Is Spectrum Sharing in the Radar Bands Commercially Attractive? - A Regulatory and Business Overview

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Abstract

The need to meet users' expectations in the "mobile data avalanche" represents a significant challenge for mobile networks operators (MNOs). More spectrum is a natural way to meet these requirements in a cost and time-efficient way; but new, exclusively licensed, spectrum is increasingly hard to come by. Instead, vertical spectrum sharing has been discussed as a potential solution for finding additional spectrum for mobile communications. In this paper, we focus on vertical spectrum sharing in the radar bands for providing short-range wireless access, e.g. indoors and in "hotspots" that "offload" mobile traffic demand. We propose a methodology for dealing with the technical, regulatory and business aspects of deploying large-scale wireless networks. Moreover, we identify the following criteria for achieving business success: spectrum availability, availability of low-cost end-user devices, system scalability in terms of number of concurrently used devices and finally, the ability to guarantee a quality of service for the users.

Our technical availability assessment has identified geo-location database support as necessary technical enabler and detect-and-avoid mechanism as a beneficial technical enabler for improving sharing conditions. Therefore, we propose a

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sharing mechanism based on three components: a central spectrum manager with a geo-location database controlling the aggregate interference, a spectrum sensing mechanism and a fast feedback between the radars and the central spectrum manager. Moreover, Licensed Shared Access (LSA) was found to be the suitable regulatory framework to support the proposed sharing mechanism and regulatory policies in real-life implementation.

Our business feasibility assessment concludes that there is enough spectrum available for indoor and hotspots communication in urban areas in the radar bands to make a large scale system commercially viable. Service quality can be guaranteed and there is a strong potential to construct low-cost devices. Uncertainties do, however, remain regarding the spectrum access cost.
Keywords: radar bands, short range communication, regulatory framework, business analysis.

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1. Introduction

The unprecedented success of mobile services has resulted in the exponential growth of wireless data traffic. The substantial traffic increase is expected to continue in the coming years with the proliferation of high-end handsets (Cisco, 2013). There is a widespread concern about the shortage of available radio spectrum to fulfill the future demand, which is dubbed as spectrum deficit (FCC, 2010). Secondary spectrum access, referring to the sharing of already-licensed but under-utilized radio spectrum while protecting primary systems, has emerged as a practical means to address the perceived spectrum scarcity (Hwang et al., 2012).

Although the concept of secondary spectrum access has been studied extensively from theory to practice in the last few years, most of the practical work has focused on a specific portion of spectrum, i.e., VHF/UHF band primarily allocated to digital terrestrial television (DTT) so-called TV white spaces (TVWS) (Nekovee, 2010; Harrison et al., 2010; Van de Beek et al., 2012; Shi et al., 2012). This means that the vast amount of radio spectrum remains unexplored with regard to the potential of the secondary usage. ITU spectrum allocation table indicates that the majority of frequency bands below 6 GHz are allocated currently to various systems such as aeronautical navigation, radar, satellite, and fixed link. Significant research efforts will have to be spent to investigate the viability of secondary access to those spectrum bands [1]. Our previous work showed that there are ample sharing opportunities for the deployment of ultra-dense networks (UDNs) in the radar bands, both above and below 10 GHz (e.g. S- and Ku-Bands). However, as claimed in (Zander et al., 2013), the fact that secondary spectrum access is technically feasible does not necessarily guarantee its commercial success. Whether the deployment of large-scale wireless networks employing secondary spectrum access or vertical spectrum sharing in the radar bands can really happen or not is a multi-dimensional problem which includes technical, regulatory and business aspects. Therefore, we aim at answering the following research questions: *What are the main factors that would facilitate business success for short range communication in the radar bands? Is there a suitable regulatory framework that can ensure the protection of the primary system and still provide enough spectrum for secondary use to make it commercially interesting?*. In this work, *short range*

[1] Besides the studies on TVWS, only a handful can be found on radar and aeronautical spectrum. See, e.g., (Saruthirathanaworakun et al., 2012; Peha, 2013; Rahman & Karlsson, 2011; Tercero et al., 2013)

communication refers to indoor and outdoor hotspot communication providing high-capacity broadband services.

We can find substantial literature that studied individual aspects of secondary spectrum access: technical, regulatory, and business aspects. For example, fundamental limits of the secondary sharing were investigated in (Ghasemi & Sousa, 2007; Devroye et al., 2006), the regulatory and policy aspects were discussed in (Medeisis & Minervini, 2013; Forde & Doyle, 2013), and the business side was looked into in (Markendahl et al., 2012; Gronsund et al., 2013). However, it is difficult to find a cross-boundary study. Thus, the main contribution of this paper is to establish a well-defined methodology for dealing with the technical, regulatory and business aspects of deploying large-scale wireless networks with secondary spectrum access. Moreover, this methodology is tailored to the radar bands which had not been clearly addressed.

The remainder of the paper is organized as follows: the methodology for assessing technical, regulatory and business aspects that can make vertical spectrum sharing in the radar bands attractive is explained in Section 2. Section 3 focuses on defining the business case and identifying key factors that impact its business success. In Section 4 and Section 5, we give a detailed technical description of the sharing usage scenario, sharing mechanism and technical enablers; which are essential inputs for selecting the regulatory framework in Section 6. Finally, the business feasibility analysis is provided in Section 7 and our main findings are discussed and summarized in Section 8.

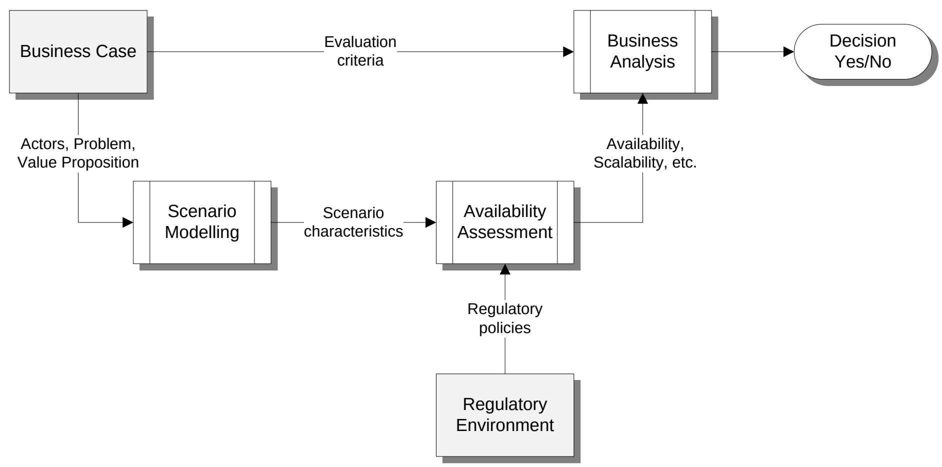


Figure 1: Methodology for Assessing Sharing Opportunities

2. Methodology

Towards assessing the commercial viability of sharing opportunities in the radar bands, we propose the methodology illustrated in Fig. 1. This methodology includes technical, regulatory and business aspects which are needed to make an assessment whether secondary spectrum access in the radar bands can take-off or not from the commercial point-of-view.

We first describe the business case by identifying the main actors, problems and value proposition. Based on a clearly defined business case, we establish the key factors that would facilitate business success. These factors are the evaluation criteria for the business feasibility analysis. Also based on the characteristics of the business case, we model the secondary access scenario modeling that will be employed for technical spectrum availability assessment. Another input to the technical assessment is the regulatory environment, such as sharing mechanism and spectrum etiquettes. Notice that the results of the assessment will depend strongly on the selected regulatory policies, As a next step, we identify the most suitable regulatory framework (i.e. licensing regime) for enabling vertical spectrum sharing in the radar bands is a sequential approach. This evaluation is made in a systematic manner by employing a spectrum sharing toolbox proposed within the EU FP7 METIS project, which allows to have a direct mapping between technical enablers, spectrum sharing scenarios and regulatory framework. First, we start by defining the secondary access scenario and the sharing mechanism to then identify the tools or enablers that make this scenario feasible from the technical point-of-view. Later, the regulatory framework is chosen to bring the selected policies to real-life implementation. The selection of suitable regulatory policies are based on their impact on the exploitation of sharing opportunities. More detailed explanation on the the different components of the toolbox can be found in (Irnich et al., 2013).

Finally, we proceed to *qualitatively* assess the business potential of the selected secondary access scenarios by employing the defined evaluation criteria and the results of the availability assessment, which includes technical and regulatory aspects.

3. Identifying Factors for Business Success

In this section, we identify and discuss different factors that would facilitate business success for short range communication (i.e. indoor and outdoor hotspot communication providing high-capacity broadband services.) in the radar bands. These factors will depend highly on the particular business case, which is defined by the type of actors that provides the service, their pains or problems and the specific value proposition. We detail the business case in the following:

- Main Actors: An *incumbent MNO* who has a strong incentive to offer significantly higher capacity to satisfy *their customer's* demands in indoor and hotspots locations. We consider the incumbent MNO in this study based on the argument in (Markendahl et al., 2012) that a new entrant does not have a competitive edge over the incumbent MNO for deploying in secondary spectrum.

- Problem: The MNO needs a solution that offers the best cost-performance trade-off since it has already been *challenged by the revenue gap* which refers to a discrepancy between soaring mobile data demand and dwindling revenue increase.

- Value Proposition: Short range communication in the radar bands *offloading mobile broadband traffic demand in indoor and hotspot* environments where the demand is extremely high.

In order to analyze the potential of the business case, we need to identify the different factors that could influence business success or in other words *what should the radar bands offer?*

- **Enough Spectrum Availability** to alleviate the increasing data demand in current MNOs networks in indoor and hotspot locations.

- **Availability of affordable radio technology** is crucial for estimating when the solution can be deployed and the cost it will generate. Particularly, the availability of low-cost end-user devices is important for reaching mass adoption. Current alternatives offer low-cost devices, thus it is critical for the proposed solution to also have low-cost end-user devices or being able to use existing devices with minor modifications that will not have a significant impact on the total cost.

- **System Scalability** is also essential for motivating investments. Moreover, given that this solution is proposed for alleviating the high capacity demand, then system scalability is a must.

- **Guaranteed quality of service** should be provided in order to attract investments given that other best-effort alternatives are available for free. Thus, there is a need to establish a regulatory framework that could guarantee quality of service for short range communication in the radar bands.

4. Sharing Usage Scenario

In this section, we provide a brief of description of the selected sharing usage scenario which is conformed by the characteristics of the primary system (incumbent) and the secondary system (newcomer).

4.1. Radar systems as Incumbent

Radar is an acronym for Radio Detection And Ranging. The basic operation principle of the radar consists of generating pulses of radio frequency energy and transmitting these pulses via a directional antenna. The radar indicates the range to the object of interest based on the elapsed time of the pulse traveling to the object and returning to the radar antenna. The most common uses of radar are Ground based Aeronautical Navigation, Marine Navigation, Weather Detection and Radio Altimeters (Alenia Marconi Systems Limited, 2002).

This paper focuses on the radar systems allocated below and above 10 GHz due to the good propagation characteristics for providing mobile broadband services. Specifically, we consider the ground-based rotating radars deployed in the S- and Ku-Bands: Air Traffic Control (ATC) radars in the 2.7-2.9 GHz band and

Surveillance radars such as Airport Surface Detection Equipment (ASDE) in the 15.7-17.2 GHz band, respectively. For the ATC radars, the 3 dB channel bandwidth can vary from 0.5 MHz to 15 MHz, depending on the radar type (International Telecommunication Union (ITU), 2003). In contrast for Surveillance radars, the 3 dB channel bandwidth could reach up to 100 MHz (Alenia Marconi Systems Limited, 2002). Notice that within 15.7-17.2 GHz, the precise allocation of Surveillance radars could vary depending on the country or region.

Protection criteria

A maximum interference-to-noise ratio (INR) threshold is established to guarantee that the detection performance of radar systems is not degraded by harmful interference. The INR threshold defines the maximum allowable interference level relative to the noise floor at the radar receivers. This threshold is often set to very conservative value (i.e. -10dB) for radars with safety-related due to the high sensitivity of the radar receivers and very high antenna gain of the typical radar (International Telecommunication Union (ITU), 2003).

Due to the random nature of the radio propagation, the protection of the radar is expressed as a interference probability which refers to maximum allowable probability that the aggregate interference exceeds the tolerable interference level. The interference probability is mathematically expressed as follows,

$$\Pr\left[I_a \geq A_{thr}\right] \leq \beta_{PU} \tag{1}$$

where I_a is the aggregate interference from the UDN or secondary system, A_{thr} is the maximum tolerable interference at the radar and β_{PU} is the maximum permissible probability of harmful interference at the primary receiver. Due to the safety-related functionality of the radar, we applied conservative values for A_{thr} and β_{PU} which implies practically almost no interference violation. We adopt a very small value for β_{PU} that is used for air traffic control (ATC) radar in 2.7-2.9 GHz, $\beta_{PU} = 0.001\%$ (International Telecommunication Union (ITU), 2003). We set A_{thr} based on the INR value, $A_{thr}(dB) = INR + N$, which drops to $A_{thr} = -119$ dBm/MHz for co-channel secondary access for a noise figure (N) of 5 dB.

4.2. Ultra-Dense Networks as Newcomer

Various types of secondary usage were described in (Hwang et al., 2012). Secondary spectrum access or vertical spectrum sharing would be the most beneficial and attractive from the commercial point-of-view where we find the highest capacity needs taking into account that it has emerged as a solution to deal with the exploding mobile traffic demand. Approximately, 70% of the current data consumption is generated in indoor locations and ”hotspots” (Ericsson, 2012) followed by urban areas with high user density (Zander & Mahonen, 2013). Thus, it is natural to assume that the secondary system provides high-capacity broadband services for customers located in these locations.

We envisage a scenario where an UDN as the secondary system in the radar bands, which is employed to expand the network capacity of a cellular network already operating in dedicated/licensed spectrum. The extremely high density of active UDN transmitters over a large geographical area raises the need of controlling the aggregate interference with very high reliability, which is a challenging task. Moreover, the secondary APs must be much cheaper than traditional outdoor base stations in order to make the massive deployment affordable. Thus, a simple interference control functionality is desired at the device level. A detailed description of the sharing mechanism and functionality of the different involved entities will be provided in Section 5.

5. Sharing Mechanism and Technical Enablers

5.1. Sharing Mechanism

In this section, we introduce a spectrum sharing mechanism that enables vertical spectrum sharing between the radar systems and the UDN. The key requirements for designing this mechanism are: guaranteed reliable protection of the primary system as well as good sharing opportunities for the secondary users. Moreover, it is desirable to implement a simple interference control functionality at the device level so the price of secondary APs can be kept below traditional outdoor base stations. Thus, large-scale investments can become attractive from the economic point-of-view. The design principles of the sharing mechanism are:

- *First principle: the aggregate interference should be controlled by a central spectrum manager.* This entity should external and independent of the incumbent's and newcomer's interest , guaranteeing the fair enforcement of sharing rules. The central spectrum manager communicates and supervises constantly the correct operation of the geo-location databases, which collects all relevant information of the system. Given that the radar receiver can potentially receive interference from millions of UDN transmitters, thus each UDN user is unable to know whether its own transmission would cause a interference violation to the primary user. It is essential that the central unit estimates aggregate interference and makes a decision on who can transmit with what power based on the information provided by the geo-location databases. A real-time execution of the decision (whether to transmit *now* or not) may be delegated to the individual secondary users, but the guideline for the decision must be provided and updated constantly by the spectrum manager.

- *Second principle: the combined use of spectrum sensing and geo-location database should be employed by the secondary users for the interference estimation*. For the central spectrum manager to calculate the aggregate interference, each secondary user must be able to estimate the interference it would inflict to the radar and report it to the spectrum manager through the databases.

- *Third principle: the establishment of a fast feedback loop between the primary user and the spectrum manager*. It requires that the primary user be attached to the spectrum manager and provides a feedback when it receives the interference above a certain level. This feedback loop might turn out to be redundant in practical secondary access situations because the application of the second principle is expected to produce an accurate estimation of the aggregate interference. However, it will contribute to the guaranteed protection to the safety-of-life functionality of the primary user.

Our proposed spectrum sharing mechanism is illustrated in Fig. 2, which shows the basic architecture and communication links between the different entities, i.e. the primary system, the secondary system, the geo-location database and the regulatory entity. Communication links 1, 2 and 3 are employed to fulfill the first design principle. The second design principle is illustrated by the communication links 2 and 3, while Communication link 1 illustrates the third design principle. Notice that the existing radars cannot measure the interference nor have

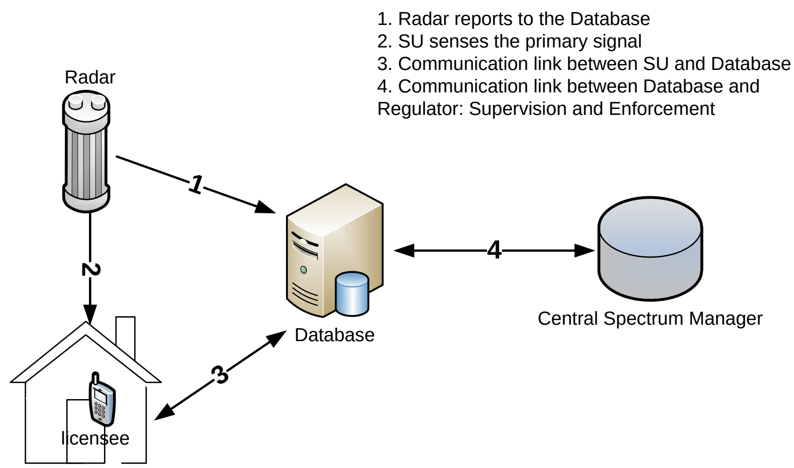


Figure 2: Sharing mechanism

a back-haul connection. Thus, an upgrade of primary equipment is necessary for establishing the feedback loop. Finally, communication link 4 shows the close collaboration between the geo-location database and the regulatory entity that aims at monitoring the correct operation of the geo-location database and enforcing the coexistence rules.

5.2. Technical Enablers

Based on the proposed sharing mechanism, we have identified technical enablers within the METIS toolbox that would enable vertical spectrum sharing in the radar bands, which are the combination of geo-location database support and Detect-and-avoid mechanisms.

The support of geo-location databases is required to guarantee the reliable control of the aggregate interference, crucial for enabling vertical spectrum sharing in the radar bands. With the help of geo-location databases, the central unit can reliably estimate the aggregate interference from a huge number of secondary users deployed in a very large geographical area. Moreover, the central unit can make the decisions on who can transmit with what power and constantly update them based on the geo-location database information. It is important to notice that this database support is required mainly for the protection of the primary system. However, it could also be employed to manage interference between multiple secondary systems (e.g. postal address licensing).

We also consider the detect-and-avoid mechanisms (i.e. spectrum sensing) as a beneficial enabler that should be employed by the secondary users for the interference estimation. Thus, each secondary user must be able to estimate the interference it would inflict to the primary receiver and report it to the geo-location databases or spectrum manager. Spectrum sensing is considered unreliable in many scenarios of commercial interest (Zander et al., 2013) since it does not tell us the whereabouts of the primary receiver which should be protected [2]. In radar systems, the secondary user can actually detect the presence of the primary receiver since the hidden node problem is not an issue. This will bring more reliability and precision for calculating the aggregate interference, making sharing conditions less rigid. For instance, if only geo-location databases are employed, the need for additional interference margins arises in order to cope with the uncertainty on the interference estimation. Fig. 3 shows how the minimum required separation distance increase with different margins.

Notice that the combination of these two enablers is not necessary but beneficial for improving sharing conditions. This means that geo-location databases could potentially be employed alone. However, the spectrum sensing, if used

[2] A typical example is the DTT spectrum where thousands of passive TV receivers are kilometers away from a TV transmission tower.

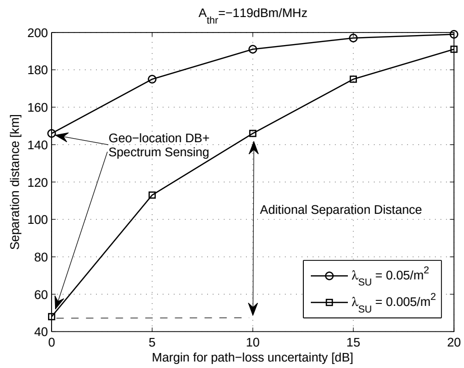


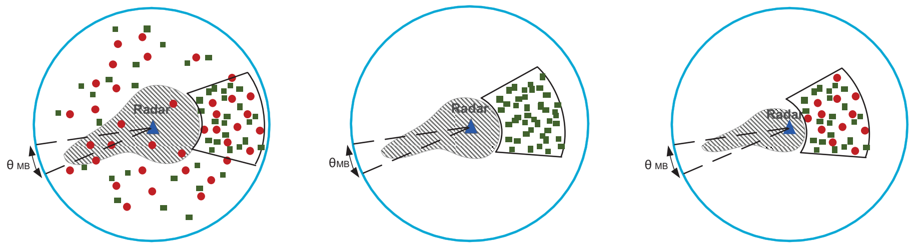
Figure 3: Benefit of applying geo-location databases and spectrum sensing

alone, cannot provide the required accuracy because it could be affected by detection errors. Any missed detection in the vicinity of the primary user could be critical to the radar operation.

6. Regulatory Framework

The objective of this section is to identify the most suitable regulatory framework (i.e. licensing regime) that can support the above-discussed sharing mechanism in real life implementation. Various options can be envisaged under the umbrella of vertical spectrum sharing. Based on the METIS toolbox, two potential regulatory framework alternatives for vertical coexistence are license-exempt (countless licensees) and licensed shared access (LSA) (only a few licensees). One of the key factors that distinguishes these different frameworks is the number of entities who are granted usage rights.

From the incumbent point of view, reliable protection against harmful interference is critical. This becomes an essential requirement when choosing the regulatory framework. In the same way, the newcomer is willing to have guaranteed access to the available spectrum and manageable sharing conditions so long-term



(a) (b) (c)

Figure 4: Regulatory Policy Options: a)Area Power Regulation, b)Deployment Location Regulation and c)Combined Regulation. The radar (blue triangle) is surrounded by transmitting secondary users (green squared), not transmitting secondary users (red circles) and an irregular exclusion region (shadow area).

investments can be justified. Based on these two point-of-views, our previous work investigated regulatory policies that improve sharing conditions for the newcomers in areas with high capacity demand (i.e. indoor and urban hotspots) while keeping the incumbent protection criteria fulfilled (Obregon et al., 2014). We evaluated three regulatory policies: area power regulation, deployment location regulation and the combination of them. Sharing opportunities were inversely proportional to the required time-averaged separation distance between the radar receiver and the UDN that guarantees a minimum transmission probability for the UDN user.

Our results showed that applying any of the regulatory policies improves sharing conditions, particularly for radars allocated below 10 GHz. Overall, deployment location regulation was the most effective means to limit interference to the radar system and improve UDN's sharing opportunities, in particular when the difference in network density between urban and rural areas is dramatic. This means that not only traditionally regulated transmission power level and operating

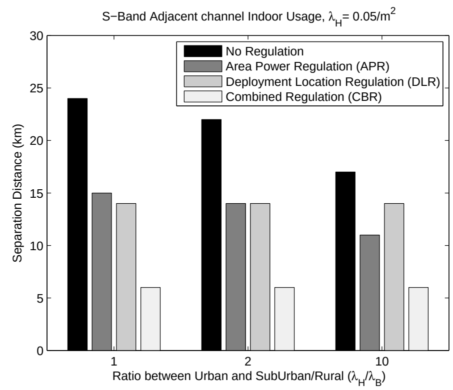


Figure 5: Impact of spatial heterogeneity: S-Band Indoor Adjacent Channel Usage

frequency, but also location of the UDN needs to be strictly regulated to fulfill primary protection criteria and to make sharing conditions less rigid. Based on these requirements, we consider that LSA[3] would be the suitable regulatory framework that could allow the real-life implementation of the selected regulatory policies enabling UDN deployment in the radar bands. We ruled out license-exempt vertical coexistence given that it does not required to obtain a specific decision or permission before users exercise their right coming from a *general authorization*, which basically defines basic sharing conditions. For instance, license-exempt use of TVWS in the USA is applied since 2008 (FCC, 2008b,a). This model

[3]Notice that LSA concept is still under development. Hence, our discussion is based on the definition by CEPT: *"A regulatory approach aiming to facilitate the introduction of radio communication systems operated by a limited number of licensees under an individual licensing regime in a frequency band already assigned or expected to be assigned to one or more incumbent users. Under the LSA framework, the additional users are allowed to use the spectrum (or part of the spectrum) in accordance with sharing rules included in their rights of use of spectrum, thereby allowing all the authorized users, including incumbents, to provide a certain QoS"* (ECC Report 205, 2013).

allows the white space devices (WSDs) to have access to the DTT spectrum without an individual license but subject to technical restrictions, allowing the access of an unlimited number of WSDs who provide different applications. This however cannot be employed in the radar bands since it cannot guarantee that sharing conditions and regulatory policies are *enforced to all* the UDN devices without exception. This does not allow to reliably protect the primary system and apply regulation on the deployment of UDN users, which requires an individual authorization instead.

Customizing the general LSA concept to the context of radar spectrum would be a challenge to be addressed. One of the most important aspects to address this challenge would be the terms of the LSA contract between the primary system and the licensees, which should contemplate mainly the following: the potential changes or variations in the radar system that could negatively impact the secondary licensees and the technical and economic conditions in case of evacuation request from the primary system, e.g. request frequency, time period, time response, economic compensations, etc.

7. Business Feasibility Analysis

In this section, we revisit the evaluation criteria and discuss what the radar bands offer with respect to them. Moreover, we identify the existing alternatives or competitors and analyze how indoor and hotspot communication in the radar bands is positioned with respect to other alternatives.

Enough Spectrum Availability can significantly impact business viability in the radar bands. However, there is no a single answer and availability can significantly vary between different countries. For instance, there is a single civilian

ATC radar in Macedonia while there are around 77 ATC radars between civilians and military type in the UK. Here, we will give an estimate of the availability in Europe based on our previous work in the aeronautical and radar bands (Obregon et al., 2013a, 2014), and current European allocation table. Results in (Obregon et al., 2013a) found that at least 30% of the Distance Measuring Equipment (DME) band was available for secondary usage and results in (Obregon et al., 2014) showed that applying regulation on the deployment of secondary users could be further improve availability in the urban areas. Considering that below 10 GHz there is around 1.2 GHz allocated to radar systems, then up to 400 MHz could be available for secondary access in the radar bands assuming that similar results to the ones in the DME (30% availability) will be obtained given the technical similarities. However, availability in the radar bands would be very much fragmented and with large separation in the frequency domain. This means that a equipment would be able to access at most 100 MHz at a given location, even if it has advanced carrier aggregation capabilities. It is important to notice that the availability in the radar spectrum has low spatial granularity, which means that the available amount of spectrum is spatially uniform for large geographical areas. Therefore, the availability in a city will be most likely constant in space and time domain, which is a key difference from the availability in the TV bands.

Availability of affordable radio technology will depend on the selected radar band. Here, we are mainly discussing the bands below 10 GHz (i.e. L-Band and S-Band) which are located close to already available radio technology dedicated to mobile communications. Moreover, filter characteristics, sensing capabilities and carrier aggregation functionalities, which are extremely relevant due to the non-contiguous availability, are already quite advanced in their development. Thus, adaptation of devices (i.e. transmitters and end-user devices) that are able to operate in the radar bands below 10 GHz can be done within a reasonable time period and cost. In contrast, the radar bands above 10 GHz would require much more time to make radio technology available since currently there is no radio technology for mobile communication in these bands.

System Scalability in the radar bands has been previously demonstrated in (Obregon et al., 2013b,a, 2014) where a system with a very high network density can share the radar bands with reasonable requirements (i.e. small exclusion region size), especially for adjacent channel access. Moreover, complex cross-layer interference management between the cellular networks and short range network will not be required in order to provide quality of service since they operate in different frequency bands.

Guaranteed quality of service is feasible in the radar bands due to the selected regulatory framework, LSA, which allows access to few licensees so that the sharing rules are effectively enforced and quality of service can be guaranteed for all licensees.

As a next step, we identify the alternatives that are currently available in the market:

- **Unlicensed Option**: Indoor offloading in the license-exempt ISM bands (2.4 GHz or 5 GHz band) by employing Wi-Fi technology.

- **Licensed Option**: Indoor offloading in frequency band exclusively licensed to the MNO by employing LTE technology.

We compare these options with our value proposition, short range communication in the radar bands, which will be called **LSA option** given that this is

Table 1: Comparison between three solutions for indoor offloading

	Unlicensed	**Licensed**	**LSA**
Spectrum availability	Anywhere (538 MHz)	Anywhere (100 MHz)	Location-based (approx. 100 MHz)
Affordable Technology	Available	Available	Near-Term Available
System Scalability	Poor	Good	Good
Quality of Service	Best-effort	Guaranteed	Guaranteed
Spectrum access cost	Free	Marginal	Undefined
Spectrum access	Open	Exclusive	Few Licensees

the selected regulatory framework. Table 1 shows this comparison by identifying the advantages and disadvantages that the MNO will face if LSA option is chosen. One of the main disadvantages is the location-based availability of the radar bands. However, applying regulation on the deployment of secondary users leads us to talk about area-based or city-based availability making this solution competitive with the existing alternatives in the areas with high capacity demand. The LSA option offers guaranteed quality of service and a level of system complexity that is perfectly manageable for traditional MNO that is used to complex systems. Also, the fact of only few licensees will access the available spectrum makes this option more valuable for competition with other players.

Finally, we identify that spectrum access cost is still an undefined parameters for the LSA option which will directly impact the business attractiveness of this solution for long-term investments. Thus, it should be set according to the potential benefits that could bring for the licensee, which will highly depend on the characteristics of the secondary access availability such as: the amount and the granularity of the available spectrum over space and time domain that strongly depend on the region or country where the evaluation is made. Establishing the right spectrum access cost or license fee is critical for motivating the MNOs to make long-term investments on this solution.

8. Discussion

This paper has provided a comprehensive qualitative assessment of the *commercial viability of secondary access in the radar bands* mainly focused on the case of indoor and hotspots communication in the radar bands offloading mobile traffic demand of incumbent MNO's wireless networks. For that, this work has proposed a well-defined methodology for dealing with the technical, regulatory and business aspects of deploying large-scale wireless networks with secondary spectrum access in the radar bands.

By employing this methodology, we have identified the necessary conditions or *criteria for achieving business success* the deployment of high-capacity wireless system with secondary spectrum access in the radar bands, which are the following: spectrum availability, radio technology availability (e.g. low-cost end-user devices), system scalability and guaranteed quality of service. In oder to understand what the radar bands can offer with respect to these criteria, this paper conducted a technical availability assessment where we proposed sharing mechanism that enables vertical spectrum sharing between the radar systems and the UDN based on three design principles: the aggregate interference should be controlled by a central spectrum manager, the combined use of spectrum sensing and geo-location database for the interference estimation and a fast feedback loop between the primary user and the central spectrum manager.

Based on the proposed sharing mechanism, we have identified the combination of geo-location database support and detect-and-avoid mechanisms as necessary technical enablers. Notice that the combination of these two enablers is not necessary but beneficial for improving sharing conditions. Moreover, we also identified that applying regulation on the deployment of the UDN could also improve sharing conditions. LSA was found to be the suitable regulatory framework to support the above-discussed sharing mechanism and proposed regulatory policies in real-life implementation. License-exempt was ruled out since it cannot guarantee the enforcement of sharing conditions and regulatory policies to all UDN devices, which is critical for radar bands with many safety-related services.

Finally, we conducted a business feasibility assessment based on the devised technical and regulatory conditions. In this assessment, we compared short range communication in the radar bands (LSA option) with two existing alternatives, Unlicensed and Licensed options, by employing the identified evaluation criteria for business success. We conclude that there is enough spectrum availability for indoor and hotspots communication in urban areas in the radar bands, therefore meeting the MNO's needs where it is needed. This is a crucial characteristic for long-term investments as well as guaranteed quality of service, potential low-cost devices and proven system scalability that also favor the commercial viability of the LSA option. However, the commercial viability is still not clearly determined given the remaining uncertainties in the radio technology cost and the spectrum access cost. These uncertainties need to be resolved to proceed to quantitative evaluation of the business viability, leading to more explicit conclusions the commercial viability of indoor and hotspots communication in the radar bands.

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