QUASAR scenarios for white space assessments and exploitation

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Abstract—**This paper presents a unifying scenario classification model and a selection of scenarios, developed within the EU FP7 QUASAR project to study secondary spectrum usage. The classification model categorizes scenarios from technical, regulatory, and economic perspective. It enables the derivation of the most promising scenarios of secondary spectrum access: Cellular and WiFi-like usage of TV white spaces, wireless backhauling using secondary spectrum access, license exempt use of the radar bands, use of the aeronautical bands for mobile broadband and cognitive machine-to-machine communication. These scenarios are presented in more detail along with motivations of why they are interesting to study further. The scenarios will provide the basis for the future work within the QUASAR project, which has the overall objective to assess the amount of useful spectrum opportunities for secondary spectrum access.**

Keywords-secondary spectrum access, white space, assessment, scenario classification model, scenario

I. Introduction

The need for more radio spectrum resources to fulfil the demands of the rapidly growing mobile and converged broadband access services is evident. Abundant and fast access to spectrum has three main advantages: It fosters rapid innovation in wireless systems and services lowering entry barriers to the market; it enables affordable broadband access to all, and; it potentially improves services and business models of established mobile operators.

Secondary use of already licensed, but underutilized spectrum allotments has been proposed as one solution to increase spectrum availability. Low spectrum occupancy in a number of measurement campaigns worldwide has been the basis for claims of large gains in spectrum efficiency by cognitive radio and opportunistic spectrum access, see e.g. [1], [2]. However, little research has been done to substantiate these claims with technological, regulatory or economic feasibility studies. For discussions on issues and feasibility analysis of the generic problems related to secondary spectrum access see [3], [4]. Except for secondary use of TV white space, which has been extensively studied (e.g. [5] and references therein), there are few concrete studies on other sharing scenarios. The EU FP7 QUASAR [6] project aims at bridging this gap between the claims made in conventional cognitive radio research and practical implementation by assessing and quantifying the "real-world" benefits of secondary (opportunistic) access to primary (licensed) spectrum.

The remainder of this paper is organized as follows: In section II the scenario classification model that we base our scenario selection on is introduced. Then, the various derived scenarios are presented and motivated. The paper is concluded by some remarks on the intended future use of the scenarios within the QUASAR project.

II. Scenario classification model

To the end of identifying similarities and differences in the future implementation and to cover the waterfront of secondary spectrum usage, the QUASAR consortium has developed a unified scenario classification model. The model categorizes particular bands, primary and secondary systems along diverse aspects.

All scenarios described hereafter are derived from this model framework based on the intended usage by the secondary system. The introduced scenario classification model consists of four hierarchical levels:

1) The secondary usage type,
2) the spectrum sharing type,
3) the licensing type,
4) and, the level of cooperation between the primary and secondary systems.

In addition to these four main levels possible additional attributes such as the frequency band to be used, primary system type, secondary duplex mode and opportunity detection method under consideration differ and thus need to be addressed in scenario descriptions.

The **top classification level** in the scenario model hierarchy specifies the usage type in terms of deployment mode, the level of dependency on secondary spectrum and data rate requirements imposed by the services intended to be offered by the secondary system.

The deployment mode is classified according to the intended coverage area and coverage structure of the secondary system. Typical examples here include spatial limited indoor and short range wireless systems, highly focused wireless backhauls, or stretched wide area wireless networks. In the top classification level the dimension of secondary dependency type is present. This dimension describes how dependent the secondary system is on the availability of spectrum opportunities on a long time scale. E.g., a secondary system may rely only on secondary spectrum opportunities for its operation, or use them as additional communication resources when available. In the first case the system is completely dependent on the secondary opportunities to offer its service, while for the later case the secondary service may not become severely affected if opportunities become rare.

The quality requirements put on the secondary opportunities by a system is considered as another dimension of the top level classification. This dimension emphasizes requirements on the short time scale achievable communication quality. Other service-oriented features of the scenario consider requirements on the average achievable data rate as well as the variance of the data rate. A secondary system with high QoS requirements may impose stringent demands on this dimension as it is sensitive to variance in the achievable data rate. Best effort driven communication may not have high requirements on the variance of the data rate but instead prefer a short peak data rates over long slow transmissions.

The **second level** of the classification model concerns the type of secondary sharing type applicable in the scenario. In *overlay operation* the aim of the secondary system is to transmit at the same time on the same frequency as the primary system, while employing a scheme that ensures that the primary system performance is not negatively affected by the secondary operation. In *interweave operation* a secondary system aims at transmitting only on frequencies, locations and times where the spectrum is free from primary transmissions. In *underlay operation* the received interference at any given primary receiver should be assured to remain below the noise floor to not significantly degrade the primary communication [7].

The **third classification level** addresses the license type considered in the scenario. An envisioned licensing scheme for a secondary system is an *exclusive license*, which assures that the secondary users do not need to consider sharing the spectrum opportunities with other secondary systems. Another envisioned secondary licensing scheme is the issuing of a *secondary sharing license*, which provides a well defined set of secondary systems need to share the secondary opportunities. And finally, *secondary spectrum commons*, in which any secondary system is allowed to operate in the spectrum opportunities provided that its operation does not cause harmful interference to the primary users of the spectrum. Under this scheme a secondary system is expected to co-exist with an unknown number of other secondary systems possibly employing different access schemes.

Sharing mechanisms needs to be specified for the cases where sharing of opportunities between secondary users is required. Such mechanisms may e.g., be based on sharing etiquettes or on market mechanisms. In the former case the secondary sharing is specified by a set of etiquette rules that each secondary system must follow, and in the latter the sharing may be done via e.g., micro auctions, dynamic competitive pricing schemes or contract exchanges. This sharing problem is closely related to sharing of unlicensed bands, but with the complication that the sharing takes place under additional constraints imposed on secondary systems, by regulators, through agreements with a band manger entity, spectrum broker, or the primary system.

The third classification level also comprise aspects related to properties of the primary system license: Technological requirements defines the freedom of choice of technology and service type that is being operated in the band, regulatory involvements considers the position of the regulator in any spectrum trading activities and their monitoring/enforcement, and trading freedom describes which constraints are put on the license holder with regard to the trading partners and trading mechanisms.

The **fourth classification level** concerns the level of cooperation between the primary and secondary system and is classified according as *none*, *low*, or *high*. Where the case 'none' indicates that there is no interaction at all between the primary and secondary systems, requiring e.g. opportunity detection to be based on spectrum sensing alone. A low cooperation level may be achieved by a geo-location database approach to opportunity detection. A high level of cooperation may be achieved by close cooperation between the primary and secondary systems, e.g., as is required for some types of overlay operations [8].

III. SCENARIOS

The scenarios presented in this section are scenarios developed by the QUASAR consortium as promising and of interest for performing assessments of the useful amount of white space available for secondary spectrum usage. However, as the evaluations of the various scenarios are work in progress, the list of scenarios may grow or become modified during the lifespan of the QUASAR project.

A. *Cellular use of white spaces*

[Wide area or indoor– interweave –secondary exclusive license]

This scenario is devised to address the question: How can a present day cellular system benefit from of white spaces?

To this end the secondary system in this scenario is assumed to be a cellular system that uses spectrum sensing and/or a geo-location database solution for finding secondary opportunities to either enhance its throughput by access to extra spectrum, in addition to spectrum that it has exclusive rights to, or simply obtain spectrum for its normal operation. The cellular secondary system may thus access (additional) carriers that are available outside protection zones of a static primary system. The secondary system is assumed to spatially interweave its transmissions with the primary transmissions. The deployment of such a system is illustrated in Fig. 1.

For the case where the cellular system uses the spectrum opportunities to enhance its capacity the dependence on secondary opportunities is low while for the case where the system relies solely on the opportunities the dependence is high. The latter may reduce the feasibility of the scenario significantly.

One part of this scenario considers wide area cellular operation while another considers indoor deployments. The latter is motivated by forecasts [9] that states that by year 2015 more than 70% of the data traffic will originates from indoor locations. A base station or relay for indoor coverage approach is adopted, where an indoor base station is connected to the operator network via e.g. fixed broadband. This part of this scenario is also expandable to include home-networks. The main advantage envisioned with the indoor setting is that the secondary transmissions are typically low power and to some extent isolated by the walls of the building. This implies that, given accurate opportunity detection methods, the amount of spectrum opportunities may be greater for indoor operation, in compared to a situation where wide area coverage is required.

To motivate large-scale infrastructure investments a cellular operator is likely to require guarantees for having access to some secondary spectrum opportunities at any given point in time. To this end a secondary exclusive licensing is assumed, which avoids the problem of sharing the resources with other secondary systems. The issuing of these licenses may be realized by regulator managed auctions, or perhaps more likely, via a spectrum broker entity. As such the primary licence will need to require the primary system to allow secondary usage of the spectrum. Also trading and subleasing by the primary system may be part of this scenario. The regulative involvement in this scenario is envisioned to be limited to identifying systems that interferes with the primary systems, i.e., secondary systems that misbehave.

Even though the secondary exclusive licensing scheme contributes positively to the feasibility of the scenario, the operation in a secondary spectrum commons mode may also be addressed within this scenario. Then sharing between secondary systems becomes an issue that needs to be addressed.

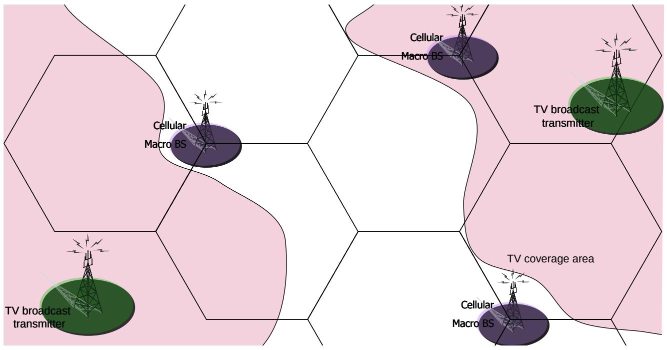

Figure 1. A cellular system that accesses the white spaces in the TV bands opportunistically to enhance its capacity in these regions.

This scenario is in principle applicable for any static primary system. However, the main focus will be on having a DTV broadcast network as the primary system operating on the TV broadcasting bands.

B. *WiFi-like use of white spaces*

[Wide area or indoor – interweave – secondary sharing license]

The secondary system in this scenario is assumed to be end-user deployed opportunistic spectrum access enabled wireless LAN like devices. The aim of this scenario is to support nomadic secondary systems with high data rates. The system is to use both uplink and downlink TDD in the detected secondary opportunities and to share the opportunities with a known set of other secondary systems as this enables coordination and coexistence simplifications. Another potential sharing scenario for this use cases is the secondary spectrum commons type of access of the spectrum opportunities.

The assumed primary system in this scenario is a DTV broadcasting network operating in the TV broadcasting spectrum. These bands allow better propagation characteristics, resulting in better coverage, than the ISM band, which is used with present day wireless LAN devices. An example use cases of this scenario is depicted in Fig. 2.

C. *Secondary wireless backhaul*

[Backhaul – interweave – secondary exclusive or secondary sharing license]

Capacity provision of backhaul has become a stringent challenge to cellular operators with the increasing data rates of advanced cellular air interfaces [10]. This scenario assumes a cellular system that performs backhauling and relaying via secondary exclusive or sharing license secondary access. The term wireless backhaul in this scenario refers to any kind of point-to-point wireless communications employing highly directional antennas. The primary frequency spectrum for this scenario is considered to be the TV broadcasting bands, but other bands such as radar may also be considered.

Wireless backhaul has distinct properties compared to the other presented scenarios. First, it has an advantage in the device complexity in the sense that the technical challenge goes into the fixed installations, i.e., base stations, backhaul, and relay nodes, and not into the end user terminals. Thus the user

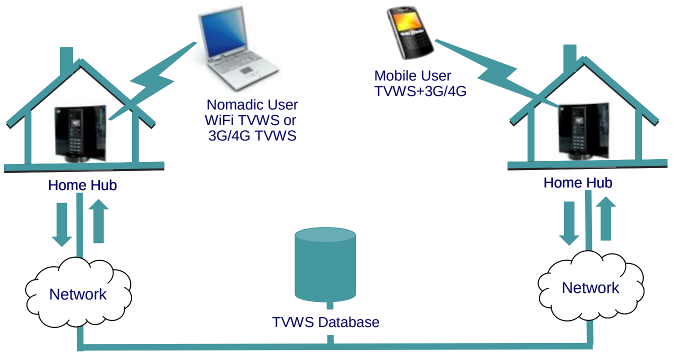

Figure 2. Indoor-to-outdoor broadband wireless access using WiFi-like home access points operating in TV White Spaces.

terminals need not be modified for the system to take advantage of the secondary access. Second, it does not cause significant harmful interference outside the path between transceivers pair because of the sharp antenna pattern. Moreover, the transceivers are usually located at a lofty place such as tower or rooftop. This gives a potential of good spatial separation from other wireless systems.

The deployment of backhaul links and relays are usually static in time. This makes the acquisition and planning of spectrum opportunity possible rather than relying on opportunistic detection methods. On the other hand, backhauling to mobile relays is also of interest as the propagation characteristics of low frequencies may be beneficial for this type of operation.

This scenario can benefit from using TV broadcasting band as primary spectrum in terms of low equipment cost and transmission power saving. Difficulty in antenna design in the low frequency spectrum [11] is a challenge to be addressed.

D. License exempt use of radar band

[Indoor or wide area wireless – interweave – secondary spectrum commons]

This scenario is to investigate the technical challenges and economic viability of license exempt secondary access to radar spectrum band. Large portion of useful spectrum is primarily allocated to various types of radars that are mainly used for aeronautical navigation, maritime navigation, radiolocation, and meteorological aid in S band (2.7-3.1 GHz) and C band (5 GHz) [12].

The secondary system is assumed to be wide area or indoor wireless system employing license exempt scheme such as WLAN, i.e. operating in a secondary spectrum commons environment. It is important to mention that 5150 MHz to 5350 MHz and 5470 MHz to 5725 MHz are already open to secondary usage by WLAN devices. In [13], Dynamic Frequency Selection (DFS) algorithm is specified in order to protect radars from harmful interference. DFS relies on spectrum sensing to decide whether to transmit or not. In short, a secondary device is entitled to transmit if the received radar pulse power is less than -62 dBm.

Despite the presence of DFS, more investigation is needed to figure out the technical and economic feasibility of this scenario. First, the amount of spectrum opportunity has not been revealed. The economic value of this scenario can be analyzed only after the spectrum opportunity is quantified. Second, the impact of aggregate interference has to be addressed. DFS is designed by implicitly assuming a single WLAN device. The effect of multiple secondary users has to be carefully verified.

Spectrum sensing is considered to be the main method of primary system detection. Use of geo-location database can also be a reasonable complement because the locations of the radars are static and open to public in many cases. For example, Fig. 3 shows the locations of meteorological radars operating in 5600-5650 MHz in Sweden. However, reliable detection of the non-stationary radars is a challenge in opportunity detection. Also, the detection should consider various types of radars. The detection threshold should be dependent on the purposes and technical specifications of radars.

E. Indoor broadband in aeronautical spectrum

[Indoor wireless – interweave – secondary sharing license]

Aeronautical usage accounts for a large portion of useful radio spectrum. Various systems are currently in operation under the aeronautical category for the purpose of navigation aid, landing aid, air traffic control, airborne collision avoidance, etc [14]. This scenario is developed in order to investigate the possibility of secondary access to aeronautical spectrum. The primary system under consideration is distance measuring equipment (DME) for aeronautical navigation operating in 960-1215 MHz band. It should be emphasized that DME in this scenario is chosen as an example of aeronautical communication systems. Different requirement and solution approaches should be applied to different aeronautical system. Thus, thorough interdisciplinary studies are needed in order to fully investigate the spectrum opportunity of the aeronautical spectrum.

The secondary system is assumed to be a mobile broadband system that provides indoor coverage through operator coordinated deployments. Indoor application is considered for three reasons. First, as mentioned above, most of traffic is expected to originate indoors in a few years [9]. Second, indoor use of secondary communication will give better protection to

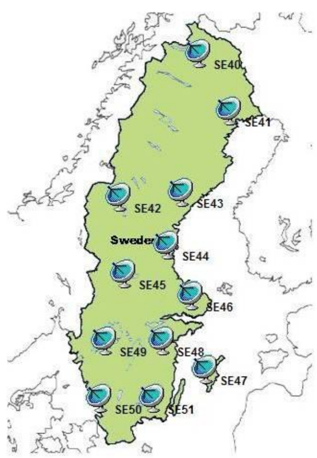

Figure 3. Locations of meteorological radars in Sweden, image from [15].

the primary system by means of low transmission power and wall penetration loss. The possibility of wide area wireless can be investigated depending on the feasibility of this scenario. Third, this scenario has a strong orthogonality in spatial domain between primary and secondary systems. The effective range of the primary DME is over 100 km and the transmission power of DME equipment is over 100 kW. On the contrary, secondary communication is made in a distance around 20 m with the transmission power of about 100 mW. It is believed this contrast between primary and secondary systems will provide room for efficient spectrum sharing. Spectrum sensing aided by a geo-location database approach is considered for opportunity detection. Further, to avoid aggregating harmful interference to the sensitive primary system a secondary sharing licensing scheme is assumed. Stringent requirement for protecting airborne safety related primary system is the major technical challenge. Regulatory aspects needed to realize this scenario will also be addressed.

F. Cognitive machine to machine

[Infrastructured outdoor – interweave/underlay – secondary sharing license] and [Ad hoc indoor/micro-environments – underlay – secondary spectrum commons]

The secondary system in this scenario is for machine-to-machine (M2M) communications. The "machine" includes all levels of devices with communication functionality embedded. Similar ideas are also currently under investigation by ETSI, 3GPP 0, 3GPP2 and IEEE 802.16m. This scenario supports device-to-device (D2D) wireless connecting services, which include all levels of M2M, from networked home electronics, body area networks (health), smart meters, networked robots (automation/security), to V2V (inter-vehicle and intra-vehicle) communications. The data requirements for such applications may initially be low and limited to control and observation but as M2M technologies advance higher volumes of data communication can be expected.

The secondary usage type is mostly for indoor or isolated micro-environments. The primary band is considered to be the TV broadcasting bands, but also other bands may be of interest to investigate. The primary receivers that need to be protected are assumed to be DTV receivers. Due to the mobility of the secondary devices, they may not be assumed to have a connection to a database of the primary DTV receivers. For illustrative example, imagine a small team of wireless robots (secondary system) in a disastrous area, where the secondary users move around the microscopic area using the TV spectrum with very low power. In most cases, due to the simplicity of the device, spectrum sensing may not be available by the secondary system. However, interference to the primary system is envisioned to be minimized by the use of low transmit power and the isolation provided by the closed environments. Also the problems of aggregated interference and sharing of spectrum opportunities are envisioned to be mitigated by the isolation of the closed environment.

IV. Concluding Remarks

The scenarios outlined above will be used as the basis for the work to be conducted within the QUASAR project. The overall objective of this work is to assess the amount of useful spectrum opportunities available for secondary use in the various scenarios, and to develop the necessary solutions to enable this usage. This will serve the purpose of providing a decision basis for regulation rule making as well as for feasibility evaluations of business opportunities.

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