexity of expressing total capacity in a single metric and the uncertainty over the capacity that can be delivered by mobile networks today.

7.17 To give a sense of the performance delivered by mobile networks Ofcom published research in May 2011 including in particular average speeds delivered by mobile broadband networks.[45] This research was based on data collected in 2010 and is

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[44] Estimated increase in total mobile network downlink capacity (peak hour throughput in Mbit/s). Excludes Wi-Fi capacity.

[45] Ofcom, May 2011, "Measuring Mobile Broadband in the UK", http://stakeholders.ofcom.org.uk/market-data-research/other/telecoms-research/broadband-speeds/main/mobile-bb-10

now out of date. Ofcom has announced plans to undertake further research into mobile broadband performance which we expect to conduct around December 2013 and publish the results in spring 2014.

7.18 Total capacity can be broken down into capacity delivered to indoor users and capacity delivered to outdoor users. We explore this split in more detail below.

## Indoor capacity

7.19 Capacity to serve indoor users can be delivered in two ways: from outdoor wide area mobile networks e.g. macro sites and outdoor small cell sites; or from indoor small cell networks e.g. Wi-Fi and femtocells.

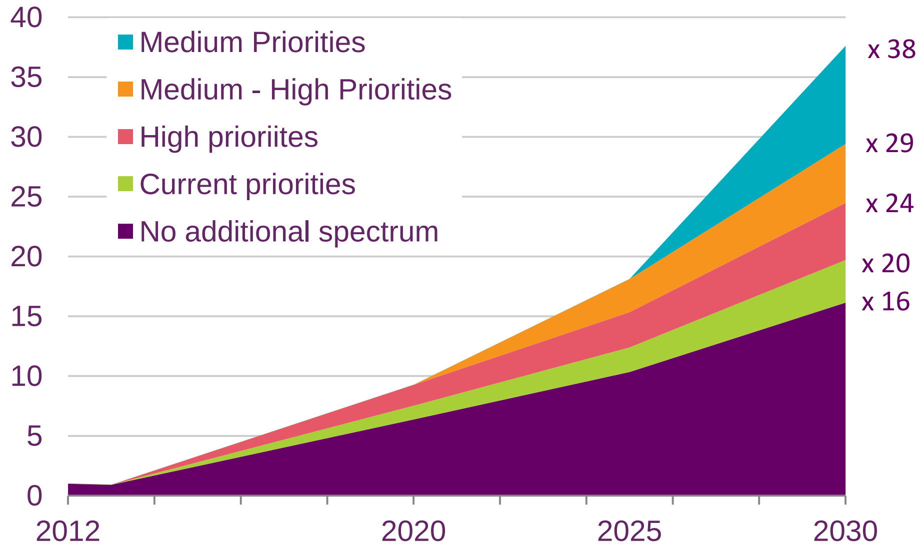
7.20 In the future we would expect consumers to benefit from greater use of indoor small cells as offloading becomes more prevalent. Offloading is likely to increase as automatic switching between cellular and Wi-Fi networks is addressed by initiatives such as Hotspot 2.0. This is discussed in more detail in Section 5 paragraphs 5.33 - 5.35. Users who are not offloading will also benefit from an increase in offloading as the capacity on the mobile networks will be shared between fewer users.

7.21 We have not attempted to quantify the increase in capacity that can be delivered through increased offload onto indoor small cell networks. However, we do not anticipate Wi-Fi capacity will be a major constraint for offloading mobile traffic due to the ability to re-use Wi-Fi spectrum. Additional Wi-Fi spectrum will still be important for increasing the maximum speeds users can expect.

7.22 As discussed in Section 6, the current allocation of spectrum at 5 GHz is capable of supporting a maximum of 5 non-overlapping channels of 80 MHz and a maximum of 2 channels of 160 MHz at a given location. The proposed increase of spectrum at 5 GHz would result in a larger, contiguous band of spectrum. This would effectively increase the number of 80 MHz and 160 MHz channels available to approximately nine and four respectively. It could therefore help ensure that sufficient spectrum is available to deliver the highest speeds to a much larger proportion of consumers. This will be particularly important in areas where networks are densely deployed, such as in terraced housing or blocks of flats.

7.23 For those times when consumers are unable to offload onto indoor networks the outdoor wide area mobile network will be needed to provide capacity. These users will benefit from increased mobile network capacity from increased spectrum availability, technological improvements and deployment of additional sites. Figure 12 below shows the estimated increase in indoor capacity (delivered by mobile networks) for the different spectrum scenarios.

**Figure 12: Potential increase in indoor mobile data capacity relative to 2012 (excluding Wi-Fi)**

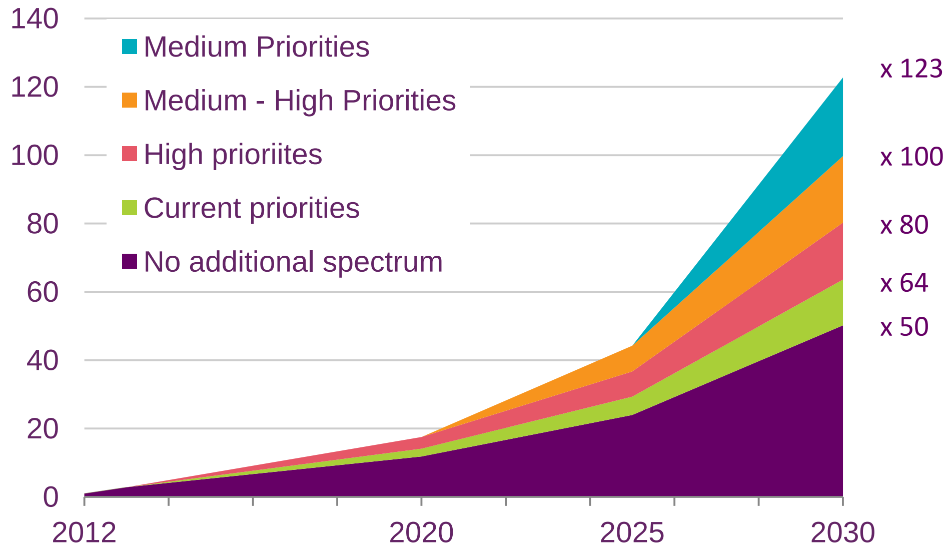



## Outdoor capacity

7.24 Users who are outdoors will need to rely on mobile networks for capacity. This can be delivered through the macro cell network or through outdoor small cells.

7.25 These users will benefit from increased mobile network capacity from increased spectrum availability, technological improvements and deployment of additional sites. Figure 13 below shows the increase in outdoor capacity for the different spectrum scenarios.

**Figure 13: Potential increase in outdoor mobile data capacity relative to 2012 (excluding Wi-Fi)**




7.26 Outdoor capacity may increase by a greater factor than indoor capacity. For example, if all our current priority bands were available for mobile data use by 2030 outdoor capacity might increase by x 64 compared to x 20 for indoor capacity. This is because we anticipate that a growing proportion of indoor traffic could be met through offloading onto indoor small cells (Wi-Fi or femtocells). Therefore fewer resources from the outdoor macro and small cell network may need to be dedicated to indoor use. The exact split between indoor and outdoor capacity is dependent on the modelling assumptions explained in Annex 7.

## Implications for the hardest to serve locations

7.27 Whilst Table 10 focuses on the overall capacity implications for the average consumer, we have also considered the implications for the hardest to serve locations. These are users at the edge of the cell and include some users in urban and suburban locations as well as users in less densely populated areas.

7.28 These users tend to experience a lower level of service than average for two reasons:

7.28.1 The nature of mobile networks means that single user throughput is lower for users who are further from the centre of the cell. For example, previous technical modelling estimates that the 10% of users closest to the edge of each cell receive a single user throughput that is only 20% of the average.

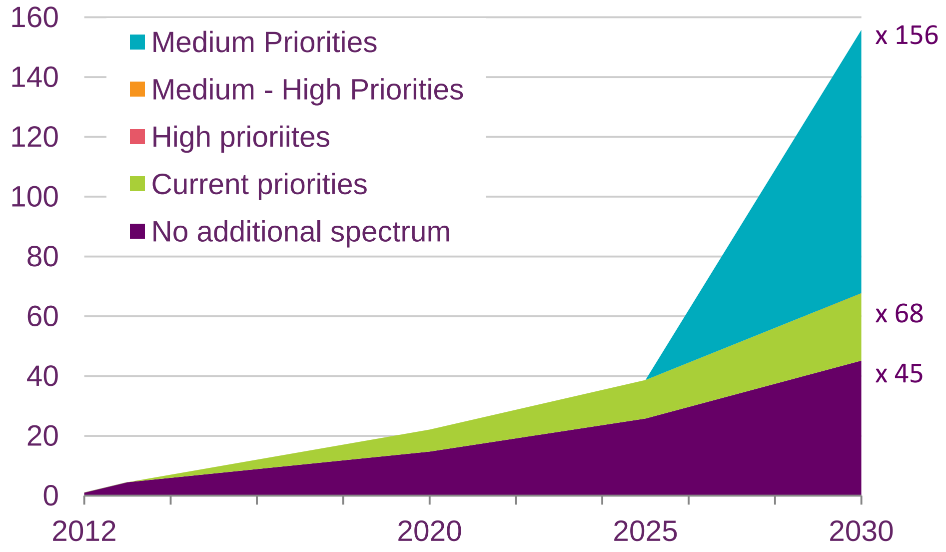
7.28.2 Users at the cell edge are likely to be covered only by sub 1 GHz spectrum when indoors (unless offloading onto Wi-Fi or femtocells). The speed and capacity of the service available to them may therefore be limited by the amount of sub 1 GHz spectrum available.

7.29 The relative disadvantage of these locations could decrease in the future as networks at 800 MHz are rolled out; as 900 MHz is further re-farmed; and if 700 MHz is released. Table 10 shows the percentage of total spectrum that is sub 1 GHz for the different spectrum scenarios.

7.30 If further spectrum were made available only at higher frequencies then in principle this could increase the relative disadvantage faced by users at the cell edge in the long term. However in most of the scenarios we identify the percentage of spectrum that is sub 1GHz could be higher than it was in 2012, when there was only a small amount of re-farmed 900 MHz spectrum in use below 1 GHz for mobile broadband. Only one scenario, the release of our high and medium to high priorities, would result in the spectrum that is sub 1 GHz falling slightly - to 10% of the total in 2030 compared to a percentage of 11% in 2012.

7.31 To illustrate how capacity may increase for those users only served by sub 1 GHz spectrum we have modelled capacity assuming that only sub 1 GHz spectrum is available (see Figure 14).

**Figure 14: Potential increase in total mobile data capacity relative to 2012 (excluding Wi-Fi) for locations served by sub 1 GHz spectrum only**




7.32 As the percentage of total spectrum that is sub 1 GHz goes up over the period, the increase in capacity is greater than the average increase.

7.33 Increased availability of sub 1 GHz spectrum is one factor that is likely to improve the service at the band edge, but users in these locations will also benefit from deployment of more mobile sites. This will increase network density and reduce the distance of these users from the cell.

*Question 12: Do you agree with the possible timelines we have identified in this section?*

*Question 13: Do you have any comments on the capacity implications outlined in this section?*

## Section 8

# Next Steps

8.1 This section sets out the potential next steps for our work related to mobile data strategy covering a range of areas:

- The band specific implications, based on the priorities proposed in this document, for:
  - o Further domestic work, for example further technical and strategic studies;
  - o Developing a UK position for international discussions, recognising this will be developed based on a range of factors.
- The next step for our consultation process in relation to the proposals in this document.

## Next steps for specific bands

8.2 Table 11 below sets out the potential next steps for the specific bands considered in this document if the priorities proposed in this document are confirmed in our subsequent statement.

8.3 The domestic next steps cover the actions that Ofcom expect to undertake for spectrum it manages as well as relevant next steps that Government expects to take for public sector spectrum. We will also consider additional potential sharing opportunities identified in response to our spectrum sharing consultation.

8.4 The implications for international next steps need to be seen in a slightly wider context. As indicated in Section 4, we are closely engaged in the international preparatory work for WRC-15 agenda item 1.1 and our work on our mobile data strategy is an important input to this process. The statement following this consultation will inform our position on additional candidate bands, beyond those that we have already proposed, for the final meeting of the ITU-R JTG 4-5-6-7 meeting in July 2014.

8.5 However, the UK's next steps in international arena will be informed by a number of factors in addition to the band prioritisation we have proposed, including Government input and the degree of support (or opposition) to particular bands from other countries. In many cases the UK has started to develop an international position as part of preparations for WRC-15 (in particular through CEPT CPG and ITU-R JTG 4-5-6-7) and the implications of our prioritisation are consistent with a continuation of our existing position. In other cases, the prioritisation may shift the future direction of our engagement, subject to other factors.

8.6 Beyond July 2014, the UK position on bands for mobile allocation or IMT designation at WRC in November 2015 will be informed by a number of factors including additional band specific studies that we may undertake and other external developments.

*Question 14: Do you agree with the next steps we have identified for further domestic work based on the proposed priorities?*

*Question 15: How do you think we should adjust our support for international harmonisation based on our proposed priorities?*

### Table 11: Overview of band specific next steps

| | Relative priority for future potential release | Implications for domestic next steps | Implications for international next steps |
|---|---|---|---|
| **700 MHz** | Existing priority | Consultation on future of the band Spring 2014; Statement Autumn 2014 | Continue to support harmonisation (mobile allocation and work on CEPT band plan) |
| **2.3 GHz and 3.4 GHz** | Existing priority | Due to be awarded in Autumn 2015 | Continue to support further harmonisation<br><br>(ECC Decision on 2.3 GHz and EC Decision on 3.4 GHz expected in March 14) |
| **UHF white spaces** | Existing priority | Undertaking pilot in 2014 with full solution after that. | Continue to support harmonisation |
| **1452-1492 MHz** | High | Expect to deal with licence variation request from existing licensee to reflect recent ECC Decision. | Continue to support harmonisation in CEPT<br><br>Support as a potential candidate band for WRC-15 (IMT designation) |
| **1980-2010 / 2170-2200 MHz (2 GHz MSS)** | High | We are in the process of assessing compliance with the common conditions to determine whether it would be appropriate for us to take any further action. | We will continue to engage with the European Commission and other Member States to secure the efficient use of this spectrum |
| **3.6-3.8 GHz** | High | Consider costs & feasibility of mobile broadband sharing with earth stations in more detail | Continue to support further harmonisation in CEPT/EU<br><br>Continue to support as a potential candidate band for WRC-15. |
| **5 GHz** | High | Sharing and compatibility studies to understand the conditions under which Wi-Fi sharing with incumbent services would be feasible & enforceable. | Continue to support studies on potential for harmonised Wi-Fi use whilst seeking to ensure protection of existing uses |

| | Relative priority for future potential release | Implications for domestic next steps | Implications for international next steps |
|---|---|---|---|
| **2.7-2.9 GHz** | Medium-High | Government programme to consider options for re-planning radars in order to release spectrum | Continue to support as a potential candidate band for WRC-15 |
| **3.8-4.2 GHz** | Medium-High | As 3.6-3.8 GHz | Would consider supporting as a potential candidate band for WRC-15 in future if wider international interest in this. |
| **450-470 MHz** | Medium | Mobile data use to be considered as part of planned review of competing demands in this band (proposed priority in our spectrum management strategy) | Already harmonised globally. No further action at present |
| **470-694 MHz** | Medium | Develop scenarios for longer term future of DTT and free-to-view TV more generally | Engage with further international work on band whilst seeking to ensure that consumers and citizens can continue to enjoy benefits delivered by DTT (and PMSE) use of the band in the UK. |
| **1350-1518 MHz**<br><br>(excluding 1400-1427 and 1452-1492 MHz) | Medium | MOD is assessing what spectrum in the 1427-1452 MHz band could be shared. Further work on Government spectrum release programme will take account of the potential value for mobile data services.<br><br>Consider costs and feasibility of sharing and/or migration of fixed links | Continue support the sub band 1427-1452 MHz as a potential candidate band for WRC-15<br><br>Consider supporting other bands depending on outcome of further studies & international interest |

## Next steps for our consultation process

8.7 Our consultation closes on 30 January 2014. Following consideration of responses we intend to publish a statement in Q2 2014. This will establish our relative prioritisation of future work across a range of bands and set out how we intend to take that forward, building on the next steps outlined above. We will also take account of the outcome of our related consultations on spectrum management strategy and the role of spectrum sharing.

8.8 In addition, we recognise that these priorities will not remain static and will need to respond to market and international developments. Consequently, following our statement we expect to review these priorities periodically and/or to respond to major external developments, including in the international arena.

## Annex 1

# Responding to this consultation

## How to respond

A1.1 Ofcom invites written views and comments on the issues raised in this document, to be made **by 5pm on Thursday 30 January 2014**.

A1.2 Ofcom strongly prefers to receive responses using the online web form at http://stakeholders.ofcom.org.uk/consultations/mobile-data-strategy/howtorespond/form as this helps us to process the responses quickly and efficiently. We would also be grateful if you could assist us by completing a response cover sheet (see Annex 3), to indicate whether or not there are confidentiality issues. This response coversheet is incorporated into the online web form questionnaire.

A1.3 For larger consultation responses - particularly those with supporting charts, tables or other data - please email: mobiledatastrategy@ofcom.org.uk attaching your response in Microsoft Word format, together with a consultation response coversheet.

A1.4 Responses may alternatively be posted or faxed to the address below, marked with the title of the consultation.

Justin Moore
Ofcom
Spectrum Policy Group
Riverside House
2A Southwark Bridge Road
London SE1 9HA

A1.5 Note that we do not need a hard copy in addition to an electronic version. Ofcom will acknowledge receipt of responses if they are submitted using the online web form but not otherwise.

A1.6 It would be helpful if your response could include direct answers to the questions asked in this document, which are listed together at Annex 4. It would also help if you can explain why you hold your views and how Ofcom's proposals would impact on you.

## Further information

A1.7 If you want to discuss the issues and questions raised in this consultation, or need advice on the appropriate form of response, please contact justin.moore@ofcom.org.uk

## Confidentiality

A1.8 We believe it is important for everyone interested in an issue to see the views expressed by consultation respondents. We will therefore usually publish all responses on our website, www.ofcom.org.uk, ideally on receipt. If you think your response should be kept confidential, can you please specify what part or whether all of your response should be kept confidential, and specify why. Please also place such parts in a separate annex.

A1.9 If someone asks us to keep part or all of a response confidential, we will treat this request seriously and will try to respect this. But sometimes we will need to publish all responses, including those that are marked as confidential, in order to meet legal obligations.

A1.10 Please also note that copyright and all other intellectual property in responses will be assumed to be licensed to Ofcom to use. Ofcom's approach on intellectual property rights is explained further on its website at http://www.ofcom.org.uk/about/accoun/disclaimer/

## Next steps

A1.11 Following the end of the consultation period, Ofcom intends to publish a statement in Q2, 2014.

A1.12 Please note that you can register to receive free mail Updates alerting you to the publications of relevant Ofcom documents. For more details please see: http://www.ofcom.org.uk/static/subscribe/select_list.htm

## Ofcom's consultation processes

A1.13 Ofcom seeks to ensure that responding to a consultation is easy as possible. For more information please see our consultation principles in Annex 2.

A1.14 If you have any comments or suggestions on how Ofcom conducts its consultations, please call our consultation helpdesk on 020 7981 3003 or e-mail us at consult@ofcom.org.uk . We would particularly welcome thoughts on how Ofcom could more effectively seek the views of those groups or individuals, such as small businesses or particular types of residential consumers, who are less likely to give their opinions through a formal consultation.

A1.15 If you would like to discuss these issues or Ofcom's consultation processes more generally you can alternatively contact Graham Howell, Secretary to the Corporation, who is Ofcom's consultation champion:

A1.16 Graham Howell
Ofcom
Riverside House
2a Southwark Bridge Road
London SE1 9HA

Tel: 020 7981 3601

Email Graham.Howell@ofcom.org.uk

## Annex 2

# Ofcom's consultation principles

A2.1 Ofcom has published the following seven principles that it will follow for each public written consultation:

## Before the consultation

A2.2 Where possible, we will hold informal talks with people and organisations before announcing a big consultation to find out whether we are thinking in the right direction. If we do not have enough time to do this, we will hold an open meeting to explain our proposals shortly after announcing the consultation.

## During the consultation

A2.3 We will be clear about who we are consulting, why, on what questions and for how long.

A2.4 We will make the consultation document as short and simple as possible with a summary of no more than two pages. We will try to make it as easy as possible to give us a written response. If the consultation is complicated, we may provide a shortened Plain English Guide for smaller organisations or individuals who would otherwise not be able to spare the time to share their views.

A2.5 We will consult for up to 10 weeks depending on the potential impact of our proposals.

A2.6 A person within Ofcom will be in charge of making sure we follow our own guidelines and reach out to the largest number of people and organisations interested in the outcome of our decisions. Ofcom's 'Consultation Champion' will also be the main person to contact with views on the way we run our consultations.

A2.7 If we are not able to follow one of these principles, we will explain why.

## After the consultation

A2.8 We think it is important for everyone interested in an issue to see the views of others during a consultation. We would usually publish all the responses we have received on our website. In our statement, we will give reasons for our decisions and will give an account of how the views of those concerned helped shape those decisions.

## Annex 3

# Consultation response cover sheet

A3.1 In the interests of transparency and good regulatory practice, we will publish all consultation responses in full on our website, www.ofcom.org.uk.

A3.2 We have produced a coversheet for responses (see below) and would be very grateful if you could send one with your response (this is incorporated into the online web form if you respond in this way). This will speed up our processing of responses, and help to maintain confidentiality where appropriate.

A3.3 The quality of consultation can be enhanced by publishing responses before the consultation period closes. In particular, this can help those individuals and organisations with limited resources or familiarity with the issues to respond in a more informed way. Therefore Ofcom would encourage respondents to complete their coversheet in a way that allows Ofcom to publish their responses upon receipt, rather than waiting until the consultation period has ended.

A3.4 We strongly prefer to receive responses via the online web form which incorporates the coversheet. If you are responding via email, post or fax you can download an electronic copy of this coversheet in Word or RTF format from the ‘Consultations’ section of our website at www.ofcom.org.uk/consult/.

A3.5 Please put any parts of your response you consider should be kept confidential in a separate annex to your response and include your reasons why this part of your response should not be published. This can include information such as your personal background and experience. If you want your name, address, other contact details, or job title to remain confidential, please provide them in your cover sheet only, so that we don’t have to edit your response.

## Cover sheet for response to an Ofcom consultation

| BASIC DETAILS |
|---|
| Consultation title: |
| To (Ofcom contact): |
| Name of respondent: |
| Representing (self or organisation/s): |
| Address (if not received by email): |

| CONFIDENTIALITY | | | |
|---|---|---|---|
| Please tick below what part of your response you consider is confidential, giving your reasons why | | | |
| Nothing | ☐ | Name/contact details/job title | ☐ |
| Whole response | ☐ | Organisation | ☐ |
| Part of the response | ☐ | If there is no separate annex, which parts? | |
| If you want part of your response, your name or your organisation not to be published, can Ofcom still publish a reference to the contents of your response (including, for any confidential parts, a general summary that does not disclose the specific information or enable you to be identified)? | | | |

| DECLARATION | |
|---|---|
| I confirm that the correspondence supplied with this cover sheet is a formal consultation response that Ofcom can publish. However, in supplying this response, I understand that Ofcom may need to publish all responses, including those which are marked as confidential, in order to meet legal obligations. If I have sent my response by email, Ofcom can disregard any standard e-mail text about not disclosing email contents and attachments. | |
| Ofcom seeks to publish responses on receipt. If your response is non-confidential (in whole or in part), and you would prefer us to publish your response only once the consultation has ended, please tick here. | ☐ |
| Name | Signed (if hard copy) |

## Annex 4

# Consultation questions

*Question 1: Have we correctly identified the future characteristics of mobile data demand?*

*Question 2: Do you agree that there is a prospect of significant continuing growth in demand for mobile data services?*

*Question 3: Have we identified all the challenges in realising future growth in citizen and consumer benefits from use of mobile data services and do you have any comments on the nature or the scale of the challenges we have identified?*

*Question 4: Have we correctly identified all the areas where Ofcom has a role in addressing the challenges of growing demand for mobile data services?*

*Question 5: Do you agree that the main additional area that our mobile data strategy needs to address is in relation to potential future spectrum options?*

*Question 6: Is Ofcom doing all that it needs to do in other areas identified as being relevant to the mobile data challenge?*

*Question 7: Do you agree with our high-level assessment of likely technology and topology trends and their implications for future spectrum use? We are particularly interested in views on:*

*a) the potential demand for spectrum above 10 GHz;*
*b) the potential impact of integrating broadcast capability into mobile networks;*
*c) whether the technical and commercial challenges of supporting additional frequency bands in mobile devices drives interest towards bands close in frequency to existing bands;*
*d) the relative importance of large contiguous blocks of spectrum versus aggregation of smaller blocks*

*Question 8: Are there any additional technology or topology trends that we need to consider that could have an effect on spectrum use?*

*Question 9: Do you agree with the short list of bands we have identified for more detailed consideration?*

*Question 10: Do you agree with our methodology for prioritising potential bands for mobile data use?*

*Question 11: Do you agree with our provisional assessment and the results of our band prioritisation?*

*Question 12: Do you agree with the possible timelines we have identified in this section?*

*Question 13: Do you have any comments on the capacity implications outlined in this section?*

*Question 14: Do you agree with the next steps we have identified for further domestic work based on the proposed priorities?*

*Question 15: How do you think we should adjust our support for international harmonisation based on our proposed priorities?*

**Annex 5**

# Technology and network developments

A5.1 This annex provides more detail on the technology and network trends identified in section 5 of the consultation document.

## Support for wider channel bandwidths

A5.2 As the demand for mobile data has increased, the technologies underpinning mobile networks have evolved to support faster connections. One way this has been achieved is through the use of wider channel bandwidths. For example, the 2G GSM standard used a 200kHz channel to support its voice, text messaging and limited data services. The introduction of 3G UMTS networks led to faster data services, initially based on 5MHz carriers. The latest evolutions of the 3G standards are able to aggregate two channels together to form carriers of 10MHz, with emerging standards able to support further aggregation of up to eight carriers. The 4G, LTE-based networks currently being deployed in the UK are based on carriers of up to 20MHz. Future enhancements, known as LTE-Advanced, will be able to aggregate multiple channels together to make a 100MHz carrier, supporting theoretical data rates in excess of 1Gbps. The channels to be aggregated can either be neighbouring (i.e. in the same band) or, in later evolutions, in different frequency bands.

A5.3 The ability to aggregate relatively narrow channels is particularly valuable if wider contiguous bandwidths are not readily available (for instance this is the practical situation for frequencies below about 3GHz, where the availability of wide, contiguous channels needed support very high data rates is limited). One potential disadvantage associated with channel aggregation is the need for more complex transmitter and receiver hardware in both the base station and mobile device, as discussed later in this section.

A5.4 Greater use of frequencies higher than those currently used to support mobile broadband services, such as above 10GHz, raises the possibility of using channel bandwidths in excess of 100MHz without need for aggregating multiple narrower channels. This is because spectrum at these frequencies is likely to be available with wider bandwidths than is the case with lower frequencies. Recent press releases from companies such as Japan's NTT DoCoMo[46] and Korea's Samsung[47] indicate this is an active area of research for next generation mobile systems. However, there are several associated challenges, including:

- *Building practical networks*: signals at higher frequencies, such as above 10GHz, typically propagate over shorter distances, are unable to penetrate far into buildings and could be entirely blocked by obstacles. Building networks that offer reliable coverage in a given area will therefore be challenging; and

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[46] NTT DoCoMo and the Tokyo Institute of Technology demonstrated prototype equipment operating in a 400MHz channel bandwidth at 11GHz, delivering a downlink data rate of 10Gbps, February 2013, www.nttdocomo.co.jp/english/info/media_center/pr/2013/0227_00.html

[47] Samsung demonstrated a prototype operating at 28GHz in channel bandwidths of up to 500MHz and delivering data rates in excess of 1Gbps, May 2013, http://global.samsungtomorrow.com/?p=24093

- *Manufacturing of equipment*: The semiconductor materials that form the basis of the electronics used in consumer communications equipment have properties that influence the frequencies and technologies that can be supported at a given point in time. Silicon is the most commonly used semiconductor; the raw materials are abundant and a considerable amount of investment in manufacturing plant over many years has led to the development of significant expertise globally. However, as technologies become more complex (e.g. to support higher frequencies or faster data rates), the use of alternative materials may be required. Materials such as gallium arsenide (GaAs) may offer better performance in these cases, supporting frequencies in excess of 100GHz. However, the manufacturing process is less mature compared to silicon which, in turn, has made the manufacture of cheap components for consumer equipment more challenging.

A5.5 Recent developments in Wi-Fi standards offer an example of how the availability of wider bandwidths at higher frequencies is enabling support for higher data rates, as summarised in Table 12: . Early versions of Wi-Fi, based on the IEEE[48] 802.11b and 802.11g standards, operated in the 2.4GHz band in bandwidths of up to 20MHz. This frequency band is shared with a number of other users and technologies, and later generations of Wi-Fi, notably 802.11n, also supported operation in the less congested 5GHz band. This has opened up the possibility of supporting higher data rates through the use of a 40MHz channel bandwidth. The latest versions of Wi-Fi have taken this a step further, with the 802.11ac variant operating only in the 5GHz band supporting data rates greater than 1 Gbps with channel bandwidths of up to 160MHz and the 802.11ad variant operating only in the 60GHz band supporting even higher data rates with channel bandwidths of 2GHz.

**Table 12: Wi-Fi standards have evolved to use wider bandwidths to support higher data rates**

| Wi-Fi standard | Year standard approved[49] | Frequency bands supported | Maximum channel bandwidth, MHz | Theoretical maximum data rate, Mbps [50] [51] |
|---|---|---|---|---|
| 802.11b | 1999 | 2.4GHz | 20 | 11 |
| 802.11a | 1999 | 5GHz | 20 | 54 |
| 802.11g | 2003 | 2.4GHz | 20 | 54 |
| 802.11n | 2009 | 2.4GHz 5GHz | 40 | 450 |
| 802.11ac | 2014 | 5GHz | 160 | 1300 |
| 802.11ad | 2012 | 60GHz | 2000 | 7000 |

[48] Institute of Electrical and Electronics Engineers, a professional and standardisation organisation that is, amongst other things, responsible for furthering communications technologies, including Wi-Fi.
[49] Official IEEE 802.11 working group project timelines, dated 21 September 2013, http://www.ieee802.org/11/Reports/802.11_Timelines.htm
[50] Introduction to Wi-Fi technologies from the Wi-Fi Alliance website, http://www.wi-fi.org/discover-and-learn
[51] White paper on Wi-Fi at 60GHz from the Wi-Fi Alliance website, http://www.wi-fi.org/sites/default/files/downloads-registered/WiGig_White_Paper_20130909.pdf

A5.6 Not all technical development is about the move to higher speeds and wider channel bandwidths. For example, another variant of the Wi-Fi standard, known as IEEE 802.11af, is being designed to operate in TV white spaces in channel bandwidths of around 8MHz. Here the intention is to exploit available spectrum opportunities, rather than maximise headline data rate.

A5.7 The potential implication for the use of wider channel bandwidths on spectrum demand is:

- Demand may increase for bands where wider channels can be accommodated. These may be at higher frequencies where wider bandwidths tend to be easier to accommodate, or based on the aggregation of multiple, narrow channels at lower frequencies. The latter will require user devices with advanced receivers that are capable of supporting the processing of multiple carriers simultaneously.

<u>Support for advanced antenna techniques</u>

A5.8 Multiple Input Multiple Output (MIMO) antenna systems form part of the current generation of cellular (both 3G and 4G) and Wi-Fi networks. MIMO is a technique for improving link performance by sending the data over multiple antennas concurrently; this can have the effect of either increasing the link data rate or improving the robustness of the link. Current systems use 2 or 3 antennas, with next generation systems likely to support up to 8 transmit and receive antennas. Favourable radio environments are required to achieve the maximum improvements in performance. For example, where there are high signal and low noise levels, and where reflections off obstacles or the terrain result in signals arriving at the receiving antennas via different routes[52]. While the use of MIMO can lead to improvements in link performance, the advanced receivers and signal processing required can lead to an increase in power consumption, and therefore a shortening of battery life, in devices.

A5.9 Looking further into the future, antenna systems with even more elements are likely to be deployed, in particular at higher frequencies. So-called massive MIMO or beam forming systems, with in excess of one hundred antenna elements, facilitate the accurate horizontal and vertical steering of narrow beams between transmitter and receiver to improve both range and data rate. The development and successful implementation of these technologies in real-world environments will be a key enabler for the exploitation of higher frequencies (e.g. above about 10GHz), where range can otherwise be limited by buildings and other obstructions.

A5.10 The elements within a MIMO system can either be co-located, or distributed. In the latter case, the antennas of neighbouring base stations can be connected via high performance signalling links to create a combined or “virtual” MIMO system, delivering performance enhancements such as increased data rates.

A5.11 The potential implications for the use of advanced antenna techniques on spectrum demand are:

- Demand may increase for higher frequency spectrum, e.g. above about 10GHz. This is because advanced antenna techniques, such as beam forming and MIMO go some way to addressing the challenges of building reliable and robust mobile networks at these frequencies.

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[52] This is known as multipath propagation.

- Demand may also increase for spectrum at frequencies between 3 and 6GHz. The antenna sizes and configurations at these frequencies are particularly suited to advanced antenna techniques, compared to the relatively large antenna sizes at lower frequencies.

## Development of technologies that can deal with traffic asymmetry (between uplink and downlink)

A5.12 Mobile data demand in the future is likely to be driven strongly by services which are predominantly downlink oriented, e.g. video. The delivery of these services using paired spectrum with equally quantities of uplink and downlink spectrum, as is the case with the majority of today's commercial networks which are based on frequency division duplex (FDD technology), may not be the most optimal approach.

A5.13 2G and 3G networks are almost entirely based on FDD technologies[53]. The 4G standard has a TDD variant, known as TD-LTE, which is likely to be deployed alongside the FDD variant. This was reflected in our 4G spectrum auction, which concluded in February 2013 and involved the award of both paired and unpaired bands (for FDD- and TDD-based networks respectively). Commercial TD-LTE systems have already been deployed (e.g. in Hong Kong) and it is reasonable to expect UK operators with suitable spectrum holdings to follow suit as part of their ongoing network roll out.

A5.14 FDD and TDD approaches differ in their use of spectrum. For example, FDD systems require distinct allocations for uplink and downlink respectively. To avoid interference, these allocations need to be separated by a block of spectrum known as the duplex gap. In contrast, TDD systems use a single, contiguous allocation for both uplink and downlink, however, unless synchronised, neighbouring TDD networks need to be separated in frequency to avoid inter system interference.

A5.15 At present, FDD systems tend to have the same amount of spectrum allocated to both uplink and downlink.. TDD systems are potentially capable of optimising the ratio of spectrum allocated to the uplink and downlink depending on the overall traffic requirements of the network – however this flexibility can be restricted if neighbouring TDD networks are required to be synchronised to avoid inter-system interference.

A5.16 In future, FDD systems may also be able to deal more optimally with highly asymmetric traffic with advances such as supplementary downlink (SDL). This is where a separate spectrum block is used to provide additional downlink resource to supplement the normal (symmetrical) FDD arrangement.

A5.17 It is also possible that traffic asymmetry may be dealt with effectively by developments in the use of higher order modulation schemes. These tend to be easier to implement in the downlink thus allowing more data to be carried in the downlink direction even when the spectrum assigned is symmetrical.

A5.18 An increasing amount of spectrum is being allocated for unpaired use. In addition to the 45 MHz of bandwidth at 2.6 GHz that was awarded as part of the 4G auction

[53] A TDD version of the 3G standard used in the UK was developed but not deployed globally due to a lack of commercial interest.

and the 20 MHz of existing unpaired 3G spectrum at 2 GHz, we have recently proposed that the forthcoming award of former MoD spectrum at 2.3 GHz and 3.4 GHz could be for unpaired use[54].

A5.19 Demand may increase for unpaired spectrum suitable for the deployment of technologies such as supplementary downlink (SDL) and TDD networks.

## Sharing of spectrum

A5.20 In addition to advances to improve the performance or spectral efficiency of wireless network technologies, work is progressing on approaches that could enable the better sharing of spectrum for multiple purposes. In particular, there are some frequencies that are not in use at all times and in all places by the existing licensed users (this is often referred to as 'white space' spectrum). These frequencies could potentially be used for other purposes on a shared basis either through licensing or licence exemption. The advantage of this shared approach is that, in principle, it increases the supply of spectrum at a lower cost than clearing a band for a new use. The future role of spectrum sharing for mobile and wireless broadband services is considered in more detail in our recent consultation[55].

A5.21 These technology developments improve the detail and accuracy of information about how spectrum is actually used at a particular location and time, leading to the identification of white spaces that could be exploited by suitably-equipped devices. This is an active area of research but two broad approaches are emerging:

- *Geolocation databases*, which store information about spectrum use at particular locations and inform devices of which frequencies can be shared while protecting licensed users; and

- *Spectrum sensing*, in which devices identify unused frequencies by listening for transmissions from other devices.

A5.22 A further potential advantage is that the same techniques can be used to improve the utilisation of spectrum. This information could be used to make local optimisations to the way spectrum is used to reduce interference or improve performance. The concept of using accurate information, often collected in real-time, in order to make decisions about how to access spectrum is often called dynamic spectrum access (DSA). We have recently published an early consultation, which is exploring whether DSA techniques could play a role in spectrum sharing.

A5.23 To date, the use of such technologies has been largely limited to the UHF band, where, in the UK and US, trials are seeking to confirm their efficacy in authorising spectrum access without causing interference to incumbent users. However, we expect the same fundamental approaches to be applicable to granting access to white spaces in other frequency bands. A first step in this direction has been taken by the Federal Communications Commission (FCC) in the US, where plans are being developed to use geo-location databases to authorise access to the 3.5GHz band for small cell, low power use. Many of the fundamental technology enablers for DSA are still in development but, in principle, DSA could lead to some of the

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[54] http://stakeholders.ofcom.org.uk/binaries/consultations/2.3-3.4-ghz/summary/2.3-3.4-ghz.pdf
[55] Ofcom consultation, The Future Role of Spectrum Sharing for Mobile and Wireless Data Services – Licensed sharing, Wi-Fi and Dynamic Spectrum Access, August 2013, http://stakeholders.ofcom.org.uk/consultations/spectrum-sharing/

benefits enjoyed by licensed users (e.g. more predictable access to spectrum and some protection from the effects of interference) being conferred to licence exempt users. These benefits may be more likely to be realised by low power users of spectrum, such as small cells and area networking.

A5.24 Similarly, the same technology enablers could facilitate increased sharing of spectrum on a licensed basis. Licensed Shared Access (LSA) is a concept in which a licensed user of spectrum is able to transfer access rights, including the right to protection from interference, to one or more other users. One application of LSA could be to facilitate the release of bands held by the public sector. LSA may be appropriate in those cases when a full release is not possible, due to the need to retain some spectrum for continued public sector use. The Radio Spectrum Policy Group (RSPG) has recently published a consultation on a draft opinion on LSA[56].

A5.25 The potential implication for spectrum sharing on spectrum demand is:

- Demand may increase for bands where incumbent use is limited geographically or by time; and so where the spectrum can be shared for other uses.

## Development of broadcast capability for mobile networks

A5.26 A significant proportion of projected future demand for data is expected to be for video services. Much of this demand is expected to be for on-demand video, such as accessing videos via You Tube or streaming content from BBC iPlayer. This content is typically specific to a given user at a given point in time and delivery is via a dedicated, or unicast, connection between the content server and end user.

A5.27 Some of the expected future demand may be for linear or broadcast content. This content is inherently suited to broadcast delivery, whereby the same content is delivered to multiple users via a single connection. Delivery of this content via a broadcast network is more efficient, and will use less bandwidth, than delivering multiple unicast streams to many users over a conventional mobile network.

A5.28 Any such spectrum efficiency benefits will depend on the future demand for linear or broadcast video, versus on-demand video. Previous trials of delivering broadcast TV content to mobile handsets did not lead to enduring commercial deployments in the UK. However, there remains sufficient interest within the network equipment community to have developed technical standards that support delivery of broadcast content over 4G mobile networks.

A5.29 The Evolved Multimedia Broadcast Multicast Service (eMBMS) has been specified as part of the LTE family of standards and is capable of delivering full high definition video, as well as broadcast radio services. The technology is relatively immature and there are currently no commercial deployments in the UK.

A5.30 In addition to providing service to mobile handsets, there is also an emerging debate[57] regarding the use of technologies such as eMBMS to deliver broadcast content to conventional TVs. The proposed advantage of this approach is that eMBMS could deliver multi-channel content more efficiently than the current

[56] RSPG public consultation on licensed shared access, https://circabc.europa.eu/sd/d/dc44e39f-7fab-4cc2-8513-f6fce5c25c34/RSPG13-529rev1-Draft%20RSPG%20Opinion%20on%20LSA.pdf

[57] Within the European Electronic Communications Committee (ECC) Task Group 6 on developing a long term vision for UHF spectrum, http://www.cept.org/ecc/groups/ecc/tg6

approach of using the DVB-T and DVB-T2 broadcast standards. This debate is at a very early stage and we are planning to monitor this and other relevant activities as part of our ongoing programme of technical work.

A5.31 This may lead to the same spectrum to being used to deliver broadcast TV to homes as well as broadcast mobile video data thus reducing the overall demand for mobile specific spectrum for the delivery of these services.

## Mobile device support for multiple bands

A5.32 Each generational change in mobile networks brings with it new technologies that need to be supported in both mobile devices and base stations. Often the introduction of a new generation of mobile technology has taken place alongside existing generations rather than replacing them entirely, for instance mobile networks today include 2G, 3G and 4G technologies with, in many cases, each technology being deployed in a new set of spectrum bands. In addition, as the demand for mobile data has increased the number of spectrum bands made available overall has increased. This means that mobile handsets have become progressively more complex, supporting ever more technologies and frequency bands. Though we do expect some consolidation in future (e.g. the eventual phasing out of older generations of technology in favour of newer ones), it is likely that this trend will continue for the foreseeable future.

A5.33 Adding a new technology and frequency to mobile devices, particularly mobile handsets, is a complex design and implementation task. Many of the radio frequency (RF) components are frequency specific, to the extent that adding support for a new band often requires the duplication of components leading to inevitable increases in cost and complexity. Furthermore, the addition of new RF components into a transceiver design can lead to increased signal losses and a reduction in the handset’s real-world performance; this many manifests itself as a reduction in achievable data rate or network coverage.

A5.34 In general the benefit from adding a new technology to a handset usually more than offsets the disadvantage of adding additional bands. For example, users migrating from a 3G to a 4G handset are likely to see an increase in achievable data rates that this generational change brings. However, the proliferation of bands needing support in handsets is still a major challenge to handset manufacturers. Such manufactures often make choices about which bands to supports and in some instances may elect not to include certain bands if the overall (global/regional) market for their use is limited.

A5.35 As previously discussed, carrier aggregation may be an important tool for operators to deliver higher data rates by combining spectrum allocations to form wider virtual carrier bandwidths. Support for carrier aggregation in a handset requires the duplication of receiver components and the addition of new components to split the received aggregated carriers for processing. This will inevitably add cost and complexity and may contribute to increased signal losses in the receivers, although any impact on performance is difficult to assess at this time.

A5.36 Carrier aggregation is an emerging technology, which is likely to deliver benefits through increased data rates irrespective of other reductions in performance resulting from the addition of more advanced receivers in handsets. However, it may reduce network costs to deliver wider channel bandwidths through the use of contiguous blocks of spectrum, where possible.

A5.37 Research into the materials used for RF components is continuing and is expected to lead to steady improvements in the ability to integrate more components with lower signal losses. More significant improvements, such as those leading to the ability to manufacture components that are tuneable across a wide range of frequencies, are likely to emerge in the longer term but will take time to make a significant impact.

A5.38 Given this, it may continue to be challenging to support an increasing number of bands and technologies in a device, especially in devices with small form factors like mobile phones. In this case, one outcome may be that particular bands become device-specific. For example, a given band might be used by larger form factor devices, such as tablets or laptop PCs, or used by niche devices or applications, such as machine to machine (M2M) or personal Wi-Fi hotspots (Mi-Fi).

A5.39 This is a complex topic that reflects both the demand for additional spectrum and the challenges in supporting those bands in a cost effective way. In particular, it may not be possible to make a straightforward assessment of the cost or performance implications for supporting a particular band purely on the basis of the frequency. For example, it may not be possible to conclude that 3.4GHz is easier to implement in a device than 2.3GHz without a detailed and hardware-specific analysis. We have commissioned a study to inform our thinking..

A5.40 The potential implications for handset support for multiple bands on spectrum demand are:

- Demand may be higher for those bands that are closer, in frequency terms, to existing bands, as it may be easier and less expensive to support these bands in handsets.

## Other developments that might influence demand

A5.41 While developments in new technologies are increasing the reach and data rates supported by mobile networks, other changes in technology are acting as substitutes for additional coverage and capacity. They can be broadly categorised as either client- or server-side developments.

A5.42 Client-side developments include changes in technology that have an impact on the capability of user devices, such as mobile phones or tablets. The most relevant of these developments is the increase in storage capacity of mobile devices, with current devices typically supporting up to 64GB. This makes it possible for users to store all, or a significant proportion of, their music, video and photo libraries in the device and reduces the need to download or stream this content whilst on the move. Increases in storage capacity have also made it possible for other applications that would otherwise require streaming of data, such as mapping tools, to be stored locally within the mobile device.

A5.43 Server-side developments include changes within the network infrastructure or content servers which reduce the amount of data that needs to be delivered to end users. These approaches were first used soon after 3G networks launched to reduce the size and complexity of web pages, for example by compressing images; they were a relatively simple approach to manage traffic delivered across the network to devices that were often not able to process and display complex content. While networks and devices have evolved, these approaches still could have some value in optimising multimedia content, especially video, to ensure the appropriate trade-off between quality and size.

A5.44 The potential implications for the above client- and server-side developments on spectrum demand are:

- Demand may be lower if client-side developments lead to a reduced need to stream or download multimedia content or large amounts of data to mobile devices. Demand may also be lower if servers are able to reduce the volume of data sent to mobile devices, especially if this can be achieved without a perceivable loss in quality.

## Network topology trends

A5.45 In addition, and often related to, technology changes, there are clear trends emerging in how networks are deployed. Some trends reflect new ways of deploying an existing technology within a network, whilst others reflect the integration of a number of technologies into a more complex service delivery network.

A5.46 The term often used to describe these trends is heterogeneous networking, or *hetnets* for short. The term reflects heterogeneity in two ways:

- Different cell sizes formed of the same technology, e.g. the integration of macro, micro and small cells based on LTE into the same network; and

- Different technologies built into the same overall network, e.g. 3G, LTE and Wi-Fi cells, with the ability to roam between them.

A5.47 A number of specific initiatives are outlined below. The high level theme is that in the long term networks will be even more intelligent than today, enabling devices to seamlessly take advantage of the optimum mix of spectrum and networks available at any particular location and time.

### Smaller cells

A5.48 The move towards deployment of smaller cells in mobile networks, often called pico- or femtocells, is driven by the need to serve areas of high demand for data. These typically cover smaller areas, as a consequence they can use lower powers and require much less site than traditional macro cells. Higher frequency spectrum is typically used for small cells, as propagation constraints are less important for local area use. As previously mentioned, in the US steps are being taken to open up the 3.5GHz band on geographically limited basis for the use of small cells.

A5.49 One consequence arising from the move to small cells is the need to provide high performance backhaul (between base station and core network) and interconnection (between base stations). This is likely to be based on fixed, fibre connections, where available, but there is also likely to be a requirement for wireless backhaul using higher frequency spectrum. For example, we understand some outdoor Wi-Fi deployments in London are using 5GHz spectrum to connect neighbouring access points back to a shared backhaul link.

A5.50 The potential implications for the adoption of small cells on spectrum demand are:

- Demand may increase for higher frequency spectrum, which could be used to support small cells operating at lower powers.

- While not a direct implication on demand for spectrum for access networks, the increased deployment of small cells may increase demand for higher frequency spectrum for wireless backhaul use.

A5.51 Other potential implications include:

- The increased use of small cells may increase the demand, or may be dependent on, widespread availability of fibre connections for high performance backhaul.

- There may also be practical implications for network deployment, including the need for changes to planning regulations to facilitate the identification of new cell sites and the installation of new equipment.

## Automatic switching between cellular and Wi-Fi networks

A5.52 The hetnet concept also includes the use of multiple technologies to deliver services. The most obvious example is Wi-Fi, which is playing an increasingly important role in delivering mobile and wireless data, either for local area networking or as a means of delivering traffic that has been offloaded from a mobile network.

A5.53 In the home and office, an increasing number of devices support Wi-Fi. Outside the home and office, use of public Wi-Fi networks has been more limited. One reason for this is the inability of smartphones, which are the most commonly used devices on the move, to move seamlessly between cellular and Wi-Fi networks. A number of technology developments are aiming to resolve this, leading to automatic switching between cellular and Wi-Fi networks. They include[58]:

- Hotspot 2.0 from the Wi-Fi Alliance, which aims to simplify the ease of network switching from the user's perspective. It achieves this by enabling automatic authentication with Wi-Fi networks based on, amongst other things, credentials stored in a mobile handset's SIM[59] card. This means that it will be possible to automatically connect a mobile phone to a public Wi-Fi network based on information stored in the SIM. Support for Hotspot 2.0 is included in some of the latest smartphones, including the Apple iPhone 5S. Hotspot 2.0 is certified by the Wi-Fi Alliance under the name Passpoint;

- Access Network Discovery and Selection Function (ANDSF) from the 3GPP, which is intended to allow mobile operators to influence which public Wi-Fi networks their subscribers can connect to; and

- Next Generation Hotspot (NGH) from the Wireless Broadband Alliance, which is a collection of initiatives, including a programme of interoperability testing of Passpoint certified equipment with network operator back-end systems.

[58] More information can be found in technical report for Ofcom, Study on the Use of Wi-Fi for Metropolitan Area Networks, August 2013, http://stakeholders.ofcom.org.uk/market-data-research/other/technology-research/2013/wifi-met-area/
[59] Subscriber Identity Module, the chip that is installed into a mobile handset to identify the subscriber to the network.

A5.54 The potential implications for the automatic switching between networks on spectrum demand are:

- The use of Wi-Fi networks in public areas could be driven up as more mobile traffic is automatically offloaded onto local area networks. This may result in ‘offload via Wi-Fi’ becoming a more important way of providing indoor service.

- There will be additional demand for Wi-Fi spectrum and ensuring adequate supply of spectrum for Wi-Fi, to accommodate growth in fixed wireless use as well as mobile data offloading to Wi-Fi, will be important.

Load balancing

A5.55 Mobile devices are becoming more complex and able to connect to a wider range of networks in an increasing number of frequency bands. This means that the number of options for delivering services to mobile and wireless devices is increasing, as is the scope for selecting the most appropriate option at any given time. The decisions about which network or frequency to use could, in principle, be made in the mobile device or in the network. Such decisions could be taken for a number of reasons, including to improve the quality of service for a given application or to reduce the number of users connected to a base station.

A5.56 We use the term "load balancing" to refer to the case in which decisions taken in the network which result in the optimal distribution of mobile terminals across networks and frequencies administered by a single operator. Rather than a specific technology, load balancing is a broad approach to network management that can be adopted by operators to deliver outcomes including:

- The even distribution of mobile devices across networks to avoid base station congestion;

- Reducing signalling overhead by steering fast-moving mobile devices onto macrocells with better geographic coverage; and

- Better quality of service by actively steering mobile devices on to the most appropriate network.

A5.57 Load balancing is likely to become an increasingly important tool as the number of network technologies and the frequencies they use continues to increase. The impact on spectrum usage is currently unclear. However, one possible use of load balancing to improve quality of service for users towards the cell edge. In this case, devices close to the centre of the cell could be actively steered onto small cells using higher frequencies (e.g. 2 or 2.6GHz). This would free up capacity for those users towards the edge of the cell that would be served by lower frequency spectrum.

A5.58 Load balancing increases the effective spectral efficiency of the network thus mitigating the overall demand for spectrum. It may also help to reduce overall demand for additional low frequency spectrum as this can be more efficiently targeted on users in harder to serve locations.

## Annex 6

# High level band review

A6.1 This annex provides a very high level review (of bands between 410 MHz and 6425 MHz and identifies those which we consider in more detail in section 6 of our consultation document. We have chosen this range as it encompasses the spectrum generally considered to be most suitable for the delivery of mobile broadband services. There may also be technology advances that will open up possibilities to exploit other spectrum bands in the future, particularly bands above 6 GHz, (see Annex 5) although these are not considered in detail in this consultation.

**Table 13: High level band review**

| Band (MHz) | Capacity (MHz) | Current use includes (non-exhaustive) | Priority for further consideration at this stage? |
|---|---|---|---|
| **410 - 430** | 20 MHz | MOD, Private Mobile Radio (PMR), Emergency Safety Services, Programme Making & Special Events (PMSE) and Short Range Devices (SRDs) | ✕ Low priority. Not supported by RSPG. Not considered in detail further (but may be emerging interest internationally) |
| **430 - 450** | 20 MHz | MOD, Private Mobile Radio (PMR), Emergency Safety Services, Programme Making & Special Events (PMSE) and Short Range Devices (SRDs) | ✕ Low priority. Not supported by RSPG. Not considered further |
| **450 - 470** | 2 x 5 MHz 452.5-457.5 (paired with 462.5 - 467.5) | Private Mobile Radio (PMR), Emergency Safety Services, Programme Making & Special Events (PMSE) Short Range Devices (SRDs) and Maritime radio | ~ Warrants further consideration. See detailed review of band. |
| **470 -694** | Up to 224 MHz | DTT services, PMSE | ~ Warrants further consideration. See detailed review of band. |
| **694 - 790** | 2 x 30 MHz | DTT services and PMSE | Work already underway to consider release of this band (in line with UHF Strategy) |
| **791 – 821** (paired with 832 - 862 MHz) | 2 x 30 MHz | ALREADY USED FOR MOBILE (800 MHz band) | |
| **821 - 832** | 11 MHz | | ✕ Low priority. This band is the duplex gap for the paired configuration of the adjacent band already used for mobile. Not considered further. |
| **862 - 870** | 8 MHz | Low power short range devices including PMSE microphones all of which are licence exempt. | ✕ Low priority. Large number of licence exempt users and insufficient bandwidth. Not considered further |
| **870 -876** | 6 MHz | Recent decision to release for low power short range devices e.g. smart meters and RFID tags | ✕ Low priority. Ofcom statement in 2013 supports short range device (SRD) use. Also not supported by RSPG. Not considered further |

| Band (MHz) | Capacity (MHz) | Current use includes (non-exhaustive) | Priority for further consideration at this stage? |
|---|---|---|---|
| **876 - 880** | 2 x 4 MHz (paired with 921 - 925 MHz) | Licensed to GSM-R (Network Rail) in UK. Same use in Europe | ✕ Low priority. No prospect for relocating GSM-R; limited bandwidth; not supported by RSPG - therefore not considered further. |
| **880 – 915** (paired with 925 - 960 MHz) | 2 x 35 MHz | ALREADY USED FOR MOBILE (900 MHz band) | |
| **915 - 921** | 6 MHz | Recent decision to release for low power short range devices e.g. smart meters and RFID tags | ✕ Low priority. Ofcom statement in June 2013[60] supports SRD/RFID use. Also not supported by RSPG. Not considered further |
| **960 – 1215** | 390 MHz | Extensive military use under agreement with CAA. Radar and navigation sat services. Amateur and Galileo platform will also use band. | ✕ Low priority. Combined aeronautical use (civil & military) and Galileo interest means significant international interest and little prospect of change of use. Not supported by RSPG. Not considered further. |
| **1215-1300** | 85 MHz | As above. | ✕ Low priority. As 960 - 1215 MHz above. |
| **1350 - 1518** | Up to 110 MHz | Aeronautical, radar, amateur TV (repeaters) and Fixed links. | ~ Warrants further consideration. See detailed review of band. |
| **1518-1559** | 41 MHz | Satellite. Some PMSE audio in 1417 - 1525 MHz | ✕ Low priority. RSPG supportive of satellite use. Not considered further. |
| **1559 - 1610** | 51 MHz | GPS | ✕ Low priority. Very strong consumer interest in GPS use (eg Sat-Nav) and expected Galileo use in future. Not considered further. |
| **1610-1690** | 80 MHz | Mobile Satellite Service, Radio Astronomy, public safety, oil, local authority use | ✕ Low priority. Strong UK satellite interest..Not considered further. |
| **1690 - 1710** | 20 MHz | RSA grant for single receive-only satellite earth station. Emergency Services use (Scotland only) CEPT study into possible PMSE use in 1700 - 1710 MHz. | ✕ Low priority. No RSPG support. Band not considered further. |
| **1710 - 1785** | 75 MHz | ALREADY USED FOR MOBILE (1800 MHz band) | |
| **1785 - 1805** | | UK mainland Emergency services use (1790 - 1798) | ✕ Low priority. Emergency services have continuing use of this band. This band is used as the duplex gap for the paired configuration of the adjacent band already used for |

60 http://stakeholders.ofcom.org.uk/binaries/consultations/870-915/statement/statement.pdf

| Band (MHz) | Capacity (MHz) | Current use includes (non-exhaustive) | Priority for further consideration at this stage? |
|---|---|---|---|
| | | | mobile. Not considered further. |
| **1805-1880** | 75 MHz | ALREADY USED FOR MOBILE (1850 MHz band) | |
| **1880 - 1900** | 20 MHz | DECT cordless telephones | ✕ Low priority. EC DECT Directive gives DECT cordless telecommunications priority and protection in this band. Not considered further. |
| **1900 - 1920** | 20 MHz | Licensed to mobile network operators but currently unused. | ✕ Low priority. Awarded with 3G licences so already available for mobile. Technical issues with adjacent 3G band. CEPT looking into other potential uses. Not considered further. |
| **1920 - 1980** | 60 MHz | ALREADY USED FOR MOBILE (2100 MHz band) | |
| **1980 - 2010** | 2 x 30 MHz (paired with 2170 - 2200 MHz) | Inmarsat/Solaris allocation for MSS but no service launched. | ~ Warrants further consideration. See detailed review. |
| **2010 - 2025** | 15 MHz | Wireless cameras (on temporary basis established through Ofcom 2011 statement) | ✕ Low priority. CEPT looking into other uses - e.g. PMSE, SRD, air to ground communications. Relatively low value due to poor configuration. Not considered further. |
| **2025 - 2110** | 2 x 85 MHz ( paired with 2200 - 2290) | MOD, Space Science/ Space ops (incl satellite control and tracking), wireless cameras. | ✕ Low priority. Not supported by RSPG. Not considered further. |
| **2110 - 2170** | 60 MHz | ALREADY USED FOR MOBILE (2100 MHz band) | |
| 2170 - 2200 | 2 x 30 MHz (paired with 1980 - 2290 MHz) | Inmarsat/Solaris allocation for MSS | ~ Warrants further consideration. See detailed review. |
| **2290 - 2300** | 10 MHz | Secondary use of MOD spectrum by PMSE users (wireless cameras) | ✕ Low priority. Not considered further |
| **2300 - 2400** | 100 MHz | Work already underway to release for mobile use under Public Sector Spectrum Release (PSSR) programme. | |
| **2400 - 2483.5** | 83.5 MHz | ALREADY USED FOR WI-FI | |

| **Band (MHz)** | **Capacity (MHz)** | **Current use includes (non-exhaustive)** | **Priority for further consideration at this stage?** |
|---|---|---|---|
| **2483.5 - 2500** | 16.5 MHz (Paired with 1610 - 1626.5 MHz) | IMT satellite component pairing (1610 – 1626.5). PMSE wireless camera use | ✕ Low priority. Not considered further |
| **2500 - 2570** | 2 x 70 MHz (paired with 2620 - 2690 MHz) | ALREADY USED FOR MOBILE (2600 MHz band) | |
| **2570 - 2620** | 50 MHz | ALREADY USED FOR MOBILE (2600 MHz band) | |
| **2690 - 2700** | 10 MHz | UK Radio Astronomy service | ✕ Low priority. Not considered further |
| **2700-2900** | Up to 200 MHz | Civil and military aeronautical radar | ~ Under consideration as part of government spectrum release programme. See detailed review of band. |
| **2900 - 3100** | Up to 200 MHz | Maritime radar - both coastal and on board ships. | ✕ Low priority. Not considered further. |
| **3100 - 3400** | 300 MHz | Range of ongoing MOD uses. | ✕ Low Priority. Not considered further. |
| **3400 - 3600** | 100 MHz | Work already underway to release for mobile use under Public Sector Spectrum Release (PSSR) programme. | |
| **3600-3800** | 200 MHz | Permanent Earth Stations (PES), some fixed links | ~ Warrants further consideration. See detailed review of band. |
| **3800-4200** | 400 MHz | Permanent Earth Stations (PES), some fixed links | ~ Warrants further consideration. See detailed review of band. |
| **4200 - 4400** | 200 MHz | CAA & MOD. Used by aircraft (radio altimeters). | ✕ Low priority. Little international support. Not considered further. |
| **4400 - 5000** | 600 MHz | CAA & MOD. Used by aircraft (radio altimeters). MOD have identified 4.8-2.9 GHz for sharing. | ✕ Low priority. Not considered further. |
| **5000 - 5150** | 150 MHz | Band managed and licensed via CAA. Limited microwave landing system. Galileo will use bottom 30 MHz | ✕ Low priority. Not considered further |
| **5150 - 5350** | Up to 200 MHz | ALREADY USED FOR WI FI | |
| **5350-5470** | 120 MHz | MOD radar and satellite | ~ Warrants further consideration. See detailed review of band. |
| **5470 - 5725** | Up to 255 MHz | ALREADY USED FOR WI-FI | |

| Band (MHz) | Capacity (MHz) | Current use includes (non-exhaustive) | Priority for further consideration at this stage? |
|---|---|---|---|
| **5725-5925** | 200 MHz | MOD radar, EESS, FWS & PMSE | ~ Warrants further consideration. See detailed review of band. |
| **5925 - 6425** | 500 MHz | PMSE, Fixed satellite uplink and fixed links. | ✕ Low priority. Not supported by RSPG. Not considered in detail further (but may be emerging interest internationally). |

## Annex 7

# Capacity and Coverage Modelling

A7.1 In this section we explain the modelling approach behind the capacity illustrations in section 7 on spectrum scenarios and the (relative) capacity and coverage estimates for specific bands in section 6.

## Introduction

A7.2 The purpose of our modelling was to give a high level illustration of how mobile network capacity and coverage may develop in the next 10 – 20 years.

A7.3 The modelling approach that we have adopted is highly simplified and depends on forecasts of the future that are highly uncertain. Therefore the results should be viewed as one possible scenario of a future state of the world.

A7.4 Our modelling approach uses the results from an adaptation of the technical LTE model we developed for the award of the 800 MHz and 2.6 GHz spectrum bands (noting that many of the caveats we expressed in relation to that modelling work still apply). This work is outlined in the next section; the rest of the annex explains our revised modelling approach and the key results.

## Previous modelling

A7.5 In our previous work we modelled the downlink performance of LTE macro cell networks using paired spectrum.[61]

A7.6 The model generated a signal to interference plus noise ratio (SINR) for different population points in a simulation area. This SINR is translated into a single user throughput to give coverage, speed and capacity metrics for different simulation areas.

A7.7 The model was run for different spectrum portfolios (800 MHz, 1800 MHz or 2600 MHz spectrum), base station network sizes, network loadings, carrier bandwidths and building penetration depths. For a detailed description of the modelling approach see Annex 8 of the July 2012 Statement.

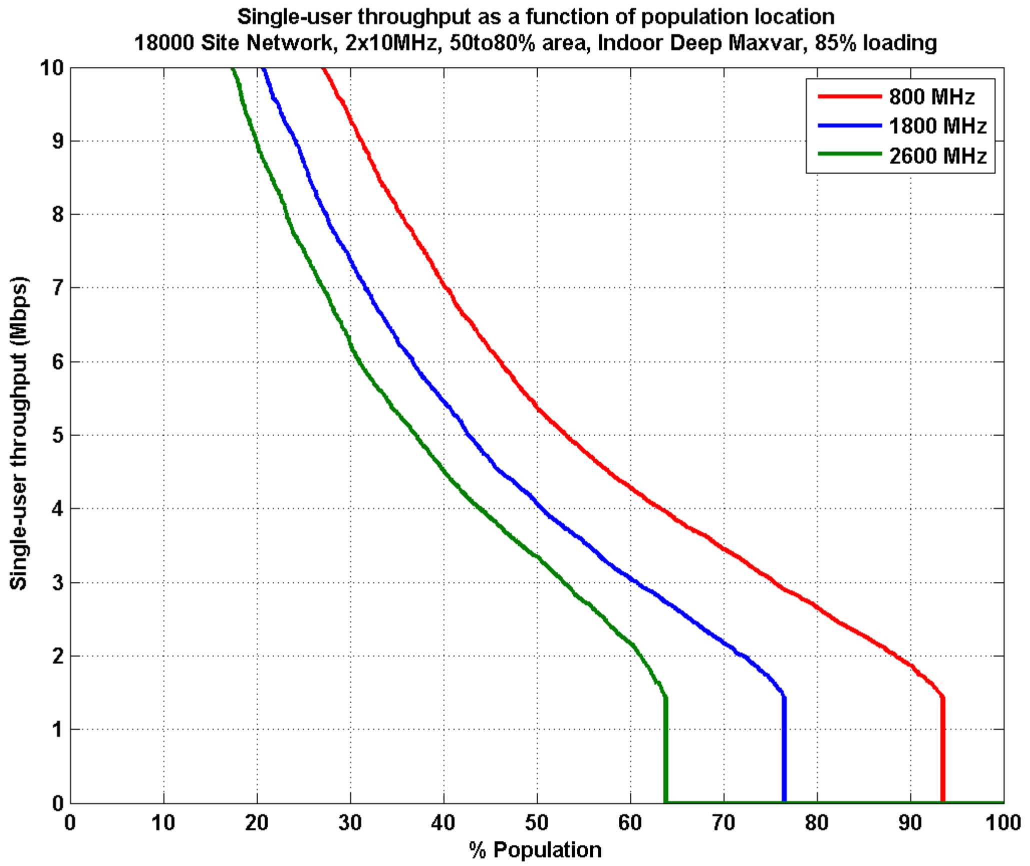
A7.8 The technical results were based on three simulation areas, based on population density, to represent:

- The zero to 50% most densely populated area; and
- The 50% to 80% most densely populated area; and
- The 80% to 90% most densely populated area

[61] For further information see the latest version of this work. presented in Annex 7 of “Assessment of future mobile competition and award of 800 MHz and 2.6 GHz”, Ofcom, July 2012. http://stakeholders.ofcom.org.uk/binaries/consultations/award-800mhz/statement/Annexes7-12.pdf

A7.9 The results that we have used from the technical model are based on the single user throughput as a function of population covered graphs. An example graph is shown below:

**Figure 15: Single user throughput, 18,000 sites 50-80% area, deep**




A7.10 We have made the following changes to the model for the purpose of this work:

a) We have run the technical model for an additional simulation area; the 90% to 100% most densely populated area. This allows us to model the whole country, however the results for the last 10% are less reliable than the other areas because the model was not designed with these low density areas in mind.

b) We have modelled the results for outdoor single user throughput in addition to shallow and deep indoors building penetration depths.

c) As a result of comments receive in relation to our modelling for the July 2012 Statement, we have included an number of additional checks in the modelling as follows:

- A check to ensure that an uplink data-rate of at least 80 kbps can be achieved (this represents 4% of a the guaranteed minimum downlink data-rate of 2 Mbps to account for TCP acknowledgements);
- An check against a minimum uplink SINR threshold of -7.5 dB; and

- A check against a minimum RSRP threshold of -124 dBm/15kHz for macro cells and -122 dBm/15kHz for micro cells.

d) In addition to modelling a macro cell network we have modelled the single user throughput for a low power network to approximate small cell deployment (micro cells). This is modelled using the same hypothetical base station network deployment as the macro cell modelling but with antenna heights restricted to 6 metres and transmit powers of 40 dBm/10MHz EIRP (as opposed to 64 dBm/10MHz for the macro cell network). This is unlikely to be an accurate reflection of small cell deployments, but is, we believe, a reasonable approximation given the constraints of our technical model in the absence of real small cell site data. However, the low power results should be treated as indicative only.

A7.11 We have estimated the average single user throughput for the different simulation areas, frequencies (2 x 10 MHz) and building penetration depths for an 18,000 site network, 85% loaded. We have defined the average single user throughputs as the area under the single user throughput curve.

A7.12 The results for the macro cell modelling are presented in Table 14.

**Table 14: Average single user throughputs (Mbps) for an 18,000 site macro cell network, 85% loaded, 2 x10 MHz**

| Simulation area | **0 - 50%** | | **50 - 80%** | | **80 - 90%** | | **90 - 100%** | |
|---|---|---|---|---|---|---|---|---|
| Building penetration depth | **Out-doors** | **Deep** | **Out-doors** | **Deep** | **Out-doors** | **Deep** | **Out-doors** | **Deep** |
| 800 MHz | 8.16 | 8.03 | 8.11 | 7.67 | 8.50 | 7.68 | 9.06 | 7.75 |
| 1800 MHz | 8.11 | 7.22 | 7.97 | 6.25 | 8.23 | 5.89 | 8.61 | 5.61 |
| 2600 MHz | 8.07 | 6.55 | 7.87 | 5.37 | 8.05 | 4.99 | 8.34 | 4.61 |

A7.13 The results for the low power modelling are presented in Table 15.

**Table 15: Average single user throughputs (Mbps) for an 18,000 site low power network, 85% loaded, 2 x 10 MHz**

| Simulation area | **0 - 50%** | | **50 - 80%** | | **80 - 90%** | | **90 - 100%** | |
|---|---|---|---|---|---|---|---|---|
| Building penetration depth | **Out-doors** | **Deep** | **Out-doors** | **Deep** | **Out-doors** | **Deep** | **Out-doors** | **Deep** |
| 800 MHz | 8.05 | 4.40 | 7.11 | 3.00 | 6.58 | 2.50 | 8.49 | 4.11 |
| 1800 MHz | 6.45 | 1.89 | 5.06 | 1.19 | 4.50 | 1.00 | 6.43 | 1.72 |
| 2600 MHz | 5.69 | 1.28 | 4.28 | 0.77 | 3.76 | 0.66 | 5.62 | 1.09 |

A7.14 As expected average single user throughputs are lower for higher frequencies, with the change more apparent for deep indoor use and the low power network.

A7.15 These results are used to estimate the relative utility multiplier in the capacity model (see below) and the coverage metric for assessing the benefits of releasing our priority bands.

## Coverage

A7.16 We have used the results of the modelling to estimate the coverage benefits that different frequencies can provide. This is used as an input to assessing the overall benefits of releasing a band outlined in Section 6 and Table 5.

A7.17 As outlined above the model estimates the percentage of the population that will receive a certain single user throughput in a given simulation area.

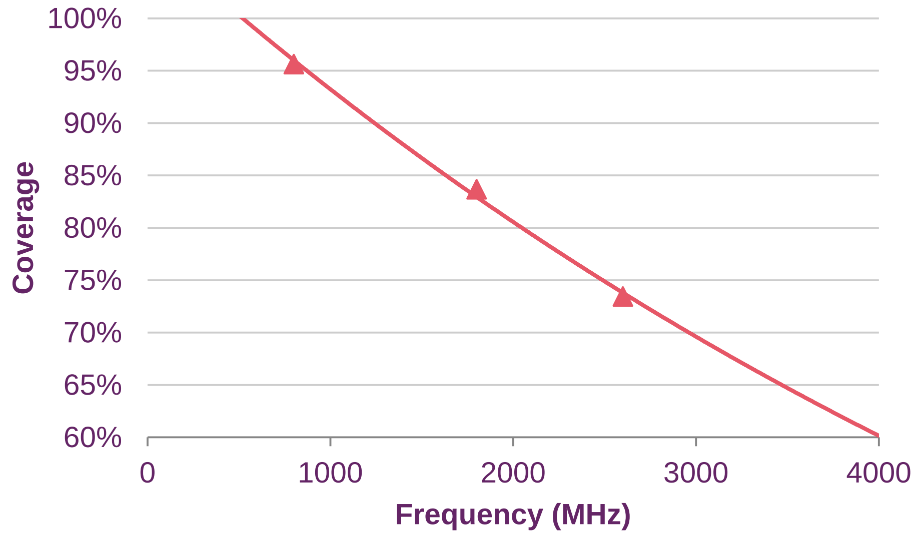
A7.18 For this consultation we have used the percentage of the population who can receive a single user throughput of 2 Mbps deep indoors as the measure of coverage. Table 16 shows the coverage estimate for the three frequency bands modelled assuming 2 x 10 MHz of spectrum, an 18,000 site network and 85% loading.

**Table 16: Percentage of the population who receive a single user throughput of 2 Mbps deep indoors**

| Frequency | Coverage |
|---|---|
| 800 MHz | 96% |
| 1800 MHz | 84% |
| 2600 MHz | 73% |

A7.19 We have extrapolated these results to other frequencies using an exponential curve, this is shown in Figure 16.

**Figure 16: Coverage estimate for different frequencies**




A7.20 To estimate the coverage benefit of an individual band we take the mid-point of the band and estimate the percentage of the population who would receive 2 Mbps deep indoors for an 18,000 site network at that frequency based on the exponential curve in Figure 16. For example for the 3.6 – 3.8 GHz band the mid-point is 3700 MHz, the population who can receive 2 Mbps deep indoors at this frequency is 63%.

## Capacity modelling

A7.21 In this section we outline how we have adapted the results of the technical model described above to produce the results used in this consultation.

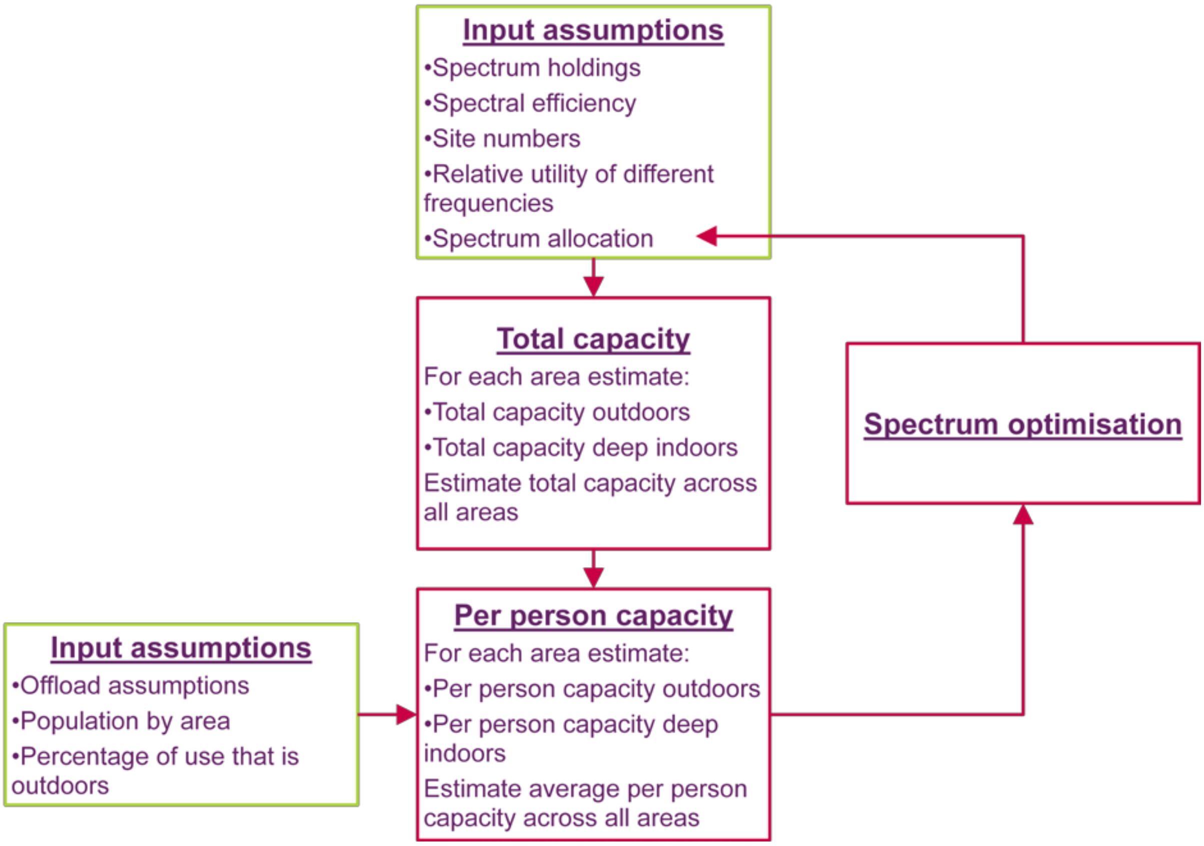
A7.22 The purpose of this additional modelling was to estimate how mobile network performance may grow in the next 10 – 20 years as more spectrum becomes available, spectral efficiency improves and more mobile sites are deployed.

A7.23 The model estimates the total capacity and per person capacity in the four simulation areas outlined above for 2012, 2013, 2020, 2025 and 2030. Figure 17 below shows the structure of the model.

A7.24 The model does not give absolute outputs and therefore the results should be used for a relative comparison against the base year (2012) or other areas e.g. comparing the zero to 50% most densely populated area and the 80% to 90% most densely populated area.

A7.25 The rest of this sections explains how total capacity and per person capacity are calculated for each area and outlines the input assumptions.

**Figure 17: Structure of additional modelling**




## Modelling approach

Total capacity

A7.26 The overall modelling approach was to estimate the total capacity that could be delivered by mobile networks in different areas, based on the spectrum available, spectral efficiency and number of mobile sites.

$$\text{Capacity (Mbps)} = \text{Spectrum (MHz)} \times \text{Number of sites (\#)} \times \text{Spectral efficiency (Mpbs/MHz)}$$

A7.27 We have made an adjustment to reflect the results from the technical modelling that different frequency bands provide different levels of capacity, i.e. lower frequencies provide higher average capacity due to greater population reach and higher single user throughputs.

$$\text{Capacity} = \sum_{\forall i} \left[ \text{Spectrum at frequency } i \times \text{Relative capacity of frequency } i \right] \times \text{Number of sites} \times \text{Spectral efficiency}$$

A7.28 The relative capacity multiplier is based on the results of the technical modelling and is discussed in more detail below.

A7.29 We estimate the total capacity for indoor and outdoor use and for the macro cell network and the small cell network. We assume that spectrum can serve either indoor users or outdoor users, see assumptions below. Spectrum can be used on macro cells, small cells or both depending on the frequency band, see assumptions below.

A7.30 We then estimate the total capacity (the sum of indoor and outdoor capacity delivered by both the macro cell network and small cell network) for each of the population areas and the country as a whole. We estimate outdoor capacity, indoor capacity and total capacity in 2012, 2013, 2020, 2025 and 2030.

Per person capacity

A7.31 As well as estimating total capacity, we estimate capacity per person for indoor and outdoor users.

A7.32 The outdoor capacity per person is the total outdoor capacity divided by the number of outdoor users:

$$\text{Outdoor Capacity per person} = \frac{\text{Total outdoor capacity}}{\text{Population} \times \text{Proportion of use that is outdoors}}$$

A7.33 For indoor users we have made an adjustment to reflect offload to indoor networks. We assume that at a given time a certain proportion of indoor users offload onto a fixed network. The total indoor (mobile) capacity is shared between the remaining users who do not offload. The offload percentage is different for the different areas.

$$\text{Indoor Capacity per person} = \frac{\text{Total indoor capacity}}{\text{Population} \times \text{Proportion of use that is indoors} \times \left[1 - \text{Offload proportion}\right]}$$

Spectrum optimisation

A7.34 Mobile operators can plan their networks to deliver different levels of service to different users. We have tried to approximate this network planning by estimating how operators will use different spectrum bands to deliver services to indoor and outdoor locations.

A7.35 We vary the spectrum allocations between indoor and outdoor locations to maximise the per person capacity subject to the constraint that per person capacity is equal for outdoor and indoor users.

## Input assumptions

A7.36 The model assumes that there is a single network operator, who has access to all of the spectrum available for mobile broadband use. We recognise that this is not an accurate reflection of current networks in the UK and we are not suggesting this may be the case in future years. This simplifying assumption allows us to estimate the total capacity delivered by mobile network. As all our results are measured relative to 2012, modelling two or more networks, with a different number of starting sites would not significantly change the results.

A7.37 The results are based on an initial network of 18,000 sites in 2012.

Spectrum availability for mobile broadband

A7.38 We have assumed that spectrum can either be deployed on macro cells, small cells or both macro cells and small cells. Spectrum below 2 GHz is deployed exclusively on macro cells. Spectrum above 2 GHz can be deployed on either small cells or both small cells and macro cells, however higher frequencies are more likely to be deployed on small cells only.

A7.39 We have modelled total downlink capacity and therefore we have concentrated on downlink spectrum. Table 17 shows the downlink spectrum available to the single network operator.

**Table 17: Spectrum holdings (downlink spectrum, MHz)[62]**

| Spectrum band | Use | 2012 | 2020 plus current priorities | 2030 plus all priorities |
|---|---|---|---|---|
| 800 MHz | Macro Cells | 0 | 30 | 30 |
| 900 MHz | Macro Cells | 10 | 30 | 35 |
| 1800 MHz | Macro Cells | 22 | 72 | 72 |
| 2100 MHz | Both | 60 | 60 | 60 |
| 2600 MHz (paired) | Both | 0 | 70 | 70 |
| 2600 MHz (unpaired) | Both | 0 | 28 | 28 |
| 2300 MHz (unpaired) | Small Cells | 0 | 28[63] | 28 |
| 3400 - 3600 MHz | Small Cells | 0[64] | 133 | 133 |
| 700 MHz | Macro Cells | 0 | 30 | 30 |
| 1452 - 1492 MHz | Macro | 0 | 0 | 40 |
| 2 GHz MSS | Both | 0 | 0 | 30 |
| 3.6 - 3.8 GHz | Small Cells | 0 | 0 | 100 |
| 2.7 - 2.9 GHz | Both | 0 | 0 | 50 |

[62] For those bands where TDD is likely to be deployed (2.3 GHz, 3.4 GHz and 1452 – 1492 MHz) we have assumed that 70% of the spectrum is used for downlink. For those bands where a band plan has not been announced and there is no evidence whether the band will be used for FDD or TDD we have assumed that 50% of the bandwidth is available for downlink.

[63] 40 MHz of spectrum will initially be made available; it is possible that in the future additional spectrum in the band will be made available on a shared or cleared basis.

[64] Although some spectrum in this band is currently assigned to UK Broadband it has only deployed services in select locations, therefore we have not included it in this estimate.

| | | | | |
|---|---|---|---|---|
| 3.8 - 4.2 GHz | Small Cells | 0 | 0 | 200 |
| 450 – 470 MHz | Macro Cells | 0 | 0 | 5 |
| 470 – 694 MHz | Macro Cells | 0 | 0 | 112 |
| 1350 - 1518 MHz[65] | Macro Cells | 0 | 0 | 25 |
| **Total** | **NA** | **92** | **481** | **1,043** |

Spectral efficiency

A7.40 We have used spectral efficiency numbers based on a previous report from Real Wireless.[66] We have assumed that spectral efficiency grows at a linear rate between 2012 and 2030.

A7.41 In addition to increases in spectral efficiency, capacity can increase by increasing the number of sectors on a site. Today most macro sites have 3 sectors. Sites with more sectors can be deployed however they are relatively rare to date. In the future higher sector sites may be more common as existing sites are upgraded or new higher sector sites are deployed, however space constraints may limit their deployment.

A7.42 We have not included the impact of additional sectorisation in our modelling. This approach is conservative and additional sectorisation could deliver further capacity benefits.

A7.43 In general macro sites have three sectors, while small cell sites have one sector. To account for this we have assumed that the spectral efficiency of a small cell site is one third of a macro site. Although macro sites with a greater number of sectors may become more common in future, the same may also be true for small cells sites.

A7.44 Table 18 below shows spectral efficiency for macro sites and small cell sites.

[65] This band contains the 1452 – 1492 MHz band and therefore we have only counted the incremental spectrum available from releasing the 1350 – 1518 band over the 1452 – 1492 band i.e. in total 53 MHz of downlink spectrum would be released.
[66] Real Wireless, 2012, "Techniques for increasing the capacity of mobile networks 2012-2030", http://www.ofcom.org.uk/static/uhf/real-wireless-report.pdf

**Table 18: Spectral efficiency (Bps / Hz)**

| | 2012 | 2020 | 2030 | Annual Growth |
|---|---|---|---|---|
| **Macro sites** | 1.64 | 3.70 | 10.2 | 10.7% |
| **Small cell sites** | 0.55 | 1.23 | 3.4 | 10.7% |

Site numbers

A7.45 As stated above we have assumed there is a single network operator with an 18,000 macro site network. The split of sites between areas is based on the assumptions of the 2012 technical LTE model.

A7.46 We have also assumed that the single operator has a number of small cell sites deployed. We have based the number of small cell sites on the ratio of macro sites to small cell sites in the aforementioned Real Wireless report. For example Real Wireless assume that in 2012 in central London there are 95 macro sites and 360 small cell sites, a ratio of 3.8.

A7.47 The areas Real Wireless modelled (urban, suburban and rural) are not directly comparable to the population density areas considered in the technical model. Therefore, for small cell site numbers, we have had to map the Real Wireless areas to the Ofcom areas as follows (these are approximate rather than exact mappings):

7.47.1 The zero to 50% most densely populated area is (according to the Real Wireless definitions) 20% Urban and 80% suburban

7.47.2 The 50% to 80% and 80% to 90% most densely populated areas are (according to the Real Wireless definitions) suburban,

7.47.3 The 90% to 100% most densely populated area has the same number of small cells as the 80% to 90% most densely populated area

A7.48 Based on these assumptions the site numbers in 2012 are shown in Table 19.

**Table 19: Site numbers in 2012**

| Area | Macro Sites | Small Cell Sites |
|---|---|---|
| 0% - 50% | 7,181 | 5,696 |
| 50% - 80% | 5,473 | 241 |
| 80% - 90% | 2,094 | 92 |
| 90% - 100% | 3,252 | 92 |
| **Total** | **18,000** | **6,121** |

A7.49 Forecasts of future site growth are highly uncertain. An increase in network sharing means that it is unclear if networks will grow or consolidate in the near future. Looking further ahead growth in sites is highly dependent on consumer willingness to pay for mobile data services and other methods of providing mobile capacity e.g. improvements in technology and spectrum release.

A7.50 We have examined evidence on past site growth based on previous versions of the Sitefinder database. We have concentrated our analysis on Vodafone, O2 and Hutchinson as other network operators stopped supplying Sitefinder data prior to 2010. Between 2006 and 2011 Hutchinson's macro cell network grew at an annual rate of 16%, O2's network grew at 7% and Vodafone's network grew at 5%.

A7.51 However during this period networks were deploying a large number of sites to meet demand for 3G services and as mentioned above past experience may not be a good indicator for future growth in this case. Overall we expect growth in the macro site network to be slower in the future and for the base case we have assumed an average growth of 1% per annum.

A7.52 There is even greater uncertainty over future deployment of small cells, as these networks are in their early stages of deployment. However we would expect small cells to grow at a faster rate than macro sites as it becomes more difficult to find suitable macro sites and small cell sites can provide a more targeted answer to providing capacity. Therefore in the base case we have assumed that small cell sites will grow at 10% per annum.

A7.53 To reflect the significant uncertainty on site growth we have modelled a number of different scenarios to see how site growth affects total capacity. The table below shows the scenarios we have considered:

**Table 20: Site growth scenarios**

| Area | Zero growth | Base | High growth |
|---|---|---|---|
| Macro sites | 0% | 1% | 2% |
| Small cell sites | 0% | 10% | 15% |

A7.54 Based on these growth rates Table 21 shows the number of small cell sites and macro sites in 2030 for the base case. In comparison the high growth scenario gives a total number of macro sites of 25,708 and 75,752 small cell sites by 2030.

**Table 21: Site numbers 2030 in the base case**

| Area | Macro Sites | Small Cells |
|---|---|---|
| 0% - 50% | 8,590 | 31,667 |
| 50% - 80% | 6,547 | 1,341 |
| 80% - 90% | 2,505 | 513 |
| 90% - 100% | 3,890 | 513 |
| **Total** | **21,532** | **34,034** |

Relative capacity of different frequencies

A7.55 To reflect the higher value of lower frequency spectrum we have applied a capacity multiplier to the spectrum available for mobile broadband use. This capacity multiplier varies by population area, frequency and building penetration depth.

A7.56 We have used the average single user throughputs estimated in the technical model as the relative capacity multipliers.

A7.57 We have split spectrum bands into 5 categories; sub 1 GHz, 1 GHz to 2 GHz, 2 GHz to 3 GHz, 3 GHz to 4 GHz and 4 GHz to 6 GHz. We have used the 800 MHz results from the technical model as our capacity multiplier for sub 1 GHz spectrum, the 1800 MHz results for 1 GHz to 2 GHz spectrum and the 2.6 GHz results for 2 GHz to 3 GHz spectrum.

A7.58 For the 3 GHz to 4 GHz and 4 GHz to 6 GHz categories we have extrapolated the results of the technical modelling using an exponential fit.

Spectrum allocation

A7.59 We have assumed that macro cell spectrum can be used to serve either indoor or outdoor users not both. An individual spectrum band can be split between serving different users i.e. 50% could be used to serve indoor users and 50% used to serve outdoor users.

A7.60 The spectrum allocation can vary across areas i.e. a higher proportion of sub 1 GHz spectrum may be used to serve indoor users in the 90% to 100% most densely populated area than the zero to 50% area.

A7.61 The spectrum allocation is initially set at 50:50 for all frequencies, this allocation is then optimised in the model to maximise indoor and outdoor per person capacity assuming indoor per person capacity equals outdoor per person capacity.

A7.62 We have assumed that outdoor small cells exclusively serve outdoor users, while indoor small cells are exclusively used for offload.

Offload assumptions

A7.63 We have assumed that a certain proportion of indoor users offload onto fixed networks e.g. using Wi-Fi. These users benefit from the higher capacity on fixed networks. Those indoor users not on Wi-Fi also benefit as the indoor mobile network capacity is shared between fewer users.

A7.64 The table below shows our offload assumptions; we assume offload grows at a linear rate between 2012 and 2020 and a linear rate between 2020 and 2030.

**Table 22: Offload assumptions**

| Area | 2012 | 2020 | 2030 |
|---|---|---|---|
| 0 - 50% | 50% | 80% | 90% |
| 50 - 80% | 50% | 70% | 80% |
| 80 - 90% | 50% | 60% | 70% |
| 90 - 100% | 50% | 60% | 70% |

Population

A7.65 The population assumptions are based on the assumptions in the previous technical model; these are shown in Table 23.

**Table 23: Population assumptions**

| Area | 2012 |
|---|---|
| 0 - 50% | 28,588,215 |
| 50 - 80% | 17,162,838 |
| 80 - 90% | 5,648,553 |
| 90 - 100% | 7,392,261 |

A7.66 We assume the population is constant across the modelling period.

Percentage of use that is outdoors

A7.67 We assume that 25% of the population is outdoors and 75% is indoors. This percentage is constant across the modelling period.[67]

## Modelling results

A7.68 The main results of our modelling - illustrations of how mobile network capacity may increase over the next 10 – 20 years - are presented in section 7. Here we present some of the other results of our modelling and some sensitivities around the base case.

### Relative capacity benefits of different frequencies

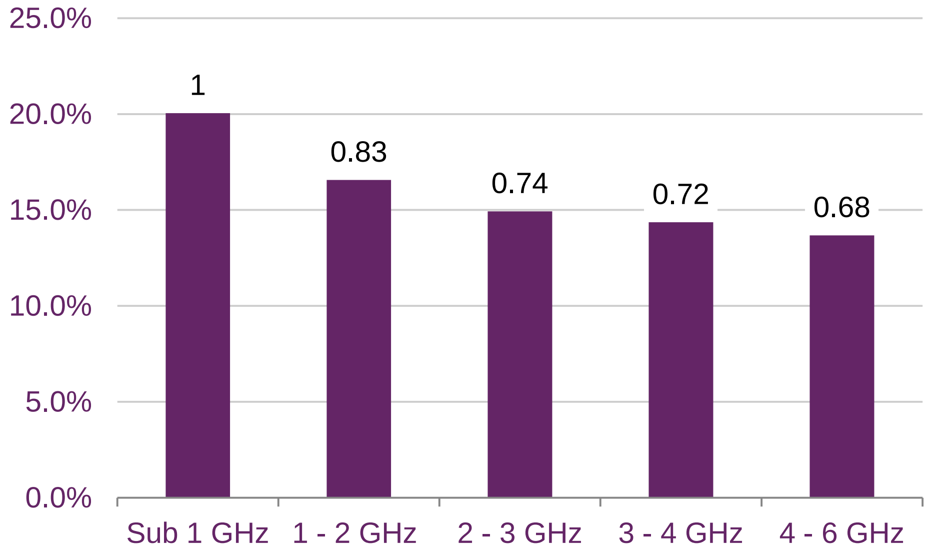
A7.69 To model the impact on capacity of adding different frequencies we have modelled an increase in spectrum availability of 50 MHz in 2020 holding everything else constant.

A7.70 We assume that this increase in spectrum is deployed on both macro sites and small cell sites.

A7.71 Figure 18 shows the increase in capacity in 2020 from releasing 50 MHz of downlink spectrum at different frequencies.

[67] http://www.huawei.com/ilink/en/solutions/broader-smarter/morematerial-b/HW_204152

**Figure 18: Increase in capacity in 2020 relative to 2012 as a result of a 50 MHz increase in spectrum availability at different frequencies**




A7.72 We used these results to estimate the relative capacity provided by potential release of different bands in Table 5 of Section 6. For example for the 2.7 – 2.9 GHz band we have assumed that 50 MHz of spectrum may be made available for downlink use. We multiply the amount of downlink spectrum available by the relative capacity benefit. In this case the relative capacity benefit (relative to sub 1 GHz spectrum) is 0.74, so the relative capacity of the 2.7 – 2.9 GHz band is 37 MHz.

### Sensitivity analysis

A7.73 As noted above there is significant uncertainty over future growth in macro site and small cell site deployments. Therefore we have modelled a zero growth and high growth scenario as outlined in Table 20. Figure 19 below shows the increase in total capacity relative to 2012 for the different site growth scenarios. This is based on release of our current priorities to 2020 and no further release of spectrum.

**Figure 19: Increase in total capacity, relative to 2012, for different site growth scenarios**