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Transient Analysis of CRN with Provision of Finite Buffer for Secondary Users

B.B.V. Satya Vara Prasad, B. Basaveswara Rao, V. Vasanta Kumar, K. Chandan

Abstract: The transient analysis of secondary users with opportunistic access to the spectrum with the provision of buffer is studied in this paper. As the research issues discussed in this paper deals with multiple channels for service provision and a buffer used for waiting to avail service, the analytical finite queuing model, M/M/C/K fits to the problem scenario is opted. With the progression of time, the spectrum management with Cognitive Radio Networks (CRN) becomes unstable as the demand from both secondary and primary users varies. To handle these fluctuations in arrival rate, this paper focuses on the issues of provision of buffer not only to interrupted secondary users but also to the newly arriving secondary users when all channels are busy. The ultimate goal of spectrum management is to avail maximum revenue with the effective usage of resources and the provision of same buffer also for newly arriving users whether increases in throughput is discussed. In this paper, much focus is carried towards the optimal usage of buffer for increasing the service rate to the secondary users waiting for opportunistic access of the spectrum so that maximum revenue can be generated. The timely varying problems are handled by modeling the system with priorities among the users while accessing the channels and occupying the buffer. The reservation of channels by newly arrived secondary users waiting in buffer deals with the admission control issues with a confidence factor in channel access. The paper modeled to deal these objectives by deriving differential equations and important performance metrics are evaluated. Numerical illustration is carried out and the analytical results presented as tables and graphs and conclusions are drawn.

Index Terms: Cognitive radio networks, M/M/C/K, queue length, throughput, blocking probability

I. INTRODUCTION

The innovations in technologies like IoT added more wireless devices increased the use the spectrum usage. The increase in demand of the Spectrum can be managed by introducing the intelligent sensing and sharing technologies like Cognitive Radio Networks. The use of Cognitive Radio technology improves the spectrum usage in efficient manner by providing the unused white spaces of the Spectrum which is a result of poor usage of Spectrum by the high priority authorized users. The paradigms like overlay, underlay and interweaving are introduced for effective usage of the white space and out of these all, the interweaving paradigm allows the complete and best utilization of the resources with available white space. Interweaving paradigms supports the opportunistic usage of the spectrum by allowing non-priority users to access and use the spectrum resources whenever a white space band is formulated in the usage scenarios of the high priority users.

The high-priority or licensed or authorized users of the Spectrum are called as Primary users (PU) who have a direct access of the Spectrum and the remaining low-priority or unlicensed or unauthorized users are called as Secondary Users (SU) who are waiting for an opportunity to use the spectrum and additional revenue can be generated by leasing the resources available in the usage intervals of Primary Users. The huge demand to the spectrum by the secondary users is the great opportunity to the system administrator to implement such strategies for effective utilization and profit generation.

In the interweaving paradigm, the advantage is that the complete utilization of the resources takes place irrespective of the type of user. The interruptions to secondary users can take place in the service provision with the arrivals of primary users when all resources are freeze up. The interruptions can be handled with the provision of the buffer where the interrupted secondary users wait for resumption of their service when the channels are freed. Most of the authors focused only on the buffer management for interrupted secondary users but not focused on the provision of empty buffer space to the newly arrived secondary users when all channels are busy. In this paper, the focus is over the optimal utilization of the buffer that can be possible by allowing the new secondary users to wait in the buffer for gaining the spectrum resources whenever an opportunity exists. The priority of interrupted secondary user is high compared to the newly arrived secondary user in the allocation of the channel.

The transient analysis of Data Traffic in CRN [1] is studied with a non-equilibrium statistical mechanics approach is the basis for carrying the transitive analysis in this paper but the referenced paper is implemented with Jackson Network that deals with equilibrium related issues. The primary queue stability constraint [2] for high bandwidth utilization also discussed related to throughput issues but not covered efficiently the buffer utilization issues. Two-server and single-queue case with interruptions from Primary Users [3] covers dynamic spectrum access but is modeled with Markov chains. The performance issues of CRN are discussed in [4] but covered with M/G/1/K Queuing model where only single server is considered with underlay model.

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* Correspondence Author

B.B.V. Satya Vara Prasad*, Research Scholar Department of CSE, Acharya Nagarjuna University, Guntur, India & Assistant Professor in KLEF, Vaddeswaram, India .

B. Basaveswara Rao, University Computer Centre, Acharya Nagarjuna University, Guntur, India.

V. Vasanta Kumar, Professor& Head of the Department, Department of Mathematics, K L E F, Vijayawada, India.

K. Chandan, Professor, Department of Statistics, Acharya Nagarjuna University, Guntur, India.

The optimal admission control in Cognitive Radio Networks [5] is helpful in throughput and forced termination but not clearly explained buffer usage for newly arrived users. The throughput of CRN under congestion constraints [6] is studied but not with the interweaving paradigm where interference can take place.

The analytical model covering with and without buffer issues for Ad Hoc networks using CRN [7] covers blocking probability issues but deals with Markov chains and Single Server issues. In this paper, an advance research is carried to implement multi-server approach. Most of the research works covered the interweaving paradigm with multi queue approach but not focused on provision of finite buffer shared to both the two classes of secondary users with multi-channel system considered with the deterministic services. To fulfill this gap, the research work is carried out with the following objectives:

- To provide an analytical model for both newly arrived and interrupted secondary users with buffer mechanism when all channels are busy using M/M/C/K where K is buffer capacity and C is no. of channels.
- To derive differential equations for analyze the variations in performance parameters like queue length, waiting time and blocking probabilities.
- Finally, numerical illustration is carried out for multiple channels with finite buffer to handle classified secondary users and conclusions are drawn.

The remaining paper is organized as follows. In Section 2, the relevant literature is presented precisely. The model was presented to explain the functionality of the system and is elaborated with the state diagram exhibiting all the possible states of the system. The mathematical model covering generalized equations with all possible cases are explained in Section 3. The numerical analysis provided in Section 4. Finally, results and conclusions are given in Section 5

II. LITERATURE SURVEY

Cognitive Radio Technology is playing major role in effective utilization of bandwidth of the Spectrum to meet the demand and requirements of the users. Queuing Models for Cognitive Radio Networks [8] explained the importance of adapting queuing model for the performance improvement of the CRN but focused on M/M/1 queuing model where multiple channel service utilization is not clearly explained. Hybrid priorities among secondary user queues [9] are discussed but the implementation focused on classifying queues but not on optimal usage of a single queue for handling multi-class secondary users. The throughput estimators [10] algorithms are widely studied but not focused on the special domain of CRN and is limited to all types of 802.11 networks. The spectrum handoffs with finite switching delays[11] explained as the average delays of cognitive users but not covered the optimal buffer usage issues clearly. Improving spectrum handoff utilization for prioritized cognitive radio users by exploiting channel bonding with starvation mitigation [12] deals with starvation issues but starvation is a low-priority issue for multi-channel system. Channel reservation [13] technique helps to improve the throughput with Markov chains is adapted in this paper but with M/M/C/K model. The probabilistic soft queuing model established as flexible queuing model for number of active users in CRN[14] deals with multi-channel reliability issues but with a non-deterministic approach. Average System Time is measured for cognitive users in [15] for the system modeled as M/G/1 is also a good performance metric in the research with CRN considered in this paper. The priority and retrial queues [16] is a variant approach to discuss the performance issues but is implemented with CTMC (Continuous Time Markov Chain) Model. The transient analysis carried with Discrete-Time Multi-Server Queuing Model [17] discussed mean response time of the users but with infinite size buffer. This paper is enhancing the previous research carried with [18] by allowing new users into buffer if all channels are occupied and buffer space is available.

III. SECONDARY USERS BUFFER QUEUING MODEL (SUBQM):

The usage of buffer is the issue to be considered for managing secondary users in Cognitive Radio Networks. When opportunistic access is given for secondary users and preemptions are considered, the buffer is used to handle the interrupted secondary users. Many authors have not given much priority to buffer related issues but the buffer usage seems to be crucial in service provision with increase in throughput. The buffer provision is initially restricted to interrupted secondary users but the extension of its use by newly arriving secondary users can affect the service issues in the positive aspect. In this work, an attempt has been made to analyze the CRN system with a buffer provided for both the interrupted and newly arriving secondary users when all channels are busy. For the evaluation of the dynamic behavior of these Cognitive Radio Networks, the M/M/C/K queuing model is proposed and analyzed for different performance metrics like Queue Length and Throughput. In this model, the primary and secondary users are covered under user population who are in need of Service and the finite buffer of size K is reserved for both interrupted and newly arriving secondary users when all channels, C in number are occupied. The generalized model covering these issues is shown in the following figure: 1.

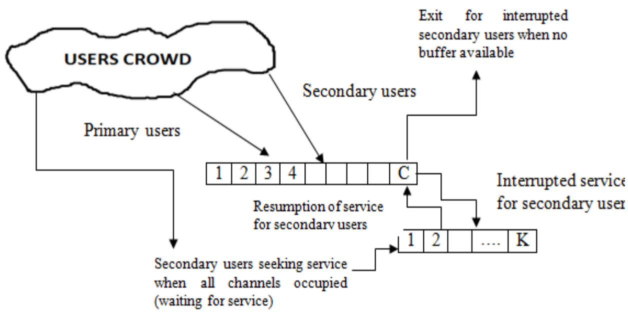

Figure 1: CRN with C channels and K buffers for Secondary Users

Assumptions:

- Both primary and secondary users arrival rate follow Poisson distribution.

- Both users service time follow exponential distribution with same service rate.
- High priority is given to Primary Users in channel allocation.
- Upon arrival of Primary user, if all channels are occupied by both users, then the Secondary user has to vacate the channel and has to wait in the buffer.
- When any channel becomes available, interrupted secondary user may resume the service.
- The number of channels C is equivalent to buffer size k because this analytical study restricted to interrupted secondary users utilize the buffer when the primary user arrives and all channels are occupied. At any time , the number of interrupted secondary users will not exceed the number of channels. So, the buffer size is limited to channel size for efficient memory utilization.
- Any new secondary user seeking service is allowed to wait in buffer if free space is available and will be given more priority than the secondary user in crowd.
- The allocation of buffer to secondary users is done with the following priorities:
  > High priority to interrupted secondary users
  > Low priority to newly arrived secondary users
- Preemption is possible with newly arrived secondary users in buffer if no free space is available for interrupted secondary user
- The channel allocation for newly arrived secondary users waiting in buffer is done only after resumption of all interrupted secondary users only

Notations:

λ_p : - Primary user arrival rate
λi : - Secondary user (Service Assured) arrival rate
λn : - Secondary user (to be waited in queue) arrival rate
μ : - Service rate
n : - Number of channels reserved for providing service
k : - Buffer size
np : - Number of channels occupied by primary users
ni : - Number of channels occupied by secondary users
nn : - Number of secondary users newly arrived and waiting in queue
L : - Average length of the Queue
Wp : - Waiting time of primary users
Ws : - Waiting time of secondary users
Pl : - Expected primary user loss
Sl : - Expected Secondary user loss
T : - Throughput of the System
Stput : - Throughput of Secondary Users
Ptput: - Throughput of Primary Users

The state diagram, Figure 2 is drawn showing the all possibilities of state changes with the arrivals and departures of both primary and secondary users. The bottom portion of the State diagram 2 covers the case of no requirement of buffer for any user as the channels are vacant and available to avail service. The upper portion of the State diagram 2 covers the scenario of occupying buffer by secondary user satisfying the constraints. The buffer is used by both interrupted and newly arrived secondary users after the allocation of all the channels is done. The buffer size is maintained as the same number of channels, n in the network.

The left to right navigation of the state diagram shows all the states of occupation of channels by secondary users when they are freed by primary users and bottom to top navigation shows the increase in buffer usage by newly arrived secondary users to the maximum extent.

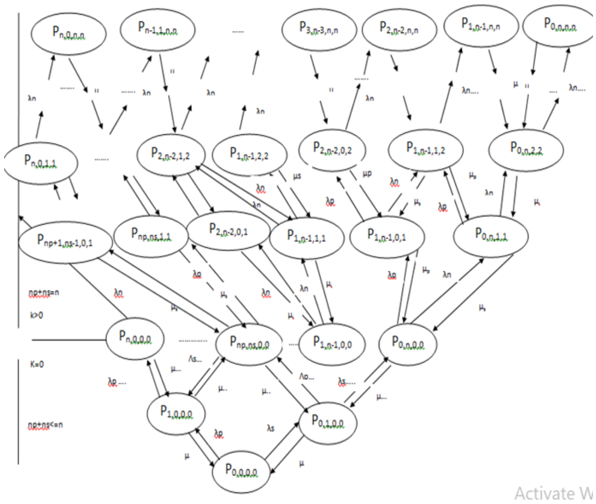

Fig 2: State transition diagram for channels c=n and buffer size k=n for secondary user management.

Let P $_{np,\ ni,\ nn,\ k}$ be the probability of occurrence of a state where np represents the no. of channels in use by primary users and ni represents the no. of channels in use by secondary users and k represents the buffer occupied by no. of interrupted secondary users for waiting the resumption of service.

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

Case 1: When all channels are free,

$$p'_{0,0,0,0}(t) = -(\lambda_i + \lambda_p)p_{0,0,0,0}(t) + \mu p_{1,0,0,0}(t) + \mu p_{0,1,0,0}(t) \quad \text{--- (1)}$$

Case 2: When channels are occupied by primary users only and vacant channels are available,

i.e. 1<= np< n, ni=0, nn=0,k=0

$$p'_{np,0,0,0}(t) = -(\lambda_i + \lambda_p + \mu)p_{np,0,0,0}(t) + \lambda_p p_{np-1,0,0,0}(t) + \mu p_{np+1,0,0,0}(t) + \mu p_{np,1,0,0}(t) \quad \text{--(2)}$$

Case 3: When all channels are occupied by primary users, i.e. np = n, ni=0,nn=0,k=0

$$p'_{n,0,0,0}(t) = -(\mu + \lambda_n)p_{n,0,0,0}(t) + \lambda_p p_{n-1,0,0,0}(t) \quad \text{--- (3)}$$

Case 4: When channels are occupied by secondary users only and vacant channels are still available,

i.e. 1<= ns< n, np=0,nn=0, k=0

$$p'_{0,ni,0,0}(t) = -(\lambda_i + \lambda_p + \mu)p_{0,ni,0,0}(t) + \lambda_i p_{0,ni-1,0,0}(t) + \mu p_{1,ni,0,0}(t) + \mu p_{0,ni+1,0,0}(t) \quad \text{--- (4)}$$

Case 5: When all channels are occupied by secondary users and the buffer is empty,

i.e. ni= n, np=0,nn=0, k=0

$$p'_{0,n,0,0}(t) = -(\lambda_n + \lambda_p + \mu)p_{0,n,0,0}(t) + \lambda_i p_{0,n-1,0,0}(t) + \mu p_{1,n-1,0,1}(t) + \mu p_{1,n-1,1,1}(t) + \mu p_{0,n,1,1}(t)$$
--- (5)

Case 6: When all channels are occupied by primary users and the buffer is partially occupied with new users, i.e. np=n, ni=0,k=nn, 1<=k< n

$$p'_{n,0,nn,k}(t) = -(\mu + \lambda_n)p_{n,0,nn,k}(t) + \lambda_n p_{n,0,nn-1,k-1}(t)$$
--- (6)

Case 7: When all channels are occupied by primary users and the buffer is fully occupied with new users, i.e. np=n, ni=0,k=nn, k=n

$$p'_{n,0,n,n}(t) = -(\mu)p_{n,0,n,n}(t) + \lambda_n p_{n,0,n-1,n-1}(t)$$
--- (7)

Case 8: When all channels are occupied by primary users and the buffer is partially occupied with interrupted users, i.e. np=n, ni=0, nn=0,1<= k<n

$$p'_{n,0,0,k}(t) = -(\lambda_n + \mu)p_{n,0,0,k}(t) + \lambda_p p_{n-1,1,0,k-1}(t)$$
--- (8)

Case 9: When all channels are occupied by primary users and the buffer is completely occupied with interrupted users, i.e. np=n, ni=0, nn=0, k=n

$$p'_{n,0,0,n}(t) = -(\mu)p_{n,0,0,n}(t) + \lambda_p p_{n-1,1,0,n-1}(t) + \lambda_p p_{n-1,1,1,n}(t)$$
--- (9)

Case 10: When all channels are occupied by primary users and the buffer is partially occupied with both users, i.e. np=n, 1<=ni,nn<n-1,2<=k<n

$$p'_{n,0,nn,k}(t) = -(\lambda_n + \mu)p_{n,0,nn,k}(t) + \lambda_p p_{n-1,1,nn,k-1}(t) + \lambda_n p_{n,0,nn-1,k-1}(t)$$
--- (10)

Case 11: When all channels are occupied by primary users and the buffer is fully occupied with both users, i.e. np=n, 1<=ni,nn<=n-1,k=n

$$p'_{n,0,nn,n}(t) = -(\mu)p_{n,0,nn,n}(t) + \lambda_p p_{n-1,1,nn,n-1}(t) + \lambda_n p_{n,0,nn-1,n-1}(t) + \lambda_p p_{n-1,1,nn+1,n}(t)$$
--- (11)

Case 12: When all channels are occupied by secondary users and the buffer is partially occupied with new users, i.e. np=0, ni=n, 1<=nn<n,k=nn

$$p'_{0,n,nn,k}(t) = -(\lambda_n+\lambda_p + \mu)p_{0,n,nn,k}(t) + \lambda_n p_{0,n,nn-1,k-1}(t) + \mu p_{1,n-1,nn,k+1}(t) + \mu p_{1,n-1,nn+1,k+1}(t) + \mu p_{0,n,nn+1,k+1}(t)$$
--- (12)

Case 13: When all channels are occupied by secondary users and the buffer is filled with new users,
i.e. np=0, ni=n, nn=n,k=n

$$p'_{0,n,n,n}(t) = -(\lambda_p + \mu)p_{0,n,n,n}(t) + \lambda_n p_{0,n,nn-1,n-1}(t)$$
--- (13)

Case 14: When channels are occupied by both primary and secondary users and some channels are still vacant, i.e. 2<= np + ni < n , np >0,ni>0, nn=0, k=0

$$p'_{np,ni,0,0}(t) = -(\lambda_i + \lambda_p + \mu)p_{np,ni,0,0}(t) + \lambda_p p_{np-1,ni,0,0}(t) + \lambda_i p_{np,ni-1,0,0}(t) + \mu p_{np+1,ni,0,0}(t) + \mu p_{np,ni+1,0,0}(t) +$$
--- (14)

Case 15: When all channels are occupied by both primary and secondary users & buffer is empty, i.e. np + ni = n , np >0,ni>0, nn=0, k=0

$$p'_{np,ni,0,0}(t) = -(\lambda_n + \lambda_p + \mu)p_{np,ni,0,0}(t) + \lambda_p p_{np-1,ni,0,0}(t) + \lambda_i p_{np,ni-1,0,0}(t) + \mu p_{np+1,ni-1,0,1}(t) + \mu p_{np+1,ni-1,1,1}(t) + \mu p_{np,ni,0,1}(t) + \mu p_{np,ni,1,1}(t)$$
--- (15)

Case 16: When all channels are occupied by both users and buffer is partially filled with interrupted secondary users only,

i.e. np + ni = n , np >0,ni>0, nn=0, 1<=k<np

$$p'_{np,ni,0,k}(t) = -(\lambda_n + \lambda_p + \mu)p_{np,ni,0,k}(t) + \lambda_p p_{np-1,ni+1,0,k-1}(t) + \mu p_{np+1,ni-1,0,k+1}(t) + +\mu p_{np,ni,0,k+1}(t)$$
--- (16)

Case 17: When all channels are occupied by both users and buffer is filled with interrupted secondary users only,

i.e. np + ni = n , np >0,ni>0, nn=0, k=np

$$p'_{np,ni,0,k}(t) = -(\lambda_n + \lambda_p + \mu)p_{np,ni,0,np}(t) + \lambda_p p_{np-1,ni+1,0,np-1}(t) + \mu p_{np+1,ni-1,0,np+1}(t)$$
--- (17)

Case 18: When all channels are occupied by both users and buffer is partially filled with new secondary users only,

i.e. np + ni = n , np >0,ni>0, nn>0, 1<=nn<n,k=nn

$$p'_{np,ni,nn,nn}(t) = -(\lambda_n + \lambda_p + \mu)p_{np,ni,nn,nn}(t) + \lambda_n p_{np,ni,nn-1,nn-1}(t) + \mu p_{np+1,ni-1,nn+1,nn+1}(t) + +\mu p_{np,ni,nn+1,nn+1}(t) + \mu p_{np+1,ni-1,nn,nn+1}(t) + \mu p_{np,ni,nn,nn+1}(t)$$
--- (18)

Case 19: When all channels are occupied by both users and buffer is filled with new secondary users only,
i.e. np + ni = n , np >0,ni>0, nn=n, k=n

$$p'_{np,ni,n,n}(t) = -(\lambda_p + \mu)p_{np,ni,n,n}(t) + \lambda_n p_{np,ni,n-1,n-1}(t)$$
--- (19)

Case 20: When all channels are occupied by both users and buffer is filled partially with both new & interrupted secondary users,
i.e. np + ni = n , np >0,ni>0, 1<= k<n,0<nn<k<n,

$$p'_{np,ni,nn,k}(t) = -(\lambda_p + \lambda_n + \mu)p_{np,ni,nn,k}(t) + \lambda_n p_{np,ni,nn-1,k-1}(t) + \lambda_p p_{np-1,ni+1,nn,k-1}(t) + \mu p_{np+1,ni-1,nn,k+1}(t) + \mu p_{np,ni,,nn,k+1}(t)$$
--- (20)

Case 21: When all channels are occupied by both users and buffer is filled with both new & interrupted secondary users,
i.e. np + ni = n , np >0,ni>0, k=n

$$p'_{np,ni,nn,n}(t) = -(\lambda_p + \mu) p_{np,ni,nn,n}(t) + \lambda_n p_{np,ni,nn-1,n-1}(t) + \lambda_p p_{np-1,ni+1,nn+1,n}(t) + \lambda_p p_{np-1,ni+1,nn,n-1}(t) \quad \text{--- (21)}$$

IV. PERFORMANCE ANALYSIS

In this section various performance metrics: Expected Queue Length, Throughput, Average Waiting Time and Packet Blocking Probability for both the users are presented based on the model explained above.

a. Queue Length (L):

Depending on inter-arrival times of between inputs and Processor 's processing time, the length of time an input waits in Buffer can vary widely. Thus the number of waiting inputs (queue size) can be a random number.

The Queue Length of system is defined for SUBQM based on

$$L = \sum_{i=0}^{n} \sum_{j=0}^{n-i} \sum_{k=0}^{n} \sum_{x=k}^{n} (i + j + x) P_{i,j,k,x}$$

b. Waiting Time (W):

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

$W = L / \lambda$ where $\lambda = \lambda i + \lambda n$

c. Blocking Probability of Primary User (P_{loss}):

When primary user arrives, the secondary user if any in service will be interrupted for providing service to primary user. When all the channels are occupied by primary users, the new primary user will not be given service and this situation will give the blocking probability of primary user. It can be shown as

$$P_{loss} = \left((\lambda p/\mu)^n / n! \right) / \left(\sum_{i=0}^{n} ((\lambda p/\mu)^i / i! \right)$$

d. Blocking Probability of Secondary User (S_{loss}):

When the secondary users are not given to utilize the channel service when all the channels are occupied , the blocking probability is given as

$$S_{loss} = \left(((\lambda n + \lambda i)/\mu)^n / n! \right) / \left(\sum_{i=0}^{n} (((\lambda n+\lambda i)/\mu)^i / i! \right)$$

e. Throughput (T):

Throughput is the maximum rate of production or the maximum rate at which something can be processed. When $\boldsymbol{\lambda = \lambda p + \lambda i + \lambda n}$ is considered as the arrivals of users, the final throughput can be considered as

T = λp- λp *{Total probability of primary users unable to get the service} + (λi + λn) – (λi + λn)*{Total probability of secondary users unable to get the service}

Numerical Illustration:

In this section, using MAT Lab, the performance metrics presented in the above section are evaluated for various values of λp, λi, λn, μ, n and k. In all the cases, the size of buffer is considered as k=n as n is the maximum number of users that can be interrupted at any instance. 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.

Case-1: Time-Dependent Performance Metrics:

To evaluate the performance metrics, the values of the parameters are considered in the following manner:

Parameter	Range
Primary user arrival rate, λp	0.4 – 0.6
Secondary user (Service gained) arrival rate, λi	0.4 – 0.6
Secondary user (queued) arrival rate, λn	0.4 – 0.6
Service Rate, μ	1.6 – 1.8
Number of channels, n	2 – 4
Time, t	0.1 - 0.5 (interval 0.1)

Table 1: Range of values considered for different input parameters

The derived values of performance metrics with the parameters considered from Table 1 are presented in the following tables.

Table 2: Calculations of Queue Length-L(t) and Secondary User Throughput T(t) for different values of secondary users' arrivals with number of channels raging from 2 to 4 :

Table 2.1 : Effect of λn under different values of 't' when λp = 0.4 , λi=0.4 and μ=1.6

λn							
		Time	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**
0.4	n=2	**L(t)**	0.07812565	0.14168688	0.19498295	0.24090525	0.28140762
		T(t)	0.8	0.79997792	0.79990204	0.79975593	0.79953335
	n=3	**L(t)**	0.07844248	0.1430824	0.19754733	0.24443873	0.28563766
		T(t)	.8	0.8	0.79999996	0.7999997	0.79999886
	n=4	**L(t)**	0.07844248	0.14311728	0.19768748	0.24476104	0.28621855
		T(t)	0.8	0.8	0.8	0.8	0.8
		Time	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**
0.5	n=2	**L(t)**	0.07812217	0.14174592	0.19528037	0.2416688	0.28288159
		T(t)	0.9	0.89996882	0.89986129	0.89965354	0.89933611
	n=3	**L(t)**	0.07844248	0.14308254	0.19755268	0.24446355	0.28570667
		T(t)	0.9	0.9	0.89999994	0.89999952	0.89999816
	n=4	**L(t)**	0.07844248	0.14311727	0.19768757	0.24476185	0.28622184
		T(t)	0.9	0.9	0.9	0.9	0.9
		Time	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**
0.6	n=2	**L(t)**	0.07811871	0.14180526	0.19557918	0.24243633	0.28436446
		T(t)	1	0.99995826	0.99981373	0.9995335	0.99910399
	n=3	**L(t)**	0.07844248	0.14308268	0.19755807	0.24448871	0.28577688
		T(t)	1	1	0.99999991	0.99999928	0.99999722
	n=4	**L(t)**	0.07844248	0.14311727	0.19768765	0.24476266	0.28622516
		T(t)	1	1	1	1	1

Table 2.2 : Effect of λn under different values of 't' when λp = 0.5 , λi=0.4 and μ=1.6:

λn							
		Time	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**
0.4	n=2	**L(t)**	0.08773778	0.15903659	0.21889775	0.27061272	0.31636053
		T(t)	0.8	0.79997253	0.79987836	0.79969751	0.7994 27
	n=3	**L(t)**	0.08808254	0.16053723	0.22164199	0.27441651	0.32101128
		T(t)	0.8	0.8	0.79999995	0.79999958	0.79999839
	n=4	**L(t)**	0.08808254	0.16057738	0.22180339	0.2747911	0.3216985
		T(t)	0.8	0.8	0.8	0.8	0.8
		Time	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**
0.5	n=2	**L(t)**	0.0877332	0.15910824	0.21925993	0.27153925	0.31814082
		T(t)	0.9	0.89996121	0.8998278	0.89957076	0.89917911
	n=3	**L(t)**	0.08808254	0.16053737	0.22164908	0.27444973	0.32110353
		T(t)	0.9	0.9	0.89999992	0.89999933	0.89999741
	n=4	**L(t)**	0.08808254	0.16057737	0.22180351	0.27479231	0.32170343
		T(t)	0.9	0.9	0.9	0.9	0.9
		Time	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**
0.6	n=2	**L(t)**	0.08772865	0.15918028	0.21962393	0.27247095	0.31993253
		T(t)	1	0.99994807	0.99976878	0.99942216	0.99889245
	n=3	**L(t)**	0.08808254	0.1605375	0.22165624	0.27448341	0.32119747
		T(t)	1	1	0.99999987	0.99999899	0.9999961
	n=4	**L(t)**	0.08808254	0.16057737	0.22180363	0.27479352	0.3217084
		T(t)	1	1	1	1	1

Table 2.3: Effect of λn under different values of 't' when λp = 0.6

λn							
0.4		**Time**	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**
	n=2	**L(t)**	0.0973476	0.17637894	0.24279619	0.30027754	0.35121339
		T(t)	0.8	0.79996718	0.79985493	0.7996398	0.79931363
	n=3	**L(t)**	0.09772476	0.17801674	0.24581531	0.30455515	0.35664741
		T(t)	0.8	0.8	0.79999993	0.79999944	0.79999785
	n=4	**L(t)**	0.09772476	0.17806459	0.24600884	0.30501078	0.35750099
		T(t)	0.8	0.8	0.8	0.8	0.8
		Time	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**
0.5	n=2	**L(t)**	0.09734167	0.17646236	0.24322125	0.30136241	0.35328942
		T(t)	0.9	0.89995367	0.89979465	0.89948897	0.89902432
	n=3	**L(t)**	0.09772476	0.1780168	0.24582413	0.30459729	0.3567647
		T(t)	0.9	0.9	0.89999989	0.8999991	0.89999655
	n=4	**L(t)**	0.09772476	0.17806458	0.24600899	0.30501245	0.35750791
		T(t)	0.9	0.9	0.9	0.9	0.9
		Time	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**
0.6	n=2	**L(t)**	0.09733577	0.17654627	0.24364859	0.3024537	0.3553795
		T(t)	1	0.99993797	0.99972426	0.99931208	0.99868378
	n=3	**L(t)**	0.09772476	0.17801687	0.24583306	0.30464008	0.35688428
		T(t)	1	1	0.99999983	0.99999865	0.99999482
	n=4	**L(t)**	0.09772476	0.17806457	0.24600915	0.30501413	0.35751487
		T(t)	1	1	1	1	1

Table 2.4 : Effect of λn under different values of 't' when λp = 0.5 , λi=0.5 and μ=1.6

λn							
0.4		**Time**	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**
	n=2	**L(t)**	0.0971571	0.17559756	0.2412525	0.29793906	0.34812921
		T(t)	0.9	0.89996154	0.89983075	0.89958149	0.89920545
	n=3	**L(t)**	0.09764117	0.17774105	0.24527173	0.30369809	0.35545773
		T(t)	0.9	0.9	0.89999991	0.8999993	0.89999733
	n=4	**L(t)**	0.09764117	0.17780767	0.2455426	0.30433286	0.35663008
		T(t)	0.9	0.9	0.9	0.9	0.9
		Time	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**
0.5	n=2	**L(t)**	0.09715167	0.17568862	0.24170478	0.29908514	0.35031484
		T(t)	1	0.99994638	0.99976348	0.99941391	0.9988853
	n=3	**L(t)**	0.09764117	0.17774132	0.24528197	0.30374505	0.35558678
		T(t)	1	1	0.99999986	0.9999989	0.99999579
	n=4	**L(t)**	0.09764117	0.17780767	0.2455428	0.30433478	0.35663779
		T(t)	1	1	1	1	1
		Time	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**
0.6	n=2	**L(t)**	0.09714626	0.17578014	0.24215919	0.30023727	0.35251379
		T(t)	1.1	1.09992894	1.09968569	1.09921934	1.09851222
	n=3	**L(t)**	0.09764117	0.1777416	0.24529231	0.30379263	0.35571807
		T(t)	1.1	1.1	1.09999979	1.09999838	1.09999379
	n=4	**L(t)**	0.09764117	0.17780766	0.245543	0.3043367	0.35664553
		T(t)	1.1	1.1	1.1	1.1	1.09999999

Table 2.5 : Effect of λn under different values of 't' when λp = 0.5 , λi=0.6 and μ=1.6

λn							
		Time	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**
0.4	n=2	**L(t)**	0.10654895	0.19202698	0.263331	0.3248099	0.3792525
		T(t)	1	0.99994894	0.99977658	0.99945043	0.99896169
	n=3	**L(t)**	0.10720252	0.19496157	0.26894076	0.33304221	0.389982
		T(t)	1	1	0.99999986	0.99999891	0.99999587
	n=4	**L(t)**	0.10720252	0.1950676	0.26937404	0.3340612	0.39186601
		T(t)	1	1	1	1	1
		Time	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**
0.5	n=2	**L(t)**	0.10654247	0.19213725	0.26387318	0.32617347	0.38180843
		T(t)	1.1	1.09992953	1.099691	1.09923851	1.09855902
	n=3	**L(t)**	0.10720252	0.19496196	0.26895451	0.33310472	0.39015272
		T(t)	1.1	1.1	1.09999979	1.09999832	1.09999362
	n=4	**L(t)**	0.10720252	0.19496196	0.26895451	0.33310472	0.39015272
		T(t)	1.1	1.1	1.09999979	1.09999832	1.09999362
		Time	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**
0.6	n=2	**L(t)**	0.10653601	0.19224806	0.2644178	0.32754395	0.38440678
		T(t)	1.2	1.19990739	1.19959287	1.19899445	1.19809357
	n=3	**L(t)**	0.10720252	0.19496235	0.26896838	0.33316802	0.39032628
		T(t)	1.2	1.2	1.19999969	1.19999756	1.19999072
	n=4	**L(t)**	0.10720252	0.19506758	0.26937464	0.33406682	0.39188846
		T(t)	1.2	1.2	1.2	1.2	1.19999999

Table 2.6 : Effect of λn under different values of 't' when λp = 0.5 , λi=0.5 and μ=1.7

λn							
		Time	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**
0.4	n=2	**L(t)**	0.09711208	0.17462185	0.23891444	0.29403561	0.34256846
		T(t)	0.9	0.89996157	0.89983195	0.89958693	0.89922023
	n=3	**L(t)**	0.09760233	0.17677495	0.2429264	0.29976262	0.34985017
		T(t)	0.9	0.9	0.89999991	0.8999993	0.89999735
	n=4	**L(t)**	0.09760233	0.17684228	0.243198	0.30039569	0.3510158
		T(t)	0.9	0.9	0.9	0.9	0.9
		Time	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**
0.5	n=2	**L(t)**	0.09710663	0.1747133	0.23936574	0.29517312	0.34472742
		T(t)	1	0.99994642	0.99976515	0.99942154	0.99890602
	n=3	**L(t)**	0.09760233	0.17677524	0.24293671	0.29980949	0.34997812
		T(t)	1	1	0.99999986	0.9999989	0.99999584
	n=4	**L(t)**	0.09760233	0.17684227	0.24319821	0.30039761	0.35102347
		T(t)	1	1	1	1	1
		Time	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**
0.6	n=2	**L(t)**	0.0971012	0.1748052	0.23981913	0.29631658	0.34689949
		T(t)	1.1	1.09992899	1.09968791	1.09922948	1.09853984
	n=3	**L(t)**	0.09760233	0.17677552	0.24294711	0.29985698	0.35010829
		T(t)	1.1	1.1	1.09999979	1.09999838	1.09999385
	n=4	**L(t)**	0.09760233	0.17684226	0.24319841	0.30039954	0.35103118
		T(t)	1.1	1.1	1.1	1.1	1.09999999

It is observed that the queue lengths are increasing with increase in values of parameters λi and n respectively at fixed

Table 2.7 : Effect of λn under different values of 't' when λp = 0.5 , λi=0.5 and μ=1.8

λn		Time	0.1	0.2	0.3	0.4	0.5
0.4	n=2	**L(t)**	0.09706498	0.17364532	0.23659403	0.29018569	0.33711097
		T(t)	0.9	0.89996159	0.89983314	0.89959233	0.89923477
	n=3	**L(t)**	0.09756142	0.17580748	0.24059719	0.29587819	0.34434215
		T(t)	0.9	0.9	0.89999991	0.89999931	0.89999738
	n=4	**L(t)**	0.09756142	0.1758755	0.24086945	0.29650937	0.34550077
		T(t)	0.9	0.9	0.9	0.9	0.9
		Time	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**
0.5	n=2	**L(t)**	0.09705951	0.17373716	0.23704433	0.29131466	0.33924356
		T(t)	1	0.99994646	0.99976682	0.99942909	0.99892641
	n=3	**L(t)**	0.09756142	0.17580777	0.24060756	0.29592496	0.34446899
		T(t)	1	1	0.99999986	0.99999891	0.99999588
	n=4	**L(t)**	0.09756142	0.17587549	0.24086966	0.2965113	0.34550841
		T(t)	1	1	1	1	1
		Time	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**
0.6	n=2	**L(t)**	0.09705405	0.17382945	0.23749671	0.29244949	0.34138906
		T(t)	1.1	1.09992904	1.09969012	1.09923953	1.09856703
	n=3	**L(t)**	0.09756142	0.17580807	0.24061802	0.29597235	0.34459804
		T(t)	1.1	1.1	1.09999979	1.09999839	1.09999392
	n=4	**L(t)**	0.09756142	0.17587549	0.24086986	0.29651323	0.34551609
		T(t)	1.1	1.1	1.1	1.1	1.09999999

Based on the values derived above, the graphs plotted for different arrival rates of primary and secondary users with n channels system to analyze the behavior of queue length and throughput parameters are shown as

For the performance parameter Queue Length(L) :

1. Secondary User Arrivals (Service Assured) Rate is taken on X-axis and number of channels (n) taken on Y-axis:

Based on the calculated values for Queue Lengths, a 3-D graph is plotted by considering service assured secondary user arrival rate (λi) as X-axis at different values of number of channels (n) taken as Y-axis for new Secondary user arrival rate (λn) fixed at 0.5 the fixed time interval 0.25 with service rate(μ) as 1.6.

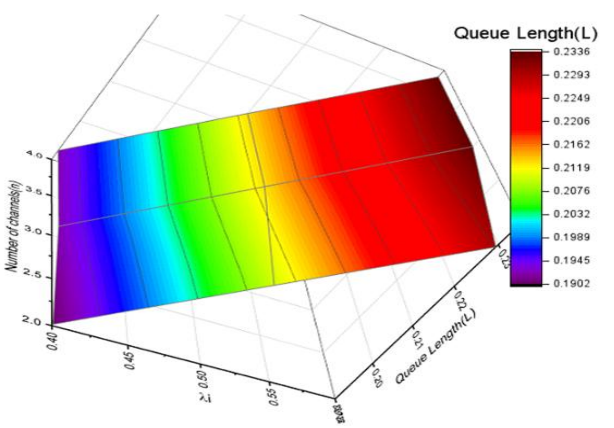

Figure 3.1: Throughput evaluation with number of channels(n) and Secondary user (service assured) arrival rate (λi)

service rate and fixed interval t=0.25. At a fixed λi value, the queue length seems to increasing in small quantities as the number of channels increases.

2. Secondary User Arrivals (Service Assured) Rate is taken on X-axis and number of channels (n) taken on Y-axis:

The 3-D graph plotted by considering new secondary user arrival rate (λn) on X-axis at different intervals of time (t) taken over Y-axis for new Secondary user arrival rate (λi) and primary user arrival rate (λp) fixed at 0.4, n=2 and service rate, μ=1.6 is shown as

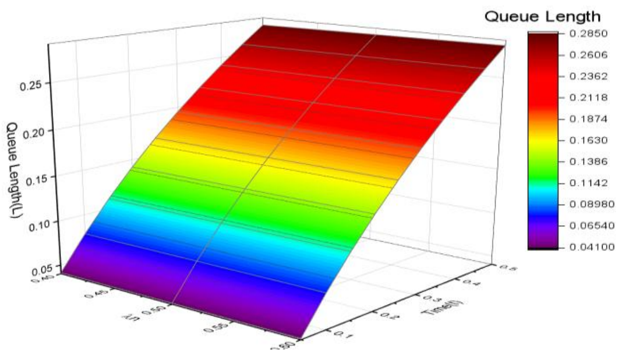

Figure 3.2: Throughput evaluation with Tme(t) and Secondary user (service assured) arrival rate (λi)

3. Secondary User Arrivals (Service Assured) Rate is taken on X-axis and primary user arrival rate is taken on Y-axis:

The 3-D graph plotted by considering secondary user arrival rate (λn) on X-axis at at fixed interval of time t=0.25 over Y-axis considered for primary user arrival rate (λp) at fixed λi= 0.4,n=2 and service rate, μ=1.6 is shown as

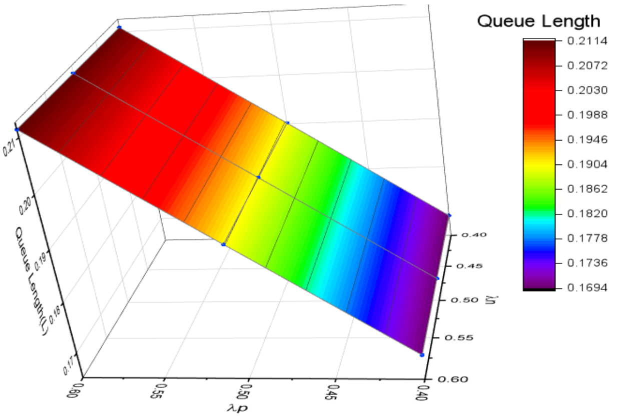

Figure 3.3: Throughput evaluation with Primary user arrival rate (λp) and Secondary user (service assured) arrival rate (λi)

It is observed that the queue lengths are increasing with increase in values of parameter λp but the increase in λn shows only minor increase in queue length. The primary user arrivals are affecting the queue length compared to other parameters of the system.

3. Primary User Arrival Rate is taken on X-axis and time interval is taken on Y-axis:

The 3-D graph plotted by considering primary user arrival rate (λp) on X-axis and time interval, t over Y-axis at fixed λi= 0.4, λn=0.4, n=2 and service rate, μ=1.6 is shown as

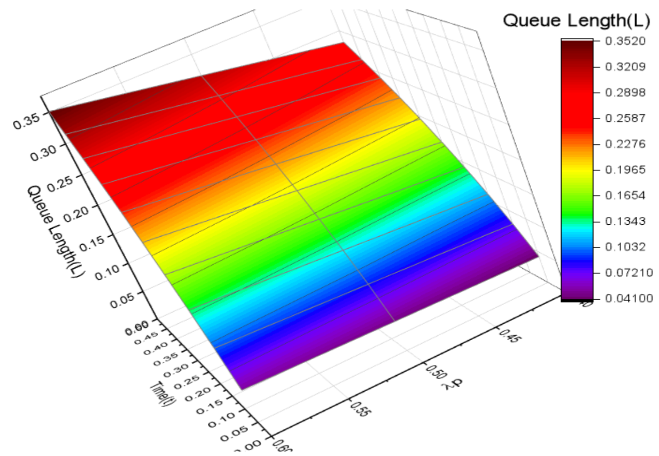

Figure 3.4: Throughput evaluation with Primary user arrival rate (λp) and Time (t)

The decrease in queue length is observed with the decrease in primary user arrival rate and as the time progresses, the increase in queue length is more at high arrival rates compared to low arrival rates of primary users. The graph also indicates the increase in waiting time of secondary users with increase in arrival rate of primary users as the queue length is increasing.

4. Service Rate is taken on X-axis and time interval is taken on Y-axis:

The 3-D graph plotted by considering service rate (μ) on X-axis and time interval t over Y-axis at fixed λi= 0.5, λp=0.5, λn=0.5 and n=2 is shown as

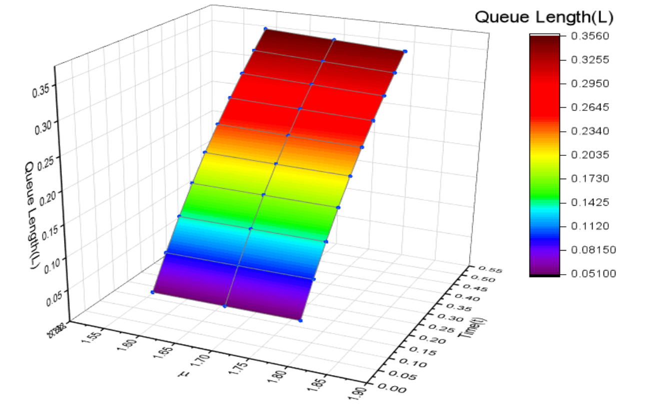

Figure 3.5: Throughput evaluation with number of channels(n) and time(t)

It is observed that the increase in service rate causes a slight decrease in queue length can be clearly observed at top portion of the graph and as the time progresses , the queue length variation also minimizes.

5. Secondary user (service assured) arrival Rate is taken on X-axis and time interval is taken on Y-axis:

The 3-D graph plotted by considering secondary user (service assured) arrival rate (λi) on X-axis and time interval (t) on Y-axis at fixed λp= 0.5, λn=0.4,μ=1.6 and n=2 is shown as

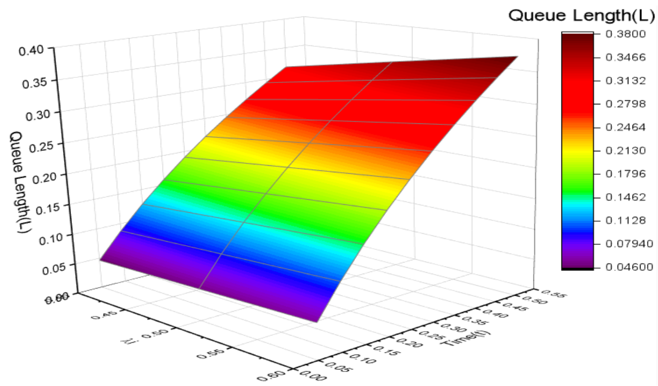

Figure 3.5: Throughput evaluation with time(t) and Secondary user (service assured) arrival rate (λi)

It is observed that the increase in secondary user arrival rate where service is directly given causes an increase in queue lengths at fixed number of servers. The queue length increases as the time progresses and the increasing rate diminishes as time progresses.

6. Secondary user (new arrivals) Rate along with number of channels is taken on X-axis and service rate is taken on Y-axis:

The 3-D graph plotted by considering new secondary user arrival rate (λn) combination with varying number of channels, n on X-axis and time interval (t) on Y-axis at fixed λp= 0.5, λn=0.5,μ=1.6 at t=2.5 is shown as

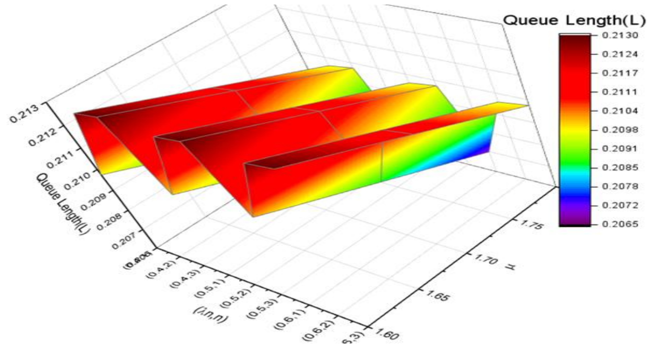

Figure 3.6: Throughput evaluation with service rate (μ) and New Secondary user (service assured) arrival rate (λn) with number of channels (n) It is observed that the queue length decreases as the number of channels increases at a particular secondary user arrival rate and with the increase in service rate, the decrease in queue length is also observed.The service rate better influences the queue length than the arrival rate of secondary users.

For the performance parameter Secondary Users Throughput (S_{tput}) :

The throughput parameter derived shows the maximum throughput in the beginning of the system and only sligh variation is observed as time progresses.

1. New Secondary User Arrivals Rate is taken on X-axis and time is taken on Y-axis:

The 3-D graph plotted by considering new secondary user arrival rate (λn) with time, t on X-axis at fixed λp= 0.4, λi=0.4,μ=1.6 at n=3 is shown as

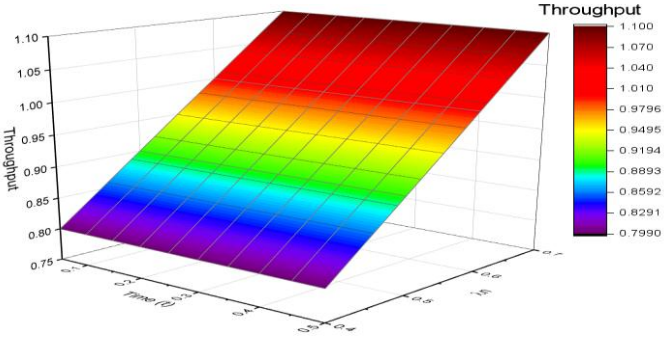

Figure 4.1: Throughput evaluation with Time (t) and new Secondary user (service assured) arrival rate (λn) It is observed that the throughput increases as the number of newly arriving secondary users increases and through shows no identifiable variation as time t progresses at particular arrival rates.

2. New Secondary User Arrivals Rate is taken on X-axis and time is taken on Y-axis:

The 3-D graph plotted by considering new secondary user arrival rate (λn) on X-axis and at fixed λp= 0.5, λi=0.5, n=2 and t=0.25 is shown as

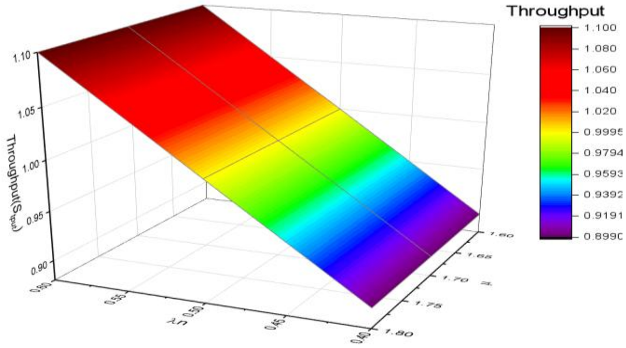

Figure 4.2: Throughput evaluation with Service Rate(μ)

The increase in throughput is observed with the increase in secondary user arrival rate and the service rate has no effect on throughput.

Case-2: Time independent performance metrics:

The both users blocking probabilities are calculated for the values of μ ranging from 1.2 to 1.4 for different number of channels from 2 to 5 with changes in arrival rate from 0.4 to 0.7 for all types of users.

When the service rate changes i.e. μ is changed, the user loss probabilities will be changed. The user loss probabilities are diminished exponentially with the increase of no. of channels i.e. an inverse relationship was observed with the increase in number of channels and user loss probabilities.

The same phenomenon is observed with the different values of μ and the λ, the blocking probability values are decreasing with the increase in service rate is well supported.

Table 3: Blocking Probabilities of Primary and Secondary Users

μ	λp/λi/λn	Primary / Secondary User Blocking Probability			
		n=2	n=3	n=4	n=5
1.2	0.4	0.04	0.00442478	0.0003686	0.00002457
	0.5	0.05773672	0.0079552	0.00082798	0.00006899
	0.6	0.07692308	0.01265823	0.00157978	0.00015795
	0.7	0.0970297	0.01851752	0.0026932	0.00031411
1.3	0.4	0.0349345	0.00357023	0.00027456	0.0000169
	0.5	0.05070994	0.00645928	0.0006207	0.00004774
	0.6	0.06792453	0.01034186	0.00119187	0.00011001
	0.7	0.08611599	0.01522144	0.00204485	0.00022017
1.4	0.4	0.03076923	0.00292184	0.00020866	0.00001192
	0.5	0.0448833	0.00531485	0.00047432	0.00003388
	0.6	0.06040268	0.00855513	0.00091578	0.00007849
	0.7	0.07692308	0.01265823	0.00157978	0.00015795

Based on values derived above , when a graph is plotted for different arrival rates of primary / secondary users with n channels, the blocking probability parameter has shown an exponential decrease in its value as the no. of channels increases.

Primary / Secondary User Blocking Probability (P_{loss}/ S_{loss}):

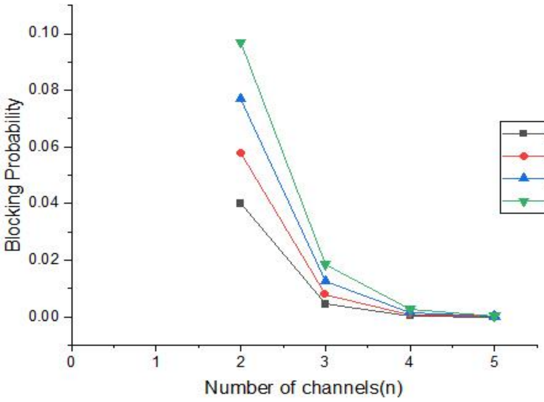

Fig.6.1. Primary user blocking probability when μ =1.2

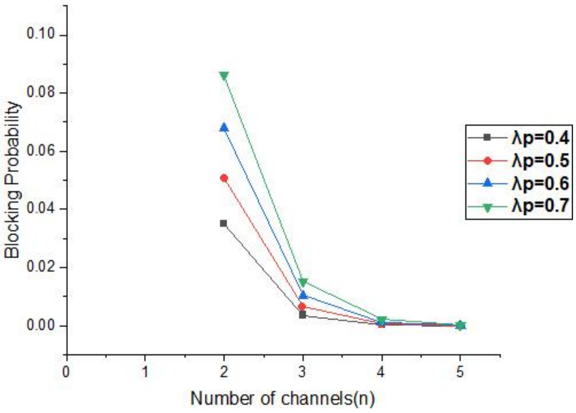

Fig.6.2. Primary user blocking probability when μ =1.3

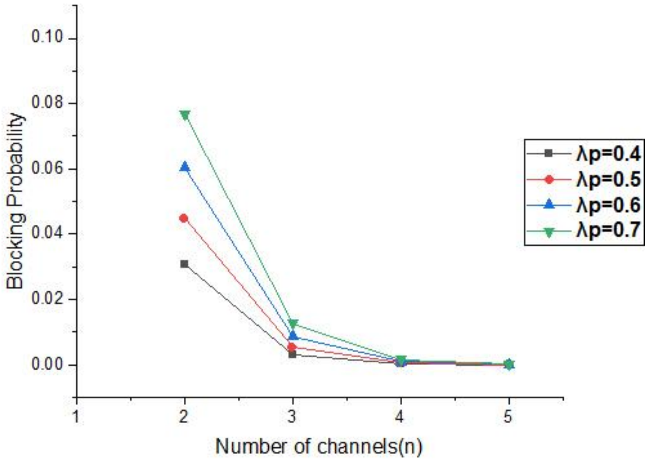

Fig.6.3. Primary user blocking probability when μ =1.4

V. CONCLUSION:

This paper investigates the effect of both the interrupted and newly arrived secondary users occupancy performance when buffer mechanism provided with M/M/C/K analytical queuing model. The differential difference equations are derived supporting the state diagram. The performance metrics, queue length (L) and throughput (t) are derived for time dependent model and blocking probabilities are found with time independent model. The transient analysis is carried with different values of μ, λ_p ,λi and λn with the time progression. The increase in primary user arrival rate shows much influence on throughput compared to other and the throughput shows the maximum output not much influenced. The conclusion can be drawn that the throughput value with buffer allowing interrupted users only is less than the throughput of the system with buffer allowing both types of users. The primary and secondary users loss probability decreases when μ is increases for constant λ_p, λn and λi. As the user arrival rate is increasing, the blocking probability is decreasing and is reaching to a minimal value. This analysis is helpful in spectrum management decision process of CRN with optimal usage of buffer.

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AUTHOR PROFILE

Mr. B.B.V.SatyaVara Prasad, He is a research scholar of department of C.S.E., Acharya Nagarjuna University. He presented the several research papers in reputed international journals and he attended several national and international conferences. His area of interest is Computer Networks&Security,IoT and Data mining.

Dr. B. Basaveswara Rao, He awarded his Ph.D from Acharya Nagarjuna University. His research areas of interest are Computer Networks, DataMining and Cloud Computing. He has 20 years of experience. He has 8 research scholars.

Dr. V. Vasanta Kumar, He awarded his Ph.D from Acharya Nagarjuna University. He is working as Professor & Head of the Department of Mathematics, K L E F, Vijayawada. His research areas of interest are Queueing Theory and Operations Research.

Dr. K. Chandan, He awarded his Ph.D from Indian Institute of Technology, Kharagpur. His areas of research are Operations Research, Queuing Theory, Game Theory, Investment Analysis, Stochastic Process, Sampling Theory, Management Information System, DBMS. He is a Professor of Statistics department in Acharya Nagarjuna University since-2004 , Member-Academic Senate, ANU and he is also Co-coordinator of Joint CSIR - UGC NET for JRF ICS .