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Dynamic Spectrum Access in Cognitive Radio Using Markovian Queuing Model

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Abstract: Today there is huge demand for radio spectrum in wireless communication networks. Fixed spectrum policy is a major problem in solving spectrum crisis. Dynamic spectrum access is one method which gives the solution by allocating the available limited radio spectrum band between different licensed and unlicensed users. Dynamically accessing the unused spectrum is known as dynamic spectrum access (DSA) which becomes a promising approach to increase the efficiency of spectrum usage. This allows unlicensed wireless users (secondary users) to dynamically access the licensed bands from legacy spectrum holders (primary users) on an opportunistic basis. In this paper, DSA approach by using hierarchical access model is proposed with Markovian Queuing model for centralized architecture. The blocking probability and mean access delay for infinite and finite users are also found out. Results are then compared.

Keywords: Dynamic spectrum access; Primary users; Secondary user; Markovian Queuing model; blocking probability

I. INTRODUCTION TO DYNAMIC SPECTRUM ACCESS

National regulatory bodies provide the radio spectrum band for utilization in different wireless services. In the U.S., the main authority for radio spectrum regulation is the Federal Communication Commission (FCC). The FCC's spectrum policy gives the actual spectrum usage measurements. Radio spectrum is not fully utilized often and so the proper way for utilization of radio spectrum is to use dynamic spectrum access technique which is adopted in cognitive radio.

Dynamic spectrum access is a technique by which a radio system dynamically adapts to available spectrum holes with limited spectrum use rights, in response changing circumstance and objectives: interference created changes the radio's state, changes in environmental constraints [1]. The main objective of the DSA is to overcome two types of interference concern: harmful interference caused by malfunctioning device and harmful interference caused by malicious users. Dynamic spectrum management is also referred to as dynamic spectrum access. DSA that was first demonstrated in 2006 by the Defense Advanced Research Project Agency (DARPA) and Shared Spectrum Company (SSC) of Vienna, VA [2]. Dynamic spectrum access overcomes the limitation of fixed frequency spectrum assignment and management. Dynamic spectrum access models can be broadly categorized under three models as dynamic exclusive-use, open sharing model, and hierarchical access model as shown in Fig. 1 [3].

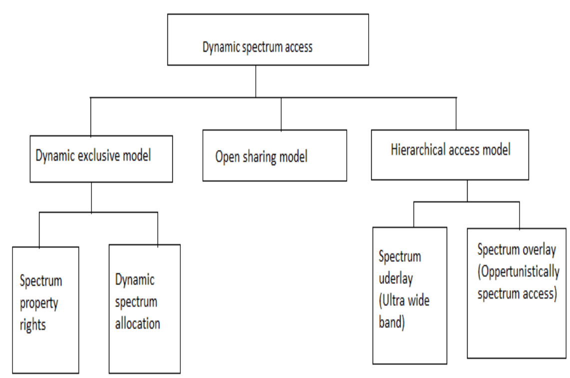

Figure 1. Dynamic Spectrum Access

A. *Dynamic exclusive use model:*

Dynamic exclusive use model maintains the basic structure of the current spectrum regulation policy. Spectrum bands are licensed to services for exclusive use. The main objective of the dynamic exclusive use model improves the flexibility and spectrum efficiency. It manages spectrum in finer scales of time, space and frequency and use dimensions. There are two types of dynamic exclusive use model [3]:

a. ***Spectrum property rights:*** In spectrum property rights licenses are allowed to sell and trade spectrum and to freely choose the technology. The economy and market will thus play a more important role in driving toward the most profitable use of this limited resource. Licenses have the rights to lease or share the spectrum for profit, such sharing is not mandated by the regulation policy.
b. ***Dynamic spectrum allocation:*** Dynamic spectrum allocation improves spectrum efficiency through dynamic spectrum assignment by exploiting the

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spatial and temporal traffic statistics of different services. Spectrum is allocated to services for exclusive use in a given region and at a given time. This allocation varies in a much faster scale than the current policy.

B. Open sharing mode:

Open sharing model is also called spectrum commons model. This model employs open sharing among peer-users as the basis for managing a spectral region. This model is supported from the phenomenal success of wireless services operating in the unlicensed industrial, scientific and medical (ISM) radio band. It has three types [4]: Uncontrolled- commons, Managed-commons, Private-commons.

a. ***Uncontrolled-commons:*** This is also referred as open spectrum access. When a spectrum band is managed no entity has exclusive licensed to the spectrum band. It is maximum transmit power constraint.

b. ***Managed-commons:*** This represents an effort to avoid the tragedy of commons by imposing a limited form of order or structure of spectrum access.

c. ***Private-commons:*** Spectrum owner specifies technology and protocol for the CR user access. CR user may receive a command from spectrum owner (transmission parameter). CR user may sense and access the spectrum.

C. Hierarchical access model:

Hierarchical access model [5], in which radio spectrum can be simultaneously shared between primary (licensed) user and secondary (unlicensed) user. CR users can opportunistically access the radio spectrum if it is not occupied or fully utilized by primary users. There are also two types of model; Spectrum overlay and Spectrum underlay.

a. ***Spectrum overlay:*** The spectrum overlay model actively explored in a going DARAP XG program and advocated by Mitola targets for aggressive opportunistic exploitation of white-space or spectrum "gaps" in spatial-temporal domain [4]. Cognitive Radio will have to identify the idle spectrum band, which are not used by licensed users at a certain time and location and use those idle spectrum bands dynamically to unlicensed users. This model is shown in Fig. 2 (a). This model allows primary and secondary transmission. Secondary users can use part of their power for secondary communication and remain part of the power to relay primary transmission, these enabling premises for an overlay system model [6]. Example of spectrum overlay is TDMA, FDMA, and OFDMA system [7].

b. ***Spectrum underlay:*** The spectrum underlay approach imposes constraints on the transmission power of secondary users so they operate below the noise floor of primary users. By spreading transmitted signals over a wide frequency band (UWB), secondary users can potentially achieve a short-range high data rate with very low transmission power shown in Fig. 2 (b). In the worst case, the assumption is made that the primary users transmit all the time; this approach does not rely on detection and utilization of spectrum white space [3].

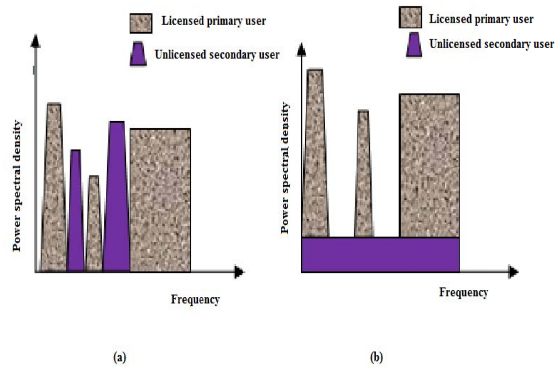

Figure 2. Spectrum overlay and underlay approaches

In spectrum overlay approach relies on spectrum holes detection by SU in the network and does not impose serve restriction on their transmission power. Therefore in both cases, the licensed spectrum is open to the SU while limiting interference to PU. In this paper the spectrum overlay approach is used which is also referred to as opportunistic spectrum access (OSA) [6].
It is seen that availability is increased with queue and hence queue model is chosen for Dynamic Spectrum allocation in cognitive radio.

II. QUEUING SYSTEM

A single station queuing system consists of a queuing buffer of finite or infinite size and one or more identical server, as shown in Fig. 3. An elementary queuing system is also referred to as a service station or simply a node. A server can serve only one customer at a time. It works in a "busy or "idle" state. If all servers are busy upon the arrival of the customer, the newly arriving customer is buffered, assuming that buffer space is available, and wait for its turn. When the customer currently service departs, one of the waiting customers is selected for service according to a queuing discipline [8]. Different types of arrival pattern, distribution of the service-time, queuing discipline and the number of servers can be classified by a queuing system that is denoted by a standard notation. It was proposed by D. G. Kendall and it is named as Kendall's Notation [9].
Kendall's Notation
The Kendall's notation is widely used to describe elementary Queuing system A/B/X/Y/Z in queuing discipline and is sown in Table I. Most of the time first three symbols, i.e. A/B/X are mentioned since they are the most important parameters to represent a queuing model.

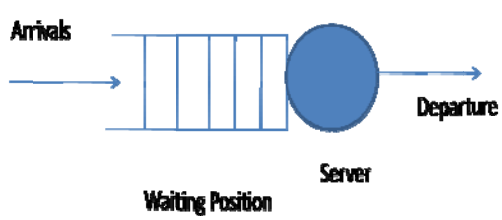

Figure 3. A Standard Graphical Notation for the queue

Many practical situations customers arrive according to a passion stream (exponential inter-arrival times) and their service times are independent and identically distributed. Service time can be deterministic or exponentially distributed. There may be a single server or a group of servers to process the service requests of the arrived customers. Practically the number of waiting position of a queuing system is limited.

TableI. Kendall's Notation

Parameters	***Refers To***	***Example***
A	Inter-arrival distribution of customer	M-Exponential, G-General,
B	Service Time Distribution	D-Deterministic M-Exponential, G-General
X	Number of Parallel servers	D-Deterministic 1, 2, 3…
Y	Maximum number of customers allowed in the queue	1, 2, 3…
Z	Scheduling discipline or queuing strategy	FCFS, LCFS, Priority, RSS

The rule that a server uses to select the next customer from the queue when the server is finished the service of the current customer is called queuing discipline. Commonly used queue disciplines are:

- ***a.*** ***FCFS*** - Service requests are served on a first-come first-serve basis. In FCFS, if a service request arrives when the queue is full then the system blocks the request.
- ***b.*** ***LCFS*** - Service requests are served in a last-come first-serve manner.
- ***c.*** ***Priority***- According to the importance of the service, Service requests are served.
- ***d.*** ***RSS*** - Random Selection for Services.
- ***e.*** ***FQ*** - Fair queuing does not consider the order or priority, but serve the service requests in a fair way.

III. PROPOSED QUEUING MODEL

This model is unique in sense based distributed Markovian queuing for Cognitive radio networks. An interesting feature of our model is its adaptability for both infrastructure based and infrastructure-less centralized networks. A record of spectra and its allocation to intended users is to be performed by the master or cluster head and by the fixed controller or base station (BS) in infrastructure-less and infrastructure based networks respectively. The MAC scheme is analyzed using distributed Markovian queuing network model where one of the two distributed queues is modeled as M/M/1 queue and the other as a semi Markovian M/G/S/N queue. The equivalent model of a network of queues for the system is as shown in Fig. 4. In this model SUQ is M/M/1 type queue where M means Markovian distribution and one denotes single server and bandwidth allocation queue (BAQ) is modeled as an M/G/S/N loss queuing system. Here G is general distribution as there may be a variety of requests from both PU and SU entering to this system. S denotes the available of unoccupied channels available with head and N denotes limited BAQ capacity. A special case when queue size is same as the number of available channels in the system, i.e. S=N, the BAQ becomes an M/M/S/S queue. If the arrival process is Poisson and the service time distributions are exponential for a queuing model. It is said to be Markovian queuing model. These queues are special cases of stochastic processes, characterized by an arrival process of service requests, a waiting list of requests to be processed, queuing discipline i.e. the manner the requests are selected to be served and a service process [10].

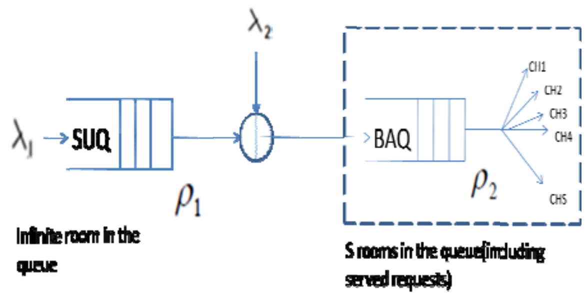

Figure 4. Queuing model for DSA in CR Network

The queue stacking all entries of SUs is referred as a secondary user queue (SUQ) and all the requests entering this queue are served on a first come first serve (FCFS) basis. At any time when bandwidth needs are allocated to the SU, the Head considers both the requests from SU and the PU who needs it licensed channel. Thus while distributing a number of frequencies to PU and SU; the arrival rates of both the users are summed to access the frequencies with the Head. The queue so formed is referred to as bandwidth allocation queue (BAQ) [10].

A. Performance Analysis using Erlang-B model:

The Erlang B formula was developed by Anger Krarup Erlang (1878-1929) and is also known as Erlang loss formula [11]. It is used for infinite users and finds the blocking probability. Erlang model is also known as queuing model and is based on queuing theory. Here, SUQ (secondary user queue) is of M/M/1 type. Under the assumption that the traffic intensity of this queue . is less than unity (i.e. <1Erlang), SUQ becomes stable and the output process is still Poisson with mean rate , due to Bruke's theorem. The master to be updated with CR engine capabilities to handle bandwidth requests of both licensed as well as unlicensed users, independent Poisson processes with mean rates . and are summed at the input of bandwidth allocation queue BAQ. The total mean arrival rate at BAQ is + . The value of traffic intensity for BAQ is = + E[X], where E[X] is the mean service duration for BAQ. For the bandwidth request by CR that finds all the channels with Head as occupied, blocking probability P_B is given by the well known Erlang-B formula as given below in (1)[10] .

$$P_B \quad \frac{\qquad}{\quad} \tag{1}$$

Let N_1 and N_2 denote the mean number of messages in queues SUQ and BAQ respectively. According to the M/M/1 classical theory, we have for queue SUQ [10]:

$$N_1=\frac{\rho_1}{1-\rho_1} \quad (2)$$

According to the M/M/S/S classical theory, we have for queue BAQ:

$$N_2=\rho_2(1-P_B) \quad (3)$$

Let T_1 and T_2 denote the mean delay experienced by a message in crossing SUQ and BAQ, respectively in (4) from the little theorem:

$$T_1=\frac{N_1}{\lambda_1} \text{ and } T_2=\frac{N_2}{(\lambda_1+\lambda_2)(1-P_B)} \quad (4)$$

To determine the total mean access delay T, we have considered two different cases depending on the input of the message in our system as follows:

Case a. SU messages arriving at SUQ from outside the system. The probability that these messages arrive at SUQ from outside the system is given as $\lambda_1/(\lambda_1\lambda_2)$ with a mean message delay T_{D1} given as (5):

$$T_{D1}=T_1+(1-P_B)T_2 \quad (5)$$

Case b. PU messages arriving at BAQ from outside the system. This situation occurs with probability $\lambda_1/(\lambda_1\lambda_2)$with the mean message delay T_{D2} given as (6):

$$T_{D2}=P_B\times 0+(1-P_B)\,T_2=(1-P_B)\,T_2 \quad (6)$$

Thus, T can be obtained as in (7):

$$T=\frac{\lambda_1}{\lambda_1+\lambda_2}[T_1+(1-P_B)\,T_2]+\frac{\lambda_1}{\lambda_1+\lambda_2}[(1-P_B)\,T_2]$$

$$T=\frac{\lambda_1}{\lambda_1+\lambda_2}T_1+(1-P_B)\,T_2 \quad (7)$$

By means of expressions of T_1 and T_2 using (4) and N_1 and N_2 using (2) and (3), we obtained the overall access latency, T as follows in (8):

$$T=\frac{N_1+N_2}{\lambda_1+\lambda_2}$$

$$T=\frac{\frac{\rho_1}{1-\rho_1}+\rho_{2(1-P_B)}}{\lambda_1+\lambda_2} \quad (8)$$

The equation defines the overall delay encountered by any SU to access a channel for transmission of its own voice/data. Thus, T represents the time interval between the request initiated by the SU and the request granted the required bandwidth.

TableII. Parameter Used in Calculation

Notation	***Parameter***
Poisson arrivals with a rate	λ
Exponentially distributed service time with a rate	μ
Traffic intensity	ρ
Blocking probability	P_B
Total mean delay	T

Blocking probability from (1) is plotted in Fig. 5. Fig. 5 shows the relation between the numbers of channels (s) and blocking probability (P_B) for different values of traffic intensity (SU). So it is clear from the figure that when number of channel increases, blocking probability decreases and when the traffic intensity (SU) increases, blocking probability also increases.

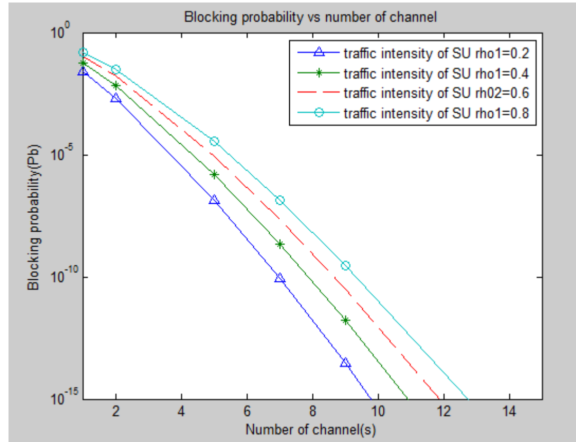

Figure 5. Blocking probability (P_B) as a function of different number of channel(s)

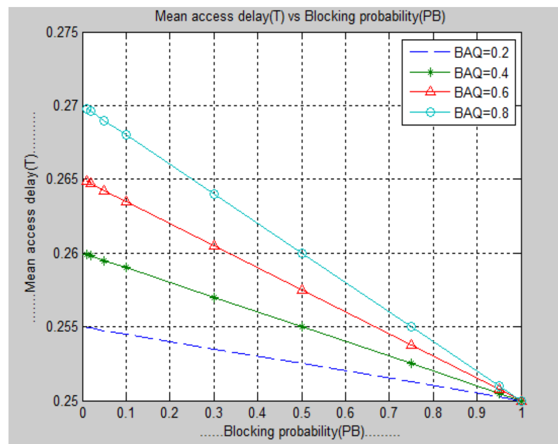

Figure 6. Mean access delay (T) against traffic intensity of BAQ

From (8), total access delay against blocking probabilities of 5%, 10%, 30%, 50%, 75% and 95% are plotted in Fig. 6 for variation in traffic intensity of BAQ as 0.2, 0.4, 0.6, 0.8. The plot shows that for any given traffic intensity of BAQ, T increases with increase in traffic intensity of BAQ while decreases for an increase in the blocking probability.

B. Performance Analysis using Engset formula:

The Engset formula was developed by Tore Olaus Engset. Engset is used with "Finite sources" when blocked call is cleared [11]. The Enset loss formula applies to situations where the number of customers is small relative to the number of available channel [12]. SU type M/M/1/L queue used, where L is the size of waiting room. The case of the M/M/1/L queue represents the queue in which the arrival and departure rates are not constant. The customer arrival rate is λ_1 is less than L in the system either in service or in the queue. When the waiting room becomes full, would be arriving customers are turned away [13]. The call holding times for SU be IID (identically independent distribution) exponentially with mean $1/\mu_1$ and the time until an idle source attempts to make a call is also exponential with mean $1/\lambda_1$. Let there is no dependence between the holding times and the idle periods of the

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sources. The number of customers is assumed to be M, the number of channel S and the blocking probability P_B [12].

The Engset loss formula gives the blocking probability for the case M>S as follows

$$P_B=\frac{\binom{M-1}{S}\rho_2{}^S}{\sum_{i=0}^{S}\binom{M-1}{i}\rho_2{}^i} \quad (9)$$

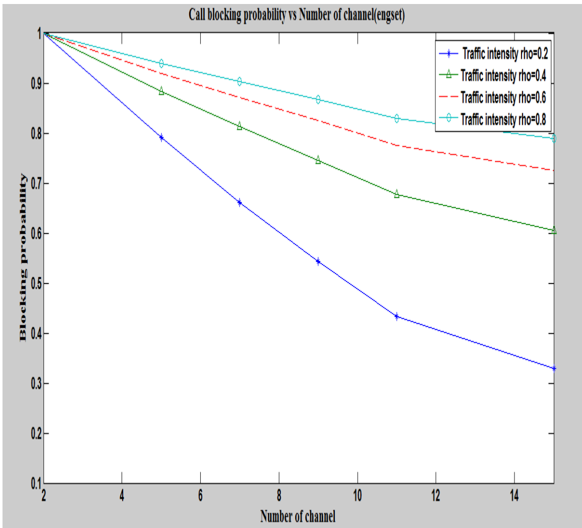

Figure 7. Blocking probability(P_B) as a function of different number of channel(s)

Blocking probability from (9) is plotted in Fig. 7. It shows the relation between the number of channels (s) and blocking probability (P_B) for different values of traffic intensity (SU). It is clear that when number of channel increases, blocking probability decreases. It is also analyzed that when the traffic intensity (SU) increases, blocking probability also increases. From equation (8), total access delay against blocking probabilities of 5%, 10%, 30%, 50%, 75% and 95% are calculated for variation in traffic intensity of BAQ as 0.2, 0.4, 0.6, 0.8 and plotted in Fig. 8. The plot shows that for any given traffic intensity of BAQ, T increases with increase in traffic intensity of BAQ while decreases for an increase in the blocking probability.

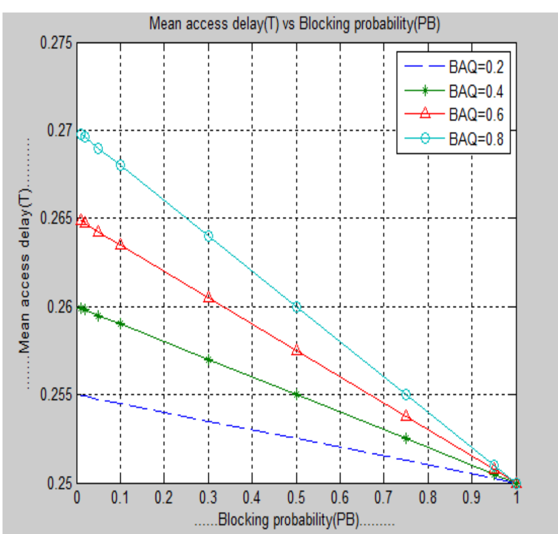

Figure 8. Mean access delay (T) against traffic intensity of BAQ

C. Performance comparison between Erlang-B and Engset formula:

Comparison between the results obtained using Erlang-B and Engset formula are shown in Fig.9. For equal traffic intensities, the engset formula gives a lower blocking probability than the Erlang formula and tends to the later when the user population grows to infinity. Regarding the computational complexity the engset model is much more simple than the bidirectional markov chain used in Erlang formula.

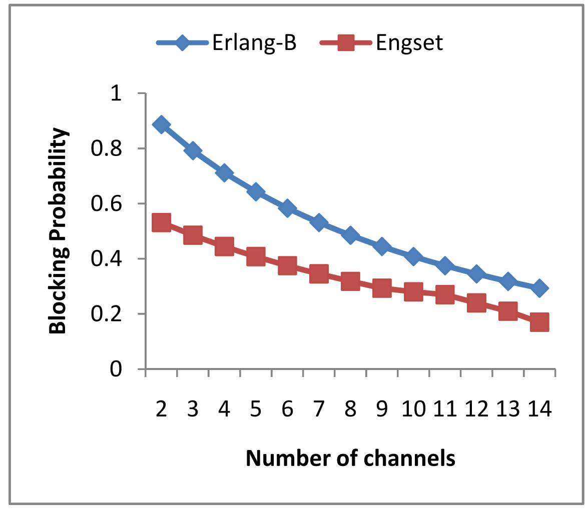

Figure 9. Comparison between Erlang-B and Engset model

IV. CONCLUSION

Dynamic Spectrum access is a promising approach to utilize the unused spectrum by the primary user. In this paper, a centralized architecture coexisting with licensed users and unlicensed users is used for Markovian queuing model. Blocking probability and mean access delay for infinite users are calculated using Erlang-B formula and for finite users using Engset formula. Results obtained are found to be satisfactory. The results are then compared. For equal traffic intensities, the Engset formula gives a lower blocking probability than the Erlang formula and tends to be equal when the user population grows to infinity. The future work will include separate queue for high and low priority users.

V. ACKNOWLEDGMENT

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