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# Performance analysis of cognitive radio networks under spectrum sharing using queuing approach

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ABSTRACT

Cognitive radio is considered to be an emerging technology that provides a platform to share the spectrum between primary and secondary users. As a result, the quality of service and the network usage is bound to improve. In order to evaluate the performance of such a system queuing theory can be considered as an important tool. In the aforementioned context, the central focus of this work is on evaluating and analyzing the network performance using queuing approach. This approach uses the Dimensional Reduction Scheme to reduce the dimension of the Markov chain and the matrix-analytic method for calculating the stationary probabilities. The performance of the system is evaluated on four performance measures namely, utilization, mean response time, mean number of jobs and waiting time. The simulation results show that the performance of the system is satisfactory when primary and secondary users share the network.



## 1. Introduction

Cognitive radio networks, being an emerging technology, is used for efficient utilization of the spectrum, by introducing cognitive users to search for data transmission opportunities in the absence of primary or licensed users. Mittola [1] introduced the architecture of cognitive radio in 1999. Spectrum sensing, spectrum sharing, spectrum decision and spectrum adaptation constitute the main functions of a cognitive cycle. In this cycle, each function plays an important role.

The communication in cognitive radio networks can be done using spectrum sensing and spectrum sharing [2,3]. In spectrum sensing, the spectrum holes are detected, and secondary users use these holes in such a way that the quality of service of primary users is not affected. Queuing theory is an important tool to analyze the performance of any system using the concept of priority queues.

In cognitive radio networks, queue based model can be used for spectrum scheduling, performance evaluation [4] of the system, etc. There exist few recent works that focus on it as [5–11]. The authors in [5] analyzed the performance for preemptive transmission. They used M/M/1 and M/M/G queue model for evaluating the system in underlay cognitive radio network. In [6], a queue based model is presented to evaluate the performance of the secondary users in the network. They considered cooperative cognitive radio network with imperfect sensing. Suleiman et al. [7] used M/D/1 queue model with priority queues to analyze the opportunistic spectrum access in cognitive radio networks. They derived waiting time and queue length using M/D/1 queue model. Farraj et al. [8] considered M/G/1 queue model to evaluate the performance measures for cognitive radios in spectrum sharing system. The work in [9] proposed a spectrum allocation scheme based

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on M/M/c queue model. They also used M/G/1 queue model to analyze the system. In [10], the researchers presented a queue-aware frame-based opportunistic spectrum scheduling scheme. The scheduling scheme is used for channel allocation in such a way that the scheduling overhead should be minimum, and the throughput of the system should be maximum. Carvalho et al. [11] developed a queue based framework to validate their proposed scheme.

The above study and observation provide the basic understanding regarding the proposed scheme for evaluating the system. In this paper, Recursive Dimensionality Reduction (RDR) [12] is used to reduce the two-dimensional infinite Markov chain to one-dimensional infinite Markov chain. After this, the matrix-analytic methods [13], are used to analyze the system. As per the best of our knowledge, this method has not been used to analyze the cognitive radio networks, when the primary and secondary users share the spectrum. In this work, the M/M/s dual priority queue model is designed. The mean number of jobs, mean response time, utilization and waiting time have been considered as measures to evaluate the performance of the system.

The rest of the paper is organized as follows: In Section 2, the related work and motivation towards designing the proposed scheme have been discussed. The system model has been presented in Section 3. Section 4 presents the simulations and results analysis. Finally, Section 5 presents the conclusion and the future road-map of this work.

## 2. Related work and motivation

In [14], Laourinc et al. present the queue behavior of cognitive radio networks. They investigated the performance of secondary users for a hierarchical network in which N identically independent distributed primary users were considered, and each primary user follows a slotted transmission. To investigate the performance of secondary users, the researchers studied the decay rate of the tail distribution of the secondary users queue. They have given a complete characterization of the decay rate for two primary users. In case, if there are more than two primary users, they have derived the upper and lower bounds of the decay rate. For this, the channel is defined into two categories viz. positive correlated and negative correlated based on the probability of the states. These bounds are found to be asymptotically tight when a primary transmission is in the positive correlated category. The researchers also determine the maximum arrival rate that is supported by secondary users till the buffer overflow probability is within a predefined quality of service threshold. In this work, the secondary users perform limited sensing, that is, sensing only senses one channel out of the existing N channels at a time, but it can be done with multiple channels. Therefore, it is a drawback of this work.

In [15], Tadayan et al. proposed an analytic and synthesis model for multi-channel cognitive radio networks. They used the concept of the priority queue. Using the concept of the priority queue, the authors have modeled the interaction between the primary and the secondary users. With the help of this model, the authors represent the dynamics of secondary users as two-dimensional continuous time Markov chain. On solving the continuous time Markov chain, the joint and marginal probability mass functions of primary and secondary queue lengths were obtained. In the second part of this paper, they concentrate on the application part of the network, using a conservative law. Further, to find the condition for the existence trade off between quality of services of secondary users and the interference with the primary users, the mixed strategy has been defined and used.

In [16], Aissa et al. present an analytic framework for the modeling and performance evaluation of the multi-interface multi-channel cognitive radio networks. This model captures the behavior of the secondary users when the secondary users are permitted to transmit over multiple channels in the presence of primary users. To develop this model, they used a queuing approach where M/M/k queue was used to model the secondary users. This M/M/k queue model was used to map as a two-dimensional discrete state continuous time Markov chain for performance evaluation. This chain was used to characterize the dynamics of secondary users. It is also used to find the stability condition for a stable network. The researchers obtained the probability mass function and the cumulative distribution function of the secondary users queue length. They also derived closed form expressions for the delay. In addition, using statistical analysis, they analyzed the total behavior of secondary users queue length. To characterize sensing, the detection probability $P_d$ and false alarm probability $P_f$ have been used through approximation results.

In [17], Tumulum et al. evaluated the spectrum handoff prioritization with the help of some new Dynamic Spectrum Access (DSA) schemes under centralized and distributed cognitive radio networks. For this, they considered two level prioritization viz. high and low priority class. The authors have introduced an analytical model for cognitive radio networks using all the dynamic spectrum schemes. To evaluate the performance of the system, they obtained the blocking probability, call complication rate, mean handoff delay and forced termination probability for both priority classes in the secondary user traffic. They have analyzed the sub-channel reservation for high priority secondary users. One of the shortcomings of the proposed scheme is that the authors have not analyzed their work with imperfect sensing.

In [18], Tran et al. presented a model using queue theory to evaluate the delay characteristics of cognitive radio networks. They imposed a peak interference power constraint at the primary user receiver, and it is assumed that each packet of secondary users has a threshold for the delay. To evaluate the performance over Rayleigh fading, the researchers obtained the probability density function(PDF) of transmission time and outage probability. Also, the stable transmission condition for the secondary user was formulated. The average waiting time, an average number of packets and average transmission time in secondary user transmitter queue, was calculated using the stable transmission. The Rayleigh fading environment is considered in this work along with other fading environments to evaluate the system.