Chapter 1
Introduction to Cognitive Radio Networks: Communication Protocols and Security Issues

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ABSTRACT
A cognitive radio (CR) is a radio that can change its transmission parameters based on the perceived availability of the spectrum bands in its operating environment. CRs support dynamic spectrum access and can facilitate a secondary unlicensed user to efficiently utilize the available underutilized spectrum allocated to the primary licensed users. A cognitive radio network (CRN) is composed of both the secondary users with CR-enabled radios and the primary users whose radios need not be CR-enabled. In this chapter, the authors provide an exhaustive analysis of the issues and the state-of-the-art literature solutions available with regards to the following four layers of the TCP/IP protocol layer stack, in the context of CRNs: physical layer (spectrum sensing), medium access control, routing, and transport layers. We discuss the various techniques/mechanisms/protocols that have been proposed for each of these four layers, in the context of CRNs. In addition to the above, we discuss in detail several security attacks that could be launched on CRNs and the countermeasure solutions that have been proposed to avoid or mitigate them. This chapter serves as a good comprehensive review and analysis of all the critical aspects for CRNs, and would lay a strong foundation for someone to further delve onto any particular aspect in greater depth.

INTRODUCTION
A cognitive radio is defined as a radio that can change its transmitter parameters based on the interaction with the environment in which it operates (FCC, 2003a). A cognitive radio (CR) has the ability (cognitive capability) to sense and gather information (such as the transmission frequency, bandwidth, power, modulation, etc) from the surrounding environment (FCC, 2002) as well as has the ability (reconfigurability) to swiftly adapt the operational parameters, for optimal performance, according to the information sensed (Haykin, 2005). With the above features, the cognitive radio technology is being perceived as the key enabling technology for the next generation dynamic spectrum access networks that can efficiently utilize...
the available underutilized spectrum allocated by the Federal Communications Commission (FCC) to licensed holders, known as primary users. Cognitive radios facilitate a more flexible and comprehensive use of the limited and underutilized spectrum (Akyildiz et al., 2006) for the secondary users, who have no spectrum licenses.

Cognitive radios enable the usage of temporally unused spectrum, referred to as spectrum hole or white space (Haykin, 2005), and if a primary user intends to use this band, then the secondary user should seamlessly move to another spectrum hole or stay in the same band, altering its transmission power level or modulation scheme to avoid interfering with the primary user. Traditional spectrum allocation schemes (Han & Liu, 2008) and spectrum access protocols may no longer be applicable when secondary unlicensed users coexist with primary licensed users. If secondary users are allowed to transmit data along with primary users, the transmissions should not interfere with each other beyond a threshold. On the other hand, if secondary users can transmit only in the absence of primary users, then a secondary user transmitting data in the absence of a primary user should be able to detect the reappearance of the primary user and vacate the band. There is a significant amount of research currently being conducted and more need to be performed to develop new spectrum management approaches related to cognitive radio for both spectrum sensing and dynamic spectrum sharing.

A cognitive radio network architecture (Figure 2) includes components corresponding to both the secondary users (secondary network) and the primary users (primary network). The secondary network is composed of a set of secondary users with or without a secondary base station, all of which are equipped with CR functions. A secondary network with a base station is referred to as the infrastructure-based CR network; the base station acts as a hub collecting the observations and results of spectrum analysis performed by each CR secondary user and deciding on how to avoid interference with the primary networks. As per this decision, each CR secondary user reconfigures his communication parameters. A secondary network without a base station is referred to as the infrastructure less–cognitive radio ad hoc network (CRAHN). In a CRAHN, the CR secondary users employ cooperation schemes to exchange locally observed information among the devices to broaden their knowledge on the entire network, and decide on their actions based on this perceived global knowledge. A primary network comprises of primary users and one or more primary base stations, all of which are in general not equipped with CR functions. Hence, if a secondary network shares a licensed spectrum band with a primary network, the secondary network is required to be able detect the presence of a primary user and direct the secondary transmission to another available band that will not interfere with the primary transmission. Figure 1 illustrates the opportunistic access of the spectrum white space and switching of the frequency bands by a CR secondary user at the incidence of use by a primary user. Figure 2 illustrates cognitive radio network architecture with both the primary user network and the secondary user network (with and without infrastructure–base station support).

The current spectrum allocation and sharing schemes according to three criteria: (1) Spectrum

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**Figure 1. Spectrum usage: opportunistic access of spectrum white space and channel switching by a cognitive radio user**

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