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7 - 24 GHz opportunities for 6G - final report

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Plum Consulting

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About Plum

Plum is an independent consulting firm, focused on the telecommunications, media, technology, and adjacent sectors. We apply extensive industry knowledge, consulting experience, and rigorous analysis to address challenges and opportunities across regulatory, radio spectrum, economic, commercial, and technology domains.

About this study

This study for the UK SPF examines the potential bands within the range 7 – 24 GHz for 6G network deployment.

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Summary

Introduction

This study investigates spectrum that might be usable for 6G networks in the 7-24 GHz band and under which conditions these networks could be facilitated – for example sharing arrangements, refarming of incumbent users, taking into account which radio services are currently operational in the bands and any future plans associated with these radio services. The output should help inform both national and international activity, not least in the run up to WRC23, where Agenda Item 10 is crucial for the identification of bands that might be utilised for 6G / IMT-2030. However, undertaking this work early on in the development of 6G means that the information that we have been able to obtain is in many cases formative, and there will inevitably be changes as 6G develops. This study has captured as much information as possible within the study's time and research constraints and we very much appreciate the inputs provided by interviewees which are a key input to this report.

7-24 GHz band use

The 7 – 24 GHz band is allocated to a total of sixteen ITU-R radio services in Region 1, including the Mobile Service. A number of incumbent primary allocations make active use of allocated frequencies. Examples include the following.

- Fixed links are deployed in 6.4 – 7.1 GHz, 7.4 – 7.9 GHz, 7.9 – 8.5 GHz, 12.75 – 13.25 GHz, 14.5 – 15.35 GHz, 17.7 – 19.7 GHz and 22 – 23.6 GHz and used extensively in the UK. There may be the potential to clear some parts of these bands with further roll-out of fibre and to use the 15 GHz (14.5 – 15.35 GHz) band centre gap where there is 616 MHz (14.62 – 15.23 GHz[1]) noting that the 15 GHz centre gap is a type-1 NATO band.

- NATO bands include 7.25 – 8.4 GHz, 8.5 – 10.5 GHz, 13.4 – 14 GHz, 14.62 – 15.23 GHz, 15.7 – 17.7 GHz and 20.2 – 21.2 GHz. UK defence use covers 7.1 – 7.7 GHz, 7.9 – 8.4 GHz, 10.25 – 10.6 GHz, 10.7 – 12.75 GHz, 14.3 – 15.25 GHz, 17.7 – 19.7 GHz and 21.2 – 21.4 GHz. It is noted the 15.7 – 17.1 GHz is only allocated to Radio Location services but it is not clear how intensively the spectrum is used and whether there may be any potential to release some of this band or to share.

- Satellite networks are deployed in 6.7 – 7 GHz, 7.75 – 7.85 GHz, 10.7 – 14.5 GHz and 17.3 – 20.2 GHz bands. Agenda items for WRC 23 already indicate the need for further spectrum for new satellite services.

- Maritime and radionavigation services use 9 – 9.5 GHz and 15.4 -15.7 GHz spectrum and support safety of life services.

- Science services use 10.7 GHz, 18.6 – 18.8 GHz and 23.6 – 24 GHz bands for Earth surface and atmospheric observations. There are also many allocations for EESS, RAS and SRS which are expected to be used globally.

The extensive allocations and active use of allocated bands indicate that there is no clear sufficiently large contiguous block of spectrum apparent for 6G use based on current technologies. Therefore, there need to be

[1] According to https://docdb.cept.org/download/2405, "*the band 14.62 - 15.23 GHz is a harmonised NATO band for fixed and mobile services.*"

more advanced approaches employed to make spectrum available than current ones such as geographic and frequency sharing, to admit additional services.

Spectrum sharing

Sharing studies based on traditional analysis methods indicate that there is very limited opportunity for 6G systems to share with incumbent services. Therefore, other options for sharing will need to be developed. Many stakeholders (including incumbents and vendors) suggested that sharing should be an integral part of 6G specifications. While 6G will incorporate novel network architectures and may make use of AI extensively to achieve, amongst others, dynamic spectrum sharing and use of polite access, there have not been concrete proposals put forward yet. Also, as 6G use cases and their quality-of-service requirements are not yet defined, it is not possible at this time to foresee whether/how these novel sharing strategies could be put into practice, but they clearly warrant detailed investigation alongside the introduction of new technologies for incumbent services.

Matters for further investigation

Based on inputs from interviewees and Plum's analysis, a number of areas that might merit further investigation and actions were identified:

- On the assumption that additional mid band spectrum is required for 6G – are the limited options identified from our research on 7-24 GHz likely to provide sufficient bandwidth for 6G services? A secondary consideration is the likely implications of the outcome at WRC23 regarding possible identification of the upper 6 GHz band for IMT.

- Considering 7-24 GHz there is further work required on whether the emphasis for 6G should be on spectrum in the 7 – 15 GHz frequency range for implementation reasons (e.g. economies of deployment, availability of new enhanced digital technologies, practicalities of systems operating at above 15 GHz)?

- There may be the possibility of using the centre gap in the fixed service at 15 GHz which could provide up to 616 MHz (14.62 – 15.23 GHz) of spectrum noting that the 15 GHz centre gap is a type-1 NATO band[2]. This needs to be explored further.

- There is the opportunity now to design 6G solutions that can facilitate more advanced spectrum sharing techniques to enable coexistence with other services such as fixed links, satellites and military use – this should be promoted as opportunities for exclusive access for 6G are unlikely to be possible in 7-24 GHz without significant upheaval and cost for incumbent services.

- The UK should monitor developments in the US, Japan, China and Korea as potential leaders in identifying spectrum. The 10.0 – 10.5 GHz band is being investigated for mobile use in Region 2 for WRC-23. US is assessing the 12.75 – 13.25 GHz band. For the time being, however neither option is likely to be attractive in the UK due to current use of these bands and Ofcom has already signalled it does not yet support the 10.0-10.5 GHz proposal.

- 15.7 – 17.1 GHz is only allocated to Radio Location services but it is a harmonised type 1 NATO band. It is not clear how intensively the spectrum is used and whether there may be any potential to release some of this band or to share. This may be worth exploring further.

[2] In the longer term, there may also be the potential to use 400 MHz centre gap in the 23 GHz band (22.6 – 23 GHz). The implications of sharing with EESS need to be considered.

- Satellite services operate in significant part of 7 – 24 GHz, it is therefore important to consider if there is any potential for true convergence between satellite and mobile that will facilitate sharing.
- Consideration should be also given to any institutional blockages that might limit sharing even if it could be implemented through technology enhancements – for example sharing with defence users and the need for the basis to be opaque to other users.

1 Introduction

This study investigates which radio services are currently operational in the bands between 7-24 GHz and any future plans associated with these radio services. The main objective is to identify which portions of the band 7-24 GHz could be suitable for 6G networks and under which conditions these networks could be facilitated – for example through spectrum sharing arrangements, or refarming of incumbent users. Recognising the ongoing discussions and the challenges of identifying spectrum for future mobile generations the UK SPF has commissioned this study early in the development of 6G. Its output will help inform both national and international activity, not least in the run up to WRC-23, where Agenda Item 10 is crucial for the identification of bands that might be utilised for 6G / IMT-2030. However, undertaking this work early on in the development of 6G means that the information that we have been able to obtain is in many cases formative, and there will inevitably be changes as 6G develops. We have therefore tried to capture as much information as possible within the study's time and research constraints. The focus of this study is the UK but the nature of the issues being investigated means that, where required, a broader perspective has been considered.

In the following we first provide a summary of the learnings from our research and interviews. We then address:

- 6G spectrum requirements including information on currently available spectrum in the UK and demand analysis from Ofcom,
- Current allocations in Region 1, spectrum identified for NATO use and use in the UK between 7 and 24 GHz.
- Spectrum access potential and sharing considerations,
- Initial conclusions, and
- Matters for further consideration

2 Learnings from research and interviews

A total of fourteen interviews have been undertaken for this report with a range of interested parties including spectrum incumbents (users), equipment vendors, mobile network operators, technology thought leaders and policy/regulatory organisations. The majority of respondents requested that their inputs were anonymised so the following provides an overview of inputs received:

Demand drivers:

- A prerequisite of the study is the assumption that additional mid-band spectrum is required for deployment of 6G and there were concerns voiced that UK should not fall behind in developing 6G and that this requires early visibility of spectrum opportunities. However, several incumbents said that the need for a new band to support 6G requires justification in terms of the services envisaged. Concerns were voiced that MNOs already have access to spectrum which is not all utilised efficiently, with the potential to refarm spectrum for more efficient technologies and increase the number of cells (densification). On the latter point we encountered mixed views on actions required as demand grows, and current spectrum allocations become exhausted. There is a balance to be made between the addition of spectrum to meet demand vs. the potential for network densification but we are aware that some MNOs disagree and claim that, in addition to a level of densification, in the medium term (between 2025 and 2030), MNOs will require additional spectrum to meet demand if they are to avoid significant congestion in key areas.

- We have been unable to form a definitive view on services 6G will support and the nature of their spectrum demands. Some demand will undoubtably be driven by growth of current services, and the ongoing introduction of services requiring differing bandwidth profiles and lower latencies. We were advised by at least one vendor that particularly in outdoor environments there might be a need for use of more mid-band spectrum to support services that could be supported on mmWave indoors. While the sorts of more advanced use cases talked about for 6G, such as Internet of Senses (IoS), are possible there is a lack of information on how extensive deployment is likely to be.

- Some incumbents questioned why target the 7 – 24 GHz band as it is unlikely to be useful for coverage or capacity? The current discussions on use of upper 6 GHz were noted as potentially having an impact on the level of demand for spectrum in the 7-24 GHz frequency range and the outcome in the UK of these decisions will feed into 6G spectrum discussions and requirements.

- The frequency range 7 – 11 or 7 – 15 GHz is preferred by some vendors and operators as these potentially support reuse of existing mobile network assets. We were advised that currently spectrum above 16 GHz presents greater challenges with implementation of electronics and form factors and may not deliver the scale economies achieved at lower frequency bands for implementing new digital technologies.

- It is also argued by a vendor that while spectrum above 7 GHz might be an important frequency range as an enabler for 6G, higher transmit power (eirp) is required in the downlink along with active antennas and beam forming to achieve effective economic deployment and coverage similar to that achieved in the lower mid-band (e.g. C-band).

- It was pointed out to us that the growth in data usage may be slowing down rather than speeding up. Barclays recently published a report which shows annual growth for mobile data consumption slowing in Europe at present from a growth of over 50% per annum in 2017 to around 30% per annum in 2021 and continuing to trend down (i.e. mobile data traffic continues to grow but more slowly).[3] However, Ofcom has set out its view on growth in its Mobile Spectrum Demand Discussion Paper, which takes a view across three scenarios (low, medium and high). Under Ofcom's medium scenario by 2030 traffic will have grown by 21 times from 2021 levels.[4]

Incumbent uses:

- Type 1 NATO frequencies[5] for general military use in NATO Europe are unlikely to be viable for IMT as there appear to be few opportunities to share and it is unclear how pre-emption would work. Hence, it is not clear for these frequencies if they would be attractive for investment in mobile networks. More generally there is unlikely to be further defence spectrum that can be released and refarmed. About 85% of military bands in the UK are already shared with other users.

- Fixed links continue to be deployed in parts of 7 – 24 GHz. Whilst the number of links may be decreasing there is increasing need for wider bandwidth channels and use of band carrier aggregation and higher modulation schemes to deliver higher bit rates. Spectrum demand is fairly steady for Ofcom managed bands between 7 and 24 GHz – there is increasing use of 70/80 GHz bands[6]. There was a view that Increasing availability of fibre is likely to substitute for fixed links over the timescales for spectrum needed for 6G. This should allow some fixed service spectrum to be released.

- Some fixed services bands such as 15 GHz have wide centre gaps that might be worth exploring to assess their ability to support other services.

- Few examples have been identified where sharing between IMT and the fixed satellite service is feasible. Co-frequency co-coverage sharing is not feasible. WRC-23 agenda items indicate more extensive use of satellite bands and future satellite focus will be on more intensive / efficient use mainly through NGSO systems, ESIMs and Earth observation satellites.

- It is expected there will be continued need for Sky reception in Ku band (10.7-12.4 GHz) beyond 2025 and there is no clear end date.

- There are a range of frequencies falling between 7 – 24 GHz used for Earth observation (e.g. 6.8 GHz band used for ocean temperature measurement, 10.7 GHz band used for direct sensing of precipitation, 18.7 GHz band used for Earth surface measurements and 24 GHz passive band). The use of these bands is expected to continue and they will need to be protected.

- There is also use of spectrum by aeronautical and maritime applications as indicated by Ofcom's Interface Requirements.

- UWB currently uses 6.24–6.7392 GHz (particularly in the US) and 7.7376–8.2368 GHz (globally), with expansion to higher frequencies planned (e.g. 8.2368–8.736 GHz, 8.736–9.2352 GHz and 9.2352–9.7344 GHz). In Europe the 6–9GHz band is generally made available for unlicensed UWB use under ECC Decision (06)04 on a non-interference, non-protected basis. UWB is being included in smartphones such as those from Apple and Samsung.

[3] Telecom Services – Fixed wireless access – revisiting the potential to disrupt. Barclays Equity Research 13th September 2022
[4] https://www.ofcom.org.uk/__data/assets/pdf_file/0017/232082/mobile-spectrum-demand-discussion-paper.pdf
[5] Type 1: A frequency band which is in general military use in NATO Europe.
[6] Some fixed link users have advised us that demand has dropped significantly in recent years in the 18Ghz and 23 GHz bands.

Sharing considerations:

- Given the already extensive use of 7 – 24 GHz frequencies, 6G specifications need to be designed to enable spectrum sharing and implement sensing and politeness technologies, and other sharing techniques / protocols that might be developed during 6G standardisation. Dynamic spectrum access (DSA) does not necessarily assist in sharing unless it is standardised and implemented as part of 6G technology.[7]
- Stakeholders generally believe that sharing for 6G will need to be more intelligent than many of the sharing solutions implemented to date to cope with the more dynamic bandwidth environment for both IMT and incumbents. There is a window of opportunity to build more advanced sharing techniques into the 6G specifications (e.g. through 3GPP). The challenge will be securing the agreement of incumbents to new sharing arrangements.
- It is argued by an incumbent user that to enable sharing there is a need for accurate real time usage information to establish the potential for sharing and the parameters to be employed (especially for dynamic sharing). There is also a need for process to be defined. Automated sharing where spectrum assignments take place dynamically with the use of AI could encompass a wide range of operators (public and private) and support more flexible assignments without band clearance. Some stakeholders suggested that there should be consideration of models based on the principles adopted for CBRS (e.g. hierarchy of users and use of databases).
- There was discussion of possible convergence between 6G and satellite services. There is a need to establish what, if any, are the implications of direct to mobile initiatives, whether this could facilitate mobile and satellite sharing, and whether there is the potential for true convergence.
- It was noted that the FCC/NTIA is addressing 12.75 – 13.25 GHz by considering the current Fixed Service, Fixed Satellite Service and Mobile Service allocations[8].
- New technologies being developed for IMT, and in particular 6G, could be applicable to incumbent services, such as satellite and radars, and enable sharing due to the availability of improved performance transmitters, receivers and phased arrays / other antenna technologies. Adoption of such technologies over time may also allow some incumbent spectrum to become available for alternative use through improved efficiency. We also noted that active antenna systems might improve sharing potential between services given their ability to focus energy more efficiently.
- Sharing with meteorology services is unlikely to be a viable option with the future deployment of constellations of cube-satellites to provide more extensive meteorological and climate information, and the need to switch 6G transmitters on and off to avoid interference to these services.
- Sharing with airborne radars may be facilitated on a time basis by switching off IMT base stations when radar signals are detected and if this occurs infrequently it may be an acceptable solution.
- Sharing could provide benefits to defence users if base stations switched off randomly as well as when necessary and so allow defence transmitters and receivers to be hidden in a “cloud” of transmitters.

[7] Dynamic Spectrum Access (DSA) – Ofcom’s definition of DSA is “An approach where access to spectrum is dynamically controlled via a database and machine-to-machine communication to grant access and set operational parameters”. (Ofcom spectrum workshop: Understanding dynamic spectrum access virtual event, 5 May 2022)

[8] https://docs.fcc.gov/public/attachments/DOC-387974A1.pdf

Connectivity considerations:

- We noted that based on inputs there are multiple means of providing connectivity and that the mix of these will change over time as solutions evolve and increase in capability. There will be more expansion of very high-capacity networks with high bandwidth local wireless (could be a range of licensed and licence exempt solutions). There is also likely to be an increase in the adoption of LEO technologies as constellations of NGSO satellites expand.

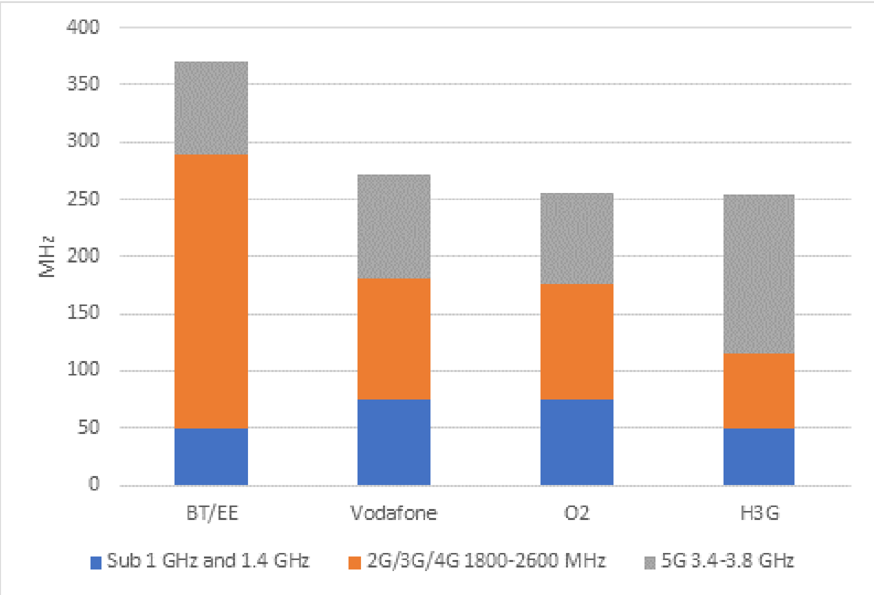
- Mobile network operators are major users of fixed links to provide connectivity. If they were awarded blocks of fixed services frequencies they could have the option of prioritising these for mobile or backhaul use.

3 6G spectrum requirements in 7 – 24 GHz band

3.1 Introduction

Mobile networks already have access to spectrum in bands below 7 GHz in the UK –1152 MHz in bands below 3.8 GHz[9] which deliver 2G to 5G services.

Figure 3.1: Spectrum awarded for mobile use in UK



Source: Meeting future demand for mobile data, Ofcom, 9 February 2022

A prerequisite of this study is the assumption that additional mid-band spectrum is required for deployment of 6G, that UK should not fall behind in developing 6G and that this requires early visibility of spectrum opportunities to support the launch of 6G. However, some incumbents in the 7 to 24 GHz bands have expressed the view that there is a need to verify demand for additional spectrum to meet the future needs of 6G before refarming any spectrum. It is also important to consider approaches that could be used to improve mobile network capacity without resorting to new spectrum allocations (as indicated in the Ofcom's discussion paper). These include:

- The use of spectrally efficient new technologies within the spectrum already assigned;
- expanding the use of existing spectrum assignments (for example by continuing to expand the geographical areas where existing spectrum is used); and
- densifying existing networks by adding more small cells and macro cells where feasible.

3.2 Demand

It is early in the development cycle for 6G with the main emphasis on technology options and developments. The landscape for system concepts and 6G applications is very formative at this stage. However, this is not

[9] Discussion paper: Meeting future demand for mobile data (ofcom.org.uk),

necessarily an issue when considering how 5G is developing, including new applications not prevalent previously for 4G and 3G. What is noted is that, in terms of bandwidth requirements, equipment vendors see that these have increased by a factor of 4 or 5 for each new mobile generation. This provides a guide as to what might happen with 6G.

Identification of potential spectrum for 6G is already a key consideration due to the typical time lag of 10 – 15 years for gaining access to spectrum in practice and the importance of identifying a new band for 6G. There is currently no specific demand identified but a range of different frequencies are being discussed – mid band, mmWave and THz. Initial research and development views are around 300 – 500 MHz to 1 GHz channel bandwidth will be required per operator in the mid band frequencies and this is necessary to balance coverage and capacity requirements but it is not sufficient for hot spots.

6G use cases will include improved cellular services (eMBB, ultra-reliable low latency communications (URLLC) and massive machine type communications). These will be delivered over area networks and blanket coverage, indoor, private and enterprise networks. For example, Augmented Reality applications today over 5G macro cells can only support 4 to 5 users per cell and to support more users for more intense applications such as Extended Reality, 6G capacity is needed.

In the Next G Alliance Report on 6G technologies[10], it notes the 6G foundation services as:

- "Network Enabled Robotics and Autonomous Systems" perceive their surroundings using sensors such as Global Positioning System (GPS), Light Detection and Ranging (LiDAR), sonar, radar, and odometry.
- Multi-Sensory Extended Reality (XR) is the umbrella term for the collection of immersive technologies that include things like Virtual and Augmented Reality (VR/AR).
- Distributed Sensing and Communications use cases and categorization include sensors tightly integrated with communications to support autonomous systems.
- Personalized User Experiences are real-time, fully automated, and secure personalization of devices, networks, products, and services based on a user's personal profile and context information (e.g., user's preferences, trends, and biometrics)."

There are also new 6G services proposed by Samsung[11]:

- XR which combines virtual reality (VR), augmented reality (AR) and mixed reality (MR) and requires 0.44 Gbps,
- Mobile holograms that require several Tbps, and
- Digital replication that requires 0.8 Tbps.

Samsung has summarised 6G as aiming to provide:

- A peak data rate of 1000 Gbps and user experience of 1 Gbps,
- 2 x higher spectral efficiency than 5G,
- Over-the-air latency <100μs

[10] See https://www.nextgalliance.org/wp-content/uploads/dlm_uploads/2022/07/TWG-report-6G-technologies.pdf
[11] Samsung – 6G The Next Hyper-Connected Experience for AI (See https://cdn.codeground.org/nsr/downloads/researchareas/6G%20Vision.pdf)

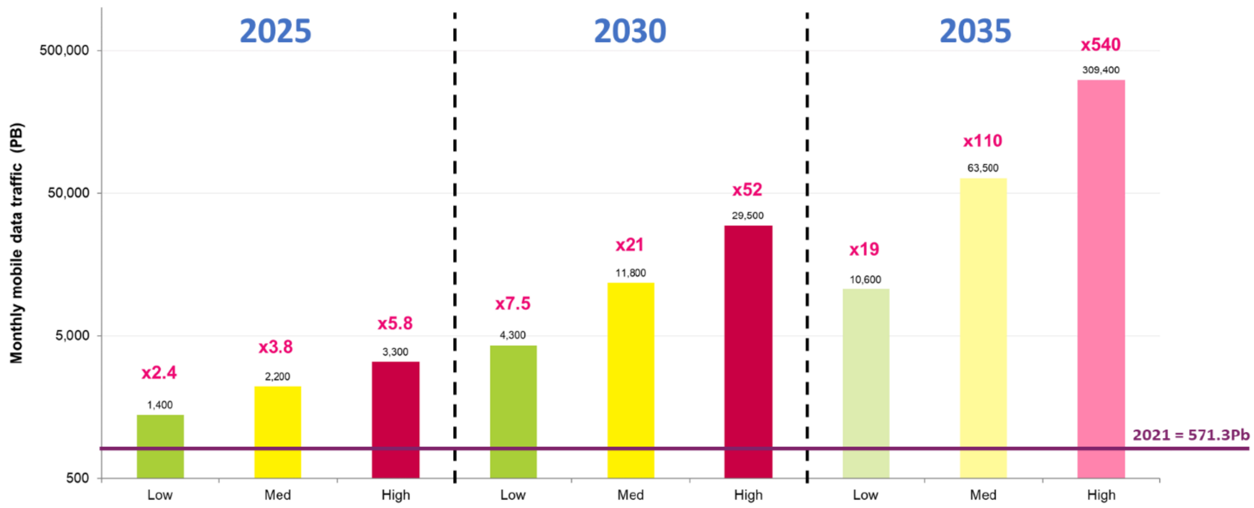
- End to end latency <1ms
- User experienced latency <10ms

There were concerns voiced by incumbents that additional mid band frequencies may not be necessary to meet 6G spectrum requirements as the potential contribution may not be sufficiently significant because:

- MNOs are looking to provide consistent quality services and not necessarily higher capacity and bandwidth and this can be achieved with existing spectrum and densification, but not all MNOs agree with Ofcom's analysis.
- In countries where the 6 GHz band is available for IMT and not WiFi6 this reduces the need for further spectrum.
- There are issues associated with utilising additional frequencies at existing sites with implications for exceeding ICNIRP levels and potential for increased noise so it is not possible to achieve the economic benefits of overlaying the existing network grids if spectrum between 7 and 15 GHz can be identified.

There are differing views on the rate of annual growth seen in mobile traffic demand. Ofcom[12] has argued that there has been an annual growth rate of 40% over the past few years in mobile data traffic. To predict the mobile data traffic growth until 2035 under different scenarios, Ofcom has assumed the 40% rate to be the medium growth scenario. The low growth scenario assumes that there is an annual 25% increase until 2030 followed by an annual 20% increase until 2035. The high growth scenario is based on 55% annual increase until 2030 and 60% annual increase between 2030 and 2035. Based on these scenarios, Ofcom predicted total mobile data traffic in 2025, 2030 and 2035 and the following figure illustrates these predictions.

Figure 3.2: Ofcom's mobile data traffic predictions[13]



Source: Meeting future demand for mobile data, Ofcom, 9 February 2022

In the figure above, multiples are relative to 2021 monthly mobile data traffic which is 571 PB[14]. Ofcom states that "*our expectation is that the mobile data traffic will most likely be somewhere close to the medium growth level, with the low and high growth levels representing the outer bounds of an uncertain future*".

[12] Ofcom discussion paper published 9 February 2022 Discussion paper: Meeting future demand for mobile data - Ofcom
[13] Discussion paper: Meeting future demand for mobile data (ofcom.org.uk),
[14] One Petabyte (PB) = 1,000,000 Gigabyte (GB)

Based on these predictions, it is argued by Ofcom that networks will need capacity and additional mid-band spectrum added to macro-sites could help meet demand growth:

- Medium growth requires greater than 150 MHz additional spectrum per operator,
- High growth in the order of 1 GHz by 2030, and
- Low growth additional 150 MHz might be sufficient until 2035.

But Ofcom notes that more spectrum is not the only way to deliver this and technology upgrade to more spectrally efficient deployments, more efficient use of existing allocations and network densification could be considered to meet some of this demand.

Vodafone's response to Ofcom's discussion paper raises the following points:

- Widespread adoption of small cells assumes static demand rather than varying hotspots. The deployment of macro cells addresses the latter and mid-band spectrum meets the sweet spot of coverage versus capacity.
- Re-using frequencies for both macro and small cell deployments is problematic.
- Mass network densification not currently feasible due to the cost and current industry profitability.
- There is only sufficient spectrum, as proposed by Ofcom, if this includes Upper 6 GHz range.

3.3 How new architecture may facilitate spectrum sharing

Spectrum clearance is becoming increasingly difficult requiring new services to be implemented in bands on a sharing (spatial and temporal) basis. Samsung has identified different sharing options[15] of:

- Spectrum Access Systems (SAS) that use database systems to facilitate sharing, and
- Environmental Sensing Capability (ESC).

Samsung propose there should be more dynamic spectrum sharing rather than semi-static based on databases. The use of Artificial Intelligence (AI) to facilitate sharing by predicting spectrum usage of other entities, particularly between cellular networks, is a potential option. It is noted from discussions with stakeholders that defence use of spectrum already is based on sensing in some cases to facilitate sharing, so such an approach could provide a way to unlock spectrum for 6G.

The view that sharing should be dynamic was supported by a number of interviewees, noting that existing use may be limited in time and space and there is the opportunity to define / design 6G to support specific use case sharing requirements. It was considered that database location assignment can provide a new window of opportunity for spectrum access. However, it does require proper usage information that is not available for many current uses.

It was suggested that typical use of 6G could be the provision of wireless access at the edge of fibre based wide area broadband networks. 6G specifications could be developed from the start based on facilitating sharing with other radio services. Assignments could be automated whereby access to unused spectrum could be

[15] See https://cdn.codeground.org/nsr/downloads/researchareas/6G%20Vision.pdf

implemented dynamically. The use of AI to achieve the desired flexibility in dynamically assigning local unused spectrum could be an efficient approach.

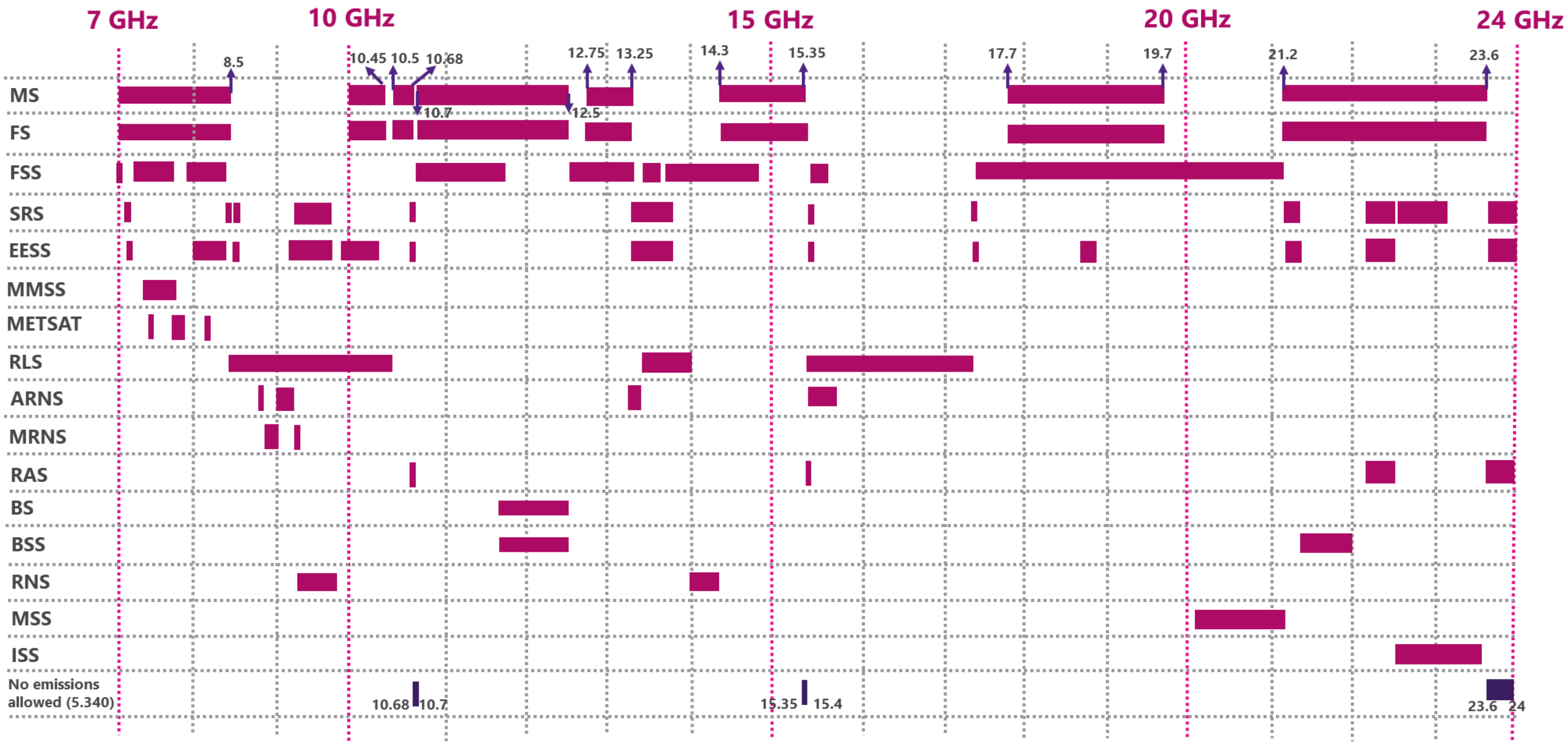
The implementation of new technologies that not only apply to 6G but could be adopted by other services, such as satellite and radars, may facilitate greater sharing with improved transmitters and receivers and phased antenna arrays.

4 Current use of 7 – 24 GHz spectrum

4.1 Situation in Region 1

The current ITU-R region 1 primary allocations for the 7 – 24 GHz range are shown in the following figure.

Figure 4.1: ITU-R region 1 primary allocations



MS: Mobile Service
FS: Fixed Service
FSS: Fixed Satellite Service
SRS: Space Research Service
EESS: Earth Exploration Satellite Service
MMSS: Maritime Mobile Satellite Service
METSAT: Meteorological Satellite Service
RLS: Radiolocation Service
ARNS: Aeronautical Radionavigation Service
MRNS: Maritime Radionavigation Service
RAS: Radioastronomy Service
BS: Broadcasting Service
BSS: Broadcasting Satellite Service
RNS: Radionavigation Service
MSS: Mobile Satellite Service
ISS: Inter Satellite Service

The figure indicates that there are a total of sixteen ITU-R radio services, including MS, with allocations in the 7 - 24 GHz range. This necessitates 6G to share any potential band with some of these services. It is therefore necessary to consider:

- What the actual use associated with the radio services, shown in the allocation figure, is; and
- whether any potential sharing mechanisms have been considered/adopted among these services.

4.2 Implications of WRC-23

There are a number of World Radio Conference agenda items which, depending on the outcome, may have implications for future use of spectrum in the 7 – 24 GHz frequency range.

Mobile broadband

Agenda Item 1.2 addresses potential identification for IMT of bands including 6.425 – 7.025 GHz in Region 1, 7.025 – 7.125 GHz globally and 10 – 10.5 GHz in Region 2.

Satellite

Agenda item 1.15 addresses use of satellite terminal stations on aircraft, operating in bands around 13 GHz. In CEPT an ECC Decision (19)04 covers the harmonised use of spectrum, free circulation and use of earth stations on-board aircraft operating with GSO FSS networks and NGSO FSS systems in the frequency bands 12.75-13.25 GHz (Earth to-space) and 10.7-12.75 GHz (space-to-Earth). It is noted that the UK has not implemented this Decision[16].

Agenda item 1.16 addresses Satellite Earth Stations in motion working to non-geostationary satellites in bands around 18 & 28 GHz. Work is ongoing in CEPT to update ECC decision (15)04 which harmonises use of Land, and Maritime ESOMPs[17] (Earth Stations on Moving Platforms) operating with non-geostationary satellite systems in the frequency bands 17.3-20.2 GHz, 27.5-29.1 GHz and 29.5-30.0 GHz.

Inter satellite network links in satellite bands around 12, 18 & 28 GHz are covered by agenda item 1.17.

Only in Region 2 agenda item 1.19 is looking at fixed-satellite service in 17.3-17.7 GHz, space to earth.

These WRC-23 agenda items indicate the expectation of more intensive use of satellite bands.

Science services

Agenda item 1.13 addresses possible allocation upgrade from secondary to primary, in 15 GHz, for the Space Research Service.

[16] See Call for input: UK preparations for the World Radiocommunication Conference 2023 (WRC-23) (ofcom.org.uk)
[17] Term interchangeable with ESIMs

4.3 NATO frequencies in Europe

A number of frequencies are identified for general military use in NATO Europe (Type 1[18] harmonised band) and planned for military use (Type 2[19] harmonised in Europe)[20], as shown below:

Figure 4.2: NATO frequencies in Europe

Frequency bands (GHz)	Service allocations used by military forces	Military requirements / usage
7.250 – 7.750	FIXED FIXED SATELLITE (s-E) MOBILE SATELLITE (s-E)	Essential military requirements for satellite downlinks 7250 – 7300 is harmonised NATO band type 1 for satellite downlinks; the mobile satellite sub-band 7250-7300 MHz is for naval and land mobile earth stations. Military requirement for fixed systems in some countries.
7.750 – 7.900	FIXED	Existing fixed systems in some countries
7.900 – 8.400	FIXED SATELLITE (s-E) MOBILE SATELLITE (s-E) FIXED Earth exploration satellite (s-E)	Essential military NATO band type 1 for satellite links; the mobile satellite sub-band 7975-8025 MHz is for naval and land mobile satellite earth stations. Military requirement for earth exploration satellite (downlink) purposes in the band 8025-8400 MHz. Military requirement for fixed systems in some countries.
8.5 – 10.5	RADIOLOCATION Radiolocation	Military requirement for land, airborne, and naval radars. NATO type2 band
13.4 – 14	RADIOLOCATION	Essential military requirements for land, airborne, and naval radars.
14.62 - 15.23	FIXED MOBILE	Essential military requirements for fixed and mobile services. Harmonised type 1 NATO band
15.7 – 17.3	RADIOLOCATION	Essential military requirements for land, airborne, and naval radars. 15.7 – 17.1 GHz harmonised type 1 NATO band
17.3 – 17.7	Radiolocation	Military requirement for land, airborne, and naval radars.
20.2 – 21.2	FIXED SATELLITE (s-E) MOBILE SATELLITE (s-E)	Essential military requirements for satellite downlinks. Harmonised type 1 NATO band

4.4 Situation in UK

4.4.1 Fixed services

OfW 446 Technical Frequency Assignment Criteria for Fixed Point-to-Point Radio Services with Digital Modulation OfW 446: Technical Frequency Assignment Criteria for Fixed Point-to-Point Radio Services with Digital Modulation (ofcom.org.uk)

[18] Type 1: A frequency band which is in general military use in NATO Europe.
[19] Type 2: A frequency band which is planned for military use in NATO Europe.
[20] See NATO Joint Civil and Military Frequency Agreement (NJFA) - HB Radiofrequency (halberdbastion.com)

Figure 4.3: Fixed services

Frequency band	Frequency limits (GHz)	Comment
U6	6.425 – 7.125	Shared and coordinated with FSS
7.5	7.425 – 7.900	No comments associated with this band
8	7.9 – 8.5	Opened for FS in December 2019 on shared and coordinated basis with Ministry of Defence. 3 paired 28 MHz bands available currently in Southeast UK in 8075 – 8162 MHz paired with 8286 – 8370 MHz.
13	12.75 – 13.25	Shared and coordinated with FSS
15	14.5 – 15.35	Coordinated with FSS
18	17.7 – 19.7	Shared and coordinated with FSS
23	22 – 23.6	Shared and coordinated with RAS

Comment: In general IMT and FS cannot share in the same area, but there may be potential for sharing if 6G base stations are placed well below rooftops or indoors; furthermore active beam forming may limit the time period over which there is potential interference into FS. Also fixed links designed with additional margins will limit interference potential and facilitate sharing.

There is continuing demand for fixed links – lower frequency bands for longer links and higher frequency bands for shorter links – as well as a need for higher bandwidth links. This nationwide demand may continue past 2030 or it may decrease as fibre continues to be rolled out across the UK. This may enable 6G to share on a geographic basis with fixed links with 6G focussed in cities in these bands and fixed links outside of the cities.

The 15 GHz band has a centre gap of 616 MHz (14.62 – 15.23 GHz) and the 23 GHz band a centre gap of 400 MHz[21] (22.6 – 23 GHz) that may merit further investigation.

4.4.2 Satellite earth stations

OfW 241 UK Frequency Allocations for Satellite Earth Stations UK Frequency Allocations for Satellite Earth Stations (ofcom.org.uk).

Figure 4.4: Satellite earth stations

Frequency band (GHz)	Frequency limits (GHz)	E-s / s-E	Comments
6	6.725 – 7.075	E-s	Coordinated with fixed links
7 – 8	7.75 – 7.85	s-E	Meteorological satellite RSA. Coordinated with fixed links

[21] See OfW48 UK Frequency Allocations for Fixed (Point-to-Point) Wireless Services and Scanning Telemetry (ofcom.org.uk) for details of frequency allocations. In the 23 GHz band the centre gap is 22.6 – 23 GHz and it would need to be confirmed that a 600 MHz guard band is sufficient for EESS operating in 23.6 – 24 GHz band.

Frequency band (GHz)	Frequency limits (GHz)	E-s / s-E	Comments
11	10.7 – 12.75	s-E	10.7 – 12.5 Direct to home TV. 12.5 – 12.75 Direct to home and VSATs Coordinated with remaining fixed links in the 10.7 – 11.7 GHz band which is closed for further assignments 11.7 – 12.5 ES receivers VSAT/HDFSS (High Density FSS) on uncoordinated basis
13	12.75 – 13.25	E-s	Used for commercial TV and interactive services Requires coordination with fixed links Use for PES not generally feasible within M25 and other major conurbations due to extensive use by fixed links
14	13.75 – 14	E-s	Permanent ES (PES) and Temporary ES (TES) (13.78 – 14 GHz)
14	14 – 14.25	E-s	Low density including VSATs and TESs
14	14.25 – 14.5	E-s	PES and TES. Requires coordination with fixed links
17	17.3 – 17.7	E-s	BSS feeder links ES receivers VSAT/HDFSS on uncoordinated basis
17	17.7 – 18.1	E-s, s-E	PES
17	18.1 – 18.4	E-s	BSS feeder links ES receivers VSAT/HDFSS on uncoordinated basis
18	17.7 – 20.2	s-E	Requires coordination with fixed links

Comment: Sharing with direct to home broadcasting may not be feasible depending on density of receivers. Note 27.1% of homes have satellite pay TV and 4.8% free to view satellite services. Changing viewing habits mean an increasing amount of content viewed online via streaming video on demand services such as Amazon and Netflix. Direct to home broadcasting may continue past 2030 or it may begin to decrease as online services (including services such as Sky Glass) continue to be increasingly adopted and direct to home decreases which may enable the possibility for 6G to be considered in the longer term.

Ofcom's UK Interface Requirements 2016[22] suggests that the use of land mobile satellite service terminals is licence-exempt in the bands 14.0 – 14.25 GHz (Earth-to-space), 12.5 – 12.75 GHz (Earth-to-space) and 10.7 – 11.7 GHz (space-to-Earth).

It is worth noting that there are several mega-constellation initiatives in low earth orbits, using frequencies in Ku- and Ka- bands (e.g. 10.7 – 14.5 GHz and 17.8 – 30 GHz). Examples are Starlink (constructed by SpaceX) and OneWeb (constructed by a joint venture between Airbus and OneWeb). These systems are designed to provide global broadband services to fixed and portable ground terminals deployed ubiquitously. There is also a growing interest in providing reliable and high data rate (>100 Mbps) satellite broadband services to aircraft, ships and land vehicles (e.g. trains, trucks and coaches) when they are out of reach of terrestrial networks. Earth stations in motion (ESIM) are earth stations operating with GSO and NGSO satellite systems under FSS allocations in Ka-band (17.7-20.2 GHz and 27.5-30 GHz) and Ku-band (10.7-13.25 GHz and 14.0-14.8 GHz) allocations to provide high-capacity communication links to moving platforms. At WRC-19, a new Resolution was adopted to define regulatory and technical conditions under which ESIMs can operate in the Ka-band. With the expected growth in ground terminal numbers and the requirement for mobility associated with these systems, it would be difficult to facilitate sharing with IMT services.

[22] https://www.ofcom.org.uk/__data/assets/pdf_file/0032/84659/ir2016.pdf

Ofcom's Space Spectrum Strategy Statement[23] sets out Ofcom's strategy for managing radio spectrum used by the space sector. The key relevant points to note are as follows.

- In order to use the Ku-band uplink at 14.25 – 14.5 GHz more efficiently, Ku-band user terminal access to this band is now allowed by Ofcom. The band was previously available for satellite gateway uplinks (permanent earth stations) and transportable earth stations but not for satellite user terminals. The potential benefits of user terminal access by both NGSO and GSO systems are expected to be more capacity for applications including inflight broadband and consumer satellite broadband services.

- The use of ESIMs on aircraft and ships is increasing and these services typically make use of Ku and Ka band frequencies. WRC-23 Agenda Item 1.15 is studying ESIMs in 12.75 – 13.25 GHz band and Ofcom is engaging to ensure that existing services are adequately protected.

- Ofcom is considering appropriate protection for sites in the UK used for downlinking data from Earth observation satellites operating in the 8 GHz band which is referred to be one of the two key bands for Earth observation downlink (the other band is 26 GHz). The 8 GHz band is currently used by a small number of Receive Only Earth Stations (ROES) in the UK but the use of this band is growing. The band is also used by the MoD for military applications and fixed links are used in the southeast of the UK. Ofcom is therefore exploring what needs to be done to protect ROES sites from interference (e.g. Recognised Spectrum Access, RSA). Ofcom is also encouraging any new ROES sites to be established further north to meet the needs of users downlinking data from polar orbiting Earth observation satellites.

4.4.3 Maritime Radionavigation Service

The following uses have been identified.

Figure 4.5: Maritime radionavigation service use

Frequency band (MHz)	Use	Reference
9000 – 9500	Maritime radars (non-SOLAS) shore stations	UK Interface Requirement 2020[24]
9300 – 9500	Maritime radars (non-SOLAS) ship stations and shore stations	UK Interface Requirement 2020
9300 – 9500	Radar Beacons (Racons)	UK Interface Requirement 2031[25]
9300 – 9500	Radar Target Enhancers	UK Interface Requirement 2081[26]

4.4.4 Aeronautical Radionavigation Service

The following uses have been identified.

[23] Statement: Space spectrum strategy - Ofcom https://www.ofcom.org.uk/__data/assets/pdf_file/0023/247181/statement-space-spectrum-strategy.pdf
[24] https://www.ofcom.org.uk/__data/assets/pdf_file/0035/84869/ir_2020_120711.pdf
[25] https://www.ofcom.org.uk/__data/assets/pdf_file/0025/84508/IR_2031.pdf
[26] https://www.ofcom.org.uk/__data/assets/pdf_file/0025/84661/ir_2081.pdf

Figure 4.6: Aeronautical radionavigation service use

Frequency band (MHz)	Use	Reference
9300 – 9500	Primary radar for Air Traffic Control	UK Interface Requirement 2050[27]
15400 – 15700	Primary radar for Air Traffic Control	UK Interface Requirement 2050

4.4.5 Defence

Defence utilise and already share spectrum between 7 and 24 GHz - about 85% of all military bands are already shared. An important consideration is those frequencies identified as NATO bands and the requirement to have immediate access.

Figure 4.7: Defence use

Frequencies	Defence use	Comments
7.125 – 7.725 GHz	Satellite downlinks	Over ✂ assignments in satellite downlink band for mainly aircraft and ships
7.9 – 8.4 GHz	Believe satellite downlinks	Spectrum already shared with EESS. Recently released frequencies for fixed services on a geographic basis (2 x 86 MHz)
10.25 – 10.6 GHz	Radars	Over ✂ assignments as well as fixed service and mobile service military uses. NATO band.
10.7 – 12.75 GHz	Radars	Majority are aeronautical radars
14.3 – 15.25 GHz	Fixed and mobile	Over ✂ assignments including data links
17.7 – 19.7 GHz	Radars	Not NATO. Limited information on use
21.2 – 21.4 GHz	NATO including mobile	Noted likely demand for additional spectrum for Skynet 5 and 6

Whilst it is considered unlikely that any further frequencies can be released there may be the potential for Defence Controlled DSA (DCDSA) in the longer term in limited portions of some of these bands.

4.4.6 Meteorology

The 7 – 24 GHz band provides the necessary lower frequencies which are used by meteorological satellites to sense and from this define what is happening near the earth's surface and correct information collected at higher frequencies. There is a trend towards integrated systems utilising both lower and higher frequency information and this will lead to greater importance of the lower frequency (7 – 24 GHz) data. Parts of 7 – 24 GHz are also used for data downlinking.

The 6.7 – 6.9 GHz band is used for ocean surface temperature measurements. If IMT systems are deployed in this band there is an ongoing debate if these measurements can be implemented in the 8 GHz band.

At 10.7 GHz there is a narrow band used to measure precipitation and it is the only band that can be used to directly identify precipitation.

[27] https://www.ofcom.org.uk/__data/assets/pdf_file/0028/59086/ir2050.pdf

The 18.6 – 18.8 GHz band is heavily used and is the primary source of meteorological information for sea ice analysis. It is noted that interference at the Polar Regions (above 65 degrees North and below 60 degrees South) is very rare.

The trend is to develop cubesat constellations to make continuous Earth observations rather than the use of a large satellite for infrequent observations at a given point.

In terms of the potential for sharing it is important to recognise that low level, geographically widespread radio interference causes the largest problem as it is difficult to identify and can lead to misinterpretation of data. Weak or very strong localised interference is not difficult to detect and the outcome is limited loss of data. In order to facilitate sharing it would be necessary to switch off IMT emissions when the satellite is overhead and with the proposed move to satellite constellations this will require accurate and frequent switching on and off of IMT transmitters.

5 Sharing potential

There are established sharing principles, for example geographic distances, guard bands, antenna pointing etc., that have been traditionally considered to facilitate co-existence between mobile broadband and other radio services. It remains to be seen if these principles would also play a key role in facilitating sharing between 6G and other radio services given the uncertainties associated with potential 6G network architectures and use cases. The use of novel architectures and AI together with dynamic spectrum access based on environment sensing and polite protocols may result in different sharing approaches and parameters. One vendor noted that a) environmental sensing approaches are not trivial, as evidenced by recent reports that the environmental sensing capability in CBRS systems in the US is subject to review and may be substituted with alternative mechanisms, and b) polite protocols are inevitably accompanied with degradations in performance and in the management of quality of service.

Currently, sharing studies are being implemented in ITU-R study groups as part of WRC-23 preparations and these include some parts of 7 – 24 GHz range. The following sections highlight the key sharing principles considered in recent work submitted to ITU-R where compatibility between mobile networks and some of the other radio services shown in Figure 4.1 is investigated.

5.1 Sharing with FS

The potential for sharing with fixed point to point links is dependent in part on the density of links in any geographic area and the service level required by those links. Fixed links are highly directional and the maximum geographic separation between a fixed service receiver and IMT network is defined by the interference into the FS main lobe scenario for a given protection criteria.

Work ongoing in WP5D for WRC-23 provides an indication of separation distances between IMT and fixed point to point links in the 6.425 – 7.125 GHz band assuming co-channel interference, macro cells in urban and suburban areas and aggregated multiple interferers analysis[28]. Studies assuming a protection criterion of I/N= -10 dB have calculated protection distances from 16 to 94 kms for the main lobe scenario and less than 1 km to 6 kms for side lobe scenario.

It can be seen from Figure 4.1 that many fixed service bands are already shared with FSS.

This nationwide demand for fixed links may continue past 2030 or it may decrease as fibre continues to be rolled out across the UK. This may enable 6G to share on a geographic basis with fixed links with 6G focussed in cities in these bands and fixed links outside of the cities.

5.2 Sharing with FSS

In the context of interference between mobile networks and earth stations, the traditional approach is to deploy a deterministic method and consider establishing coordination areas around earth stations to minimise the impact of interference to/from mobile networks, assuming that earth stations are deployed at known locations. Coordination areas are conservative and generally based on worst case assumptions in terms of radio and deployment characteristics. Any potential deployment within a coordination area is subject to case-by-case sharing analysis to explore the feasibility of any potential mitigation techniques (e.g. antenna height and pointing, power reduction, shielding etc.). For example, this is the approach proposed within a recent Working

[28] See 5D/1361 (Annex 4.18) from WP5D chairman's report

Party 5D working document[29] towards a preliminary draft new recommendation on guidelines to assist administrations to mitigate interference from FSS earth stations into IMT stations operating in the frequency bands 24.65-25.25 GHz and 27-27.5 GHz.

In the case of ubiquitous mobile and FSS deployments, the sharing principle changes from deterministic to probabilistic. The issue then becomes establishing the probability of interference between earth stations and mobile networks based on representative deployment scenarios and limiting this to an acceptable level.

Recent sharing and compatibility studies[30] relating to FSS (space-to-Earth) operating in the frequency band 6700 - 7075 MHz and IMT operating in the frequency band 6425 - 7125 MHz indicate that separation distances ranging from a few km to tens of km could be required to protect the earth stations.

In the context of interference between mobile networks and satellites, the impact of total aggregate power generated by mobile networks at satellite receiver is the key consideration. This is typically calculated by integrating mobile transmitter emissions towards the satellite receiver. The issue then ultimately boils down to estimating the maximum density of mobile transmitters within the satellite footprint area and judging whether this number is likely to be a representative deployment figure in practice.

There are a significant number of studies examining interference into space receivers in the context of "Sharing and compatibility of FSS (Earth-to-space) operating in the frequency band 6 425-7 075 MHz and IMT operating in the frequency band 6 425 -7 125 MHz" [31]. A range of results are presented with some studies showing interference below the protection criterion and others showing interference above the criterion.

Interference from satellite transmitters into terrestrial receivers are limited by power flux density limits described in ITU RR Article 21.

For all scenarios mentioned above, if co-frequency sharing is not feasible, consideration can be given to adjacent band deployment where additional guard bands and/or filtering at receivers can be taken into consideration to minimise the impact of interference.

It is worth noting that emerging technologies, for example configurable antenna beams and environment sensing, will inevitably play an important to role to facilitate 6G deployments in bands where multiple incumbent radio services are in operation.

5.3 Sharing with SRS

The protection of SRS satellite receivers needs to consider the impact of interference aggregation from mobile network transmitters over an area visible to the satellite receiver. The impact will vary with the satellite's position which includes low orbit heights at launch and early orbit phase or in the mission return phase and very far distances (millions of kms) in deep space. Interference can be aggregated as a function of satellite height by taking account of mobile network transmitter population, transmit power, antenna gain towards the satellite receiver and propagation effects. This can then be compared against the representative satellite receiver threshold to determine the impact of aggregate interference.

On the ground, the impact of interference between SRS earth stations and mobile network stations can be analysed by coordination area calculations as explained in the preceding section for sharing with FSS.

[29] Annex 4.3 to Working Party 5D Chairman Report (Document 5D/1361) dated 30 June 2022, Working Party 5D (WP 5D) - IMT Systems (itu.int)
[30] Annex 4.20 to Working Party 5D Chairman Report (Document 5D/1361) dated 1 July 2022, Working Party 5D (WP 5D) - IMT Systems (itu.int)
[31] Annex 4.19 to Working Party 5D Chairman Report (Document 5D/1361) dated 1 July 2022, Working Party 5D (WP 5D) - IMT Systems (itu.int)

The use of interference aggregation methodology for the protection of SRS satellite receivers and coordination area calculation approach for SRS earth stations has been adopted in a recent Working Party 5D working document on sharing and compatibility studies of IMT systems in the frequency band 6425 – 7125 MHz addressing sharing and compatibility of SRS operating in the frequency band 7145 – 7190 MHz and IMT operating in the frequency band 6425 – 7125 MHz[32]. Studies presented in this document indicate that potential for interference from IMT deployments on the surface of the Earth into an SRS space station receiver is minimal and there is no compatibility problem where large margins are calculated with respect to the interference protection criteria. Large protection distances (up to 400 km) were calculated for the protection of IMT receivers from SRS earth station transmitter out of band emissions.

It is important to note that there are several bands within the 7 – 24 GHz range (see Figure 4.1) where no-emissions are allowed and passive services including SRS have allocations.

5.4 Sharing with EESS

EESS (active) service satellite antennas are typically characterised by narrow elevation and azimuth beams creating a small area of sensor footprint on the Earth's surface which moves with the satellite located typically at low earth orbit. The impact of mobile network interference into EESS (active) satellite antennas is analysed through the aggregation of emissions from dense areas (e.g. cities) from the satellite footprint or the entire area visible to the EESS satellite receiver. Parameters including mobile network transmitter density, transmitter antenna sidelobe gain towards the satellite receiver, satellite antenna receiver gain towards the mobile network transmitters, mobile network load factor and propagation end clutter effects will have impact on whether the EESS satellite receiver threshold is exceeded or not.

Sharing and compatibility of EESS (active) operating in the frequency band 10 – 10.4 GHz and IMT operating in the frequency band 10 – 10.5 GHz is part of the latest ITU Working 5D chairman's report[33]. Studies presented in this report make use of the approach summarised above. An important assumption is outdoor/indoor hotspot mobile network deployments with beam forming antennas. The results of studies show that there is a high risk of interference into EESS active operations where protection criterion is exceeded by up to 11 dB. Satellite antenna sidelobe suppression can be considered to improve the sharing potential.

In the case of EESS (passive) service sharing with mobile systems, the analysis approach is similar to that described for the EESS (active) sharing with mobile networks in that aggregate interference from the sensor footprint area or the entire area visible to satellite is analysed by taking into account the gain of mobile network transmitters towards the EESS satellite, the gain of the EESS sensor towards mobile network transmitters and propagation and clutter effects. The latest ITU Working 5D chairman's report includes an attachment[34] on adjacent band sharing and compatibility of EESS (passive) operating in the band 10.6 – 10.7 GHz and IMT operating in the frequency band 10 – 10.5 GHz. Sharing studies are based on the assumptions that mobile network transmitters are outdoors and EESS (passive) sensors are conical scan with narrow beam antennas. The results show that IMT base station out of band emissions need to be tightened significantly (tens of dBs) to protect the EESS (passive) receivers.

5.5 Sharing with RAS

For the protection of RAS receivers, geographic exclusion areas around radio astronomy sites where mobile network transmitters are not allowed to operate as well as mobile network transmit antenna pointing angle

[32] Annex 4.16 to Working Party 5D Chairman Report (Document 5D/1361) dated 22 June 2022, Working Party 5D (WP 5D) - IMT Systems (itu.int)
[33] Annex 4.23 Attachment 2 to Working Party 5D Chairman Report (Document 5D/1361) dated 15 July 2022, Working Party 5D (WP 5D) - IMT Systems (itu.int)
[34] Annex 4.24 Attachment 3 to Working Party 5D Chairman Report (Document 5D/1361) dated 4 July 2022, Working Party 5D (WP 5D) - IMT Systems (itu.int)

exclusion zones (for example avoidance of antenna beam steering within +/- X degrees in azimuth plane towards a radio astronomy telescope) can be considered. For example, this approach is proposed in the context of compatibility of RAS operating in 10.6 – 10.7 GHz and IMT operating in the frequency band 10 – 10.5 GHz[35]. An example study result indicates that co-existence is feasible when separation distances are above 90 km and the base station beam is not steered within 25° of the direction to the radio astronomy station.

5.6 Sharing with RLS

The implications of sharing with ground, airborne and shipborne radars need to be considered.

An example sharing study submitted to Working Party 5D examines the impact of interference aggregation at an airborne radar receiver (operating at a given height with randomised azimuth and elevation) from mobile network transmitters using 100 MHz wide channels with beam forming antennas randomly distributed at an area located some distance from the aeroplane in 10 – 10.5 GHz[36]. Interference statistics are compared against the radar receiver threshold to determine the minimum distance on the ground between the aeroplane and the edge of an area where mobile network transmitters are located. Example results show required separations between 150 - 180 km.

In the case of ground and shipborne radars, further example sharing studies analyse required separation distances between the edge of an area where mobile network transmitters are distributed randomly in hotspots and the victim radar receiver located at some distance away. Example results show separations of up to 30 km for ground and ship based radars.

5.7 Conclusion

Sharing studies presented above which are based on traditional analysis methods indicate that there is very limited opportunity for 6G systems to share with incumbent services. Therefore, other options for sharing will need to be developed.

While 6G is expected to incorporate novel network architectures and may make use of AI extensively to achieve, amongst others, dynamic spectrum sharing there have not been concrete proposals put forward yet. Consequently, current sharing studies involving IMT systems and other radio services employ traditional methods where an extensive set of IMT deployment parameter values are agreed in advance and co-existence analyses are conducted using deterministic and statistical methods. IMT parameters are typically based on urban/suburban deployments with detailed base station and user terminal antenna and radio emission characteristics. Currently, there is no certainty that novel sharing concepts will emerge from adoption of new technologies currently under development.

[35] Annex 4.26 Attachment 5 to Working Party 5D Chairman Report (Document 5D/1361) dated 4 July 2022, Working Party 5D (WP 5D) - IMT Systems (itu.int)

[36] Annex 4.22 Attachment 1 to Working Party 5D Chairman Report (Document 5D/1361) dated 4 July 2022, Working Party 5D (WP 5D) - IMT Systems (itu.int)

6 Initial conclusions on possible bands

As shown in Figure 4.1, there are a total of fifteen incumbent primary allocations placed between 7 – 24 GHz in addition to the Mobile Service. A number of incumbent primary allocations make active use of allocated frequencies. Examples include the following.

- Fixed links are deployed in 6.4 – 7.1 GHz, 7.4 – 7.9 GHz, 7.9 – 8.5 GHz, 12.75 – 13.25 GHz, 14.5 – 15.35 GHz, 17.7 – 19.7 GHz and 22 – 23.6 GHz although there may be potential in the 15 GHz band centre gap where there is 616 MHz (14.62 – 15.23 GHz) of spectrum (noting that the centre gap is a type-1 NATO band). Increased deployment of fibre may facilitate release of some fixed link spectrum and future demand will need to be monitored.

- NATO bands include 7.25 – 8.4 GHz, 8.5 – 10.5 GHz, 13.4 – 14 GHz, 14.62 – 15.23 GHz, 15.7 – 17.7 GHz and 20.2 – 21.2 GHz. UK defence use covers 7.1 – 7.7 GHz, 7.9 – 8.4 GHz, 10.25 – 10.6 GHz, 10.7 – 12.75 GHz, 14.3 – 15.25 GHz, 17.7 – 19.7 GHz and 21.2 – 21.4 GHz. Whilst it is considered unlikely that any further frequencies can be released there may be the potential for defence Controlled DSA (DCDSA) in the longer term in limited portions of some of these bands.

- Satellite networks are deployed in 6.7 – 7 GHz, 7.75 – 7.85 GHz, 10.7 – 14.5 GHz and 17.3 – 20.2 GHz.

- Maritime and radionavigation services use 9 – 9.5 GHz and 15.4 -15.7 GHz spectrum.

- Science services use 10.7 GHz, 18.6 – 18.8 GHz and 23.6 – 24 GHz bands for Earth surface and atmospheric observations. There are also many allocations for EESS, RAS and SRS which are expected to be used globally.

Extensive allocations and active use of allocated bands indicate that there is no clear sufficiently large contiguous spectrum available for 6G use based on current technologies and current allocations. There needs to be sharing arrangements to admit additional services. Many stakeholders suggested that sharing should be an integral part of 6G specifications. We have noted in this report the existing use of AI assisted sensing and polite access to bands used by services such as defence. As 6G use cases and their quality of service requirements are not well defined yet it is not possible at this time to foresee whether/how these novel sharing strategies could be put into practice but they clearly warrant investigation alongside the introduction of new technologies.

The centre gap in the 15 GHz band may be considered further but there may be constraints from NATO[37].

[37] In the longer term, there may also be the potential to use 400 MHz centre gap in the 23 GHz band (22.6 – 23 GHz). The implications of sharing with EESS need to be considered.

7 Matters for further consideration

Based on inputs from interviewees and Plum's analysis a number of areas that might merit further investigation and actions were identified:

- On the assumption that additional mid band spectrum is required for 6G, are the limited options identified from our research on 7-24 GHz likely to provide sufficient bandwidth for 6G services? A secondary consideration is the likely implications of the outcome at WRC-23 of a possible IMT identification in the upper 6 GHz band?
- Considering 7-24 GHz there is further work required on whether the emphasis for 6G should be on spectrum in the 7 – 15 GHz frequency range for implementation reasons (e.g. economies of deployment, availability of new enhanced digital technologies, practicalities of systems operating at above 15 GHz)?
- The possibility of using the centre gap in the fixed service at 15 GHz could provide up to 616 MHz (14.62 – 15.23 GHz) and may be worth further consideration noting that the 15 GHz centre gap is a type-1 NATO band[38].
- There is the opportunity now to design 6G solutions that can facilitate more advanced spectrum sharing techniques to enable coexistence with other services such as fixed links, satellites and military use – this should be promoted as opportunities for exclusive access for 6G are unlikely to be possible in 7-24 GHz without significant upheaval and cost for incumbent services.
- The UK should monitor developments in the US, Japan, China and Korea as potential leaders in identifying spectrum. The 10.0 – 10.5 GHz band is being investigated for mobile use in Region 2 for WRC-23. US is assessing the 12.75 – 13.25 GHz band. For the time being however neither option is likely to be attractive in the UK due to the current use of these bands and Ofcom has already signalled it does not support the 10.0-10.5 GHz proposal.
- 15.7 – 17.1 GHz is only allocated to Radio Location services but it is a harmonised type 1 NATO band. It is not clear how intensively the spectrum is used and whether there may be any potential to release some of this band or to share. This may be worth exploring further.
- Is there any potential for true convergence between satellite and mobile that will facilitate co-channel and/or geographic/altitude sharing?
- Are there any institutional blockages that might limit sharing even if it could be implemented through technology enhancements – for example sharing with defence users and the need for the basis to be opaque to other users?

[38] In the longer term, there may also be the potential to use 400 MHz centre gap in the 23 GHz band (22.6 – 23 GHz). The implications of sharing with EESS need to be considered.