Spectrum Sharing: Licensed Shared Access (LSA) and Spectrum Access System (SAS)

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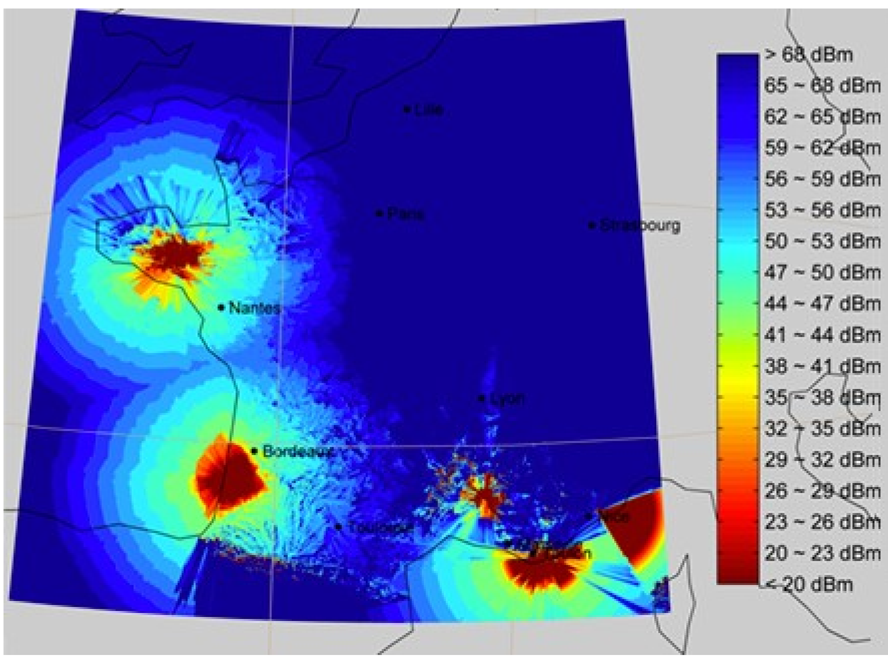

White paper

Spectrum sharing technology is steadily gaining both attention and momentum within various regulatory bodies (European CEPT, US FCC), standards groups (ETSI, 3GPP) and industry fora (Wireless Innovation Forum). It is expected to be a key tool that will enable regulators to provide the capacity required for 5th Generation (5G) mobile applications. This white paper provides a detailed and comparative overview of shared spectrum technologies currently deployed in Europe (Licensed Shared Access – LSA) and the U.S. (Spectrum Access System – SAS).

Contents

List of figures

List of acronyms

3GPP	3rd Generation Partnership Project
BS	Base Station
CBRS	Citizen's Broadband Radio Service
CBSD	Citizens Broadband Radio Service Device
CEPT	Conférence Européenne des Administrations des Postes et des Télécommunications
DL	Downlink
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
FDD	Frequency Division Duplex
HetNet	Heterogeneous network
LTE	Long Term Evolution
LSA	Licensed Shared Access
MIMO	Multiple Input Multiple Output
NOI	Notice of Inquiry
NPRM	Notice of Proposed Rulemaking
NRA	National Regulation Administration
QoS	Quality of service
R&O	Report and Order
RAT	Radio access technology
SAS	Spectrum Access System
TDD	Time Division Duplex
TDMA	Time-Division Multiple Access
TVWS	TV White Space
UE	User Equipment
UL	Uplink

Definitions

Sharing Framework[1]**:** a sharing framework is established under the responsibility of the Administration/NRA, and comprises (as a minimum) the identification of the incumbent and the spectrum to be made available under LSA, and the corresponding conditions for access to the spectrum by both incumbent and LSA licensee.

Licensed Shared Access (LSA) System[1]**:** a system that enables and/or facilitates the realization of an LSA framework. The LSA System includes means to enable coordination of resource usage between incumbents and LSA licensees. A realisation of the entire LSA sharing framework or a subset of it for a specific band(s). There can be multiple LSA Systems that support the LSA sharing framework. Different implementations of the single LSA sharing framework can lead to multiple LSA systems that all support the LSA sharing framework. The LSA System defines the specific technical features, architecture, and operational conditions that realize the LSA Framework.

Spectrum Access System (SAS)[2]. A system that authorizes and manages use of spectrum for the Citizens Broadband Radio Service in accordance with subpart F.

[1] The Definitions are in alignment with ETSI TS 103 154: "Reconfigurable Radio Systems (RRS); System requirements for operation of Mobile Broadband Systems in the 2300 MHz - 2400 MHz band under Licensed Shared Access (LSA) regime" [6].

[2] The Definition is in alignment with FCC **Part 96 – Citizens Broadband Radio Service** [5]**.**

1. Spectrum Scarcity and need for a new Spectrum Usage Paradigm

Fifth generation (5G) communication systems are foreseen to provide a 1000x to 10,000x capacity increase compared to legacy 4th Generation (4G) technology. For this ambitious goal, the identification of new spectrum for 5G applications is essential. Currently, there are two distinct leading tracks being investigated.

First, technology is under definition for the usage of spectrum in higher frequency bands, in particular cm and mm wave bands (typically, 10 GHz and above). While this approach may be useful for some applications, not all use cases are compatible with wireless propagation characteristics in high GHz bands - such as user devices being operated in a highly dynamic and mobile environment. For this reason, a second direction is investigated in parallel: enabling more efficient usage of spectrum below 6 GHz. Indeed, traditional cellular spectrum below 6 GHz is expected to still play a key role in the future 5G ecosystem.

The challenge for the bands below 6 GHz is obvious. Figure 1 illustrates the current spectrum allocation in the U.S. Traditionally, cellular spectrum has been made available through repurposing of spectrum. However, this traditional approach is meeting its limits. Below 6 GHz, spectrum is fully allocated to incumbents that fiercely oppose proposals to repurpose "their" spectrum to other stakeholders. National Regulation Administrations (NRAs) are clearly under pressure to identify new and novel means for managing spectrum such that cellular applications are able to meet their 5G performance targets while satisfying the needs of existing incumbents.

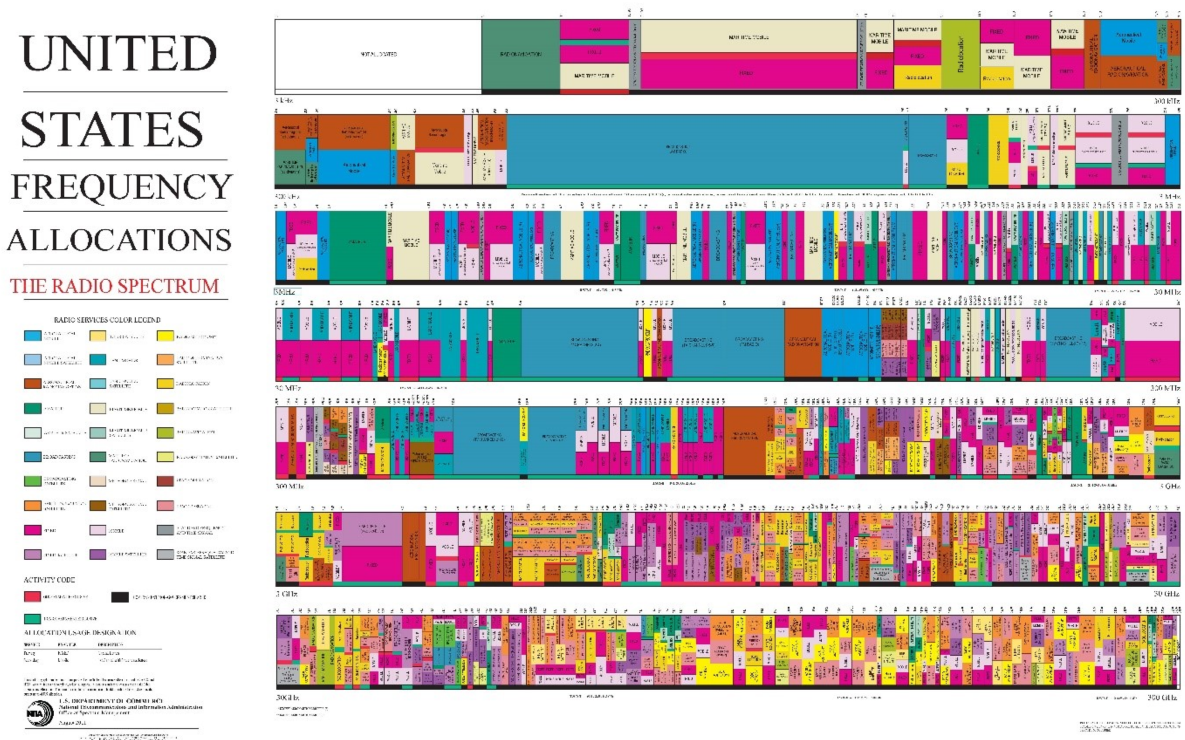

Figure 1: United States Frequency Allocations [1].

In this context, new spectrum management mechanisms have been introduced, such as TV White Space (TVWS) solutions. TVWS technology implements the regulatory requirements for unlicensed sharing of unused space sometimes found between licensed, local terrestrial TV channel coverage areas. The basic principle relates to the idea of allowing unlicensed, secondary devices to access spectrum at specific geographic locations and/or during specific time intervals, in geographically-limited spectrum where it would not interfere with terrestrial TV transmission or reception. Importantly, the TVWS regulations require TVWS devices to obtain authorization before they can transmit, and requires those devices to cease operation when they are located inside the protected areas. While the U.S. [2] and UK [3] administrations have driven the introduction of a TVWS regulatory framework, the level of market acceptance still is low and remains below the original expectations. TVWS systems must not interfere with TV operations (including consumer TV reception), and combined with the fact that they are unlicensed and secondary users, quality of service (QoS) for TVWS operations typically cannot be guaranteed.

Furthermore, the future availability of TVWS spectrum is uncertain in light of the intent by many countries to repackage the TV bands for greater licensed broadband use, particularly in densely populated areas. These issues, among others such as lack of support from major device manufacturers and major carriers, have prevented any real commercial success for TVWS technology.

With the lessons learned from the definition, deployment and operation of TVWS systems, an improved second generation spectrum sharing technology is being developed in Europe and the U.S. with the objective to eventually provide global coverage in applicable bands. ETSI and CEPT have developed a number of documents enabling the usage of the so-called Licensed Shared Access (LSA) scheme in Europe in the 2.3-2.4 GHz LTE Time Division Duplex (TDD) Band 40 [4]. The Federal Communications Commission (FCC) issued a report and order related to the operation of the so-called Spectrum Access System (SAS) in the U.S. in frequency band 3.55-3.7 GHz (LTE TDD Band 42) and 43 [5]. These systems are expected to provide a key component for future generation spectrum management. An overview and analysis of those systems is given in the following chapters.

2. Overview of Licensed Shared Access (LSA) and Spectrum Access System (SAS) Spectrum Sharing

2.1 Key Use Cases

The main use case for LSA technology relates to the extension of cellular capacity below 6 GHz in Europe. LSA specifically enables a 3GPP LTE network to be operated on licensed shared basis in the 2.3-2.4 GHz frequency band, which corresponds to 3GPP LTE Band 40. It is expected that LTE mobile network operators (MNOs) will engage in a multi-year sharing contract with incumbents such as military stakeholders, professional video camera services, and others. Sharing contracts are typically 10 years or more in length. This long-term certainty is a key requirement for justifying large scale investments into cellular network infrastructure. Still, the incumbent (tier-1) user is prioritized over the licensee (tier-2), i.e. the concerned MNO is required to vacate the LSA band for the given geographic area, the given frequency range, and the given period of time for which the incumbent is requiring access to the resource.

Typically, the LSA band is combined with LTE operation in dedicated licensed spectrum through suitable carrier aggregation mechanisms. Because legacy LTE systems in Europe are mainly employing Frequency Division Duplex (FDD) technology, the 3GPP Release-12 FDD/TDD carrier aggregation feature is required for a suitable combination of existing deployment with LTE LSA modes. The basic principle is illustrated in Figure 2.

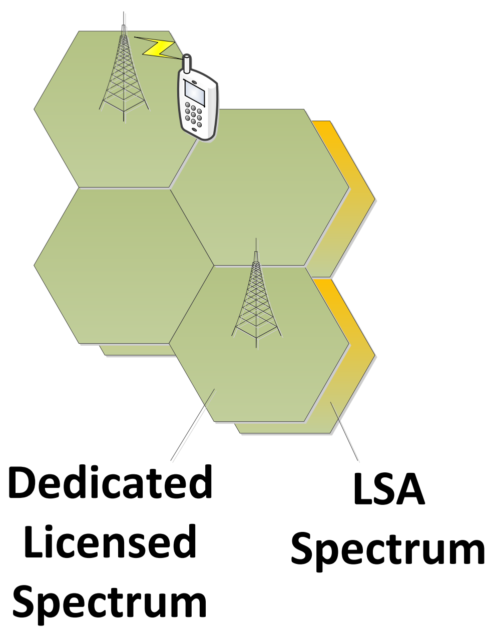

Figure 2: LSA based Spectrum Sharing.

The main use case for SAS technology is similar to the LSA case above, but currently defined for usage in the US market. A so-called Citizens Broadband Radio Service (CBRS) network, such as a 3GPP LTE network, is operated on licensed shared basis in the 3.55-3.7 GHz frequency band, i.e. 3GPP LTE TDD Bands 42 and 43. A major difference to LSA consists in the fact that licensed spectrum slots are only available in parts of the entire SAS band (up to 70 MHz) for so-called Priority Access License (PAL) tier-

2 users. The remaining part of the spectrum, as well as unused portions of the PAL spectrum ("use-it-or-share-it" rule), are available to a new user class called General Authorized Access (GAA) tier-3 users. This tier-3 class does not exist in the LSA system definition. GAA users may typically operate systems which have originally been defined for industrial, scientific and medical (ISM) radio bands, such as LTE Licensed Assisted Access (LAA) or Wi-Fi type systems, including modifications in order to be adapted to the SAS requirements imposed by the FCC [5].

It should be noted that both systems—LSA and SAS—are currently defined for usage in a specific frequency band. The basic operational principles of those systems, however, are frequency agnostic and can be applied to other bands. NRAs will be able to utilize the technologies as a new tool in the frequency management toolbox in order to allocate suitable bandwidth to wireless broadband systems.

2.2 System Overview

A basic system overview is illustrated in Figure3 and Figure 4 for both LSA and SAS.

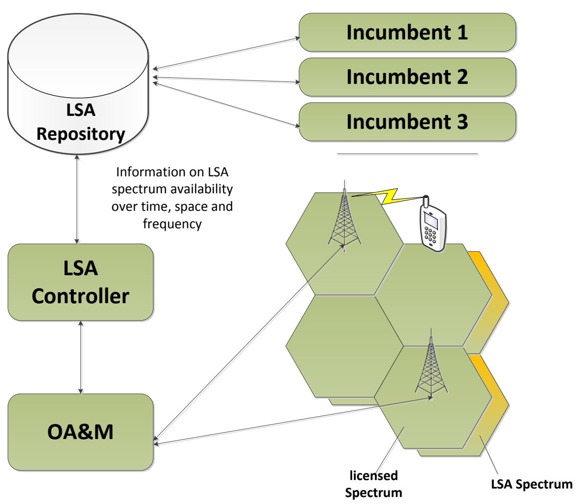

Figure 3: LSA Architecture.

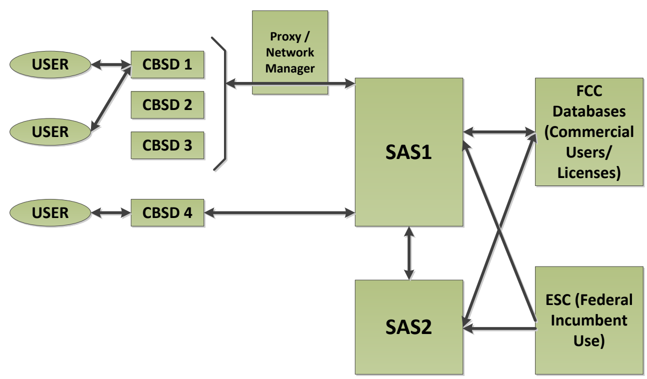

Figure 4: SAS Architecture.

Figure 3 illustrates the LSA System Architecture as defined in ETSI TS 103 235 [7]. In this context, spectrum management mainly relies on a centralized database known as the LSA Repository. Incumbents are required to provide *a priori* usage information to the database on the availability of LSA spectrum over space and time. Depending on this information, the LTE system is either granted access or requested to vacate concerned bands through the control mechanisms within the LSA Controller. In this operational approach, no sensing mechanisms are required to support the system for the identification of incumbent operation. The LSA Repository is considered to be located outside of a specific MNO network and typically provides information to a multitude of such networks. The LSA Controller, on the other hand, is part of an MNO network. Both entities interact through an interface which is currently defined in ETSI.

Figure 4 illustrates the SAS Architecture. A main difference to LSA lies in the fact that SAS is designed to ensure coexistence with incumbent users who are not able to provide any *a priori* information to a central database. In the context of SAS, the incumbents are military services using networks operated mainly close to U.S. coastal areas. For this reason, the FCC proposes a step-by-step approach: SAS can be operated throughout the U.S. territory except within Exclusion/Protection Zones close to coastal areas. In a second step, an ESC component is added which performs required sensing tasks. The spectrum access decisions for tier-3 and tier-2 users are ultimately based on these sensing results. In the latter case, the operation of the system is possible even within the Protection Zones. It is obvious that the ESC component needs to comply with strict rules and undergo corresponding certification in order to ensure confidentiality of sensitive information related to military incumbents.

3 Introduction to LSA and Relevant Incumbents

3.1 System Design

The LSA system will address the needs of the following stakeholders:

- Incumbent user(s), i.e. primary users who may sub-license spectrum to LSA licensees under certain conditions;
- LSA licensee(s) operating a wireless system under a sharing agreement, typically a MNO providing 3GPP LTE services;
- NRA(s), which will monitor spectrum sharing activities.

Note that the upper guidelines imply a substantial change over legacy spectrum sharing technology, overcoming in particular the insufficiencies of the TVWS communication system approach. The LSA scheme provides a clear business case in which a long-term rental relationship between Incumbents and LSA Licensees leads to a defined money flow with LSA Licensees obtaining guaranteed quality of service (QoS) conditions in a given geographic area, frequency band, and time period. TVWS neither offer such a clear business model for all stakeholders nor a guaranteed level of QoS, which may at least partly explain the technology's lack of commercial success. Further, the LSA approach is supported by major device manufacturers and major carriers, which is a key advantage for LSA in gaining marketplace acceptance.

In Europe, the 2.3-2.4 GHz band has been identified for an initial deployment of LSA [4]. This band corresponds to LTE TDD Band 40 and is used in other regions as dedicated licensed LTE spectrum. ETSI's Reconfigurable Radio Systems (RRS) Technical Committee has developed corresponding system requirements [6] and system architecture [7] documents, defining the key building blocks and interfaces related to the upper framework.

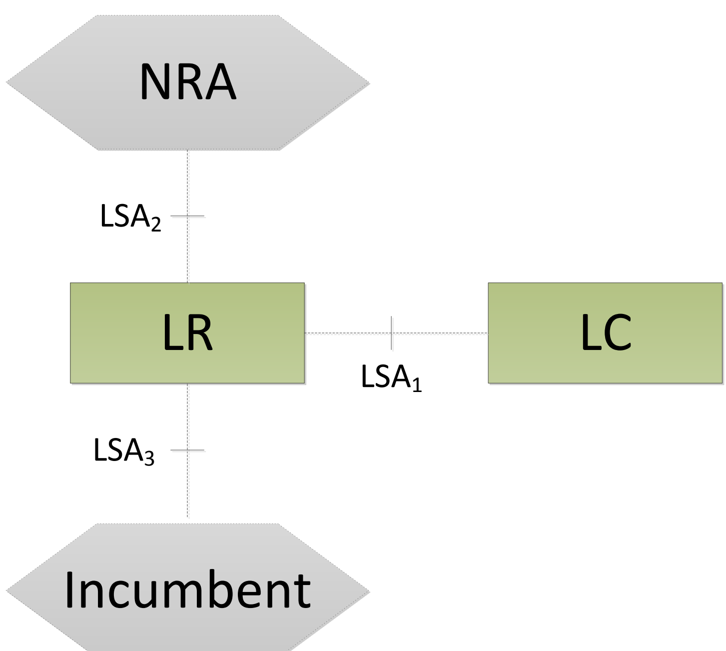

Figure 5: LSA Architecture Reference Model.

The LSA Repository is an entity providing database and other functionalities as it will be detailed below. In the European LSA context, the LSA Repository plays a key role because relevant information related to spectrum occupancy is provided by the Incumbent(s) to the database. The U.S. model follows a different strategy for users entering coastal Protection Zones: all such information needs to be derived by an ESC and must comply with strict confidentiality requirements, as detailed further on in this in paper. The LSA Controller features processing and decision making capabilities building on the data elements provided by the LSA Repository. The LSA Controller will interact with an MNO's Operations, Administration and Management (OA&M) framework in order to indicate spectrum availability, request short-term vacating of the spectrum and other functions as illustrated in Figure 5.

In accordance to the definitions in [7], a more detailed explanation of the LSA Repository and LSA Controller components is given below:

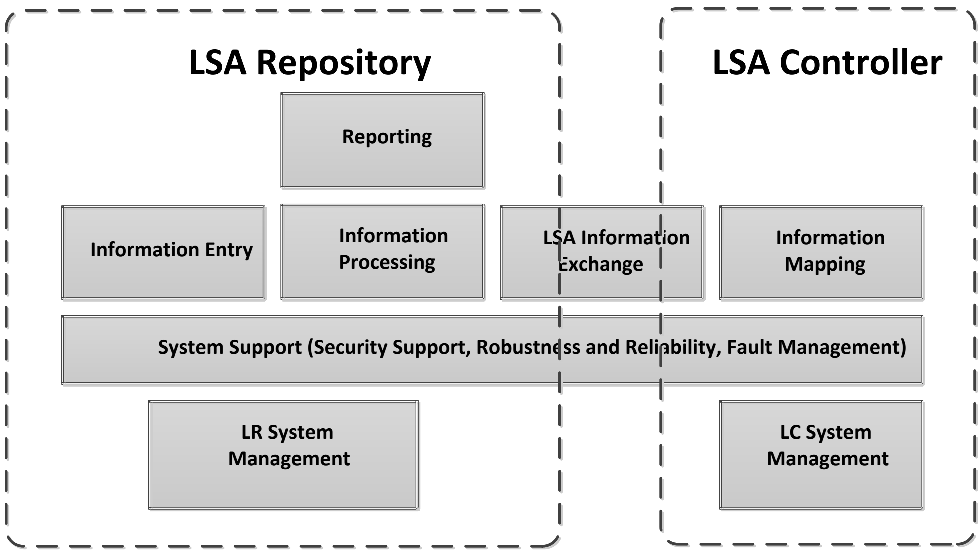

Figure 6: Mapping of high level functions and function groups to logical elements.

The high level functions introduced in Figure 6 are derived from the ETSI requirements document [6] and they are further detailed below:

- The Information Entry Function enables the entry and storage of information which is required for the operation of the LSA system and is comprised of the following:

  i) Information on the Sharing Framework between Incumbent(s) and LSA Licensee(s) indicating mutually agreed sharing conditions for the concerned band(s);

  ii) LSA Licensee information such as its identity;

  iii) Information on the Incumbents' LSA spectrum resource usage and protection requirements.

- The Information Processing Function supports the derivation of LSA spectrum resource availability information for each Licensee, to be provided to the Information Exchange function for forwarding to the respective Information Mapping function of the LSA Licensee. This function uses data provided through the Information Entry Function. It also includes support for multiple Incumbents and multiple LSA Licensees, scheduled and on-demand modes of operation, and logging of processing information.

- The Information Mapping Function receives LSA spectrum resource availability information, confirms reception, and initiates respective operations in the MFCN. Furthermore, it provides acknowledgements to the Information Exchange Function (for forwarding to the Information Processing Function) when changes in the MFCN are processed.
- The Reporting Function is responsible for creating and providing reports regarding the LSA System operation to Administration/NRA, Incumbent(s), and/or LSA Licensee(s) on an on-demand or scheduled basis.
- The LSA Information Exchange Function supports communication mechanisms, internal to the LSA System, to exchange LSA spectrum resource availability information, and related acknowledgement information.
- The System Support Functions Group is comprised of the following elements:

  i) Security Support Function for support of authentication and authorization as well as services to support integrity and confidentiality of data;

  ii) Robustness and Reliability Function for support of mechanisms to maintain robustness and reliability against failures and malicious attacks;

  iii) Fault Management Function for support of failure detection in the LSA System, subsequent generation and delivery of respective failure notification(s) to LSA Licensee(s) and Incumbent(s) and initiation of respective operations in the LSA System.
- The System Management Functions Group includes:

  i) Operation, administration and maintenance tasks in the LSA System,

  ii) Identity management (comprising user identity and authentication management, and user authorization profiles)

  iii) System management is separate for LR and LC since these logical entities belong to different operation domains.

It is expected that the upper System Approach is able to satisfy the needs of all stakeholders, including Incumbents, LSA Licensees, NRAs and others such that:

i) The Incumbent(s) will be able to monetize spectrum which is underused in a given geographic area, a given frequency band and a given time;

ii) The LSA Licensee will be able to access additional spectrum enjoying guaranteed QoS conditions and

iii) The NRAs ensure the best possible usage of already allocated spectrum

3.2 Standards and Regulation Framework

LSA and SAS related standards (system definitions) activities are currently ongoing in the ETSI Reconfigurable Radio Systems (RRS) Technical Committee with a focus on LSA; in the Wireless Innovation Forum (WInnForum) with a focus on SAS; and in 3GPP targeting a global solution encompassing LSA and SAS.

Thus far, the ETSI work has mainly produced documents [4], [6] and [7] and will likely continue its activity with a focus on stage-3 interface definition which are outside of the 3GPP system, such as the definition of the LSA_1 Interface as illustrated in Figure 5.

3GPP is discussing the integration and linkage of the LSA and SAS components into the 3GPP architecture. Document [8] proposes one possible option on how to include both sides under a common umbrella as it is illustrated in Figure 7. As defined in [19], the corresponding entities provide the following functionalities:

- A Network Manager (NM) provides a package of end-user functions with the responsibility for the management of a network, mainly as supported by the EM(s) but it may also involve direct access to the Network Elements. All communication with the network is based on open and well-standardized interfaces supporting management of multi-vendor and multi-technology Network Elements;
- A Domain Manager (DM) provides element management functions and domain management functions for a sub-network. Inter-working domain managers provide multi-vendor and multi-technology network management functions;
- An Element Manager (EM) provides a package of end-user functions for management of a set of closely related types of network elements. These functions can be divided into two main categories: Element Management Functions and Sub-Network Management Functions;
- A Network Element (NE) corresponds to a discrete telecommunications entity, which can be managed over a specific interface, e.g. the RNC.

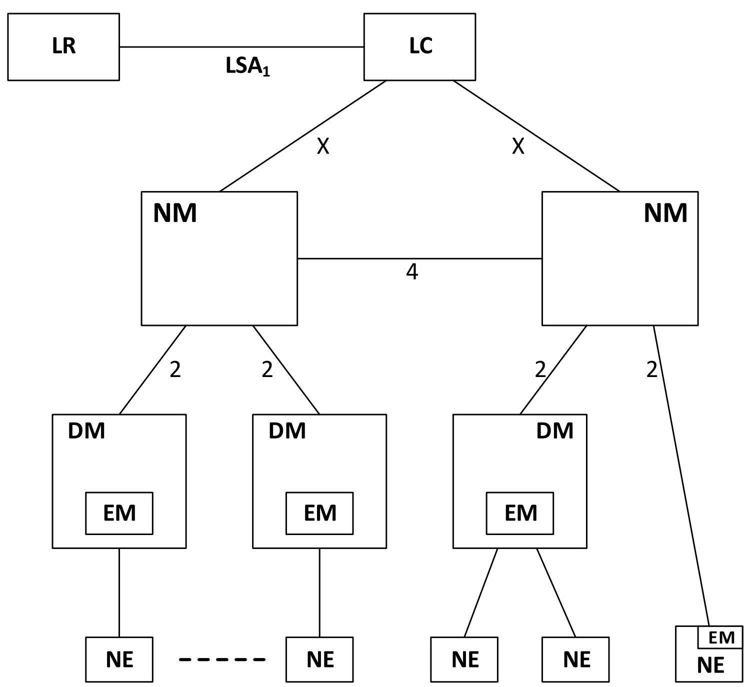

Figure 7: Integration and Linkage of LSA Components to 3GPP SA5 Architecture.

The WInnForum leverages its long-term relationship with the U.S. Department of Defense (DoD) in order to define a SAS system approach compatible with the needs of the U.S. Incumbents, which are mainly Naval shipborne radar and satellite services. Protection of satellite services is a key aspect of the FCC's second further notice of proposed rulemaking [5].

From a regulatory perspective, the European CEPT organization has acted following investigations and a corresponding mandate by the European Commission [9-11]. CEPT has produced a number of Reports, Recommendations and Decisions [12-16] and has finally closed the corresponding working groups. From a CEPT perspective, the work is complete and the actual usage of the LSA band in Europe now depends on NRAs to enable the usage of spectrum sharing in the national territories.

3.3 Protection of Incumbents and Neighboring Licensees

The current usage of the 2.3-2.4 GHz LSA band varies over the European Countries. While professional video camera services represent the main incumbents for some countries, others have allocated the spectrum also to (military) aircraft telemetry services, amateur radio, police wireless communication and others. Detailed information for each country is available in the ECO Frequency Information System [18]. Based on information where corresponding incumbent systems are operated and which level of protection they require, the maximum LSA output power levels can be derived as shown in Figure 8, which illustrates France as an example.

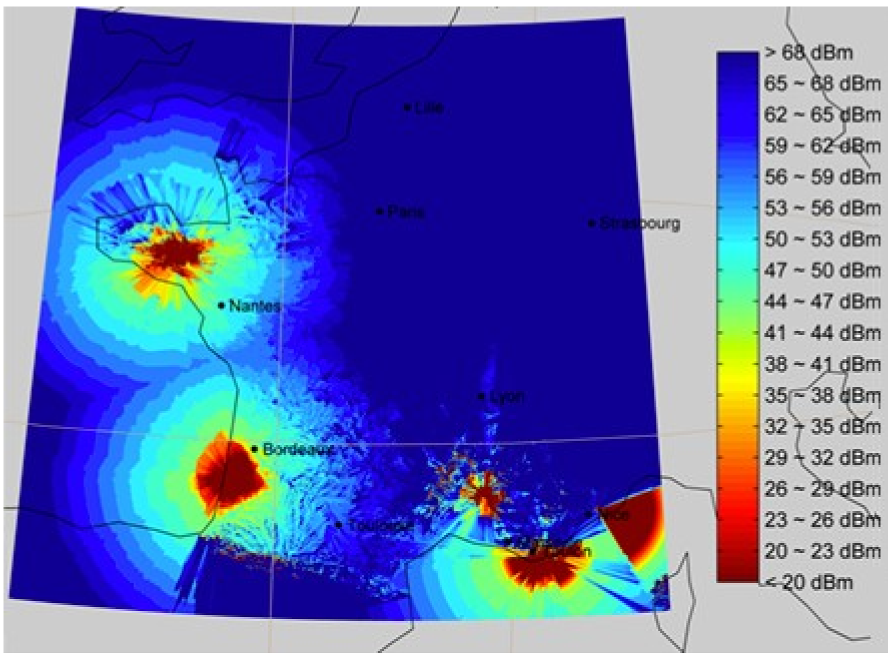

Figure 8: LSA Spectrum Availability in France [17].

Traditionally, incumbent systems are protected by so-called Exclusion Zones which prohibit the usage of interfering equipment within a given Zone. In order to ensure a sufficient level of protection, corresponding Zones are typically defined for a geographic area of substantial size, since the interfering system can operate without restrictions starting from the boundaries of the Exclusion Zone. In order to maximize the geographic area in which the operation of LSA is possible, the standards committee ETSI RRS has identified further Zone types to reduce the constraints on the LSA system [6]:

- **Exclusion Zone:** geographical area within which LSA Licensees are not allowed to have active radio transmitters. NOTE: An Exclusion Zone is normally applicable for a defined frequency range and time period.
- **Restriction Zone:** geographical area within which LSA Licensees are allowed to operate radio transmitters, under certain restrictive conditions (e.g. maximum EIRP limits and/or constraints on

antenna parameters). NOTE: A Restriction Zone is normally applicable for a defined frequency range and time period.

- **Protection Zone:** geographical area within which Incumbent receivers will not be subject to harmful interference caused by LSA Licensees' transmissions. NOTE: A Protection Zone is defined using specific measurement quantities and thresholds (e.g. a mean field strength that does not exceed a defined value in dBμV/m/MHz at a defined receiver antenna height above ground level). A Protection Zone is normally applicable for a defined frequency range and time period.

Concerning requirements on protection of neighboring (LSA) systems operated by distinct MNOs, mainly cross-border issues need to be considered for an efficient operation close to national country borders. Note that complex interference mitigation is not required for LSA across small geographic areas with different licensing situations - it is assumed that an LSA license is allocated to an MNO (or other LSA licensee) across an entire country or at least for a large geographic area (with the inherent limitations for Exclusion-, Restriction- and Protection-Zones). This is in contrast to the FCC SAS concept, where interference mitigation is required between neighboring *Census Tracts* which may be of small geographic size in particular in densely populated areas.

3.4 Intra-MNO-System Interference mitigation through LSA

Future 5G network deployments will provide increased energy efficiency and spatial utilization of the licensed spectrum, but such a diverse and heterogeneous cell deployment will create some important technical challenges that need to be overcome first. One of the critical aspects in such high dense heterogeneous networks is a rich and uncoordinated inter-cell interference within the system of a given MNO. LSA is expected to provide a new tool in order to address at least some of the interference cases.

While LSA spectrum can straightforwardly be used as additional spectrum for voice and data communication, the available LSA spectrum can be also exploited for Inter-Cell-Interference-Coordination. As LSA provides additional spectral resources over a given geographic area, for a given time interval and a given frequency band, depending on interference levels and the need for interference mitigation, a trade-off can be made between LSA resources assigned for voice and data and LSA resources assigned for inter-cell interference coordination. Introducing collaborative spectrum sensing and more flexibility in spectrum sharing, the licensed users can dynamically access and share spectrum without causing interference to primary users. By intelligently allocating LSA spectrum to center and cell-edge cells in a network, interference can be reduced significantly and implementation of complex and high-cost interference mitigation techniques in the User Equipment receiver chain can be avoided.

3.5 Challenges and Next Steps

The regulatory circumstances related to LSA have been developed by CEPT, and the corresponding work is complete. The standards work is in an advanced stage in ETSI's RRS Technical Committee while 3GPP will provide its first solution in 3GPP's Release 13 standard by 2016. The technology is likely to further evolve in 3GPP Release 14 and beyond. The main challenge relates to the willingness of the NRAs to finally enable the usage of the target 2.3-2.4 GHz band and possibly other bands in the future. Corresponding trials are in preparation in France and Italy, and additional countries are expected to follow. Once LSA has been proven to operate efficiently, the obvious next step will be to identify additional target bands. It is expected that LSA will become a key tool in the regulation toolbox in order to provide spectrum resources for 5G systems and beyond in order to meet the expected 1000x to 10,000x capacity requirements.

4 Introduction to SAS and relevant incumbents

4.1 Regulation Framework

Following an NOI (Notice of Inquiry) and an NPRM (Notice of Proposed Rulemaking), the FCC formally released the Report and Order (R&O) to the Citizen's Broadband Radio Service (CBRS) 3.5 GHz band in April 2015. The FCC outlines a three-priority access system for sharing the band with the incumbents. It requires protection of Incumbent military radar and fixed satellite services. The three tiers of the band are: Incumbent (tier-1), Priority Access (PA, tier-2) and General Authorized Access (GAA, tier-3) as described below. Note that LSA is based on a two-tier model while SAS introduces three levels of priority.

1. **Incumbent**: They are the current users of the spectrum. They can use the spectrum that they have been hereto using without any limitations. In the SAS target band, the main incumbent is the DoD with Naval shipborne radars. Other incumbents include Fixed Satellite Systems (FSS), Radio Location Services (RLS) and Terrestrial Wireless systems. The incumbents get interference protection from the lower two tiers.

2. **Priority Access (PA)**: This is similar to a licensed spectrum that can be won in an auction. However, PA users have to vacate the spectrum for an incumbent should they need to use it. Priority Access operations receive protection from GAA operations. Priority Access Licenses (PALs), defined as an authorization to use a 10 megahertz channel in a single *Census Tract* for three years, will be assigned in up to 70 megahertz of the 3550-3650 MHz portion of the band [5]. Currently there are over 74,000 *Census Tracts* with a targeted population of 4000 in the U.S. However, one has to note that the frequencies themselves are not necessarily fixed. In other words, if a carrier wins a 10 MHz channel, then it is guaranteed 10 MHz of licensed spectrum (provided there is no incumbent) in the 3.5 GHz band, but the actual channel is not fixed. This approach guarantees an ongoing availability of the channel in case a narrow-band Incumbent comes in through appropriate and dynamic re-allocation of the PAL spectrum. However, the FCC also indicates that the frequency will remain as static as possible. The suggested use cases include smart grids, rural broadband, small cell backhaul, and other point-to-multipoint networks. The PALs get interference protection from the tier below them but not from Incumbents.

3. **General Authorized Access (GAA)**: GAA is allowed throughout the 3.55-3.7 GHz band but get no interference protection from other CBRS users (PA and incumbent). They are guaranteed at least 80 MHz of spectrum.

The deployment of systems is divided into two phases with the first phase using the SAS to coordinate spectrum access outside the Exclusion/Protection Zones. In phase two, the ESC Capability coordinates transmissions inside the Protection Zones. The ESC is expected to be a form of sensor network.

The FCC outlines the high level SAS architecture in the R&O as shown in Figure 9.

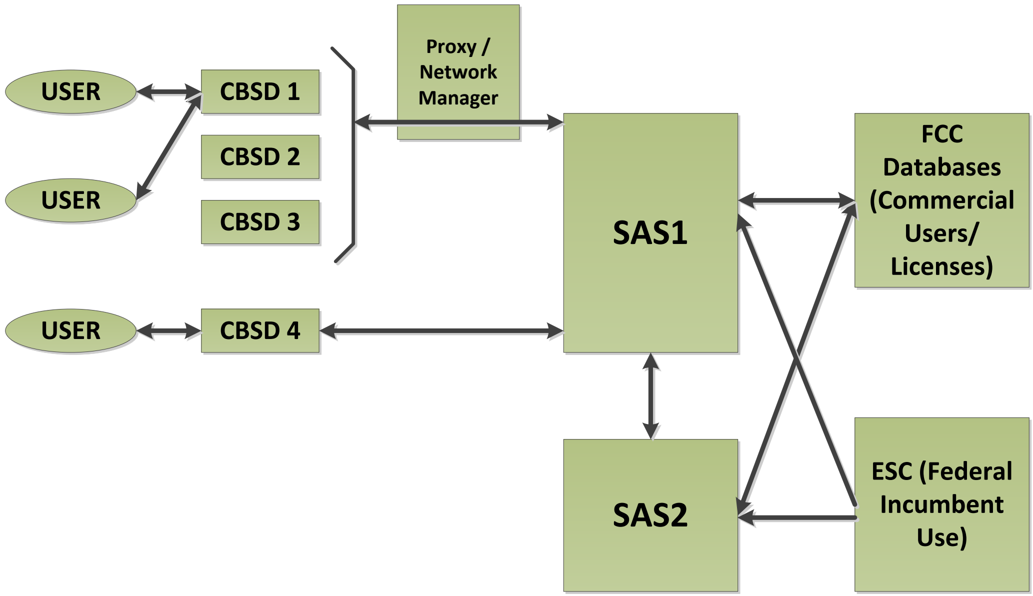

Figure 9: FCC's SAS Architecture.

The main functions of the SAS include incumbent protection and protection of PALs from GAA. To perform these functions, the FCC outlines a set of rules where the Citizens Broadband Radio Service Devices (CBSDs) have to register with the SAS giving it their location and other details [5]. The SAS then allocates channels that PA and GAA users can access. The SAS can also limit the maximum power of CBSDs to perform interference mitigation between tiers. The end user terminals wait for authorization from the corresponding CBSD before transmitting in the band. All devices are required to be able to transmit and receive in the entire 3.5 GHz band, even if they are not deployed in that manner. Comparing SAS and LSA, the SAS entity can be interpreted to be the LSA Controller counterpart. However, ETSI defined in ETSI TS 103 235 [7] that this entity must be within the MNO network. In SAS, the interference coordination across multiple networks is expected to require a SAS entity that is at least partly located outside of a specific MNO's network domain.

The FCC defines three types of devices categories: Category A with a maximum EIRP of 30 dBm/10 MHz; a slightly higher power Category B (non-rural) with an EIRP of 40 dBm/10 MHz; and a Category B device with an EIRP of 47 dBm/10 MHz.

The emission mask itself is specified as shown in Figure 10, where the Out Of Band (OOB) emissions are limited to -13 dBm at the adjacent channel and -25 dBm at the alternate adjacent channel. There is a special requirement of -40 dBm (20 MHz away) at the two edges of the 3.5 GHz band.

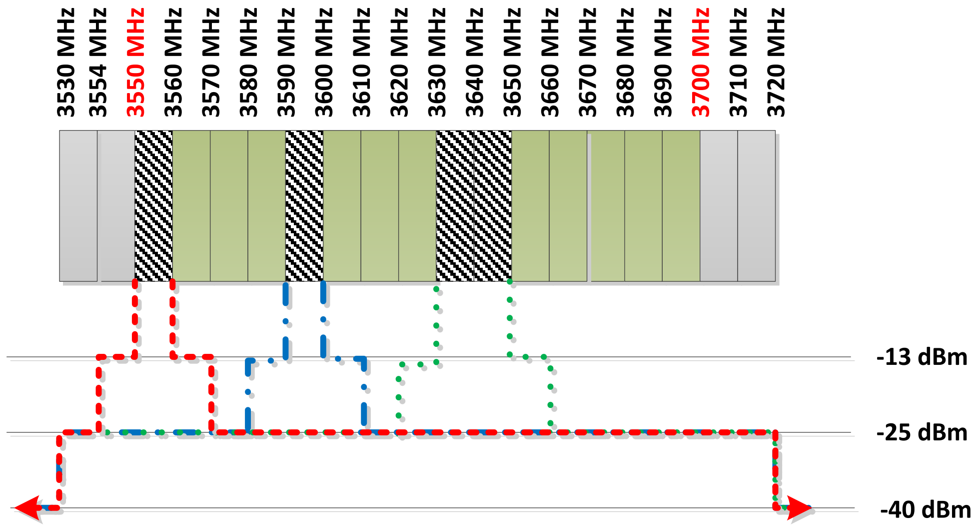

Figure 10: 3.5 GHz emission mask.

4.2 Differences to LSA

The LSA system is based on two tiers: Incumbents and LSA Licensees which each gets exclusive access right to the spectrum while they are using it. Furthermore, the incumbent populates a database indicating when the LSA Licensee can access the spectrum in a given geographic area, a given frequency band and a given period of time. The 3.5 GHz spectrum has three tiers with a tier-3 component to it (requiring communication capabilities with the SAS entities for interference mitigation, etc.) which closely relates to unlicensed operation and does not exist in the LSA system. However the most notable difference is probably the fact that the DoD will not populate any databases giving usage information and it has to be entirely determined by sensing. It puts accurate and reliable sensing technologies in the forefront unlike LSA, where sensing could be used to improve network performance but is not essential for accessing the band.

The interference mitigation problem is also enhanced in the 3.5 GHz system for two reasons. First, the size of a *Census Tract* (i.e., the minimum geographic area which can be auctioned/used independently for each 10 MHz band) is based on population and not area. As a result, in densely populated urban areas, these *Census Tracts* could be as small as a few blocks and greatly increases the coordination needed for interference mitigation along each of these boundaries. Second, the GAA users need to be actively managed to prevent interference to the PAL users; something that is not needed in LSA.

4.3 Standardization and System Design

The FCC provides high level functionalities of the SAS (the SAS coordinates and authorizes access across users) and the ESC that is needed for transmitting inside an Exclusion/Protection Zone. The WInnForum currently develops corresponding specifications with the support of its members from industry (equipment and device manufacturers, and service providers) and DoD. A possible approach for SAS architecture and interface definition is shown in Figure 11.

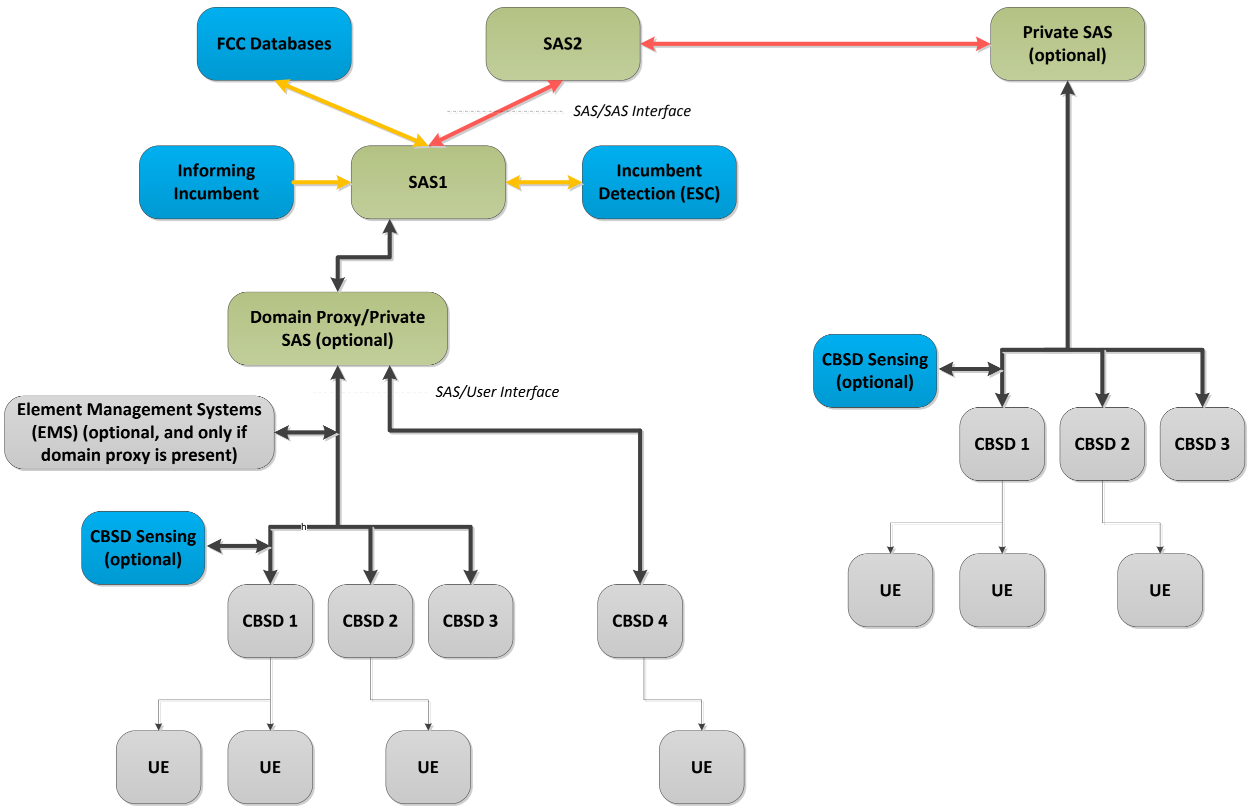

Figure 11: SAS system and interfaces

The SAS needs to interface with other SASs, with the ESC, and with the FCC's databases. Additionally, there could be incumbents willing to report their band usage either directly to the SAS or via a database that has to be accommodated by the SAS. This requires interfaces between SAS entities and registered CBSDs. Additionally, there could be special types of SASs that serve the needs of the service provider but that have to interface with other SASs for interference and incumbent protection.

4.4 Protection of Incumbents and neighboring users

Similar to LSA, the SAS system needs to protect Incumbent systems. Furthermore, as mentioned previously, the FCC introduces a *Census Tracts* based spectrum auctioning mechanism which requires mutual protection of PAL and GAA users across neighboring *Census Tracts*. The latter aspect is not considered in LSA, since it is assumed that a given LSA spectrum block is licensed to a given LSA Licensee across an entire regulation domain (meeting the requirements of Exclusion-, Restriction- and Protection-Zones).

4.4.1 Protection of Incumbents

The 3.5 GHz band is critical to DoD radar operations and other systems. This band offers a specific propagation and atmospheric condition which is unique to this frequency range. In this region of the spectrum, multipath propagation problems decrease, which is critical to radar systems for the detection of targets at low elevation angles. High-powered defense radar systems are operated on fixed, mobile, shipborne, and airborne platforms. Radar systems are used for radio-location and radio-navigation services. Among these are:

- Fleet air defense,
- Missile and gunfire control,
- Bomb scoring,
- Battlefield weapon location,
- Air traffic control (ATC),
    - Radionavigation services including air operations, ATC, and approach control.
    - The ATC also serves as backup short-range, air-search radar systems. The Navy shipborne radars operate on 21 frequencies or channels throughout this band.
- Range detection.

More specifically, in 3.55-3.65 GHz Radiolocation Services (RLS) are operated with priority on military RLS operations (DoD radar systems) and ground based Aeronautical Radio Navigation Systems (ARNS). In 3.6-3.65 GHz, the spectrum is used by Fixed Satelite Systems (FSS), Space-to-Earth, for finite time. 3.65-3.7 GHz is currently exploited for Fixed Satellite and grandfathered terrestrial wireless systems, federal RLS and ship stations (44nm off shore).

In 2010, the NTIA recommended that the 3.55-3.65 GHz bands can be made available for wireless broadband, with some geographic limitations. Staying above 3.55 GHz greatly reduces the potential for interference from high-power radars operating below 3.5 GHz. It was already noted that service rules based on license Exclusion/Protection Zones have to be implemented along the U.S. coastline to protect base stations from high-power U.S. Navy radar systems.

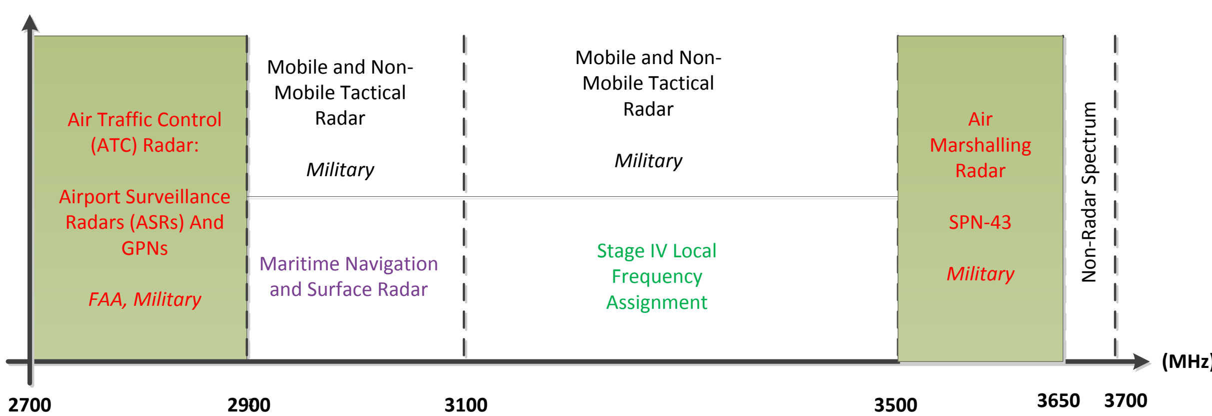

Figure 12: S-Band Radar.

While the Exclusion/Protection Zones originally proposed by NTIA were covering approx. 60% of the U.S. population, those Zones have recently been reduced by 77% [20]. In its current form, they are expected to exclude about 40% of the U.S. population in the first phase of SAS deployment, i.e. without the usage of the ESC dedicated to spectrum sensing. Once suitable ESC technology is available and certified by the FCC, SAS PAL and GAA system can operate also within Protection Zones while ensuring a sufficient protection of the incumbent(s).

Figure 13: Shipborne Radar –Exclusion Zone, Lower 48 States (Yellow Line – Fast Track Exclusion Zone, Blue Line – Revised Exclusion Zone) [20].

In addition to shipborne radar systems, ground-based radar systems are operated at locations within the United States. The number of sites requiring Protection/Exclusion Zones is limited to a small number of sites since the use of the upper portion of the tuning range of these radar systems is not required. The radio frequency filter has to provide 30 to 40 dB of attenuation at 3.5 GHz to mitigate the potential of high-power interference effects.

Figure 14: Ground-Based Radar Exclusion Zones, Middle West Coast [20].

4.4.2 Protection of neighboring users

PALs are assigned for 10 MHz unpaired channels in a single *Census Tract*. *Census Tracts* vary in size depending on the population density of the region, with tracts as small as one square mile or less in dense urban areas and up to 85,000 square miles in sparsely populated rural regions. Note that this allocation is substantially different to the LSA case where a given frequency block is allocated to a single given LSA Licensee across an entire regulation domain, i.e. typically an entire country.

A snapshot of the allocation of *Census Tracts* in New York City is illustrated in Figure 15. Since PAL and GAA allocations may be different between neighboring *Census Tracts*, the usage of SAS implies the requirement for a complex interference mitigation solution. Indeed, PAL and GAA users are required to interact with SAS entities and to share required information such that sufficient levels of interference mitigation can be achieved.

Figure 15: Census Tracts in New York City [21].

4.5 Challenges and Next Steps

The concept of the three tier model as introduced by FCC for SAS [5] is a completely new concept in worldwide regulations. Service providers are accustomed to the certainty that exclusive licenses provide. A key challenge would be to ensure that industry and ecosystem collaborate closely in order to deploy systems using this band. For the band to be viable to service providers as a PAL channel, the regulations need to ensure there is some guarantee for renewing the spectrum licenses. Further, the concept of the SAS needs to be developed very carefully such that the needs of both incumbents and commercial users are met. The incumbents' main concerns include interference protection, privacy and security of DoD-related data, such as ship locations and activity details. At the same time, confidentiality of network information is equally important to the service providers. Designing the ESC and SAS to accommodate the needs of the ecosystem players will ensure success in the band.

Furthermore, as mention in section 3.4 for the LSA case, interference mitigation is expected to be a key challenge in future wireless networks. While SAS can address this challenge in a similar way as LSA, the interference situation is more complex in the case of SAS deployment: In contrast to LSA, SAS needs to consider interference originating from distinct MNOs with networks being deployed in neighboring *Census Tracts*. As there is typically no coordination between distinct MNOs, it is difficult to deploy any conventional interference mitigation technique. Therefore, novel and disruptive approaches and techniques will be needed to reduce interference levels between two MNOs while limiting the exchange of information between the two to a strict minimum.

5 A Look into the Future – LSA/SAS Evolution

The introduction of LSA and SAS marks a substantial change in spectrum management by NRAs. It is a *de facto* confirmation that traditional re-farming approaches are reaching their limits and cannot guarantee the availability of broadband wireless bandwidth as required for future 5G communication systems and beyond. It will take time until all stakeholders will accept this fact and finally rely on shared spectrum as a key ingredient to their network.

Furthermore, there are two distinct technologies on the table – LSA and SAS – which should ideally converge into a single framework in order to guarantee rapid adoption and deployment. 3GPP has recently begun to consider spectrum sharing in a study item [22] and targets a worldwide solution. It remains to be seen whether a harmonized that covers the current European and U.S. approaches – and possibly includes specific flavors required for Asia and other markets – can finally be agreed upon.

While spectrum sharing represents one way forward for providing additional capacity for future broadband wireless systems, its future success will certainly depend on the level of adoption of alternative approaches. Among the latter, the usage of higher frequency bands, including mmWave spectrum up to 70 GHz and beyond, is currently considered to be promising. However, the suitability of mmWave technology to mobile use cases is currently under study and its sustainability needs to be proven. The final success and feasibility of such alternative technologies will substantially impact the need and adoption of spectrum sharing below 6 GHz, and potentially the application of solutions like LSA and SAS in even higher frequency bands [23].

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