Cognitive Relay: Detecting Spectrum Holes in a Dynamic Scenario

(Extended Abstract)

Ankit Kaushik, Marcus Mueller, Friedrich K. Jondral
Communications Engineering Lab, Karlsruhe Institute of Technology (KIT)
{Ankit.Kaushik, Friedrich.Jondral}@kit.edu, Marcus.Mueller@student.kit.edu

I. Introduction

Cognitive radio as first coined by Mitola [1] in 1999 illustrates a dynamic model that provides human intervention to the underlying radio hardware. Dynamic spectrum access (DSA) is one of the many applications of cognitive radio. The DSA umbrella [2] considers the secondary usage of the spectrum. On these grounds, we meant to design a working prototype for Cognitive Relay (CR), a device that dynamically accesses the spectrum to support wireless services operating indoor.

Through the concept of CR the authors attempt to bring the basic aspects of the cognition cycle: *sensing* and *learning* using real hardware. The concept of dynamic access is accomplished through a cross layer optimization. The information gathered through sensing and the intelligent access to the spectrum have already been considered in literature [3].

Yet there have been limitations: Firstly, in many cases the physical parameters and protocols are specific to the underlying standards. Secondly, due to the complexity involved, the time required to implement these concepts is large. To overcome these problems the CR considers a general architecture for sensing and a basic algorithm for scheduling the resources. This paper discusses the implementation of its prototype.

The paper is organized as follows: Section II discusses the scenario for the CR. Section III explains the detection technique and the scheduling algorithm. Section IV describes the implementation of the device. Finally, section V presents the user interaction of the demonstrator in a real-world scenario followed by section VI which concludes the paper.

II. Cognitive Relay

Fig. 1 depicts a scenario for the CR. It is a network element that belongs to the mobile network operator (MNO), who aims to access the spectrum as a Secondary User (SU) when it is not used by the Primary User (PU). Through the deployment of CR in an indoor environment, the MNO can improve its networks' capacity by optimizing spectral efficiency. The CR has a *outdoor antenna* that is situated at an elevated position and an *indoor antenna* that communicates with the user equipment (UE) registered for indoor usage.

The *backhaul link* between the SU and CR is directional. This simplifies the channel and reduces the transmitted power both at the CR and the SU.

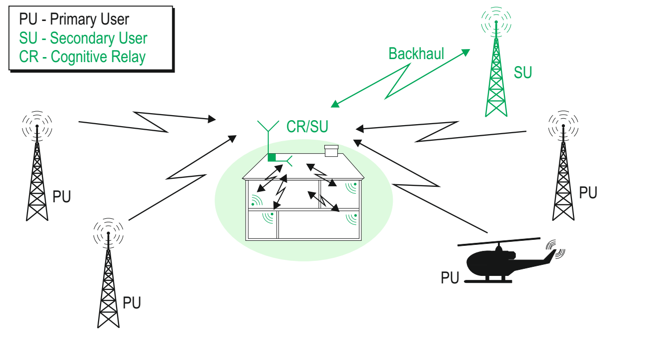

Fig. 1. A scenario demonstrating the interaction between the PU and the CR. The CR senses PU operating on different channels the outdoor to provide a dynamic access to the devices operating indoor.

By nature of their access, the PUs leave temporal and spatial gaps in the spectrum termed as *Spectrum Holes* [4]. The CR enables dynamic access to the spectrum and utilization of these spectrum holes. The biggest challenge for the cognitive radio devices acting as SUs is to avoid interference at the primary receiver while accessing the PU spectrum.

III. Detection and Learning

We consider the receiver model $Y[n] = X[n] + W[n]$, representing the signal at the receiver $Y[n]$ in terms of input signal $X[n]$ with additive white Gaussian noise $W[n]$. Following the Neyman Pearson approach, the CR uses a binary hypothesis $\mathcal{H}_0$, $\mathcal{H}_1$ to determine the absence of PUs ($W[n]$) or their presence ($X[n] + W[n]$). Energy detection [5] is used to decide upon the hypothesis. The test statistic

$$T(\mathbf{Y}) = \frac{1}{K} \sum_{n=0}^{K-1} |Y[n]|^2 \underset{\mathcal{H}_1}{\overset{\mathcal{H}_0}{\gtrless}} \gamma \tag{1}$$

corresponds to the energy of the K complex input samples. For large K, $T(\mathbf{Y})$ fulfills the requirements of the Central Limit Theorem and follows a Gaussian distribution for the given hypothesis.

With signal power σ_X^2 as unknown parameter, a constant false alarm rate scheme is applied to determine the threshold γ. Usually, the PU's spectrum has a wide bandwidth. The CR employs multiband sensing to retrieve the spectrum occupancy information. As a result, the CR divides the PU spectrum into subchannels and scans each individual subchannel by tuning the RF hardware parameters through a software interface.

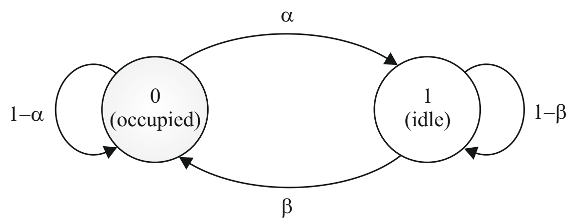

Fig. 2. Channel model illustrating the PU access.

In the next phase, the binary values for each subchannel are utilized to implement a scheduling algorithm. Through this algorithm, the CR ranks the scanned subchannels. Following the ranking, a search order is found that minimizes the latency of finding a suitable subchannel for data transmission. The CR considers the PU as realizing slotted medium access, the subchannels as independent from each other and the slots for each subchannel as following the Gilbert channel model [6].

$Z^i(k) = 1$ represents an idle state, while $Z^i(k) = 0$ describes channel i being occupied at time k. Fig. 2 depicts the slots following a discrete time Markov process with transitional probabilities (α, β). The utilization probability u is defined as the probability of finding a channel in occupied state $Z^i(k) = 0$. Using the given channel model and knowledge of the transition probabilities (α, β), u can be evaluated as

$$u = \frac{\alpha}{\alpha + \beta} \ . \tag{2}$$

While sensing consecutive slots, the CR estimates $(\widehat{\alpha}, \widehat{\beta})$ using Maximum Likelihood Estimation (MLE) [7]. After obtaining u for the subchannels, the CR ranks the subchannels and optimizes its transmission capacity.

IV. Implementation

The CR or demonstrator maintains a scanning list inside its database. The list consists of the PU subchannels to be used for secondary usage over the indoor link. For the demonstration GSM subchannels are used, however the demonstrator can be configured for any other PU architecture that realizes slotted medium access.

The demonstrator does a live scan of the individual subchannels in the list. The energy of the input samples is compared to γ to derive the binary values $z^i(k)$. The binary values for the individual subchannels are stored in the database. The channel model parameters $(\widehat{\alpha^i}, \widehat{\beta^i})$ are estimated for each subchannel. The demonstrator then determines the u^i for each subchannel over the past observed 1000 slots.

The hardware of the demonstrator is realized using a calibrated Ettus Research USRP N210, a software defined radio (SDR) frontend. The baseband signal processing, the Gilbert channel modelling and the tuning of RF parameters are done using a general processing unit running GNU Radio.

V. User Interaction

The demonstrator works in a real-world scenario by monitoring the GSM bands at 1800 MHz. The spectrum holes in subchannels are displayed through a spectrogram, see the snapshot in Fig. 3. Simultaneously the bar plot shows the subchannels' utilization probability u^i to inform about the ranking of individual subchannels. The demonstrator updates the plots upon each complete scan.

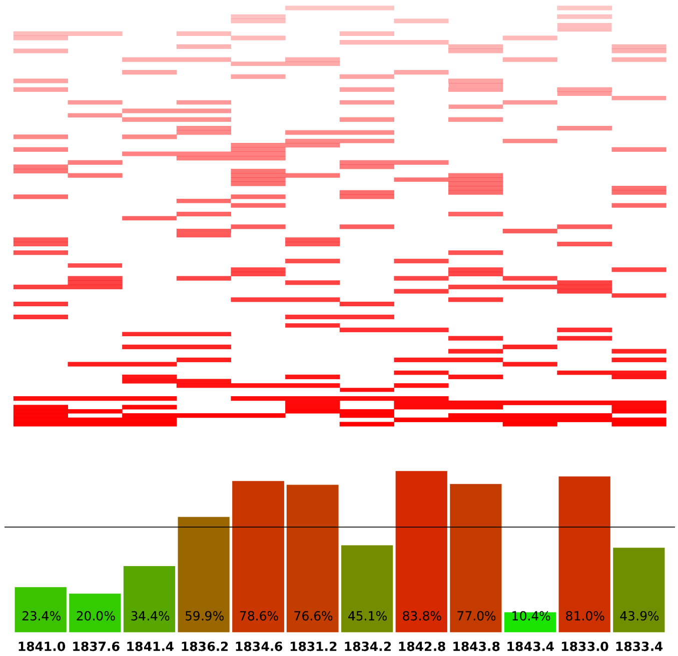

Fig. 3. Utilization probability for ranking the GSM subchannels.

VI. Conclusion

The paper considers a demonstration of the Cognitive Relay, a network element that utilizes the spectrum for secondary usage. It has the potential to sense and access non contiguous multiple bands and also is capable to learn and interact with its environment.

References

[1] I. Mitola, J. and J. Maguire, G.Q., "Cognitive radio: making software radios more personal," *Personal Communications, IEEE*, vol. 6, no. 4, pp. 13 –18, aug 1999.

[2] Q. Zhao and B. Sadler, "A survey of dynamic spectrum access," *Signal Processing Magazine, IEEE*, vol. 24, no. 3, pp. 79 –89, May 2007.

[3] E. Hossain, D. Niyato, and Z. Han, *Dynamic Spectrum Access and Management in Cognitive Radio Networks*. Cambridge University Press, 2009.

[4] T. Weiss and F. Jondral, "Spectrum pooling: an innovative strategy for the enhancement of spectrum efficiency," *Communications Magazine, IEEE*, vol. 42, no. 3, pp. S8 – 14, mar 2004.

[5] H. Urkowitz, "Energy detection of unknown deterministic signals," *Proceedings of the IEEE*, vol. 55, no. 4, pp. 523 – 531, april 1967.

[6] E. N. Gilbert, "Capacity of a burst-noise channel," *Bell System Technical Journal*, vol. 39, pp. 1253–1265, Sep. 1960.

[7] X. Long, X. Gan, Y. Xu, J. Liu, and M. Tao, "An estimation algorithm of channel state transition probabilities for cognitive radio systems," in *Cognitive Radio Oriented Wireless Networks and Communications, 2008. CrownCom 2008. 3rd International Conference on*, may 2008, pp. 1 –4.