Chapter 5
Cross-Layer Design in Cognitive Radio Systems

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ABSTRACT

The main functionalities of a cognitive radio system, to ensure efficient operation of the primary users without harmful intervention from the secondary users and to simultaneously satisfy the requirements of the secondary users, are spectrum sensing, spectrum management, spectrum mobility, and spectrum management. These functions involve more than one layer of protocol stack rather than being performed at a single layer. This chapter briefly revisits these functions from the perspective of classification of the roles of different communication network layers in carrying out these functions. An exhaustive study is then presented of the key properties of cross-layer design applications in cognitive radio systems by taking examples from the existing literature and highlighting some open challenges and new opportunities. A cross-layer design example for interference-limited spectrum sharing systems is discussed in detail, which considers the parameters from the Physical Layer (PHY) and the Data Link Layer (DLL) in order to maximize the overall spectral efficiency of the Secondary User (SU). The numerical results show that the secondary link of spectrum sharing systems combining ARQ with adaptive modulation and coding achieves significant gain in throughput depending on the maximum number of retransmissions.

INTRODUCTION

The long familiar and widely referred Open Systems Interconnection (OSI) model is based on the hierarchical abstraction of various features of data communication networks. It organizes the network in certain number of layers (7 layers in the original OSI model), each layer performing a well-defined function to offer services to the higher layers without revealing the details of how the service was implemented. Although the traditional layered approach enjoys the benefits

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of modularity, standardization, and expansibility, its rigid and strict architecture makes the layered structure inefficient to solve the problems related to wireless networks (the protocol stack was defined for wired networks). The boundary between different layers of network is blurring day by day because of evolution of the wireless networks, and rising demand of QoS satisfaction.

Cross-layer design, when it comes to Cognitive Radio (CR) systems, becomes even more trickier, because of the inherent characteristics (or required features) of observing, learning, reasoning, and adaptation (Rashid, 2009). A CR user needs to take into account several input sources at the same time including its own past observations as a result of learning property. Furthermore, a CR needs to consider a number of factors simultaneously such as application preferences of the Secondary Users (SU)s, several constraints such as interference limit to the Primary Users (PU)s and sensing capabilities, and its own capabilities to exploit the available primary spectrum and the channel conditions. Reaching to an optimal solution by merging all the requirements, constraints, and limitations into a single problem needs an adaptation and compromise covering multiple layers (Qing Zhao, 2007; Le & Hossain, 2008; Zhao & Sadler, 2007; Foukalas, et al., 2008; Foukalas, Gazis, & Alonistioti).

The main functionalities of a CR to ensure the efficient operation of the primary users without harmful intervention from the Secondary Users (SU) and simultaneously satisfying the requirements of the SUs are spectrum sensing, spectrum management, spectrum mobility, and spectrum sharing. These functions are inter-dependent and involve more than one layer of protocol stack rather than being performed at a single layer. The capacity of AWGN channels under received power constraints at the primary receiver for different scenarios including relay networks, multiple access channels with dependent sources and feedback, and collaborative communication, was analyzed in Gastpar (2004). The authors in Musavian and Aissa (2009a) derived capacity and optimum power-allocation schemes for different capacity metrics, e.g. ergodic, outage, and minimum-rate in Rayleigh fading channels under average and peak received-power constraints at the primary's receiver. Spectrum sharing systems with an additional statistical delay QoS constraint as well as interference-power constraint at the primary receiver were studied in Musavian and Aissa (2009b). The authors determined the maximal possible arrival rate supported by the secondary user's link under aforementioned constraints. Where majority of the available CR cross-layer literature focuses on joint optimization of the Physical Layer (PHY) and link (or MAC) layer (for example Digham, 2008; Vu et al., 2007; Bansal, 2008), interactions with higher layers have recently been subject of many works. Advantages of coordination between PHY and Network layer were analyzed in Xin et al. (2005), Wu and Tsang (2009), Yang and Wang (2008), and Shi et al. (2010). Whereas joint design of PHY- Data Link layer-TCP was presented in Luo et al. (2010a), in order to maximize TCP throughput. However, from user's viewpoint, QoS at the application layer is more important than that at the other layers. The improvement in performance using cross-layer design which considers application layer QoS, has been witnessed in Khan et al. (2006), Bobarshad et al. (2010), and references therein for non-CR systems. Recently application-layer QoS has captured attention in CR cross-layer research and few works including Luo et al. (2010b), Ali and Yu (2009), Luo et al. (2009), and Hu et al. (2010) have dealt with this.

This chapter describes the key properties of cross-layer design applications in CR systems. Furthermore, a new cross-layer design strategy for the systems employing spectrum underlay access technique is explained in detail. It is organized as follows. Section 2 revisits the main functionalities of CR: spectrum sensing, spectrum management, spectrum mobility, and spectrum sharing, by outlining the role played by different network layers