Opportunistic Secondary Spectrum Access
-opportunities and limitations

***Jens Zander* and Ki Won Sung**[1]

[1] Wireless@KTH , Royal Institute of Technology (KTH), Stockholm, Sweden, {jenz,sungkw}@kth.se

Abstract

Dynamic spectrum sharing technique ("Cognitive Radio") where secondary users opportunistically utilize temporarily or locally unused spectrum has emerged as a prime candidate technology to relieve the perceived spectrum shortage. Making a realistic assessment of the amount of spectrum available for secondary services is the objective of the EU FP7 QUASAR project. In the project it is found to be fundamentally difficult to reliably determine which part of the spectrum is available, which leads to large safety margins consequently to poor spectrum utilization. Further, the business success of future systems depends on the scalability of the secondary access techniques. Also, the vast majorities of spectrum opportunities are highly localized in time and spaces and strongly dependent on the intended use such that they defy common models for spectrum trading.

1. Introduction

The need for more radio spectrum resources to fulfill 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. In this paper we will report some of the initial findings of the project and their (high-level) consequences. We will discuss primarily three areas of concern:

- Spectrum detection schemes and technical parameters of the secondary system determine the amount of practically available spectrum. In many popular scenarios the fundamental reliability of the techniques to determine which part of the spectrum is available is usually not sufficient to protect the primary users. This leads to large safety margins for secondary spectrum use and consequently to poor spectrum utilization (small amounts of secondary spectrum). Limited knowledge/flexibility regarding the system parameters (a.k.a. technology neutrality) has a similar effect.

- Scalability is important for business success. Most previous work also focuses on the availability of spectrum for a single user, whereas the business success of future systems depends on the scalability of the secondary access techniques, i.e. what will be aggregate interference on primary users in large scale usage.

- Conventional economic models for spectrum trading fail, since spectrum opportunities largely depend on the technical parameters of the intended user and the potential interference victim. Creating exclusive and technology neutral spectrum is associated with massive losses in efficiency.

In the remainder of this paper we will exemplify these finding with preliminary results/studies from QUASAR project.

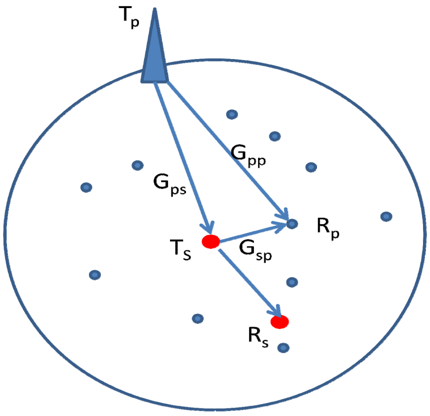

Fig 1. Secondary Use and Interference Scenario

2. Reliability of finding Opportunities by Signal Detection

Previous work has shown that spectrum sensing based access leads to quite poor performance in terms of spectrum utilization in realistic scenarios [7]. There are mainly two reasons for this:

i) the detection of the primary system transmitter (T_P in Fig 1) signal over the path (G_{PS}) does not provide very reliable information regarding the properties of the critical path, that between the secondary users transmitter (T_S) and the primary receiver (R_P), nor the primary user's wanted path gain (G_{PP}), and

ii) the required protection of the legacy primary systems is usually very high – less than a few percent of the primary receiver can be allowed not to reach their signal-to-interference ratio (SIR) targets.

Let us use a simple TV white space scenario in Fig 1 to exemplify these difficulties. Assume that the secondary transmitter (T_S) knows the primary user's transmit power and thus can perfectly estimate the path gain G_{PS}. The SIR in the primary receiver is now (in dB scale)

$$\Gamma = P_P - P_S + G_{PP} - G_{SP} = P_P - P_S + G_{PP} + 10\alpha \log_{10}(r_{SP}) - X_{SP}, \quad (1)$$

where we have used the simple propagation model with an inverse α–power law distance dependence and a log-normal shadow fading component X. The distance between T_S and R_P is denoted by r_{SP}. Now assume that we can express the wanted path G_{pp} by using the estimated gain G_{ps}.

$$G_{PP} = G_{PS} + (1-\beta)X_{PP}, \quad (2)$$

where the constant $\beta \in [0,1]$ is a measure of the correlation between the observed path gain G_{PS} and the primary path gain G_{PP}. Then, the SIR is given by

$$\Gamma = P_P - P_S + G_{PS} + 10\alpha \log_{10}(r_{SP}) + [(1-\beta)\, X_{PP} - X_{SP}]. \quad (3)$$

In (3), the last two terms represent the uncertainty related to the unknown distance to the primary receiver and the uncertainty due to shadow fading, respectively. Table 1 illustrates the required interference margin in some practically interesting cases. The table suggests that the key problem is not knowing the location of the primary receiver. The interference margin in this case is excessively high and secondary reuse becomes impractical in the whole area – unless the secondary user transmit power (and the data rate) is extremely low. Even "perfect" sensing of the primary transmitter does not make any sense(!) – a data base indicating that the channel is used (somewhere) in the same geographical area provides this information in a more reliable way. Sensing becomes more interesting when the path loss to the primary receiver becomes known – e.g. in those cases when the primary system is a two-way communication system, when the primary system has very short range (T_P is very close to R_P) or when primary transmitter and receiver are co-located (e.g. radar systems).

Scenario	Standard deviation	IM (95%)	IM (99%)	Rate (IM=95%)	Rate (IM=99%)
Low detection correlation (β =0)	23,0	37,8	53,5	1,66E-04	4,51E-06
High detection correlation (β =1)	21,5	35,4	50,1	2,86E-04	9,75E-06
Known primary receiver position	11,3	18,6	26,3	1,38E-02	2,33E-03
Known path gain G_{SP}	8,0	13,2	18,6	4,83E-02	1,38E-02
Genie aided access (full knowledge)	0	0	0	1	1

Table 1: Required interference margin *IM* and achievable relative secondary transmission rate for 95% and 99% availability for primary receiver and various detection scenarios. The shadow fading standard deviation is 8 dB and the primary receivers are assumed to be uniformly distributed over the area. As a consequence the distance to the nearest primary receiver is exponentially distributed. The standard deviation of the distance term for α=4 is roughly 20dB

3. Scalability of Secondary Access

An availability of secondary access in a particular location by a secondary device is not attractive enough from a business perspective. Secondary access will be commercially interesting only when it is scalable, i.e. it can support sufficient secondary traffic in a large area. This means that the primary spectrum should be “re-used” by multiple secondary users. However, the impact of multiple secondary users has not been properly addressed in the existing regulatory approaches.

In TV white spaces, recent ECC report 159 proposes a methodology to regulate transmission powers of secondary users and assess the value of the spectrum [8]. In a nutshell, the methodology can be described as follows: a large geographical area is divided into pixels. Then, the maximum allowed transmission power for a secondary user, $P_{S,max}$, is calculated in each pixel with the constraint of the TV coverage probability as shown below:

$$\Pr\left[RX_P \geq RX_{P,min} + I_{TV} + I\left(P_{S,max}\right) + IM\right] \geq q \ , \tag{4}$$

where q is the required TV coverage probability, RX_P is the received signal power at a TV receiver, $RX_{P,min}$ is the minimum TV receiver sensitivity, I_{TV} is the interference from other TV transmitters, and $I\left(P_{S,max}\right)$ is the interference from the secondary user as a function of $P_{S,max}$. Safety margin and multi-user margin are accounted for by the term IM. It should be noted that the methodology in [8] takes only a single secondary transmitter into account. Although the effect of multiple secondary users can be considered by IM, a method for obtaining proper IM value has not been established yet. A conservative IM will result in the loss of spectrum opportunity, while insufficient multi-user margin has a risk of failing to protect TV receivers.

Another example of secondary access is the use of radar spectrum in 5 GHz by low power devices such as WLAN. ETSI standard EN 301 893 specifies the thresholds and requirements for the secondary devices [9]. The transmission decision of each secondary user is regulated by individual detection result: a secondary device with a power density of 10 dBm/MHz can use a primary spectrum if a detected radar signal power is less than -62 dBm. Notably, the detection threshold of -62 dBm remains constant regardless of the number of secondary devices.

In [10], a mathematical framework to describe the aggregate interference in the radar spectrum is proposed under the assumption of uniformly distributed secondary users. Key findings of the study are as follows: first, aggregate interference hugely depends on the propagation environment. Thus, accurate description of propagation loss is a prerequisite for reliable interference modeling. Second, the impact of multiple secondary users should not be ignored particularly when path loss does not attenuate fast, e.g. rural or line-of-sight propagation environments. This implies that we need to be more cautious in dealing with primary users in rural area. Similar result is reported when airborne equipments are considered to be the potential primary users [11].

In this section, we focused on the aggregate interference from multiple secondary users to primary users as one of the main challenges for the scalability of secondary access. There are other issues to be addressed such as the mutual interference among secondary users and medium access control (MAC) mechanism for the secondary users. More discussion on secondary sharing schemes can be found in [12]. Overall, substantial research efforts are required to ensure the scalable secondary access.

4. Low efficiency of Secondary Spectrum Trading

Traditional economic models for trading tell us that an efficient market requires assets that are general enough to attract the interests of many potential players [13]. The more constraints are put on the use of the asset, the lower is the expected value. In opportunistic spectrum access, the vast majorities of spectrum opportunities are not "spectrum holes" that anyone can use anywhere and for any purpose, but instead they are highly localized in time and space. Furthermore, if there are opportunities to be found, these strongly depend on the technical parameters of the intended user. QUASAR results show that there in many cases is plenty of such "specific availability" of spectrum for a specific transmission at a given place and time, but this is not very useful to others – not even in the local surroundings. Making the spectrum asset more general in the sense that it should be available over large geographical areas and for a wide range of applications (a.k.a. "technology neutrality"), will require significant interference margins as demonstrated in section 2, lowering the spectrum availability with many orders of magnitude. An example on how difficult it is to come by exclusive, technology neutral spectrum, are the recent spectrum reallocations in the 800 and 900 MHz band due to conflicts with legacy systems (e.g. GSM-R, TV-broadcast).

5. Conclusion

Some of the key findings demonstrated in QUASAR project thus far are that there is plenty of availability of spectrum for opportunistic reuse, in particular when it comes to short range secondary systems. Broadcast spectrum is more difficult to reuse since spectrum sensing does not provide sufficient information for protecting the broadcast receivers. Scalability, i.e. the effects of massive secondary spectrum usages, is identified as a significant problem for further study.

6. Acknowledgments

This work has been performed in the framework of the EU FP7 project INFSO-ICT-248303 QUASAR. The authors would like to acknowledge the contributions of their colleagues.

7. References

1. J. Peha, "Sharing Spectrum through Spectrum Policy Reform and Cognitive Radio", *Proc. of the IEEE*, Vol. 97, No. 4, April 2009.
2. A. Tonmukayakul and M. B. Weiss, "Secondary Use of Radio Spectrum: A Feasibility Analysis," Telecommunications Policy Research Conference, 2004.
3. J. Peha and S. Panichpapiboon, "Real-time secondary markets for spectrum", *Telecommunications Policy*, Vol. 28, 2004.
4. S. Srinivasa and S. A. Jafar, "The Throughput Potential of Cognitive Radio: A Theoretical Perspective", *IEEE Comm. Mag.*, May 2007.
5. M. Nekovee, "Cognitive Radio Access to TV White Spaces: Spectrum Opportunities, Commercial Applications and Remaining Technology Challenges," Proc. IEEE DySPAN, Singapore, 6-9 April, 2010.
6. INFSO-ICT-248303 QUASAR Project, http://www.quasarspectrum.eu/
7. J. Zander, "Can we find (and use) Spectrum Holes", Proc. IEEE VTC, Barcelona, Spain, April 2009.
8. "Technical and operational requirements for the possible operation of cognitive radio systems in the "white-spaces" of the frequency band 470-790 MHz," ECC Report 159, Jan. 2011, available at http://www.ero.dk.
9. ETSI EN 301 893 V1.5.1, "Broadband Radio Access Networks (BRAN); 5 GHz high performance RLAN; Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive," Dec. 2008.
10. M. Tercero, K. W. Sung, and J. Zander, "Impact of Aggregate Interference on Meteorological Radar from Secondary Users," Proc. IEEE WCNC, Cancun, 28-31 March, 2011.
11. K. W. Sung, E. Obregon, and J. Zander, "On the Requirements of Secondary Access to 960-1215 MHz Aeronautical Spectrum," Proc. IEEE DySPAN, Aachen, 3-6 May, 2011.
12. QUASAR deliverable D4.1., "Sharing Strategies for Unaware Secondary Systems," March 2011, available at http://www.quasarspectrum.eu/
13. P. Crocioni, "Is allowing trading enough? Making secondary markets in spectrum", *Telecommunications Policy*, Vol. 33, September 2009.