Evaluation of recent spectrum sharing models from the regulatory point of view

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***Abstract*— For over a decade the quest for new means to improve the efficiency of spectrum use has motivated researchers all over the world to come up with innovative concepts for spectrum sharing. During this time, several concepts have been created and investigated, however, only a small part of them has raised industry interest or stimulated further discussions in the regulatory domain. Even a smaller part is deployed in real life wireless systems. This is due to the fact that there are different criteria that make a spectrum sharing model attractive or even feasible from an industry or regulatory point of view compared to the academic world. In this paper, we introduce key criteria from the regulatory side for a successful sharing model and evaluate two of the recent regulatory spectrum sharing concepts – Licensed Shared Access (LSA) and Spectrum Access System (SAS) – against the identified criteria.**

I. INTRODUCTION

In order to develop a feasible spectrum sharing model, where several radio systems would operate in the same spectrum band, close cooperation between regulatory, industry and research domains is needed. The research domain plays a critical role in the innovation, testing and trialing of new spectrum sharing concepts. However, without support and interest from the industry and regulatory domains these concepts will not find their way to real life applications. Therefore, industry is often involved in the creation of spectrum sharing concepts by co-operating, financing and setting the framework for the research by deploying pilots with real systems. In addition to industry requirements such as creating new business models that provide viable business opportunity and guaranteed spectrum access, also the complexity and implementation cost need to be reasonable.

The National Regulatory Authorities (NRAs) are considered responsible to provide a feasible regulatory framework to support new approaches meeting the needs of the public. The regulatory framework that governs the spectrum use consists of three different levels as discussed in more detail in [1]. The Radiocommunication sector of the International Telecommunication Union (ITU-R) defines the recommended allocation of frequency bands to radiocommunication services together with related technical parameters and coordination procedures and conducts high level sharing studies between the radio services in the international level. These allocations are implemented on the regional level where the interoperability and the border coordination between the numerous countries must be ensured. Ultimately, NRAs have the right to authorize the spectrum use in their own country. To be successful, this framework requires tight collaboration at the different levels as well as across the levels.

There are several spectrum sharing models currently under discussion in the regulatory framework. After extensive studies on the unlicensed TV white space concept in the US and Europe, sharing models that encompass licensing have emerged in recent years. Two of the more recent spectrum sharing concepts that are currently being studied in the regulatory domain: Spectrum Access System (SAS) (or three-tier Hierarchy model) from US [2] and Licensed Shared Access (LSA) [3] from Europe. As these models are new, there is not much prior work on their analysis. An initial evaluation of the LSA concept from the regulatory point of view can be found in [4]. We extend that work by providing general criteria to evaluate spectrum sharing concepts from the regulatory point of view and evaluate both sharing models against the criteria.

The rest of the paper is organized as follows. In Section II, LSA and SAS models are briefly described followed by a short comparison. Section III, provides an insight on what criteria a spectrum sharing model needs to fulfil in order to be feasible or promoted from the regulatory point of view. In Section 0, these criteria are used for the evaluation of LSA and SAS models. Finally, conclusions are drawn in Section V.

II. RECENT ADVANCES ON SPECTRUM SHARING IN REGULATORY BODIES

This section provides a general description of two of the most promising spectrum sharing models from the regulatory perspective. Both of them aim at more efficient spectrum usage by allowing additional users to access a spectrum band on the geographical areas and time periods when it is not being used by the existing system(s) with current spectrum usage rights, so called incumbent system. More detailed description of these models including enabling techniques for LSA and SAS can be found for example in [5] and [6], respectively. It should be noted that these models are currently under development and discussion in the regulatory fora and thus are subject to refinement and further amendment.

A. Licensed Shared Access

In Europe, the LSA concept has gained significant interest as a potential means for more efficient spectrum use. It was initially introduced by the European Commission (EC) based on an industry initiative for spectrum sharing that allowed a mobile system to share spectrum bands with other type of incumbents [3]. LSA is a broader regulatory approach enabling the introduction of any radio system to a frequency band with incumbent usage based on an individual licensing scheme. The LSA license together with the related sharing framework is negotiated between the incumbent and the new entrant, so called LSA licensee, and the license is issued by the NRA [7].

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Additionally, the NRA may take an active role in identifying possibilities for LSA and in defining the sharing framework, including technical and operational conditions related to the LSA approach [8]. The LSA license together with the sharing framework will allow full control over the interference and enable provision of certain Quality-of-Service to all users.

While the generic LSA concept [8] encompasses sharing between any types of radio systems, the current activities in standardization and regulation are specifically concentrating on the application of LSA to the International Mobile Telecommunications (IMT) bands. This would enable mobile communication systems to access those bands on a shared basis that are currently not available for them on an exclusive basis. The 2.3-2.4 GHz band is currently under study as the first use case for LSA. In the regulatory domain, European Conference of Postal and Telecommunications (CEPT) has considered harmonized implementation measures [9] and introduced cross-border coordination procedures [10] for this band. From a standardization perspective, European Telecommunications Standards Institute (ETSI) has published a system reference document describing at a high level the mobile broadband services for the 2.3-2.4 GHz band under the LSA regime [11]. ETSI is currently in the process of specifying the requirements, functional architecture and protocols for LSA.

In standardization [11] as well as in research [5], it is predicted that LSA can be implemented with relatively small changes to the infrastructure of the existing mobile network. In practice, two additional functional units are needed on top of the existing cellular network infrastructure to support the varying LSA spectrum availability and for the preservation of the rights of the incumbent users. Firstly, a database is needed for storing and updating the information about the availability and use of LSA spectrum together with operating conditions. This information is needed to guarantee the incumbent protection from interference. LSA database may also handle the coordination between multiple incumbents and LSA licensees. Secondly, a functional management unit is needed to grant permissions within the mobile network to access the LSA bands based on the information and policies provided by the database. A practical implementation of the LSA in field trials and the results obtained are presented in [12], [13].

B. Spectrum Access System

Another database centric sharing model, currently attracting significant interest in the US, is the SAS, which supports spectrum sharing with three levels of hierarchy in spectrum usage [2]. The incumbent system(s) are accorded the highest level of usage rights including exclusive spectrum access and guaranteed protection from harmful interference when and where they deploy their networks or systems. Secondary licensees occupy the middle level and are generally expected to be a commercial service provider i.e. a cellular service provider. The secondary licensee would have short-term priority operating rights, so called Priority Access License (PAL), for a specified geographic area. PAL is also issued for a pre-defined term and bandwidth (e.g. one minute or even one year for a 10 MHz unpaired channel) with possibly varying spectral location [6]. PAL would guarantee the secondary licensee interference protection from the third level of the hierarchy often referred to as opportunistic use. Third level of access is called the General Authorized Access (GAA) and is light licensed similarly to a Wi-Fi with the critical distinction that the GAA device or system must be capable of effectively interacting with the controlling SAS. GAA users are allowed to opportunistically access a specific spectrum band in a geographical area or time period when it is otherwise unoccupied by both the incumbent and the PAL licensee. The amount of spectrum reserved for PAL and GAA and the PAL license durations will strongly influence their demand.

The core functions of SAS include determination and assignment of the available frequencies at a given geographic location; registration, authentication and identification of user information and location as well as protection of the incumbent from harmful interference. This is accomplished through enforcing an Interference Limits Policy based approach to insure that harm claims threshold limits aren't exceeded in exclusion or coordination zones [14], [15]. The SAS model is a general framework that could be applied to any bands and between any systems [2]. The current efforts in the FCC are concentrated on the 3550-3650 MHz band with possible extension until 3700 MHz as the first use case to explore new methods of spectrum sharing [6].

C. Comparison of models

The two regulatory sharing models described above present the state of the art sharing models. On the highest level in both models is the incumbent system as shown in Figure 1. In fact, protection of the incumbent spectrum users' rights is the starting point for both models. Additional users are introduced on times and geographical areas where the incumbent user is not using the spectrum. LSA is foreseen to be based on the voluntariness and the incumbent can define on which bands, geographical areas and times to allow additional usage via licensing [7]. The SAS is based on the assumption that the incumbent has an exclusive right to actual use but all spectrum resources unused by the incumbent user would be subject to additional usage. The second level on both spectrum sharing models introduce additional users on a controlled manner based on individual licensing. The major difference between the two models is that the SAS introduces a third level of usage rights. This additional level of the SAS introduces opportunistic access for light licensed users.

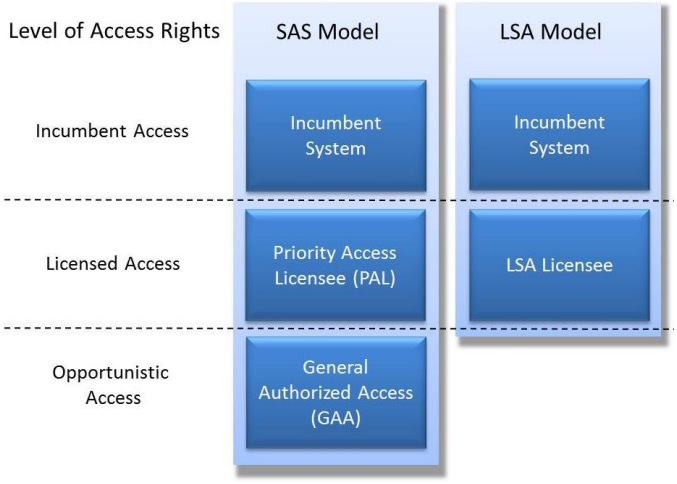

Figure 1. Overview of different levels in the sharing models.

III. REGULATORS' CRITERIA FOR SPECTRUM SHARING MODELS

This section will provide guidance on the evaluation of spectrum sharing models from the regulatory point of view. It presents a checklist of the criteria that the spectrum sharing model should fulfil in order to be feasible from the regulatory point of view. An overview of the criteria is shown in Figure 2. The detailed descriptions are presented in the following sub-sections.

Figure 2. Regulators' criteria for a successful sharing model.

A. *Efficient spectrum utilization*

One important criterion for regulators is the promotion of efficient spectrum utilization. This is particularly important as the demand for new spectrum for the various radiocommunication services keeps increasing and it is getting more and more challenging to respond to the demand. New approaches for more efficient spectrum utilization are of interest to the regulators and may actually result in tangible benefits to their citizens. In this case, there should be measurable gains in spectrum efficiency, which result in the ability to enhance existing services, offer better coverage and new services, or some combination of these features.

B. *Protection from the interference*

Regulators are particularly interested how the sharing model handles the protection from interference. Technical measures are needed to minimize harmful interference to the incumbent spectrum user and to the extent possible to the new user as well. Depending on the usage of the bands by the incumbents and the business model of the additional users, all possible technical measures in time, frequency and space domain shall be taken into account to assure protection of the existing services operating in the band to be shared. These might be realized by general approaches like spatial separation (e.g. by establishment of exclusion zones). Alternatively, if the characteristics of the incumbent allow for time based sharing, coordination zones can be implemented using a database focused time slot reservation system. Even mitigation techniques such as listen before talk (LBT), dynamic frequency selection (DFS) and/or transmit power control (TPC) can be deployed to realize sharing. The additional user is required to undertake the technically feasible steps to protect incumbents, by meeting the limitation of the bands and/or the license. Also additional users should be protected from harmful interference, but these protections are subsidiary to the protections provided to the incumbent system.

C. *Minimum impact to the technology of the systems*

Another criterion is that the new systems should be compatible with the incumbent systems and their evolutions in such way that ideally no changes are forced on them. The technology of the additional user should not impact possible developments of the incumbent use of the bands or hinder investment for innovation. This applies to other new users who might share the bands in the future or even to those who currently occupy an adjacent band or may do so in future.

Technical parameters and limitations of the existing usage are the only boundary to the new users. Within this framework, usually provided by the licenses of the existing service, the new user is free to decide on the technology and service to be provided. To avoid the creation of harmful interference conditions, new services should coordinate with the existing users who may be impacted.

D. *Reliable access and usage conditions*

One of the main requirements on a sharing model is the provision of predictable access and reliable usage conditions for the resource made available for sharing. The incumbents will be required to establish a related framework, preferably together with the new user(s), in which the planned business models of the possible additional user(s) must be able to successfully operate. It has to be noted, that incumbents can only provide conditions, which are also imposed to their own use.

E. *Implementation and enforcement by the regulatory authorities*

The enforcement of spectrum sharing regulations will be a critical component of the broad successful implementation of a spectrally efficient dynamic spectrum sharing system (see e.g. [16]). The sharing model should consist of both ex ante and ex post measures, which allow the NRA for direct implementation and possible enforcement in accordance with their national framework. In practice this implementation means that the NRA has the ability to monitor that all users are behaving in accordance to implemented rules.

NRAs are responsible to allow for efficient access to the relevant sharable frequency bands on a national basis. Enforceability will be based e.g. on the national authorization process by any type of licensing of the bands in accordance to the mentioned national/regional circumstances and regulation [4]. Implementation allowing for enforcement, if necessary, may also be aided by predetermination of international standard(s) for the networks or devices to be deployed.

F. Fairness and Pro-Competition

A sharing model should not provide special advantage to any particular entity. It should promote the introduction of new players and lower the entry barrier to access the markets. The opportunity of the additional use might also be subject to awarding procedures, which will allow for competition and fairness. This especially applies for bands regionally harmonized for certain use, but assigned for different purpose by some NRAs [8]. The principle of transparent and non-discriminatory access to the bands must be respected.

G. Legal and operational certainty

Any sharing model needs to fulfil the basic legal certainty requirements to support e.g. investment planning. Certainty must also exist as it relates to the security in the exchange of information between incumbents and new users. Of special interest here is the security of the operational databases, and additional entities in the process and the business case related information (i.e. if more than one new user is sharing the resource of an incumbent).

H. Foster innovation

The introduction of any new technology to provide services to the public and to encourage investments through the creation of relevant business models is the key to foster innovation. Any sharing model in general should follow this principle. A sharing model should in fact foster innovation by among other features shortening the required time to gain access to spectrum (e.g. compared to re-farming). Less stringent coverage obligations may result in shorter technology life cycles and new business models for more localized services. Innovations are foreseen in field of optimizing spectrum sharing between the systems in terms of e.g. new interference mitigation techniques. It also offers the opportunity for more services to be supported by the available spectrum over the long term. This allows more services to be created and their business models to be explored in real world deployments.

IV. Comparison of the Spectrum Sharing Models Against the Criteria

Two regulatory spectrum sharing models introduced in Section II – LSA and SAS – are next evaluated against the criteria presented in Section III. The summary of this evaluation is given in TABLE I.

A. Efficient spectrum utilization

Both LSA and SAS systems provide enhanced spectrum efficiency through improved utilization of spectrum in time and geographical domains. Through the addition of the GAA tier and associated class of users in the SAS, spectrum utilization may be further enhanced on geographical locations where there is neither an incumbent, nor a secondary user for the specific spectral band. The improved spectrum utilization under either of the spectrum sharing systems should provide NRAs a strong incentive for pursuing dynamic spectrum sharing. However, the availability of the enabling techniques for spectrum sharing should be demonstrated. This has already been done in the case of LSA [12], [13] and is yet to be done for SAS.

B. Protection from the interference

A key idea in both LSA and SAS is to protect the incumbents from harmful interference and to also guarantee entrants predictable interference conditions. Protection from the interference in both systems is based on spatial and/or temporal separation that is obtained through individual licensing and protection zones enforced via the LSA or SAS specific database and management unit. LSA license is granted to only one LSA licensee to a certain band, time and geographical area [7] and this is not overlapping to the permanent incumbent spectrum usage. If there is a change in the spectrum use of the incumbent, the LSA licensee is informed via the LSA database and management unit to modify its spectrum usage accordingly. This guarantees both the incumbent user and the LSA licensee exclusive access to the spectrum when they are using it and therefore they are protected from interference.

The SAS system is intended to operate in a similar, albeit more complex manner in that it is intended to ultimately operate with not only a secondary user, i.e. the PAL license holder, but also with potentially numerous GAA "lightly licensed" users contending for access to the spectrum if neither the incumbent nor the PAL licensee are present. This provides a level of concern as to the ability to insure an interference free environment and could call for the use of enhanced mitigation techniques.

C. Minimum impact to the technology of the systems

Within the LSA framework, the incumbent user maintains a higher level of usage rights over the LSA licensee. Therefore, the enabling techniques for LSA should allow changes in the usage characteristics and deployed technologies of the incumbent user by adapting the protection accordingly. The incumbent user together with the LSA licensee may agree on the spectrum usage terms and conditions already on the licensing phase and the incumbent only needs to inform licensee when there is a change. The incumbent will need to inform the LSA licensee about the LSA band availability which can be done with relatively simple add-on tools (see e.g. incumbent manager [13]) and requires no change to the system itself.

The LSA concept does not limit the technical approaches for the LSA licensee. However, the LSA licensee needs to have mechanisms to respond to the changes in the incumbent user's spectrum usage and to be able to modify its spectrum usage accordingly. For example, in the case of MNO as an LSA licensee this could be implemented on top of the existing network architecture as was discussed in [5] where commercially available TD-LTE equipment were used in the 2.3-2.4 GHz band with additional components for the LSA spectrum information.

In the SAS environment, the view is that the system will more directly interact with the licensee systems, either PAL or GAA, and therefore may require greater modification to the licensee system and in the case of GAA systems becomes a direct design constraint.

D. Reliable access and usage conditions

LSA license together with the sharing framework negotiated between the incumbent and the LSA licensee allow the LSA licensee to evaluate the spectrum access and usage conditions and thus the business opportunity beforehand. In the LSA, the incumbent has a proactive role in defining the bands, areas and times for possible implementation of LSA on a voluntary basis [7]. This offers assurance on the availability of the LSA resource while preserving incumbent user's rights.

SAS has similar goals, though its third tier, multiple GAA user approach dramatically increases the complexity associated with the implementation of the goals. Moreover, the PAL license conditions in terms of license duration and availability of PAL spectrum vs. GAA spectrum influence the potential PAL licensees' interest to invest in the band. In parallel however the Interference Limits Policy approach does offer the ability to considerably enhance the usage conditions.

E. Implementation and enforcement by the regulatory authorities

Enforceability in LSA concept is assured by the LSA license. This allows the relevant NRAs to monitor and insure that the license terms are obeyed similar to the case of an exclusive license. Potentially large number of GAA devices and systems present in the SAS environment may pose additional challenges on the SAS implementation. Since these devices and systems are not controlled by a large entity such as cellular provider, the identification of the sources of interference and the enforcement of the SAS rules is much more challenging.

F. Fairness and Pro-Competition

Cases where the demand for spectrum is higher than the amount of available spectrum lead to an awarding procedure. The traditional awarding procedures, such as auctions, guarantee fairness and competition. Similar procedures could be used in the awarding of LSA or SAS PAL licenses. To foster innovation in the first phase, a temporary licensing mechanism could be used, allowing for an experimental period. In the LSA case however, the license and the related conditions are currently seen as being based on negotiations between the incumbent and the LSA licensee. In case more than one potential LSA licensee is interested in getting an LSA license, it should be clarified how these negotiations can be implemented in a fair and transparent manner before the awarding of the LSA license. This represents a challenge in the fairness and pro-competition space.

For SAS systems the PAL license is envisioned to be acquired through an open auction process to insure fairness and a pro-competitive position. Further, the presence of GAA users should promote competition to a considerable degree encouraging PAL licensees to deploy systems quickly to utilize the spectrum assets that they have acquired through auction. The GAA based entities should be fiercely competitive with one another further enhancing the pro-competitive SAS stature.

G. Legal certainty

LSA and PAL licenses provide the licensees with legal certainty for the whole duration of the LSA or PAL license (though this license might be much shorter in the SAS case). This allows LSA or PAL licensees to evaluate the required investment versus the possible business benefit obtained with the LSA or SAS resource based on its incentives and market demand.

For LSA legal certainty in terms of information exchange means that business sensitive information of both the incumbent and the LSA licensee, such as network information and spectrum usage, should be considered as classified information and protected. Information shared should be limited to minimum necessary and not extended beyond the LSA license. In some cases it might be necessary to add safety periods and areas to mask the actual usage of the spectrum. The information on incumbent's spectrum usage on LSA bands should be accessible only to that LSA licensee that the information is intended to and the spectrum usage information of one LSA licensee should not be accessed by another LSA licensee.

For SAS, much of what has been described for the LSA case applies to the relationship between the incumbent and the PAL licensee. However, the sensitivities on the exchange of information are much greater in the SAS case in that the presence of the GAA tier of users means that the database information about the incumbent and even the PAL licensee needs to be very carefully protected. This adds an encumbrance to the SAS system that doesn't exist in the LSA approach. Moreover, the amount of transactions envisaged in the SAS case for PAL licenses, which are specified for smaller space-time-frequency resource blocks, at a different order of magnitude compared to LSA, which significantly increases the complexity of the system.

H. Foster innovation

The core of the innovation consideration for LSA or SAS, as any new sharing model, is the potential to make spectrum available in a fast pace compared to traditional methods such as re-farming. LSA and SAS both provide a more flexible regulatory framework that allows awarding licenses tailored to the needs of the licensees in terms of time duration or geographical area. This should enable the introduction of a wide variety of new innovative wireless services such as the range of Internet-of-Things (IoT) based devices and services, and new localized services. LSA and the PAL layer in SAS provide access to a limited number of new systems. The presence of the GAA level in the SAS case provides even stronger support for this area in that numerous new devices and services can be deployed in rapid order, much like what is happening the unlicensed space today. These services may ultimately grow in their impact and reach to the point that they one day become the PAL licensees of the future.

TABLE I. EVALUATION OF THE SPECTRUM SHARING MODELS

Criterion	Licensed Shared Access	Spectrum Access System
Efficient Spectrum Utilization	Enhanced utilization through shared access to spectrum	Enhanced utilization through shared access to spectrum, further efficiency obtained via GAA
Protection from the interference	Spatial separation obtained via LSA license and protection zones enforced by LSA database and management system	Spatial separation obtained via SAS license and protection zones enforced by SAS database. Number and character of GAA devices create interference concerns
Minimum impact to the technology of the systems	The incumbent reports changes in licensing terms, LSA licensee needs means to respond to possible changes	Reporting all spectrum usage in SAS, direct interactions between systems pose changes to systems
Reliable access and usage conditions	License, spectrum sharing framework, voluntariness	PAL license, access not guaranteed GAA
Implementation and enforcement by the regulatory authorities	Based on licensing procedure	PAL, device standardisation for opportunistic access, enforcement for GAA more challenging
Fairness and pro-competition	Based on licensing procedure, negotiations between the incumbent and LSA licensee challenging	Based on licensing procedure, but GAA option provides a "pro-competitive edge" to SAS
Legal certainty	License provides legal certainty, database security	Legal certainty is provided for PAL level licensees, GAA licensees are only provided with opportunistic access to the spectrum. Both are provided with, database security
Foster innovation	Makes spectrum available, flexible regulatory framework allows access to new systems and new innovative services	Makes spectrum available, flexible regulatory framework allows access to new systems and new innovative services, GAA allows for broad set of innovators

V. CONCLUSIONS

As the demand for spectrum keeps increasing, spectrum sharing as the means to enable more efficient spectrum usage is gaining an ever increasing level of interest in the regulatory domain. However, the criteria for a successful spectrum sharing model from the regulatory point of view will obviously vary from the viewpoint of the research or industry. This paper has addressed these criteria and evaluated two recent spectrum sharing models, the European Licensed Shared Access (LSA) and the US Spectrum Access System (SAS), with respect to these criteria. The analysis indicates that in the case of both of the sharing models, some further considerations are needed in order to fully address all of the regulatory criteria. In general, it can be concluded that the LSA is a simple sharing approach that provides a high degree of certainty for both the incumbent and the LSA licensee with low impact to the systems. The enforcement of the concept for non-malicious use is relatively simple and it has already been tested and approved. Therefore, LSA is likely to be deployable in a reasonable timeframe. SAS on the other hand, is a flexible but also complex sharing model which is likely to promote competition and foster innovation. It is also more likely to provide the most efficient spectrum utilization. Its deployment timeframe is also later than the LSA approach.

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