Chapter 27

Interference Statistics and Capacity–Outage Analysis in Cognitive Radio Networks

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ABSTRACT

This chapter presents a study on the interference caused by Secondary Users (SUs) due to miss-detection errors and its effects on the capacity-outage performance of the Primary User (PU) in a cognitive radio network assuming Rayleigh and Nakagami fading channels. The effect of beacon transmitter placement on aggregate interference distribution and capacity-outage performance is studied considering two scenarios of beacon transmitter placement: a beacon transmitter located at a PU transmitter or at a PU receiver. Based on the developed statistical models for the interference distribution, closed-form expressions for the capacity-outage probability of the PU are derived to examine the effects of various system parameters on the performance of the PU in the presence of interference from SUs. Furthermore, the model is extended to investigate the cooperative sensing effect on aggregate interference statistical model and capacity-outage performance considering OR (i.e., logical OR operation) and Maximum Likelihood (ML) cooperative detection techniques.

INTRODUCTION

The limitations of current static spectrum management policy drive the idea of a more dynamic and cognitive access policy to improve the efficiency of radio spectrum usage and accommodate the increasing demand for wireless communication applications. Known as the opportunistic spectrum access (OSA), the new paradigm allows cognitive SUs to identify and utilize instantaneous spectrum opportunities in the licensed spectrum, provided that the interference to the licensed PUs is limited (Akyildiz, Lee, Vuran, & Mohanty, 2006; Goldsmith, Jafar, Marie, & Srinivasa, 2009; Haykin, 2005; Mitola, 2000).
In cognitive radio networks with OSA, beacon signaling can be used by the PU in order to facilitate SUs in the detection of spectrum holes. Upon detecting the beacon, SUs will keep silent to avoid interference to the PU. Although the beacon is designed to improve the PU detection performance at each SU, there is a non-zero probability of beacon miss-detection due to noise and channel fading, and in such a case, SU transmission will cause interference to the PU (Buchwald, Kuffner, Ecklund, Brown, & Callaway, 2008; Hulbert, 2005; Yu-Chun, Haiguang, & Zhang, 2009).

The development of cognitive radio networks with OSA has to deal with many technical and practical issues, so that its full potential can be realized. One of the key design issues is sufficiently protecting PUs’ communications from the interference caused by SUs. To be able to support quality-of-service (QoS) requirements for PUs, in this chapter, we present a study on the aggregate interference imposed by SUs to a PU due to miss-detection errors. Moreover, we look into how this interference affects the performance of the PU and how it relates to design parameters. Subsequently, we propose a network-level interference constraint to ensure non-intrusive communications of SUs.

To guarantee a certain level of QoS for PUs, different approaches are considered in the OSA design literature. In (Qianchuan Zhao, Geirhofer, Tong, & Sadler, 2008; Qing Zhao, Tong, Swami, & Chen, 2007), the proposed OSA schemes limit the probability of collision of SUs with PUs. However, the collision probability is not a precise measure to protect PUs since the effects of propagation channel gains from SUs to PUs are not considered. Another proposed approach is to keep the aggregate interference level caused by SUs below a prescribed tolerable threshold for PUs assuming the perfect knowledge of instantaneous channel gains from SU transmitters to PU receivers (Gatsis, Marques, & Giannakis, 2010; Le & Hossain, 2008). However, knowing and tracking the instantaneous channel gains from SU transmitters to PU receivers might be difficult in practice.

Recognizing such practical limitations, in this chapter, we present a statistical model on the aggregate interference caused by SUs to a PU due to miss-detection errors. In particular, the probabilistic properties of the aggregate interference are investigated in consideration of random SU locations and their propagation characteristics. Based on the developed statistical model, we subsequently derive the PU capacity-outage probability (i.e., the probability that the PU capacity falls below a prescribed level). This will help to examine the effects of various system parameters on the performance of the PU in the presence of interference from SUs. Consequently, PU capacity-outage probabilities are introduced as a measure to maintain QoS for PUs in designing OSA schemes for SUs.

In a cognitive network with beacon, different locations are considered for the beacon transmitter to study the aggregate interference. The beacon transmitter is located at the PU receiver (Ghasemi & Sousa, 2008; Hulbert, 2005) or at the PU transmitter (Derakhshani & Le-Ngoc, 2012; Vu, Ghassemzadeh, & Tarokh, 2008). Accordingly, we analyze the effects of the beacon transmitter location on the aggregate interference caused by SUs and the performance of the PU dealing with such aggregate interference.

In the case of locating beacon transmitter at the PU receiver, analysis shows that the aggregate interference has a Gamma distribution in Rayleigh fading channels. For the case of beacon transmitter located at the PU transmitter, it is shown that shifted Gamma distribution is a better fit to characterize the aggregate interference in Rayleigh fading channels. Furthermore, interference distribution analysis is extended to Nakagami fading channels by proposing Gamma distribution as a close approximation for interference distribution. In this case, beacon transmitter is assumed to be located at the PU receiver since it causes lower interference than the case with beacon transmitter at the PU transmitter. In addition, the capacity-outage probabilities of the PU are developed to examine the effects of various system parameters on the performance of the PU in the presence of interference from SUs for two scenarios in
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