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Risk and decision analysis of dynamic spectrum access

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ABSTRACT

Considerable research and policy development work has been conducted to construct methods and frameworks for ever denser sharing of radio spectrum. Since spectrum sharing necessarily constitutes a rearrangement of rights among stakeholders, considerable focus has been on examining the risks and incentives for license holders. But for spectrum sharing to be successful, it is critical to consider the incentives and risk for the entrants as well. This problem is challenging because the entrants are emergent entities that often do not participate in the policy or research debates. Because of this diversity, it is difficult to consider incentives, so this paper focuses instead on the risks faced by spectrum entrants and their mitigation. With clear understanding of risk and mitigation strategies associated, spectrum entrants can choose the method that maximize their utilities.

1. Introduction

The ultimate goal for spectrum sharing is to allow various applications to operate on different frequency bands and heterogeneous infrastructures. It is an *ex post* strategy to assign spectrum on demand. Users would have the opportunity to negotiate spectrum sharing etiquette and achieve expected Quality of Services (QoS). Spectrum sharing is necessary to address the inefficiency of *ex ante* spectrum assignment, due to technology innovation and demands change. In the non-federal spectrum domain, the Federal Communications Commission (FCC) has two broad *ex ante* spectrum management approaches: the issuance of exclusive use licenses and open access for unlicensed bands. In the licensed approach, a fixed amount of spectrum is assigned to wireless service providers through auctions or administrative action for a certain technology, application and specific period of time. The dominant challenge for licensed bands is that the rapid proliferation of various forms of mobile devices, coupled with the expansion of wireless Internet services, made it impossible to allocate enough spectrum to new entrants and incumbents[1] (Commission, 2002). This spectrum scarcity situation is a spectrum access problem rather than full usage problem (Flood Ben & Forde, 2007); in other words, the spectrum is not fully utilized but cannot be accessed due to the regulation. On the other hand, the unlicensed bands allow unlimited number of spectrum access that are governed by technical standards. The main advantage of unlicensed usage is flexibility and the absence of licensing costs. The challenge of unlicensed usage derives from this as well; without the ability to reserve spectrum or coordinate its usage (Weiss, Lehr, Acker, & Gomez, 2015), catastrophic interference among spectrum users may occur.

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[1] In fact, license holders face a tradeoff between investments in spectrum and infrastructure. The amount of attention paid to increasing spectrum resources suggests that this is the cheaper input.

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Although spectrum sharing provides flexibility, certain level of QoS guarantees and improves spectrum utilization efficiency, it has been adopted slowly. Several factors impede spectrum users from sharing spectrum: (1) the quantity of shareable spectrum; (2) cost of accessing spectrum, including both monetary cost and processing time; and (3) risk in spectrum access. In the United States, the FCC and the National Telecommunications and Information Agency (NTIA) have made progress in enlarging the number of shareable spectrum bands. For example, the TV white space (TVWS) is free for unlicensed access, and federal frequency bands, such as 1670 MHz and 3.5 GHz, are under consideration for federal-commercial sharing. Moreover, with database assisted approach, the processing time of authorization is significantly shortened. Additionally, spectrum is allowed to be traded in the secondary spectrum market. When requirements are met, the trading can be approved within 24 h.

Although more spectrum has been made available for sharing and the cost has been reduced, spectrum access risks still exist. These risks are a significant barrier to the adoption of spectrum sharing, in part because both Primary Users (PUs) and Secondary Users (SUs) will not share spectrum when future conditions are difficult to predict. These spectrum access risks include but are not limited to monetary risks, competition risks, and environment risk. Furthermore, risks change with spectrum usage method and frequency bands. In addition, like any engineering investment, spectrum sharing is a decision making process for spectrum users. They only share the spectrum when it is profitable to do so. Consequently, minimizing risks and understanding spectrum users' incentives in spectrum sharing are essential to fulfill the great potential of spectrum sharing. PUs' risks and incentive in spectrum sharing have been analyzed by Peha and Panichpapiboon (2004). Minimizing risks for SUs are equally important, since they are the demand side of spectrum sharing. However, research is scarce on this topic.

In order to promote spectrum sharing from a radical approach to commercial reality, this paper aims at examining the risks for SUs from several perspectives. First, it quantifies spectrum access risks for different DSA methods. Second, it assists SUs making informed decisions considering their incentives (decision criteria), limitations, and risks. The outcome of this paper will assist spectrum entrants in selecting the most appropriate spectrum usage model given their situations. It will also help understanding the potential problems for each spectrum sharing method. Therefore, policy makers, operators, and the spectrum market could create interventions in order to obtain the favorable outcomes.

The rest of the paper is organized as follows. Section 2 provides an overview of the decision model for a spectrum entrant that want to choose a spectrum usage method in order to minimize future risks. Section 3 illustrates different spectrum usage methods and risks that each spectrum usage method may encounter during the life cycle of investigation. It further quantifies the risks based on the expected value and required value. Consequently, determining the expected value is the focus of risk calculation. Since we only analyze QoS risks in terms of throughput and monetary risks with respect to profits, Section 4 and 5 model expected throughput and monetary gains. Risks may not necessarily lead to system and business failure, since active management can mitigate risks. Section 6 is numerical results, which begins with an executive summery that concludes interesting and important observations. The last section is conclusion and future research directions.

2. Background on spectrum usage risks

2.1. Spectrum usage methods

In dynamic sharing, spectrum access opportunities are not reserved for spectrum entrants. Moreover, there is no explicit cooperation requirements among SUs and between PUs and SUs. When SUs operate in the licensed bands, they can only transmit when PUs are absent and vacate the spectrum upon PUs arrival. Three types of dynamic sharing will be investigated in this paper: Cognitive Radio (CR) based DSA, unlicensed usage in TV White Space (TVWS), and WiFi usage in ISM bands.

Cognitive radios sense the spectrum utilization environment and then make transmission decisions based on their goals and limitations. Transmitters and receivers are configured accordingly to optimize the communication. The full realization of CR based DSA will take place on both licensed and unlicensed bands, we only focus on CR based DSA in licensed bands in this paper. Further, it is assumed that CR based DSA can use the same transmission parameters as determined in the PUs' license terms. In other words, the transmission power is much higher than unlicensed usage in TVWS and ISM bands, which gives a larger communication range.

TVWS are frequencies made available by the FCC for unlicensed usage at locations where the spectrum is not being utilized by licensed users such as TV broadcasters and microphones. It includes frequency bands in the VHF (54–216 MHz) and UHF (270–698 MHz).

WiFi is a IEEE 802.11 standard focuses on 2.4 GHz and 5 GHz ISM bands. We only focus on 2.4 GHz in this paper. Spectrum users in TVWS and ISM bands need to follow FCC determined transmission parameters including maximum transmission power, maximum equivalent isotropically radiated power, antenna gain, etc, which limit the communication range.

2.2. Pool of risks

Common risk factors that are faced by every DSA method include but not limited to:

1. Customer demand: when SUs build out infrastructures and start providing services, there are no guarantees on the service demand. Thus, no matter which spectrum usage method that SUs choose, they have risks in demand.
2. Technological risk: the adoption of new technology reduces the demand in legacy technology. For example, when Long Term Evolution (LTE) emerged, cellphones and networks that build for GSM are abandoned.
3. Physical risk: including property loss and damage. In this specific case, physical properties include base stations, transmitters,