1st International Conference on Recent Trends in Engineering & Technology, Mar-2012
Special Issue of International Journal of electronics, Communication & Soft Computing Science & Engineering, ISSN: 2277-9477

Modeling and Performance Analysis of the Cognitive Radio Network in Presence of Queue for Secondary Users

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***Abstract* — Cognitive Radio Network has been widely researched to improve utilization of radio electromagnetic spectrum efficiency usage. Spectrum occupancy in Cognitive framework includes licensed and unlicensed users sharing set of channel over a coverage area. In this paper, we develop a 2-D Markov Model to define transition rate and analyze call dropping probability for unlicensed users and channel utilization in presence of queue. Our results suggests that in presence of queue our system can significantly improve channel efficiency and reduce call dropping probability for unlicensed users without interference to licensed users.**

***Key Words* — Channel Utilization and Dropping Probability, Cognitive Radio Network, Markov Model, Opportunistic Spectrum Sharing.**

I. INTRODUCTION

The electromagnetic *radio spectrum* is a natural resource, the use of which by transmitters and receivers is licensed by governments. Conventionally, wireless networks are regulated by a fixed spectrum assignment policy, i.e. the spectrum is regulated by governmental agencies and is assigned to license holders or services on a long term basis for large geographical regions. In addition, a large portion of the assigned spectrum is used sporadically as illustrated in Fig. 1, where the signal strength distribution over a large portion of the wireless spectrum is shown. The spectrum usage is concentrated on certain portions of the spectrum while a significant amount of the spectrum remains unutilized. According to Federal Communications Commission (FCC) [1], temporal and geographical variations in the utilization of the assigned spectrum range from 15% to 85%. Although the fixed spectrum assignment policy generally served well in the past, there is a dramatic increase in the access to the limited spectrum for mobile services in the recent years. This increase is straining the effectiveness of the traditional spectrum policies.

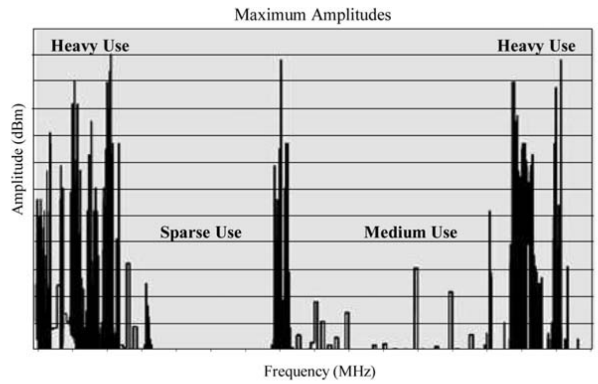

Fig. 1. Spectrum Utilization

The limited available spectrum and the inefficiency in the spectrum usage necessitate a new communication paradigm to exploit the existing wireless spectrum opportunistically [2]. Dynamic spectrum access is proposed to solve these current spectrum inefficiency problems. As a potential solution for this inefficiency, Cognitive Radio (CR) technology is considered by many researches to improve the spectrum usage inefficiency. The CR concept introduces a scenario in which the unused spectrum by the licensed (primary) users can be identified through spectrum sensing and reused by the unlicensed (secondary) users.

A number of papers related to Dynamic and Opportunistic Spectrum Sharing have appeared in literature. Reference [3] analyzed the modeling of interference in spectrum access based on the listen before talk scheme. In [4], measurement based model for statistically describing the idle and busy periods of a WLAN is proposed. Reference [5] proposed a network in which a primary user coexists with *N* secondary users with different types of traffic. They showed that the spectral efficiency can be increased by giving permission to reuse free bands of secondary users [6]. In [7], a channel reservation method for a spectrum sharing system has been introduced. Also several works has been done to use queues in cognitive radio networks; reference [8] analyzes the performance of the network with a delay and discard queue.

Authors in [9] have used channel bonding/aggregation for multi-channel cognitive radio networks in order to take more advantage of bandwidth. Using this method, a secondary user can utilize separate parts of spectrum as a channel. In [10], two channel aggregation methods (fixed and variable) are compared. Reference [6] proposes a performance model of an opportunistic spectrum sharing scheme. Since the detection mechanism in practical systems is associated with errors, then the authors have been extended their model to the unreliable sensing cases in [11] and [12].

In this paper, we evaluate performance of generic opportunistic spectrum sharing system in terms of dropping probability and channel utilization in presence of queue. We consider wireless network in which primary user (PU) and secondary user (SU) are in same spectrum band. Secondary users opportunistically make use of channels that are not occupied by primary users. We assume that the secondary users are capable of sensing when a channel is idle and then making use of such a channel. Conversely, a secondary user can detect when a primary user accesses a channel that it is using and then either move to another channel, if an idle channel is available, or move to a queue. In the latter case, call of secondary user waits in a queue until either a new channel becomes available or until a timeout occurs after a predefined maximum waiting time. The spectral efficiency of channels with the presence of the secondary users can be increased by putting secondary users in the queue. This increases the probability of the channel being occupied and thus increases the channel efficiency. In this paper, we have investigated the presence and absence of queue in cognitive radio systems and derive mathematical equation for performance parameters like dropping probability and channel utilization by varying number of secondary users.

The rest of this paper is organized as follows: Section II discusses the Markov Model analytical work to derive transition rate with the help of state transition diagram. In Section III, we derived performance parameters like dropping probability and channel efficiency for PU and SU. In Section IV, we perform numerical analysis of Cognitive Radio System in two cases in absence and presence of queue. Finally, we conclude the paper in Section V.

II. System Model, Assumption And Analysis

An OSS system model is depicted in Fig. 2. In this system model, we assume that the primary system and secondary system are both having infrastructure wireless networks. However, the performance model discussed in this paper applies to more general scenarios. For example, one or both of the primary and secondary systems may be without any infrastructure ad hoc networks. Suppose there are a total of N channels managed by the primary system with access point AP1 in a given cell. The PU calls operate as if there are no SU calls in the system. When a PU call arrives to the system, it occupies a free channel if one is available; otherwise, it will be blocked. Secondary users detect the presence or absence of signals from primary users and maintain records of the channel occupancy status. The detection mechanism may involve collaboration with other secondary users and/or an exchange with an associated access point called AP2, as shown in Fig. 2.

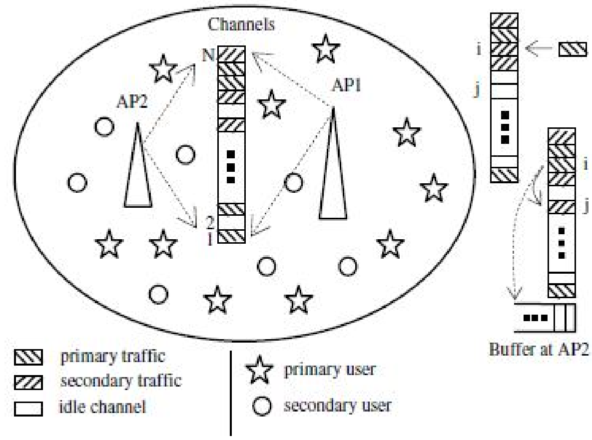

Fig. 2. Opportunistic Spectrum Sharing System Model

When an SU node detects or is informed (by AP2 or other SU nodes) of an arrival of a PU call in its current channel, it immediately leaves the channel and switches to an idle channel, if one is available, to continue the call. If at that time all the channels are occupied, the SU call is placed into a buffer located at AP2. In Fig. 2, when an SU call detects the arrival of a PU call at channel *i*, it immediately leaves that channel and changes to channel *j*. If all of the *N* channels are occupied at that time, the SU call will be queued. Queued SU calls are served in first in first out (FIFO) order. SU call is reconnected to the system when a channel becomes available before a predefined *maximum mean waiting time* expires. We set this time of an SU call equal to its residence time in the considered service area. Thus, an SU call is lost if it is forced to wait for a period of time equivalent to its residence time in the service area, i.e., until it moves out of the service area.

Now we explain our model assumptions; N channels are used to carry the traffic of both primary and secondary networks. We assume all cells are statistically identical, so we analyze our model in a cell. In each cell, the arrival time of both PU and SU calls follows an independent Poisson processes with rates λ_1 and λ_2 respectively. Also, the holding times of PU and SU calls are exponentially distributed with means $1/h_1$ and $1/h_2$ respectively. We assume that the resident time of PU and SU calls in the service area is exponentially distributed with mean $1/r_1$ and $1/r_2$ respectively. Also channel holding times are set to the minimum holding time of calls and residence time in the area under the service. Therefore, channel holding time for PU and SU calls is exponentially distributed with mean $\mu_1^{-1} = 1/(h_1 + r_1)$ and $\mu_2^{-1} = 1/(h_2 + r_2)$ respectively [13]. For the sake of simplicity, we also assume that both PU and SU calls occupy only one channel for each call. Now we write $(X_1(t), X_2(t))$ as a 2-D Markov process with state spaces $S = \{(k_1, k_2) \mid 0 \le k_1 \le N, 0 \le k_2 \le N)$ in which $X_1(t)$ and $X_2(t)$ are the number of channels that are used by PU and

SU at time *t*, respectively. The transition rate from (k_1,k_2) state to (k_1',k_2') is denoted by $T_{k_1,k_2}^{k_1',k_2'}$. Also, the indicator function $1_{\{x\}}$, is defined as 1 if x is true and is 0 otherwise. Based on the above definitions, we can define three types for the state (k_1,k_2) in Markov process; type-1: $(k_1+k_2<N)$, type-2: $(k_1+k_2=N)$; and type-3: $(k_1+k_2>N)$. In the next section, we express the system model for three types of occupancy channel status.

A. Analysis in absence of queue:

Type-3 will not exist in case of absence of queue. The state diagram for type-1 and type-2 is shown in Fig. 3 (a) and (b) respectively. From state diagram, the transition rate $T_{k_1,k_2}^{k_1',k_2'}$ for Markov model in absence of queue is obtained as follows:

$$T_{k_1,k_2}^{k_1+1,k_2} = \lambda_1\, 1_{\{0\le k_1\le N\text{-}1,0\le k_2\le N\text{-}k_1-1\}}$$
$$T_{k_1,k_2}^{k_1\text{-}1,k_2} = k_1\,\mu_1\, 1_{\{1\le k_1\le N,0\le k_2\le N\text{-}k_1\}}$$
$$T_{k_1,k_2}^{k_1,k_2+1} = \lambda_2\, 1_{\{0\le k_1\le N-1,0\le k_2\le N\text{-}k_1\}}$$
$$T_{k_1,k_2}^{k_1,k_2\text{-}1} = k_2\,\mu_2\, 1_{\{0\le k_1\le N\text{-}1,1\le k_2\le N\text{-}k_1\}}$$
$$T_{k_1,k_2}^{k_1+1,k_2\text{-}1} = \overline{\delta}(k_2)\,\lambda_1\, 1_{\{0\le k_1\le N,k_2=N\text{-}k_1\}} \quad \text{…. (1)}$$

where $\overline{\delta}(j)$. As $\delta(k_2)$ is Kronecker delta function defined by $\delta(k_2)=1$ if $k_2=0$ and $\delta(k_2)=0$ if $k_2\neq 0$.

Transition from state (i,j) to $(i+1,j-1)$ occurs when the PU arrives, while all channels are occupied and there is at least one SU in the system. In this case, the PU gets the channel of SU by dropping its call. A forced SU disconnection depends on the remaining number of channels and users in the system.

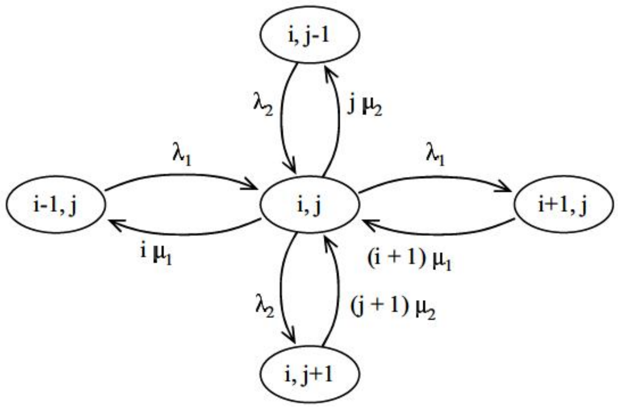

Fig. 3 (a) State transition diagram for $(k_1+k_2<N)$.

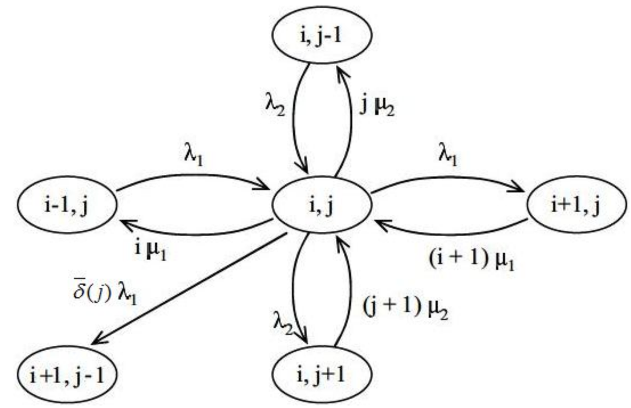

Fig. 3 (b) State transition diagram for $(k_1+k_2=N)$.

B. Analysis in presence of queue:

Type-1 will not exist in this case. When all the channels are occupied by PUs and SUs, we consider a queue of length N. We choose the length of the queue equal to the number of channels; therefore, all of the on-going SU calls can transfer to the queue to avoid SU dropping. The state diagram for type-2 and type-3 is shown in Fig. 4 (a) and (b) respectively. From state diagram, the transition rate in presence of queue is obtained as follows:

$$T_{k_1,k_2}^{k_1+1,k_2} = \lambda_1\, 1_{\{0\le k_1\le N-1,0\le k_2\le N\}}$$
$$T_{k_1,k_2}^{k_1-1,k_2} = k_1\,\mu_1\, 1_{\{1\le k_1\le N-1,0\le k_2\le N\}}$$
$$T_{k_1,k_2}^{k_1,k_2+1} = \lambda_2\, 1_{\{0\le k_1\le N-1,0\le k_2\le N-k_1\}}$$
$$T_{k_1,k_2}^{k_1,k_2-1} = k_2\,\mu_2\, 1_{\{0\le k_1\le N-1,1\le k_2\le N-k_1\}} + \left[(N\text{-}k_1)\mu_2+(k_2-N+k_1)r_2\right]1_{\{1\le k_1\le N,N-k_1+1\le k_2\le N\}} \quad \text{…. (2)}$$

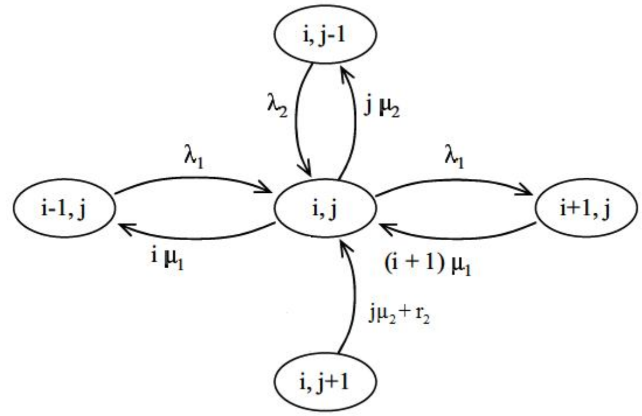

Fig. 4 (a) State transition diagram for $(k_1+k_2=N)$.

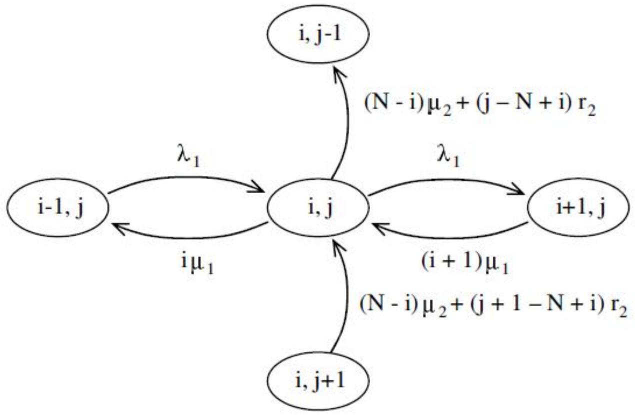

Fig. 4 (b) State transition diagram for $(k_1 + k_2 > N)$.

We define $I_{\{k_1,k_2\}}$ is a function which has two cases; it is equal to 1 if $0 \le k_1 + k_2 \le N$ (in presence of queue) and if $k_2 \le N$ (in absence of queue) or equal to 0 otherwise. The balanced state equation can be obtained as follows:

$$(T_{k_1,k_2}^{k_1+1,k_2} + T_{k_1,k_2}^{k_1-1,k_2} + T_{k_1,k_2}^{k_1+1,k_2-1} + T_{k_1,k_2}^{k_1,k_2+1} + T_{k_1,k_2}^{k_1,k_2-1}) I_{\{k_1,k_2\}}$$
$$\pi\{k_1,k_2\} = T_{k_1+1,k_2}^{k_1,k_2} I_{\{k_1+1,k_2\}} \pi\{k_1+1,k_2\} + T_{k_1-1,k_2}^{k_1,k_2} I_{\{k_1-1,k_2\}}$$
$$\pi\{k_1-1,k_2\} + T_{k_1,k_2+1}^{k_1,k_2} I_{\{k_1,k_2+1\}} \pi\{k_1,k_2+1\} + T_{k_1,k_2-1}^{k_1,k_2}$$
$$I_{\{k_1,k_2-1\}} \pi\{k_1,k_2-1\} \qquad .... (3)$$

$$\sum_{k_2=0}^{N} \sum_{k_1=0}^{N} \pi\{k_1,k_2\} I_{\{k_1,k_2\}} = 1 \qquad …. (4)$$

where, $\pi\{k_1,k_2\}$ the steady state probability for the state (k_1,k_2). Now we can derive mathematical equation for dropping probability and channel utilization.

III. PERFORMANCE ANALYSIS

A. Call Dropping Probability for Unlicensed Users:

The ongoing call of SU is dropped, when a PU call request arrives, all the channels are occupied by either PU and/or SU, and at that time there is no empty channel to switch to it. Note that, call dropping only happens when there is queue in the system. Also note that, in this case there should be at least one SU in the system. The drop-ping probability of the SUs is denoted by PD_2 , and it is obtained as:

$$PD_2 = \sum_{k_2=1}^{N} \pi(N - K_2, k_2) \qquad …. (5)$$

B. Channel Utilization:

The ratio of the average number of busy channels to the number of all channels is called 'channel utilization' and is denoted by η and can be written as follows:

$$\eta = \frac{1}{N} \sum_{k_1=0}^{N} \sum_{k_2=0}^{N-k_1} ((k_1 + k_2)\pi(k_1,k_2)) I_{\{k_1,k_2\}} \qquad …. (6)$$

$$\eta = \frac{1}{N} \sum_{k_1=0}^{N} \sum_{k_2=0}^{N-k_1} ((k_1 + k_2)\pi(k_1,k_2)) I_{\{k_1,k_2\}} + \sum_{k_1=1}^{N} \sum_{k_2=N-k_1+1}^{N} (N\pi(k_1,k_2)) I_{\{k_1,k_2\}} \qquad …. (7)$$

The equation (6) and (7) represents channel utilization for absence and presence of queue respectively.

IV. NUMERICAL RESULTS

In this section, we present numerical results for our system model under following parameter settings: Number of channels available in each cell = N = 10. $\lambda_1 = \lambda_2 = 1$. Time is represented in terms of dimensionless time unit which can be mapped to a specific unit of time. It is assumed that number of PU in each cell is constant and is set to 500. However, number of SU is variable. Following table I shows numerical results for dropping probability in absence or presence of queue.

I. Call Dropping Probability for SU

Number of Primary Users = 500		
No. of SU	Dropping Probability (in %)	
	Absence of Queue	Presence of Queue
100	6	2
200	8	3
300	10	3.8
400	11.7	4.1
500	13.1	4.3
600	14	4.6
700	15.2	5
800	15.8	5.2
900	16	5.2
1000	16.2	5.2

This demonstrates that the call dropping probability of the SUs as the call traffic of SU increase in both cases. This indicates that the dropping probability of the SUs in presence of queue is dramatically lower than the case in absence of queue, because as the SUs are dropped by the PUs, they move to the queue and the queued secondary calls reconnect back to the system as soon as they find an idle channel. The table II indicates that the channel utilization will be slightly increased when queue is used for SUs. This is due to reconnection of SUs call into the channel that increases the probability of busy channel consequently.

II. Channel Utilization

Number of Primary Users = 500		
No. of SU	Channel Utilization (in %)	
	Absence of Queue	Presence of Queue
100	48	48
200	56	58
300	62	64
400	65	68
500	72	75

600	75	78
700	78	81
800	81	84
900	83	87
1000	85	92

V. Conclusion And Future Work

We presented 2-D Markov Model of Cognitive Radio Network with opportunistic spectrum sharing. Our analysis and numerical results shows that our system can significantly improve channel utilization and spectrum efficiency and also dropping probability for unlicensed users can significantly reduce in presence of queue without affecting licensed users. This is a topic of ongoing work. So, in future, we will try to correlate numerical results with simulation results with the help of MATLAB as Software Platform.

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