Feasibility study on existing spectrum sharing frameworks for temporary and flexible spectrum access

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TERMS, CONDITIONS & NOTICES

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Executive Summary

The present study addresses technical approaches for automated spectrum access to support dynamic, temporary, and flexible spectrum sharing. The applications and use cases described require a certain, typically high Quality of Service (QoS) but are often limited in range and differ in the duration of operation which can vary from short-term (e.g., some days to some weeks) to long-term (e.g., some weeks to some years). Some use cases allow for prior network planning, others require very short-term deployment without a prior planning phase.

To support the use cases described, the study shall evaluate:

- suitability of sharing frameworks for temporary and flexible spectrum access to support ad hoc and on-demand use cases,
- procedures and functionalities for automated spectrum negotiation, assignment, and application specific QoS guarantee,
- suitability for the support of scalable localized dedicated networks,
- suitability for the support of fixed, nomadic, or mobile deployments, and
- requirements, system architectures and high-level procedures for spectrum access for use cases described.

If required, this study proposes evolution and improvement of the existing technical approaches or develops new technical solutions for spectrum sharing.

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1 Audio Programme Making & Special Events (PMSE) Use Case and its requirements

This section's objective is to analyse the requirements and characteristics of selected sectors such as Culture and Creative Industry (audio PMSE), Public Protection & Disaster Relief (PPDR), e-Health, Industrial Automation, etc. Inputs were received only for the audio PMSE use case, which is covered in this section.

Programme Making and Special Events (PMSE) is a term summarizing front-end wireless applications used to support broadcasting, news gathering, audio and video production for film, theatre, music, education, houses of worship, and government, as well as special events such as sport events, culture events, conferences, and trade fairs.

PMSE equipment is divided into:

- video PMSE: wireless cameras,
- audio PMSE: wireless microphones, in-ear monitor systems (IEM), wireless conference systems, talkback, and
- remote control: wireless light and effect remote controls.

The individual user of audio PMSE equipment configures a system according to the requirements of the production i.e., number of performers or speakers, musical instruments, sound effects and location with careful consideration of the link budget. Available spectrum at a location has a major impact on the possible number of wireless microphones and IEMs. A lack of spectrum restricts the size and quality of the overall audio production. Further considerations are:

- the tuning ranges of the available equipment,
- co-located events at the location,
- other wireless equipment in use e.g., security, etc., and
- the total number of audio channels, which has to fit into a given amount of spectrum. Many manufacturers now offer modes which double or triple the channel count but this currently comes at a price of reduced coverage, robustness or audio performance, or a combination of these.

Usually, the use of audio PMSE frequencies in and around a location site is known. With these considerations and the observed use of radio spectrum the 'worst case' scenario of all equipment being in use can be assessed and calculated. This allows to establish a controlled interference scenario even in hotspot areas with dense audio PMSE use.

Audio PMSE equipment operates on a free tuning range concept. A tuning range is the frequency range in which equipment is able to operate. Within this tuning range, the use will be limited to the range of frequencies identified for audio PMSE nationally or geographically and the audio

PMSE equipment will be operated in accordance with the related national regulatory conditions and requirements.

Audio PMSE equipment's primary frequency band is 470 MHz to 694 MHz which is globally available.

Professional use of audio PMSE needs detailed frequency planning in advance to make spectrum sharing possible and to guarantee interference-free operation with the broadcast service which is the primary user in the 470 MHz to 694 MHz band. Spectrum that is useable for professional audio PMSE needs to be:

- observable, e.g., by spectrum scanning procedures or other information and
- predictable, e.g., stable in its operational times and frequency for the PMSE event time and location.

Table 1 : Summary of audio PMSE use cases

	Live Audio Production / Special Events		Electronic News Gathering
Deployment	Nomadic	Fixed	nomadic, mobile
Reliability requirements	Very high, no audible disturbance allowed	Very high, no audible disturbance allowed	High to very high
RAT	Proprietary	Proprietary	Proprietary
Harmonised standard	Yes	Yes	Yes
Location area	Localized, but worldwide use	Localized	Localized, but worldwide use
Period of spectrum use	Short-term to longer-term	Longer-term to long-term	Short-term
Spectrum planning	Planned prior to event	Planned	Ad hoc
Spectrum access	Shared	Shared	Shared
Spectrum bands	Low / mid band	Low / mid band	Low / mid band
Spectrum demand	Mid to high	Mid to high	Low
Spectrum occupancy of primary / other secondary users	Deterministic	Deterministic	Deterministic
Interval of spectrum access	Continuous	Continuous	Continuous

Degree of spectrum harmonization	Mid in TV UHF, low in all other ranges	Mid in TV UHF, low in all other ranges	Mid in TV UHF, low in all other ranges
License conditions (e.g., time to set up licenses, evacuation time, etc)	Varies by country; may include licensed and unlicensed access	Varies by country; may include licensed and unlicensed access	Varies by country; may include licensed and unlicensed access
Network infrastructure (non-public, public)	Non-public (stand-alone)	Non-public (stand-alone or public integrated)	Non-public (stand-alone or public integrated), Public
Willingness to pay for spectrum	High	High	Low

Mid-band spectrum from 470 MHz up to approximately 7 GHz is suitable for PMSE operation for the following reasons:

- Low ambient RF noise level
- High antenna efficiency for antennas used with small portable devices; e.g. wireless microphones and small body receivers
- Efficient propagation in both indoor and outdoor spaces over short distances
- Ability to pass through moderate amounts of clutter; e.g. stage equipment and scenery; without excessive losses

2 Existing frameworks for spectrum sharing

2.1 Licensed Shared Access / enhanced Licensed Shared Access

2.1.1. Licensed Shared Access (LSA)

Licensed Shared Access (LSA) offers a complementary spectrum management tool to the existing spectrum release mechanisms such as re-allocation and clearing. It fits under an individual licensing regime and aims to ensure a certain level of guarantee in terms of spectrum access and protection against harmful interference for both the incumbent and LSA licensees.

The first practical use cases for LSA aimed to provide access to additional spectrum within the 2.3 – 2.4 GHz band for mobile broadband services (MFCN) but has not been commercially deployed until now apart from the Netherlands which is the first and only European country to deploy a permanent LSA service based on ETSI specifications in the 2.3 -2.4 GHz band in 2019. Here, it does not enable the deployment of cellular services as secondary spectrum users but enables ENG teams using audio/video PMSE in the field to share the use of spectrum.

LSA focuses on nation-wide, long-term sharing arrangements between incumbents and LSA licensees. Within the national territory, the LSA system can establish the following different types of zones:

- exclusion zone: geographical area within which LSA licensees are not allowed to have active radio transmitters,
- protection zone: geographical area within which incumbent receivers will not be subject to harmful interference caused by LSA licensees' transmissions, and
- restriction zone: geographical area within which LSA licensees are allowed to operate radio transmitters, under certain restrictive conditions (e.g. maximum EIRP limits and/or constraints on antenna parameters).

Protection criteria and restrictive conditions are agreed between the LSA licensee/s and the incumbent under the oversight of the NRA. All zones are usually applicable for a defined frequency range and time period.

From a technological perspective, LSA is a centralized, coordinated approach to spectrum sharing which requires a central system element such as a database, that contains the operating parameters of the various systems (i.e., incumbents and LSA licensees), the environment, basic coexistence criteria, and a set of rules or models to apply these criteria to the various systems so that they can operate within acceptable levels of interference. The details of the sharing framework will be determined at national level and will depend on the particular use case. This case-by-case definition of the LSA sharing framework makes the LSA concept generally applicable to any target band, even though the technical specifications were originally defined for the specific 2.3-2.4 GHz band. For the 3600–3800 MHz range, ECC Report 254 [1] provides operational guidelines for national regulatory administrations (NRAs) on the implementation of LSA.

According to ETSI ([2] – [5]), a deployment of an LSA system requires the introduction of two architecture building blocks: the LSA repository (LR) and the LSA controller (LC). Figure 1 shows the LSA architecture reference model [2] with its interfaces. Only the LSA_1 interface and its corresponding interface functions were defined by ETSI.

<u>LSA repository (LR):</u> the LR supports the entry and storage of information describing incumbent's usage and protection requirements [3]. It can convey the related availability information to authorized LSA Controllers and is also able to receive and store acknowledgement information received from the LSA controllers. The LR also provides means for the NRA to monitor the operation of the LSA system [3], and to provide the LSA System with information on the sharing framework and the LSA licensees. The LR ensures that the LSA system operates in conformance with the sharing framework [6] and the licensing regime and may in addition realize any non-regulatory details of the sharing arrangement.

<u>LSA controller (LC)</u>: the LC is located within the LSA licensee's domain and enables the LSA licensee to obtain LSA spectrum resource availability information from the LR, and to provide acknowledgment information to the LR. The LC interacts with the licensee's MFCN in order to support the mapping of availability information into appropriate radio transmitter configurations and to receive the respective confirmations from the MFCN.

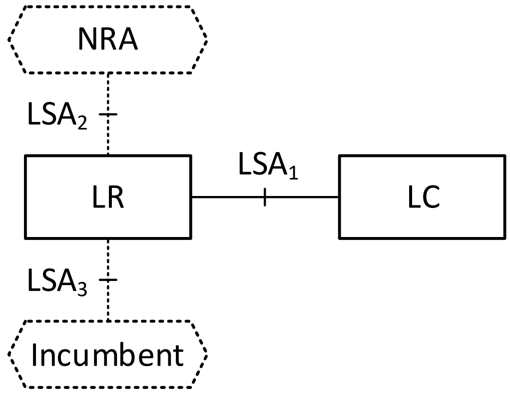

Figure 1: LSA architecture reference model [2]

Incumbent: the incumbent is the current holder of spectrum rights of use. He stores usage of his spectrum in the LSA system.

National regulatory administrations (NRA): the NRA defines and controls the application of the sharing framework.

The LSA_1 interface provides support for the exchange of LSA Spectrum Resource Availability Information and respective acknowledgement information between LR and LC, and for maintaining and recovering synchronization of such information between LR and LC.

Based on the ETSI standardization work for LSA in the 2.3-2.4 GHz band, 3GPP published several technical studies on LSA ([7] – [10]) which investigate the interoperation between the LSA system and 3GPP mobile network operators (MNOs). The solution envisages that the LC is located within the LSA licensee domain (i.e. within the mobile network operator domain). The LC interacts with the PLMN network management (NM) system to translate spectrum-resource-availability-information from the LSA system into appropriate radio transmitter configurations and receive the appropriate acknowledgements from the PLMN.

2.1.2. enhanced Licensed Shared Access (eLSA)

Enhanced Licensed Shared Access (eLSA) is the further development of LSA to support the concept of local high-quality wireless networks as described in [11]. This term is used to group together use cases that target local area services and require predictable levels of QoS, e.g. in vertical industrial sectors such as industrial automation, PMSE, PPDR and e-Health. Their need for predictable levels of QoS mostly precludes operation in a license-exempt spectrum, due to coexistence issues, and targets exclusively licensed spectrum.

According to [12], local high-quality wireless networks refer to MFCNs (Mobile/Fixed Communication Network) capable of supporting different use cases with following commons:

- their operation is confined in a local geographical area,
- have short-term to long-term deployments,

- need predictable levels of QoS, particularly in terms of deterministic communication behavior, reliability, and latency, etc.,
- network infrastructure and management with a suitable combination of private and public networks for implementing specific security standards or due to privacy reasons.

The main advantage of eLSA over LSA is that it aims to ensure a predictable level of QoS at a defined location for all spectrum resource users, i.e. LSA licensees and incumbents. The LSA framework was designed to share spectrum resources between incumbents and LSA licensees acting as MNOs. The eLSA framework supports vertical local area service providers as a new type of LSA licensees, requiring more dynamic spectrum for very short- to long-term spectrum sharing with a predictable level of QoS. Evolvement took place at
regulatory level:

- extension of the secondary licensing spectrum access approach in LSA to include two additional spectrum access methods: local area licensing and local area leasing,
- broadening the role of eLSA licensees beyond MNOs, including private network operators (vertical sector player (VSP) in terms of ETSI TC RRS), and
- simplifying the LSA license process.

technical level:

- establishing allowance zones, i.e. geographical areas within which an eLSA licensee is allowed to operate on its assigned spectrum resources for a certain period of time,
- supporting automatic and dynamic request/release of local spectrum resources, deployment durations may range from several hours to several years, and
- delivering deterministic and predictable channel allocation (e.g. fixed channel plans) to satisfy the stringent QoS requirements of local high-quality wireless networks.

The eLSA architecture reference model [13] is show in Figure 2. It is based on the architecture reference model for LSA defined in [2] and supports additionally the spectrum access schemes for local area licensing and the local area leasing. Reference points shown in dashed format indicate that the respective interfaces and corresponding interface functions are not defined.

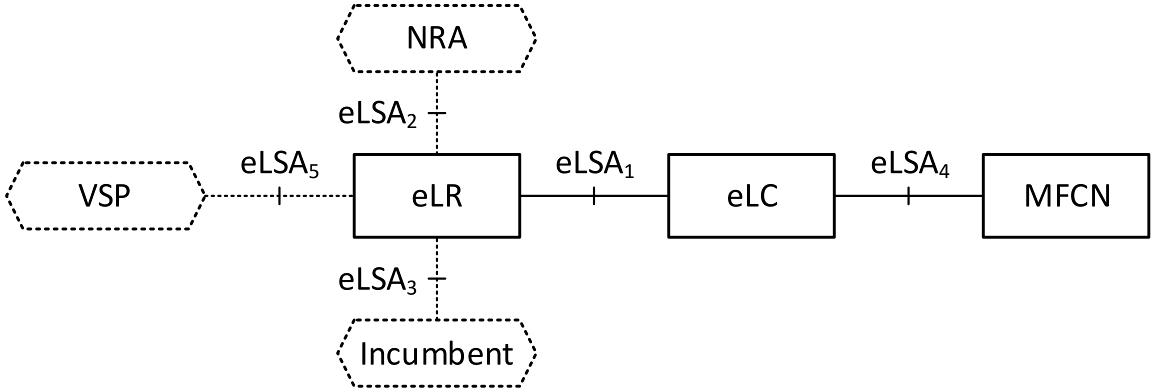

Figure 2: eLSA reference architecture model [13]

The logical elements of the eLSA architecture are the following:

eLSA Repository (eLR): The eLR supports the entry and storage of information describing the shared spectrum resources as well as incumbent's and VSP's usage and protection requirements. It is able to convey spectrum resource information including related availability information to eLSA controllers. The eLR also provides means for the NRA to monitor the operation of the eLSA system (see [1]) and to provide the eLSA system with information on local area licensing and local area leasing. The eLR ensures that the eLSA system operates in conformance with the sharing framework and the licensing regime and may in addition realize any non-regulatory details of the sharing arrangement.

eLSA Controller (eLC): The eLC is associated with the VSP's domain. The eLC enables the VSP to obtain eLSA spectrum resource and availability information from the eLR. The eLC interacts with the VSP's MFCN in order to support the mapping of spectrum resource and availability information into appropriate radio transmitter configurations and receive the respective confirmation from the MFCN.

The $eLSA_1$ interface provides support for the exchange of eLSA spectrum resource availability information and respective acknowledgement information between eLR and eLC, and for maintaining and recovering synchronization of such information between eLR and eLC. This interface is also designed to support operation in a detached mode, i. e. that the VSPs operate and control their MFCN without a permanent network connection to the eLSA system.

The $eLSA_4$ interface supports the exchange of appropriate radio transmitter configuration information between eLC and VSP’s MFCN. It can be temporarily disconnected.

LSA/eLSA represent a European generic technical platform able to supporting any national regulative framework, by adjusting the underlying spectrum-sharing framework. This means LSA/eLSA are not limited to any set of licensing rules or set of frequency bands.

2.2 Shared spectrum for Audio PMSE

There are different ways in which audio PMSE can be used:
- license exempt,
- licensed, shared, and non-coordinated, and
- licensed, shared, and coordinated

For example, in the United States, FCC Rules permit both licensed and unlicensed operation in the core 470-608 MHz band and some other bands including the 600 MHz duplex gap band. Unlicensed operation is limited to 50 mW EIRP in 470-608 MHz and 20 mW in the duplex gap and lower guard band, while licensed users may operate with up to 250 mW in 470-608 MHz and 20 mW in the duplex gap. Licensed operation is also permitted in certain other bands subject to additional conditions, including advance frequency coordination in certain cases.[1]

Table 2: Current Frequency Ranges Permitted for Wireless Microphones in the U.S.A.

Frequency Range	License Requirement	Notes
26.100-26.480 MHz	License Required (FCC Part 74)	Rarely used due to long wavelength
54.000-72.000 MHz	License Required (FCC Part 74) Unlicensed Operation (FCC Part 15 Subpart C)	Rarely used due to long wavelength
76.000-88.000 MHz	License Required (FCC Part 74) Unlicensed Operation (FCC Part 15 Subpart C)	Rarely used due to long wavelength
88.000-108.000 MHz	Unlicensed Operation (FCC Part 15 Subpart C)	Rarely used due to very limited power and interference
161.625-161.775 MHz	License Required (FCC Part 74)	(except in Puerto Rico or the U.S. Virgin Islands)
169.000-172.000 MHz	License Required (FCC Part 90)	Limited frequencies available
174.000-216.000 MHz	License Required (FCC Part 74) Unlicensed Operation (FCC Part 15 Subpart C)	Shared with VHF TV Broadcast
450.000-451.000 MHz	License Required (FCC Part 74)	Rarely used
455.000-456.000 MHz	License Required (FCC Part 74)	Rarely used
470.000-488.000 MHz	License Required (FCC Part 74)	Core PMSE band

[1] Licensed operation is covered under FCC Part 74 Subpart H rules. Technical requirements are found in section §74.861: Unlicensed operation is under FCC Part 15 Subpart C rules. Certain rules specific to radio microphones can be found in section FCC §15.236.

	Unlicensed Operation (FCC Part 15 Subpart C)	
488.000-494.000 MHz	License Required (FCC Part 74) Unlicensed Operation (FCC Part 15 Subpart C)	Core PMSE band (except in Hawaii)
494.000-608.000 MHz	License Required (FCC Part 74) Unlicensed Operation (FCC Part 15 Subpart C)	Core PMSE band
614.000-616.000 MHz	Unlicensed Operation (FCC Part 15 Subpart C)	Lower guard band
653.000-657.000 MHz	License Required (FCC Part 74)	Primarily Electronic News Gathering use
657.000-663.000 MHz	Unlicensed Operation (FCC Part 15 Subpart C)	Shared with White Space Devices
902.000-928.000 MHz	Unlicensed Operation (FCC Part 15 Subpart C)	Shared with ISM devices
941.500-944.000 MHz	License Required (FCC Part 74)	Subject to coordination
944.000-952.000 MHz	License Required (FCC Part 74)	Subject to coordination
952.850-956.250 MHz	License Required (FCC Part 74)	Subject to coordination
956.450-959.850 MHz	License Required (FCC Part 74)	Subject to coordination
1435.00-1525.00 MHz	License Required (FCC Part 74)	Subject to coordination
1920.000-1930.000 MHz	Unlicensed Operation (FCC Part 15 Subpart C)	DECT devices
5725.000-5850.000 MHz	Unlicensed Operation (FCC Part 15 Subpart C)	Shared with ISM devices; e.g. Wi-Fi
6875.00-6900.00 MHz	License Required (FCC Part 74)	Subject to coordination

7100.00-7125.00 MHz	License Required (FCC Part 74)	Subject to coordination

Other bands could be opened for PMSE in the future.

2.3 National local licensing and shared access licensing in Europe

In the UK, the British Broadcasting Corporation (BBC) and other entities have been trialing private 5G networks for media content production in the shared access 3.8-4.2 GHz band made available by UK regulator, Ofcom, "for people and businesses to access spectrum for a wide range of local wireless connectivity applications".[2] [3] Germany's regulator BNetzA has been awarding licenses for deploying private networks (called "campus or local networks" in Germany) using 3.7GHz-to-3.8GHz spectrum. BNetzA expects the band to be used mostly for Industry 4.0 applications.[4]

The European Commission Radio Spectrum Policy Group (RSPG) even recommended that its Member States investigate the possible use of the band 3.8-4.2 GHz for local vertical applications (i.e. low/medium power) and issued a mandate inviting the European regulatory body, CEPT, to "assess the technical feasibility of the shared use of the 3.8-4.2 GHz frequency band by terrestrial wireless broadband systems providing local-area network connectivity with focus on vertical users and other terrestrial wireless use cases and, on that basis, deliver harmonised technical conditions for the shared use of the band." [5] Therefore, there is the possibility that 400 MHz of spectrum in the 3.8-4.2 GHz band (compared to "only" 150 MHz in the CBRS band) will become available not just in the UK, but in all of Europe for local networks on a shared basis. Locally licensed spectrum is assigned on an exclusive basis in defined geographical regions. The assignment process is done via a manual process right now and regulators may move to an automated license assignment process in the future. UK Ofcom recently announced that they will do that.

2.4 Japan Local 5G Example

In its Radio Act of 2020, the Japanese Ministry of Internal Affairs and Communications (MIC) implemented a pioneering spectrum sharing approach in the 4.6-4.9 GHz and in the 28.2-28.3 and 28.3-29.1 GHz bands to allow multiple coexisting Private Local 5G implementations by enterprises, etc. in small geographically limited coverage areas such as a factories, campuses, and municipalities.

[2] https://www.svgeurope.org/blog/headlines/bbc-rd-strikes-two-firsts-in-5g-trial-at-commonwealth-games-2022/
[3] https://www.ofcom.org.uk/manage-your-licence/radiocommunication-licences/shared-access
[4] https://www.bundesnetzagentur.de/SharedDocs/Downloads/EN/Areas/Telecommunications/Companies/TelecomRegulation/FrequencyManagement/FrequencyAssignment/LocalBroadband3,7GHz.pdf?__blob=publicationFile&v=1
[5] https://digital-strategy.ec.europa.eu/en/library/radio-spectrum-cept-mandates

As of its 2020 Frequency Reorganization Action Plan, MIC has under various stages of study further geographic and dynamic spectrum sharing of the following bands: 1.2 GHz, 2.3 GHz, 2.6 GHz, 5.8 GHz, 5.9 GHz, 9 GHz, 26 GHz, 28 GHz, 38GHz, 40 GHz."

2.5 U.S. Citizens Broadband Radio Service

United States Federal Communications Commission (FCC) issued a Report and Order (R&O) [15], adopting rules for commercial use of 150 MHz of spectrum in the 3550-3700 MHz band (3.5 GHz Band). The R&O establishes a roadmap for making the whole 150 MHz available for commercial under the Citizen Broadband Radio Service (CBRS). The 3550-3650 MHz band segment is allocated for use by US Department of Defence (DoD) radar systems. In 2010, the National Telecommunications and Information Administration (NTIA) proposed making the band available for shared use with commercial systems though large exclusion zones to protect DoD radar systems. In 2015, however, NTIA recommended the reduction of the geographic area of the zones by approximately 77 percent, and by using sensor technologies they permitted commercial use inside the zones. FCC issued two further Amendments in 2016 (FCC 16-55 [16]), and 2018 (FCC 18-149 [17]) in FCC dockets GN 12-354 and GN 17-258. The CBRS-specific rules themselves are codified in Part 96 of Title 47 the U.S. Code of Federal Regulations [18].

CBRS uses a three-tiered sharing framework enabled by a Spectrum Access System (SAS), a centralized management system for spectrum that leverages sensor technologies. The DoD radar system along with FSS at 3625-3650 MHz, and, for a finite period, grandfathered terrestrial wireless operations in the 3650-3700 MHz portion compose the highest tier of the sharing framework entitled “Incumbent” users. The second and third tiers encompass commercial services and are titled Priority Access Licenses (PAL) and General Authorized Access (GAA), respectively. The incumbents must be protected from anybody else using the band. The SAS authorizes certain frequencies in any given location by the PAL or GAA. PALs are authorized to use a 10 MHz channel in a single county for ten years. PAL users must protect the incumbent system, and other PAL users, while being protected from General Access Authority (GAA) users. GAA users must protect both PAL and incumbent users but will receive no interference protection from other users in the band. Figure 3 depicts hierarchical structure of users in CBRS band. PAL users may be assigned in up to 70 MHz of the first 100 MHz portion of the band (3550-3650 MHz). However, the rule allows the GAA use over the entire 150 MHz band.

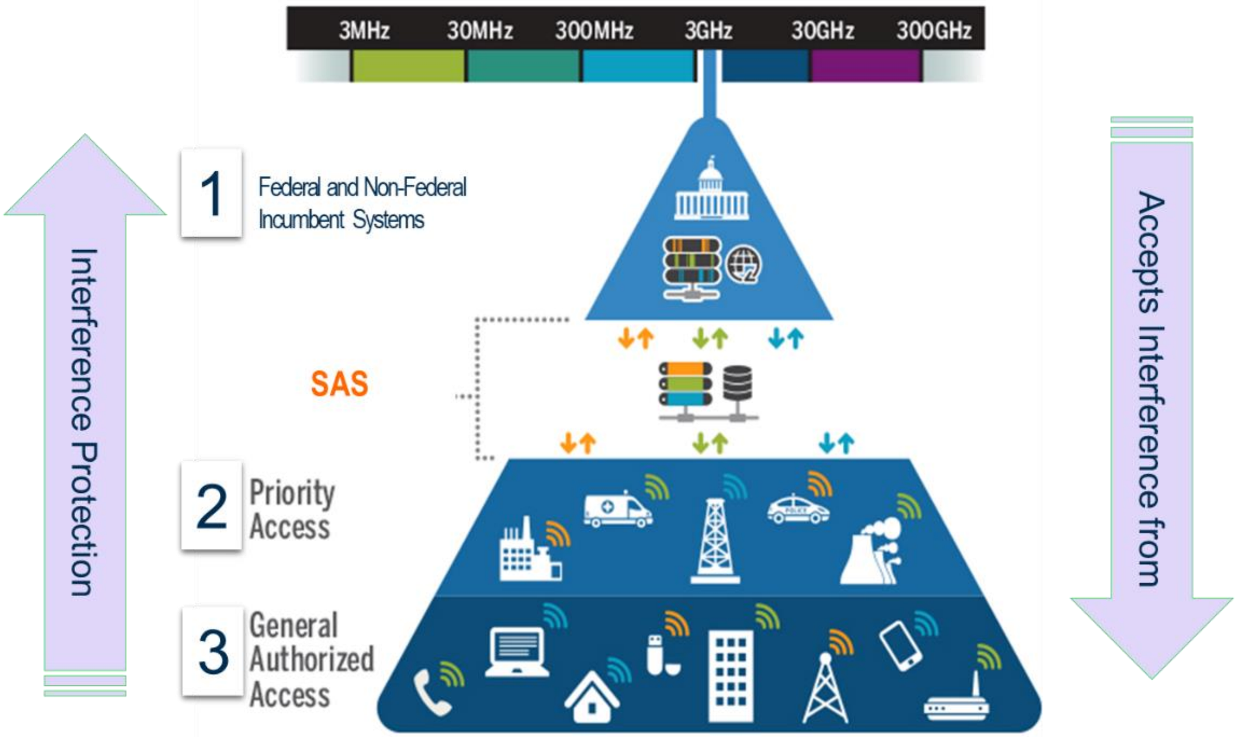

Figure 3: CBRS Hierarchical Architecture

2.5.1. SAS Functional Architecture and Protocols

Figure 4 depicts the SAS functional architecture. In this figure, any CBSD is using a standardized SAS-CBSD protocol to communicate its location, height, antenna characteristics, indoor/outdoor status, and other configuration parameters with its managing SAS, either directly or through a Domain Proxy (DP). A DP aggregates protocol messages from multiple CBSDs and exchanges them with the SAS on their behalf. Figure 5 summarizes the SAS-CBSD/DP protocol messages.

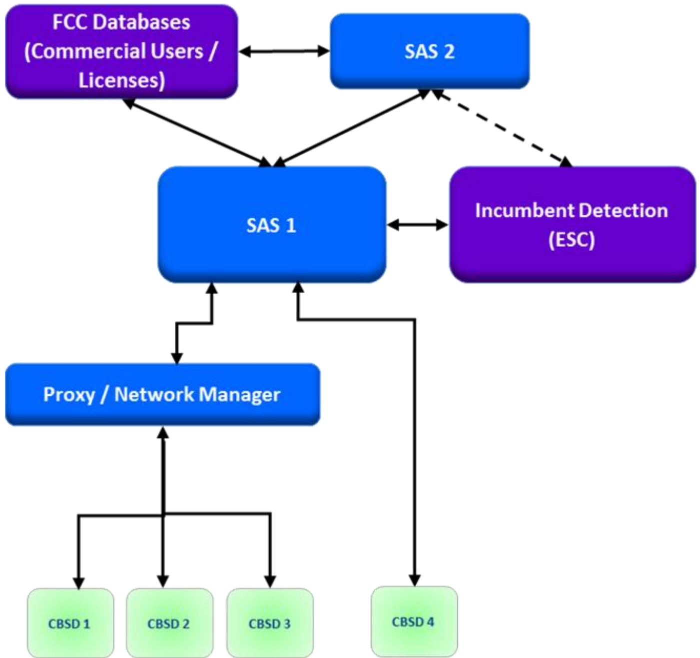

Figure 4: CBRS Functional Architecture

The SAS obtains incumbent information and their updates from multiple sources, such as FCC Universal Licensing System (ULS), FCC Equipment Authorization System (EAS), and NTIA database Keyhole Markup Language (KML) files.

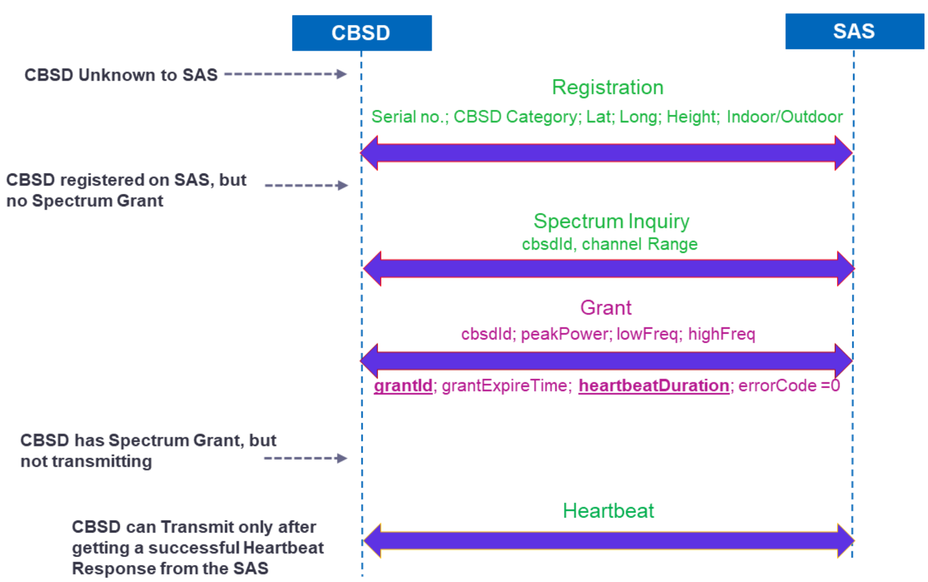

Figure 5: SAS-CBSD/DP Protocol Exchange

FCC Part 96 has required SAS Administrators to obtain the information about Federal Radar operation, including their activation/deactivation from a network of sensors deployed and administered or commissioned by SAS Administrators. These sensors are called Environment Sensing Capability (ESC). Department of Defence (DoD) has agreed to provide the activation/deactivation of some Federal inland operation using Informing Incumbent system (e.g., Portals).

Finally, SASs are expected to synchronize their information and co-ordinate to apply aggregate interference to some of the incumbents (see Section 3.8.2). The information shared among SASs are CBSD information, ESC information, and PAL operations managed by each SAS. A periodic operation called Coordinated Periodic Activities Among SASs performed every midnight enables the synchronization and coordination among SASs.

2.5.2. Incumbent Protection

In order to apply incumbent proception, SAS is required to determine the interference from any impacting CBSD (e.g., $CBSD_i$) to the incumbent or incumbent point (so-called Protected Entity j), using the standardized propagation model, Irregular Terrain Model (ITM) point-to-point mode, and a hybrid model based on eHata and ITM. These standardized propagation models predict statistical propagation loss between the two points according to morphologies and terrains.

From the perspective of protection methodologies, CBRS incumbents are categorized into the following classes

a- Aggregate Interference protection: All SASs apply aggregate interference protection to the incumbent from all CBSDs regardless of which SAS manages them. To that end, neighbourhood areas are defined around the incumbent, for category A and category B CBSDs, where all CBSDs located within those areas, using a spectrum grant that overlaps with the frequency range occupied by the incumbent. The aggregate interference is calculated using certain statistics of aggregate interference, such as median or 95-percentile of aggregate interference. Shore-based federal operation and some inland federal operations, FSS, PAL, GWPZ, and ESCs are protected using this mode of operation. Note that the license for grandfathered wireless users are expected to expire in early 2023, and therefore no GWPZ protection are required beyond that date.

b- Individual CBSD interference protection: Each SAS, independently applies protection to some primary users of the band from individual registered CBSDs, depending on their location, antenna characteristics and transmission power level. There is no synchronization and co-ordination required among SASs. There are some quiet zones (such as Colorado's Table Mountain), and international borders.

c- Exclusion zones: For some primary users of the band, SASs are required to generate exclusion zones around the incumbent, so that no CBSD can operate at any point within the exclusion zone, regardless of CBSD distance to incumbent, antenna characteristic, and power level. However, the exclusion zones are applied in a certain frequency range, and CBSDs are allowed to operate outside those frequency ranges. Some inland federal operations, and some FSS operations using FCC Part 90 subpart Z (when a grandfathered wireless licensee is operating within 150 km of the FSS) are protected using exclusion zones. Note that the license for grandfathered wireless users are expected to expire in early 2023, and therefore no Part 90 subpart Z exclusion zones are required beyond that date.

2.5.1.1 Dynamic Protection Area (DPA)

DPAs are used to protect federal incumbent users from harmful interference due to secondary users sharing CBRS frequencies. They are pre-defined area (or a point) in/at which an incumbent operates on a dynamic basis (i.e., operations change with time and frequency). Shore-based DPAs in USA mainland are shown in Figure 6.

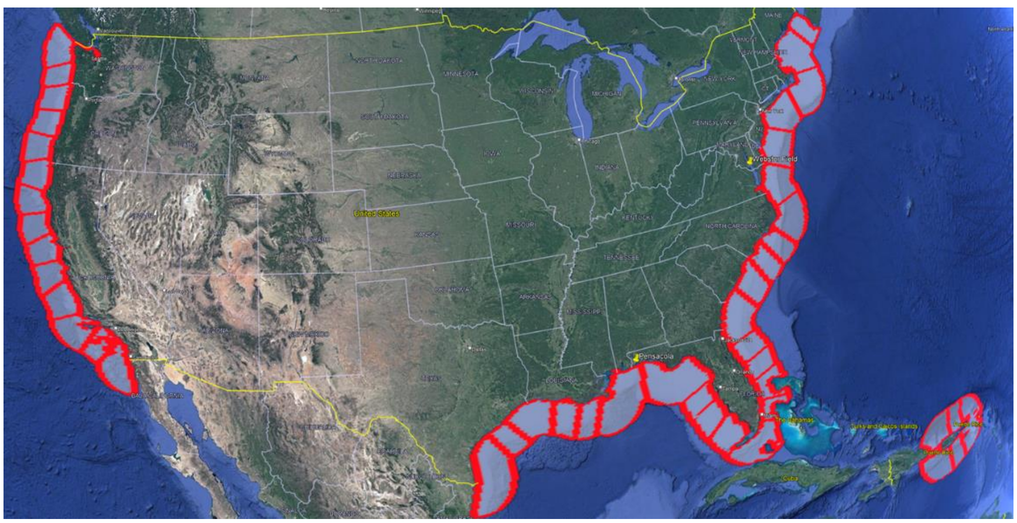

Figure 6: Shore-based DPAs in USA Mainland

When a federal radar is operating within a DPA, secondary users in the neighbourhood of the DPA could be required to change their operating parameters (frequency or power) to protect the incumbent.

A DPA neighbourhood is a pre-defined area surrounding the DPA in which a secondary user could in theory contribute to producing harmful interference to the incumbent, typically based on worst-case assumptions. Secondary users outside of the DPA neighbourhoods are not expected to cause interference and are not affected by the presence of the DPA activity. The size of the neighbourhood is based on assumed deployment models, the DPA interference criterion, and a standardized propagation model. It is important to note that the DPA neighbourhoods are not treated as exclusion zones.

2.5.1.2 DPA Activation

As the term DPA implies, the protection of federal operations within DPAs applies only when federal radar operation is detected within the DPA. This is referred to as DPA activation. During the times when no federal operation is detected within DPAs (or after a certain time when a DPA deactivates) no CBSD operation is impacted and DPAs are not protected.

However, SASs are expected to be notified about federal incumbent activity in a DPA. Part 96 has determined two approaches for DPA activity notification:

- ESC monitored DPAs: A network of sensors are deployed and are responsible for detection of DPA activity, after which they send a notification to the SAS about the DPA in which the incumbent is operating, and its operational frequency range. It is important to note that SASs are required to limit the aggregate interference from CBSD operation at the sensor radio front ends to avoid raising the noise level at the sensor hardware. Raising noise-levels at ESC front-end deteriorates the sensor capability to detect radar operation within the DPA.

- portal-controlled DPA: a DoD spectrum manager responsible for operations at the given portal DPA site logs into a calendar and specifies when, and at which frequencies, they plan to operate. SASs read the portal DPA calendars on a regular basis and protect the DPAs accordingly when an operating event is scheduled

Note that if a SAS does not have access to an ESC or the ESC has suffered a failure, or there is a problem with the SAS accessing the portal, the respective DPA must be assumed to be active on all unmonitored frequencies.

2.5.3. GAA Coexistence and TDD alignment

As described in Section 3.8.1, GAA users are not entitled to interference protection from higher tier users in the band. However, to make the use of CBRS band efficient, SASs apply mechanisms to minimize or eliminate interference among co-channel GAA users. This process is called “GAA Coexistence”.

Proprietary solutions could be applied to enable GAA coexistence in the band. However, Graph-based methods based on creating “Connected Sets” are considered as primary solutions for GAA coexistence. Each individual CBSD (or a group of CBSDs belonging to some certain single frequency groups) are considered as the node of the graph. The edge between two nodes is determined when the two nodes have radio wireless coverage overlap with each other. Using these concepts, a Connected Set is a graph including CBSDs with directly or indirectly interference relation with other CBSDs in a connected set. i.e. a graph wherein there is a path between any two nodes of the graph. Figure 7 depicts the concept of Connected Sets.

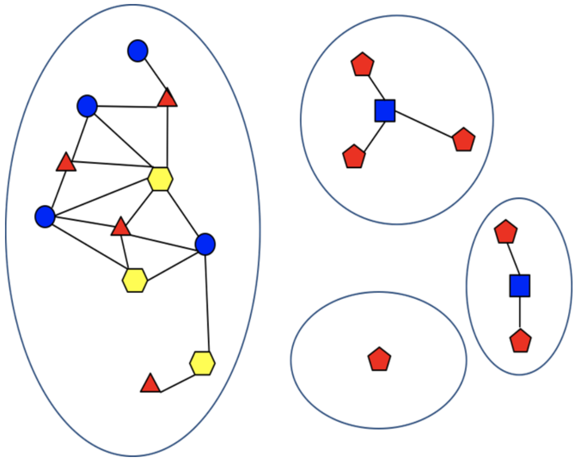

Figure 7: Connected Sets

Moreover, since the operation mode in CBRS band is using Time Division Duplex (TDD), it is essential to ensure alignment of TDD operation among CBSDs that are operating in the same geographical vicinity. To that end, protocols and procedure are defined to allow SASs to ensure TDD alignment among CBSDs using 3GPP LTE, 3GPP 5G NR, and non-3GPP radio technologies in CBRS band.

2.5.4. CBRS Core Network Architecture

CBRS is a primary shared spectrum technology that enables the proliferation of Private Wireless Networks deployed using 3GPP LTE, 3GPP 5G NR, and non-3GPP radio technologies. To that end, certain features are required in the core network architecture, specifically for 3GPP LTE and non-3GPP radios. 3GPP 5G NR has developed the concept of Non-Public Networks (NPN) in Release 16, enabling private wireless deployment using two modes of operations.

- Stand-alone Non-Public Network (SNPN): operated by an NPN operator and not relying on network functions provided by a public operator (Public Land Mobile Network (PLMN)
- Public network integrated NPN (PNI-NPN): a non-public network deployed with the support of a public operator (PLMN).

3GPP private network deployment requires broadcasting PLMN IDs, which are not available for by non-public operators and SNPNs. The combination of PLMN IDs and Network IDs (NID) are required to enable network (re-)selection, overload control, access control and cell-barring.

To that end, Shared PLMN IDs, or Shared Home Network IDs (SHNI) are being managed by OnGo Alliance to enable shared spectrum private wireless deployment in CBRS. The value for SHNI is 315-010 (Mobile Country Code = 315, and Mobile Network Code = 010), which allows one block of 10,000 sub-IMSI-blocks with 100,000 unique IMSI each created. Since the SHNI is shared among multiple CBSDs, core-network architecture and functionalities, such as roaming, network (re-)selection, etc., need to be customized to avoid any confusion.

3GPP has defined band 48 in LTE and band n48 representing CBRS operation, and meeting CBSD and UE CBSD radio requirements. Many major network and UE manufacturers (such as Ericsson, Nokia, Apple, and Samsung) have selected to implement band 48 and n48 in their products. Moreover, 3GPP has enabled carrier aggregation and E-UTRA-NR Dual Connectivity (EN-DC) with many other bands. Figure 8 depicts some ENDC use cases using b48 and n48.

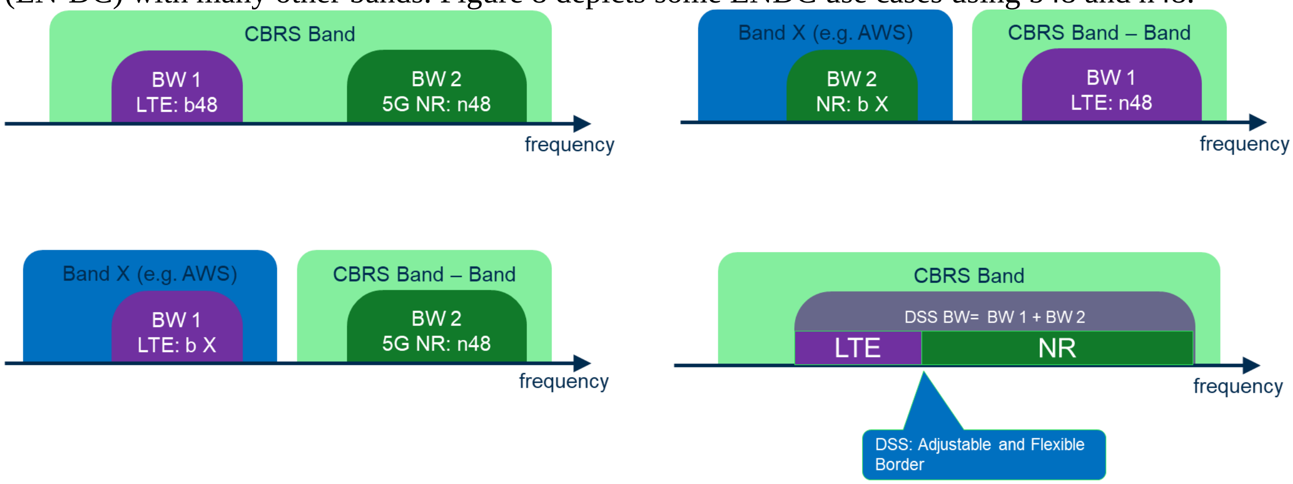

Figure 8: EN-DC combinations using b48 and n48

2.5.5. CBRS Standardization

Upon issuing the Part 96 Rule and Order (R&O) by FCC, Wireless Innovation Forum (Winn Forum or WinnF) was determined to define technology requirements for SAS, CBSD, and ESC operations, the required standardized SAS-CBSD and SAS-SAS protocols, security requirements, and test and certification plans for CBRS operation.

It is important to note that WinnF specifications and test/certification plans are radio technology agnostic and are applied regardless of underlying radio technology. To enable promotion of deployment of 3GPP-based technologies using CBRS shared spectrum, six companies (Ericsson, Federated Wireless, Google, Intel, Qualcomm, and Ruckus Network) initiated CBRS Alliance in 2016, joint by 190+ additional member companies including nation's largest mobile carriers (such as Verizon Wireless, AT&T, and Dish Networks). The objective of CBRS Alliance was to define 3GPP network architecture, GAA coexistence, 3GPP radio requirements, operational aspects of 3GPP-based CBRS deployment, and other marketing and business promotions of 3GPP deployment in CBRS band. In 2020, CBRS Alliance extended its objectives to include other shared spectrum developments in other spectrum bands inside and outside United States, and changed its name to OnGo Alliance.

In addition to WinnF and OnGo Alliance, the radio requirement of CBRS operation were defined in 3GPP in the context of band b48 (LTE) and n48 (5G NR) and many carrier aggregation and EN-DC combinations.

3 Analysis and evaluation of the existing frameworks in relation to audio PMSE

3.1 Spectrum for audio PMSE

The current process for gaining access to spectrum for PMSE productions is often manual, involving emails, telephone calls, and website visits. In almost all cases, spectrum is shared with other services, and PMSE users must contact a frequency coordinator to obtain access. They must determine who the appropriate coordinator is, locate that person, contact them, and wait for a response. Most coordinators are volunteers who have many other responsibilities. Thus, they may not be readily available to respond. Many PMSE productions are planned well in advance, but some require quick action like, for example, a breaking news story. Automated spectrum access technology would greatly simplify frequency coordination and make spectrum access faster and simpler.

3.2 Audio PMSE utilization of the 3.5 GHz CBRS band

3.2.1. Overview

Audio PMSE is an important service that operates in shared spectrum in several bands. Currently, the most widely used Audio PMSE band is the UHF television band (470-608 MHz). However, over time, the amount of spectrum available in this band has been reduced dramatically as a result of spectrum auctions and reallocations. In some U.S. cities there are no unused channels available for PMSE operation.

The 5G Media Action Group, which includes members from the broadcasting, Programme Making & Special Events (PMSE)[6], and the mobile industries, is actively studying the use of 5G private networks for media production and contribution in shared bands like CBRS in USA or 3.8-4.2 GHz in Europe. [7] The following section discusses the potential use of the CBRS band for audio PMSE.

Many Audio PMSE users are small or very small businesses or private individuals that would not have the financial resources to purchase spectrum at auction. Therefore, they would probably be candidates for CBRS General Authorized Access operation. Although GAA users may operate throughout the 3550-3700 MHz band, under FCC Rules, up to seven PAL users may be authorized in a given county, leaving a minimum of three 10 MHz channels available for GAA use in the 3550-3650 MHz band in addition to the five 10 MHz channels in the 3650-3700 MHz band that are only shared with incumbents. Thus, GAA users could obtain shared access to a minimum of eight 10 MHz channels at a given location.

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[6] PMSE: an ITU's inclusive term consisting of radio microphones, in-ear monitors, wireless cameras, talkback systems, etc

[7] https://www.5g-mag.com/explainers

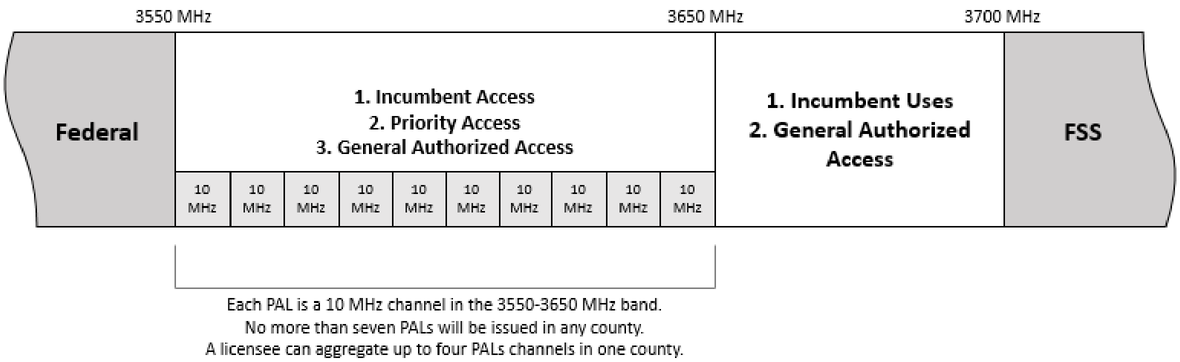

Figure 9: The CBRS Band Plan[8]

CBRS spectrum is managed by county. There are 3,243 counties and county equivalents in the United States[9] . Across these, there is a large variation in population and land area. PMSE operation is concentrated in larger population centers, but may occur anywhere, for example schools, houses of worship, and government buildings in remote areas. Thus, certain counties may have a large demand for PMSE spectrum while others may not have as much. This is likely to be true for non-PMSE GAA operation as well.

It is important to note that GAA users have no expectation of interference protection from any other class of users. In addition, they may not cause harmful interference to incumbent or priority access users. The first point is more problematic than the second one. The reason is that PMSE is normally required to provide a very high Quality of Service (QOS). For large events where more spectrum is needed, or where greater certainty of interference protection is desired, PMSE users could obtain priority access through one of the licensees. FCC Rules allow secondary licensing by Priority Access Licensees to other users through partitioning and disaggregation. They can also partially assign or transfer their licenses.

According to the FCC, Priority Access Licensees can engage in spectrum manager leasing for any bandwidth or duration of time within the terms of the license. Thus, a PMSE operator needing additional spectrum for an event lasting a few days or longer might be able to lease it from a PAL. Availability would depend on the terms of the lease and how much other demand for that spectrum existed. Some licensees might be open to leasing spectrum for PMSE operation, while others might not.

A SAS Administrator can accept leasing notifications and support leasing arrangements under a “light touch” leasing procedure. Potential spectrum lessees must pre-certify with the FCC that they meet non-lease-specific licensing eligibility and qualification criteria. After that, the PAL notifies the SAS Administrator of the leasing arrangements with the pre-certified lessees. The SAS Administrator will then confirm that the lessee(s) meet the criteria in their pre-certification

[8] Ibid.
[9] See: https://en.wikipedia.org/wiki/List_of_United_States_counties_and_county_equivalents

filings and any lease-specific eligibility requirements. PALS are deemed to meet the certification requirements. Lessees must also file with the FCC Universal Licensing System (ULS) and submit FCC Form 608. Once the SAS Administrator approves, the lessee can immediately start using the spectrum under the terms of the lease. There is an alternative 21-day notification procedure in the ULS that PALS and lessees may use instead of the "light touch" notification process, if they prefer. In either case, an SAS Administrator must be notified before operation may start.

3.2.2. Implications for PMSE End User Devices

PMSE End User Devices (EUD) must comply with the technical and operational requirements in Part 96 of the FCC Rules.[10] Here are a few notable points:

- §96.41(a) Digital Modulation: Systems operating in the Citizens Broadband Radio Service must use digital modulation techniques.
- §96.41(b) Power Limits: Maximum EIRP (dBm/10 MHz): 23. Maximum PSD (dBm/MHz): n/a
- §96.41(c) Power Management: End User Devices shall include transmit power control capability and the capability to limit their maximum EIRP in response to instructions from their associated Citizens Broadband Radio Service Device (CBSD).
- §96.47(a) End User Devices may operate only if they can positively receive and decode an authorization signal transmitted by a CBSD, including the frequencies and power limits for their operation.
    - §96.47(a)(1) An End User Device must discontinue operations, change frequencies, or change its operational power level within 10 seconds of receiving instructions from its associated CBSD.

Some of the operational requirements for CBRS devices may limit the usefulness of the band for certain types of PMSE equipment at certain locations and under certain conditions. For example, wireless microphones are expected to provide continuous high-quality audio transmission with very low latency (typically less than 3 msec). Interruptions caused by changes in transmission parameters (e.g., frequency changes) would not be acceptable for this type of use. On the other hand, other PMSE devices such as wireless conferencing and discussion systems might be able to accept a limited number of interruptions depending on timing and suppression of noise and audio artifacts.

Factors that would maximize the usefulness of CBRS spectrum for Audio PMSE operation include:

- It would be helpful if an Audio PMSE user could specify a preference for GAA channel assignments in the 3650-3700 band in locations where incumbents are not operating.
- It would be helpful if an Audio PMSE user could ask the SAS to minimize frequency changes whenever possible, to reduce audio disruptions.

[10] FCC Part 96 Rules are available at: https://www.ecfr.gov/current/title-47/chapter-I/subchapter-D/part-96

3.2.3. Open Issues for further discussion

- Since frequency changes can cause interruptions and noise in audio transmissions, could a PMSE user ask the SAS to minimize non-mandatory frequency changes during operation?
- Could a PMSE user ask the SAS to prioritize the use of the 3650-3700 band over operation in the 3550-3650 band?

4 Conclusion

We initiated this project between ETSI Reconfigurable Radio Systems (RRS) and WInnForum to address technical approaches for automated spectrum access to support dynamic, temporary, and flexible spectrum sharing for a variety of use cases. However, the only use case for which inputs were received in WInnForum is audio PMSE.

In terms of bands for application of the output of this project, the 3.8-4.2 GHz band in Europe and the CBRS band in USA would be good candidates. This Technical Report can be used to feed into the one developed in ETSI RRS with the goal to develop a joint white paper with ETSI.

5 References

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[3] ETSI TS 103 154 V1.1.1 (2014-10): Reconfigurable Radio Systems (RRS); System requirements for operation of Mobile Broadband Systems in the 2 300 MHz - 2 400 MHz band under Licensed Shared Access (LSA)

[4] ETSI TS 103 379 V1.1.1 (2017-01); Reconfigurable Radio Systems (RRS); Information elements and protocols for the interface between LSA Controller (LC) and LSA Repository (LR) for operation of Licensed Shared Access (LSA) in the 2 300 MHz - 2 400 MHz band

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[14] ETSI TS 103 652-3 V1.1.1 (2021-06): Reconfigurable Radio Systems (RRS); evolved Licensed Shared Access (eLSA); Part 3: Information elements and protocols for the interface between eLSA Controller (eLC) and eLSA Repository (eLR)

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