Laying the foundations for next generation mobile services

Update on bands above 6 GHz

Publication date: 20 April 2015

About this document

Ofcom is working to enable future mobile services, including ‘5G’ – the fifth generation of mobile services, whilst taking account of other users of spectrum. 5G networks are expected to comprise a number of different elements, each with different spectrum requirements. Spectrum at frequencies both below and above 6 GHz is expected to be relevant.

This document provides an update on our 5G work considering bands above 6 GHz. It summarises the responses to the Call for Input (CFI) that we published in January, sets out our current views on bands and outlines next steps.

Having considered the responses to the CFI and other developments, we believe it is desirable to identify specific potential bands above 6 GHz to help focus an agenda item for the World Radio Communication Conference in 2019 (WRC-19) and to maximise the potential for international harmonisation of 5G spectrum. .

We have therefore identified a preliminary set of bands in different parts of the 6 - 100 GHz range that we currently believe offer the best potential for use in the UK and harmonisation of 5G mobile services globally. This approach will also allow for the technical uncertainties present at this early stage in 5G development.

This does not guarantee that these bands will be adopted in the future and we do not rule out consideration of other options ahead of WRC-15, pending further developments and research.

We will now take forward the bands we have identified in forthcoming international discussions, including the relevant European preparatory meetings for WRC-15 at which the scope of a future WRC-19 agenda item on bands above 6 GHz will be considered.

Contents

Section 1

Introduction and Summary

Background

1.1 Ofcom is working to identify potential spectrum for future mobile services, including 5G mobile networks, whilst taking account of other existing and potential users of spectrum.

1.2 5G networks are expected to comprise a number of different elements, each with different spectrum requirements. The use of frequencies below 6 GHz is expected to be a key part of these networks. Ofcom published a strategy[1] in May 2014 on bands below 6 GHz, for example 3.6 - 3.8 GHz and 3.8 - 4.2 GHz, that could potentially be suitable for future mobile services, including 5G networks.

1.3 In addition, some of the 5G technologies being developed are expected to be able to utilise spectrum in bands above 6 GHz. With this in mind we published, on 16 January 2015, a Call for Input (CFI) on Spectrum above 6 GHz for future mobile communications. The CFI closed on 27 February 2015.

1.4 In the CFI we presented a set of frequency ranges above 6 GHz, identified on the basis of contiguous bandwidth of 1 GHz and current global allocation in the Radio Regulations to the mobile service. We did not propose that these criteria should be applied rigidly, so as to absolutely rule out options, but as a means of focusing efforts where they are more likely to be fruitful. We asked stakeholders about alternative and additional criteria for narrowing down the range of potential bands, as well as views on specific bands.

1.5 Stakeholders from a wide range of sectors made substantive submissions to the CFI, including mobile operators and manufacturers, telecommunications providers, broadcasters, the satellite industry, space science community, Government, radio amateurs, research and standards bodies.

1.6 The CFI was one element in a wider work programme undertaken by Ofcom to help assess what the exact nature of 5G may be and understand what the potential spectrum requirements might be to enable its future introduction. In addition to the CFI, we have informed our current views on bands above 6 GHz through:

- an external technical study (undertaken by Quotient) to analyse the technical suitability and options for different bands;
- the ‘Future technology and 5G’ event, hosted by Ofcom on 12 March 2015 at which stakeholders discussed the potential use of bands above 6 GHz for 5G services;
- our own (high level) review of the technical suitability of bands above 6 GHz and incumbent UK use;

[1] Mobile Data Strategy statement (May 2014): http://stakeholders.ofcom.org.uk/binaries/consultations/mobile-data-strategy/statement/statement.pdf

- informal discussions with a range of countries in Europe and worldwide to start to understand the potential for bands to be harmonised and used for 5G services globally; and

- consideration of the frequency bands highlighted by other international NRAs and organisations.

1.7 This update provides a summary of the responses from the CFI, an update on the bands we will be focusing on in forthcoming international discussions, and our next steps.

Summary

1.8 The CFI responses indicated that at this stage of 5G development, there is no consensus amongst stakeholders on specific bands to prioritise for further study, with some stakeholders indicating that it is currently too early to exclude any band for study.

1.9 Protection of incumbent services from interference was viewed by many stakeholders, including respondents from the satellite industry (and broadcasters in relation to broadcast satellite), the space science community, the Met Office, the RSGB and Government (MOD), as the main concern. This was expressed in both terms of existing use and future planned use / investment.

1.10 Having considered the responses to the CFI and other developments, we believe it is beneficial and possible to identify a number of frequency bands to focus on in forthcoming international discussions. These include the relevant European preparatory meetings for WRC-15 at which the scope of a future WRC-19 agenda item on bands above 6 GHz will be considered[2] as well as bi-lateral and multi-lateral discussions with other administrations around the world. We think this will help maximise the potential for global harmonisation of 5G spectrum.

1.11 Studying a very wide frequency range (6 – 100 GHz) for a WRC-19 agenda item would place a huge resource requirement on the UK and international community between now and WRC-19, possibly resulting in significant implementation delays for 5G. To avoid these problems, we believe it is appropriate to identify an initial set of potential frequency bands on which a WRC-19 agenda item can focus.

1.12 On the basis of our work so far, our preliminary view is that the frequency bands 10.125 - 10.225 / 10.475 - 10.575 GHz, 31.8 - 33.4 GHz; 40.5 - 43.5 GHz; 45.5 - 48.9 GHz and 66 - 71 GHz should be considered for study under a focussed agenda item on 5G mobile broadband for WRC-19. We have deliberately identified bands in different parts of the range 6-100 GHz in order to allow for the technical uncertainties present at this stage in 5G development.

1.13 We think these bands may be relatively straightforward to make available in the UK compared to other options within the range 6 - 100 GHz (although the 10 GHz band is likely to be significantly more challenging than higher frequency bands) and could have potential for being harmonised and developed for future 5G use globally. However, this does not guarantee that these bands will be adopted in the future or preclude other bands being added.

[2] Our submission to the CEPT project team (PTA) which reflects our position in this update is available at http://www.cept.org/ecc/groups/ecc/cpg/cpg-pt-a

1.14 We will continue to engage with other countries to exchange views on the bands we have identified and test the degree of international support they are likely to receive. We believe it is beneficial to identify bands that have the potential for global support.

1.15 Further discussion, both at domestic and international level, and development of technical sharing and coexistence studies, may result in us refining our preferred list of bands for study in the lead up to WRC-15 in November. Whilst we are aiming to develop a focused agenda item for WRC-19, we do not rule out consideration of other options, particularly if there is wide supported internationally. For example:

- Spectrum adjacent to the bands we have identified above may also be of interest. This includes spectrum around 10 GHz, 43.5 – 45.5 GHz, and 71 – 76 / 81 – 86 GHz. Nonetheless, these bands may present more challenges than those in our initial list.

- It is particularly difficult to identify bandwidths of least 1 GHz below 30 GHz taking account of incumbent use of these bands. At present we have only identified 2x100 MHz at 10 GHz. Therefore we will continue to consider if there are other potential options below 30 GHz with narrower bandwidths (say 500 MHz or 250 MHz).

Rest of this document

1.16 In the rest of this update we provide:

- An overview of the responses to the January 2015 Call For Input (CFI) (Section 2)

- An overview of other developments since we published the CFI (Section 3);

- An update on our thinking on factors for selecting bands and the preliminary bands we have identified (Section 4);

- Our next steps (Section 5).

Section 2

Overview of responses to Call for Input

2.1 The CFI on Spectrum above 6 GHz for future mobile communications ran from 16 January to 27 February 2015. We received 33 responses from stakeholders (four of which were confidential), including comments from mobile operators and manufacturers, telecommunications providers, broadcasters, the satellite industry, space science community, Government, radio amateurs, and research and standards bodies. All the non-confidential responses to the CFI are available on the Ofcom website.[3]

2.2 Based on the responses to the questions posed in the CFI, Table 1 below highlights the main themes that emerged. Annex 1 contains a detailed summary of responses.

Table 1: Main themes identified from CFI responses

Question 1: *Are there practical ways of achieving the very high performance that use of wide channels above 6 GHz could offer, for example using carrier aggregation of lower frequency bands?*	Carrier aggregation of frequency bands below 6 GHz will be a key component of the overall 5G solution, but even with technological improvements, it is unlikely to be sufficient or practical to meet the peak data rates and spectral efficiency required for 5G networks due to spectrum scarcity and the complexity of the Radio Frequency (RF) front ends required.
Question 2: *What recent or emerging advances in technology may provide effective solutions to the challenges in higher frequency bands? For example can increased propagation losses be mitigated by using the high gains available with massive MIMO?*	Technical solutions are potentially possible for spectrum use above 6 GHz to enable 5G. Examples provided included: massive MIMO, directional and phased array antennas, beamforming (analogue, digital and hybrid), ultra-dense small cell networks, semiconductor technology, polarisation, and dynamic spectrum access. In addition to this it was also stated that these technologies are still under study and further research into this area is required, especially in relation to outdoor-in coverage.

[3] Non-confidential responses to the CFI: http://stakeholders.ofcom.org.uk/consultations/above-6ghz/?showResponses=true

***Question 3:** Are there any fundamental/inherent frequency constraints of the 5G technologies currently being investigated with regard to:* *a) minimum contiguous bandwidth per operator? Will the spectrum for multiple operators need to be contiguous (i.e. a single band) or could multiple operators be supported through multiple bands?*	The availability of wider, contiguous, harmonised blocks of spectrum above 6 GHz will be needed to offer simpler and more cost-effective 5G solutions. However, there was no clear view on how much contiguous spectrum would be required. Views expressed varied, from at least a minimum of 100 MHz to in excess of 1 GHz. Some manufacturers argued a non-contiguous band allocation would be difficult to implement due to technology limitations. However some respondents stated 5G would not be constrained by a requirement for a minimum contiguous bandwidth.
b) frequency range over which the technologies are expected to be able to operate, for example due to propagation, availability of electronic components, antenna designs and costs of deployment? For example, is 10-30 GHz better or worse than 30-50 GHz and why?	Difficult to assess at this stage. No consensus on frequency range over which the technologies are expected to be able to operate. Various ranges proposed, but noted that it would not be desirable to rule out any frequency band options in this early phase of 5G studies. Overall it was considered that propagation and coverage in lower frequencies tend to have better propagation and less path loss, but higher bands tend to have more available bandwidth and better localised frequency re-use. Also noted that all bands in 10 – 100 GHz are more-or-less equal due to their radio propagation characteristics.

Question 4: *Will 5G systems in higher frequency bands be deployed, and hence need access to spectrum, on a nationwide basis or will they be limited to smaller coverage areas? And if so, what sort of geographic areas will be targeted?*	Whilst noted that this subject was still under study it was generally expected deployment would be on a nationwide basis, but concentrated in hotspots, high density metropolitan areas and dense urban / sub-urban and possibly rural areas, due to the indicative small cell ranges (up to approx. 100 - 200m) of mmW. Likely to be achieved through the use of heterogeneous mesh access networks using existing sub-6 GHz infrastructure for nationwide (outdoor / long range) coverage with an underlay of ultra-dense small (pico/femto) cells using mmW spectrum for hotspot access or backhaul and to support growing traffic demands. A counter-position was also proposed: 5G would need to be capable of autonomous operation in local deployments and should not be dependent on systems at lower frequencies.
Question 5 *a) To what extent will 5G systems in higher frequency bands need dedicated spectrum on a geographical and/or time basis or can they share?*	A variety of views was expressed in relation to whether dedicated spectrum is required or sharing possible. Some argued that dedicated spectrum is desirable and beneficial to ensure a high performance mobile network and high quality of service/experience. However flexible geographic and/or time sharing options should be studied, whilst recognising that the potential for sharing will vary from band to band. There was also a division of views on the possible licensing approach, e.g. exclusive licences or licence exemption, to enable access to spectrum.
b) If they can share, what other types of services are they likely to be most compatible with?	No specific services were identified as being able to share with 5G. It was noted that it is difficult to provide an answer at this stage due to the uncertainty of the 5G technical characteristics. A counter-argument was that sharing between different operators that have complementary or restricted geographic coverage and/or low density usage might be possible, but will require further study.
c) What technical characteristics and mitigation techniques of 5G technologies could facilitate sharing and compatibility with existing services?	Increased isolation due to short frequency re-use distances; traditional resource sharing (e.g. listen before talk/dynamic frequency selection); and advanced antenna technologies may permit sharing, but more detailed studies will be required, particularly as no suitable mitigation techniques have currently been identified.

d) Could spectrum channels be technically shared between operators.	In principle, there was overall support for the proposition that sharing may be possible, but the standards/techniques have yet to be developed for such joint operations. Counter-arguments to this were: traditionally, spectrum use by mobile operators has been on an exclusive basis and this model will be the dominant approach for some time; sharing between operators is likely to be a commercial matter; and spectrum could only be technically shared between operators if they are not operating in the same location. To avoid interference the spectrum would need to be partitioned.
Question 6 *a) Given the capacity and latency targets currently being discussed for 5G how do you anticipate backhaul will be provided to radio base stations? Are flexible solutions available where the spectrum can be shared between mobile access and wireless backhaul?*	Whilst elements of 5G backhaul are still under study, it was identified that: • backhaul is important and it would be preferable to develop a joint access/backhaul spectrum allocation strategy; • spectrum in the mmW bands is well suited for backhaul; • some of the bands identified already support fixed links; and • whilst 5G could accommodate different fixed/mobile backhaul uses an increasing number of cell sites will use fibre backhaul instead. There was some disagreement with this view due to 5G latency targets being very demanding and challenges in fixed / mobile sharing / deployments.
b) What, if any, spectrum will be required? What channel sizes will be needed? Will the bands used be similar to those currently used for wireless backhaul?	There was no clear consensus in response to this question. It is seen as too early to say and would require further careful study, but may require a similar or greater amount of spectrum (possibly up to 2 GHz) as for mobile access.

Question 7: *Should we expand the scope of bands being reviewed beyond the 6-100 GHz range?*	The majority of stakeholders agreed that the scope of the frequency range 6 – 100 GHz should not be extended for study, but bands above 100 GHz could be investigated for backhaul. There was also support from the satellite community to reduce the range of the band to 31 – 100 GHz to protect incumbent services and reduce the number of coexistence studies required.
Question 8: *Do you agree that it is likely to be necessary for bands to have an existing allocation to the mobile service? Does this need to be a primary allocation?*	There was a general consensus that an existing primary mobile allocation would be desirable (to aid harmonisation), but other spectrum options, without a mobile allocation, should not be ruled out. Bands without a mobile allocation, that might have a good potential for a new global mobile allocation due to underutilization or reduced usage by existing users on a global scale, should not be excluded.
Question 9: *Do you agree with the criteria we have used for our initial filter of bands, and are there other criteria that could also be used?*	Majority agreement that the criteria used were correct. Some responses argued that the criteria were unrealistic and bandwidths narrower than 1 GHz, for example 200 – 500 MHz, should be considered. Other views were expressed about other filtering criteria, e.g. usage and compatibility for sharing, and analysing bands not having a primary mobile allocation.
Question 10: *Of the spectrum bands/ranges mentioned in this section, are there any that should be prioritised for further investigation?*	No consensus by stakeholders on the bands that could be prioritised. Some stakeholders considered that further study is required, and that it is too early to express a preference or exclude any band for study. Satellite stakeholders stated that only bands above 31 GHz should be prioritised. Frequency ranges with more frequent mentions included 25 – 29.5 GHz, 36 – 39 GHz, and 55 – 70 GHz and 81 – 86 GHz. A full summary of the frequency ranges supported and not supported by different stakeholders is included in Annexes 1 and 2.

***Question 11:** Are there any bands/ranges not mentioned in this section that should be prioritised for further investigation? If so, please provide details, including why they are of particular interest?*	Various other bands were identified that stakeholders stated could be further investigated, but there was no clear consensus on what these should be. The one frequency band that did have some support was 31.8 – 33.4 GHz. This was directly identified by 4 stakeholders (on the basis it was included in the METIS[4] study, despite not having a mobile allocation). A full summary of the frequency ranges supported and not supported by different stakeholders is included in Annexes 1 and 2.
***Questions 12:** Are there any particular bands/ranges that would not be suitable for use by future mobile services? If so, please provide details?*	No overall consensus on particular bands/ranges that would not be suitable for use by future mobile services. Protection of existing incumbent services from interference was an overall concern from stakeholders (notably satellite, passive / space services and amateur). This was expressed in terms both of existing use and future planned use / investment. A full summary of the frequency ranges supported and not supported by different stakeholders is included in Annexes 1 and 2.
***Question 13:** What additional information, beyond that given in Annex 5 would be useful to allow stakeholders to develop their own thinking around spectrum options?*	Requests included information on: • numbers of licences and incumbent usage; • public sector spectrum availability; • nature and extent of the existing uses in the allocated spectrum ranges; • the current usage and, especially, the future plan for the current incumbents; • geographical distribution; • long term plans of incumbent users; • usage of the bands across other nations and • bands not having a primary mobile allocation.
***Question 14:** What are the most important criteria for prioritising bands going forward?*	Harmonisation, mobile allocation, bandwidth, coexistence, technical suitability, timeframe and deployment cost seen as key criteria for prioritising bands going forward.

[4] An EU project on Mobile and Wireless Communications Enablers for the Twenty-Twenty Information Society https://www.metis2020.com/

Section 3

Other developments since the CFI

3.1 In addition to the CFI responses there have been other developments since we published the CFI in January which are relevant to this update. This section provides a brief overview of those as well as noting some of the on going developments.

5G and Future Technologies event

3.2 On 12 March 2015 Ofcom hosted an important debate to explore the impact of new mobile and wireless broadband technologies, including those underpinning 5G, on spectrum access, regulation and management.

3.3 The event was part of our ongoing work to understand the potential impact and opportunities created by future technologies, and complemented our Call for Input on use of bands above 6 GHz. Keynote speakers and panel input were provided by a range of forward thinking voices on 5G and future technologies. Details about the event and a copy of the slides presented are available on the Ofcom website.[5]

3.4 Relevant points from the event included:

- 5G is not all about bands above 6 GHz, bands below 6 GHz are just as, if not more, important. The coverage layer below 6 GHz is important to give a consistent quality of service.

- Although some felt it is too early to narrow down on specific bands now, there was also recognition that there is a need by WRC-15 at the end of this year to establish a viable WRC-19 agenda item. There may be enough additional information available by then to narrow down the bands and begin standardisation work.

- There is a preference for spectrum with limited use that can be used relatively simply. Although sharing might be feasible it could be difficult and/or costly. Some spectrum might be relatively easy to make available to meet the needs of 5G.

Quotient study

3.5 Ofcom commissioned Quotient at the beginning of January to investigate the suitability of frequency bands above 6 GHz for potential future 5G mobile systems.

3.6 Quotient has now completed its independent report on bands above 6 GHz and this has been published on the Ofcom website[6] in parallel to this document. In its study Quotient identified five potential bands with bandwidth of at least 1 GHz, summarised in Table 2 below.

[5] Ofcom 5G and Future Technologies presentations:
http://stakeholders.ofcom.org.uk/spectrum/spectrum-events/5g-future-technology/

[6] Quotient Associates - 5G Candidate Band Study:
http://stakeholders.ofcom.org.uk/binaries/consultations/above-6ghz/qa-report.pdf

Table 2: Quotient top five priority bands

Rank	Band, GHz	Usage, trend	Sharing or clearance required?
1	66-71	Low or none, fallow	No current use found
2	45.5-48.9 (three sub-bands)	Low or none, fallow	No current use found
3	40.5-43.5	Low, low growth (except in UK auctioned portion)	Either sharing with, or clearance of fixed; allocation to mobile; UK auctioned band is already technology neutral;
4	71-76; 81-86	Medium, growing	Sharing with fixed under light licensed regime[7]
5	57-66	Medium, growing	Sharing under licence exemption

3.7 Quotient found that it was more challenging to find suitable spectrum in the range 6-30 GHz and they believe that the aim of achieving 1 GHz bandwidth per operator for 5G may be difficult in this range. Consequently Quotient recommends that 6-30 GHz be re-examined with a significantly lower bandwidth requirement.

Other ongoing work

METIS

3.8 METIS is an EU project on Mobile and Wireless Communications Enablers for the Twenty-Twenty Information Society and has the objective of laying the foundations for 5G. A number of METIS deliverables were completed in February 2015 (https://www.metis2020.com/documents/deliverables/) on architecture, channel models, radio access, network level solutions and antenna transmission technologies. Its final project report is due on 30 April 2015.

ITU

3.9 The International Telecommunication Union Radiocommunication Committee (ITU-R) is continuing to produce a report under its ITU-R WP5D (Working party 5D) working group regarding the technical feasibility of 5G in the bands above 6 GHz.[8] The report is due to be finalised in Summer 2015.

[7] Parts of these bands are coordinated in the UK.
[8] Draft new Report ITU-R M.[IMT.ABOVE 6 GHz], http://www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/imt-2020/Pages/default.aspx

FCC Notice of Inquiry (NOI) on bands above 24 GHz

3.10 The FCC Notice of Inquiry (NOI) to examine use of bands above 24 GHz for mobile broadband[9] was published in October 2014 and closed on 15 January 2015 with reply comments due by 17 February 2015.

3.11 The aim of the NOI was to assist the FCC in assessing the wireless industry's interest in using mmW spectrum for wireless mobile services. The FCC received 78 responses from across the communications industry. These responses are available via the FCC's Electronic Comment Filing System – Proceeding Number 14-177 filings.[10]

3.12 The FCC is currently reviewing the responses they received.

[9] FCC Use of Spectrum Bands Above 24 GHz For Mobile Radio Services http://www.fcc.gov/document/noi-examine-use-bands-above-24-ghz-mobile-broadband

[10] Responses to FCC NOI http://apps.fcc.gov/ecfs/comment_search/paginate?proceeding=14-177&pageNumber=1&pageSize=100&sortColumn=dateDisseminated&sortDirection=DESC&pageView=Tabular

Section 4

Update on bands above 6 GHz

Introduction

4.1 This section provides an update on the factors we believe are relevant to identifying bands for study above 6 GHz and our preliminary views on an initial set of bands that an agenda item at WRC-19 could focus on. Our views take account of stakeholder input from the CFI and 5G event, external research (including that undertaken by Quotient and METIS), international discussions, as well as our own further research.

Factors relevant to identifying bands for study

Technical suitability of different frequency ranges

4.2 Although there is a general view that 100 GHz is currently a sensible upper bound for 5G access networks (while above 100 GHz could be considered for future wireless backhaul solutions), there is currently no technical consensus on which, if any, part(s) of the range between 6 and 100 GHz will be more or less suitable for 5G. Annex 3 provides our current understanding of the range of technical factors and trade-offs involved.

4.3 One view, expressed in the Quotient research, is that there are no fundamental technical reasons for favouring one part of the range 6 - 100 GHz more than another. They separately note that use of frequencies above approximately 30 GHz will enable steerable array antennas to be more easily integrated into handsets.

4.4 On the other hand, some stakeholders claimed that frequencies up to 30 or 40 GHz are less “difficult” from a technology perspective, in particular due to lower losses in RF components/feeds, more efficient power amplifiers and other hardware aspects.

4.5 Our current view is that in order to have a clearer view on the technical suitability of different parts of the range 6-100 GHz, further work is needed to better understand propagation and technology enablers (e.g. MIMO, beamforming, antenna arrays) at these frequencies. Research into some of these issues is at a relatively early stage and the outcome of ongoing research may have an impact on which parts of the 6-100 GHz range could be most useful for 5G mobile services.

4.6 We think it is therefore desirable at this stage to identify bands in different parts of the 6 - 100 GHz range in order to mitigate the various technology uncertainties and make it more manageable to facilitate the development of an agenda item at WRC-19. For example, we think there are potential risks associated with focusing on bands only in the 40 - 70 GHz range if subsequent research uncovers disadvantages of that range compared to other possible ranges elsewhere between 6 – 100 GHz.

Contiguous spectrum

4.7 Respondents to the CFI generally agreed that contiguous spectrum is required. However, it might not be necessary for the spectrum for all operators to be in a single contiguous block, provided the blocks were sufficiently close (say ±5 - 10%) to use the same components.

4.8 Views from the CFI were that requirements could be from 100 MHz to in excess of 1 GHz per operator. We believe that a smaller bandwidth nearer 6 GHz may be able to provide a similar throughput as a wider bandwidth nearer 100 GHz. Therefore there may be a technical case for looking for narrower blocks of spectrum lower down in the frequency range.

Other users of spectrum and scope for sharing or re-purposing

4.9 A number of concerns were expressed in CFI responses from incumbent users of bands above 6 GHz, including from:

- The satellite industry, who asked for new mobile services to be above 31 GHz in order not to harm UK investments in the space sector;
- The space science community and Met Office, in respect of in and out of band interference to space and passive services due to the sensitivity of their equipment and importance of their work;
- Manufacturers and standards bodies, which stated that it is important to preserve sufficient spectrum already allocated for fixed services. In their view, bands allocated to the Fixed Services that are / expected to be heavily used in certain areas or regions are likely to present a challenge for deployments of 5G systems;
- The RSGB, which seeks protection of the radio amateur and amateur satellite bands; and
- MOD, who said 5G plans above 6 GHz need to take account of their use, as defence spectrum is a key factor in national security.

4.10 In addition to existing use, other relevant considerations include our current understanding of future spectrum demand for non-mobile uses and the impact on other policies, for example where uses are migrating into a band in response to changes elsewhere.

4.11 New possibilities for spectrum sharing may be opened up as a result of beam widths being smaller at higher frequencies. However, we recognise that sharing may introduce additional costs and complexity compared to access to a clear band and further studies would be needed to assess the opportunities and risks on a case by case basis.

4.12 Finally we note that Ofcom auctioned spectrum in the 10, 28, 32 and 40 GHz bands in 2008.[11][12][13] The current licensing structure of these bands might facilitate re-purposing in the future as they are mostly held as blocks of spectrum by a small number of operators, in contrast to some bands which have a more fragmented licensee base. In addition, Ofcom has a long standing policy of spectrum liberalisation, and so would in principle be interested in ensuring that relevant

[11] 10, 28, 32 and 40 GHz Licences - http://licensing.ofcom.org.uk/radiocommunication-licences/mobile-wireless-broadband/cellular-wireless-broadband/policy-and-background/licensee-freq-tech-information/uk-spectrum-access/

[12] 10, 28, 32 and 40 GHz Information Memorandum - http://stakeholders.ofcom.org.uk/binaries/spectrum/spectrum-awards/completed-awards/10-28-32-40-ghz-awards/10-40IM.pdf

[13] 10, 28, 32 and 40 GHz Information Memorandum Update- http://stakeholders.ofcom.org.uk/binaries/consultations/10-40notice/statement/imupdate.pdf

spectrum bands are opened up as appropriate to facilitate the provision of 5G services. There could be a separate question for us to consider nearer to time, about how the spectrum is assigned in order to promote spectrum efficiency and promote competition, noting that we have the regulatory tools to achieve this if necessary.

International harmonisation

4.13 The theme from the responses to the CFI was that while an existing primary mobile allocation in the Radio Regulations would be desirable to aid international harmonisation, other spectrum options should not be ruled out. For example, we received stakeholders' support for two bands that were not included in our initial list because they did not have a mobile allocation: 31.8 - 33.4 and 40.5 - 42.5 GHz.

4.14 To help us understand the potential for international support, we have taken into account the bands being considered by other bodies, particularly the FCC and METIS as they have both published information on the bands being considered. We will continue to actively to discuss with other countries and bodies, although we recognise that many are currently at an early stage in their thinking.

Preliminary views on specific bands

4.15 Our overall aim is to identify an initial list of specific bands, which

a) are likely to be relatively straightforward to make available in the UK (at least compared to other options), so that UK consumers could benefit from new 5G services without undue delay and costs in making spectrum available; and

b) could have potential for international support so that 5G equipment can benefit from global economies of scale.

4.16 In order to develop an initial list we have drawn on input from others, including stakeholders input to the CFI and Quotient's report, and used high level filters, rather than undertaking a 'bottom up' analysis of all bands between 6 and 100 GHz.

4.17 As noted previously there was no consensus among stakeholders on the bands that should be prioritised. Some frequency ranges including 25 - 29.5 GHz, 31 - 33 GHz, 36 - 39 GHz, 55 – 70 GHz, and 81 - 86 GHz, had been supported by a number of stakeholders. However, some of these ranges, particularly below 30 GHz, were not supported by other stakeholders. A summary of the bands supported and not supported by different stakeholders in contained in Annexes 1 and 2.

4.18 Quotient recommended a number of bands at 40 GHz and above in their report. However they did not identify any bands below 40 GHz. Given the technology risks we identify above, we have also looked at other options at lower frequencies.

4.19 The result of our initial analysis is that we have identified at least one band in each range of 6 - 20 GHz, 20 – 40 GHz, 40 – 60 GHz, and 60 - 100 GHz as set out in Table 3 below.

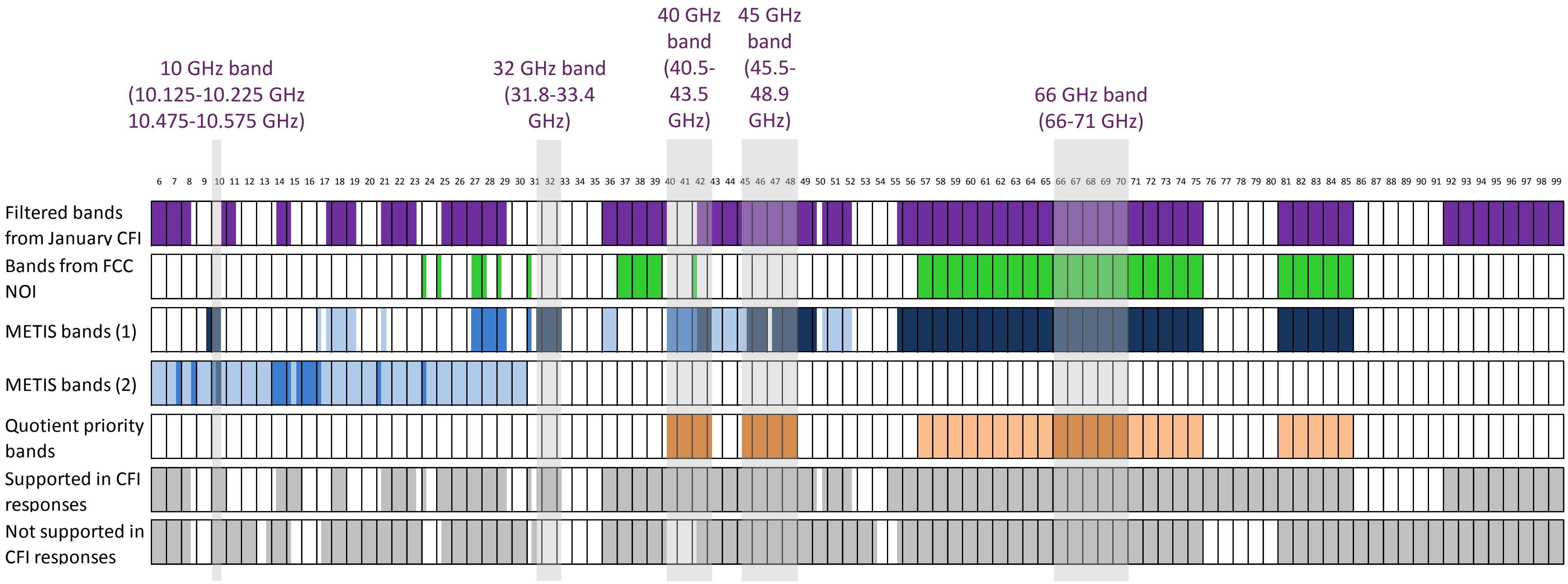
Table 3: Summary of preliminary bands identified

Frequency range	**6-20 GHz**	**20-40 GHz**	**40-60 GHz**	**60-100 GHz**
Specific bands identified	***10 GHz band*** 10.125-10.225 GHz / 10.475-10.575 GHz	***32 GHz band*** 31.8-33.4 GHz	***40 GHz band*** 40.5-43.5 GHz ***'45 GHz' band*** 45.5-48.9 GHz	**66 GHz band** 66-71 GHz
Potential bandwidth	*2 x100 MHz*	*1.6 GHz*	*5.8 GHz total*	*5 GHz*

4.20 Of these preliminary bands, the 32 GHz band and the 40.5-42.5 GHz segment of the 40 GHz band were not included in the spectrum ranges highlighted by our CFI, as they do not have a global primary mobile allocation. Despite this, the 32 GHz band received support from a number of stakeholders in their responses to the CFI and the 40 GHz band was recommended by Quotient as a high priority due to low incumbent use. Following further analysis, we have decided to include these in our preliminary list of bands.

4.21 Figure 1 below provides a high level overview of the bands that have been identified between 6 GHz - 100 GHz both through our CFI and from other sources.

Figure 1: High level spectrum map 6 - 100 GHz



METIS bands (1): Spectrum band assessment in Deliverable 5.1 (30-08-13). Assessment focused on finding very wide bands of contiguous spectrum (1 GHz was preferable).

METIS bands (2): Spectrum band assessments in Deliverable 5.3 (29-08-14). An additional band assessment with modified assessment criteria was performed on the 5.925 – 31 GHz range. A reduced target minimal contiguous bandwidth of 60 MHz was used, and a larger focus was given to outdoor deployments.

Metis High priority
Metis Medium Priority
Metis Low priority

Note: the lines 'Supported in CFI responses and 'Not supported in CFI responses' show only where stakeholders have made reference to specific frequencies. Non-specific frequency preferences, such as all bands above or below a given frequency, are not reflected.

4.22 Table 4 below provides a summary of the current UK use and international position for each of the bands identified. Annex 4 provides more detail on each of the bands.

Table 4: Summary of UK and international position for preliminary bands

Frequency range	Current UK authorisation	International allocations
10 GHz band *10.125-10.225 GHz / 10.475-10.575 GHz*	Auctioned bands, 2 operators (Digiweb and Mobile Broadband Network Limited as Agent of Everything Everywhere and Hutchison 3G UK Limited). Currently licensed for fixed terrestrial use or wireless cameras. The lower 10 GHz award block (10.125-10.225 GHz) and the lower 25 MHz of the upper spectrum block (10.475-10.5 GHz) fall within MOD managed spectrum, and a class A band for NATO.	In ITU regions 1 and 3 the frequencies 10-10.45 GHz are allocated on a primary basis to fixed, mobile and radiolocation, with a secondary allocation to amateur. In region 2 there is no mobile or fixed allocation, although a number of countries within region 2 have an additional allocation for these services.[14] The frequencies 10.45-10.5 GHz are allocated on a primary basis to radiolocation with a secondary allocation to amateur and amateur-satellite, although a number of states have an additional allocation to fixed and mobile.[15] 10.5-10.6 GHz is allocated to fixed, mobile and radiolocation, with the radiolocation allocation on a secondary basis from 10.5-10.55 GHz in region 1 in and in all regions from 10.55-10.6 GHz.
32 GHz band *31.8-33.4 GHz*	Auctioned band, 4 operators (MLL 32 GHz Limited, British Telecommunications Plc., Mobile Broadband Network Limited as Agent of Everything Everywhere and Hutchison 3G UK Limited and EE Limited).	These frequencies are allocated to the fixed and radionavigation services, with allocations to space research (deep space) (space to Earth) from 31.8 to 32.3 GHz, and inter-satellite from 32.3 to 33 GHz. Space Science use in the band is for data downlink for deep space missions. Sites are very few globally and located in remote areas – there are none in the UK. EFIS shows applications as the fixed service in Europe.[16]

[14] Footnote 5.480 Additional allocation: in Argentina, Brazil, Chile, Costa Rica, Cuba, El Salvador, Ecuador, Guatemala, Honduras, Mexico, Paraguay, the Netherlands Antilles, Peru and Uruguay, the band 10-10.45 GHz is also allocated to the fixed and mobile services on a primary basis. In Venezuela, the band 10-10.45 GHz is also allocated to the fixed service on a primary basis.
[15] Footnote 5.481 Additional allocation: in Germany, Angola, Brazil, China, Costa Rica, Côte d'Ivoire, El Salvador, Ecuador, Spain, Guatemala, Hungary, Japan, Kenya, Morocco, Nigeria, Oman, Uzbekistan, Pakistan, Paraguay, Peru, the Dem. People's Rep. of Korea, Romania, Tanzania, Thailand and Uruguay, the band 10.45-10.5 GHz is also allocated to the fixed and mobile services on a primary basis.
[16] European Communications Office Frequency Information System

Frequency range	Current UK authorisation	International allocations
40 GHz band *40.5-43.5 GHz*	Auctioned band, 3 operators (UK Broadband Limited, MLL 40 GHz Limited, Mobile Broadband Network Limited as Agent of Everything Everywhere and Hutchison 3G UK Limited). Recognised Spectrum Access for radio astronomy (one UK site)	The frequencies 40.5-42.5 GHz are allocated on a primary basis to the fixed, fixed-satellite (space to Earth), broadcasting and broadcasting-satellite services. There is a secondary allocation to mobile in all three regions. Region 2 also has a secondary allocation to mobile-satellite in 40.5-41 GHz. 42.5-43.5 GHz is allocated to fixed, fixed-satellite (Earth to space), mobile and radio astronomy on a primary basis. 40.5-43.5 GHz was designated in Europe for MWS (Multimedia Wireless System), and was recently re-designated also for the fixed service. EFIS shows applications in Europe in this range as MWS, fixed and FSS earth stations, with radio astronomy also in the frequencies 42.5-43.5 GHz.
45 GHz band *45.5-48.9 GHz*	Largely unallocated. There is a 200 MHz assignment to amateur radio, as well as a 400 MHz allocation to PMSE which is not currently used.	The band 43.5-47 GHz is allocated to the mobile, mobile-satellite, radionavigation and radionavigation-satellite services on a primary basis. 47-47.2 GHz is allocated to amateur and amateur-satellite only. 47.2-48.9 GHz is allocated to the fixed, fixed-satellite (Earth to space) and mobile services; in region 1 the fixed-satellite allocation is also (space to Earth) in 47.5-49.5 GHz and 48.2-48.54 GHz. EFIS shows no applications in Europe in 45.5-47 GHz. In 47-47.2 GHz amateur and amateur-satellite. Above 47.2, FSS Earth stations, feeder links and PMSE, with high altitude platform stations in 47.2-47.5 GHz.
66-71 GHz	Allocations to the radio navigation and radionavigation satellite service, which are either not in use or not expected to be a coexistence issue	This band is allocated to the inter-satellite, mobile, mobile-satellite, radionavigation and radionavigation-satellite services. Primary mobile allocation EFIS shows no applications in Europe.

4.23 Our current thinking is that these bands, based on current allocations and use, may offer better prospects than others within the range 6-100 GHz. Although we are not ruling bands out at this stage, we simply note that that the challenges of co-existing with existing services in some bands may make them less useful and/or more costly and complex for 5G use than bands where there are fewer coexistence issues to deal with. However, as we engage with other administrations internationally we will seek to understand if coexistence challenges in other bands can be overcome.

4.24 We remain open to consideration of other options particularly if there is wide support internationally. For example, we think there are two areas potentially worthy of further consideration.

4.25 First, spectrum adjacent to the bands we have identified above may also be of interest. This includes spectrum around 10 GHz, 43.5 – 45.5 GHz and 71 – 76 / 81 – 86 GHz. These bands may present more challenges than those in our initial list, but might become important if they can help expand the range of contiguous bandwidth available to 5G equipment.

4.26 Second, it has been particularly difficult to identify bandwidths of at least 1 GHz below 30 GHz taking account of incumbent use of these bands. This challenge was also recognised by Quotient and METIS. At present we have only identified 2x100 MHz at 10 GHz, and these bands are more challenging than those we have been able to identify above 30 GHz. Therefore we will continue to consider if there are other potential options below 30 GHz with narrower bandwidths, perhaps with a minimum of 200 MHz.

Section 5

Next steps

5.1 The information and analysis gathered from the Call for Input, related work and international developments will now inform our contribution to forthcoming international discussions. We will also undertake further analysis of potential bands, drawing on feedback from these international discussions.

International engagement

5.2 We will work bi-laterally and multi-laterally with other administrations around the world to better understand which bands could garner wide international support. Our aim in these discussions is to work towards the identification of potential 'global' 5G band(s) above 6 GHz.

5.3 Within Europe it is likely that IMT services above 6 GHz will be supported by CEPT for inclusion as an agenda item for WRC-19 and Ofcom will continue to seek to influence the development of the European Common Proposal (ECP) on future agenda items. We are providing our initial view on the specific bands identified in this document (as summarised in Table 3) to the CEPT CPG PTA[17] (project team A) meeting on 27 – 30 April 2015. We will consider whether to provide an updated view to the meeting on 20 – 24 July 2015.

5.4 Following these discussions it is possible that we may have a better understanding of the bands suitable for a worldwide agreement and we will be open to amending our position based on the outcome of the discussions.

Further work

5.5 We will continue to review available options taking into account feedback from international discussions. This includes:

- considering if there is scope for including bands adjacent to the ones in our initial list
- considering if there are any narrower (less than 1 GHz) bands below 30 GHz that may be appropriate to include.

5.6 Looking further ahead we will consider if and when it would be appropriate to publish a strategy consultation on bands above 6 GHz (similar to our Mobile Data Strategy that looked at bands below 6 GHz), that considers the issues for specific potential bands in more detail. Such a consultation is more likely to be after WRC-15, when the scope of any future agenda on bands above 6 GHz item is clearer.

5.7 We will also continue to look at ways to improve the accessibility and usability of existing information and aim to make more detailed information available to stakeholders. Although we already make available a lot of information concerning civil spectrum use in the UK, a number of stakeholders asked for additional

[17] http://www.cept.org/ecc/groups/ecc/cpg/cpg-pt-a

information. The provision of extensive high quality spectrum information is a key objective in our Spectrum Management Strategy

Annex 1

Summary of responses to Call for Input

Introduction

A1.1 The CFI on Spectrum above 6 GHz for future mobile communications ran from 16 January to 27 February 2015. We received 33 responses from stakeholders (four of which were confidential), including comments from mobile operators and manufacturers, telecommunications providers, broadcasters, the satellite industry, space science community, Government Departments, radio amateurs, and research and standards bodies. All non-confidential responses to the CFI are available on the Ofcom website[18].

A1.2 The purpose of the CFI was to gather information from stakeholders on spectrum above 6 GHz that might be suitable for future 5G mobile communication services, whilst taking account of the other existing and potential users of that spectrum.

A1.3 In the rest of this Annex, we set out a summary of stakeholders' responses to the individual questions that we asked in the CFI. Where there is some overlap in stakeholders' responses to specific questions (for example addressing a point under one question that asked by a later question), we have generally reported their comments under the question to which they responded.

Question 1: Are there practical ways of achieving the very high performance that use of wide channels above 6 GHz could offer, for example using carrier aggregation of lower frequency bands?

A1.4 There was broad agreement that whilst carrier aggregation of frequency bands below 6 GHz will be a key component of the overall 5G solution, even with technological improvements, it is unlikely to be sufficient or practical to meet the peak data rates and spectral efficiency required for 5G networks.

A1.5 A number of stakeholders said that carrier aggregation of lower-band carriers is seen as a complement to, rather than an alternative to, the use of frequencies above 6 GHz as the services, applications and traffic requirements anticipated within 5G are expected to require spectrum bands both above and below 6 GHz. Reasons for this were cited as:

- Achieving the 5G data rates would require aggregation of a larger number of channels than currently supported in LTE-A Release-12;
- Carrier aggregation of only low frequency channels is not likely to meet 5G requirements due to spectrum scarcity and the complexity in RF front ends (power consumption, filtering and transceiver complexity), which limits the number of simultaneous carriers and raises the cost of the RF components and deployment;
- Spectrum below 6 GHz is limited, fragmented and challenging to harmonise;

[18] Non-confidential responses to the CFI: http://stakeholders.ofcom.org.uk/consultations/above-6ghz/?showResponses=true

- Some combinations for aggregation of bands are mutually exclusive, so can compromise the potential for global harmonisation and roaming;
- Sub-6 GHz spectrum already and potentially available to mobile operators would not be sufficient for the 5G performance requirements / bandwidths required, even if aggregated;
- Existing mobile spectrum allocations will be required to deliver wide area mobile network capacity and cannot additionally support the new very high speed short range component of 5G mobile;
- Sufficient spectrum below 6 GHz will be required to provide the coverage layer required to deliver a good user experience for 5G; and
- Increased complexity and cost of the user device. The lack of harmonisation would not enable reaching economies of scale for the 5G handsets and infrastructure equipment, and negatively impact global circulation.

A1.6 Due to these reasons, some stakeholders considered that the availability of wider, contiguous, harmonised blocks of spectrum in higher mmW bands (above 6 GHz) will be needed to offer simpler and more cost-effective techniques critical to achieving 5G capabilities (for achieving the higher peak and average data rates along with increasing overall area capacity density), and acting as a catalyst for the development of new applications and services.

A1.7 For frequencies below 6 GHz, examples given for practical ways to increase and achieve 5G performance targets were:

- Massive MIMO and CoMP;
- New multiple access schemes and higher order modulations;
- Integration with other air interface technologies (e.g. WLAN);
- Carrier aggregation between licensed bands and with licence-exempt bands can increase the available system bandwidth; and
- Denser heterogeneous network

A1.8 For higher frequencies above 6 GHz examples given for practical ways to increase and achieve 5G performance targets were:

- Network densification, due to small inter-site distance and hence more densely deployed cells,
- Massive MIMOs, which are being discussed as ways to achieve higher performance and spectral efficiency; and
- Aggregating lower frequencies with mmW frequencies to provide an overlay architecture capable of using the properties of high available bandwidth and high frequencies to achieve high data rates while using the low frequencies to extend control and signalling coverage.

A1.9 Three responses (Iridium, RSGB and a confidential response) said that aggregation of bands below 6 GHz is possible and should not be discounted as it offers a more predictable migration path for the development of higher-rate services as the demand for the ultra-high bitrate services identified is unproven and such bandwidth with the right waveform could be capable of delivering 1-10Gb/s from future software defined radios using low cost CMOS chip-sets, supplemented by existing WiGig technology in the 57-64 GHz license-exempt band.

A1.10 In addition to this, Airbus stated that recent research has shown that of the spectrum already available to IMT and actually licensed, at least a third is not used. It was argued that these already allocated bands should be used to achieve higher efficiency in spectrum use by 5G systems.

Question 2: What recent or emerging advances in technology may provide effective solutions to the challenges in higher frequency bands? For example can increased propagation losses be mitigated by using the high gains available with massive MIMO?

A1.11 Stakeholders presented a wide range of views in response to this question. In summary, stakeholders made the following comments in relation to the emerging technologies that, in their view, may provide effective solutions to the challenges in higher frequency bands:

- Inter Digital Europe, and the BBC stated a greater use of small cell technology would support the use of higher frequencies;
- EE noted that the evolving concept of ultra-dense networks will help as small cells operating in the higher frequency bands will be tightly packed and therefore path length to a given UE (user equipment) will be minimised. A number of stakeholders stated that directional antennas, phased array antennas, high gain narrow beam antennas and Massive-MIMO are critical emerging technologies for the evolution of wireless systems in the mmW bands. They can be implemented in small form factors suitable for "mmW hotspot" base stations and access points and alleviate the high path loss associated with use of higher frequencies;
- A number of stakeholders stated that beam-forming techniques, dynamic beaming tracking and beam steering arrays will enhance the link performance in the higher frequency bands for line of sight conditions and mitigate propagation loss;
- Huawei referenced adaptive spatio-temporal signal processing techniques and the development of suitable integrated circuits (SiGe, CMOS and SoC);
- Intel and Huawei stated that advancements in semiconductor technology processes in manufacturing RFICs for the bands above 6 GHz allow several different processes, such as CMOS and GaAS MMIC, to be used to manufacture integrated and cost effective system-in-package modules consisting of mixers, LNAs, power amplifiers and IF amplifiers;
- EE stated that more robust waveforms (for example, Filter Bank Multi-Carrier modulation) will help compensate for loss due to diffraction and reflections in non-line of sight conditions;
- COST IC1004 noted that the 802.11ad WLAN standard at 60 GHz is now fully commercial and has been shown to reliably provide robust room scale performance;

- Nokia noted that polarization is also expected to play an important role in higher frequency ranges;

- Intel stated that that mmW access technology is expected to be developed at the same time as network technologies migrate towards general information technology infrastructure that enable Software Defined Networks (SDN) and Network Function Virtualisation (NFV). This could enable the deployment of self-contained, localised mmW access networks; and

- Airbus stated that dynamic spectrum management could be used to move assigned frequencies into localised hot-spots to meet demand.

A1.12 In support of this:

- BT stated that practical experience of higher frequency bands demonstrates that non line of sight propagation can benefit from reflections from buildings and other obstacles and the antenna scheme is important in determining the overall path loss;

- BT also stated that the group ITU-R WP5D is actively looking at the technical issues associated with mobile spectrum access in bands above 6 GHz and is preparing a Report ITU-R M.[IMT.ABOVE 6 GHz] on “The technical feasibility of IMT in the bands above 6 GHz ”which provides a very good summary of the technology issues and propagation considerations of the various bands;

- Angie stated that antenna technology is still a topic of study for most of the mmW spectrum. With regards to mmW spectrum in the E-band, multiple antenna techniques will be essential to provide beamforming gain to compensate the inherent propagation loss;

- Telefónica stated that additional research is needed to address mobility issues with such narrow beams, as well as the increased inter-cell interference that might appear in such configurations;

- Vodafone stated that it will not be feasible for a terminal to contain many hundreds of mm-wave transmit and receive chains, so some means will need to be found to reduce the MIMO complexity. It is therefore not yet possible to assess what complexity of massive MIMO would be needed in a mm-wave terminal;

- EE stated that the challenge of outdoor-in coverage requires much research including industries beyond the cellular and traditional radio communication domains; building designers and materials scientists could add significantly to this debate and should be consulted as part of a wider holistic approach to future communications requirements for the 21st Century.

Question 3: Are there any fundamental/inherent frequency constraints of the 5G technologies currently being investigated with regard to:

a) minimum contiguous bandwidth per operator? Will the spectrum for multiple operators need to be contiguous (i.e. a single band) or could multiple operators be supported through multiple bands?

A1.13 A majority of stakeholder responses indicated that contiguous spectrum is important, but there was no clear view on how much contiguous spectrum would be required. Various proposals were provided on what the bandwidth should be and ranged between a minimum of at least 100 MHz, up to at least 1 GHz per operator. It was also argued that there are few reasons why spectrum or infrastructure cannot be shared, potentially on a more dynamic basis than at present, to provide contiguous bandwidth.

A1.14 Nokia, EE, Intel and a confidential response agreed that to meet the high performance and traffic growth expectations of future 5G systems, a wide contiguous bandwidth was required.

A1.15 Nokia stated that the technical requirements for different 5G use cases and applications are still under study and that to facilitate the very high performance expected from future systems, a wide contiguous bandwidth of several hundred MHz, up to at least 1 GHz would be needed per operator, depending on operators required user/service bit rates, use cases and deployment scenarios.

A1.16 Nokia also noted that discussions related to minimum bandwidth per operator are still on going and that at this early phase of 5G studies it is not desirable to rule out any frequency band options.

A1.17 EE stated that a wide-band of contiguous spectrum per operator would be available however there are techniques related to carrier aggregation to realise wider logical channels from multiple narrower allocations, albeit with some additional complexity in comparison with single wider channels that will be possible above 6 GHz.

A1.18 Intel stated that operational bandwidths from in the 100 MHz to 1+ GHz range depending on the frequency band and mode of deployment. Although channel bandwidths of 100 MHz could be acceptable for certain applications, we believe there should be enough bandwidth available to 5G systems to ideally accommodate multiple contiguous channels of 500 MHz and even higher to simplify transceiver design.

A1.19 A confidential response stated that traffic growth and estimations indicate that GHz bandwidth is needed. A single wider band solution would be preferred due to user equipment limitation.

A1.20 Whilst a number of stakeholders said that there is no fundamental minimum bandwidth requirement, they also submitted that channelisation of at least 100 MHz or higher would make the offering of rates and services compelling to operators and end-users for adopting this technology. In their view, although channel bandwidths of 100 MHz could be acceptable for certain applications, there should be enough bandwidth available to 5G systems to ideally accommodate multiple contiguous channels of 500 MHz - 1 GHz and possibly even higher to simplify transceiver design. Therefore they foresee that several GHz of total bandwidth would be required to support mobile networks.

A1.21 Huawei and Samsung argued that it will benefit for implementations if the spectrum made available to multiple service providers is in a single contiguous block enabling a number of service providers to be served over a single unbroken frequency band. According to some respondents, this would help facilitate multi-operator roaming, whilst multiple bands could lead to implementation difficulties and potentially fragment the device market.

A1.22 Other views put forward by stakeholders suggested that in general they considered that sharing between multiple operators will be possible in 5G. According to some stakeholders, the perceived benefits from this would be:

- overall better spectrum efficiency if multiple operators could share contiguous band(s);
- economies of scale and global roaming; and
- contiguous bandwidth for operators should provide a simpler option to achieve high data rates and will enable more efficient ways of sharing spectrum access between multiple operators to improve spectrum usage further in the future.

A1.23 A number of respondents (EE, Alcatel-Lucent, Intel, Airbus and Huawei) said that it is essential that international harmonisation of any new spectrum is realised to ensure a mass market economic for equipment and systems operating at these frequencies. Mobile manufacturers viewed, that it is unlikely to be practical to support many higher frequency bands in devices, due to component costs and complexity. Therefore great care must be taken to select those bands which offer the greatest overall benefits.

A1.24 Other important considerations for frequency range indicated by stakeholders when considering frequency constraints were:

- adverse propagation characteristics (e.g. path, atmospheric and environmental losses) which are specific to each band;
- penetration losses (buildings etc.);
- harmonisation (international and regional) support across different regions to enable common standards and economies of scale;
- coexistence;
- cost of components;
- form factors (size and spacing) of the antennas at different frequency bands, different configurations (e.g. size of antenna arrays) and eventually architectures (e.g. analogue and/or digital) of the beamforming technology need to be considered to achieve the best trade-off between the performance gains and costs.

A1.25 In parallel, it was suggested by EE that whilst ideally a wide-band of contiguous spectrum per operator would be desirable, there are techniques related to carrier aggregation to realise wider logical channels from multiple narrower allocations, albeit with some additional complexity in comparison with single wider channels that will be possible above 6 GHz.

A1.26 COST IC1004 and Qualcomm noted that sharing should be possible in 5G, and could offer better overall spectrum efficiency if multiple operators could share contiguous bands. Whilst sharing across multiple non-contiguous bands may also be possible it will probably require more complexity. Both approaches should therefore remain possible.

A1.27 Ericsson also advised caution against relying too heavily on carrier aggregation between large numbers of non-contiguous frequency bands in higher frequency bands as user equipment manufacturers will need to design adaptive antennas that will simultaneously cover multiple, separated frequency bands, which may not be feasible if they are significantly far apart from one another.

A1.28 Two counter arguments were proposed to this view:

- Airbus stated that 5G technologies will not be inherently constrained by availability of a minimum contiguous bandwidth and that spectrum blocks would not need to be contiguous to support multiple operators. It was said that if operators are willing to share then contiguous multiple bands might make this more convenient; and

- UKSA argued that this spectrum identification exercise should not be pre-judged with considerations over markets and competition. Instead it should plan for spectrum allocations that satisfy the overall capacity needs of consumers. In relation to this, it was argued that multiple operators do not require multiple individual dedicated spectrum bands. This is likely to be the least efficient solution. Spectrum for multiple operators cannot be contiguous as there is not enough space available to achieve this given the bandwidths required.

b) frequency range over which the technologies are expected to be able to operate, for example due to propagation, availability of electronic components, antenna designs and costs of deployment? For example, is 10-30 GHz better or worse than 30 - 50 GHz and why?

A1.29 Whilst Nokia, Intel and Qualcomm noted that it would not be desirable to rule out any frequency band options in this early phase of 5G studies some (wide) bands were proposed by stakeholders:

- BT stated that all frequencies between 6 - 80 GHz –would be potentially of interest for evaluation;

- Samsung, Ericsson and a confidential response proposed 10 - 30 GHz. This was considered better for mobile services due to less complicated design requirements (e.g. more efficient RF components and sub systems), and improved mobility characteristics (e.g. longer range / uniform coverage), but beamforming gain requirements are reduced and antenna array elements increase in size.

A1.30 Counter arguments to the 10 – 30 GHz range were:

- O3b stated that any mobile terrestrial services transmitting in the 10-30 GHz band, specifically in the identified (filtered) band at the 17.8-19.7 GHz ranges, are likely to cause interference into satellite earth stations receiving signals from satellite downlinks currently allocated in the identified band. Thus, this would argue for excluding the identified 17.8 - 19.7 GHz range from consideration for 5G mobile terrestrial services;

- UKSA argued the 10 - 30 GHz range contains many important space science and telecommunications services that cannot move elsewhere. When coupled with the high bandwidth requirements it is difficult to see how 5G could fit into the lower part of the suggested range. There is likely to be much more opportunity for 5G at higher frequencies, including those above 50 GHz;

- A confidential response stated that the benefit of using 6 – 30 GHz as compared to 30 - 100 GHz at these distances will be minimal in terms of propagation. Therefore, due to the physical propagation characteristics of the atmosphere and physical antenna size the 30 – 100 GHz range should be given priority. In order to protect satellite services below 31 GHz, the frequency range for new 5G services should begin above 31 GHz.

A1.31 Other views on frequency ranges included:

- Above 31 GHz – A view shared among some satellite stakeholders is that any operation of 5G networks in the satellite Ku bands below 31 GHz will lead to significant sharing issues with those incumbent services, and, if such sharing were possible at all, it would inevitably lead to higher implementation costs and a less efficient use of the overall spectrum. As 5G/IMT intends to utilize cells with a radius less than 200 m, it is feasible for 5G/IMT to close their link budget at frequencies above 31 GHz. It was also stated use of bands above 31 GHz corresponded with EU sponsored research (METIS[19]);

- Up to 60 GHz –Vodafone stated that given the likely scale of 5G product development, they anticipated that the challenges in technologies and components can be addressed for frequencies up to at least 60 GHz;

- 20 – 50/60 GHz – Alcatel-Lucent considered that this would probably present the best opportunities for future mobile communications above 6 GHz, but should not exclude the possibility of considering bands outside this range, depending on their ability to satisfy the criteria.

- 30 – 50 GHz - Qualcomm advised that this spectrum can also be useful for mobile use. It is possible that the ability to fit in more antennas at the higher frequencies make it possible to achieve higher beamforming gains to overcome the additional losses.

- 60 - 70 GHz – InterDigital Europe considered that this band might be advantageous to others in particular from the viewpoint of mass and fast market adoption, by leveraging existing systems (e.g. WiGig) and enabling tight integration and flexible sharing of the spectrum between the access and the backhaul segments. They also noted that 60 GHz suffers from severe oxygen absorption yielding an attenuation of 15 dB per Km, but such attenuation drops as the centre frequency shifts away from 60 GHz.

[19] https://www.metis2020.com/

A1.32 UKSA and Airbus stated that it is not clear if 10 - 30 GHz is better or worse than 30 - 50 GHz as far as technology and components are concerned and that spectrum above 50 GHz should not be ruled out. Airbus stated that it is clear that the configuration of user terminals, antennas, and base-stations will be different to enable them to operate efficiently in these two example bands. It is likely that the current trend to integrate components optimised for multiple technologies into this equipment will continue and that it will be driven by the economics of the 5G business.

A1.33 Alcatel-Lucent stated that bands below 20 GHz would not present a high potential for mobile access systems due to the bands already used for backhaul below 20 GHz. In such cases where bands are widely used for backhauling, it was argued that mobile communications should be developed only if sharing between mobile and fixed networks is possible.

A1.34 A number of stakeholders expressed the view that propagation and coverage in lower frequencies tends to be more robust due to, for example, better propagation around obstacles (e.g. diffraction losses get worse at higher frequencies) and less path loss. In terms of implementation as well, there are lower losses in RF components/feeds, more efficient power amplifiers etc. at the lower bands.

A1.35 Whilst higher bands tend to have more available bandwidth and better localised frequency re-use it was also noted that propagation conditions compatible with effective use for mobile communications may limit the attractiveness of bands above 50/60 GHz for mobile communications, except for very short range cells where the use would rather be stationary than fully mobile.

A1.36 Huawei stated that to the extent that all the bands in the range 10-100 GHz experience radio propagation that is largely limited to line-of-sight or shorter range non-line-of-sight communications, the listed bands are more-or-less equivalent. It was stated that whilst the lower frequencies may be slightly preferred due to reduced propagation and building penetration losses, the upper bands may also benefit from increased specular reflections that may be exploited to increase throughput or reduce interference.

A1.37 Vodafone also considered that as video may form a large proportion of mobile traffic in the future this would favour a frequency closer to 6 GHz than 100 GHz due to the ability to penetrate into buildings from outdoor base stations and to support mobility, but noted there was little data on mmW propagation into buildings at this stage but what there is suggests attenuation rises with frequency.

A1.38 BT considered that the choice of band will need to balance many factors including the total bandwidth that needs to be accommodated, the propagation losses as frequency increases and the cost of components to deliver a given power level.

A1.39 EE argued that the lower the frequency the greater the range for a given set of parameters however this does not address all likely deployment scenarios. While sub-6 GHz spectrum continues to be essential for cellular communications due to its coverage properties; tight spatial reuse to enable ultra-dense small cell deployments as part of an optimised heterogeneous network will be essential to realise the necessary improvements in area capacity density that can be achieved more efficiently with higher frequency spectrum from this spectrum.

Question 4: Will 5G systems in higher frequency bands be deployed, and hence need access to spectrum, on a nationwide basis or will they be limited to smaller coverage areas? And if so, what sort of geographic areas will be targeted?

A1.40 Nokia noted that how 5G would be deployed geographically is still being studied. However, in general, there was agreement from a large number of stakeholders that 5G will likely be deployed on a nationwide basis, but concentrated in hotspots (for example shopping centres, airports, railway stations etc.), high density metropolitan areas (stadium, business parks etc.) and dense urban / sub-urban and possibly rural areas. This is due to the indicative small cell ranges (up to approx. 100 - 200m) of mmW.

A1.41 According to some stakeholders, this is likely to be achieved through the use of a heterogeneous mesh access networks using existing sub-6 GHz infrastructure for nationwide (outdoor / long range) coverage with an underlay of ultra-dense small (pico/femto) cells using mmW spectrum for hotspot access or backhaul and to support growing traffic demands.

A1.42 Essentially it is considered that 5G services in bands above 6 GHz will need to be supplemented by 5G operations in lower bands. The use of frequencies below 6 GHz will therefore continue to be an important element of the overall 5G system ensuring robust, reliable and ubiquitous network coverage in a cost effective manner.

A1.43 A number of stakeholders stated that as this type of deployment will be quite flexible and suitable for different kinds of deployment scenarios there might be scope for geographic sharing with other services to some extent. In particular, when deployed indoors it is less likely that 5GmmW will radiate outside of the building. More generally the propagation characteristics above 6 GHz are such that it would not be convenient to use these bands for providing wide area coverage. However additional techniques could be used, such as tracking capabilities and adaptive beamforming to enable wider area coverage, but would need to be weighed against other factors such as power consumption.

A1.44 Qualcomm stated that handoffs between indoor and outdoor base stations present challenges because indoor-outdoor penetration losses are generally higher at higher frequencies. Also, broadcast type operations will continue to be best supported by lower band spectrum due to its inherent omnidirectional transmission capabilities.

A1.45 Ericsson offered a counter-argument and stated that 5G systems must be capable of autonomous operation in local deployments, and should not be dependent on systems at lower frequencies. The ability of a 5G radio access component to independently handle local synchronization and mobility tracking may be important for low latency access and high capacity. Accordingly, while assistance from lower frequency signals may be a means of enhancing performance of the system using higher frequencies, it should not be required by design for its operation. Hence the availability of spectrum for 5G systems below 30 GHz will be crucial for obtaining coverage in urban areas on a nationwide basis, although there may be only sparse deployment in rural areas.

Question 5:

a) To what extent will 5G systems in higher frequency bands need dedicated spectrum on a geographical and/or time basis or can they share?

A1.46 Some stakeholders argued that dedicated spectrum would be necessary and potentially hugely beneficial to ensure a high performance mobile network and high quality of service / experience, but there was a division of views on the possible regulatory approach to authorising spectrum. Some argued that non-exclusive licensing would be preferred to avoid forms of "spectrum abuse" whilst others argued an exclusive unilateral national licensed basis would remain important and should be applied to ensure stability for long term investment into networks. Others stated that regulatory approaches such as LE and LSA should also be considered.

A1.47 It was noted that the elements related to sharing (either geographical and/or time basis) and aspects related to compatibility are on going and require further study. It was considered by some stakeholders that the challenging short-range, (e.g. 100 - 200m), propagation characteristics of the proposed technologies indicates that flexible geographic frequency sharing may be possible across multiple operators. This is because very high speed short range systems are not likely to be confined to smaller coverage areas and not deployed ubiquitously.

A1.48 According to some respondents, the spatial propagation characteristics of the higher frequency bands would allow for dense spatial reuse. Indoor and outdoor applications may offer sufficient isolation to enable coexistence between use cases. This, coupled with technical advances (interference limiting beamforming etc.), would make sharing possible on a geographical basis between small-cell access, small-cell backhaul, device-to-device and vehicle-to-vehicle communications.

A1.49 Other views expressed about the need for dedicated spectrum or the possibility of sharing included:

- InterDigital Europe stated that mmW technology is well placed to take advantage of spectrum sharing to enable active RAN sharing;
- The MOD stated that when assessing compatibility against other types of service, all MOD systems will need to be considered, e.g.: satellite, radiolocation, radiodetermination, fixed and mobile data link systems;
- Intel argued that the scope of this issue varies from band to band due to the variety and level of usage of incumbent services;
- Vodafone stated that they expect 5G systems will offer greater potential for spectrum sharing in higher frequency bands, not only geographically and in time, but also through angular discrimination of antennas;
- Airbus noted that the ability to share depends on the locality of the service and whether the spectrum can be reused efficiently in time and space;
- Telefónica stated that sharing is problematic; however, it might be possible for operators to create opportunities for sharing in spectrum above 6 GHz. For example, in the case of services where the QoE does not need to be guaranteed;

- Iridium stated that small amounts of dedicated spectrum may be more efficient than larger amounts of shared spectrum;
- The UKSA argued that:
  - To enable more equitable sharing it will be necessary to place constraints on mobile systems deployment and characteristics. It is important to recognise that permitting spectrum trading and technology neutrality unintentionally creates an artificial barrier to sharing. This places constraints on the scope for mitigation to enable spectrum sharing; and
  - A difficulty arises when administrations allow a change of use to a different service or a new technology. The replacement systems may have very different characteristics and this will impact the sharing.

b) If they can share, what other types of services are they likely to be most compatible with?

A1.50 Alcatel-Lucent, Airbus and SES stated that at this stage it is difficult to provide an answer and may even be premature to do so. 5G waveforms and air-interfaces are not yet known and can only be answered properly after further study of the interactions between the services once 5G specifications have been agreed.

A1.51 Several stakeholders (Vodafone, BT, Huawei and Qualcomm) expressed the view that services in bands above 6 GHz might be able to share with services that have complementary or restricted geographic coverage and/or low density of usage.

A1.52 Huawei added that sharing is least challenging where the geographic locations of the other service's receivers are fixed and well known, and the number of receivers is low.

A1.53 BT added that it may be possible to share the band for fixed backhaul.

A1.54 Both Vodafone and Qualcomm stated that directional antennas could provide some mitigation. Directional setups – links like fixed backhaul and/or satellite communications that are directionally limited could potentially coexist with mobile links in higher frequencies which are also spatially constrained. Specific use-cases need to be studied to see if the spatial domains of the services can be made non-interfering.

A1.55 The UKSA advised that 5G systems will share best with services that are not sensitive to interference, for example other mobile services and non-protected services like ISM and RLAN.

A1.56 SES stated that whilst there are currently many R&D efforts towards development of the 5G eco-system, the 5G system requirements are very ambitious, cover a wide range of performance requirements and are likely to change over time. These aspects will make sharing studies of such high density networks with incumbent services a real challenge.

A1.57 SES, ESOA and a confidential response stated that sharing between high-gain antennas like those used by satellite and point-to-point microwave has generally been shown to be feasible. However, once low-gain or uncontrolled-gain antennas are used, and multipath is used to boost channel capacity, interference cases multiply and sharing becomes problematic.

A1.58 O3b proposed that 5G mobile use is likely to be less compatible with intensively deployed satellite services between 6 – 30 GHz because, generally, ubiquitously deployed mobile services present issues of harmful interference in sharing with fixed-satellite services. The extent to which interference will be an issue depends on the proposed technology and its characteristics.

A1.59 Other views expressed by stakeholders were:

- Angie stated that operators should not be restricted by any regulator in any way or form of their (upcoming) commercial activity in 5G;
- Intel stated that compatibility between mobile and other services (particularly backhaul and trunk networks) are usually extremely difficult due to the different grades of acceptable service. The impact from mobile interference into other networks is therefore far more critical than the impact in the other direction;
- Samsung stated that the most interesting bands for high frequency IMT technology are generally in use either by fixed services (FS - coordinated point to point links) or the fixed satellite service (FSS);
- The RSGB stated that the only likely sharing scenario is where a mobile service may be deliberately [using] a similar frequency to its wireless backhaul (where sharing could be enabled by common hardware, network design etc.);
- A confidential response stated that high density IMT / 5G systems, which are high-density by their very nature, cannot share with other services;
- The UKSA said that 5G systems cannot share with space-borne services that are highly sensitive to interference. Where 5G systems are sharing spectrum with passive radiometers, even where the contribution from one device is small, the cumulative effect of many millions of devices is likely to result in an increase in the noise floor resulting in a loss of sensitivity.

c) What technical characteristics and mitigation techniques of 5G technologies could facilitate sharing and compatibility with existing services?

A1.60 It was noted here too by Airbus and the RSGB that further detailed studies are required.

A1.61 The RSGB noted that no detailed sharing studies are conceivable at present, until 5G is developed further and its principle parameters determined. Airbus argued that the eventual deployment of 5G services should be done with due care and attention paid to compatibility with existing users.

A1.62 Iridium also stated that currently no suitable mitigation techniques have been identified.

A1.63 A number of other stakeholders noted that the characteristics and mitigation techniques of 5G technologies which could facilitate sharing and compatibility with existing services included:

- Increased propagation / penetration losses in high frequency bands and hence short frequency re-use distances would increase isolation and facilitate coexistence and easier implementation of interference mitigation techniques to facilitate geographic sharing if necessary.

- Traditional resource sharing functionalities such as listen before talk "polite protocols" and dynamic frequency selection / database-assisted spectrum access could be employed;

- The introduction of advanced antenna technologies (for instance adaptive beamforming) coupled with the directional nature of transmissions in the mmW bands could facilitate sharing and coexistence with other incumbent applications / services and

- The inherent high directionality of high frequency IMT systems may facilitate interference management and sharing.

A1.64 Samsung also noted that new mitigation techniques may also emerge once the final radio spectrum management environment is understood.

A1.65 SES reiterated their argument that sharing of high density and ubiquitous 5G services with other services such as satellite services is not feasible. Indeed, sharing of such a service with any incumbent service and implementing some highly sophisticated mitigation techniques are often very challenging and would first need to be proven to work, before they can be proposed in any sharing scenario. ESOA added that even the relatively short range of communication of such IMT systems above 6 GHz (in the order of 100s of meters) does not change that premise.

A1.66 The UKSA also stated that any mitigation techniques agreed to enable sharing must be designed to be easily enforceable and compliance must be built in in a way that cannot by bypassed. It is therefore important to engage all stakeholders in the process in order to facilitate sharing.

d) Could spectrum channels be technically shared between operators?

A1.67 Both Airbus and the RSGB argued that there is no technical reason why spectrum channels could not be shared between operators. Airbus added that there is no doubt that there are technical means to enable sharing even if they are not fully mature or understood in operational terms at this stage. It is expected that this will be an attractive possibility given the large bandwidths under consideration for 5G and should therefore be a core part of future research activity.

A1.68 Qualcomm stated that in principle sharing may be possible, but the standards/techniques have yet to be developed for such joint operations.

A1.69 ViaSat UK Ltd stated that it believed that innovative sharing techniques could facilitate even more efficient use of spectrum by satellite and terrestrial mobile networks. For instance, a variety of cognitive and other sharing technologies exist and are being developed that can facilitate satellite uses of spectrum without impeding terrestrial uses in the same bands. These recent developments should negate the decades-old perception that broad use of spectrum by satellite operators somehow would constrain use of the same band by terrestrial users.

A1.70 A confidential response stated that the 5G standard should be developed to allow spectrum sharing and common infrastructure to be used by multiple operators.

A1.71 In support of this a confidential response noted that studies are ongoing at present within 3GPP to modify the LTE protocol to operate in shared spectrum, so technically this could be feasible in time for the launch of 5G.

A1.72 However, whilst this may be technically feasible it was considered by Alcatel-Lucent that sharing of spectrum channels between operators is likely to be a commercial matter.

A1.73 BT stated that the same spectrum channels could only be technically shared between operators if they are not both operating in the same area. However it is likely that operators may want to operate in the same area and this would mean that the spectrum would need to be partitioned, or else interference or reduction in capacity would occur.

A1.74 BT added that in some circumstances it may be cost effective and practical to share mobile network infrastructure between two or more mobile operators for high speed mobile coverage in bands above 6 GHz, but this is to be studied further.

A1.75 A confidential response stated that technical sharing is a key area for study and spectrum could be shared between operators very easily. It will be beneficial because at these frequencies cell sizes will be small and cell count will be high with both indoor and outdoor deployments. To achieve rapid deployment with good coverage in urban and suburban areas one shared radio access network on common infrastructure with a single band manager would be highly beneficial as there would be a large capex reduction for the whole industry.

A1.76 Huawei noted that traditionally, the preferred approach for the use of spectrum by mobile network operators has been on an exclusive basis and that this model will be the dominant approach for some time. Going forward, with the mmW deployments for mobile services in which the cell sizes are small and the geographic coverage may be non-contiguous, further arrangements may be considered.

Question 6:

a) Given the capacity and latency targets currently being discussed for 5G how do you anticipate backhaul will be provided to radio base stations? Are flexible solutions available where the spectrum can be shared between mobile access and wireless backhaul?

A1.77 Whilst some stakeholders (Telefónica, Nokia, Airbus, Digital Europe and SES) noted that the elements related to 5G backhauling are still under study and require more research, it was recognised by Samsung that proper backhaul provisioning will be an important element for successful 5G networks. InterDigital Europe and BT also considered that it might even be advantageous, in some circumstances, if backhaul and mobile access could use the same spectrum band.

A1.78 InterDigital Europe, COST IC1004, and Qualcomm all thought that the spectrum available in the mmW bands is attractive and well suited for backhaul solutions.

A1.79 Ericsson and the ISG mWT noted that microwave backhaul (point-to-point Fixed Services) is a key element of current backhaul networks and will continue to evolve with LTE and as part of the future 5G ecosystem.

A1.80 Nokia and Telefónica stated that it is most likely that there could be flexible solutions available where the spectrum can be shared between 5G mobile access and wireless backhaul, but the ISGmWT was of the opinion that these flexible solutions are likely to present a challenge that may need particular attention, if considered for sharing spectrum between applications with very different behaviours, as (dynamic) mobile services and (static) fixed services can be.

A1.81 Digital Europe, Intel and Qualcomm pointed out that in fact, some of the bands being considered already support fixed point-to-point microwave links. 5G operations in these bands being able to seamlessly integrate and dynamically share spectral resources between mobile access and fixed links would further enhance the efficient use of spectrum and help reduce the cost and complexity of backhaul network deployment.

A1.82 Airbus stated that they would expect that existing backhaul solutions and spectrum allocated for such purposes will continue to be used and that the number of such links will increase to provide more user capacity incrementally. The use of satellite systems in providing this capacity should be considered. Additional spectrum will undoubtedly be needed.

A1.83 However, whilst it was foreseen that 5G spectrum could accommodate different types of fixed and wireless backhaul uses, many stakeholders argued that an increasing number of traditional cell sites will have fibre based backhaul (or other microwave, geostationary or non-geostationary satellite links) instead. But the need for wireless backhaul would still be significant for areas where fibre or other technologies are not an (immediate, feasible or cost effective) option.

A1.84 An example of this provided by EE would be where ultra-dense networks are implemented to manage urban capacity requirements. Here there is likely to be a need for short range high capacity wireless backhaul as it would not be cost effective or indeed practical to connect fibre to every small cell site.

A1.85 To support this several stakeholders (InterDigital Europe, COST IC1004 and Intel) stated that innovations in antenna array technology that enable mmW antenna arrays and multi-hop mesh architectures, could add the capability of integrated access and backhaul to 5G small cells. Small cells operating in mmW could then support both access links to users and backhaul links to other network nodes (e.g. other small cells or macro-cells) on an as needed basis by creating different beams with varying levels in both directivity and direction.

A1.86 In addressing the 5G key latency requirements and support the increased data rate of new 5G radio access: Samsung thought that 5G networks will evolve towards a distributed and flat architecture; Vodafone understood that solutions are already being developed that meet the latency targets being discussed for 5G; and Ericsson stated that the latency of microwave backhaul is already today a fraction of that being discussed for 5G systems and it is also used in ultra-low latency networks to provide a latency lower than that of fibre transport.

A1.87 It was noted that these flexible solutions are likely to present challenges and that more research is needed before considering requirements for wireless backhaul in 5G. However:

- Qualcomm said that the ability to use high-gain antennas at both ends of the fixed link make these bands attractive for backhaul use. It provides a transport network that is convenient to deploy and has higher capacity than the access network. However, in contrast to using these bands for access, where link failover to lower bands may be tolerable from the end-user perspective, backhaul use needs to be substantially more tolerant to link failures due to propagation and misalignment issues, among other technical challenges. Support of such robustness can be addressed through flexible regulations and technology innovation; and

- Cost IC1004 said that multi-hop mesh-relaying technology customised for directional links may be an enabling technology for small-cell mmW backhaul. The mesh solution would also improve the connection reliability in difficult propagation environments. Using long-range discovery mechanisms, self-configuration techniques and electrically steerable antenna arrays, each node establishes optimal paths to its neighbours.

A1.88 Airbus disagreed and proposed that as 5G latency targets are very demanding and, given the parallel increase in demand, it is not certain that a simplistic approach that overprovides the backhaul networks and core network components will reduce latency significantly.

A1.89 A confidential response expressed a concern that it was possible that transitioning different backhaul layers in a network will drive up the latency to unacceptable values.

A1.90 Ericsson noted that further investigations into sharing possibilities would be needed if these bands are to be considered for 5G terrestrial services. Bands allocated to the Fixed Service that are expected to be heavily used in certain areas or regions are likely to present a challenge for deployments of 5G systems in the Mobile Service in such locations and may need careful consideration.

A1.91 The ISG mWT stated that not only is it important to preserve sufficient already allocated spectrum for fixed services but it is planning to work on bands around and above 100 GHz for additional future wide bandwidth spectrum for backhaul. Therefore, initiating the process for identifying the suitable bands (possibly up to 175 GHz) would be beneficial.

b) What, if any, spectrum will be required? What channel sizes will be needed? Will the bands used be similar to those currently used for wireless backhaul?

A1.92 There was no clear consensus from stakeholders in response to this question.

A1.93 Samsung, Qualcomm stated it was too early to say at this time what the spectrum / channel size requirements would be for 5G backhaul. Samsung considered that at this stage it would be difficult to fully understand the demand for wireless backhaul and the capacities required.

A1.94 SES and Ericsson stated that any spectrum requirements for 5G backhaul will have to be carefully assessed, and the technical characteristics of the backhaul links should continue to be reviewed and studied.

A1.95 RSGB, a confidential response and Huawei offered the view that an equivalent amount or several GHz of spectrum bandwidth would be required and each RF channel will also need a wider bandwidth as the growth in demand for mobile traffic will produce a corresponding increase in demand for backhaul.

A1.96 BT argued that 5G backhaul may require a similar amount of spectrum as the mobile access, i.e. 500 - 1000 MHz per network. Whilst Huawei argued that if the backhaul links can be engineered as point-to-point links with high gain antennas, then they may be more efficient than the access links and so further reduce the backhaul spectrum requirement. None-the-less, the backhaul requirement is a significant technical and administrative challenge

A1.97 A confidential response offered the view that the rule of thumb is that for a wireless backhaul fed 5G radio site for every 1 GHz used in the radio access layer an additional 100 to 500 MHz is required depending on the network architecture to support peak traffic in the wireless backhaul. There should be channel bandwidths of up to 2 GHz for the backhaul.

A1.98 EE were of the view that current microwave and mmW will continue to play a role in cellular backhaul with the acceptance that coexistence/self-backhauling will be a feature in any band(s) which are identified for 5G radio access.

A1.99 Several other stakeholders proposed that the various existing fixed links bands may be suitable:

- A confidential response stated that the existing fixed link frequencies should be preserved sub 39 GHz for long-haul managed links running over a number of kilometres as the atmospheric propagation is favourable at these frequencies for long haul backhaul;
- Alcatel-Lucent said that 57-66 GHz, 71-76 GHz and 81-86 GHz should remain fully accessible for further development of backhauling solutions, including point-to-point solutions;
- Interdigital Europe see the 64-71 GHz bands as good candidates for joint access and in-band backhaul deployments, especially since each of the bands 64-65, 65-66 and 66-71 has a mobile allocation);
- EE stated there is some promising work ongoing in the 92 – 95 GHz band, however we need to extend this scope. Bands up to 165 GHz offer some opportunities while 200 to 300 GHz has longer term potential; and
- ISG mWT stated that preliminary lab tests are ongoing up to about 140 GHz, as far as is known to them and suggests extending the range of analysis up to 175 GHz, when considering backhaul allocations.

Question 7: Should we expand the scope of bands being reviewed beyond the 6-100 GHz range?

A1.100 Overall there was majority support from stakeholders that the scope of the band 6 – 100 GHz should not be extended, but a few responses (Angie, EE, Airbus, UKSA and a confidential response) did advocate looking at bands above 100 GHz, primarily for backhaul, due to research currently being undertaken and potential technological improvements in the future.

A1.101 Ericsson stated that the upper bound of 100 GHz is sufficiently high for the scope of bands being reviewed. In addition they understand that based on the present usage by Governments of the frequency range 6 – 10 GHz, concerns have been expressed regarding the practicability of using this spectrum for terrestrial mobile. Therefore they suggested studies should initially focus on the frequency range 10 – 100 GHz.

A1.102 In addition some stakeholders (ESOA, Iridium, SES and two confidential responses) suggested that the band be reduced, ideally to 31 – 100 GHz, to protect incumbent services (and their investment) below 31 GHz and reduce the number of coexistence studies, and associated resource requirements, to avoid delaying the implementation of 5G services.

Question 8: Do you agree that it is likely to be necessary for bands to have an existing allocation to the mobile service? Does this need to be a primary allocation?

A1.103 Whilst most stakeholders expressed the opinion that an existing global mobile allocation was important, and where possible this should be primary, (preferably in all 3 ITU-RR regions), to assist in international harmonisation and the timely deployment of 5G. They also stated that it would still be appropriate to explore other bands without an existing global mobile allocation but which present a good potential for global harmonisation (e.g. underutilised globally by existing incumbent users or easy to re-allocate), but possibly with a lower priority.

A1.104 A number of stakeholders argued that only bands that are internationally harmonised are likely to be economically viable for the delivery of mass market mobile data services and more typically able to share with other allocated services. Careful study will be required to make sure that 5G can co-exist with any existing allocations and uses.

A1.105 Samsung and EE disagreed with this view. Samsung stated that a primary mobile service allocation did not necessarily need to exist to be considered and should not be a prerequisite for international work leading to an IMT identification. EE stated that investigations into new bands should not be restricted to those with an existing primary mobile allocation and other suitable bands should be considered, and, if appropriate a case made for modifying the allocation to include mobile services.

A1.106 The University of Manchester stated that it would not be necessary for the bands to have an existing allocation to the mobile service if they were above 100 GHz.

A1.107 Nokia, Digital Europe and Telefónica expressed the view that all possibilities should be open for consideration and that it would not be desirable to rule out any frequency band options at this early stage.

A1.108 Telefónica considered that if technological advances allow spectral efficiencies to be improved, then bands that currently have no primary allocation to mobile services should also be considered.

Question 9: Do you agree with the criteria we have used for our initial filter of bands, and are there other criteria that could also be used?

A1.109 There was a majority agreement from stakeholders that the criteria used as an initial filter for bands was correct, but some disagreed (Iridium, Telefónica, Nokia, and Digital Europe) and stated the criteria was unrealistic, especially in relation to bandwidth.

A1.110 Those stakeholders who supported this approach stated that:

- An existing global mobile allocation would be essential to ease international harmonisation and improve the potential for successful global economies of scale for services and equipment; and
- As 5G channel bandwidth will likely be greater than 100 MHz. A contiguous bandwidth in excess of 1 GHz per operator would be necessary to offer a Gbit/s experience to the user.

A1.111 Some stakeholders argued that the criteria were unrealistic:

- Telefónica said a 1 GHz minimum bandwidth was too high and may affect the performance of the systems and the choice of bands;
- Telefónica, Iridium and Digital Europe shared the opinion that narrower bandwidths (e.g. 200 - 500 MHz) may permit a much wider range of potential candidate bands; and
- Nokia said 5G spectrum aspects need to be studied in detail in the next ITU-R study period; and a CEPT/regulator led process to find a most suitable spectrum solution for 5G, covering all services above 6 GHz may be of benefit.

A1.112 Other opinions expressed by stakeholders regarding the criteria used were:

- Intel noted that in addition to this that such criteria should not be applied rigidly thereby ruling out other options.
- InterDigital Europe also noted that whilst bands with existing global mobile allocation need therefore to be considered as a priority, it might still be appropriate to investigate the potential of other bands without existing global mobile allocation but which are underutilized globally by existing incumbent users.
- Huawei noted that further filtering of the band choices could be based on the existing usage of the bands and compatibility for sharing as well as the usage in adjacent bands (e.g. passive scientific services) which may require protection through significant guard bands or low signal levels.
- The RGB suggested that a weighting factor for where existing Fixed Service bands used for backhaul could be synergistically repurposed (as it is similar technology) could be applied.

A1.113 BT stated that another analysis that includes bands not already having a primary mobile allocation is necessary, for example there may be lightly used bands that could be technically suitable and which, unlike other bands in the current analysis, are not already assigned to operators.

Question 10: Of the spectrum bands/ranges mentioned in this section, are there any that should be prioritised for further investigation?

A1.114 There was no clear consensus on what bands should be prioritised. Half of the stakeholders offered views on bands to be prioritised which overall involved various frequency bands between 25 – 86 GHz.

A1.115 Frequency ranges that received the frequent mentions (both supported and not supported) included 25 – 29.5 GHz, 31 - 33 GHz, 36 – 39 GHz, 55 – 76 GHz, and 81 – 86 GHz.

A1.116 Only a few stakeholders (Met Office, Vodafone and Ericsson, and a confidential response) suggested that frequency bands below 20 GHz could be prioritised. Alcatel Lucent also noted that frequencies below 20 GHz could be prioritised, but treated with lower priority due to low harmonisation potential or already being used for backhaul.

A1.117 There was a general consensus among satellite stakeholders and a confidential response that frequency bands above 31 GHz or bands that do not have an existing FSS allocation should only be considered.

A1.118 Ericsson indicated support for bands in the 10 GHz, 15 GHz and 30 GHz and stated that the bands that are not allocated to passive services on a primary bases should be studied in the next study period of ITU-R. Bands allocated to the Broadcasting Service on a primary basis should be investigated further to determine if they too should be considered for exclusion.

A1.119 They also considered it necessary to provide spectrum below 30 GHz for 5G; however, considerations should not be limited to the 10 GHz, 15 GHz and 30 GHz frequency.

A1.120 The RSGB stated that the focus should be where mobile is already primary (and may be synergistically used with the Fixed Service) and that logic tends to support (for example) Intel, Samsung and similar work at 28, 39 and 60 GHz.

A1.121 The BBC, BT, Telefónica and ISG mWT had either not decided or had no specific comments or on which bands to prioritise at this stage.

A1.122 In addition several stakeholders (Angie, Qualcomm, Nokia, EE, Intel, and Digital Europe) said that it was too early to limit / prioritise any bands at this stage and that either the whole band should be looked at or wait until further investigations and research, (coexistence studies), has been conducted to provide some clarity on the band.

A1.123 Table A1.1 below shows the specific bands identified that stakeholders considered should be prioritised for further investigation. Annex 2 provides a full summary of which bands were supported (or not supported) and by which stakeholders.

Table A1.1: Bands proposed by stakeholders for prioritisation to be studied for 5G

Response	Bands proposed for prioritisation to be studied for 5G
Alcatel-Lucent	27 - 29.5 GHz (higher part of the range 25.25 - 29.5 GHz) noting the need to share the band with microwave links; 36 - 37.5 GHz and 39.5 - 40.5 GHz; 42.5 - 52.6 GHz (except 50.2 - 50.4 GHz); Possibly 55.78 - 66 GHz. Bands proposed to consider with lower priority: 5925 - 8500 MHz: 15 GHz and 18 GHz bands; 21.2 - 23.6 GHz; 25.25 - 27 GHz; 36 - 40.5 GHz.
COST IC1004	25.25-29.5 GHz 36-40.5 GHz 55.78-76 GHz, 81-86 GHz 92-100 GHz
Ericsson	Supports bands in 10 GHz, 15 GHz and above 30 GHz. Prioritise bands not allocated to passive services on primary basis. Bands allocated to broadcasting services on primary basis should be investigated to determine if they should be considered.
Huawei	27.5 - 28.35 / 29.1 - 29.25 GHz 37.0 - 38.6 GHz 64 - 71 GHz, 71 - 76 GHz, 81 - 86 GHz
InterDigital Europe Ltd	55-71 GHz band
Met Office	14.4 - 15.35 GHz, 25.25 - 29.5 GHz, 42.5 - 49 GHz, 64 - 76 GHz 81 - 86 GHz
Samsung Electronics UK	25.25 – 43.5 GHz (focusing on 28 GHz)
Confidential Response	6 – 30 GHz for mobile service. Above 50 GHz for backhaul
Vodafone	5925 – 8500 MHz 43.5 – 47 GHz 51.4 – 52.6 GHz 72 – 77 GHz 81 – 86 GHz.

This table only shows the specific bands identified by stakeholders. Other stakeholders also responded to this question with either proposing wider ranges, e.g. 31 – 100 GHz, saying that they had no view at this stage or that they considered it too early to rule out any frequency options.

A1.124 Nokia argued that the whole spectrum between 6 -100 GHz needs to be investigated in detail in order to find a most suitable spectrum solution for 5G. A reason for this was seen as there not being enough public information about the current usage and, especially, the future plans of current incumbents at this stage.

A1.125 O3b suggested that the bands that should be prioritised for any new allocation for terrestrial mobile services would be bands that do not already have an existing FSS allocation.

Question 11: Are there any bands/ranges not mentioned in this section that should be prioritised for further investigation? If so, please provide details, including why they are of particular interest?

A1.126 Various other bands were identified that stakeholders stated could be further investigated, but there was no clear consensus on what these bands should be.

A1.127 The bands identified ranged between 24 – 81 GHz. The range with the most support was the 30 – 60 GHz band.

A1.128 One specific frequency band that did have some support was 31.8 – 33.4 GHz. This was directly identified by EE, Alcatel-Lucent, Huawei and ISG – mWT (on the basis it was included in the METIS study, despite not having a mobile allocation).

A1.129 Ericsson stated that we should look to prioritise any band that did not have a passive allocation and further investigate the broadcasting bands.

A1.130 Digital Europe noted that current research within the mobile broadband industry is also focused on spectrum ranges below 31 GHz, including research in the range between 10 and 20 GHz.

A1.131 There was also support here from Angie, COST IC1004 and Nokia for not prioritising / ruling out any band at this stage and considering the whole band.

A1.132 Table A1.2 below shows the specific bands identified that stakeholders considered should be prioritised for further investigation:

Table A1.2: Other bands/ranges identified by stakeholders that should be prioritised for further investigation

Response	Other bands to include
Confidential Response	37 – 39 GHz 43.5 – 47 GHz 57 – 64 GHz 70 – 80 GHz
Alcatel-Lucent	31.8 – 33.4 GHz 40.4 – 43.5 GHz
EE	31.8 - 33.4 GHz. (as per METIS).
ESOA	37 – 39 GHz 43.5 – 47 GHz 57 – 64 GHz 70 – 80 GHz
Huawei	31.8 – 33.4 GHz.
Intel	CFI criteria limits ranges that may be included and favoured by other admins, e.g.: 24.25 - 24.45 GHz 25.05 - 25.25 GHz 31 - 31.3 GHz 42.0 - 42.5 GHz
ISG mWT	31.8 – 33.4 GHz.
Samsung Electronics UK	40.4 – 42.5 GHz
Vodafone	77 – 81 GHz

This table lists just the specific frequency bands identified by stakeholders. Other stakeholders did offer views on this question either in wider terms (e.g. bands whole spectrum range should be reviewed or all bands above 31 GHz), or commented that it was too early at this stage to rule out any frequency options.

Questions 12: Are there any particular bands/ranges that would not be suitable for use by future mobile services? If so, please provide details?

A1.133 Numerous bands were identified as not being suitable for future mobile service use, but there was no overall consensus. These included all the bands used by the satellite industry below 31 GHz; the passive / radio astronomy bands (as identified by ITU-RR 5.340 or 5.149) and amateur bands at 47 and 75 GHz.

A1.134 SES, ESOA, and O3b (and two confidential responses) stated that Ofcom should look to accommodate 5G/IMT terrestrial services in higher mmW frequencies in relevant frequency bands above 31 GHz, where possible in frequency bands not allocated on a primary or co-primary basis by the ITU to satellite or space services. The BBC partially shared this view due to its use of the Ka and Ku satellite bands.

A1.135 ESOA and a confidential response also noted that for 5925 – 8500 MHz, the ITU-R has recently completed relevant studies on the possible use by IMT systems ("draft new Report ITU-R [FSS-IMT C-BAND UPLINK]". This has found that use of these bands by IMT systems is not possible in the band 5850 – 6425 MHz. Although the band 6425 – 7075 MHz was not studied, the same characteristics of FSS systems apply, and the same conclusions would apply. Hence the band 5925 – 7075 MHz can already be ruled out on the basis of recent existing technical studies.

A1.136 Airbus argued that existing allocations to military services, to fixed and mobile satellite services, to space exploration services in the 6-30 GHz range would not be suitable for use by future mobile services. They also noted that there are also significant uses of spectrum up to 60 GHz, e.g. by satellite communications gateways.

A1.137 It was highlighted by the University of Manchester (Jodrell Bank) that all of the frequency ranges listed in section 3.9 of the Call for Input either contain radio astronomy bands or are immediately adjacent to them and was therefore of very great concern to radio astronomers. The main UK concerns being the bands 5.9 - 8.5 GHz and 21.2 GHz - 23.6 GHz bands, both of which represent two of the UK's prime frequency bands of operation. It was considered that IMT allocations within these bands could be a very serious threat to radio astronomy.

A1.138 Three other stakeholders (Met Office, UKSA and Ericsson) also noted that spectrum allocated to passive and space services on a primary basis (as identified by Radio Regulation 5.340) should be protected and excluded from any possible frequency bands for terrestrial 5G mobile services. These include: 10.68 -10.70 GHz, 15.35 - 15.4 GHz, 23.6 - 24.0 GHz, 31.3 - 31.8 GHz, 48.94 - 49.04 GHz, 50.2 - 50.4 GHz, 52.6 - 54.25 GHz and 86 - 92 GHz.

A1.139 The UKSA noted that appropriate guard bands may be required to prevent unwanted emissions from 5G devices being radiated into the passive bands and that the bands used for passive remote sensing that are not covered by Radio Regulation 5.340 would also be required to be protected, but there may be potential for sharing in some of the higher frequency fixed and mobile satellite allocations above 40 GHz.

A1.140 The RSGB stated that the range 42.5 – 52.6 GHz should exclude the exclusive Primary amateur and amateur-satellite allocation at 47 - 47.2 where there is no Mobile allocation at all. They also stated that 24.0 – 24.05 GHz would not be suitable as this is a globally harmonised primary amateur band and disagreed with use of 10.0 – 10.5 GHz and 75.875 – 76.0 GHz too.

A1.141 Samsung advised that sharing with any band that accommodates radiolocation / radar services may be problematic and present coexistence challenges.

A1.142 The ISG mWT group advised that Specific sharing criteria need to be defined when introducing access services in the existing fixed service bands, allowing protection of existing services (fixed) from harmful interference.

A1.143 Vodafone stated that they were not aware of any technical factor that makes a part of the 6-100 GHz range unsuitable for mobile use. However, lower frequencies are generally more suitable for mobile services, provided that sufficient bandwidth is available. For the licence-exempt bands around 60 GHz, the current technical conditions would make them less suitable for some of the applications envisaged for 5G.

A1.144 BT, Telefónica, Nokia, Intel and EE also stated that it was too early to discount any bands at this early stage, especially in the absence of any sharing studies, and the whole band should be looked at.

A1.145 The MOD stated that of the “filtered bands” listed for consideration they had responded to Ofcom’s Strategic Review of Satellite and Space Science Services detailing its current and proposed satellite frequency use. In this response the MOD stated that based on its current use of Government owned Fixed and Mobile Satellite Services, that the X, Mil Ka and V Bands must be retained for military satellite communication (milsatcom) use.

A1.146 Table A1.3 below shows the bands identified by stakeholders as not being suitable for use by future mobile services:

Table A1.3: Bands identified by stakeholders that would not be suitable for use by future mobile services.

Response	Not suitable for 5G
Airbus	6 – 30 GHz Satellite communication gateway use up to 60 GHz Military bands.
Confidential response	No bands below 31 GHz. Start by considering only frequency bands above 31 GHz.
Confidential response	Bands below 31 GHz not suitable, specifically: 5925 – 8500 MHz.(5925 – 7075 MHz) 10.7 – 11.7 GHz 14.4 – 14.8 GHz 17.3 – 22 GHz 27.5 – 31 GHz
Confidential response	21.4 – 21.7 GHz
BBC	7 GHz band (7110 - 7250 MHz & 7300 - 7425 MHz Ku Band 10 - 12.75 GHz; Ka band 19.7 – 20.2 GHz & 29.5 – 30 GHz.

ESOA	Bands below 31 GHz not suitable, specifically: 5925 – 8500 MHz.(5925 – 7075 MHz) 10.7 – 11.7 GHz 14.4 – 14.8 GHz 17.8 – 19.7 GHz 27.5 – 29.5 GHz
Inmarsat	5925 – 7075 MHz 27.25 – 29.5
Met Office	Any of the Passive bands protected by Radio Regulations 5.340: 10.68 - 10.70 GHz, 15.35 - 15.4 GHz, 23.6 - 24.0 GHz, 31.3 - 31.8 GHz, 48.94 - 49.04 GHz, 50.2 - 50.4 GHz, 52.6 - 54.25 GHz 86 - 92 GHz
MOD[20]	7250 – 7750 MHz (X Band) 7900 – 8400 MHz (X Band) 10.9 – 11.7 GHz (Ku Band) 12.25 – 12.75 GHz (Ku Band) 13.75 – 14.5 GHz (Ku Band) 20.2 – 21.2 GHz (Ka Band) 30 – 31 GHz (Ka Band) 43.5 – 45.5 GHz (V Band)
RSGB	10 – 10.5 GHz 24.0 - 24.05 GHz 47 – 47.2 GHz (Primary amateur / satellite) 75.875 – 76 GHz
SES	Avoid bands with primary allocation to satellite. Bands below 31 GHz would not be suitable, specifically: 5925 – 8500 MHz 10.5 – 11.7 GHz 14.4- 15.35 GHz 17.8 – 19.7 GHz 21.2 – 23.6 GHz 25.25 – 29.5 GHz.
University of Manchester	Almost all of the frequency ranges listed in section 3.9 either contain radio astronomy bands (listed in 5.340 or 5.149) or are immediately adjacent to them. Bands of concern are: 5925 - 8500 MHz; 10.5 - 11.7 GHz; 14.4 - 15.35 GHz; 21.2 - 23.6 GHz; 36.0 - 40.5 GHz; 42.5 - 52.6 GHz; 55.78 - 76 GHz; 81 - 86 GHz.

[20] MOD satellite frequency use provided separately in response to Ofcom’s Strategic Review of Satellite and Space Science Services.

UK Space Agency	Consider passive bands used for public good services, including remote sensing should not be targeted: 10.5 – 11.7 GHz 11.7 – 12.75 GHz 14.4 – 15.35 GHz 17.8 – 19.7 GHz 21.2 – 23.6 GHz 25.25 – 29.5 GHz 36 – 40.5 GHz 42.5 – 52.6 GHz 55.78 – 76 GHz 81 – 86 GHz 92 – 100 GHz

This table only lists the specific frequency bands identified by stakeholders. Other stakeholders did offer views on this question either in wider terms, (e.g. bands not allocated to passive services or all bands below 31 GHz), or commented that it was too early at this stage to rule out any frequency options.

Question 13: What additional information, beyond that given in Annex 5 would be useful to allow stakeholders to develop their own thinking around spectrum options?

A1.147 Varied requests for additional information were provided in response to this question. Some are outside of Ofcom's remit, but one area that had some shared support was for further information about spectrum usage in the range 6 – 100 GHz relating to:

- information about numbers of licences (Ericsson);
- information on public sector spectrum availability (Vodafone);
- nature and extent of the existing uses in the allocated spectrum ranges (Vodafone);
- information relating to coexistence / deployment constraints services may face (Samsung and Huawei);
- information about the current usage and, especially, the future plan for the current incumbents (Nokia, Alcatel-Lucent, Samsung and Vodafone);
- geographical distribution (Ericsson and Vodafone);
- capacity demand, based on existing mobile network demand(Iridium);
- potential long term plans of incumbent users(Nokia); and
- information about bands not already having primary mobile allocations (BT).

A1.148 In addition to these areas there were some specific requests for information in relation to:

- technical solutions and regulatory approaches be examined which may best enable future mobile services above 6 GHz (ViaSat);

- In the case of Space based observations the remaining lifetimes and launch dates of new systems would be useful if Ofcom is able to share them (Ericsson);
- An additional input should be the maturity of RF components in each frequency band, as well as the ability to do mass-scale production and any identified technical drawbacks (e.g. phase noise, oscillator stability, etc.) (Telefónica);
- It would be useful to add to Annex 5 references to space sector use for the many current and planned sensors and control and data links operating within these bands and also to the many satellite filings on the ITU Master Frequency Register (UKSA); and
- Access to specific channel measurements and propagation field trials data would be very useful additional information for this purpose (EE).

Question 14: What are the most important criteria for prioritising bands going forward?

A1.149 Various criteria were provided in response to this question, but there was some broad agreement on certain main criteria. These being:

- International (or at least regional) harmonisation. This was considered to be one of the most important criteria for prioritising the bands above 6 GHz;
- An existing global mobile allocation. Required to ease the task for international harmonization;
- Available contiguous bandwidth, preferably in excess of 1 GHz, in order to be able to achieve the emerging challenging requirements of multi-Giga bits per second data rates;
- Technical suitability, e.g. propagation characteristics that enable coverage on 100-200m outdoors and within rooms; spectral and energy efficiency; proximity of bands to allow common implementation in terminals;
- Interference avoidance and coexistence with other (existing or new) services in the band and/or adjacent to it. As well as the potential for sharing between different segments (e.g. access and in-band backhaul) and applications;
- Cost of deployment and devices. Likelihood of technology availability at realistic costs;
- Timeframe to meet the expected deployment of terrestrial 5G systems around the year 2020 and be able to synchronise deployment internationally; and
- Availability of the band, in particular the extent of use by the current incumbents. A minimum number of incumbents or low level of incumbent usage would facilitate sharing.

A1.150 In addition to these broadly agreed criteria there was some specific support for including this criteria too:

- Not to exclude other bands that might still have a good potential for new global mobile allocation for example due to underutilization or reduced usage by existing users on a global scale (InterDigital Europe);

- Bands above 31 GHz should be prioritised due to the relative low-density use in them currently (Iridium);

- The effective and planned uses of the bands by currently allocated services. Existing and future usage and investment of incumbent services needs to be considered (Alcatel-Lucent);

- The duplexing, the multiplexing capability in terms of the number of channels that can be allocated to one or more operators (InterDigital Europe)

- The bands for public mobile services should be considered in a holistic way, without an artificial boundary at 6 GHz, so that the demand for 5G services can be met in rural areas as well as urban (Vodafone);

- Consideration of sufficient backhaul spectrum to support the terrestrial 5G mobile service; which may suggest that a separate review might be needed for this purpose (Ericsson);

- needs to take into account the uncertainty created which will affect incumbent users and their ability to invest in services (BBC, RSGB and UKSA); and

- It would be far better to identify common narrower ranges at an early stage, where the chipsets can be optimised for performance/battery-life as well as cost - than to keep too many options open and prolong uncertainty for 5G designers as well as incumbents (RSGB).

A1.151 The MOD also stated that in considering prioritising specific bands, account must be taken of existing spectrum users and in particular MOD spectrum use which varies from commercial use, in those bands under consideration. Defence spectrum use is a key factor of our national security whilst underpinning industrial/commercial growth.

Annex 2

Summary of frequency ranges supported and not supported in CFI responses

Frequency range	Supported	Not supported
Below 10 GHz	Vodafone - 5925 – 8500 MHz Alcatel – 5925 - 8500 MHz (lower priority / technically difficult)	Confidential response - 5925 – 7075 MHz BBC – 7110 - 7250 MHz BBC – 7300 - 7425 MHz ESOA – 5925 – 8500 MHz Inmarsat - 5925 – 8500 MHz MOD – 7250 – 7750 MHz MOD – 7900 – 8400 MHz SES – 5925 - 8500 MHz Jodrell Bank - 5925 - 8500 MHz UKSA - 5925 - 8500 MHz
10 – 13 GHz	Ericsson – 10 GHz	Confidential Response - 10.7 – 11.7 GHz BBC – 10.7 - 12.75 GHz ESOA – 10.7 – 11.7 GHz Met Office - 10.68 - 10.70 GHz RSGB 10 – 10.5 GHz MOD – 10.9 – 11.7 GHz MOD – 12.25 – 12.75 GHz MOD – 13.75 – 14.5 GHz SES - 10.5 – 11.7 GHz (excl. 10.68 – 10.7 GHz) Jodrell Bank - 10.5 - 11.7 GHz UKSA - 10.5 – 11.7 GHz / 11.7 – 12.75 GHz
14 – 16 GHz	Met Office - 14.4 - 15.35 GHz, Alcatel - 15 GHz (lower priority / technically difficult) Ericsson – 15 GHz	Confidential response - 14.4 – 14.8 GHz ESOA – 14.4 – 14.8 GHz SES - 14.4 - 15.35 GHz Met Office - 15.35-15.4 GHz Jodrell Bank - 14.4 - 15.35 GHz UKSA - 14.4 – 15.35 GHz
17 – 20 GHz	Alcatel - 18 GHz (lower priority / technically difficult)	Confidential response – 17.3 - 22 GHz BBC - 19.7 – 20.2 GHz ESOA – 17.8 - 19.7 GHz MOD – 20.2 – 21.2 GHz SES - 17.8 – 19.7 GHz UKSA - 17.8 – 19.7 GHz

Frequency range	**Supported**	**Not supported**
21 – 24 GHz	Alcatel - 21.2 - 23.6 GHz (lower priority / technically difficult) Intel - 24.25 - 24.45 GHz [Ruled out by CFI criteria, but may be favourable to other Administrations]	Confidential response – 21.4 – 21.7 GHz Met Office - 23.6 - 24.0 GHz, RSGB – 24 – 24.05 GHz SES - 21.2 – 23.6 GHz Jodrell Bank - 21.2 - 23.6 GHz UKSA - 21.2 – 23.6 GHz
25 - 30 GHz	Alcatel – 27 - 29.5 GHz (higher part of the range 25.25 – 29.5 GHz) – noting need to share with microwave links. Alcatel - 25.25 - 27 GHz (lower priority / technically difficult) Cost IC1004 - 25.25 - 29.5 GHz Ericsson – 30 GHz Huawei - 27.5 - 28.35 GHz / 29.1 - 29.25 GHz Met Office - 25.25-29.5 GHz Samsung – 25.25 – 43.5 GHz (focus on 28 GHz) Intel - 25.05 - 25.25 GHz [Ruled out by CFI criteria, but may be favourable to other Administrations]	Confidential response – 27.5 - 29.5 GHz BBC - 29.5 - 30 GHz ESOA – 27.5 – 29.5 GHz Inmarsat - 27.5 – 29.5 GHz Iridium – 27.5 – 31 GHz MOD – 30 – 31 GHz SES - 25.25 – 29.5 GHz UKSA - 25.25 – 29.5 GHz
31 – 34 GHz	Alcatel – 31.8 – 33.4 GHz EE – 31.8 – 33.4 GHz Huawei - 31.8 – 33.4 GHz Intel – 31 - 31.3 GHz [Ruled out by CFI criteria, but may be favourable to other Administrations] ETSI ISG mWT - 31.8 – 33.4 GHz	Met Office - 31.3 - 31.8 GHz
36 - 40 GHz	Confidential response – 37 - 39 GHz Alcatel – 36 - 37.5 GHz Alcatel 37.5 – 39.5 GHz (lower priority / technically difficult)Alcatel - 39.5 - 40.5 GHz COST IC1004 36 - 40.5 GHz ESOA – 37 – 39 GHz Huawei - 37.0 - 38.6 GHz	Jodrell bank - 36.0 - 40.5 GHz UKSA - 36 – 40.5 GHz

Frequency range	Supported	Not supported
40-43.5	Met Office - 42.5 - 49 GHz Alcatel – 40.4 – 43.5 GHz Intel - 42.0 - 42.5 GHz [Ruled out by CFI criteria, but may be favourable to other Administrations] Samsung - 40.4 – 42.5 GHz	Jodrell Bank - 42.5 - 52.6 GHz UKSA - 42.5 – 52.6 GHz
43.5 - 47 GHz	Alcatel - 42.5 - 52.6 GHz (except 50.2 – 50.4 GHz) Vodafone - 43.5 – 47 GHz Confidential response – 43.5 - 47 GHz ESOA - 43.5 - 47 GHz	Jodrell Bank - 42.5 - 52.6 GHz MOD – 43.5 – 45.5 GHz UKSA - 42.5 – 52.6 GHz
47-52 GHz		RSGB – 47 – 47.2 GHz Met Office - 48.94 - 49.04 GHz Met Office - 50.2 - 50.4 GHz
52 – 55 GHz	Vodafone - 51.4 – 52.6 GHz	Met Office - 52.6 - 54.25 GHz
55 – 70 GHz	Confidential response - 57 – 64 GHz Alcatel (possibly) – 55.78 – 66 GHz Cost IC1004 – 55.78 – 76 GHz ESOA – 57 – 64 GHz Huawei - 64 - 71 GHz InterDigital – 55 – 71 GHz Met Office - 64 - 76 GHz	Jodrell Bank - 55.78 - 76 GHz UKSA - 55.78 – 76 GHz
70 – 80 GHz	Confidential response 70 – 80 GHz ESOA – 70 – 80 GHz Huawei - 71 - 76 GHz Vodafone - 72 – 77 GHz / 77 – 81 GHz	RSGB – 75.875 – 76 GHz.
80 – 92 GHz	COST IC1004 – 81 - 86 GHz Huawei - 81 - 86 GHz Met Office – 81 - 86 GHz Vodafone - 81 – 86 GHz	Met Office - 86 - 92 GHz Jodrell Bank - 81 - 86 GHz UKSA - 81 – 86 GHz
92 – 100 GHz	COST IC1004 – 92 - 100 GHz	UKSA - 92 – 100 GHz

Other non-specific frequency preferences

Frequency range	Supported	Not supported
Airbus		6 – 30 GHz; Satellite use up to 60 GHz; Military bands.
Confidential response	Bands above 31 GHz should be prioritised for 5G services and backhaul.	Bands below 31 GHz
Confidential response	Bands above 31 GHz	Bands below 31 GHz
COST IC1004	All relevant bands between 6 –.	
Ericsson	Bands not allocated to passive or broadcasting services on primary basis. Supports bands in 10 GHz, 15 GHz and above. Prioritise bands not allocated to passive or broadcasting services on primary basis	Exclude bands allocated on primary basis to passive services and investigate broadcasting bands.
ESOA	Bands above 31 GHz	Bands below 31 GHz
Iridium	Bands above 31 GHz	Bands below 31 GHz
MOD		Account must be taken of existing spectrum users and in particular MOD spectrum use. Defence spectrum use is a key factor of our national security whilst underpinning industrial/commercial growth
Nokia	Whole spectrum between 6 - 100 GHz needs to be investigated	Whole spectrum between 6 -100 GHz needs to be investigated
O3b	Bands that do not have an existing FSS allocation.	Bands that have an existing FSS allocation should be avoided.
RSGB	The focus should be where Mobile is already Primary (and may be synergistically used with the Fixed Service). Logic tends to support, for example, the Intel, Samsung and similar work at 28, 39 and 60 GHz.	
Samsung		Frequency ranges accommodating radiolocation/radar services may present difficulties for coexistence.
SES	Bands above 31 GHz	Avoid bands with primary allocation to satellite.
Confidential response	6 – 30 GHz mobile; Above 50 GHz for backhaul	Bands above can only be used for backhaul not mobile.

Annex 3

Overview of technical trade-offs in use of spectrum above 6 GHz

A3.1 This annex (Table A3.1 below) provides an overview of our current understanding of the technical factors that could influence how good different frequencies above 6 GHz might be for the provision of 5G mobile services.

A3.2 Whilst technological developments enabling 5G mobile are at a relatively early stage there was positive feedback from stakeholders in response to the CFI on the potential technologies that could be developed to address the challenges and technical factors that will need to be addressed to enable 5G deployment / spectrum sharing.

Table A3.1: Technical factors that could influence how good different frequencies above 6 GHz might be for the provision of 5G mobile services

Green = low technology risk; Yellow = medium technology risk; Red = high technology risk

	6 GHz ⟷ 100 GHz
Propagation loss in free space	 Transmissions may improve as a function of the frequency. By keeping the antennas size the same at both transmitter and receiver the link budget can improve at higher frequencies. For example, there is 31.5 dB more gain at 90 GHz compared to 2.4 GHz if antenna size is kept constant[21]. However, the gain reduces if smaller antennas are used.
Propagation loss in free space – Channel sounding[22]	 During channel sounding the transmitter and receiver cannot in general apply beamforming, because they have not yet estimated the channel. Channel sounding is therefore more effective at low frequencies. The same may apply to non-precoded common channels and broadcast channel transmissions. For non-mobile applications, successive beam refinement can be used; however the application of this approach might be more challenging for mobile applications.

[21] F. Khan and J. Pi, "Millimeter-wave Mobile Broadband: Unleashing 3-300 GHz Spectrum", available on-line.

[22] To correctly form a beam, the transmitter needs to understand the characteristics of the channel. This process is called channel sounding. Understanding the channel allows for manipulation of the phase and amplitude of each transmitter in order to form a beam.

Real-world propagation effects

At ranges typical of small cells (up to 200m) rain attenuation is not a major impairment and can be overcome by beamforming.

However, in a similar way as propagation loss, rain attenuation could create a problem for all transmission procedures for which beamforming is not available (sounding, common channels, channel estimation, etc.). This effect is therefore stronger at higher frequencies.

As a general rule, higher frequencies suffer more from object blockage. In particular, object blockage is a major impairment for outdoor-to-indoor and indoor-to-outdoor service. Body loss could also lead to a connection drop, due to a hand covering the antennas or due to a person turning their head away from a base station.

Due to this effect, high frequencies are not always able to provide a consistent quality of service over time and space.

In addition:

- Measurement campaigns have shown that diffraction is a major impairment at both 28 GHz and 73 GHz;
- Natural or induced (via beamforming) reflections can be exploited to overcome diffraction-related problems, but more measurement campaigns are needed to compare the behaviour of different materials at different frequencies.
- Penetration loss is a major issue for outdoor-to-indoor mmW deployments. However, some materials could allow the signal to pass from one (internal) room to another. This effect is likely to be stronger at high frequencies.
- More measurements campaigns are needed to compare the propagation behaviours at different frequencies in real world outdoor and indoor environments.

Intra-cell and inter-cell interference/ opportunities for sharing

Beamwidths are smaller at higher frequencies. This is a clear benefit for intra and inter-cell interference. Moreover, it opens the possibility of spectrum sharing with or without a common resource allocation layer.

Antenna dimensions	 Antennas are smaller at higher frequencies. However, it should be noted that higher frequencies require antennas with higher gains to maintain the link budget.
Transceivers design - beamforming and MIMO solutions	 Frequencies in the lower end of the mm spectrum allow the use of beamforming solutions that are similar to the ones already used for LTE and LTE-advanced systems. For the higher end of the mmW spectrum, traditional solutions are not feasible and further work is needed to develop solutions ready for mass production that give a good trade-off between cost and benefits.
Transceiver design – other aspects	 Transceiver design for mobile applications is better understood and ready for the mass market at lower frequencies. However, in recent years a lot of work has been undertaken and commercial solutions at 60 GHz for fixed and semi-fixed applications could provide the enabling solutions.

Annex 4

Additional information on preliminary bands

A4.1 This annex provides more information on the preliminary bands we have identified for further study and inclusion in an agenda item for WRC-19.

10 GHz band (10.125 - 10.225, 10.475 - 10.575 GHz)

A4.2 In 2008, Ofcom auctioned spectrum in the 10 GHz band: 10.125 - 10.225 GHz paired with 10.475 - 10.575 GHz nationally. The band 10-10.5 GHz is MOD managed and crosses the lower 10 GHz award block (10.125-10.225 GHz) and the lower 25 MHz of the upper spectrum block (10.475-10.5 GHz). These licences are not technologically neutral at present. A licensee wishing to vary its licence to permit mobile use may submit a variation request to Ofcom. Ofcom would then consider the request on its merits, in the light of its statutory duties and in consultation with MoD. Licensees are not permitted to transmit within certain MoD training areas.[23]

A4.3 Ofcom is aware that the band 10 - 10.5 GHz is used for active phased array radars by non-UK naval vessels. Operation takes place during military training exercises held off the south west and north west coasts of the UK.

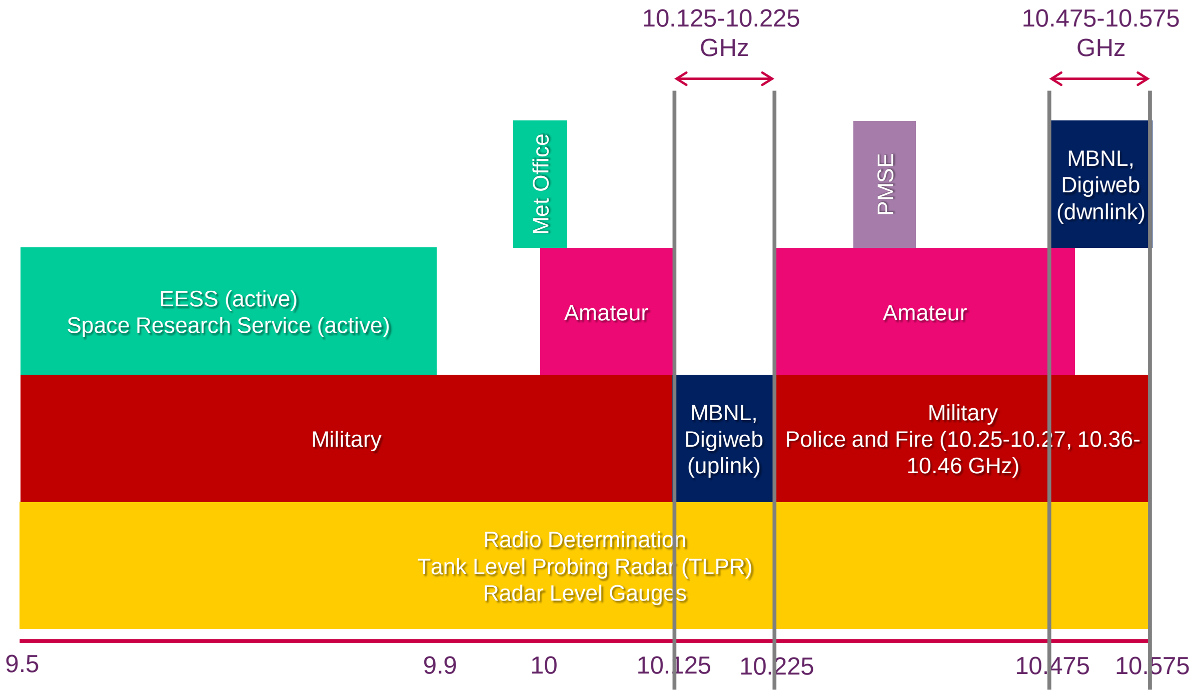
A4.4 The range 8.5 - 10.5 GHz is listed in the NATO Joint Civil/Military Frequency Agreement (NJFA) as a class A band for NATO; meaning a NATO harmonised frequency band for which a permanent essential military requirement exists in NATO Europe. It is considered to be essential to NATO for the military use by land, airborne and naval radars in the radiolocation service. The bands with respective allocations are essential to NATO for the military use by radionavigation, earth exploration-satellite (active) and mobile services.

A4.5 There is a primary mobile allocation in the range 10 - 10.450 GHz in ITU Regions 1 and 3, but not 2. There is no mobile allocation in 10.45 - 10.5 GHz (radiolocation on a primary basis, and amateur and amateur-satellite on a secondary basis). The frequency range10.5 - 10.6 GHz is allocated to the mobile service globally.

A4.6 We note that there is a draft ECP (European Common Proposal) for WRC-15 supporting earth exploration-satellite service (EESS) allocation in the bands 9.2 - 9.3 GHz and 9.9 - 10.4 GHz. When ITU-R Working Party 5A (covering the land mobile service excluding IMT; amateur and amateur-satellite service) provided information on mobile use in the band to Working Party 7C (covering remote sensing systems) for the EESS compatibility study, they highlighted that there is no mobile use other than PMSE, and the sharing studies were based on PMSE type use, not IMT use.

[23] http://stakeholders.ofcom.org.uk/binaries/spectrum/spectrum-awards/completed-awards/10-28-32-40-ghz-awards/10-40IM.pdf

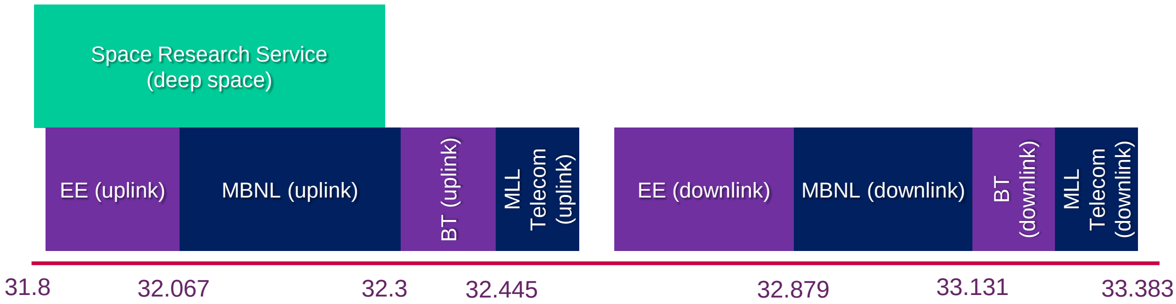
Figure A2.1 - Illustration of spectrum use 9.5 – 10.575 GHz



32 GHz band (31.8 - 33.4 GHz)

A4.7 This band was not originally identified as part of the CFI we published in January, as it does not have a mobile allocation. However it was supported by a number of respondents to the CFI. It was auctioned by Ofcom in 2008 (specifically 31.85 - 33.383 GHz).

Figure A2.2 - Illustration of spectrum use 31.8 - 33.4 GHz



A4.8 Space Science use in the band is for data downlink for deep space missions. We do not anticipate issues due to this use. Sites are very few globally and located in remote areas – there are none in the UK.

A4.9 Information published by the ITU Radiocommunication Bureau notes the existence of a number of satellite filings in this frequency range.

A4.10 It should be noted that the frequencies below this range (31.3 - 31.8 GHz) are heavily used for EESS. The band 31.3 - 31.5 GHz is protected by footnote 5.340 in all three regions; the band 31.5 - 31.8 also has footnote 5.340 in Region 2. Footnote 5.340 means that all emissions are prohibited. The need to protect these passive bands may decrease the amount of bandwidth available.

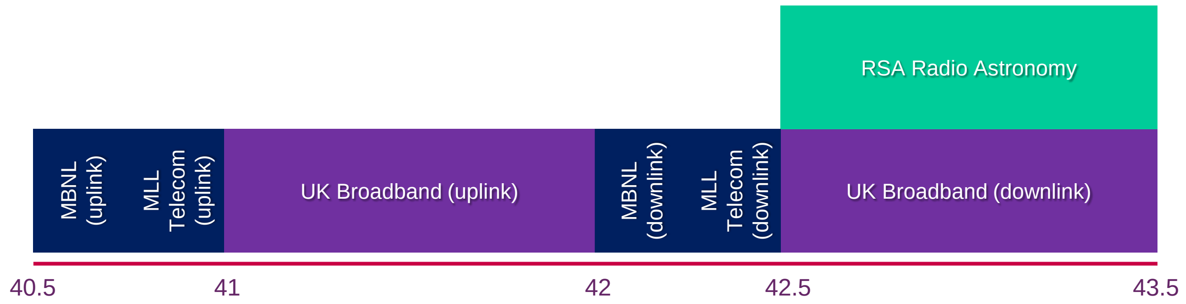
40 GHz band (40.5 - 43.5 GHz)

A4.11 The frequency range 40.5 - 42.5 GHz was not identified in our initial filter of spectrum in the January CFI because it only has a secondary mobile allocation. 42.5 - 43.5 GHz has a primary mobile allocation.

A4.12 This spectrum has been auctioned on a technology neutral basis in the UK. The 40.5 - 43.5 GHz band was harmonised in Europe for the multimedia wireless systems, but this has not been a market success at this frequency. Consequently the band was opened to the fixed service in 2010.

A4.13 There is currently one RSA radio astronomy site in this band in the UK, located in Cambridge. This operates within the auctioned spectrum, with a 50km exclusion zone. We are not expecting any further radio astronomy use in this band.

Figure A2.3 - Illustration of spectrum use 40.5-43.5 GHz



A4.14 The 40.5 - 42.5 GHz portion of this range includes the Q/V satellite band (37.5 - 42.5 GHz, space to earth). This is identified as an HDFSS (high density fixed satellite systems) band for use by uncoordinated and coordinated satellite services. The Q/V band is seen by the satellite industry as having potential for increased future demand, specifically for new feeder link and gateway use. Our current understanding is that Q/V band is mainly used for military applications and we are not aware of commercial entities that have launched services here. However, we note the existence of a number of satellite filings in this frequency range.

45 GHz band (45.5 - 48.9 GHz)

A4.15 Much of 45.5 - 48.9 GHz is unallocated in the UK. There are small bands for amateur and PMSE. There has not been any PMSE use in this band for a number of years. The amateur band is the 6mm band. Even if these were avoided, 2.8 GHz is available, albeit not contiguously.

Figure A2.4 - Illustration of spectrum use 45.5 - 48.9 GHz

A4.16 45.5 - 47 GHz is allocated to RNSS, but our current information is that this is not used. EFIS shows no applications on a European level.

A4.17 Information published by the ITU Radiocommunication Bureau notes the existence of a number of satellite filings in this frequency range.

A4.18 We note that a revised ECC recommendation (ECC Rec 12-11) on a new harmonised channel plan for the fixed service, which includes the band 48.5 - 48.9 GHz, has recently been published by CEPT to cater for higher bandwidth and small cell backhaul fixed link applications. There is light use at present within Europe in this band but with this recent change the use in these bands may increase.

A4.19 Internationally, most of 45.5 - 48.9 GHz has a mobile allocation in Europe, China, South Korea and USA. In China 802.11aj, the ‘China mmW’ version of WiGig is expected to access part of this band. In Japan, the mobile allocation stops short at 47 GHz.

A4.20 METIS describes 45.5 - 47 GHz as one of the least used bands currently in Europe. It is considered by METIS to be a very good candidate for more detailed investigation. The frequency range 47.2 - 50.2 GHz was also considered high priority by METIS.

66 GHz band (66 - 71 GHz)

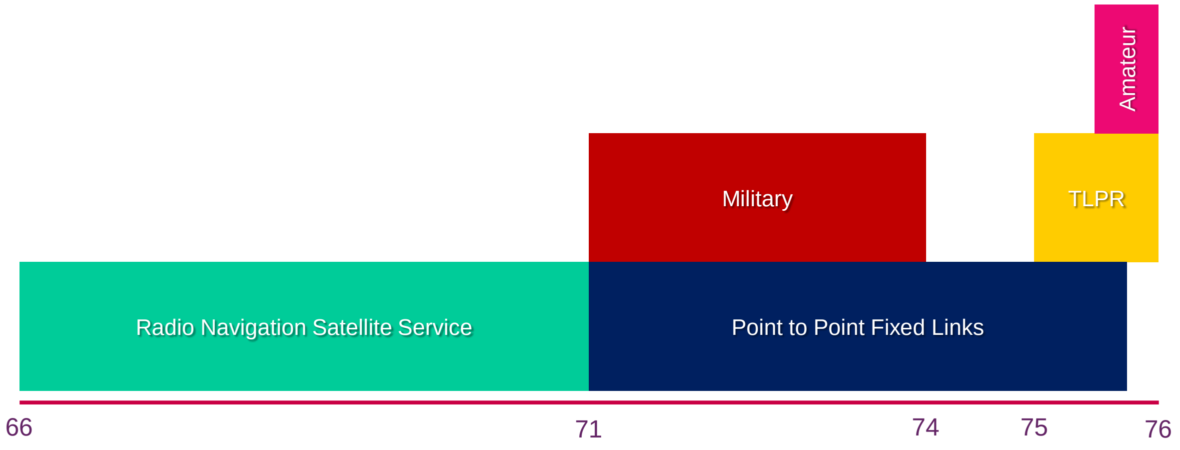
A4.21 Quotient made this their highest priority band. It is suitably wide at 5 GHz, and is adjacent to the WiGig band so low cost technology should be readily available.

A4.22 66-71 GHz has allocations to the radionavigation and to the radionavigation-satellite services, which are either not in use or not expected to be a major coexistence issue. There is no declared NATO military interest here for present or future use. The band is also allocated to inter-satellite and the mobile-satellite service. Information published by the ITU Radiocommunication Bureau notes the existence of a number of satellite filings in this frequency range.

A4.23 Internationally, this band is allocated to mobile in at least Europe, China, Japan, South Korea and USA.

A4.24 METIS’ analysis concluded that there is no apparent terrestrial usage of the band in Europe, or elsewhere in the world. Due to the global allocation status and the very limited usage, METIS concluded there is a high possible potential for global harmonisation. They also note that coexistence studies in other bands have typically shown that sharing between terrestrial services and the inter-satellite service is feasible without significant limitations.

Figure A2.7 - Illustration of spectrum use 66-76 GHz



A4.25 We note that some interest was also expressed in 71 - 76 GHz and 81 - 86 GHz. These bands have been used in the UK by the fixed service since 2007. These bands offer the ability to deploy applications with very high capacity capabilities (e.g. 1 Gbit/s and above) that are not supported in lower frequency bands used by the Fixed Service. Due to performance concerns from industry the self-managed light licensing regime has been reduced in the UK in favour of more centralised management, and the bands are divided between a coordinated block in the lower part of each band (71.125 - 73.125 and 81.125 - 83.125 GHz) and a self-coordinated block in the upper part (73.375 - 75.875 GHz and 83.375 - 85.875 GHz) .

Annex 5

Glossary

4G	Fourth generation mobile phone standards and technology
5G	Fifth generation mobile phone standards and technology
5GIC	5G Innovation Centre. The research centre at the University of Surrey that will conduct research into the next generation of mobile communication technology
CEPT	The European Conference of Postal and Telecommunications Administrations
CFI	Call for Input
CMOS	Complementary Metal-Oxide Semiconductor
CoMP	Co-ordinated Multipoint
CPG	Conference Preparatory Group
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission (of the United States)
FS	Fixed Service
FSS	Fixed Satellite Service
GaAs	Gallium Arsenide
GHz	Gigahertz. A unit of frequency of one billion oscillations per second.
IF amplifier	Intermediate-Frequency amplifier
IMT	International Mobile Telecommunications. The ITU term that encompasses 3G, 4G and 5G wireless broadband systems
ITU	International Telecommunication Union - Part of the United Nations with a membership of 193 countries and over 700 private-sector entities and academic institutions. ITU is headquartered in Geneva, Switzerland
ITU-R	International Telecommunication Union Radiocommunication Sector
LNA	Low-Noise Amplifier

METIS	An EU project on Mobile and Wireless Communications Enablers for the Twenty-Twenty Information Society
MHz	Megahertz. A unit of frequency of one million cycles per second
MIMO	Multiple Input Multiple Output. The use of multiple antennas at both the transmitter and receiver to improve communication performance
MMIC	Monolithic Microwave Integrated Circuit
mmW	Millimetre Wave
MOD	Ministry of Defence
NRA	National Regulatory Authority
PMSE	Programme-making and special events. A class of radio application that support a wide range of activities in entertainment, broadcasting, news gathering and community events
RSGB	Radio Society of Great Britain
SiGe	Silicon-Germanium
SoC	System-on-a-chip
UKSA	United Kingdom Space Agency
WLAN	Wireless Local Area Network
WRC	World Radiocommunication Conference. The WRC reviews and revises the Radio Regulations, They are held every two to three years