Chapter 12
Cross-Layer Design for Cognitive Radio Networks

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ABSTRACT

Nowadays, due to the tremendous growth of wireless communications technologies and multimedia applications, the radio spectrum is starting to be crowded and scarce to meet the continuous growth of frequency requirements. Additionally, interference management is one of the key issues in wireless networks. Therefore, network solutions and evolutions have crucial challenges to overcome the inefficiency in configuring and managing network resources. To optimize wireless network operations and spectrum scarcity, a new networking paradigm, known as cognitive radio networks (CRNs), has been introduced. Due to the limited capabilities of the conventional layered protocol, CRNs adjust layer parameters adaptively according to the spectrum environment and Quality of Service (QoS) requirements. Hence, cross-layer design (CLD) solutions were necessary to allow for improving and optimizing CRNs performance. This chapter provides an extensive and exclusive overview of cognitive networks, CLD methodologies and properties, and cross-layer optimization (CLO) schemes among different layers. Moreover, it presents possible research solutions for cognitive networking. Finally, indispensable highlights of future work research directions are provided.

12.1 INTRODUCTION

Cognitive Radio Networks (CRNs) have gained importance in recent years. Addressing the issues of CRNs is a challenging task. The purpose of this chapter is to provide an overview of the key issues that face CRNs and the suggested solutions by researchers. Additionally, this chapter presents possible research avenues that can be explored by researcher in the area of CRNs.

The Cognitive Radio (CR) technology addresses a very important fact in wireless commu-

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nications which is the scarcity of the frequency spectrum. The huge demand for frequency bands and the expected growth in wireless technologies required attention to how to utilize the limited frequency spectrum. The CR technology presents a promising solution for spectrum scarcity issues as it provides the capability to share the wireless spectrum with licensed users in an opportunistic manner (Akyildiz; Lee; Vuran; & Shantidev, 2008). Therefore, the CR technology concentrates on what's called "spectrum holes" utilization without interfering with *primary users* (PUs) signals (Reddy & Bullmaster, 2008). These "holes" are parts of the frequency spectrum that are underutilized. The CR mode searches for these "spectrum holes" and selects the best channel to use for communicating with other CR nodes. While the CRN nodes are responsible for the coordination among each other on how to access the selected communication channel, they must pay close attention to PUs' needs and presence. Once the PUs are detected, CRNs must free the selected channel.

Designing efficient CRNs is challenging due to the fact that the secondary users (SUs) are required not to interfere with the PUs. Hence, interference management is a key issue in CRN design. Additionally, whenever multimedia services are part of the traffic, *Quality of Service* (QoS) guarantees are challenging issues (Liu & Zhou, 2009). Since CRNs are wireless by nature, the conventional layered protocol architectures, such as the Open system Interconnection (OSI) and TCP/IP, don't address all the design aspects of the wireless medium of communication. Layered architectures were initially designed for wired networking environments; therefore, they are not completely ready to combat all the characteristics of the wireless environment.

To avoid the rigidity of the layered architectures, cross-layered architectures have become the suitable frameworks for CRNs (Reddy & Bullmaster, 2008; Liu & Zhou, 2009; Foukalas, Gazis, & Alonistioti, 2008; Shakkottai, Rappaport, & Karlsson, 2003). Cross-layer design (CLD) provides an adaptive framework which is aware of the working conditions of wireless networks. Consequently, the CLD provides a new and promising design paradigm which is responsive to wireless network variations (Foukalas et al., 2008; Shakkottai et al., 2003). The CLD is meant to improve the performance of wireless networks, in general, CRNs in particular.

The thrust of this chapter is to provide an overview of the usage of CLD in CRNs. The chapter is divided into six sections. The second section presents the background information. The third section discusses the focus topics in details. The fourth section is the solutions section. The fifth section presents future research directions. Finally, the chapter is concluded.

12.2 BACKGROUND

The recent development in radio communications and mobile computing provides several technologies for wireless connectivity where, different wireless network standards have appeared such as *wireless local area networks* (IEEE 802.11b or HiperLAN), *wireless wide area networks* (WiMax and UMTS) (Baldo & Zorzi, 2008a). The deployment of wireless networks can be in two modes: *infrastructure-based mode* in which access point links the nodes to the wired network and *infrastructureless-based* or *ad hoc* mode. *Mobile ad hoc networks* (MANETs) consist of wireless mobile nodes without reliance on fixed base stations or wired infrastructures (Ayyash, Ucci, & Alzoubi, 2010).

A wireless ad hoc network is a complex distributed system which consists of a collection of wireless mobile or static nodes that can dynamically self-organize into an arbitrary and temporary topology to form a network without necessarily using any pre-existing infrastructure (Al Hanbali, Altman, & Nain, 2005). Therefore, wireless ad hoc