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# Dynamic Licensed Shared Access - A new architecture and spectrum allocation techniques

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**Abstract** — This paper proposes a new system architecture for Licensed Shared Access (LSA) wireless networks, as well as novel band management techniques for fair and ranking-based spectrum allocation. The proposed architecture builds upon recently standardized and regulatory-accepted LSA systems and stems from the work done in the EU-funded project ADEL. Two new resource allocation algorithms are introduced and their behavior is validated via system-level simulations.

**Keywords** — LSA; ETSI; CEPT; Regulatory body; Wireless networks; Standardization body; Resource allocation algorithms.

## I. INTRODUCTION

This paper focuses on the Licensed Shared Access (LSA) technology paradigm. Our starting point is the latest status of the work of regulatory and standards bodies in the field, upon which we propose enhancements in the direction of *dynamic* LSA, derived in the context of the EU-funded collaborative research project ADEL (Advanced Dynamic spectrum 5G mobile networks Employing Licensed shared access) [1].

Previous works elaborated on key LSA scenarios and on an initial proposed enhancement to the wireless communication system architecture to support LSA [2]. The authors provided an overview of the LSA technology and the status of its definition in 2014 following the European conference of postal and telecommunications administrations (CEPT) regulation and the European Telecommunications Standards Institute (ETSI) standardization [3].

In this work we present important updates on the CEPT and ETSI works, highlighting the usage of wireless broadband communication services in the 2.3-2.4 GHz band. We propose to move LSA technology forward in two ways: first, by further refining the LSA system architecture proposed in [2] (which compares to similar approaches of other research projects like the CORE+ one); second, by focusing on the LSA Band Manager block, we introduce two new resource allocation algorithms, whose expected traits are validated via system-level simulations.

The rest of the paper is organized as follows: Section II reviews the main concepts of LSA and provides updates on the

latest status of the work in regulatory and standards bodies. Section III explains the advantages of the proposed refinements to the LSA architecture. Section IV presents system level investigations assessing two algorithms for resource allocation. Section V draws the paper conclusions and potential next steps.

## II. REGULATORY AND STANDARDIZATION STATUS OF LSA

### A. The LSA Regulatory Framework

The LSA definition, as currently accepted by the CEPT, assumes that LSA is a licensing approach that foresees the sharing of bands with low incumbent activity by a limited number of new licensed users, called LSA licensees. Although any combination of incumbents and LSA licensees is allowed [4][5], provided its conformance with the ITU-R Radio Regulations, the LSA is more relevant to vertical sharing situations, i.e. when the LSA licensee and the incumbent deploy different radio services [5][6]. The sharing conditions are country-specific and must be set by the relevant National Regulatory Authority (NRA) after consultation with LSA licensees and incumbents. Then NRA issues individual rights of use of radio frequencies to the LSA licensees, so they can share the LSA band with the respective incumbents following the pre-defined sharing conditions. In this way, LSA licensees have a pre-determined guarantee to access the spectrum on an exclusive basis when not used by the incumbent, and are protected from interference caused by neighbor LSA licensees and incumbents, thus allowing predictable QoS levels. A deployment of an LSA system requires the introduction of two new architecture building blocks: the LSA repository and the LSA controller (see Fig.1).

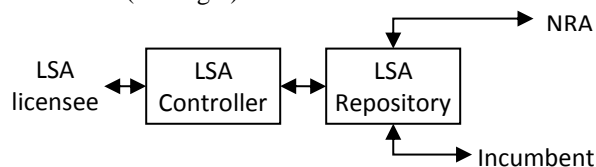


Fig.1 – Baseline LSA architecture as described in [6].

The LSA Repository contains information on the spectrum that the incumbent is using and its required level of protection. The LSA Repository may be managed by the NRA, the

incumbent, or delegated to a 3<sup>rd</sup> party. The LSA Controller retrieves information from the LSA Repository about the spectrum the incumbent uses, and manages the access of the LSA licensee to the available spectrum. The LSA Controller may interface with one or more LSA Repositories and LSA licensees. The LSA Controller may be managed by the NRA, the incumbent, the LSA licensee, or delegated to a 3<sup>rd</sup> party.

### B. The LSA Regulation for Mobile Broadband Applications

In April 2014, the European Commission issued a mandate to the CEPT to regulate the introduction of mobile broadband (MBB) applications in the 2.3-2.4 GHz band under the LSA regime, as this band has limited incumbent activity in most of the European territory. The CEPT Reports 55 [7], 56 [8] and 58 [9] are in response to this mandate; they list harmonization measures *to be mandatorily implemented by the EU member states willing to introduce MBB in this band*.

The CEPT Report 55 [7] defines the following technical parameters for MBB applications: *be based on 5MHz channels, use TDD duplexing mode, and emit below a specified block-edge-mask*. These conditions are sufficient to ensure the co-existence between multiple MBB applications within the band, and with other applications in adjacent bands. Information collected by several NRA allowed the CEPT to identify as the incumbents of the band 2.3-2.4 GHz in Europe the Programme Making and Special Events (PMSE) video links, telemetry services, fixed links, other governmental uses, and amateurs (as a secondary service).

The easiest way to protect incumbents from potentially harmful interference caused by LSA licensees is to pre-define a fixed channel plan, identifying the channels that are reserved for each licensee when the incumbent is not using them. In alternative, the CEPT Report 56 [8] proposes more efficient methods to protect the incumbents from interference. These additional protection options are geographical areas where:

- *Exclusion zones*: no interferer transmitters are allowed.
- *Restriction zones*: interferer transmitters are allowed to operate under restrictive conditions (usually limited power and / or antenna height).
- *Protection zones*: affected receivers will not suffer aggregated interference above a given threshold.

Such protection mechanisms may be static or *dynamic*, the latter implying that the mentioned zones adapt automatically based on information updates provided by the incumbents. It is worth noting that for the same type of incumbent, several of protection options are suitable, depending on the incumbent's license details and the spectrum utilization dynamics

For the specific case of PMSE incumbents, which are the main incumbents of the 2.3-2.4 GHz band in Europe, the CEPT Report 58 [9] proposes a *step-by-step procedure* to define the technical and regulatory solutions to be included in the sharing framework. Although exclusion zones may also be used, *the report selects protection zones as the most adequate protection mechanism*, and defines the maximum field strength that MBB interferers may cause on PMSE receivers as the metric that should define such zone. Moreover, it is stated that, if PMSE receivers are moving, the MBB network

needs to adapt the transmission power to ensure that the interference caused to PMSE receivers is below the given threshold. For this, the PMSE incumbent should provide information about the new location of the PMSE receiver, and the frequency it will use.

### C. The LSA Standards for Mobile Broadband Applications

The ETSI activities on LSA have the 2.3-2.4 GHz band in focus and started with the technical report [10] providing examples of network topologies and MBB technologies that may be utilized under an LSA framework, and then with the technical specification [11], defining system requirements for operation of MBB systems. These requirements served as an input for defining harmonized European LSA standards under the standardization mandate for Reconfigurable Radio Systems (RRS). Recently, ETSI proposed [12] the LSA system architecture depicted in Fig.2, to enable the operation of MBB systems under the LSA regime. This sketchy LSA architecture builds on the scenarios and applications described in [10] and the system requirements listed in [11].

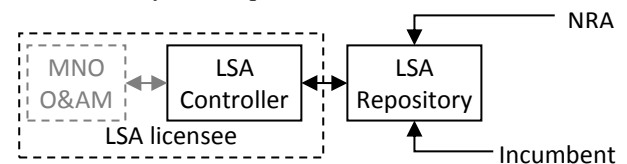


Fig. 2. – Baseline LSA architecture for mobile broadband applications.

Comparing Fig.1 and Fig.2 when applied to multiple LSA licensee scenarios, one can see that the CEPT and ETSI architectures exhibit differences related to the role and ownership of the controller. For CEPT, the controller manages the access of multiple LSA licensees to the band, while for ETSI the controller is always owned by the LSA licensee and is responsible for re-configuration decisions that would allow that (single) LSA licensee to access the LSA spectrum. In addition, the ETSI proposal further restricts the number of the LSA Repositories to a single unit.

### III. THE ADEL ARCHITECTURE FOR USE OF THE LSA BAND

Attempting to move forward the ongoing LSA regulation, which focus on long-term sharing arrangements, and standardization activities, which are based on fixed channel plans, the ADEL project proposes an architecture that supports dynamic LSA configurations, aiming at better overall spectrum utilization through the use of advanced Radio Resource Management (RRM) techniques and sensing reasoning. To this end, the basic two-node LSA architecture depicted in Fig.2 is complemented with additional modules, as depicted in Fig.3, that would allow to detect (and adapt to) changes in the radio environment, caused either by the incumbents or by the LSA licensees, and to coordinate the access of multiple LSA licensees to the LSA band.

The LSA functional architecture proposed in this paper, which builds upon [2], addresses multiple LSA licensee and multiple incumbent dynamic configurations. It contains a building block (LSA Band Manager) to coordinate the access of multiple LSA licensees to the LSA band, thus avoiding the need to have a fixed band plan, as presumed by the ETSI standard [12] and by the CORE+ single-licensee trials [13].

In addition to the LSA Repository, which contains information only about the incumbent, the ADEL project also proposes the use of *one or more collaborative spectrum sensing networks* to provide periodical updates about the radio environment. These information sources will be used to compute (and keep updated) a Radio Environment Map (REM) whose role is to reflect the real environment as accurately as possible. When there is an LSA licensee request for spectrum, the information contained in the REM will be used by the LSA Band Manager to allocate the most adequate resources (frequency and power) to that specific LSA licensee.

The proposed architecture also includes modules dealing with authentication, storage of the LSA sharing agreement rules, and spectrum usage accounting and billing. These functional modules may be implemented by the same, or by different, physical modules. A detailed description of the proposed LSA system can be found in [2].

This architecture is also ETSI-compliant, since each LSA licensee has an LSA controller responsible for translating the spectrum availability information, provided by the LSA Band Manager, into networking reconfiguration commands.

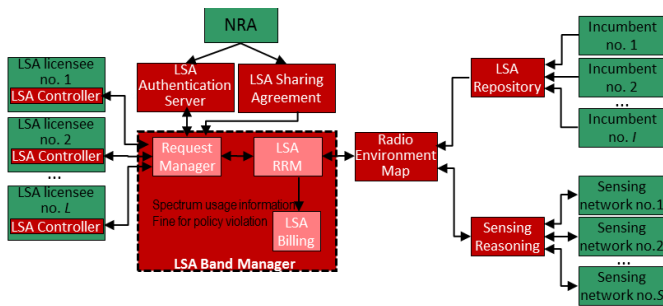


Fig. 3. – The LSA system architecture proposed by ADEL.

#### IV. SYSTEM-LEVEL SIMULATOR AND FIRST RESULTS

The ADEL system-level simulator implements all the major entities of an LSA system, as depicted in Fig. 4, i.e. the incumbent (with a possible extension to a multi-incumbent case), the LSA Repository, the LSA Band Manager, and multiple LSA licensees (MNOs). The simulator supports centralized and distributed resource allocation and spectrum sharing policy reinforcement algorithms, and can test both macro-cell and small-cell ADEL scenarios, as defined in [2].

The LSA Band Manager contains two sub-blocks: the Request Manager, which performs priority management according to the LSA spectrum usage rules, and the LSA RRM block, which performs the computation of available resources to assign to the LSA licensee, based on spectrum usage rules and the information stored in the Repository. With regard to the LSA Licensee block, currently a multi-licensee scenario is supported, where within a licensee network each User Equipment (UE) associates to the licensee’s Base Station (BS) providing the strongest received power.

In the LSA Repository, the incumbent’s activity is mapped into a matrix of “pixels” (each representing a geographic area), with one matrix per LSA channel; each incumbent is associated with a given LSA channel. The incumbent’s protection zone is implemented as a circular area within which

the constraint Interference-to-Noise Ratio (INR) < -6dB needs to be met by LSA licensees over that spatial region.

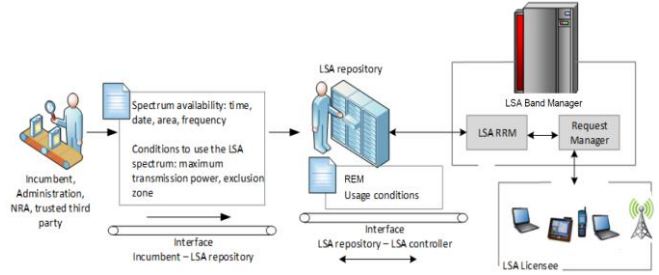


Fig. 4. – The ADEL System-Level Simulator blocks.

In the following Sections we focus on the LSA Band Manager block (see Fig. 3) and present two newly developed resource allocation algorithms: the first one achieves a strictly fair spectrum allocation among licensee networks, assuming that they all behave identically; the second one is a ranking-based resource allocation approach, which can penalize misbehaving Licensee operators.

#### A. Fairness-driven resource allocation algorithm

In [14] the authors present a mechanism to allocate incumbents idle spectrum to licensee access points from different operators, combining independent set selection by bidding and a group bid. The target of [14] is a policy aiming for revenue and market regularity, whereas in the algorithm we propose, we aim for fairness in spectrum allocation among the competing MNOs from a purely technical standpoint.

Denoting by  $n \in \{1, \dots, N\}$  the MNO index out of  $N$  MNOs, we define the **priority index (PI)**  $PI_n$  for MNO  $n$  as:

$$PI_n = \lim_{W \rightarrow \infty} \frac{\text{BW awarded to MNO } n}{\text{Sum BW allocated by the incumbent}} = \lim_{W \rightarrow \infty} \frac{\sum_{j=1}^W B_n^a(j)}{\sum_{j=1}^W B(j)} = \lim_{W \rightarrow \infty} \frac{\sum_{j=1}^W B_n^a(j)}{\sum_{j=1}^W \sum_{n=1}^N B_n^a(j)}$$

where  $B_n^a(j)$  and  $B(j)$  denote the bandwidth awarded to MNO  $n$ , and the total offered bandwidth by the incumbent at the  $j^{\text{th}}$  spectrum allocation instant, respectively. Note that we assume that all the offered spectrum is allocated to the MNOs.

Denoting by  $B$  the available spectrum at a single allocation instant  $j$ , the proposed spectrum allocation algorithm operates in the following steps:

- 1) Initialize the assigned spectrum to every MNO  $B_n^a$  with zero in round  $i = 1$ .
- 2) In round  $i$ , divide the bandwidth  $B$  in proportion to the PI for each MNO with demand  $B_n^d > 0$ , i.e., the MNO  $n$  is allocated spectrum in inverse proportion to its PI s.t.

$$B_{n,i}^a = B \cdot \left( \frac{1 - PI_n}{\sum_{n=1}^N (1 - PI_n)} \right)$$

- 3) If the spectrum demand for any MNO  $n$  is less than  $B_{n,i}^a$ , the bandwidth  $B_{n,i}^a - B_n^d$  becomes the residual bandwidth  $B_n^r$ , which is zero otherwise. All the MNOs with  $B_{n,i}^a > B_n^d$  do not take further part in the allocation.

- 4) After completing the allocation procedure in each round  $i$ , update the assigned and requested spectrum by,
 
$$B_n^a = B_n^a + \min(B_{n,i}^a, B_n^d), \text{ and}$$

$$B_n^d = B_n^d - \min(B_{n,i}^a, B_n^d), \forall n.$$
- 5) Set  $B = \sum_{n=1}^N B_n^r$  for the next round and go back to step 2.
- 6) The process terminates when  $B = 0$  or  $B_n^d = 0, \forall n$ .

This algorithm allocates spectrum in a fair fashion to every MNO in each allocation round. We use Monte Carlo simulations to evaluate the performance of this algorithm and demonstrate its short- and long-term fairness characteristics. The window size  $W$  for computing the PI is set to 20 allocation instants to ensure more short term fairness. As the PI computation for each MNO requires bandwidth allocation in the last  $W$  instants, simulations are initialized by having  $W-1$  time slots with zero spectrum allocation and the  $W^{\text{th}}$  time slot with allocation depending on a random PI (chosen between 0 and 1) for every MNO. In the simulations,  $N = 4$  and the incumbent spectrum  $B$  is normalized to 100 units, without loss of generality. At each spectrum allocation instant, every MNO  $n$  chooses the demand randomly out of a vector of values [50,100] with uniform probability. 10,000 spectrum allocation instants are simulated to compute the mean spectrum allocation for each MNO.

Fig. 5 shows the performance of the proposed spectrum allocation algorithm, plotting the spectrum allocation instants 21-200, where the first 20 instants were initialized with zero spectrum allocation and random PI. As all of the MNOs behave symmetrically, the spectrum allocation statistics are plotted for one MNO only.

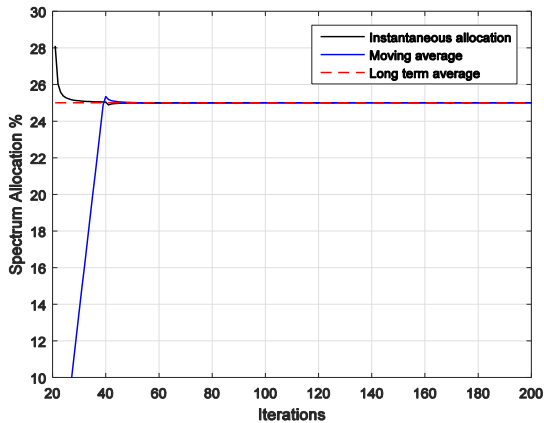


Fig. 5. – Performance evaluation for the spectrum allocation algorithm.

The algorithm provides a strictly equal share of available bandwidth from the incumbent to each MNO (25% for  $N = 4$ ) and provides long-term fairness. The short-term allocation for each operator for the first 200 allocation instants is evaluated. It is evident that the algorithm allocates spectrum to each MNO in such a way that its moving average (evaluated over  $W$  allocation instants) converges to its mean very quickly. After the initialization phase, the algorithm starts dividing the instantly available spectrum equally among the competing MNOs as the PIs for all the MNOs converge to same values.

The instantaneous allocation remains constant at  $0.25B$  for  $N = 4$  (strictly fair), if the minimum demand for every MNO is greater than  $0.25B$  (it is  $0.5B$  in this example). However, if the minimum possible demand is less than  $0.25B$ , the instantaneous allocation varies and the moving average slightly diverges from the mean, recovering very quickly.

### B. Ranking-based resource allocation algorithm

The primary aim of LSA is to maximize the system-wide utility through the sharing of underutilized resources. However, selfish operators may try to maximize their own utility, usually impeding the utility of other LSA operators, or of the incumbent, therefore hindering the complete ecosystem's social welfare.

Node misbehaviour under the cognitive radio concept has been considered in the literature. A comprehensive summary of possible attacks to a cognitive radio system is provided in [15]. The authors review the different steps in requesting and granting spectrum access in a hypothetical cognitive radio system and identify actions that malicious or selfish nodes could take to disturb and / or improve their own utility against that of the cognitive radio community. The majority of the identified attacks relate to obstructing the communication between the spectrum licensees and the auctioneer, or bypassing authentication systems to present false credentials to the controlling entity that opens the way to malicious manipulation of the decision making center. Similarly, [16] reviews the threats present in “Sensing-Driven” and “Database-Driven” Spectrum Sharing architectures. Emphasis is given on attacks that aim to compromise the privacy of either the Primary User or the Secondary User, or the access to the shared database. The authors then present possible *ex ante* (preventive) and *ex post* (punitive) measures to enforce compliance with the shared access agreements. The preventive measures focus on protecting the devices' software and hardware layers from tampering with, while the punitive measures aim to identify the misbehaving users and punish them with either (i) *exclusion* from shared access, or (ii) by imposing *financial penalties*.

Instead we propose the use of a ranking system to monitor the behaviour of the LSA parties. Each LSA party's score is kept in the database and is used to decide which operator should be allocated the available resources, as well as the temporal duration of the allocation. Our proposed rating system has two distinct qualities; (i) it punishes misbehavior; and, (ii) it gradually forgives (or forgets) the penalty. In addition, the ranking system should consider the scarcity (or abundance) of resources in different geographic areas, the type of Incumbent operator, as well as the longer term behavior of the licensee operator, weighting the punishment accordingly.

We propose that the LSA controller maintains a rank ( $R_k$ ) for each licensee  $k$  with

$$R_k = \sum_{i=0}^n a_{k,i} \cdot e^{-\frac{t-t_i}{\lambda_{k,i}}}$$

where  $a_{k,i}$  and  $\lambda_{k,i}$  represent the magnitude and the temporal effect of the penalty of event  $i$  from licensee  $k$ , respectively, while  $t_i$  is the time at which the penalty or reward was



applied.  $\alpha_{k,i}$  takes negative values for penalties. Both  $\alpha_{k,i}$  and  $\lambda_{k,i}$  are functions of the type of misbehaviour, the demand for the resources that were misused, weights applied by the incumbent operator representing the incumbent's detriment from the LSA violation, as well as weights representing the long term behavior of the licensee. The rank ( $R_k$ ) of the licensee affects its ability to reserve the resources it wants, when other licensees are also interested in the same resources. In particular, we propose that those operators that are ranked higher are prioritized in the resource allocation procedure.

Fig. 6 shows the share of allocated resources in a scenario where five licensee operators contend for three available allocation blocks. The probability for each operator to misbehave is 0.0, 0.1, 0.2, 0.3, and 0.4, respectively, while  $a$  and  $\lambda$  are the same for all operators and take the values of -1, and 10, respectively. In our simulations, we assume that an operator can misbehave only when it is allocated a resource block, and that each operator can only be allocated a single allocation block in each allocation period. This restricts the spread of the shares of allocated resources. In the extreme case where only one block is available, all resources are allocated to operator 1, who is never misbehaving.

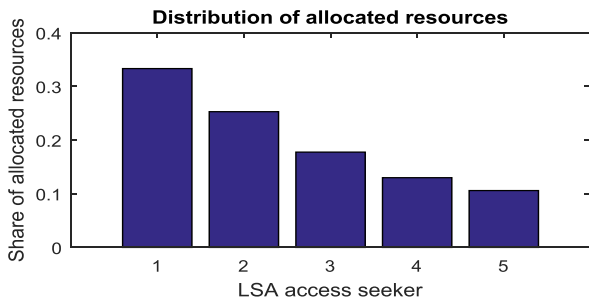


Fig. 6. – The share of allocated resources among the five LSA operators.

Fig. 7 shows the change in the LSA operators' rank over time, according to their behavior. Operator 1 follows always the allocation rules and maintains the highest rank (0).

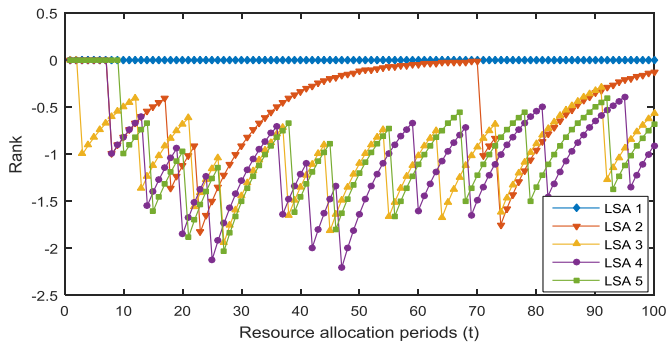


Fig. 7. – The ranks of the five LSA operators over time.

## V. CONCLUSIONS AND NEXT STEPS

Building upon the latest updates on the LSA spectrum sharing paradigm at the standardization and regulatory fronts, in this paper we provide a new LSA system architecture, as well as novel spectrum allocation policies. These are aimed at

the evolution of the LSA concept towards a more dynamic mode of operation, targeting a better overall spectrum utilization. Future work is geared towards large-scale evaluations of the proposed dynamic LSA concept embodied in the proposed LSA architecture.

## ACKNOWLEDGMENT

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