Cognitive Radio: State of the art

Bart Scheers & Vincent Le Nir

Royal Military Academy – Department CISS

Renaissance Avenue 30 – B1000 Brussels, Belgium

bart.scheers@rma.ac.be, vincent.lenir@elec.rma.ac.be

Abstract

Cognitive Radio is a paradigm for wireless communication in which a wireless node (or a network) can change its transmission and reception parameters according to the user needs and the wireless environment. A cognitive radio transceiver is able to sense, learn, decide and react adaptively to avoid interference with licensed or unlicensed users and to achieve greater spectrum efficiency compared to existing systems. Cognitive radio opens a new era in digital communications involving numerous topics, such as spectrum sensing, spectrum management, spectrum mobility, etc.

1. Definition of cognitive radio

Cognitive radio has been introduced by Mitola in 1999 [1]. Following the definition of Haykin [2]: “Cognitive radio is an intelligent wireless communication system that is aware of its surrounding environment (i.e., outside world), and uses the methodology of understanding-by-building to learn from the environment and adapt its internal states to statistical variations in the incoming RF stimuli by making corresponding changes in certain operating parameters (e.g., transmit-power, carrier-frequency, and modulation strategy) in real-time, with two primary objectives in mind:

- highly reliable communications whenever and wherever needed
- efficient utilization of the radio spectrum”

An example of a military cognitive radio scenario can be seen on Figure 1 with two users from two different coalition nations, where Tx1 wishes to communicate with Rx1, and Tx2 wishes to communicate with Rx2. Some of the spectrum bands at a given time might be unavailable due to other civilian or military communication systems (represented by the antenna on the figure). If the users are equipped with legacy radios and share the same bands, they might even not be able to transmit reliably their information due to the high level of interference temperature in the environment.

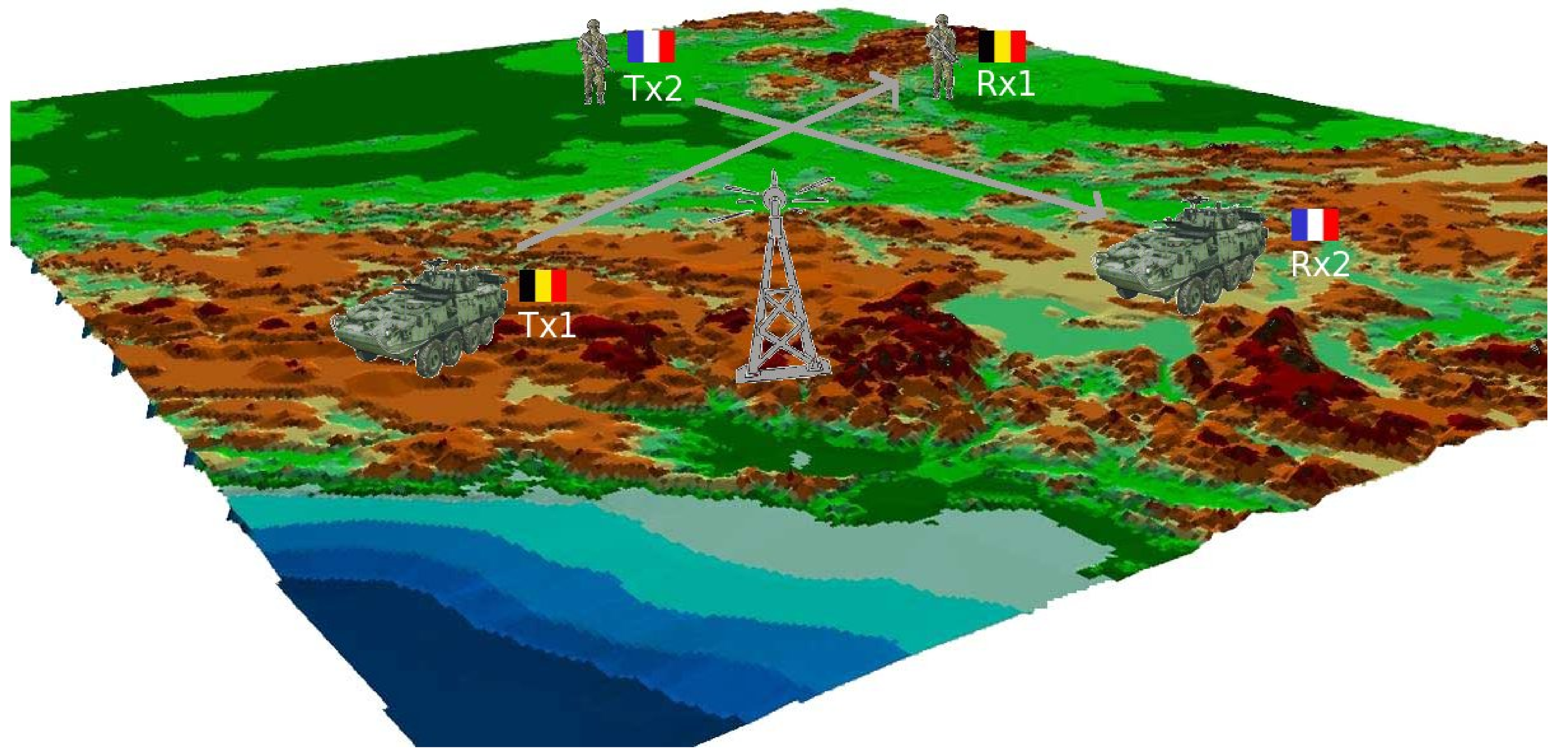

Figure 1: *Military cognitive radio scenario*

Therefore, the fundamental principles of cognitive radio are on one hand to identify other radios in the environment that might use the same spectral resources by means of spectrum sensing and on the other hand to design a transmission strategy that minimizes interference to and from these radios by means of spectrum management. A basic cognitive cycle as proposed by Haykin [2] which is shown on Figure 2 (left) is composed of three cognitive tasks:

- radio-scene analysis which estimates the interference temperature of the radio environment and detects the spectrum holes
- channel identification which estimates the channel state information (CSI) and the channel capacity available to the transmitter
- transmit-power control and dynamic spectrum management

Some measurements have been performed in Brussels at the Royal Military Academy (RMA) in 2008. Figure 2 (right) reveals a typical utilization of roughly 24% in the 30-1300 MHz frequency band. It can be seen that, although all the frequency bands are allocated, the spectrum utilization is far from optimal.

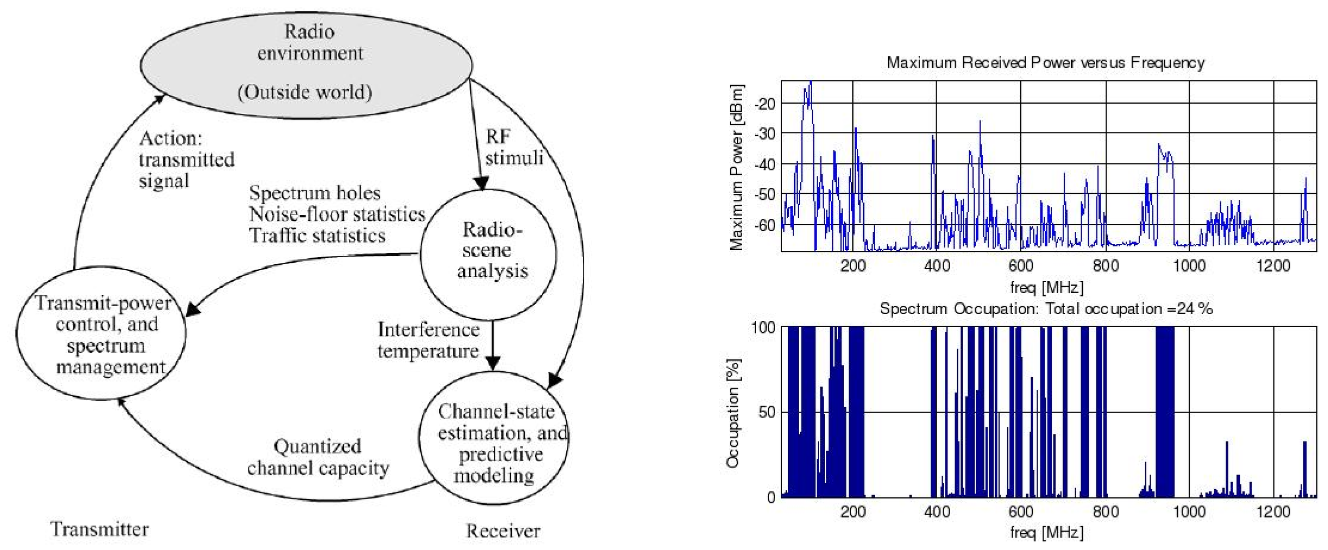

Figure 2: *Basic cognitive cycle (left) and spectrum utilization measurement in the 30-1300 MHz band in Brussels (right)*

2. Spectrum sensing

Spectrum sensing is a task performed by the cognitive users. It consists of finding holes in the radio spectrum. A binary hypothesis model can be used for the detection:

$$\begin{array}{l} H_0 : y(t) = n(t) \\ H_1 : y(t) = s(t) + n(t) \end{array} \quad (1)$$

with H_0 and H_1 the hypotheses of absence and presence of the signal respectively. The most common spectrum sensing techniques are the matched filtering detection, the energy detection and the cyclostationarity feature detection [3]. The matched filtering detection requires the knowledge of the transmit signal parameters, therefore it is difficult to implement in practical cognitive radio receivers. The energy detection is based on parametric or non-parametric power spectral density (PSD) estimation, but performs poorly for spread spectrum or frequency-hopped signals. Finally, cyclostationarity feature detection exploits the cyclic periodicity present in most of the current digital communication standards [5]. Figure 3 shows for instance the cyclic autocorrelation function (CAF) for a conventional OFDM signal (Wifi).

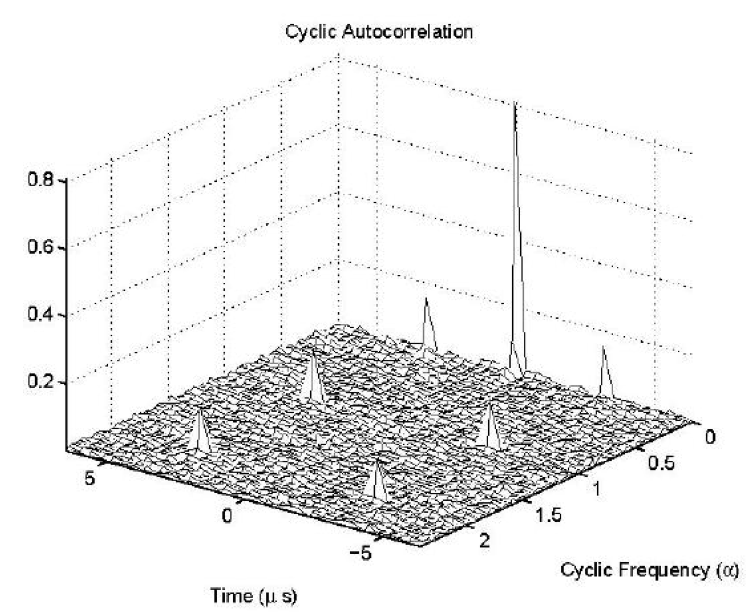

Figure 3: *Cyclic autocorrelation function for a conventional OFDM system*

3. Spectrum management

Spectrum management is a task devoted to the cognitive manager which can be centralized or distributed with respect to the cognitive users. It consists of finding the transmit powers of the different cognitive users to improve the performance of a communication network as a whole (capacity, stability, delay, etc.). A set of techniques have been developed in network information theory and in game theory to deal with this optimization problem. Game theory for instance casts the cognitive users into players that try to maximize an objective function until a Nash equilibrium is reached, i.e. no player has anything to gain by changing his own transmit parameter. In network information theory, a common strategy is to use iterative waterfilling which leads to a sub-optimal solution [4]. Simulation results have been performed with the distributed iterative waterfilling algorithm shown in Figure 4 (with strong crosstalk channels similar to Figure 1). Two users are competing for four sub-bands, leading to a FDMA solution, where Tx1 is only using sub-band 2 and 3, and Tx2 only sub-band 1 and 4.

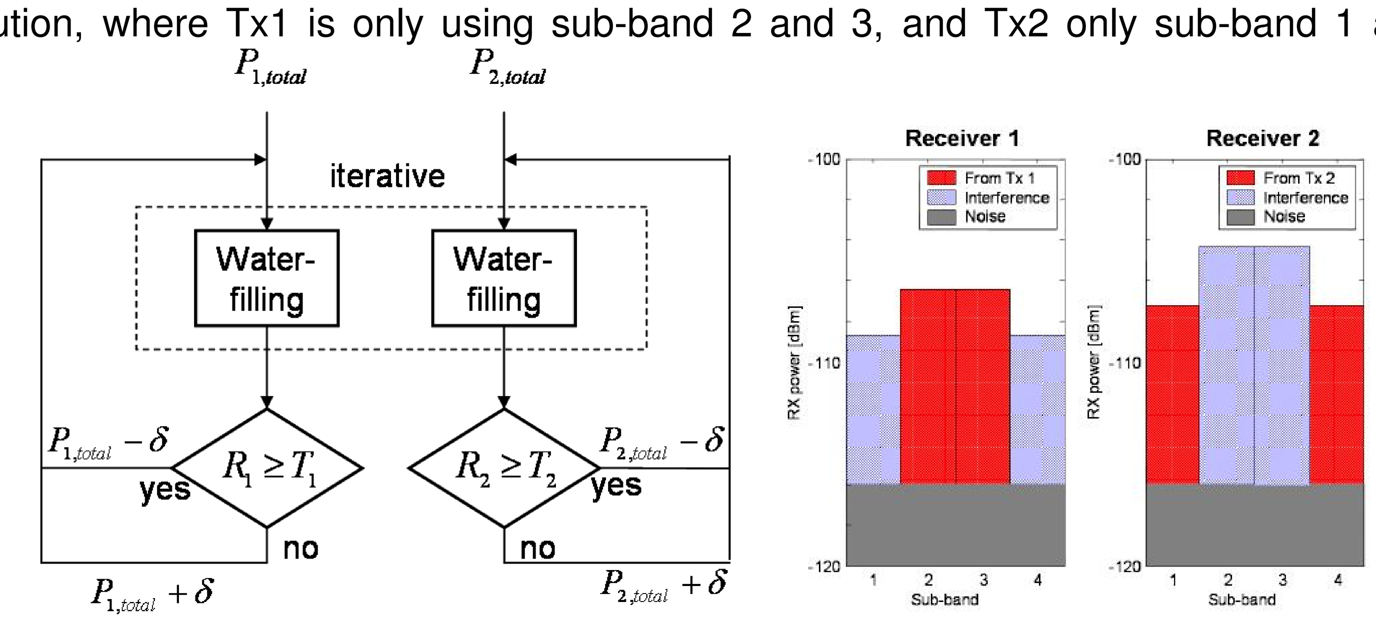

Figure 4: *Iterative-waterfilling algorithm results with 4 sub-bands and two users*

4. Conclusion

This poster reviews the concept of cognitive radio which will be used in future digital communication systems. The spectrum sensing techniques and the spectrum management techniques are described. A practical example with a distributed iterative waterfilling has been implemented, where the two users converge to a kind of FDMA solution for strong crosstalk channels. Future directions are waveform design in military communications for low probability of detection and interception LPD/LPI, and dynamic spectrum management in cognitive radio ad-hoc networks.

References

[1] J. Mitola Cognitive radio: making software radio more personal *IEEE Personal Communications*, 13–18, August 1999.

[2] S. Haykin Cognitive radio: Brain-empowered wireless communications *IEEE Journal on Selected Areas in Communications*, 23:201–220, February 2005.

[3] D. Cabric, I. D. O’Donnel, M. S. Chen, and R. W. Brodersen Spectrum sharing radios *IEEE Circuits and Systems Magazine*, 30–45, second quarter 2006.

[4] W. Yu Competition and cooperation in multi-user communication environments *PhD dissertation*, 2002.

[5] W. Yucek and H. Arslan Feature suppression for physical-layer security in OFDM systems *IEEE Military Communications Conference, MILCOM*, October 2007.