realwireless
independent wireless experts

Spectrum timing investigation

Final report

Issued to: Three
Issue date: January 2017
Version: 1.4

Real Wireless Ltd
PO Box 2218
Pulborough
West Sussex
RH20 4XB
United Kingdom

t +44 207 117 8514
f +44 808 280 0142
e info@realwireless.biz
www.realwireless.biz

realwireless
independent wireless experts

Version Control

Item	Description
Source	Real Wireless
Client	Three
Report title	Spectrum timing investigation
Sub title	Final report
Issue date	January 2017
Document number	V1.4
Document status	Final report
Comments	

Version	Date	Comment
1.0	13/12/2016	Interim report issued to Three
1.4	27/01/2017	Addressing three's comments

realwireless
independent wireless experts

About Real Wireless

Real Wireless is a leading independent wireless consultancy, based in the U.K. and working internationally for enterprises, vendors, operators and regulators – indeed any organization which is serious about getting the best from wireless to the benefit of their business.

We seek to demystify wireless and help our customers get the best from it, by understanding their business needs and using our deep knowledge of wireless to create an effective wireless strategy, implementation plan and management process.

We are experts in radio propagation, international spectrum regulation, wireless infrastructures, and much more besides. We have experience working at senior levels in vendors, operators, regulators and academia.

We have specific experience in LTE, UMTS, HSPA, Wi-Fi, WiMAX, DAB, DTT, GSM, TETRA – and many more.

For details contact us at: info@realwireless.biz

Tap into our news and views at: realwireless.biz/blog

Stay in touch via our tweets at twitter.com/real_wireless

Executive summary

Real Wireless are engaged by Three to carry out an independent study on the *timing* of usability of the 700 MHz, 1.4 GHz, 3.4 GHz and 3.6 GHz spectrum bands. The key question we seek to answer in this report is "Considering all relevant factors examine when these spectrum bands might be useable (or made useable)".

We first examine the factors affecting the "usability" of a spectrum band and the factors we consider pertinent to this study. Qualitative criteria are used to compute the usability of spectrum for the mobile use case, these are grouped around three main factors and their sub-factors.

The report provides the following information for each factor:

1. **Spectrum**: spectrum availability, harmonisation at International, European and UK level and the information about the constraints on the use of the spectrum for mobile access in the UK.
2. **Infrastructure and equipment**: timings of supply and deployment of infrastructures
3. **Devices**: device availability and operator timescales

Below are the main conclusions from the individual factor analysis:

Spectrum availability, harmonisation and constraints on the use of the spectrum for mobile access in the UK:

- The 700 MHz band will be made available by Q2 2020 and that, at least for the paired 2x30 MHz portion, further delay for technical reasons is unlikely.
- The 1.4 GHz band is already available to two UK operators.
- The 3.4 GHz band could be made available in 2017. Even if delayed, there is no reason why the delay should extend by more than two years.
- For the 3.6 GHz band, it is difficult to see how release of the band could be brought forward before 2018 and it could be delayed into the late 2020s, with some constraints remaining almost indefinitely.

The network infrastructure and equipment:

- Network equipment is available now that can operate in the 4 bands that are the subject of this study. In many cases it is already deployed elsewhere in the world, specifically for Bands 28 (CEPT 700 FDD), Band 32 (1.4GHz Supplementary Downlink), Band 42 (3.4GHz TDD) and Band 43 (3.6GHz TDD).
- The time taken to rollout the new frequency band is not likely to vary significantly between the bands in question; rollout timings depend hugely on the operator strategy for how the spectrum will be used and the resources available for deployment.

Device availability and operator timescales:

- 700 MHz band devices are available at scale, at least for the paired frequencies, and able to support innovative services now. However, in the UK, spectrum for use is not yet released. Rapid uptake is anticipated when spectrum becomes available.
- 1.4 GHz devices are becoming available during 2017 in their initial form, and we anticipate rapid growth in their use by 2019. The band will attract sufficient

device support to make useful to operators in supporting additional capacity but will not be a priority band for original equipment manufacturers (OEMs).

- 3.4 GHz devices are currently available, but primarily for Fixed Wireless Access devices. We anticipate scale availability for smartphones from 2019.
- 3.6 GHz devices will lag the 3.4GHz devices. If the global regulatory barriers can be removed in the coming years, we anticipate a rapid introduction. The timescales are somewhat uncertain. It could be delayed into the late 2020s, with some constraints remaining almost indefinitely. Within the UK, barriers exist since an incumbent occupies a large fraction of the available bandwidth.

Considering our views on each of the factors as given above, we conclude that:

- **700 MHz** band is usable on Q2 2020.
- **1.4 GHz** band is already available. However, operators need to find use cases to influence the OEMs as currently it will not be a priority band for OEMs. We anticipate rapid introduction of devices from 2019 onwards hence, usable from 2019 onwards.
- **3.4 GHz** band will be usable as soon as smartphone type devices are available from 2019, at scale, but could be earlier from some OEMs.
- **3.6 GHz** band could become usable around 2023. The timescales are somewhat uncertain. it could be delayed into the late 2020s, with some constraints remaining almost indefinitely.

Contents

Tables

Figures

1. Introduction

1.1 Scope and Principal Question

Real Wireless are engaged by Three to carry out an independent study on the *timing* and the usability of the 700 MHz, 1.4 GHz, 3.4 GHz and 3.6 GHz spectrum bands i.e. when will mobile operators reasonably expect to be ready to deploy networks in these bands in the coming years.

This **principal question** we seek to answer in this report is:

Considering the factors that Ofcom used in the consultation related to the Public Sector Spectrum Release (PSSR) in November 2014 [1], and any other factors that may be relevant, examine whether these four bands are likely to be useable (or made useable) on the timescales that Ofcom expects.

1.2 Background

1.2.1 Spectrum band definitions

Table 1-1 provides a description of the spectrum bands that are analysed in this report.

Table 1-1: Spectrum band definitions

Band name	Spectrum range and notes	3GPP band number [2]
700 MHz	694 to 790 MHz, 60 MHz paired + 20 MHz unpaired [3]	Band 28-FDD* UL=703 MHz–748 MHz, DL=758 MHz–803 MHz Band 67-FDD** DL=738 MHz–758 MHz
1.4 GHz	1452-1492 MHz, 40 MHz (20 MHz each held by Vodafone and Three) [3]	Band 32-FDD** DL=1452 MHz–1496 MHz
3.4 GHz	150 MHz of spectrum above 3410 MHz and below 3600 MHz, at 3410-3480 MHz and 3500-3580 MHz + 40 MHz held by UK Broadband (UKB). The upcoming auction will make available 150 MHz of spectrum in the 3.4 GHz band [3]	Band 42-TDD: 3400 MHz –3600 MHz
3.6 GHz	200 MHz at 3.6-3.8 GHz (84 MHz held by UKB) [3]	Band 43-TDD: 3600 MHz –3800 MHz

* In Europe, the consideration is 2x30 MHz (703-733 MHz and 758-788) in the FDD mode Based on the European Commission (EC) Decision[1] European Union (EU) 2016/687. Hence, we consider this band.

** Restricted to the downlink operation when carrier aggregation is configured. This has to be paired with an uplink operating in a band (external) of the carrier aggregation configuration.

1.2.2 Ofcom consultations

Relevant details from two key Ofcom consultations are provided below:

- In its recent publication, Ofcom sets out proposals on competition issues for the forthcoming auction of spectrum in the 2.3 and 3.4 GHz bands ('the PSSR auction') [3]
- Ofcom considers that the 2.3 GHz spectrum is usable 'immediately' whereas the 3.4 GHz spectrum "*is not expected to be* usable *for at least two to three years after the auction due to a lack of suitable user devices*"
- Ofcom identifies a 'transitional period' from immediately after the PSSR auction until the time when the 3.4 GHz spectrum is useful for mobile services because it is available in the handsets of a sufficient proportion of the customer base. Ofcom considers that the 'transitional period' to last for at least two to three years.
- Ofcom states that in the long term, i.e. the period from the end of this transitional period up to 5-10 years after the auction, when 3.4 GHz is usable, there will be other spectrum available (i.e. 700MHz and 3.6GHz) and any competition issues can be addressed by this other spectrum
- Ofcom also considers that 1.4 GHz spectrum band (1452-1492 MHz) is not currently in use because it is not supported by mainstream mobile devices.
- Ofcom considered that "*spectrum can be useful for adding capacity even when it is in only a minority of user devices. This is because traffic can be offloaded from those devices that can use the spectrum, freeing up other bands for those devices that cannot use the spectrum*".

Figure 1-1 illustrates the "transitional period" and "long term" as defined in [3].

[1] Commission Implementing Decision (EU) 2016/687 of 28 April 2016 on the harmonisation of the 694-790 MHz frequency band for terrestrial systems capable of providing wireless broadband electronic communications services and for flexible national use in the Union.

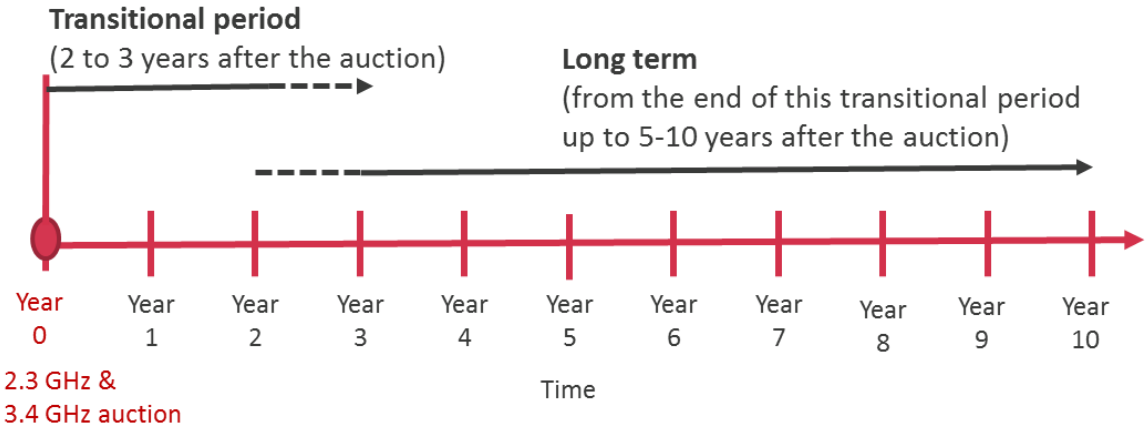

Figure 1-1: Definition of transition period and long term

1.3 Our approach

We approached the work in the following sequence:

- Study of Ofcom consultation documents and other background materials.
- Determine the factors that influence the deployment of mobile services in a spectrum band and specifically the timelines:
  - Assess the spectrum availability and harmonisation activities
  - Assess timings of networking equipment supply and deployment of infrastructure.
  - Assess timings of device supply, taking into account launch cycle 'heartbeats'.
  - Assess the market penetration characteristics including when we expect sufficient deployment of devices capable of supporting new spectrum to impact operator and consumer experience.
  - Identify other factors that might influence the availability of these spectrum bands i.e. 700 MHz, 1.4 GHz, 3.4 GHz and 3.6 GHz bands
  - Develop a range of timings for each of the above factors and the critical path(s) that have the greatest influence on the overall new band deployment timescales for the bands under review.
- Data assimilation to support our independent view on when it might be reasonable for the UK mobile industry to expect these four spectrum bands to be useable (or made useable).

In this study, we consider spectrum "usability" from the operators point of view rather than consumers point of view.

1.4 Report Structure

Our report is organised as follows:

1. In this chapter, we introduce the scope of the study, the principal question we seek to answer, background and our approach.
2. Chapter 2 explains the factors affecting the "usability" of a spectrum band and the factors we consider in this study.

3. Chapter 3 provides a detailed analysis of spectrum availability, harmonisation at International, European and UK level. It also presents the information about the constraints on the use of the spectrum for mobile access in the UK. Findings are summarised in Chapter6.
4. Chapter 4 provides a detailed analysis of timings for supply and deployment of equipment and infrastructure. Findings are summarised in Chapter6.
5. Chapter 5 provides a detailed analysis of device availability and operator timescales. Findings are summarised in Chapter6.
6. Chapter 6 provides the summaries of insights gained from prior detailed analysis chapters and assimilates to provide a holistic view regarding when it might be reasonable to expect these four spectrum bands to be useable (or made useable) based on all the factors that would influence such an outcome.
7. Chapter7 provides Conclusions and suggestions for further work.

2. Factors affecting the "usability" of a spectrum band

Qualitative criteria are used to compute the usability of spectrum for the mobile use case, these are grouped around three main factors and their sub-factors. The three main factors are:

1. Spectrum
2. Infrastructure and equipment
3. Devices

Table 2-1 shows the main factors and sub factors considered by Ofcom in the relevant consultations [1,4] and by Real Wireless in this study.

Table 2-1: Summary of factors affecting the usability of spectrum

Main factors	Sub factors	Ofcom 2014 condoc . [1]	Ofcom 2016 condoc. [3]	RW recommended criteria
Spectrum	Status of international harmonisation for mobile use	✓		✓
	Availability of the spectrum short to medium term	✓		✓
	Material constraints on the use of that spectrum for mobile access	✓		✓
Equipment & Infrastructure	Availability of equipment capable of using the frequency			✓
	Deployment time			✓
Devices	Availability of chipset and handsets	✓	✓	✓
	Device ecosystem beyond handsets e.g. CPE for FWA			✓

Table 2-1 provides a high level view of the factors affecting the usability of spectrum. In the next three chapters, we investigate the three main factors and sub factors and their potential to influence timing.

Ofcom primarily considered mobile handsets in their recent assessment [3]. However, handsets are only one part of the potential device eco system, which contains Customer Premises Equipment (CPEs), Internet of Things (IoTs) end points, dongles etc. In our assessment, we considered a range of devices beyond the standard Mobile Broadband (MBB) mobile platforms, especially if they are regarded as having a potential impact on the wide scale deployment and, therefore, the influence on the "usability" of spectrum. To support this, we also consider potential services relevant to fixed wireless or IoT which are considered as the services beyond the main stream MBB platform.

3. Spectrum availability, harmonisation and constraints

In this section, we examine the regulatory situation relating to the use of mobile services in the four bands under study. It deals purely with the national and international spectrum allocations, harmonisation decisions and UK national plans for release. This section does not consider the suitability of these bands for specific applications and technologies, nor the availability of equipment but references are made to the technical conditions specified in relevant EC Decisions and any constraints likely to be imposed by other users of the spectrum.

3.1 700 MHz band

3.1.1 International

In the International Radio Regulations [4], the band 694-790 MHz is allocated in Region 1[2] to the Mobile (except aeronautical mobile) and Broadcasting services, both on a primary basis[3]. There are the same allocations in the other Regions but in Region 2[4] the mobile allocation is secondary below 698 MHz. The use of the band by the mobile service in Region 1 is subject to the provision of a Resolution that provides for the protection of other services in the band. The band, or portions of it, is specifically identified for IMT[5] in many Region 3 countries, including China, Japan and the Republic of Korea. These international regulations are either already in force for some time or entered into force on 1st January 2017.

3.1.2 Europe

In Europe, an EC Decision[6] adopted in 2016 specifies the frequency arrangements and other technical conditions for the use of this band in Member States. This requires Member States to "*designate and make available the 703-733 MHz and 758-788 MHz frequency bands, on a non-exclusive basis, for terrestrial systems capable of providing wireless broadband electronic communications services*" in compliance with the parameters specified in the Decision. For the remainder of the band, 694-790 MHz, parameters are provided but there is considerable scope for national discretion. The Decision reads: "*subject to national decisions and choice, designate and make available*".

The EC Decision specifies that the 2x30 MHz bands mentioned above shall be used in the FDD mode and assigned in multiples of 2x5 MHz. The Decision specifies that should all or part of the centre gap be used for "wireless broadband communication services" it shall be limited to downlinks (base station transmit) only. Further conditions are specified should

[2] Europe, Africa and the Middle East

[3] Allocations in the Radio Regulations generally have either "primary" or "secondary" status. Stations in a primary service can claim protection from interference from any station with a frequency assignment at a later date. Stations in a secondary service cannot claim protection from stations in a primary service, even if they are assigned at a later date. A secondary service allocation is therefore not generally considered sufficient on which to offer a commercial service.

[4] The Americas

[5] International Mobile Telecommunications – a generic term used by the ITU which embraces public mobile radio technologies, including 3G, 4G and 5G.

[6] Commission Implementing Decision (EU) 2016/687 of 28 April 2016 on the harmonisation of the 694-790 MHz frequency band for terrestrial systems capable of providing wireless broadband electronic communications services and for flexible national use in the Union

parts of the band outside of the core 2 x 30 MHz be used for Public Safety and Disaster Relief (PPDR), Machine to machine (M2M) communications, or Programme Making and Special Events (PMSE). The Decision also specifies power limits and block edge masks.

3.1.3 National

Spectrum harmonisation and availability.
At the national level, Ofcom had initially suggested that this band could not be made available for mobile services before the end of 2021. This was to allow sufficient time to re-plan broadcasting services and re-accommodate them in the remaining parts of the Ultra high frequency (UHF) terrestrial broadcasting band. However in a statement issued on 17th October 2016 [5], Ofcom announced that it would work to accelerate the programmes and release the band in Q2 2020. In that statement, it also announced that a 20MHz-wide band in the centre gap should be allocated for use by mobile data, specifically mobile downlinks.

In its statement, Ofcom announced arrangements for clearing the band. Existing broadcasting multiplexes will be allowed to continue operating in this spectrum until at least 1st May 2020, or until mobile downlink services in this spectrum are deployed. PMSE users have been notified that from 1st May 2020 they will no longer have access to spectrum in the 700 MHz band. It is expected therefore that the band will be cleared of all existing users by the time that mobile services are deployed and that the full 80 MHz (2x30 MHz plus 20 MHz downlink band) will be available throughout the UK. The remaining 16 MHz of the 694-790 MHz band will be used as guard bands.

The timing of the release of the 700 MHz band seems even more certain following a decision by the European Parliament, the Council and the Commission that the 700 MHz band shall be made available for wireless mobile in all Member States by 30th June 2020 at the latest [6]. Member States are required to adopt and make public their national plans for releasing this band by 30th June 2018. They will need also to conclude cross-border coordination agreements by the end of 2017.

Constraints on the use of the spectrum for mobile access in the UK
9 MHz band gap at the lower edge allows sufficient protection to Digital Terrestrial Television (DTT) services from the out-of-band interference (from Long Term Evolution, LTE) to be achieved with existing filtering technology [7]. At the upper edge, the 3 MHz from 788 to 791 MHz is sufficient since both the 700 and 800 MHz bands will be used for mobile downlinks at this spectrum boundary. The 9 MHz guard band at the lower edge of the 700 MHz band is there at the insistence of the broadcasters and takes into account existing technology. Therefore, no further constraints are expected that could impact on the timing of use of the band for mobile technologies.

3.2 1.4 GHz band

3.2.1 International

The band 1452-1492 MHz is allocated globally to the mobile, fixed, broadcasting and broadcasting-satellite services. In Region 1 the mobile allocation is limited by excluding aeronautical mobile services. The allocation for broadcasting-satellite services, with provision for complementary terrestrial stations, has existed since 1992 but has been little used. The band is specifically identified for IMT in many African and some Middle East

countries. European countries also intend using this band for International Mobile Telecommunications (IMT) but at the 2015 World Radio Conference (WRC-15) it was decided not to seek such identification in the international Radio Regulations as this would have resulted in potential onerous requirements for coordination with other countries.

3.2.2 Europe

Use of this band for mobile services (embraced by the EU terminology of "electronic communications services") is harmonised through an EC Decision adopted in May 2015[7]. This states that "*No later than six months after the date of notification of this Decision, Member States shall designate and make available, on a non-exclusive basis, the 1 452-1 492 MHz frequency band for terrestrial systems capable of providing electronic communications services in compliance with the parameters set out in the Annex*." The Annex referred to specifies that the use of the band be limited to downlinks only and that assignments shall be in multiples of 5 MHz blocks. Block edge masks are specified. There is no mandatory maximum power limit but a suggested figure is given.

3.2.3 National

Spectrum harmonisation and availability.
The band 1452-1492 MHz was awarded by auction and won by Qualcomm in May 2008. On 22 September 2015, Ofcom announced that it had agreed to the transfer of this spectrum holding to Vodafone Limited (for 1452-1472 MHz) and Hutchison 3G UK Limited (for 1472-1492 MHz). Licences (which are tradable) were issued to these two operators on 8 October 2015.

The EC Decision has been implemented in the UK by means of a Statutory Instrument - "The 1452-1492 MHz and 3400-3800 MHz Frequency Bands (Management) Regulations 2016." [8]

Constraints on the use of the spectrum for mobile access in the UK
In the 1452-1492 MHz Spectrum Access Licence Variation [9] Ofcom mentioned that they had changed the way in which the adjacent 1492-1517 MHz band (paired with 1350-1375 MHz) is made available for new fixed link assignments. No new fixed links assignments will be made in the 6 MHz immediately above 1492 MHz. We do not therefore anticipate the adjacent fixed usage is an issue.

The lower edge is adjacent to Ministry of Defence (MOD) managed spectrum. However, any MOD usage is likely to be for fixed links, mainly transportable, and not used extensively in the UK except in training areas. Therefore, no constraints are expected in this band that could impact the timing of usage of mobile technologies.

[7] Commission Implementing Decision (EU) 2015/750 of 8 May 2015 on the harmonisation of the 1452-1492 MHz frequency band for terrestrial systems capable of providing electronic communications services in the Union

3.3 3.4 GHz band

3.3.1 International

The band 3400 -3600 MHz is allocated globally to the mobile, fixed and fixed-satellite services, although in Region 3 the mobile allocation is on a secondary basis. The allocation in Region 1 is identified for IMT and there are certain coordination and technical requirements associated with this use. The secondary mobile allocation in Region 3 in the band up to 3500 MHz is raised to primary status in several countries, including China, India, the Republic of Korea, Japan and Pakistan and identified for IMT.

3.3.2 Europe

Use of the band 3400-3600 MHz for "electronic communications services" is harmonised in the EU through a Commission Decision of May 2008[8], which was amended by a further Decision in May 2014[9]. Both of these Decisions relate to the whole band from 3400 to 3800 MHz and are therefore also relevant to Section 2.4 below.

The original 2008 Decision required Member States to designate and make available, no later than six months after entry into force of that Decision, "*on a non-exclusive basis, the 3 400-3 600 MHz band for terrestrial electronic communications networks*", in compliance with the parameters set out in the Decision. The subsequent amendment in 2014 replaced the specific requirements regarding timescales for implementation as given in 2008 (presumably as these had already been met) and added further operational and technical requirements. Member States were required to apply the conditions laid down in the amending Decision by 30 June 2015 at the latest and report on to the Commission by 30 September 2015. The original Decision specifies in-block emission limits and block edge masks but not mode of operation or channelling arrangements. The 2014 amendment specified TDD as the preferred duplex arrangement, and specifies block sizes of 5 MHz, with in-band power limits and block edge masks. The parameters quoted, based on a CEPT Report, correspond to TD-LTE technology. Parameters are also provided should FDD be used.

In a consultation document published on 7 November 2014[10], Ofcom noted that "*the 3.4 GHz band is already used for wireless broadband in a number of countries. In Europe there have been authorisations in Estonia, Germany, Ireland, Italy, Latvia, Macedonia, Norway, Portugal, Spain, Sweden, Switzerland, and the UK (by UK Broadband). By July 2014 six TDD networks had been launched commercially in the 3.4 GHz band in Bahrain, Belgium, Canada, the Philippines, Spain and the UK.*"

There is a possibility that the EC harmonisation Decision relating to the 3.4-3.8 GHz band will need to be reviewed, and possibly revised, to cover the use of this spectrum for 5G services, especially given the focus on this band as a "pioneer" band for 5G. It is

[8] Commission Decision (2008/411/EC) of 21 May 2008 on the harmonisation of the 3 400-3 800 MHz frequency band for terrestrial systems capable of providing electronic communications services in the Community

[9] Commission Implementing Decision of 2 May 2014 on amending Decision 2008/411/EC on the harmonisation of the 3 400-3 800 MHz frequency band for terrestrial systems capable of providing electronic communications services in the Community

[10] PSSR: Award of the 2.3 GHz and 3.4 GHz bands – published by Ofcom on 7 November 2014

understood that at a meeting of the EC's Radio Spectrum Committee (RSC) in early December 2016, consideration was given to issuing a mandate to CEPT to carry out the work. Although the proposed mandate had not been published at the time of writing this report, it is expected that work under this mandate will have been completed by mid-2018.

3.3.3 National

Spectrum harmonisation and availability.
In the UK, the 3.4 GHz band had previously been reserved for defence use, although various civil services have been permitted. These include: two specific blocks (3480-3500 MHz and 3580-3600 MHz) which were awarded by Ofcom to UK Broadband Ltd (UKB) for Fixed Wireless Access; "recognised spectrum access" rights[11] in the remainder of the band; radio amateur use from 3400-3475 MHz and certain frequencies for "programme making and special events".

This band was considered under the Government's PSSR programme for release from MOD control to the commercial sector. In November 2014, Ofcom consulted [1] on proposals for auctioning spectrum in the 3.4 GHz band, together with spectrum in the 2.3 GHz band. In the 3.4 GHz band, the frequencies to be awarded comprise 150 MHz of spectrum at 3410-3480 MHz and 3500-3580 MHz. Ofcom indicated that the spectrum to be awarded would be fully cleared of existing uses apart from in a very small number of specific areas where there will be continued MOD use. There may also be some very limited use for PMSE. With regard to the 40 MHz in the same band currently held by UKB at 3480-3500 MHz and at 3580-3600 MHz, it was noted that if UKB entered the auction, the frequencies making up its current holding may change. The arrangements proposed for the auction were designed to ensure that spectrum can be awarded in contiguous blocks for all successful bidders.

Ofcom expected the auction to take place in late 2015 or early 2016. On 26 October 2015, Ofcom published a statement [10] setting out its decision to conduct an auction of the spectrum in the 2.3 and 3.4 GHz bands following the release of those bands to Ofcom by the Ministry of Defence as part of the Government's Public Sector Spectrum Release programme. Ofcom indicated its intention to start the auction in December 2015 and "*recognised that there is demand for this spectrum and took the view that spectrum efficiency is best achieved by bringing available frequencies into use as soon as possible to benefit consumers*."

However on 3rd December 2015, Ofcom issued an update [11] which announced its decision to delay the auction process. This followed a threat of judicial review proceedings by Telefonica UK Limited and Hutchison 3G UK Limited against Ofcom's decision to commence the auction process before the outcome of the European Commission's consideration of the proposed merger between those two companies. Ofcom also took into account the provisional findings of the Competition and Markets Authority ("CMA") on the proposed merger between BT Group plc and EE Limited.

On 20th July 2016, Ofcom issued an update [12] which read: "*Following the European Commission's decision to block the proposed acquisition of O2 by CK Hutchison (H3G),*

[11] Recognised Spectrum Access (RSA) is a means by which receiving radio stations can be granted rights to recognition and hence a degree of protection from interference in return for a fee.

Ofcom intends to publish in the autumn a further consultation on competition measures and on specific aspects of auction design for the award of the 2.3 and 3.4 GHz spectrum bands."

On 21st November 2016, Ofcom issued a further consultation on competition issues [3] with a closing date of 30th January 2017. In this document, Ofcom stated: "*We have already consulted on other aspects of this award and the matters discussed in this document therefore represent the last issues on which we need to conclude before the auction can proceed*." Ofcom have recently confirmed [13] that they intend to publish an update to the Information Memorandum prior to the auction and intend to publish a statement on the award in Q1 2017/18. The implication therefore is that the auction proceedings for both the 2.3 and 3.4 GHz bands could be initiated in 2017.

The original EC Decision, amended by the 2014 Decision, has been implemented in the UK by way of the Statutory Instrument titled "The 1452-1492 MHz and 3400-3800 MHz Frequency Bands (Management) Regulations 2016 [14]", which require Ofcom to exercise its functions under the WTA so as to give effect to the obligations of the United Kingdom under the Commission Decision. Any award of the 3.4 to 3.8 GHz band has to be compliant with the Commission Decision.

Ofcom has noted in its consultation on the 3.6 to 3.8 GHz band that "*there is not yet clarity regarding technical parameters for its use in the 3.4 to 3.8 GHz band. It is possible that these parameters will not be aligned with those designated in relevant domestic and European legislation. If that turns out to be the case, the future use of the 3.4 to 3.8 GHz band for 5G services in the UK would require a new Statutory Instrument. Additionally, Commission Decision 2008/411/EC may need to be amended to take account of 5G's requirements in order to enable the future use of the band for 5G services across the EU".* There is no indication that this development will further delay the release of the 3.4 GHz band. It would presumably be possible for the auction to go ahead on the understanding that the conditions for using the spectrum for 5G may change.
As noted in Section 3.3.2 above, work is likely to start on this topic in CEPT soon and should be completed in mid-2018. If a new EC Decision is needed, it will take some time for this to be drafted and adopted, and then a new Statutory Instrument will be needed to implement this in the UK. However, as the conclusions of the work in CEPT will start to emerge before the formal date for completing the mandate, it should be possible to conduct some of the necessary activities in parallel. Certainty on this issue should therefore be possible by say late 2018 or early 2019 at the latest.

Constraints on the use of the spectrum for mobile access in the UK

Once released, there will be a number of limited restrictions on the use of the spectrum to protect MOD operations and civil air traffic control radars. Coordination will be required with sites in Cornwall (up to 25km), Portsmouth (8km), Portland (large area but requirement ceases on 31st December 2020), BUTEC[12] area (off North West Scotland – requirement ceases 21st December 2023), and numerous airborne locations (mainly coastal and offshore areas – this requirement will cease when the MOD has taken remedial action, currently expected to be by 31st Mar 2018). In addition, there will be coordination requirements to protect air traffic control radars operating in the band 2.7-3.1 GHz. Although there will be many locations requiring protection (the list has not yet been

[12] British Underwater Test and Evaluation Centre

published) it is not expected that this will unduly restrict the deployment of mobile services in this band. Once released therefore, the whole of the 150 MHz should be available over most of the UK, including nearly every major centre of population. Some of these geographical restrictions will have disappeared by 2020.
The coordination requirements are clear and limited to specific relatively isolated parts of the country. In [1], Ofcom has not identified any constraints on the type of service, technology or specific equipment requirements for the spectrum to be released. Ofcom, as set out in the technical coexistence consultation, indicates that the requirement for additional spectrum for PMSE access is low. Therefore, Ofcom expects requests for coordinated access to the 3.4 GHz bands to be infrequent.

3.4 3.6 GHz band

3.4.1 International

The band 3600 -3800 MHz is allocated globally to the fixed and fixed-satellite services on a primary basis. There is also an allocation to the mobile service but this is on a secondary basis in Region 1 and primary in Regions 2 and 3. The only identification for IMT in this band is in four Region 2 countries, including the USA and Canada, and is limited to the range 3600-3700 MHz.

3.4.2 Europe

Use of the band 3600-3800 MHz for "electronic communications services" is harmonised in the EU through the Commission Decisions described in Section 2.3 above. These Decisions cover the whole range from 3400 to 3800 MHz. In the original 2008 Decision the timetable for implementation in the band above 3600 MHz was later than that for the band below but this deadline (1st January 2012) has long passed. The 2014 amending Decision specifies that TDD shall be used above 3600 MHz (there is no FDD option as for the band below 3600 MHz) but generally the parameters given in the Decision apply across both bands.

3.4.3 National

Spectrum harmonisation and availability
In the UK, the 3.6 GHz band has been used for fixed links and fixed-satellite receiving earth stations. UKB has access to 84 MHz of this spectrum to provide electronic communication services.

On 6th October 2016, Ofcom published a consultation on proposals for the future use of this band [15]. This consultation originally had a deadline for responses of 1st December 2016 but this was extended to 15th December. The consultation notes that fixed link usage in the band in the UK is light (total of 35 links) and that the fixed-satellite use is light compared with other satellite bands (5 sites operate under "recognised spectrum access" and 14 sites have permanent earth station licences). The consultation proposes making the upper part of this band, 3.6 to 3.8 GHz, available for future mobile services including 5G "In view of the identification by regulators across Europe and industry of the wider 3.4-3.8 GHz band as a

potential first 5G band"[13]. The amount of spectrum under consideration to be released for mobile use is 116 MHz.

The Ofcom consultation offers two alternative approaches to existing fixed and fixed-satellite users. The first would retain existing users' rights but in in view of the significant restrictions these would place on future mobile use Ofcom "would be likely to consider reviewing fees to existing users to reflect this". In other words, fees might rise significantly to reflect the opportunity cost and as an incentive for users to reduce protection requirements or move out altogether. The second option would revoke existing licences and grants of Recognised Spectrum Access (RSA) in the band, although satellite receiving terminals would still be able to operate but without protection from interference.

In view of the potential impact of incumbent users, the reaction to consultation is likely to be hostile. That could have an impact on timescales especially if Ofcom has to change its position and consult again.

There is considerable uncertainty about the timescales in which this band could be made available for mobile services. Even if Ofcom is able to pursue the proposals in the current consultation quickly after the consultation period has ended, Ofcom would need to develop more detailed proposals for the treatment of existing users and consult on these, prepare licence changes and implement. Proposals for auction processes would need to be developed and an information memorandum prepared. It is difficult to see how an auction could be held before 2018. This timetable could be extended if Ofcom wishes to make the band specifically available for 5G and has to wait for European harmonisation.

The timetable could slip considerably beyond 2018 should Ofcom's proposals be legally challenged or if, at any stage of the process, the situation changes sufficiently to necessitate further rounds of consultation. However there is likely to be considerable pressure on Ofcom to have plans in place to release the spectrum, in a form suitable for 5G, before 2020 as the Opinion of the Radio Spectrum Policy Group (RSPG) states: "*The RSPG considers the 3400-3800 MHz band to be the primary band suitable for the introduction of 5G -based services in Europe even before 2020*".

However, this view of availability does not take into account the usability of the spectrum, under both of Ofcom's options, as a result of existing users. In the more extreme scenario proposed in Ofcom's consultation on 3.6GHz, existing licences would be revoked, the whole 116 MHz would be available for use after existing user's notice periods had expired. Ofcom have not yet indicated how long the notice period for revocation would be (the term "appropriate notice period" is used) but where certain licences have been extended indefinitely (e.g. for auctioned spectrum following the expiry of the initial licence period), they are subject to a 5-year rolling notice period. It is possible therefore that Ofcom would propose a similar period.

Under the scenario in which Ofcom would allow existing users to remain and be protected, extensive areas of the UK would be unavailable for 5G / mobile services at least by the time of an initial roll-out. The situation would improve if users were willing to accept a lower

[13] RSPG16-032 FINAL: Opinion on spectrum related aspects for next-generation wireless systems (5G) - Brussels, 9 November 2016

level of protection or moved out of the band entirely. Ofcom has suggested the possibilities of commercial agreements with mobile licensees and the use of licence fees as an incentive. However, the rate at which users might transition out of the band or accept greater interference in response to increased ALFs or commercial deals, making the band more useable, is highly uncertain.

In summary, a final decision on how existing users of this band will be dealt with is unlikely to be reached until late 2017. It will then be necessary to consult and agree upon all of the terms and conditions for an auction. It is concluded that the potentially available 116 MHz of spectrum in the 3.6 GHz band is unlikely to be released before late 2018 and possibly into 2019. There are likely to be severe geographical restrictions on its use for mobile services until at least 2022 and possibly later.

Constraints on the use of the spectrum for mobile access in the UK

The 3.6 to 3.8 GHz band is part of a wider band, 3.6 GHz to 4.2 GHz, which is used by fixed links and satellite earth stations [15]. There are considerable uncertainties as to if, and when, this band will become usable throughout most of the UK.

4. Availability and timings for infrastructure and equipment

This section investigates the availability and timing of radio network infrastructure for the frequency bands in question. Since the vendor support is essential, an assessment of the level of network infrastructure vendor support for each band has been made in this section. This has been undertaken for each of the five main infrastructure vendors (Ericsson, Huawei, Nokia, Samsung and ZTE) using a combination of publicly available information, their web-sites and by direct communication with the vendors. As this section is not intended to be a comparison between the vendors, the information received has been combined and individual results are not presented. In general, where at least one vendor supports the frequency band in question then that band is considered as supported. This is deemed appropriate, as typically the requirement to support a new band is driven by the market and once one vendor provides support the others will usually follow. Where multiple vendors support a new band then this is made clear in the accompanying text. Within the qualitative assessment (details of stages in Annex A) a distinction has been made where a band is supported by just one vendor, or by two or more vendors.

Infrastructure vendors typically support a range of different BTS types, for example products suitable for macrocells, small cells or indoor solutions. They also have different generations of hardware – often older generations are still manufactured and available even after a later version becomes available. Sometimes new frequency bands will be supported on new generation products but perhaps not on older generation products. Within this analysis, we have considered that as long as the frequency band is supported by at least one generation of hardware and one BTS type then it is considered as supported. Most often this will be a macrocell BTS with the most recent generation of hardware.

4.1 700 MHz band

The CEPT 700MHz second digital dividend band in Europe actually consists of two bands – a FDD part and a SDL (Supplemental DownLink) part.

The FDD part of the 700MHz band defined in Europe is a subset of the 700MHz Asia-Pacific Telecommunity (APT) band 28 in 3GPP. Full implementation of band 28 requires 2 duplexers as shown in Figure 4-1. The CEPT 700MHz band is the lower portion covered by the bandwidth of the lower duplexer. Band 28 is already supported and deployed in many parts of the world including Australia and Latin America. The same infrastructure can therefore also be used for the portion of this band to be deployed in Europe. There is evidence showing that multiple infrastructure vendors and operators already support this band [16, 17, 18].

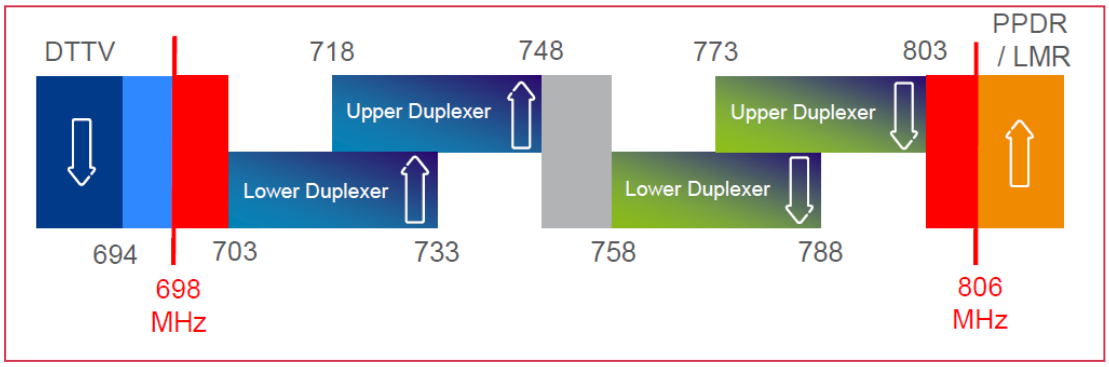

Figure 4-1: APT700 (Band 28) band plan (Source: Ericsson [19])

The SDL part of the CEPT 700MHz band (3GPP band 67) is unique to Europe. At present, there are no known operators seeking to deploy this band. As such there is currently no known infrastructure support from the main vendors. As indicated previously it typically takes around 9-12 months for vendors to undertake the necessary developments to introduce a new band into their infrastructure, although it can be quicker. It can therefore be assumed that band 67 would take a similar duration for vendors to implement, once there is market demand or a significant operator order.

4.2 1.4 GHz band

The 1.4GHz spectrum (band 32) is a SDL. This band has been harmonised in Europe [20] and is already awarded in the UK and Germany.

In LTE, Supplemental Downlink is used in conjunction with another standard FDD band through carrier aggregation to provide additional downlink only spectrum. If the 1.4GHz SDL spectrum is paired with a low frequency band such as 700 or 800 MHz, then it can typically provide coverage levels similar to sub-1GHz spectrum. This is because the uplink, which is usually the limiting link for coverage purposes is carried on the low band, while the 1.4 GHz SDL spectrum is only used for the downlink. Some vendors [21] utilise this benefit by providing the additional downlink radios for the 1.4GHz band in conjunction with additional receivers for the low band to support 4-way Rx diversity in the uplink. This has the benefit of further enhancing coverage and indoor performance.

From our investigation, there is good evidence that network infrastructure supporting the 1.4 GHz SDL band 32 is becoming available. At least 2 vendors indicate that they support this band or will do so in early 2017.

4.3 3.4 GHz band

The TDD 3.4GHz band (band 42) is already in use in several areas of the world, in particular providing Fixed Wireless communication services. Several of these networks are utilising LTE technology, such as UKB and Imagine in Ireland. NTT DoCoMo in Japan also have an allocation of spectrum in this band and have been active in progressing the development of Carrier Aggregation allowing this band to be used with their existing spectrum allocations. In June 2016 DoCoMo launched a service called “Premium 4G” using their allocation in band 42 in conjunction with other LTE bands to offer speeds of up to 370MBps. [22]

The above information together with positive confirmation from the vendors indicates that there is already good LTE infrastructure support for this frequency band from most vendors. [23, 24]

4.4 3.6 GHz band

The 3.6GHz band (43) together with the 3.4GHz band (42) has been identified as one of the key launch bands for 5G networks in Europe. Nevertheless, whilst band 43 is not so widely used today for LTE TDD networks as band 42, there are several declared deployments [25].

We have received confirmation that LTE TDD in band 43 is already supported by more than one infrastructure vendor [24,26].

5. Device availability and operator timescales

This section provides an overview of device availability in the bands in question. For the years to 2022, this is based on a detailed survey of device makers, their chip suppliers and mobile operators, about their plans to deploy smartphones and other products in these bands. The topics covered are:

- Plans to launch commercial devices in each band to assess what percentage of manufacturers will offer products, and what percentage of the market they cover.
- Assessment of the timescales for manufacturers to deploy devices commercially, and for mobile operators to launch services, bearing in mind the 'chicken and egg' effect of these two factors.

This assessment also considers the likely speed of uptake by consumers, especially of smartphones.

5.1 Spectrum uptake drivers and the Rethink market survey

A key driver in deciding whether a spectrum band will be commercially usable for wireless services is availability of affordable, attractive devices. This is something of a 'chicken and egg' situation, and this can make precise forecasting difficult.

Chip and device suppliers are typically planning commercial launches a year in advance and working to a 5-year roadmap. However, the prioritisation of certain spectrum combinations and the timing for launch, is heavily driven by operator commitments, which will drive scale into particular options.

Conversely, operators' decisions about which spectrum combinations to prioritise must take into account the availability of a wide choice of devices from different vendors (to improve negotiating position) and at good prices. While their first driver is access to a particular spectrum band, their decision on whether to acquire this spectrum, and then how quickly to commercialise it, and for what services, will be driven partly by the device situation.

The benefits of scale and harmonised equipment standards dominate and are critical to uptake of spectrum bands. Regulators recognise this and adapt licence conditions to allow use of standardised equipment – failure to use standardised, mass market equipment can delay or obstruct commercial service. For example, in recent years Ofcom has relaxed technical licence conditions in order to accommodate (more spectrally efficient) emerging standards even if this resulted in (slightly) more interference to neighbouring users [27]. In considering different 700MHz band-plan options in the UK [28], though it was possible to facilitate 2x40MHz with existing technology, operators, equipment providers and Ofcom all preferred a solution that was consistent with the existing APT band plan, even though it resulted in less spectrum being able to be released [29]. This demonstrated that, for the 700MHz band, use of spectrum, harmonised with Asia, is more important than more (FDD) spectrum available only on a European basis. Technical considerations relating to protection of existing users are important –and are addressed by changing the sub-set of harmonised IMT spectrum that will be assigned for use in a country like the UK, though it will not dictate the availability or capability of the (global) device ecosystem. For this reason, in the following, we will focus on the market aspects and combinations of bands

that can be supported. We consider this market data from the perspectives of both the equipment providers (OEMs) and mobile network operators (MNOs).

Although the ability to support multiple bands within a mobile device has been greatly enhanced by modern modem chip technology, software-defined radios and other advances, there is still a limit to how many bands a mainstream commercial device can accommodate. Device makers therefore have to make choices about which combinations to prioritise in their roadmaps, and this will help shape adoption patterns (e.g. if there is no iPhone to support a particular band, it is likely to drop down the MNOs' deployment agenda even if the spectrum itself is usable).

In recent years, there has been a swing in this balance of power towards the MNOs. While top device vendors, notably Apple, used to dictate the timing for mass support for a particular band, now the device ecosystem is more likely to follow the lead of key operators, according to survey interviewees. This is particularly seen in certain Asian markets, for instance in China Mobile's drive to create a broad ecosystem for TD-LTE in 2.3 GHz, previously a little-supported band [30]. This is because of the intensifying competition in the handset market, which has weakened the leadership position of the tier one vendors, and because the deployment of advanced LTE and prototype 5G technologies is and will be driven by a small group of pioneer operators, with the network OEMs (i.e. Tier 1 network equipment vendors such as Ericsson) and Qualcomm. Qualcomm aside, the chip and device makers increasingly prioritise spectrum bands according to commitments of these pioneer MNOs.

Rethink Technology Research conducts a biannual ecosystem survey to examine likely adoption rates for key spectrum bands for LTE and potential 5G services. The most recent survey was conducted in September to November 2016 and included:

- 27 device supply chain players, all major players with international reach and commercial products
- 11 chip and modem suppliers
- 11 handset providers
- 5 IoT device specialists
- 55 MNOs, 31 in Europe and 24 in APAC.

North America, Latin America (LATAM) and Middle East and Africa (MEA) were included in the survey but their results have been excluded from this report[14]. The key focus of the report is on the scale and timing of a critical mass of devices in Europe, while Asia Pacific (APAC) has been included because its operators and vendors are currently the key drivers behind deployment of new LTE and 5G spectrum and services, so their pace of adoption will impact the options for European MNOs too. Although this is a UK study, it is essential to assess device availability on a regional and global basis since these are global products. The UK on its own is too small to drive product decisions for the major chip suppliers, which take an international view when making product strategy, even if they later adopt localised go-to-market tactics.

Respondents were asked to indicate their likely timeline for commercial deployment (trials or single-customer niche services excluded) of devices and services in a range of 4G and 5G

[14] This survey excludes the USA. It has very different band plans for 700 MHz and 3.5 GHz, which will drive their own ecosystem, but will not easily drive scale into the European band plans

bands, and in key combinations. Responses relevant to all bands identified in Table 1-1, the subject of this report, have been used in this analysis.

For the purposes of this report, 900 MHz (Global System for Mobile communication or GSM) and 2.1 GHz (3G) have been assumed to be in use in most mobile broadband networks in Europe. They will be switched off and refarmed by many MNOs from the end of the decade (earlier in parts of APAC), and this factor may affect 5G spectrum decisions, but this was beyond the scope of this particular survey. For the purposes of this study, we focused only on potential new LTE (or 5G) bands, excluding 2G and 3G from the combinations surveyed.

Further, the data we have indicates that there is not enough interest in band 67 to make a difference to the timing of availability of 700 MHz band compared to band 28. Therefore, we focus on band 28 for 700 MHz usability analysis.

5.2 Market survey results

As noted above, spectrum availability and use is driven by a combination of equipment availability and operator plans. In the following we present a survey of the expectations of the band support from both equipment and operator perspectives.

5.2.1 Spectrum band support envisaged by OEMs to 2022

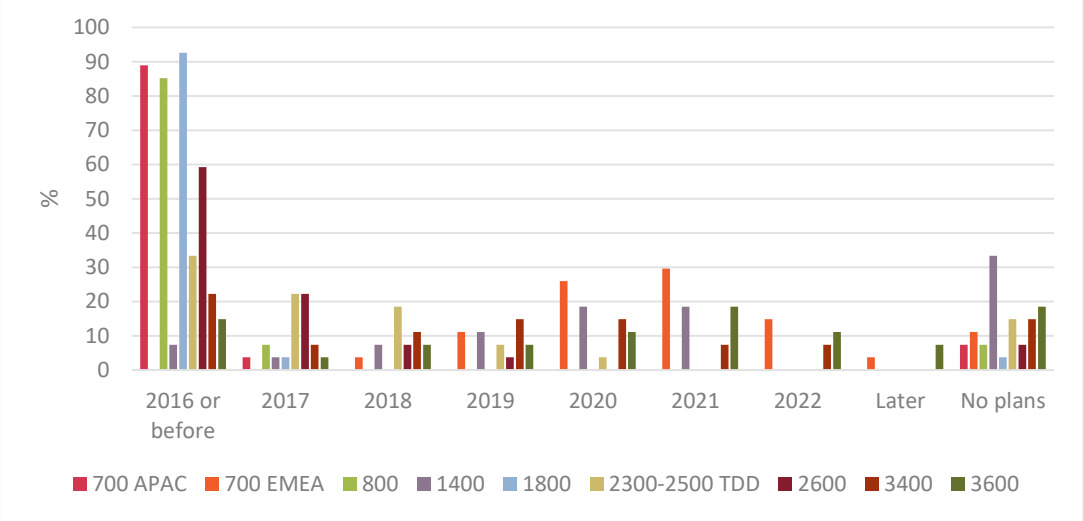

Figure 5-1: Percentage of suppliers (chip and device) which expect to support each band. Percentages are cumulative. In many cases deployment may be in combination with other bands (see Figure 5-2).

We have separated the availability of equipment that supports the 700MHz band plan into 700 APAC and 700 Europe, Middle East and Africa (EMEA). We anticipate that devices supporting the 700 APAC will be compatible with the lower 2x30MHz of the 700 EMEA FDD spectrum, but not necessarily with the 20 MHz spectrum in the duplex spacing. The utility of this SDL spectrum in band 67 is likely to be low, and it is likely that European operators will (at least initially) use APAC devices in their mass market smartphone products. Hence the date of availability for use of the 700 band will be driven by APAC device availability.

All the other bands are assessed on an international basis (APAC and Europe) since device and chip makers are weighing their potential on a global basis and assuming significant harmonization.

Support for 700 MHz specifically for Europe takes off more slowly than the other new bands because it is assumed to be a 5G band and will not, in most cases, be cleared for use until 2020. By 2020, 41% of the major suppliers surveyed will have commercial products for 700 MHz in Europe and the figure rises to 71% in 2021. We can assume a one-year lag between launch/trials and commercial availability from an operator.

In the cases of 1.4 GHz and 3.4 GHz, it is assumed there will be LTE usage, which stimulates the device ecosystem at an earlier stage. Early support for 3.4 GHz LTE is heavily focused on fixed wireless, with early adopters including UKB, Imagine in Ireland and NTT docomo in Japan. The latter went live with 3.5 GHz TD-LTE services in June 2016, with the band aggregated with other TDD spectrum. The first devices are fixed wireless routers but a significant base of devices will build up from 2018 (40% of suppliers) to 2022, when 85% expect to support it.

The 1.4 GHz is regarded as a more niche option, though this opinion may change if commercial deployments build up. The main activity so far has been in Japan, where the spectrum is used commercially, and in trials for supplemental downlink in LTE, including in France. ZTE was the first vendor to launch commercial 1.4 GHz TD-LTE terminals, in 2012, when it unveiled IoT modules, USB cards and fixed CPE for trials in China.

There is also uncertainty about near term deployment of 3.6 GHz because it was not included in the WRC-15 allocations. Most device support is focused on fixed wireless, often migration from Worldwide Interoperability for Microwave Access (WiMAX) or other fixed wireless networks. However, by 2022, three-quarters of device players expect to have products supporting 3.6 GHz, often for 5G. This band is regarded as a 5G 'pioneer band' by European regulators because it can support channel bandwidths of at least 100 MHz.

Figure 5-2 shows the percentage of device and chip suppliers supporting key combinations of spectrum bands in EMEA (cumulative). It is notable that the new bands are not expected to reach the same scale of adoption within a five-year period as the LTE bands have achieved to date. The 4.5G and 5G device landscape will be more fragmented because of:

- Wider variety of spectrum bands, some suited to relatively specialized applications
- Wider variety of use cases included fixed broadband and IoT, with a lower relative focus on smartphones

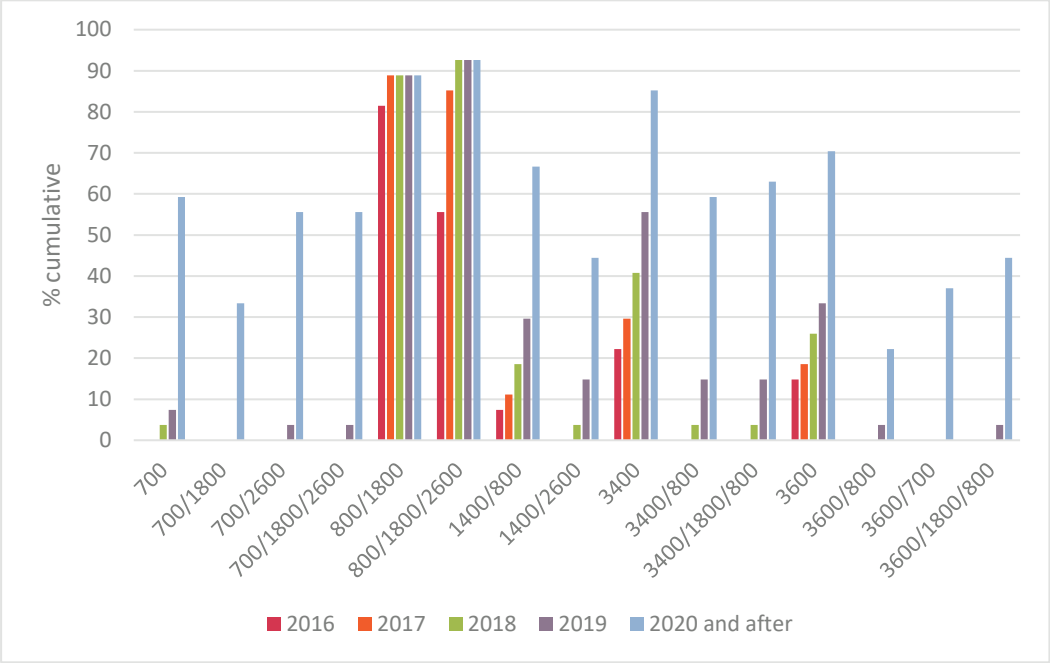

Figure 5-2: Percentage of device and chip suppliers supporting key combinations of spectrum bands in EMEA (cumulative). Key UK band combinations which are already in use for LTE are included for reference (e.g. 800/1800/2600).

By 2020 to 2022, the most heavily supported combinations in EMEA, with the exception of current 4G bands, are expected to be:

- 3.4 GHz: 85% expect to support 3.4 GHz standalone (fixed wireless, some IoT) and about 60% in combination with LTE bands
- 3.6 GHz: 70% expect to support it standalone (mainly for 5G and some fixed wireless migration), but fewer than 40% in combination
- 700 MHz standalone (for IoT): 59% of suppliers expect to support
- 700 MHz in combination: 56% expect to support 700 MHz with LTE bands
- 1.4 GHz: 74% expect to support it, in combination with LTE bands, most commonly with 800 MHz for SDL

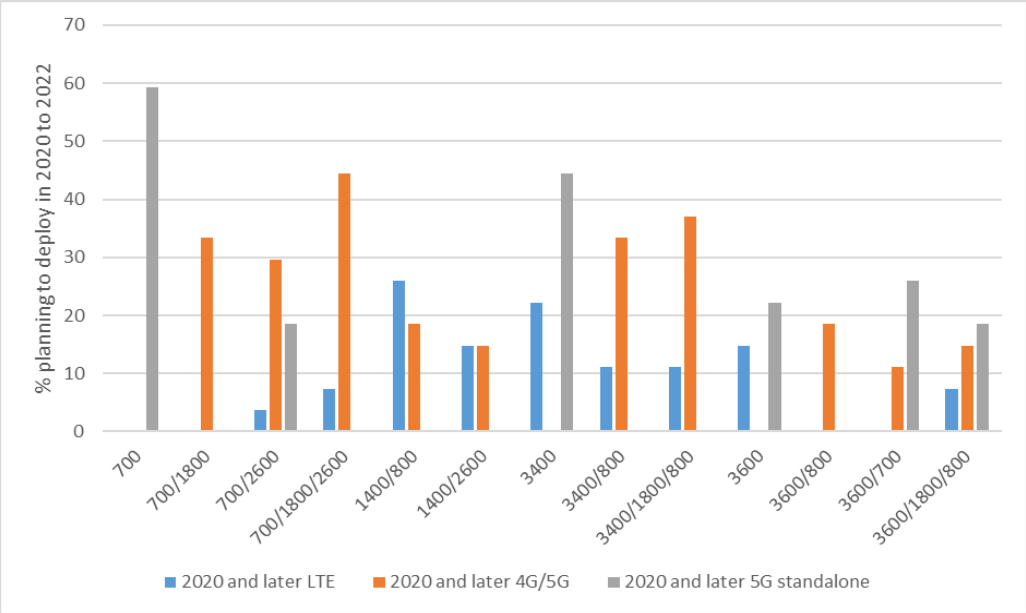

Figure 5-3: Support for new bands divided by LTE and 5G

Figure 5-3 shows that some of the emerging bands will not have a wide range of LTE devices but will mainly be used for 5G, or LTE/5G combinations, which will affect the timescales for availability in Europe. While there is fairly significant usage of 1.4 GHz (SDL) and 3.4 GHz for LTE, the main availability of 700 MHz and 3.6 GHz devices will be for 5G.

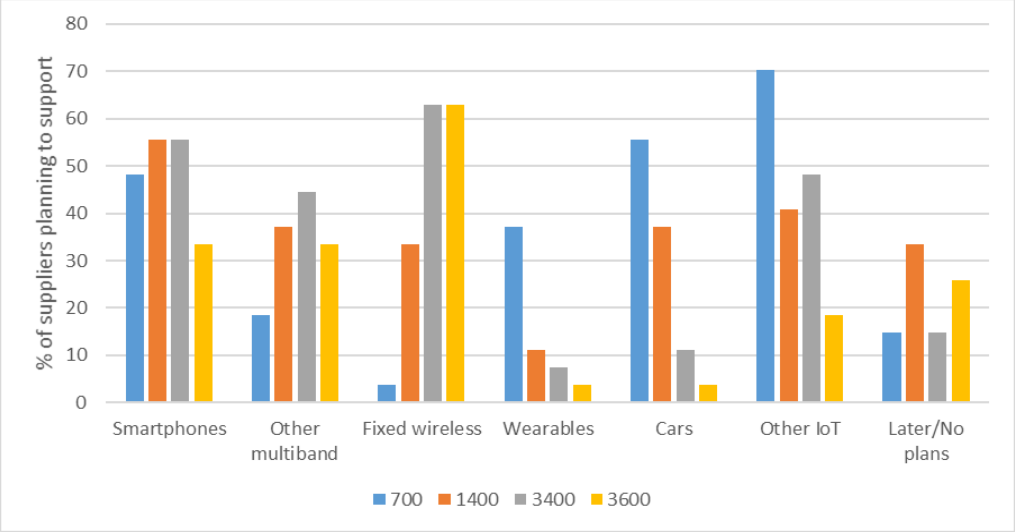

Figure 5-4: Percentage of chip and device suppliers expecting to support the four bands in question, by device category (most will target more than one category)

Figure 5-4 shows that, while smartphones remain the bedrock of business for most suppliers, they expect some of the new bands to be prioritized for other devices and applications, notably fixed wireless, consumer IoT (wearables and in-car systems) and enterprise IoT (e.g. smart cities, industrial). By 2022, cumulative vendor support for IoT applications is outrunning that for smartphones in 700 MHz and the higher frequency bands, while fixed wireless is heavily supported in 3.4 GHz and 3.6 GHz. This indicates the need of vendors and operators to use new spectrum to drive new revenues rather than just

enhancing existing services. However, the wide variety of devices for IoT applications, from ultra-low power modules with simple receivers, to in-car systems, points to a highly-fragmented device ecosystem, in which some form factors and spectrum bands are likely to struggle to achieve critical mass.

In the OEM survey, some key findings emerged, summarised here. The most important factors (or sub-factors in the overall context of this report) which will affect decisions about band and device support in 2016 to 2021 (i.e. to the start of 5G) are the following:

- Focus on capacity
- TDD
- International Telecommunications Union (ITU) identification
- SDL
- Spectrum sharing
- Densification
- Device lifecycles
- Fixed wireless
- New revenue opportunities
- Migration to 5G

Each of these are discussed below; highlighting where issues may be pertinent to the considerations relating to the bands that are the focus of this report.

Focus on capacity
Many LTE operators round the world have achieved significant 4G roll-out with a focus on wide coverage, often harnessing sub-1 GHz spectrum. As users migrate to 4G and mobile broadband traffic rises, operators are switching their attention to capacity. This means a growing emphasis on deploying in higher frequency (and higher channel bandwidth), capacity bands above 2 GHz.

TDD
The need to support high levels of capacity, especially in urban areas, is also driving new interest in TDD spectrum, which has generally played a minority role in many MNOs' strategies. Unpaired spectrum is often more readily and affordably available; has efficiency advantages for small cells; and allows for asymmetric uplink/downlink services, and can more efficiently support higher order MIMO methods. The TDD portion of the bands between 2.3 GHz and 2.6 GHz, as well as the C-band from 3.4 GHz to 3.8 GHz (and potentially up to 4.2 GHz) are leading the way internationally.

ITU identification
The bands identified for global mobile broadband in the International Radio Regulations of the ITU (by the 2015 or earlier World Radio Conferences) have a significant impact on device makers' strategies since their primary objective is to support bands which enable global, or large regional, reach and consequent economies of scale.

At WRC-15, the ITU added three new bands to the list of those globally identified and harmonized for mobile broadband, supporting a mixture of coverage and capacity for LTE or, in future, IoT and 5G networks. The three additions were the 700 MHz band (694-790 MHz, promoted from a regional to a global identification); the lower 200 MHz of the C-band (3.4-3.6 GHz); and the L-band spectrum in 1427-1518 MHz. However, the GSMA and other

parties failed to get the sub-700 MHz band (especially 610-694 MHz, but even down to 450 MHz) allocated for mobile broadband too, as well as the upper portion of the C-band (3.6-4.2 GHz).

SDL
Operators are looking for creative ways to increase bandwidth by tying several spectrum bands together, even when they are non-contiguous. Inter-band carrier aggregation and supplemental downlink are key approaches, and are even being extended to unlicensed spectrum (which is also outside the scope of this study). The 1.4 GHz band is earmarked for SDL in Europe.

Spectrum sharing
Sharing spectrum with incumbents while limiting interference will be essential to mobile broadband capacity as virgin spectrum below 6 GHz runs out. Precedents have been set in the US for 3.5 GHz (the CBRS shared spectrum scheme) and in unlicensed bands like the TV white spaces. Dynamic and shared spectrum schemes will be increasingly important to maximise usage, especially when incumbents only use airwaves lightly (as in 1.4 GHz and parts of the C-band).

Densification
The need for capacity is driving plans to deploy dense zones of small cells, especially in urban areas, indoors and outdoors. This drives the shift towards higher bands such as 3.4 GHz, whose range:capacity ratio is well suited to small cells.

Device lifecycle
The length of time which a user keeps a smartphone is increasing, especially as operators abandon subsidies and offer alternatives such as device financing. Gartner expects [31] that, by 2020, consumers in mature mobile markets will keep their handsets for 2.8 years on average, up from 2.5 years now, and that will lead to a fall in sales of 100 million handsets.

The lifecycle for other connected devices, such as tablets, home hubs and in-car systems, is likely to be far longer in most cases. This means that it will take longer for a large number of subscribers to have devices able to operate in new spectrum bands.

Fixed wireless
There has been a revival of interest in using cellular technologies for fixed broadband access. This is partly driven by trials in the USA, in high spectrum bands and using pre-5G technology. However, there are also several commercial deployments, and trials, using 3.5 GHz LTE for fixed access [32]. These bands have been allocated for fixed wireless in many areas and some deployments exist, often using proprietary or WiMAX technology which can be converted to TD-LTE, especially to support fixed/mobile services. In many cases, regulatory changes are needed to permit mobile usage. This trend means that, in some cases, OEMs and MNOs will first prioritise on fixed wireless devices rather than handsets.

The search for new revenue streams:
As the growth and profits achievable from mobile broadband services come under intense pressure – from competition, falling ARPUs and other factors – MNOs need to find additional revenue streams to justify investment in their networks. The most keenly pursued are vertical and enterprise services, especially replacing private networks (e.g. public safety), or helping businesses to move towards the Internet of Things.

Spectrum and device decisions will increasingly be driven by these considerations as well as by consumer usage, which will result in a proliferation of devices supported by MNOs, including wearables, cars, smart home hubs, industrial IoT gateways, smart city platforms etc.

Similarly, chip and device providers are also facing slowing growth and squeezed margins in smartphones and are focusing development resources heavily on the IoT.

Migration to 5G

One of the key decisions facing MNOs and device makers is whether to prioritise LTE in new spectrum bands, or to wait for early 5G deployment. If device and chip providers see a limited lifespan for LTE in a certain band, they may prefer to focus on existing spectrum combinations for 4G, and develop early 5G products for the new bands. This factor is particularly important in certain APAC markets, which expect to start 5G deployment early, and are starting to push their device ecosystems towards early device availability, even if this is pre-standard. The UK is unlikely to be a trailblazer in pre-standard 5G or in ultra-dense networks, but the pressure exerted by MNOs elsewhere will start to affect the type of devices a UK operator can secure.

5.2.2 Spectrum band support envisaged by MNOs to 2022

Figure 5-5 shows the percentage of European MNOs planning to deploy 700MHz for different uses. Most are planning to deploy a combination of use cases and network technologies. In many cases 700 MHz will support multiband devices including carrier aggregation.

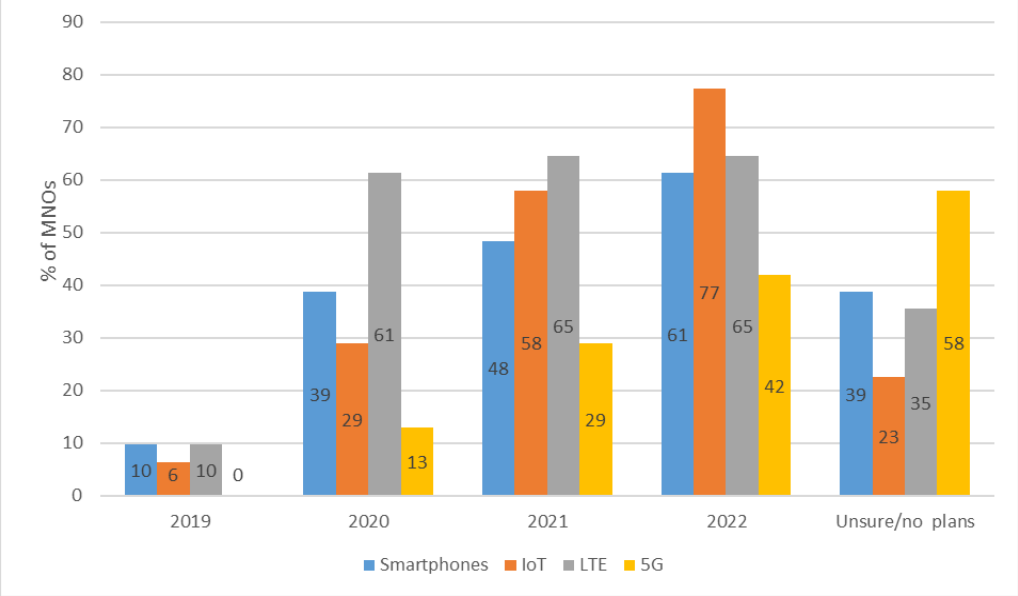

Figure 5-5: Percentage of European MNOs planning to deploy 700 MHz FDD spectrum, by key use case (mobile or IoT), and by LTE/5G.

Figure 5-5 shows that European Tier 1 and 2 MNOs expect to begin significant deployment of 700 MHz for LTE in 2020 (regulations allowing), with 61% embarking on this, 13% of them also with some pre-5G applications. LTE remains the key focus until 2023 – in that year 65% will have deployed LTE in 700 MHz, though this roll-out will have slowed and new

deployment will be focused on 5G (42% of MNOs by end of 2022). IoT applications in 700 MHz overtake mobile broadband, in terms of new commercial service launches, in 2021, when 58% will have launched new IoT services in 700 MHz, compared to 48% in mobile broadband (smartphones and tablets).

The key use cases for 3.4 GHz and 3.6 GHz are urban capacity (densification with small cells) and fixed wireless. Some IoT use cases are also emerging, particularly those requiring high capacity in dense zones, including connectivity to IoT gateways and hubs in cities or industrial/enterprise locations. Figure 5-6 shows the percentage of European and APAC MNOs planning to deploy 3.4 GHz TDD spectrum, by key use case (mobile, fixed or IoT), and by LTE/5G.

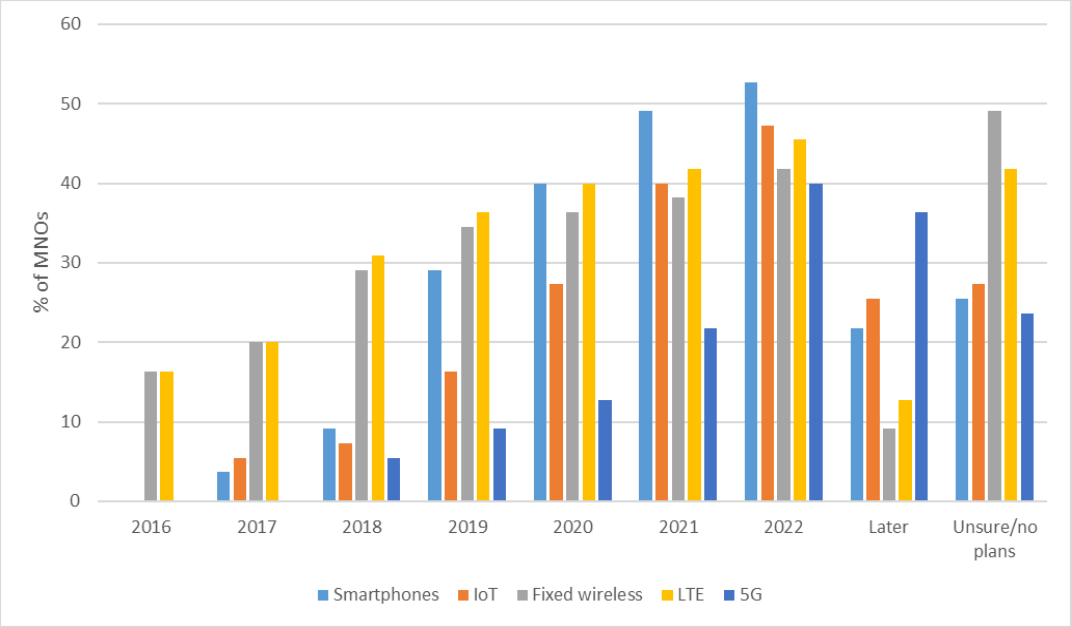

Figure 5-6: Percentage of European and APAC MNOs planning to deploy 3.4 GHz TDD spectrum, by key use case (mobile, fixed or IoT), and by LTE/5G.

The urban capacity requirement drives significant deployment in mobile broadband (smartphone) services, with almost 50% having launched these services in 3.4 GHz in 2021, while 40% will have IoT services running in the band, and 38% fixed wireless. The fixed wireless application has a headstart in terms of the ecosystem because of existing deployments by companies like UKB and Italy's Linkem and Tiscali. However, a high level of uncertainty remains about the need to include 3.4 GHz in an MNO's near term roll-out, and how the ecosystem for devices and equipment will develop. Operators are also weighing up other factors such as the potential to use LTE-Licensed Assisted Access (LTE-LAA) in unlicensed spectrum to boost capacity at low cost, or to refarm 2.1 GHz in future.

There is even greater uncertainty around 3.6 GHz. Despite fixed wireless and a few mobile deployments, many in emerging markets, this band was not included in the WRC-15 global allocations for mobile broadband.

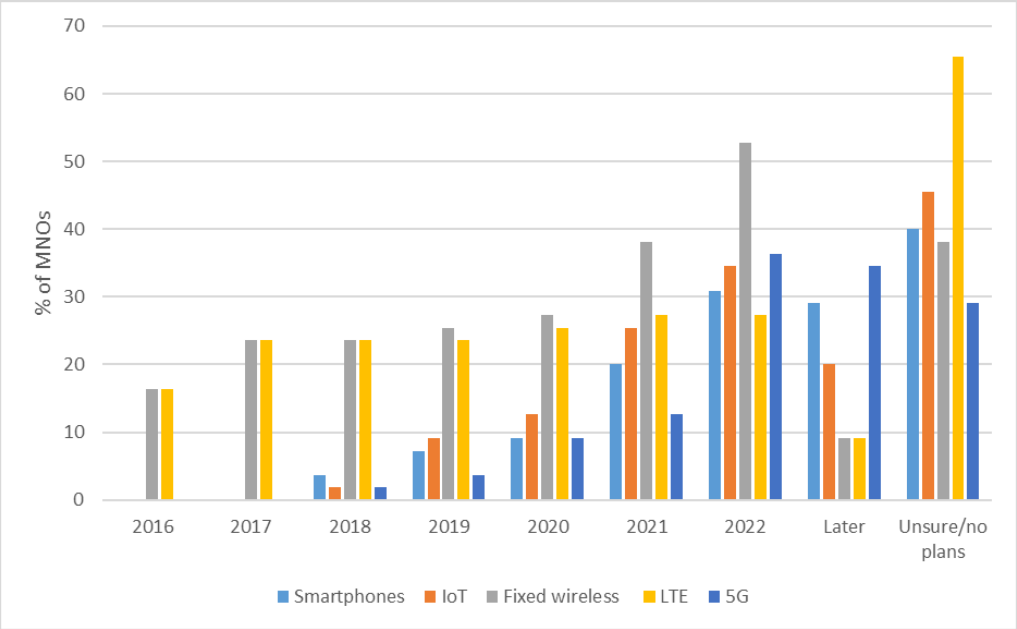

Figure 5-7: Percentage of European and APAC MNOs planning to deploy 3.6 GHz TDD spectrum, by key use case (mobile, fixed or IoT), and by LTE/5G.

The commercial deployment of 3.6 GHz in Europe and APAC is more heavily weighted to 2022 and later than 3.4 GHz, and therefore to 5G. While 27% of operators believe that they will have deployed some LTE services in the band by 2022, two-thirds remain unsure whether they will use this spectrum at all for 4G. By contrast, 36% think they will have started to deploy 5G in 3.6 GHz by the end of 2022 and only 29% have no plans at all for 5G in this band.

In the operator survey, some key findings emerged, summarised here:

- The 3.4 GHz band is seen as a near term option to support fixed wireless and, soon, mobile broadband capacity especially in urban areas. As seen in Japan, fixed wireless may be a seed use case, and then the spectrum can be woven into mobile broadband services to enhance capacity and support new services.
- The 700 MHz and 3.6 GHz bands are regarded primarily as early 5G bands (or more commonly, to support a parallel 4.5G/5G platform) from 2021. This will be a strong coverage/capacity combination for 5G, with operators particularly eyeing new revenue streams in the IoT and enterprise, to enhance their business model alongside enhanced mobile broadband.
- The 1.4 GHz band is regarded as useful to supplement LTE capacity but is less strategic to many operators – it is a tactical band in Europe and its adoption will depend heavily on the attitudes of device makers, whereas in the other three bands, MNOs are driving device and chip providers to accelerate development.

In all cases, OEMs' and chip vendors' plans are always under constant review and can be adapted when market conditions change. This means that projected deployment times and volumes can be improved or held back when those conditions differ from vendors' expectations. We asked the survey respondents to name any factors which would accelerate or hold back their expected launch plans. Of the four factors, in each case, which

were most commonly cited, we asked the respondents to name the most important to their decision. The results provide a top-level indicator of the kind of variations which may affect device availability over the coming years.

Figure 5-8 shows that the most important factors which might accelerate a vendor's launch in a given band relate to spectrum availability, and conversely, any delay in its availability to be deployed by MNOs is the most important barrier to launch. The other significant accelerants relate to market landscape – previously unexpected support by a major MNO and/or a major supplier adds significantly to total addressable market and the attractiveness of a particular band. In some cases, specialised suppliers may be positive about a band that is neglected by tier one players because they can carve out a niche, but in smartphones it is critical to have a massive addressable market with economies of scale. That means that fragmentation is a key barrier, as are decisions by large MNOs to de-prioritise on a particular band. The final top four accelerant is emergence of new rules or technologies which make a band more usable and more likely to be deployed, such as enhanced sharing; similarly, concerns about whether a band can be effectively shared with incumbents is a significant deterrent to many vendors as it creates uncertainty.

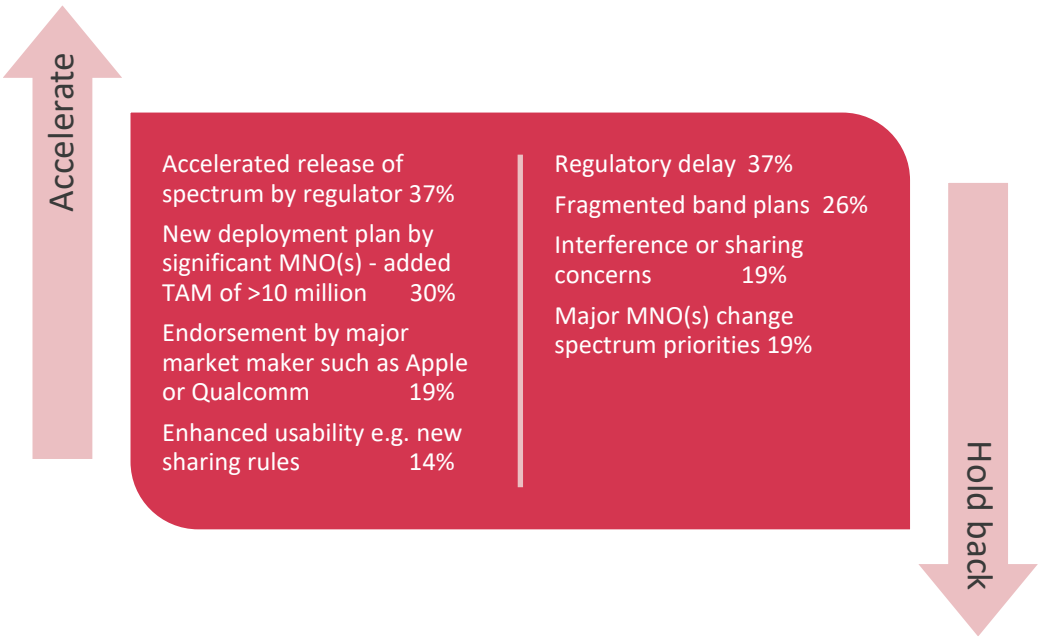

Figure 5-8: The top four changes in expected market conditions, which would alter OEMs' timescales to launch commercial devices in any given band. Percentage of respondents naming each factor as their most important. Source: Rethink survey.

6. Conclusions and further work

This chapter summarises our key findings from this study and recommendations for Three for further investigations which would enhance the spectrum strategies.

6.1 Conclusions

6.1.1 Spectrum availability and harmonisation

- The 700 MHz band is already allocated internationally to mobile services and is harmonised in Europe. Ofcom is aiming to release the spectrum, which will amount to a total of 80 MHz. **We conclude that the 700 MHz band will be made available by Q2 2020 and that, at least for the paired 2x30 MHz portion, further delay is very unlikely.**
- The 1.4 GHz band (40 MHz wide) is allocated internationally to the mobile service and harmonised in Europe. **This band is already available to two UK operators**.
- The 3.4 GHz band is harmonised in Europe. There will be a number of geographical constraints but these are mainly in areas of low population density and some will disappear over the period from 2018-2023. **The 3.4 GHz band could be made available in 2017. Even if delayed, there is no reason why the delay should extend by more than two years.**
- The 3.6 GHz band is harmonised in Europe. Currently it is in early stages, with plans for making 116 MHz available for mobile use in the UK. There are a number of issues to be addressed regarding existing users of the band which will take time to resolve, although there will be pressure to minimise any further delay. Even when released, there could be significant geographical constraints well into the future. **Thus, it is difficult to see how release of the band could be brought forward before 2018 and it could be delayed into the late 2020s, with some constraints remaining almost indefinitely.**

6.1.2 Timings of supply and deployment of infrastructure

- The network equipment is already available now for the 4 bands subject to this study. In many cases is already deployed elsewhere in the world, for Bands 28 (CEPT 700 FDD), Band 32 (1.4GHz Supplementary Downlink), Band 42 (3.4GHz TDD) and Band 43 (3.6GHz TDD).
- We find no evidence to suggest that equipment that supports Band 67 (the Supplemental Downlink part of the CEPT 700 band) is currently available, although if an operator were to place a significant order or there was market demand then infrastructure could be developed and made available within around 9-12 months.
- The time taken to rollout the new frequency bands is not likely to vary significantly between the bands in question; it depends hugely on the operator strategy for how the spectrum will be used and the resources available for deployment.

6.1.3 Device availability and operator timescales

- 700 MHz band devices are available at scale and able to support innovative services now. However, in the UK spectrum for use is not yet released. Rapid uptake is anticipated when spectrum becomes available.
- 1.4 GHz devices are becoming available during 2017 in their initial form and we anticipate rapid growth in their use in 2019. The band will attract sufficient device support to make useful to operators in supporting additional capacity but will not be a priority band for OEMs.
- 3.4 GHz devices are currently available, but primarily for FWA devices. We anticipate scale availability for smartphones from 2019. This band will be able to support higher bandwidths and user experience.
- 3.6 GHz devices will lag the 3.4GHz devices, but if the global regulatory barriers can be removed, we anticipate a rapid introduction since, like the 3.4 GHz band, it will also support higher bandwidths, TDD and additional antennas. 3.6 GHz band devices are not currently available at scale. The timescales for take-up are somewhat uncertain. Further, as discussed elsewhere in this document within the UK, particular barriers exist since an incumbent occupies a large fraction of the available bandwidth.

6.1.4 Overall findings

From the above analysis we have applied a factor scoring and combing that establishes the following conclusions:

- **700 MHz** band is usable on Q2 2020.
- **1.4 GHz** band is already available. However, operators need to find use cases to influence the OEMs. Currently it will not be a priority band for OEMs. We anticipate rapid introduction of devices from 2019 onwards hence, usable from 2019 onwards.
- **3.4 GHz** band will be usable as soon as smartphone type devices are available from 2020, at scale, but could be earlier from some OEMs.
- **3.6 GHz** band could become usable around 2023. The timescales are somewhat uncertain. it could be delayed into the late 2020s, with some constraints remaining almost indefinitely.

6.2 Future work

We make following the recommendations for further work beyond this project:

- An international comparison of these spectrum bands might be useful to strengthen the device and the spectrum availability.
- Study on the low band spectrum prior to 700MHz awards. This is heavily skewed to Vodafone/O2 at present, so there is an argument that perhaps Vodafone/O2 should be prevented from participating in those awards or should be limited in what they can buy.
- Development of further arguments and studies that demonstrate the whole spectrum allocation in the UK is not evenly distributed between operators – e.g. in comparison to other countries and this will hold back effective competition in the UK. This is not something that can be corrected overnight – but future awards should seek to improve the situation and not make it worse (as for example happened with the 800/2600 MHz auction).
- With reference to the point above – what should the 'maximum' allocation limits per operator be for future awards to achieve a better balance of spectrum in the UK. Ofcom argued strongly for a 4-player market during the recent take-over activities – they should now consider taking action to ensure that there are 4 viable players from a spectrum perspective – not two dominant ones and two weak ones as exists at present.
- Review of optimum deployment scenarios for new bands such as 2300 and 3500 MHz which are TDD. This would cover aspects such as is it best to deploy these bands as a TDD overlay, or integrate them via Carrier Aggregation into the existing FDD network. Also, whether to use the spectrum on macrocells, small cells, etc.
- Advanced preparation work on sites, to prepare for new bands and determine what form the site should take –e.g. 8x8 Multiple Input Multiple Output (MIMO) for 3.5 GHz might require a very different site deployment to standard 2x2 MIMO for 800/1800 MHz, etc.
- Explore different sharing options (including spectrum) to reduce costs and maximize user experience. Establishing whether emerging spectrum sharing initiatives have the potential to reduce capital spend. Establishing a radical departure from conventional thinking that would challenge regulatory positions prior to auctions. Our work from the 5G Infrastructure Public Private Partnership (5G-PPP) Horizon2020 project 5G- Novel Radio Multiservice adaptive network Architecture (5G-NORMA) [33], establishes the potential for economic gains, and user experience benefits, and viable steps to mainstream 5G techniques.

7. References

1 Ofcom consultation on Public Sector Spectrum Release (PSSR) Award of the 2.3 GHz and 3.4 GHz bands, 7 November 2014, https://www.ofcom.org.uk/__data/assets/pdf_file/0025/78055/Public_Sector_Spectrum_Release_2-3_and_3-4_ghz_award.pdf

2 3GPP TS 36.104 V14.1.0 (2016-09), E-UTRA Technical Specification; Base Station (BS) radio transmission and reception (Release 14), www.3gpp.org

3 Ofcom consultation on Award of the 2.3 and 3.4 GHz spectrum bands. Competition issues and auction regulations, 21 November 2016, https://www.ofcom.org.uk/__data/assets/pdf_file/0026/93545/award-of-the-spectrum-bands-consultation.pdf

4 The International Radio Regulations, published by the International Telecommunication Union. http://www.itu.int/pub/R-REG-RR.

5 Maximising the benefits of 700MHz clearance - Enabling acceleration of 700 MHz clearance and use of the 700 MHz centre gap. Statement published by Ofcom 17th October 2016, https://www.ofcom.org.uk/__data/assets/pdf_file/0031/92659/Maximising-the-benefits-of-700-MHz-clearance-Statement.pdf

6 European Commission - Press release, Brussels, 14 December 2016, europa.eu/rapid/press-release_IP-16-4405_en.pdf

7 Real Wireless report to Ofcom on Terminal capabilities in the 700 MHz band, 09 October 2013, https://www.ofcom.org.uk/__data/assets/pdf_file/0029/78581/Terminal_capabilities_in_the_700mhz_band.pdf

8 The 1452-1492 MHz and 3400-3800 MHz Frequency Bands (Management) Regulations 2016, April 2016, http://www.legislation.gov.uk/uksi/2016/495/pdfs/uksi_20160495_en.pdf

9 Ofcom statement on 29 May 2015, https://www.ofcom.org.uk/__data/assets/pdf_file/0022/82237/statement_on_1.4_ghz_licence_variation.pdf?lang=en

10 Public Sector Spectrum Release (PSSR) Competition and auction design issues for the 2.3 and 3.4 GHz spectrum award, including reserve prices – published by Ofcom on 26 October 2015, https://www.ofcom.org.uk/consultations-and-statements/category-1/2.3-3.4-ghz-auction-design/statement

11 Public Sector Spectrum Release, Update-3rd December, 2015 https://www.ofcom.org.uk/spectrum/spectrum-management/public-sector-spectrum-release

12 Public Sector Spectrum Release (PSSR): Award of the 2.3 GHz and 3.4 GHz bands. https://www.ofcom.org.uk/consultations-and-statements/category-1/2.3-3.4-ghz-auction-design

13 Email from Ofcom on the 16th December 2016.

14 The 1452-1492 MHz and 3400-3800 MHz Frequency Bands (Management) Regulations 2016, April 2016, http://www.legislation.gov.uk/uksi/2016/495/pdfs/uksi_20160495_en.pdf

15 Ofcom consultation on Improving consumer access to mobile services at 3.6 to 3.8 GHz, 6 October 2016, https://www.ofcom.org.uk/__data/assets/pdf_file/0035/91997/3-6-3-8ghz-consultation.pdf

16 Nokia extends 5G-ready AirScale radio and services portfolio to meet demands of cloud-based, ultra-connected world. 12 Sept 2016. http://www.nokia.com/en_int/news/releases/2016/09/12/nokia-extends-5g-ready-airscale-radio-and-services-portfolio-to-meet-demands-of-cloud-based-ultra-connected-world
17 700 MHz band - current status & approaches, 2nd Annual Asia-Pacific Spectrum Management Conference, Bangkok, April 2016, Hans-Martin Ilhe, NERA. http://www.nera.com/content/dam/nera/publications/2016/700_MHz_band_Hans_Ihle_NERA.pdf
18 Spectrum Strategic Opportunities and Enriching MBB, (page 17), http://extensia-events.com/wp-content/uploads/2014/06/Huawei-Workshop-Spectrum-Strategic-Opportunities-and-Enriching-MBB.pdf
19 APT700 A Truly Global LTE Band, Ericsson, February 2014. https://www.ericsson.com/res/docs/2013/ericsson-apt700-creating-a-truly-global-band.pdf
20 Global momentum and economic impact of the 1.4/1.5 GHz band for IMT, A report for the GSMA, October 2015, Plum. http://www.gsma.com/spectrum/wp-content/uploads/2015/10/1-4-1-5GHz-L-band-for-IMT-OCTOBER-2015.pdf
21 Nokia:- Easiest way to supplement downlink capacity. By Sukhpreet Sandhu on Tue 20 September, 2016. https://blog.networks.nokia.com//mobile-networks/2016/09/20/easiest-way-supplement-downlink-capacity/
22 NTT DoCoMo efforts concerning technical developments for Introducing TD-LTE in the 3.5-GHz frequency band https://www.nttdocomo.co.jp/english/binary/pdf/corporate/technology/rd/technical_journal/bn/vol18_2/vol18_2_002en.pdf
23 Nokia Networks, Deutsche Telekom and Cosmote show world's first 3.5 GHz LTE FDD-TDD 3 carrier aggregation, 24 Nov 2015. http://www.nokia.com/en_int/node/40701
24 UK Broadband switches on first commercial 4G TD LTE system in the UK. http://www.ukbroadband.com/about-us/press-releases/press-release-1
25 GSA, Evolution to LTE report, 4G MARKET and TECHNOLOGY UPDATE, LTE TDD (TD-LTE) global status, October 26, 2016. http://gsacom.com/paper/gsa-snapshot-lte-tdd-td-lte-global-status-2/
26 Nokia announces AirScale-powered 4.5G Pro and 4.9G to establish smooth path for operators to 5G. 1st Sept 2016. http://www.nokia.com/en_int/news/releases/2016/09/01/nokia-announces-airscale-powered-45g-pro-and-49g-to-establish-smooth-path-for-operators-to-5g

27 Ofcom consultation on the variation of Concurrent Spectrum Access 1781 MHz Licence. May 2016. https://www.ofcom.org.uk/consultations-and-statements/category-1/talk-talk-licence-variation.
28 Real Wireless report for Ofcom, Terminal capabilities in the 700MHz band. Oct 2013.https://www.ofcom.org.uk/__data/assets/pdf_file/0029/78581/Terminal_capabilities_in_the_700mhz_band.pdf.
29 Ofcom Statement. Decision to make the 700 MHz band available for mobile data – statement. Nov 2014. https://www.ofcom.org.uk/consultations-and-statements/category-1/700mhz/statement.
30 Huawei: China Mobile goes big with TDD LTE. 2014

http://www1.huawei.com/en/about-huawei/publications/winwin-magazine/hw-319348.htm
31 Gartner: RIP double-digit smartphone growth. 2016 has killed you. March 2016. http://www.theregister.co.uk/2016/03/31/gartner_2016_smart_phone_boom_years_gone/

32 Imagine to start roll-out of €200m fast broadband system in 2016. Dec 2015. http://www.independent.ie/business/technology/news/imagine-to-start-rollout-of-200m-fast-broadband-system-in-2016-34297484.html.
33 5GNorma Project project website, https://5g-ppp.eu/5g-norma/

Annex A: Network Infrastructure: Stages

Typically, there are several stages leading to the support of a new frequency band within network infrastructure, as follows (note some of these stages may be conducted in parallel):

1. Standards development
2. Base Transceiver Station (BTS) hardware development
3. BTS software development
4. Testing and Trials
5. General availability for commercial deployment.

A brief overview of each of these steps is presented in turn. Unless otherwise stated, where full infrastructure support is indicated for a new band then all of these steps will have been completed. This infrastructure support is a necessary (but not sufficient) condition for a frequency band to be useable for mobile. Where some or all of these steps are yet to be completed, this is indicative of a significant lead time for a band to become useable.

Standards Development

Any new frequency band needs to be incorporated into the 3GPP standards. The speed with which this is achieved will largely depend on the market drivers for the band and the 'weight' and commitment of the organisations pushing it. Much of the work in the standards is undertaken by the vendor community, so the approach is usually for the operators that require the new band to gain support from their vendors and then together they will drive it through the various 3GPP committees.

All the bands in question have been standardised and are therefore included in the LTE specifications with band allocations as have been presented earlier in the paper. Therefore, standard support does not present a barrier to their introduction.

It should be noted however, that operators may wish to combine some of these new bands with other pre-existing bands through Carrier Aggregation. This also requires work in standards, and the development of specific test regimes. As the number of 3GPP bands grows, so do the possible number of band permutations that can be combined through Carrier Aggregation. In this analysis, we have considered that a band is standardised and supported in network infrastructure once this is the case for the primary band. This does not necessarily imply that all the potential Carrier Aggregation band permutations are supported.

BTS Hardware Development

A new frequency band requires BTS hardware to be developed to support it. Typically, this requires new or modified Radio modules (transmitters and receivers) and filters. New or replacement antenna systems may also be required. Normally the BTS Baseband Unit (BBU) is spectrum band agnostic from a hardware perspective, but would require new software (see next section).

Information from vendors indicates that new bands are now taking typically 9-12 months to develop and be produced in volume, but for small quantities it is possible to produce

prototypes in significantly less time. Also, lead times are reduced when it is possible to reuse elements from other bands, for example the MIMO order or especially an existing filter design. This is important when considering, for example, sub-bands of Band 28 (at 700MHz) or when it is necessary to increase the MIMO order from 2x2 up to 8x8 and beyond for a certain frequency band. It is understood that special filters with quicker roll-off were required to support the 800MHz band (band 20) and it is likely that this learning and similar technology would be re-used to support 700MHz (Band 28).

BTS Software Development

As well as new hardware, a new frequency band also requires new software. Typically, this is developed in parallel with the hardware and included in the next available overall software release. In the case of development for a new band, the software can include support for the new frequency as both a new standalone band, as well as in combination with other bands through Carrier Aggregation. Once the basic frequency band is supported then new Carrier Aggregation combinations can be added within future software releases.

Testing and Trials

The next stage is to undertake testing of the infrastructure hardware and software solution supporting the new band. Initially, this will be undertaken in a lab environment, potentially with a simulated device if no commercial devices are available which support the new band. The final stage of testing is to undertake a pilot with a friendly operator. This usually takes place in a controlled area of a commercial network but is subject to commercial traffic, and ideally commercially available devices.

General Availability

Once the hardware and software has been tested and the infrastructure successfully deployed in a pilot, then it can be released for General Availability. This indicates that the infrastructure solution is now fully available and supported. Processes and procedures vary between individual vendors, but many vendors will not declare an infrastructure solution as GA (General Availability) unless they have been able to verify it with a commercially available device, or at least a pre-release device.

realwireless
independent wireless experts

Real Wireless Ltd
PO Box 2218
Pulborough
West Sussex
RH20 4XB
United Kingdom

t +44 207 117 8514
f +44 808 280 0142
e info@realwireless.biz
www.realwireless.biz