Chapter 2
Large Scale Cognitive Wireless Networks:
Architecture and Application

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ABSTRACT

Cognitive radio has been proposed to have spectrum agility (or opportunistic spectrum access). In this chapter, the authors introduce the extended network architecture of cognitive radio network, which accesses not only spectrum resource but also wireless stations (networking nodes) and high-level application data opportunistically: the large-scale cognitive wireless networks. The developed network architecture is based upon a re-definition of wireless linkage: as functional abstraction of proximity communications among wireless stations. The operation spectrum and participating stations of such abstract wireless links are opportunistically decided based on their instantaneous availability. It is able to maximize wireless network resource utilization and achieve much higher performance in large-scale wireless networks, where the networking environment can change fast (usually in millisecond level) in terms of spectrum and wireless station availability. The authors further introduce opportunistic routing and opportunistic data aggregation under the developed network architecture, which results in an implementation of cognitive unicast and cognitive data-aggregation wireless-link modules. In both works, it is shown that network performance and energy efficiency can improve with network scale (such as including station density). The applications of large-scale cognitive wireless networks are further discussed in new (and smart) beyond-3G wireless infrastructures, including for example real-time wireless sensor networks, indoor/underground wireless tracking networks, broadband wireless networks, smart grid and utility networks, smart vehicular networks, and emergency networks. In all such applications, the cognitive wireless networks can provide the most cost-effective wireless bandwidth and the best energy efficiency.

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INTRODUCTION

Modular design and well-defined architecture have played an important role in many engineering success. In the world of communications and networking, the fundamentals of Open System Interconnection (OSI) architecture have defined multiple hierarchy layers in the communication protocol stack, which provide abstracts of network functionalities and hide implementation complexity. Among these hierarchy layers, the physical layer defines the waveform being transmitted in the communication medium and the conversion of information (modulation/demodulation). The data-link layer, including Medium Access Control (MAC) sub-layer, provides the abstraction of communication channel where information is transmitted. The network layer routes the communication across the network, and the transport layer defines an end-to-end tunnel to hide the network complexity from higher layers. In cable and computer networks, the definition of these layers has been quite appropriate, since 1) it converts complicated system into simplified modules (layers); 2) methods developed for particular module will benefit overall system as well; 3) modifications on a single module will not need a system re-design. The related success stories include the telephone networks and the Internet.

When wireless communications and networking are being considered, engineering efforts have been trying to adapt the hierarchy layers, for the communication protocol stack to work appropriately in wireless medium. For example, in the physical layer, digital communications have defined mechanisms to modulate (demodulate) digital sequence onto (from) a carrier frequency as mapped in the radio spectrum. The MAC layer is developed to set up point-to-point wireless linkage over wireless medium, with predetermined spectrum (or wireless channel) allocation. A network topology can then be determined, where the network layer implements routing protocols to further set up end-to-end communications.

This adaptation can be appropriate only when the network resource availability can be predetermined, including such as radio spectrum and wireless station. In addition, a "virtual wired" network topology shall be set up, with wireless links as "virtual lines" and wireless stations as "virtual dots." In engineering practices, it has limited most real-world wireless networks to a star-topology, or to the very last hop. In a star-topology, the predetermined spectrum allocation is feasible to avoid intra-network interference as introduced by the broadcasting nature of wireless medium; and predetermined wireless station availability can be realized by having the base-station (or point coordinator) to coordinate access terminals. The related success stories in wireless communications include such as cellular networks and Wireless Local Area Networks (WLAN).

However, the methodology above has also made large-scale wireless infrastructure very expensive to build and maintain; and radio spectrum becomes a scarce resource. For example, in cellular networks, operators need to acquire spectrum license to prevent other networks using the same spectrum and offer the required Quality of Service (QoS). The cellular base-stations shall also be installed on towers to provide necessary coverage; and network cable/fiber is needed for every base-station to provide connection to backbone networks. In WLAN, although unlicensed spectrum is utilized, setting up multiple access points to provide sufficient coverage and bandwidth is usually a challenging and costly task in municipal and enterprise applications, due to spectrum planning and device installation costs.

In beyond 3G smart infrastructures, most applications require cost-effective wireless bandwidth and energy efficiency (green communications) that current wireless networks cannot support. In this chapter, we introduce the architecture and application of large-scale cognitive wireless networks that differentiate from traditional wireless networks. Instead of depending on predetermined spectrum allocation and wireless stations,