Basics of Cognitive Radio: An appraisal

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Basics of Cognitive Radio Networks: An Appraisal

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2.1 Introduction

When we look for the meaning of the word "cognition," it shows the mental process of knowing, including aspects such as awareness, perception, reasoning, and judgment. Similarly, when we frame the name "cognitive radio" (CR), the best definition in Haykin's words can be quoted as,

> Cognitive Radio is an intelligent wireless communication system that is aware of its surrounding environment 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 (radio frequency) stimuli by making corresponding changes in certain operating parameters in real-time.

The number of mobile users is increasing day by day in the current wireless communication domain, which is apt to create a bandwidth crisis due to limited spectrum availability. CR is a future technology capable of solving the spectrum scarcity problem. It provides a solution by which efficient spectrum utilization is possible by applying the optimistic spectrum sharing techniques [1]. Mitola is considered as the pioneer who brought the concept of CR into existence. In synchrony with the name, CR is capable of detecting dynamically varying environments. Once it senses any changes in the surroundings, it adapts its communication variables such as carrier frequency, bandwidth, power, coding schemes, and modulation scheme in an intelligent way. In this chapter, we basically deal with the fundamental aspects of CR, which include its properties (based on spectrum sensing), an outline of a CR transceiver, and other architectures.

2.2 Properties of CRs

Generally, CR is considered to possess two important characteristics which are completely based on its spectrum-sensing capability. These are as follows.

2.2.1 User Centric

The framework of CR is based upon radio knowledge representation language (RKRL). It manifests itself like a small physical world. It uses and disseminates information with adaptable changes in unison with the surrounding environment, albeit keeping track of the user over different timescales which do not resemble each other. As it involves many sensors, it first gathers knowledge from its neighborhood and then employs relevant software. With their help, CR gets access to databases and makes contact with other sources of information. It clearly shows that CR is a unique electronic aid for the developer. Owing to its versatile operability, it will not be an exaggeration to say that CR provides assistance in day-to-day life irrespective of the fact whether its owner realizes it or not. It is often looked upon as a small part of a huge physical world, using and providing information over different timescales [1–11].

2.2.2 Technology Centric

With the advent of advanced spectrum sharing systems, there is a need to implement higher version of algorithms. To do that, lots of tactics are to be executed by the CR. For example, suppose an access mode is already sharing a portion of the spectrum. Corresponding to the demand of the user, CR first inspects the data rate and then the mode of transmission. To accomplish its own mode of transmission, it starts searching space allocations (spectrum) which are redundant. In such circumstances, CR is presumed to have specific features such as self-location (information about its own location) and self-awareness (knowing its ability). In addition to that, it should have knowledge of accessible base stations. To overcome interference, it has to find out other active signals in the neighboring bands, and must have knowledge of their transmission standards [11]. Consequently, a CR should be in possession of a location sensor as well as an intelligent monitoring system to keep an eye on its spectral environment [11] (see Figure 2.1).

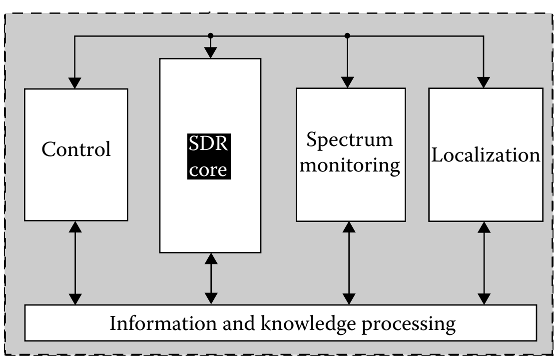

FIGURE 2.1
Technology centric radio. (From Jondral, F.K., *EURASIP J. Wirel. Commun. Netw.*, 3, 275–283, 2005. With permission.)

2.3 CR Transceiver

Software-defined radio (SDR) possesses a unique transceiver, which can be reconfigured, unlike the conventional one (see Figure 2.2). The reconfiguration and standard operational efficiency of CR are achieved by a control bus, which creates processing parameters for the desired standard of CR. Hence, the system is named as parameter-controlled SDR. Chiefly, an SDR terminal is composed of front-end radio, base-band processing, and data-processing modules [3,4]. The process is as follows.

The analog RF signal is first transformed into its digital complex baseband representation and then band-pass filtered, followed by amplification. An additional RF is locally generated. A two-way splitter is adapted to mingle the radio frequency with the signal. The entire mode of modulation is based on quadrature modulation. The main components I and Q undergo low-pass filtering and analog-to-digital conversion. In the process of analog-to-digital conversion, the sampling rate is optimized to match the signals standard. This is done so that signal processor operates at the least possible rate [11]. During sampling, the rate of digitization should be uniform for all the signals to be processed. This is in accordance with Shannon's sampling theorem. Prior to the adaptation of sampling rate to that of signal standard, another crucial factor was figured out. During the signal processing, signal mixer, filter, and analog-to-digital converter induce impairments in two-branch signal processing owing to their inherent mechanism. To circumvent this problem, corrections [5] are introduced before adapting sampling rate to the signal standard. The minimum rate of digitization is dependent on the chip rate. Generally, sampling rate is

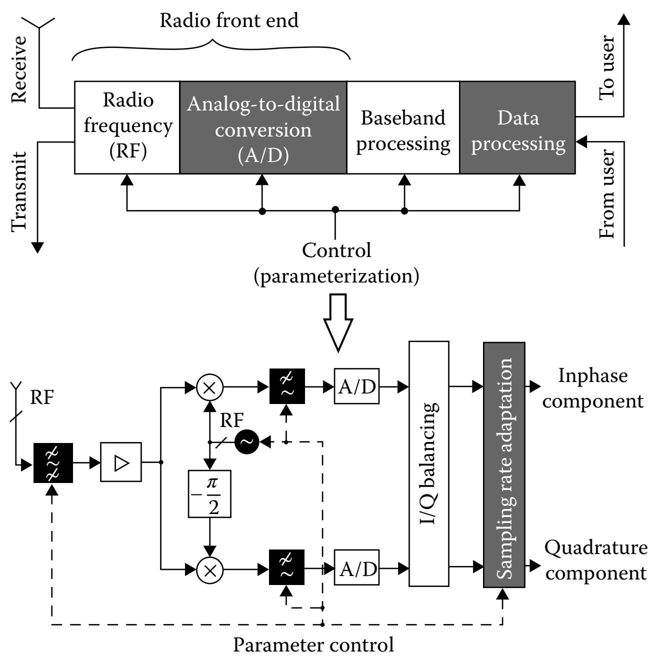

FIGURE 2.2
CR transceiver. (From Mitola, J., III., *1999 IEEE International Workshop on Mobile Multimedia Communications (MoMuC '99)*, San Diego, CA, 1999. With permission.)

kept as four times the chip rate, which is sufficient for the subsequent processing. Once it is precisely synchronized, there occurs a diminution by a factor of four.

In Section 2.4, a general model of CR is presented.

2.4 General Model of CR Networks

In general, CR acts as a multitasking platform. The modus operandi of CR can be visualized with a model elaborated in this section.

Figure 2.3 illustrates the simplified model of CR interactions devoid of the symbols used herein. Generally, each CR has its own goal. This goal-centric CR reacts to the external environment within its chosen adaptation (or waveform). In chosen adaptation, CR makes a proximal connection to its goal irrespective of its structure, content, etc. Whatever CR is going to observe at any given point of time is decided by the passive network. As constituents of the passive operating environment, channel conditions and interference environment along with the adjacent CR are taken into account. However, goal-centric adaptation plays an important role. Here, we present some general symbols and conventions that actually characterize the features of the CR environment.

Suppose there are J number of CRs in the network designated by l, m particular devices. Each one is linked to an available set of actions represented by B_l. In general, CR possesses limited number of sets which try to contain all prevalent adaptations. These adaptations are

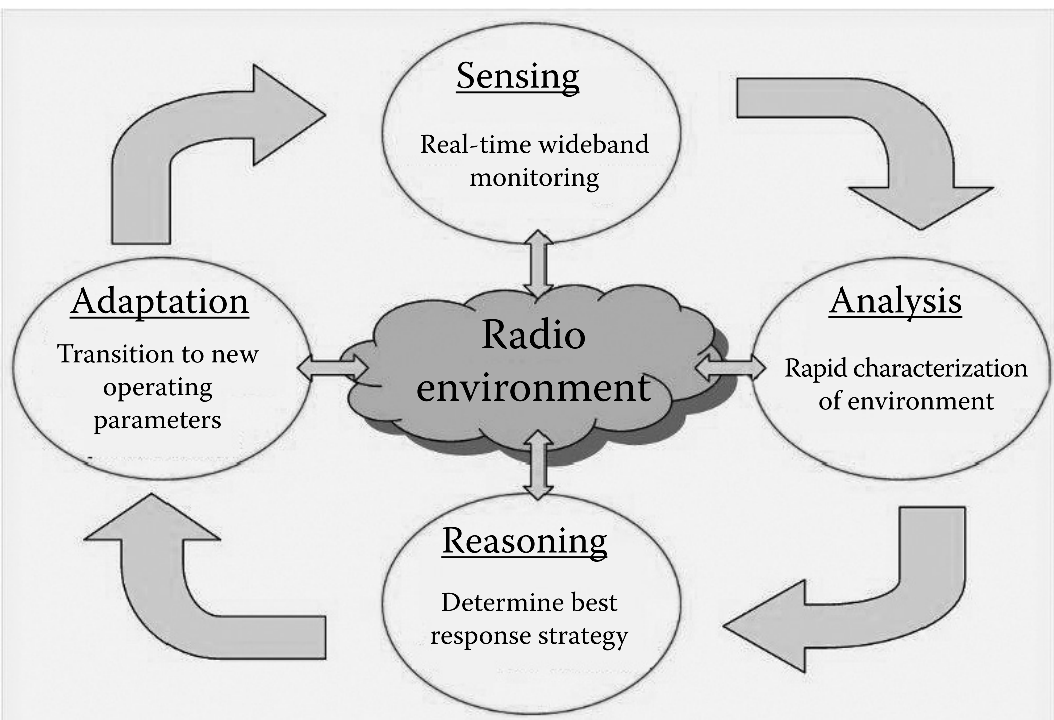

FIGURE 2.3
General model of CR network.

found to be influenced by several parameters, for example, power levels, center frequency, modulation, and source coding schemes. As a result, B_l becomes multidimensional, which is not affected by time. This can be interpreted as the reluctance of the CR to learn new actions during their very short span of adaptations. Consider B as the action space constructed by the Cartesian product of each radio action set, $B = B_1 \times B_2 \times B_3 \times \ldots \times B_l$. Similarly, if we use b as a particular set of action in B space pertaining to a specific lth CR, we can write b_l, which denotes its contribution. Again, P denotes the outcomes corresponding to outside world; p_l in similitude to this implies an observation associated with or furnished to radio l. Lastly, we introduce two additional parameters: p as a vector space inclusive of observed outcome and d_l designating the decision rule as updated by radio l on the basis of observation.

Specifically, d_l assumes the form e_d: $p_l \rightarrow B_l$. Since, there is statistical coverage of observed outcome by the action vector, each decision rule becomes a function, i.e., d_l: $B \rightarrow B_l$.

For different types of CRs, there is an explicit definition of decision rules, subjected to selection of *locally optimal action* or *selfish action*. Again, when the CR's goal is practically implemented, numbers with the radio's observed outcome, p_l, need to be associated. The detailed description is beyond the scope of this chapter.

2.5 Architecture of CR Network

The whole framework of CR is generally a mapping from spectrum sensing to spectrum utilization. CR inspects the available networks and communication systems which are in its immediate vicinity. A CR network is composed of various types of communication systems and networks. Consequently, the whole configuration can be regarded as networks characterized by heterogeneity. This is apparent in every single component of a CR's network. It includes the service providers, user terminals, etc. [10]. The true objective behind the design of cognitive radio network (CRN) architecture is to make optimal utility of network, which overshadows its other prime target of linking spectral efficiency. When we use network utilization, we actually mean that the users can complete their demand regardless of their location and time. Similarly, from the operator's viewpoint, it provides the operators a platform to provide maximal packets per bandwidth efficiently. There are several ways in which CRN can be framed. To name two, distributed and ad hoc are some of the significant ones. They actually contain licensed and unlicensed applications.

2.6 Conclusion and Future Directions

In this chapter, we provide a basic review of CRNs. Outlining the properties of CR, we have documented the fundamentals related to the CR transceiver and its functioning. Moreover, the general model of CR has also been presented. Although so far CR has come a long way since its invention, there are still some hurdles which need to be overcome. For an effective CR, better rates among transceivers are stressed, which necessitates incapacitating many practical engineering aspects. For example, an efficient coding scheme is of major importance. Another future direction for effective implementation is scaling this behavior to large networks. In a given network with cognitive nodes, one important aspect is to find the extent of collaboration among them for efficient distribution of their respective messages.

Acknowledgments

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