Dynamic Spectrum Allocation Technique with Reduced Noise in Cognitive Radio Networks

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Abstract— **We propose a novel algorithm to model the dynamic channel allocation problem in cognitive radio networks. In the proposed work, we define a unique model to assign priorities to the secondary users based on the required Quality of Service and on the interference delay to minimize the switching of secondary users. The proposed scheme also mitigates the delay of the licensed primary users due to minimized switching. In this paper, we also discuss the techniques used to deal with the issues related to spectrum sensing and interference avoidance for cognitive radio systems.**
Keywords- Quality of Service (QoS), lookup table, hashing, usage matrix, xG Network, xG User

I. INTRODUCTION

Cognitive Radio (CR) is relatively a new technology, which wisely finds a particular segment of the radio spectrum currently in use and chooses unused spectrum quickly without interfering with the transmission of authorized users. Cognitive Radios can find out about current use of spectrum in their operating region, make intelligent decisions, and react to immediate changes in the use of spectrum by other authorized users. The goal of CR technology is to mitigate radio spectrum overcrowding, which actually translates to a lack of access to full radio spectrum utilization. Due to this adaptive behaviour, the CR can easily preclude the interference of signals in a crowded radio frequency spectrum.

According to a statistical analysis, the spectrum exploitation by the licensed users also called *primary users* (*PU*), can be as low as 15% [7]. Thus, the cognitive radio technology is seen to be a panacea for spectrum dearth, thereby enabling coexistence of unlicensed users with the licensed ones. This encourages the cognitive radio technology which allows unlicensed users, known as secondary users (SUs), to make use of the licensed spectrum opportunistically. The cognitive radio perceives the environment and allocates the inoperative bands, not utilized by the licensed users, to the SUs thereby rising the spectral efficiency. Opportunistic spectrum usage is discussed in the perspective of spectrum sharing. The idle bands, also referred to as *white spaces or holes*, is a collection of frequencies which are assigned to the primary users (*PUs*) but are not being used during a given time span. In this scenario, *SUs* can utilize these white spaces for transmissions while also softening interference to the PUs. It is called as *next generation* (xG) radio technique. Secondary users are also called *xG Users*. The network dedicated specially to *xG* users is called *xG or secondary network.*

The main role for cognitive radios in cognitive networks can be summarized as follows:

- Spectrum sensing: identifying unused spectrum and sharing the spectrum without destructive interference with other users.
- Spectrum management: Capturing the best available spectrum to greet user communication needs.
- Spectrum mobility: Maintaining seamless communication requirements during the switch to better spectrum.
- Spectrum sharing: Providing the fair spectrum scheduling method among contemporaneous cognitive users.

The schematic diagram for spectrum sensing is given in Figure 1.

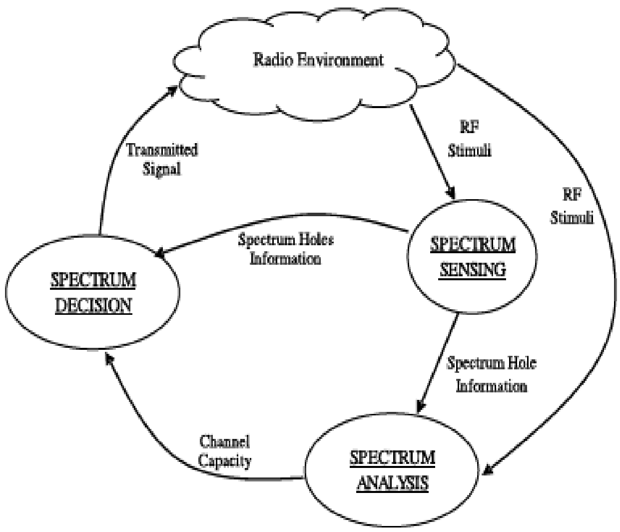

Figure 1: Schematic diagram for spectrum sensing

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Section II contains a brief description of the work done in the related field. Section III describes the proposed model. Study of power allocation to SU to avoid interference is given in Section IV. Concluding remarks are provided in Section V.

II. RELATED WORK

Basic constituent of *Opportunistic Spectrum Access (*OSA) include spectrum opportunity identification, spectrum opportunity exploitation, and regulatory policy. The opportunity identification module is responsible for precisely identifying and wisely tracking unused frequency bands that are dynamic in both time and space. The opportunity exploitation module acquires input from the opportunity identification module and determines whether and how a transmission should occur. The regulatory policy defines the vital protocol for secondary users to ensure compatibility with legacy systems. The overall design objective of OSA is to impart adequate benefit to secondary users while protecting spectrum licensees from interference. The conflict between the secondary users' covet for performance and the primary users' need for protection determines the interaction across opportunity identification, opportunity exploitation, and regulatory policy. The optimal design of OSA thus calls for a cross-layer approach that amalgamates signal processing and networking with regulatory policy making [8].

In recent years, several papers have analyzed problems pertaining to spectrum sensing and dynamic spectrum access. Reference [1] proposes the white space reservation algorithm to reduce spectrum handover in turn minimizing the delay introduced due to spectrum change. Hence, spectrum matching and system performance is improved by trimming down spectrum switch-over.

In reference [2] the authors proposed scheduling schemes such as rate and interference alleviation based scheduling exploiting channel variation across the *xG* user and delay, interference based scheduling exploiting packet delay along with Quality of Service (QoS) provisioning for multiple *xG* users escalating the capacity, attaining fairness among the *xG* users and minimizing interference to PUs.

In reference [5], the authors used Hidden Markov Models (HMMs) to model and envisaged the spectrum occupancy of licensed radio bands. In their work, they attempted to predict the duration of spectrum holes of primary users, the CR can utilize them more efficiently by leaving the band before the commencement of the traffic from the primary user of the band.

In practice, the exact path of the states is hidden to SU and the only data available to the SU are perceived data. Hence, spectrum sensing is prone to faults in the form of mis-detection and false alarms. In reference [6] authors exploited the probabilities of mis-detection and false alarms by using Hidden Markov Models and incorporated them in channel / band sharing to SU. They have used the Virtebri Algorithm to lower the computational complexity. All the existing channel allocation algorithms concentrate on user request priorities or channel conditions, joint user requests and channel priorities can be predicted in formulating power efficient channel allocation to support QoS among SUs.

Two main characteristics of the cognitive radio can be defined [10,11]:

- Cognitive capability: It refers to the capability of the radio technology to capture or perceive the information from its radio environment.
- *Reconfigurability*: It enables the radio to be dynamically programmed according to the radio environment.

More specifically, the cognitive radio can be programmed to transmit and receive on a range of frequencies and to use different transmission access technologies supported by its hardware design [12].

Following are the reconfigurable parameters [13]:

- ✓ *Operating frequency*: A cognitive radio is capable of altering the operating frequency.
- ✓ *Modulation*: A cognitive radio should reconfigure the modulation scheme adaptive to the user needs and channel conditions.
- ✓ *Transmission power*: Transmission power can be reconfigured within the power constraints. Power control enables dynamic transmission power configuration within the allowable power bounds.
- ✓ *Communication technology*: A cognitive radio can also be used to provide interoperability among various communication systems.

Based on the user requirements, the data rate, bandwidth of the transmission, acceptable error rate, the transmission mode, delay bound can be determined. Then, according to the decision rule, the set of suitable spectrum bands can be preferred. In [15], spectrum decision rules are presented, which are focused on fairness and communication cost. However, the method assumes that all channels have comparable throughput capacity. In [17], an opportunistic frequency channel skipping protocol is proposed for the search of superior quality channel, where this channel decision is based on Signal to Noise Ratio (SNR). In order to consider the primary user activity, the number of spectrum handoff, which happens in a specific spectrum band, is used for spectrum decision [16].

Spectrum allocation decision for SU is also based upon route selection. In [20], the inter-dependence between route selection and spectrum management is explored. First, a decoupled route selection and spectrum management methodology is proposed. Initially, the route selection is done independent of the spectrum management using the shortest-path algorithm. The spectrum sharing is performed using the scheme in [18]. In this scheme, routing layer invokes path detection to select routes. The spectrum management is then performed on each hop. A cross-layer solution that takes into account joint route selection and spectrum management is also proposed. In this approach, each source node uses Dynamic Source Routing (DSR) to find contender paths and schedules a time and channel for each hop. This source-based routing technique is performed centrally using an overall view of the network to show the ceiling in achievable performance.

III. PROPOSED MODEL

In the paper, we propose an algorithm to assign a channel to SU based on data stored on prior experienced as a spatial function of time. In this approach, the cognitive radio technology uses the real time knowledge of its environment to adapt its behaviour, in terms of frequency selection, dynamically with the intent to enhance its operational efficiency. Our primary objective is to:

- ✓ minimize switching of SU to trim down the average switching delay
- ✓ keep a database of past usages of channels by PU as a function of time duration.

A time band counter is maintained based on the past utilization of the channel by PU.

We assume that there are *m* channels and 24 *hour* time is divided into *n* various time bands (not necessarily of same duration).

It is maintained in a two dimensional array as shown in Figure 2.

← 24 hrs →				
	t_1	t_2	…	t_n
Channel - 1	*c[1,1]*	*c[1,2]*	…	*c[1,n]*
Channel -2	*c[2,1]*	*c[2,2]*	…	*c[2,n]*
…				
Channel- m	*c[m,1]*	*c[m,2]*	…	*c[m,n]*

Figure 2.The usage matrix maintaining the usage history of channels

Here, *c[i,j]* maintains the count how many times the i^{th} channel has been utilized in j^{th} time band on an average by PU. A sorted list in ascending order is maintained according to value of *c[i,j]*. Based on the matrix, we formulate the counter as a continuous function of time *t* and channel frequency *f*:

$$c(f, t) = \frac{d\ (c_{ft})}{df\ dt} \qquad \ldots(1)$$

A value '*v'* is associated with each channel based on:

- ✓ its usage function *c(f,t)*
- ✓ interference value *'f'*

$$v\ \alpha\ \left(\frac{1}{f * c(f,t)}\right)$$

Hence, $$v = k1*\left(\frac{1}{f * c(f,t)}\right) \qquad \ldots(2)$$

Here *k1* is a constant, based on the environmental circumstances. Higher the value of *v*, more will the channel be appropriate for allocation to SU.

When a demand from SU arrives, it is coupled with a priority value *'p'* based on:

- ✓ the maximum delay permitted '*d'*
- ✓ the minimum *QoS* required '*q'*. (*QoS* - Quality of Service)

The priority value

$$p\ \alpha\ \frac{q}{d}$$

Hence $$p = k2 * \frac{q}{d} \qquad \ldots(3)$$

Here *k2* is a constant, based on the environmental situations.

Higher the value of *p*, more will be the need of better quality channel for the request.

Following are the parameters for determining Quality of Service:

- *Interference*: Some spectrum bands are more congested compared to others. Hence, the spectrum band in use determines the interference characteristics of the channel. From the quantity of the interference at the primary receiver, the permissible power of a cognitive user can be derived, which is used for the estimation of the channel capacity.
- *Path loss*: The path loss escalates as the operating frequency increases. Therefore, if the transmission power of a cognitive user remains the same, then its transmission range drops off at higher frequencies. Similarly, if transmission power is increased to compensate for the increased path loss, then it causes higher interference for other users.
- *Wireless link errors*: Depending on the modulation scheme and the interference level of the spectrum band, the error rate of the channel varies.
- *Link layer delay*: To accommodate different path loss, wireless link error, and interference, different types of link layer protocols are needed at various spectrum bands. This results in different link layer packet transmission delay.
- *Holding time*: The behavior of primary users can affect the channel quality in cognitive networks.

Holding time refers to the expected time span that the cognitive user can occupy a licensed band before preemption. Obviously, the longer the holding time, the superior the quality would be. Since frequent spectrum handoff can decrease the holding time, previous statistical patterns of handoff should be taken into considered while designing cognitive networks with large expected holding time.

The equation for Quality of Service (*QoS*) can also be formulated by defining *QoS* as the ability to guarantee a certain level of performance to a data flow. Precisely speaking the QoS factor *q* is:

- ✓ proportional to the channel capacity *c*
- ✓ proportional to a required minimum bit rate *b*,
- ✓ inversely proportional to packet dropping probability *d* and
- ✓ inversely proportional to bit error rate *e*.

So

$$q \ \alpha \ \frac{b * c}{d * e}$$

Hence, $$q = k3 * \frac{b * c}{d * e} \qquad \text{. . . (4)}$$

Here *k3* is a constant.

In [14], a spectrum capacity estimation method has been proposed that considers the bandwidth and the tolerable transmission power. Accordingly, the spectrum capacity, C, can be estimated as follows:

$$c = B \log \left(1 + \frac{S}{N + I}\right) \qquad \text{. . .(5)}$$

where, B is the bandwidth, S is the received signal power from the cognitive user, N is the cognitive receiver noise power, and I is the interference power received at the cognitive receiver due to the primary transmitter.

The jitter factor should also be taken into account. Packets from the source will reach the destination with different delays. A packet's delay varies with its position in the queues of the routers along the path between source and destination and this position can vary unpredictably; and, various packets may transmit through different frequency bands with different number of hands-off. This variation in delay is known as *jitter* and can seriously affect the quality of streaming audio and/or video. The constant *k3* is adjusted according to the jitter aspect.

A lookup table is maintained to match the most suitable *v* value for a *p* value by using hashing to provide fast mapping. Based on the most perfect match, channel is allocated to the SU.

This approach guides us to allocate a channel to SU based on past utilization of a channel by PU. We try to allocate a channel to SU with minimum usage by PU so far keeping in view that the recent past is the best approximation of the near future (optimal algorithm).

This data structure is maintained at each base station as a result of channel sensing module. Obviously, the highest priority is given to the request of PU.

When a match is found [9], the transmitter first senses the receiving activities of primary users in its neighborhood as shown in Figure 3. If the channel is available (no primary receivers nearby), it conveys a short request-to-send (RTS) message to the receiver. The receiver, upon successfully receiving the RTS, knows that the channel is also free at the receiver side and responds with a clear-to-send (CTS) message. A successful exchange of RTS-CTS completes opportunity detection and is followed by data transmission.

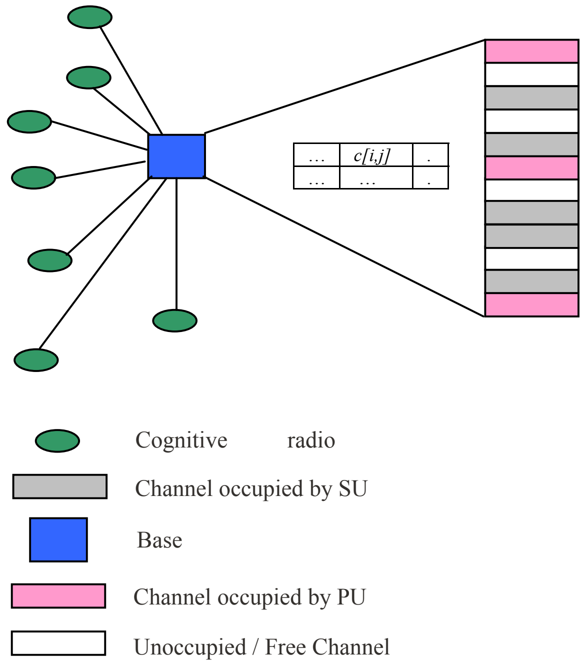

Figure 3.The Block Diagram of Proposed model

The queuing analysis is discussed below.

There is a base station that is keeping the trace of all unused channels; it can be considered as server. A demand from SU arrives to the base station. The entrance of new request is purely random; moreover its burst time is also random. Hence, it is modeled as M/M/1: ∞/FCFS queuing system (we consider that there are adequate number of channels to serve the SU and PU requests).

The average waiting time *t* is given as:

$$t = \frac{\lambda}{\mu * (\mu - \lambda)} \qquad \text{. . . (6)}$$

where, λ is the mean arrival rate, μ is the mean service time.

If each channel is considered as a sub-server, and allocates the SU requests according the usage matrix and the function *c(f, t)* [Figure 2], the mean arrival rate λ is reduced for a particular channel. It will reduce the average waiting time of the SU requests. Keeping μ, the mean service time, constant; the graph shown in Figure 4 illustrates the behavior of average waiting time as a function of arrival rate λ:

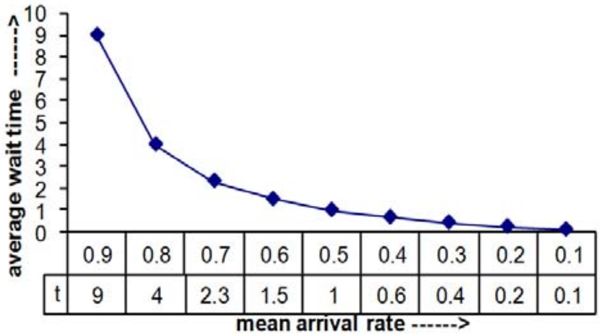

Figure 4. Behavior of average waiting time v/s arrival rate

It can be seen that as the arrival rate decreases, the average waiting time also reduces.

Moreover, the probability of an arrival of a request either by PU or by SU during the service time of a SU request is given as:

$$p_a = \left(\frac{\lambda}{\lambda+\mu}\right) * \left(\frac{\mu}{\lambda+\mu}\right) \quad \ldots (7)$$

Again, if each channel is considered as a sub-server, and allocates the SU requests according to the usage matrix and the function *c(f, t)* [Figure 2], the mean arrival rate λ is decreased for a particular channel. It will reduce the probability of an arrival of a request either by PU or by SU during the service time of a SU request. Keeping μ, the mean service time as constant; the graph shown in Figure 5 depicts the behavior of the probability p_a as a function of arrival rate λ:

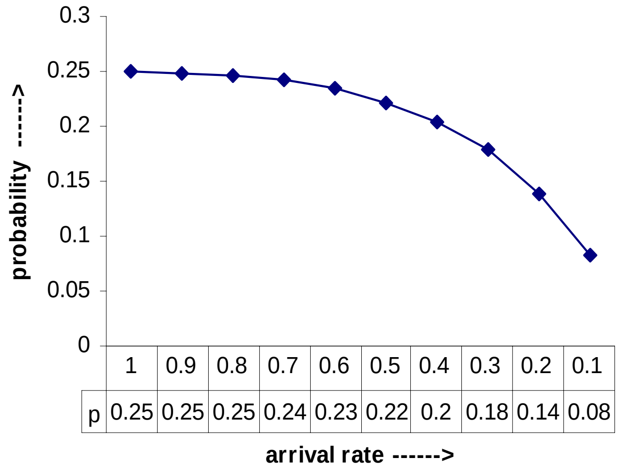

Figure 5. Behavior of probability v/s arrival rate

The graph depicts that lower the arrival rate; lower will be the probability of an arrival of a request either by PU or by SU in the span of the service time of a SU request.

Prior to channel allocation, spectrum sensing is done. The allocation must be such that there must be minimum interference to the PU.

IV. AVOIDING INTERFERENCE AND POWER ALLOCATION

The goal of spectrum sensing is to decide between the following two hypotheses:

H_0 : Primary user is absent;
H_1 : Primary user is present.

In cognitive systems, the cognitive users have to be designed to efficiently use and share the spectrum and at the same time without causing harmful interference to the licensed users. In fact, one of the most challenging problems of cognitive radio is the interference. It results when a cognitive radio accesses to some licensed bands on the spectrum and fails to notice the presence of licensed user. To address this problem, the cognitive radio should be able to coexist with the primary user without creating harmful interference. In the literature, orthogonal frequency division multiplexing (OFDM) modulation has been considered [21] as a candidate for cognitive radio to avoid interference by nullifying a certain set of sub-carriers where the second users are working in the spectrum.

Attractive techniques for power control rule have been used to allow cognitive radio to not interfere with the licensed users. Reference [23] gives a spectrum sharing problem in an unlicensed band where multiple systems coexist and interfere with each other. An analysis for a cooperative setting where all the systems collaborate to achieve a common goal is considered and then a non cooperative situation, where the systems act in a selfish and rational way is analyzed.

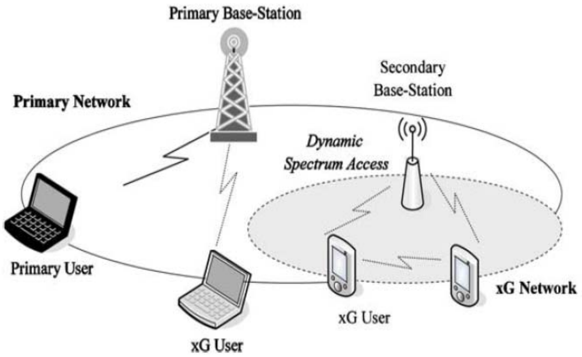

Figure 6. Coexisting primary network and xG network

In the cooperative situation, the authors model the situation in which M systems, each formed by a single transmitter-receiver, coexist in the same area. Reference [24] explores the idea of using cognitive radio to reuse locally unused spectrum for their own transmissions. Using received SNR as a proxy for distance, it has been shown that a cognitive radio can vary its transmit power while maintaining a guarantee of service to primary users. A power control rule which allows secondary users to aggressively increase their transmit powers while still guaranteeing an acceptable level of aggregate interference at the primary receivers.

Now we shall discuss a framework on power allocation based on spectrum sensing side information is presented. A power control approach in cognitive radio systems based on spectrum sensing side information is implemented to utilize the spectrum efficiently by allowing the cognitive radio to co-exist with the primary system. The distance between the primary transmitter and the cognitive radio is determined based on spectrum sensing side information. Then, the transmit power of the cognitive radio is controlled based on the distance in order to guarantee a quality of service (QoS) requirement of the primary receiver [22]. In order to avoid the harmful interference to the primary system, a cognitive radio senses the availability of the spectrum sensing. The average probability of false alarm P_f, detection P_d and missing of energy detection P_m over Rayleigh fading channels can be given by, respectively,

$$Pf = \mathbf{E}[\text{Prob}\{H1|H0\}] \quad \ldots(8)$$

$$Pd = \mathbf{E}[\text{Prob}\{H1|H1\}] \quad \ldots(9)$$

$$Pm = \mathbf{E}[\text{Prob}\{H0|H1\}] = 1 - Pd, \quad \ldots(10)$$

The transmit power of the cognitive radio that guarantees a good QoS for the primary receiver is determined from the following steps for power control.

Step 1: Calculate *Pm* based on the following estimation:

$$Pm = 1 - \frac{1}{L}\sum_{i=1}^{L} I(Y_i) \quad \ldots(11)$$

where

$$I(Yi) = \begin{cases} 1, & \text{if } Yi > \lambda \\ 0, & \text{otherwise} \end{cases} \quad \ldots(12)$$

for $i = 1\ldots L$. Yi denotes the energy collected by the cognitive radio in time slot i and L is the total number of time slots.

Step 2: Derive the distance d from $Pm = f(d)$, which can be easily derived based on the *SNR* and the expression of *Pm*.

Step 3: Calculate max{Qc}, the maximum value of cognitive transmitted power, based on the condition of decidability SNR $\geq \gamma_d$, where γ_d is the threshold of decidability[25].

The relation between *max{Qc}* and *Pm* based on the proposed scheme is illustrated in Figure 7. By calculating *Pm*, the maximum transmit power *max{Qc}* can be determined to guarantee the quality of service for the licensed user in the presence of cognitive radio.

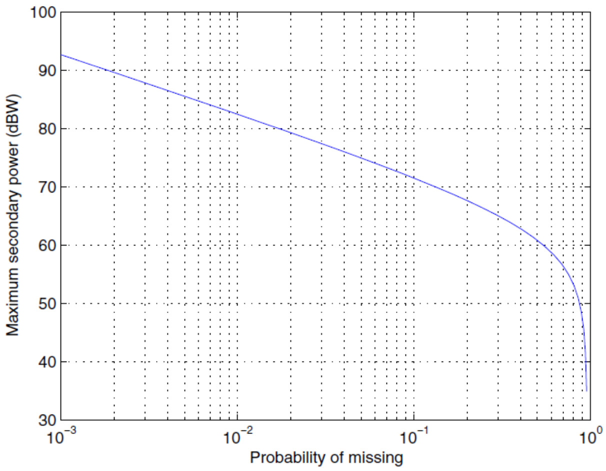

Figure 7 Max $\{Q_c\}$ Vs P_M

V. Conclusion and Future Work

In this paper, we have proposed a novel algorithm to model the dynamic channel allocation problem in cognitive radio networks. The proposed work is unique as no other approach takes into consideration the priorities for both the SUs as well as the channels in the operating spectrum along with the past usage data. We defined the channel characteristic to mitigate the delay. As a future work we are planning to incorporate the factor of time span a channel is used by a PU. It may be associated with the permitted delay of the request by SU as a waiting time. Moreover, to serve the requests in FCFS order may cause some smaller requests to wait for longer requests to finish. It will increase the average waiting time. SJF algorithm will be better to reduce the average waiting time. Hence, the M/M/1: ∞/SJF queuing model will be more appropriate as compared to M/M/1: ∞/FCFS. The analysis is under study.

The exact dependence of λ on the usage matrix is also under study. There is one open issue also, that is spectrum decision based on routing process. It is also under study.

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