

We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,900

Open access books available

186,000

International authors and editors

200M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com



A Quality of Service Based Model for Supporting Mobile Secondary Users in Cognitive Radio Technology

Neeta Nathani and G. C. Manna

Additional information is available at the end of the chapter

<http://dx.doi.org/10.5772/intechopen.80072>

Abstract

Current wireless networks are characterized by a static spectrum allocation policy, where governmental agencies assign wireless spectrum to license holders on a long-term basis for large geographical regions. The operators claim that the spectrum bands for mobile operation are highly occupied. Even then, a significant amount of licensed spectrum remains underutilized. Cognitive radio senses the radio environment with a twofold objective: identify those subbands of the radio spectrum that are underutilized by the primary (i.e., legacy) users and providing the means for making those bands available for employment by secondary (i.e., unlicensed) users. For unlicensed communication, the Quality of Service parameters need to be considered. Quality of Service comprises of channel availability, accessibility, and maintainability. Assessment of vacant channels of licensed band in a geographical region is termed as availability. An analysis of the collected data lead to arrive at the conclusion that more than one-eighth part of resources of each band are nearly permanently vacant, which is enough to design in-band common control signaling methods for cognitive radio. Measurement result plot of vacant channels in cities with known population will help to assess availability of vacant channels for any city and hence, measurement complexity can be avoided. The strategy to occupy the vacant channels without disturbing the primary user operation is referred as accessibility (or selection). Accessibility of a channel is dependent on blocking probability (or Quality of Service) measured in duration of minutes instead of hours. Instantaneous blocking probability has been calculated based on current minute occupancy for all available channels as reference. A comprehensive prediction model is employed in the proposed work to compute the instantaneous blocking probability both on immediate minute occupancy basis and its preceding 60 min basis from time of request by SU. Validation through actual data establishes that channelized blocking probability estimation model has lower error value compared to estimation through prediction models of other researchers. It was also observed that hourly basis prediction model has constant blocking probability value during clock hour, whereas minutewise Grade of Service (GoS) prediction model addresses the local peak demand and hence leads to a stringent GoS estimation. On secondary user request for vacant channel, the cognitive radio network needs to evaluate

the expected holding time of the particular Secondary User and to ensure channel maintainability (or allocation), and it shall predict that the allotted channel shall be able to provide interruption-free service for holding time duration. Minutewise channel occupancy traffic is bumpy in nature; hence, the present work predicts call arrival rate using Holt Winter's method. Also, at the instant of SU channel request, the channel allocation processor inputs all PU channel status minutewise, calculates actual mean residual lifetime (MRL) in minutes for each vacant channel and selects the channel with highest predicted free time. A simulation program runs on data collected from mobile switch of cellular network, which creates pseudo-live environment for channel allocation. The present work has compared the mean residual lifetime (MRL) method with the other researchers using probabilistic method of channel allocation and MRL method has been established as more accurate. The selection and allocation process with defined blocking probability model has been verified retrieving big data from data warehouse.

Keywords: cognitive radio, Quality of Service, blocking probability, mean residual lifetime

1. Introduction

The first decade of the twenty-first century belongs to a new wireless world indeed! The rapid growth of cellphones, Wireless Local Area Networks (WLANs), and recently the wireless Internet, in short, wireless communication is driving the whole world toward greater integrity with wireless communications. By 2020, two-thirds i.e. 66% of total IP traffic shall be occupied by Wi-Fi and mobile devices whereas wired devices will account for 34% of IP traffic in access network [1]. Licensed bands claim to be heavily congested but different research work shows that the channels in the form of time and frequency are still available. In future, wireless networks may face the problem to find suitable frequency spectrum to fulfill the demands of future services. To solve the problem of inefficient use of spectrum utilization, a new concept is evolved known as cognitive radio (CR) [2]. In 1999, Joseph Mitola III introduced the concept of CR. This new concept of CR which is called as intelligent wireless communications is capable of sensing its environment and dynamically accessing the technology. It adjusts according to the input variations of statistical data for: (a) very dependable communication wherever and whenever needed; and (b) efficiently utilizing the radio spectrum [3, 4]. This can be done by sensing the radio environment: (i) by finding spectrum bands which are unused by the PU (i.e., licensed user), and (ii) by allocating unused bands of radio spectrum to SU requesting service [5]. The underused frequency bands of PUs are called as in-band spectrum holes [6]. The spectrum holes can be used to allocate the channels to CR user. However, to ensure efficient communication for such unlicensed communication, the Quality of Service (QoS) parameters need to be considered. Quality of Service can be defined as a set of specific requirements provided by a network of users, which are necessary in order to achieve the required functionality of a service.

Cognitive radio (CR) concept is based on vacant spectrum in licensed band which sometimes referred to as combination of channels. In telecommunication, a channel refers either to a physical transmission medium such as wire or to a logical connection over a multiplexed medium such as a radio channel. Global System for Mobile Communication-900 (GSM-900)

has been allocated an operational frequency from 890 to 960 MHz. GSM uses the frequency band 890–915 MHz for uplink (reverse) transmission, and for downlink (forward) transmission, it uses the frequency band 935–960 MHz. The available 25 MHz spectrum with 100 kHz guard band at two edges of the spectrum is divided into 124 Frequency Division Multiplexing (FDM) channels, each occupying 200 kHz as mentioned in **Figure 1**.

A large amount of information is transmitted between the MS and the BS, particularly, user information (voice or data) and control or signaling data. Depending on the type of information transmitted, different logical channels are used. These logical channels are mapped onto the physical channels (time slots). In the GSM system, a traffic channel will be made by a combination of a 200 kHz frequency channel and one of the eight time slots. For example, digital speech is carried by the logical channel called the traffic channel which during transmission can be allocated to a certain physical channel. There are two basic types of logical channels in GSM: traffic channels (TCHs) and control channels (CCHs). TCHs are used to carry either encoded speech or user data both in the uplink (UL) and downlink (DL) directions. The CCHs are used to communicate service between network equipment nodes.

Code Division Multiple Access (CDMA or Interim Standard-95) uses the frequency band 824–849 MHz for uplink (reverse) transmission, and for downlink (forward) transmission, it uses the frequency band 869–894 MHz. With CDMA, all users share the same 1.25 MHz wide carrier, but unique digital codes are used to differentiate subscribers. The codes are shared by both the mobile station and the base station and are called “pseudo-random code sequences”. Base stations in the system distinguish themselves from each other by transmitting different portions of the code at a given time. In other words, the base stations transmit time-offset versions of the same pseudo-random code.

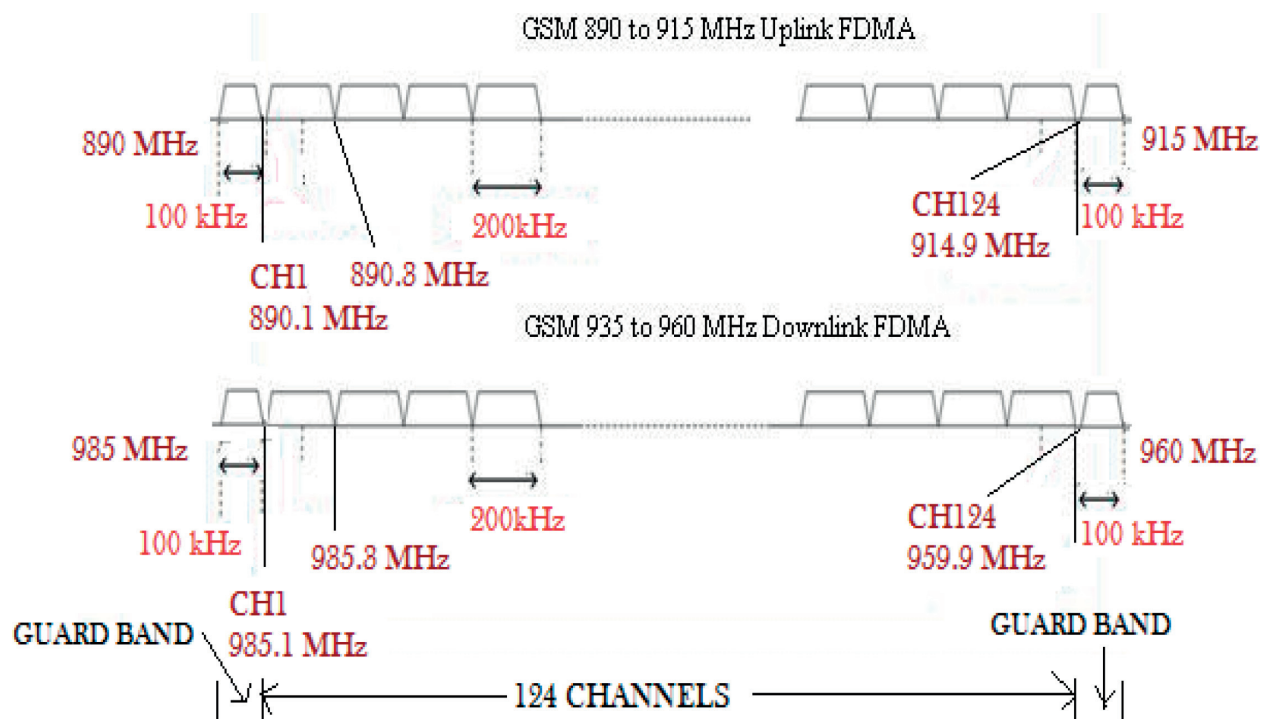


Figure 1. Frequency channels in GSM-900.

The 3rd Generation Partnership Project (3GPP) and 3rd Generation Partnership Project 2 (3GPP2) have indicated that orthogonal frequency division multiple access (OFDMA) is the choice for the physical-layer transmission technology in 4G standards. In OFDM, usable bandwidth is divided into a large number of smaller bandwidths that are mathematically orthogonal using fast Fourier transforms (FFTs). Reconstruction of the band is performed by the inverse fast Fourier transform (IFFT).

CR utilizes both licensed and unlicensed bands for communication. Among these bands, GSM bands have less attenuation; their wavelength is more resilient to phenomenon like diffraction, absorption, scattering, etc. GSM channels use FDM-TDM technique with low bandwidth of 200 kHz and hence better scalable. In practice, technologies like CDMA, OFDM, etc. uses large bandwidth and total allotted spectrum and hence, only chance to obtain large bandwidth is the un-allotted part of the licensed band. Cognitive radio users (human and machine) are low end users (users in lower or lowest economic bracket or free public utility users with minimum vocabulary or information) and expected mainly to use voice, short message and short data services. These reasons make GSM is a good choice for cognitive radio implementation.

The QoS for mobile services which has been defined by ITU-T includes different parameters of QoS like availability, accessibility, maintainability and user perception of service. These parameters have been defined in context of cognitive radio in Section 2. Availability refers to detection of unused spectrum by way of signal strength measurements. In conventional method, the signal strength of a received radio signal is measured. The measurement setup used for detection of spectrum holes in CR along with the cognitive radio issues for availability has been discussed in detail in Section 4. The proposed work calculates blocking probabilities both on immediate minute occupancy basis and its preceding 60 min basis at the instant of service request by SU. The new concept of channelized blocking probability has been defined along with the general definitions of blocking probabilities in Section 5. An algorithm has been developed to accept SU service requests with different classified Quality of Service (QoS) from a set of PU channels. Allocation of a PU vacant channel on SU call request is done based on prediction that the channel will remain vacant for more than the assessed holding time of SU. The channel allocation model works based on inputs from (a) the channel call arrival rate prediction model and (b) SU holding time assessment model and has been discussed in Section 6. The model accepts collected data as input in time serial manner for running through residual lifetime based prediction model program. The comparison of proposed work has also been done and its results and conclusion has been discussed in Section 6.

2. Quality of Service

Quality of Service (QoS) is the capability of a network to offer better service to selected network traffic over specific underlying technologies [7, 8]. The various parameters for QoS are:

- i. **Availability:** The operator maintains a dynamic list of available channels. When the user wants to communicate, operator is liable to assign one or more communication channel to the user as per his demand and within tolerable specified time limit. In case

of telecom service, this delay is maximum 6 s but usually, the delay noticed is less than a second. This function is referred to as availability.

- ii. **Accessibility:** When the operator assigns channels to the user, the user equipment (UE) should be capable to use the allocated spectrum to the extent possible. For example, when a 200 kHz channel is allocated for some time τ , the user handset should be able to communicate at highest modulation supported by operator and RF condition. This phenomenon is called accessibility. Proper handshaking shall take place between UE and access network (AN) before establishing communication at acceptable speed by both ends.
- iii. **Maintainability:** In mobile communication, as the user is mobile, there is a continuous change in environment and RF condition. The operator has to take into consideration various parameters like speed of communication, handover, etc. for proper maintenance of established communication. This is known as maintainability.
- iv. **User perception of service:** It is the ability to deliver the service meeting the user's quality of expectations. It is measured by the customer satisfaction using access equipment behavior audit, drive test for mobile as pseudo customer and actual satisfaction through interrogation by customer survey specialists.

3. Availability

Over the last few years, a lot of research has undergone on spectrum sensing (SS) techniques for the detection of spectrum holes [9]. Energy detection (ED) approach, also known as radiometry or periodogram, is a popular technique for spectrum sensing due to low computational and implementation complexities [10]. The conventional SS method includes waveform-based sensing (WBS), matched filter-based sensing (MFBS) and cyclostationary-based sensing (CBS). WBS is a coherent method that correlates the received signal with the previous patterns available in database [11]. This technique is susceptible to synchronization errors which can cause false detection of primary users [10]. MFBS is the best detecting method where the received signal is interrelated with the transmitted signal [12]. The periodic characteristics of the received signals i.e., pilot sequences, carrier tones, etc. is explored by CBS technique [13]. It requires less time to achieve high processing gain due to coherent detection. In MFBS technique, it is assumed that it has the previous information of the primary's signal. It indicates that method is not suitable in some bands as some of the communication technologies are not operating with the previous information. On the other hand, CBS is unfeasible for signals that don't show cyclostationarity properties. CBS has high computational complexity [14]. Energy-based sensing (EBS) is the easiest SS method [15, 16]. This technique does not require any previous knowledge of primary user's signal but its performance is less when noise's variance is unknown or at the higher side [17]. Energy-based sensing based on sub-Nyquist sampling shall be beneficial as per as sensing duration is concerned [18]. The performance of the EBS is characterized where the PUs reflects a constant characteristic during the sensing period as well as during the sensing period where PUs can alter their ON/OFF status, thus, affecting the spectrum sensing decision [19]. A brief comparison various SS techniques is enlisted in **Table 1** as follows [10, 20]:

Spectrum Sensing Method	Characteristics
ED	1. Low complexity.
	2. No primary knowledge required.
	3. Unreliable in low SNRs.
MFBS	1. Requires prior knowledge of waveform patterns of all primary users in the various spectrum bands.
	2. Noise variance and uncertainty makes this technique unreliable as CR devices are unable to detect transmitted signal from primary users.
	3. High power consumption
WBS	1. Requires prior knowledge of synchronization.
	2. Is susceptible to synchronization errors which can cause false detection of primary users.
CBS	1. Robustness to the uncertainty in noise power.
	2. Improves the overall CR throughput
	3. High computational complexity.

Table 1. Comparison of different spectrum sensing methods.

In mobile communication, primary user occupied channels are known to network. So, a new call is eligible to occupy any of the vacant channels. In contrast, in cognitive radio network, a dynamic spectrum management is used which shall include information about the traffic pattern of the channels occupied by primary users at an instant. Basically, a CR should characterize whether the traffic pattern is static or dynamic and based on that it should use different methods for idle time prediction before selecting a channel.

Much of the spectrum below 50 GHz is available for low-powered unlicensed use. Based on environmental variations, the utilization of the licensed band is approximately 15–85% [21]. The actual utilization of mobile communication spectrum in licensed band has not yet been taken into consideration. The variation of channel utilization for various types of cities has also not been studied. These studies may be very useful to perfectly recognize the frequency

channels with no active or low occupancy so that the CR technology can be successfully deployed. Few such studies has been mentioned below:

3.1. Vacant channels in Barcelona, Spain

A spectrum measurement campaign for a frequency band of 75 MHz to 3GHz was conducted through a survey in an outdoor urban environment for a continuous period of 48 h at Barcelona, Spain [22]. The six consecutive frequency bands of 500 MHz were formulated and it was found that only 22.57% of the whole frequency range was utilized.

3.2. Vacant channels in Singapore

To find the spectrum occupancy for the frequency range from 80 MHz to 5.85 GHz, another survey was conducted at Institute for Infocomm Research's building in Singapore for 24-h over 12 weekday periods [23]. It was observed that the average utilization of frequency band was only 4.54%.

3.3. Vacant channels in Limestone Maine

At the Loring Commerce Centre, a similar survey was conducted during a normal work week for 72 h for the frequency band of 100 MHz to 3 GHz [24]. In the survey, it was found that only 17% of the average spectrum is utilized during the measurement period. The ISM bands and mobile licensed bands are partly utilized and the remaining part of the spectrum band resembles noise.

3.4. Vacant channels in India

In India, the RFs are being used for different types of services like mobile communication, broadcasting, radio navigation, satellite communication, defense communication, etc. The wireless equipment are developed and manufactured based on the spectrum utilization in the country as decided by the National Frequency Allocation Plan (NFAP). The various frequency spectrums allotted to mobile communication services is shown in **Table 2** [25, 26].

CR technology has been developed to dynamically access and release channels in licensed bands. There is a scope of getting the unutilized channels in licensed spectrum with or without having a stable infrastructure for CR. Thus it is expected that at zero cost public authorities providing public utility services may be authorized to operate over unutilized spectrum even though licensed. However, such public utility service providers are very limited. Field test should be essentially conducted for the evaluation of quasi-permanently unused channels for use of in-band common control signaling purposes.

3.4.1. Measurement setup

To dynamically measure the occupancy rate of the PUs and to calculate the quantum of vacant channels available for CR use, a measurement setup called drive test equipment is used that collects data on a moving vehicle. A motor vehicle containing mobile radio network air

Technology used	Band and Channel Width	Technology Bandwidth	*Occupancy/ Remarks
CDMA	824-849MHz; 869-894MHz; Channel B/W 1.25MHz FDD; 20 channels	25+25	50% vacant
GSM 900MHz	890-915MHz; 935-960MHz; 124 channels of 200 kHz spacing	25+25	Experimentally observed results and empirical relationship (depicted in figure 2) shows that 30% of GSM channels are vacant; whereas 12% of each RF is required to manage logical 7 channels.
GSM 1800 MHz	1710-1785MHz; 1805-1880MHz; 374 channels	75+75	60% vacant channels; actual to find
WCDMA	1920-1980MHz; 2110-2170MHz	60+60	75% vacant channels
Wimax & 4G	2500-2690MHz	190	77% vacant channels
Wimax (fixed)	3400-3600MHz	200	90% vacant channels

* As per available information.

Table 2. Licensed spectrum of various wireless technologies.

interface measurement equipment is used in the drive test. The equipment measures different types of virtual and physical parameters of mobile cellular service in a given geographical region. Data relating to the network itself is collected by drive test equipment, radio frequency scanner information, services running on the network such as voice or data services and GPS information to provide location logging. The hardware and software used in the setup includes data cable and global positioning system (GPS), digital radio frequency (RF) scanner, laptop with charger and USB hub license dongle for TEMS, engineering handsets with 4 (2G/3G) SIMs of different operators mounted simultaneously and cable terminal, cell site database and link budget, clutter diagram from Google website, MapInfo software. In the setup, data collection software is installed in the laptop where mobile set is used along with GPS. Data related to signal strength, downlink and uplink frequency etc. is collected by the mobile whereas GPS collects the data of latitude and longitude of each point. All the information is stored with its geographical locations along with their respective time and date.

3.4.2. Data acquisition for availability of vacant channels

Data was collected for spectrum utilization measurements in GSM 900 MHz band in an outdoor environment of other cities viz. Bhopal, Ranchi, Patna, Dibrugarh, Shillong & Port Blair with population in the range of 1.5 million to 6.6 million as per 2011 census. The study reveals that there is 74.19% spectrum occupancy in lower band in Bhopal, while in Ranchi it is only 52.42% as

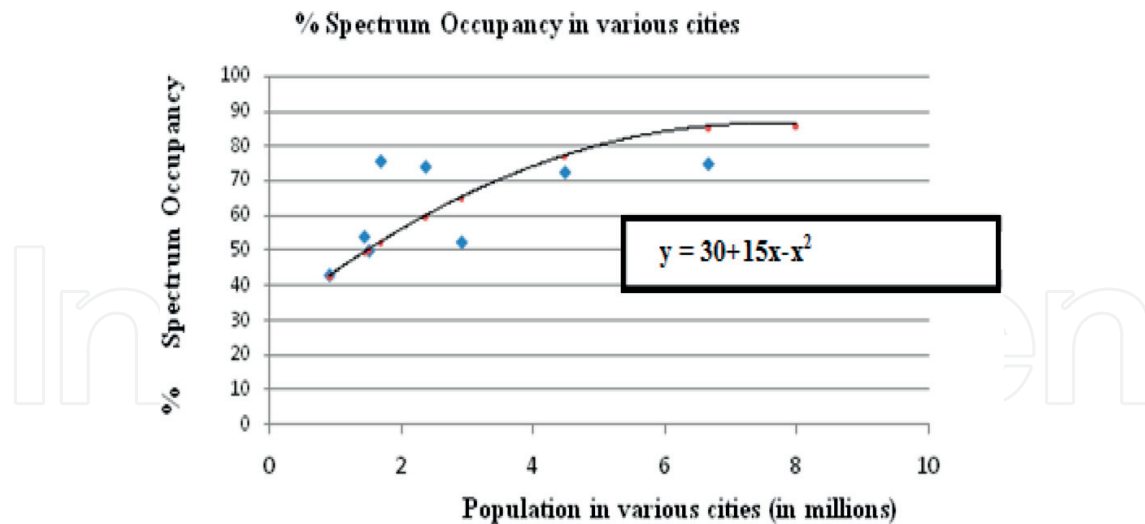


Figure 2. Population spectrum graph.

it switches to upper band where it has spectrum occupancy of 83%. In the lower band of Patna, the measurements indicate that there is 75.8% spectrum occupancy. Shillong, the capital of Meghalaya state of India is located at 25.57°N and 91.88°E on a plateau in the eastern part of the state. The population of the city is 1.43 million where spectrum occupancy is 54%. Port Blair located at 11° 40' N and 92° 46' E is the capital city of Andaman and Nicobar Islands in India. The next survey was conducted at Port Blair which is the municipal council in the southern part of Andaman, a part of India's Union Territory. Being the lowest populated area, it has spectrum occupancy of 43%. It is evident that most of the bands in lower band of various cities are quasi-permanently vacant. These vacant channels can be used for control signaling in CR communication.

3.4.3. Empirical formula for channel availability

The spectrum occupancy of eight cities of India is represented in **Figure 2**. It is shown in the diagram that there is 30% occupancy for the most sub-urban area with less population. For population between 1 million to 4 million, the increase is almost linear. In the range of population between 4 million to 7 million, it is observed that the occupancy reaches a saturation level. Also, with projected expansion of highly populated city core areas to 8 million, occupancy level is projected to reach up to 86%, leaving a clear space of 14% of channels for CR use [25].

As population increases, there will be requirement of more number of channels and this need can be managed through effective optimization methods. This can be mathematically calculated as negative requirement of channels and graphically expressed as saturation. Due to continuous growth in population, operators can request access for TCHs from higher frequency band and consequently, the occupancy at lower frequency band is reduced. Thus, the channel occupancy with growth in population can empirically be given as:

$$y = 30 + 15x - x^2 \quad (1)$$

where x = size of population in millions, y = channel occupancy percentage in lower frequency band.

Thus, it is found that 20% or more of the licensed bandwidth is almost practically unused even in a saturated market environment. In other words, more than 1/8th part of all bands were not in use which closely matches the need of one signaling channel for 7 traffic channels. This is more than the channel demand of 12% of the whole band to get access to the whole of the bandwidth at a time by cognitive radio and is adequate to take additional MAC level overhead required for CR. There is no urgent requirement of these channels by the licensed operators, whereby it can be carefully allotted as common control channel for CR purpose. Further, to doubly enhance protection of common control channel, a disaster recovery common control channel may be designated. It will hold the replica of allotments and processing status of CR Primary Common Control Channel. The above findings for common control channel are highly dynamic and sensed information may be able to provide user mobility in a most competitive environment at an economically affordable cost. The approximation of channel occupancy is possible depending upon the population and hence CR technology planners can propose a long term plan for efficient use of it for public benefits.

4. Accessibility

As per as the need of QoS is concerned, CR networks should have the ability to choose the best frequency band for use [27]. Spectrum decision is based on the channel characteristics and operations of PUs. Spectrum decision follows two steps: (i) every spectrum band is distinguished based on the statistical information of PUs and the local observations of CR users [28]. The available spectrum holes represent different characteristics that differ over time. (ii) After the available spectrum bands are characterized by considering spectrum characteristics and the QoS requirements, the most appropriate spectrum band should be selected. To minimize capacity variation, spectrum decision method is used which incorporates minimum variance-based spectrum decision (MVSD) scheme. To maximize the total network capacity, a maximum capacity-based spectrum decision (MCSD) scheme is used [29]. Accordingly a database is maintained where the data is purified based on signal to noise ratio (SNR), vacant holding time, etc. which is then used for channel allocation to SU.

After the holes are detected and best selected in licensed band, the next function of the CR user includes accessing the channel which is known as spectrum sharing. The wireless channel needs the synchronization of transmission attempts between CR users. The spectrum sharing aims to address four aspects:

- a. As per the architecture, the classification can be distributed or centralized. In centralized spectrum sharing, a central entity controls the procedures of spectrum allocation and access. In distributed spectrum sharing, local or probably global policies that are independently executed by each node decide the spectrum allocation and access [30].
- b. Based on allocation behavior, spectrum access can be cooperative or non-cooperative. In cooperative (or collaborative) allocation, the interference measurements of each node is exploited in such a way that it considers the effect of the communication of one node on other nodes. In non-cooperative allocation, only a single node is considered. To promote cooperation among conflicting decision makers, efficient spectrum sharing schemes

such as game theory have been used for more efficient, flexible, and fair spectrum usage [31–34].

- c. Based on the access technology, it is of two types: overlay and underlay. In overlay spectrum sharing, nodes access the network using the spectrum band that has not been used by PUs so as to minimize interference to the primary network. In underlay spectrum sharing, the spread spectrum techniques are exploited such that the transmission of a CR node is regarded as noise by PUs [35].
- d. Spectrum sharing methods are concentrated on two types of solution: where spectrum sharing can be within a CR network, which is called intranetwork spectrum sharing; and among multiple coexisting CR networks, which is called internetwork spectrum sharing.

4.1. Daily traffic behavior

The conventional telecom uses hourly prediction for estimating mobile communication traffic. In hourly prediction, peak time is not determined neither in the beginning of the hour nor at the end of hour. The clock hour is not authentic as it does not tell exactly about the peak time at which the traffic was maximum. Hourly traffic data is insufficient to decide whether a call can be initiated at a particular instant of time. Thus, it becomes necessary to study minutewise traffic pattern. Minutewise occupancy data is computed on hourly basis for various cells of varying channel numbers, e.g., each cell with 7/14/28/60 channels for 1/2/4/8 radio frequencies (RFs) of GSM system to assess the traffic behavior of PU. There are channels with same number of RFs which are lightly loaded at some places as well as highly loaded at some other locations.

Conventionally, a telecom operator analyzes the total traffic on hourly basis and identifies the busy hour where total traffic is maximum. Hourly data arranged on weekly basis does not give a clear picture of the peak hour as it contains many peaks. The traffic variations within a clock hour are not predictable in weekly analysis. Thus, data arranged on daily basis is taken to estimate the behavior of hourly traffic. For example, the minutewise collected occupancy data was taken on hourly basis for 50 cells of different channel numbers. **Figure 3** depicts daily occupancy pattern for the locations with 60 channels (8 RFs) and differently loaded at various traffic places [36, 37]. The results are similar for other RF counts also. The figure indicates double heaps in the channel occupancy. The heap pattern shows near parabolic nature from 07:00 to 15:00 and 17:00 to 22:00 h.

Usually, peak traffic is bell-shaped around peak few minutes. Hence, the busy hour may or may not include peak traffic minute which is of serious concern for prediction of channel availability. The clock hour is not authentic as it does not exactly tell about the peak time at which the traffic was maximum. The PU busy hour is redefined in context of CR as 1 h during which peak channel occupancy occurs and calculates the growth and decay of traffic 30 min each around peak traffic minutes.

4.2. Grade of service and blocking probability

The determination of QoS provided by a particular network configuration is required for an efficient design of communication networks. The Grade of Service (GoS) is a benchmark used

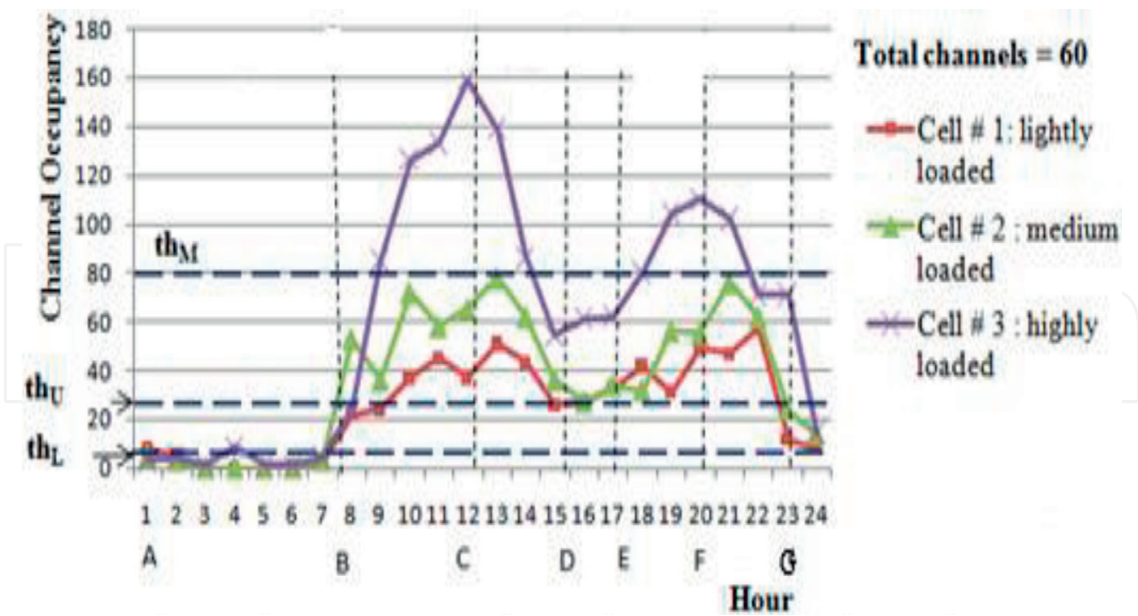


Figure 3. Daily channel occupancy pattern for three cells with 60 channels.

to define the desired performance of a particular cellular communication system by specifying a desired probability of a mobile subscriber obtaining channel access given a specific number of channels available in the system. The concept of trunking allows a large number of mobile subscribers to share the relatively small number of available channels in a cell by providing access to each mobile subscriber, on demand, from a pool of available channels.

Cellular communication systems are examples of trunked radio systems in which each mobile subscriber is allocated a channel on a per-call request basis. Upon termination of the call, the previously occupied channel is immediately returned to the pool of available channels. When a mobile subscriber requests service and in case all of the radio channels are already busy, the incoming subscriber call is blocked, or denied access to the system. In some communication systems, a queue may be used to hold the requesting mobile subscribers until a channel becomes available.

The GoS is a measure of the ability of a mobile subscriber to access a cellular system during the busiest hour. The busy hour is based upon the subscriber's demand for the service from the system at the busiest hour during a week, month or year. It is necessary to estimate the maximum required capacity in terms of available channels and to allocate the proper number of channels in order to meet the GoS. GoS is typically specified as the probability that a call is blocked, or the probability of a call experiencing a delay greater than the predefined queuing time. A call which cannot be completed at the time of call request made by a mobile subscriber is referred to as a blocked call or lost call. This may happen due to channel congestion or non-availability of a free channel. In other words, GoS is a measure of channel congestion which is specified as the probability of a call being blocked, or the probability of a call being delayed beyond a specified time.

When the offered traffic exceeds the maximum capacity of the system in terms of the allocated number of channels, the carried traffic becomes limited due to the limited number of channels.

The maximum traffic is the total number of channels in Erlangs. Let us consider a cellular system that is designed for a GoS of 2% blocking. This implies that the channel allocations for cell sites are designed in such a way so that 2 out of 100 calls requested by mobile subscribers will be blocked due to channel congestion during the busiest hour.

Practically, there are two types of trunked cellular systems. The first type of trunked cellular system offers no queuing for call requests, which is known as “Erlang B” system. This means that for every mobile subscriber making a service request; it is assumed that there is no set up time to a requesting mobile subscriber. He mobile subscriber is given immediate access to a channel if it is available. If no channels are available, the requesting mobile subscriber is blocked without access to the system and is free to try again later. This type of trunking is called “blocked calls cleared or blocked calls lost”. It assumes that calls arrive as determined by a Poisson distribution.

In performance evaluation of cellular systems or telephone networks, Erlang B formula is a formula for estimating the call blocking probability for a cell (or a sector, if sectoring is used) which has N “trunked” channels and the amount of (“offered”) traffic is A Erlang [38]:

$$B_B(N, A) = \frac{\frac{A^N}{N!}}{\sum_{i=0}^N \frac{A^i}{i!}} \quad (2)$$

where, $i = 1$ to N denotes the steady-state number of busy servers. It is directly used to determine the probability B that call requests will be blocked by the system because all channels are currently used.

The second type of trunked cellular system is called “blocked calls delayed” and its measure of GoS is defined as the probability that a call is blocked after waiting a specific length of time in a queue. In this system, a queue is provided to hold the calls requested which are blocked. If a channel is not available immediately, the call request may be delayed until a channel becomes available. Customers who find all N servers busy join a queue and wait as long as necessary to receive service. The probability of a call not having immediate access to a channel is determined by the “Erlang C” formula [38]. If no channels are immediately available, the call is delayed. The Erlang C formula is expressed in terms of blocking probability as:

$$B_C(N, A) = \frac{\frac{A^N}{N! \left(1 - \frac{A}{N}\right)}}{\sum_{i=0}^N \frac{A^i}{i!} + \frac{A^N}{N! \left(1 - \frac{A}{N}\right)}} \quad (3)$$

where, N = number of trunks or service channels, A = offered load.

4.3. Limitation of Erlang traffic models

The basic unit of channel busy/idle status is recorded for each frequency and each time slot. All the channel activities (busy/idle) during each time slot and frequency correction are monitored through different counters. In addition, user friendly graphical user interface (GUI) is available from where the data can be collected and stored in backup support.

Conventionally, the data related occupancy of channel is collected on hourly basis from the counters like m15, m16, m25, m17, m18, m23, m147, and m148. Telecom occupancy related data is stored in several counters of base station controller (BSC). To get secondwise accurate data, an interrupt driven learning mechanism is required which is practically not used in telecom network because the requirement is purely academic. In earlier telecommunication, very few processors were used in the radio access logic boards. The speed of working of processors was much less as compared to present day. Further, minutewise transfer of counter data to a central computer adds to transport overhead and hence avoided. Presently, the data speed is available in processors along with high speed links. Hence, capturing of minutewise data is now feasible. Thus, the counters are read every minute for free/occupied status. A scale below minutes was not explored due to the reason that the measurement traffic is a great appreciable part of the total signaling traffic. Thus, disastrous situation cannot be introduced in a live system.

The data for individual subscriber was taken offline from Billing Center at extreme leisure hour for few subscribers. It was expected that a similar set of users shall be the SUs also. For example, the minutewise occupancy of 32 channels during a busy hour has been taken into consideration and is shown in **Figure 4** which helps to determine the availability of spectrum holes. The red color cell indicates that the channel is busy or in dedicated mode and cannot be used for channel allocation to CR. The green color cell indicates that the channel is free and can be used for CR use after ensuring its QoS parameters. The parameters like call arrival rate and user holding time of PUs is predicted for the purpose of utilization of channel by SUs.

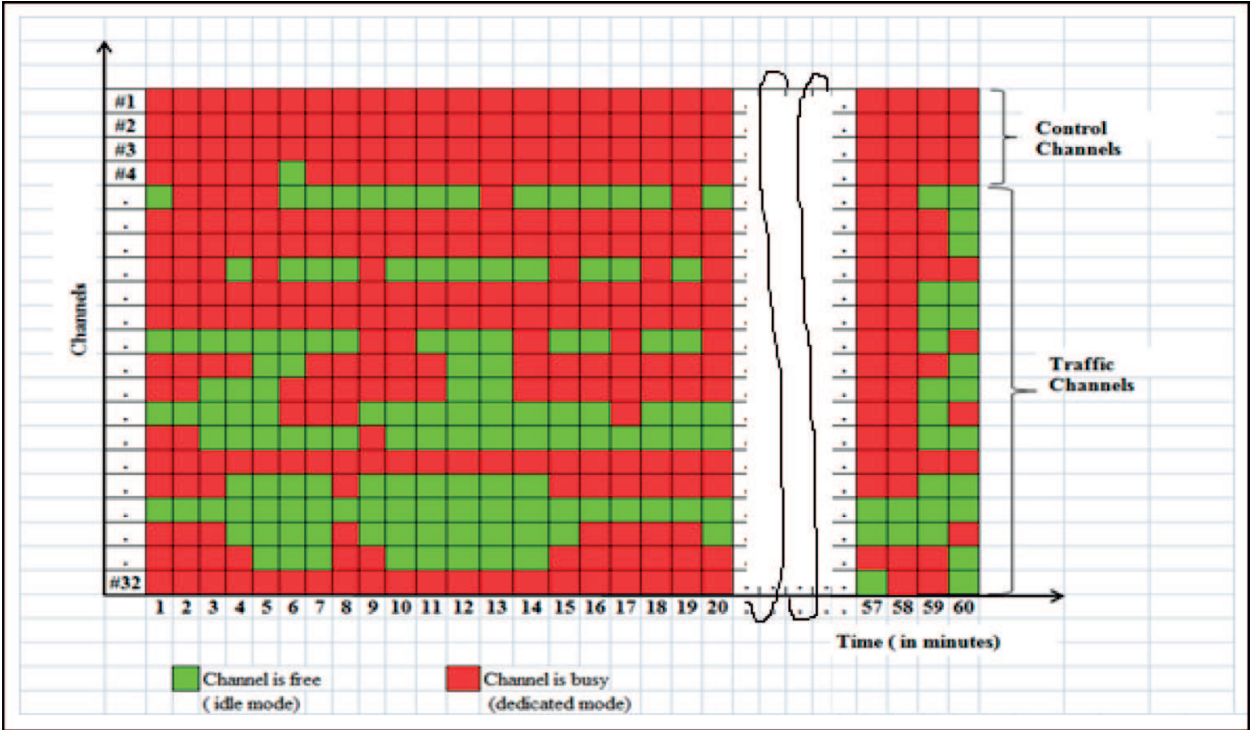


Figure 4. Minutewise occupancy chart for 32 channels in a day during busy hour.

4.4. Modified blocking probability

Blocking probability can be estimated by channel occupancy during last clock hour, e.g., 9 am–10 am at 10 am, 10 am–11 am at 11 am, etc., as in classical teletraffic theory and this estimation has been further improved through prediction models. In present chapter, clock has been considered only for hourly prediction purpose. For channel allocation, considering the instant of channel request as origin, an observation hour is defined in 2 more ways viz., (a) each hour has been composed of 60 immediately preceding minutes or channelized minutes, (b) current minute, or instantaneous minute.

For a lost call system, the GoS for CR shall be measured by using modified Poisson's model, as proposed in this chapter is given by the equation:

$$P(c, N) = 1 - \sum_{k=0}^{c-1} \frac{N^k}{k!} e^{-N} \quad (4)$$

where, $k = 0$ to $(c-1)$ with c = total number of trunked channels, $N = N_p + N_s$, N_p = count of PUs in the system, $N_s = \sigma N_p + \text{offset}$ = count of SUs in the system, where, $0 < \sigma \leq 1$. A portion of the PU, σ (known as SU factor) can be considered for the calculation of the blocking probability of a secondary call combined with PUs traffic in the system. Also, $0 < \text{offset} < 1$ such that N_s is an integer of higher value. These values of GoS help to determine whether the channel allocation to SU shall be successful or fail.

Consider a network with 'n' licensed channels ($j = 1$ to n) where the wireless nodes are static. A CRN is located within the licensed coverage area of licensed operator. The CRNs are equipped with spectrum sensor devices. The sensors monitor and report channel states to the central node via dedicated channels. Also, the outcome of the sensor state can be represented by binary signal $\{0,1\}$, where '0' represents the vacant state and '1' represents the occupied state of observed channels at an instant of time, t . All the channels are sensed assuming that the sensing time is very less than the duration of idle and busy time. The history database is periodically updated with the new sensing information. The collected database of different channels can be used to compute the different blocking probabilities as described below to estimate GoS.

4.4.1. Predicted blocking probability (PBP)

The probability computed by autoregressive moving average (ARMA) model that is a mathematical model of the persistence, or autocorrelation, in a time series is called as PBP. In ARMA model, a time series is observed for total number of calls (y_1, y_2, \dots, y_T). To predict the total number of calls in d^{th} day, forecast is done by minimizing the mean squared error (MSE), i.e., $\text{Min.}_{y'_{T+d}} E((y_{T+k} - y'_{T+d})^2)$. In that case, the best forecast is the mean of y_{T+d} , conditional on the information up to T , (y_1, y_2, \dots, y_T):

$$a = y'_{T+d} = E(y_{T+d} | y_1, y_2, \dots, y_T). \quad (5)$$

The BS monitoring system records the minutewise channel occupancy of licensed users for continuously 7 days of a week. The predicted value of offered load during the 8th day

is calculated by using data of total calls of a particular hour for 7 days (i.e., $T = 1$ to 7) using ARMA model and has been depicted in **Table 3** [39]. The predicted value of total calls of 8th day of a particular hour is taken for computation of blocking probability using the formula:

$$PBP = \frac{\frac{a^c}{c!}}{\sum_{i=0}^c \frac{a^i}{i!}} \quad (6)$$

where $i = 0$ to c = total channels in the system.

4.4.2. Instantaneous blocking probability (IBP)

The blocking probability provided by the system at an instant of time, $(t + 1)$, is called as IBP. The IBP is on every minute basis as shown in **Table 4** [39]. In this case, the offered load, a , is defined as, $a = \sum_{j=1}^n a_j$ = number of channels busy during the minute of observation, where, $a_j = 1$, if channel is busy & $a_j = 0$ if channel is free of $j = 1$ to n channels at that particular instant of time. The instantaneous blocking probability at time t , is defined as:

$$IBP = \frac{\frac{a^c}{c!}}{\sum_{i=0}^c \frac{a^i}{i!}} \text{ for } c = n \quad (7)$$

where, $i = 0$ to c = total channels in the system.

PREDICTION OF OFFERED TRAFFIC FOR CHANNELS $j=1$ to n								
HOUR →	1:00AM	2:00AM	.	.	.	22:00PM	23:00PM	00:00AM
DAY ↓								
#1	1243	1587	-	-	-	-	-	1325
#2	1453	1325	-	-	-	-	-	1243
-	-	-	-	-	-	-	-	
-	-	-	-	-	-	-	-	
-	-	-	-	-	-	-	-	
-	-	-	-	-	-	-	-	
#7	1000	1106	-	-	-	-	-	1106
#8*	1102*	1258*	-	-	-	-	-	1151*
*Predicted offered load								

Table 3. Prediction of offered load in a particular hour using ARMA model.

CALCULATION OF OFFERED TRAFFIC AT AN INSTANT OF TIME $t+1$ FOR CHANNELS $j=1$ to n											
TIME (in minutes)	1	2	t	** $t+1$.	3600
CHANNEL NO.↓											
#1	1	0	0	1	1	0	1	1			
#2	1.INITIALIZE		0	0	0	0	4.IBP				
#3	2.START		1	1	0	1	0	0			
#4	3.Press CTRL & PAUSE		0	0	0	1	5.PROCESS				
#5			0	1	0	0	0	0			
#6	1	0	0	0	1	0	6.CBP				
#7	1	1	1	0	1	0	0	0			
#8	1	1	0	0	0	0	0	0			
**Estimation of IBP at an instant of time ($t+1$)											
Active-X Command buttons for programme control											

Table 4. Calculation of offered load at an instant of time $t = (t + 1)$. (a snapshot taken from software).

4.4.3. Channelized blocking probability (CBP)

The blocking probability provided by the system at an instant of time $(t + 1)$ considering the traffic of the preceding 60 min is called as CBP and is depicted in **Table 5** [39]. The offered load in this case is defined as,

$a = \sum_{j=1}^n \sum_{t=60}^t a_t$; where, $a_j = 1$, if channel is busy & $a_j = 0$ if channel is free for $j = 1$ to n channels. The channelized blocking probability is defined as:

$$CBP = \frac{\frac{a^c}{c!}}{\sum_{i=0}^c \frac{a^i}{i!}} \quad (8)$$

where, $i = 0$ to $c = 60 \times n =$ total channels in the system.

The values of CBP and IBP helps to decide the probability of success whenever a SU initiates a request. The data has been chosen at peak busy hours for 50 channels and minutewise occupancy for 300 min calls is practically taken for estimation purpose for various trunk servers ranging from 7 to 50 channels. The CBP as shown in **Table 5** can be computed by the program developed by the author.

Figure 5 is plotted for comparison of CBP and PBP for consecutive 4 h. It is evident that the standard deviation of PBP is fixed with respect to IBP but the standard deviation of CBP matches with that of IBP during the busy hour which shows that the CBP is better than PBP [39]. The CBP is much more prominent during the peak hours where random variation of instantaneous values is more.

ESTIMATION OF OFFERED TRAFFIC CONSIDERING PRECEDING 60 MINUTES DATA FOR CHANNELS j=1 to n											
Time → (in minutes)	1	2	-	-	t-60	-	-	t	**t+1	-	3600
CHANNEL NO. ↓											
#1	1	0	-	-	1	-	-	1	1		
#2	0	0	-	-	0	-	-	1	0		
.	-	-	-	-	-	-	-	-	-		
.	-	-	-	-	-	-	-	-	-		
.	-	-	-	-	-	-	-	-	-		
#50	1	0	-	-	1	-	-	1	1		
**Estimation of CBP at time (t+1) based on immediate past 60 minutes											

Table 5. Calculation of offered load based on immediate preceding 60 min data.

4.4.4. Error estimation of blocking probability

The error is estimated by the computation of standard deviation between IBP and PBP, and IBP and CBP. The standard deviation of the sample is the degree to which individual data within the sample differ from the sample mean. Since PBP is fixed for a clock hour, the error between IBP and PBP is given by:

$$e_{pbp} = \frac{\sqrt{\sum_{i=1}^p (x_i - x')^2}}{p} \quad (9)$$

where x = value of IBP, x' = predicted value of PBP with $i = 1$ to p = total observation, $p = 60$ in present case.

As CBP varies minutewise, the error between IBP and CBP is given by:

$$e_{cbp} = \frac{\sqrt{\sum_{i=1}^p (x_i - x_i')^2}}{p} \quad (10)$$

where, x_i' = estimated value of CBP. The present chapter proves that $e_{pbp} - e_{cbp} \geq 0$.

It is evident from **Table 6** [39] that as the number of trunk server increases, error between IBP and CBP {calculated using equation (Eq.(10))} is less than that of error between IBP and PBP

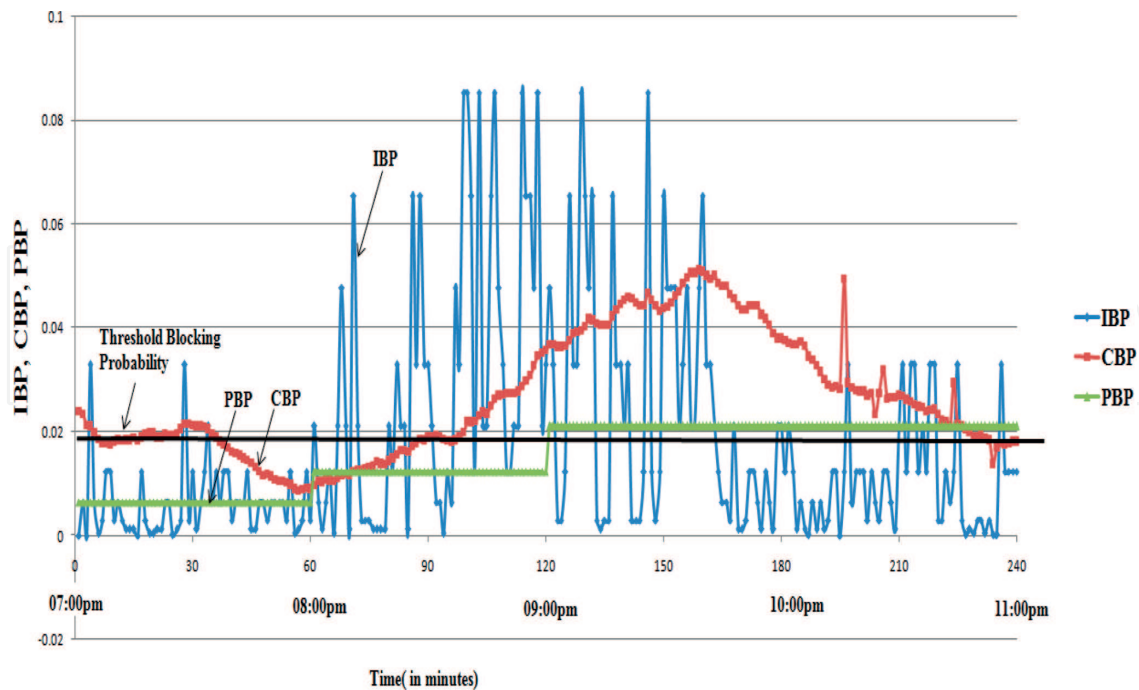


Figure 5. IBP, CBP and PBP vs. time in minutes in the system with trunk servers (c) = 22.

Trunk Servers	Std. Dev. (IBP & PBP)	Std. Dev. (IBP & CBP)	Difference
7	0.0139	0.0118	0.0021
15	0.0046	0.004	0.0005
22	0.0017	0.0018	-0.0001
29	0.0014	0.0013	0.0001
36	0.0007	0.0007	0
43	0.0003	0.0003	0
50	0.0003	0.0003	0

Table 6. Difference between standard deviation of IBP & CBP vs. IBP & PBP.

{calculated using equation (Eq.(9))}. Thus, the estimation of CBP is a better method than the estimation of PBP. The eligible list of channels available for use by SU can be formed where the channels have blocking probability ≤ 0.02 .

4.4.5. Estimation of blocking probability at a particular instant of offer

Whenever a SU initiates a call, at an instant, the blocking probability P from Eq. (4) is measured at that instant for all channels in the cell. The value of blocking probability must be less

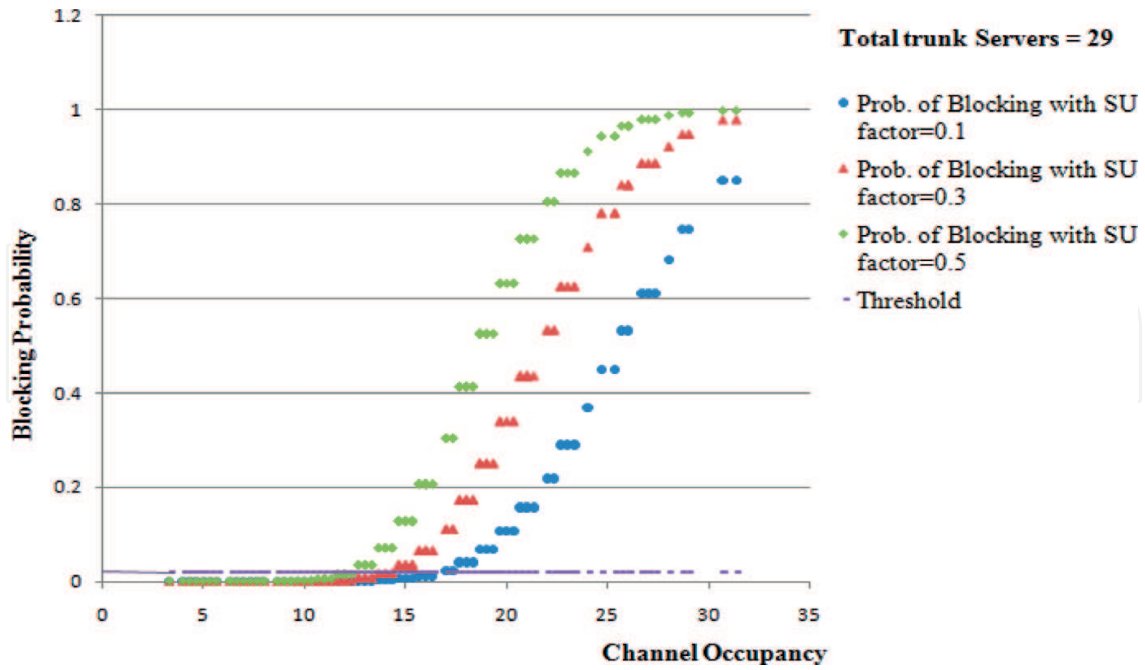


Figure 6. Call blocking probability with trunk servers ($c = 29$) using Poisson's model.

than some pre-determined value. An observation for different channels was made with $c = 29, 44, 60$ servers to assess the blocking probability and is shown in **Figure 6** [37].

It is observed from **Figure 6** that when the primary channel occupancy $< 50\%$ then the CR-BS is capable of providing mobile channel to the SU with blocking probability less than 0.02 which is equivalent to wireline. The channels which have blocking probability less than 50% are eligible used for allocation to SUs.

5. Maintainability

After capturing the best available spectrum by CR, the user may change its operating frequency band(s) that may require modifications to the operation parameters, based on the PU activity. This process is referred to as spectrum mobility. The purpose of the spectrum mobility management in CRN is to ensure smooth and fast transition that may lead to minimum performance degradation during a spectrum handoff.

5.1. Estimation of channel specific lifetime

CR users and CR infrastructure are essentially the identical as licensed authorized user system. But CR systems shall follow the guideline that: (a) only free channels of PU are to be used and when PU is active, the channels shall be returned to PU immediately, (b) it will not create any noise to PU system. Thus, architecture of SU should have some extra logic than PU system, otherwise they are similar. Therefore, there is a necessity to understand complete system architecture of PU along with PU traffic behavior for making conclusions about CR traffic handling effectively. This can be done by using prediction models.

The parameters like call arrival rate and user holding time of PUs can be predicted for the purpose of utilization of channel by SUs. The probability that the channel would be accessible for a given time period is evaluated according to the prediction or estimation results. The evaluated probability is then compared with some threshold, according to which, SUs can decide whether to use this channel or not. For the purpose of prediction, the study has been arranged in two broad divisions viz. (a) daily traffic analysis for long term prediction; (b) minutewise traffic analysis for immediate prediction of availability of vacant channels.

5.1.1. Long-term prediction model

Primary channel is allotted by the network operator according to demand. The channel occupancy is recorded during each hour. The traffic pattern of each channel is seasonal in terms of daily traffic. The present study uses long term prediction model to compute call arrival rate of the PU. It takes the weekly values of call arrival rate during a particular hour as an input and predicts its weekly values for the same hour. These predicted values can be used to assess the hourly traffic of PU, based on which SU channel allocation is done.

5.1.1.1. Seasonal auto regressive integrated moving average (SARIMA) model

In SARIMA, weekly data of each cell was gathered and organized on hourly basis and one particular hour was selected and analyzed. SARIMA model was used to forecast call arrival rate of weekly data for a specific hour depending on monthly monitored data of the same hour. The prediction of traffic pattern for a week follows the following relationship:

$$\text{Forecast occupancy} = F_i = S_i * T_j \quad (11)$$

where, $i = 1$ to 7 for 1 week is assumed as a seasonal unit, $j = 1$ to n , n = count of days for observation, S_i = seasonal coefficients; and,

$$T_i = \{A_0 - A_1 * D_j\}, \quad (12)$$

where, A_0 & A_1 = intercept coefficients obtained from SARIMA modeling.

5.1.1.2. Holt-Winter's (HW) method

A study of channel occupancy pattern shows that the occupancy varies every hour in a day and again daily occupancy pattern has variations over the days of a week. SARIMA uses moving average and auto regression methods which assures sample variations from predicted channel occupancy rate $\hat{\lambda}_{(j,t)}$ for j th channel at time t , as white noise. For further accurate prediction of channel occupancy rate $\hat{\lambda}_{(j,t)}$, it shall include three exponential smoothing factors viz. (a) the level (or mean) that is smoothed to give a local average value for the series of data, (b) the trend that is smoothed, and (c) each seasonal sub-series (i.e., all the values of Monday, all the values of Tuesday, etc. for weekly data) that is smoothed separately to give a seasonal estimate for each of the seasons. A combined effect of the three parameters is utilized to predict the call arrival rate by using the Holt-Winter's (HW) additive technique [40–42] given by equations as:

$$a_t = \alpha(\lambda_t - s_{t-p}) + (1 - \alpha)(a_{t-1} + b_{t-1}) \quad (13)$$

$$b_t = \beta(a_t - a_{t-1}) + (1 - \beta)b_{t-1} \quad (14)$$

$$s_t = \gamma(\lambda_t - a_t) + (1 - \gamma)s_{t-p} \quad (15)$$

where, α , β and γ are the smoothing parameters and usually their values are chosen heuristically; a_t is the smoothed level at time t , b_t is the change in the trend at time t , s_t is the seasonal smooth at time t , p is the number of periods per season.

Here, term j is omitted from $\lambda_{(j,t)}$, and is written as λ_t for simplicity. The Holt-Winters algorithm requires starting (or initializing) values given by equations as below:

$$a_p = (1/p) (\lambda_1 + \lambda_2 + \dots + \lambda_p) \quad (16)$$

$$b_p = (1/p) [(\lambda_{p+1} - \lambda_1)/p + (\lambda_{p+2} - \lambda_2)/p \dots + (\lambda_{p+p} - \lambda_p)/p] \quad (17)$$

$$s_1 = \lambda_1 - a_p, s_2 = \lambda_2 - a_p, \dots, s_p = \lambda_p - a_p \quad (18)$$

The HW forecasts are then calculated using the latest estimates given by the equations (Eq. (13)), (Eq. (14)) and (Eq. (15)) that have been applied to the series. Thus, the predicted value for $\hat{\lambda}_{(j,u+1)}$ for time period $(u + 1)$ for j th channel as:

$$\hat{\lambda}_{(u+1)} = a_u + \tau b_u + s_u \quad (19)$$

where s_u is the smoothed estimate of the appropriate seasonal component at u , b_u is the smoothed estimate of the change in the trend value at time u and a_u is the smoothed estimate of the level at time u .

5.1.2. Short-term prediction model

The minutewise occupancy data is used as compared to hourly occupancy data that has been used in traditional traffic prediction models.

5.1.2.1. Conventional traffic prediction

The conventional telecom uses hourly prediction for estimating mobile communication traffic. In hourly prediction, peak time is not determined neither in the beginning of the hour nor at the end of hour. The clock hour is not authentic as it does not tell exactly about the peak time at which the traffic was maximum. Hourly traffic data is insufficient to decide whether a call can be initiated at a particular instant of time. Thus, it becomes necessary to study minutewise traffic pattern. In the present work, minutewise occupancy data was computed on hourly basis for various cells of varying channel numbers.

5.1.2.2. Granular traffic distribution

The nature of traffic distribution for few cells at busy hours around the peak for half an hour on both the sides with time resolution of 1 min is studied. For prediction of channel occupancy by PU, it has been established that: "The rate of change of occupancy at a particular point of

time near peak time is proportional to its separation from peak time" [43]. Mathematically, it can be expressed as:

$$\frac{dy}{dt} = m' (t - t_p) \quad (20)$$

where, y = occupancy of primary channels at time t , t_p = expected time where peak occupancy occurs, m' is an arbitrary constant.

$$\text{This evolves to : } y = at^2 + bt + c \quad (21)$$

which is the equation of a parabola with: $h = -b/2a$, $n = ah^2 + bh + c$; (h, n) are the equation of the vertex. $h = t_p$.

The peak of parabola may be different from peak occupancy minute. Also peak occupancy projected at peak of parabola shall be different from actual peak obtained.

5.2. Maximum duration lifetime

The authors Hao Chen and L. Trajkovic had captured 92 days (2208 h) of traffic data to study calling behavior of users [44]. They concluded that (a) time scale of minutes is too small for recording the calling activity as an average holding time of a call is usually 3–5 min, (b) time scale larger than an hour (day) is too coarse to capture. The other authors Xiukui Li and Seyed A. (Reza) Zekavat have used the concept of accessing the channel for SU which is vacant with maximum duration [45].

Hence, most of the computations in telecommunication industry are based on hourly number of calls. Accordingly, existing literatures have indicated the need for counting free lifetime of a channel as a probabilistic parameter based on hourly occupied time and hence unaware about residual lifetime, particularly in case of ON/OFF traffic channel conditions.

5.3. Mean residual lifetime (MRL)

Methods like dynamic spectrum access (DSA) are proposed to access the channel but the actual channel allocation is not taken into consideration. In case of CR, spectrum or channel mobility is the main challenge as the SU can only access a call without interfering the PU. The program in the present work shall determine the best channel eligible for allocation to SU using the concept of mean residual lifetime (MRL). The procedure for computation of MRL has been described below.

The PU channel state shall be considered as $\{H_0, H_1\}$ where, H_0 = free and H_1 = occupied. The primary status as sensed or predicted by the SU is shown in **Figure 7** [JAF1]. False alarm and missed detection occurs during assessment which leads either to an inefficient system or interference with PU.

Considering a small unit of time ' τ ' which is the minimum time period such that BS can upload scanned RF data to Mobile Switching Centre (MSC) and fusion center without affecting routine CR operation. ' T ' is the time period during which the traffic is recorded based on pulled data from different CR-BS counters and used for statistical records e.g. number of seizures of a channel per hour, total holding time of the channel per hour etc. A SU can request for a channel anytime

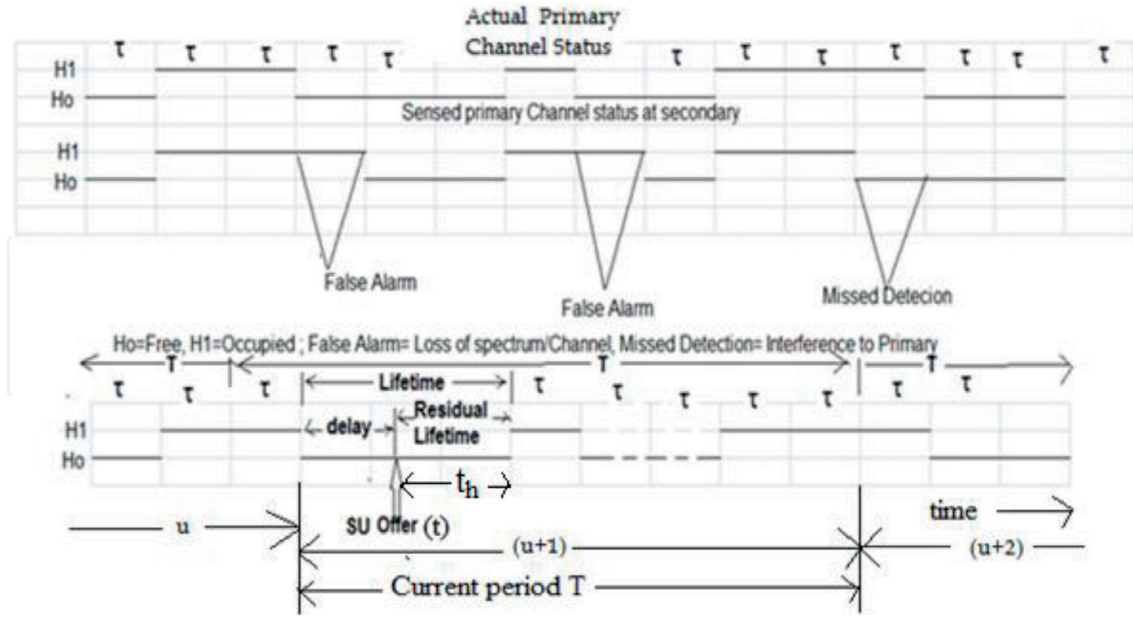


Figure 7. Channel occupancy in binary state.

within τ . The request is conveyed to the fusion center where the decision for allocation of a suitable channel is taken based on MRL and particular requesting SU's channel holding time profile.

T will be taken as an hour and $(1/\lambda)$ in minutes. It is also considered that ' τ ' is in minutes. It is also further considered that:

1. τ is the atomic unit of time and further decomposition of it is not practically feasible,
 2. MSC is updated by BS every τ units of time,
 3. MSC updates warehouse every T units of time
 4. MSC updates SU traffic data in warehouse every T units of time
 5. Channel occupancy request (PU&SU) is instantly passed on by the BS to MSC in real time t
- These aspects will be taken up for application in different models.

Let λ is the number of calls arrived on a particular traffic data acquisition interval T . If t_h is the call holding time of a SU requesting a free PU channel at any time t , then the probability that none of the PU occupies a channel till $t = t + t_h$ is given by:

$$p_0 = \exp \left\{ - \left(\hat{\lambda}/T \right) * \hat{t}_h \right\} \text{ for } t_h > \tau \text{ \& } t_h > h_p, \quad (22)$$

where, $\hat{\lambda}$ = predicted call arrival rate at time t to be determined by Holt-Winter's method, h_p = predicted optimal holding (service) time, and, \hat{t}_h = mean of all residual life time (t_h).

Let F be the lifetime distribution with discrete random sample and no call arrival intervals $\Gamma_1, \Gamma_2, \dots, \Gamma_n$ in the span of observation T . We arrange them in order such that:

$$\Gamma_1 < \Gamma_2 < \dots < \Gamma_{kn} < \Gamma_{nn} \text{ when } \Gamma_{0n} = 0.$$

The empirical mean residual lifetime (MRL) is defined as:

$$m_n(t) = \frac{\sum_{i=k+1}^n (T_{in} - t)}{(n - k)} \text{ for } t_e \in [\Gamma_{kn}, \Gamma_{(k+1)n}] \quad (23)$$

and, $m_n(t) = 0$ for $t_e \geq \Gamma_{nn}$ and $k = 0, 1, 2, \dots, (n-1)$.

where, $m_n(t_e)|_j$ = mean residual lifetime of j th channel which has 'n' number of vacant intervals at observation instant 't' which can be offered a SU call.

Here, t_e is the time which has elapsed since it became free; Γ_j = mean residual lifetime of j th channel at an instant t of SU call offer, and $j = 1, 2, \dots, r$ with r = total number of vacant channels at an instant 't' of offer.

The program developed by the author computes probability of success using the method proposed by Li and Zekavat, i.e., without MRL and with MRL. **Figure 8** depicts the probability of success with and without MRL for various trunk servers vs. time demanded by CR. The **Figure 8** clearly depicts that the proposed model using MRL method is superior than the method used by previous researchers [46].

5.4. Estimation of user holding time

A traffic model is required to represent traffic characteristics and to estimate the performance evaluation of the volume of traffic load place on network capacity and subscriber mobility. The present work assumes that the arrival rate is Poisson's distributed. The inter-arrival rate is also assumed to be exponentially distributed. The traffic model is determined assuming a certain number of channels in a cell system. The two crucial factors for mobile communication in the traffic pattern are called arrival rate of the channel and user call holding time. Hence, the traffic model is developed based on the prediction of call arrival rate and the study of holding time distribution of individual customers.

5.4.1. Poisson's distribution

A telecommunication network consists of expensive hardware (trunks, switches, etc.) which carries telecommunications traffic (phone calls, data packets, etc.). The physical network is fixed, but the traffic is random for which it is designed, i.e., the call arrival rate and the user holding time is unpredictable. Thus, to accommodate this random demand of traffic, the network designers must predict the call arrival rate for allocation of resources. The usual assumption in classical teletraffic theory is that the call arrivals follow a Poisson's process. The Poisson's assumption is consistent with data for voice traffic when the calls are generated by a large number of independently acting subscribers.

The French Mathematician Simeon Denis Poisson developed Poisson's formula. It states that for non-overlapping events, arriving at an average rate λ , the probability of 's' arrivals in time t equals:

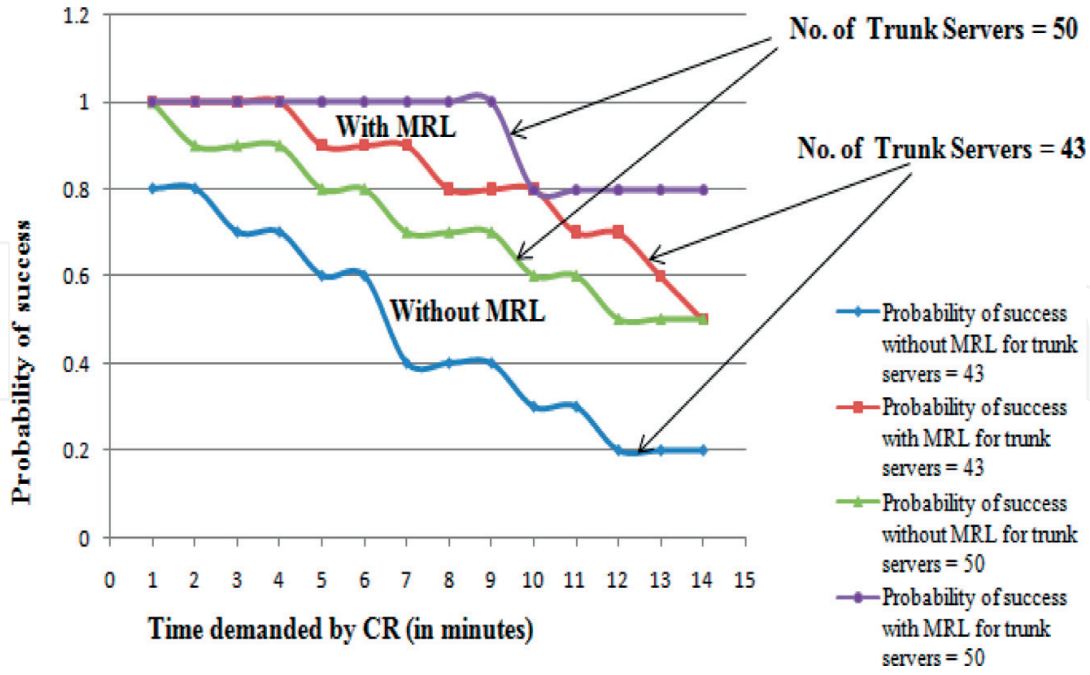


Figure 8. Comparison of probability of success with and without MRL vs. time demanded by CR for trunk servers = 43 and 50.

$$P('s' \text{ arrivals in time 't'}) = \frac{(\lambda t)^s e^{-\lambda t}}{s!} \quad (24)$$

Poisson's distribution is taken for traffic measurement as it is based on memoryless system and it generally gives a better estimate of the traffic related parameters.

5.4.2. Holding time distribution

Telecom occupancy related data is stored in several counters of Base Station Controller (BSC). To get secondwise accurate data, an interrupt driven learning mechanism is required which is practically not used in telecom network because the requirement is purely academic. In earlier telecommunication, very few processors were used in the radio access logic boards. The speed of working of processors was much less as compared to present day. Further, minutewise transfer of counter data to a central computer adds to transport overhead and hence avoided. Presently, the data speed is available in processors along with high speed links. Hence, capturing of minutewise data is now feasible.

The channel occupancy duration depends on individual person depending upon profession, status, time of day, etc. and varies widely at different hours of a day. This is most predominant in case of speech communication when the channel holding time depends upon caller and various customers called parties. Thus, the holding time data shows different variation at different levels of the time series and hence, a transformation of the data series can be useful. The Box-Cox method is used to transform this data into normality. The Box-Cox method obtains a normal distribution of the transformed data (after transformation) and a constant variance.

Let us denote original observations $h_{i,u,p}$ as h_p for the i^{th} user at u^{th} hour and write the series as h_1, h_2, \dots, h_t and transform the observations as w_1, w_2, \dots, w_t . According to Box-Cox principle [47]:

$$\begin{aligned} w_t &= \log(h_t); & \text{for } \zeta = 0 \\ \text{and } w_t &= (h_t^\zeta - 1)/\zeta; & \text{for } \zeta \neq 0 \end{aligned} \quad (25)$$

where, ζ is a parameter used to compute the confidence level (CL). Using the values of $\zeta = \{-2, -1, -0.5, 0, 0.5, 1, 2\}$ and to gain confidence level (CL) limit up to 95%, the optimum value of ζ shall be used to assess h_p as:

$$\begin{aligned} h_p &= \exp(w_t); & \text{for } \zeta = 0 \\ \text{and } h_p &= (\zeta \cdot w_t + 1)^{1/\zeta}; & \text{for } \zeta \neq 0 \end{aligned} \quad (26)$$

where, h_p = optimal holding (service) time of the user at time t .

The Box-Cox method can be used to decide the optimum holding time of the user.

5.5. Channel allocation model

On placement of service request by an SU, all vacant channels from eligible list has to be evaluated for allocation based on (i) predicted call arrival rate during the hour created through long term table; (ii) IBP at the instant for primary decision on allocation; (iii) mean residual lifetime of the channel at the time of service request; (iv) expected service holding time of a particular user requesting service; (v) CBP at the instant based on short term table. Finally, the best channel with highest probability of survival is selected for offer to the incoming SU traffic [46].

The interworking of different blocks for channel allocation is shown in **Figure 9** and is described below:

- A. Channel traffic updation: The Gateways (GWs) monitor PU activities using dedicated RF scanners. G_1, G_2, \dots, G_k are responsible for monitoring PU activities as well as for SUs. Any change in channel occupancy is passed on by GW to CR-BS and MSC in real time t . BS maintains several counters for traffic recording purposes. The counts of the counters are polled by MSC every ' τ ' interval and then the counters are reset. When $T = k\tau$ where, $k = 2, 3, \dots$ MSC prepares a table for the call arrival rate for T interval for each channel and deposit to the warehouse where the data is stored in format $\lambda(j, u)$ where, j = channel number and u = current T period number. This module also provides idle time information d_1, d_2, \dots , etc. in τ units since a channel is free.
- B. SU traffic updation: SU traffic information is recorded in the billing register after the completion of each call. The traffic details in respect of each SU are stored in warehouse. It is used for predicting holding time of SU at the time of service request.
- C. Channel traffic prediction: Primary channel is allotted by network operator according to demand. The channel occupancy is recorded during each T . The predicted value for channel occupancy $\hat{\lambda}_{(j,u+1)}$ for time period $(u + 1)$ for j th channel is computed using HW method using (Eq.(19)).

As soon as a new predicted value of call arrival rate is available during a particular hour, HW updates its estimated three components (level, trend, seasonal) for that particular

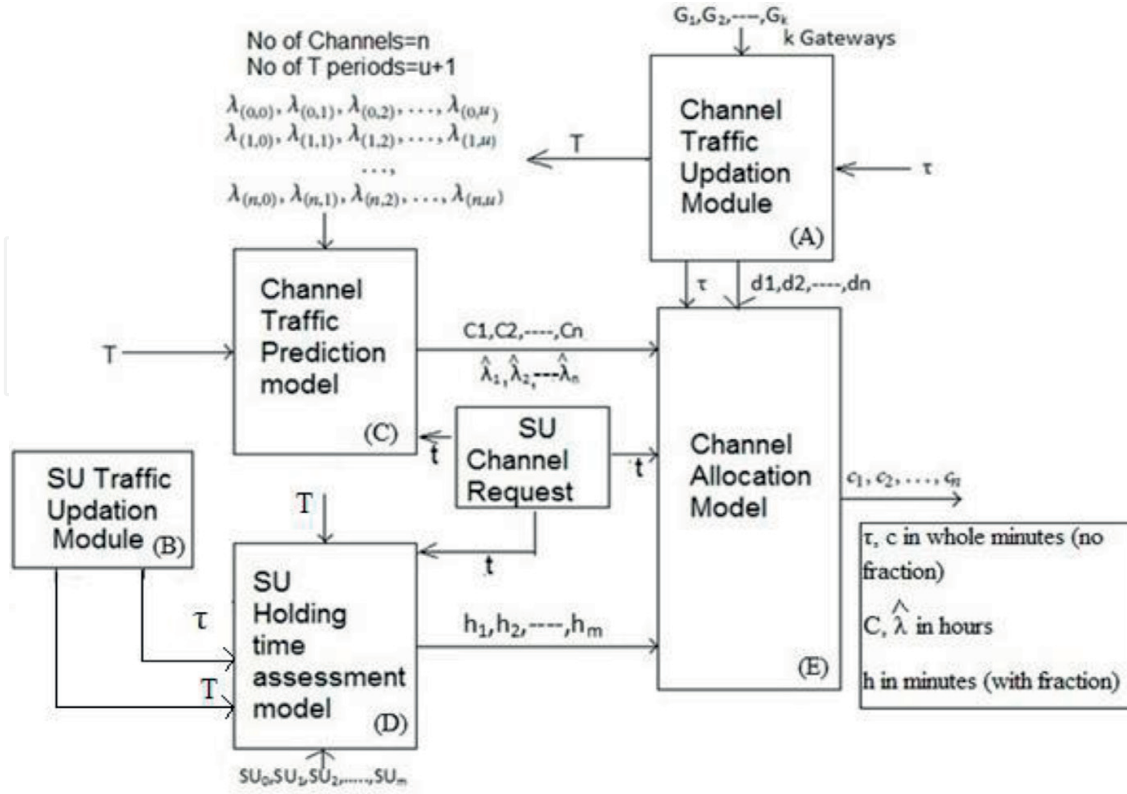


Figure 9. Channel selection block diagram.

hour. The value of smoothing constant for each component falls between zero and one. Larger smoothing constants mean more weight is placed on the value suggested by the new predicted value and less on the previous estimate. This means that the method will adapt more quickly to genuine changes in the call arrival pattern.

The list of channels $\{C_1, C_2, \dots\}$ which satisfies the above condition are predicted during the last hour and are then transferred to the channel allocation model for assessment of holding time during the current hour of allocation.

- D. SU holding time assessment: The holding time data shows different variation at different levels of the time series and hence their transformation is done by Box-Cox method using (Eq.(25)) and the optimum holding time needed by SU is obtained by (Eq.(26)).
- E. Channel allocation model: The set of eligible channels obtained by (Eq.(22)) are with residual lifetime:

$$t_j = \Gamma_j - h_p > 0 \quad (27)$$

where, h_p = service time needed by SU at time t .

The eligible channel set $\{c_1, c_2, \dots, c_r\}$ is arranged and the probability of the success in the offered j th channel shall be:

$$p_{0,j} = \exp \left[- \left\{ \hat{\lambda}_{(u+1)} / T \right\} * t_j \right] \quad (28)$$

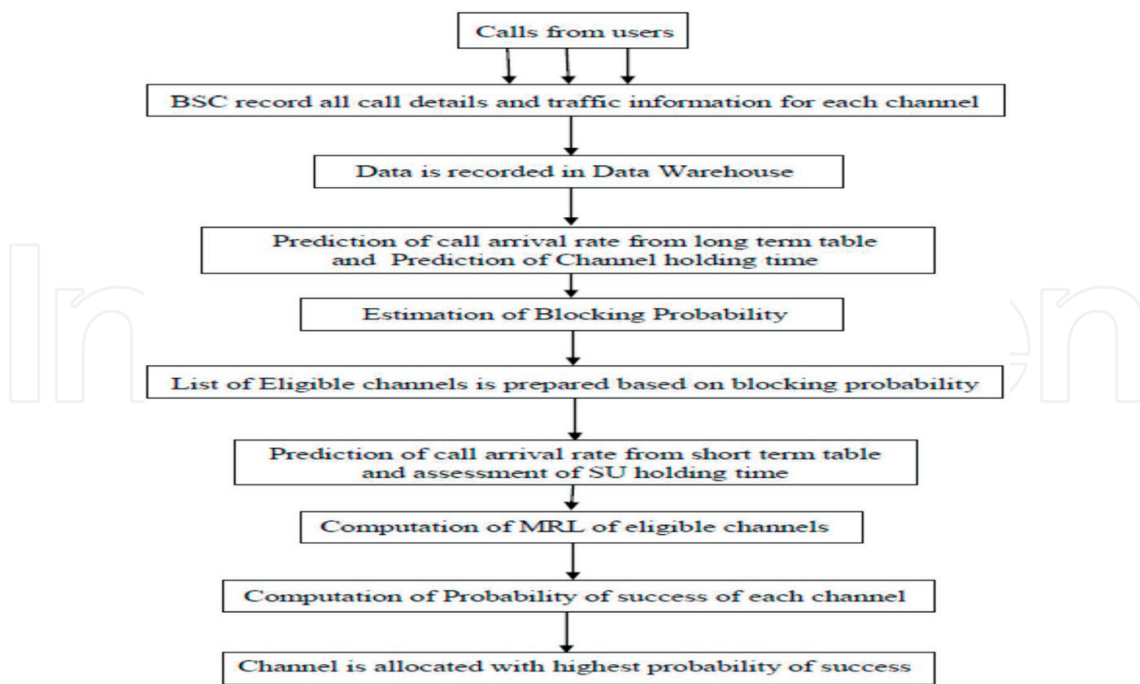


Figure 10. Process for channel allocation.

A sequential flowchart of data flow from all the blocks and computation of MRL has been given in **Figure 10**. Based on the measurement of the call arrival rate, holding time of PUs and various parameters of QoS, the channel allocation is done.

5.6. Simulation and verification of results

Minutewise traffic data acquisitioned online is collected in a table in OMC-R. SU can raise service request at any time. To serve channel allocation engine inputs,

- At the beginning of each hour, for all channels predicted call arrival rate $\hat{\lambda}_{(j,t)}$ for the current hour from channel prediction model;
- estimated holding time in minutes for the service request from SU holding time assessment model;
- all channel occupancy status is 'free' or 'busy' mode for last 60 min starting from current minute from channel traffic updation module is taken, and
- their MRL is computed.

Finally, channels with highest probability of survival given by Eq. (28) are selected for offer to the incoming SU traffic.

A trial run for 25 times each for available channels 7, 15, 22, 29, 36, 43 and 50 were carried for holding times from 1 to 14 min in the program developed by the author. A snapshot of the program is depicted in **Figure 11**, where different SUs demand varying holding times. The 'red' color indicates that the channel is busy while the 'green' color indicates that the channel is free. Whenever an SU requests a channel at time t for a certain holding time, the channel is allocated to

** CHANNEL ALLOCATION TO SU AT AN INSTANT OF TIME $t = t+1$ FOR CHANNELS $j=1$ to 22											
TIME (in minutes)	1	2	t	**t+1	.	3600
CHANNEL NO.											
#1	1	0	0	1	1	0	1	1			
#2	0	1. INITIALIZE	0	0	0	0	4. IBP	1			
#3	1	1	1	1	0	1	0	0			
#4	0	2. START	0	0	0	1	5. PROCESS	1			
.	0	0	1	0	1	0	0	0			
.	1	3. Press CTRL & PAUSE	0	1	0	6. CBP	1				
#21	1	1	1	0	1	0	0	1			
#22	1	1	0	0	0	0	0	0			
Channel Allocation is successful if holding time demanded by CR = 3 minutes											
Channel Allocation fails if holding time demanded by CR = 3 minutes											

Figure 11. A snapshot of the program for channel allocation at an instant of time t .

that particular SU if the channel is free for continuous holding time demanded by SU, and is shown in 'yellow' color in **Figure 11**. If the channel is busy even for the last holding time demanded by SU, the program indicates that the channel allocation is unsuccessful and is shown with 'red' color in continuation with yellow color.

To study success rate for channel allocation various cases were considered with varying available number of channels and different holding times demanded by SU, where the total number of channels in the cell is denoted by t_{ch} .

Case (i): Consider $t_{ch} = 15$ and the time demanded by the SU = 2 min. The result is obtained when the program is initialized at 100th min and stopped at 102nd min out of 300 min total available data. At 102nd min, when a call request is made by SU, the total available vacant channels are 5 out of 15 channels. The values of blocking probabilities are obtained as IBP = 0.03649 and CBP = 0.0308. The MRL is computed for all the five vacant channels. The MRL of the five channels are 4.7, 0.82, 0.5, -27 and -27.25. As one of the channels has maximum MRL and has value > holding time demanded (2 min), it is selected for channel allocation to SU. The result is depicted in snapshot given in **Figure 12** and is shown with continuity of yellow color for 2 min, which signifies that the channel allocation was successful. **Table 7** shows analysis of success rate for 15 channels with various holding times demanded by CR.

Case (ii): Consider $t_{ch} = 43$ and the time demanded by the SU = 9 min. The result is obtained when the program is initialized at 80th min and stopped at 82nd min out of 300 min total available data. At 82nd min, when a call request is made by SU, the total vacant channels are 14 out of 43 channels. The values of blocking probabilities are obtained as IBP = 1.102×10^{-3} and CBP = 6.442×10^{-4} . The MRL is computed for all the 14 vacant channels. The MRL of the 14 channels are: 4, 0.75, 0.444444, -0.6875, -1.5, -2.6, -4, -5.66667, -5.8, -11.6667, -12.5, -13.5714, -13.8, -14.2222, -20. As the MRL of one of the channels has value > holding time demanded (9 min); thus, the channel allocation was successful. The result is depicted in snapshot given in **Figure 13** and is shown with yellow color which signifies that the channel allocation was successful. **Table 8** shows analysis of success rate for 43 channels with various holding times demanded by CR.

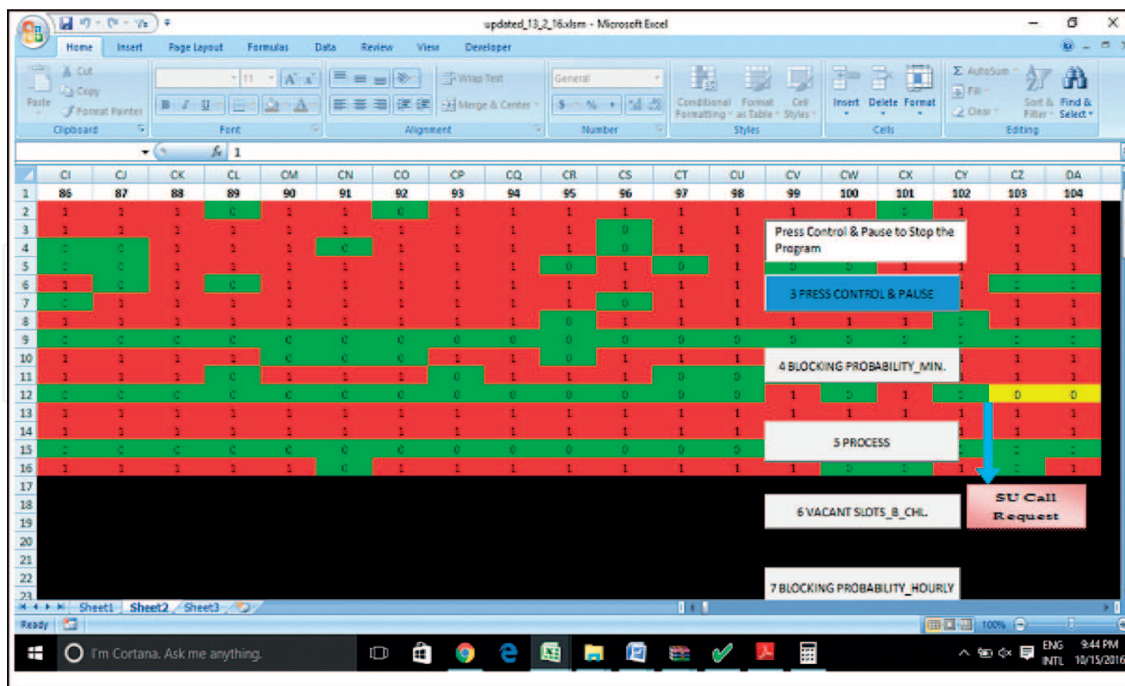


Figure 12. Validation result for total channels = 15; SU holding time demanded = 2 min.

OBSERVATION	INSTANT OF OFFER	TIME DEMANDED BY CR													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
#1	65														
#2	70														
#3	75														
#4	80														
#5	85														
#6	90														
#7	95														
#8	100														
#9	105														
#10	110														
#11	115														
#12	120														
#13	125														
#14	130														
#15	135														
#16	140														
#17	145														
#18	150														
#19	155														
#20	160														
#21	165														
#22	170														
#23	175														
#24	180														
#25	185														
SUM (SUCCESS)		20	15	7	5	6	4	1	1	1	1	1	1	1	1
PROBABILITY OF SUCCESS		0.8	0.6	0.28	0.2	0.24	0.16	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04

Table 7. Computation of success rate for total channels = 15 for CR holding time = 1 to 14 at various runs of the program.

Thus, the channel allocation is successful as the count of channels increases in the system with the precondition that the $MRL > \text{time demanded by the SU}$.

5.7. Validation of result

The data was chosen at busy hours for various channels ranging from 15 to 50 and minutewise occupancy for 300 min calls is taken for simulation purpose. A program has been developed for

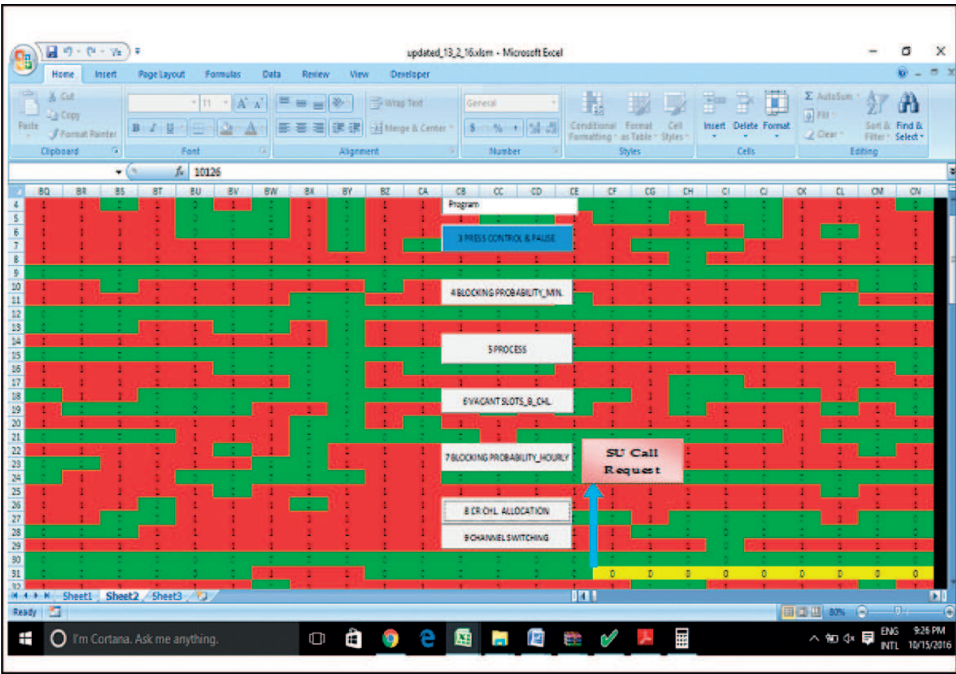


Figure 13. Validation result for total channels = 43; SU holding time demanded = 9 min.

OBSERVATION	INSTANT OF OFFER	TIME DEMANDED BY CR													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
#1	65														
#2	70														
#3	75														
#4	80														
#5	85														
#6	90														
#7	95														
#8	100														
#9	105														
#10	110														
#11	115														
#12	120														
#13	125														
#14	130														
#15	135														
#16	140														
#17	145														
#18	150														
#19	155														
#20	160														
#21	165														
#22	170														
#23	175														
#24	180														
#25	185														
SUM (SUCCESS)		25	24	21	21	20	18	18	16	16	14	13	13	10	10
PROBABILITY OF SUCCESS		1	0.96	0.84	0.84	0.8	0.72	0.72	0.64	0.64	0.56	0.52	0.52	0.4	0.4

Table 8. Computation of success rate for total channels = 43 for CR holding time = 1 to 14 at various runs of the program.

real time offering and verification if the call request succeeds or fails for the duration demanded by SU. The program calculates the predicted λ upto last hour at background and has been included in simulation program as offline. Similarly, holding time needed for SU has also been imprinted interactively. The program accepts any number of PU channels upto 50 selectively at the time of trial. The position of occupancy can be seen on screen starting from any instant after 60 min upto 300 min for any duration. Also, one or more SU calls can be offered to the system and minute by minute observation of SU call progress can be monitored on screen.

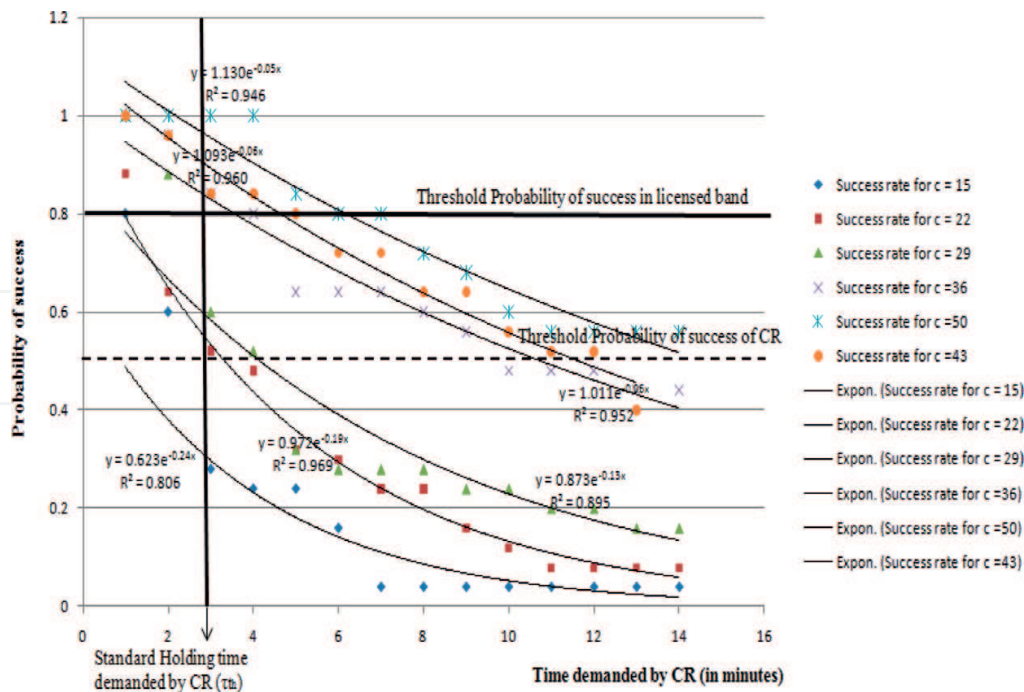


Figure 14. Probability of success rate vs. time demanded by CR for various trunk servers.

The program was run repetitively and at random, under various channel availability conditions and differently demanded holding time. The result has been plotted in **Figure 14**, where the probability of success (or QoS) has been calculated as:

$$\text{probability of success (or QoS)} = \frac{\text{number of times call success}}{\text{total number of trials}},$$

where, number of trials were 25 times for each run condition at random input time.

As depicted in **Figure 14**, in case, if the threshold probability in licensed band is taken to be 0.8, the success rate for CR users is still achieved if the channels are ≥ 36 and holding time ≤ 2.5 min demanded by the SU [46]. When the threshold probability for SU is 0.5, the success rate is achieved if the channels are ≥ 22 with minimum holding time ≤ 2.5 min demanded by the SU. Thus, when the PU channel occupancy is 50%, the CR-BS shall provide mobile channel to SU with blocking probability ≤ 0.02 , where industry standard for blocking is 2% (0.02).

Thus, the CR-BS shall be capable of providing vacant channels to SU. Grade of Service (GoS) of SU is at par with GoS standard specified for PU when traffic intensity is below 50%. Success rate of channel allocation is increased as number of channels increases in the system.

6. Conclusion

In mobile communication network, despite heavy usage of communication channels, vacant channels are available which can be used for cognitive radio network. From the present work it is found that practically 20% or more of the total licensed bandwidth is permanently unused or vacant even in a crowded region. This is well above the need of 1 out of 8th part of the band to get access to the whole of the bandwidth at a time by CR and adequate to take additional MAC

level overhead required for CR. Remaining 80% of the licensed bands are dynamically vacant which can be used for traffic purpose. Based on results, an empirical relationship has been established for channel occupancy for a city, where such survey has not been conducted but population is known. The blocking probability of the channels are available for allocation and duration of remaining unoccupied can be mapped to the instant status of the channels. The present work has established that when the PU channel occupancy is 50%, the CR-BS shall provide voice channel to SU with blocking probability ≤ 0.02 , where industry standard for blocking is 0.02. The GoS improves linearly with total number of channels in the system at a given per channel availability. It is also evident that Erlang theory is effective for Poisson's distribution theorem with ≥ 20 channels for GoS to achieve.

A program that has been developed to accept SU service requests with different QoS from a set of PU channels can be used for dynamic allocation to SU. A SU call request can be placed in such a dynamic environment and status of the SU call progress can be noticed till the end of requested holding time. The mean residual lifetime (MRL) of the free channels was computed based on requesting SU call holding time for PU channel allocation to a requesting SU. The channel with highest MRL is allocated. If the threshold probability in licensed band is taken to be 0.8, the success rate for CR users is achieved if the channels are ≥ 36 and holding time ≤ 2.5 min demanded by the SU. When the threshold probability for SU is 0.5, the success rate is achieved if the channels are ≥ 22 with minimum holding time ≤ 2.5 min demanded by the SU. Thus, success rate of channel allocation increases with the increase in number of channels in the system.

The proposed model shall be deployed to provide services for IoT through wireless communication. The implementation of the proposed work shall be a good solution where high volume of devices with low mobility is required for new wireless technologies.

Author details

Neeta Nathani^{1*} and G. C. Manna²

*Address all correspondence to: neeta_nathani@yahoo.com

1 Electronics Engineering, G.H. Raison College of Engineering, Nagpur, Maharashtra, India

2 BSNL, Jabalpur, Madhya Pradesh, India

References

- [1] Cisco Visual Networking Index: Forecast and Methodology, 2015–2020. February 3, 2016
- [2] Ghosh G, Das P, Chatterjee S. Cognitive radio and dynamic spectrum access: A study. *International Journal of Next-Generation Networks*. March 2014;6(1):43-60. DOI: 10.5121/ijngn.2014.6104
- [3] Mitola J, Maguire GQ Jr. Cognitive radio: Making software radios more personal. *IEEE Personal Communications*. August 1999;6(4):13-18

- [4] Haykin S. Cognitive radio: Brain-empowered wireless communications. *IEEE Journal on Selected Areas in Communications*. February 2005;23(2):201-220. ISSN: 0733-8716
- [5] Hiremath S. Transmission rate prediction for cognitive radio using adaptive neural fuzzy inference system. In: *Proceedings of 5th International Conference on Industrial and Information Systems (ICIIS)*; July 29–August 1; September 2010. ISSN: 2164-7011
- [6] Haykin S. Fundamental issues in cognitive radio. In: *Cognitive Wireless Communication Networks*. Boston, MA: Springer; 2007. pp. 1-43. DOI: <https://doi.org/10.1007/978-0-387-68832-9>. Print ISBN: 978- 0-387-68830-5
- [7] Nathani N, Manna GC. Analysis of quality of service of cognitive radio systems. In: *2013 6th IEEE International Conference on Emerging Trends in Engineering and Technology (ICETET 13)*; IEEE Computer Society; 16-18 December 2013. pp. 107-108. ISBN: 978-1-4799-2561-2/13
- [8] Nathani N, Manna GC. Quality of Service challenges for mobile cognitive radio. In: *2015 International Conference on Computer Science and Environmental Engineering*; 17-18 May 2015; Beijing; China. DESTech Publications. pp. 967-998. ISBN: 978-1-60595-240-6
- [9] Yucek T, Arslan H. A survey of spectrum sensing algorithms for cognitive radio applications. *IEEE Communications Surveys Tutorials*, First Quarter. 2009;11:116-130
- [10] Al haj Mustafa SI, Amin Babiker A, Mustafa N. Comparison of detection techniques in spectrum sensing. *International Journal of Science and Research (IJSR)*. May 2015;4(5): 1949-1953. ISSN (Online): 2319-7064
- [11] Zahedi-Ghasabeh AT, Daneshrad B. Spectrum sensing of OFDM waveforms using embedded pilots in the presence of impairments. *IEEE Transactions on Vehicular Technology*. March 2012;61:1208-1221
- [12] Bouzegzi A, Ciblat P, Jallon P. Matched filter based algorithm for blind recognition of OFDM systems. In: *Proceedings: IEEE Vehicular Technology*; September 2008. pp. 1-5
- [13] Al-Habashna A, Dobre O, Venkatesan R, Popescu D. Cyclostationarity-based detection of LTE OFDM signals for cognitive radio systems. In: *Proceedings: IEEE GLOBECOM 2010*; December 2010. pp. 1-6
- [14] Mourad Mabrook M, Hussein AI. Major spectrum sensing techniques for cognitive radio networks: A survey. *International Journal of Engineering and Innovative Technology (IJEIT)*. September 2015;5(3):24-33. ISSN: 2277-3754
- [15] Urkowitz H. Energy detection of unknown deterministic signals. In *Proceedings: IEEE*. April 1967;55(04):523-531a
- [16] Ghasemi A, Sousa ES. Optimization of spectrum sensing for opportunistic spectrum access in cognitive radio networks. In *Proceedings: IEEE CCNC*. January 2007:1022-1026
- [17] Bhargavi D, Murthy C. Performance comparison of energy, matched-filter and cyclostationarity-based spectrum sensing. In: *Proceedings: IEEE SPAWC 2010*; June 2010. pp. 1-5
- [18] Tian Z, Giannakis G. Compressed sensing for wideband cognitive radios. In: *Proceedings: IEEE ICASSP 2007*, Vol. 4; April 2007. pp. 1357-1360

- [19] Furtado A, Lúis M, Oliveira R, Dinis R, Bernardo L. Channel availability assessment for cognitive radios. In: 4th Doctoral Conference on Computing, Electrical and Industrial Systems (DoCEIS); April 2013. pp. 495-504
- [20] Moghaddam SS, Kamarzarrin M. A comparative study on the two popular cognitive radio spectrum sensing methods: Matched filter versus energy detector. *American Journal of Mobile Systems, Applications and Services*. 2015;1(2):132-139. Available from: <http://www.aiscience.org/journal/ajmsas>
- [21] Federal Communications Commission. Spectrum Policy Task Force. Report of the Spectrum Efficiency Working Group; November 15; 2002
- [22] Benitez ML, Umbert A, Casadevall F. Evaluation of spectrum occupancy in Spain for cognitive radio application. In *Proceedings: IEEE 69th Conference on Vehicular Technology; VTC Spring 2009; Barcelona; April 26-29, 2009*. pp. 1-5
- [23] Islam Md H, Koh CL, Oh SW, Qing X, Lai YY, Wang C, Liang T, Toh BE, Chin F, Tan GL, Toh W. Spectrum survey in Singapore: Occupancy measurements and analysis. In: 3rd International Conference on Cognitive Radio Oriented Wireless Networks and Communications, 2008; CrownCom 2008, Singapore; May 15-17, 2008. pp. 1-7
- [24] Erpek T, Lofquist M, Patton K. Spectrum Occupancy Measurements: Loring Commerce Center Limestone Maine; 18-20 September 2007
- [25] Neeta N, Manna GC, Mule SB. An empirical assessment of quasi-permanently vacant channels in mobile communication bands for cognitive radio. *ICTACT Transactions on Advanced Communications Technology (TACT)*. January 2014;3(1):389-394
- [26] Nathani N, Manna GC, Mule SB. Assessment of quasi-permanently vacant channels in mobile communication bands for cognitive radio. In: 15th IEEE International Conference on Advanced Communications Technology (ICTACT 2013); 27-30 January 2013. pp. 484-488. ISBN: 978-89-968650-0-1
- [27] Gao M-L. The self-adapt spectrum management formula base on cluster model. In: 2011 International Conference on Multimedia Technology (ICMT); 26-28 July 2011
- [28] Parvin S, Hussain FK, Hussain OK, Han S, Tian B, Chang E. Cognitive radio network security: A survey. *Journal of Network and Computer Applications*. 2012;35(6):1691-1708
- [29] Dere B, Bhujade S. An efficient spectrum decision making framework for cognitive radio networks. *International Journal of Electrical and Electronics Engineers; IJEEE*. Jan-June 2015;07(01):47-55. ISSN: 2321-2055 (E)
- [30] Akyildiz IF, Lee W, Mehmet C, Mohanty S. A survey on spectrum management in cognitive radio networks. *IEEE Communications Magazine*; April. 2008;46(04):40-48. ISSN: 0163-6804
- [31] Li H, Liu Y, Zhang D. Dynamic spectrum access for cognitive radio systems with repeated games. In: *IEEE International Conference on Wireless Communications, Networking and Information Security (WCNIS)*; 25-27 June 2010
- [32] Lee WY, Akyildiz IF. A spectrum decision framework for cognitive radio networks. *IEEE Transactions on Mobile Computing*. February 2011;10(02):1536-1233

- [33] Shweta P. Spectrum sharing in cognitive radio using game theory. In: IEEE 3rd International Conference on Advance Computing Conference (IACC); 22-23 February 2013
- [34] Grokop LH, David NC. Spectrum sharing between wireless networks. IEEE/ACM Transactions on Networking. October 2010;18(5):1401-1412
- [35] Qun P, Zhang X, Chang Y, Yang D. Downlink dual modes multiple user MIMO cognitive radio system. In: 2nd IEEE International Conference on Network Infrastructure and Digital Content; 24-26 September 2010
- [36] Nathani N, Manna GC. Call arrival rate prediction and blocking probability estimation for infrastructure based mobile cognitive radio personal area network. Advances in Science Technology and Engineering Systems Journal. August 2017;2(3):1609-1615. Special Issue on Recent Advances in Engineering Systems. ISSN: 2415-6698
- [37] Nathani N, Manna GC, Dorle SS. Network architecture model of infrastructure based mobile cognitive radio system in licensed band with blocking probability assessment. In: IEEE Future Technologies Conference (FTC 2016); 6-7 December 2016. pp. 231-236. ISBN: 978-1-5090-4171-8/16
- [38] Rao GS. Mobile Cellular Communication. India: Pearson Education; 2013. pp. 135-136. ISBN 978-81-317-7361-1
- [39] Neeta N, Manna GC, Dorle SS. Channelized blocking probability estimation model for infrastructure based mobile cognitive radio. Indian Journal of Science and Technology. December 2016;9(45):1-7. DOI: 10.17485/ijst/2016/v9i45/106355, ISSN (Print): 0974-6846, ISSN (Online): 0974-5645
- [40] Kalekar PS. Time Series Forecasting Using Holt-Winters Exponential Smoothing. 2004
- [41] Introduction to time series analysis. Available from: <http://www.itl.nist.gov/div898/handbook/pmc/section4/pmc4.htm>
- [42] Tirkeş G, Güray C, Çelebi N. Demand Forecasting: A Comparison between the Holt-Winters, Trend Analysis and Decomposition Models
- [43] Nathani N, Manna GC, Mule SB. Dynamically available channel model for cognitive radio in GSM band. In Proceedings: National Conference on Trends in Signal Processing & Communication (TSPC'14); 12-14 April 2014. pp. 8-12. ISBN: 978-93-83842-40-7
- [44] Hao C, Ljiljana T. Trunked radio systems: Traffic prediction based on user clusters. International Conference on Wireless Communication Systems. September 2004
- [45] Li X, Seyed A, Zekavat R. Cognitive radio based spectrum sharing: Evaluating channel availability via traffic pattern prediction. Journal of Communications and Networks. 2009;11(2): 104-114
- [46] Nathani N, Manna GC. Predicted call and residual lifetime based channel allocation model for PU equivalent QoS in cognitive radio cellular network. In: Second International Conference on Smart Trends for Information Technology and Computer Communications (SmartCom 2017); Conference Proceedings by Springer CCIS Series—Communications in Computer and Information Science; 18-19 August 2017. ISSN Number: 1865-0929
- [47] <http://www.statisticshowto.com/box-cox-transformation>

