A Preliminary View of Spectrum Bands in the 7.125 - 24 GHz Range; and a Summary of Spectrum Sharing Frameworks

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1. Executive summary

The need for additional spectrum for future applications has been expressed by numerous federal, scientific and commercial entities. However, spectrum is a finite resource and can be exclusively allocated to only a handful of users. Additionally, many wireless systems prefer to deploy in certain parts of the spectrum due to various technical and commercial reasons, such as better propagation and infrastructure cost. Hence, the only practical way to satisfy the demands of all applications -- commercial, scientific and federal -- is to encourage spectrum sharing among incumbent users and new entrants. However, this is a challenging task, because the feasibility of robust and efficient spectrum sharing that protects incumbents from harmful interference while allowing new entrants sufficient performance depends upon the operational characteristics and use cases of the systems that will share the band: often, these are not publicly available with the level of detail required to develop efficient spectrum sharing methods.

This document summarizes the current allocations in the 7.125 - 24 GHz band and spectrum sharing frameworks that could be considered for sharing between commercial wireless and incumbent services. This band is largely allocated for federal use today, however, there is additional demand for various commercial applications due to the favorable propagation characteristics compared to mmWave and higher bands and the availability of larger bandwidths compared to the lower bands. The word “sharing” in this document refers to possible simultaneous use of the spectrum by various incumbent federal and commercial systems on one side and new wireless communication providers on the other side. The terminology “wireless communication providers” in this document refers to fixed and mobile, licensed and unlicensed, and terrestrial and non-terrestrial service providers.

The additional spectrum required for commercial terrestrial wireless communications services is projected to be approximately 2 GHz by 2030 and the preference is for this to be available in the 7.125 - 15 GHz range. Non-terrestrial wireless communications services also need additional spectrum to meet growing demands, but perhaps in bands other than 7.125 - 24 GHz band.

In the United States, a large portion of the spectrum in the 7.125 - 24 GHz range has been allocated to various federal agencies as primary users, though commercial wireless service providers also have operations in the band. International use of this spectrum band follows a similar pattern (i.e., extensive government use), though there are country-specific variations and commercial operations. In order to leverage the global ecosystem, it is important that spectrum sharing techniques continue to be coordinated internationally between government and commercial entities, as is done today.

The United States leads the world in developing innovative spectrum sharing frameworks, as shown by the Federal Communications Commission’s (FCC) proceedings in TV White Spaces, Citizens Broadband Radio Service (CBRS), and 6 GHz. Efficient use of spectrum leads to economic activity around new use cases and expands social benefits by enabling new business sectors. In order to sustain these trends, further action is needed towards spectrum sharing in additional frequency bands that minimizes the impact on incumbents.. The new techniques developed will further technological supremacy among both federal and commercial entities.

This document summarizes existing allocations in the 7.125 - 24 GHz band, but actual usage by all current users is essential information that is required before appropriate spectrum sharing techniques can be developed. Hence, it is recommended that a detailed assessment of current spectrum usage, as opposed to just allocations, be undertaken in 7.125 - 24 GHz. This task should be followed by identification of specific spectrum ranges that may be suitable for sharing among federal and the various commercial entities. Finally, new sharing techniques need to be developed, depending on incumbent and new-entrant use cases and operational characteristics.

2. Introduction

The demand for wireless data traffic continues to grow at a steady pace. While currently available spectrum and deployed technologies, for example 4G, 5G, Wi-Fi 6, Wi-Fi 6E and satellite, will be leveraged to the fullest extent, the projections from industry point to a continued need for additional capacity. There are three fundamental ways of delivering this additional capacity:

1. Improved **spectral efficiency**: the theoretical limits of spectral efficiency (bits/sec/Hz) on a per link basis have been approached with current technologies such as Low Density Parity Check (LDPC) codes and MIMO and while research will continue in this area, the pace of further enhancements has slowed.

2. Increased **spatial density** for cellular deployments: dense urban deployments often reach the limits of interference mitigation and thus incur performance degradation; multi-user MIMO (MU-MIMO) methods do not always lead to improved performance since they incur overhead for channel estimation and control signaling. Site densification also faces challenges of site acquisition, operational complications (including costs), and sustainability.

3. Enhanced **amount of spectrum**: spectrum in desired frequency ranges is already occupied by various services so it is nearly impossible to find any spectrum with no

incumbents. However, effective spectrum sharing can potentially unlock additional spectrum for certain new services, while protecting important incumbent uses.

Next generation technologies in the form of 6G (3GPP Release 20 and beyond), Wi-Fi 7/8 and non-terrestrial networking (NTN, also being specified in 3GPP) are on the horizon, and are expected to be deployed commercially before the end of the decade. As observed with previous technology generations, there are often at least two previous generations still operational at the time of introduction of a new generation. Thus, spectrum assets often end up accommodating three generations of technologies at any given point in time. It is expected that 4G/5G/6G as well as Wi-Fi 5/6/7/8 will coexist for some time after deployment of the latest generation. In addition, there is an increasing demand for NTN wireless services for a wide range of frequency bands that need to be accommodated, especially as these services become increasingly important to ensure that the United States retains its leadership in next generation technologies.

Thus, we anticipate the need for significant additional spectrum for wireless services in the foreseeable future. Given that no desirable spectrum band is currently free of incumbents, the need for spectrum sharing is obvious. The term “spectrum sharing” can have many different interpretations – across (i) different services (e.g., radiolocation and mobile services), (ii) across users of different technologies within the same service (e.g. 4G and Wi-Fi 5), (iii) across users of the same technologies (e.g., different operators of mobile services or private wireless networks) and (iv) across different technologies by the same user (e.g., Wi-Fi 5 and Wi-Fi 6 by the same private network owner or 4G and 5G by the same mobile network operator).

This document primarily focuses on spectrum sharing across **different services** as opposed to the other types listed above, as that is often technically the most challenging, since different services can have very different technical and operational requirements and thus may need different mechanisms for sharing spectrum while minimizing negative impacts on system performance. However, as a solution to increasing spectrum demands, spectrum sharing amongst other users, as listed above, should also be considered.

The U.S. has led the development of many innovative spectrum-sharing techniques for various bands. The widespread use of CBRS (Citizens Broadband Radio Service), the rapid adoption of AMBIT (America’s Mid-Band Initiative Team) for 3.45 GHz and the current effort at EMBRSS (Emerging Mid-Band Radar Spectrum Sharing) for 3.1 - 3.45 GHz are testimony to the innovative efforts of federal and commercial entities in exploring spectrum sharing. TV White Space and 6 GHz, both low-power-indoor (LPI) and standard-power (SP) with Automated Frequency Coordination (AFC), are other examples of spectrum sharing where the U.S. has led the world. Such efforts in spectrum sharing need to be extended to other parts of the spectrum (as needed) to maximize the value and utilization of spectrum.

By various estimates [1, 2, 3], up to 2 GHz of additional spectrum may be needed in the next 5 - 7 years for terrestrial wireless communications in order to support emerging use cases and user densities; furthermore, it is desirable to obtain this spectrum in the lower part of the frequency range (as close as possible to current deployments under 7.125 GHz) as these frequencies have better propagation characteristics resulting in better coverage. NTN services also have significant demands for access to additional spectrum, over 10 GHz, in low, medium, and high bands, based on the WRC 2027 Preliminary Agenda and current proposals for future agenda items in [4], which however do not propose additional allocations in 7.125 - 24 GHz. A recent report [5] provides further details on current satellite allocations in 7.125 - 24 GHz.

Given the current federal and non-federal allocations in the United States, it is impossible to find a large amount of spectrum below 7.125 GHz that is not already utilized. From a practical perspective, the next best alternative is to examine the 7.125 - 15 GHz range. For completeness, this paper also analyzes the 15 - 24 GHz range.

It is conceivable that the total spectrum available for sharing may not be contiguous; the components may not even be the same across the entire geography of the United States (due to varying incumbent use); and there may be a need to adopt multiple sharing schemes. Additionally, sharing may have to be enabled by using different levers of frequency, geography, time and power, driven by emerging technologies (including tools that utilize AI/ML). Also, sharing should not be the responsibility only of new entrants; incumbents should also actively pursue technology advancements in their own domain to continually improve their utilization to make spectrum sharing a success across all services.

As this investigation indicates, the lack of unused spectrum in 7.125 - 24 GHz is not unique to the U.S. as most other countries also have spectrum in this range being used by a variety of services. Consequently, it is important that carrier aggregation, spectrum agility, and spectrum sharing are adopted as an integral part of international technical standards developments for future wireless technologies. By doing so, the U.S. can benefit from harmonization and the global economies of scale in the deployment of network equipment and devices.

3. Current allocations and uses in 7.125 - 24 GHz in the U.S.

This section examines bands in the 7.125 - 24 GHz range, excluding 12.2 - 13.25 GHz, which is already being considered in current FCC proceedings. In particular, we present the main allocations [6] in this band, even though we do not have data on usage intensity of the services described.

In the following subsections, the 7.125 - 24 GHz band is split into four sub-categories for ease of presentation and analysis [6, 7]. The following abbreviations are used for the services described, in accordance with the FCC allocation chart:

AMS: Aeronautical Mobile service
ARNS: Aeronautical Radionavigation Service
AWS: Advanced Wireless Service
BSS: Broadcasting Satellite Service
EESS: Earth Exploration Satellite Service
FS: Fixed Service
GPS: Global Positioning Service
GSO: Geostationary Orbit
MetAids: Meteorological Aids Service
MetSat: Meteorological Satellite Service
MMS: Maritime Mobile Service
MMSS: Maritime Mobile Satellite Service
MS: Mobile Service
MSS: Mobile Satellite Service (includes GSO and NGSO)
NGSO: Non-Geostationary Orbit
RAS: Radio Astronomy Service
RLS: Radiolocation Service
RNS: Radionavigation Service
RNSS: Radionavigation Satellite Service (including GPS)
SRS: Space Research Service
SF&TSS: Standard Frequency and Time Signal Satellite

Space-to-Earth transmissions are denoted as downlink (DL), and Earth-to-space as uplink (UL).

In the following charts, green cells represent a PRIMARY allocation, yellow cells represent a Secondary allocation, an up-arrow indicates Earth-to-space (UL), a down-arrow indicates space-to-Earth (DL) and shading indicates that the allocation is established by a footnote to the allocation table. Such footnote allocations may not apply to the entire frequency range and may not apply in all areas. Shading without either green or yellow means that the footnote provides some level of protection (or at least consideration) for a service, but no allocation status. Please refer to the allocation table and the footnotes for more information.

The rows are labeled as follows:

F: U.S. federal government allocations
N: U.S. non-federal-government allocations
R1: ITU Region 1 allocations
R2: ITU Region 2 allocations
R3: ITU Region 3 allocations

The ITU Regions are indicated on the following map:

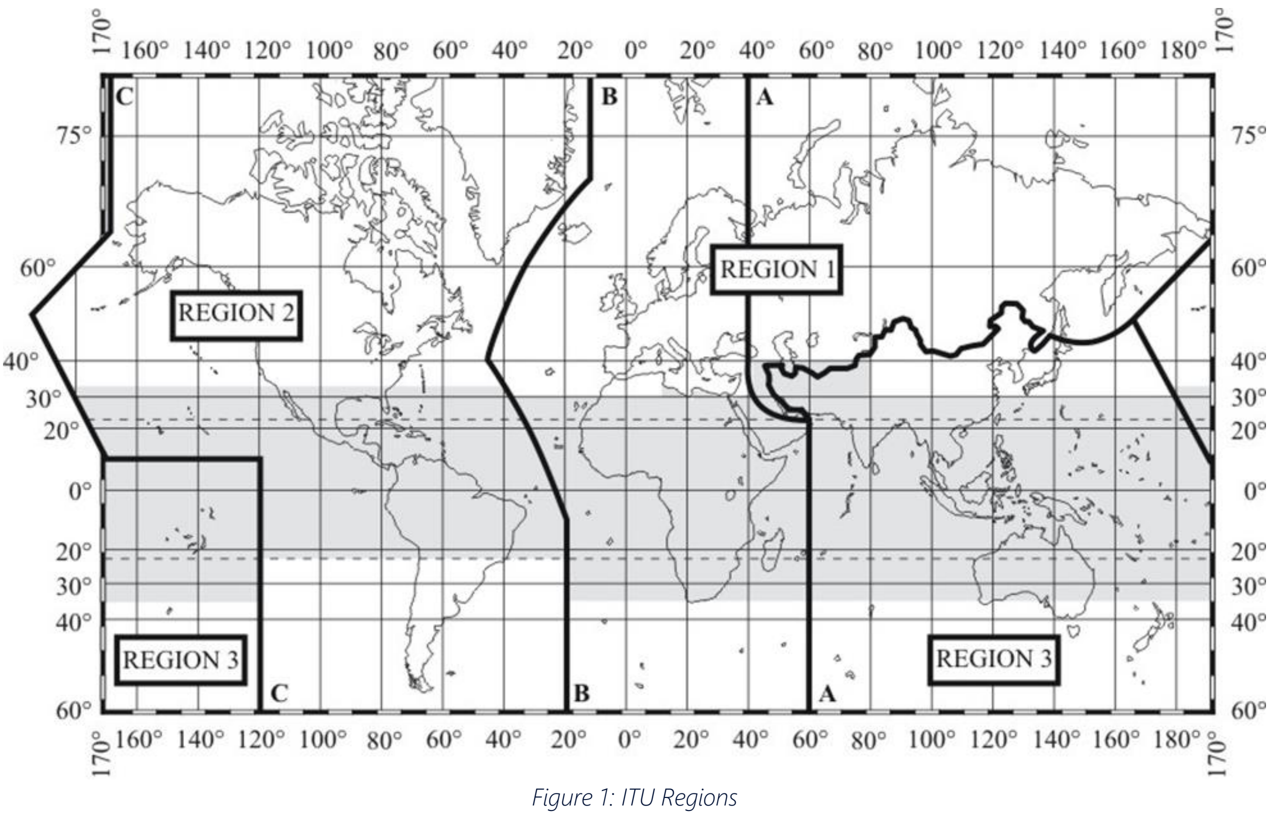

Figure 1: ITU Regions

The U.S. allocations in these charts are from the FCC Online Table of Frequency Allocations dated July 1, 2022, and the international allocations are based on the 2020 ITU Radio Regulations. Both of these tables are the latest available as of this writing.

3.1. 7.125 - 8.5 GHz

This band is just above the unlicensed 6 GHz band (5.925 – 7.125 GHz) which is currently used primarily for extensive fixed services but was recently designated for unlicensed use in the U.S. on a non-interference basis to existing incumbents. Figure 2 shows the current allocations in the 7.125 - 8.5 GHz band, with the following principal characteristics:

- FS, FSS and MSS are the largest current allocations and will be the biggest challenge for sharing with terrestrial mobile systems.
- Approximately 20% of FS use is by the Department of Defense (DoD), and the satellite allocations also include DoD operations.
- Other uses may not be ubiquitous and hence perhaps more amenable to sharing.

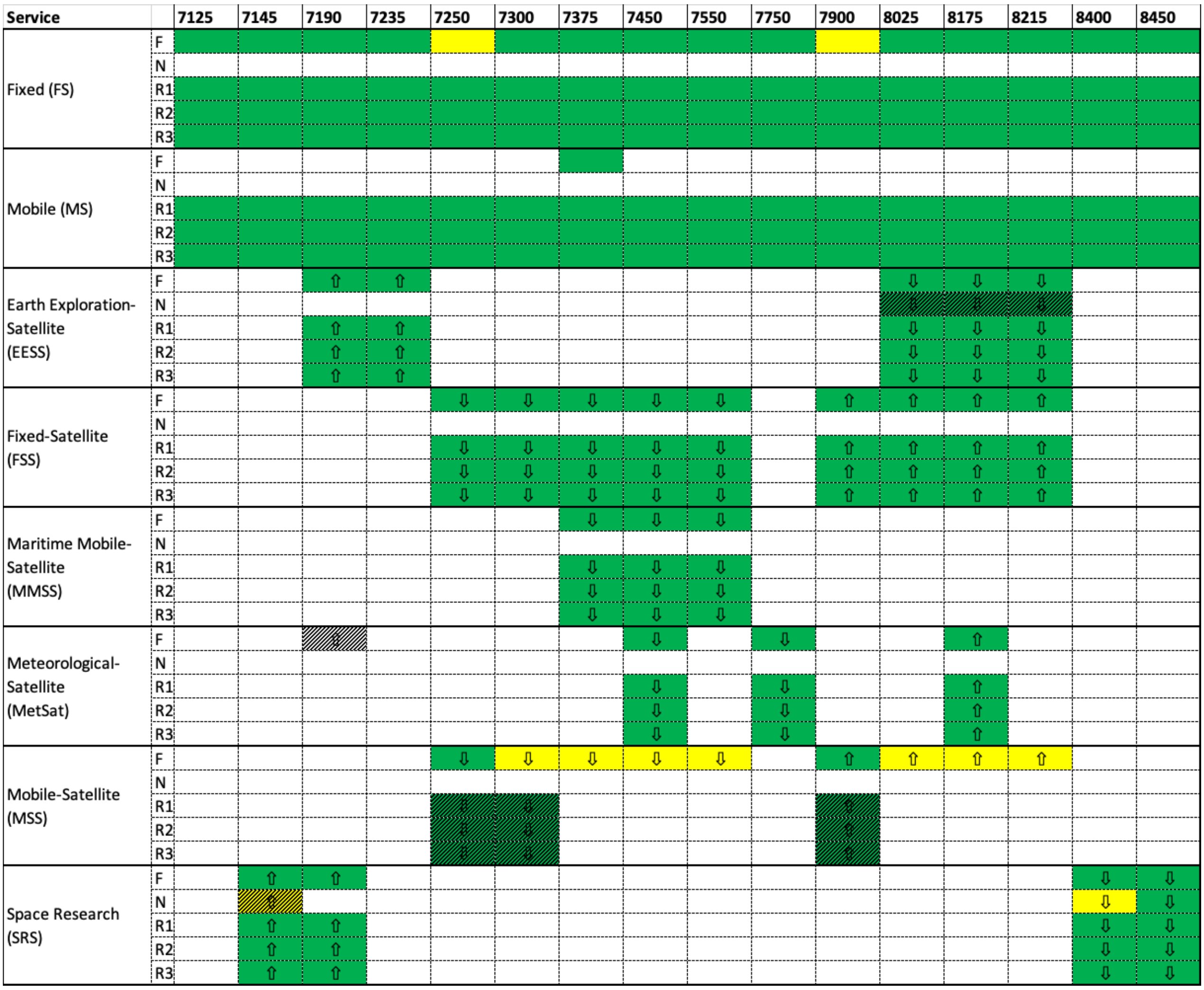

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Figure 2: 7.125 - 8.5 GHz spectrum allocations

In addition to federal allocations for fixed and satellite services, the 8400 – 8500 MHz band is allocated for SRS (DL).

The federal agencies use of this band is mostly for fixed point-to-point microwave communication systems. This includes the Federal Aviation Administration's (FAA) use of this band for fixed point-to-point microwave communications networks to connect remote long-range aeronautical radio-navigation radars to air traffic control centers. However, the use of the band for fixed assignments in the 7.125 – 8.5 GHz has been declining.

This band is also used for FSS and MSS. Federal agencies operate the Defense Satellite Communications Systems (DSCS) series of geostationary satellites (DL) in this frequency band. Federal agencies also operate the Wideband Gapfiller Satellite (WGS) in this band. FSS uses 7.25 – 7.75 GHz as downlink and 7.9 – 8.4 GHz as uplink; this includes support for both DSCS and WGS.

Non-federal use includes unlicensed use for ultra-wideband devices under Part 15.501-525 rules, utilizing primarily the 7.75 - 8.75 GHz frequency range. These devices include personal item tracking devices, mobile phones and other personal consumer electronics, including wearables, wall-penetrating radars, and automotive applications thereby crossing several consumer sectors.

3.2. 8.5 – 13.75 GHz

Figure 3 shows the current allocations in the 8.5 - 13.75 GHz band, with the following principal characteristics:

- RLS is the single largest allocation.
- ~2500 MHz in 10.7 – 13.25 GHz is allocated for non-federal use, of which 12.2 - 13.25 GHz is already under consideration by the FCC for sharing with other services.
- 13.25 - 13.75 may also be available for sharing with limited restrictions.

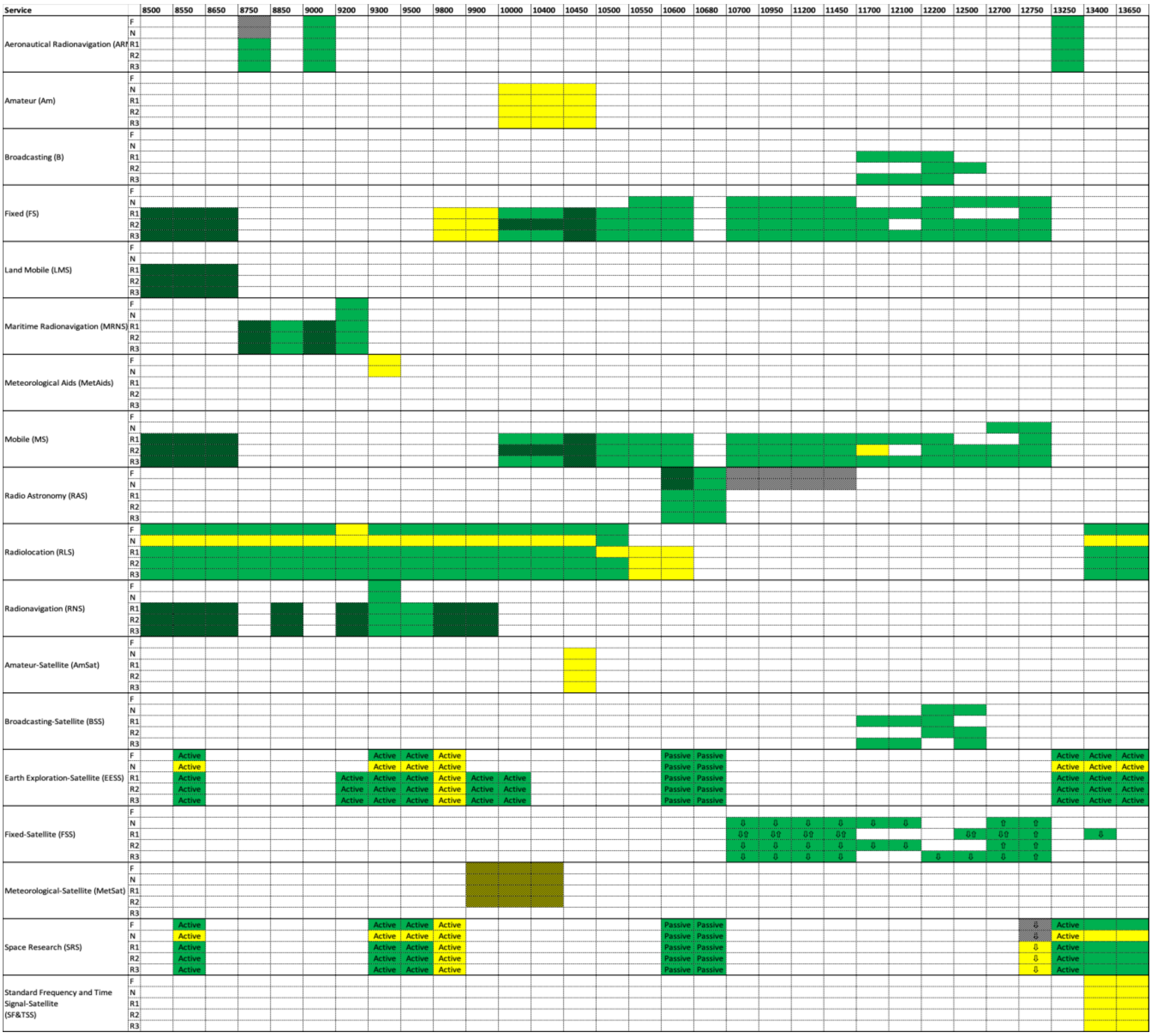


Figure 3: 8.5 - 13.75 GHz spectrum allocations

Current use in this band includes federal and non-federal allocations. RLS is allocated to much of the band as detailed in Figure 3. Other uses include EESS, SRS, RNS, MetAids and MetSat. A part of this band is used by the federal agencies for radar systems, including meteorological and airborne navigation. Federal agencies use the 8.55 - 8.65 GHz band to map ocean currents in harbor areas. The National Aeronautics and Space Administration (NASA) operates active radars in the 8.55 - 8.65 GHz band to obtain multi-spectral images used in studying Earth sciences such as rain, ocean wave structure, and surface topology. NASA also operates the Goldstone, CA Solar System Radar in this, and other bands, to conduct research studies of planetary bodies, asteroids, and orbital debris.

The FAA uses the 9.0 - 9.2 GHz band for airport surface detection equipment (ASDE) radars to monitor aircraft and vehicles on the ground near airports for airport safety. The Coast Guard uses the 9.2 - 9.5 GHz band for maritime radionavigation radar systems to observe harbor and coastal traffic. The Coast Guard and other federal agencies use the 9.3 - 9.5 GHz band for shipboard radars for maritime radionavigation that can detect search and rescue transponders (SARTs) installed on large vessels to locate distressed vessels. Federal agencies operate meteorological radar systems in the 9.3 - 9.5 GHz band. NASA operates surveillance, navigation, and avian detection radars in the 9.3 - 9.5 GHz band.

NASA uses airborne radar in the 9.5 - 9.8 GHz band to research convective storms and mesoscale phenomena. NASA also uses the 9.5 - 9.8 GHz band for synthetic aperture radars on satellites for high precision active sensing of the Earth's surface topology.

The National Oceanographic and Atmospheric Administration (NOAA) uses the 9.8 - 10 GHz band for radar systems onboard meteorological satellites.

A part of this band is used for non-federal FS and FSS (DL) on a primary basis in 10.7 - 11.7 GHz. The 11.7 - 12.2 GHz band is used for FSS (DL) as a primary service on a non-federal basis: this is the downlink that is paired with the uplink in the 14.0 - 14.5 GHz band. There are widely deployed earth stations and user devices (e.g., gateways, user terminals) for commercial FSS (and MSS systems that use these bands as well) to support broadband, as well as fixed and mobile satellites ; this includes deployment of user terminals and gateways, a variety of satellite services, such as direct to home satellite and broadband to users, enterprises and the government, including schools, hospitals and emergency response.

Civilian and federal agencies operate communications satellite earth stations for voice, data, and video signals using commercial GSO satellites. NOAA uses the 10.7 - 10.8 GHz band for passive (receive-only) sensing of the Earth from space using numerous sensing instruments such as radiometers, imagers, sounders, and temperature and water vapor profilers, etc.

Another part of this band is used by non-federal FS and FSS (DL) and MS on a primary basis between 12.7 - 13.25 GHz. From an international perspective, the 12.7 - 12.75 GHz is allocated for FS, Mobile except aeronautical mobile, and FSS (UL) in Region 2 (the Americas). From 12.75 - 13.25 GHz, the band is also allocated for FS, Mobile except aeronautical mobile, FSS (UL) in Region 2 and SRS (deep space, DL). The National Science Foundation (NSF) uses this band for radio astronomy research of various spectral-lines, including quasars and a spectral line of formaldehyde.

In the 13.25 - 13.75 GHz band, federal agencies operate airborne Doppler navigation radars and shipborne radiolocation point defense weapon systems, including search radars, tracking radars, and missile and gun fire-control radars. NASA uses this band for active sensor systems used in joint programs with the French Centre National d'Etudes Spatiales (CNES) for space-based observations and measurements of surface topography, ocean winds and precipitation. In addition, NASA uses this band for space-based precipitation radars in the Tropical Rainfall Measurement Mission (TRMM), Global Precipitation Mission (GPM), and terrestrial precipitation radars. NASA also uses this band for spacecraft communications downlinks involving space research, tracking and data relay satellite systems (TDRSS) and to provide communications to spacecraft.

In Region 2, the 13.25 - 13.75 GHz band is used for EES (active), ARNS, and SRS on a primary basis.

NTIA's comment on the open 12 GHz proceeding, submitted on August 9, 2023, [8] provides additional detail on unclassified federal usage in 12.7 - 13.75 GHz in the U.S.

3.3. 13.75 - 17.1 GHz

Figure 4 shows the current allocations in the 13.75 - 17.1 GHz band, with the following characteristics:

- RLS, SRS, FS and MS are the largest allocations in this part of the spectrum.
- 200 MHz between 14.2 – 14.4 GHz is not allocated for federal use.

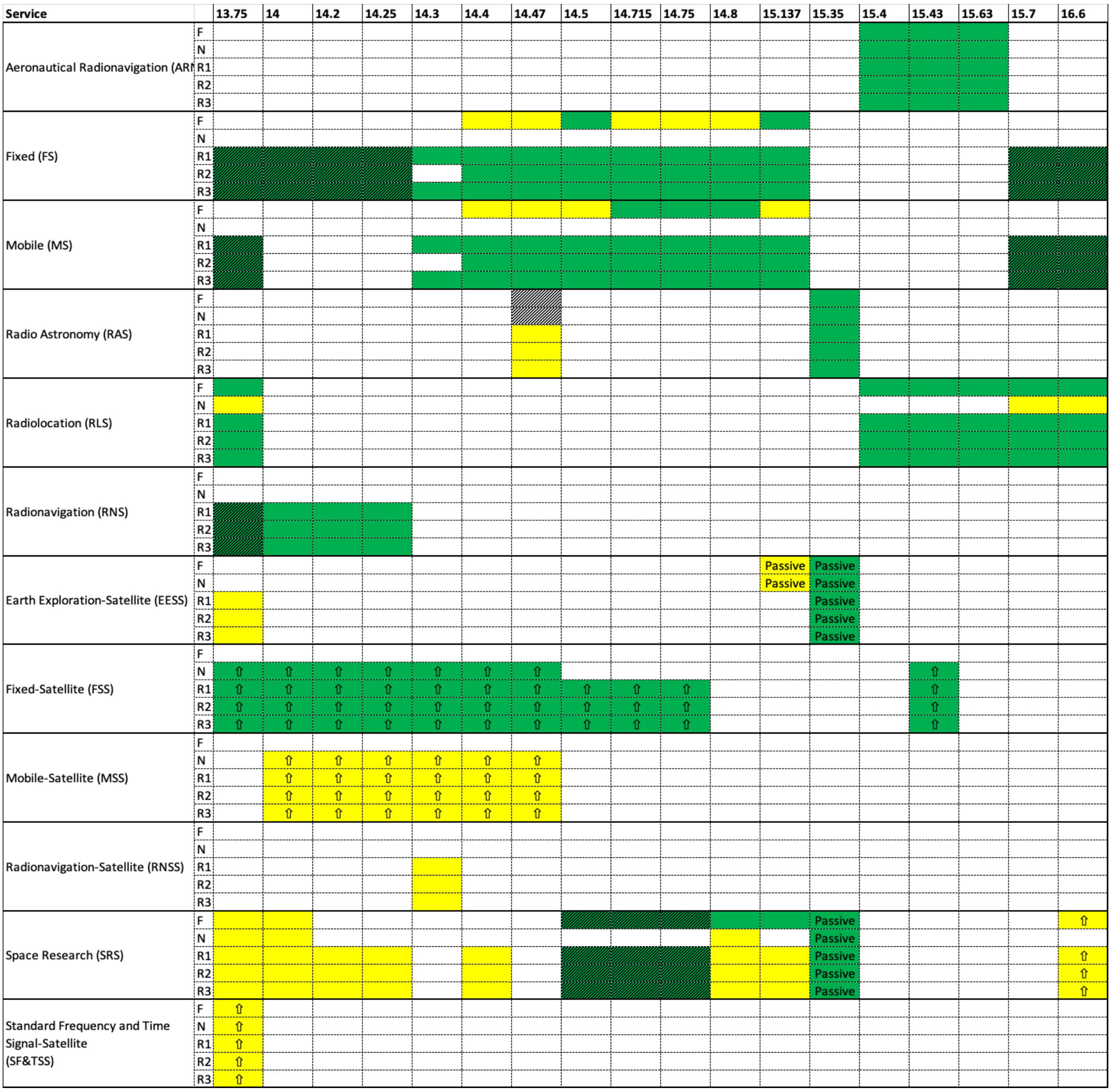


Figure 4: 13.75 - 17.1 GHz spectrum allocations

The 13.75 - 14.5 GHz part of the band is allocated to FSS (UL) on a co-primary basis for non-federal use. The 13.75 - 14 GHz band is allocated to RLS on a co-primary basis for federal use. In the 14.5 - 14.7145 GHz band the spectrum is allocated to FS on a primary basis and in 14.7145 - 14.8 GHz to MS on a primary basis for federal use. In the 14.8 - 15.35 GHz band the spectrum is allocated to MS and SRS on a primary basis for federal use.

Specific federal uses of the band include:

- In 13.75 - 14 GHz, federal agencies operate shipborne defense weapon systems, including search radars, tracking radars, and missile and gun fire-control radars on a co-primary basis. From a non-federal perspective this band is used by FSS (UL) on a co-primary basis and SRS and RLS on a secondary basis.

- NASA uses the 13.75 - 14.2 GHz band on a secondary basis for spacecraft communications downlinks involving space research, and parts of the 13.75 - 14.8 GHz band on a secondary basis for TDRSS, and the 14 - 14.2 GHz band on a secondary basis for satellite uplinks for the transmissions of meteorological information as part of the automated weather distribution system (SAWDS) through non-federal satellite systems.
- NSF uses 13.75 - 15 GHz for radio astronomy research into quasars and various spectral-lines.
- The band 13.75 - 14.5 GHz band is used on a primary basis for civilian and federal agencies satellite earth stations for voice, data, and video signals using commercial geostationary satellites as well as gateways for fixed and mobile satellite networks. This band is the uplink that is paired with the downlink in the 11.7 - 12.2 GHz band.
- Federal agencies use 14.4 - 14.5 GHz on a secondary basis and 14.5 - 15 GHz on a primary basis for fixed point-to-point microwave relay communications for voice, data, and video. Federal agencies use this band for airborne downlink data transmissions.
- NASA operates the Tropical Rainfall Measurement Mission precipitation radar in this band on a non-interference basis, as well as other terrestrial based precipitation radars.
- The federal agencies operate fixed, mobile, and maritime mobile air-to-air and air-to-ground data links in 14.5 - 14.7145 GHz on a secondary basis and 14.8 - 15.1365 GHz on a primary basis via a common data link. The transmissions are in both directions. NASA also uses the band for deep-space communications to and from planetary spacecraft conducting radio science experiments as well as exchanging some command and ranging data.

There are also widely deployed earth stations and user devices for commercial FSS to support broadband; this includes deployment of user terminals and gateways, a variety of satellite services, such as direct to home satellite and broadband to users, enterprises and the government, including schools, hospitals and emergency response.

3.4. 17.1 – 24 GHz

Figure 5 shows the current allocations in the 17.1 - 24 GHz band, with the following characteristics:

- 100 MHz spectrum in 17.7 – 17.8 GHz is not allocated for federal use.
- 2,200 MHz of spectrum in 17.8 – 18.6 GHz and 18.8 – 20.2 GHz may be practical for coexistence if used for earth stations rather than user devices. However, there are widely deployed earth stations and user devices for commercial FSS to support broadband; this includes deployment of

user terminals and gateways, a variety of satellite services, such as direct to home satellite and broadband to users, mobility service on airplanes, maritime, enterprises and the government, including schools, hospitals and emergency response.

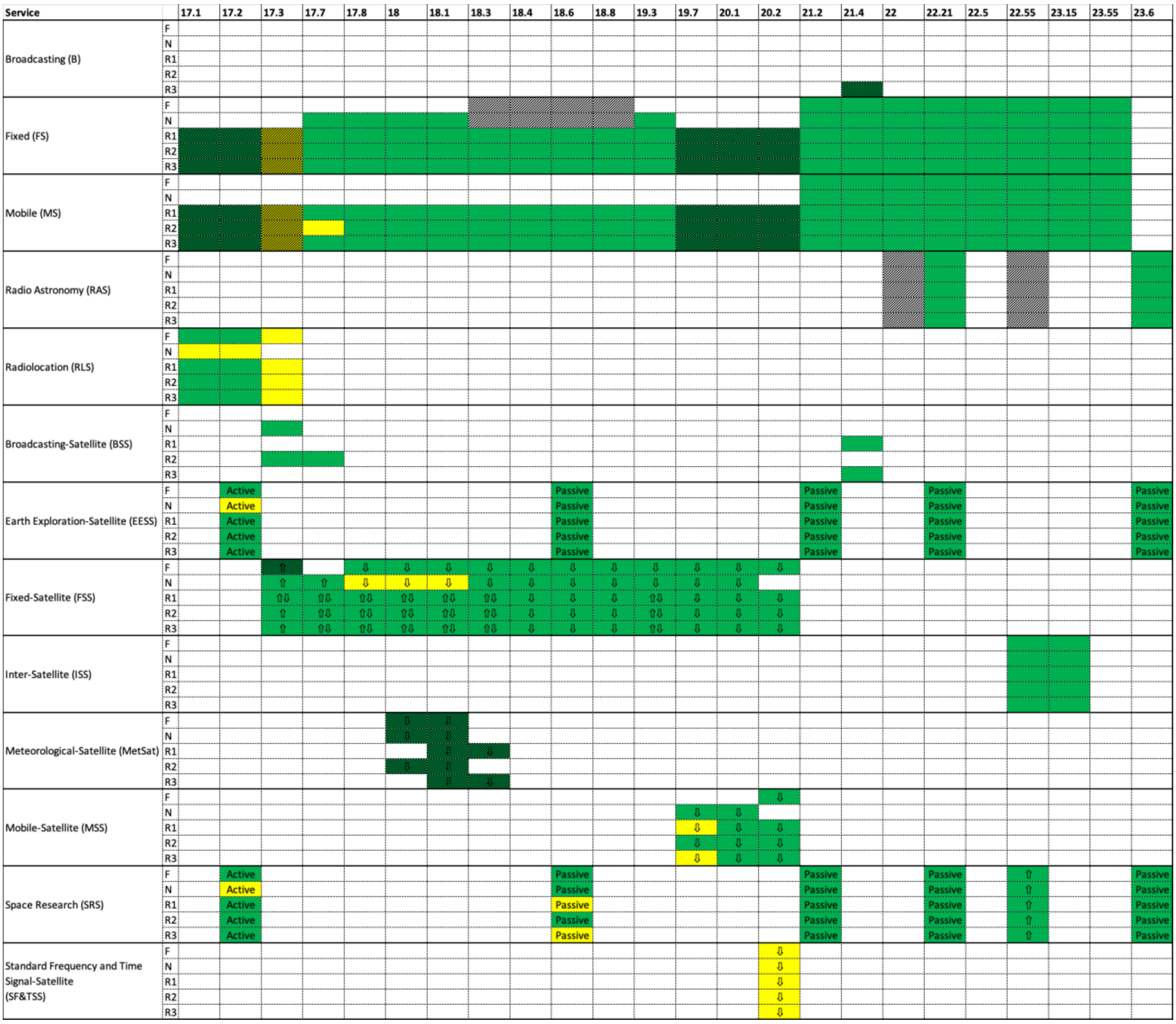


Figure 5: 17.1 - 24 GHz spectrum allocation

Below are some further insights into the usage of this band:

- The 17.7 - 18.3 GHz and 19.3 - 19.7 GHz bands are allocated to non-Federal FS on a primary basis.
- The 17.7 - 17.8 GHz and 18.3 - 19.7 GHz bands are allocated to non-federal FSS (DL) on a primary basis, non-federal FSS (DL) is allocated on a secondary basis in 17.8 - 18.3 GHz. Federal FSS (DL) is allocated 17.8 - 19.7 GHz on a primary basis.
- The 18.6 - 18.8 GHz band is allocated to both federal and non-federal use for EES (passive), and SRS (passive).
- The 17.7 - 19.7 GHz band is allocated to MS in Regions 1 and 3 (Asia-Pacific and Europe) on a primary basis; in Region 2 the mobile allocation is on a primary basis except for 17.7 - 17.8 GHz in which it is secondary.
- The 17.7 - 19.7 GHz band is allocated on a primary basis to the FS and FSS (DL) on a primary basis in all regions.
- The 17.7 - 17.8 GHz band is allocated on a primary basis to the Broadcasting-Satellite Service in Region 2.

- The 18.6 - 18.8 GHz band is allocated on a primary basis to EES (passive) in all regions. SRS (passive) is primary in Region 2 and secondary in Regions 1 and 3.
- The 17.8 - 19.7 GHz band is used by NSF for radio astronomy research of various spectral lines and continuum measurements. The federal agencies use this band as a downlink for some satellite networks.
- The 18.6 - 18.8 GHz band is used by NASA for passive sensing of the Earth from space using microwave radiometers to obtain data on rain rates, sea state, sea ice, water vapor, ocean wind speed, soil emissivity and humidity.

3.5. Additional details of satellite use in 7.125 - 24 GHz

Many of the bands discussed above have incumbent commercial satellite services as listed below:

- 10.7 - 11.7 GHz: FSS (DL) co-primary with FS. NGSO is secondary to GSO and all of it has coordination requirements for NGSOs and GSOs.
- 11.7 – 12.2 GHz: In ITU Region 2 (which includes the US), this is also used for BSS. In Region 2 this is allocated for FSS (DL). There are strict rules on terrestrial use in the ITU Radio Regulations. It has coordination requirements for NGSOs and GSOs; NGSOs are secondary.
- 12.2 - 12.7 GHz: BSS in Region 2. This is a complex band with FSS and BSS largely mixed. It has coordination requirements for NGSOs and GSOs; NGSOs are secondary.
- 12.7 - 13.25 GHz: FSS (UL) in Region 2.
- 13.75 - 14.8 GHz: Globally FSS (UL) primary; MSS (UL) secondary in the 14.14 - 14.5 GHz band. It has coordination requirements for NGSOs and GSOs; NGSOs secondary.
- 15.43 - 15.63 GHz: FSS (UL). Limited to MSS feeder links.
- 17.3 - 18.1 GHz: Globally FSS (UL) and in Region 2 the 17.3 - 17.8 GHz band is also BSS. A portion of this band is under consideration in Region 2 to allow FSS gateways and is available today in the U.S. in the 17.3-17.8 GHz band. There are limits on NGSO use too. Identified for high density FSS.
- 18.1 - 19.3 GHz: FSS (DL) globally. Some limits on NGSO use (protections for GSOs). Identified for High density FSS. 18.1 to 18.4 is limited to BSS feeder links.
- 19.3 - 19.7 GHz: FSS (DL and UL) globally. Coordination requirements on NSGOs. 19.3 - 19.6 GHz limited to MSS feeder links (though there have been waivers).
- 19.7 - 20.1 GHz: FSS globally. Identified for high density FSS (up to 20.2 GHz). This is also an ESIM (Earth Stations In Motion) band.
- 20.1 - 21.2 GHz: Globally FSS (DL) and MSS (DL) co-primary. No commercial satellites in 20.2 - 21.2 GHz. Coordination requirements for NGSOs
- 22.55 - 23.6 GHz: Global inter-satellite service

Some of these bands are highly congested today as there is widespread deployment of earth stations and user terminals for commercial broadcast, fixed and mobile satellite services. This congestion is expected to get more pronounced with growing demands for satellite services and the potential for non-terrestrial networks supported by 5G and 6G.

3.6. Information required about incumbents to facilitate sharing

As is clear from the above discussion, significant parts of the 7.125 - 24 GHz spectrum are already allocated to, and are being shared by, federal and non-federal FS, FSS, MSS, SRS RLS and RNS applications. To facilitate further sharing, in addition to incumbent service parameters such as transmitted power profile, system bandwidth and duty-cycles, it is necessary to know how widespread the **actual use** of these services is, either through measurements or improved data reporting, and what criteria should be used to assess suitability of spectrum sharing with new commercial communication services. In addition to co-channel protection criteria, attention must be paid to adjacent channel interference concerns as well. Other high-level information requirements are listed below:

- **Fixed and mobile services:** How widely is service in this frequency band used (e.g., number of links, geographical distribution etc.)? What are they used for (e.g., backhaul/transport, last mile connectivity, etc.)? Is it used for civil or military purposes? Are there future plans for adding new services or consolidating operations in another band?
- **Fixed-Satellite Services:** What are the operational characteristics (e.g. power, EIRP, bean-width, altitude)? What is the geographical coverage and are there adjacent country issues? Are the services direct to users or distributed via ground stations? How many subscribers and/or ground stations? Which part of the spectrum is for uplink vs. downlink?
- **Mobile-Satellite Services:** What is the geographical coverage? How many users? How much spectrum uplink vs. downlink?
- **Radiolocation Services:** Are these confined to limited geographies? Are these for military or civilian use? What are the protection criteria?
- **Radionavigation Services:** How much spectrum is truly used? What is the geographical coverage?
- **Space Research Services:** Where are the main sites located? What protection criteria need to be considered?
- **Tx/Rx characteristics of existing incumbent devices:** what is the state of technical capability of the incumbent systems and what would be the cost to upgrade?

3.7. Sharing Scenarios and Use Cases

The type of application that will be deployed in shared spectrum will also dictate which bands can be shared and under what conditions. Sharing is a “two-way street” - information about incumbents as well as knowledge of potential sharing scenarios/use cases is essential for making informed decisions. The following is a list of potential terrestrial use cases for sharing in the 7.125 - 24 GHz spectrum range, with no specific priority order.

- **Mobile broadband with licensed spectrum:** this is the traditional wide area commercial mobile service as it evolves from 5G to 5G-Advanced/6G in the foreseeable future.
- **Wireless broadband with unlicensed spectrum:** evolution of wireless local area networks, e.g., Wi-Fi, to deliver enhanced performance with Wi-Fi 7 and beyond.
- **Local licensing:** used by private entities/enterprises within a relatively small geographic area (e.g., campus, factories, warehouses, stadium, airports etc.)
- **Indoor use:** to be used only indoors, to minimize interference with outdoor incumbent deployments; low power in conjunction with building penetration loss will mitigate interference.
- **Low Power Wide Area Networks (LPWAN):** such as IoT/sensor networks where the systems and applications are designed such that wide area coverage isachieved without high power communication, which reduces interference to other services in the same or adjacent bands.
- **Geographic regional licensing**, covering areas larger than typically covered for local licensing.
- **Point-to-Point or Point-to-MultiPoint communication networks:** these services focus on directed communications so may not cause interference to other services so long as some geographical separation is maintained or directional transmission is employed.

4. International use of 7.125 - 24 GHz

In other countries around the world, there are both government and commercial applications in this spectrum band that are used quite extensively. Since non-terrestrial uses such as satellites are often global, globally harmonized spectrum should remain available for this use. In addition, there are emerging low-power applications that also need accommodation.

Below are summary descriptions of government/defense and commercial use of the spectrum ranges [9, 10, 11] Usages vary extensively across individual countries and the information below focuses on widespread allocations rather than details on each and every country.

4.1. Current government/defense use

X band (8 - 9 GHz) radars are widely used in civil and defense-related applications in a large number of countries, including members of NATO.

There are significant global investments in satellites yet to be launched. Given these satellites have a lifespan of 15+ years, these systems are expected to be in place well into the 2040s.

Information on actual use of these spectrum bands is hard to come by but insistence by certain administrations to protect these frequency ranges speaks volumes of the importance of these frequencies as perceived by corresponding countries.

Frequency range (GHz)	Status
7.1 – 8.5	“NATO Frequency” in Europe; primarily used for Fixed, Fixed Satellite and Mobile Satellite purposes and limited use of earth exploration (DL). The band is also widely used in Australia, Saudi Arabia, Brazil, China or India. On the other hand, there is less widespread use of this band in the UAE, Japan, South Korea and Latin America (except Brazil)
8.55 – 13.75	Land-based, naval and military radars in NATO countries in Europe (8.55 – 10.5 GHz, 13.4-14.0 GHz) and similar usage in some other countries. Commercial satellite services are widely deployed.
13.75 – 17.1	Fixed and Mobile use for 14.6 - 15.2 GHz; Radiolocation allocation for 15.7 - 17.7 GHz in NATO countries in Europe but the actual extent of usage is questionable.

17.1 - 24	15.7 – 17.7 GHz for radiolocation and 20.2 - 21.2 GHz for Fixed, Broadcast Satellite and Mobile Satellite Services (DL) in NATO countries in Europe.

4.2. Current non-government/non-defense uses

The government/defense community relies heavily on commercial satellite uses. Accordingly, it should be considered in any analyses that commercial satellites are used for both commercial and non-commercial uses, domestically as well as globally.

Fixed, Broadcast-Satellite, Fixed-Satellite and Mobile-Satellite services in the 7.125 - 24 GHz spectrum range are widely used in the world, using several parts of the spectrum.

There is well-established demand for GSO services and NGSO services for backhaul and access. Currently many direct-to-home satellite services use frequencies in this range, but there is fast-growing interest in direct-to-device services as well, such as Supplemental Coverage from Space (SCS) addressed in a recent FCC NPRM [12]. There is tremendous growth potential in these bands as high throughput GSO and NGSO satellite networks can bring broadband connectivity around the globe. In addition, there are mobile satellite uses and other non-terrestrial uses of these bands throughout the United States and globally.

Frequency range (GHz)	Status
7.1 – 8.5	Extensive use for Fixed and SRS Earth Stations, with the exception of the UAE, Japan, South Korea and Latin America (except Brazil).
8.55 – 13.75 GHz	WRC-23 Agenda item 1.2 will consider identification of the 10 - 10.5 GHz band for International Mobile Telecommunications (IMT) in countries in ITU Region 2, but the US and Canada have already indicated that they do not support identification of this for mobile use. Extensive use of 10.7 - 11.7 GHz for Fixed Satellite Service (FSS) downlink and Fixed Services (FS), especially in SE Asia and some MEA countries. Some major economies of the world (Brazil, Canada, China, India, South Korea, the UAE and Saudi Arabia) are using 11.7 - 12.75 GHz for broadcasting. The UK and India use 12.75 – 13.25 GHz extensively for FS but the band is not used heavily in other countries.
13.75 – 17.1 GHz	Most parts of this spectrum range are extensively used by a majority of countries for Fixed Services and radionavigation. 14 - 14.5 GHz is not widely used in France, the UK (where there is a radiolocation allocation, but no evidence of use), Brazil, Canada, Japan and South Korea.

17.1 - 24 GHz	Primary uses are FS, SRS for Earth Stations and limited radio astronomy. 21.4 - 22.1 GHz range is not widely used in Germany, Saudi Arabia, the UAE, Brazil, the USA, Australia, China, Japan and South Korea. 23.15 – 23.6 GHz range is not widely used in Saudi Arabia, the UAE, Brazil, the USA, Australia, China, Japan and South Korea. There is heavy commercial satellite broadband, as well is for mobile satellite use and broadcasting satellite service use in the 17.7 - 20.2 GHz bands.

4.3. UWB as an emerging unlicensed use case

An example of an emerging unlicensed use is ultra-wideband (UWB). UWB operates over 3.1 - 10.6 GHz and is most frequently found in 7.7 - 9.3 GHz bands. The CSMAC UWB subcommittee has produced a report on the use of UWB in the US [13].

UWB is a short-range radio communication technology that involves the spreading of radio-frequency energy over a very large frequency range (often >500 MHz). This technology has many areas of application, including radar imaging, precision location and tracking, and sensor data collection. UWB's greatest strengths are being able to produce high-resolution time of flight information with a low probability of interception while offering resilience to narrowband interference. With a low spectral density and offering the potential for improved security because it is more challenging to track or intercept when compared to narrowband communications solutions, the potential of UWB has been recognized, if not realized, for decades.

Factors behind a significant increase in the number of commercial examples of UWB are adoption for mobile phone applications, a demand for spatial awareness products, and successful commercial and industry standardization efforts such as 802.15.4 and FiRa Consortium.

Technical challenges include the following. First, the very short pulses in the range of 1 ns produce distorted pulse shapes. Receive power decreases quadratically with respect to frequency and receivers, even correlators or rakes, can only do so much with extremely broad signals under this condition. Second, channel estimation is necessary and can be complicated. Compromises in the channel estimation directly affect UWB performance. Third, high-frequency synchronization requires high-frequency analog-to-digital converters. Fourth, multiple access interference, on top of channel noise and narrowband interference, can seriously degrade low-powered UWB signal performance. Fifth is the fact that UWB is a low-power application.

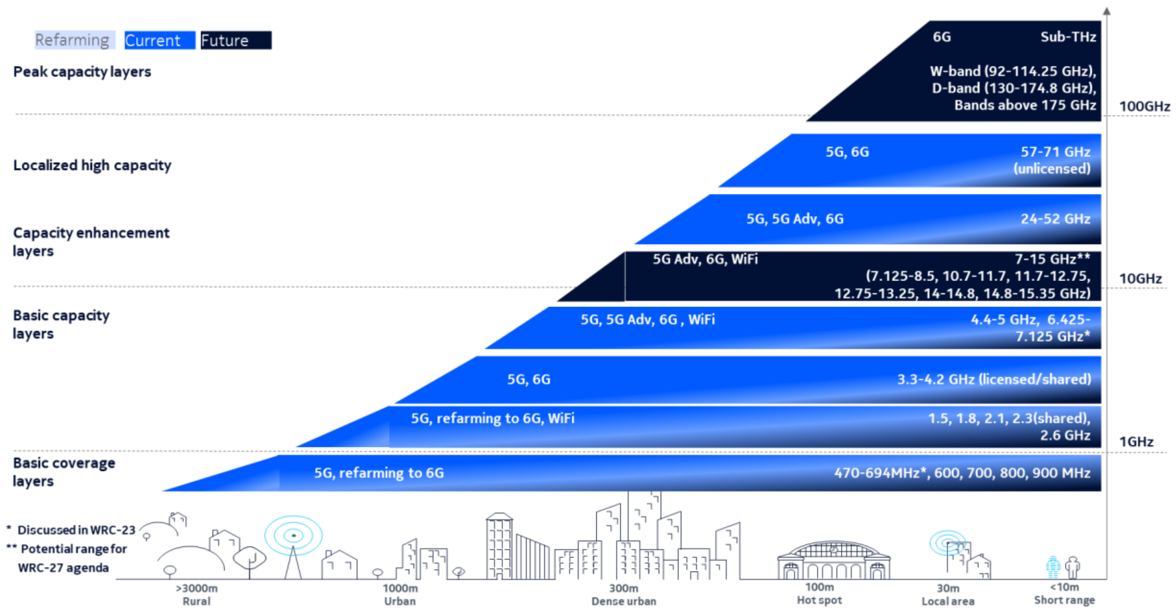
Successful UWB use cases are generally quite tolerant of high-power services. These high-power services are narrowband in comparison to UWB. UWB is inherently resistant to narrowband interference. However, when you stack narrowband interference on top of low power limits, add in multiple access interference from other UWB signals, and then account for channel noise, which may be high because of the difficulty of channel estimation for very wideband channels, then UWB services may be interrupted.

Examples of current products using UWB include the iPhone as of version 11, Google Pixel 6 Pro and 7 Pro, Samsung Galaxy SmarTag, Apple AirTag, and BMW Digital Key Plus. There are multiple announced products incorporating UWB. Some examples include Tile Ultra and Tesla Key Fob.

These successful UWB use cases are interruption tolerant. If a car key fob fails to unlock a car door due to interference, then failures may not even be noticed because many attempts to unlock are made in a single session. Successful UWB use cases often involve little or no state, such as reporting sensor readings. A stream of independent packets of sensor data or position information remains immensely useful even if some of the packets are lost. Reporting time of flight to other stations in a mesh network has a similar characteristic. Even if some reports are lost, the overall quality of the position location service remains high because outages to a resilient low-power technology like UWB can be tolerated.

There are proposed applications for UWB where interruptions are less tolerable or where state is required. For example, medical device networking, file sharing, vehicle-to-vehicle, and vehicle-to-everything have been proposed. These applications may require a watchdog timer function or error correction or error control in order to prevent long outages or erasures from doing any harm. Since UWB is an unlicensed communications technology, it does not receive any special treatment from the FCC.

5. Band preferences for terrestrial wireless communications services



So far in this document, current allocation of spectrum for different types of services has been presented. It is equally important to assess future usage of spectrum for various services that may drive the needs for sharing. In this section, spectrum needs of future terrestrial mobile wireless communication services – the most demanding application of recent years – is explored.

Wireless communication systems may be classified as terrestrial or non-terrestrial. The primary form of non-terrestrial wireless communication today is satellite communications and this topic will require further analysis. Terrestrial services may be delivered via licensed or unlicensed spectrum. While there are other forms of categorizations of these services (e.g., private wireless, Low Power Wide Area Networks, Personal and Body Area Networks etc.), the focus of this section will be the three above-mentioned ones which are most prevalent in the wireless communications industry.

The lower part of the 7.125 - 24 GHz spectrum is preferred for these services due to inherent propagation characteristics of this part of the spectrum. Specifically, the 7.125 - 15 GHz part of the spectrum is considered more desirable as the propagation characteristics in these bands are closer to those of spectrum currently deployed for wireless communication purposes in the majority of networks and reduces the costs associated with densification. Below is a closer look at some key aspects of this range and any further studies must also look at commercial non-terrestrial use of this spectrum:

- **7.125 - 8.5 GHz**: This range is of key interest for mobile services and interest in this range has been expressed by both the Wi-Fi industry and the commercial mobile industry. The Wi-Fi industry considers it important because it serves to augment the 5.975 - 7.125 GHz band with adequate spectrum to accommodate an integer number of 320 MHz channels in the 6GHz U-NII bands. The commercial mobile industry is interested in it because this range provides the best opportunity to satisfy coverage and capacity needs and augments the current spectrum in 3.7 – 3.98 GHz (exclusively licensed) and 3.45 – 3.55 GHz and 3.55 – 3.7 GHz (shared licensed).
- **8.5 – 10.6 GHz**: A significant part of this spectrum range is expected to see proliferation of low-power UWB applications. UWB devices operate on a non-interference basis and are not permitted to cause harmful interference to licensed services. Studies are needed to understand opportunities for other licensed or shared allocations in this range, especially associated with federal uses within. The 10.0 - 10.5 GHz portion of the band is also allocated to the Amateur Radio Service worldwide.
- **10.7 – 13.25 GHz**: This spectrum range has minimal federal allocations. There is significant use of commercial satellite communications in parts of this spectrum. Typically, mobile satellite systems and non-geostationary satellite services, in the downlink direction, pose challenges for shared operation of wide-area outdoor terrestrial wireless communication services. In general, co-primary sharing of terrestrial mobile services with satellite services operating in the uplink direction is possible, subject to the completion of sharing studies of typical city-scale networks. There are current proceedings exploring sharing in the 12.2 - 13.25 GHz portion of this band.

6. Mechanisms for spectrum sharing

There are many different approaches to spectrum sharing currently being used and many more are under exploration.

6.1. Fundamental sharing framework

Making efficient use of available spectrum is the responsibility of all users concerned – both incumbents as well as new entrants. Traditionally, the burden has been placed on new entrants to ensure incumbent operations are not impacted but in the larger interests of the nation, spectrum sharing responsibility should be borne by all stakeholders and balanced with the investments and innovations of incumbent users.

Success of spectrum sharing depends upon a few basic components:

- **New entrant capabilities**: Understand the interference mitigation capabilities; avoid causing harmful interference that degrades the performance of incumbents (as well as other potential new entrants) ; be resilient to acceptable levels of interference from other users of the spectrum.
- **Incumbent capabilities and limitations**: Understand the interference susceptibility of existing users; develop features to accept a certain level of interference from new entrants and capacity to minimize interference towards new entrants. Continuous technology upgrades to improve Tx/Rx performance and related spectrum utilization.
- **Frequency and time coordination capabilities**: Assess the needs of all users of a given spectrum band and enable situational awareness. All users may not need the entire spectrum range all the time.
- **Interference reporting mechanisms:** Ability for both incumbents and new entrants to report interference (beyond harm-claim thresholds) to aggressor so that aggressor systems can take appropriate actions.

The above capabilities are not mutually exclusive – they have to work in harmony with each other for the overall benefit of all stakeholders. Some of these capabilities may be in nascent research stages currently but careful nurturing is needed for long term success that will benefit the entire community of spectrum users.

An example of "new entrant capabilities" is a set of interference mitigation techniques often available in 5G radios (e.g., electronic tilt, beam steering etc.). An example of "incumbent capabilities" would be for a radar system to be able to perform radiolocation with reasonable accuracy, even in the presence of 5G signals. An example of "frequency coordination capabilities" would be to recognize the presence of a new user and adjust transmission characteristics to account for relative priorities when mitigating the effects .

Implementation of such a sharing framework requires the right set of policies and principles in place, a common repository of information that is essential for taking real-time action by any of the system components and a security infrastructure to protect critical infrastructure – whether governmental or civilian.

6.2. Current mechanisms and their possible extensions

Spectrum can be shared by several different means which generally depend on the circumstances of the band being shared and the systems and services that must coexist. Some of the mechanisms that have been used so far are described in this section. There is not a one-size-fits all approach when it comes to spectrum sharing.

The concept of spectrum sharing can range from very simple to very complex. On the simple end, for example, assigning different users to different channels within the same geographic area is a type of spectrum sharing. So is geographically distinct licensing, in which different users are assigned the same frequencies but in different, defined geographic areas. On the complex end, the same frequencies in the same geographic area can be shared directly, as in Code Division Multiple Access (CDMA), or on a dynamic basis (on a short timescale through tightly managed air interface techniques such as Time Division Multiple Access (TDMA), or on longer time scales such as in CBRS. Spectrum sharing can also be accomplished through coordination, where users work out among themselves who will use which frequencies at what locations, depending on calculations showing acceptably low risk of harmful interference. In modern cellular systems, spectrum is reused by combining information transmission over distinct or separable spatial modes, using dynamic channel characteristics as an opportunistic spreading code that can divide capacity between multiple link layers terminated at one or more users. Non-terrestrial networks, such as satellites, also rely on spectrum re-use to make the most efficient use of the spectrum they operate on. Many forms of spectrum sharing employ more than one of these techniques.

As spectrum bands become more crowded and sharing spectrum becomes more challenging, increasingly sophisticated methods to share have been developed. Fundamentally, all of them implement some form of sharing by geography and/or time, but accomplish this by various automated means. In general, the most common techniques used are:

1. White Space techniques such as TV White Space, automatic frequency coordination systems such as the 6 GHz U-NII-5 to U-NII-8 bands;
2. Authorized Shared Access techniques such as those used in CBRS;
3. Licensed Shared Access as in AWS3 and the 3.45 GHz band.

A brief description of the above examples follows.

6.2.1. TV White Space: VHF and UHF bands

Unlicensed devices sharing the television band with TV broadcast stations connect to a centralized cloud-based system, called a TV White Space database, to request a list of frequencies on which they can operate. The database contains information on TV stations in the area, and informs the device which frequencies are available that are not predicted to cause harmful interference to those stations. Generally, devices must check the database every 24 hours. TV stations are relatively static in nature, but other incumbent users which are not, such as wireless microphones, may reserve spectrum in the band on a temporary basis and the TVWS devices must protect them from interference.

6.2.2. CBRS: 3.55 - 3.7 GHz

CBRS shares its band with incumbent systems, notably DoD radar and a few fixed-satellite service earth stations. Devices (which are licensed) must connect to a centralized cloud-based Spectrum Access System (SAS) to find which frequencies are available in the area. Mobile devices known as CBRS devices (CBSDs) can access the spectrum in two tiers, a priority access licensing (PAL) tier that is licensed exclusively over a county, and a General Authorized Access (GAA) layer that can access spectrum on a licensed by rule basis and on non-interfering terms with the incumbents and PALs. The fixed-satellite service is essentially static in nature, while Naval activity in littoral waters and in ports is dynamic. A coastal sensor network senses dynamic radar activity and the SAS subsequently reconfigures devices in the area to avoid interference. The devices must check with a SAS every four minutes or less in case DoD activity starts occurring in their area. CBRS takes into account aggregate interference, so every SAS must be aware of all devices authorized by it and every other SAS to perform the aggregation calculation, which can be quite complex and is subject to an offline validation process that is carried out overnight.

6.2.3. 6 GHz Automated Frequency Coordination (AFC) System: 5.925 - 7.125 GHz

Standard-power unlicensed devices in the 6 GHz band share spectrum with a large number of fixed point-to-point links. Similar to TVWS, such devices are required to perform automatic frequency coordination by synthesizing incumbent usage information from public database sources. Commercial realizations of Automated Frequency Coordination (AFC) systems are available that allow devices, on a daily basis, to determine which frequencies are available for use in their area. While new or temporary fixed service links may arise on occasion, the incumbent fixed-service operations are relatively static in a given area.

6.2.4. AMBIT band (3.45 GHz Service)

Licensed devices in this band share the spectrum with DoD radar. The spectrum blocks in this band were auctioned for exclusive use under terms that allow binary sharing between a commercial licensee and the radar facility. Certain areas of the country were designated by DoD as Cooperative Planning Areas (CPAs). These areas are those in which the DoD uses the band relatively intensively, and use of the band (for example, placement of full-power commercial flexible-use service base stations) by licensees within CPAs must be coordinated with DoD in advance. Some of the CPAs are also coincident with Periodic Use Areas (PUAs), in which occasional intensive use by DoD may occur. During such periodic use events, operations by 3.45 GHz licensees may be further curtailed within the PUA. The details of coordination, and the mechanism by which PUA activity is notified, are generally determined directly between the DoD and the licensee(s).

6.2.5. Advanced Wireless Services 3 (AWS-3)

The AWS frequency range spans 1695 - 2200 MHz and constitutes four segments of paired spectrum. Parts of this spectrum range are subject to sharing requirements. In the 1710 - 1755 MHz band, DoD will continue to operate systems at some locations indefinitely, while transitioning systems out of the band at other locations (see "NTIA transition information" for information from the NTIA on the transition status). Some of these systems are airborne. AWS-3 mobile broadband users in the band must coordinate with DoD over areas as large as 160 km in radius to avoid causing harmful interference.

The AWS-3 uplink band in 1695 - 1710 MHz is subject to sharing requirements with Geostationary Operational Environmental satellites (GOES) and Polar-Orbiting Environmental Satellites (POES) transmitting to earth stations in the 1675 - 1695 MHz and 1695 - 1710 MHz respectively.

6.2.6. 5 GHz Dynamic Frequency Selection (DFS)

Unlicensed devices in a portion of the 5 GHz band share the band with Terminal Doppler Weather Radar (TDWR) systems at various airports around the country. The radars are important as they detect wind shear in the vicinity of the airport. Unlicensed devices in this band are required to monitor the frequencies used by such radars, and avoid those frequencies if radar activity is detected. Before first transmitting, a device must listen for 60 seconds to detect any radar signal. They must continually listen for radar signals and if detected, they must stop transmitting or relocate to other frequency within 10 seconds of detection. The unlicensed devices are not connected to a centralized spectrum sharing system.

6.2.7. Summary

The following table summarizes the key characteristics of the various spectrum sharing mechanisms that are currently in use.

Sharing Situation	Share by Geographic Separation	Share by Time Separation	Centralized/ Database Managed	Aggregate Interference	Incumbent Sensing	Note
TV White Space	X		X			
CBRS	X	X	X	X	X	
6 GHz AFC	X		X			
AMBIT (3.45 GHz Service)	X	X		X		Operators coordinate directly with DoD
AWS						Operators coordinate directly with government
5 GHz DFS	X				X	

Table 1: Spectrum sharing characteristics

6.3. Incumbent Responsibilities

Sharing is often employed for the overall benefit of society. Therefore, while shared spectrum often involves a secondary user that shares spectrum on a non-interference basis with an incumbent primary user, this usually does not mean that the incumbent has no responsibility for helping to ensure success of the shared spectrum environment.

Generally speaking, an incumbent may be reasonably expected to:

- Coordinate with the secondary users in a fair and reasonable manner to help maximize shared use while reducing the risk of harmful interference to the incumbent.
- Provide feedback to the secondary users on the interference environment encountered in practice.
- Revisit technical assumptions as the sharing environment evolves to either implement more conservative sharing assumptions if harmful interference is shown to occur in practice, or conversely, move to more liberal assumptions if harmful interference rarely or never occurs.
- In an informing incumbent environment, avoid reserving spectrum resources when not needed, and relinquish resources expeditiously when no longer needed. For example, minimize reservations in geography, frequency, and time to only those that are truly needed to meet mission objectives.

6.4. New Sharing Frameworks

The shared spectrum frameworks that have been adopted so far typically have relatively slow time scales for reaction to new users or new incumbents. For example, in CBRS, a new user may wait as long as 24 hours to get a grant at full power, as the proposed activities have to be aggregated with all other users in the area to predict aggregate interference, and data about other users is only shared nightly among the SASs that manage CBRS spectrum. In 6 GHz AFC, unlicensed devices only check in once per day, so that any new incumbent users that begin operating may have to wait up to 24 hours for full interference protection.

6.4.1. Dynamic sharing using active antennas

Future shared spectrum frameworks may be able to reduce the timescales over which interference management is implemented. For example, active antennas and related technologies, such as beamforming and massive MIMO, can be used to transmit signals in directions that are desired, while reducing emissions in other directions, such as towards incumbents. The current timescale for beamforming can be well below milliseconds, so interference management could in theory be pushed down to similar timescales. The challenge, however, is that if spectrum sharing is centralized, such as through a SAS or AFC system, the centralized systems must communicate with devices under their management on timescales as fast as the technology such as beamforming requires. In the current frameworks that require https connections to and from the centralized management structure be used, it is currently impossible to support active management on sub-second timescales, or likely anything close to it, at scale (if at all). Therefore, employing new and highly dynamic technologies such as beamforming will likely require decentralized (i.e., edge or embedded) control of spectrum sharing.

6.4.2. Multi-Tiered Access

Most spectrum sharing frameworks adopted so far offer two-tiered access, in which the incumbent (the top tier) shares spectrum with an underlay service (the second tier). The second tier operates on a non-interference basis with the top tier.

CBRS is the first framework to employ three tiers. The top tier is again the incumbent, and the underlay services are split into two additional tiers. The PAL Tier 2, is licensed exclusively via auctions for a portion of spectrum in a county-wide license area. When a PAL licensee deploys one or more base stations (CBSDs) in its license area, the operations of those specific base stations are protected by the SAS from aggregate co-channel interference caused by all other co-channel CBRS users. The SAS also ensures that PALs do not cause interference to incumbents. The third and lowest tier user belongs to the GAA tier. GAA use in the same spectrum is allowed, subject to a protection criterion in favor of the PAL deployments in that county. GAA users do not pay for a license, but cannot cause excessive aggregate interference to PALs or incumbents. There is currently no active coexistence management among GAA users in CBRS.

A unique aspect of CBRS is that PALs are not granted geographically exclusive use of their spectrum in their license area. Instead, the service areas of their operating CBSDs are protected, but outside of these service areas (but still within the county), the GAA tier is free to use the PAL's spectrum.

The three-tier model has some appealing features. For example, more spectrum is available for GAA than would be if PALs were granted geographically exclusive use, since PALs may not deploy in every part of their license area. This also prevents spectrum warehousing, where a PAL purchases spectrum but does not use it, and thus keeps others from using it. PAL licensees are allowed to lease their licenses to third-parties, thus retaining the economic utility of their license beyond their own deployment areas.

The three-tiered model has not yet been adopted again after CBRS, but limited comparable shared spectrum has become available. The adjacent 3.45 - 3.55 GHz band was auctioned for two-tier access, in which the incumbent is free to operate outside of certain zones (Cooperative Planning Areas and Periodic Use Areas) but must coordinate with the incumbent (the U.S. DoD) for operations within those zones. This multi-tiered approach drives the potential for greater utilization of spectrum.

It is not yet known under what model any or all of the 3.1 - 3.45 GHz band will be shared, if it is shared at all.

6.4.3. Hybrid sharing

Ofcom in the UK is exploring hybrid sharing [14] where the upper 6 GHz spectrum (6.4 – 7.1 GHz) may be shared between incumbents, licensed and unlicensed users either on an outdoor-indoor basis or on urban-rural basis. The challenge is the uncertainty in boundary conditions as well as which service would have priority in a geographic area as both licensed and unlicensed use is needed. For example, if the mobile signal penetrates indoors through windows, would that cause interference to Wi-Fi? The practicality of such a sharing solution is still under investigation. Such hybrid sharing schemes may have applicability in bands in the 7.125 - 24 GHz spectrum range where the protection requirements of incumbents and service needs of new entrants can be met due to the propagation and operational characteristics.

7. Incumbent services and steps to identify new bands for sharing

7.1. Incumbent services and their characteristics

Spectrum sharing opportunities with incumbent services depend upon multiple fundamental criteria (and combinations thereof):

- Whether the services are ubiquitous or limited in geography.
- Whether the services are intermittent or continuous, including the level of susceptibility to interference from other users of the spectrum; (this may include an analysis of impact to operations of any class of users from interference).
- Whether the services always need the entire spectrum range.
- National security considerations, including the level of transparency possible between concurrent or shared uses of the spectrum.
- Technology/service sunset/evolution, including repacking possibilities and incentive mechanisms to enable transition of obsolete equipment towards a more efficient utilization of spectrum. Continuous technology upgrades by incumbents to maximize spectrum utility should be encouraged.

Additionally, specific technical criteria for each service (e.g., transmit power, receiver sensitivity, antenna characteristics etc.) will need to be considered for spectrum sharing conditions. As a matter of guideline, spectrum sharing between terrestrial wireless communications and other incumbent services are highly challenging for services that cover wide contiguous geographical areas on a continuous basis (e.g., radio navigation, mobile satellite, fixed satellite direct to consumers, aeronautical radio navigation etc.). On the other hand, services that do not cover large geographic areas on land (e.g., maritime radio navigation, inter-satellite communications etc.) are the easiest to share spectrum with. Passive services typically require a very high degree of protection to maintain sensor characteristics that depend on high receiver sensitivities. However, many passive services do not require spectrum over large periods of time and may indeed only access spectrum at a specific location for a few seconds or minutes of use that are spread over the course of a day. Radio astronomy services are geographically fixed and need to be protected only within a coordination zone around the equipment facility.

Numerous studies have been conducted in standards bodies (e.g., 3GPP, ITU-R) to assess possible coexistence between commercial mobile and fixed services, fixed satellite services, space research, earth exploration, radio astronomy and radiolocation. Such analyses need to continue and expand as new bands in 7.125 - 24 GHz, with different incumbents and propagation characteristics, are considered for possible sharing.

Each service has its unique characteristics that require thorough investigation customized for specific spectrum bands. Some prior studies of interference susceptibility have been introspective and were based on conservative assumptions about what constitutes harmful interference. In the occasions where compatibility studies between services must be carried out, there is a need for data-aided approaches to consensus building between stakeholders, with consideration of all the possible avenues for enabling high utilization of spectrum. Future approaches may benefit from the introduction of statistical risk-informed analysis of interference susceptibility as well as from systems that can provide feedback to sharing participants about the impact on critical operations in a co-channel or adjacent channel situation.

The ability to share spectrum is greatly improved when sharing methodologies are capable of mitigating the effects of harmful interference. Very often, this will mean understanding current allocations, the extent to which those allocations are utilized on a geographical coverage basis as well as time of use, and the best-known characteristics of equipment and corresponding propagation characteristics. Very often, operational conditions can vary due to a number of factors that include environmental characteristics, mobility, seasonal variations, e.g., loss of leaf cover in foliage during winter, atmospheric effects like fog and refractive effects across atmospheric layers etc. In some services, use cases can require high availability, as in the case of critical microwave links associated with safety of life or carrier grade backbones serving remote areas. Prior interference studies have typically tended to treat a specific incumbent service uniformly by according a high barrier to entry for sharing.

Sometimes, mitigation techniques are as simple as retrofitting legacy equipment with better selectivity in their receiver front ends, while in others, it may be the introduction of spatial diversity or advanced digital signal processing. Some services, especially those that are employed for sensitive scenarios such as for national security or safety-critical applications, including radiolocation, radionavigation, some aeronautical applications etc., may not however be able to offer transparency in the feedback for timely control of spectrum availability. An inability to communicate incumbent activity can sometimes be alleviated by means of sensors if the operation of sensors is not subject to the creation of whisper zones that prevent the deployment of the very systems those sensors are trying to enable.

Many commercial services depend on a level of flexibility in being able to use the spectrum across a variety of geographies and it is important to consider how the technical parameters of a spectrum band impact the diversity of users and use cases that are developing to support innovative and advanced needs of consumers and businesses. Traditional commercial cellular technologies have successfully used bands where there are no strict restrictions on the power levels used for wide area coverage, while still having the ability to lower power for smaller cell geographies in densely populated areas. Spectrum sharing approaches must consider the mode of sharing that is most suitable for the commercial user and how different power levels impact the diverse and growing commercial uses. As ubiquitous mobile coverage has been achieved, other commercial needs are becoming more prominent, including capacity augmentation where data consumption is highest. A reduction or variability in power levels can be conducive to meeting emergent commercial needs, and increases compatibility of commercial services with existing uses in a shared spectrum environment. Lower power levels may be useful to better support spectrum re-use in localized areas, providing greater spectrum efficiency and allowing more operators to provide a diversity of new use cases. In general, business models and economic considerations demand a certain scale for solutions. Lower power levels are undesirable for wide-area coverage. Dynamic changes in spectrum allocation reduce dependability of the spectrum. Inflexibility in providing diverse types of radio equipment will limit the scale in the market. High availability of capacity is a goal for many enterprise/vertical or non-public users as is autonomy of network operations.

7.2. Potential new bands for sharing

There are several factors that need to be considered in the process of identification of bands that may be suitable for sharing between incumbent services and wireless communications:

- Band characteristics (lower vs. upper part of the 7.125 - 24 GHz band): the lower part, 7.125 - 15 GHz, is more desirable for wireless communications.

- Amount of spectrum likely available: while carrier aggregation across the entire spectrum band is theoretically possible, it increases complexity and cost, especially impacting user equipment.
- Incumbents in potential wireless communications deployment bands and adjacent bands:
  - Current and future spatial, directional (UL/DL) and temporal usage.
  - Corresponding power levels, in-band and out-of-band emission regulations and protection requirements.
- Special protection requirements of certain incumbent services, e.g., passive services, special federal operations, etc.
- Lead time for any clearance requirements: some services may require a long time to migrate to another frequency range.
- Usage by neighboring countries: important for coordination at borders.
- Global harmonization: important for economies of scale

The very first criterion for identifying new bands for commercial wireless communications is to detect a part of the spectrum that is currently least used and where there is no planned large-scale use in the future. This turns out to be an extremely challenging exercise as there appears to be no common repository of spectrum usage for federal applications. Per FCC's spectrum allocation table, different federal agencies are primary users of many of the 7.125 - 24 GHz spectrum bands. These agencies may maintain disparate databases of their own spectrum usage, but it is virtually impossible to obtain a full picture of actual spectrum usage vis-à-vis spectrum allocation. Other parts of the range are typically used by commercial entities for fixed, fixed satellite, broadcast or mobile satellite services.

To determine which part of the spectrum is lightly used, there needs to be an analysis of both federal and commercial use. This analysis must also include planned uses of the bands, as some bands, such as the 17 - 24 GHz band, are seeing dramatic increase by incumbents as user demands increase and new systems are deployed.

Once a sizable part (e.g., 500 MHz or more) of spectrum has been identified as "lightly used", the next step would be to analyze the current primary/secondary services in that band as well as services in adjacent bands to assess suitability of spectrum sharing. As recent experiences with radio altimeters show, services in bands that are significantly away from the bands targeted for new usage can sometimes be impacted unexpectedly and a very careful evaluation is necessary.

The final step in the process is to match potential spectrum for wireless communications use with the needs of commercial services and applications.

8. Recommendations

The TAC Advanced Spectrum Spectrum Sharing Workgroup makes recommendations in the following four categories:

8.1. Required data

Various types of data are necessary to make spectrum sharing a successful effort:

- FCC and NTIA should work together to perform a detailed quantitative assessment for 7.125 - 24 GHz that is similar to the one that was done in 2016 for select bands up to 3.5 GHz [15]. A more recent example of such data is included in NTIA's comments on 12 GHz [8], which provides details of unclassified federal usage in 12.7 - 13.25 GHz.

- Public information about actual spectrum usage (not just allocations) should be collected in an online website, e.g., 'Spectrum Wiki" which should be kept updated.
- Information on spectrum occupancy for federal users similar to what is being requested by the FCC for non-federal users [16]: a process by which classified information can be shared may be necessary to implement this. Non-federal usage data should include both terrestrial and non-terrestrial usage.
- Additional data from past spectrum sharing techniques and lessons learned, e.g., building on NTIA's CBRS assessment with measurements [17].

8.2. Potential Shared Spectrum Bands

The working group's preliminary list of potential spectrum ranges suitable for sharing, based on the limited information available at this time are listed below.

- 7.125 – 8.5 GHz, for sharing with federal fixed, fixed satellite and mobile satellite services.
- 10.7 – 13.25 GHz for sharing with non-federal satellite (there is an NPRM on 12.7 – 13.25 GHz and FNPRM in 12.2 – 12.7 GHz).
- 14.0 - 14.2 GHz for sharing with space research.
- 17.8 – 18.6 GHz and 18.8 – 20.2 for sharing with federal satellite. Additional analyses need to be done with regard to commercial satellite use of this part of the spectrum.

All of the above frequency ranges will require extensive analysis to determine spectrum sharing methodology, new entrant applications and operational parameters that will protect co-channel and adjacent channel incumbents from harmful interference.

8.3. Spectrum Needs

Target amount of spectrum required for terrestrial wireless communications is approximately 2 GHz, preferably in the 7.125 - 15 GHz range. Potential ways that this need can be met:

- Contiguous spectrum that is partly exclusive for wireless communications and partly shared among wireless communications and other incumbent services.
- Non-contiguous spectrum that is partly exclusive for wireless communications and partly shared among wireless communications and other incumbent services.
- Contiguous spectrum that is fully shared among incumbents and wireless communications services.
- Non-contiguous spectrum that is fully shared among incumbents and wireless communications services.

It is anticipated that NTN applications and services may need over 10 GHz of spectrum in the wider range of 900 MHz - 80 GHz. However, analysis by ITU for WRC 27 does not show demand in the near future for new allocations for satellite services in the bands 7.125 - 24 GHz [18].

8.4. Future work

There are a significant number of activities that a future TAC may want to pursue as a follow-up to this effort:

- Assess spectrum needs of the country with a holistic view – scientific, federal and commercial, terrestrial and non-terrestrial, fixed and mobile.

- Evaluate emerging spectrum sharing techniques, for example, using active antenna arrays [15] in addition to evolving spectrum sharing techniques used in CBRS and AMBIT bands to move towards dynamic sharing amongst incumbent users and new entrants.
- Implement a specific project to investigate possible practical implementations of spectrum sharing techniques with collaboration between relevant federal and commercial entities, including sharing of real-time or near real-time data that may be necessary for such solutions. The required information will include current allocations, actual usage of spectrum, protection criteria for services in the band as well as for sensitive (e.g., passive, scientific or military) services in adjacent bands.
- Develop a real-time database to assess spectrum utilization with sensors and measurement entities; this database may be supplemented with crowdsourced data. This is required for federal and non-federal bands.

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