A Comparative Study of Interrupted Secondary User Buffer Mechanism with No buffer mechanism for Cognitive Radio Networks

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Abstract. Cognitive Radio Networks is the focused research area where optimal usage of resources takes place. The spectrum scarcity is cause for searching new techniques to serve resources to the users other than privileged (primary) which are called as Secondary users. By using interleaving paradigm, the secondary users also served the license bands without interrupting Primary users. While serving the Secondary users, the preemption of secondary users takes place because of high priority of Primary users and they have to leave the system if no buffer is provisioned for the interrupted secondary users. The focus of this research paper is to compare the impact of keeping a buffer to hold the interrupted Secondary users with the case of providing no buffer in the System. A comparative study reveals the necessity and role of the buffer in the System for the provision of better service to Secondary users. The main focus of this paper is the consideration of the system performance with and without the buffer mechanism for interrupted secondary users and this scenario is modeled as M/M/C/K analytical queuing model. The differential difference equations are derived for both the cases and based on these equations, performance metric average queue length and waiting time are calculated. Finally numerical illustrations are carried out for different values of primary, secondary user arrival rates, service rate, buffer size and number of channels. The analytical results are presented through tables and graphs were shown to draw the conclusions.

1. Introduction

Everyone is aware of the scarcity of spectrum as the demand is growing in exponentially with the evolution of advanced technologies like IoT. The white spaces and related statistics of spectrum utilization showing that poor utilization of the spectrum is taking place even the demand is increasing. Cognitive radio networks are the research area which helps in effective utilization of the spectrum which is a part of next generation wireless networks [1]. Cognitive radios helps in dynamic frequency selection and also in band allocation and reallocation to the users based on the requirements [2]. To minimize the white space and effective usage of the spectrum, so many paradigms are evolved like overlay, interweaving and underlay. In this paper, the interweaving paradigm is adapted where each user is given an opportunity to best utilize the complete resources whenever a channel is free.

The primary users or licensed users will be given high priority for reserving and use of the spectrum and when an underutilization takes place, the secondary users or unlicensed users will be given an opportunity for using the spectrum resources under the supervision of a service provider (SP). The secondary users are allowed to utilize all the resources completely and effectively like a primary user whenever a channel is free.

The optimal channel usage actually starts by sensing the spectrum for availability of the channels before occupation [3]. Once the vacant channels are identified, finding the suitable channel for amount of data to be transferred in the specified time interval by using Swam Intelligence like techniques [4]. The selection of best secondary user for the vacant channel [5] also helps in improving the performance of the System. So much research gone in channel assignment and false alarms [6] is also helpful in this research paper as the focus is on performance improvement. Once these steps are
implemented, the secondary user channel assignment takes place opportunistically and the channel management comes into force.

As per the interweaving scenario opted in this paper, the interruption to secondary users in service takes place by the primary users when no other channels are free. Interweaving paradigm shows a great concern of providing service in effective manner but the issue to be exercised is the interruptions to secondary users under service because of the arrivals of primary users when the channels are busy. To handle the issue of interrupted users, buffers can be used to temporarily hold them for resuming the services to interrupted secondary users until the channels become free. In this paper, a comparative study of service provision to secondary users with and without buffers is carried. The performance metrics like queue length, waiting time and delays of users are considered for the comparative analysis. Several models with queuing mechanism are proposed with and without buffers in effective utilization of channels.

The handoffs and their impact on throughput of the system is also a part of research carried by many researchers [7]. For the optimization of throughput and minimizing energy consumption, clustering techniques also used [8]. The blocking probabilities, throughput, waiting time like performance parameters are derived with teaching like techniques [9]. The Resource Utilization of multi-channel model supported by Multi-Radio Environment in Cognitive Radio environment based on Wireless Mesh Networks is also made possible with the cooperative transmitters and antennas with different strategies [10].

All the research works not much focused on the basic concepts of interweaving paradigm with and without buffer constraints and type of service patterns. The deterministic services are only considered by most of the researchers and the effective utilization of M/M/C/K finite queuing model where K is buffer capacity and C is no. of channels is not properly done. The primary focus of this paper is to provide the role and importance of buffers reserved only for interrupted secondary users. The comparative analysis will provide the importance of buffers in service provision to users by comparing the results obtained with two service channels and one buffer to be used only for interrupted secondary users with the case of two service channels with no buffer.

The remaining paper is organized as follows. In Section 2, the relevant literature is presented precisely. The mathematical model and the transitional state diagram are explained in Section 3. The numerical analysis is carried in Section 4. Finally, conclusions are given in Section 5.

2. Literature Survey

Cognitive radios are the intelligent devices helps in optimal usage of the Spectrum. The different paradigms, architecture and working mechanism [11] helps in implementing the Channel usage strategies. The admission control mechanism for the channel usage is discussed in [12] but the dynamic model chosen is far from real-time implementation. The decision to join the system for service is discussed in some research papers but not considered the interruption of secondary users. The throughput and waiting time are the most importance parameters considered in research but no comparison with no buffer approach is done. Queuing analysis with multi level priority queues [13] is limited to underlay networks is not effective in spectrum utilization compared with interweaving paradigm. The admission of secondary users into buffer with variations [14] and [15] is also considered but no comparisons were drawn without buffer option.

3. Interrupted Secondary Users Buffer Queuing Model (ISUBQM)

Different authors proposed and analyzed Cognitive Radio Networks with M/D/1 and other queuing models for obtaining the optimum spectrum usage by both types of users. But many of them have not considered the idea of creating a buffer for interrupted secondary users. In this work, an attempt has been made to analyze the CRN with a dedicated buffer for the interrupted secondary users.

To evaluate the dynamic behavior of the CRN with buffer mechanism, the M/M/C/K (multi-channel with buffer) queuing model is proposed and analyzed for the different performance metrics with two channels supported by one buffer for the interrupted secondary users. The two channels option is considered to minimize the complexity of the problem. This model covers the users’ population containing both types of users: Primary and Secondary who are in need of Service. The generalized CRN with C channels and K buffers is depicted in the following figure 1.
3.1 Assumptions:

I. Both primary and secondary users arrival rate follow Poisson distribution.
II. Both users service time follow exponential distribution with same service rate.
III. Primary users given high priority.
IV. Secondary users have to vacate channel and kept in available buffer slot if primary user arrives and also all channels are occupied.
IV. When any channel becomes available, interrupted secondary user may resume the service.

3.2 Notations:

$\lambda_p$ - Primary user arrival rate
$\lambda_s$ - Secondary user arrival rate
$\mu$ - Service rate
$C$ - Number of service channels
$K$ - Buffer size
$L$ - Average length of the Queue
$W_p$ - Waiting time of primary users
$W_s$ - Waiting time of secondary users
$P_{loss}$ – Expected primary user loss
$S_{loss}$ – Expected Secondary user loss

The state diagrams 2.(a) and 2.(b) are drawn showing the all possibilities of state changes with the arrivals and departures of both primary and secondary users with two channels with one buffer and without buffer.
Let \( P_{i,j,k} \) be the probability of occurrence of a state where \( i \) used to represent the number of channels in use by the primary users and \( j \) is used for representing the number of channels in use by the secondary users and \( k \) is used to represent the buffer occupied by number of secondary users interrupted and waiting for resumption of service.

The differential difference equations for all possible cases considered for availing the service are

A) For M/M/C/K Model for two channels with one buffer

Case 1: When all channels are free,

\[
P_{0,0,0}(t) = -(\lambda_p + \lambda_s)P_{0,0,0}(t) + \mu P_{1,0,0}(t) + \mu P_{0,1,0}(t) \tag{1}
\]

Case 2: When one channel is engaged by secondary user and second channel is free,

\[
P_{0,1,0}(t) = -(\lambda_s + \lambda_p + \mu)P_{0,1,0}(t) + \lambda_s P_{0,0,0}(t) + \mu P_{0,2,0}(t) + \mu P_{1,1,0}(t) \tag{2}
\]

Case 3: When all channels are allocated to secondary users,

\[
P_{0,2,0}(t) = -(\lambda_p + \mu)P_{0,2,0}(t) + \lambda_p P_{0,1,0}(t) + \mu P_{1,1,0}(t) \tag{3}
\]

Case 4: When one channel is engaged by primary user and the second channel is not occupied by any user,

\[
P_{1,0,0}(t) = -(\lambda_s + \lambda_p + \mu)P_{1,0,0}(t) + \lambda_s P_{0,1,0}(t) + \mu P_{2,0,0}(t) + \mu P_{1,1,0}(t) \tag{4}
\]

Case 5: When all channels are reserved to both primary and secondary users,

\[
P_{1,1,0}(t) = -(\lambda_p + \mu)P_{1,1,0}(t) + \lambda_p P_{0,1,0}(t) + \lambda_s P_{1,0,0}(t) + \mu P_{2,1,0}(t) + \mu P_{1,1,0}(t) \tag{5}
\]
Case 6: When all channels are engaged by both users & buffer is occupied by interrupted secondary user,
\[ p_{i,1,1}(t) = -((\lambda_p + \mu)p_{i,1,1}(t) + \lambda_p p_{i,2,0}(t)) \] --(6)

Case 7: When all the channels are occupied by the primary users,
\[ p_{i,0,0}(t) = -((\mu)p_{i,0,0}(t) + \lambda_p p_{i,1,0}(t)) \] --(7)

Case 8: When all the channels are engaged by primary users and the buffer is filled up by interrupted secondary users,
\[ p_{i,0,1}(t) = -((\mu)p_{i,0,1}(t) + \lambda_p p_{i,1,0}(t) + \lambda_p p_{i,1,1}(t)) \] --(8)

The sum of all probabilities for all the 8 cases being equated to 1,
\[ p_{0,0,0}(t) + p_{0,1,0}(t) + p_{1,0,0}(t) + p_{1,0,1}(t) + p_{i,1,0}(t) + p_{i,1,1}(t) + p_{i,2,0}(t) + p_{i,2,1}(t) = 1 \] --(9)

B) For M/M/C/K Model for two channels with no buffer

Case 1: When all channels are free,
\[ p_{0,0}(t) = -((\lambda_2 + \lambda_p)p_{0,0}(t) + \mu p_{0,1}(t) + \mu p_{0,1}(t)) \] --(10)

Case 2: When one channel is engaged by secondary user and second channel is free,
\[ p_{0,1}(t) = -((\lambda_2 + \lambda_p + \mu)p_{0,1}(t) + \lambda_2 p_{0,0}(t) + \mu p_{1,1}(t) + \mu p_{0,1}(t)) \] --(11)

Case 3: When all channels are engaged by secondary users,
\[ p_{0,2}(t) = -((\lambda_2 + \mu)p_{0,2}(t) + \lambda_2 p_{0,1}(t)) \] --(12)

Case 4: When one channel is engaged by primary user and second channel is free,
\[ p_{1,0}(t) = -((\lambda_2 + \lambda_p + \mu)p_{1,0}(t) + \lambda_2 p_{0,0}(t) + \mu p_{2,0}(t) + \mu p_{1,1}(t)) \] --(13)

Case 5: When all channels are occupied by both primary and secondary users,
\[ p_{1,1}(t) = -((\lambda_2 + \mu)p_{1,1}(t) + \lambda_2 p_{0,1}(t) + \lambda_2 p_{1,0}(t) + \lambda_p p_{0,2}(t)) \] --(14)

Case 6: When primary users engages all the channels,
\[ p_{2,0}(t) = -((\mu)p_{2,0}(t) + \lambda_2 p_{1,0}(t) + \lambda_p p_{1,1}(t)) \] --(15)

3.4 Performance Analysis

a. Probability generating functions:

By considering two channels for service provision and one buffer is maintained
2 \sum_{i=0}^{2} \sum_{j=2-i}^{2} \sum_{k=0}^{1} (i+j+k) P_{i,j,k} x_i y_j z_k

By considering two channels for service provision and no buffer is maintained,

\[ G_1(x,y,0) = \sum_{i=0}^{2} \sum_{j=0}^{2-i} x_i y_j \]

b. Average Queue Length:

The length of time to wait in buffer by the input depends on inter-arrival times of between the inputs and the Processor’s processing time. The number of inputs (queue size) under waiting can be a random number.

The Average Queue Length is defined for ISUBQM based on

\[ L = 1*p(2)+2*p(3)+3*p(4)+1*p(5)+2*p(6)+3*p(7)+2*p(8)+3*p(9) \]

The Average Queue Length is defined for IBUNBQM based on

\[ L = 1*p(2)+2*p(3)+1*p(4)+2*p(5)+2*p(6) \]

c. Average Waiting Time:

The users waiting in buffer to utilize the channel service is called waiting time.

\[ W = L/\lambda \quad \text{where} \quad \lambda = \lambda_p + \lambda_s \]

4. Numerical Illustration

In this section, using MAT Lab, the performance metrics are evaluated as presented in the above section for various values of \( \lambda_p, \lambda_s, \mu, c=2 \) and \( k=1 \). The numerical illustrations are carried out in two scenarios, they are time-dependent performance metrics and time independent performance metrics i.e. both users’ loss probabilities.

4.1 Time-Dependent Performance Metrics:

\( \lambda_p \) values are raised from 0.3 to 0.7 for different values of \( \lambda_s \) ranging from 0.4 to 0.7 are taken for calculating time dependent performance metrics. For all these calculations, the \( \mu \) value is taken as 1.1.

**Table 1: Calculating Avg. Queue Length and Avg. Waiting time for different primary and secondary users arrival rates:**

| \( \lambda_s \) | \( \lambda_p \) | For M/M/C/K Model for two channels with one buffer | For M/M/C/K Model for two channels with no buffer |
|-----------------|-----------------|-----------------------------------------------|-----------------------------------------------|
|                 |                 | Avg. Queue length | Avg. Waiting time | Avg. Queue length | Avg. Waiting time |
| 0.4             | 0.3             | 0.37057           | 0.42846           | 0.38913           | 0.55747           |
|                 | 0.4             | 0.43747           | 0.48385           | 0.43731           | 0.54663           |
Case-1 : Based on Average Queue Length:

Based on values derived above, when a graph is plotted for different arrival rates of primary and secondary user considering the average queue length values.

| λp | λs | Avg Que Length with Buffer | Avg Que Length without Buffer |
|----|----|----------------------------|------------------------------|
| 0.5| 0.48551 | 0.53946 | 0.48591 | 0.5399 |
| 0.6| 0.53353 | 0.59483 | 0.53448 | 0.53448 |
| 0.7| 0.58465 | 0.64995 | 0.58266 | 0.52971 |
| 0.5| 0.43766 | 0.4863 | 0.43814 | 0.54768 |
| 0.4| 0.48478 | 0.53863 | 0.48237 | 0.53596 |
| 0.5| 0.53308 | 0.59132 | 0.52735 | 0.52735 |
| 0.6| 0.57952 | 0.64392 | 0.57261 | 0.52054 |
| 0.7| 0.62654 | 0.69617 | 0.61775 | 0.51481 |
| 0.6| 0.4892 | 0.53557 | 0.48611 | 0.54012 |
| 0.4| 0.53362 | 0.59293 | 0.52646 | 0.52646 |
| 0.5| 0.57849 | 0.64308 | 0.56788 | 0.51625 |
| 0.6| 0.62342 | 0.69269 | 0.6099 | 0.50824 |
| 0.7| 0.66814 | 0.74238 | 0.65211 | 0.50161 |

It is observed from fig.3 that the average queue length parameter has shown a relative increase in its value as the arrival rates increases. With increase in secondary user arrival rate, the average queue length increasing compared to without buffer which is showing the increase in service to users when a buffer is available.

Case-2 : Based on Average Waiting Time:

When average waiting time parameter is considered with different values of $\lambda_p, \lambda_s$, with the increase in arrival rates of primary or secondary users is shown in figure 4.
Fig 4: Effect of $\lambda_p, \lambda_s$ on Average Waiting time

It is observed from fig.4 that the average waiting time parameter has shown a relative increase in its value as the arrival rates increases in with buffer case. But the decrease in waiting time is observed with no buffer case as the secondary users are dropped because of no space in queue. From the graph, it can be concluded that the reverse phenomenon takes place between with and without buffer and the as no waiting issue with no buffer, the waiting time shows a decrease in values as primary user arrivals increases. This also shows the loss of secondary user service when the system has no buffer.

5. Conclusion
This paper investigates the effect of the interrupted secondary users occupancy performance when buffer mechanism provided. M/M/C/K analytical queuing model is formulated and derived differential difference equations based on state transition diagram. Average Queue Length and average queuing time shows upward trend when $\lambda_p, \lambda_s$ increases. The system shows the increase in waiting time of secondary users when primary user arrivals increases and indirectly it shows increase in throughput compared to system without buffer to hold interrupted secondary users. This analysis is helpful in spectrum management decision process of CRN. Further scope of this work to enhance the buffer capacity and derive the differential difference equations and then find the effect of the buffer capacity.

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