Chapter 1

Cognitive Wireless Sensor Networks: State-of-art

This chapter shows an approach to the fundamentals of Wireless Sensor Networks and the current development state of new paradigms such as Cognitive Radio, Cognitive Networks or Cognitive Wireless Sensor Networks. It describes current related devices, applications and implementations, and introduce terms used all along this dissertation.

1.1. Cognitive Radio

Nowadays, it is commonly believed that there is a crisis of spectrum availability for wireless communications[1]. However, according to regulatory bodies as the FCC (*Federal Communications Commission*)[2] or the Ofcom (*Office of Communications*), most radio frequency spectrum is under-utilized while some spectrum bands are heavily used. Military, amateur radio or satellital frecuencies, for instance, are insuffiently utilized compared to cellular networks or the overcrowded ISM (*Industrial, Scientific and Medical*) bands[3].

Most of the spectrum is allocated to specific applications and the static assignment of the spectrum results in an inefficient use of it. Figure 1.1 shows how the actual utilization in the 3-4 GHz frequency band is 0.5 % and drops to 0.3 % in the 4-5 GHz band. This seems totally in contradiction to the concern of spectrum shortage.

Spectrum utilization depends strongly on time and place, however, fixed spectrum allocation prevents specific assigned frequencies from being used, even when this use would not cause noticeable interference to the assigned service. These facts lead to the current inneficiency situation where the utilization of the total spectrum can be considered around 10 % and more than 95 % of the use is below 3GHz.

The concept of CR (*Cognitive Radio*) was first published by Joseph Mitola III and Gerald Q. Maguire, Jr. in 1999[5] and later on within Mitola's phD Dissertation in 2000[6]. It describes a novel paradigm for wireless communication in which a wireless device changes its transmission or reception parameters to communicate efficiently. This alteration of parameters is based on the active monitoring of several factors in the

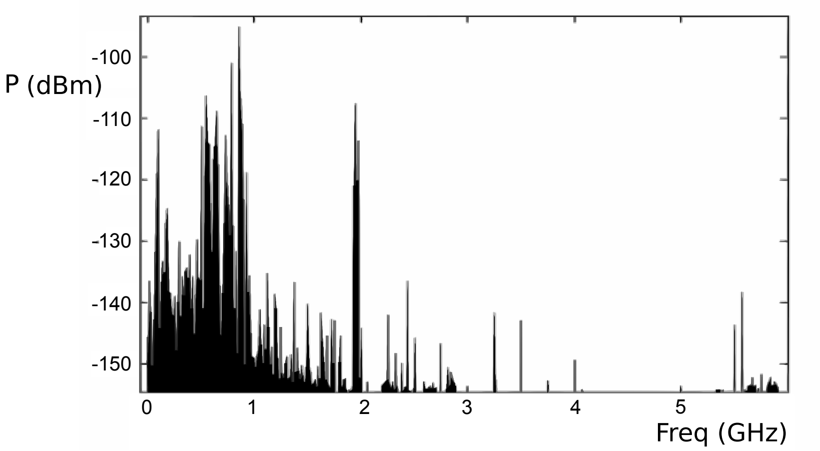

Figure 1.1: A snapshot of the spectrum utilization up to 6 GHz in an urban area: taken at mid-day with 20 kHz resolution taken over a time span of 50 microseconds with a 30 degree directional antenna at Berkeley Wireless Research Center [4].

external and internal radio environment, such as radio frequency spectrum, application behavior, and network state. The idea was thought of as an ideal goal towards which a SDR (*Software-Defined Radio*) platform should evolve.

The CR is defined as an intelligent wireless communication system that is aware of its environment and uses the methodology of understanding-by-building[7] to learn from the environment and adapt to statistical variations in the input stimuli, with two primary objectives:

- Hihighly reliable communications.
- Efficient utilization of the radio spectrum.

Although the concept of CR was defined originally as an extension to SDR[5], which is able to reason about external factors, recently the term is mostly used in a narrower sense. FCC suggests in [8] that any radio having the adaptive spectrum awareness should be referred to as CR:

> *"A cognitive radio (CR) is a radio that can change its transmitter parameters based on interaction with the environment in which is operates. The majority of cognitive radios will probably be SDRs (Software Defined Radios), but neither having software nor being field programmable are requirements of a cognitive radio."*

Attending to some subtle differences between systems we can differenciate two main different types of CR:

- *Spectrum-Sensing Cognitive Radio*, in which only the radio-frequency spectrum is considered.[7]
- *Full Cognitive Radio or Mitola radio*, in which every possible parameter observable by a wireless node is considered.[5]

Although cognitive radio was initially thought of as full cognitive radio, most research work focuses on spectrum-sensing cognitive radio, particularly in the TV bands. The great problem in spectrum-sensing cognitive radio is designing high-quality spectrum-sensing devices and algorithms for exchanging the so called knoledge domain [7]. The practical implementation of spectrum-management functions is a complex and multifaceted issue, since it must address a variety of technical and legal requirements.

Picture 1.2 ilustrates the changes the OSI (*Open Systems Interconnection*) model suffer when affected by cognition. CR model can be referred to the first and second layers, thus the *Phisical* and *Link* layers.

Figure 1.2: CWSN protocol model

Depending on parts of the spectrum used, CR can be:

- *Licensed-Band Cognitive Radio*, capable of using bands assigned to licensed users. This licensed users are known as primary users.
- *Unlicensed-Band Cognitive Radio*, which can only utilize unlicensed parts of the RF (*radio frequency*) spectrum. One such system is described in the IEEE 802.15 Task Group 2 specifications[9].

The main functions of CR devices are:[10][11]

- *Spectrum sensing*: An important requirement is detecting unused spectrum and sharing it, without causing interferences to other users; Spectrum-sensing techniques may be grouped into three categories:
  - *Transmitter detection*: CR must have the capability to determine if a signal from a primary transmitter is locally present in a certain spectrum. Enclosed here we can find approaches such as *matched filter detection, energy detection or cyclostationary-feature detection* are common.
  - *Cooperative detection*: Refers to spectrum-sensing methods where information from multiple CR users is integrated[12].
  - *Interference-based detection.* It tries to take advantage of the difference between the detected noise level and the maximum noise level the primary users can afford. In this way, if there is enough difference, the nodes might stablish RF activity considered by primary users as just noise. This technique is not so common because of disagreements with primary users.