Chapter 12
Cross-Layer Design in Cognitive Radio Networks

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ABSTRACT

Radio spectrum has become a precious resource. Most frequency bands have been allocated for exclusive use in the US. However, studies have shown that a very large portion of the radio spectrum is unused or underused for long periods of time at a given geographic location. Therefore, allowing users without a license to operate in licensed bands while causing no interference to the license holder becomes a promising way to satisfy the fast growing need for spectrum resources. Dynamic spectrum access and cognitive radio are technologies for enabling opportunistic spectrum access and enhancing the efficiency and utilization of the spectrum. A cognitive radio adapts to the environment in which it operates by sensing the spectrum and then opportunistically exploiting unused and/or underused frequency bands in order to achieve certain performance goals. Due to the close coupling and interaction among protocol layers, the optimal design of opportunistic spectrum access and cognitive radio networks calls for a cross-layer approach that integrates signal processing and networking with regulatory policy making. This chapter introduces basic concepts, design issues involved, and some recent development in this emerging technological field. Future research directions are also briefly examined.

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INTRODUCTION

Today's spectrum usage follows a long-standing fixed allocation policy. The spectrum use is regulated by government agencies. Spectrum segments are licensed to users for exclusive use in specific geographic areas. In the United States, the authority for radio spectrum regulation is the Federal Communications Commission (FCC) for commercial applications (FCC, 2003). The past decades have witnessed several trends: wireless devices are getting smaller, data transfer rates are increasing, and wireless applications become more and more popular. With the booming wireless systems and applications, only a few small unlicensed bands are left open for anyone to use as long as certain power regulations are followed. As more devices such as laptops, cell phones, wireless sensors, and radio frequency ID go wireless, they must share a finite and overly crowded radio spectrum. As a result, these unlicensed bands have become crowded with everything from wireless networks to digital cordless phones. Radio spectrum over-crowding resulting in congestion is a problem concerning both commercial and military applications alike. Decreasing electromagnetic spectrum availability is a fact facing today's wireless communication as more wireless transmissions and applications are being deployed and envisioned, and the available contiguous spectrum becomes narrower.

On the other hand, current rigid spectrum control policies have resulted in severe spectrum under-utilization. As shown in Figure 1 (FCC Spectrum Policy Task Force, 2002), some frequency bands are largely unused most of the time and some other frequency bands are only seldom used. FCC measurements show that occupancy of approximately 700 MHz of spectrum below 1 GHz is less than 6-10% (FCC Spectrum Policy Task Force, 2002). A field spectrum measurement taken in New York City has also shown that the maximum total spectrum occupancy is only 13.1% from 30 MHz to 3 GHz frequency band (McHenry, 2005). Moreover, studies have shown that the spectrum usage varies significantly in time, frequency, and geographic locations. Meanwhile, a 20 MHz frequency band fetches multi-billion dollars in European 3G spectrum auction. In November 2002, the FCC released a report generated by the Spectrum Policy Task Force that reshaped the traditional models of spectrum allocation and control. As a result, allowing users without a license to operate in licensed bands while causing no interference to the license holder becomes a promising way to satisfy the fast growing need for spectrum resources.

Dynamic spectrum access and cognitive radio are technologies for enabling opportunistic spectrum access and enhancing the efficiency and utilization of the spectrum (Wyglinski, Nekovee, & Hou, 2010). A cognitive radio adapts to the environment in which it operates by sensing the spectrum and then opportunistic exploiting unused and/or underused frequency bands in order to achieve certain performance goals (Steenstrup, 2005; Akyildiz, et al., 2006). Using these technologies, the next generation communication system may adaptively detect the existence of unused and/or underused spectrum bands and intelligently exploit these potentially non-contiguous spectrum opportunities to improve the network performance in a complex and possibly hostile environment, e.g., military Mobile Ad-Hoc Networks (MANETs) such as Soldier Radio Waveform (SRW).

Due to close coupling and interaction among protocol layers, the optimal design of opportunistic spectrum access and cognitive radio networks calls for a cross-layer approach that integrates signal processing and networking with regulatory policy making. For instance, power control directly affects the receiving power at a destination node (signal power) and at other nodes (interference power), therefore profoundly influencing the interference relationship among the nodes and on spectrum sensing and access.