Annex 13 - Final report for Three UK

Consequences of Ofcom's categorisation of frequency bands in its latest consultation on the award of the 2.3GHz and 3.4GHz spectrum bands

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Contents

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1 Executive summary

1.1 Introduction and context

This document sets out Analysys Mason's assessment of the timing of likely future spectrum availability in the UK and its potential for use by mobile network operators (MNOs) in the provision of 4G and 5G services. The assessment has been prompted by Ofcom's latest consultation on the award of spectrum in the 2.3GHz and 3.4GHz bands.

1.1.1 Background and overview of Ofcom's proposals

Ofcom initially consulted on competition issues associated with the award as part of a wider call for inputs in October 2013,[1] followed by a second consultation in November 2014,[2] a statement and further consultation in May 2015, and a final statement and accompanying Information Memorandum published in October 2015.[3]

In previous consultations, Ofcom's view moved from an initial position in which competition issues arising from highly asymmetric spectrum holdings between different UK MNOs would warrant a cap on total spectrum holdings including both 2.3GHz and 3.4GHz (as per the October 2013 consultation proposals), to one where no competition measures at all were proposed (as per the Information Memorandum, in October 2015).

In the latest consultation, Ofcom sets out in its assessment of the potential competition concerns and associated competition measures required in the 2.3GHz and 3.4GHz spectrum award, that it sees a distinction between 'immediately usable' bands and those that are 'not immediately usable'. In Ofcom's view, the 2.3GHz band will be immediately usable following the PSSR award, whereas the 3.4GHz band will not. Hence, Ofcom proposes a cap encompassing holdings in the 2.3GHz band but no longer in the 3.4GHz band. Both the nature of the assessment (i.e. the division of bands into different time windows of availability and use) and the nature of the competition measure now being proposed (i.e. a cap only applying to immediately usable spectrum holdings, excluding 3.4GHz) depart from Ofcom's previous assessments where both PSSR bands have been considered together from the perspective of calculating spectrum shares and assessing competition issues.[4] It is noted that the level of the proposed cap (255MHz) has the effect of preventing BTEE from bidding for any 2.3GHz spectrum, but has no impact on any other potential bidder.

1 https://www.ofcom.org.uk/__data/assets/pdf_file/0018/45630/2.3-3.4-ghz.pdf.

2 https://www.ofcom.org.uk/__data/assets/pdf_file/0026/33497/pssr.pdf.

3 https://www.ofcom.org.uk/__data/assets/pdf_file/0023/71717/pssr-statement.pdf.

4 The different treatment of the two bands comes about because Ofcom considers that the 3.4GHz spectrum is 'not immediately usable' and takes the view that MNOs will be able to mitigate not winning 3.4GHz spectrum through a variety of measures, such as the acquisition of other mobile spectrum to be awarded by Ofcom in the future.

Ofcom notes possible concerns about unintended consequences of competition measures related to the 3.4GHz band in view of recent interest in this band for 5G and uncertainty over how 5G plans will emerge. However, it does not identify specific concerns to be addressed within the PSSR award concerning the consequences of an asymmetric assignment of 3.4GHz frequencies between operators in the context of subsequent feasibility of 5G introduction into the UK market.

Ofcom's current proposals therefore set no limit on 3.4GHz holdings, with the result that all bidders are unconstrained in their bidding in this band. This approach results in risks to the UK MNOs with smaller existing spectrum holdings (i.e. Three and O2) in relation to concentration of spectrum holdings both in the short and longer term. The transitional period that Ofcom identifies between the PSSR award and subsequent planned awards (e.g. of 700MHz) overlaps with a period during which 5G services are expected to enter the UK market. Hence, it will be important that competition issues (both short and long term) are addressed to avoid significant uncertainty during a period in which MNOs are planning major new infrastructure investments for 5G.

1.1.2 Scope of our assignment and approach followed

Three has asked Analysys Mason to examine these issues, producing this report. Specifically, Analysys Mason has been asked to focus in detail on two points:

- The likely timing of availability and usability of the PSSR spectrum bands (2.3GHz and 3.4GHz) along with other bands that might be used for mobile services in the UK in the short-to-medium term, including L-Band (1.4GHz) spectrum, which is available to UK MNOs but is not yet usable, and two other yet-to-be awarded spectrum bands that Ofcom considers in its consultation, namely the 700MHz band and the 3.6–3.8GHz band.

- Whether any of the above spectrum bands are likely to offer MNOs a route to offering 5G services – along with other possible bands that might be relevant to 5G – and the implications of this.

In light of our findings, our report aims to consider:

- Whether or not the framework adopted by Ofcom to categorise spectrum into distinct categories of 'immediately usable' and 'not immediately usable' is appropriate and, if so, whether the relevant bands have been correctly categorised.

- To the extent that Ofcom's framework is inappropriate and/or bands are incorrectly categorised within that framework, the impact (qualitatively) on the appropriateness of the competition measures proposed by Ofcom.

- Whether or not Ofcom's concern about potential unintended consequences of competition measures related to 3.4GHz is valid given what we know about future 5G services, and indeed whether Ofcom fails to recognise other potential competition concerns in relation to 5G provision.

Our approach to examining the issues relevant to the timing of spectrum availability and use has been to focus on three key factors affecting the availability and usage of different bands for mobile:

- the availability of network equipment, through consideration of existing deployments of each band
- the ecosystem for devices (handsets, dongles, routers and other devices) in each band
- timing of harmonisation measures at a European Union (EU) level and plans for future awards of the different bands in other parts of Europe.

From these factors, we have developed an 'overall readiness for use' assessment to compare the availability and usability of different bands for mobile services and to identify where uncertainties (in timing of availability and usability) might lie. In relation to 5G, we have specifically examined recent developments in standards and statements on spectrum priorities relating to early 5G deployment in Europe and considered the relevance of these developments to the award of the 3.4GHz frequencies within the PSSR.

1.2 Key findings, implications and conclusions

1.2.1 The framework adopted by Ofcom to categorise spectrum appears inappropriate

Deployment of networks and availability of network equipment

A significant number of commercially deployed networks already use LTE TDD technology in the 2.3GHz band, and a growing number of devices (including handsets and smartphones) are available to use this band. There are somewhat fewer LTE TDD networks operating the 3.4GHz band than in the 2.3GHz band when considered globally, and significantly fewer devices. However, there are more LTE TDD commercial networks in Europe in the 3.4GHz band than in the 2.3GHz band, with the likelihood of additional networks being deployed in the 3.4GHz band in future. Hence, prospects for usability of the 3.4GHz band are likely to quickly improve once further European 3.4GHz awards are completed. We note there are various other European 3.4GHz awards in preparation (with some of these awards relating to frequencies both in the 3.4GHz band and in parts of 3.6–3.8GHz).

Current use of the 2.3GHz spectrum by the military in most European countries leads to some uncertainty as to how quickly the European deployment map will change in the 2.3GHz band. However, given deployments outside of Europe, and their effect on availability of network equipment, this is unlikely to constrain the deployment of 2.3GHz in the UK once it is awarded.

By comparison, the European 3.4GHz deployment map is likely to change more quickly, driven by the industry's ambition to make the 3.4GHz band available for mobile use for LTE TDD or 5G. The implication of this is that network equipment should be readily available for the 3.4GHz band for LTE TDD deployment in Europe, and a broader device ecosystem, including handsets, is expected to develop. Whilst there are also prospects for the 3.6–3.8GHz band to be awarded for mobile use in various European markets, we note that the ecosystem for this band is some way

behind both 2.3GHz and 3.4GHz at present. In particular, there has, to date, only been one deployment of LTE TDD in this band globally.

The ecosystem for devices in each band

There is a strong device ecosystem in the 2.3GHz band, even when accounting only for devices that are suitable for use in Europe. Our analysis – based on data obtained from the Global mobile Suppliers Association analyser for mobile broadband devices (GAMBoD),[5] cross-checked against our own understanding based on devices being marketed by MNOs – shows that the 2.3GHz device ecosystem is unlikely to be a significant hindrance to 2.3GHz deployment. This is because, although there has been only limited implementation of 2.3GHz networks in Europe to date, it is a band that is widely used in other parts of the world, meaning that it is already supported in devices. Hence, it is a band that can be deployed alongside the other spectrum bands that UK MNOs use, to supplement existing network capacity. It is noted that implementation options for 2.3GHz will have some limitations in the short term, because enabling TDD operation alongside the FDD bands more commonly used by UK MNOs may give rise to some implementation issues. For example, there has been a delay in devices supporting carrier aggregation (CA) between 2.3GHz and other mobile bands relevant to the UK 4G market (e.g. 1800MHz) becoming available. Furthermore, although a range of 2.3GHz handsets is already available, these handsets have tended to be priced at the high end of the market, typically only used by a smaller subset of mobile subscribers. These issues are likely to only affect the short-term use of the 2.3GHz band in the UK however, and it is expected that, as the 2.3GHz band becomes more widely implemented in Europe, a broader range of handsets across all price points in the market will rapidly develop.

Although the device ecosystem for 3.4GHz is currently some way behind that of 2.3GHz, we expect that, with increasing certainty around the future intended use of the 3.4GHz band, the device ecosystem has the potential to grow very rapidly, as has been observed previously for 'new' frequency bands for mobile use, such as for the 2.6GHz FDD and TDD bands for example.

The 3.6–3.8GHz band, whilst starting from a similarly low base of devices to the 3.4GHz, is likely to develop much more slowly. This is due to the lack of existing deployments in the band and the more significant uncertainty surrounding the timing of its future harmonised use.

EU harmonisation and planned network deployments

European countries are generally following the European Common Allocation (ECA) agreements on the use of 2.3GHz, 3.4GHz and 3.6–3.8GHz. It is noted that the ECA table gives co-primary status to 'Fixed' and 'Fixed Satellite' use in the 3.4GHz and 3.6–3.8GHz bands, meaning that there is some variation in practice across Europe (with fixed satellite use being dependent on the location of satellite earth stations, which are unevenly distributed between different countries). There are a few countries in Europe where mobile use does not have a primary allocation in both the 3.4GHz and 3.6–3.8GHz bands, with a greater number of instances of this in the 3.6–3.8GHz

5 See Global mobile Suppliers Association for details, http://gsacom.com/gambod/.

band. We have examined two countries (Belgium and Italy) where mobile does not even have a secondary allocation in the 3.6–3.8GHz band, being principally used for fixed links and fixed satellite service (FSS) earth stations.

Plans for future awards of 2.3GHz, 3.4GHz and 3.6–3.8GHz are somewhat fragmented at present, although a noteworthy number of regulators are now recognising the potential use for mobile services in one or more of these bands and are launching consultations. Several European countries – notably the UK – have a greater concentration of satellite earth station use in the 3.6–3.8GHz band, which raises concerns about the ease with which it will be able to be freed up for future awards for mobile use. Hence, where there are proposals (even at a preliminary level) to award the 3.6–3.8GHz band for mobile use, it tends to be in those countries without satellite earth stations using the spectrum. The fragmented picture of potential mobile use of the 3.6–3.8GHz band in different European countries is likely to affect the scale and timing of ecosystem development and take-up of this band.

Summary of our findings in relation to the relevant spectrum bands

Based on our analysis, future spectrum availability and usability in the UK across all the bands considered (2.3GHz, 3.4GHz, 3.6–3.8GHz, L-Band and 700MHz) could range from 2017 to 2023 (or beyond). The potential timelines for different bands becoming usable, and the uncertainties associated with each, are summarised below.

- 2.3GHz spectrum will be available for use shortly after the PSSR auction. Deployment and device considerations suggest the spectrum could be put into commercial deployment in the UK as early as the end of 2017 to address some segments of the market (particularly high-data subscribers using high-end devices). Fully flexible deployment options for the 2.3GHz band to be combined with other FDD bands used by MNOs in the UK may have some limitations initially, but these are expected to only be short-term effects – for example, in relation to potential for CA with existing FDD bands, which has been delayed compared to other CA options due to the sequence of standardisation within 3GPP, but is now becoming available.

- 3.4GHz will also be usable shortly after the PSSR auction, although widespread use will initially be limited due to a lack of device availability. However, the high level of industry attention that the 3.4GHz band is receiving in the context of the global spectrum squeeze and early planning for 5G suggests that the ecosystem for this band could develop rapidly. Taking this into account, full usability of this band, including a critical mass of customers holding compatible handsets, could occur from the end of 2019, in our view.

- L-Band spectrum is already licensed for use to Three and Vodafone and has also been awarded for mobile use in some other European markets. Our view is that the L-Band could begin to become usable in a similar timeframe to the 3.4GHz band, and potentially as early as 2018 or 2019, although there is some uncertainty due to the relatively limited device ecosystem for this band to date.

- 3.6–3.8GHz spectrum is also receiving a high level of industry attention in Europe, and the eco-system for this band could, in theory, also evolve rapidly once there is greater certainty surrounding harmonised European plans for 5G. However, to date there have been virtually no mobile deployments in this band, and harmonisation is less clear than for other bands, meaning that availability of both network equipment and devices is uncertain. Furthermore, this band is not immediately available for mobile use in the UK and various other European countries due to the need to transition existing fixed and fixed satellite services from the band. Hence, although this band is being proposed for mobile award in some other European countries (such as Ireland, Slovenia, Switzerland and the Czech Republic), ensuring sufficient availability of spectrum in this band for mobile use in the UK is not straightforward. As such, timescales for this spectrum being available for mobile use in the UK are far from certain, and we do not expect this spectrum to be usable until after 2022.

- Ofcom has previously stated that the 700MHz spectrum cannot be available for mobile use before Q2 2020 and possibly later, due to the need to complete digital terrestrial television (DTT) and programme making and special events (PMSE) clearance in 700MHz. A similar picture on timing for mobile use applies in various other European countries. At a European level, the European Commission (the Commission) is recommending this band should be awarded for mobile use by around 2020. We note that an accelerated timescale for DTT migration has been proposed in the UK, however the detailed implementation of this is subject to some uncertainty both in relation to the complexity of re-deploying DTT networks and to ensuring a smooth migration (and usable alternative spectrum) for PMSE. Notwithstanding this, once available, at least 2×30MHz of spectrum in the 700MHz band is likely to be quickly usable due to the growing equipment eco-system supporting the use of this band that is being developed from outside Europe at present. Therefore, we estimate that this spectrum will become usable within six months of its availability for mobile, once network equipment has been deployed i.e. the end of 2020.

Implications and conclusions in relation to Ofcom's categorisation framework

Our view is that various factors affect when spectrum will be usable within different UK networks, many of which are subject to some uncertainty. Taking these uncertainties into account, a more holistic view of spectrum availability is needed rather than Ofcom's imprecise categorisation into buckets labelled 'immediately usable' and 'not immediately usable'. The reality is more likely to be that new spectrum is likely to become available and usable in the coming years on a continuous basis. Hence, bands are not readily categorised into 'immediately usable' and 'usable following a transitional period of set length' as Ofcom attempts to do.

Specifically, our analysis finds that the timeframe in which the 2.3GHz band could be deployed in UK networks might be around two years ahead of the 3.4GHz band. The 3.4GHz band ecosystem could develop quickly once spectrum is available for mobile use and therefore timescales for use of 3.4GHz are not likely to be materially different to the L-Band, with the 700MHz and 3.6–

3.8GHz bands (and potentially 5GHz and millimetre-wave bands for 5G) becoming usable after this.

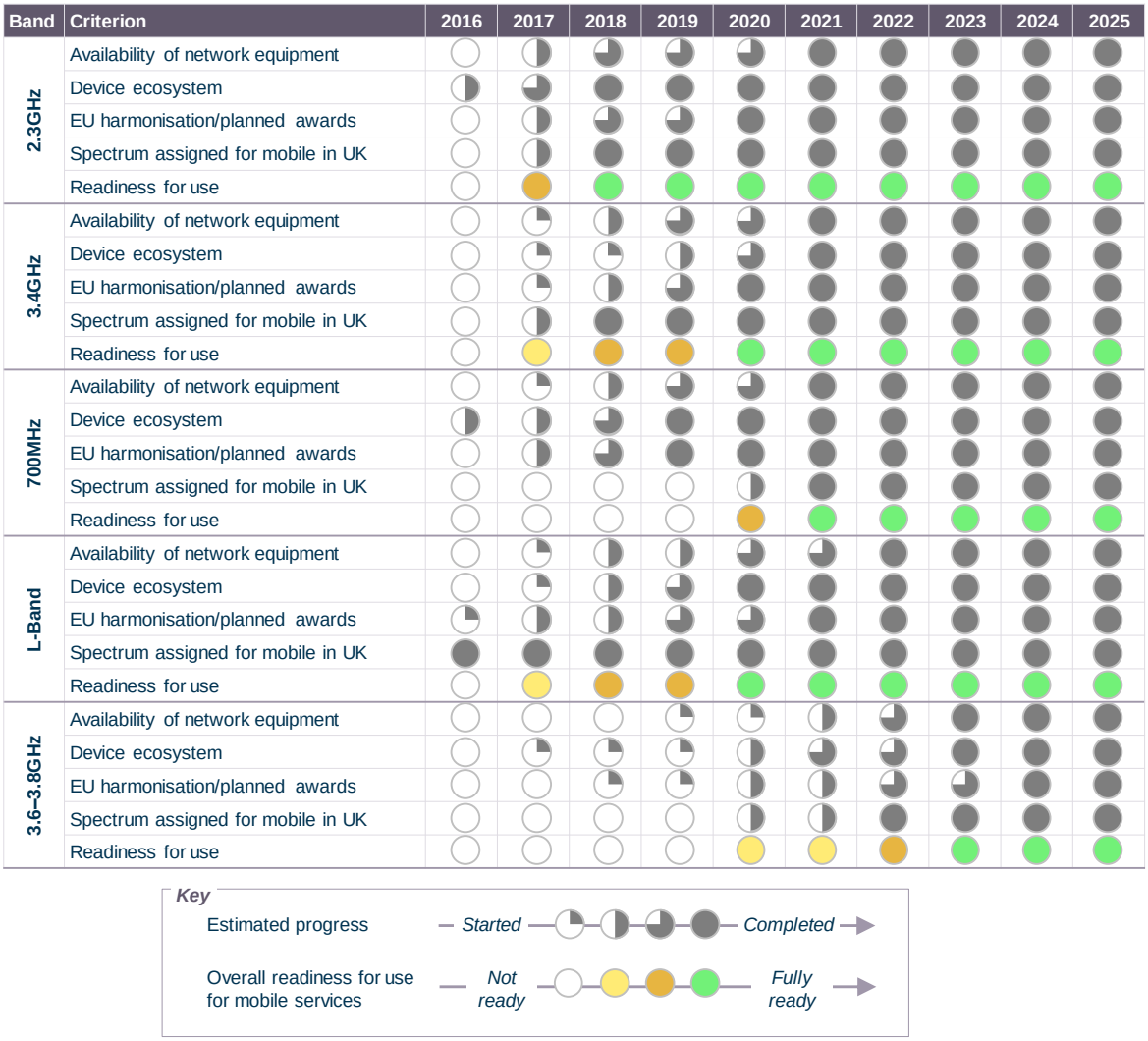
We have summarised the factors driving the readiness of each band for use in the UK in Figure 1.1 below. The figure considers the three factors discussed above (namely the availability of network equipment, the device ecosystem and the level of EU harmonisation) alongside consideration of when the spectrum is likely to be assigned for mobile use in the UK. An overall 'readiness for use' indicator is then provided by combining the individual factors. The overall readiness indication is based on colour coding as follows:

- *Green* – indicates a high level of confidence that spectrum will be available for use by mobile operators in the UK without any significant impediments, based on harmonisation being in place network equipment readily available, a range of suitable devices being available and sufficient economies of scale existing to ensure that the band is attractive for MNO use.

- *Orange* – indicates that the band could be used by MNOs in the UK, but with some uncertainties and/or impediments to its use. There is likely to be some uncertainty in relation to one or more key factors in determining the band's readiness for use, as well as potentially to whether it will have been licensed for mobile use in the UK.

- *Yellow* – indicates that the band is unlikely to be usable by mobile operators in the UK due to one or more specific impediments to its use, although some progress is likely to have been made towards resolving these issues. For example, whilst there may be some network equipment and suitable devices, along with some level of international harmonisation, we expect that more development will be needed in each of these areas. It may also be uncertain as to whether the spectrum will have been licensed for use by UK mobile operators within the relevant timeframe (e.g. due to uncertainty associated with migrating incumbent users from a band).

Figure 1.1: Estimated readiness of spectrum bands for mobile use in the UK in the next 10 years based on findings presented in this report [Source: Analysys Mason, 2017]

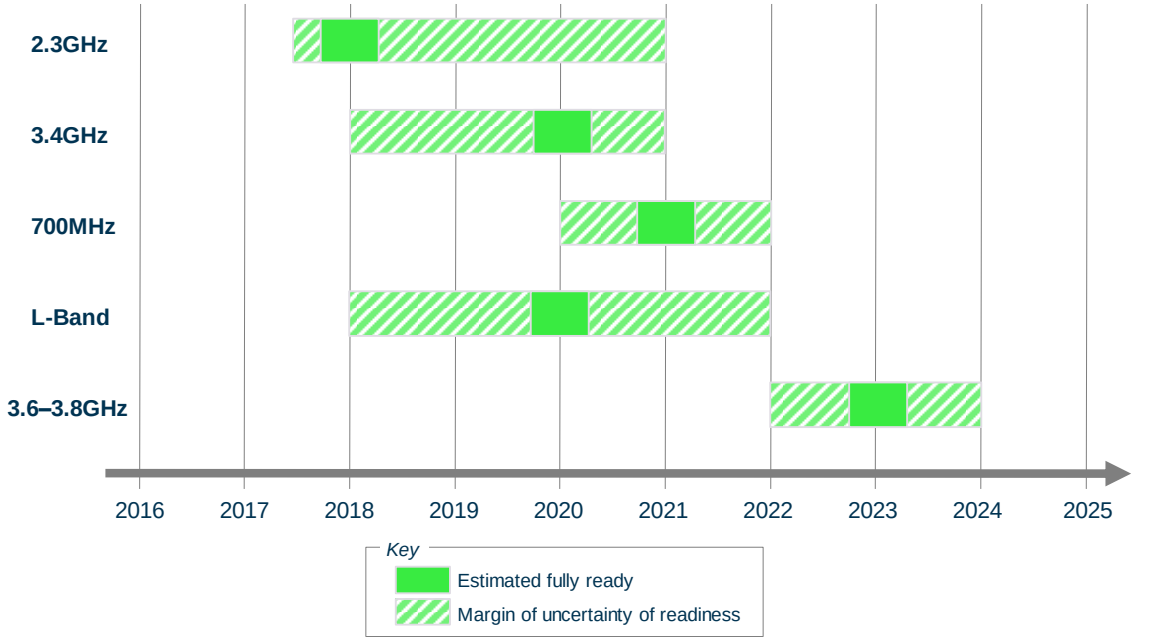


Based on the analysis above, we can conclude that whilst the 3.4GHz band lags behind the 2.3GHz band by around two years, the 3.4GHz band is likely to be available and ready for use ahead of both the 700MHz and 3.6–3.8GHz bands. Whilst the L-Band is already assigned for mobile use, devices have only recently started to become available and hence, although there might be initial deployment before 2020, full usability will depend on a broader range of devices becoming available. The 700MHz band is a further year behind this and the 3.6–3.8GHz band is only likely to be available and ready for wide-scale use in the UK beyond 2022.

The analysis shows that there is some uncertainly in factors affecting readiness for use of different bands (e.g. European awards might be delayed, or device availability might not develop as expected). Based on the analysis set out in Figure 1.1, Figure 1.2 provides our best view on where these uncertainties lie in relation to when each band may become available and ready for use in the UK. In the diagram below, the shaded area shows the possible margin of error on the timing of readiness for each band around our estimation of the year in which the band becomes fully ready for use. For example, while we estimate the L-Band being usable by 2020, the full usability could

be delayed to 2022 if there is a delay to a full ecosystem of devices for the L-Band (including at all relevant price points in the UK market) becoming available.

Figure 1.2: Spectrum availability and usability in the UK [Source: Analysys Mason, 2017]



On the basis of our analysis, we consider it is not possible to conclude that bands are either 'immediately usable' or not, since some bands that do not appear to be immediately usable could become so if certain factors in their development are accelerated beyond current predictions. It is therefore not possible to conclude that the only immediately usable band for additional mobile use in the UK will be the 2.3GHz band. As such, the framework does not appear appropriate as a means of assessing competition concerns. We also note some specific competition concerns that fall outside of Ofcom's framework (e.g. in relation to 5G), which are further elaborated below.

1.2.2 The competition measures proposed by Ofcom may fail to solve the real competition concerns

Because the framework used by Ofcom is inappropriate, the competition concerns that Ofcom identifies are not, in our view, assessed properly. This, in turn, leads to competition measures being designed to address the wrong competition concerns.

As such, our view is that Ofcom needs to adopt a more appropriate framework and, based on that, identify a revised set of competition concerns. Only then can it be determined whether the proposed competition measures are likely to be adequate or not.

Our high-level view is that there are very real concerns about an asymmetric distribution of spectrum that are not limited to any 'transitional period'. That being the case, it seems likely that a competition measure applying narrowly to a small portion of the available spectrum is not likely to be adequate to address these competition concerns.

If the correct framework is used and appropriate competition concerns are identified, it seems likely that competition measures would need to encompass both 2.3GHz and 3.4GHz spectrum in aggregate, although this would need to be carefully determined by Ofcom.

Furthermore, although not strictly within the scope of our detailed analysis, we consider that there is an additional factor which should be considered in relation to the 700MHz band. Although the 700MHz band is almost certain to become available in the UK and, due to high levels of international harmonisation, is likely to be usable not long after 3.4GHz, it is not a particularly close substitute. For 700MHz, there is limited bandwidth available in the band so its distribution is unlikely to significantly affect asymmetries in spectrum holdings. Further, policy goals related to coverage may make specific award proposals in this band incompatible with an aim of reducing spectrum asymmetries. Awards to date in this band in Europe tend to exhibit reasonably equitable distributions of the spectrum amongst MNOs due to the primary use being for coverage. Therefore, it seems unlikely that any competition concern relating to asymmetric distributions of spectrum following the PSSR award could, in practice, be solved using the 700MHz award mechanism.

1.2.3 Ofcom's concern about potential unintended consequences related to 5G appear to miss the bigger picture

Despite a fragmented picture in Europe in terms of current use of 3.4GHz and 3.6–3.8GHz, European regulators have broadly united behind a key goal of making the combined 3.4–3.8GHz band available for early 5G deployment. However, there is acknowledgement that the current use of the two sub-bands (i.e. 3.4GHz and 3.6–3.8GHz) is fragmented, with different regulators opting for different solutions at present.

Vendors are suggesting that channel widths of 80–100MHz or more are optimal for 5G-New-Radio use. However, it is considered likely that channels can be aggregated in the same way as they can for LTE-A (e.g. between 3.4GHz and 3.6–3.8GHz).

Given the potential delay in the availability of 3.6–3.8GHz in the UK, it seems likely that 3.4GHz provides the earliest route to 5G, followed, potentially, by 700MHz and then 3.6–3.8GHz. In this context, we consider that Ofcom's analysis potentially underplays the longer-term competition risks arising from the 3.4GHz band being assigned asymmetrically in the UK market. Not addressing these longer-term competition issues at the current time has the potential to create significant uncertainty that it is not clear that measures within subsequent awards (e.g. of 700MHz and 3.6–3.8GHz) will address.

In our view, there is a clear competition concern with assigning the spectrum such that not all MNOs gain a reasonable portion of 3.4GHz, if it turns out that this band is the only early route to 5G. At the very least, this would significantly disadvantage at least one MNO from a marketing perspective as well as in terms of ability to attract new customers and retain existing ones. Even though there may be benefits of having larger bandwidths available to individual MNOs in the 3.4GHz band for the purposes of providing full 5G functionality (although the magnitude of this

benefit is uncertain), it is probable that these benefits would still be outweighed by the likely harm to competitive intensity if not all MNOs have the same early route to 5G. We also understand that the industry's intention is that CA (or equivalent) will be specified between 3.4GHz and 3.6–3.8GHz, such that it is not necessary for MNOs to hold contiguous wider spectrum blocks in one or other of these bands but that smaller blocks can be aggregated in a similar way to in 4G. Hence operators acquiring 3.4GHz spectrum in the PSSR award would have the opportunity to aggregate this with spectrum acquired in the 3.6–3.8GHz band once this is available for mobile use in the UK.

Hence, the optimal approach for competition in the UK would seem to be that each MNO gains a minimum portion of the available 3.4GHz spectrum, which can then be combined with more spectrum in 3.6–3.8GHz band once available.

2 Introduction

This document is the final report of Analysys Mason's assessment of the timing of likely future spectrum availability in the UK and its potential for use by mobile network operators (MNOs) in the provision of 4G and 5G services. The assessment has been prompted by Ofcom's latest consultation on the award of spectrum in the 2.3GHz and 3.4GHz bands.

2.1 Background and context

The Public Sector Spectrum Release (PSSR) programme has resulted in the release of spectrum in the upper 2.3GHz and 3.4GHz bands by the Ministry of Defence to Ofcom. This spectrum is now the subject of a planned auction by Ofcom, which Ofcom indicates in the consultation will occur "as soon as practical after the publication of our final statement on the award", which we expect to be in 2017.

In previous consultations, Ofcom has indicated competition concerns associated with the risk of highly asymmetric spectrum holdings between different UK MNOs following the award. Ofcom had originally proposed a cap on total spectrum holdings for the PSSR award, including within the cap all spectrum to be awarded in the 2.3GHz and 3.4GHz bands (consistent with the approach taken by Ofcom during the '4G auction' for 800MHz and 2.6GHz frequencies).

However, in the latest consultation, Ofcom has instead proposed a cap on 'immediately usable' spectrum, limiting the effect of the proposed competition measures to the 2.3GHz spectrum only. Ofcom has not included the 3.4GHz spectrum in competition measures in the latest proposals because it considers this band is 'not immediately usable' and takes the view that MNOs will be able to mitigate not winning 3.4GHz spectrum through a variety of measures, though mainly the acquisition of other spectrum to be awarded by Ofcom in the future. Ofcom also notes possible concerns about unintended consequences of competition measures related to the 3.4GHz band in view of recent interest in this band for 5G and uncertainty over how 5G plans will emerge.

2.2 Scope of our assignment

Three has asked Analysys Mason to examine these issues, producing this report. Specifically, Analysys Mason has been asked to focus in detail on two points, which are related to Ofcom's analysis:

- The likely timing of availability and usability of the PSSR spectrum bands (2.3GHz and 3.4GHz) along with other bands that might be used for mobile services in the UK in the short to medium term, including L-Band (1.4GHz) spectrum, which is available to UK MNOs but is not yet usable, and two other yet-to-be awarded spectrum bands that Ofcom considers in its consultation, namely the 700MHz band and the 3.6–3.8GHz band.

- Whether any of the above spectrum bands are likely to offer MNOs a route to offering 5G services – along with other possible bands that might be relevant to 5G – and the implications of this.

In light of our findings, our report aims to consider:

- Whether or not the framework adopted by Ofcom to categorise spectrum into distinct categories of 'immediately usable' and 'not immediately usable', is appropriate and if so whether the relevant bands have been correctly categorised.

- To the extent that Ofcom's framework is inappropriate and/or bands are incorrectly categorised within that framework, the impact (qualitatively) on the appropriateness of the competition measures proposed by Ofcom.

- Whether or not Ofcom's concern about potential unintended consequences of competition measures related to 3.4GHz is valid given what we know about future 5G services, and indeed whether Ofcom fails to recognise other potential competition concerns in relation to 5G provision.

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- the availability of network equipment, through consideration of existing deployments of each band
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- timing of harmonisation measures at an EU level and plans for future awards of the different bands in other parts of Europe.

From these factors, we have developed an 'overall readiness for use' assessment to compare the availability and usability of different bands for mobile services and to identify where uncertainties (in timing of availability and usability) might lie. In relation to 5G, we have specifically examined recent developments in standards and statements on spectrum priorities relating to early 5G deployment in Europe and considered the relevance of these developments to the award of the 3.4GHz frequencies within the PSSR.

2.3 Structure of this document

The remainder of this document is laid out as follows:

- Section 3 provides an overview of Ofcom's past and present proposals relating to competition measures for PSSR spectrum and identifies the issues with these proposals related specifically to our scope of work
- Section 4 discusses deployment of LTE and LTE-A networks in the relevant bands to help understand the likely availability of network equipment
- Section 5 assesses the development of device ecosystems for LTE and LTE-A

- Section 6 summarises the current usage and award proposals in other European markets in the relevant bands with a view to understanding possibilities for harmonised use in the UK
- Section 7 discusses global opportunities for 3.4GHz and 3.6–3.8GHz spectrum in the context of 5G commercialisation
- Section 8 summarises the overall implications and conclusions from our analysis.

The report includes several annexes containing supplementary material:

- Annex A provides additional material in support of data and analysis presented in the main body of the report
- Annex B includes further analysis of the availability of devices from major manufacturers that are compatible with the different spectrum bands
- Annex C contains supporting data on current use of the 3.4GHz and 3.6–3.8GHz bands in Europe.

3 Overview of Ofcom's proposed competition measures and the aspects of these proposals we have been asked to assess

In this section, we summarise how Ofcom has arrived at its proposed competition measures based on previous and the current consultation, followed by our views on the issues arising from assessing these proposals.

3.1 How Ofcom has arrived at its proposed competition measures

Ofcom has published a series of consultations associated with finalising award conditions for 2.3GHz and 3.4GHz spectrum – the latest consultation published on 21 November 2016 follows on from a series of earlier consultations, statements and an Information Memorandum. Most of the previous consultations and statements considered competition issues and award proposals, treating the PSSR spectrum bands together. The November 2016 consultation is the first time that Ofcom has proposed a competition measure only applying to the 2.3GHz band.

3.1.1 Ofcom's previous consultations and statements

Ofcom's proposals for the award of PSSR spectrum have evolved since 2013.

Ofcom's first detailed consultation and call for input on various aspects of the PSSR award (October 2013) invited views on likely uses of the 190MHz of spectrum being released by MOD in the 2.3GHz and 3.4GHz bands. In this document, Ofcom indicated that, in view of the amount of spectrum being released, it would be appropriate for Ofcom to consider the potential implications for competition in mobile markets, and that "we will conduct a more detailed assessment of these implications in a subsequent consultation".[6] The initial assessment in this document was that, if potential competition concerns were identified, an overall spectrum cap on relevant bands might be appropriate (proportionally consistent with the overall cap in the UK 4G award).[7]

A more detailed assessment on competition issues was then set out in Ofcom's PSSR consultation document in November 2014. In that consultation, spectrum relevant to the assessment (of competition concerns) was considered in detail, indicating that both the 2.3GHz and the 3.4GHz bands were relevant to consider.[8]

6 Paragraph 5.11 of the October 2013 consultation, https://www.ofcom.org.uk/__data/assets/pdf_file/0018/45630/2.3-3.4-ghz.pdf.

7 Paragraph 5.17 of the October 2013 consultation.

8 Paragraphs 7.49 to 7.63 of the November 2013 consultation, https://www.ofcom.org.uk/__data/assets/pdf_file/0025/78055/Public_Sector_Spectrum_Release_2-3_and_3-4_ghz_award.pdf.

Hence, common treatment of the 2.3GHz and 3.4GHz bands has been a consistent theme until the current consultation:

- In the initial consultation proposals (October 2013), Ofcom indicated that there was a potential competition concern related to asymmetric distribution of spectrum (a view that has been maintained throughout all subsequent consultations). To address this concern, Ofcom initially proposed an overall spectrum cap, such that no one operator could hold spectrum exceeding 37% of the total "in the relevant bands at the end of the auction",[9] citing consistency with the 4G auction (where a total spectrum cap at the same level was also applied) as being the motivation for this. Ofcom was not specific initially on what the "relevant bands" referred to, stating "we have not considered exactly which bands should or should not be included within any such overall spectrum cap". However, the October 2013 consultation document did suggest there were no significant competition issues relating only to the 2.3GHz band and not to the 3.4GHz band.

- This view was reiterated in November 2014 in Ofcom's second consultation, which considered both bands together, referencing them as being substitutable.

- By May 2015, the market structure in the UK was shifting with the acquisition of EE by BT and the merger proposal between Three and O2. At this point, Ofcom issued a decision statement and further consultation, which revised its original proposal. Instead of imposing an overall spectrum cap, Ofcom instead proposed the option of withholding "some of the 2.3GHz and/or 3.4GHz spectrum"[10] from the auction, to be awarded at a later stage. There would be no overall cap in this case. The suggestion of withholding spectrum from one or other (or both) of the bands suggested Ofcom was still considering both bands together at this stage.

- In October 2015, upon issuing a final statement and accompanying Information Memorandum, Ofcom shifted its position, stating that the proposal to hold back some spectrum had been "universally opposed amongst respondents to the May 2015 consultation".[11] The decision in October 2015 was to proceed with award of all available spectrum, but without applying any competition measures. This was based on a 'balance of probabilities' assessment, which assumed that the merger between Three and O2 would be approved: something we now know to be incorrect.

We also note that when considering spectrum share and competition measures ahead of the UK 4G spectrum award (i.e. the auction of 800MHz and 2.6GHz frequencies, which was conducted in 2013), Ofcom considered that all of the paired bands either in use or planned for use (i.e. 800MHz, 900MHz, 1800MHz, 2.1GHz and 2.6GHz FDD) were '*relevant*'[12] since "these bands are

9 Paragraph 5.17 of 2.3 and 3.4GHz Spectrum Award: Consultation on a 3.4GHz band plan, varying UK Broadband Limited's licence and a call for inputs on other aspects of the award, October 2013, Ofcom.

10 Paragraph 1.8 of Public sector spectrum release: award of the 2.3 and 3.4GHz band, May 2015, Ofcom.

11 Paragraph 3.44 of Public sector spectrum release: Competition and auction design issues for the 2.3 and 3.4GHz spectrum award, including reserve prices, October 2015, Ofcom.

12 Paragraphs 4.65 to 4.68 of Statement on Assessment of future mobile competition and award of 800MHz and 2.6GHz, July 2014, Ofcom.

mainstream harmonised mobile bands in Europe and … there will be a wide range of devices (either HSPA or LTE) for these bands in the future…".[13] This illustrates the high degree of certainty at the time regarding the relatively timely use of the spectrum being awarded for mobile use despite the lack of available devices. Hence, Ofcom considered at that point that bands were relevant for consideration within the context of competition measures if there were expected to be a range of devices for them *in the future*, irrespective of whether bands would be immediately usable or not, and without consideration of transitional periods.

3.1.2 Ofcom's current consultation

Ofcom's latest assessment published in November 2016 has reviewed market developments since October 2015 resulting, for the first time, in Ofcom separating the risks associated with the distribution of the 2.3GHz spectrum from those associated with the distribution of the 3.4GHz spectrum. This is on the basis that firstly the former is 'immediately usable' whereas the latter is 'not immediately usable',[14] and secondly that competition concerns that Ofcom identifies as being most serious mainly relate to short-term effects.

Ofcom's assessment of MNO capacity requirements and the need for PSSR spectrum

Ofcom's review of market developments leading it to this conclusion refers to the rapid increase in mobile data traffic and consumer demand for higher speed mobile broadband services. The consultation indicates three ways in which mobile operators can meet this increased demand, namely:

- increasing the amount of spectrum used (including licence exempt 5GHz spectrum)
- increasing the efficiency of spectrum use
- increasing the number of sites (including densifying in urban areas and further sectoring e.g. from 3 to 6 sectors).

Ofcom states that it expects operators will need to do all three of these things in order to meet increased demand.

- In terms of options to increase the amount of spectrum used, Ofcom refers to awards of spectrum at 700MHz and 3.6–3.8GHz, and to the use of 5GHz licence-exempt spectrum.

- In terms of increasing the efficiency of spectrum use, Ofcom refers to re-farming of 2G and 3G spectrum, use of LTE-A and higher order MIMO but states that "we recognise that the timings and practicality associated with different ways of addressing capacity will vary significantly".[15]

13 Paragraph 4.67 of Statement on Assessment of future mobile competition and award of 800MHz and 2.6GHz, July 2014, Ofcom.

14 Paragraph 1.12 of Award of the 2.3 and 3.4GHz spectrum bands, November 2016, Ofcom.

15 Paragraph 8.28, Award of the 2.3 and 3.4GHz spectrum bands, November 2016, Ofcom. Additionally, in Annex 8 (paragraph A8.43) of the consultation, we note that Ofcom also suggests "if it needs to, H3G is probably able to

In this context, Ofcom states that the PSSR award is important because it will increase the total amount of spectrum available to mobile operators by 190MHz (from 647MHz to 837MHz – an increase of 29%). Ofcom then goes on to describe that the 2.3GHz and 3.4GHz bands are different, on the basis that:

- Ofcom considers that the 2.3GHz band can be used immediately, since it is already supported by "mainstream mobile devices such as the Apple iPhone".[16]

- Ofcom considers that the 3.4GHz spectrum is not currently supported by mobile devices, but '*is likely to become useful in two to three years*'.[16] Ofcom also notes the 3.4GHz band might be relevant for 5G and that, by the time the 3.4GHz band is usable, '*there are a variety of means by which operators will be able to adapt their strategies to meet consumer demand*.[17] Ofcom also makes references to responses to its previous consultations in which some stakeholders disagreed with previous statements suggesting the 2.3GHz and 3.4GHz bands are substitutable. Stakeholders who argued the bands were not substitutable indicated three reasons: handset and network ecosystem for 3.4GHz being less developed than for 2.3GHz, inferior propagation characteristics of 3.4GHz compared to 2.3GHz, and less compatibility (of 3.4GHz) with existing network infrastructure affecting speed/ease of deployment.

Ofcom's competition concerns in the short-term

The analysis of competition concerns that follows purports to take into account the Competition and Markets Authority (CMA) assessment of the merger between BT and EE, including the relevance of capacity and speed in the mobile market (noting "it is possible that in the future customers will value increased speeds more than they currently do"[18]) and the short-term risks that competition might weaken as mobile data use continues to grow if some operators can add capacity into their networks more cost effectively than others. It is noted some of the analysis that appears to be relevant is redacted from the consultation document (e.g. paragraph 4.69).

The analysis also considers the risk from intrinsic value bidding and the risk of strategic investment in spectrum, concluding that "there is a concern that a very asymmetric distribution of spectrum arising from bidding based on intrinsic values could be against consumers' interests"[19] and "the possibility of strategic investment in the 2.3GHz band is a significant concern".[20] Ofcom highlights the risk of asymmetric holdings of the immediately usable PSSR spectrum (i.e. 2.3GHz) weakening competition in the transition period (i.e. the time lag between the 2.3GHz spectrum being usable and the 3.4GHz spectrum being usable).

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change its commercial strategy to reduce usage by very heavy data users, so as to make more capacity available…".

16 Paragraph 1.12, Award of the 2.3 and 3.4GHz spectrum bands, November 2016, Ofcom.

17 Paragraph 1.27, Award of the 2.3 and 3.4GHz spectrum bands, November 2016, Ofcom.

18 Paragraph A7.19, Award of the 2.3 and 3.4GHz spectrum bands, November 2016, Ofcom.

19 Paragraph 4.168, Award of the 2.3 and 3.4GHz spectrum bands, November 2016, Ofcom.

20 Paragraph 4.206, Award of the 2.3 and 3.4GHz spectrum bands, November 2016, Ofcom.

Ofcom's competition concerns in the longer term

Longer term, Ofcom concludes that competition concerns are not sufficient to require competition measures in relation to 3.4GHz. Reasons Ofcom uses to justify this conclusion include that adding capacity by densifying networks could be more achievable in the longer term and that "there will be more spectrum available for mobile services in future, including at 700MHz and proposed at 3.6–3.8GHz".[21]

Ofcom's proposed competition measures

By disregarding the longer-term effects, Ofcom therefore focuses the requirement for competition measures in the award of the PSSR spectrum on short-term effects (and the risk of asymmetric spectrum holdings influencing the extent to which different operators can address mobile data growth in the short term). Hence the focus of competition measures is the 2.3GHz band, since Ofcom considers this to be 'immediately usable' spectrum.

Ofcom also considers that intervention in the 3.4GHz band could result in "unintended consequences",[22] in view of this band being identified by European regulators as an important band for early 5G deployment. It is not particularly clear what unintended consequences Ofcom is referring to but broadly we understand this relates to the possible need for operators to benefit from having larger contiguous blocks of spectrum from within the 3.4GHz and 3.6–3.8GHz bands to use emerging New Radio (NR) technology for 5G. Ofcom acknowledges that "exactly how operators deploy 5G is currently uncertain but we believe there to be a material risk that (over) specifying limitations on spectrum holdings … might constrain an operator's ability to innovate".[22] Ofcom also suggests there to be various mitigations to suggest competition might not be weaker in 5G if only one or two operators win 3.4GHz spectrum in the auction, namely:

- that there is other 5G-compatible spectrum currently in the market (i.e. that held by UK Broadband)
- other spectrum suitable for 5G will be available in the future (3.6–3.8GHz and 700MHz)
- uncertainty over how important 3.4GHz will be for 5G relative to existing mobile bands (which could be re-farmed for 5G use).

3.2 The issues arising from these proposals that we have been asked to assess

Ofcom's proposes to focus on competition concerns associated only with short-term spectrum holdings, whilst considering that longer-term concerns do not need to be addressed in the PSSR award (based on the potential for those to be mitigated through release of further spectrum and/or network modifications). This approach results in risks to the UK MNOs with smaller existing spectrum holdings (i.e. Three and O2) in relation to concentration of spectrum holdings both in the short and longer term. The transitional period that Ofcom identifies between the PSSR award and

21 Paragraph 1.19, Award of the 2.3 and 3.4GHz spectrum bands, November 2016, Ofcom.

22 Paragraph 1.28, Award of the 2.3 and 3.4GHz spectrum bands, November 2016, Ofcom.

subsequent planned awards (e.g. of 700MHz) overlaps with a period during which 5G services are expected to enter the UK market. Hence, it will be important that competition issues (both short and long term) are addressed to avoid significant uncertainty during a period in which MNOs are planning major new infrastructure investments for 5G.

In our view, a priori, the areas of Ofcom's analysis on which we have been asked to comment do not appear robust:

- the framework adopted by Ofcom to categorise spectrum into 'immediately usable' and 'not immediately usable' categories appears highly questionable.
- if this framework is inappropriate, then the appropriateness of the competition measures proposed by Ofcom is highly doubtful since the rationale for Ofcom to propose these competition measures is heavily predicated on the framework it has adopted.
- whether or not any potential unintended consequences related to 5G deployment of competition measures affecting the 3.4GHz band outweigh the consequences for competition of not acting appears far from clear, based on the evidence that Ofcom has put forward.

We present the findings of our research to explore these points in more detail through the remainder of this document.

4 Deployment of LTE and LTE-A in the relevant bands

In this section, we assess networks deployed in the bands under consideration, focusing on market differences between 2.3GHz, 3.4GHz and 3.6–3.8GHz. We note that networks to date using the 2.3GHz band are principally in selected countries in Asia and the USA, with only three commercial networks deployed in Europe (Latvia, Lithuania and Russia). We also consider the deployments to date in the 3.4GHz band and how this band is currently used across the world, comparing this to the extremely limited deployment in the 3.6–3.8GHz band. Finally, we discuss the evolution of LTE-A technology more broadly, including the supplemental downlink (SDL) deployment proposed in the L-Band.

4.1 LTE TDD network deployments in the 2.3GHz, 3.4GHz and 3.6–3.8GHz bands

A significant number of commercial networks deployed are already using LTE TDD technology in the 2.3GHz and 3.4GHz bands, albeit somewhat fewer in the 3.4GHz band than the 2.3GHz band. Figure 4.1 summarises commercial networks in the 2.3GHz and 3.4GHz bands worldwide, showing networks deployed to date and planned future deployments using LTE TDD or WiMAX technologies.

At present, there are 33 commercial LTE TDD networks in the 2.3GHz band and 19 in the 3.4GHz band worldwide. Currently, the number of LTE TDD commercial networks in the 3.4GHz band is comparable to that in the 2.6GHz TDD band (24 in total), despite the 2.6GHz TDD spectrum having been awarded for LTE TDD in Europe since around 2011 (varying by country), and even earlier in Asia–Pacific countries (since 2009).

It is particularly noteworthy that there is currently only one LTE TDD commercial network in the 3.6–3.8GHz band, deployed by Swan Mobile in Slovakia since February 2016.

Figure 4.1: Summary of worldwide 2.3GHz, 3.4GHz and 3.6–3.8GHz networks[23] deployed to date and future planned deployments using LTE TDD or WiMAX technologies [Source: Analysys Mason based on data from GSA and GSMAi, 2017]

Networks by bands	Live		Planned	
	LTE TDD	WiMAX	LTE TDD	WiMAX[24]
2.3GHz	26	9	9	3
3.4GHz	17	20	7	8
3.6–3.8GHz	1	-	-	-
2.3 / 2.6GHz	5	-	-	-

[23] 2.6GHz TDD networks are also shown for comparison purposes with 2.3GHz and 3.4GHz networks as discussed in this section.

[24] We were unable to confirm the final intended technology for these deployments. However, we anticipate that given the market trends in technology evolution from WiMAX to LTE TDD, it is highly likely that these planned WiMAX networks may in fact use LTE TDD technology by the time they are deployed.

Networks by bands	Live		Planned	
	LTE TDD	WiMAX	LTE TDD	WiMAX[24]
2.3 / 3.4GHz	2	-	-	-
2.6 / 3.4GHz	-	-	1	-
2.6GHz TDD	19	16	5	3
Total 2.3GHz	**33**	**9**	**9**	**3**
Total 3.4GHz	**19**	**20**	**8**	**8**
Total 3.6–3.8GHz	**1**	**-**	**-**	**-**

More commercial LTE TDD deployments both in the 2.3GHz and 3.4GHz bands are expected to be deployed. As seen in Figure 4.1, there are confirmed plans of commercial LTE TDD networks being deployed by a total of 17 operators in the 2.3GHz and/or the 3.4GHz bands. Additionally, there are a noteworthy number of commercial WiMAX networks in the 3.4GHz band, as well as some in the 2.3GHz band. LTE TDD technology represents the logical commercial progression for WiMAX operators (subject to licence conditions permitting this). Several European WiMAX operators have already replaced WiMAX networks with LTE TDD technology, including in the 3.4GHz band (for example, MEZON in Lithuania and UK Broadband in the UK). Hence, we would expect the number of commercial deployments in the 3.4GHz band, as well as the 2.3GHz band, to increase further than the declared planned LTE TDD networks to date indicate. Furthermore, there appear to be several planned future WiMAX networks, based on data published by the GSMA. We anticipate that given the trends in technology evolution from WiMAX to LTE TDD, it is highly likely that these future WiMAX networks may in fact use LTE TDD technology by the time they are deployed.

Current levels of commercial LTE TDD networks in the 2.3GHz and 3.4GHz bands have been reached through gradual deployment over the last five years. Figure 4.2 shows the total number of LTE TDD commercial networks worldwide live at the end of each year since 2011, when the first commercial 2.3GHz network was launched by STC in Saudi Arabia in September 2011. Figure 4.3 shows the same time evolution of the LTE TDD networks in Europe only. We have included details of the live LTE TDD commercial networks in the 2.3GHz, 3.4GHz and 3.6–3.8GHz bands in Figure A.1 in Annex A.

Figure 4.2: Timescale of LTE TDD network deployments worldwide in the 2.3GHz and 3.4GHz bands [Source: Analysys Mason based on data from GSA and GSMAi, 2017]

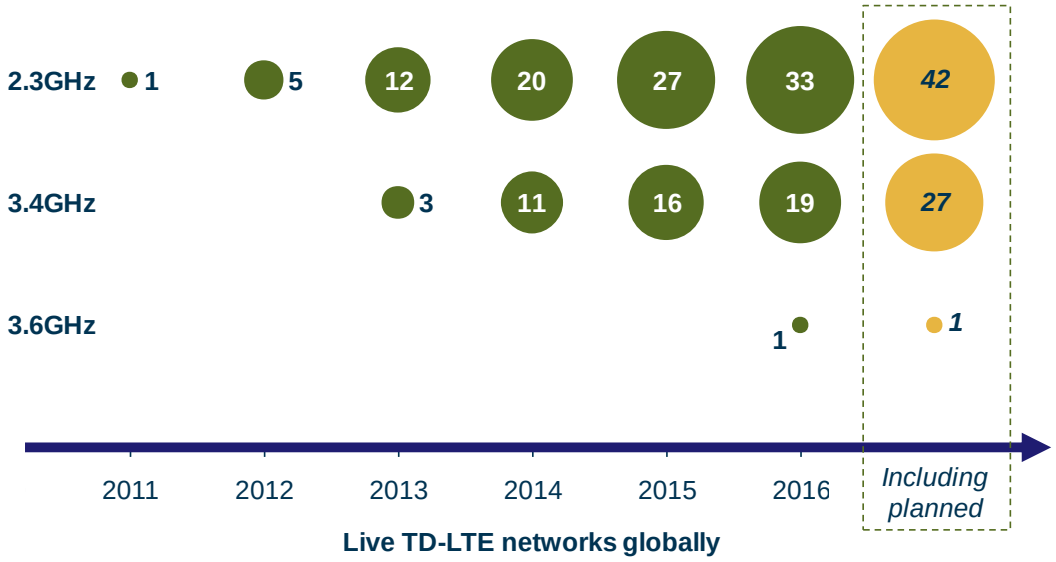
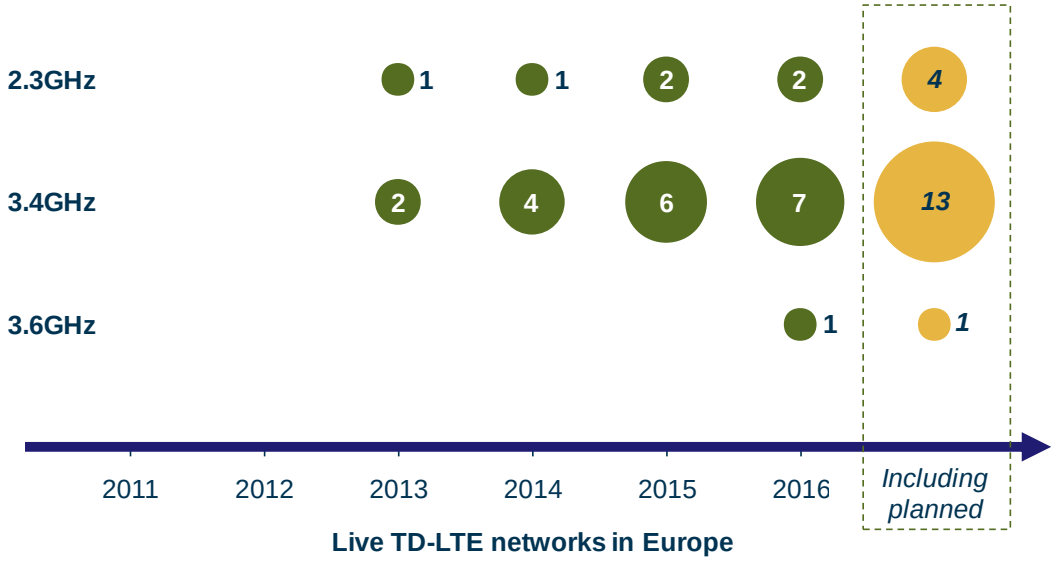


Figure 4.3: Timescale of LTE TDD network deployments in Europe in the 2.3GHz and 3.4GHz bands [Source: Analysys Mason based on data from GSA and GSMAi, 2017]



Despite the greater number of 2.3GHz LTE TDD commercial networks live worldwide, the number of 3.4GHz commercial deployments in Europe actually exceeds the number of 2.3GHz networks, as seen by comparing Figure 4.2 and Figure 4.3. This can be seen more clearly when analysing the number of current LTE TDD networks by region, as shown in Figure 4.4.

Figure 4.4: Worldwide 2.3GHz and 3.4GHz network deployments by geography, including future planned networks [Source: Analysys Mason based on data from GSA and GSMAi, 2017]

Region	2.3GHz networks			3.4GHz networks		
	Live LTE TDD	Live WiMAX	Planned LTE TDD	Live LTE TDD	Live WiMAX	Planned LTE TDD
Europe	2	1	2	7	7	6
Africa	10	1	-	3	3	-
Asia	17	7	5	3	7	2
Americas	1	-	1	6	2	-
Oceania	4	-	1	-	1	-
Total	**34**	**9**	**9**	**20**	**20**	**8**

The table above shows there are more LTE TDD commercial networks in Europe in the 3.4GHz band than in the 2.3GHz band, with potential for additional networks being deployed in the 3.4GHz band in future. The implication of this is that network equipment should be readily available for the 3.4GHz band for a LTE TDD deployment in Europe. This is also expected to result in increased ecosystem development for devices supporting the 3.4GHz band, as discussed in Section 5.

A further point to note from Figure 4.4 is that there are 6 confirmed plans for further LTE TDD deployments in 3.4GHz, out of a total of 8 globally (which were identified in Figure 4.1). Similarly, of the 8 globally planned WiMAX networks in this band, 2 are planned for deployment in Europe, in addition to the 7 live WiMAX networks, with upgrades to LTE TDD being, in our opinion, likely, as discussed above.

Comparison of geographical deployments worldwide highlights that, in Europe, neither of the 2.3GHz or 3.4GHz bands are deployed en masse for LTE TDD. Global live and planned LTE TDD deployments are shown in Figure 4.5 and Figure 4.6 for 2.3GHz and 3.4GHz bands, respectively. The maps show that the 2.3GHz band has been deployed reasonably extensively outside Europe. In several European countries, spectrum in the 2.3GHz band remains reserved for military use, leading to uncertainty in Analysys Mason's view as to how quickly the European deployment map will change in the 2.3GHz band. By contrast, the European 3.4GHz deployment map is likely to change quickly, fuelled by the industry's drive to make the 3.4GHz band available for mobile use for LTE TDD and/or 5G.

Figure 4.5: Location of LTE TDD 2.3GHz networks deployed to date and planned, showing number of operators per country [Source: Analysys Mason based on data from GSA and GSMAi, 2017]

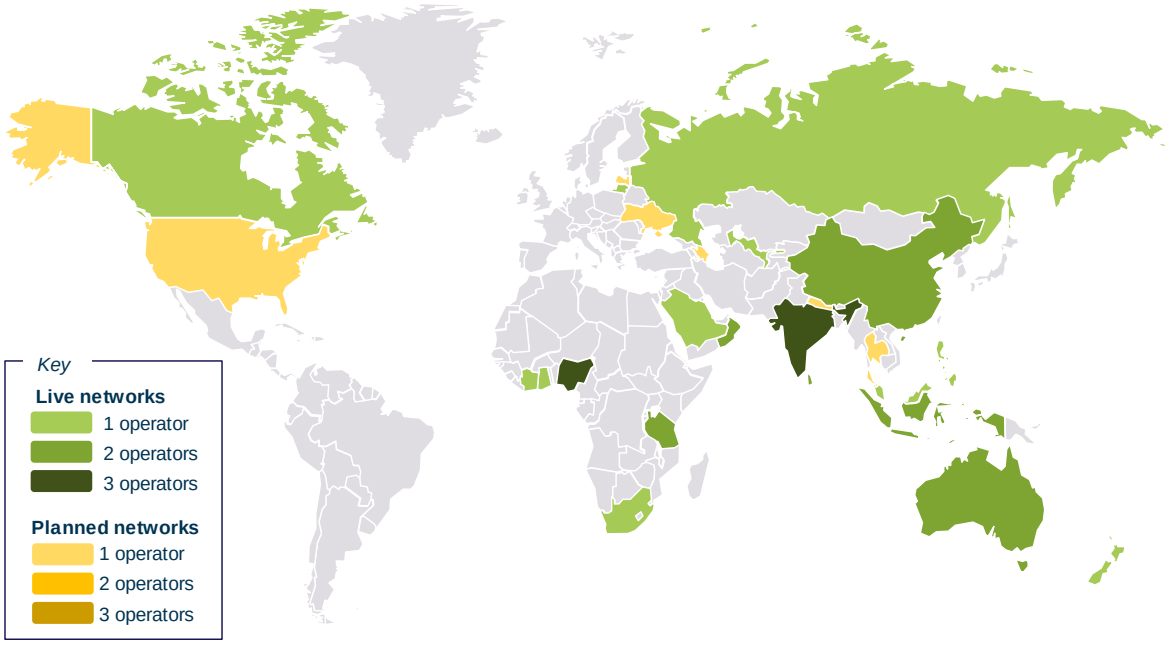
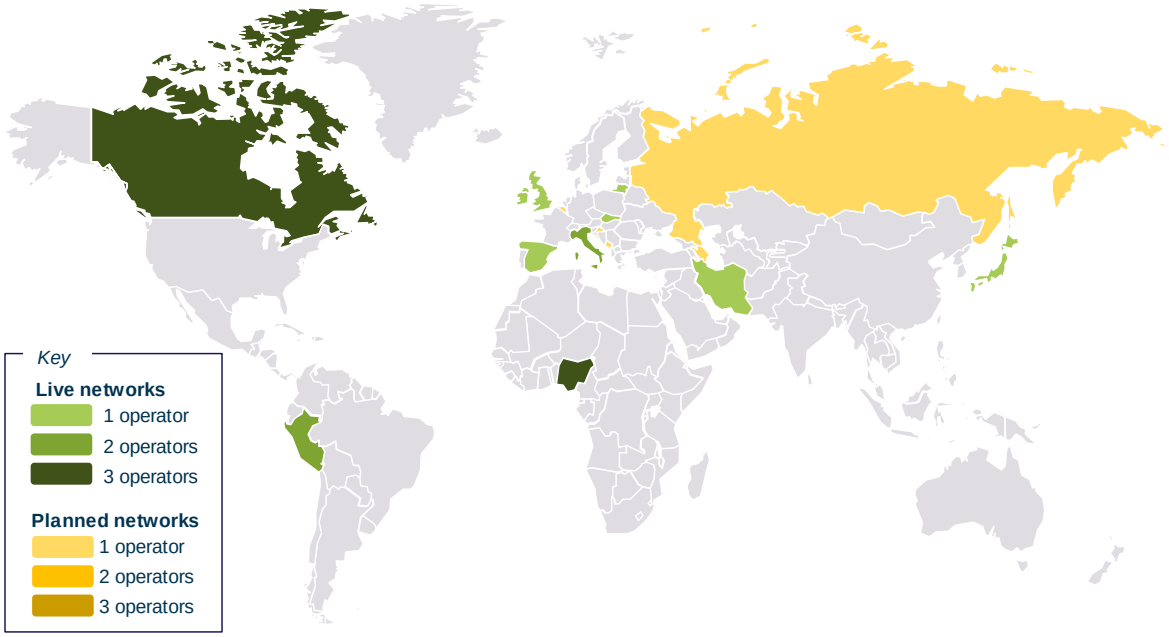


Figure 4.6: Location of LTE TDD 3.4GHz networks[25] deployed to date and planned, showing number of operators per country [Source: Analysys Mason based on data from GSA and GSMAi, 2017]



25 Note that currently four small regional operators have deployed LTE TDD networks in the 3.4GHz band in Canada, despite the map colouring showing only three.

4.2 Impact of further evolution of LTE-A

One of the key drivers for further development of LTE-A technology within 3GPP has been to enable networks to be able to support more intensive data usage. LTE-A technology provides several key enhancements over the original LTE specification to support more intensive data usage and to deliver higher speeds. Frequency bands above 1GHz are particularly well suited to meeting capacity requirements since these frequencies have more bandwidth and enable more intensive re-use. SDL technology has emerged as a solution to increase downlink capacity, and will be deployed in the L-Band. Although device availability for this technology is currently lagging behind that of other mobile bands, the ecosystem is expected to develop as more regulators make this spectrum available for mobile use. This is explored later in this report, in Figure 6.3.

A key feature of LTE-A is carrier aggregation (CA), enabling operators to provide higher peak speeds by aggregating two or more non-contiguous frequency carriers from the same or different standardised frequency bands. This is driving demand for spectrum across a range of frequency bands and it is apparent that 3GPP is continually expanding the range of bands that can operate together using CA. It is useful to note that both the 2.3GHz and 3.4GHz bands support CA with many other mobile frequency bands, as shown in Figure 4.7 below.

Figure 4.7: Intra- and inter-band CA options for 3GPP bands 38, 40 and 42[26] [Source: Analysys Mason, 2017]

Carrier aggregation options with band	**2.3GHz** (band 40)	**3.4GHz** (band 42)	**2.6GHz TDD** (band 38)
Intra-band			
Contiguous	✓	✓	✓
Non-contiguous	✓	✓	✗
Inter-band			
Two bands:	**+700MHz** **+800MHz** **+900MHz** **+1800MHz** **+2.1GHz** **+2.6GHz FDD** **+2.6GHz TDD** *+850MHz**	**+700MHz** **+800MHz** **+1800MHz** **+2.1GHz** **+2.6GHz FDD** **+5GHz**[27] *+850MHz** *+1500MHz** *+2.6GHz TDD (band 41)*[28]*	**+800MHz** **+1800MHz** **+2.3GHz** *+850MHz**

26 This table is based on currently standardised carrier aggregation combinations, as specified in 3GPP TS36.101, 13.2.1 (Version 13). It is noted that further combinations are under study and likely to be standardised in subsequent 3GPP releases including aggregation between B40 and B42. Options including up to five carrier aggregation are being considered e.g. B1 + B3 + B40 + B42 +B42 (assuming two non-contiguous carriers in B42, for example).

27 The 5GHz band is primarily used for radio local area networks based on Wi-Fi at present. Development of carrier aggregation technology between 5GHz and other licensed 4G frequency bands (so-called licensed assisted access, or LAA) could increase the bandwidth available for densifying LTE networks. The 5GHz band is only likely to be suitable for small-cell deployment based on existing licence-exempt regulations, which impose power limits. See Section 6 of this report for further discussion.

Carrier aggregation options with band	**2.3GHz** (band 40)	**3.4GHz** (band 42)	**2.6GHz TDD** (band 38)
Three bands[29]:	**+1800MHz+2.1GHz** **+900MHz+2.1GHz** **+900MHz+1800MHz** **+700MHz+1800MHz** *+850MHz+2.1GHz** *+850MHz+1800MHz**	**+1800MHz+2.1GHz** *+850MHz+2.1GHz** *+1500MHz+2.1GHz** *+850MHz+1800MHz** *+1800MHz+2.6GHz TDD** *+850MHz+1500MHz**	**+800MHz+2.6GHz FDD** **+1800MHz+2.6GHz FDD**
Four bands:	**+900MHz+1800MHz+2.1GHz** *+850MHz+1800MHz+2.1GHz**	*+850MHz+1800MHz+2.1GHz** *+850MHz+1500MHz+2.1GHz**	*(none)*
Total inter-band CA options	**12**	**7**	**5**

(*) Spectrum frequency band plans not used in Europe currently

Both the 2.3GHz and 3.4GHz bands are reasonably well supported by inter-band CA within the latest 3GPP specifications, indicating an increased interest in FDD/TDD CA amongst worldwide MNOs to use assigned unpaired spectrum. Notably the inter-band CA options within both bands exceed those of more established bands such as 2.6GHz TDD.

The 3.6–3.8GHz band has been envisaged more recently for mobile use than the other bands being considered in this report and hence specifications are less well developed. The 3.6–3.8GHz band is currently included in the 3GPP specifications as band 43. Although not currently included in CA combinations, we understand from informal consultation with selected 3GPP equipment vendors that inter-band CA (or equivalent) is expected to be specified between the 3.4GHz and the 3.6–3.8GHz bands. Hence, if CA can be implemented, it is not necessary for MNOs to hold wide contiguous channels in 3.4GHz band, since operators that acquire spectrum blocks in the 3.4GHz band can deploy these to provide wider bandwidth using inter-band CA by acquiring further blocks of spectrum in the 3.6–3.8GHz band when available. The immediate issue with 3.4GHz, however, remains i.e. that since 3.4GHz is the only band likely to be available for 5G in the UK in the short term, a highly asymmetric distribution of spectrum in this band would be problematic for the MNOs with little or no spectrum holdings in that band.

4.3 Summary of key points

A significant number of commercial networks deployed already use LTE TDD technology in the 2.3GHz and 3.4GHz bands although there are somewhat fewer in the 3.4GHz band than in the 2.3GHz band when considered globally. However, there are more LTE TDD commercial networks in Europe in the 3.4GHz band than in the 2.3GHz band, with the likelihood of additional networks being deployed in the 3.4GHz band in future. Hence, prospects for usability of the 3.4GHz band are likely to quickly improve once further European 3.4GHz awards are completed.

28 This is a TDD band plan for the 2.6GHz band that is not used in Europe.

29 There is also an option to aggregate three non-contiguous carriers from within two bands e.g. B1 + B42 + B42 or B3 + B42 + B42, or four carriers from three bands e.g. B1 + B3 + B42 + B42.

Current use of the 2.3GHz spectrum by the military in most European countries leads to some uncertainty as to how quickly the European deployment map will change in the 2.3GHz band. However, given deployments outside of Europe, and their effect on availability of network equipment, this is unlikely to constrain the deployment of 2.3GHz in the UK once it is awarded.

By comparison, there are fewer LTE TDD networks being deployed globally using the 3.4GHz band, but the European 3.4GHz deployment map could develop quickly, driven both by the increasing demand for mobile data services (generating a need for additional spectrum for MNOs suited to capacity deployment) as well as by the industry's ambition to make the 3.4GHz band available for mobile use both for LTE TDD and for 5G.

The implication of this is that network equipment should be readily available for the 2.3GHz and 3.4GHz band for LTE TDD deployment in Europe. Current and planned deployments are also expected to result in increased ecosystem development for devices supporting the 3.4GHz band, as discussed in Section 5. Options for CA supported by the 3GPP specifications are broadly similar between the two frequency bands, suggesting similar utilisation possibilities when deployed in a UK MNO's networks (albeit with somewhat reduced propagation range for 3.4GHz compared to 2.3GHz).

Developments relating to the 3.6–3.8GHz band are somewhat harder to predict. Whilst there are also prospects for the 3.6–3.8GHz band to be awarded for mobile use in various European markets, we note that the ecosystem for this band is some way behind both 2.3GHz and 3.4GHz at present. In particular, there has, to date, only been one deployment of LTE TDD in this band globally, which may be affected by the uncertainty over the future harmonisation in the band, which we go on to describe in Section 6. However, we note that specifications to enable CA between 3.4GHz and 3.6–3.8GHz are envisaged and there are a growing number of European regulators publishing plans for future mobile awards in this band (described in the Section 6).

In relation to the L-Band, there are also a growing number of mobile awards being planned (as described in Section 6), whilst the band has already been assigned for nationwide mobile use in the UK. The device ecosystem for this band is in its infancy (described in Section 5), however, the prospects for greater uptake and use are good.

To date, there are no commercial mobile networks deployed in the 700MHz band within Europe, however, licences have been awarded in a few countries, with more to follow. The EU harmonisation of this band for mobile use means that, once available, there are good prospects for immediate use of at least 2×30MHz of this band.

5 Device ecosystem development

We have seen that commercial deployment of networks using the 3.4GHz band is behind that of the 2.3GHz band, although it is on a par with deployment timescales for the L-Band, and ahead of potential mobile deployment timescales both in the 2×30MHz part of the 700MHz band and the 3.6–3.8GHz band. In this section, we explore device availability in each band through a review of the numbers of devices currently available in each of the bands under consideration (i.e. the PSSR bands compared with other bands becoming available for mobile use), including the 2×30MHz in the 700MHz band, the 3.6–3.8GHz band and the L-Band.

Whilst the number of devices supporting the 2.3GHz band are currently some way ahead of those supporting the 3.4GHz band, we anticipate that 3.4GHz device availability may grow rapidly given international harmonisation and as deployment of networks using the band increase. By way of comparison, we also consider device numbers for the 2.6GHz TDD band to demonstrate how quickly a device ecosystem can develop once the use within the band becomes clear across a large number of countries.

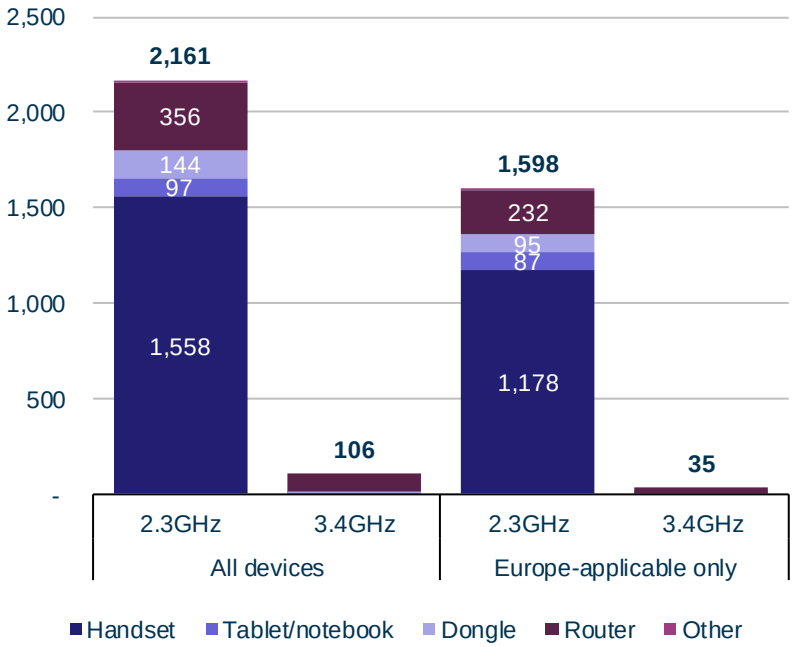
Devices compatible with the 3.6–3.8GHz band may be comparable with those supporting the 3.4GHz band today, but are expected to develop far less quickly for reasons explained in the remainder of this section.

5.1 Number of devices supporting different bands

At a headline level, there appears to be a strong device ecosystem in the 2.3GHz band. This is confirmed by the large number of devices that are suitable for use in Europe. There are still some limitations in the range of 2.3GHz devices available – until recently, devices supporting 2.3GHz tended to be those at the high-end of the market, typically used by a smaller subset of users, with a lack of availability of devices supporting 2.3GHz CA with other mobile bands relevant to the UK 4G market (e.g. 1800MHz).

Figure 5.1 shows the number of currently available devices that support the 2.3GHz and 3.4GHz bands; on the left are all available devices, whilst on the right are a subset that would be suitable for use in Europe, selected on the basis that these devices also support other bands licensed for 2G, 3G and 4G services in Europe.

Figure 5.1: LTE devices supporting the 2.3GHz and 3.4GHz bands, showing availability worldwide and suitable for use in Europe only[30] as of January 2017 [Source: Analysys Mason based on GaMBOD data, 2017]



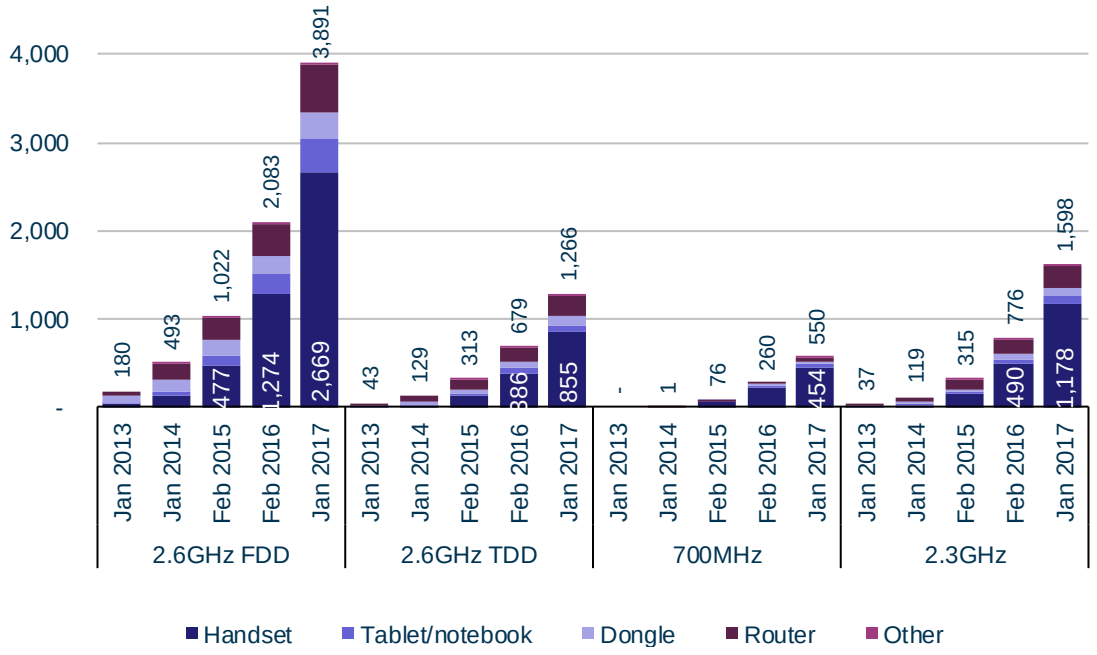
As of today, the number of devices currently supporting the 3.4GHz band (and the L-Band) is limited, particularly when looking at devices compatible with networks combining the 3.4GHz band with other frequencies within typical European mobile bands. However, analysis of historical evolution of device ecosystems in other bands entering European markets in the last few years shows that a weak device ecosystem at present can quickly change, as shown next. Although the TDD device ecosystems have generally been slower to commence in Europe, given a historically strong FDD device ecosystem, the development rate of TDD devices is nonetheless similarly rapid once devices start to appear. Figure 5.2 shows the historical evolution of device ecosystems in Europe in the 2.6GHz FDD and TDD, 700MHz and 2.3GHz bands. 2.6GHz FDD had more devices available in January 2013 but the compound annual growth rate (CAGR) of the number of devices since then of 116%[31] is comparable to that for 2.6GHz TDD (133%) and 2.3GHz (156%).[32]

30 Devices suitable for use in Europe were distinguished from others on the basis of compatibility with at least one other band plan used for 2G, 3G or 4G mobile services in Europe, e.g. the 900MHz, the 1800MHz, the 2100MHz or the 2.6GHz FDD bands.

31 CAGR calculation is measured over four annual periods from January 2013 to January 2017.

32 Note that we would expect the CAGR to fall as the ecosystem reaches maturity and therefore a higher CAGR may sometimes be expected where an ecosystem is in an earlier stage of development. Considering the CAGR for 700MHz between February 2015 and January 2017, for example, gives a value of 169%.

Figure 5.2: Time evolution of availability of LTE devices in the 2.6GHz FDD and TDD, 700MHz and 2.3GHz bands suitable for use in Europe[30,33] [Source: Analysys Mason based on GaMBOD data, 2017]



It is noteworthy that device availability can grow rapidly once there is greater certainty over the future use of a band. The historical evolution of the 700MHz FDD device ecosystem[34] in Figure 5.2 shows that device availability can grow very fast once there is international harmonisation providing certainty over the future use of the band, even though the spectrum itself will not become available for a few years in most European countries. Although the 3.4GHz device ecosystem is currently nascent, it is likely to benefit from strong industry interest in this band for future mobile use for both 4G and 5G technologies. As certainty about the future intended use of the 3.4GHz band on a wider international scale continues to increase, the device ecosystem is likely to grow rapidly, as has been observed for other bands such as the 700MHz band.

Devices for the L-Band, although not widely available at present, are expected to become available over the next few years. Further European harmonisation in the L-Band, potentially over the full 90MHz bandwidth from 1427–1517MHz identified for use by International Mobile Telecommunications (IMT) at the World Radiocommunication Conference in 2015, is also showing good potential.[35]

Data on the availability of devices for the 3.6–3.8GHz band is not readily available. We understand that some, or all, of the currently small number of devices that support the 3.4GHz band may also function with the 3.6–3.8GHz band (from GAMBoD data, we estimate that up to

33 In order to show devices suitable for use in Europe in the 2.6GHz FDD, 2.6GHz TDD and 700MHz bands, we include devices supporting 3GPP bands 7, 38 and 28, respectively.

34 We note there is potential use of supplemental downlink in the 700MHz band (i.e. as proposed by Ofcom for use in the 700MHz centre gap), but the ecosystem for this is not addressed here.

35 For example, see http://www.cept.org/ecc/groups/ecc/ecc-pt1/news/latest-news-from-ecc-pt154/.

70% of 3.4GHz devices could also be suitable for use in 3.6–3.8GHz). However, as the 3.4GHz device ecosystem develops as a result of increasing harmonisation in the band, there is no clear reason to expect that those new devices will also support 3.6–3.8GHz in the same timeframe. It is understood that inclusion of 3.6–3.8GHz into devices will involve higher costs relative to adding 3.4GHz into devices, due to the increased complexity of components as the frequency range increases. We would expect the device ecosystem to develop more slowly for 3.6–3.8GHz than for 3.4GHz from this point onwards since the current deployments for the two bands are different (as discussed in Section 4), and the outlook for the two bands is also different, as we go on to discuss in Section 6.

5.2 Analysis of device availability in Europe by manufacturers and models

There are various manufacturers producing handsets, including smartphones that are popular in the UK, that already support the 2.3GHz band. Some vendors have shown interest in developing handsets for the 3.4GHz band and data in the GAMBoD database suggests at least one major vendor has incorporated the 3.4GHz band into recent devices (we have not been able to verify this based on available specifications for these devices, however). Annex B provides an overview of the manufacturers and device models supporting the 2.3GHz and 3.4GHz bands. Additionally, also summarised in Annex B are developments in other bands that may provide an indication of the likely future developments in the 2.3GHz and 3.4GHz bands (i.e. by comparing 2.3GHz and 3.4GHz to 700MHz, 2.6GHz TDD and L-Band device models and manufacturers).

Growth of the device ecosystem in the 3.4GHz band may be being held back by the uncertainty regarding demand as well as the technology that will be deployed in the 3.4GHz band, and how it will be used. It can be observed that although the 2.6GHz TDD band has been licensed for a number of years, the handset models supporting the 2.6GHz TDD band are the mostly recent, higher-end, handsets. These have become available as demand for 2.6GHz TDD devices has grown following deployments of commercial networks in the 2.6GHz TDD band. Similarly, the 700MHz devices used in other markets currently are provided by the same popular manufacturers in the UK and, generally, supported by the more recent higher-end model releases. We expect that, as clearer uses are identified for the 3.4GHz band, there will be rapid take-up and roll-out of compatible devices by the popular manufacturers, similarly to what has been observed in the 2.3GHz and 2.6GHz TDD bands, as well as in 700MHz (still an emerging band in Europe).

Somewhat similarly to the 3.4GHz band, device availability in the L-Band is in its infancy as operators holding licences in the L-Band are yet to deploy it in their networks and relatively few European regulators have awarded this band for mobile use. However, the European harmonisation decision on the L-Band and global identification of L-Band frequencies for International Mobile Telecommunications (IMT) use at the World Radiocommunication Conference in 2015 (WRC-15) is expected to spur further developments in this band (similarly to the 3.4GHz band).

We note that there is growing interest in the potential of both the 3.4GHz and 3.6–3.8GHz bands for mobile services outside Europe. Google, a leading innovator in the smart cities industry, began

testing broadband deployment of spectrum in the 3.4GHz–3.8GHz range in selected cities in the USA in April 2016. Google is one of six companies[36] in the USA that have taken advantage of a framework created by the Federal Communications Commission (FCC) in 2015 which allows dynamic spectrum sharing in the 3400–3800MHz range alongside military use.[37] Additionally, Google has previously conducted successful trials of operation of LTE and Wi-Fi networks alongside US Navy radar systems in the 3.4GHz band, which enabled it to launch Project Fi in summer 2015, a small-scale Wi-Fi and LTE commercial network supported by several smartphone models[38] and roaming over networks by Sprint and T-Mobile.[39] Such developments show an active interest from industry parties in using the large bandwidths available in the 3.4GHz and 3.6–3.8GHz, and will directly contribute to the growth of the device ecosystem in the future, although timings are uncertain.

5.3 Summary of key points

There is a strong device ecosystem in the 2.3GHz band, even when accounting only for devices that are suitable for use in Europe. Our analysis – based on data obtained from the Global Mobile Suppliers Association analyser for mobile broadband devices (GAMBoD),[40] cross-checked against our own understanding based on devices being marketed by MNOs – shows that the 2.3GHz device ecosystem is unlikely to be a significant hindrance to 2.3GHz deployment. This is because, although there has been only limited implementation of 2.3GHz networks in Europe to date, it is a band that is widely used in other parts of the world, meaning that it is already supported in devices. Hence, it is a band that can be deployed alongside the other spectrum bands that UK MNOs use, to supplement existing network capacity.

It is noted that implementation options for 2.3GHz will have some limitations in the short term, because it is a band that uses LTE TDD, and enabling TDD operation along with the FDD bands more commonly used by UK MNOs may give rise to some implementation issues. For example, there has been a delay in devices supporting CA between 2.3GHz and other mobile bands relevant to the UK 4G market (e.g. 1800MHz) becoming available, as the result of the sequence of standardisation of CA within 3GPP (where a sub-set of bands were initially focused on for CA before significantly more band options were added in subsequent versions of the 3GPP standards). Furthermore, although a range of 2.3GHz handsets is already available, these handsets have tended to be priced at the high end of the market, typically only used by a smaller subset of mobile subscribers. These issues are likely to only affect the short-term use of the 2.3GHz band in the UK

36 Other parties involved in the Spectrum Access System project are Qualcomm, Nokia, Intel and Federated Wireless. See http://www.dynamicspectrumsummit.com/2016/05/27/multiple-u-s-trials-underway-for-shared-3-5ghz-wireless-spectrum/.

37 The framework is known as Spectrum Access System (SAS) and uses database technology to protect important federal government uses of spectrum, whilst freeing up unused spectrum for other companies to share available bandwidth in the 3400–3800MHz band. Google received authorisation by the FCC to conduct testing in up to 24 US areas. No other details have been disclosed on Google's 'secret commercially valuable plan'.

38 Models include Pixel, Nexus 6P, Nexus 5X or Nexus 6 smartphones. See https://fi.google.com/about/faq/#supported-devices-7.

39 See https://blog.google/products/project-fi/from-hi-to-fi-to-goodbye-to-invites/.

40 See Global mobile Suppliers Association for details, http://gsacom.com/gambod/.

however, and it is expected that, as the 2.3GHz band becomes more widely implemented in Europe, a broader range of handsets across all price points in the market will rapidly develop.

Although the device ecosystem for 3.4GHz is currently some way behind that of 2.3GHz, we expect that with growing certainty around the future intended use of the 3.4GHz band, the device ecosystem has the potential to grow very rapidly, as has been observed previously for 'new' frequency bands for mobile use, such as for the 2.6GHz FDD and TDD bands for example.

Devices for the L-Band are expected to become available over the next few years. We note that prospects for further European harmonisation across the full 90MHz of L-Band spectrum from 1427–1517MHz for mobile use appear favourable.

On the other hand, the 3.6–3.8GHz band, whilst starting from a similarly low base of devices to the 3.4GHz, is likely to develop much more slowly. This is due to the lack of existing deployments in the band and the more significant uncertainty regarding the timing of its future harmonised use, as we discuss in the next section.

More generally we note that a growing device ecosystem is only one factor in the readiness of a band for use in the UK. Other factors such as availability of network equipment and harmonisation of technology standards, as discussed next, will also form a key part of understanding the overall readiness for use.

6 European award proposals in the PSSR bands

This section discusses the broader European landscape for use of the bands under consideration. We begin by reviewing European-level statements with regards to the 2.3GHz, 3.4GHz and 3.6–3.8GHz bands and the plans of selected European regulators to allocate primary mobile use in these bands. We then review the latest announced plans from regulators to award spectrum in the 2.3GHz, 3.4GHz and 3.6–3.8GHz bands for mobile services.

Future award plans in the 2.3GHz, 3.4GHz and 3.6–3.8GHz bands highlight a mixed approach currently being followed in Europe. Although there are plans for awards in all three bands, the greater harmonisation at 2.3GHz and 3.4GHz, along with difficulties in many European countries of clearing the 3.6–3.8GHz band, implies that more awards may occur sooner at 2.3GHz and 3.4GHz.

6.1 Current use of the 2.3GHz, 3.4GHz and 3.6–3.8GHz bands in Europe

The European Conference of Postal and Telecommunications Administrations (CEPT) publishes a harmonised European table of frequency allocations, called the ECA table. The table is maintained by European regulators within the Electronic Communications Committee (ECC), with a view to developing harmonisation decisions and recommendations for use of radio spectrum across the 43 members of the CEPT from across Europe. Figure 6.1 represents the current European common allocations for each of the bands of interest[41] (i.e. the 2.3GHz, 3.4GHz and 3.6–3.8GHz bands).[42] Shown alongside this for information is the corresponding national allocations for a selection of European countries where data was readily available.

Figure 6.1: Current European Common Allocation agreements for 2.3GHz, 3.4GHz and 3.6–3.8GHz and selected national implementations [Source: Analysys Mason, 2017]

	2.3GHz	**3.4GHz**	**3.6–3.8GHz**
Overall European Common Allocation (*shown in italic is the secondary allocation*)	**Fixed, mobile**, *amateur and radiolocation*	**Fixed, fixed satellite, mobile except aeronautical mobile,** *amateur and radiolocation*	**Fixed, fixed satellite and mobile**
Country	Detail of agreement or not of the national allocation for selected European countries with the European Common Allocation - A tick indicates an exact agreement between allocations - Where allocations differ from ECAs, the national allocation is provided		
Belgium	Mobile, *amateur and radiolocation*	Fixed, *radiolocation* and *mobile*	Fixed and fixed satellite

41 The European table of frequency allocations and applications in the frequency range 8.3kHz to 3000GHz (ECA table) approved June 2016.

42 The 700MHz and L-Band are also considered relevant spectrum for the purposes of this document. We discuss the L-Band in Section 6.3, whilst our view is that harmonisation of the 700MHz band is already well-established and is not likely to be an impediment to its use in the UK.

	2.3GHz	3.4GHz	3.6–3.8GHz
Bulgaria	✓	✓	Fixed, fixed satellite and *mobile*
Cyprus	✓	✓	✓
Czech Republic	Fixed, mobile, *amateur and amateur-satellite*	Fixed, fixed satellite, mobile and *radiolocation*	Fixed, mobile and *fixed satellite*
Estonia	Fixed, mobile, *amateur, radiolocation and short range devices*	Fixed, *mobile and short range devices*	Fixed, fixed satellite, *mobile and short range devices*
France	Fixed, mobile, radiolocation and *amateur*	Fixed, fixed satellite, mobile except aeronautical mobile and *radiolocation*	✓
Germany	Mobile, *amateur and radiolocation*	✓	Fixed, fixed satellite, mobile except aeronautical mobile and *radiolocation*
Hungary	Fixed, mobile and *amateur*	Fixed, fixed satellite, mobile except aeronautical mobile and *radiolocation*	✓
Ireland	✓	✓	Fixed, fixed satellite and *mobile*
Italy	Fixed and *amateur*	Fixed, fixed satellite, mobile except aeronautical and radiolocation (primary for 3.4–3.5GHz and secondary for 3.5GHz-3.6–3.8GHz)	Fixed and fixed satellite
Latvia	✓	Fixed, fixed satellite, *mobile and radiolocation*	Fixed, fixed satellite and *mobile*
Netherlands	Mobile and *amateur*	Fixed satellite, mobile except aeronautical, radiolocation (primary for 3.4–3.41GHz and secondary for 3.41GHz-3.6–3.8GHz), *mobile and amateur*	Fixed satellite and mobile
Poland	Fixed and mobile except aeronautical mobile	Aeronautical mobile (3.4–3.5GHz) Amateur, fixed and mobile expect aeronautical mobile (3.5GHz-3.6–3.8GHz)	Amateur, fixed and mobile expect aeronautical mobile
Portugal	✓	Fixed, fixed satellite, *mobile and radiolocation*	Fixed, fixed satellite and *mobile*

	2.3GHz	3.4GHz	3.6–3.8GHz
Romania	✓	✓	✓
Spain	✓	Fixed, *mobile and radiolocation*	Fixed, fixed satellite and *mobile*
United Kingdom	Fixed, mobile, *amateur, amateur-satellite and radiolocation*	Mobile, radiolocation and *amateur*	Fixed, fixed satellite and *mobile*

The uses of each band are broadly similar across each country and include: fixed, fixed satellite, mobile, radiolocation, short range devices, amateur and amateur satellite. The main difference observed between national and European allocations is the use being allocated on a primary or a secondary basis. From the countries examined, only Romania and Cyprus follow the ECA exactly. In summary, focussing on allocation of each band for mobile use, we note the following:

- In the 2.3GHz band, every country has followed the ECA and allocated mobile on a primary basis except for Italy which has refrained from allocating mobile at all in this band
- In the 3.4GHz band, there is a split between priority of allocations, with Belgium, Estonia, Latvia, Portugal and Spain steering away from the ECA and awarding mobile on a secondary basis
- In the 3.6–3.8GHz band, Belgium and Italy have not allocated mobile to the band at all, and the remaining countries are split, just under half allocating on a primary basis and just over half on a secondary basis.

The ECC has published two decisions[43] seeking to harmonise the 2.3GHz, 3.4GHz and 3.6–3.8GHz bands for mobile/fixed communications networks (MFCN). In line with these decisions the ECA allocates each of the spectrum bands to mobile on a primary basis. ITU region 1 also allocates mobile on a primary basis to 2.3GHz and 3.4GHz; however, only on a secondary basis to 3.6–3.8GHz. The harmonised ECC decision for the 3.4GHz band (ECC Decision (11)06) is now under review within the European Communications Committee (ECC) Project Team 1 (PT1), with a view to confirm its suitability for 5G. ECC PT1 are also understood to be working on the development of band plans across the 3.4–3.8GHz range for 5G.[44] However, these ECC decisions are non-mandatory and hence, as described in the next section of this report, the current picture in terms of pan-European assignment of 2.3GHz, 3.4GHz and 3.6–3.8GHz is mixed.

There is also a European Commission (the 'Commission') Decision on harmonised use of 3.4–3.8GHz (2008/411/EC),[45] requiring Member States to make the 3.4GHz band available for terrestrial electronic communication networks, followed by the 3.6–3.8GHz band subsequently. However, the terms of this decision are broad, covering fixed, mobile and nomadic systems. It is

43 *ECC Decision (11)06: Harmonised frequency arrangements for mobile/fixed communications networks (MFCN) operating in the bands 3400-3600MHz and 3600-3800MHz,* approved December 2011, amended March 2014 & *ECC Decision (14)02: Harmonised technical and regulatory conditions for the use of the band 2300-2400MHz for Mobile/Fixed Communications Networks (MFCN),* amended June 2014.

44 http://eccwp.cept.org/WI_Detail.aspx?wiid=581.

45 http://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX:32008D0411.

understood that the Commission is currently considering (in the context of follow-up to the 5G Action Plan) what further harmonisation measures might be required in the 3.4–3.8GHz range in relation to deployment for 5G.

Overall, although harmonisation across Europe for the 2.3GHz, 3.4GHz and 3.6–3.8GHz bands is developing towards primary use for mobile, the current use in each band is fragmented. Harmonisation of the 3.6–3.8GHz band seems to be the least developed of the three bands. For 2.3GHz and 3.4GHz, the harmonisation positions are not materially different for 4G. Given the likelihood of further Commission decisions on 5G, however, it is possible that harmonisation in 3.4GHz (and possibly eventually 3.6–3.8GHz) might overtake that of 2.3GHz.

It is noted that, like in the UK, there is also military use (radiolocation) in the 2.3GHz (and 3.4GHz) bands in some other European countries. The concept of 'licensed shared access' (LSA) has been proposed within the ECC as a mechanism for regulators to make spectrum available in the 2.3-2.4GHz band in particular on a shared basis with military use. This approach has not seen wide uptake. To date, the UK Government has opted to release 40MHz from the MOD spectrum in the 2.3GHz band rather than offer spectrum on a shared basis. However, Ofcom has indicated possible future plans to assess whether any of the un-released spectrum could be made available on a shared basis with the Ministry of Defence (MOD).

6.2 Plans for European spectrum awards in 2.3GHz, 3.4GHz and 3.6–3.8GHz

Although the national plans summarised in Figure 6.1 illustrate that some European countries have started to plan for mobile use in the 2.3GHz, 3.4GHz and 3.6–3.8GHz bands, there is a fragmented picture at present with some regulators opting to award licences in 2.3GHz and others in 3.4GHz and/or 3.6–3.8GHz.

We have investigated published plans from regulators in different European countries to award the 2.3GHz, 3.4GHz and 3.6–3.8GHz bands for mobile use. Our findings, which highlight recent developments (either awards carried out in 2016 or planned future awards) are summarised in Figure 6.2 below.

Figure 6.2: Summary table of recent and planned future awards in the 2.6GHz, 3.4GHz and 3.6–3.8GHz bands [Source: Analysys Mason, 2017]

Country	Award plans	Estimated time of award[46]
	2.3GHz	
Hungary	NMHH has announced plans to auction the 2.3GHz band on a licence shared access (LSA) basis (i.e. shared with incumbent use) as part of its 2016-2020 spectrum strategy[47]	Q1-Q2 2018

46 In this column, we list estimated timeframes provided by the regulator in question. In general, there is a tendency for these initially suggested timeframes to be optimistic and it is likely that several of the awards happen later than is currently being suggested.

47 National Media and Infocommunications Authority Spectrum Strategy 2016-2020, see http://english.nmhh.hu/dokumentum/170996/rss_nmhh_2016_komm_fin.pdf.

Country	Award plans	Estimated time of award[46]
Slovenia	AKOS announced plans in November 2014 to auction spectrum in the 700MHz, L-Band, 1800MHz, 2.1GHz, 2.3GHz, 3.4GHz and 3.6–3.8GHz bands.[48] An auction in 2016 awarded licences in the 1800MHz and 2.1GHz bands, leaving the other bands yet to be awarded[49]	Expected before 2020
Ireland	ComReg launched a consultation in September 2014 on the potential auctioning of spectrum in the 700MHz, L-Band, 2.3GHz and 2.6GHz bands. ComReg reconfirmed their intention for future releases in these bands in June 2016, with no further details on dates or amounts[50]	No timescales indicated yet
Denmark	The Danish Business Authority (DBA) indicated in 2014, that there could be an auction for the band in 2016/17, however no further information has been published	No details on award yet
Ukraine	NCCIR has announced plans to award 4G licences in 2017, which might include spectrum in European harmonised 4G bands including 1800MHz, 2.3GHz and 2.6GHz bands (precise plans unknown at present)	2017
Sweden	The Post and Telecom Authority (PTS) launched a consultation in December 2016 regarding the use of the 2.3GHz band for mobile broadband use[51]	2020 or later
Austria	Austrian telecommunications regulator, RTR, launched in December 2016 a consultation for future spectrum release in multiple bands, including the 2.3GHz band[52]	2020 or later
	3.4GHz	
Spain	A 4G licence for 20MHz was awarded to Orange in a multi-band auction with the 2.6GHz FDD spectrum[53]	Awarded Mar 2016
Slovakia	The RU awarded O2 regional 4G licences of 1×20MHz and 2×5MHz in Aug 2016. Additionally, 4G licences of 2×20MHz and 2×10MHz had been awarded previously to O2 and Swan, respectively, in July 2015[54]	Awarded Aug 2016
France	ARCEP has plans to assign the band for mobile use via auction,	Q2 2017

48 See http://www.akos-rs.si/radio-4g-2558-700-mhz--public-procurements-modifications-of-tender-documentation-for-selection-of-tenderer-to-deliver-professional-consulting-services-and-access-to-the-software-for-the-implementation-of-multiobject-multiround-electronic-auction.

49 See http://www.akos-rs.si/agency-for-communication-networks-and-services-of-the-republic-of-slovenia-successfully-concluded-first-spectrum-auction-for-public-mobile-services.

50 ComReg Radio Spectrum Management Strategy for 2016 to 2018, see file:///C:/Users/gentiana.shiko/Downloads/ComReg_1650.pdf.

51 See http://www.pts.se/sv/Nyheter/Radio/2016/Remiss-av-PTS-forstudierapport-om-23-GHz-bandet/ and http://www.pts.se/upload/Remisser/2016/Rapport-forstudie-2300-2400-MHz-20161213.pdf and http://www.pts.se//Pts/Templates/Dokument.aspx?id=58025.

52 See https://www.rtr.at/en/tk/FRQplan/Spectrum_Release_Plan.pdf.

53 For details on the auction see http://www.xatakamovil.com/conectividad/la-subasta-de-nuevo-espectro-para-telefonia-movil-en-los-2-6-ghz-y-3-5-ghz-se-aplaza-a-enero, with details of the award here http://economia.elpais.com/economia/2016/03/21/actualidad/1458582306_344874.html.

54 Summary of final award decisions in the 3.4GHz band can be found here http://www.teleoff.gov.sk/index.php?ID=162.

Country	Award plans	Estimated time of award[46]
	alongside the L-Band and 2.6GHz, with trials being encouraged in both bands.[55] ARCEP launched a consultation in January 2017 on the future use of several bands including 3.5GHz and methods on how to allocate the bands. ARCEP plans to make 40MHz of the 3.5GHz band available for fixed wireless ultrafast networks in rural areas[56]	
	3.6–3.8GHz	
Slovakia	The RU awarded 40MHz regional 4G licences of up to 80MHz per region to AMTEL, Slovanet, DSI Data, and Oranet (with winners varying by region)[57]	Awarded Oct 2016
Czech Republic	CTU has published a tender for its planned auction of five lots of 40MHz TDD blocks[58]	2017
	3.4GHz and 3.6–3.8GHz	
Hungary	LTE licences issued to Vodafone for 60MHz in the 3.4GHz band and to Digi for 20MHz in the 3.6–3.8GHz band[59]	Awarded 2016
Ireland	Regional licences to be awarded for 150MHz in the 3.4GHz band (25MHz from 3410-3425MHz and 3475-3600MHz) plus 200MHz in the 3.6–3.8GHz band[60,61]	2018
Romania	ANCOM has included in its 2017 'action plan' the intention to launch consultations on awarding spectrum for broadband services in the 450MHz, 700MHz, 800MHz, 1500MHz, 2600MHz and 3.4–3.8GHz bands[62]	Consultation in Q2 2017
Sweden	PTS has identified the potential use of the band for 5G and has postponed plans for auctioning it until it reached a position where the 3.4GHz and 3.6–3.8GHz bands would benefit from greater harmonisation[63]	Beyond 2017
Austria	Austrian telecommunications regulator, RTR, published in December 2016 a spectrum release plan for the 3.4–3.8GHz range.[52] The band is designated for 5G broadband services[64]	Q2 2018

55 ARCEP press release on 30 Mar 2016, see http://www.arcep.fr/index.php?id=8571&no_cache=1&L=1&tx_gsactualite_pi1%5Buid%5D=1843&tx_gsactualite_pi1%5Bannee%5D=2016&tx_gsactualite_pi1%5Btheme%5D=0&tx_gsactualite_pi1%5Bmotscle%5D=&tx_gsactualite_pi1%5BbackID%5D=2122&cHash=f18b77434b5ba2d8655dea0163d9acd4.

56 ARCEP press release on 6 Jan 2017, see http://www.arcep.fr/index.php?id=8571&no_cache=1&L=1&tx_gsactualite_pi1%5Buid%5D=2026&tx_gsactualite_pi1%5Bannee%5D=&tx_gsactualite_pi1%5Btheme%5D=&tx_gsactualite_pi1%5Bmotscle%5D=&tx_gsactualite_pi1%5BbackID%5D=26&cHash=4591898503b8f9d255f564e759d02457.

57 See http://www.teleoff.gov.sk/index.php?ID=11102.

58 http://www.ctu.cz/sites/default/files/obsah/ctu/vyzva-k-uplatneni-pripominek-k-upravenemu-navrhu-textu-vyhlaseni-vyberoveho-rizeni-za-ucelem-udeleni/obrazky/20161110-vyhlasenivyberovehorizenien.pdf.

59 Official confirmation of spectrum award http://english.nmhh.hu/cikk/170841/NMHH_Two_bidders_won_80_MHz_in_the_34003800_MHz_band.

60 See https://www.comreg.ie/industry/radio-spectrum/spectrum-awards/3-6ghz-spectrum-award/.

61 https://www.comreg.ie//media/2016/03/3.6-GHz-Band-Spectrum-Award_Workshop_Slides_as_presented.pdf.

62 See http://www.ancom.org.ro/plan-de-actiuni_119.

63 See http://www.pts.se/sv/Nyheter/Radio/2016/PTS-avvaktar-med-tilldelning-av-frekvenser-i-35-GHz-bandet-/.

64 See the award procedure at https://www.rtr.at/en/tk/FRQ5G_2018.

Country	Award plans	Estimated time of award[46]
Switzerland	Ofcom has launched a tender for consultancy services for a multi-band auction to take place in 2018. Ofcom plans to award up to 1×190MHz or 2×80MHz in the 3.4GHz band, and up to 1×200MHz in the 3.6–3.8GHz band, recognising the need for coordination with satellite ground stations in the 3.6–3.8GHz band. Spectrum is expected to be available for use for mobile from 2019. The award is part of a multi-band auction alongside the 700MHz, L-Band and 2.6GHz FDD bands[65]	H2 2018
Slovenia	As per above, the AKOS plans include both the 3.4GHz and 3.6–3.8GHz bands[48]	Expected before 2020
Cyprus	In 2011 applicants were invited to apply for spectrum in the two bands, however no new entrants came forward, resulting in the process being cancelled. The ministry still aims to award the spectrum and launched a consultation in 2015, with no further developments announced since[66]	No details yet

Where plans for assigning one or more of the bands for mobile use have been published, they vary greatly between different markets in terms of the prioritisation of bands and the sequence in which they are being released. This potentially reflects the fragmentation in current use and availability.

- In some European countries, military use in the 2.3GHz band (and in the 3.1–3.5GHz band) preclude nationwide availability of all or part of this spectrum for commercial mobile use
- In some countries, fixed wireless access (FWA) licences in the 3.4GHz band with long licence durations could delay regulators from re-licensing spectrum in this band for mobile use.
- In the 3.6–3.8GHz band it is apparent that restrictions arising from incumbent fixed and fixed satellite use vary across Europe. For example,[67] practically all of the countries that have indicated plans to award 3.6–3.8GHz have no satellite earth stations, the only exception being Cyprus (which has just two). By contrast many other European countries have significantly greater numbers, which will add considerable complication to clearing the band for mobile use. The UK for example has around 50 satellite earth stations. The findings of our research into the number of satellite earth stations in different European countries are shown in Annex C.

65 Details of the tender for consultancy services to the Swiss regulator can be found here http://www.publictenders.net/node/3551719.

66 http://www.mcw.gov.cy/mcw/DEC/DEC.nsf/All/7FC4C0AA7C8D3B4FC2257EB5002927DE?Opendocument.

67 We note that the concentration of satellite earth stations is one example of a factor complicating the change of use of the band to mobile, but there are others, including the presence of fixed links.

6.3 Mobile use of the L-Band

Another band that is of interest for making available in Europe for commercial mobile networks using 4G technology is the L-Band. Indeed, 40MHz between 1452–1492MHz is already assigned to Vodafone and Three in the UK.

The L-Band has been identified as suitable for SDL use alongside other spectrum bands deploying LTE-A technology. The band is not yet widely licensed for mobile use across Europe, but several countries have announced plans to award it, as summarised in Figure 6.3 below. As shown in Section 5.2, the device ecosystem in the L-Band is in its infancy at present; however, the identification of L-Band spectrum for IMT use at the WRC-15, European harmonisation for SDL and the subsequent expected awards of licences for mobile use of the L-Band may fuel its growth.

Figure 6.3: Summary of past awards and future planned awards in the L-Band in Europe [Source: Analysys Mason, 2016]

Country	Award plans	Estimated time
Past awards		
Germany	Two lots of 20MHz unpaired spectrum awarded to each of Telekom Deutschland and Vodafone, as part of the Mobile Broadband Project	Awarded in May 2015
Italy	Two lots of 20MHz unpaired spectrum awarded to each of Telecom Italia and Vodafone for mobile broadband use	Awarded in May 2015
UK	Two lots of 20MHz unpaired spectrum sold by Qualcomm to each of Vodafone and Three	Privately sold to MNOs in July 2015
Future planned awards		
France	ARCEP is planning to assign the band alongside 2.6GHz and 3.4GHz, likely within the next two years[55]	2017–2018
Romania	ANCOM has included in its 2017 'action plan' the intention to launch consultations on awarding spectrum for broadband services in the 450MHz, 700MHz, 800MHz, 1500MHz, 2600MHz and 3.4–3.8GHz bands[68]	Consultation in Q2 2017
Hungary	NMHH has identified the L-Band as a potential future band to auction in order to meet growing demand for mobile data[59]	2018
Switzerland	Ofcom has announced plans to award up to 91MHz of SDL spectrum alongside the 700MHz, 3.4–3.8GHz and 2.6GHz FDD bands. L-Band spectrum is expected to be available for use for mobile from 2019[65]	H2 2018
Ireland	ComReg launched a consultation in September 2014 on the potential auctioning of spectrum in the 700MHz, L-Band, 2.3GHz and 2.6GHz bands. ComReg reconfirmed its intention for future releases in these bands in June 2016, with no further details on dates or amounts.[50] Currently, the entire band of 40MHz is available for licensing. There has been no	No details released yet

[68] See http://www.ancom.org.ro/plan-de-actiuni_119.

Country	Award plans	Estimated time
	further news published since Feb 2015	
Greece	A public consultation has been launched regarding issuing of mobile licences in the L-Band[69]	No details released yet
Netherlands	Following a consultation demonstrating demand for future spectrum release in the L-Band, ACM has announced plans to release the band for mobile services in SDL mode[70]	No details released yet
Malta	Malta Communications Authority (MCA) published a consultation in July 2016 regarding the assignment of the 1452–1492MHz band for wireless broadband supplemental downlink[71]	No details released yet
Sweden	PTS in December 2016 published a feasibility study in preparation for the allocation of 1427–1518MHz to be used for supplemental downlink mobile broadband[72]	No details released yet
Austria	RTR published a spectrum release plan in December 2016. The 1.5GHz core band[73] is part of a multiband auction plan to take place in 2019 whilst the expansion band will be considered from 2020 onwards depending on the need and availability[52]	Q2 2019

6.4 Summary of key points

European countries are generally following the ECA agreements on the use of 2.3GHz, 3.4GHz and 3.6–3.8GHz. It is noted that the ECA table gives co-primary status to 'Fixed' and 'Fixed Satellite' use in the 3.4GHz and 3.6–3.8GHz bands, meaning that there is some variation in practice across Europe (with fixed satellite use being dependent on the location of satellite earth stations, which are unevenly distributed between different countries). There are a few countries in Europe where mobile use does not have a primary allocation in both the 3.4GHz and 3.6–3.8GHz bands, with a greater number of instances of this in the 3.6–3.8GHz band. Furthermore, there are two countries from our sample (Belgium and Italy) where mobile does not even have a secondary allocation in the 3.6–3.8GHz band, being principally used for fixed links and fixed satellite service (FSS) earth stations.

Plans for future awards of 2.3GHz, 3.4GHz and 3.6–3.8GHz are somewhat fragmented at present, although a noteworthy number of regulators are now recognising the potential use for mobile services in one or more of these bands and are launching consultations. Several European countries – notably the UK – have a greater concentration of satellite-earth station use in the 3.6–3.8GHz

69 Consultation took place 21 Oct to 21 Nov 2016, see http://www.eett.gr/opencms/opencms/admin/News_new/news_0522.html.

70 We were unable to confirm this from the Dutch regulator, ACM, with the news originally published by Telecompaper on 9 May 2016, see https://www.telecompaper.com/news/dutch-govt-approves-sdl-spectrum-plan--1142537.

71 See, http://www.mca.org.mt/consultations-decisions/assignment-process-15-ghz-band-use-wireless-broadband-electronic.

72 See, http://www.pts.se/sv/Dokument/Remisser/2016/Remiss-av-PTS-forstudierapport-om-15-GHz-bandet/.

73 Core band compromises 1452–1492MHz whilst the expansion band comprises 1427–1452MHz and 1492–1518MHz.

band, which raises concerns about the ease with which it will be able to be freed-up for future awards for mobile use. Hence, where there are proposals (even at a preliminary level) to award the 3.6–3.8GHz band for mobile use, it tends to be in those countries without satellite-earth stations using the spectrum. The fragmented picture of potential mobile use of the 3.6–3.8GHz band in different European countries is likely to impact the scale and timing of ecosystem development and take-up of this band.

7 Global opportunities for the 3.4GHz and 3.6–3.8GHz spectrum in the context of 5G

Ofcom has suggested that intervention in the 3.4GHz band could result in 'unintended consequences', in view of this band being identified by European regulators as an important band for early 5G deployment. In particular, Ofcom appears to be concerned that large bandwidths of 80–100MHz may be required for 5G and that competition measures affecting the distribution of 3.4GHz spectrum could restrict the outcome of the auction to make such distributions less likely. Whilst that is a factor to consider, another is the importance of all MNOs having a route to 5G at the same time, to avoid commercially distortive effects which 'latecomers' to the 5G market may struggle to recover from.

In this context, it is important to understand the potential for both the 3.4GHz and the 3.6–3.8GHz bands to be used for 5G as well as whether and how spectrum in these two bands could potentially be combined. This section therefore discusses market opportunities and challenges in the context of the potential use of the 3.4GHz and 3.6–3.8GHz bands for 5G.

7.1 The case for 3.4GHz and 3.6–3.8GHz as initial bands for 5G deployment

European policy focus

UK and European discussions on 5G have moved quickly during 2016 from a broad vision and analysis of use cases towards detailed discussion on standardisation, spectrum and implementation. It is clear European-level regulators and policy makers – as well as those in the UK – have early 5G availability as one of their top priorities in relation to deployment of next-generation infrastructures.

The Commission has developed an EU-wide '5G action plan',[74] which builds on inputs from a range of sources, including from European mobile network operators (MNOs) and vendors, which have presented a '5G manifesto' setting out the industry's priorities for coordinated action to ensure successful and timely deployment of 5G. From the Commission's 5G action plan, it is noted that there is a target for "at least one city in each European country to be 5G-enabled by 2020". The Commission has called for regulators and governments in EU Member States to confirm plans for achieving this and other targets over the coming 12 months.

In the UK, Ofcom has been proactive in planning for 5G deployment and has taken an active role in the European regulator's Radio Spectrum Policy Group (RSPG). It is not yet clear if and how the UK plans to meet the targets set out in the Commission's 5G action plan, however it is understood that a 5G strategy will be published by the UK Government during the early part of

74 *5G for Europe: An Action Plan*, communication from the EC to the European Parliament and others (published on 14 September 2016).

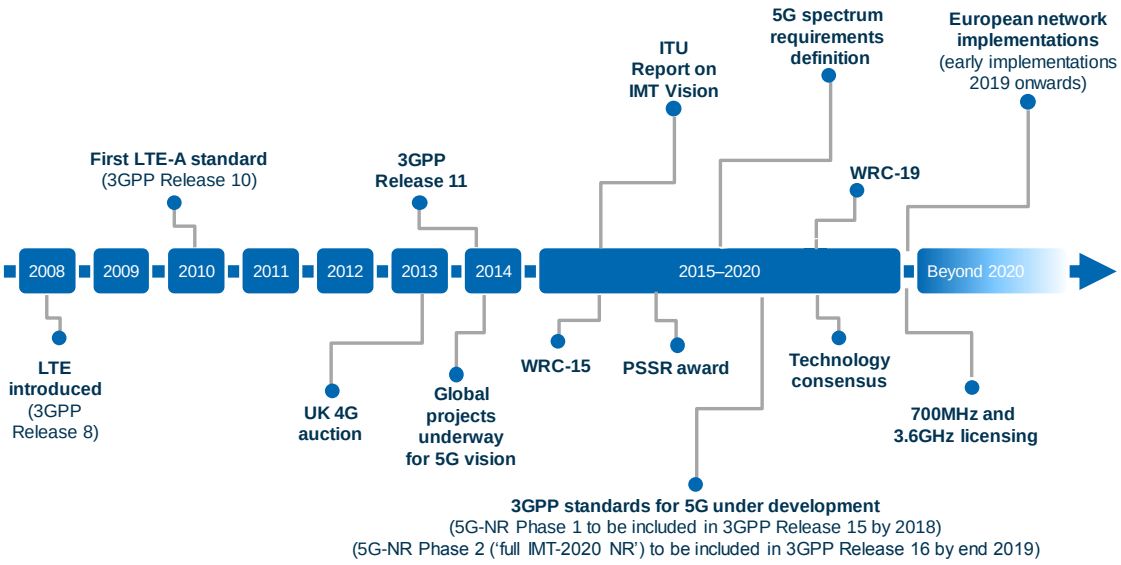
2017. Relevant questions in relation to enabling one UK city with 5G will include questions about which operator(s) will deploy the services (whether one mobile network, or all mobile networks), the technology, and the frequency bands to be used as well as a question on the chosen city(s) for early 5G enablement.

Industry standardisation

The Third-Generation Partnership Project (3GPP) refers to '5G new radio' or 5G-NR as being the new radio interface technology being specified for the 5G era. 3GPP have indicated Release 15 will be the initial new release of its specifications that will include 5G-NR. The 5G specifications will be further developed in Release 16 and in subsequent releases.

We understand from the timetable that 3GPP is currently working on the assumption that Release 15 will include 5G-NR capability in 'sub 6GHz bands' (which is likely to be in the 3.4–3.8GHz range) and in millimetre-wave bands up to 30GHz (in practice, focusing on the 26–28GHz range).

Figure 7.1: 5G timeline [Source: Analysys Mason, 2017]



A key aspect of 5G-NR is the use of wider contiguous spectrum (channels of 80–100MHz or more). Although the early focus of 5G research effort was on use of spectrum in the millimetre-wave portion of radio spectrum to realise these wider channels, more recent statements both from industry and from regulators have suggested spectrum below 6GHz being equally important for 5G. Although there is recognition that existing mobile bands could be used for 5G (and Ofcom's PSSR consultation refers to re-farming of existing mobile spectrum for 5G as being one of the options to deploy 5G without necessarily requiring spectrum in the 3.4GHz band), the design of 5G-NR to optimally operate in wide channels would seem to constrain the bands that it can be deployed in. For example, 5G-NR in the format currently being proposed would not be suited for

deployment in any of the existing spectrum assignments to MNOs in the UK (e.g. in the 800MHz, 1800MHz, 2.1GHz or 2.6GHz bands), due to insufficient bandwidth.

Spectrum implications

European regulators have actively discussed the bands that might be used for early 5G deployment in Europe during 2016, with a view to meeting the Commission targets (as set out in the 5G Action Plan and preceding documents) for deployments potentially taking place from 2018. The RSPG published its first opinion on 5G spectrum in July 2016, pointing to initial deployment of 5G services requiring both low (e.g. 700MHz) and mid (e.g. 3.4–3.8GHz) spectrum as well as millimetre-wave bands. The Commission's 5G Action Plan also points to spectrum in the 700MHz, 3.4–3.8GHz and millimetre-wave bands being needed to address the full scope of 5G network requirements. Within the millimetre-wave portion of spectrum, the three European priorities are 24.25–27.5GHz, 31.8–33.4GHz and 40.5–43.5GHz.[75]

Noting that decisions on harmonisation of millimetre-wave bands will not be reached until the World Radio Conference meets in 2019 (WRC-19) and that the 700MHz band is not immediately usable for mobile in most of Europe (and not until Q2 2020 at the earliest in the UK), there is now increasing focus on spectrum in the 3.4–3.8GHz range as being the most promising for early 5G deployment in Europe. Hence, we understand that most of the effort of major mobile vendor towards commercialising 5G is now focused on 3.4–3.8GHz and on the 26–28GHz frequencies in the millimetre-wave region.

A second RSPG opinion on 5G is expected to focus in more detail on how the 3.4–3.8GHz spectrum can be made available in time for early 5G deployment in Europe,[76] noting the fragmented picture in terms of availability between the 3.4GHz and 3.6–3.8GHz portions in different European countries, as described in the previous section.

7.2 Opportunities and challenges relating to availability and use of 3.4GHz and 3.6–3.8GHz for 5G in the UK

The Commission's 5G Action Plan and the RSPG's first opinion on 5G both identify 'pioneer bands' for early 5G deployment in Europe as being 700MHz, 3.4–3.8GHz and 24.25-27.5GHz. It is understood that the 700MHz band has been included primarily for coverage (and potential to address targeted use cases for future mobile communications such as 'connected cars'). However, it is clear from the bandwidth available in the 700MHz band that 5G-NR technology using wider channels cannot be deployed in this band. By contrast, the 24.25-27.5GHz band has ample bandwidth available for multiple operators to deploy channels greater than 100MHz wide. However, propagation characteristics in this region of the spectrum tend to limit deployments to smaller cells only. Although some global operators (e.g. in the USA) are proposing use of

75 These bands are part of a longer list under study for 5G, as specified in ITU-R Resolution 238 as agreed by the World Radiocommunication Conference in 2015 (WRC-15).

76 http://rspg-spectrum.eu/wp-content/uploads/2013/05/RPSG16-032-Opinion_5G.pdf.

millimetre-wave 5G to provide 'wireless fibre' (high speed broadband services) to homes in urban areas, it seems more likely in Europe that millimetre-wave 5G will cover targeted outdoor and indoor hot spots where MBB traffic density is at a peak.

The 3.4–3.8GHz range falls between the extremes of sub-1GHz wide area coverage, and millimetre-wave small cells. We understand vendors are suggesting this band with MIMO antennas will have similar properties to the 2.6GHz band in terms of the cell grid that can be used. However, compared to 2.6GHz, a key benefit vendors are keen to promote for 3.4–3.8GHz is that it will allow 80–100MHz carriers to be deployed allowing for Gbit/s data rates to be achieved.

In practice, it appears that most European regulators will not award all the spectrum in the 3.4–3.8GHz range in one block, but will make available one or more sub-bands initially (i.e. 3.4GHz or 3.6–3.8GHz), or portions of both, depending on current uses. We understand that the Commission will publish a mandate to CEPT shortly that might request study on the feasibility of making the full bandwidth available and relevant timeframes, to avoid a fragmented picture of different availability developing across Europe.

In the UK, Ofcom's sequence of award will be to make available the 3.4GHz spectrum as part of the PSSR award, followed by 3.6–3.8GHz at a later, but as yet undefined, point in time.

In the UK, the 3.6–3.8GHz spectrum is currently assigned for use by fixed links, satellite services and wireless broadband services.[77] A consultation document published by Ofcom in October 2016 entitled 'Improving consumer access to mobile services at 3.6–3.8GHz'[78] discusses alternative options for making 116MHz of bandwidth in the 3.6–3.8GHz band available for mobile use. Two options are proposed to make the spectrum available – an option in which existing services retain rights to use the spectrum (and hence mobile use must avoid locations where there is existing use) and an option in which existing services are migrated from the band (and/or lose their authorisations for interference protection).

Ofcom's proposals are framed as being about making spectrum available to meet future demands for mobile data use, and specifically 5G. Ofcom's proposal is to '*eventually award for mobile use… 116MHz of the band*'.[79] Ofcom indicates in the consultation that making this spectrum available will **help fulfil its duties regarding 'competition and innovation'**.[80]

Upon reviewing the proposals however, it is evident that uncertainty surrounds the timescales by which the 3.6–3.8GHz band might be used for mobile services in the UK. We understand that a notice period of five years might be typical to implement Ofcom's proposal of revoking the rights of current users in the band for example. Taking this into account (combined with the time

77 Specifically, UK Broadband has a UK-wide licence to access 84MHz of spectrum within the band, from 3605–3689MHz, which is paired with 3925–4009MHz. The spectrum that UK Broadband is licensed to use in 3.6–3.8GHz is shared on a first-come-first-served basis with the other existing uses (i.e. fixed links and satellite), with transmitter locations and sharing coordinated through Ofcom.

78 *Improving consumer access to mobile services at 3.6 to 3.8GHz*, October 2016, Ofcom.

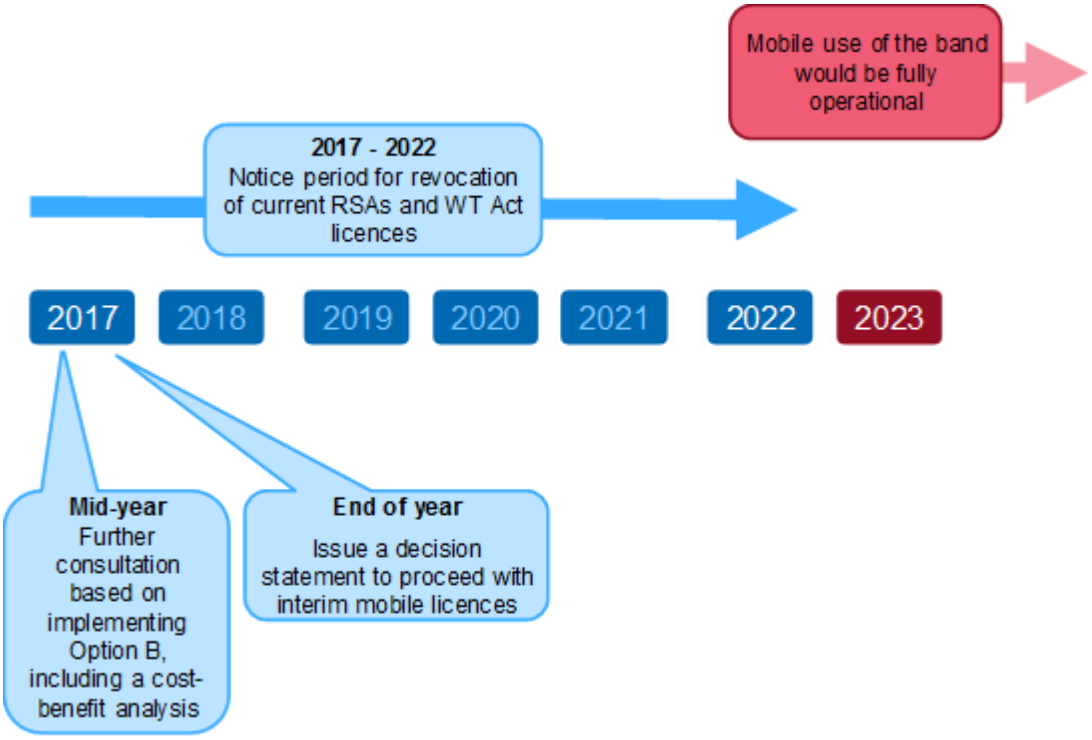
79 Paragraph 4.50 of Award of the 2.3 and 3.4GHz spectrum bands, November 2016, Ofcom.

80 Paragraph 2.22 of Award of the 2.3 and 3.4GHz spectrum bands, November 2016, Ofcom.

required to consult on proposals, and to finalise the mobile award), a possible timeline for the 3.6–3.8GHz spectrum becoming available is shown below.

This is based on Analysys Mason's estimates of possible timelines; it is possible that actual timelines could be longer (e.g. if more time is needed to prepare final proposals/consultation(s)).

Figure 7.2: Possible timeframe for the 3.6–3.8GHz band becoming available, under Ofcom's 'option B' approach[81] [Source: Analysys Mason, 2017]



Although it is not clear what the precise benefits to operators will be from having 80–100MHz channels available, what is clear from the above is that the prospect of achieving these wider channels is uncertain in the UK based on Ofcom's current proposals, given that the only part of the band available in the short term will be the 190MHz in the 3.4GHz, of which 150MHz will become available through the PSSR award with UK Broadband holding the remainder. However, under Ofcom's latest proposals, with no competition measures applying to the 3.4GHz band, it is quite possible that the band will be assigned asymmetrically (e.g. entirely to the larger operators in the market), leaving operators without 3.4GHz spectrum with an uncertain route into the 5G market.

We also note that even if the benefits of having large bandwidths available to individual MNOs in the 3.4GHz were certain, it is probable that they would still be outweighed by the likely harm to

81 Ofcom's consultation, *Improving consumer access to mobile services at 3.6-3.8GHz*, sets out two options to enable mobile use at 3.6-3.8GHz, see https://www.ofcom.org.uk/__data/assets/pdf_file/0035/91997/3-6-3-8ghz-consultation.pdf. Option B, which would result in a greater amount of spectrum being made available for mobile use over a wider geographic area, refers to removing existing users' authorisations to transmit for fixed links and removing interference protection for earth stations receiving in this band.

competitive intensity if not all MNOs have the early route to 5G. Hence, it seems reasonable to conclude that Ofcom should consider 5G deployments as an additional reason to consider imposing competition measures in the PSSR award related to the 3.4GHz band rather than a reason to justify not doing so.

7.3 Relevance of the 5GHz band and other possible bands for 5G

We note Ofcom's consultation refers to using the 5GHz band as a possible solution for operators to address capacity issues within their networks. In this section, we discuss the possible use of the 5GHz band, along with other possible frequency bands that might be standardised for 5G use (specifically including the 26GHz band).

As 4G networks evolve towards the 5G era, there will be increased inter-working among different existing radio access network (RAN) technologies to make optimal use of available technologies within a common infrastructure. Seamless interworking between LTE-A and Wi-Fi will give mobile operators greater control over quality of service (QoS) and more flexibility to use licence-exempt spectrum bands such as 5GHz, under the control of a licensed network. Hence, Ofcom has indicated in its consultation that it sees greater use of the 5GHz band within mobile networks, providing a possible solution for operators to address capacity issues in the longer term (mitigating the longer-term competition issues, in Ofcom's view).

Licence assisted access is the term being used to describe use of LTE technology to aggregate 5GHz unlicensed spectrum with an operator's licensed bands. The unlicensed spectrum is in the 5GHz band, also used by Wi-Fi, must be used in accordance with the licence exempt regulations applying in that band, which effectively limits use to small cells with low powers. It is noted in some parts of the 5GHz band there is an 'indoor use only' regulation applying to Wi-Fi, to avoid interference to other primary services at 5GHz (military and civil radar, including weather radar, and satellites).

Hence, key concerns from use of 5GHz to provide additional capacity are (a) usefulness of the spectrum given the low power and other restrictions; and (b) quality of service, which will vary based on the uncertainty of other users using similar channels in similar locations that exists in licence exempt bands.

In relation to other prospects for 5G deployment, opinions on the use of frequencies in the millimetre-wave portion of radio spectrum for 5G have developed both within Europe and globally over the past twelve months. In Europe, there are strong prospects of frequencies in the 26GHz band being harmonised for early 5G deployment, based on opinions published during the second half of 2016 by the Commission and the Commission's Radio Spectrum Policy Group (RSPG).[82] The Commission's 5G action plan advocates identification of a list of 'pioneer spectrum bands' and the RSPG's final (first) opinion on 5G (published 9 November 2016) recommends using

[82] 5G for Europe Action Plan, see https://ec.europa.eu/digital-single-market/en/5g-europe-action-plan and RSPG 'Strategic roadmap towards 5G for Europe – opinion on spectrum related aspects for next-generation wireless systems (5G)', see http://rspg-spectrum.eu/wp-content/uploads/2013/05/RPSG16-032-Opinion_5G.pdf.

24.25–27.5GHz as a pioneer band and developing European harmonisation measures, such that this band is available for 5G use by 2020. The RSPG opinion also indicates that 31.8–33.4GHz"looks a promising band […] for future deployment of 5G in Europe" and the 40.5–43.5GHz band "is a viable option for 5G in the longer term", but without specific timescales attached.

In terms of what these bands might be used for in the 5G context, use cases might focus on the highest-capacity outdoor and indoor hotspots, mostly in urban areas (requiring very high data rates and accommodating large volumes of traffic). Research suggests that 5G could require significant bandwidth in such hotspots (e.g. in the range from 3GHz to 6GHz per hotspot, using channel widths of between 100 and 500MHz, or greater).[83] Alternative use cases include fixed-mobile convergence (FMC) type business models. At the point at which these bands are being planned for 5G award, there might be separate competition issues for Ofcom to consider. However, given the distinctly different uses of bands such as 26GHz compared to 3.4GHz and 3.6–3.8GHz (possibly including different ecosystems and a broader range of relevant market players), we consider that the spectrum share and competition issues are different and, as such, are not relevant to the immediate issues in the PSSR award.

7.4 Summary of key points

Despite a fragmented picture in Europe in terms of current use of 3.4GHz and 3.6–3.8GHz, European regulators have broadly united behind a key goal of making the combined 3.4–3.8GHz band available for early 5G deployment. However, there is acknowledgement that the current use of the two sub-bands (i.e. 3.4GHz and 3.6–3.8GHz) is fragmented, as our analysis in Section 6 describes. Different regulators seem to be opting for different solutions at present. For example, the Irish regulator is in the latter stages of planning an auction of 3.6–3.8GHz licences, whereas the likely availability of 3.6–3.8GHz in the UK will not be before 2020.

Vendors are suggesting that channel widths of 80–100MHz or more are optimal for 5G-NR use. However, it is considered likely that specifications will allow for channels to be aggregated in the same way as they can for LTE-A (e.g. between 3.4GHz and 3.6–3.8GHz). Hence, it may not be necessary for an operator to hold a contiguous 100MHz carrier in the 3.4GHz band, if spectrum is also available in the 3.6–3.8GHz band that can be aggregated.

Given the potential delay in availability of 3.6–3.8GHz in the UK, it seems likely that 3.4GHz provides the earliest route to 5G, followed, potentially, by 700MHz and then 3.6–3.8GHz.

In our view, there is a clear competition concern with assigning the spectrum such that not all MNOs gain a reasonable portion of 3.4GHz, if it turns out to be the only early route to 5G. At the very least this would significantly disadvantage at least one MNO from a marketing perspective. Even though there may be benefits of having large bandwidths available to individual MNOs in the 3.4GHz band (although the magnitude of this benefit is uncertain), it is probable that these benefits would still be

[83] See http://www.analysysmason.com/About-Us/News/Press-releases/UK-Spectrum-Policy-Forum-Report-Identifies-Success-Factors-for-Making-the-UK-a-5G-World-Leader/.

outweighed by the likely harm to competitive intensity if not all MNOs have the same early route to 5G.

The optimal approach for competition in the UK would seem to be that each MNO gains a minimum portion of the available 3.4GHz spectrum, which can then be combined with more spectrum in 3.6–3.8GHz once available.

8 Implications and conclusions

8.1 The framework adopted by Ofcom to categorise spectrum appears inappropriate

Summary of our findings in relation to the relevant spectrum bands

Based on our analysis we consider that future spectrum availability and usability in the UK across all the bands considered (2.3GHz, 3.4GHz, 3.6–3.8GHz, L-Band and 700MHz) could range from 2017 to 2023 (or beyond). The potential timelines for different bands becoming usable, and the uncertainties associated with each, are summarised below:

- 2.3GHz spectrum will be available for use shortly after the PSSR auction. Deployment and device considerations suggest the spectrum could be put into commercial deployment in parts of MNO networks in the UK as early as the end of 2017. Full deployment combining 2.3GHz with the other bands widely deployed in UK MNO networks will be subject to some limitations in the short term – for example, in relation to potential for CA of 2.3GHz TDD spectrum with existing FDD bands.

- 3.4GHz will also be usable shortly after the PSSR auction, although widespread use will initially be limited due to a lack of device availability. However, the high level of industry attention that the 3.4GHz band is receiving in the context of the global spectrum squeeze and early planning for 5G suggests that the ecosystem for this band could develop rapidly. Taking this into account, full usability of this band, including a critical mass of customers holding compatible handsets, could occur from the end of 2019, in our view.

- L-Band spectrum is already licensed for use to Three and Vodafone and has also been awarded for mobile use in some other European markets. Our view is that the L-Band could become usable in a similar timeframe to the 3.4GHz band, and potentially as early as 2018 or 2019, although there is some uncertainty due to the relatively limited device ecosystem for this band to date.

- 3.6–3.8GHz spectrum is also receiving a high level of industry attention in Europe, and the eco-system for this band could in theory also evolve rapidly once there is greater certainty surrounding harmonised European plans for 5G. However, to date there have been virtually no mobile deployments in this band, and harmonisation is less clear than for other bands, meaning that availability of both network equipment and devices is uncertain. Furthermore, this band is not immediately available for mobile use in the UK and various other European countries due to the need to transition existing fixed and fixed satellite services from the band. Hence, although this band is being proposed for mobile award in some other European countries (such as Ireland, Slovenia, Switzerland and the Czech Republic), ensuring sufficient availability of spectrum in this band for mobile use in the UK is not straightforward. As such, timescales for

this spectrum being available for mobile use in the UK are far from certain, and we do not expect this spectrum to be usable until after 2022.

- Ofcom has previously stated that the 700MHz spectrum cannot be available for mobile use before Q2 2020 and possibly later, due to the need to complete digital terrestrial television (DTT) and programme making and special events (PMSE) clearance in 700MHz. A similar picture on timing for mobile use applies in various other European countries. At a European level, the Commission is recommending this band should be awarded for mobile use by around 2020. We note that an accelerated timescale for DTT migration has been proposed in the UK, however the detailed implementation of this is subject to some uncertainty both in relation to the complexity of re-deploying DTT networks and to ensuring a smooth migration (and usable alternative spectrum) for PMSE. Notwithstanding this, once available, the 2×30MHz of FDD spectrum in the 700MHz band is likely to be quickly usable due to the growing equipment eco-system supporting the use of this band that is being developed from outside Europe at present. Therefore, we estimate that this spectrum will become usable within six months of its availability for mobile, once network equipment has been deployed i.e. the end of 2020.

Implications and conclusions in relation to Ofcom's categorisation framework

Our view is that there are various factors affecting when spectrum will be usable within different UK networks, many of which are subject to some uncertainty. Taking these uncertainties into account, a more holistic view of spectrum availability is needed rather than Ofcom's imprecise categorisation into buckets labelled 'immediately usable' and 'not immediately usable'. The reality is more likely to be that new spectrum is likely to become available and usable in the coming years on a continuous basis. Hence, bands are not readily categorised into 'immediately usable' and 'usable following a transitional period of set length' as Ofcom attempts to do.

Specifically, our analysis finds that the timeframe in which the 2.3GHz band could be deployed in UK networks might be around two years ahead of the 3.4GHz band. The 3.4GHz band ecosystem could develop quickly once spectrum is available for mobile use and therefore Timescales for use of 3.4GHz are not likely to be materially different to the L-Band, with the 700MHz and 3.6–3.8GHz (and potentially 5GHz and millimetre-wave bands for 5G) becoming usable after this.

We have summarised the factors driving the readiness of each band for use in the UK in Figure 8.1 below. The figure considers the three factors discussed above (namely the availability of network equipment, the device ecosystem and the level of EU harmonisation) alongside consideration of when the spectrum is likely to be assigned for mobile use in the UK. An overall 'readiness for use' indicator is then provided by combining the individual factors. The overall readiness indication is based on colour coding as follows:

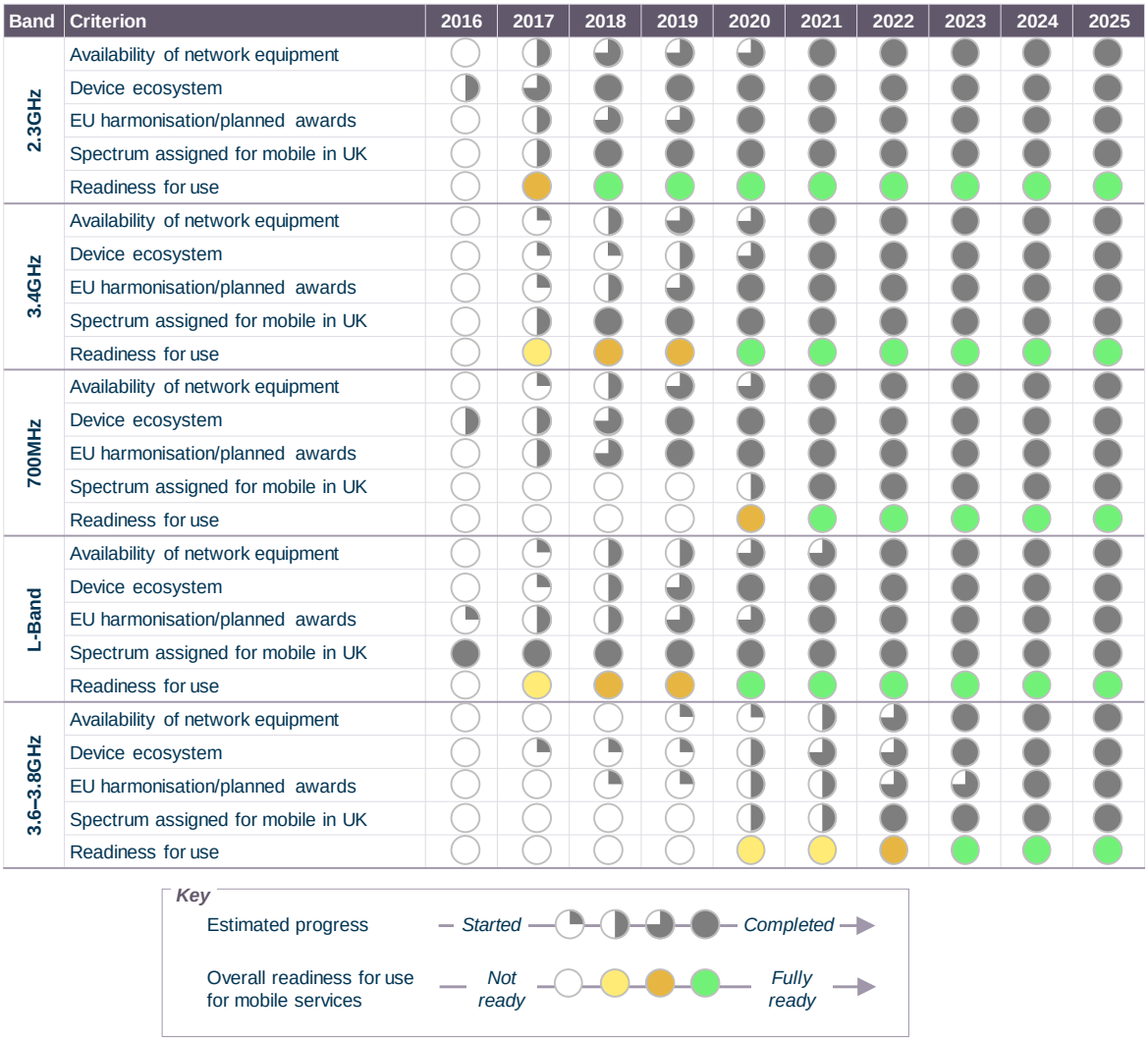
- *Green* – indicates a high level of confidence that spectrum will be available for use by mobile operators in the UK without any significant impediments, based on harmonisation being in

place network equipment readily available, a range of suitable devices being available and sufficient economies of scale existing to ensure that the band is attractive for MNO use.

- *Orange* – indicates that the band could be used by MNOs in the UK, but with some uncertainties and/or impediments to its use. There is likely to be some uncertainty in relation to one or more key factors in determining the band's readiness for use, as well as potentially to whether it will have been licensed for mobile use in the UK.

- *Yellow* – indicates that the band is unlikely to be usable by mobile operators in the UK due to one or more specific impediments to its use, although some progress is likely to have been made towards resolving these issues. For example, whilst there may be some network equipment and suitable devices, along with some level of international harmonisation, we expect that more development will be needed in each of these areas. It may also be uncertain as to whether the spectrum will have been licensed for use by UK mobile operators within the relevant timeframe (e.g. due to uncertainty associated with migrating incumbent users from a band).

Figure 8.1: Estimated readiness of spectrum bands for mobile use in the UK in the next 10 years based on findings presented in this report [Source: Analysys Mason, 2017]

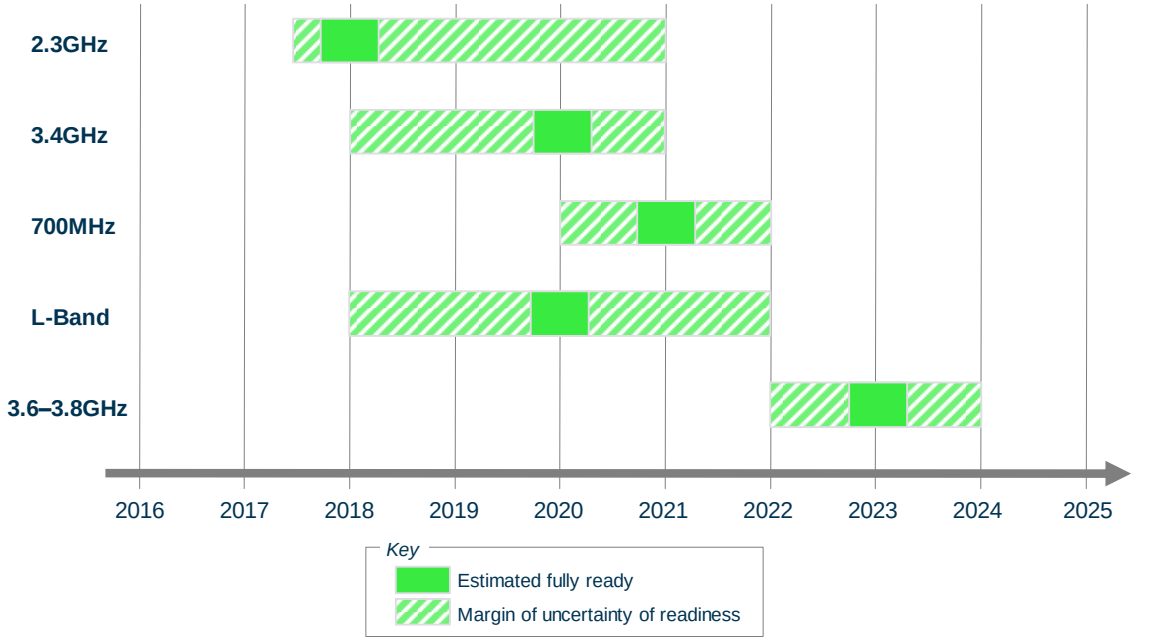


Based on the analysis above, we can conclude that whilst the 3.4GHz band lags behind the 2.3GHz band by around two years, the 3.4GHz band is likely to be available and ready for use ahead of both the 700MHz and 3.6–3.8GHz bands. Whilst the L-Band is already assigned for mobile use, devices have only recently started to become available and hence although there might be initial deployment before 2020, full usability will depend on a broader range of devices becoming available. The 700MHz band is a further year behind this and the 3.6–3.8GHz band is only likely to be available and ready for use beyond 2022.

The analysis shows that there is some uncertainly in factors impacting readiness for use of different bands (e.g. European awards might be delayed, or device availability might not develop as expected). Based on the analysis set out in Figure 8.1, Figure 8.2 provides our best view on where these uncertainties lie in relation to when each band may become available and ready for use in the UK. In the diagram below, the shaded area shows the possible margin of error on the timing of readiness for each band around our estimation of the year in which the band becomes fully ready for use. For example, while we estimate the 2.3GHz band being usable by 2018, the

full usability could be delayed to 2021 if the individual factors in the analysis above are not in place within the timescales we have estimated.

Figure 8.2: Spectrum availability and usability in the UK [Source: Analysys Mason, 2017]



On the basis of our analysis, we consider it is not possible to conclude that bands are either 'immediately usable' or not, since some bands that do not appear to be immediately usable could become so if certain factors in their development are accelerated beyond current predictions. It is therefore not possible to conclude that the only immediately usable band for additional mobile use in the UK will be the 2.3GHz band. As such, the framework does not appear appropriate as a means of assessing competition concerns. We also note some specific competition concerns that fall outside of Ofcom's framework (e.g. in relation to 5G), which are further elaborated below.

8.2 The competition measures proposed by Ofcom may fail to solve the real competition concerns

Because the framework used by Ofcom is inappropriate, the competition concerns that Ofcom identifies are not, in our view, assessed properly. This, in turn, leads to competition measures being designed to address the wrong competition concerns.

As such, our view is that Ofcom needs to adopt a more appropriate framework and, based on that, identify a revised set of competition concerns. Only then can it be determined whether the proposed competition measures are likely to be adequate or not.

Our high-level view is that there are very real concerns about an asymmetric distribution of spectrum that are not limited to any 'transitional period'. That being the case, it seems likely that a competition measure applying narrowly to a small portion of the available spectrum is not likely to be adequate to address these competition concerns.

If the correct framework is used and appropriate competition concerns identified, it seems likely that competition measures would need to encompass both 2.3GHz and 3.4GHz spectrum in aggregate, although this would need to be carefully determined by Ofcom.

Furthermore, although not strictly within the scope of our detailed analysis, there is an additional factor which should be considered in relation to the 700MHz band. Although the 700MHz band is almost certain to become available in the UK and, due to high levels of international harmonisation, is likely to be usable not long after 3.4GHz, it is not a particularly close substitute. For 700MHz there is limited bandwidth available in the band so its distribution is unlikely to significantly affect asymmetries in spectrum holdings. Further, policy goals related to coverage may make specific award proposals in this band incompatible with an aim of reducing spectrum asymmetries. Awards to date in this band in Europe tend to exhibit reasonably equitable distributions of the spectrum amongst MNOs due to the primary use being for coverage. Therefore, it seems unlikely that any competition concern relating to asymmetric distributions of spectrum following the PSSR award could, in practice, be solved using the 700MHz award mechanism.

8.3 Ofcom's concern about potential unintended consequences related to 5G appear to miss the bigger picture

Given the potential delay in the availability of 3.6–3.8GHz in the UK, it seems likely that 3.4GHz provides the earliest route to 5G, followed, potentially, by 700MHz and then 3.6–3.8GHz. In this context, we consider that Ofcom's analysis potentially underplays the longer-term competition risks arising from the 3.4GHz band being assigned asymmetrically in the UK market. Not addressing these longer-term competition issues at the current time has the potential to create significant uncertainty that it is not clear that measures within subsequent awards (e.g. of 700MHz and 3.6–3.8GHz) will address.

In our view, there is a clear competition concern with assigning the spectrum such that not all MNOs gain a reasonable portion of 3.4GHz, if it turns out that this band is the only early route to 5G. At the very least this would significantly disadvantage at least one MNO from a marketing perspective as well as in terms of ability to attract new customers and retain existing ones. Even though, there may be benefits of having larger bandwidths available to individual MNOs in the 3.4GHz band for the purposes of providing full 5G functionality (although the magnitude of this benefit is uncertain), it is probable that these benefits would still be outweighed by the likely harm to competitive intensity if not all MNOs have the same early route to 5G. We also understand that the industry's intention is that CA (or equivalent) will be specified between 3.4GHz and 3.6–3.8GHz, such that it is not necessary for MNOs to hold contiguous wider spectrum blocks in one or other of these bands but that smaller blocks can be aggregated in a similar way to in 4G. Hence operators acquiring 3.4GHz spectrum in the PSSR award would have the opportunity to aggregate this with spectrum acquired in the 3.6–3.8GHz band once this is available for mobile use in the UK.

Hence, the optimal approach for competition in the UK would seem to be that each MNO gains a minimum portion of the available 3.4GHz spectrum, which can then be combined with more spectrum in 3.6–3.8GHz once available.

Annex A Additional supporting data

This annex provides additional information in support of data and analysis presented in Section 4 of the report.

Figure A.1: Details of live LTE TDD commercial networks in the 2.3GHz, 3.4GHz and 3.6–3.8GHz bands deployed in Europe and worldwide, in support of Section 4 of the report [Source: Analysys Mason based on GSA and GSMAi, 2017]

Region	Country	Band	Operator	Launch date
Europe	Ireland	3.4GHz	Imagine Communications	Feb 2016
Europe	Italy	3.4GHz	Linkem	Dec 2014
Europe	Italy	3.4GHz	Go Internet	Sep 2015
Europe	Lithuania	2.3/3.4GHz	MEZON (LRTC)	Nov 2015
Europe	Russian Federation	2.3GHz	Vainakh Telecom	Jan 2013
Europe	Slovakia	3.4GHz	Slovanet	Jan 2013
Europe	Slovakia	3.6–3.8GHz	4ka (Swan Mobile)	Feb 2016
Europe	Spain	3.4GHz	Neo-Sky	Jun 2013
Europe	United Kingdom	3.4GHz	Relish Broadband (UK Broadband)	Jun 2014
Africa	Côte d'Ivoire	2.3GHz	YooMee	Apr 2014
Africa	Gambia	2.3GHz	Netpage	Mar 2015
Africa	Ghana	2.3GHz	Busy (Afrimax)	Jan 2016
Africa	Nigeria	2.3GHz	Spectranet	Aug 2013
Africa	Nigeria	2.3GHz	Bitflux	Aug 2016
Africa	Nigeria	3.4GHz	MTN Hynet	Jul 2015
Africa	Nigeria	3.4GHz	Cyberspace	Aug 2015
Africa	Nigeria	2.3/3.4GHz	Swift Networks	Nov 2013
Africa	South Africa	2.3GHz	Telkom Mobile	Apr 2013
Africa	Tanzania	2.3GHz	Smart	Aug 2015
Africa	Tanzania	2.3GHz	TTCL	Aug 2015
Asia	Bahrain	3.4GHz	Menatelecom	Feb 2014
Asia	China	2.3/2.6GHz	China Telecom	Feb 2014
Asia	China	2.3/2.6GHz	China Unicom	Mar 2014
Asia	Hong Kong	2.3/2.6GHz	3 (CK Hutchison)	Sep 2016
Asia	Hong Kong	2.3GHz	China Mobile	Dec 2012
Asia	India	2.3GHz	Airtel (Bharti Airtel)	Apr 2012

Region	Country	Band	Operator	Launch date
Asia	India	2.3GHz	Aircel (Maxis)	Jul 2014
Asia	India	2.3GHz	Reliance Jio (Reliance Industries)	Sep 2016
Asia	Indonesia	2.3GHz	BOLT! (Internux)	Nov 2013
Asia	Indonesia	2.3GHz	Smartfren	Jul 2015
Asia	Iran	3.4GHz	MTN Irancell	Oct 2016
Asia	Japan	3.4GHz	NTT DOCOMO	Jun 2016
Asia	Malaysia	2.3/2.6GHz	Yes (YTL Communications)	Jun 2016
Asia	Oman	2.3GHz	Omantel	Jul 2012
Asia	Oman	2.3GHz	Ooredoo	Sep 2014
Asia	Philippines	2.3GHz	Smart (PLDT)	Apr 2015
Asia	Saudi Arabia	2.3GHz	STC	Sep 2011
Asia	Sri Lanka	2.3GHz	Dialog (Axiata)	Dec 2012
Asia	Sri Lanka	2.3GHz	Lanka Bell	Feb 2014
Asia	Uzbekistan	2.3GHz	EVO	Apr 2015
Americas	Canada	2.3/3.4GHz	Telus	Mar 2014
Americas	Canada	3.4GHz	Bell (BCE)	Sep 2014
Americas	Canada	3.4GHz	ABC communications	Sep 2014
Americas	Canada	3.4GHz	CCI Wireless	Dec 2014
Americas	Peru	3.4GHz	Americatel	Oct 2014
Americas	Peru	3.4GHz	Claro (América Móvil)	Jul 2015
Oceania	Australia	2.3GHz	Optus (Singtel)	Jun 2013
Oceania	Australia	2.3GHz	NBN Co.	Jun 2013
Oceania	New Zealand	2.3/2.6GHz	Spark	Aug 2016
Oceania	Vanuatu	2.3GHz	WanTok	Mar 2014

Annex B Further analysis of device availability in Europe by manufacturers and models

This annex provides additional information in support of data and analysis presented in Section 5 of the report. A number of manufacturers producing smartphones popular in the UK are already supporting the 2.3GHz band and have shown interest in the 3.4GHz band. This annex provides an overview of manufacturers and device models supporting the 2.3GHz and 3.4GHz bands in Europe, and summarises developments in other bands that may provide an indication of the likely future developments in the 2.3GHz and 3.4GHz bands (i.e. by comparing 2.3GHz and 3.4GHz to 700MHz, 2.6GHz TDD and L-Band device models and manufacturers). **All data presented here is based on analysis of the GaMBOD device database (January 2017), focussing on devices suitable for use with other traditional European bands (e.g. 900MHz, 1800MHz or 2.1GHz).**[30]

2.3GHz-compatible devices

Devices

Currently, 1598 devices support the 2.3GHz band and are compatible with other LTE bands deployed in Europe. Of these, there are 1178 phones, 232 routers and 87 tablets, with the remainder being mainly dongles.

Manufacturers

As many as 107 different manufacturers supply 2.3GHz-compatible phones, with a further 78 manufacturing other 2.3GHz-compatible devices.

Popular phone models

- Apple (iPhones 5c/5s/6/7)
- HTC (Desire 610 to 828, One E9/M8/M9/S9/X9, Butterfly 2/3/S)
- Huawei (various models in the Ascend, G9, Honor, Mate, Nova, P8 and P9 series)
- Lenovo (various models including Vibe, Moto, Motorola, Zuk)
- LG (various models including G3-5, Spirit, Nexus, Stylus 2 Plus)
- Microsoft (Lumia 638-950, Moto 2nd Gen/ 3rd Gen/ X Style)
- Samsung (various models in the Galaxy series)
- Sony Mobile (various models in the Xperia series)
- TCL (various models in the Alcatel series)
- ZTE (various models including the Axon, Blade, Nubia and Star series).

Exceptions

Some other popular phone manufacturers in the UK appear to be slow at adopting the 2.3GHz band. These include:

- Nokia and Doro (No models supporting the 2.3GHz band yet)
- Google (supported only by HTC's Pixel launched in Q4 2016 as well as Motorola's Google Nexus)
- Blackberry (supported only by DTEK series launched in Q4 2016, as

well as the PRIV series).

Other bands supported	The majority of these phone models also support other bands deployed traditionally (900MHz, 1800MHz and 2.1GHz) and relatively new bands (2.6GHz FDD and TDD, 800MHz, 700MHz, etc.).

3.4GHz-compatible devices

Devices	Currently, 35 devices support the 3.4GHz band and are compatible with other LTE bands deployed in Europe. Of these, there are two phones and 28 routers, with the remainder being dongles.
Manufacturers	A total of 12 different manufacturers supply 3.4GHz-compatible devices suitable for use in Europe.
Popular phone models	According to GAMBod, the two phone models which support the 3.4GHz band are made by Samsung, namely Samsung Galaxy S7 and Galaxy S7 Edge. However, we have not been able to verify that these two models do support the 3.4GHz band, based on the available online specifications for these devices available from Samsung.[84]
Exceptions	None
Other bands supported	Both phones also support other bands deployed traditionally (900MHz, 1800MHz and 2.1GHz) and relatively new bands (2.6GHz FDD and TDD, 800MHz, 700MHz, 2.3GHz, etc.).

700MHz-compatible devices

Devices	Currently, 550 devices support the 700MHz band and are compatible with other LTE bands deployed in Europe. Of these, there are 454 phones and 44 tablets, with the remainder being dongles and routers.
Manufacturers	Only 39 manufacturers supply 700MHz-compatible phones, with a further 19 manufacturing other 700MHz-compatible devices.
Popular phone models	The same manufacturers that provide 2.3GHz-compatible phones also provide 700MHz-compatible phones, except that models supporting the 700MHz band are limited to more recent releases. • Apple (iPhone 6/6s/7) • HTC (various models in the Butterfly, Desire, One and Pixel series)

[84] For example, according to Samsung's information published here - http://www.samsung.com/uk/consumer/mobile-devices/smartphones/galaxy-s/SM-G935FZDABTU - 3GPP band 42 is not included in the supported frequency list.

- Huawei (various models in the Ascend, Honor, Nova, Mate, P8, P9 series)
- Lenovo (various models in the Moto and Motorola series)
- LG (various models in the G3-5, H, K and X series)
- Microsoft (Lumia 650 and 950 only)
- Motorola (various models in the Moto E/G/X/Z series)
- Samsung (various models in the Galaxy series)
- Sony Mobile (various models in the Xperia series)
- TCL (various models in the Alcatel One, Pixi and Shine series)
- ZTE (various models including the Blade, Nubia and Telstra series).

Exceptions

Similarly to the 2.3GHz-compatible phones, some other popular phone manufacturers in the UK have been slow to adopt the 700MHz band. These include:

- Nokia and Doro (no models supporting the 700MHz band yet)
- Google (supported only by HTC's Pixel launched in Q4 2016, as well as Motorola's Google Nexus)
- Blackberry (supported only by DTEK series launched in Q4 2016, as well as the PRIV series).

Other bands supported

The majority of these phone models also support other bands deployed traditionally (900MHz, 1800MHz and 2.1GHz) and relatively new bands (2.6GHz FDD and TDD, 800MHz, 2.3GHz, etc.)

2.6GHz TDD-compatible devices

Devices

Currently, 1266 devices support the 2.6GHz TDD band and are compatible with other LTE bands deployed in Europe. Of these, there are 855 phones, 231 routers and 73 tablets, with the remainder being dongles.

Manufacturers

As many as 82 manufacturers supply 2.6GHz TDD-compatible phones, with a further 76 manufacturing other 2.6GHz TDD-compatible devices.

Popular phone models

The same manufacturers that provide 2.3GHz-compatible phones also provide 2.6GHz TDD-compatible phones, except that models supporting the 2.6GHz TDD band are limited to more recent releases. In addition to the manufacturers listed below, which are popular in the UK, other manufacturers are better known in Asia (e.g. China-based GiONEE, Hisense, Oppo and Xiaomi)

- Apple (iPhone 5s/6/6s/7)
- HTC (various models in the Butterfly, Desire and One series)
- Huawei (various models in the Ascend, Honor, Mate, Nova, P8, P9

series)
- Lenovo (various models in the Lemon, Moto, Motorola, Phab, Vibe and Zuk series)
- LG (various models in the G3-5, H, K and X series)
- Microsoft (various models in the Lumia series)
- Motorola (various models in the Moto G/X/Z series)
- Samsung (various models in the Galaxy series)
- Sony Mobile (various models in the Xperia series)
- TCL (various models in the Alcatel One and Shine series)
- ZTE (various models including the Axon, Blade, Nubia and Star series).

Exceptions

Similarly to the 2.3GHz-compatible phones, some other popular phone manufacturers in the UK have been slow to adopt the 2.6GHz TDD band. These include:

- Nokia and Doro (no models supporting the 2.6GHz TDD band yet)
- Google (supported only by HTC's Pixel launched in Q4 2016, as well as Motorola's Google Nexus)
- Blackberry (supported only by DTEK series launched in Q4 2016, as well as the PRIV series).

Other bands supported

The majority of these phone models also support other bands deployed traditionally (900MHz, 1800MHz and 2.1GHz) and relatively new bands (2.6GHz FDD, 800MHz, 2.3GHz, 700MHz, etc.).

L-Band-compatible devices

Devices

Currently, seven devices support the L-Band and are compatible with other LTE bands deployed in Europe. Of these, there are six phones and one router.

Manufacturers

Only three manufacturers supply L-Band-compatible devices.

Popular phone models

According to GAMBoD, the six phone models which support the L-Band are made by Sony (two models in the Xperia XZ series) and HTC (two models in the HTC 10 series and two models in the Google Pixel series). The router is manufactured by ZTE (model MF980).

Other bands supported

The phones and the router also support other bands deployed traditionally (900MHz, 1800MHz and 2.1GHz) and relatively new bands (2.6GHz FDD and TDD, 800MHz, 700MHz, 2.3GHz, etc.).

Annex C Supporting data on current use of the 3.4GHz and 3.6–3.8GHz bands in Europe

This annex provides additional information in support of data and analysis presented in Section 6 of the report.

Figure C.1: Overview of the number of satellite earth stations in European countries [Source: Analysys Mason, 2016; ECO, 2016] NOTE: ECO has informed us that an updated database of the earth stations should be available from early January 2017. We will endeavour to obtain this information in time for the final report

Country	Number of Earth stations operating in the 3.4–3.8GHz band as of June 2010[85]	Number of sites operating in the 3.4–3.8GHz band as of June 2010[85]	Number of sites as of December 2016 (frequency not known)[86]
Austria	**6**	1	-
Belgium	**3**	2	2
Bulgaria	**3**	3	-
Cyprus	**2**	2	2
Czech Republic	**-**	-	-
Denmark	**4**[87]	3	1
Estonia	**-**	-	-
Finland	**-**	-	-
France	**18**	11	5
Germany	**31**	15	11
Greece	**3**	3	2
Hungary	**-**	-	-
Ireland	**-**	-	1
Italy	**10**	5	11
Latvia	**-**	-	-
Lithuania	**-**	-	-
Luxembourg	**1**	1	1
Malta	**-**	-	1
Netherlands	**15**	5	3
Norway	**17**	4	1
Poland	**5**	1	2

85 The most recent consolidated source on earth stations in Europe is based on questionnaire results collected by ECO in 2010, which is expected to be updated in early January 2017. See Effective implementation of Commission Decision 2008/411/EC on 3400-3800MHz, 14th June 2010 available here http://www.efis.dk/views2/questionnaires.jsp.

86 The latest data on live satellite earth stations was gathered from deployed earth stations by teleport operators that are members of the World Teleport Organisation, by searching at country level from http://www.worldteleport.org/?SearchNew4.

87 Information from the 2010 published data updated to reflect the latest information provided from communicating with ECO. An update on all countries expected in early January 2017.

Country	Number of Earth stations operating in the 3.4–3.8GHz band as of June 2010[85]	Number of sites operating in the 3.4–3.8GHz band as of June 2010[85]	Number of sites as of December 2016 (frequency not known)[86]
Portugal	**1**	1	-
Romania	**2**	2	1
Slovakia	**-**	-	-
Slovenia	**-**	-	1
Spain	**-**	-	3
Sweden	**-**	-	2
United Kingdom	**50**	19	15
Total	**171**	**78**	**65**