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The impact of spectrum policies on the secondary spectrum market: A system dynamics approach

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ABSTRACT

There has been a growing significance for Dynamic Spectrum Access (DSA) technology as a method to relieve the spectrum shortage problem and improve the efficiency of spectrum usage. For DSA technology to provide social and economic benefits, however, the dynamics of the secondary spectrum market must also co-evolve with the technology. Using the system dynamics (SD) methodology, we developed a secondary spectrum market model. The objective of this model is to integrate the SD approach, scenario and simulation analysis into a holistic dynamic consideration of the secondary spectrum market. Drawing on the model, we examined how the secondary spectrum market could evolve in the future and investigated how spectrum policies could influence spectrum utilization in the secondary spectrum market.

1. Introduction

In recent years, demand for spectrum increased dramatically and is expected to grow exponentially. This is partly due to the increasing interest of consumers in wireless services which in turn is driving the evolution of wireless networks toward high-speed data networks. A recent study by Cisco (2016) shows that global mobile data traffic is expected to increase at a compound annual growth rate (CAGR) of 53% from 2015 to 2020, growing to 30.6 exabytes per month by 2020. This study also points out that the increasing number of mobile devices, which is one of the main contributors to global mobile traffic, would reach 11.6 billion by 2020. With the compelling need for wireless data and Internet services, many complain about severe spectrum shortage. However, the Spectrum Policy Task Force (SPTF) within the Federal Communications Commission (FCC) found that many portions of the spectrum are either unused or lightly used for significant periods of time. For instance, spectrum utilization is estimated at best 17% in urban areas and 5% elsewhere (Berggren et al., 2004; ABI Research, 2007). These findings suggest that spectrum scarcity is largely due to the inefficient utilization of spectrum rather than the physical shortage of spectrum. Given the spectrum shortage and the underutilized spectrum, wireless spectrum specialists and spectrum policy makers are looking for solutions that would exploit the existing wireless spectrum opportunistically (Ballon, Lehr, & Delare, 2013).

DSA technology has been proposed as a promising approach to improve the efficiency of spectrum usage by creating assigned, but sparsely used, frequency bands to secondary users while protecting the rights of the incumbent holders (Krenik, Wyglinski, & Doyle, 2007). With this technology, primary users can share spectrum with secondary users in the secondary spectrum market, resulting in relieving the spectrum shortage problem. While the advances of DSA technology can make more efficient spectrum usage possible, there still exists uncertainty over how this technology would integrate into the spectrum market and what would be barriers to its

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successful introduction. Due to technical, economic and regulatory challenges, in fact, DSA technology has not been successfully introduced into the spectrum market (Ballon et al., 2013; Casey, 2009). For DSA technology to provide social and economic benefits, it is important to understand the underlying dynamics of the secondary spectrum market as well as the technology itself.

Despite the growing interest in DSA technology, few studies have examined the dynamics of the secondary spectrum market (Zhu, Niyato, Wang, & Han, 2012). Since there are active interactions among technological, economic, and regulatory factors in this market, some studies acknowledge the need to analyze the spectrum market as a complex system with the system dynamics (SD) methodology (Casey, 2009; Sridhar, Casey, & Hämmäinen, 2012). SD is an interdisciplinary approach that is based on the theories of linear/nonlinear dynamics and feedback control (Sterman, 2000) and is used to represent complex systems by analyzing their dynamic behavior over time (Forrester, 1994). Recently, SD has been applied to the mobile communications context both for examining market development (Jain & Sridhar, 2003; Pagani & Fine, 2008) and regulatory policy (Casey & Toyli, 2012). While some studies used SD methodology to analyze the spectrum market (Basaure, Sridhar, & Hämmäinen, 2016; Casey, 2009), few studies investigated the dynamic relationship among technological, economic, and governmental variables. Thus, the compelling purpose of this study is to fill this gap by applying the SD methodology to the analysis of multidimensional nature of the secondary spectrum market. Based on the SD model of the secondary spectrum market, this study also conducted scenario and simulation analysis to investigate the impact of government spectrum policies on spectrum utilization.

This research made two major contributions. First, this study provides a holistic modeling approach to the secondary spectrum market, in order to disclose the functions of its variables and the mechanisms which increase the efficiency of spectrum usage. The modeling approach in this study is based on SD theory and constitutes a tool for the analysis of relations between variables of interest in the secondary spectrum market. Second, this study investigates the impact of spectrum policies on spectrum utilization. In particular, we used the developed SD model to conduct scenario and simulation analysis, which aims to investigate how spectrum policies influence spectrum utilization in the secondary spectrum market. Results of this study show the dynamic structure of the secondary spectrum market and reveal insights for spectrum utilization.

The rest of the paper is organized as follows. In Section 2, we present a literature review of the spectrum market and system dynamics methodology. Section 3 describes the causal loop diagram and the stock and flow diagram of the secondary spectrum market. Section 4 provides the results of the simulation. In Section 5, we discuss contributions and limitations of this study.

2. Literature review

2.1. Spectrum market

Spectrum is an important yet finite resource in the wireless service industry. It is one of the most difficult and costly procedures to acquire a spectrum license and develop any new wireless service. Traditionally, spectrum assignments have been allocated by regulators in a centralized, static way. For instance, firms can buy long-term spectrum contracts covering very large geographic regions. Due to the large amount of capital required, only a few firms can participate in this type of static spectrum allocation. Moreover, many spectrum ranges assigned to those few buyers are not being utilized at a particular time and specific geographic location (D'Itri & McHenry, 2008; Islam et al., 2008). Organizations such as the FCC are recognizing that traditional spectrum allocation is inefficient in terms of spectrum usage and there is abundant opportunity for underutilized spectrum within licensed bands to be exploited by unlicensed right holders (FCC, 2000; FCC,2003).

In the spectrum market, there are two types of spectrum right holders. First, a primary user is an entity who owns spectrum access rights without any interference. In most cases, a single user acquires these spectrum access rights. Second, there is a secondary user who wants to access portions of the spectrum without interfering any primary users. DSA technology has been proposed as a solution to alleviate the spectrum scarcity, where secondary users temporarily "borrow" frequency bands from primary spectrum holders without interrupting the rights of the existing license holders. IEEE 1900.1 defines DSA as "a technique by which a radio system dynamically adapts to select operating spectrum space to use available (in local time-frequency space) spectrum holes with limited spectrum use rights." In addition, cognitive radio (CR) technology has been identified as an enabling key technology for DSA networks, where the unlicensed device can be easily rearranged to the changing requirements and conditions of the transmission environment. IEEE 1900.1 defines CR as "a radio in which communication systems are aware of their environment and internal state and can make decisions about their radio operating behavior based on that information and predefined objectives." The advances of CR technology facilitates more efficient and intensive use of spectrum (Ji & Liu, 2007).

DSA technology has the potential to change the existing spectrum market significantly in two major ways (Chapin and Lehr, 2007). Firstly, DSA technology creates the active secondary spectrum market where spectrum can be traded between primary and secondary users. Due to the efficient wireless technologies, Mayo and Wallsten (2010) found that spectrum trading in the secondary market has significantly increased in the US. The secondary spectrum market has its uniqueness which differs from the primary spectrum market. While regulators allocate spectrum to primary users through long-term spectrum leases in the primary spectrum market, the spectrum can be traded among secondary users through short-term leases in the secondary spectrum market. Since primary right holders need not to vacate a band before offering access rights to someone else, they are likely to open up underutilized spectrum, and provide a competitive spectrum price and size of the spectrum to secondary users who can take advantage of spectrum opportunities. In this secondary spectrum market, service providers and spectrum brokers act as intermediaries, playing key roles to exploit primary users' underutilized spectrum (Zhu et al., 2012). For example, spectrum brokers first announce the availability of spectrum in the market. Then, service providers lease available spectrum from spectrum brokers and provide service to the secondary spectrum users. In this case, the success of spectrum trading depends on the demand of secondary providers and the