Chapter 28
Modeling and Performance Evaluation

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ABSTRACT

Performance evaluation and analysis are of key importance to obtain deep understanding of cognitive radio networks. Some effects have been made to model and analyze the performance of cognitive radio networks. In the literature, there are two methodologies: queuing theory/Markov chain-based analysis and stochastic network calculus-based analysis. These two methodologies rely on different mathematical basics and modeling approaches. Thus, they lead to different output metrics on various viewpoints. This chapter aims to give an overall introduction to both methodologies. First, the fundamental models used in queuing/Markov chain-based analysis are presented, followed by their applications in cognitive radio networks. Then, network calculus basics are introduced with the modeling and application in performance analysis of the cognitive radio network.

INTRODUCTION

Cognitive radio has become a promising technique to increase spectrum utilization through spectrum sharing among the licensed users (called as primary users; PUs) and unlicensed users (called as secondary users; SUs). Performance evaluation and analysis are of key importance to obtain deep understanding of this newly emerged technique. Due to the characteristics and key mechanisms in cognitive radio networks, several vital aspects should be well studied in the performance evaluation, which makes the analysis not straightforward. The most important parts that should be considered include wireless channel model, spectrum sharing/access policy, spectrum sensing errors, and etc.

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Some effects have been made to model and analyze the performance of cognitive radio networks. In the literatures, two methodologies are discussed mainly, i.e., queuing theory/Markov chain based analysis and stochastic network calculus based analysis. These two methodologies rely on different mathematical basics and modeling approaches. Thus, they lead to different output metrics.

In the queuing theory/Markov chain based analysis, Poisson arrival and exponentially distributed service time are mostly assumed. With these assumptions, the existing queuing theory results, particularly M/M/1 priority queue results, can be directly applied, and the Markov chain model can be established. Considering the cognitive radio scenario, the state space of the Markov chain can be defined in two different ways, such as based on the channel occupancy state (that is, whether a channel is free, occupied by PU, occupied by SU or collision), or based on the number of PUs and the number of SUs in the system. The queuing/Markov chain based analysis helps to derive the average delay, average queue length in the system as well as throughput.

Network calculus is a newly developed theory that can be used to deal with some queuing problems in communication networks. It has evolved into two branches, i.e. deterministic network calculus and stochastic network calculus, where the deterministic branch is indeed a special case of the stochastic branch. Like the classic queuing theory, network calculus also has its foundation on three basic elements, namely input traffic, server and output traffic. Specifically, the traffic of a flow is modeled by a stochastic arrival curve, while a server is described by a stochastic service curve. Given the stochastic arrival curve of the input traffic and the stochastic service curve of a server or a system, the probabilistic delay bound and the backlog bound can be derived. Furthermore, the delay-constrained capacity can also be defined and studied which gives the admission region of the network.

This chapter will focus on the modeling and performance evaluation of a cognitive radio network, and aims to give an overall summarization to both queuing theory/Markov chain based analysis and stochastic network calculus based analysis. At the same time, how to use these methodologies to model and analyze cognitive radio networks will be discussed through several specific instances as well.

**QUEUING THEORY/MARKOV CHAIN BASED ANALYSIS**

In this section, queuing theory/Markov chain basics and the priority mechanism in cognitive radio networks will be introduced. Then, cognitive radio networks will be modeled and some application instances will be presented and discussed.

**Queueing Theory/Markov Chain Basics**

Queueing theory is a traditional methodology to model and analyze the performance of communication networks, and it has been also applied to the cognitive radio network. In the queuing theory/Markov chain based analysis, the M/M/1 model and Markov chain model are the mostly used, which will be introduced in this section first. Then, their applications and particular instances will be studied and discussed.