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## Research Article

**Keywords:** Cognitive Radio, Blocking probability, throughput, Random assignment, First fit assignment, Selective channel Assignment

**Posted Date:** July 12th, 2021

**DOI:** <https://doi.org/10.21203/rs.3.rs-188797/v1>

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# Selective Channel Assignment Method in Cognitive Radio System

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*Abstract*— An Efficient Channel assignment method for cognitive radio system has been proposed in this paper, by considering primary and secondary calls separately in the network for the cases of with and without usage of converters. The proposed channel assignment method known as selective channel assignment method its performance is compared with the existing first fit assignment and uniformly distributed random assignment methods. Each of the models has variant for with conversion and without conversion of wavelength. The simulations are run for a network having 10, 20 channels, 12, 15 and 25 links and 8 Erlangs of load. By carrying out the simulations of the proposed and existing channel assignment methods, the blocking probabilities, throughput and channel usage frequencies are computed for each of the assignment methods. When the selective channel assignment method was used, the blocking probabilities are around 41% and 39% for 50% PU calls case and 64% and 26% for 75% PU calls case when there were no converters in the network. When converters are used, the blocking probabilities are around 30% and 36% for 50% PU calls case and 38% and 18% for 75% PU calls case. Our simulations validated the effectiveness of the proposed channel assignment scheme in terms of blocking probability, throughput and channel usage as performance parameters.

*Index Terms*—Cognitive Radio, Blocking probability, throughput, Random assignment, First fit assignment, Selective channel Assignment

## 1. INTRODUCTION

Wireless communication is the fastest growing and most widely used technology in the field of information and communication in the past decade. The rapid development of wireless devices and applications is changing people's way of life and thinking. The continuous growth of the demand for wireless communication business has resulted in explosive growth in the amount of communication data in wireless communication systems.

In order to break through the bottleneck caused by scarcity of spectrum resources and the low utilization rate for the further development of wireless communication, in addition to the spectrum regulation policy, a new wireless communication technology, including dynamic spectrum access, dynamic spectrum sharing and high frequency spectrum efficiency, is also a feasible means to effectively alleviate the frequency

spectrum resource shortage. This new DSA paradigm can be realized by cognitive radio networks (CRN), which is accomplished by superior ways of handling the spectrum [1]. Cognitive Radio (CR) technology is regarded as an intelligent and dynamically reconfigurable radio system. The basic idea of cognitive radio technology is that secondary users observe the surrounding environment, obtain access to the spectrum resources called "Spectrum holes", and access authorization frequency band by adaptive adjustment of the transmission parameters. "Spectrum holes" is a spectrum resource with multi-dimensional characteristics, that is, the spectrum resources that are not occupied by the primary user (PU) in the time, space and frequency domain, and can be access for secondary users. The emergence of cognitive radio technology provides a strong support for alleviating the current shortage of spectrum resources, improving spectrum utilization and realizing dynamic spectrum access.

In a cognitive radio system, there are two types of calls, namely, primary unit calls and secondary unit calls. The primary calls are those calls which belong to the licensed user and secondary calls belong to the unlicensed users. When a call arrives for transmission through a network, it should be transmitted without any hindrance from source node to destination node. The calls of licensed users must be given preference over the calls of unlicensed users. For a higher throughput, channels meant for licensed users must not be assigned to the unlicensed user. A cognitive radio system should be designed to increase the throughput or decrease the blocking probabilities.

### 1.1 Motivation and Research Contribution:

Channel assignment design is a challenging problem in Cognitive Radio Networks. Various Channel assignment methods have been previously proposed for CRNs [1-6]. Most of them were designed for wireless networks without backhaul networks. Thus, there is a need to investigate the channel assignment problem in the context of backhaul networks which are connected through optical fiber, hence optical network. Thus, new channel assignment scheme that suit the unique feature and capabilities of CRN are needed such that the maximum possible CR performance can be achieved. Therefore, the motivation behind this study is to obtain an efficient channel assignment method with the usage of full wave length converters to reduce blocking probability and improve channel utilization and throughput.

We proposed a selective channel assignment method for allocation of unused channels by the primary users to cognitive users in an effective way by selecting a center node and dividing the channels towards higher end to be utilized by primary user and towards lower end to be used by cognitive users, by doing so the blocking probability of the selective channel assignment method is lower than the existing methods like first-fit and random assignment methods, hence throughput is increased.

Our contributions are summarized as follows:

- Formulate the channel assignment problem for cognitive users, in order to reduce the blocking probability and hence increase the throughput.
- Proposed a selective channel assignment method for allocating channels to cognitive users in an effective way by dividing the channels towards higher end for primary users and towards lower end for cognitive (secondary) users with center node and full wave length converters.
- Compared the performance of our proposed scheme with the existing methods like first-fit channel assignment and random channel assignment methods, by considering blocking probability, channel utilization and throughput as parameters.
- Computed unnecessary handover probability (UHP) by considering three nodes tandem networks.

In the next section, the literature survey related to channel assignment methods in cognitive radio networks is presented in section 2, mathematical background of blocking probabilities and the details of selective channel assignment method is discussed. In Section 3, simulation results are presented for cases like with and without conversions, type of channel assignment method and percentage of PU calls in section 4. Finally, in Section 5, the conclusions are presented.

## 2. RELATED WORK

This section provides details regarding the work reported in the literature related to channel assignment techniques in cognitive radio system. In [1], authors proposed a Guard-Band (GB)-aware channel assignment scheme, which aims at increasing network capacity and minimizing the number of assigned channels per user subject to rate demand and interference constraints by considering the channel-dependent achieved transmission rates at different time slots while simultaneously assigning channels to several CR transmissions.

In [2], authors have proposed a joint FD-aware channel-assignment and route selection protocol in FD-based CR networks (CRNs) under time-varying channel conditions and transmission rates. This protocol computes the channel-assignment over each path that maximizes the end-to-end network throughput subject to interference constraints. They have shown that this assignment problem as an NP-hard binary linear programming (BLP) that can be sub-optimally solved in polynomial-time using the sequential-fixing procedure. They have also determined the path with the highest end-to-end network throughput and their proposed routing protocol

significantly improved the end-to-end throughput compared to previous FD-aware routing protocols.

In [3], authors have investigated the routing and channel assignment problem in full-duplex (FD)-based CRNs, by considering two types of FD communications, the first type only allows for simultaneous transmission and reception over different channels, while the second type allows for simultaneous transmission and reception over the same channel, and also they have formulated the channel assignment problem for each path between the communicating pair as an optimization problem with the main objective of minimizing the number of distinct assigned channels for that path such that the number of simultaneous active hops across the path is maximized and also they have shown that the optimization problem is a binary linear programming problem. They have presented a near-optimal solution based on a sequential fixing procedure, where the binary variables are iteratively determined by solving a sequence of relaxed programs, and also they have developed a novel routing scheme that selects the best path along with the channel assignment such that the highest capacity is achieved. They have shown that the routing and channel assignment scheme for FD CRNs, significantly improved the network performance.

In [4], authors have investigated the problem concerned with the amount of time with which a secondary user can hold a primary channel or more in cognitive radio networks as well as the average amount of data that can be transmitted during this time. They have derived closed-form probabilistic expressions for the distribution of time, which includes identical and non-identical primary channels, in terms of the activity levels of primary users and for a different number of secondary users. Also, authors, have derived closed-form expressions to approximate the derived expressions for all considered scenarios to reduce the computational complexity and they have implemented two simple channel allocation strategies to demonstrate the simplicity of expression which they have derived.

In [5], the authors tried to minimize the interference among secondary nodes by employing interference index as interference minimization key which in turn maximizes the system capacity. The authors used an existing distributed greedy algorithm, to validate their results, on the introduction of interference index, furnished a gain of 60% in the CR network capacity. Also a trade-off analysis between the interference index and channel leakage ratio is presented with an interference bound of 10 dBm, which may form the basis of interference management in CRN.

In [6], authors, proposed a spectrum assignment scheme for CR networks, which provides a proper sharing of the available channels such that spectrum utilization is improved. They have incorporated a concurrent strategy for channel allocation, the model constraints to the allocation limitation stating that one channel can be allotted to only one user at a time, and also one secondary user can gain access to at most one channel at a time. In [11], authors proposed cognitive radio channel allocation scheme, which selects a channel where the primary user arrives least frequently and limits the secondary user's allocation time to reduce interference to the primary user.

In some cases, when secondary calls are being assigned channels, the network keeps the track of primary calls (PU). It

has been proposed that [12] secondary units (SU) can in fact occupy the channels meant for the primary units. The SU need to monitor the channels meant for PU. Also, there many methods to predict if a call is a PU or SU. These models only monitor the channel occupation and only predict if the next call is going to be a PU or SU, but it does not have the channel updating schemes. There is also a scheme that is designed based on the infrastructure of the cognitive radio system [13]. In another scheme, the cognitive radio system is designed based on the allocation of the spectrum. The spectrum is divided between the primary and secondary units. The proposed scheme [14] involved in leasing out the spectrum meant for PUs to SUs. But the authors have left the spectrum detection only to the hardware and the methodologies to identify a spectrum were not clearly spelt out.

The PU and SU traffic were estimated in [15] by using a prediction algorithm. The probability of allocation of a channel to a SU was predicted and it was related to the channels meant for PUs. However, these methods have higher computational complexity. There is also another methodology [16] proposed to predict the PU traffic. The research was focused on the methods to improve the predictability of PU traffic. Cooperative spectrum sharing was also proposed by some researchers. Cooperative spectrum sharing involves sharing of static CR nodes of various service providers [17-18].

In another methodology, channel assignment was performed [19-25] at a central location. The centralized channel allocation can be made with a mobile switching center. The mobile switching center has all the details about how and when a particular channel was used and its current status. The current status is obtained by the mobile switching center by getting the information from the local networks as soon as a channel was assigned to a PU or SU call. With this method, the mobile switching center has all the required information to avoid interference of the calls there by reducing the blocking probabilities to minimum or zero. In case the mobile switching center fails, then it leaves a chaotic situation and the network will go out of control in terms of interference. Hence proper care and maintenance should be undertaken on periodic basis to avoid the single fault failure of the centralized channel allocation system.

To overcome the above problem, many designs of decentralized channel allocation system have been proposed [26-30]. The decentralized channel allocation system does not suffer the drawback of single fault failure. The entire cognitive radio system is divided into cells and each cell is equipped with a base station. The purpose of a base station in a cell is to manage the PU and SU traffic of that cell. The base station allocates a channel based on the information present at the point of time about that particular node. It will not have any dependency from other cells while allocating the channels and completely dependent only on the local information about the channel's status. There is also a model where the channels of one cell are allocated by base stations of other cells. In such a case, whenever a channel of a cell is assigned by a base station; it informs the decision to allocate a channel to all other base stations so that other base stations will not assign the same channel.

In [7-10], authors discussed three channel allocation methods. All the allocations are carried out in a base station of a cell. The

channel assignment methods like first fit, random assignment and selective assignment methods are implemented and compared. The selective channel assignment specifically suitable for a case like cognitive radio system where there is more than one type of calls in the network.

Based on the literature review, it is observed that most of the channel assignment methods are either first fit or uniformly distributed channel assignment methods. The first fit assignment is much superior to random assignment method. But the first fit assignment also leads to 100% blocking probability in some cases. Therefore, there is a need to develop a new channel assignment method that reduces the blocking probability. This is very essential for the case of cognitive radio system where there are two types of calls, namely, PU and SUs. In this work, a new channel assignment, namely, selective channel assignment method is proposed to divide the channels between the PU and SUs. In other words, there is need to build two first fit assignment models in one single model to treat each of the PU and SUs separately. Also, there should be a flexibility to decide which part of the channel to be centered around for the allocation of PU and SUs. In this work, an attempt is made to design such a model. The performance of the model is tested on the network that has converters and also on network that does not have any converters installed. The percentage of PU calls over all the calls is also varied to determine the change in blocking probabilities.

## 2.1 Problem Statement:

The channel allocation algorithms by the base station can be based on the first fit or random assignment, both for PUs and SUs for same sequence of channels. When a new PU/SU arrives, if the channel is already occupied by a PU or SU, then it results in blocking and when a call is handed over from one network to another network, there is a possibility of unnecessary handover, even if it is successfully handed over, there is a probability that the call may get blocked in the new network.

Hence it is required to develop a common approach to compute the overall probability of successful channel assignment considering both unnecessary handover and blocking probability due to no-conversion, conversion with selective channel assignments.

## 3. PROBABILITY MODEL

A call gets blocked when there is no free link at the end of the current link in the chain. The call will get blocked as the next link is already occupied and it cannot be propagated. Various assumptions made in calculating the blocking probabilities are:

1. Every channel has its characteristic wavelength.
2. There is only finite number of channels in the network.
3. The links are connected in the form of a chain.
4. The call in the form of electric signal and will be converted into a light pulse. The wavelength of the light pulse is the channel assigned.
5. A call will be toned down if it gets blocked.
6. The load on each link is independent of others.

Let,

$P_B$ : Blocking probability

$n_B$ : Quantity of blocked calls

$n_G$ : Quantity of generated calls

$$P_B = \frac{n_B}{n_G} \quad (1)$$

Based on Erlangs formula, the blocking probability is

$$P_B(E, C) = \frac{E^C}{C!} \frac{C!}{\sum_{j=0}^C \frac{E^j}{j!}} \quad (2)$$

where

$P_B(E, C)$ : Probability of blocking of network

$E$ : Load in Erlangs

$C$ : Number of non-overlapping channels.

$$\text{Throughput} = 1.0 - P_B(E, C) \quad (3)$$

**3.1 Selective Channel Assignment:** In selective channel assignment, when a call arrives, it will be assessed if it is a PU call or an SU call. In case if it is a PU call then that call is assigned to the lower order nodes and if it is an SU call, it is assigned to higher order nodes. There will be some channels around the chosen center nodes both for PU and SU calls. For example, if the channel N is chosen as center node for PU, then nodes  $N \pm 1$ , and  $N+2$  are the surrounding nearby nodes. All the PU calls will be assigned to channel N first if it is free and to channel  $N \pm 1$ , if N is not free. Then if channels  $N-1$ , N and  $N+1$  are busy, then channel  $N+2$  is assigned. If channels N,  $N+1$  and  $N+2$  are busy and if channel  $N-1$  becomes free, then channel  $N-1$  is assigned to the next new call. This way only freely available channels in the lower order are utilized for allocation. Similarly, when an SU arrives, if the center node chosen for SU call is S, where  $S > N$ , then nodes  $S \pm 1$ , and  $S-2$  are the surrounding nodes. In this work, channels  $N=2$  and  $S=9$  are chosen as the center nodes. The algorithm has the flexibility to choose the center node. Higher the gap between the center nodes between PU and SU, lower the blocking probability and higher the throughput.

### 3.2 Selective Channel assignment algorithm

The flow chart of the selective channel assignment is explained in a step by step as follows:

Initialize the number of channels, number of links, load on each link and number of iterations (simulations). Each iteration is considered as one call, say 2000 iterations means, 2000 calls exists. For each link, channel holding time, the number of times the channel used and the number of calls blocked is initially set to zero.

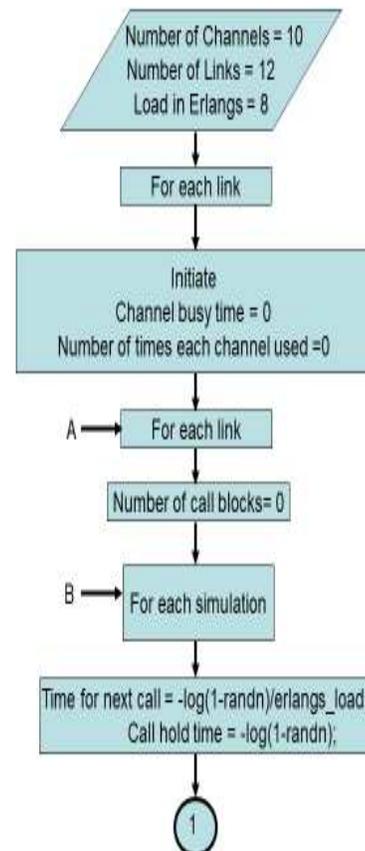
For each simulation, the time for next call and call holding time are calculated, then find the channels that are free in each link. Random numbers are generated based on normal distribution with predefined mean and standard deviation separately for primary user (PU) and secondary user (SU), then convert the random number to a corresponding channel number.

Check whether the selected channel is free or not, if it is free then assign call to channel based on random number generated, now calculate the number of times each channel used, which is equal to number of times each channel used plus one, channel busy time is equal to call holding time.

If the selected channel is not free then find channels that are occupied in each link, then assume new variable called difference which is equal to the difference between the channel busy time and time for next call. If the difference is greater than zero, then reduce the channel busy time by the difference value, otherwise reduce the channel busy time to zero.

If the selected channel in all the links is free then number of free channels is equal to number of free channels plus one, otherwise the number of call blocks is equal to the number of call blocks plus one. This process is repeated for each simulation (iteration). Then the blocking probability is calculated as the ratio of the number of call blocks to the number of simulations. The number of channels, links or nodes are varied in our research work from 10, 20 channels and nodes are varied from 12, 15 and 25 for an load of 8 Erlangs per link with 8000 simulation.

The flowchart for the selective channel assignment method is provided below:



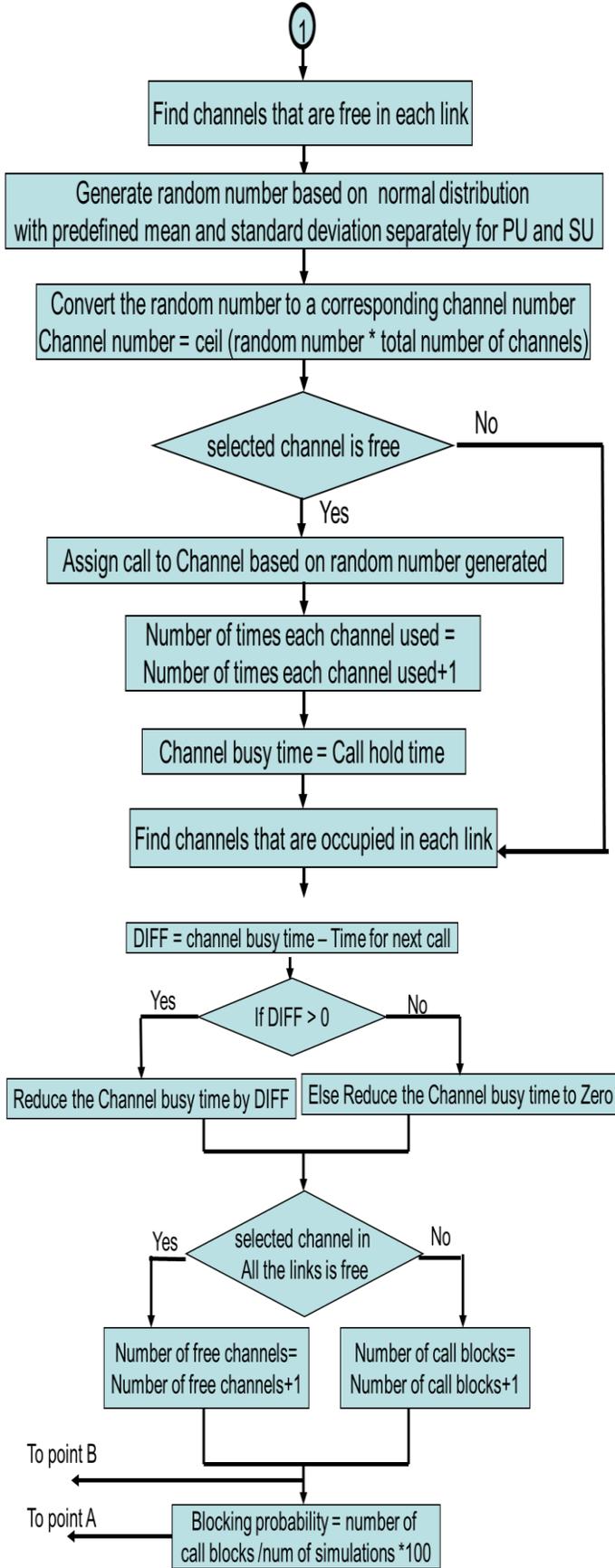


Fig 1. Flow chart of selective channel assignment method

### 3.3 Probability of Unnecessary Handover

The unnecessary handover probability can be derived for the case of call getting handed over unnecessarily to another network. The overall probability of call getting blocked is the product of unnecessary handover probability and blocking probability. Unnecessary handover refers to the events that a mobile node decides to move to the other network at  $t_1$ , but the new network cannot satisfy its bandwidth requirement in the next time period  $t_2$ .  $D$  is the Decision time interval, which is equal to  $D = t_2 - t_1$ . The time when mobile node makes a decision to move or stay as  $t$  and the time to decide if the decision is correct or wrong is  $t+D$ . For each network and mobile node,  $D$  is pre-defined. Unnecessary handover is a major issue leading to two problems in the network, firstly it increases the network load since each handover requires network resources and secondly it causes shortage in channel resources leading to call dropping. Hence an efficient handover algorithm which increases the efficiency of handover decision process is proposed in this paper.

$$P_{unsuccessful}$$

$$= \text{Unnecessary Handover Probability} \times \text{Blocking Probability} \quad (4)$$

Unnecessary Handover Probability

$$\begin{aligned}
 &= P_{n1} P_{n2/n1} \sum_{j=L}^{B_2} \prod_{2,B_2-j} \sum_{k=0}^{j-L} \prod_{1,B_1-k} \xi_1(k, r, D) \\
 &\quad \cdot \sum_{i=0}^{B_1} \prod_{1,B_1-i} \sum_{k=i+L}^{B_2} \prod_{2,B_2-k} \psi_2(k, r, D) \\
 &+ P_{n1} P_{n3/n1} \sum_{m=L}^{B_3} \prod_{3,B_3-m} \sum_{k=0}^{m-L} \prod_{1,B_1-k} \xi_1(k, r, D) \\
 &\quad \cdot \sum_{i=0}^{B_1} \prod_{1,B_1-i} \sum_{k=i+L}^{B_3} \prod_{3,B_3-k} \psi_3(k, r, D) \\
 &+ P_{n2} P_{n1/n2} \sum_{j=L}^{B_1} \prod_{1,B_1-j} \sum_{k=j-L+1}^{B_1} \prod_{1,B_1-k} \psi_1(k, r, D) \\
 &\quad \cdot \sum_{i=0}^{B_2} \prod_{2,B_2-i} \sum_{k=0}^{i+L-1} \prod_{2,B_2-k} \xi_2(k, r, D) \\
 &+ P_{n2} P_{n3/n2} \sum_{j=L}^{B_3} \prod_{3,B_3-j} \sum_{k=j-L+1}^{B_3} \prod_{3,B_3-k} \psi_3(k, r, D) \\
 &\quad \cdot \sum_{m=0}^{B_2} \prod_{2,B_2-m} \sum_{k=0}^{m+L-1} \prod_{2,B_2-k} \xi_2(k, r, D) \\
 &+ P_{n3} P_{n1/n3} \sum_{m=L}^{B_1} \prod_{1,B_1-m} \sum_{k=m-L+1}^{B_1} \prod_{1,B_1-k} \psi_1(k, r, D) \\
 &\quad \cdot \sum_{i=0}^{B_3} \prod_{3,B_3-i} \sum_{k=0}^{i+L-1} \prod_{3,B_3-k} \xi_3(k, r, D) \\
 &+ P_{n3} P_{n2/n3} \sum_{j=L}^{B_2} \prod_{2,B_2-j} \sum_{k=0}^{j-L} \prod_{3,B_3-k} \xi_3(k, r, D) \\
 &\quad \cdot \sum_{m=0}^{B_3} \prod_{3,B_3-m} \sum_{k=m+L}^{B_2} \prod_{2,B_2-k} \psi_2(k, r, D)
 \end{aligned} \quad (5)$$

The notations and definitions of the quantities expressed in Eq.5 can be found in author's paper [7-10].

The probability for the unnecessary handover is computed using MATLAB and the results are presented in the figure.18.

### Notations used in the algorithm:

Channel Busy time ( $C_{BT}$ )  
 Number of times each channel used ( $C_U$ )  
 Number of Call Blocks ( $N_{CB}$ )  
 Time for Next Call ( $T_{NC}$ )  
 Call Hold Time ( $C_{HT}$ )  
 Blocking Probability ( $P_B$ )  
 Number of free channels ( $N_{FC}$ )  
 Selected Channel ( $C_S$ )  
 Number of selected channels ( $N_{SC}$ )

### Pseudo code of Selective Channel Assignment Algorithm:

#### Algorithm 1 Pseudocode for Selective Channel Assignment Method

Input: Number of Channels ( $C_N$ )  
 Number of Links (Nodes) ( $L_N$ )  
 Load on each link ( $E_N$ )  
 Number of Simulations ( $N_S$ )

Output: Blocking Probability, Throughput, Channel Utilization

```

Step: 1 initialize:  $C_{BT} = 0$ ,  $C_U = 0$ ,  $N_{CB} = 0$ ;
Step: 2 for  $i = 1:L_N$  do
Step: 3 for  $N_S = 0:N_S - 1$ ;
Step: 4  $T_{NC} = -\log(1 - randn)/E_N$ ;
Step: 5  $C_{HT} = -\log(1 - randn)$ ;

Step: 6 if  $N_{FC} = L_N$ ; channels that are
free in each link;
Step: 7 Generate random numbers
based on uniform distribution
with predefined mean & standard deviation
separately for PU & SU;
Step: 8 Convert the random number to
the corresponding
channel number;
Step: 9 if  $C_S = 0$ ; selected channel is free
Step: 10 Assign call to the channel
based on random number generated;
 $C_U = C_U + 1$ ;
 $C_{BT} = C_{BT} + T_{NC}$ ;
Step: 11 if  $N_{FC} = L_N$ ;
 $diff = C_{BT} - T_{NC}$ 
Step: 12 if  $diff > 0$ 
 $C_{BT} = C_{BT} - DIFF$ ;
else
 $C_{BT} = 0$ ;
Step: 13 if  $C_S = L_N = 0$ ; selected channel
in all the links is free;

```

```

Step: 14  $N_{FC} = N_{FC} + 1$ ; Go to Step: 3
else
Step: 15  $N_{CB} = N_{CB} + 1$ ; Go to Step: 2
 $P_B = N_{CB}/N_S * 100$ ;

end if
end if
end if
end if
end for
end for

```

Parameter	Notation	Numerical Value
Number of Channels	$C_N$	10, 20
Number of Links (Nodes)	$L_N$	12, 15 & 25
Load on each link	$E_N$	8
Number of Simulations	$N_S$	8000

Table 1: Simulation Parameters

## 4. SIMULATION RESULTS

Simulation environment and simulation software: To conduct our simulation, MATLAB programs are used. In this section, blocking probabilities are derived for tandem networks with conversion and without conversion. The converters are used when there is a call blockage. The converters are assumed to be installed at all nodes. Both type of calls, namely, primary unit calls and secondary unit calls are treated in these simulations. When calls arrive, three types of assignment methods are used in these simulations to allocate a channel to the calls. The three types of assignment methods are:

1. First fit assignment
2. Uniformly distributed random assignment
3. Selective channel assignment

Hence the following models based on type of channel assignment and conversion is developed.

1. PU-SU-NC-FF: First fit assignment method with no conversion and both types of calls
2. PU-SU-NC-RANDOM-ASSIGN: Random assignment method with no conversion and both types of calls
3. PU-NC-SEL-ASSIGN: Selective channel assignment method with no conversion and only PU calls
4. SU-NC-SEL-ASSIGN: Selective channel assignment method with no conversion and only SU calls

5. PU-SU-C-FF: First fit assignment method with conversion and both types of calls
6. PU-SU-C-RANDOM-ASSIGN - Random assignment method with conversion and both types of calls
7. PU-C-SEL-ASSIGN: Selective channel assignment method with conversion and only PU calls
8. SU-C-SEL-ASSIGN: Selective channel assignment method with conversion and only SU calls

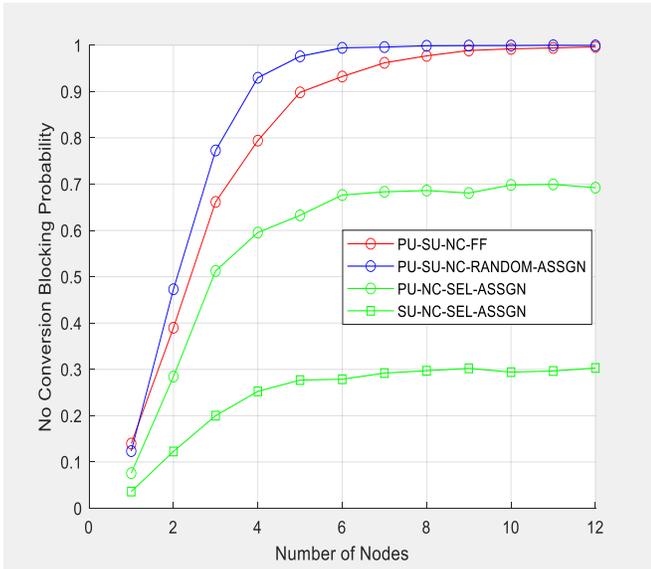


Figure 2: Blocking Probability of assignment methods for a load 8 Erlangs per link and with 12 Links (nodes), 10 Channels and 8000 iterations and 70% of PU calls with no conversion.

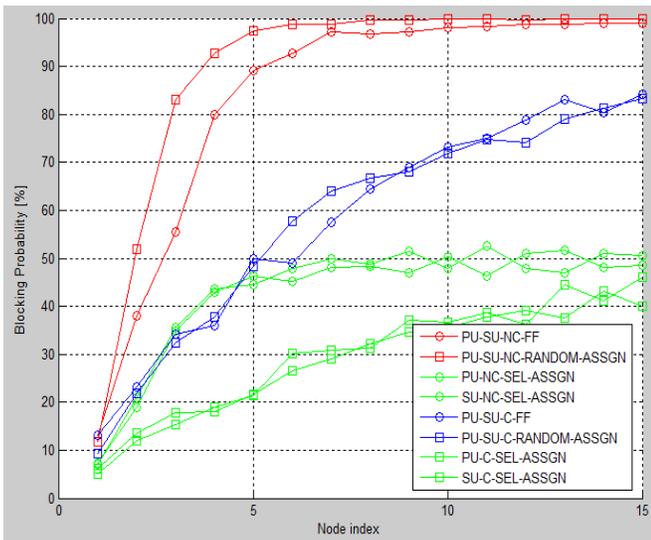


Figure 3: Blocking Probability of Assignment methods for a load 8 Erlangs per link and with 15 Links (nodes), 10 Channels and 8000 iterations and 50% of PU calls with and without conversion.

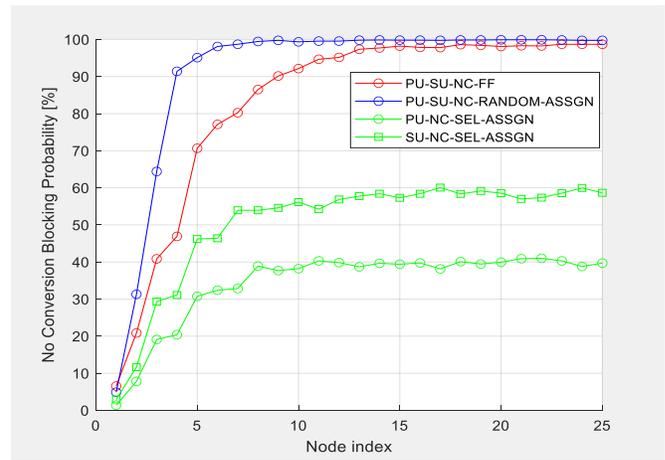


Figure 4: Blocking Probability of assignment methods for a load 8 Erlangs per link and with 25 Links (nodes), 10 Channels and 8000 iterations and 70% of PU calls with no conversion.

Fig.2, 3 and 4 shows the blocking probability of First fit assignment, uniformly distributed random assignment and Selective channel assignment methods for a load 8 Erlangs per link and with 12, 15 and 25 Links (nodes), 10, 20 Channels, 8000 iterations and 70%, 50% and 60% of PU calls with no conversion. It can be observed that blocking probabilities of selective channel assignment method is much lower than that of first fit assignment and uniformly distributed random assignment methods. The blocking probabilities of PU-NC-SEL-ASSIGN and SU-NC-SEL-ASSIGN are 70%, 50% and 60% of PU-SU-NC-FF and PU-SU-NC-RANDOM-ASSIGN models. This is attributed to the reason that in selective channel assignment, the assignment is made near the channels towards the end of lower order (near channel 1) for PU calls and towards end of higher order (near channel 10) for SU calls.

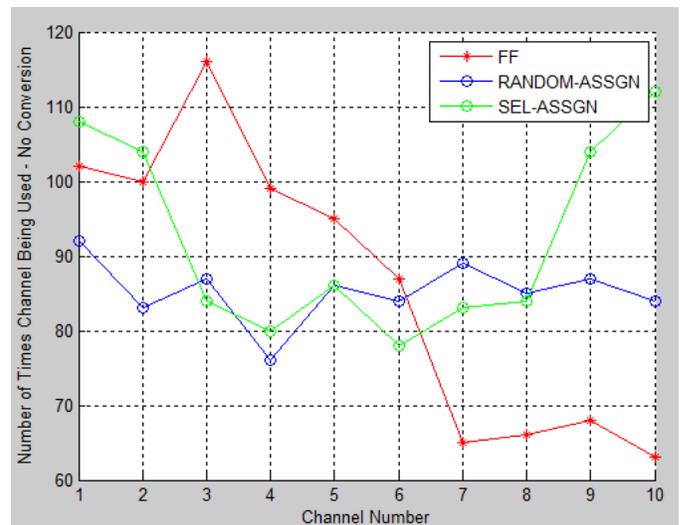


Figure 5: Channel utilization of Assignment methods for a load 8 Erlangs per link and with 12 Links (nodes), 10 Channels and 8000 iterations and 70% of PU calls with no conversion.

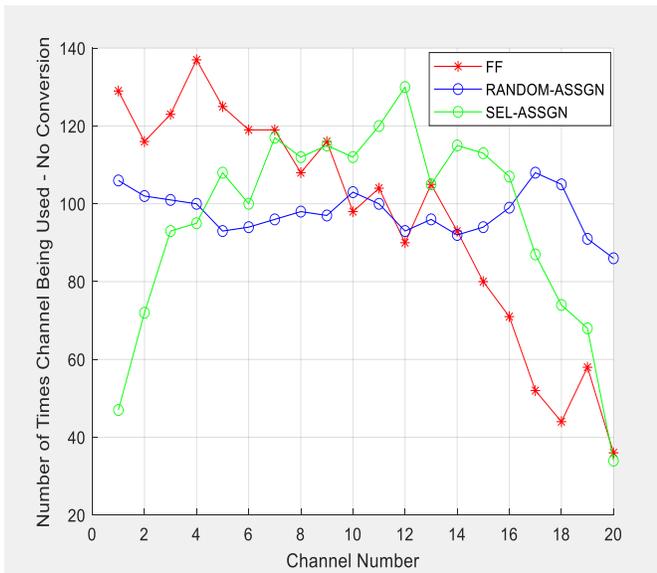


Figure 6: Channel utilization of Assignment methods for a load 8 Erlangs per link and with 12 Links (nodes), 10 Channels and 8000 iterations and 70% of PU calls with no conversion.

Fig. 5 and 6 shows the channel utilization of First fit assignment, uniformly distributed random assignment and Selective channel assignment methods for a load 8 Erlangs per link and with 12, 25 Links (nodes), 10 and 20 Channels, 8000 iterations and 70% of PU calls with no conversion. It can be noticed that in first fit (FF) assignment method, the only channels near lower order is assigned most. In case of random assignment (RANDOM-ASSGN) all channels are assigned uniformly. In case of selective channel (SEL-ASSGN) assignment, channels near 1 and 10 are assigned most.

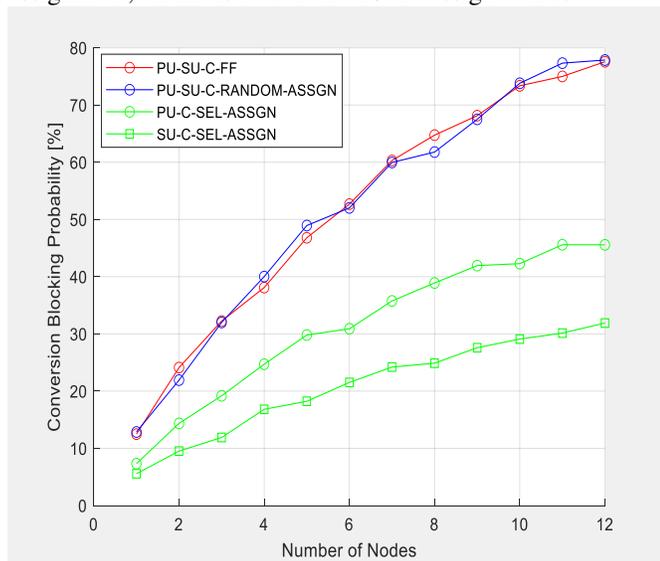


Figure 7: Blocking Probability of Assignment methods for a load 8 Erlangs per link and with 12 Links (nodes), 10 Channels and 8000 iterations and 50% of PU calls with conversion.

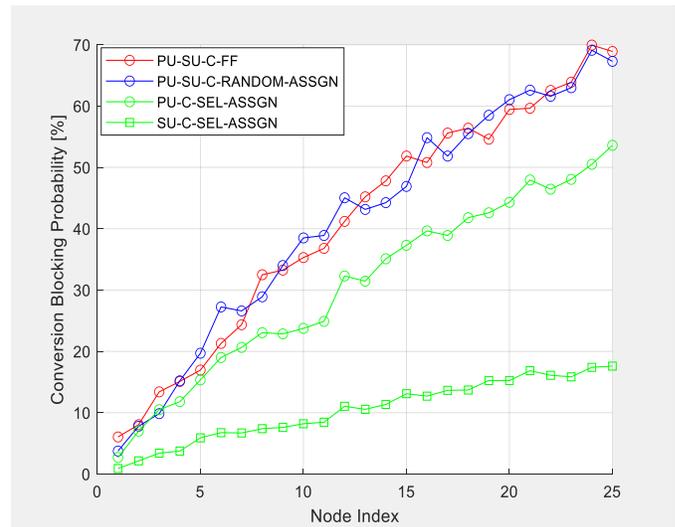


Figure 8: Blocking Probability of Assignment methods for a load 8 Erlangs per link and with 12 Links (nodes), 10 Channels and 8000 iterations and 50% of PU calls with conversion.

Fig.7 and 8 shows the blocking probability of First fit assignment, uniformly distributed random assignment and Selective channel assignment methods for a load 8 Erlangs per link and with 12 and 25 Links (nodes), 10 and 20 Channels, 8000 iterations and 50% of PU calls with conversion. It can be observed in this case also, blocking probabilities of selective channel assignment method is much lower than that of First fit assignment and uniformly distributed random assignment methods. Similar to the no conversion models, in selective channel assignment, the assignment is made near the channels towards the end of lower order (near channel 1) for PU calls and towards end of higher order (near channel 10) for SU calls, whereas all the calls are assigned only near lower order in First fit and uniformly across all channels in random assignment methods. Hence the blocking probabilities of PU-C-SEL-ASSIGN and SU-C-SEL-ASSIGN are nearly 50% of PU-SU-C-FF and PU-SU-C-RANDOM-ASSIGN models. It can also be observed that when conversion is used it does not matter if the first fit or random assignment methods are used since both yield almost similar blocking probabilities. This is due to the reason that call blockage is eliminated with the help of converters irrespective of assignment method.

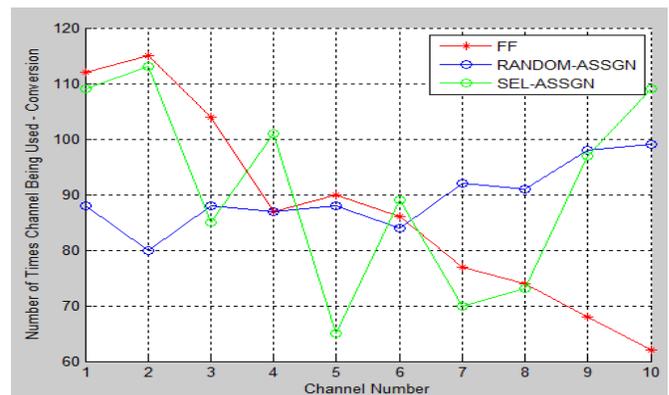


Figure 9: Channel utilization of Assignment methods for a load 8 Erlangs per link and with 12 Links (nodes), 10

Channels and 8000 iterations and 50% of PU calls with conversion.

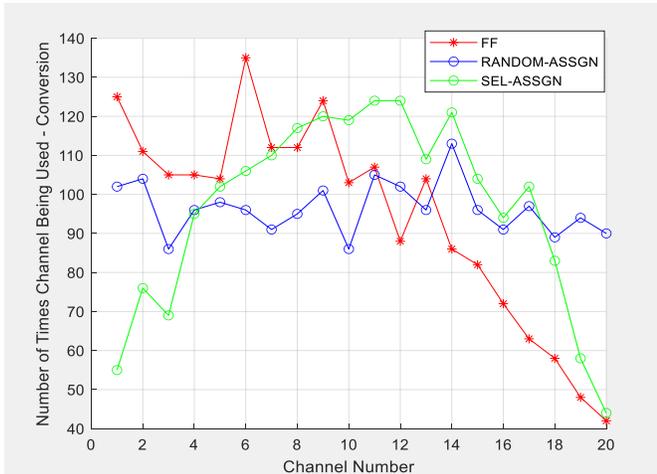


Figure 10: Channel utilization of Assignment methods for a load 8 Erlangs per link and with 12 Links (nodes), 10 Channels and 8000 iterations and 50% of PU calls with conversion.

Fig. 9 and 10 shows the channel utilization of First fit assignment, uniformly distributed random assignment and Selective channel assignment methods for a load 8 Erlangs per link and with 12 and 25 Links (nodes), 10 and 20 Channels, 8000 iterations and 50% of PU calls with conversion. In this case also, the pattern of channel utilization is also most similar to that of no-conversion models. First fit (FF) assignment method has only channels near lower order assigned most and random assignment (RANDOM-ASSGN) has all channels assigned uniformly. In selective channel (SEL-ASSGN) assignment, channels towards the end of lower order and higher order are assigned most.

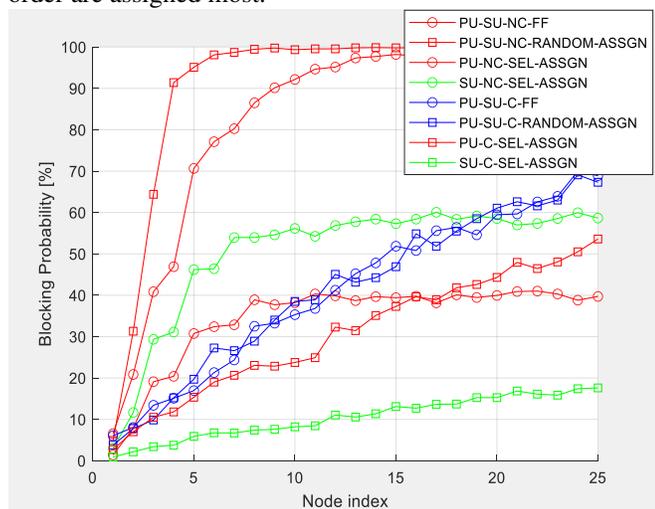


Figure 11: Blocking Probability of Assignment methods for a load 8 Erlangs per link and with 15 Links (nodes), 10 Channels and 8000 iterations and 50% of PU calls with and without conversion.

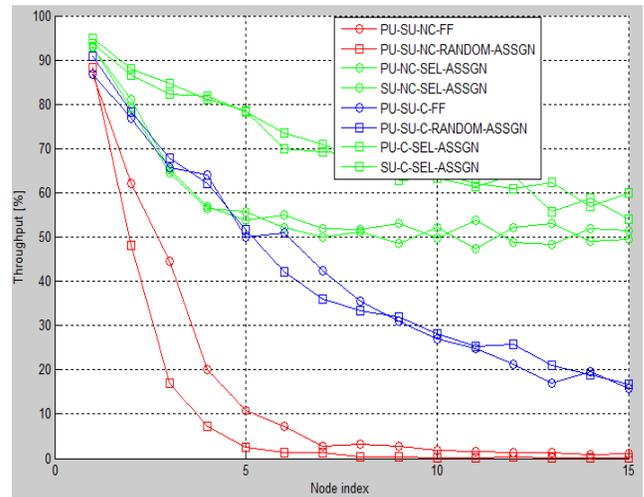


Figure 12: Throughput of Assignment methods for a load 8 Erlangs per link and with 15 Links (nodes), 10 Channels and 8000 iterations and 50% of PU calls with and without conversion.

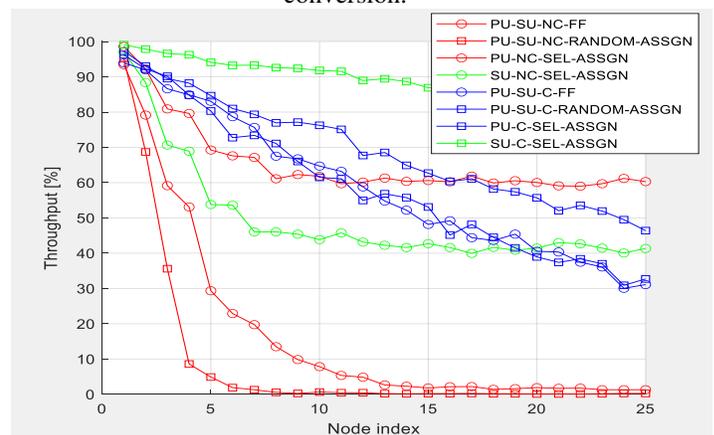


Figure 13: Throughput of Assignment methods for a load 8 Erlangs per link and with 15 Links (nodes), 10 Channels and 8000 iterations and 50% of PU calls with and without conversion.

Fig. 11, 12 and 13 shows the blocking probability and throughput, respectively, of First fit assignment, uniformly distributed random assignment and Selective channel assignment methods for a load 8 Erlangs per link and with 15 Links (nodes), 10 Channels, 8000 iterations and 50% of PU calls with and without conversion. Blocking probabilities of first fit assignment (PU-SU-NC-FF) is 99% at the node index 15, whereas it is 100% at node 15 in case of uniformly distributed random assignment (PU-SU-NC-RANDOM-ASSGN) method. These blocking probabilities can be reduced by using converters at all the nodes. The Blocking probabilities of first fit assignment (PU-SU-C-FF) are reduced to 84% and to 84% at node 15 in case of uniformly distributed random assignment (PU-SU-C-RANDOM-ASSIGN) method. The blocking probabilities can be further reduced with and without converters using selective channels assignment. With no converters, the selective channel method (PU-NC-SEL-ASSIGN and SU-NC-SEL-ASSIGN) yields approximately 50% blocking probability and with conversion (PU-C-SEL-

ASSIGN and SU-C-SEL-ASSIGN), it is approximately 43% on average.

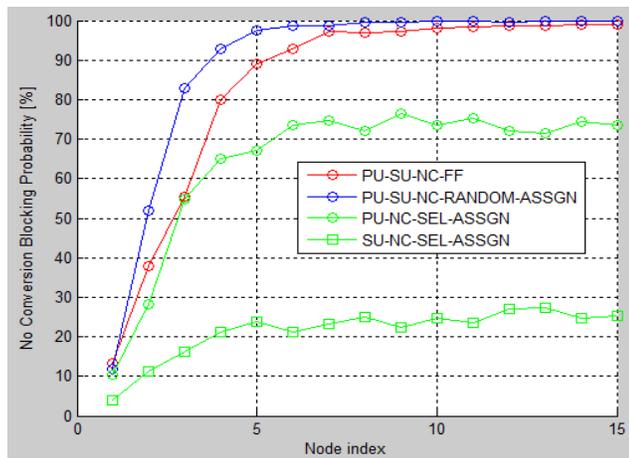


Figure 14: Blocking Probability of Assignment methods for a load 8 Erlangs per link and with 15 Links (nodes), 10 Channels and 8000 iterations and 75% of PU calls with no conversion.

Fig.14 shows the blocking probability of First fit assignment, uniformly distributed random assignment and Selective channel assignment methods for a load 8 Erlangs per link and with 15 Links (nodes), 10 Channels, 1000 iterations and 75% of PU calls with no conversion. The number of PU calls is increased from 50% to 75% in this case. When the PU calls are set at 75% of total calls, the blocking probability for the PU calls is 74% with PU-NC-SEL-ASSIGN and that for SU calls is 26% with SU-NC-SEL-ASSIGN model. In case of PU-SU-NC-FF and PU-SU-NC-RANDOM-ASSIGN models, the blocking probabilities are near 99% and 100% respectively when no converters are used.

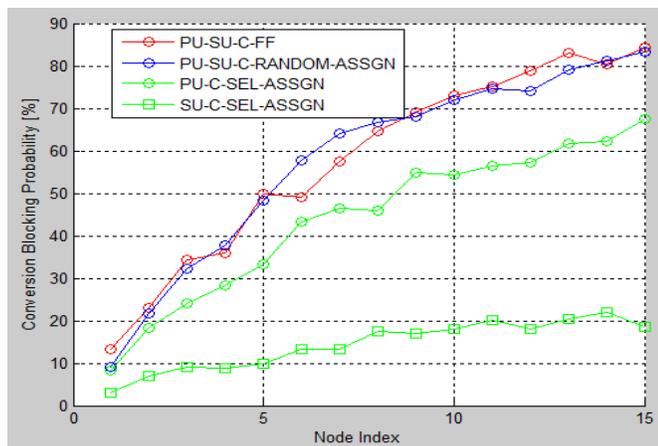


Figure 15: Blocking Probability of Assignment methods for a load 8 Erlangs per link and with 15 Links (nodes), 10 Channels and 1000 iterations and 75% of PU calls with conversion.

Fig.15 shows the blocking probability of First fit assignment, uniformly distributed random assignment and Selective channel

assignment methods for a load 8 Erlangs per link and with 15 Links (nodes), 10 Channels, 1000 iterations and 75% of PU calls with conversion. When there are 75% PU calls in the total calls, the blocking probabilities for the PU is usually higher than that of the SU calls. The same can be noticed in Fig. 7. With conversion, there is no difference between the first fit or random assignment methods. The blocking probabilities of PU-SU-C-FF and PU-SU-C-RANDOM-ASSIGN are nearly 83% at the node 15. When the selective assignment models are used, it is brought down to 68% and 19% respectively with PU-C-SEL-ASSIGN and SU-C-SEL-ASSIGN models.

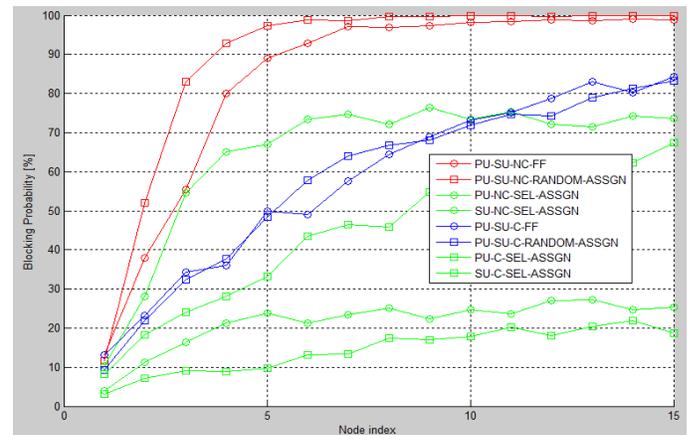


Figure 16: Blocking Probability of Assignment methods for a load 8 Erlangs per link and with 15 Links (nodes), 10 Channels and 1000 iterations and 75% of PU calls with and without conversion.

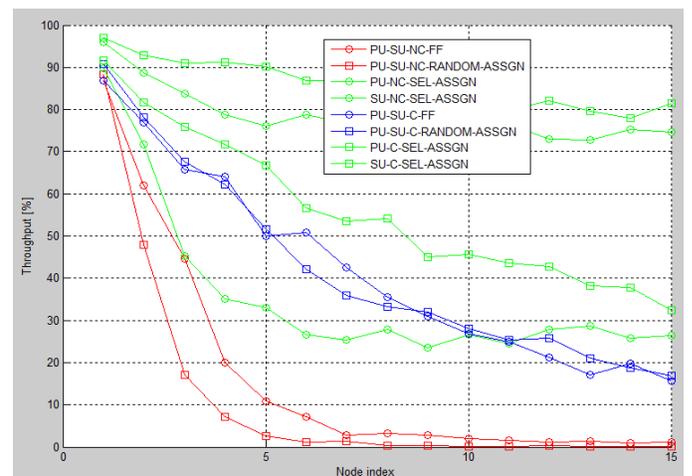


Figure 17: Throughput of Assignment methods for a load 8 Erlangs per link and with 15 Links (nodes), 10 Channels and 1000 iterations and 75% of PU calls with and without conversion.

Fig. 16 and 17 shows the blocking probability and throughput, respectively, of First fit assignment, uniformly distributed random assignment and Selective channel assignment methods for a load 8 Erlangs per link and with 15 Links (nodes), 10 Channels, 1000 iterations and 75% of PU calls with and without

conversion. The Fig. 16 shows the overall summary of all blocking probabilities with all the 8 models developed as part of this work. Blocking probabilities of first fit assignment (PU-SU-NC-FF) and of uniformly distributed random assignment (PU-SU-NC-RANDOM-ASSIGN) method are 99% and 100% respectively at the node index 15. Blocking probabilities could be brought down to 83% and to 82% at node 15 by using converters at all the nodes with first fit assignment (PU-SU-C-FF) and uniformly distributed random assignment (PU-SU-C-RANDOM-ASSIGN) methods. When selective channel assignment methods are used, the blocking probability is 74% with PU-NC-SEL-ASSIGN model and 26% with SU-NC-SEL-ASSIGN model. With conversion, that is when PU-C-SEL-ASSIGN and SU-C-SEL-ASSIGN are used it yielded approximately 68% and 20% of blocking probability respectively.

Throughput for all the above discussed models are shown in the fig 17 and it is found that the throughput of the proposed method i.e., selective channel assignment method is superior than the considered existing methods.

Model	Blocking prob. at Node 12	Blocking prob. at Node 15	Blocking prob. at Node 25
PU-SU-NC-FF	1	1	1
PU-SU-NC-RANDOM-ASSIGN	1	1	1
PU-NC-SEL-ASSIGN	0.7	0.75	0.6
SU-NC-SEL-ASSIGN	0.3	0.25	0.4
PU-SU-C-FF	0.78	0.85	0.68
PU-SU-C-RANDOM-ASSIGN	0.79	0.85	0.69
PU-C-SEL-ASSIGN	0.48	0.68	0.55
SU-C-SEL-ASSIGN	0.32	0.20	0.18

**Table 2: Summary of all the models**

From the summary presented in Table 2, the selective channel assignment methods, namely, PU-C-SEL-ASSIGN and SU-C-SEL-ASSIGN yield the best results both for 50% and 75% PU call cases.

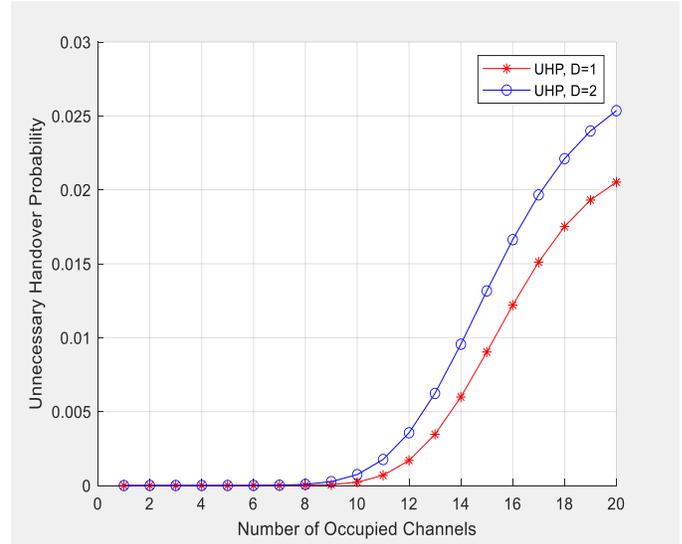


Figure 18: UHP Vs occupied channels for B1 = 20, B2=20 and B3 = 20.

From Fig. 18, the unnecessary handover probability for D=1 ms and D=2 ms can be obtained and the same can be used in Eq. 1 to determine the total unsuccessful probability. The Fig. 18 shows the UHP for a three-node network. Unnecessary handover is a major issue leading to two problems in the network—firstly it increases the network load since each handover requires network resources and secondly it causes shortage in channel resources leading to call dropping. Hence an efficient handover algorithm which increases the efficiency of handover decision process is proposed in this paper. The probability for the unnecessary handover is computed using MATLAB and the results are presented in the following plots. Simulation results are presented for the cases where number of the channel are 20 and decision times are 1 and 2 ms. Two different values of decision time are taken to show that having dynamic decision time is more advantageous than static decision time. Unnecessary handover Probabilities for Three network model is computed for conditions like the maximum bandwidth available, decision time and threshold value. Fig. 4 shows the unnecessary handover for the Three network model for same conditions but with increase in decision time to 3 ms. It can be concluded that with increase in decision time, the probability of unnecessary handover decreases for the three node network with an increased D. It is obvious that with more delay in the decision making, the probability that the available bandwidth in the present network changing will be more.

### 5. CONCLUSIONS

In this work, eight models are developed to simulate for the blocking probabilities. The models are developed with conversion and without conversion. Also, the percentage of PU calls over all the calls is varied. Two cases, one with 50% PU calls and 75% PU calls are simulated. The assignment methods, namely, first fit assignment, uniformly distributed random assignment and Selective channel assignment methods are used in the simulations. It has been observed that the blocking probabilities are nearly 100% when the first fit and random assignment methods are used for a network with 10 channels,

15 links and 8 Erlangs. of load. This is true for both 50% and 75% PU calls. When the selective channel assignment method was used, the blocking probabilities are around 41% and 39% for 50% PU calls case and 64% and 26% for 75% PU calls case when there were no converters in the network. When converters are used, the blocking probabilities are around 30% and 36% for 50% PU calls case and 38% and 18% for 75% PU calls case. Hence it is concluded that selective assignment method has outperformed over the first fit assignment and uniformly distributed channel assignment methods in conversion and no conversion as well as 50% and 75% of PU calls. The proposed algorithm i.e., selective channel assignment and the existing algorithms are going to be implemented on Field Programmable Gate Array hardware device as a future work to validate the performance of the same.

## 6. Declaration

6.1 Funding There is no funding support for this work.

6.2 Conflicts of interest/Competing interests

There are no competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

6.3 Availability of data and material Not applicable.

6.4 Code availability

Software code used in this paper can be provided upon request to authors.

6.5 Authors' contributions

All authors have participated in (a) conception and design, or analysis and interpretation of the data; (b) drafting the article or revising it critically for important intellectual content; and (c) approval of the final version.

6.6 Submission

This manuscript has not been submitted to, nor is under review at, another journal or other publishing venue.

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