Improving spectrum access for consumers in the 5 GHz band

Consultation

Publication date: 13 May 2016

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About this document

This document sets out proposals for increasing the amount of 5 GHz radio spectrum available for Wi-Fi and other related wireless technologies. It also invites the views of stakeholders on how our wider Wi-Fi strategy should be developed to meet consumer demand.

UK citizens and consumers already benefit considerably from Wi-Fi, which has become the preferred means of extending fixed broadband connections to wireless internet enabled devices in the home. Our research shows it is already used in almost 90% of all broadband connected households.

In this document we set out steps to enhance spectrum access for Wi-Fi and enable growth and innovation in new wireless services for consumers. We also want to understand the degree of commitment among industry stakeholders for engagement with international bodies to open up additional spectrum for Wi-Fi, beyond that proposed in this consultation.

Contents

Section 1

Executive Summary

1.1 This consultation sets out our proposals for increasing the amount of radio spectrum available for Wi-Fi in the 5 GHz band to deliver high speed wireless broadband for consumers.

1.2 Wi-Fi is one of the UK's most important vehicles for communications, commerce and entertainment. 85% of the UK's 27 million households have a broadband connection[1]. Virtually all of these households use Wi-Fi to provide the final link between their home broadband router and the various wireless devices in their homes. Wi-Fi also provides outdoor and indoor coverage to 'hotspots' such as transport hubs, sports stadia, shopping centres, hotels etc; and within commercial premises through enterprise networks.

1.3 Our Digital Communications Review[2] identified a strategic shift towards encouraging large-scale deployment of new ultrafast broadband networks, including fibre direct to homes and business.

1.4 Faster fixed line broadband speeds mean consumers rely on their Wi-Fi to handle a wide range of high data rate applications, such as live streaming and on-demand video. Some high data rate applications require wide spectrum channels to avoid quality issues such as 'buffering' or the break-up of video streams.

1.5 At present, the spectrum band most commonly used for Wi-Fi in the UK is the 2.4 GHz band (2400-2483.5 MHz). However, use of frequencies in the alternative 5 GHz band is catching up, in line with the development of new Wi-Fi equipment standards. There is more spectrum available in the 5 GHz band than in the 2.4 GHz band, enabling more and wider channels to support high data rate applications. Most new routers and almost all consumer client devices on the market can now use both the 2.4 GHz and 5 GHz bands.

1.6 We expect demand for Wi-Fi (and other similar technologies) to continue growing as the number of connected wireless devices increases, and those devices make use of ever more high data applications. This demand is likely to place increased pressure on the spectrum over which Wi-Fi is carried.

1.7 In light of this growing demand, we propose to open up a further 125 MHz of 5 GHz spectrum at 5725-5850 MHz - subject to first establishing the correct technical parameters to ensure the appropriate protection of other users of this sub-band. The details of these technical conditions will be the subject of a further consultation.

1.8 When combined with the existing 5 GHz Wi-Fi spectrum, our proposal will enable the creation of two additional 80 MHz channels to help address consumers' demand for high data rate applications. It will also help avoid congestion.

1.9 We have a specific short-term focus on the 5725-5850 MHz band because early results from on-going technical studies suggest that sharing with other users is feasible. Additionally, opening up the band is achievable through UK-only policy without the need for us to await wider international developments i.e. through the upcoming 2019 World Radiocommunication Conference (WRC-19).

1.10 Our consultation document also seeks the views of stakeholders on what other priorities we should pursue in making additional spectrum available for Wi-F, taking account of other users of the 5 GHz band. We have identified a number of further options for bringing more 5 GHz spectrum into use for Wi-Fi, all of which will require

[1] http://stakeholders.ofcom.org.uk/binaries/research/cmr/cmr15/UK_1.pdf
[2] http://stakeholders.ofcom.org.uk/binaries/telecoms/policy/digital-comms-review/DCR-statement.pdf

international engagement through the EU, CEPT[3] or ITU[4]. Devices able to support additional 5 GHz frequencies are already available on the market - because the sub-bands are already used for Wi-Fi in the USA. Our options include:

- Re-examining the technical requirements for Wi-Fi – such as those designed to protect radars - to ensure they remain fit for purpose and are no more restrictive than necessary;
- Removing outdoor restrictions on Wi-Fi access to the 5150-5350 MHz range;
- Retaining the longer term objective of opening up spectrum if possible at 5350-5470 MHz and 5850-5925 MHz.

1.11 We want to know the views of stakeholders about the future drivers of demand for Wi-Fi and related technologies; which use cases will be most important for consumers; and how demand is likely to change in over time. We need to understand how these demands might best be met, depending on the particular type of application and/or location (e.g. indoor versus outdoor).

1.12 We also need to understand the extent to which technology changes might help to ease demand pressures. Finally, we seek views on whether stakeholders agree with our suggested priorities on what alternative approaches we should consider. We invite stakeholders to submit any available evidence in support of their views.

1.13 Ofcom and industry will need to work together to determine where effort should be concentrated if further changes to spectrum access at 5 GHz are to be agreed at WRC-19. Ofcom has already committed significant resources to technical coexistence studies, including carrying out an airborne measurement campaign. We believe the results may help to reduce some of the uncertainties around coexistence between Wi-Fi and satellite services.

1.14 Although we will continue to provide a UK lead in international discussions , we want to emphasise to industry stakeholders that they will need to take an active part in the international decision making process, including assigning their own resources to support further demand and technical coexistence studies.

1.15 Work will be needed to analyse, and where appropriate mitigate, the risk of harmful interference to other important services that currently use the 5 GHz bands being considered for Wi-Fi extension.

1.16 This consultation closes on **22 July 2016**.

[3] European Conference of Postal and Telecommunications Administrations
[4] Inrternational Telecommunications Union

Section 2

Introduction

2.1 For consumers to benefit from existing and new high data rate applications we need to ensure that Wi-Fi will be able to support the ever-increasing volume of data expected to flow through superfast fixed broadband networks.

2.2 Wi-Fi is a short-hand phrase to describe a type of Wireless Local Area Network (WLAN) or (alternatively) Radio Local Area Network (RLAN). WLAN/RLAN systems allow the extension of a local area computer network without needing cables (e.g. wireless internet access in airports or other hotspots, or wireless networks within an individual home).

2.3 In this document we use the term Wi-Fi throughout because it is by far the most common WLAN/RLAN application and is widely understood by both industry stakeholders and consumers - but the discussion is also relevant to all other variations of WLAN/RLAN technology (e.g. LTE/LAA[5] etc.).

2.4 Broadband is already being delivered at higher speeds than ever before, making it possible for consumers to access high data rate applications, such as HD and UHD TV. Consumers expect the broadband speed delivered by their internet service provider (ISP) to be matched by the speed delivered via Wi-Fi to their wireless devices throughout the home. They want their Wi-Fi connections to deliver high quality functionality wirelessly to their devices without any 'buffering' caused by slow data throughput.

2.5 In order to deliver high data rates, Wi-Fi requires wide non-overlapping channels - for instance 80 MHz channels can deliver throughputs of up to a gigabit. Many consumer devices are now able to access the 5 GHz Wi-Fi band - where wide channels can be accommodated - in addition to the more restricted 2.4 GHz band. Reductions in cost and improvements in the battery efficiency of 5 GHz-capable devices have also encouraged wider use of these frequencies.

2.6 Among the objectives set out in our 2014 Mobile Data Strategy[6] was the aim of adding additional 5 GHz spectrum for Wi-Fi at 5350-5470 MHz and investigating the possible sharing conditions for Wi-Fi use across the range 5725-5925 MHz. However, a decision on allowing further international harmonisation across the 5 GHz band has now been delayed until the next WRC conference in 2019.

2.7 Technical studies for WRC-19 to support harmonised Wi-Fi access at 5 GHz globally are being coordinated at European level by CEPT ahead of discussion at ITU-R[7] during the WRC-19 study period. However, there are some changes we are able to make at a UK level ahead of further international agreement.

2.8 One such change is our proposed opening up of additional spectrum in the 5725-5850 MHz band - subject to addressing final coexistence issues with other spectrum users.

Legal background

2.9 In addressing issues of spectrum management, Ofcom must operate under a legal and regulatory framework. Our duties derive from both European and domestic legislation, specifically from:

[5] A means of deploying licence exempt LTE services in unlicensed spectrum alongside Wi-Fi)
[6] http://stakeholders.ofcom.org.uk/binaries/consultations/mobile-data-strategy/statement/statement.pdf
[7] ITU-R: The division of the International Telecommunication Union responsible for radiocommunications

- The EU Common Regulatory Framework[8] for electronic communications networks and services, in particular, the Framework Directive and the Authorisation Directive; and

- The Communications Act 2003 (the 'Communications Act') and the Wireless Telegraphy Act 2006 (the 'WT Act'). These acts transpose the provisions of the EU framework and directives into UK national law.

Duties under the Communications Act 2003

2.10 Section 3 of the Communications Act provides that our principal duty is:

- to further the interests of citizens in relation to communications matters; and

- to further the interests of consumers in relevant markets, where appropriate, by promoting competition.

2.11 In carrying out our functions, Section 3(2) provides that we are required, amongst other things, to secure the optimal use for wireless telegraphy of the electromagnetic spectrum; and the availability throughout the UK of a wide range of electronic communication services.

2.12 Section 3(3) provides that, in performing our duties, we must in all cases have regard to the principles of transparency, accountability, proportionality and consistency, as well as ensuring that our actions are targeted only at cases in which action is needed.

2.13 Section 3(4) requires us, in carrying out our functions, to have regard to certain factors as appear relevant in the circumstances, including the desirability of encouraging investment and innovation in relevant markets; and the different needs and interests of everyone who may wish to use the spectrum for wireless telegraphy.

2.14 In performing our duty under Section 3 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.

Duties under the Wireless Telegraphy Act 2006

2.15 Section 3 of the WT Act imposes a number of further duties relating to spectrum management. Amongst other things, in carrying out our spectrum functions, we are required to have regard to the extent to which the spectrum is available for use and to the demand, both current and future, for use of the spectrum.

ITU Regulations affecting the 5 GHz band

2.16 Radio Regulations governing the international use of spectrum are determined by the ITU at WRC conferences. ITU Resolution 229 of the Regulations specifies the restrictions for use of the 5 GHz spectrum band as follows:

- 5150-5250 MHz: Sets power limit and stipulates indoor-only use.

[8]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).

- 5250-5350 MHz: Sets power limit; specifies use of DFS[9]; requires administrations to take measures to ensure the predominant number of RLANs are operated in an indoor environment (with antenna masks for those stations permitted to operate outdoors); transmitter power control or reduction of permitted power by 3dB.

- 5470-5725 MHz: Sets power limit, DFS, transmitter power control or reduction of permitted power by 3dB.

EC Decisions affecting use of the 5 GHz band

2.17 The EU makes legislation about the use of radio spectrum through 'Decisions'. Commission Decision 2005/513/EC has harmonised 455 MHz of spectrum in the 5 GHz band (5150– 5350 MHz and 5470–5725 MHz) for RLAN/Wi-Fi. Article 4 contains the sets of technical restrictions which need to be applied. Compliance is mandatory:

- Article 4.1 5150-5350 MHz: Sets the power limit and stipulates indoor-only use.

- Article 4.2 5470-5725 MHz: Sets the power limit.

- Article 4.3 5250-5350 MHz and 5470-5725 MHz: Stipulates transmitter power control.

- Article 4.4 5250-5350 MHz and 5470-5725 MHz: Stipulates requirement for DFS.

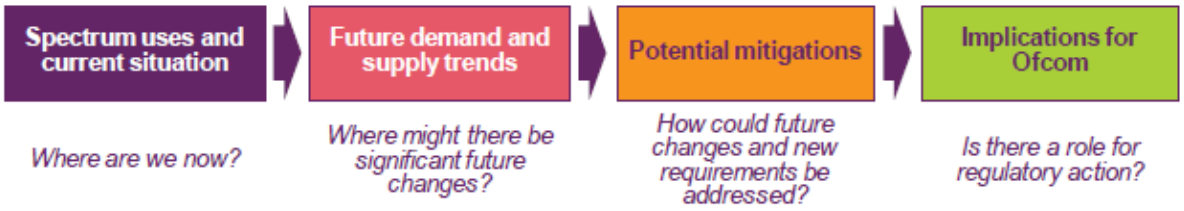
2.18 The EC Decision was amended by Decision 2007/90/EC which aligned the EIRP density limits in 5150-5250 MHz to those in 5250-5350 MHz.

2.19 Another binding EC Decision - 2006/771/EC – harmonises use of the 5725-5875 MHz band for use by short-range devices (SRDs), including allowing low power Wi-Fi (with a 25mW power limit). Article 2 of this Decision gives member states the right to allow the use of the frequencies under *less* restrictive conditions, subject to certain conditions.

Ofcom's approach to defining a strategy for Wi-Fi

2.20 Ofcom's overall approach to reviewing sectoral demand for spectrum and defining our strategic approach was set out in our Spectrum Management Strategy (see below) and is illustrated in Figure 2.1.

Figure 2.1: Framework for analysis of future developments in spectrum uses



2.21 Our consideration of a future Wi-Fi strategy will take account of a number of other initiatives already completed or underway, including:

[9] Dynamic Frequency Selection – a system whereby Wi-Fi avoids spectrum being used by radars (see section 4 paragraphs 4.27-4.32)

- Our Spectrum Management Strategy[10]. This sets out our overarching approach to managing spectrum over the next 10 years, with a key objective of delivering the greatest value to UK citizens and consumers. It provides the context and rationale for our mobile data strategy (see below).

- Our Statement on Spectrum Sharing[11]. This work highlighted the steps we will take to encourage more intense use of spectrum across all bands to ensure efficient use. These could include ensuring Wi-Fi can continue to provide high speed wireless connectivity; increasing access to spectrum for use in small mobile broadband cells; and providing the spectrum needed to support innovation in the emerging Internet of Things (IoT) sector. It also explored how spectrum can be shared more effectively between different spectrum users through advances in dynamic spectrum access technologies. These are likely to be at least part of the solution to meeting the growth in demand for mobile data services.

- Our Mobile Data Strategy[12]. This document is our long term strategy to address the increasing consumer demand for wireless data via mobile devices like smartphones, tablets and laptops. It notes different ways to increase the capacity of mobile networks (such as more efficient technology and greater use of small cells) but notes that additional spectrum is also likely to be part of any solution. It therefore identifies additional spectrum bands for mobile data.

- Our Space Spectrum Strategy consultation.[13]. This covers the use of spectrum by the satellite and space science sectors (including earth observation). One of our proposed priorities is to enable the benefits that citizens and consumers currently enjoy from these sectors to continue, where appropriate, whilst exploring opportunities for new uses. Our strategy highlights that we will take care to understand and mitigate the risk of harmful interference before new services are authorised, and take effective enforcement action where necessary if problems do arise.

Impact Assessment

2.22 This document represents an impact assessment as defined in Section 7 of the Communications Act. Impact assessments provide a valuable way of assessing different options for regulation. They form part of best practice policy-making.

2.23 In preparing this document we have considered the citizen and consumer interests in respect to our overall policy objectives, as set out in our Mobile Data Strategy. We have also considered the impact on service providers; manufacturers and users of devices and applications; and on existing users of the 5 GHz band.

2.24 Ofcom is an evidence based organisation and welcomes responses to this consultation. Any comments about our assessment of the impact of our proposals should be sent to us by the closing date for this consultation. We will consider all comments before deciding whether to implement our proposals. 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: http://www.ofcom.org.uk/consult/policy_making/guidelines.pdf .

[10] http://stakeholders.ofcom.org.uk/binaries/consultations/spectrum-management-strategy/statement/statement.pdf
[11] http://stakeholders.ofcom.org.uk/binaries/consultations/spectrum-sharing/statement/spectrum_sharing.pdf
[12] http://stakeholders.ofcom.org.uk/binaries/consultations/mobile-data-strategy/statement/statement.pdf
[13] http://stakeholders.ofcom.org.uk/binaries/consultations/space-spectrum-strategy/summary/Space_Spectrum_Strategy_consultation.pdf

Equality Impact Assessment

2.25 Ofcom is separately required by statute to assess the potential impact of all our functions, policies, projects and practices on race, disability and gender equality. 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.

2.26 We do not consider that our consideration of Wi-Fi is likely to have a particular impact on one group of stakeholders as opposed to another.

Structure for this document

2.27 The remainder of this document is set out as follows:

- **Section 3** discusses the current use of spectrum for Wi-Fi; explores future demand and considers how this might be addressed. It looks at how technology might mitigate pressure on Wi-Fi before discussing the potential role of additional spectrum in addressing demand.

- **Section 4** identifies the options for our future Wi-Fi strategy and sets out our proposals for consultation. It also invites the views of stakeholders on some further options for Wi-Fi, and summarises potential coexistence issues.

- **Section 5** sets out the next steps for our development of a Wi-Fi strategy.

Section 3

Current and future use of Wi-Fi

3.1 This section considers the current use of Wi-Fi and how demand is expected to grow in the future. It goes on to consider the extent to which that increased level of demand can be met by increasing the supply of spectrum and/or by other means, such as through the adoption of new technology.

3.2 In preparing this consultation we have engaged with a number of stakeholders to test initial industry opinions. A summary of stakeholders' views about demand is included in this section.

3.3 However, we are keen to hear the further views of stakeholders on the trends and drivers that will affect demand for wireless services delivered via Wi-Fi – and their actual impact on demand in the UK - set against potential solutions to meet that demand (via both spectrum and technology development).

Background

3.4 In November 2015 the Prime Minister announced the Government's intention to give the public a legal right to request an "affordable" broadband connection through a 'universal service obligation' (USO) by 2020. It has an ambition of setting the minimum download speed for these connections at 10 megabits per second (Mbps) . The aim is to put broadband on a similar footing to other basic services such as water and electricity. The proposals were set out in Government consultation document published in March 2016.[14]

3.5 Beyond this, our strategy to encourage large-scale deployment of new ultrafast networks, including fibre direct to homes and businesses, seeks to offer consumers much faster connections which can support new innovative data hungry services. However, it is important that Wi-Fi is able to support these high data rate applications. If not, consumers will experience a quality of service lower than their expectations when using a wireless connection in their home.

3.6 One way of meeting demand for high data wireless connectivity is through the provision of additional spectrum – although it is not the only means.

How spectrum is used for Wi-Fi

3.7 As noted, Wi-Fi is only the final step in the delivery of broadband internet. Broadband is normally brought into the home (or to an office, café or outdoor access point) through a fibre or cable connection usually supplied by an internet service provider (ISP). It is then transmitted to receiving devices such as laptops, tablets and phones via wireless connection e.g. through a household Wi-Fi router.

3.8 Wi-Fi currently operates in both the 2.4 and 5 GHz bands throughout most of the world. However, there are some variations in the precise frequencies that are used, and in the ways in which devices are allowed to operate within them. The current arrangements for the 5 GHz band - including the key differences between the UK/ Europe and some other countries - are set out more fully in annex 4.

14 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/510148/Broadband_Universal_Service_Obligation.pdf

3.9 Our engagement with stakeholders suggests that the majority of Wi-Fi access remains in the 2.4 GHz band, but that almost all new domestic routers and public access points are dual band. New mobile phones also have dual band access. Evidence collected from our publicly available Wi-Fi speed checker[15] shows an overwhelming majority of tests being conducted by consumers using 2.4 GHz (around 25 times more often) – but this may partly reflect that the application is used mainly by those experiencing problems with their Wi-Fi. This is more likely in the more crowded 2.4 GHz frequencies.

3.10 The way in which Wi-Fi spectrum is used to deliver services to consumer devices depends on the type of application being used. High data rate applications - such as streaming of high definition TV, video and games - benefit from access to wider spectrum channels. On the other hand, access to wide channels is not so important for low data rate uses, such as general internet browsing or e-mail communications.

3.11 The actual number of spectrum channels open to Wi-Fi is also an important factor. Access to a large number of channels allows a user to access Wi-Fi in a different channel to that used by neighbouring users and so avoid degradation of throughput. If there are few channels, these neighbouring uses may have to share the same channel, reducing the quality of service delivered to each user.

3.12 Neighbouring uses in this context could be different devices within the same household; or neighbouring households tuned to the same channel (2.4 GHz radio signals can travel relatively easily between neighbouring households); or a number of individual users trying to access the same channels through a number of access points in public areas etc.

3.13 In practice the sharing of a channel means users taking turns to access the spectrum due to the 'politeness' of the Wi-Fi protocol. This can affect the speeds which can be achieved by any one user/device and means individual users can experience lags and delays in service.

3.14 This is most likely to be true of the 2.4 GHz frequencies, especially when they are being used for relatively high data applications, because there are only three non-overlapping channels (of 22 MHz each).

3.15 The 5 GHz band spectrum is much more suitable than the 2.4 GHz band for delivering very high data uses because there is much more spectrum available and more and wider non-overlapping channels. Although the spectrum has a shorter transmission range, it is able to address many of the quality of service issues that may be experienced by equipment only able to access the 2.4 GHz band. However, pressure on all spectrum bands is likely to grow as more fibre is rolled out for broadband use, and consumer expectations of speed at the device end increase.

3.16 Even before this additional roll-out, data from our Wi-Fi app suggests that the presence of other Wi-Fi routers nearby significantly reduces the likelihood of a mobile phone or tablet achieving 35 Mbps via Wi-Fi. When there were no other routers detected by the mobile phone or tablet performing the test, 39% of 5GHz users could achieve 35 Mbps. If there were other routers in the vicinity, this dropped to 19%. The equivalent numbers for 2.4 GHz users were 14% for isolated users, 7% in the presence of other routers.

Drivers of future demand for Wi-Fi

3.17 A number of factors are contributing to an ever increasing demand for wireless applications delivered via Wi-Fi, not least its low marginal cost to users compared

[15] http://stakeholders.ofcom.org.uk/market-data-research/market-data/infrastructure/connected-nations-2015/wifi-checker-app/

with other means of accessing mobile data. The amount of domestic Wi-Fi that can be used by consumers is now generally unlimited for users once a subscription for broadband connectivity is paid (generally for a cable or phone line).

3.18 In contrast, alternative means to deliver wireless connectivity (e.g. through a mobile network) incurs additional charges and/or eats into a subscriber's monthly data allowance.

3.19 In our Digital Communications Review[16], we set out our high level view of the future of demand for broadband internet. We said that while we cannot predict exactly what services will drive demand, the experience of the last 10 years suggested demand will soar. We said we had arrived at this view in the context of current innovation in the technology industry, where a very large number of companies and researchers are creating new services and applications that rely on fast internet connections.

3.20 An ever growing number of devices can access Wi-Fi - e.g. laptops, mobile phones, tablets, smart TV etc. What is more, individual consumers and households own an ever-increasing number of these devices; are spending an increasing amount of time on them; and are using a number of internet-enabled devices simultaneously. These devices are becoming more powerful, with greater processing power. Application developers are making use of this additional power to create even more applications.

3.21 Although the precise nature of an increase in demand is dependent on factors that are hard to predict, including the level of take-up of new applications, there is evidence available of past and current trends.

3.22 Ofcom's Communications Market Report for 2015[17] indicates that Wi-Fi routers are being used by 95% of households with a broadband connection – an increase from 75% in Q1 2011[18]. It also shows that 66% of households now have at least one internet connected smartphone (up from 39% in 2012); 65% of households have at least one laptop; and 54% at least one tablet computer. Access to home internet had grown to 85% of the UK's adult population by 2015, a rise of three percentage points from just the previous year.

3.23 69 % of households in the UK now own three or more different types of internet-enabled device. . Smartphone owners now spend almost twice as long online via their phones than they do via laptops and personal computers. The Digital Communications Review identified that 89% of smartphone users accessed the internet via Wi-Fi in their homes. A study by Cisco Systems[19] indicates that in 2015 54% of all mobile data traffic in the UK was accessed by Wi-Fi, and predicts this will increase to 65% by 2020.

3.24 If high data rate services are to be delivered to a consistent high quality standard by Wi-Fi then wide channels able to support fast broadband speeds become increasingly more important. A minimum of 5 Mbps per screen is currently required for good High Definition (HD) services (preferably 8 Mbps). Around 20 Mbps is needed today for Ultra High Definition (UHD) – although technological improvements may reduce this in future.

3.25 Looking further ahead, using channel bandwidths of 80 MHz and 160 MHz with multi-user MIMO, the 802.11ac Wi-Fi standard theoretically allows for data rates of up to 7

[16] http://stakeholders.ofcom.org.uk/telecoms/policy/digital-comms-review/dcr-feb-16/
[17] http://stakeholders.ofcom.org.uk/binaries/research/cmr/cmr15/CMR_UK_2015.pdf, p. 340.
[18] http://stakeholders.ofcom.org.uk/binaries/research/cmr/cmr11/UK_CMR_2011_FINAL.pdf, p. 8.
[19] http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/mobile-white-paper-c11-520862.pdf

Gbps in the 5 GHz band[20]. The 802.11ax standard is currently under development[21] and will also increase speeds.

Supply of spectrum for Wi-Fi

3.26 If demand for Wi-Fi continues to grow as we predict in the Digital Communications Review then we need to ensure there is sufficient means to maintain high quality of service for consumers.

3.27 There are three main ways in which growing demand for Wi-Fi access could be met in future:

- Through advances in technology;
- By increasing the number of Wi-Fi access points in a coordinated way (densification);
- Through the provision of more harmonised spectrum (including harmonised power levels and indoor/outdoor permissions).

3.28 It is likely that increasing Wi-Fi demand will need to be met through a combination of all three, with different solutions being suited to different circumstances.

Technology

3.29 It is possible to achieve more efficient use of spectrum through wider adoption of improved Wi-Fi protocols, use of multi-antenna SDMA[22] technology and multi user MIMO[23] devices etc. These and other developments could mean that more data can be carried to more users simultaneously using the same amount of spectrum.

3.30 On the other hand, those new technologies and systems may actually drive additional use of the Wi-Fi spectrum bands - particularly the 5 GHz band - because they make new services more effective and attractive for consumers and so drive demand.

3.31 Other improvements to technology are hard to predict, and may in any case be of limited value in the short term because of the large volume of legacy equipment in the market.

Densification

3.32 On densification, we note that increasing the number of access points in a coordinated way can often help relieve demand pressure on public Wi-Fi. Densification could prove particularly useful in stadia, stations, conference centres and offices. The use of directional antennas could help address interference issues between access points.

3.33 However, it is not always the answer. One industry assessment[24] recognised that the inexpensive nature of basic Wi-Fi access points made it tempting to deploy them with very high density. However, it concluded that it could then be necessary to reduce the transmit signal powers to prevent access points generating interference to each other. In some cases, the reduction in the transmit power exactly offset the potential benefit of interference immunity.

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[20] https://standards.ieee.org/news/2014/ieee_802_11ac_ballot.html.
[21] http://www.ieee802.org/11/Reports/tgax_update.htm and http://www.ieee802.org/11/Reports/tgay_update.htm respectively.
[22] Space Division Multiple Access
[23] Multi input, multi output devices (MIMO)
[24] http://www.cisco.com/c/en/us/products/collateral/wireless/spectrum-expert-wi-fi/prod_white_paper0900aecd807395a9.pdf

Spectrum

3.34 In some circumstances additional spectrum may be the only means of meeting demand e.g. in order to support increasing demand for superfast broadband speeds at the device level. Additional contiguous spectrum may be needed to accommodate the wider channels required to deliver the expected speed without interference occurring between adjacent Wi-Fi deployments.

Summary

3.35 It is difficult to reach a conclusion on whether supply will be able to meet demand without additional spectrum. If it does not, the Wi-Fi experience for consumers is likely to be poorer. Additional spectrum, advances in Wi-Fi technology, and densification will each play different roles in different scenarios and become complementary in many cases.

Stakeholder views on demand

3.36 In preparing this document, we had informal meetings with more than 20 major stakeholders to ascertain initial views about the future demand for Wi-Fi following WRC-15. From our discussions, we noted a general consensus that demand will increase - though there are different opinions on by how much and about which scenarios are likely to benefit most from greater access to spectrum.

3.37 The Cisco analysis referred to earlier in this section notes that mobile data traffic has grown 4,000-fold over the past 10 years. Its analysis suggests pressure on spectrum may begin to take hold around 2020 for some types of use. Other stakeholders told us they broadly agreed with Cisco's conclusions. However, there was no clear consensus about the precise impact that would have or on how it should be addressed.

3.38 The stakeholders we spoke to were careful to highlight the notion that a spectrum crunch would impact certain types of data use more than others. Some stakeholders said demand for home Wi-Fi would likely be satisfied by existing spectrum for years to come due to the fairly low density of devices. However, the same stakeholders predicted a lack of spectrum for public Wi-Fi access points, both indoor and outdoor. Some others were less optimistic about the ability to meet domestic demand.

3.39 Overall, most agreed that public access networks such as coffee shops and transport hubs were the places most likely to experience a crunch. Some pointed to congestion for public use of 2.4 GHz spectrum already, and said similar issues would arise for 5 GHz spectrum in time. However, there was some disagreement over whether indoor or outdoor scenarios would experience spectrum pressure first.

3.40 One stakeholder pointed out that high data uses, such as video, were accessed mostly by users who were static and indoors. However, another said that outdoor areas like transport hubs were more of an issue because of the many uncoordinated Wi-Fi networks in line-of-sight of one another competing for access to the same spectrum. Having sufficient channels to allow for competing demands in the same area (or volume in high-rise buildings) was seen by some stakeholders as an important issue to address.

3.41 There were also different opinions on whether the priority was for wider channels to serve high data rate applications or for more, narrower channels to serve a larger number of users. Some suggested that this might vary depending on the technology used, with Wi-Fi typically using wider 80 and 160 MHz channels, whilst LTE-LAA might use more, narrower channels (20 MHz).

3.42 We also noted that opinions on Wi-Fi demand varied according to the business model of the stakeholder. Wi-Fi operators, chipset and enterprise Wi-Fi manufacturers were more confident in predicting a data crunch - whilst consumer

device manufacturers appeared less concerned with the issue, suggesting that technological developments would be sufficient to address a shortage of spectrum. One stakeholder was of the view that technological developments would be wholly sufficient to address a shortage of spectrum.

3.43 At this stage, we have spoken mainly to Wi-Fi stakeholders. However, we recognise it is also important to understand the views of other incumbent users of the 5 GHz band. We therefore invite their responses to this consultation.

Section 4

Short term proposals plus additional options for Wi-Fi spectrum

4.1 This section of the document considers the potential for addressing future demand for Wi-Fi through access to additional spectrum. It sets out our proposals for making more 5 GHz spectrum available in the short term, and invites the views of stakeholders on other options for the medium and longer term.

4.2 The section also summarises issues for coexistence between Wi-Fi and other users of the band (a more detailed account of the co-existence issues, particularly for satellite and radar technologies, is set out at annex 5).

4.3 As discussed in the previous section, spectrum is not the only means of addressing Wi-Fi demand. However, we believe it can be a very important tool for increasing Wi-Fi capacity, alongside technological change and densification.

4.4 The frequencies at 5 GHz are currently less congested than those in the 2.4 GHz band and offer scope for delivery of high data services via wide channels providing the greatest speed and quality. Channels of 80 MHz could deliver broadband data at up to a gigabit per second. Wide channels may become necessary in order to avoid Wi-Fi becoming the 'bottleneck' as faster fibre fixed line deployments are rolled out nationwide.

4.5 Before considering the options open to us we first outline how the 5 GHz band is currently arranged for different Wi-Fi uses.

Current use of 5 GHz spectrum for Wi-Fi

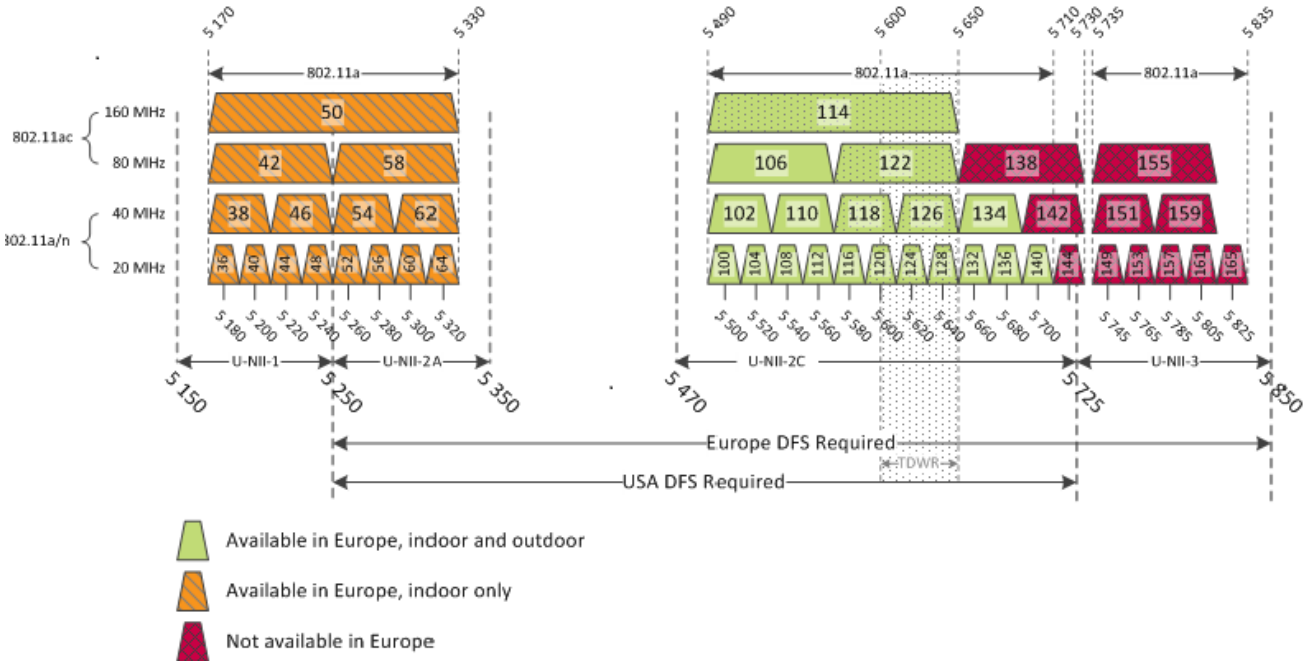
4.6 Figure 4.1 below shows the current arrangements for spectrum in the 5 GHz band. As noted in section 2, a total of 455 MHz is harmonised for Wi-Fi in Europe in the range 5150-5725 MHz through a legally binding Spectrum Decision. The spectrum is arranged in 19 channels of 20 MHz, with different conditions of use applying to particular frequency ranges:

- 5150-5250 MHz – indoor use only
- 5250-5350 MHz – indoor use only
- 5470-5725 MHz – indoor and outdoor use

4.7 There is also 150 MHz harmonised in Europe for SRDs at 5725-5875 MHz, which Wi-Fi systems may also use today at a significantly reduced EIRP (25mW) compared to other Wi-Fi bands. This is *not* used for Wi-Fi in practice because this power level is too low. However, the current limit is not binding on individual countries and the UK may therefore choose to adopt less restrictive regulations.

4.8 The current EU and CEPT arrangements differ in some respects to those of other countries. Figure 4.1 also shows that the 5725-5850 frequencies are already authorised (and being used) for higher power Wi-Fi by both the USA and by China - in spite of a lack of global harmonisation. This is possible through the adoption of regional variations. More detail on the current national and international arrangements for Wi-Fi at 5 GHz is set out in annex 4.

Figure 4.1: Channel arrangements for Wi-Fi in the 5 GHz band



4.9 The WRC-19 agenda item on wireless access systems in the frequency bands 5150-5925 MHz (including RLANs) allows for a comprehensive review of the international obligations on administrations using the 5 GHz frequencies for these applications. It therefore offers an opportunity to further increase the harmonised spectrum available to Wi-Fi and to consider more alignment of regional and national regulatory arrangements across the whole 5150-5925 MHz range.

Stakeholder views on regulatory change

4.10 As discussed in the previous section, we have engaged with more than 20 stakeholders on the issues for Wi-Fi. We asked them about the specific regulatory changes they might seek for 5 GHz at WRC-19.

4.11 The Wi-Fi stakeholders we spoke to emphasised that they would ideally seek globally harmonised spectrum regulations for Wi-Fi standards. Some cited the example of the 2.4 GHz band which is available for Wi-Fi worldwide and provides connectivity for a great number of people at low cost to consumers. Nevertheless, regional variations to equipment might be possible in the 5 GHz band, depending on the specifics of each variation.

4.12 Stakeholders also wanted to see greater consistency between the regulatory limits in each of the 5 GHz sub-bands. They identified particularly the different power limits and indoor-only usage restrictions in the 5150-5350 MHz sub-band in Europe compared to the usage allowed in the 5470-5725 MHz sub-band.

4.13 Two main reasons for increased consistency between the regulation limits of the sub-bands were identified by stakeholders:

- **Improved user experience:** Consistency in regulations means that the user experience is maintained across all channels. For example, if a Wi-Fi connection established in the higher power limit 5470-5725 MHz band was forced to move to the lower power limit 5150-5350 MHz band by a radar triggering DFS then the range of the connection is likely to drop and the user might experience a degradation or cessation of their Wi-Fi service.

- **Better use of wider channels:** Wider channels require more contiguous spectrum with consistent regulations.

Options for change

4.14 We have identified a range of options for opening up additional 5 GHz spectrum as set out below. All the options are discussed in more detail in the following sub-sections.

- **Short term:** Opening up spectrum at 5725-5850 for Wi-Fi to enable use of two 80 MHz channels (and/or one 160 MHz channel);
- **Medium term:** Re-examining the technical requirements for Dynamic Frequency Selection (DFS) to make sure they are still fit for purpose and/or are only as restrictive as is necessary to protect incumbent radar systems;
- **Medium term**: Promoting Wi-Fi use under the existing primary mobile allocation in 5850-5925 MHz (to be considered at WRC-19, but could be determined earlier through CEPT – see below);
- **Longer term:** Removing the outdoor restriction on Wi-Fi access to the 5150-5350 MHz range and/or changing existing 5 GHz radiated power limits to enable outdoor use where only indoor use is currently possible;
- **Longer term:** Opening up spectrum at 5350-5470 MHz.

4.15 In all cases we will take care to understand the risk of harmful interference to existing services that provide benefits to citizens and consumers before new uses are authorised.

Short term change

Opening up 5725-5850 MHz for Wi-Fi

4.16 Opening up spectrum at 5725-5850 would allow the use of two additional 80 MHz channels (across the full range 5650-5850 in combination with existing Wi-Fi bands) or one of 160 MHz.

4.17 For this to apply across Europe there would need to be a new harmonisation measure approved for Wi-Fi[25] in either the EU or CEPT to harmonise higher power Wi-Fi use. However, the UK is able to act unilaterally to change the national licensing rules for the 5725-5850 MHz band because - as noted, and unlike the other current 5 GHz Wi-Fi bands - there is no legally binding EC Decision that restricts the UK from doing so.

4.18 The UK will propose changes to the EN 301893 standard in ETSI[26] to allow for higher power Wi-Fi use in this band - a changed ETSI standard is not essential, but it would be helpful for manufacturers.

4.19 Having access to more 5 GHz spectrum will enhance the user experience and enable more high data services to be delivered over Wi-Fi. Initial technical analysis suggests that sharing the band with satellite users is feasible – subject to appropriate technical conditions. Our initial overview of coexistence issues is set out in annex 5. A more detailed assessment will be set out in a subsequent consultation.

[25] ECC/REC/(06)04 (for BFWA)
[26] ETSI – European Telecommunications Standards Institute

4.20 Making the 5725-5850 MHz spectrum available for Wi-Fi would be in line with our duties under the Communications Act to further the interests of consumers and to ensure the most efficient use of the spectrum.

4.21 **We therefore propose to open up the 5725-5850 MHz in the UK as a priority, subject to studying the potential impact on other services. We will also engage in discussions through CEPT to consider whether any action at European level may be appropriate.**

4.22 We may be able to achieve change at 5725-5850 MHz before the end of 2017.

Medium term change

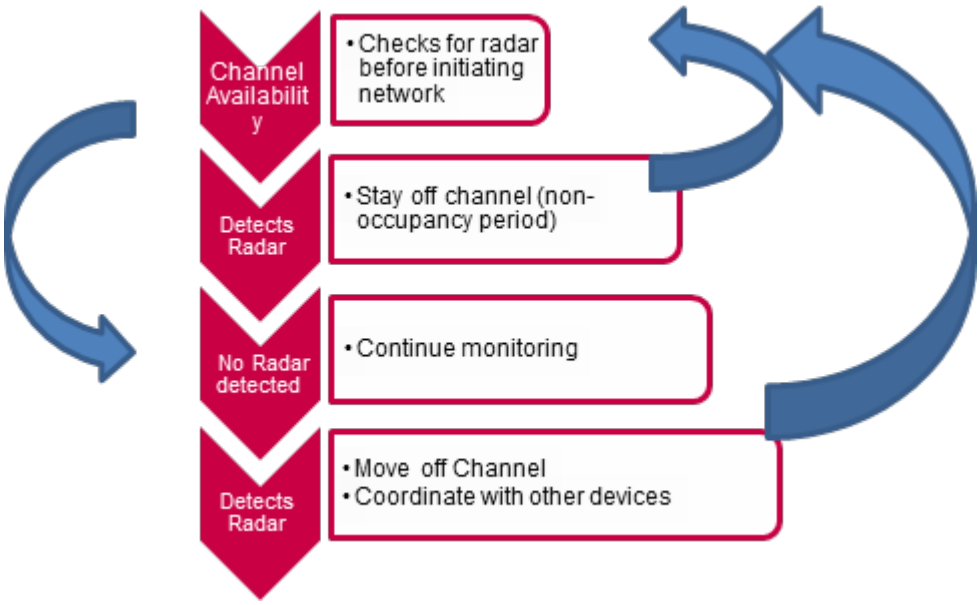
4.23 **Medium term** options include those which we could pursue through either the EU or CEPT ahead of WRC-19. This would be with a view to making changes at or possibly before the conference, if analysis is produced and accepted showing that spectrum sharing is feasible.

Dynamic Frequency Selection

4.24 Dynamic Frequency Selection (DFS) is a means of protecting radars operating in the 5 GHz band. The system detects transmissions from the radars and requires Wi-Fi devices to switch to a different channel if they detect co-channel radar pulses. The way DFS works is shown in Figure 4.2 below.

4.25 Some Wi-Fi/RLAN stakeholders we spoke to identified DFS as a particular constraint on Wi-Fi operation, and a recent study[27] has shown that Wi-Fi activity can end up concentrated in the part of the band where DFS is not required, 5150-5250 MHz. We therefore propose to re-examine how DFS is applied in each sub-band. The conclusions may be different for different sub-bands.

Figure 4.2: Operation of DFS



4.26 We believe the risk of interference to military radars in some parts of the 5 GHz band has reduced significantly in recent years because the MOD no longer deploys two particular systems designed to operate at 5725-5850 MHz. We are therefore

[27] Figure 3-9: 5 GHz channel utilisation in central London, "Future Use of Licence Exempt Spectrum", Plum Consulting, July 2015, http://www.plumconsulting.co.uk/pdfs/Plum_July_2015_Future_use_of_Licence_Exempt_Radio_Spectrum.pdf

reviewing the DFS requirements in this band in conjunction with the relevant UK stakeholders.

4.27 A decision to change the requirements could be taken at a UK level, depending on permitted EIRP levels. DFS is not required in the USA and many other territories in the 5725-5850 MHz band and Wi-Fi/RLAN stakeholders have told us the DFS use in this band can be controlled nation-by-nation in firmware without needing country specific hardware.

4.28 **We therefore propose to examine the requirement for DFS in the 5725-5850 MHz band with a view to removing it if DFS is no longer necessary.**

4.29 DFS is also essential in protecting the Met Office's rain radar network at 5600-5650 MHz. However, some stakeholders said that the requirement to specifically detect weather radar pulses should be limited to the bands where weather radars are actually used (5600-5650 MHz) and should not be required across new bands - specifically 5350-5470 MHz.

4.30 Stakeholders also indicate that they would like an opportunity to review some of the DFS parameters across the other bands in the 5 GHz range. Changes in bands other than 5725-5850 MHz may take longer because they are linked to ITU Radio Regulations and EC Decisions.

5850-5925 MHz

4.31 The 5850-5925 MHz is 75 MHz wide, and it already has a primary mobile allocation worldwide. Access to this band could deliver another 80 MHz Wi-Fi channel, alongside some spectrum from the adjacent 5725-5850 MHz band.

4.32 In the EU, 30 MHz at 5875-5905 is designated for Intelligent Transport Services (ITS) through a binding EC Decision[28]. The UK has already exempted ITS equipment from individual licensing, which means that new ITS services for infrastructure-to-vehicle and vehicle-to-vehicle communications can be deployed and used now.

4.33 CEPT and ETSI are currently working on an analysis of the potential impact on ITS applications if RLANs are used in this spectrum. CEPT will also carry out studies to assess the potential impact on FSS Space to Earth systems.

4.34 If technical studies go well and CEPT members agree that primary mobile allocation is sufficient to enable the band to be opened for RLANs, it could be harmonised at European level before WRC-19.

4.35 Alternatively, if satellite or ITS coexistence issues prove difficult - or if the European bodies decide it is better to await full alignment between European regulations and the ITU Radio Regulations - then it would need to be after WRC-19.

Longer term matters for consideration

4.36 The **longer term** options are only likely to be possible after WRC-19 because they would have an impact on mandatory EU Spectrum Decisions and may result in different technical parameters from those shown in the Radio Regulations. We seek views on whether industry is keen to explore these possibilities further.

Outdoor Wi-Fi use at 5150-5350 MHz

4.37 The binding EU Spectrum Decision that enables Wi-Fi in the frequencies 5150-5350 MHz currently limits usage to low power (maximum 200mW) and on an indoor-only basis. However, the band is available outdoors and at higher power levels in the USA.

[28] 2008/671/EC: http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32008D0671

4.38 Removing the indoor-only restriction stipulated in the EU Spectrum Decision and raising the power limits could allow UK consumers to benefit from two more wide channels for Wi-Fi outdoors and better indoor and outdoor coverage. However, EU Member States are unlikely to agree to this step while those technical conditions - which are in place to protect incumbent satellite services - remain in the Radio Regulations. The Regulations will not be changed before WRC-19.

4.39 We note there are different satellite uses at 5150-5250 compared to 5250-5350 and there may be different conclusions on the appropriate technical conditions for RLAN use in these two frequency bands. Technical analysis aimed at developing options for the usage conditions in these bands should be a focus for the CEPT and ITU preparations for WRC-19.

4.40 In summary, there are two main changes that could be sought for Wi-Fi:

- **Removal of the indoor-only restriction:** Removing the indoor restriction across the band to allow for outdoor, public access Wi-Fi to use the band. This would provide enough contiguous spectrum for two 80 MHz channels or one 160 MHz channel for providing Wi-Fi outdoors.

- **Increase power limits from 200 mW to 1 W EIRP:** Increasing the radiated power restrictions could allow for better Wi-Fi coverage both indoors and outdoors. Stakeholders have told us said that using up to 1 W EIRP at 5 GHz gave similar coverage to existing 2.4 GHz deployments in indoor environments. Increasing radiated power limits along with removing the indoor-only restriction would align the regulations with those already in force in the 5470 to 5725 MHz band.

5350-5470 MHz (the 'centre gap')

4.41 Although the 'centre gap' itself is only 120 MHz wide, 5350-5470 MHz could actually provide 160 MHz of spectrum for Wi-Fi because there are 20 MHz internal guard bands in both of the adjacent Wi-Fi bands (5150-5350 and 5470-5725 MHz). This means that access to this band could support two new 80 MHz channels or one 160 MHz channel.

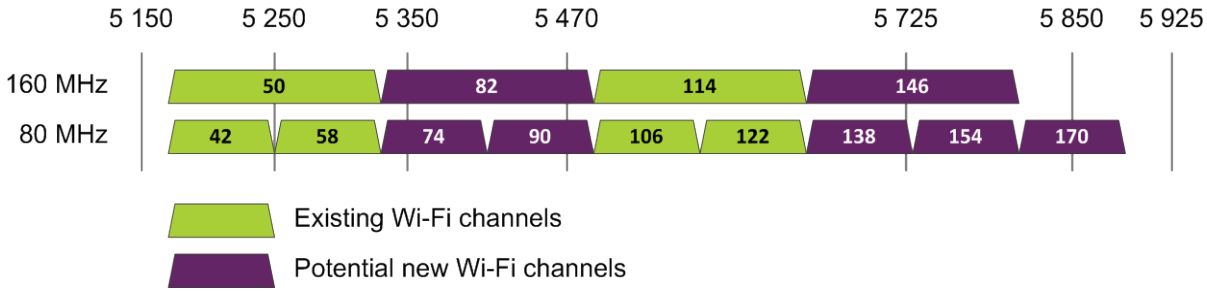
4.42 This band will be studied in CEPT and the ITU as part of the WRC-19 preparation process. The results of these studies and any resulting harmonisation measures will depend on the Wi-Fi industry successfully demonstrating that there is demand for this additional spectrum, and developing and demonstrating that effective interference mitigation methods from Wi-Fi to the incumbent EESS and radiolocation users of the band can be properly implemented and are effective.

4.43 As the studies and implementation of these mitigation techniques will call for significant resource commitment by regulators, incumbents and stakeholders, we expressly encourage the views of stakeholders on whether we should seek to pursue this option - and on whether they will support such efforts by committing their own resources.

Summary

4.44 Assuming that all the possible changes discussed above were feasible and implemented, the following channel arrangement for the 5 GHz spectrum would be possible (Figure 4.3)

Figure 4.3 Example channelisation for Wi-Fi at 5 GHz



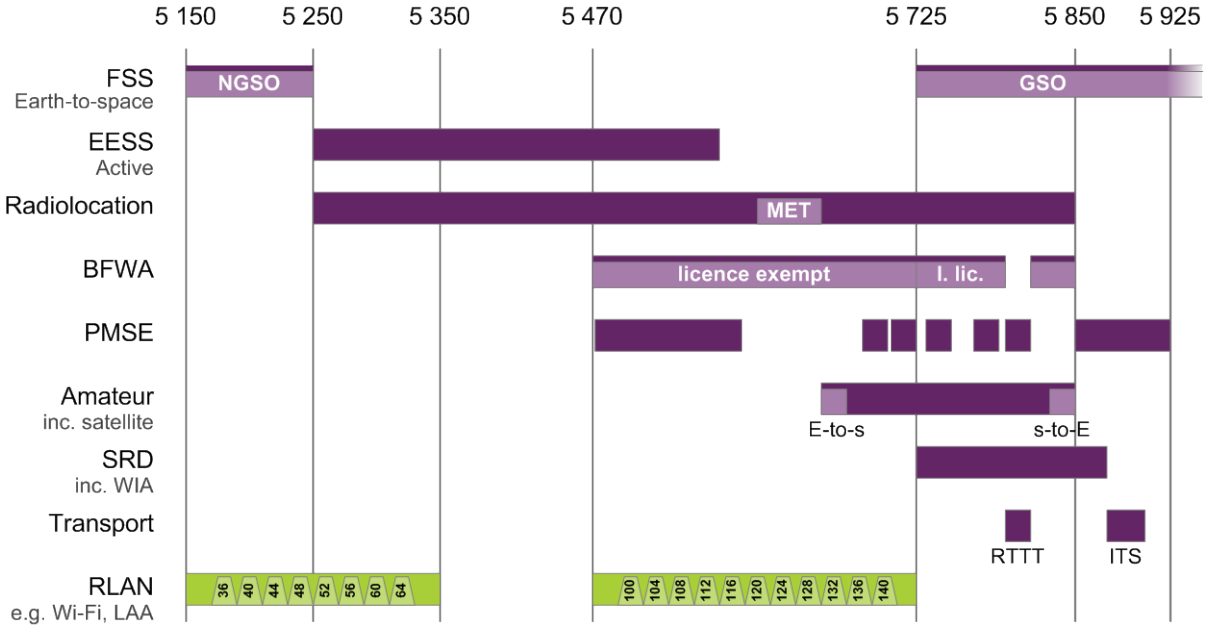
Coexistence of Wi-Fi with other uses of the 5 GHz band

4.45 The 5 GHz band is currently used by a range of other services, including satellites and radars. Any changes to the current arrangements for the band could have implications for existing uses, which provide a range of important benefits to citizens and consumers. For example, EESS satellites provide valuable information about the global environment. We therefore need to consider if and how those services can coexist with greater use of the frequencies by Wi-Fi.

4.46 A summary of incumbent and proposed new services in the 5 GHz band – alongside the current allocations for Wi-Fi - is set out in Figure 4.4. In addition to satellite (FSS[29] and EESS[30]) and radar radiolocation services, there is use by Broadband Fixed Wireless Access (BFWA), PMSE[31] and SRDs.

4.47 Details of the particular coexistence issues faced by these uses are set out in annex 5.

Figure 4.4 Existing UK, EU, and CEPT services in 5150-5925 MHz



4.48 WRC-15 mandated studies in 5150-5925 MHz for future Wi-Fi operational requirements, and for coexistence between Wi-Fi and incumbent services ahead of a

[29] Fixed Satellite Service
[30] Earth Exploration Satellite Service
[31] Programme Making and Special Events – wireless microphones and cameras etc. used by the entertainment industry

possible decision to make more spectrum available for Wi-Fi at WRC-19. The sub-bands identified were 5150-5350 MHz, 5350-5470 MHz, 5725-5850 MHz and 5850-5925 MHz (excluding 5470-5725 MHz which is already accessible for Wi-Fi outdoors and at higher power levels[32]).

4.49 However, future work will need to be sufficiently well resourced by industry if the case for opening up more spectrum for Wi-Fi is to be made at WRC-19. What studies are carried out will depend on how the individual sub-bands are prioritised, but will likely include coexistence studies, measurement campaigns and development of appropriate mitigation techniques. We seek further opinions from stakeholders on how this work should be prioritised and the resources they may be willing to commit.

4.50 Ofcom has already committed a significant amount of effort to this work both in measurements and analysis of measurement data, with a focus on reducing uncertainties and moving away from overly pessimistic coexistence scenarios. This work has included an airborne measurement campaign where we recorded real Wi-Fi emissions from London and Northampton from an aircraft.[33] [34]

4.51 In the first set of measurements we looked at the 2.4 GHz band from an aircraft over central London and rural and suburban areas to the west of London on two separate days. We took the measurements over central London because it represents a 'worst case' scenario from a UK deployment density prospective for Wi-Fi emissions.

4.52 The rationale for measuring the 2.4 GHz band is that it is a mature and relatively saturated band in terms of RLAN use, and thus could provide a sensible proxy for future activity in the 5 GHz band. We found that the measured Wi-Fi aggregate emissions were towards the lower end of the aggregate interference values that the 2.4 GHz Wi-Fi/satellite coexistence model predicted for the 'busy hour'. The aggregate interference values measured were some 20 dB lower than those predicted for the higher end inputs to the model.

4.53 In the second set of measurements we flew over Northampton in order to measure both 2.4 GHz and 5 GHz aggregate Wi-Fi emissions. The main aim of these measurements was to compare and verify our prediction that 5 GHz aggregate Wi-Fi emissions might currently be around 13 dB lower than those measured at 2.4 GHz.

4.54 The difference between the assumptions used for modelling the two bands is accounted for by a number of different factors including the greater propagation loss at 5 GHz and the expected lower density of 5 GHz Wi-Fi devices today. In any case, the new measurements showed that the difference between the two bands is just over 14 dB, proving that our prediction was about right and that 5 GHz aggregate Wi-Fi emissions might even be slightly lower than we previously predicted.

4.55 We can draw three main conclusions from these measurement campaigns:

- That we can measure both 2.4 and 5 GHz aggregate Wi-Fi emissions from the air and,
- That the higher end aggregate Wi-Fi emissions currently predicted by the model are unlikely to be realistic, and
- That the difference between current Wi-Fi signal strength at 2.4 GHz and 5 GHz is broadly in line with predictions made.

[32] Up to 1 W EIRP
[33] http://stakeholders.ofcom.org.uk/binaries/consultations/5-GHz-Wi-Fi/annexes/Airborne_measurements_over_London.pdf
[34] http://stakeholders.ofcom.org.uk/binaries/consultations/5-GHz-Wi-Fi/annexes/Airborne_measurements_over_Northampton.pdf

Priorities for further investigation

4.56 Taking into account what it is possible to achieve in the short and medium term, we seek the views of stakeholders on the following:

- Our **proposal** to consider opening up the 5725-5850 MHz frequencies as soon as possible, subject to appropriate protection of other users.
- Our **proposal** to prioritise a re-examination of the requirements for DFS in the 5 GHz band.
- The other potential changes we have identified. In particular the merit in opening up 5850-5925 MHz; in pursuing outdoor Wi-Fi use at 5150-5350 MHz; and the prospect of opening up the so-called 'centre gap' at 5350-5470.

4.57 As elsewhere in this document, we wish to make UK industry stakeholders aware that if we are to proceed with any plans to extend Wi-Fi access in the 5 GHz band they will need to engage with relevant European studies – and be prepared to make resources available.

4.58 Figure 4.7 at the end of this section summarises the full range of potential changes, including those discussed above. It notes the potential benefits in terms of greater access to spectrum for Wi-Fi, and also identifies other current uses of the various sub-bands.

Questions for stakeholders

Question 1: Do you agree with our proposal to prioritise consideration of the 5725-5850 MHz frequencies for Wi-Fi, subject to appropriate protections to other users, in particular satellite services?

Question 2: Do you agree with our proposal to re-examine the requirement for DFS across the 5 GHz band, subject to appropriate protections to other users?

Question 3: Do you think we should pursue the other options we have identified: opening up 5850-5925 MHz; outdoor Wi-Fi use at 5150-5350 MHz; and opening up the 'centre gap' at 5350-5470?

Question 4: What are your views on the future growth in demand for Wi-Fi? In which use scenarios do you expect to see the greatest pressure for delivery of high quality Wi-Fi access? What evidence do you have to support your views?

Question 5: Do you think technology improvements and densification of access points will be sufficient to meet demand or will there also be a need for more spectrum beyond that which we propose to make available? What evidence do you have to link between demand for data and demand for additional spectrum?

Question 6: What real life speed and quality of experience can consumers expect in practice from devices using the 5GHz spectrum as authorised in the UK now? What changes can we expect as the number of devices increases and technology improves? What difference in speeds and quality of experience would additional spectrum make?

Question 7: How important is contiguous spectrum? How wide should channels be to support future demand?

Question 8: Do you believe we have correctly identified the incumbent services in 5150-5925 MHz which need to be taken into account in considering opening up more 5 GHz

spectrum for Wi-Fi? Are there any other services which will need to be taken into account in future studies?

Question 9: What coexistence studies, measurement campaigns and mitigation techniques do you believe would be most effective for demonstrating coexistence between Wi-Fi and incumbent users?

Question 10: Do you intend to participate and provide technical material into the ITU and CEPT work? In what way?

Figure 4.6 Summary of potential changes in use of 5 GHz spectrum for Wi-Fi

Change Option	Benefit	Incumbent Services
Make 5725-5850 MHz available for Wi-Fi	Two additional 80 MHz channels (including outdoor and higher power, if coexistence is possible. See options for Lower 5 GHz band below) Wi-Fi devices already support this band in USA and other territories outside Europe	FSS (E-to-s, GSO) Radiolocation BFWA PMSE Amateur SRD RTTT
Liberalise use of the existing Lower 5 GHz band (5150-5350 MHz)		FSS (E-to-s, NGSO) EESS (Active)
Remove indoor-only restriction …	Two additional channels for delivering Wi-Fi outdoors Improve suitability for transport applications	 Progressively more complex to demonstrate coexistence
… and increase power limit from 200 mW to 1 W EIRP …	Better Wi-Fi coverage indoors and outdoors, similar to that at 2.4 GHz More spectrum for BFWA similar to that already used in 5470-5725 MHz Regulations would be closely aligned with those already in force in the USA	
Revisit DFS requirements	Spread activity more evenly across all 5 GHz channels and reduce contention in channels without a DFS requirement Improve suitability for transport applications	Radiolocation
Make 5350-5470 MHz available for Wi-Fi	Two additional channels for delivering Wi-Fi outdoors	EESS (Active) Coexistence likely to be possible only on a time and geographic sharing basis
Make 5850-5925 MHz available for Wi-Fi	One additional channel for delivering Wi-Fi (including outdoor and higher power, if coexistence is possible. See options for Lower 5 GHz band above)	FSS (E-to-s, GSO) PMSE SRD ITS

Section 5

Next steps

5.1 The closing date for receiving responses to this consultation is **22 July 2016**.

5.2 The responses will help us to identify our priorities for working with industry and international stakeholders to seek regulatory changes at 5 GHz in preparation for WRC-19. We will continue to provide leadership in international discussions but we expect industry to commit the necessary resources to take forward further coexistence and other technical studies.

5.3 We will consider carefully all responses we receive on our proposal to open up spectrum for Wi-Fi in the 5725-5850 MHz sub-band before reaching any conclusions.

5.4 We are planning to publish a further consultation later this year on licence exemption of Wi-Fi devices in the 5725-5850 MHz band. This will present the results of any further technical studies on coexistence and set out the technical and usage parameters we will be proposing for licence exempt use in the band.

5.5 As part of this next consultation we will also publish an appropriate UK interface requirement(s) (IR) document and, if necessary, a voluntary national specification (VNS) for Wi-Fi devices using this band. As part of the publication process for these documents they will need to be notified to the EC, and allow at least three months for comments. We intend for this notification process to run alongside the next consultation.

5.6 Following due process, and subject to addressing any coexistence issues, we may be able to make Wi-Fi devices in this band licence exempt within the next year.

5.7 Additionally, we will continue to engage with the European and ITU process for WRC-19, including the associated coexistence studies for all of the 5GHz bands under the WRC-19 AI 1.16

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 22 July 2016**.

A1.2 Ofcom strongly prefers to receive responses using the online web form at http://stakeholders.ofcom.org.uk/consultations/5-GHz-Wi-Fi/howtorespond/ 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 responses - particularly those with supporting charts, tables or other data - please email Alberto.Fernandes@ofcom.org.uk attaching your response in Microsoft Word format, together with a response coversheet.

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

Alberto Fernandes
Floor 3:105
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, as set out in sections 3 and 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 document, or need advice on the appropriate form of response, please contact Alberto Fernandes on 020 783 4418.

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/terms-of-use/

A1.11 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/email-updates/

Ofcom's processes

A1.12 Ofcom seeks to ensure that responding to a consultation is easy as possible. For more information please see our consultation principles in Annex 2.

A1.13 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.

A1.14 If you would like to discuss these issues or Ofcom's processes more generally you can alternatively contact Steve Gettings, Acting Secretary to the Corporation, who is Ofcom's consultation champion:

Steve Gettings
Ofcom
Riverside House
2a Southwark Bridge Road
London SE1 9HA

Tel: 020 7981 3601

Email Steve.Gettings@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

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 http://stakeholders.ofcom.org.uk/consultations/consultation-response-coversheet/.

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 responses

BASIC DETAILS

Document 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 ☐

Whole response ☐

Part of the response ☐

Name/contact details/job title ☐

Organisation ☐

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

Current use of spectrum for Wi-Fi at 5 GHz

A4.1 In this annex we describe the current use of 5 GHz spectrum for Wi-Fi and identify some differences between arrangements in the UK/Europe and some other countries. The need to protect other users of the frequencies has led the ITU to put in place obligations on administrations that have international recognition and treaty status.[35]

A4.2 From these international obligations, national and regional regulations have emerged that give Wi-Fi some access to the 5 GHz bands, but this varies from country-to-country and region-to-region. Recently, some administrations have changed their national regulations for Wi-Fi[36] making these regional differences more distinct. For example, the EU spectrum decision has different arrangements for Wi-Fi to those in the USA.

A4.3 In the EU Spectrum Decision 455MHz of spectrum has been harmonised and been made available on a licence exempt basis in the UK for Wi-Fi use in the 5GHz range. See below for the different regulations that apply across the 5GHz band in the UK/EU. :

- 5150 - 5250 MHz (200mW EIRP) – indoor use only
- 5250 - 5350 MHz (200mW EIRP) – indoor use only
- 5470 - 5725 MHz (1W EIRP) – indoor and outdoor use allowed

A4.4 The table below (Figure A4.2) illustrates the varying regulations for different countries or regions across the world for Wi-Fi use across the 5 GHz band.

Figure A4.2: International Wi-Fi authorisations for the 5 GHz band

Band (MHz)	UK & EU	US	Japan	China
5150-5250	Yes (indoor only)	Yes	Yes	Yes
5250-5350	Yes (indoor only)	Yes	Yes	Yes
5470-5725	Yes	Yes	Yes	No[37]
5725-5850	No	Yes	No	Yes

[35] Give the details for Resolution 229 and Article 21
[36] The FCC's decision in 2014 to remove the indoor restriction on Wi-Fi using the 5150-5250 MHz band for example.
[37] Except between 5300 – 5550 MHz where DFS/TPC is required

Comparison of requirements

A4.5 The 5 GHz Wi-Fi bands are assigned certain conditions of operation which limit how a service may operate within that band. For instance, some Wi-Fi devices may only be able to operate indoors in a particular band, or there may be limits on the amount of power a device is permitted to emit. The rules for Wi-Fi devices are broadly similar in the US and in UK/EU. We consider below a detailed comparison of how Wi-Fi is used in different countries.

Maximum EIRP

A4.6 The maximum EIRP is in effect is the amount of power that a Wi-Fi device is allowed to radiate.[38]

A4.7 Figure A4.3 illustrates the varying limits on EIRP in the UK and the USA across the 5GHz band.

Figure A4.3: 5 GHz EIRP limits in USA and UK

Country or Region	Maximum EIRP (in different 5GHz bands)			
	5150 – 5250 MHz	5250 – 5350 MHz	5470 – 5725 MHz	5725 – 5850 MHz
US	4W with 6 dBi antenna 200 W for PtP w/23 dBi antenna < 125 mW for elevation angles > 30 degrees above the horizon	1W with 6 dBi antenna	1W with 6 dBi antenna	4 W with 6 dBi antenna
UK	200mW	200mW	1W	25mW (SRDs) 4W (BFWA use only)

Maximum Conducted Output Power

A4.8 Maximum Conducted Output Power refers to the total transmit power delivered to all antennas and antenna elements when the transmitter is operating at its maximum power control level. With the exception of the 5725-5850 MHz range, devices operating in the UK and EU are normally limited by max EIRP restrictions only. In the US however, more specific limits are in place. In the 5725-5850 MHz range, devices in the US are limited to a conducted power use of 1 Watt.

Dynamic Frequency Selection (DFS)

A4.9 Dynamic Frequency Selection is a system which obligates Wi-Fi routers to change frequency when certain radio systems using the same frequency are near. DFS is

[38] This is called Equivalent Isotropically Radiated Power (EIRP

needed in order to avoid interference with radio transmissions that are considered primary-use or mission-critical such as radar services. The rules concerning DFS are broadly similar for the US and UK/EU. The lower frequencies in the 5GHz band (5150 – 5250 MHz) do not require DFS.

A4.10 Devices operating in the 5250-5725 MHz range are required to use DFS depending on whether the device is a Master, Slave DFS device. A master device is one which has unidirectional control over another (slave) device, whilst a slave device can only operate alongside a master device. The table below illustrates which frequency ranges require DFS depending on the type of device.

A4.11 Devices operating in the US in the 5725 – 5850 MHz range do not require Dynamic Frequency selection, whereas in Europe, all Fixed Wireless Access devices, i.e. devices which connect a wireless broadband data communication between two fixed locations are required to employ this system. The figure below explains this in greater detail.

Figure A4.5: Dynamic Frequency Selection in the 5 GHz band

Country or region	DFS Requirement across the bands and regions			
	5150 – 5250 MHz	5250 – 5350 MHz	5470 – 5725 MHz	5725 – 5850 MHz
US	X	Yes, for master device/No, for client devices	Yes, for master device/No, for client devices	X
EU	X	Yes, for master device/No, for slave devices	Yes, for master device/No, for slave devices	Yes, for all FWA devices as specified in ETSI EN 302 502
Japan	X	✔		X
China	Yes (Except on channel 42)	Yes (Except on channel 50 & 58)	X	Yes (Except on channel 155)

Transmit Power Control required (TPC)

A4.12 Transmit Power Control (TPC) is a mechanism designed to contain interference between Wi-Fi devices by automatically reducing the used transmission output power when other networks are within range. This mechanism is only employed when an antenna exceeds a certain power limit. TPC is often required alongside Dynamic Frequency Selection.

Figure A4.6: Transmit Power Control in the 5 GHz band

TPC Required?	5150 – 5250 MHz	5250 – 5350 MHz	5470 – 5725 MHz	5725 – 5850 MHz
US	X			
UK/EU	X	Yes	Yes	X
Japan	X			
China	X	Yes	X	

Out-of-band EIRP emissions limit

A4.13 This refers to the level of power which the user of a band is permitted to emit so as not to interfere with another user in an adjacent band.

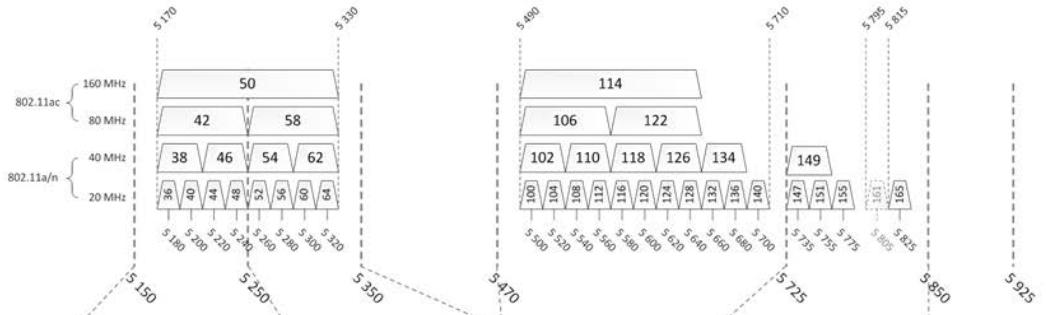
Figure A4.7 Out of band emission levels

5GHz	US	UK	Japan	China
Out-of-bound EIRP emissions limit	≤-27 dBm/MHz (5150 – 5350 MHz & 5470 – 5725 MHz) ≤-17 dBm/MHz (5715 MHz – 5725 MHz & 5850 MHz – 5860 MHz)	-30 dBm/MHz	–13 dBm/MHz	-80 dBm/Hz

Comparing US and UK Wi-Fi spectrum access

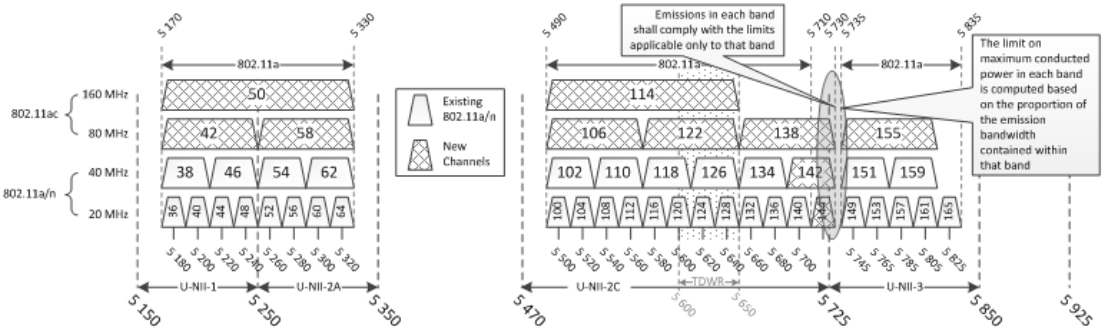
A4.14 In order to highlight the differences between the UK and US regulations for Wi-Fi we provide two figures below showing a direct comparison of 5 GHz Wi-Fi channel usage. The first diagram shows the UK arrangements for Wi-Fi and the second shows those for the USA.

Arrangements for UK/European spectrum in the 5GHz range.



Frequency Range	5 150 to 5 250 MHz	5 250 to 5 350 MHz	5 470 to 5 725 MHz	5 725 to 5 850 MHz	
Condition of Operation		Indoor only Fixed and Mobile	Indoor and Outdoor Fixed and Mobile	Indoor and Outdoor Fixed only	
Licensing Condition			License Exempt	Light Licensed 5 795 to 5 815 MHz shall not be used (to protect RTTT)	
Max. Conducted Power			N/A (EIRP condition only)	1.0	*W*
Max. EIRP	0.20 0.01	0.20 0.01 without TPC: 100 mW (5 mW / MHz)	1.00 0.05 without TPC: 500 mW (25 mW / MHz)	4.00 0.20 Skyward emissions restriction*	*W* *W / MHz*
Tx Power Reduction (dBm-by-dBi) required when antenna exceeds ...			N/A (EIRP condition only)	> 6	dBi
Out-of-band EIRP emissions limit			1 000 to 5 150 MHz: -30 5 350 to 5 470 MHz: -30 5 725 to 26 000 MHz: -30	1 000 to 5 725 MHz: -30 5 875 to 26 500 MHz: -30	dBm / MHz
Dynamic Frequency Selection required?	**No**	**Yes**, for master device		**Yes**, for ALL FWA devices as specified in ETSI EN 302 502	
		No, for slave device under control of a master			
Transmit Power Control Required?	**No**	**Yes**, RLANs must be able to reduce EIRP < 50 mW	**Yes**, RLANs must be able to reduce EIRP < 250 mW	**Yes**, ALL FWA must be able to reduce EIRP < 250 mW	
		No, for RLANs w/ EIRP < 100 mW	**No**, for RLANs w/ EIRP < 500 mW		

Arrangements for US spectrum in the 5GHz range



Frequency Range	5 150 to 5 250 MHz	5 250 to 5 350 MHz	5 470 to 5 725 MHz	5 725 to 5 850 MHz
Condition of Operation	Indoor/Outdoor, Master/Client, mobile/portable, and fixed Device, unless otherwise noted			
Max. Conducted Power	master: 1 W mobile client: 0.25 W	250 mW or 11 dBm + 10 log B, whichever is lower (B = 26 – dB emission bandwidth)		1 W
Max. EIRP	master: 4 W w/ 6 dBi antenna client: 1 W w/ 6 dBi antenna 200 W for PtP w/ 23 dBi antenna < 125 mW for elevation angles > 30° above the horizon	1 W with 6 dBi antenna		4 W with 6 dBi antenna No EIRP limit for fixed PtP (i.e. no antenna gain limit)
Tx Power Reduction (dBm-by-dBi) required when antenna exceeds ...	> 6 dBi > 23 dBi for fixed PtP	> 6 dBi		> 6 dBi Not required for PtP
Out-of-band EIRP emissions limit		≤-27 dBm/MHz outside 5 150 to 5 350 MHz	≤-27 dBm/MHz outside 5 470 to 5 725 MHz	≤-17 dBm/MHz in 5 715 to 5 725 MHz and 5 850 to 5 860 MHz ≤-27 dBm/MHz outside 5 715 to 5 860 MHz
Dynamic Frequency Selection required?	No	Yes, for master device No, for client device		No
Transmit Power Control Required?	No	Yes, RLANs must be able to reduce EIRP < 250 mW No, for RLANs with EIRP < 500 mW		No
Minimum BW requirement?	N/A			6 dB BW ≥ 500 kHz

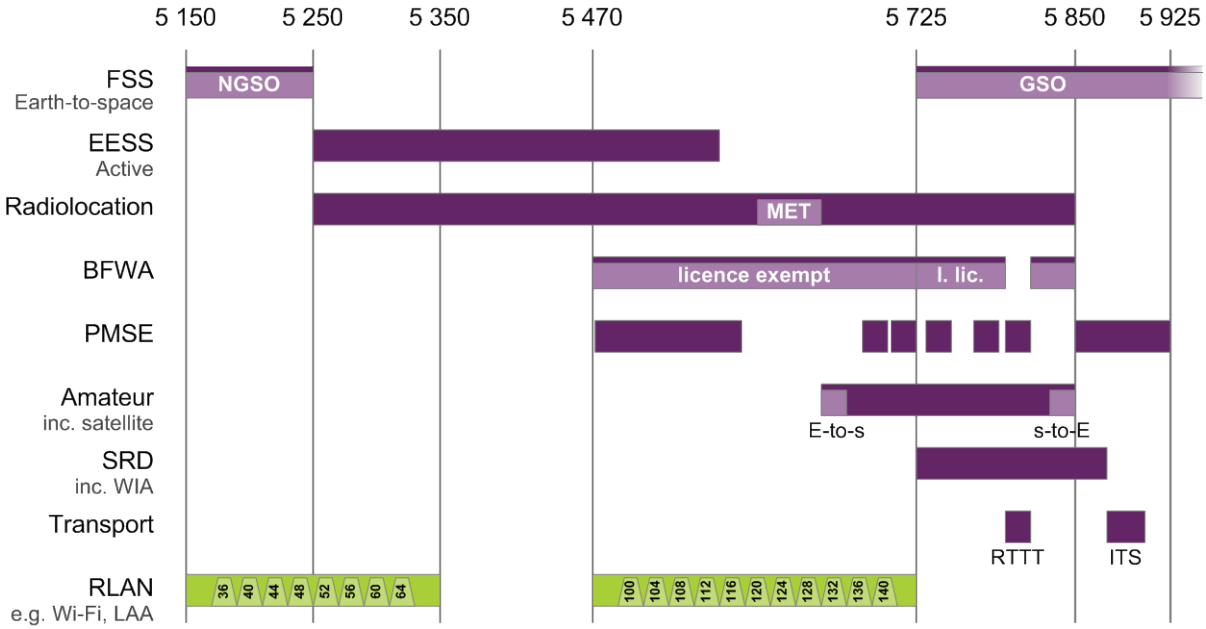
Annex 5

Coexistence of Wi-Fi with other 5 GHz services

A5.1 In this annex we set out the coexistence issues for Wi-Fi in the 5 GHz which are identified in section 4.

A5.2 As noted, the 5 GHz band is used by many services throughout the world, including satellites and radars. We focus mainly on how these systems are deployed in the UK, drawing on our early engagement with stakeholders on the feasibility of sharing. The diagram of current and planned uses presented in section 4 is reproduced here for reference.

Figure A5.1: Existing RLAN and incumbent services and applications in 5150-5925 MHz in the UK/EU



Fixed Satellite Service (Earth-to-space)

A5.3 Satellites of the FSS use spectrum at 5 GHz for data uplink in the Earth-to-space direction from ground stations across the globe. This means that coexistence studies are considering the risk from Wi-Fi devices towards receivers on satellites.

A5.4 These satellite receivers might have a footprint which is continental in size or even covering half the globe (in the case of geostationary satellites) so the coexistence studies need to consider the impact of aggregate interference from Wi-Fi devices across a large portion of the earth. The studies carried out in CEPT SE24 Group[39] estimated that these satellites are likely to view some three to five hundred million Wi-Fi access points in continental Europe alone by 2025. With certain assumptions, these studies have also shown that sharing spectrum with these FSS uplink receivers is feasible.

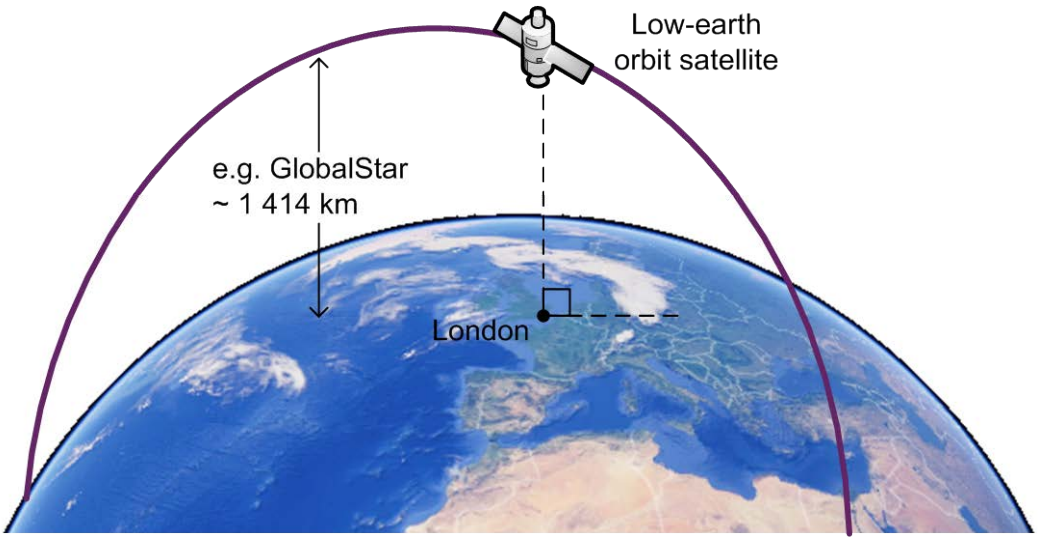
[39] A CEPT body set up to study satellite coexistence

A5.5 No coexistence studies have been carried out on the impact from 5 GHz satellite earth stations to Wi-Fi devices. In the UK, there are only six earth stations at 5850-5925 MHz so any risk of interference to Wi-Fi from FSS is likely to be highly localised and will not, in any case, impact all of the channels available for Wi-Fi.

A5.6 The 5150-5250 MHz range is allocated on a global primary basis for feeder links for the mobile satellite service (MSS) in low-earth orbit (LEO). Users include a single major MSS operator, GlobalStar. Whilst this band is used for feeder links, the satellites might not be using very high directivity tracking antennas and so can have a footprint that is continental in size[40].

A5.7 The critical coexistence scenario is shown in Figure A5.2 below, when the satellite is directly above a large area of intense Wi-Fi use such as continental Europe. This is the point at which there will be a great number of Wi-Fi devices in the footprint of the satellite and also where the high relative elevation angle will mean that there is the least 'clutter' between the satellite and those Wi-Fi devices.

Figure A5.2: Geometry of a European Wi-Fi/low-earth orbit satellite coexistence scenario in 5150-5250 MHz



A5.8 In 2014 the US Federal Communications Commission (FCC) decided[41] to liberalise the regulations for Wi-Fi in 5150-5250 MHz, raising the power limits[42] and removing the indoor-only restriction. This opened up a large amount of contiguous spectrum by providing consistent power regulations for Wi-Fi across both 5150-5250 and 5250-5350 MHz, and so allowing outdoor operation across both bands. This was

[40] The satellite footprint might be around 5 800 km in diameter

[41] "Revision of Part 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band", DA/FCC: FCC-14-30, 1 April 2014, https://www.fcc.gov/document/5-ghz-u-nii-ro

[42] Before 2014:

All devices could use 50 mW conducted power with up to 6 dBi antenna gain permitted (200 mW EIRP) and a transmitter peak power spectral density of 2.5 mW/MHz (4 dBm/MHz).

After 2014:

Master devices can use 1 W conducted power with up to 6 dBi antenna gain (4 W EIRP)
Client devices can use 0.25 W conducted power with up to 6 dBi antenna gain (1 W EIRP)
Fixed PTP devices can use 1 W conducted power with up to 23 dBi antenna gain (200 W EIRP)

important for supporting the wide bandwidth channels needed for gigabit Wi-Fi, which uses 80 and 160 MHz channels[43].

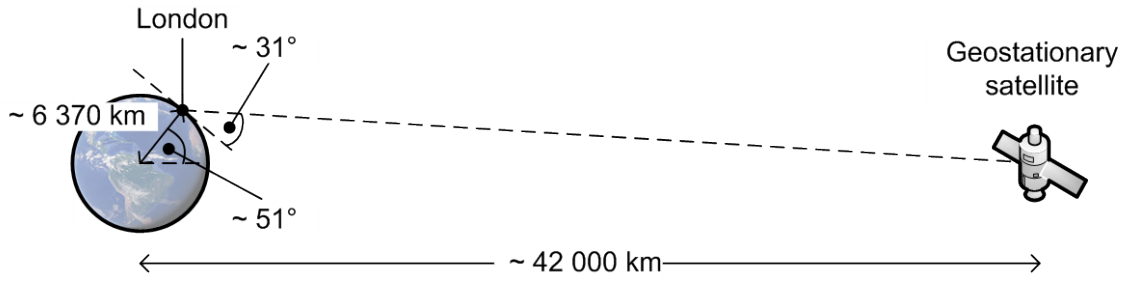
A5.9 Coexistence studies were submitted to the FCC by both GlobalStar and the National Cable & Telecommunications Association (NCTA) with the former showing that coexistence was not possible and the latter that coexistence *was* possible.

A5.10 The FCC concluded that appropriate mitigations for 5150-5250 MHz were to apply a skywards power restriction to fixed outdoor access points[44]. Organisations intending to deploy a total of more than 1,000 outdoor access points are required to submit a letter to the Commission acknowledging that, should harmful interference to licensed services in this band occur, they will be required to take corrective action[45].

A5.11 5725-5925 MHz is used in the Earth-to-space direction to uplink to satellites in geostationary orbits (GSO). From 5725-5850 MHz the FSS allocation is in ITU-R Region 1 (including Europe, Africa and northern Asia). This band is already used for Wi-Fi in the USA and other parts of the world outside ITU-R Region 1. The 5850-5925 MHz band is used globally and intensely for FSS uplinks to satellites such as INTELSAT and SES.

A5.12 These satellites are geostationary, meaning that their position in the sky remains fixed and that they occupy a 'belt' which is directly above the equator and some 36,000 km above the surface of earth. For satellites at longitudes around 0º, this 'belt' is at an elevation angle of approximately 31° from London and 26° from Glasgow as shown in Figure A5.3. This elevation angle gets shallower for satellites to the east or west of the UK. The footprint of the satellites might typically be continental in size, but can be as large as half the earth for some satellites[46].

Figure A5.3: Geometry of a UK Wi-Fi/geostationary satellite coexistence scenario in 5725-5925 MHz



A5.13 Coexistence work between Wi-Fi and other services in 5725-5925 MHz, including FSS, is currently being undertaken in CEPT. Initial results can be seen in ECC Report 244[47] which stated that it was too early to draw definitely conclusions about coexistence between Wi-Fi and FSS in 5725-5925 MHz and that further study was required. The document also showed that with certain assumptions sharing is feasible with Wi-Fi use up to 1W EIRP but recommends that further mitigations

[43] As introduced by the IEEE 802.11ac standard
[44] The maximum EIRP above 30 degrees elevation shall be limited to 125 mW (21 dBm) EIRP
[45] Paras. 37 and 38, DA/FCC: FCC-14-30
[46] "WI52: 5 GHz Sharing Studies – FSS Footprint Data", Wi-Fi Alliance, 19 February 2016, http://www.cept.org/Documents/se-24/29195/SE24(16)009_WI52-5-GHz-Sharing-Studies–FSS-Footprint-Data-and-calculations
[47] "Compatibility studies related to RLANs in the 5725-5925 MHz band", 29 January 2016, ECC Report 244, http://www.erodocdb.dk/Docs/doc98/official/pdf/ECCREP244.PDF

should be investigated[48]. These might include lower power caps or indoor-only restrictions, for example.

Earth Exploration Satellite Service (Active)

A5.14 Satellites of the EESS (active) use spectrum from 5250-5570 MHz for three main applications: synthetic aperture radars (SARs), scatterometers and altimeters. Use of this spectrum is shared with Wi-Fi between 5250-5350 MHz and 5470-5570 MHz, but Wi-Fi use is currently not permitted in 5350-5470 MHz.

A5.15 CEPT concluded[49] that sharing was not possible between Wi-Fi and EESS (active) in the 5350-5470 MHz sub-band unless further sharing and mitigation techniques could be shown to allow coexistence between the two services. Other coexistence possibilities could include limiting Wi-Fi power levels, perhaps to as low as 25 mW, or geo-location databases or enhanced DFS in order to share the band by both time and location. No firm conclusions have been drawn on the feasibility, implementation and enforcement of these mitigation techniques and further studies are currently being pursued through ETSI[50].

A5.16 Of all the EESS (active), the SARs have been determined to be the most sensitive service to interference from Wi-Fi and we show ESA's typical measurement geometries using Sentinel-1 in Figure A5.4. Altimeters and scatterometers operate across the whole of 5250-5570 MHz but we believe that SARs only operate in the 5350-5470 MHz sub-band.

A5.17 Coexistence between SARs and Wi-Fi might succeed by some method of time and geographical sharing (a geo-location database or enhanced DFS, for example) because of the very small time and geography measurement windows required by SARs. The most sensitive SARs have a low duty cycle of one to four percent[51] and the orbit repeat cycle is typically many days, meaning that most missions will not scan the same area of the earth more than once or twice a month[52]. These satellites also preferentially use polar, sun-synchronous orbits collecting data around dusk or dawn, when Wi-Fi use in the target area is likely to be off-peak. In the case of sharing using a geo-location database, any time and geographic sharing will be dependent on the ability of SAR operators to deliver accurate mission information to the database manager.

A5.18 RLANs are one of the technologies that have been developing standards for use in the TV White space (TVWS) bands which use a geo-location database to share frequency bands with both fixed broadcast stations and real time use of nomadic wireless microphones. Some the on-going studies in the ITU are looking at

[48] The studies currently model coexistence between FSS and Wi-Fi assuming that the regulatory restrictions in 5725- 5925 MHz would be the same as those already employed in 5470- to 5725 MHz which allow Wi-Fi use up to 1 W EIRP and outdoor. Stricter regulations could be an option if they were found to be effective and necessary for coexistence.

[49] "To study and identify harmonised compatibility and sharing conditions for Wireless Access Systems including Radio Local Area Networks in the bands 5350-5470 MHz and 5725-5925 MHz ('WAS/RLAN extension bands') for the provision of wireless broadband services", CEPT, 6 March 2015, http://www.erodocdb.dk/Docs/doc98/official/pdf/CEPTREP057.PDF

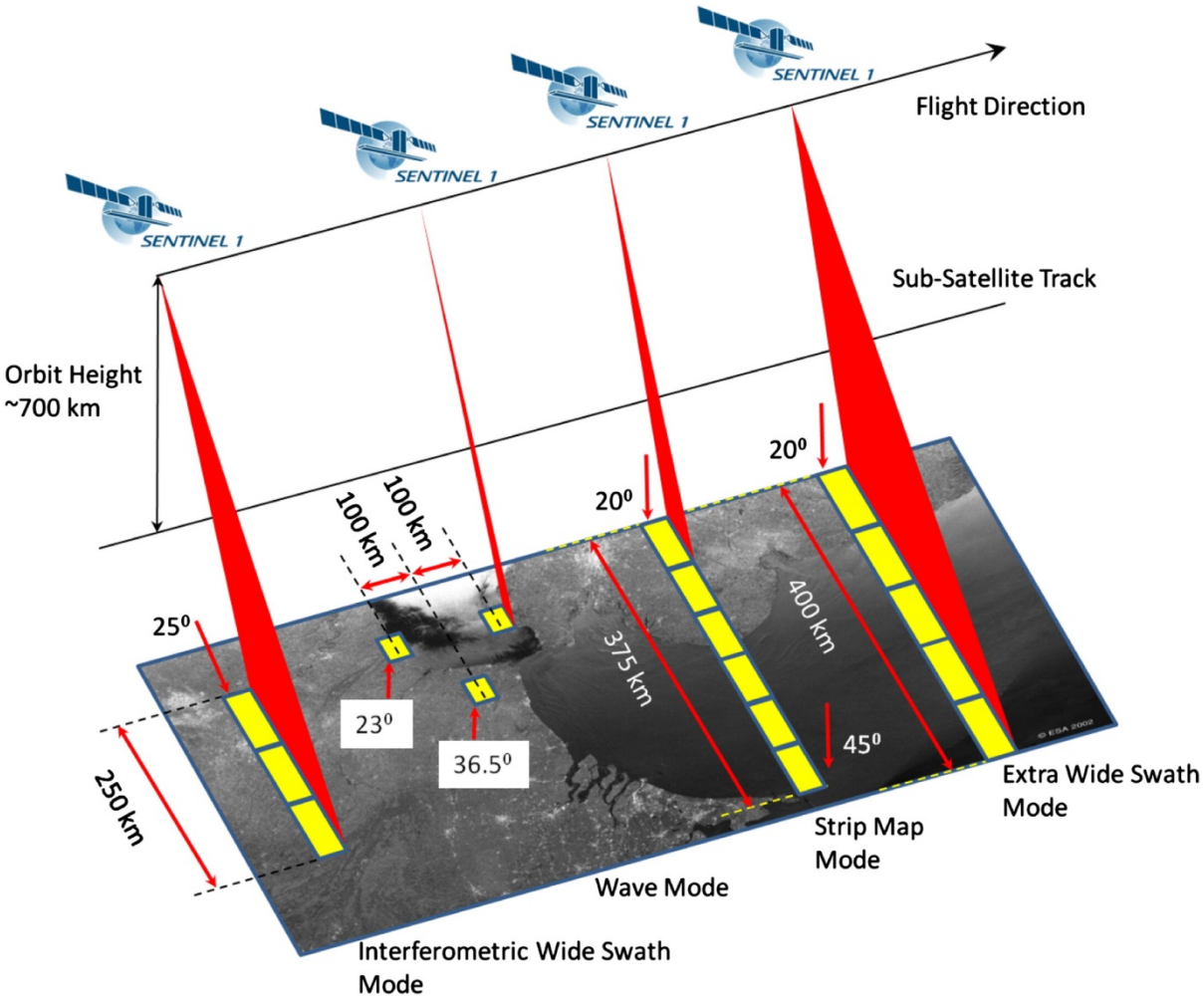
[50] "Broadband Radio Access Networks (BRAN); 5 GHz high performance RLAN; Mitigation techniques to enable sharing between RLANs and EESS in the 5 350 MHz to 5 470 MHz band", https://portal.etsi.org/webapp/WorkProgram/Report_WorkItem.asp?wki_id=46065

[51] "Earth Exploration-Satellite Service (EESS) - Active Spaceborne Remote Sensing and Operations", Bryan Huneycutt and Charles Wende, WMO/ITU Seminar, 16 to 18 September 2009, https://www.itu.int/md/dologin_md.asp?lang=en&id=R09-SEM.WMO-C-0012!!PDF-E

[52] "Home › Missions › Sentinel-1 › Observation Scenario", ESA, retrieved 14 March 2016, https://sentinel.esa.int/web/sentinel/missions/sentinel-1/observation-scenario

investigating the ability of RLANs using geo-location databases to protect the incumbent services in the 5350 – 5470 MHz EESS (active) and radiolocation from interference using a similar database and device standard to those developed for TVWS in UK and ETSI[53].

Figure A5.4: Sentinel-1 SAR measurement geometries at 5.4 GHz[54]



Radiolocation

A5.19 Radars are used across the band 5250-5850 MHz and applications include defence systems such as tactical and weapon radars as well as weather radars (ground based and airborne). Wi-Fi devices are required to implement Dynamic Frequency Selection (DFS) in order to coexist with radars in this frequency range. This technology requires Wi-Fi devices to switch to a different channel if they detect co-channel radar pulses (see section 4).

A5.20 As noted in section 4, DFS was introduced in order to protect radars operating in the band. It detects transmissions from radars and prevents use of those frequencies while the radar is operating.

[53] EN 301 598 http://www.etsi.org/deliver/etsi_en/301500_301599/301598/01.01.01_60/en_301598v010101p.pdf
[54] "Home › Missions › Sentinel-1 › Instrument Payload", ESA, retrieved 14 March 2016, https://sentinel.esa.int/web/sentinel/missions/sentinel-1/instrument-payload

A5.21 Weather radar use has an allocation in the UKFAT in 5600-5650 MHz and is also recognised in the radio regulations in this band[55].

A5.22 Some stakeholders we spoke to identified DFS as a particular constraint on Wi-Fi operation and a recent study[56] has shown that Wi-Fi activity can end up concentrated in the part of the band where DFS is not required, 5150-5250 MHz. Stakeholders generally agreed that this was a real phenomenon and identified two main reasons that it might be occurring: firstly because DFS is being frequently triggered (either by radars or 'false positives') and so activity tends to drift down towards the band where DFS is not required; and secondly because some access point manufacturers are choosing not to implement DFS and so these devices cannot access bands where DFS is required.

A5.23 There are proposals[57] to increase the scope of DFS to include bi-static radars and radars that employ advanced and fast frequency hopping techniques. Frequency hopping is a common "Electronic-Counter-Counter-Measure" (ECCM). Some stakeholders we spoke to noted that extending DFS requirements to detect these sorts of radars would be extremely difficult and might render unusable for Wi-Fi the bands where DFS is required.

A5.24 DFS is not required in the USA and many other territories in the 5725-5850 MHz ISM band. These other countries have decided that they don't need so much spectrum for their radar, and systems that could operate in this band only use the bands below. UK stakeholders have told us the DFS use in this band can be controlled nation-by-nation in firmware without needing country specific hardware. We believe that this band might only be used for radars at a small number of locations in the UK and so DFS might not be necessary in 5725-5850 MHz.

Broadband Fixed Wireless Access

A5.25 BFWA currently shares with Wi-Fi in 5470-5725 MHz on a licence exempt basis across much of the world[58] and can additionally access 5725-5850 MHz in a number of nations including the USA and some European states. In the UK[59], access to 5725-5850 MHz is subject to a light licensing regime which requires users to register their terminals accessing the band with Ofcom. Over ten thousand terminals are registered in the UK and typical deployments are point-to-point or point-to-multipoint, providing connectivity in urban centres (e.g. for CCTV) and in rural areas (e.g. for broadband).

A5.26 Simple, worst case coexistence studies[60] have suggested that separation distances of a few hundreds of metres might be required between BFWA terminals and Wi-Fi devices for the two services to coexist co-channel. However, we know from our discussions with stakeholders that the two services share well and that there is often significant isolation between the two services with BFWA almost exclusively

[55] RR. 5.452

[56] Figure 3-9: 5 GHz channel utilisation in central London, "Future Use of Licence Exempt Spectrum", Plum Consulting, July 2015, http://www.plumconsulting.co.uk/pdfs/Plum_July_2015_Future_use_of_Licence_Exempt_Radio_Spectrum.pdf

[57] ITU-R Working Party 5B are revising recommendation ITU-R M.1638

[58] BFWA can access 5 470 to 5 725 MHz outdoors and with up to 1 W EIRP

[59] "Fixed Broadband Services operating in the 5725-5850 MHz band", UK Interface Requirement 2007, Ofcom, May 2007, http://stakeholders.ofcom.org.uk/binaries/spectrum/spectrum-policy-area/spectrum-management/research-guidelines-tech-info/interface-requirements/uk_interface_2007.pdf

[60] "Compatibility between RLAN and BFWA (FS) in the band 5725 - 5875 MHz", §9, ECC Report 244

used outdoors and Wi-Fi used mostly indoors. BFWA deployments often use high gain, directional antennas (17 to 23 dBi) which further reduce the risk of interference to and from Wi-Fi.

Programme Making and Special Events

A5.27 In the UK, parts of the 5 GHz band are used by PMSE for fixed video links with geographical restrictions[61] and some airborne use is permitted above 5770 MHz[62]. Use of the band by PMSE is light, with only 27 assignments across the whole of the UK in 2015. We believe that this is because there is a risk of interference from other incumbent users (such as existing Wi-Fi and BFWA users) and so improving Wi-Fi access in the band will have minimal additional impact on PMSE.

Amateur satellite

A5.28 Amateurs can access 5650-5850 MHz with amateur satellite Earth-to-space links in 5650-5670 MHz and space-to-Earth links in 5830-5850 MHz. Most current amateur satellites are typically nano or picosats (also called 'cubesats') that occupy slightly elliptical sun-synchronous low earth orbits at 60-800 km altitude. These smaller satellites have relatively low power and antenna gain.

A5.29 No detailed studies have been carried out for Wi-Fi coexistence with amateur uses, but amateurs already share the band with other users and we believe that Wi-Fi is unlikely to pose a greater threat to coexistence than these other services.

Transport

A5.30 5795-5815 MHz is used for road tolling (RTTT) in some EU countries but we believe it is relatively lightly used in the UK. Studies into coexistence with Wi-Fi are currently ongoing at SE24.

A5.31 5875-5905 MHz has been identified for Intelligent Transport Systems (ITS) and there are proposals to extend this down (5855-5875 MHz) for non-safety related ITS and up (5905-5925 MHz) for generic ITS. Studies into coexistence with Wi-Fi are currently ongoing within CEPT and possible coexistence solutions are based on a 'listen-before-talk' principle with Wi-Fi devices detecting whether there are co-channel ITS signals nearby and taking appropriate action to avoid causing interference.

A5.32 One difference between the regulatory arrangements in the USA and EU is the allocation of 10 MHz within this this range in the US for safety-related ITS services. We are also aware that the current US rules for the ITS band do not permit outdoor use and that this is taken to mean that Wi-Fi in vehicles is not permitted unless it is very low power (i.e. less than 50 mW).

Short Range Devices

A5.33 5725-5875 MHz is used for generic short range devices (SRDs) and coexistence with Wi-Fi has not yet been studied. A subset of these devices for wireless industrial applications (WIA) has been studied at a high level for coexistence with Wi-Fi at SE24. Similar to the BFWA case, there might be a risk of interference if Wi-Fi and

[61] Fixed video links. Geographic restrictions apply: 5 472 to 5 588 MHz, 5 682.5 to 5 702.5 MHz, 5 705 to 5 725 MHz, 5 732.5 to 5 752.5 MHz

[62] Fixed video links. Geographic restrictions apply. Some airborne use permitted, restrictions apply: 5 770 to 5 790 MHz, 5 795 to 5 815 MHz, 5 850 to 5 925 MHz

WIA are operating co-channel within a few hundreds of metres of each other, but careful installation of Wi-Fi and WIA systems in a controlled industrial environment can mitigate the risk of interference in a factory environment.

Adjacent users

A5.34 Further study might be required for users of services adjacent to Wi-Fi. In the UK these services include Fixed Links (FS)[63] in the band 5925-6425 MHz which are used fairly intensively nationwide and particularly in the south and London. Microwave Landing Systems (MLS) use 5030-5150 MHz but deployments are fairly limited. In the UK, MLS is used by British Airways only at Heathrow only and uses spectrum towards the bottom of the band in order to mitigate the risk of interference from Wi-Fi.

Addressing future coexistence studies

A5.35 As noted in section 4, the 2015 World Radio Conference (WRC-15), Resolution 239[64] mandated studies in 5150-5925 MHz for future Wi-Fi operational requirements and coexistence between Wi-Fi and incumbent services ahead of a possible decision to make more spectrum available for Wi-Fi at WRC-19. The sub-bands identified were 5150-5350 MHz, 5350-5470 MHz, 5725-5850 MHz and 5850 to 5925 MHz (excluding 5470-5725 MHz which is already accessible for Wi-Fi outdoors and at higher power levels[65]).

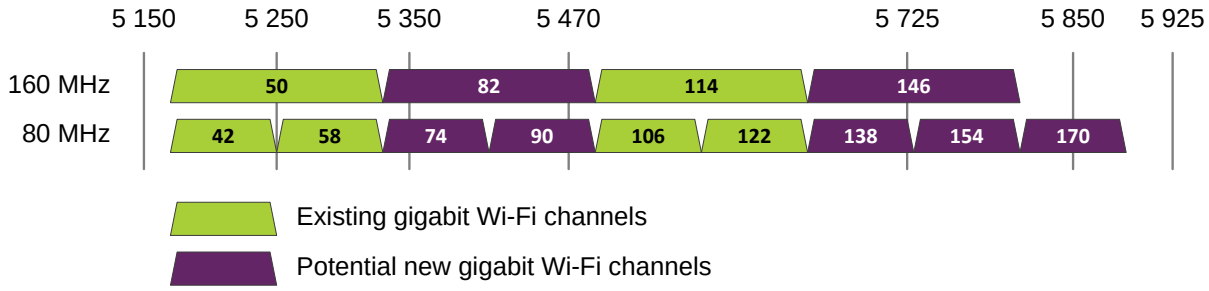
A5.36 This work will depend on how the individual sub-bands are prioritised for study and will likely include coexistence studies, measurement campaigns and development of appropriate mitigation techniques. As already noted in section 4, the figure below (Figure A5.54) identifies how channels may be arranged in future.

[63] Page 8, "OfW48 UK Frequency Allocations for Fixed (Point-to-Point) Wireless Services and Scanning Telemetry", Ofcom, Version 4.0, 27 July 2015, https://licensing.ofcom.org.uk/binaries/spectrum/fixed-terrestrial-links/guidance-for-licensees/OfW48.pdf

[64] Resolution 239, "Results of the first session of the Conference Preparatory Meeting for WRC-19 (CPM19-1)", ITU-R, 23 December 2015, https://www.itu.int/md/R00-CA-CIR-0226/en

[65] Up to 1 W EIRP

Figure A5.51: Example channelisation for Wi-Fi at 5 GHz



A5.37 The coexistence challenges are different for the different sub-bands.

A5.38 **5150 to 5350 MHz** is currently available for Wi-Fi on a low power, indoor-only basis in EU. As discussed in section 4 we could remove the indoor restriction and/or increase the power limit from 200 mW to 1 W EIRP.

A5.39 There are two incumbent satellite services in the lower and upper halves of this band. Globalstar uses 5150-5250 MHz in the Earth-to-space direction for feeder links to their MSS satellites. As far as we are aware, Globalstar is the only MSS operator using this band and no other operators are planning to use this spectrum. EESS (active) use 5250-5350 MHz but we believe that use might be limited to altimeters and scatterometers rather than the most sensitive SAR systems and there do not appear to be any plans for future SAR operation in this band.

A5.40 **5350-5470 MHz** is already the subject of an investigation of new mitigation techniques to share the spectrum on a time and geographic basis (e.g. geo-location database or enhanced DFS). Any of these techniques is likely to require a significant commitment of resources to demonstrate feasibility.

A5.41 **5725-5850 MHz** could be shared on the same regulatory basis as the adjacent 5470-5725 MHz band - but lower power, indoor only options could also be implemented if necessary for coexistence, as for the 5150-5350 MHz spectrum discussed above.

A5.42 This band is already used for Wi-Fi in the USA and a number of other territories outside of the EU. It is an ISM band and is shared with a large number of other services. Coexistence studies will be necessary for each of the systems, and we anticipate that issues for FSS (E-to-s GSO) will be the most difficult to address.

A5.43 **5850-5925 MHz** faces challenges over coexistence with ITS and FSS which use this band more intensely than 5725-5850 MHz.

Additional issues (including DFS)

A5.44 We have invited stakeholders to consider how DFS might need to be updated to protect incumbent users whilst permitting new Wi-Fi applications. We have also invited stakeholders to consider whether DFS might be necessary at all in the 5725-5850 MHz sub-band.

A5.45 Some stakeholders have told us that reducing the DFS channel availability check from sixty seconds to a few tens of milliseconds would be more appropriate for highly mobile applications such as in-vehicle Wi-Fi use.

A5.46 They also told us that the thirty minute channel non-occupancy period after radar detection was too long; for example a single ‘sweep’ of a frequency agile radar

could deny a W-Fi device access to a large number of channels for half an hour. This might best be replaced with better, more sensitive radar detection. Stakeholders also said that the DFS algorithms need to be developed to reduce the level of 'false positives' by which one Wi-Fi device might accidentally trigger the DFS of another Wi-Fi device in close proximity.

A5.47 DFS might not be necessary in the UK in 5725-5850 MHz and detection of bi-static or advanced fast frequency hopping radars might also be unnecessary. A nation-by-nation approach for these two issues might be appropriate where there is no consistent need for particular DFS elements across the EU.

Improving coexistence models with measured data

A5.48 Measurement data is needed to make coexistence studies more realistic. There can, understandably, be a tendency for coexistence studies to err on the side of pessimism when there are large, uncertain factors involved. We believe that measurement campaigns could be a solution to reducing modelling uncertainties (the 'known unknowns').

A5.49 The coexistence studies between Wi-Fi and satellite services might be subject to some of the great uncertainties because the interference risk is not from individual devices to Wi-Fi receivers but the aggregate emissions from a very large number of Wi-Fi devices, perhaps several hundreds of millions in the case of the satellites with the largest footprints when over continental Europe and other highly developed areas.

A5.50 In our recent airborne measurements campaigns we presented a methodology for reducing uncertainties by "calibrating" the SE24 aggregate Wi-Fi emissions model with measured Wi-Fi aggregate emissions captured from an aircraft and we would welcome others replicating our work. This campaign was necessary because there was a large 20 dB variation in the predicted aggregate Wi-Fi emissions depending on the particular input assumptions to the model. Other measurement campaigns exploring different elements of the model such as busy hour, building loss and other propagation effects might also help to reduce these uncertainties.

A5.51 What is very clear is that any measurement campaigns will need Wi-Fi and satellite industries to work very closely together to develop measurement techniques and agree on how to analyse the measured data in order to arrive at a mutually acceptable methodology.

A5.52 Protocol level simulations and real world testing is also needed to make coexistence studies more realistic. For example, can DFS and "politeness" techniques ameliorate coexistence in certain coexistence scenarios such as ITS and Wi-Fi; RTTT and Wi-Fi.

Improving coexistence models with a better understanding of future device behaviour

A5.53 There may also be a role for lower conducted power constraints and higher directivity multiple antenna techniques in improving coexistence between Wi-Fi and other services. We believe that the vast majority of devices on the market today do not transmit at the full regulatory power limit due to battery and power amplifier constraints.

A5.54 It would be helpful to find out whether future devices require higher transmit power levels or whether most devices could use lower power levels. We also need to

address how multiple antenna techniques, such as MU-MIMO and beamforming improve coexistence with other services. These devices may be able to use lower conducted power and higher directivity antennas to maintain the same EIRP.

Annex 6

Glossary

4G	Fourth generation mobile phone standards and technology
5G	Fifth generation mobile phone standards and technology
CEPT	European Conference of Postal and Telecommunications Administrations
Communications Act	The Communications Act 2003, which came into force in July 2003.
dBi	Decibel isotropic
dBm	The power ratio in decibels (dB) of the measured power referenced to one milliwatt (mW).
DFS	Dynamic Frequency Selection. A system that makes Wi-FI routers change frequency when a radar using the same frequency is near.
DTT	Digital Terrestrial Television. The terrestrial platform for the delivery of TV content via broadcasting in the UHF TV band (UHF Channels 21 – 60 (470 - 790 MHz)). In the UK and Europe, DTT transmissions use the DVB-T and DVB-T2 technical standards.
Earth stations	A station located either on the earth's surface or within the major portion of the Earth's atmosphere and intended for radio communication with one or more satellites or space stations
EC	European Commission
ECC	Electronic Communications Committee
EESS	Earth Exploration Satellite Service. A satellite radio communication service which obtains information relating to the characteristics of the Earth and its natural phenomena from active or passive sensors on the satellite, and distributes this information to earth stations.
EIRP	Equivalent Isotropically Radiated Power. This is the product of the power supplied to the antenna and the antenna gain in a given direction relative to an isotropic antenna (absolute or isotropic gain).
ERC	The European Research Council (the independent body that funds investigator driven frontier research in the European Union (EU)
ETSI	European Telecommunications Standards Institute.
EU	European Union
FAT	See UKFAT

FCC	Federal Communications Commission (US)
Fixed link	A terrestrial based wireless system operating between two or more fixed points
Frequency band	A defined range of frequencies that may be allocated for a particular radio service, or shared between radio services
FS	Fixed Service
FSS	Fixed Satellite Service. Two-way communication links between earth stations, usually at fixed locations, and one or more satellites
GHz	Gigahertz. A unit of frequency of one billion cycles per second.
IEEE	Institute of Electrical and Electronics Engineers
IEEE-802.11a	An evolving family of specifications for wireless local area networks (WLANs) developed by a working group of the Institute of Electrical and Electronics Engineers (IEEE).
IMT	International Mobile Telecommunications. The ITU term that encompasses 3G, 4G and 5G wireless broadband systems
ISM Bands	The Industrial, Scientific & Medical bands are radio bands reserved internationally for industrial, scientific and medical purposes other than telecommunications.
ITU	International Telecommunications Union - Part of the United Nations with a membership of 193 countries and over 700 private-sector entities and academic institutions. ITU is headquartered in Geneva, Switzerland.
ITU-R	International Telecommunications Union Radiocommunication Sector
ITU-R Region 1	Article 5 of the ITU Radio Regulations divides the world into three regions for the allocation of frequencies. Region 1 includes Europe, Africa, parts of the Middle East, the former Soviet Union and Mongolia
MDS	Mobile Data Strategy, published 28 May 2014
MHz	Megahertz. A unit of frequency of one million cycles per second.
MNO	Mobile Network Operator
MOD	Ministry of Defence
MSS	Mobile Satellite Service. Two-way communication links between portable user terminals and one or more satellites.
mW	milliwatt. A derived unit of power in the International System of Units (SI). A Milli-Watt is one thousandth (1x10-3) Watts.

PMSE	Programme Making and Special Events. A class of radio application that supports a wide range of activities in entertainment, broadcasting, news gathering and community events.
PSSR	Public sector spectrum release
Radio Spectrum	The portion of the electromagnetic spectrum below 3000 GHz used for radiocommunications
RLAN	Radio Local Area Network. A radio access system used to provide wireless access between computer devices.
TPC	Transmit Power Control. A technical mechanism used to prevent too much unwarranted interference between different wireless networks.
UKFAT	UK Frequency Allocation Table. Details spectrum allocations in the UK and identifies responsibilities for the management of frequency bands or services
U-NII	Unlicensed National Information Infrastructure radio band. U-NII is an FCC regulatory domain for 5- GHz wireless devices. It operates over four ranges: U-NII Low (U-NII-1): 5.15-5.25 GHz, U-NII Mid (U-NII-2): 5.25-5.35 GHz, U-NII Worldwide (U-NII-2e): 5.47-5.725 GHz, and U-NII Upper (U-NII-3): 5.725 to 5.850 GHz
Wi-Fi	Commonly used to refer to wireless local area network (WLAN) technology, specifically that conforming to the IEEE 802.11 family of standards. Such systems typically use one or more access points connected to wired Ethernet networks which communicate with wireless network adapters in end devices such as PCs. It was originally developed to allow wireless extension of private LANs but is now also used as a general public access technology via access points known as "hotspots".
WRC	World Radiocommunication Conference. The WRC reviews and revises the Radio Regulations. They are held every three to four years. The last four conferences were held in 2003, 2007, 2012 and 2015. The next WRC will be held in Geneva in 2019 is referred to as WRC-15.