Chapter 34

Competitive Spectrum Pricing under Centralized Dynamic Spectrum Allocation

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ABSTRACT

Dynamic Spectrum Allocation (DSA) has been viewed as a promising approach to improving spectrum efficiency. With DSA, Wireless Service Providers (WSPs) that operate in fixed spectrum bands allocated through static allocation can solve their short-term spectrum shortage problems resulting from the bursty nature of wireless traffic. Such DSA mechanisms should be coupled with dynamic pricing schemes to achieve the most efficient allocation. This chapter models the DSA problem where a centralized spectrum broker manages “white space” in the spectrum of TV broadcasters and sells the vacant spectrum bands to multiple WSPs, as a multi-stage non-cooperative dynamic game. Furthermore, an economic framework for DSA is presented and a centralized spectrum allocation mechanism is proposed. The simulation results show that the centralized spectrum allocation mechanism with dynamic pricing achieves a DSA implementation that is responsive to market conditions as well as enabling efficient utilization of the available spectrum.

INTRODUCTION

Currently, the radio spectrum is regulated by governmental authorities (e.g. FCC in USA or ICASA in South Africa) under the “command-and-control” spectrum management policy, in which radio spectrum is statically allocated to license operators over large geographical areas on a long term basis (years or even decades) along with rigid specification of the usage parameters (e.g. power, geographical scope)
strictly for specific purposes (e.g. broadcast radio/TV, cellular services, wireless LAN). License operators get exclusive access to some specific spectrum bands which are licensed to them. The advantage of such a static spectrum allocation approach is that the interference between neighboring systems is successfully and completely avoided.

However, with the spectrum utilization in cellular or other wireless networks varying spatially and temporally, the static allocation of spectrum exhibits certain limitations. It has been observed that the perceived scarcity of radio spectrum is mainly due to the inefficiency of static spectrum allocation policies (FCC Spectrum Policy Task Force, 2002). Spectrum occupancy measurements showed that temporal and geographical variations in the utilization of the licensed spectrum range from 15% to 85%, and that a large portion of licensed spectrum is severely under-utilized, e.g. over 60% of the licensed spectrum below 6 GHz remains unused or substantially underutilized (FCC Spectrum Policy Task Force, 2002). In addition, spectrum utilization measurements of 30 frequency bands from 30MHz to 2.9GHz showed that average spectrum occupancy was estimated to be no more than 17.4% while occupancy varies from less than 1% to 70.9% in densely populated cities such as Chicago (McHenry, McCloskey, Roberson, & MacDonald, 2005). The long-term command-and-control model of spectrum allocation not only results in under-utilization of spectrum for protracted periods of time in areas of low demand but also leads to slow network infrastructure and service deployments (Subramanian, Gupta, Das, & Buddhikot, 2007).

With the growth of wireless communications that resulted from the dramatic proliferation in the use of different wireless network technologies, such as cellular networks, WiFi, WiMAX, etc. as well as an increasing deployment of wireless applications with increasing bandwidth requirements, wireless networks require significantly more spectrum to accommodate the increasing demand for bandwidth of users. Under static spectrum allocation, which is very long-term and space-time invariant, if there is a higher demand for spectrum from the users than their statically allocated spectrum, wireless network operators are not able to purchase extra spectrum for a short period of time even if they are willing to pay for it.

Thus, to overcome this artificial spectrum scarcity and under-utilization dilemma, new communication techniques – Cognitive Radio (CR) and Dynamic Spectrum Sharing (DSS) have been introduced. The development of CR technologies in DSS has been viewed as an alternative to the traditional static spectrum management policy to improve inefficient static spectrum utilization by allowing unlicensed wireless networks (or users) to dynamically access the so-called “white spaces” in the spectrum owned by legacy spectrum holders based on short-term leasing agreements.

In general, DSS can be categorized into three types (Buddhikot, 2007): the commons-use model, the shared-use model of the primary licensed spectrum, and the exclusive-use model. The latter two models have been intensively studied because they are compatible with the current spectrum management policies and legacy wireless systems. An example of their applications is IEEE 802.22-based wireless regional area network (WRAN) systems (Cordeiro et al., 2005). It has been observed that the radio spectrum allocated to TV broadcasters remains largely unoccupied in many areas. The propagation characteristics of the low frequencies of these TV bands are suitable for long-range transmission. A radio signal will travel 3 times further than traditional WLAN at 2.5GHz, assuming the same transmit power. IEEE 802.22-based wireless regional area network technology is being designed to utilize this spectrum within 54-862 MHz band range using the DSS-based cognitive radio concept. Particularly, the dynamic exclusive-use model maintains the basic structure of the current spectrum regulation policy: the primary users are allowed to dynamically trade and grant the usage right of its licensed spectrum to secondary network operators or secondary users. With the exclusive-use model, since the primary users’ bands will be exclusively
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