Application of Management Technologies in Dynamic Spectrum Sharing

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TERMS, CONDITIONS & NOTICES

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Application of Spectrum Sharing Management Technologies in Dynamic Spectrum Sharing

1 Introduction

Wireless operators worldwide are under constant pressure to expand network capacity and enhance network speed and performance to meet user expectations. In addition, industrial and critical infrastructure broadband communication needs are underserved. Among a number of options available to help overcome these challenges is adding spectrum. But licensed spectrum is a finite resource, and subscribers are using more and more wireless services and bandwidth.

Starting with TV White Space (TVWS) in 2004, wireless users and regulators brought the idea of centrally-controlled, dynamic spectrum access to reality. To further address the spectrum shortage in the U.S., the Federal Communications Commission created a new Citizens Broadband Radio Service (CBRS) in 2015, adding critical new capacity opportunities for operators, but requiring the implementation of a dynamic sharing system with incumbent users. In Europe, the concept of Licensed Shared Access (LSA) systems has been developed.

A taxonomy defining the characteristics of these various types dynamic spectrum sharing systems has previously been presented by the members of the Wireless Innovation Forum, establishing five different levels as shown in Figure 1[1]:

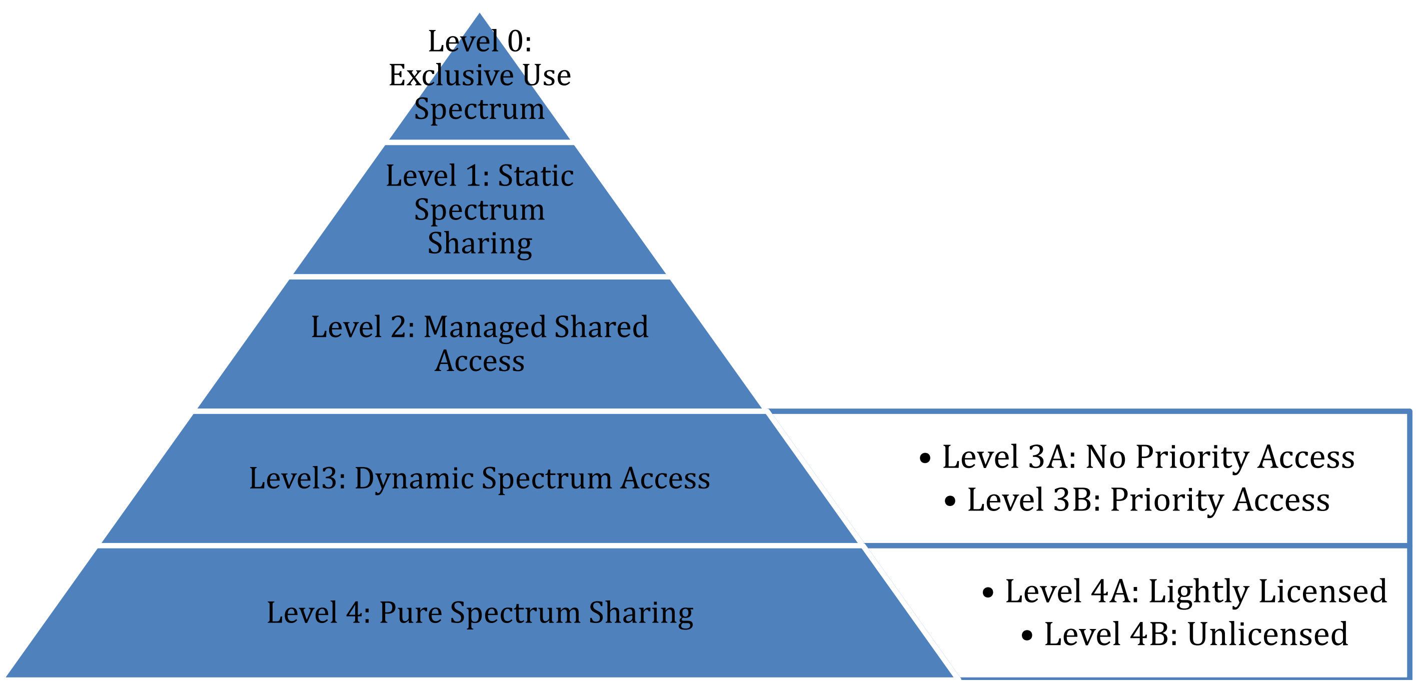

Figure 1: Levels of Spectrum Sharing

Spectrum Sharing Management Technologies are becoming more common across all levels of sharing where temporal sharing is employed (see Figure 2)[2]. These technologies can include geolocation databases containing the location of each managed wireless device and knowledge of the radio environment around those devices, protocols used in communicating with those devices and with other Spectrum Sharing Management Technologies, and policy engines used in managing those devices against a set of rules defined by regulators, manufacturers, developers, network and system operators, and system users.

This report focuses specifically on applications of Spectrum Sharing Management Technologies. The report will present the challenges and benefits of sharing in several bands while taking into consideration several factors including types of incumbents in the band, how the bands are used and the nature of usage. We discuss some of the business models for existing shared bands and possible ones in the future. We also discuss key performance indicators to evaluate the sharing arrangements in a band. We conclude with recommendations on follow-up actions. The intent of the report is to provide better understanding on the bands that might be applicable for sharing and present various sharing approaches (licensed, lightly licensed, unlicensed registered) for these bands.

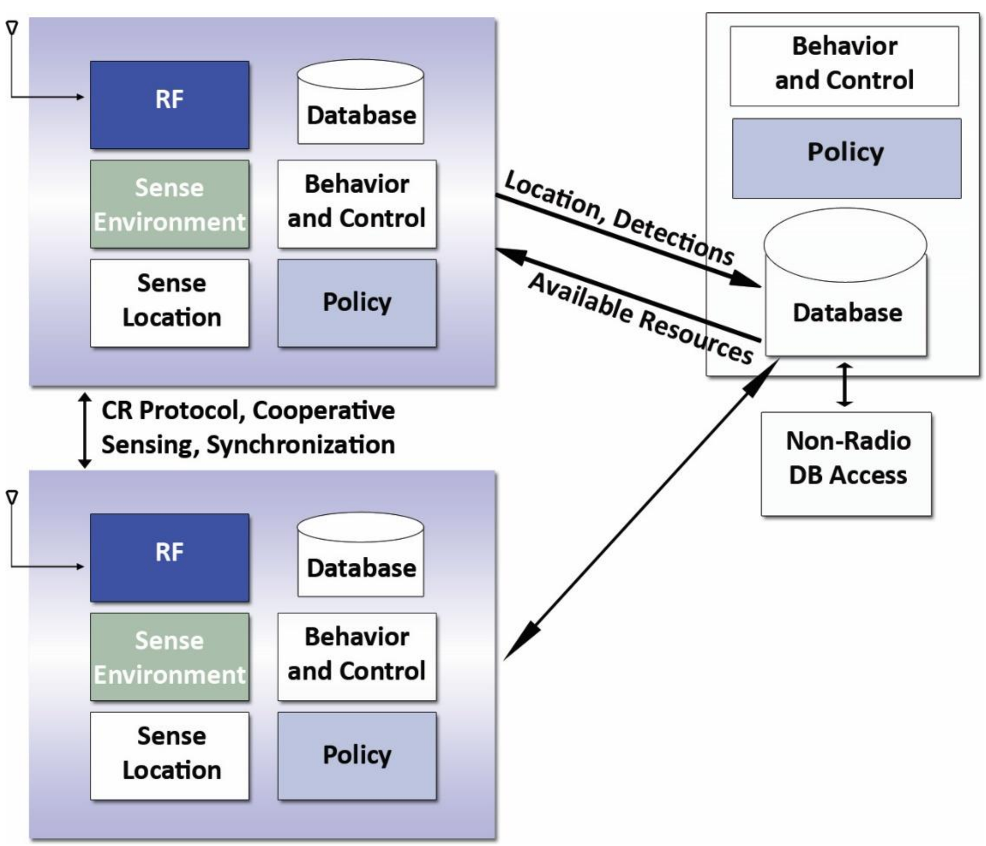

Figure 2: Notional Architecture for a Dynamic Spectrum Access System

2 Rationale: The Need for Spectrum Sharing Management Technologies

Radio spectrum is a limited resource for wireless communications. While technological innovations have led to great improvements in the utilization of spectrum in wireless communications, the search for new spectrum continues at an unprecedented pace. Increasingly, the spectrum under consideration will contain incumbents or primary users that need to co-exist along with new wireless communications applications or secondary users.

The current, traditional approach to managing the radio spectrum is through a static licensing model: granting exclusive spectrum access through a single entity, commercial or government, to one or more frequency bands both for a long duration and over a large geographic area. The primary objective of this approach has been to eliminate, to the extent possible, harmful interference among different radio services and users. Under this traditional spectrum management model, for one entity to gain new spectrum, another must clear it. However, such clearing of spectrum is an expensive and lengthy undertaking and is fast becoming an unsustainable way to accommodate increased spectrum demands due to traffic growth. Already, while spectrum scarcity for certain applications is becoming increasingly urgent, spectrum occupancy studies show that many spectrum bands are, on average, heavily underutilized due to significant variations in spectrum occupancy over frequency, time and geography.

Innovations in wireless communications have led to ongoing gains in both spectrum efficiency and utilization. These gains have allowed for great advances in licensed and license-exempt use of the spectrum. For example, mobile broadband ecosystems have demonstrated scalability in meeting the immense growth for data and growing subscriber base from the early 2nd generation systems through to the emerging 5th generation systems. Commercial operators have managed to extract tremendous value out of spectrum by reusing allocations over large geographies, in an environment rich with interference by using technologies that are able to operate amid such interference. Indeed, spectral efficiency improvements have allowed the mobile wireless industry to thrive through four generations of mobile technologies, each offering improvement in performance and data capacity over the previous. Similarly, the wireless broadband ecosystem has also provided innovative new forms of wireless communication at ever-increasing data rates as can be seen by the evolution of fixed wireless access and wireless local area network technologies that have demonstrated the potential of license-exempt use of wireless communications. These technology ecosystems will continue to expand, evolve and create growing demands on spectrum.

Recent years have seen the introduction of the concept of dynamic spectrum sharing as a promising complement to traditional clearing and reallocating spectrum by allowing access to spectrum for new users without disrupting incumbent users unduly. Going forward, dynamic sharing has an important role in accommodating future growth of wireless services of all types and to meet the demand pressures imposed on finite spectrum resources. We have seen an increased interest in the concept and evolution of spectrum sharing from both wireless broadband and mobile broadband stakeholders, where the intent is to increase the capacity of their networks by sharing licensed spectrum with incumbent services where bands are underutilized either over time or geography. Examples are sharing between licensed use on a secondary basis as Priority Access Licenses (PAL) or General Authorized Access (GAA) licenses in the U.S. Citizen's

Broadband Radio System (CBRS) in the 3.5GHz band, and Europe's Licensed Shared Access (LSA) model, which provides a generic approach for introducing additional licensed users in bands already occupied by incumbent users. Other examples that are of particular interest are International Mobile Telecommunications (IMT) bands that are available for licensed use in some markets, and at the same time subject to alternative allocation to services that are sparsely used or are separable from locations that are of interest to Commercial Mobile Radio Service (CMRS).

As 3GPP moves towards fifth-generation (5G) mobile broadband technology in Release 15, and now Release 16, providing any device with an optimized connection to always-available, secure, cloud services, so too will the next-generation of Spectrum Sharing Management Technologies. 5G will also bring its own set of challenges and opportunities that will need to be addressed in the spectrum sharing space. In particular, 5G technologies will be deployed in spectrum bands that have supported existing 4G technologies but will also use frequencies that are an order of magnitude higher than normally considered for CMRS. This millimeter-wave spectrum will permit operators to use technological solutions such as advanced beamforming and MIMO technologies to allow sharing spectrum in the Time-Frequency-spatial domain to a much greater extent than current cellular technologies manage through sectorized sites and fractional loading of spectrum. With the added dimension of beamspace, energy transfer between the transmitter and receiver antennas may be made more efficient, while simultaneously reducing the average interference rise from other users. Thus, valuable spectrum resources can potentially be used more spectrally efficient than what is possible with today's mobile technologies.

The wireless industry is beginning its migration to 5G which includes radio enhancements that allow efficient and practical use of millimeter bands. Across the globe, many of these bands are already allocated to incumbents with the spectrum often lightly used, providing an opportunity for spectrum sharing. Spectrum sharing allows for industry to easily re-purpose lightly used spectrum over time; where today the demand is mostly for CMRS usage, spectrum sharing is quite generic and future needs could require the spectrum to be re-purposed for usage we don't yet envision.

There is no question that spectrum sharing can and will eventually result in more efficient utilization spectrum. One aspect of spectrum sharing is the potential for disruption to existing stakeholders and business models. It will be critical for incumbents to gain confidence in the systems used to share spectrum and understand the advantages these systems can provide while maintaining priority access to spectrum when or where they require it. Spectrum sharing can also disrupt business models that are based on spectrum scarcity. This disruption could shift the business focus towards prioritization and spectrum access rather than spectrum holdings. However, the disruption may also see new business models emerge to enhance spectrum coordination, monitoring, or other services. All of these developments represent a revolutionary approach to spectrum usage, moving away from command-and-control to more dynamic allocation processes.

Risks remain as there has yet to be an established and stable market for stakeholders of Spectrum Sharing Management Technologies and recognition of the relevant business and operation models by regulators. Primary users in most bands still hold the view that sharing is not mature or doesn't offer the same protection as exclusive use. However, early adopters, such as those involved in the CBRS trials and certification tests in the US, have accepted these risks with the expectation of generating commercial revenues and to be a first-mover in the next phase of standards evolution.

3 Current Spectrum Sharing Management Technologies, Frameworks and Approaches

3.1 Introduction to geo-location database assisted operation

The geolocation or white space database records specific location and technical characteristics of the radio devices. Such knowledge is helpful in assisting the database in performing policy management functions. The functions of the database can address two levels of operation. The first level pertains to secondary use of the spectrum that is dedicated to a single primary use and involves authorization of use in areas that are unused by the primary user. The TVWS rules (see Section 3.2) authorize wireless broadband use on an unlicensed basis at this level of operation. In the case of co-primary use of spectrum, a database is capable of handling temporal or spatial sharing of multiple primary services that have been authorized conditionally. The second level of functionality pertains to establishing further conditions on authorization between various classes of users, both primary and secondary. Such conditions may, for example, establish coexistence mechanisms between White Space Devices (WSD). In this case, wireless broadband users are authorized with information on channel and power allocation at the device location that will protect incumbents and other broadband users. Devices would normally connect to the database over the internet.

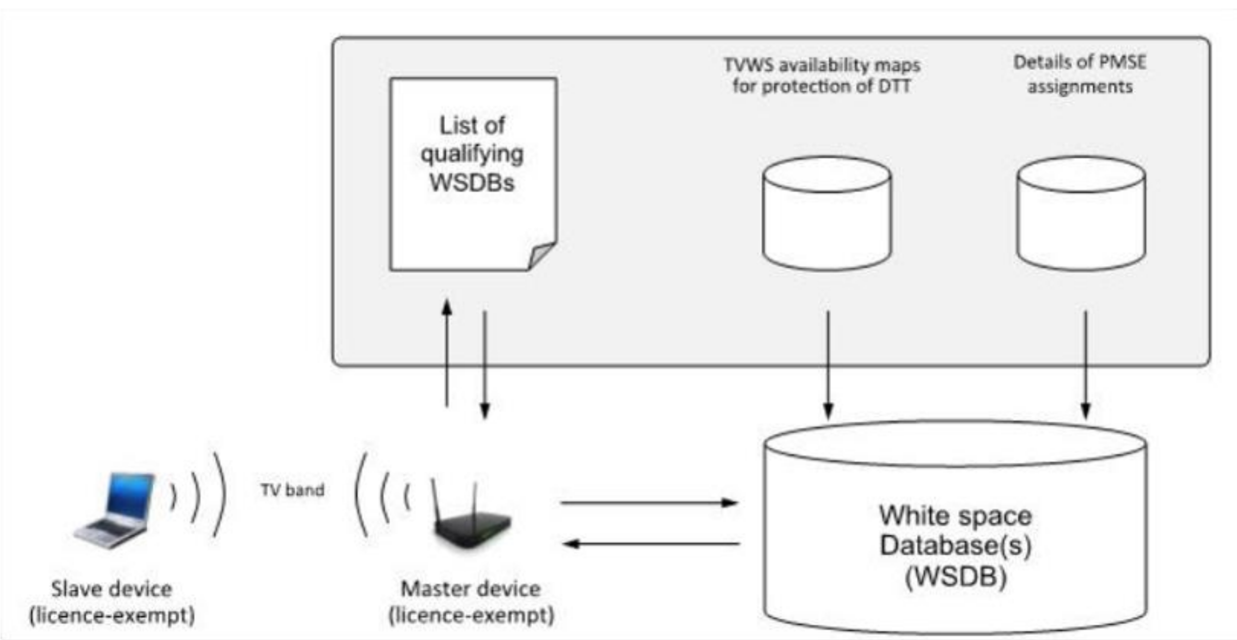

Figure 3: White Space Database (WSDB) as applied to the TV Band

Main functions achieved by geolocation databases would consist of the following:

- Collection of incumbent information;
- Provision of incumbent information;
- Calculation engine;
- Communications with the client devices.

At the heart of the system, the calculation engine translates the information on incumbent services and the technical characteristics and location of the device into a list of allowed frequencies and associated transmit powers for devices. As a critical requirement, regulators will want to be sure that a database performs the calculation process correctly as errors could lead to interference to incumbents.

3.2 TVWS – Regulatory and Standardization done, lightly adopted

The ITU-R has designated VHF and UHF bands for television broadcast services worldwide. The bands are typically underutilized in most nations around the world, and most stations tend to cover population centers with the aid of broadcast towers. A variety of analog and digital broadcast transmission standards are used all over the world, e.g., NTSC, PAL, SECAM, ATSC, DVB, etc. The available bands are typically divided into channels that are 5-10 MHz in width. TV broadcasting stations were traditionally licensed one or more of these channels. Analog transmission methods involved broadcast of a single station and a sequential program stream on each of these channel blocks. Digital transmission schemes such as the Advanced Television Standards Committee (ATSC) and DVB multiplex several program streams onto a single channel. Channels are capable of being shared between broadcasters, although they are not always utilized so.

Prior to the widespread introduction of digital television, broadcast transmission equipment was designed without regard to spectral efficiency. Station licenses were assigned over alternate channel arrangements, with channels adjacent to a station being left free. This allowed receiving equipment to be less complex, and transmission equipment to be designed with lax filtering. Television stations in urban areas do broadcast with ERPs of the order of 0.5-1 MW in many markets and are capable of providing coverage to roof-mounted antennas with directivity. TVWS was proposed as a way of encouraging the spread of broadband in rural areas, with mobile broadband coverage using TV channels that were in the inter-channel guard space between licensed TV broadcast stations. Sharing was authorized on the basis of geographical isolation from broadcast assignments that occupy the same channel.

The TVWS approach to sharing was based on the intent to reuse sparsely utilized spectrum. The concept is appealing to regulators as it potentially frees spectrum for license-exempt broadband use. Operators may, in principle, use available spectrum to provide wide area coverage without the burden of bidding for licenses, thus freeing up investment capital for infrastructure deployment. Broadcast and broadband infrastructure is deployed at fixed locations and can be easily authorized and managed.

In the U.S., conversations about opportunistic access to locally-unused portions of the previously allocated broadcast television channels (i.e. TV White Spaces or TVWS) began in the early 2000s. After more than a decade of regulatory uncertainty and policy deliberations (which were affected by other programs such as the National Broadband Plan and the Incentive Auction), and due in part to the continued advances in both licensed and unlicensed technologies for other bands, there has been little commercial activity with TVWS in the U.S. A limited number of TVWS trials and experiments have been conducted in underserved geographies around the world, with a focus on delivering wireless backhaul services utilizing these spectra. At this time, it seems likely that commercial use of TVWS will remain limited to certain geographies, use cases, and niche applications. Because of the exogenous circumstances, as well as the structural differences in sharing frameworks developed in more recent years, the TVWS experience is not expected to weigh on the success possibilities for the newer frameworks discussed below.

TVWS has seen limited success in the U.S. for several reasons:

1. Commercial mobile broadband networks typically require a wider bandwidth than possible within a TV channel. The lack of certainty of access to spectrum made TVWS more suitable for small cells. Small cell deployments are rendered irrelevant if the availability of bandwidth is low. Wide bandwidth TVWS radios would have had to support carrier aggregation, and the performance requirements in the presence of blockers were too exacting.

2. Global economic prerogatives did not favor rapid adoption of TVWS. Bands suitable for mobile broadband are driven from ITU-R decisions around primary allocations for IMT, and economies of scale favor the utilization of bands that are guaranteed commercial success in more developed countries.

3. It is very clear that IPTV and non-linear viewing of program content is supplanting the broadcast medium in most developed nations; while broadcast reception is nowhere close to disappearing, even as there is little indication that there is any growth left in broadcast as a medium.

4. The poor utilization of the UHF band for broadcasting is another factor that makes TVWS incongruous with the needs of developing nations. The majority of countries in the world use between 10-20 MHz of total spectrum for broadcast services in the UHF band. National priorities for spectrum policy favor segmentation and licensing of broadband spectrum as opposed to the use of TVWS.

3.3 Citizens Broadband Radio Service – Emerging Framework based on the Spectrum Access System

The Spectrum Access System (SAS) has emerged as a viable dynamic spectrum access solution in the U.S. and could also be used in other bands and countries in the near future. With a SAS, spectrum is managed and assigned on a dynamic, as-needed basis across three tiers of access as shown in Figure 4.

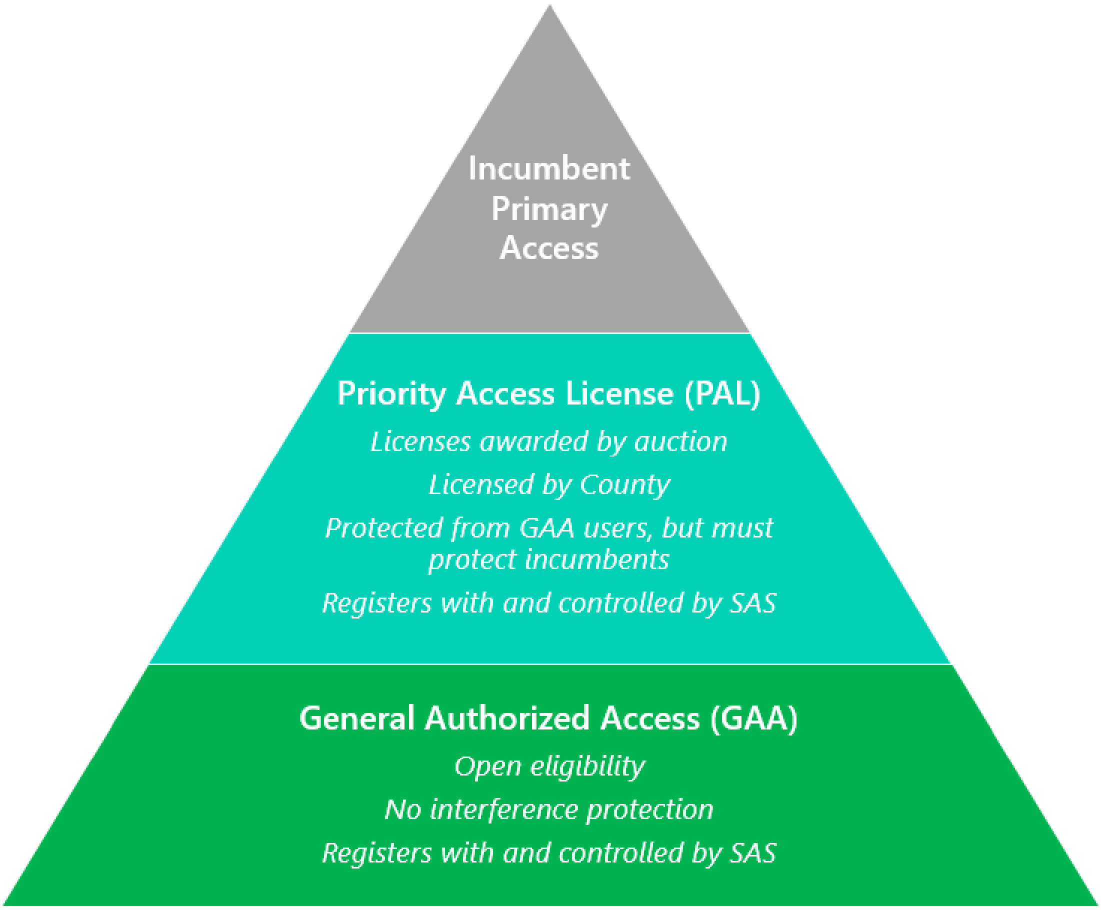

Figure 4: Three-Tiered Sharing Structure for CBRS

The three tiers are listed below in decreasing order of priority:

- Tier 1 is incumbent users such as the federal government and fixed satellite users.
- Tier 2 is Priority Access License users. These are licensed wireless operators who acquire spectrum through an auction
- Tier 3 is General Authorized Access users who will operate under an unlicensed (or “lightly-licensed) regime.

Incumbent users have primary rights in the band and are allowed to use the region of spectrum allocated to their respective services without encumbrance. Lower priority users gain access to spectrum that is not used by higher priority users via the SAS in a secure manner; i.e, they are required to protect higher priority users from interference beyond defined levels. The last tier made up of GAA users receive no regulatory protection from interference from other users (including other GAA users), although there is an abiding interest in reducing the interference from peer users by way of measurements and empirical modeling of the environment.

In CBRS, the Tier 1 incumbents include Navy radar and commercial satellite communications systems. To protect them from interference, CBRS comes with the requirement to use a SAS to manage spectrum use among stakeholders and enable operators to share the spectrum without interfering with incumbent operations. For a limited period of time ending in April of 2020, the SAS will also protect users belonging to the Wireless Broadband Service and operating within the rules of 47 CFR Part 90 Sub-part Z. These users are typically lightly licensed users providing utility metering or are Wireless Internet Service Providers (WISPs).

The SAS incorporates a dynamic database and, potentially, other interference mitigation techniques. The SAS ensures that CBRS users operate only in configurations where they would not cause harmful interference to incumbent users and helps manage interference protection among the different CBRS tiers. While the location of earth stations belonging to the Fixed Satellite Service (FSS) are recorded in the database, the SAS will be informed of the presence of naval radar through the Environmental Sensing Capability (ESC) made up of coastal sensors designed to detect incumbent radar activity.

The WInnForum SAS Functional Architecture is shown in Figure 5.

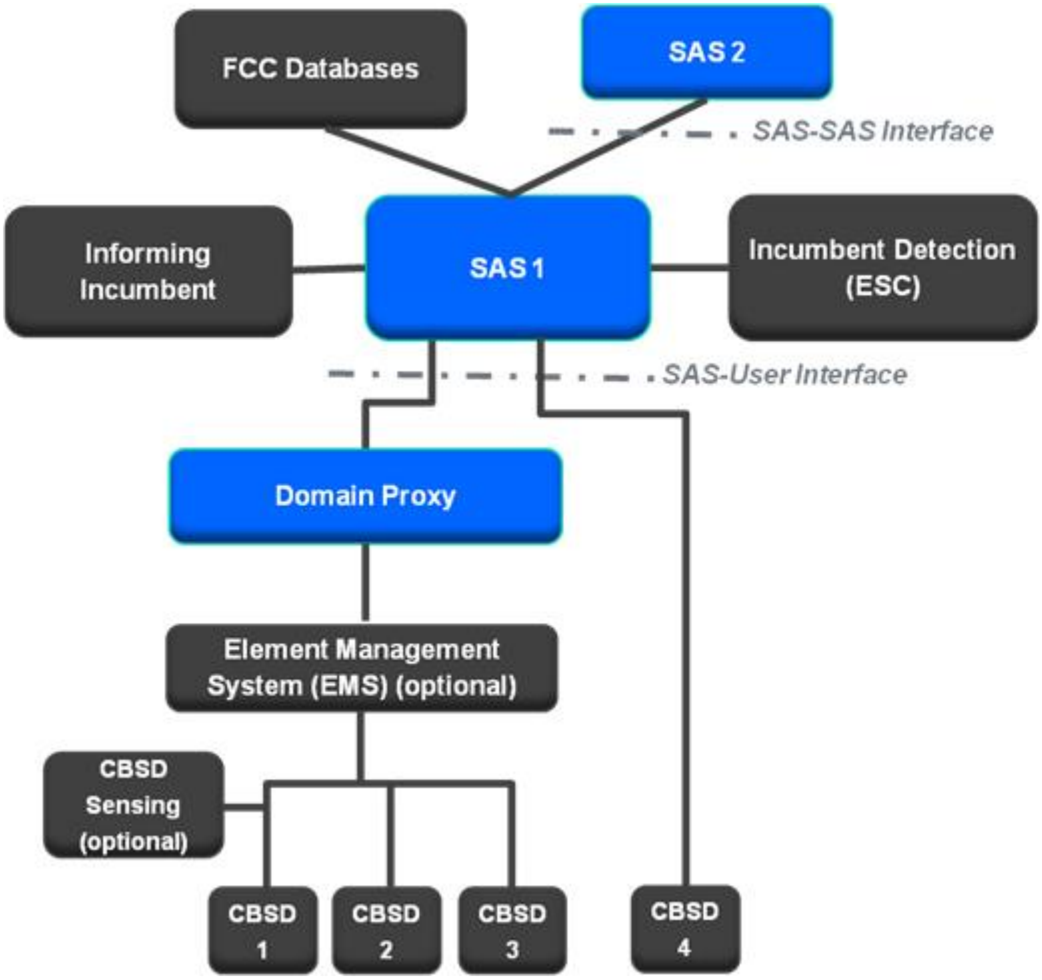

Figure 5: WInnForum SAS Functional Architecture

3.4 LSA – Regulatory and Standardization done but no commercial deployments

3.4.1 Background and Principles

Licensed Shared Access is a national issue and was first defined by the European Commission (EC) Radio Spectrum Policy Group (RSPG) in its opinion[3]

RSPG definition is as follows:

"A regulatory approach aiming to facilitate the introduction of radiocommunication systems operated by a limited number of licensees under an individual licensing regime in a frequency band already assigned or expected to be assigned to one or more incumbent users. Under the Licensed Shared Access (LSA) approach, the additional users are authorised to use the spectrum (or part of the spectrum) in accordance with sharing rules included in their rights of use of spectrum, thereby allowing all the authorized users, including incumbents, to provide a certain Quality of Service (QoS)".

Within the European ECC, it has been the subject of extensive studies within the Project Teams FM 53 (regulatory conditions for LSA) and FM 52 (implementation of LSA for the shared use of the band 2.3-2.4 GHz (3GPP Band 40)).

The ECC has also developed a guideline for spectrum sharing in the 3600-3800 MHz range (3GPP Band 43), see the ECC Report 254; the report describes how LSA can be utilized in case incumbent services (e.g. FS/FSS) still exists in the band.

Licensed Shared Access (LSA) is technology agnostic and can be implemented on any system in any frequency provided that coexistence studies are cleared. Stakeholders responsibilities are described for the case where MNOs are LSA licensee.

The 3GPP and ETSI RRS standards have defined the following different roles:

- **Incumbent**: current holder of spectrum rights of use. The incumbent stores usage of his spectrum in the LSA system.
- **LSA licensee**: entity operating a mobile network, which holds individual rights to use an LSA spectrum resource.
- **The NRA** National Regulatory Authority defines and controls the application of the sharing framework.

The main idea of LSA is to implement a database where the geographical use of spectrum bands is stored and to define spectrum access negotiation processes between the different users i.e. incumbents and LSA licensees. Further, proposed "Dynamic LSA" extensions to the LSA architecture explore enablement of multi-tier sharing as well as sharing amongst multiple operators.

The control of the spectrum access by the LSA Licensees on Incumbent spectrum resources is ensured by an LSA Repository and LSA Controllers as depicted in the figure below. This architecture has been standardized by ETSI and 3GPP.

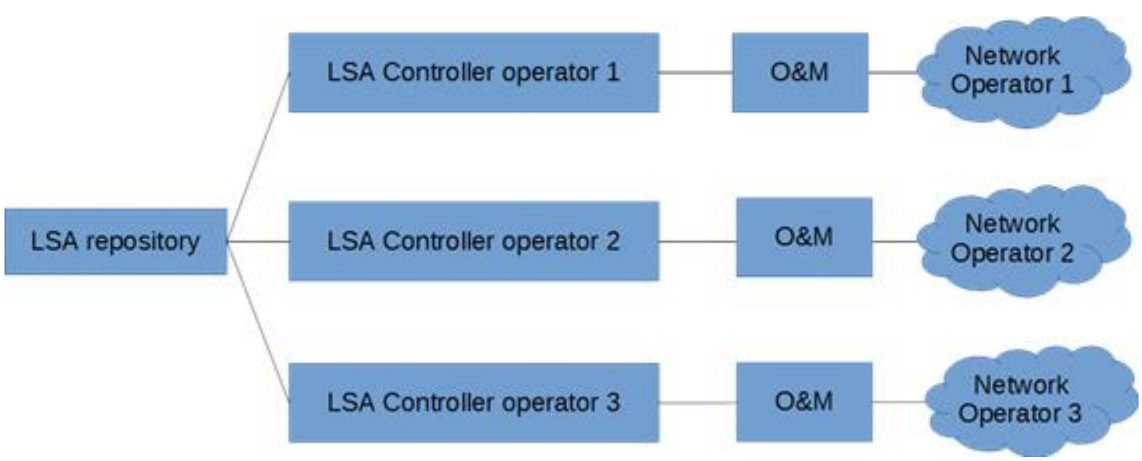

Figure 6: LSA multi-operator scenario

Field trials were done in different countries in Europe and supported by the EC, the CEPT and national regulators. The feedback was very positive and the system has been proven working for limited deployments.

3.4.2 Relevant ECC / CEPT deliverables and documentation

- ECC Report 205: Licensed Shared Access (LSA)
- ECC Decision (14)02: Harmonised conditions for MFCN in the 2300-2400 MHz band
- ECC Recommendation (15)04: Guidance for the implementation of a sharing framework between MFCN and PMSE within 2300-2400 MHz
- CEPT Report 55, CEPT Report 56 and CEPT Report 58 in response to the Mandate from the European Commission on 'Harmonised technical conditions for the 2300-2400 MHz ('2.3 GHz') frequency band in the EU for the provision of wireless broadband electronic communications services'
- Licensed Spectrum Access opens new opportunities, ECC Newsletter, October 2013
- ECC Report 254: Operational guidelines for spectrum sharing to support the implementation of the current ECC framework in the 3600-3800 MHz range

3.4.3 Related ETSI standards

Within the ETSI, TC RRS (Reconfigurable Radio Systems) is developing technical specifications for the implementation of LSA. In November 2016, TC RRS approved TS 103 379 "Information elements and protocols for the interface between LSA Controller (LC) and LSA Repository (LR) for operation of Licensed Shared Access (LSA) in the 2300 MHz-2400 MHz band", version 1.1.1. This stage-3 document completes the first release of LSA technical specification in ETSI. The relevant stage 1 and stage 2 documents are ETSI TS 103 154 v1.1.1 (2014-10) containing the System requirements for operation of Mobile Broadband Systems in the 2 300 MHz - 2 400 MHz band under Licensed Shared Access (LSA) while TS 103 235 v1.1.1 (2015-10) describes the System architecture and high level procedures for operation of Licensed Shared Access (LSA) in the 2 300 MHz - 2 400 MHz band, respectively.

3.4.4 Relevant 3GPP standards

- TS 28.301 'Licensed Shared Access (LSA) Controller (LC) Integration Reference Point (IRP); Requirements'

- TS 28.302 'Licensed Shared Access (LSA) Controller (LC) Integration Reference Point (IRP); Information Service (IS)'
- TS 28.303 'Licensed Shared Access (LSA) Controller (LC) Integration Reference Point (IRP); Solution Set (SS) definitions'

4 Technologies and Services

The demand for spectrum has consistently increased as mobile cellular technologies have progressed through four generations of evolution leading to the fifth generation standards in development. It must be noted that mobile wireless technologies have evolved in two parallel tracks for Radio Local Area Networks (RLANs) and within the Commercial Mobile Radio Service (CMRS) represented by the four generations.

Although not required, a majority of RLAN technologies today are operated in license exempt bands, and often also include Short Range Device (SRD) networks. The most prominent of the bands implementing RLAN technologies are the 2.4 GHz and 5 GHz unlicensed bands. In the USA and many other parts of the world, digital communication devices may use these bands freely within the rules of 47 CFR Part 15 and are required to accept interference from other users in the band. In Europe, ETSI has developed regulations for unlicensed operation that may be interpreted as a requirement to abide by specific etiquette for coexistence in the band. Most devices using these bands conform to a MAC protocol that implements a Listen-before-Talk etiquette. The protocol is respectful of the rights of other users already occupying a channel to continue to use it without interference and requires users occupying a channel to limit their occupancy so that others may access the same in an ad-hoc and uncoordinated manner. A number of technologies, WiFi, Bluetooth, Zigbee etc , operate by using such interference avoidance mechanisms. Clearly, RLANs share spectrum and do so between air interfaces and networks by contending with one another for access to spectrum.

The 3rd Generation Partnership Project (3GPP) is an industry consortium developing the latest cellular technologies. The prevailing technology is the Long Term Evolution (LTE) standard that has spanned seven releases of the specifications up to Release 14, and continues to evolve even as 5G NR is being standardized from Release 15 onwards. Cellular technologies typically operate in spectrum that is exclusively licensed to specific operators on a geographic or a nationwide basis. While spectrum is apportioned in various bands between operators, it should be pointed out that markets have always developed within severe limitations in bandwidth. For this reason, industry standards place a premium on spectral efficiency, and many advances in radio hardware, systems engineering, and signal processing have been motivated by interest in sharing spectrum between end-users and infrastructure emplacements and in dividing bandwidth between links across space, time and frequency. A historical analysis of the various generations of cellular technologies starting from AMPS or NMT to 5G NR will show progress by an order of magnitude in frequency span, bandwidth, data rate etc. At the same time each generation has improved spectral efficiency by palpable amounts, and it will also be apparent that the relative distance between radio base station sites has progressively decreased to accommodate the higher traffic demand, carrier frequencies and data rates.

As the demand for spectrum has increased, so has the impact on other services that occupy desirable spectrum. Services like broadcast television, satellite services, fixed services radiolocation, radio navigation, passive sensing, earth exploration, etc. occupy the very regions of interest for mobile broadband. It is therefore of interest to regulators that the burden on existing allocations be alleviated by a variety of techniques that include efficiency measures, technology improvements leading to repacking of spectrum, incentives from one service to another to cause incumbents to move, and spectrum sharing on a flexible or secondary basis with other incumbents. Some regulators, such as the FCC, are also keen on creating means by which technology can be employed to improve utility of spectrum, as opposed to spectral efficiency of single air-interfaces. Such an approach puts a premium on the percentage of a nation's geography that can be covered by wireless use. The TV White Space rules and the CBRS are examples of such approaches.

The cellular industry has also adapted to the scarcity of spectrum for 4G by developing Licensed Shared Access (LSA) for binary sharing between two co-primary licensed services, one of which is a mobile broadband services. It was also popular for operators to rely on off-loading users to unlicensed spectrum through user behavior or via features allowing authentication of cellular users within WiFi operator's RLAN deployments. In addition, LTE also supports Licensed Assisted Access (LAA) that is capable of operating in the unlicensed 5 GHz bands. While not explicitly required by rules in most countries, the LAA features have been developed with consideration for coexistence with WiFi. LAA requires the presence of a licensed anchor carrier for the 5 GHz unlicensed mode of LTE to operate. A standalone version of LTE for operation in the 5 GHz unlicensed band alone is under development within the USA in the industry organization, Multefire Alliance (MFA).

Sharing within the same technology can be done by means of interference avoidance or interference mitigation with an entire range of possibilities between these extremes that include interference suppression, spatial nulling, frequency and time division, spatial isolation etc. Sharing between technologies is a bit more involved and is typically more efficient as the services involved know more about the other. For example, it would be much better for the mobile service to utilize spectrum used by the Fixed Satellite Service if design specifications and performance characteristics of the satellite link in vicinity of operation were known and understood. In both these cases, lower levels of knowledge of other users in the operating band will impact spectrum utility adversely.

Spectrum sharing on a spatial basis is typically done using geolocation databases that clearly identify the location of each user. In the case of TVWS, the database records the location of broadband users and TV towers, permitting broadband users to operate on channels that are not in use by broadcasters. Broadband users however do not get knowledge of their neighbors' spectrum utilization or geolocation coordinates. In the case of the CBRS, the geolocation database is combined with a policy manager that is capable of monitoring spectrum availability for the different tiers dynamically. The Spectrum Access System (SAS) encompasses both these functions and is charged with protecting incumbents as well as licensed mobile broadband users from aggregate interference that exceeds limits. Measurements from broadband users can further improve spectrum utility by validating empirical models used to divide spectrum between users in proximity of each other. These Spectrum Sharing Management Technologies also allows

GAA users to occupy licensed spectrum that is free of deployment by the licensee. Lastly, the CBRS allows licensees to lease their licenses over a private deployment to third parties, allowing the licensee to monetize their spectrum holdings, and thereby giving them an opportunity to be paid for their license. The lessee in turn gets access to spectrum that is protected from interference. The standards being developed by the WInnForum for The CBRS also aim to support a best-effort coexistence between GAA users who are not accorded regulatory protection. This coexistence is based on empirical knowledge-based models that attempt to glean the potential of users to interfere with one another, and may be aided by measurements from devices in the field.

5 Interference Considerations and Requirements

This section surveys the technical and operational considerations that determine whether Spectrum Sharing Management Technologies can prevent harmful interference and enable effective sharing in a particular spectrum band. In addition to supporting later discussion in this document, this section is also intended as a standalone contribution to assist regulators and other stakeholders. It provides a checklist of topics to assess when considering the use of Spectrum Sharing Management technologies in a band.

The analysis in this section is forward-looking. Research and development on Spectrum Sharing Management Technologies will be required to leverage some of the characteristics of users and spectrum dependent systems that this section describes as beneficial for use in a band.

The topics are organized in three categories.

1. User characteristics
2. Interference protection mechanisms
3. Interference management

The topics are illustrated with examples of users or spectrum dependent systems that exhibit the characteristics being discussed. The examples listed are for descriptive purposes only. The examples listed are not the only users or spectrum dependent systems that exhibit that characteristic, and not all instances of that type of user or spectrum dependent system exhibit that characteristic.

5.1 User Characteristics

The ability of Spectrum Sharing Management Technologies to prevent harmful interference in and enable effective sharing of a band depends strongly on the characteristics of the existing and potential users of that band. The term “users” in this section refers to users of all spectrum dependent systems operating in the band, irrespective of whether they are primary or secondary, legacy or new entrant, transmitter or receiver, communications or other types of spectrum dependent systems.

5.1.1 *Operator Characteristics*

Characteristic	Attributes beneficial for Spectrum Sharing Management Technologies	Attributes challenging for Spectrum Sharing Management Technologies
Responsible Entities	Entity responsible for transmitter or receiver is registered or licensed, so Spectrum Sharing Management Technologies can gather from or share information with the entity • Land mobile radio	Entity responsible for transmitter or receiver may be unknown, so Spectrum Sharing Management Technologies cannot interact with the entity • End-user deployed WiFi access point
Trust Level	Operator is trusted to configure equipment so that it complies with Spectrum Sharing Management Technologies directives • Public safety • Cellular operators	Operator may be untrusted or incompetent, and equipment lacks technical safeguards, creating non-negligible probability that equipment fails to comply with Spectrum Sharing Management Technologies directives. • WiFi access point that permits arbitrary end-user software modifications
Sensitivity of Operator Information	Operator or end user information is public, so Spectrum Sharing Management Technologies can make decisions that reveal it. • Television transmitter	Information about operator or end users is privacy sensitive, so Spectrum Sharing Management Technologies must have a high level of protection and assurance • Location of identified individuals • Information about operator or end users is restricted, so Spectrum Sharing Management Technologies may not be permitted to process it • Military • Law enforcement
RF/Operational Information Sharing	Users can provide information on usage or RF interference, so Spectrum Sharing Management Technologies can use the feedback to better manage spectrum sharing. • Weather radars • Internet service providers • LTE cells (technology-specific sensing)	Users are non-informing for technical reasons. • Broadcast television receivers • Personal earth stations Users are non-informing for non-technical reasons. • Military radars

5.1.2 Mission Characteristics

Characteristic	Attributes beneficial for Spectrum Sharing Management Technologies	Attributes challenging for Spectrum Sharing Management Technologies
Mission Priority	General or business critical mission, so spectrum access can be based on user willingness to pay. ● Internet access ● Agricultural SCADA ● Some industrial automation applications	Life-critical mission, so spectrum access guarantees are required. ● Vehicle-to-vehicle cooperative collision prevention ● Critical Infrastructure e.g. Power grid safety
Length of Acceptable Service Interruption to Protected Users	The longer a service interruption to protected users can be without harmful mission impact, the easier it is for Spectrum Sharing Management Technologies to achieve efficient sharing, because it can use lower cost techniques. Statistical analysis of aggregate interference: potential for up to 1 sec interruption. ● Acceptable for Internet Access Use statistical multiplexing and move secondary users to a new channel if overload arises: potential for up to 30 sec interruption ● Acceptable for IoT environmental sensors	The shorter a service interruption to protected users must be to avoid causing harmful mission impact, the harder it is for Spectrum Sharing Management Technologies to achieve efficient sharing, because it must use higher cost techniques. 1 sec interruption not acceptable: Spectrum Sharing Management Technologies must conservatively prevent aggregate interference events, leading to low mean utilization if secondary devices are mobile or in a dynamic fading environment. ● Remote transmission of live news gathering 1 sec acceptable, but 30 sec interruption not acceptable: Spectrum Sharing Management Technologies must assure that sum of max utilization by secondary devices assigned to a channel stays below threshold. ● Highway information sign updates

5.1.3 Equipment Characteristics

Characteristic	Attributes beneficial for Spectrum Sharing Management Technologies	Attributes challenging for Spectrum Sharing Management Technologies
Equipment Lifespan	Equipment lifespan < 4 years, so new features to support Spectrum Sharing Management Technologies can be deployed	Equipment lifespan > 12 years, so expensive hardware modifications are likely required to add new features to support Spectrum Sharing

	without retrofit • Mass-market consumer electronics Equipment lifespan 4-12 years, so existing electronics likely has the capability to retrofit new Spectrum Sharing Management Technologies features via firmware upgrade • Commercial infrastructure • Automotive	Management Technologies • Publicly funded users with specialized radio needs • Public safety • Military • Hospitals
Antenna Directionality	Device antenna is omnidirectional, or directional but fixed with known boresight, so Spectrum Sharing Management Technologies can easily predict interference to or from the device • Satellite earth station (geostationary) • Fixed Service microwave links	Device antenna is directional but moving unpredictably, so Spectrum Sharing Management Technologies cannot predict interference to or from the device without information from the user • Electronic News Gathering microwave receiver • Airborne radionavigation or radiolocation systems
Technical Safeguards	Equipment prevents untrusted operator or end user from misconfiguring or modifying the subsystem responsible for compliance with regulatory requirements and Spectrum Sharing Management Technologies directives. • Cellular telephone	Equipment lacks technical safeguards, and operator or end user may be untrusted or incompetent, creating non-negligible probability that equipment fails to comply with Spectrum Sharing Management Technologies directives. • WiFi access point that permits arbitrary end-user software modifications

5.1.4 System-Level Characteristics

Characteristic	Attributes beneficial for Spectrum Sharing Management Technologies	Attributes challenging for Spectrum Sharing Management Technologies
Control Subsystem	Devices are centrally controlled, so Spectrum Sharing Management Technologies can interact with a small number of central control points. • Internet service provider	Devices are not centrally controlled, so Spectrum Sharing Management Technologies must interact with a large number of independent devices. • Wireless microphones
Reachability	Devices are continuously reachable from the Internet, so Spectrum Sharing Management Technologies can interact with them as needed. • Smart home devices	Devices are intermittently reachable from the Internet, so Spectrum Sharing Management Technologies may not be connected when needed. • Automotive devices (rural areas) Devices may be unreachable from the Internet for long periods of time.

		● Wildlife tracking collars
Device Mobility	Devices are fixed or slowly moving, so Spectrum Sharing Management Technologies can make spectrum assignments based on actual location. ● WiFi access points	Devices are moving quickly, so interference footprint may change faster than Spectrum Sharing Management Technologies can react. ● Automotive internet access
Coherence Time	Usage and operating constraints are stable for periods of minutes, long enough that Spectrum Sharing Management Technologies can adjust to or optimize for those needs. ● Weather radar	Usage or operating constraints change, unpredictably, faster than Spectrum Sharing Management Technologies can react. ● Seismic event alerting network

5.2 Interference Protection Mechanisms

The ability of Spectrum Sharing Management Technologies to prevent harmful interference and provide effective sharing in a band depends significantly on the interference protection mechanisms of the equipment operating in the band. To function effectively, the Spectrum Sharing Management Technologies must predict acceptable parameters for spectrum sharing. The interference protection mechanisms of the spectrum dependent systems operating in the band determine whether this prediction is straightforward or challenging, how many degrees of freedom are available to the Spectrum Sharing Management Technologies, and how much protection margin is required. Therefore they determine how much scope the Spectrum Sharing Management Technologies have to achieve for efficient sharing of the band.

5.2.1 Interference Protection Methods at Transmitter

Each entry in the following table describes a control point on a Spectrum Dependent System (SDS) that is potentially useful for Spectrum Sharing Management Technologies. If the control point is available, this is beneficial because the Spectrum Sharing Management Technologies can use control over that attribute to prevent potential interference between SDS. If the control point is not available, this is challenging because the Spectrum Sharing Management Technologies must make worst-case assumptions.

Furthermore, each attribute listed in the “beneficial” column is only beneficial if (a) a third party such as Spectrum Sharing Management Technologies can predict the effectiveness of that mechanism in a given situation, or (b) the spectrum dependent system provides real-time feedback to the Spectrum Sharing Management Technologies about effectiveness. Lacking both these characteristics, the Spectrum Sharing Management Technologies must make worst-case assumptions and thus cannot rely on the mechanism when managing interference or seeking to increase spectrum utilization.

Characteristic	Attributes beneficial for Spectrum Sharing Management Technologies	Attributes challenging for Spectrum Sharing Management Technologies
Geographic Protection	Transmitter can alter behavior based on specified exclusion or coordination zones ● Unmanned Aerial Vehicle payload data link	Transmitter does not know its location. ● Wireless microphones
Temporal Protection	Transmitter can limit its operation to times when other spectrum dependent systems are not receiving	Transmitter does not have a reliable clock ● Low-power IoT sensors
Power Control	Transmitter can limit its radiated power based on Spectrum Sharing Management Technologies specified limits	Transmitter has no flexibility in power level
Spatial Protection	Transmitter can reduce energy radiated in specific directions or to specific locations specified by Spectrum Sharing Management Technologies ● Steerable antenna ● Antenna array ● MIMO	Transmitter cannot focus radiated energy ● Traditional omni and 3-sector antenna systems
Frequency Protection	Transmitter can exclude channels, notch or shape emissions to protect specific frequencies specified by Spectrum Sharing Management Technologies ● OFDM	Transmitter cannot protect specific frequencies within its operating range

5.2.2 Interference Protection Methods at Receiver

The entries in the following table describe mechanisms that receivers of Spectrum Dependent Systems (SDS) operating in the band may utilize to protect themselves against harmful interference. If the mechanism is present, this is beneficial for use by Spectrum Sharing Management Technologies in the band because the Spectrum Sharing Management Technologies have more freedom to authorize other users to transmit in the band. Entries in this table do not describe control points on SDS receivers; it is assumed that each SDS adaptively protects its own receivers against interference.

Furthermore, each attribute listed in the “beneficial” column is only beneficial if (a) a third party such as Spectrum Sharing Management Technologies can predict the effectiveness of that mechanism in a given situation, or (b) the spectrum dependent system provides real-time feedback to the Spectrum Sharing Management Technologies about effectiveness. Lacking both these characteristics, the Spectrum Sharing Management Technologies must make worst-case assumptions and thus cannot rely on the mechanism when managing interference or seeking to increase spectrum utilization.

Characteristic	Attributes beneficial for Spectrum Sharing Management Technologies	Attributes challenging for Spectrum Sharing Management Technologies
Spatial Protection	Receiver can adapt antenna gain to reduce undesired signal energy ● Steerable antenna ● Antenna array	Receiver lacks spatial protection
Spread-spectrum Gain	Receiver can utilize diversity techniques to exploit channel coding gain, spatial diversity, or spread spectrum processing gain to reduce impact of undesired signal energy	The transmission characteristics do not provide adequate diversity for advanced receiver techniques
Multi-User Detection and interference cancellation/sup-pression	Receiver can adaptively detect multiple signals or remove undesired signals through joint detection or successive cancellation	Receiver lacks the ability to use multi-user techniques or faces a diverse interference environment with unknown sources of interference.
Frequency Protection	Receiver can notch out or adaptively filter to mitigate narrowband interference	Receiver lacks ability to adapt around narrowband interferers

5.2.3 Interference Protection Methods at Higher Layers

The entries in the following table describe mechanisms that may be present at the MAC, network or higher layers of Spectrum Dependent Systems (SDS) operating in the band. If the mechanism is present, this is beneficial for use of Spectrum Sharing Management Technologies in the band because the Spectrum Sharing Management Technologies has more freedom to authorize other users to transmit in the band. Entries in this table do not describe control points on SDS; it is assumed that each SDS adaptively adjusts its behavior to mitigate interference or exploit available communications links/bandwidth.

Furthermore, each attribute listed in the "beneficial" column is only beneficial if (a) a third party such as Spectrum Sharing Management Technologies can predict the effectiveness of that mechanism in a given situation, or (b) the spectrum dependent system provides real-time feedback to the Spectrum Sharing Management Technologies about effectiveness. Lacking both these characteristics, the Spectrum Sharing Management Technologies must make worst-case assumptions and thus cannot rely on the mechanism when managing interference or seeking to increase spectrum utilization.

Characteristic	Attributes beneficial for Spectrum Sharing Management Technologies	Attributes challenging for Spectrum Sharing Management Technologies
Delay Tolerance at long time scales	Spectrum Dependent System can schedule data transfers over time scales compatible with Spectrum Sharing Management Technologies response latency. This gives Spectrum Sharing Management Technologies the freedom to provide intermittent spectrum access. ● Downloads of software updates	Data transfer timing not flexible at Spectrum Sharing Management Technologies response time scales, so Spectrum Sharing Management Technologies must provide continuous channel access.
Adaptable Data Rate	System can reduce data bandwidth to match available channel bandwidth, giving Spectrum Sharing Management Technologies the freedom to provide channels with best-available bandwidth.	Application data rate requirements not flexible.
Adaptable Routing	System can send data via multiple routes and select the best one dynamically, giving Spectrum Sharing Management Technologies the freedom to adjust spectrum access geographically ● Ad-hoc multi-hop network	Data routing not flexible.
Informing Protected User	System can announce its spectrum usage and/or level of interference, over-the-air or via Internet, to enable other users to avoid it	System has high peak-to-average usage ratio and does not inform Spectrum Sharing Management Technologies or others of its spectrum usage or interference levels
Informing New Entrant User	System can sense its environment and share actionable information with other users or the Spectrum Sharing Management Technologies, to enable protection of some users and more effective sharing with others	System cannot sense, or information provided is unreliable or not actionable.

5.3 Interference Management

The ability of Spectrum Sharing Management Technologies to prevent harmful interference in and provide effective sharing in a band depends significantly on the overall strategy for managing interference in that band.

5.3.1 Ex-ante vs. Ex-post Management

Both *ex-ante* and *ex-post* interference management strategies are viable for Spectrum Sharing Management Technologies. Hybrids are also viable.

An *ex-ante* interference management strategy, also called open loop, is characterized by features such as:

- Key users are non-informing or provide only coarse information
- Location or relevant operating characteristics of users are not reported
- Responsible entities may be unknown, unreachable, or non-existent (e.g. WiFi)

Effective application of Spectrum Sharing Management Technologies in an *ex-ante* situation requires predictability, for example of propagation losses and of statistical user distribution. Ordinarily the achieved spectrum utilization is limited by the design margins required to tolerate uncertainties in these predictions. As the uncertainty grows, the ability to use Spectrum Sharing Management Technologies goes down.

On the other hand, an *ex-post* interference management strategy, also called closed loop, is characterized by features such as:

- Key users export information about usage, interference energy, level of mission impact
- User location is reported (in real-time if moving)
- Responsible entities controlling nodes are known & reachable

Effective application of Spectrum Sharing Management Technologies in an *ex-post* situation requires reliable communications links between band users and the Spectrum Sharing Management Technologies. As the communication links become less available, a centralized solution like Spectrum Sharing Management Technologies becomes less effective than a peer-to-peer distributed solution.

5.3.2 Interference caused by nonconforming behavior

Interference caused by nonconforming behavior is a form of interference that requires special consideration. In this document, nonconforming behavior refers to any transmission that does not comply with regulatory requirements, device specifications, or Spectrum Sharing Management Technologies specified operating limits. Nonconforming behavior can arise from multiple causes:

- Type A: Prior to deployment
  - Software design fault (“bug”)
  - Design error
- Type B: Failures after deployment
  - Hardware failure
  - User error (if not detected/mitigated by device design)
- Type C: Intentional misconduct

- ○ Intentional misconfiguration by user (rogue)
- ○ Cyber attack by a third party (not user)
- ○ Cyber attack by user

Interference caused by nonconforming behavior may be managed *ex-ante* or *ex-post* similar to other sources of interference.

If the users of a band or their missions require *ex-ante* assurance of non-interference, then the risk of nonconforming behavior implies that devices sharing the band under the Spectrum Sharing Management Technologies control must be validated to prevent Type A and mitigate Type B causes and must have technical safeguards against Type C causes. The level of validation and the strength of the safeguards will be determined by the level of assurance required by the users or missions being protected.

For any given level of assurance, validation may be more expensive for Spectrum Sharing Management Technologies-controlled spectrum-sharing devices than for devices designed for operation in exclusively licensed spectrum, due to the complexity of the hardware-software spectrum access subsystem whose correct operation is required for non-interference. For any given level of assurance, technical safeguards may need to be stronger for Spectrum Sharing Management Technologies-controlled spectrum-sharing devices than for devices designed for operation in exclusively licensed spectrum, for two reasons. Users of spectrum-sharing devices may have an incentive to bypass or ignore Spectrum Sharing Management Technologies directives in order to increase spectrum access and device performance. Malicious actors may wish to leverage a scalable cyber-attack on cheap widely-deployed secondary devices into a denial-of-service jamming attack on protected users of the band.

If for some devices, the cost of validation to the required level cannot be supported in the marketplace, or the required technical safeguards cannot be deployed for technical or market reasons, then it will be challenging for Spectrum Sharing Management Technologies to provide safe access for those devices to share spectrum in that band.

If a band can support *ex-post* interference management, then nonconforming behavior by Spectrum Sharing Management Technologies-controlled devices can be managed through detection and reaction mechanisms, combined with lower-cost validation and less-intrusive technical safeguards than those required for high-assurance *ex-ante* interference prevention. This approach is more beneficial for Spectrum Sharing Management Technologies-based sharing of the band and may enable a broader range of users, devices, and markets to access shared spectrum in that band.

5.3.3 Definition of Harmful Interference

Currently, in many bands, harmful interference is not defined in advance. Instead, it is left unspecified until unacceptable conditions arise in the field, after which the definition emerges from case law and/or bilateral agreements between neighbors.

Spectrum Sharing Management Technologies define an automated management system, built and operated by a third party to mediate among the users of a band. These characteristics make the current approach to defining harmful interference unusable. Effective application of Spectrum Sharing Management Technologies requires multilateral agreement in advance regarding harmful interference. The agreement may be imposed by the regulator or achieved by a multi-stakeholder group. Recent proposed approaches such as harm claim thresholds and risk-informed interference analysis may be useful techniques to facilitate reaching the required agreement that enables the use of Spectrum Sharing Management Technologies[4].

6 Survey of frequency bands amenable to shared use

6.1 Introduction

Increasingly, industry and governments are beginning to view radio spectrum in economic terms, as an input to the production of telecommunications services. The economic value of the radio spectrum is determined by the total value of the services that can be provided to users of that spectrum, whether in pure market terms or, more broadly, in terms of overall benefits to society. It is maintained by some that the spectral fragmentation resulting from exclusive allocation and licensing models, aimed strictly at interference avoidance, has led to artificial scarcity and constraints, preventing the full economic potential of spectrum to be realized. Yet, there are examples that belie that opinion, e.g., the success of commercial mobile systems is owed in large part to exclusive licensing. It is perhaps clearer that there is a role for examining a mixture of policies, and for regulators to enable instruments for accessing spectrum under exclusive licensing, license-exempt operation and other shared regimes, with appropriate differentiation in the economic value that users may gain from such policies. The idea of spectrum sharing is to add economic value to a given frequency band by allowing additional, secondary users to access the band. The risk of increased interference levels, potentially reducing the value of the band for individual users, particularly the incumbent user(s), is managed by means of the mechanisms described in Section 5 of this report. Some frequency bands are more suitable to be shared than others due to their intrinsic properties and current use, or their relationships to band uses at adjacent frequencies or in different regions of the world.

This section provides a survey of frequency bands amenable to shared use. The criteria used for identifying such bands are based on the rationale that the bands most suitable for sharing are those whose total social and economic value can be increased the most. This potential added value depends strongly on spectrum management and business models and is especially difficult to assess for public-interest services such as national defense and flight safety, but these considerations are not within the scope of this section. We provide a qualitative description of the main factors determining the added value resulting from shared spectrum use and apply these to a variety of candidate bands in different (low, mid and high) frequency domains[5] in order to shortlist the most promising ones. As some factors apply differently in different parts of the world, the analysis is performed separately for the United States, Canada, Europe, and Asia and Oceania.

The band selection criteria used in this section are largely derived from and compatible with a 2012 report by the ITU on spectrum value and valuation,[6] and another by the U.S. President's

Council of Advisors on Science and Technology (PCAST) on sharing government-held spectrum[7] (the PCAST report).

6.2 Selection Criteria

To assess the potential added value resulting from shared use of a given frequency band, one must consider its present value, the multiplicity of applications for which it can potentially be used, and its value when used exclusively for any one of these applications, and then factor in the sensitivity of each user to increased interference from the others. While the present value of a band depends on the type and utilization rate of the incumbent service, its potential value to new users is a function of available bandwidth, propagation characteristics, harmonization potential across markets and, when factoring in interference, compatibility with the incumbent user(s) and existing users in adjacent bands. The degree of interference compatibility among new users is evidently another important factor determining the potential overall value of a given band, but it is not a useful selection criterion as it does not favor any candidate band over the others. The aforementioned band selection criteria are described in more detail in the following.

6.2.1 Current utilization rate

Underutilized frequency bands represent low present economic value and are therefore potentially good candidates for shared use. The utilization rate of a frequency band can be meaningfully defined with respect to frequency, time and geography. The 3550-3700 MHz CBRS band is an example of a band that is underutilized both temporally and geographically, and for which a spectrum access system based on real-time sensing and exclusion zones is well suited.

6.2.2 Available bandwidth

Wider frequency bands are generally more attractive for shared use, not only because achievable aggregate data rates are approximately proportional to available bandwidth, but also because they can be more efficiently shared and require relatively smaller guard bands imposed to prevent interference from adjacent bands. The PCAST report, for example, envisages the spectrum equivalent of a multi-lane superhighway that can accommodate a wide variety of compatible uses and new technologies that are more efficient with larger blocks of spectrum. More bandwidth is typically available at the higher frequency bands, in particular at mm-wave frequencies. However, depending on the application this advantage may be offset by adverse propagation characteristics associated with these bands, or other factors, such as increased equipment cost and/or reduced power efficiency.

6.2.3 Propagation characteristics

For many coverage-oriented applications, frequency bands located towards the lower end of the radio spectrum have the highest value per megahertz due to the lower infrastructure cost resulting from their tendency to have less propagation loss across free space and through buildings and foliage, in conjunction with the availability of relatively affordable radio frequency hardware. This consideration favors low-frequency bands, especially those in the UHF range, over higher-frequency ones, particularly those in the mm-wave range. For applications where high network capacity is of the essence, on the other hand, mid- and higher-frequency bands can be valuable in that their shorter interference range offers more opportunity for geographic spectrum reuse and sharing. At higher frequencies, efficient antennas are proportionately smaller than those at lower frequencies, so that beamforming techniques facilitated by physically compact antenna arrays have the potential to overcome some of the propagation limitations associated with mm-wave spectrum, possibly requiring current perceptions about spectrum quality and valuation to be revised in future.

6.2.4 Harmonization potential

Other factors being equal, those frequency bands that can be made available for shared use regionally or even globally will represent the greatest potential added value. Without such harmonization, it will be more challenging for innovative products to evolve into viable ecosystems and achieve market success, due to insufficient economies of scale and reduced scope for cross-border frequency coordination and interoperability and roaming agreements. In practice, however, some countries (notably the United States) have adopted, with great success, several mobile bands that are not harmonized with other regions, so this consideration is often overstated.

6.2.5 Compatibility with Incumbent and adjacent-band users

The potential added value associated with shared use of a given frequency band depends on the characteristics of existing users in the target and frequency-adjacent bands. In general, the stricter these users need to be protected, the less attractive the band will be due to the higher degree of complexity and tighter access constraints imposed by sharing and emission rules. Any significant potential for harmful interference by existing services will further reduce the attractiveness of the band. In assessing the sharing capacity of a given band it is therefore important to consider both the transmitter licensing conditions and receiver performance specifications associated with all legacy systems utilizing the target and adjacent bands, and the degree to which they can co-exist with new users. It is typically advantageous to group together spectrum users with similar interference generating and tolerating characteristics, i.e., to select for sharing those frequency bands whose incumbent and, ideally, adjacent-band user(s) have technical specifications similar to the new users. Examples of services that are often inherently incompatible with broadband mobile applications, and therefore require stricter, typically more complex interference protection mechanisms, include radionavigation (e.g., GPS and radar), Earth observation and broadcasting. To facilitate clustering of compatible applications, it has been suggested that spectrum regulators set, for each shareable band, specific minimum technical standards not only on transmitter emissions, but also on receiver performance.

In addition, radios have to be designed with requirements on out-of-band emissions and in-band characteristics as well. Dynamic spectrum sharing can lead to unpredictable interference due to poor Adjacent Channel Interference Radio (ACIR) characteristics. At the same time, economic viability of a regulatory policy that admits sharing must account for the constraints placed on specific use cases by the market. Every radio will spill energy across the entire band of operation, and the Spectrum Sharing Management Technologies may have to take into account the impact of aggregate interference due to in-band users occupying other channels.

6.3 Ranking Methodology

Table 1 shows a possible high-level definition for the ranking of each criterion as it applies to flexible sharing. A higher number of bullets indicates that a given frequency band is more amenable to shared use. As previously mentioned, poor compatibility with incumbent and adjacent band users can be mitigated by means of interference protection mechanisms (e.g., Spectrum Sharing Management Technologies). As these mechanisms can be applied to any band, this does not impact and is not considered in the ranking criterion.

Table 1: Ranking definition for the criteria

Criterion	Ranking Definition			
	●●●	●●○	●○○	○○○
Current utilization	Mostly limited to rural areas	Temporally low in most densely populated areas	Temporally high in some/parts of densely populated areas	Temporally high in most densely populated areas
Available bandwidth	> 200 MHz	50-200 MHz	20-50 MHz	< 20 MHz
Propagation characteristics	< 3.7 GHz	3.7-24 GHz	> 24 GHz	N/A
Harmonization potential	Global harmonization potential	Regional /Partial harmonization potential	No perceived harmonization potential	N/A
Compatibility of incumbent and adjacent-band users	Low sensitivity to interference Unlikely to emit harmful interference	Low sensitivity to interference Likely to emit harmful interference	High sensitivity to interference Unlikely to emit harmful interference	High sensitivity to interference Likely to emit harmful interference

6.4 Canada

Innovation Science and Economic Development Canada (ISED), the spectrum regulator in Canada, have published a recent report on Spectrum Outlook for 2018-2022[8]. Four domains of spectrum use were considered in the Spectrum Outlook as being of immediate interest – commercial mobile broadband, license exempt spectrum use, backhaul and satellite communications. The interest in these domains reflects the technological developments and growth in demand for spectrum that are occurring in relation to all of these services and/or applications, and the need to enable the continued development of a robust wireless infrastructure in Canada.

Consumer demand for broadband services with faster data rates and more sophisticated applications has been driving an increase in the spectrum requirements for commercial mobile, as well as license-exempt applications. In fact, the increased demand for broadband services has created a ripple effect on the demand for backhaul spectrum and has, where commercial mobile traffic is being off-loaded, impacted the demand for license-exempt spectrum.

New services enabling the Internet of Things (IoT) are also creating additional traffic in spectrum used for both commercial and license-exempt applications. As stated by ISED, as demand for spectrum increases, traditional services are competing with new services to use the same spectrum. While technological innovations have led to great improvements in the efficient use of spectrum in wireless communications, the search for new spectrum continues. Currently, existing services are often moved to another band to free up spectrum for new uses. In the future, ISED believe this approach of moving incumbents will not always be possible given the extent to which spectrum is already being used. However, new technologies and techniques (e.g. cognitive radio, dynamic spectrum access, smart antennas, data analytics, prediction and learning techniques) that are being developed that will change the way spectrum is accessed through, for instance, intelligent proactive decision making solutions based on prediction, learning, and band geographic/operational awareness of the radio environment. These technologies and techniques will provide new opportunities for optimizing the use of spectrum and promise to make it increasingly feasible to dynamically share spectrum in real time between multiple different services.

6.4.1 Evaluation of Frequency Bands

Table 2 illustrates how the ranking definitions map to some of the frequency bands that could potentially be made available for new use in Canada to support the demand for broadband services. It is worthwhile noting that, in some cases, the selection criteria are interdependent. For example, while some services are very sensitive to interference, if they are not in use or hardly used in a band, then the overall ranking would be higher (e.g. interdependence between utilization and compatibility)

Detailed explanations of the identified bands along with discussions on how they map to the ranking criteria are elaborated in this section.

Table 2: Mapping of the ranking definition to the bands of interest

Frequency Band	Ranking				
	Utilization	Bandwidth	Propagation	Harmonization	Compatibility
800 MHz (806-821/851-866 MHz)	●●○	●○○	●●●	●●○	●●○
900 MHz (896-960 MHz)	●●○	●●○	●●●	●○○	●●○
L-band (1427-1518 MHz)	●●○	●●○	●●●	●●●	●●●
3500 MHz (3400-3800 MHz)	●●●	●●○	●●○	●●○	○○○
Lower C-band (3700-4200 MHz)	●●●	●●●	●●○	●●○	●○○
Upper C-band (5925-7055 MHz)	●○○	●●●	●●○	●●●	●○○
28 GHz (27.5-28.35 GHz)	●●○	●●●	●○○	●●●	●○○
39 GHz (37-40 GHz)	●●●	●●●	●○○	●●●	●○○
64-71 GHz	●●●	●●●	●○○	●●●	●○○

6.4.2 800 MHz Band

Currently in Canada, the 800 MHz band (806-824/851-869 MHz) is allocated to mobile and fixed communications services and is divided in two blocks. The first block (806-821/851-866 MHz) allows the use of fixed point-to-point and land mobile systems. The second block (821-824/866-869 MHz) is designated for exclusive use by public safety systems and is highly used in Canada within key markets.

There is an already available commercial mobile ecosystem in this band and a reduced demand for commercial narrowband wireless systems. Given these trends outlined in the 2018 outlook report, it is anticipated that the block from 806-821/851/866 MHz would provide 2 blocks of 10 MHz within Canada of additional spectrum to be made available for broadband commercial mobile.

6.4.3 900 MHz Band

The 900 MHz frequency band has traditionally been used in Canada for land mobile radio, license-exempt applications, paging, multipoint communications systems, narrowband Personal Communications Service (PCS) and fixed services. The demand for these services in this band is low and there are relatively few licenses in these bands compared to other land mobile radio bands. Although 60 MHz of bandwidth could be extended for use for commercial mobile, license-exempt, and fixed services, there are many incumbents in the band that would make dynamic spectrum sharing more complex as additional constraints would need to be considered in the design of an appropriate shared spectrum access system. There is also limited activity regionally and internationally regarding the harmonization of this band.

6.4.4 L-Band

Currently in Canada the L-band is used for subscriber radio service (SRS), which is limited to rural areas, and Narrowband Multipoint Communication Systems (N-MCS) which is used for data communication between "home" (i.e. devices installed in residential and commercial buildings) and hub stations, or between hub stations. The band 1427-1432 MHz is also being used for automatic meter reading and rural telephone services while the band 1427-1429.5 MHz is available for license-exempt medical telemetry in health-care centers, not available near radar stations in Nova Scotia, Newfoundland and Labrador. The L-band can be considered an important band for future 5G deployments as it is globally harmonized, that adjacent bands support LTE and it is expected to be a global equipment ecosystem. ISED considers that the L-band or portions could be released for fixed and mobile use.

6.4.5 3500 MHz

Currently in Canada, the 3500 MHz band is occupied by many types of incumbents as shown in Figure 3. There are four portions of the 3500 MHz band which different incumbents currently occupy (3400-3475 MHz, 3475-3650 MHz, 3650-3700 MHz and 3700-3800 MHz). In 2014, ISED released a document/report on "Decisions Regarding Policy Changes in the 3500 MHz Band (3475–3650 MHz) and a New Licensing Process", which included a fundamental reallocation of the band 3475-3650 MHz to allow mobile services and indicated that future mobile use would be subject to consultation. [9]

Comments received indicated a strong interest in releasing the 3500 MHz band for flexible use for commercial mobile and fixed use.

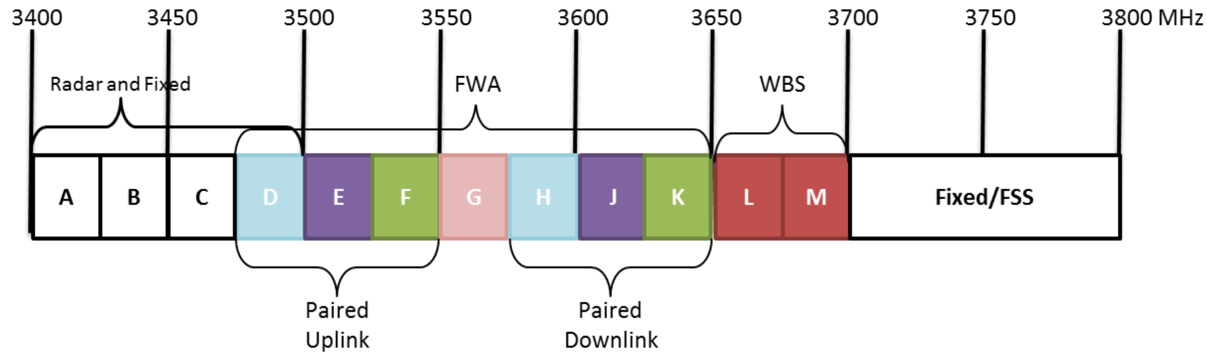

Figure 7: Incumbents in Canada in the 3500 MHz band

6.4.6 Satellite C-Band (3.7-4.2 GHz)

There appears to be extensive interest and consensus globally on the use of C-Band spectrum for 5G. There is a large amount of spectrum available in these bands.

Nearly all C-band communication satellites use the band of frequencies from 3.7 to 4.2 GHz for their downlinks, and the band of frequencies from 5.925 to 6.425 GHz for their uplinks. This band is typically used to transport voice, video and data services to satellite-dependent rural and remote communities that are not served by terrestrial transport networks.

In the lower C-band (3.7 to 4.2GHz) Incumbents are fixed service (FS) point-to-point (P2P) station radio relays and fixed-satellite service (FSS) earth stations.
In Canada, fixed stations are for rural backhaul (e.g. in Ontario, Nova Scotia and British Columbia). They have decreased substantially over the past decade, especially in the vicinity of most urban centres, as fixed links have been replaced by fibre networks. FSS earth stations can be classified into two groups:

- Licenced: stations primarily used for telecommunications backbone in the north and defense systems.
- Unlicensed/unregistered: receive-only stations (exact number/location unknown, though it is expected the number has decreased substantially since the advent of direct-to-home (DTH) satellite broadcasting, which uses Ku-band frequencies.)

The Northern Sky Research (NSR) Global Satellite Supply and Demand Study 13th Edition[10] expects the demand for C-band applications in Canada to follow a downward trend and decrease slightly over the next five years, as consumers move away from cable television services towards over-the-top (OTT) applications on the Internet. The 2014 CRTC Satellite Inquiry Report[11] stated that a significant portion of C-band capacity in Canada remained unused and the CRTC anticipated that the C-band would, in many instances where feasible, be increasingly overtaken by High-Throughput Satellites (HTS) services that currently use Ka-band frequencies. Given these trends, a significant surplus of C-band capacity in Canada is expected, which suggests that there is an opportunity to reassess how it could be more optimally used in the future. Exploring the potential of sharing the spectrum between FS, FSS and other services is a key component in determining the optimum use of the band.

6.4.7 28 GHz Band

In Canada, the use of spectrum in this band uses the soft partitioning concept that allows several services to access the spectrum, but with priority given to one service over the others. In the 28 GHz band, fixed services are given priority over fixed-satellite service systems sharing this spectrum. Fixed-satellite service implementation in this band is limited to applications that pose minimal constraints upon the deployment of fixed service systems, such as a small number of large antennas for feeder links.[12] This band is currently allocated to fixed service for Local Multipoint Communication Systems (LMCS).[13] Fixed radio systems with frequency-division duplexing (FDD) and/or time-division duplexing (TDD) operation are also permitted to be deployed.[14]

In the future, ISED suggests that priority be given to fixed and mobile over fixed-satellite in this band. Flexible use terrestrial stations and FSS earth stations could be managed by applying the existing site-by-site coordination process to all flexible use stations (i.e. both fixed and mobile stations) as well as FSS earth stations. However, ISED is still unsure about this approach and seeks comments as to whether a trigger for coordination should be established to further facilitate coordination.

In Canada soft partitioning is being considered for sharing spectrum between different services with priority given to mobile service systems over fixed satellite systems.

6.4.8 37-40 GHz Band

In Canada, fixed and mobile services are allocated in the frequency band 37-40 GHz, fixed-satellite service (space-to-Earth) in the frequency band 37.5-40.0 GHz, space research service (space-to-Earth) in the frequency band 37-38 GHz , and mobile-satellite service(space-to-Earth) in the frequency band 39.5-40 GHz; all on a co-primary basis while Earth exploration-satellite service (space-to-Earth) is allocated on a secondary basis in the frequency band 37.5-40 GHz.

There is currently no satellite use, including fixed-satellite, space research, mobile-satellite, and Earth exploration-satellite services, in the frequency band 37.5-40 GHz. However, the fixed-satellite industry has expressed interest in this band paired with the Earth-space band around 50 GHz as the next bands to be commercially developed, since the Ku and Ka bands are becoming increasingly congested.

Similar to the 28 GHz frequency band, ISED is proposing to make the frequency band 37-40.0 GHz available for flexible use for terrestrial services including both fixed and mobile services.

In order to facilitate the introduction of flexible use services in this frequency band, ISED's consultation on releasing mmWave spectrum report states that "provisions will need to be developed to ensure their co-existence with existing services. Considerations for coexistence between flexible use terrestrial stations and earth stations in the fixed-satellite service (space-to-Earth) are very similar to those in the frequency band 27.5-28.35 GHz". As noted in the previous sub-section, such considerations may include power limits for devices as well as sharing rules.

6.4.9 60-71 GHz Band

In Canada, Fixed, mobile (except aeronautical mobile) and inter-satellite services are allocated in band 64-65 GHz on a co-primary basis; radio astronomy observations may also be carried out in this portion of the band. Fixed, mobile except aeronautical mobile, inter-satellite, earth exploration satellite and space research services are allocated on a co-primary basis in band 65-66 GHz. Band 64-66 GHz is Fixed and band 66-71 GHz is allocated to mobile, inter-satellite, mobile-satellite, radio-navigation, and radio-navigation-satellite services on a co-primary basis.

Even though this band is allocated to some services, there are no existing users of this band by any service in Canada. There are no Canadian spectrum utilization policies addressing this frequency band.

6.5 U.S.

Consideration for spectrum sharing in the U.S. are similar to other countries and regions, but the band-by-band details often differ. One important consideration is that some bands, or some specific frequencies, in the U.S. have been (or will be) auctioned to the highest bidder, typically with the expectation of exclusive use. While ownership of the spectrum is retained by the U.S. government, the winning bidders rightfully have an expectation that they will be permitted exclusive use of the band or frequency during the duration of their license. General sharing of these bands is unlikely based on policy and economic considerations, at least without very tight control by the incumbent licensee. Although two-tiered shared use of such a band under incumbent control could be facilitated by Spectrum Sharing Management Technologies, for the purpose of this analysis, we excluded from consideration any auctioned spectrum.

The U.S. has a unique allocation system in that bands may be allocated for federal government use, for non-federal-government use, or for a combination of the two. Most bands fall in the latter category. In recent years, some bands allocated for federal use have been considered for sharing. For example, the 3550-3650 MHz portion of the Citizens Broadband Radio Service (CBRS) band was almost exclusively used for federal government operations but is now available for sharing with CBRS, under control of Spectrum Sharing Management Technologies. In this document, some bands reserved for exclusive federal use are considered for future spectrum sharing opportunities.

6.5.1 Evaluation of Frequency Bands

The following table shows bands that have been identified in the U.S. for potential re-allocation or for changes in rules that accommodate new services or new applications.

Table 3: Mapping of the ranking definition to the bands of interest

Frequency Band	Ranking				
	Utilization	Bandwidth	Propagation	Harmonization	Compatibility
1300-1350 MHz	○○○	●○○	●●●	●○○	●●○
1780-1830 MHz	○○○	●○○	●●●	●○○	●○○
3450-3550 MHz	●○○	●●○	●●●	●●○	●○○
3700-4200 MHz	●○○	●●●	●●○	●●○	●○○
4400-4490 MHz	●●○	●●○	●●○	●○○	●●○
4500-4800 MHz	●●○	●●○	●●○	●○○	●●○
5925-6425 MHz	○○○	●●●	●●○	○○○	●○○
6425-7125 MHz	○○○	●●●	●●○	○○○	●○○
24250-24450 MHz	●●○	●●○	●○○	●●○	●●○
24750-25250 MHz	●●○	●●●	●○○	●●○	●●○
27500-28350 MHz	●●○	●●○	●○○	●●●	●●○
31800-33400 MHz	●○○	●●●	●○○	○○○	●○○
37000-40000 MHz	●●●	●●●	●○○	○○○	●●○

6.5.2 1300-1350 MHz

Multiple U.S. government agencies use different portions of this band for aviation and weather radar systems.[15] As a result of the Spectrum Pipeline Act[16] which requires the identification of at least 30 MHz of spectrum below 3 GHz for reallocation from federal to non-federal use, and a subsequent draft bill (the AIRWAVES Act), the agencies are studying whether the radar operations in this band can be consolidated into a single system called the Spectrum Efficient National Surveillance Radar (SENSR), thus freeing up a portion of the band.

6.5.3 1780-1830 MHz

This band is adjacent to the Advanced Wireless Services 3 (AWS-3) band which is in the process of clearing from federal use to non-federal use for mobile broadband (with sharing in certain geographic areas where the federal operations cannot be cleared). As a result of the Spectrum Pipeline Act and the draft AIRWAVES Act, and a subsequent draft bill, this band is also under consideration for clearing/reallocation. The band could potentially be paired with 1300-1350 MHz for mobile broadband under a (relatively antiquated) Frequency Division Duplex (FDD) scheme.
According to the National Telecommunications and Information Administration:[17]

Operations in the 1755-1850 MHz band consist of military tactical radio relay, air combat training systems, tracking, telemetry, and control data communications for control of spacecraft. Federal agencies and the military also use this band for law enforcement video surveillance and robotics, terrestrial telemetering operations for aircraft, missile flight testing, fixed point-to-point microwave relay communications and unmanned aerial systems.

While this description does not split out the 1780-1830 MHz portion explicitly, it's clear that a variety of federal systems operate in the band. Exact deployments are not known as the federal government authorization database is not public. For ranking purposes, the worst-case is assumed.

6.5.4 3450-3550 MHz

In the United States, military radar systems currently operate in the 3450-3550 MHz band. DOD plans to submit a proposal under the Spectrum Pipeline Act to carry out a comprehensive radio-frequency engineering study to determine the potential for introducing advanced wireless services in this band without harming critical government operations. We hope the result of this hard work will be a "win-win," enabling the continuing growth of the U.S. wireless industry while protecting radars that are vital for national security.

According to the National Telecommunications and Information Administration:[18]

The Department of Defense (DoD) uses the band 3300-3500 MHz for operating various types of shipborne, land-based, and aeronautical mobile radar systems for national defense purposes.

Spectrum observations in a coastal area near significant Navy operations show that the band is heavily used for Navy radar.

6.5.5 3700-4200 MHz

As in most other regions, in the U.S. the band 3700-4200 MHz is used primarily for FSS downlinks, with minor use for FS point-to-point links. The band is allocated for non-federal services only. As of 2018, the FCC is considering more intensive use of the band for broadband delivery by potentially adopting service rules that would allow part or all of the band to be used by some combination of flexible use under a mobile allocation and by point-to-multipoint (P2MP) systems under the existing fixed allocation.

6.5.6 4400-4490 MHz

According to the National Telecommunications and Information Administration:[19]

The 4400-4500 MHz band is used for Federal Government fixed and mobile services. This band is one of the few available to the military for training. The band supports fixed Line of Sight (LOS) and transportable-fixed point-to-point microwave systems, drone vehicle control and telemetry systems. In addition to the military systems, the civilian Federal agencies also have systems in the band for nuclear emergencies and law enforcement activities. The 4400-4500 MHz band is a sub-band of the larger 4400-4940 MHz Federal Government band. Many systems authorized to operate in the 4400-4500 MHz band typically have a tuning capability from 4400-4940 MHz.

6.5.7 4500-4800 MHz

According to the National Telecommunications and Information Administration:[20]

The 4500-4800 MHz band is a sub-band of the larger Federal Government band that extends from 4400 to 4940 MHz. Many federal systems authorized in the 4500-4800 MHz band have tuning capabilities in the larger 4400-4940 MHz band. The Federal Government operates line-of-sight and trans-horizon radio communications in the 4500-4800 MHz band. Federal applications in the band support Department of Defense (DOD) training exercises at military facilities. Other Federal applications in the band include air-to-ground operations for command and control, telemetry to relay data, and various range systems. In addition to DOD applications, the federal agencies also have operations in the band for video, law enforcement, drug interdiction missions and nuclear emergency response activities.

6.5.8 5925-6425 MHz

According to the FCC:

The 500 megahertz of bandwidth in the 5.925-6.425 GHz band is currently allocated in the United States exclusively for non-Federal use on a primary basis for FSS (Earth-to-space) and FS. For FSS, the 5.925-6.425 GHz band (Earth-to-space) is associated with the 3.7-4.2 GHz band (space-to-Earth) and referred to collectively as the conventional C-band. There are about 1,535 earth station licenses in the 5.925-6.425 GHz band. While most of the earth stations operate at fixed locations, earth stations on vessels also operate in this band on a primary basis. Additionally, one licensee, Higher Ground, has been granted a waiver to operate mobile devices that transmit to geostationary satellites to provide consumer-based text messaging/light email and Internet of Things (IoT), protecting terrestrial operations by using a database-driven, permission-based, self-coordination authorization system. The 5.925-6.425 GHz band is also used for the transmission of command signals transmitted by Earth stations, typically near 5.925 or 6.425 GHz.

The 5.925-6.425 GHz band is also heavily used for FS. FS licensees may be authorized to operate point-to-point microwave links with up to 120 megahertz of paired spectrum for each authorized path. Individual paired channels may be assigned in specified bandwidths ranging from 400 kilohertz up to 60 megahertz. The Commission's licensing records reflect that more than 27,000 licenses are issued for point-to-point operations in this band. FS operations support a variety of critical services such as public safety (including backhaul for police and fire vehicle dispatch), coordination of railroad train movements, control of natural gas and oil pipelines, regulation of electric grids, and backhaul for commercial wireless traffic.

6.5.9 6425-7125 MHz

According to the FCC:

The 700 megahertz of bandwidth in the 6.425-7.125 GHz band is currently allocated in the United states exclusively for non-Federal use on a primary basis for FS at 6.525-7.125 GHz, Mobile Service at 6.425-6.525 GHz and 6.875-7.125 GHz, and FSS at 6.425-6.700 GHz and 7.025-7.075 GHz for uplink and at 6.700-7.025 GHz for both uplink and downlink.

FSS operations in the 6.425-7.125 GHz band (earth-to-space) are less intensive than in the 5.925-6.425 GHz band. In the 6.615-6.687 GHz band, currently the only Commission authorization is for feeder links for one radionavigation satellite. FSS operations in the 6.700-7.075 GHz band (spaceto-Earth) are limited by rule to feeder links for NGSO MSS in the space-to-Earth direction, while in the band 7.025-7.075 GHz such operations are further limited to two grandfathered satellite systems. Currently there are about 65 FSS earth station licenses in the 6.425-7.075 GHz band. One foreign-licensed FSS space station is authorized for U.S. market access in the Earth-to-space direction in the 6.725-7.025 GHz band.

Mobile operations are permitted in the 6.425-6.525 GHz band in channel bandwidths ranging from 1 megahertz to 25 megahertz licensed pursuant to parts 74 (BAS), 78 (CARS), and 101 (mobile including Local Television Transmission Service) of our rules. Mobile operations are also permitted in the 6.875-7.125 GHz band. The Commission's licensing records reflect that 139 BAS, 26 CARS, and 243 Part 101 licenses are issued for mobile operations in the 6.425-6.525 GHz band, and 346 BAS, 19 CARS, and 38 Part 101 licenses are issued for mobile operations in the 6.875-7.125 GHz band.

For fixed operations, FS licensees in the 6.525-6.875 GHz and 6.875-7.125 GHz bands may be authorized to operate point-to-point microwave links on paired channels assigned in specified bandwidths ranging from, respectively, 400 kilohertz to 30 megahertz and 5 megahertz to 25 megahertz. Fixed BAS operations are also authorized in these bands. The Commission's licensing records reflect that approximately 18,000 and 4900 licenses have been issued for point-to-point operations, respectively, in the 6.525-6.875 GHz and 6.875-7.125 GHz bands. The FS and BAS operations in these bands support a variety of critical services such as public safety (including police and fire vehicle dispatch), coordination of railroad train movements, control of natural gas and oil pipelines, regulation of electric grids, backhaul for wireless traffic, television studio-transmitter links (STLs), television relay, and television translator relay stations.

6.5.10 24250-24450 MHz and 24750-25250 MHz

The FCC has adopted these bands for fixed and mobile use under its "Spectrum Frontiers" proceeding.[1] According to the FCC:

There are two types of fixed licenses in this band. The 24 GHz Service has a total of 176 Economic Area (EA) or EA-like service areas. In 2004, the Commission held Auction 56, in which it made 890 24 GHz licenses available. Only seven of the 890 licenses were sold, and five of those licenses are currently active. In addition, [one company] holds a total of 38 pre-auction Digital Electronic Messaging Service licenses in this band.

There are no Federal allocations in the 24.25-24.45 GHz or 24.75-25.25 GHz band segments. The 24.75-25.25 GHz band segment is non-Federal allocated for FSS (Earth-to-space), and the 25.05-25.25 GHz band segment also has a co-primary allocation for non-Federal Fixed Service. A footnote to the U.S. Table of Frequency Allocations provides that the use of the 24.75-25.25 GHz band by the FSS (Earth-to-space) is limited to feeder links for the Broadcast Satellite Service (BSS). Section 25.203(l) of the Commission's rules provides that applicants for feeder

[1] https://www.fcc.gov/document/spectrum-frontiers-ro-and-fnprm

link earth station facilities operating in the 25.05-25.25 GHz band may be licensed only where no existing Fixed Service licensee has been authorized, and shall coordinate their operations with 24 GHz Fixed Service operations if the power flux density of their transmitted signal at the boundary of the Fixed Service license area is equal to or greater than −114 dBW/m2 in any 1 MHz. The 17/24 GHz Broadcasting-Satellite Service Report and Order determined that future Fixed Service systems locating near an authorized 17/24 GHz BSS feeder link earth station may not claim protection from interference from the feeder link earth station's transmissions, provided that those transmissions are compliant with the Commission's rules, and that future 24 GHz Fixed Service applicants would be required to take into account the transmissions from the previously authorized earth station when considering system designs, including their choices of locations for their license areas. There are four active licenses for feeder link earth stations in the 24.75-25.25 GHz band segment and one pending application….

There is no mobile allocation in either of the 24 GHz band segments, and no fixed allocation at 24.75-25.05 GHz.

As of this writing, an auction of 24 GHz licenses is scheduled to begin on November 14th, 2018. The licenses will be on a Partial Economic Area (PEA) basis, with seven licenses each of 100 MHz bandwidth up for bids. Operations will be under the FCC's Upper Microwave Flexible Use Service (UMFUS).

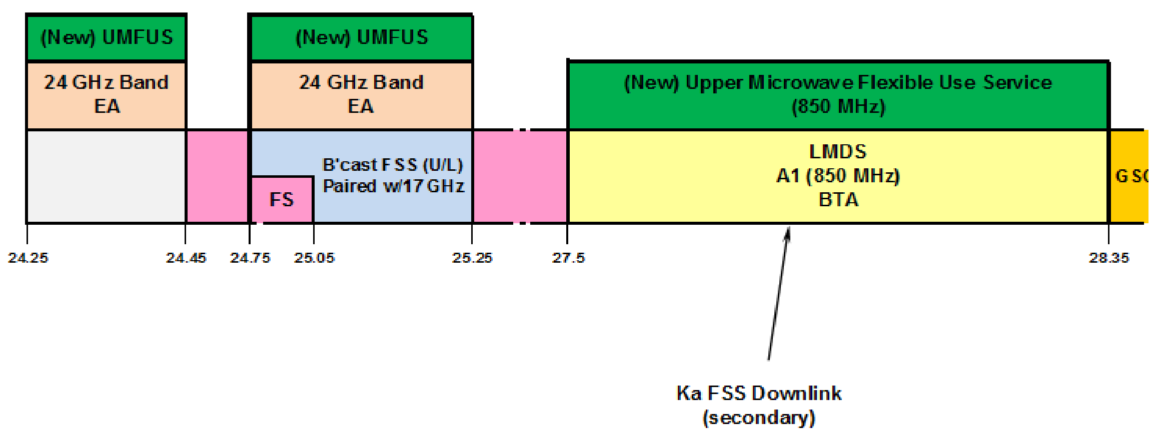

Figure 8: Example of 24 & 28 GHz Band Plans

6.5.11 27500-28350 MHz

This band has traditionally been available as part of the Local Multipoint Distribution Service (LMDS) under a primary allocation to the fixed service. The band is also allocated to FSS (Earth-to-space) on a co-primary basis, but the FCC's rules provide that FSS is secondary to LMDS.

The FCC recently approved mobile operations in the band under its Spectrum Frontiers proceeding. Mobile operations will be under the FCC's Upper Microwave Flexible Use Service (UMFUS), and will be licensed on a county basis. Existing LMDS licensees in the band will be granted mobile operating rights. As of this writing, an auction of the remaining 28 GHz licenses is scheduled to begin on November 14th, 2018.

The band has a primary mobile allocation throughout the world.

6.5.12 31800-33400 MHz

The FCC is considering opening the 31.8-33.4 GHz band under UMFUS as part of the Spectrum Frontiers proceeding. However, questions remain regarding protection of and compatibility with "existing aeronautical and shipborne radar use of the band, future radionavigation and other federal services, as well as deep space research in the 31.8-32.3 GHz portion of the band."[2] There are also concerns related to the protection of passive services (radio astronomy and Earth exploration-satellite services) in the adjacent 31.3-31.8 GHz band.

6.5.13 37000-40000 MHz

The FCC's Spectrum Frontiers proceeding considered two bands in this range: 37-38.6 GHz and 38.6 - 40 GHz.

There are no non-federal operations in the 37-38.6 GHz portion. The band is used by the federal government for space research earth stations and radio astronomy receiving sites in several locations. There are primary non-federal allocations for fixed, mobile, and FSS (space-to-Earth), but no use for such purposes currently.

6.6 Europe

6.6.1 Evaluation of Frequency Bands

Table 4 illustrates how the ranking definitions map to the frequency bands that could potentially be made available for new use in Europe to support the demand for broadband services. Detailed explanations of the identified bands along with discussions on how they map to the ranking criteria are elaborated in this section.

[2] FCC 16-89, para. 391

Table 4: Mapping of the ranking definition to the bands of interest

Frequency Band	Ranking				
	Utilization	Bandwidth	Propagation	Harmonization	Compatibility
700 MHz (FR)	●○○	●○○	●●●	●○○	●●○
2.3 - 2.4 GHz	●●●	●●○	●●○	●●●	○○○
C-band (3.4 - 3.8 GHz)	●●○	●●○	●●○	●●●	●○○
C-band (3.8 - 4.2 GHz)	●○○	●●○	●●○	●●○	●○○
24.65 - 25.25 GHz, 27 - 27.5 GHz	●●●	●●●	●○○	●●○	●●○
25.5 - 27 GHz	●○○	●●●	●○○	●●○	○○○
Q/V band (above 37 GHz)	●●●	●●●	●○○	●●○	●●○

6.6.2 700 MHz (France)

The French Ministry of Interior (MoI) is evaluating the possibility for sharing spectrum between French PPDR and commercial spectrum based on Licensed Shared Access (LSA) techniques in the 700 MHz frequency band (3GPP Band 28). The overall objective for the MoI is to move from a 2G network (Tetrapol) to a LTE/4G network shared by all operational groups with, among other things, an interest for using of commercial spectrum by the PPDR in an area not covered by the MNO and for PPDR operation on the MNO's commercial frequencies in case of doubt / problem on the commercial network. The MoI plans a launch of tender offer procedure in early 2019 and an implementation in 2021.

6.6.3 2.3 - 2.4 GHz

The band - a band harmonized for mobile broadband at international level - is used by many important services in some European countries, while being hardly used in other countries. The 2.3 GHz band was identified for IMT services at a global level at WRC-07. It has been standardised for LTE TDD by 3GPP. In Europe the band is not currently used to provide mobile broadband services; rather it is mainly used by a mix of amateur services (secondary), government use (e.g. military, including aeronautical telemetry, emergency services and wireless cameras) and PMSE applications (video links, wireless cameras). The European Commission in 2014 gave a mandate to the European Conference of Postal and Telecommunications Administrations (CEPT) to identify harmonised technical conditions for spectrum sharing in 2300 2400 MHz band. In response, the CEPT has developed a set of technical recommendations on the methodology, known as Licensed Shared Access (LSA) and the relevant sharing conditions. The LSA approach envisaged exclusive shared use of the spectrum in time, location and frequency with the incumbent who uses its spectrum allocation infrequently or less extensively. With the emergence of 5G and the lack of interest received by LSA at the time it was considered, there is an opportunity for a more dynamique approach such as the Spectrum Sharing Management Technologies enabling more business use cases.

6.6.4 3.4 - 3.8 GHz C-band

This band is targeted for early deployment of 5G systems in Europe and worldwide. The EU Radio Spectrum Policy Group (RSPG), in its 5G Opinion released in November 2016, specifically identifies this band as the primary band suitable for the introduction of 5G-based services in Europe before 2020. This band is used by FSS downlinks in many areas of the world and is seen a very important legacy band for FSS in particular in areas with adverse propagation conditions in higher FSS bands. An sharing scheme could permit to maintain those legacy FSS uses even if 5G systems are deployed, by avoiding an eviction effect generally observed when mobile services are authorized. Additionally, this band being allocated to terrestrial mobile and satellite services, it may host future converged 5G / satellite system concepts for which dynamic spectrum management schemes could be a key enabler.

6.6.5 3.8 - 4.2 GHz C-band

While this band is not currently discussed for 5G system with the exception of UK (see below), its proximity to 3.4 GHz - 3.8 GHz band and the harmonization opportunity with other region make it very appealing for 5G shared with incumbents.

Ofcom UK is considering shared access in 3.8 to 4.2 GHz starting with a Public Consultation scheduled for Q4 2018 (Ofcom Annual Plan 2018/19 says "we will continue our work to enable greater shared access in this [3.8 to 4.2 GHz] band. In doing so our aim is to protect existing users of the band while also promoting access for new users. We will consult on proposals, including consideration of the appropriate authorisation mechanism and database solutions for dynamic spectrum access").

6.6.6 24.65 - 25.25 GHz and 27 - 27.5 GHz

These frequency bands are allocated to the FSS in the Earth-to-space direction. These bands belong as well to the range of frequencies contemplated by the ITU for IMT identification under WRC-19 agenda item 1.13. Specifically in Europe, the RSPG recommends in its 5G Opinion that 24.25-27.5 GHz be considered as a pioneer band for 5G above 24 GHz. These FSS bands are intended for Gateway use.

6.6.7 25.5 - 27 GHz

Under this band, the EESS and Space Research Service downlink allocations are considered. This is already in use for Earth Observation images retrieval from space and may be increasingly used considering the growth in the amount of space imaging data. This EESS allocation overlaps most of the band in the Ka range envisioned as a pioneer 5G band by Europe, and worldwide under WRC-19 Agenda Item 1.13. The requirement to enable on the long term the deployment of new EESS receive stations has been recognized, but the technical and regulatory means to achieve this goal is to be determined. A sharing scheme could be part of such means.

6.6.8 Q/V bands above 37.5 GHz

The Q/V bands are critically important for the gateway links of future VHTS systems (Very High Throughput Satellite). Shared schemes could ensure on the long term the capability to deploy and operate such gateways. The Q/V band case present specific features such as low density deployment / highly directional earth stations, high attenuation on interference paths, small cells potentially deployed on an unlicensed basis.

6.7 Asia and Oceania

At this point, these regions have not seriously been considering dynamic sharing. Parts of Indonesia and The Philippines have experimented with TV White Space, but sharing has not been widely proposed across the region.

We leave examination of the region for future work.

7 Analysis

The World Radiocommunication Conference 2019 (WRC-19) will consider identification of frequency bands for the future development of mobile broadband services. Concurrently, industry standards are being developed in such bodies as 3GPP that will be input to the ITU. [21] Beyond those bands already identified, analysis of the preceding sections offers the following for consideration.

7.1 L Band

Given the fact that the majority of the L-band is expected to be globally harmonized, that adjacent bands support LTE, that that there is expected to be a global equipment ecosystem, The L-band or portions could be considered for new uses such as dynamic spectrum sharing for fixed and mobile use. Furthermore, for mobility use cases, the L-Band may be of future interest, since there is close to 100 MHz of bandwidth that could be shared and there is already LTE equipment in the band that is being used for outdoor mobile commercial use.

7.2 Lower C Band (3.7-4.2 GHz)

It is widely believed that any mobile use is not compatible from an interference perspective with FSS earth stations, and therefore would require clearing of those portions of the band in which mobile service is authorized. In this case, there is no need for Spectrum Sharing Management Technologies control, as the flexible/mobile use would effectively be exclusive use of the cleared spectrum. P2MP systems in the band, however, have been shown to have the potential to co-exist with FSS earth stations, as long as the locations of the earth stations are taken into account in the network design of the P2MP systems. Because the deployments of incumbent systems (FSS) and new systems (P2MP) are essentially static, dynamic control of the band is not needed, or at least not on a time scale faster than perhaps a month or longer. However, a "Spectrum Sharing Management Technologies-light" approach, where the Spectrum Sharing Management Technologies functions as a frequency coordination mechanism for the P2MP system, could be employed. The Spectrum Sharing Management Technologies could be used both as a predeployment planning tool for the P2MP system, and an automated mechanism for implementing prior coordination with FSS as required by current FCC rules.

7.3 Upper C-band (5.925-6.425 GHz)

The upper C-band (5.925-6.425 GHz) is shared primarily by two services: Fixed-Satellite Service (FSS) uplinks and fixed microwave (Fixed Service or FS) links. Frequencies above C-band (e.g., 6.855-7.055 GHz) may be used by both FS and Mobile Satellite feeder links. The characteristics of the incumbents in the upper C-Band (Ground earth station transmitters) is different than in the lower C-Band (Ground earth station receive only) and offers a different kind of challenge to enable dynamic spectrum sharing. The traffic patterns for temporal sharing need to be considered in more detail to determine if the upper C-Band is conducive for sharing in this dimension. There could be an opportunity to extend unlicensed operations to the upper C-band where similar interference mitigation techniques and regulatory constraints could be applied to those in the neighboring 5 GHz band.

7.4 6 GHz Band (5.925-7.125 GHz)

The “6 GHz band” (which overlaps with the Upper C-band mentioned above) is currently being studied for designation for unlicensed devices, essentially extending the 5 GHz Unlicensed National Information Infrastructure (U-NII) bands currently used for unlicensed operation. However, because of the extensive use of the bands for fixed and fixed-satellite use, a coordination mechanism will very likely be needed. The unlicensed community is interested in utilizing the new spectrum for Wi-Fi, which often utilizes very straightforward equipment that has not, traditionally, been “Spectrum Sharing Management Technologies aware.” If database or Spectrum Sharing Management Technologies control is required in the 6 GHz band (which may be in the form of an Automated Frequency Control (AFC) system), the community is most interested in very simple and lightweight solutions, for example, stateless solutions where the device need only coordinate once (as long as it doesn’t move), or perhaps coordinate on a very infrequent basis (30+ days).

8 Recommendations

The Advanced Technology Committee of the Wireless Innovation Forum makes the following recommendations:

1. **ITU-R** should consider addressing Spectrum Sharing Management Technologies in shared bands through the development of an ITU-R Report and or Recommendation in the appropriate Study Group. ITU is often at the forefront of spectrum-sharing discussions and members are aware of arising shared-band situations where Spectrum Sharing Management Technologies might be an applicable tool to promote sharing.

2. **Regulators** should consider the application of Spectrum Sharing Management Technologies in shared-band situations where sharing is (or may be) feasible and full or partial relocation of incumbents is (or may) not feasible or desired. For example, the FCC is considering Spectrum Sharing Management Technologies-like automatic frequency coordination (AFC) system for the protection of incumbent systems from new spectrum

entrants. Regulators can use the Spectrum Sharing Management Technologies concept to promote the notion of sharing in bands where sharing would be difficult or otherwise not feasible. Regulators can evaluate on band by band basis considering the criteria described in Section 7. Regulators can also consider hybrid licensing regimes to promote maximum flexibility among users. In addition to the 6 GHz band mentioned above, other possible bands of interest include the U.S. 4.9 GHz and 37 GHz bands.

3. **SDOs** should consider development of standards that incorporate interfaces, protocols and functionality to support development and use of Spectrum Sharing Management Technologies. Spectrum sharing standards should be extensible to multiple bands, functionality and technologies and support established policies.

4. **Equipment manufacturers** should adopt standardized Spectrum Sharing Management Technologies interfaces into equipment intended for introduction into shared-spectrum applications consistent with Recommendation 1 above.

5. **Spectrum Sharing Management Technologies providers** should work with the above-mentioned stakeholders to develop Spectrum Sharing Management Technologies which need to interoperate within the ecosystem.

6. **Spectrum users** should consider using Spectrum Sharing Management Technologies-managed, shared-spectrum bands as part of their spectrum use strategies.

7. **Research/Universities** should look at the research called out in the doc to develop Spectrum Sharing Management Technologies-like methods for sharing and adding additional features such as deep learning, knowledge-based approaches, autonomous and semi-autonomous approaches as well as policies enabling more inter-discipline (academia/industry) cooperation. Investments should be also considered in Spectrum Sharing Management Technologies and related technologies.

8. **Industry/Trade associations** should promote sharing from a viewpoint of unlocking spectrum in regulatory jurisdictions where incumbents are present.

9 APPENDIX A

9.1 Standards and Ecosystem Development for TVWS

A number of industry standards have emerged to meet the needs of the growing white space ecosystem. For example, the IEEE has developed two standards, 802.11af and 802.22, which are both designed for devices operating in the TV white spaces. ETSI has also developed a European standard for white spaces devices. Moreover, a number of commercial deployments have been launched. Trials, pilots, and commercial deployments leveraging TV white space technologies have now been launched on five continents (Africa, Asia, Europe, North America, and South America)

9.1.1 EU regulatory and standard framework

A WSD may only transmit in the territory of a country if it has successfully discovered a geo-location database approved by the National Regulatory Authority (NRA). Rules defining WS availability and associated transmit powers are set by the NRA and are implemented in WSDB.

This principle is well embedded in ETSI EN 301 598 on White Space Devices (WSD). An analysis is given on suitable regulatory regime for WSD. Overall, it suggests that a general authorisation model is adequate for TV WS, and likely to achieve efficient use of spectrum, noting that database assisted management of spectrum will technically achieve frequency coordination to ensure protection of incumbent which is, in practice, more close to a light licensed model than a pure licence exempt general authorisation.

One key feature of European regulatory developments on TVWS is that, consistently with conclusions in ECC Report 186 (2013) and ECC Report 236 (2015).

Depending on national legislation, which could exclude for specific reasons the possibility of sharing with analog and digital TV in the UHF Band, TV White spaces may not be possible to be implemented at all in the UHF-Band.

Finally, from a European implementation perspective, it should be noted that ETSI EN 301 598 contains the concept of the web-listing, which is the list of White Space Databases authorised by a NRA to operate in the geographical domain under the NRA's jurisdiction, and that the EN includes requirements for White Space Master Devices to 1) obtain the web-listing and then 2) only contact a WSDB that appears in that web-listing.

9.1.2 US regulatory and standard framework

Rules established that the FCC would be the certifying authority for TVBDs and databases, and establish a proof of performance standard to allow certification of sensing only devices that demonstrate the capability to detect protected services with a high level of accuracy.

In compliance with these orders, the FCC OET began accepting applications for white space database administrators. To date, 10 organizations have been designated as database administrators, and four have databases that have been approved for operation:

The potential success of this proceeding is still unknown as of today. While there have been some initial trials and early deployments across the United States, there has not been a large commercial investment in this band to date. The reason for this is likely tied to the regulatory uncertainty surround the TV band spectrum.

9.1.3 Canada regulatory and standard framework

Policy decision was released in October 2012 with initial focus on geo-location database concept. Following conditions should be applied:

- TVWS devices permitted on a no-protection, no interference basis to licensed users in the band;
- LPA users require a license to receive protection from TVWS devices;
- No limits on number of database administrators;
- Spectrum sensing is permitted by policy, but initial implementation of rules will focus on a geo-location database;
- License-exempt TVWS devices will require certification.

Industry Canada published on 5 February 2015 the new RSS-222 on White Space Devices (WSDs). Industry Canada's Radio Standards Specifications RSS-222 describes the various technical and operational requirements and processes to be followed when demonstrating compliance of the white space radio apparatus that is used for radiocommunication other than broadcasting. Radio Standards Specification RSS-222 sets out the requirements for the technical compliance of licence-exempt, Category I radio apparatus operating in the frequency bands 54-60 MHz, 76-88 MHz, 174-216 MHz, 470-608 MHz and 614-698 MHz, known as white space devices (WSDs).

Industry Canada emphasises that the TVWS technology uses available television airwaves to deliver improved, Wi-Fi–like services in rural regions. TVWS devices will initially provide broadband Internet, similar to Wi-Fi, but with expanded coverage that exceeds traditional Wi-Fi. This move will allow these devices to be used in Canada without interfering with existing TV broadcasts. Industry Canada follows with this step the policy permitting the use of TVWS devices in 2012 with a similar approach to TVWS, The United States has taken.

9.1.4 Singapore regulatory and standard framework (status on March 2015)

Decision paper was issued by the IDA Singapore in June 2014 regarding regulatory framework for TV white space operations in the VHF/UHF bands. IDA is planning to adopt a license-exempt approach, which will allow users to explore a range of business models and encourage the adoption of the technology.

IDA will adopt the Geo-location Database approach as the mandated method for WSDs to access TVWS spectrum as sensing technology did not reach mature stage and has not been mandated for adoption in any overseas jurisdictions.

The draft specification was developed and published by IDA in March 2015. Document defines the technical requirements of Television (“TV”) Band or White Space Devices (“WSD”) that may be permitted to operate on any available TV channels of the broadcast TV frequency bands specified in the document. The specification is applicable to the following types of radio equipment: fixed WSD, which may be a master WSD; a personal/portable WSD, which may also be a master WSD; a personal/portable mode I WSD, which is a client WSD. Document also defines technical and operations requirements for the allowed type of equipment. IDA recognises that the geo-location database is the only reliable approach to allow operation of WSD devices, therefore geo-location Database Interface Requirements are defined in the specification.

Table 5: Information on TVWS deployment (status on January 2016)

Asia-Pacific	
Bhutan TVWS trial connects remote health unit	2014
Philippines TVWS Pilot improves fisher folk registrations	2013
long-distance broadband networking using TV white space for	2013
TVWS field trial for rural aboriginal Fu-Hsing Township	2013
Singapore commercial TVWS pilots using dynamic spectrum management	2012
Africa	
TV white spaces Mozambique	2015
Botswana - Project Kgolagan	2015
Namibia World's "largest" TV white space pilot	2014
Ghana; Accra TVWS pilot network is the first of its kind in West Africa	2014
South Africa; University of Limpopo TVWS trial	2013
Malawi TV white spaces pilot	2013
Tanzania; Dar es Salaam TVWS trial	2013
South Africa; Cape Town TV white spaces trial	2013
Kenya Mawingu TVWS pilot	2013
Europe	
Finland; WISE – White space test environment for broadcast frequencies	2011
UK; London Zoo TVWS trial to save the animals	2014
UK; NICT tests combined LTE and 802.11af device communicating with TVWS database at Ofcom white space pilot	2014
Scotland; Glasgow white spaces	2014
Orkney Islands, Scotland, United Kingdom; Rural Scotland TVWS ferry services	2013
Isle of Bute, Scotland, United Kingdom; White space rural broadband trial on the Isle of Bute	2012
UK; Cambridge white spaces trial	2011
North America	
Seattle Center TV White Space	2015
Washington County Maine TVWS Deployment	2014
Louisa County, Virginia, USA; Louisa Water Tower TVWS deployment demonstrates resilience of TVWS-based WiFi	2014
Dover, Delaware, USA; Delaware State Library Pilot	2014
Humboldt County,California, USA; Humboldt County pilot	2013
Delta County, Colorado, USA; Delta County, CO pilot	2013
Skokie, Illinois, USA; Skokie, IL pilot	2013
Topeka, Kansas, USA; Kansas State pilot	2013
Pascagoula, Mississippi, USA	2013
Concord, New Hampshire, USA	2013
Pittsburgh, Pennsylvania, USA; Using TVWS to connect vessels in Pittsburgh waterway	2013
Morgantown, West Virginia, USA; West Virginia University deployment	2013
La Pointe à David, Gatineau Valley, Quebec, Canada; The great outdoors trial	2012
Wilmington, New Hanover County, North Carolina, USA; Wilmington "Smart City" deployment	2012
Kingston, Jamaica; Jamaica Connected Nation Project	2015
Plan Ceibal remote schools pilot in Uruguay	2014

Source: http://www.dynamicspectrumalliance.org/pilots

9.2 Information on LSA testing

9.2.1 Spain (October 2015)

In 2014-2015, the State Secretariat for Telecommunications and Information Society of the Ministry of Industry, Energy and Tourism of Spain (SETSI) commissioned a study whose aim was to identify spectrum availability for mobile broadband services in Spain in the 2.3 - 2.4GHz band based on LSA on a shared basis with video PMSE.

The last stage of this study was an experimentation carried out at the GSMA Mobile World Congress, Barcelona (March 2015). Its purpose was to demonstrate LSA options facilitating sharing between Mobile Services (as the LSA Licensee) and PMSE video links (as the Incumbent) both using the 2.3 GHz band.

9.2.2 Italy (November 2016)

In 2015, the Italian Ministry for Economic Development has started a pilot project in collaboration with the Joint Research Centre of the European Commission to test the sharing of radio spectrum (https://ec.europa.eu/jrc/en/news/project-testing-radio-spectrum-mobile-broadband). It is conducted under the technical coordination of Fondazione Ugo Bordoni.

The pilot project is intended to be a field test of LSA approach for wireless broadband telecommunications in the 2.3-2.4 GHz band. It is being realised in Rome at the Ministry premises, where a confined mobile LTE TDD network at 2.3-2.4 GHz is deployed and a proper architecture enabling the LSA concept is implemented.

The final results of the LSA Pilot in Rome have been presented in Rome on 23 September 2016.

9.2.3 France (October 2016)

A technical report has been published by ANFR in March 2015 to assess the technical conditions of the shared use of the band 2.3-2.4 GHz, through LSA, between broadband wireless systems and the incumbent users of the band.

An LSA trial took place during the first semester 2016 in Paris managed by industry stakeholders.

9.2.4 Finland (March 2016)

Finnish research institutes and industry members in co-operation with the Finnish Regulatory Authority (FICORA) launched the World's first over-the-air LSA trials between PMSE and Mobile Service on a live commercial LTE network already in 2013. Since then, the trial environment has been constantly improved and seven LSA trials were shown during years 2014-2015 with advanced features such as TD-FDD handover, small cells, support of the incumbent mobility, integrated SON solution and protection zone concept based on total power radiated by the mobile network. These trials were shown to scientific, standardization (ETSI workshop) and regulatory (ECC meeting) audience.

9.2.5 The Netherlands (January 2017)

The Netherlands decided in 2015 to start a pilot for an on-line booking system for PMSE in the 2.3-2.4 GHz band. De web-application for the pilot was ready in May 2016 and has been tested extensively. Via the pilot practical experience can be gained and, when successful, the pilot could be extended in future to other services.

The pilot entails that temporary spectrum use for PMSE in the 2.3 – 2.4 GHz must be booked by users via a booking system. This booking system applies at this moment only for PMSE. The use of the booking system has been made obligatory for licensees for PMSE.

The PMSE sector has requested that the lead time for receiving spectrum assignments for temporary use would be shortened and the interference problems would be reduced. This booking system fulfils this request. Possible future development of the system will look at other existing users in the band, namely, government use and radio amateurs.

The pilot lasts for one year and the web-based booking system is operational since 28th of September 2016. During the pilot several meetings with the user group are scheduled. The first has already taken place on 12th of January 2017. In this meeting, users mainly commented on the functionality and user-friendliness of the system. Where possible these comments will be taken into account by improving the functionality of the booking system, for which some new software releases are scheduled during the pilot in order to obtain a stable system. The final evaluation meeting is scheduled for 5th of October 2017 and will be followed by an evaluation report.

Furthermore, a separate project will be started in spring 2017 to prepare already for the follow-up of the current pilot. For this purpose, a roadmap will be drawn up to describe the future possibilities of LSA in the Netherlands. This roadmap will look beyond the 2.3 - 2.4 GHz band and its users and will also consider other means of sharing the spectrum than via manual booking in a web-application.

9.2.6 Portugal (January 2018)

The official launch meeting of the "Study on the Licensed Shared Access (LSA) Spectrum Sharing Model" between ANACOM and a number of strategic partners took place on January 10, 2018. This is an applied engineering study with the objective of analyzing alternative scenarios and models of spectrum management, particularly those involving the concepts of Licensed Shared Access (LSA) in the 2.3-.4 GHz range.

9.2.7 France & Greece (June 2016)

The European Commission's Seventh Framework Programme (FP7) funded the ADEL Project consortium to investigate and test a "Dynamic LSA" approach with similarities to the US CBRS Spectrum Sharing Management Technologies model of dynamic and opportunistic spectrum sharing. ADEL (Advanced Dynamic spectrum 5G mobile networks Employing Licensed shared access) extensions to the LSA architecture also allowed for sharing amongst multiple operators.

ADEL Project consortium members demonstrated their proof-of-concept dynamic LSA system on both the Eurecom testbed in Sophia Antipolis, France as well as at the European Conference on Networks and Communications, June 2016 in Athens Greece.

The methodological approach outlined will make it possible to explore and acquire, from a solid experimental basis, knowledge about the technologies and interrelationships between the various actors in the processes associated with the implementation of the LSA model of spectrum sharing, including control and management of targeted spectrum uses.https://link.springer.com/referenceworkentry/10.1007/978-981-10-1389-8_50-1

10 References

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