# CHAPTER V

# FREQUENCY REUSE FOR OPTIMUM UTILIZATION OF BANDWIDTH

## 5.1. Introduction

Many researchers used the concept of channel reservation for handoff users, because call dropping is more annoying than call blocking scenario. In some works, channels are reserved for real-time users. But it will result in more call blocking as some of the available channels are kept aside for handoff users or real-time users. In addition, because the reserved channels are also owned by PUs, there is no guarantee of their availability at the time of spectrum handoffs or request times of new SUs. One more drawback of channel reservation is when a new SU is asking for a channel and no handoffs are taking place or no real-time SUs need service at that time, those reserved channels cannot be used for new SU requests and hence results in wastage of bandwidth.

So to support the efficient utilization of bandwidth, frequency reuse concept is proposed here instead of channel reservation. Frequency reuse concept is adopted from cellular systems, where the same frequency can be used by more than one user in such a way that there is no co-channel interference. To overcome the problem of co-channel interference, simulations are carried out to know the amount of co-channel interference with respect to transmitted power. As it is known, the power values gradually decrease with increase in distance as shown in Equation 5.1.

$$P_R = \frac{P_T}{4\Pi D^2} \quad \text{…………………(5.1)}$$

where

$P_R$ is the received power,

$P_T$ is transmitted power, and

D is distance between the transmitter and receiver in meters.

Equation 5.1 indicates the impact of distance on the received power. The power $P_T$ shown in this equation refers to not only the signal from the intended transmitter, but also the interfering powers that come from distant co-channel interferers. The detailed equation of path loss that is used to represent the influence of various parameters including the distance is as given in equation 5.1b.

Free space path loss = $20\log_{10}(d) + 20\log_{10}(f) + 20\log_{10}(4\pi/c) - G_t - G_r$...........(5.1b)

Where d=distance

f=frequency

c=light velocity in free space=$3*10^8$ m/s

$G_t$=Transmitting antenna gain

$G_r$=Receiving antenna gain

As described in the above equation, influence of distance is represented as $20\log_{10}d$. In the simulation scenarios, by assigning different values of dB, different distances of the interferers are studied. The other parameters are assumed to be unchanged, while the impact of distance based interference power levels are considered.

In this work same frequency is offered to more than one SU if they are displaced by sufficient distances, and the BER values are within the acceptable range. With this frequency reuse, blocking is reduced and call completion rate is improved. Call dropping is also less due to frequency reuse applicability during spectrum mobility also.

**5.2. Related Work from Literature**

According to end user's point of view, the interruption of an ongoing session is more painful than getting rejected to initiate a new session. Therefore, some channels are reserved to take care of handoff SUs (Pacheco-Paramo, D., Pla, V., & Bauset, J., 2009).

In (Kefeng Tan, Kyungtae Kim, Yan Xin, Rangarajan, S. & Mohapatra, P., 2013), a sensing scheme named RECOG that is suitable to satisfy the QoS of VoIP is suggested. In RECOG, combination of multiple procedures is proposed. While the secondary device is engaged in transmitting the VoIP traffic, it has to sense the spectrum periodically to find out whether the primary user is back or not. To do so, it has to suspend its transmission for about 100 ms and then resume its VoIP transmission. As 100 ms is a large break for VoIP traffic, it causes jitter. To address this problem, the authors have divided the sensing period into multiple sub-slots, and based on the sensing information in each such sub-slot, a conclusion is made about the presence of primary user. To guarantee quick and reliable switching when PU returns back, they incorporated a well-organized backup channel searching component in their system.

The authors of (Jian Wang, Aiping Huang, Wei Wang, and Tony Q.S. Quek, 2013) have used two buffers, one for handoff SUs and the other for new SUs. Some channels are reserved for handoff SUs. They have considered that SUs are leaving the queues due to impatience because of long waiting times. Under these circumstances they have derived blocking and dropping probabilities using Markov chains.

In (Doost-Mohammady, R., Naderi, M. Y. & Chowdhury, K. R., 2014), the authors have considered two types of priorities for SUs: Streaming and Non-Streaming. They find the best set of successive PU channels such that cumulative bandwidth satisfies the requirement of SUs. They have derived the optimum number of channels to be kept for reservation of channels to streaming type SUs. Here they support the real-time SUs by reserving some channels for them. But reservation of channels may increase unnecessary blocking.

Some channels are reserved for hand off SUs in (Zhai, L., Wang, H. & Gao,C., 2016) to decrease dropping probability but at the cost of blocking probability. Performance metrics considered are blocking probability, termination probability and completed traffic.

In most of the above works, channel reservation is employed to support real-time users or handoff users, but at the cost of blocking new SU requests. There are three problems with channel reservation. Firstly, the reserved channels may not be available when they are needed by the handoff SUs or real-time SUs. Secondly, even when there is no need of the reserved channels for handoff SU or real-time SU, when some new SUs are requesting at a time instant, these reserved channels cannot be allotted. Finally call blocking will be increased as number of free channels available is reduced.

## 5.3. Co-Channel and Adjacent Channel Interferences

Here, the impact of co-channel and adjacent channel interferences are observed with respect to power and frequency offset factor respectively. The power of signal decreases inversely proportional to the square of the distance the signal travelled. Once the usable power levels for co-channel users are known along with distances, then, frequency reuse concept can be used without any co channel interference.

Figure 5.1 is the typical model of the radio environment. In this diagram, multiple users are shown to be transmitting. They are at different distances from the location of interest at which the opportunistic user is located. The multiple users (interferers) shown in the diagram are considered to be occupying the available channel frequencies. Some of them may be using the same frequency as the user under consideration is using. Some of them may be operating at adjacent frequencies. The opportunistic user should be capable of using any of these frequencies that are found to be free at various times. As discussed, the licensed users may not be transmitting all the times. So those unoccupied channels can be claimed by the SUs. It can claim those SU occupied frequencies also if they are far away from this opportunistic user. Co-channel interference is observed by varying the power of the co-channel interferer. Adjacent channel interference is observed by varying the frequency of the interferer.

Figure 5.2 is the simulation result of the co-channel interference in Additive White Gaussian Noise (AWGN) at 1MHz frequency. It is observed that by increasing power of the co-channel interferer (CCI), Bit Error Rate (BER) also increases. The higher powers of another user operating in the same frequency increase the disturbance levels, called co-channel interference. One more point to be noticed here is that no co-channel interference is experienced by users if their power is less than or equal to -10dB that is 0.1watts.

Figure 5.3.illustrates the simulation result of Adjacent Channel Interferer (ACI) with equal powers at the intended transmitters. Here it can be observed that BER decreases with increase in frequency offset. That means, the BER decreases when the frequency difference between the intended transmitter and interferer increases. From Figure 5.3 it is understood that a minimum of frequency offset factor 0.9MHz that is 900KHz results in no adjacent channel interference.

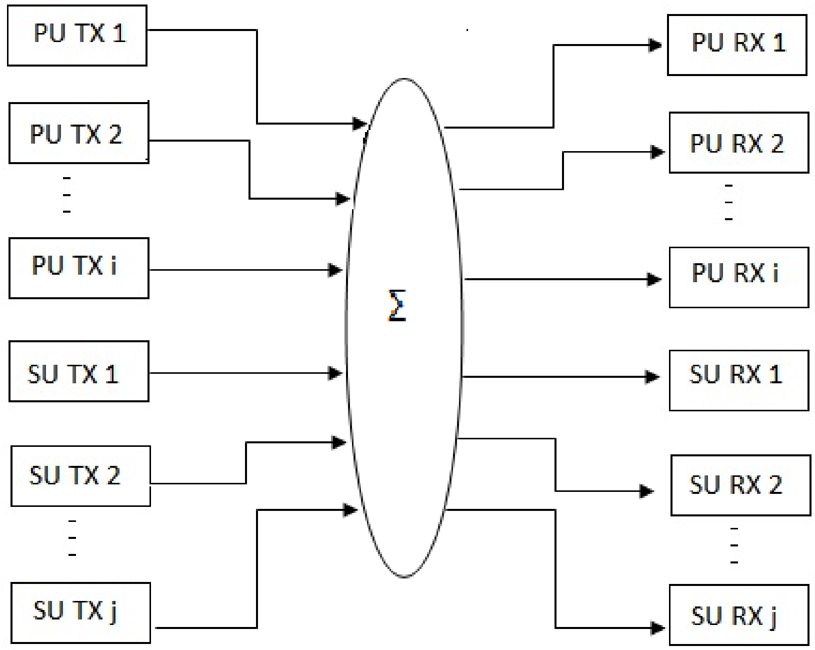


Figure 5.1.Typical Environment Diagram

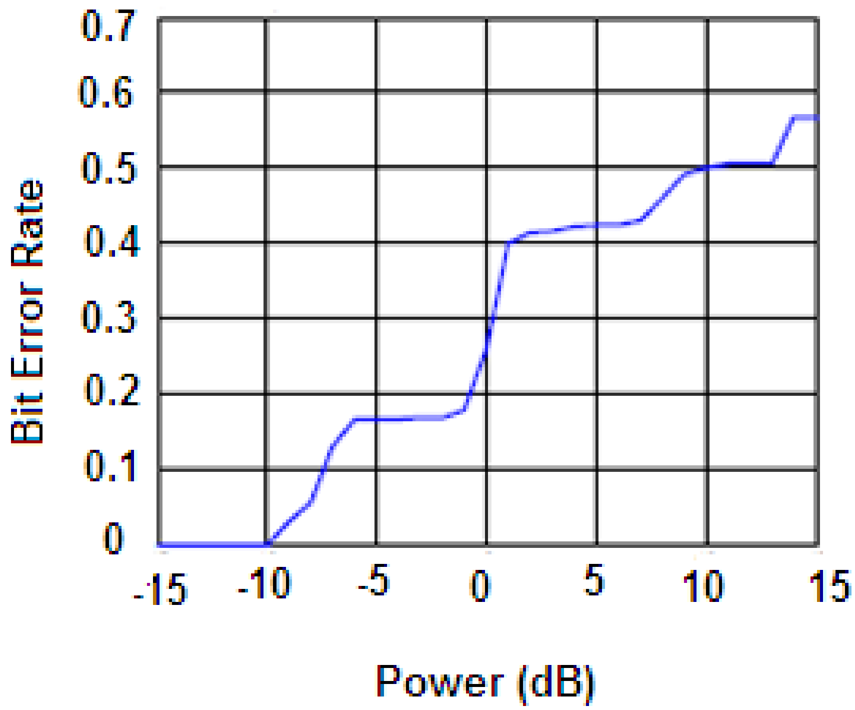


Figure 5.2. BER Vs Power in co-channel interference

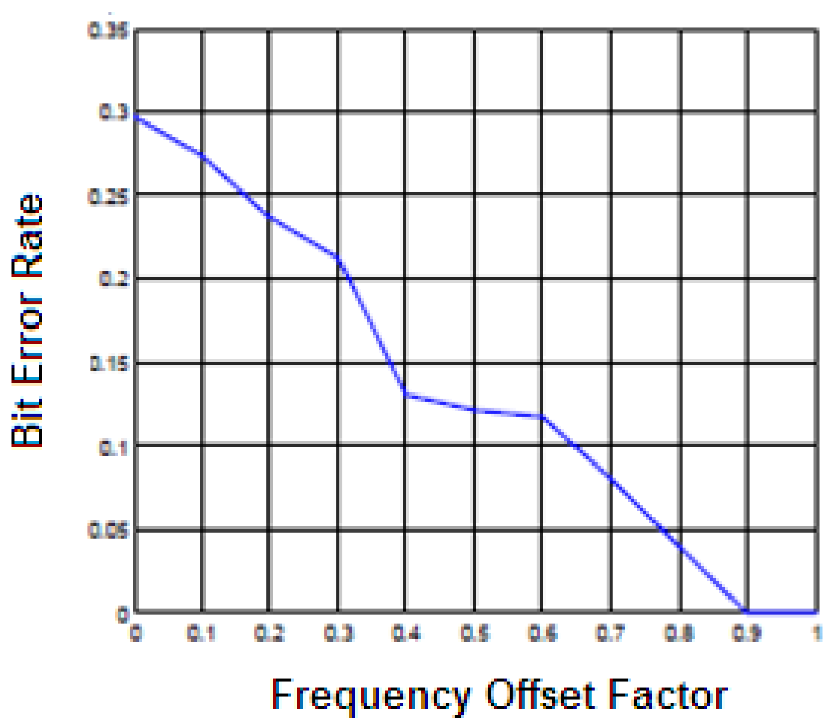


Figure 5.3. BER Vs frequency offset factor in Adjacent Channel Interference

### 5.4. Model

The network considered is a centralized network, where a central coordinator manages the traffic of all SUs in a given region. It is not confined to any cellular pattern. The SUs can be there anywhere and utilize the opportunistic channel access. In this context, even the PUs are also considered, as not belonging to cellular pattern. The reason for this consideration is that, most of the available channels that can be used through opportunistic access are not from cellular operators. Instead, they are from various other sources like television white spaces (TVWS), military, navigation, etc. frequencies. For three different cases of number of channels, results are obtained. Blocking probability, dropping probability and call completion rate are obtained with respect to number of SUs located in the area.

Blocking probability represents the chance of not getting the free channel due to unavailability of free channels. Dropping probability is the chance of not getting free channel during spectrum handoffs. Call completion rate represents successful completion of the average number of calls (Vamsi Krishna,T, Wang, P., Niyato, D. & Song, W. , 2012).

When a channel request is received from an SU by the central coordinator, it checks for the availability of free channels and assign a channel if found, otherwise it will check the distance between the requesting SU and an SU which is already assigned channel and assign the same channel if they are displaced by sufficient distance. BER or PER values above a threshold value (0.01 or more, typically) is an indication of interference occurrence. So distances that cause the high BER values are considered to be due to the interference from co-channel neighbors. In Equation 5.1b, it is written in terms of dB values and implemented accordingly in MATLAB- Simulink environment. While carrying out this analysis, channel frequency, gains of transmitting and receiving antennas are kept unchanged. This frequency reuse is applicable during the spectrum handoffs also. So with this concept the utilization of bandwidth is improved.

### 5.5. Results and Discussion

The comparative results taken for various channel availability scenarios are shown in Table 5.1 and SU requesting scenarios shown in Table 5.2.

Table 5.1. Simulation parameters of channel occupancies

| Parameter | High PU occupancy | Medium PU Occupancy |
|---|---|---|
| Maximum holding time of PUs | 30 minutes | 20 minutes |
| Maximum number of times each PU is reappearing | 30 | 20 |

Table 5.2. Simulation parameters of SUs

| Parameter | High SU demand | Medium SU Demand |
|---|---|---|
| Maximum holding time of SUs | 30 minutes | 20 minutes |
| Maximum number of times each SU is reappearing | 30 | 20 |

The frequency reuse concept is more advantageous when there is high PU occupancy and high demand from SUs.

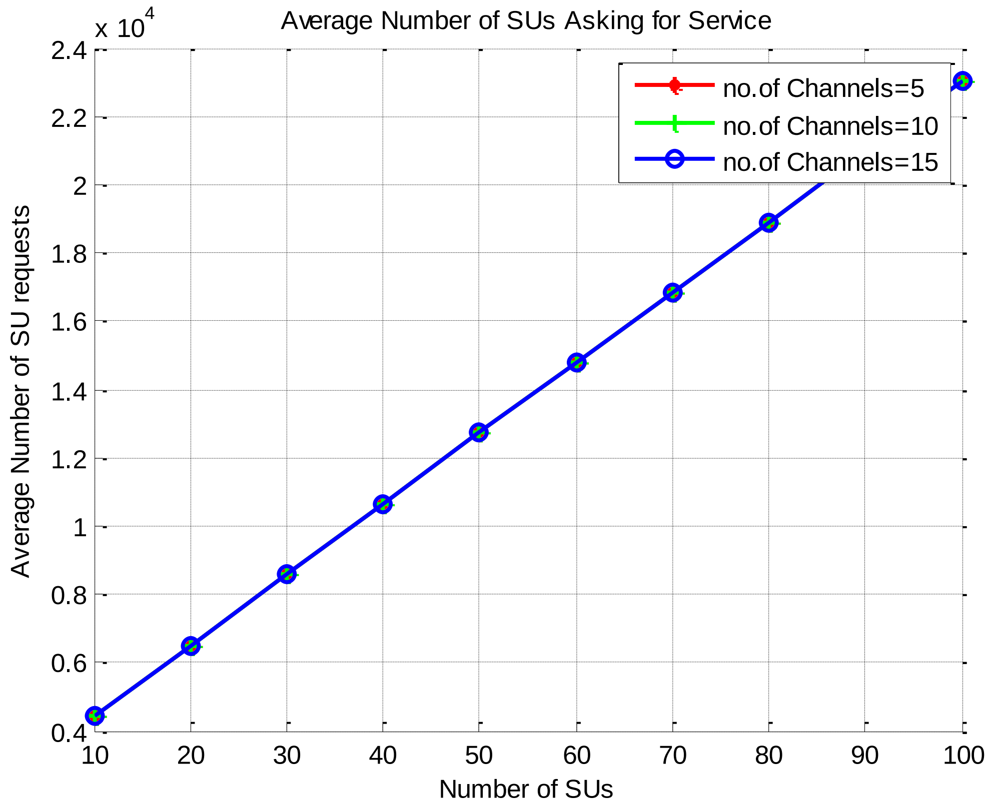


Figure 5.4. Average Number of SU Requests for High SU Demand Scenario

Figure 5.4 shows the average number of SU requests, Figure 5.5 shows the blocking probability, Figure 5.6 shows the dropping probability and Figure 5.7 shows the call completion rate of SUs in both Channel Reservation (CR) and Frequency Reuse (FR) concepts.

From Figure 5.4, it is observed that the average number of SU requests is linearly increasing with number of SUs. It is common for all cases as it depends only on number of SUs, but not on PUs or on the type of technique to be used.

Figure 5.5 illustrates the cumulative average blocking probabilities of SUs for both CR and FR scenarios. It can be observed that the blocking of SUs is more in CR case compared to FR case. In addition, blocking is reducing with number of channels used, because of the opportunities of getting more spectrum holes. It can also be observed that the blocking probability is directly proportional to the number of SUs in CR case, but not in FR case as some more opportunities are getting from frequency reuse concept.

Dropping probability of SUs is more in FR compared to CR as observed in Figure 5.6. It is due to the fact that some channels are reserved for spectrum handoff in CR, so dropping is less. As the number of channels are increased the dropping probability of FR also very less.

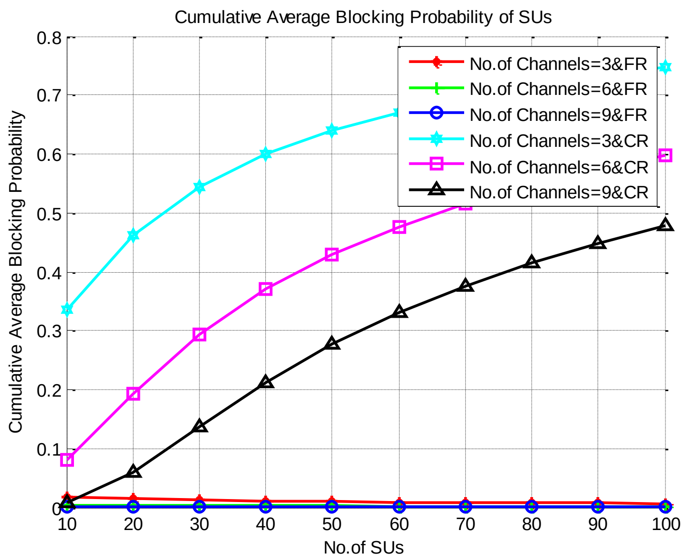


Figure5.5.Cumulative Average Blocking Probability of SUs for High PU Occupancy and High SU Demand Scenario

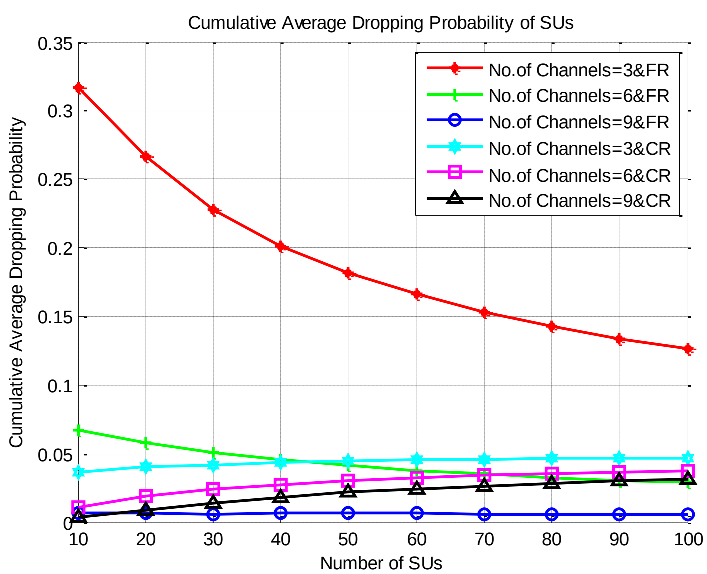


Figure 5.6. Cumulative Average Dropping Probability of SUs for High PU Occupancy and High SU Demand Scenario

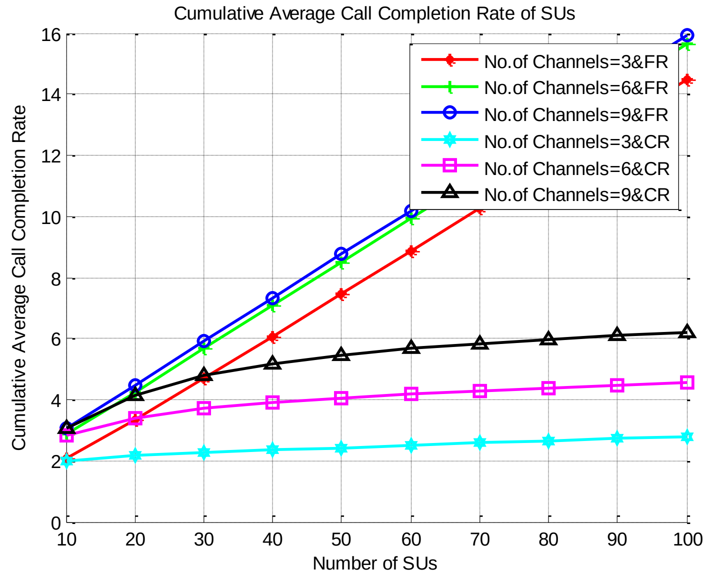


Figure 5.7. Cumulative Average Call Completion Rate of SUs for High PU Occupancy and High SU Demand Scenario

The call completion rate of FR is better than CR scenario. It is due to the fact that even if dropping is increased there is a great decrease of blocking. The results for medium PU occupancy and medium SU demand are shown in Figures 5.8 to 5.11. Here number of requests is less and hence it results in less blocking, less dropping and less call completion rate as number of requests received is less.

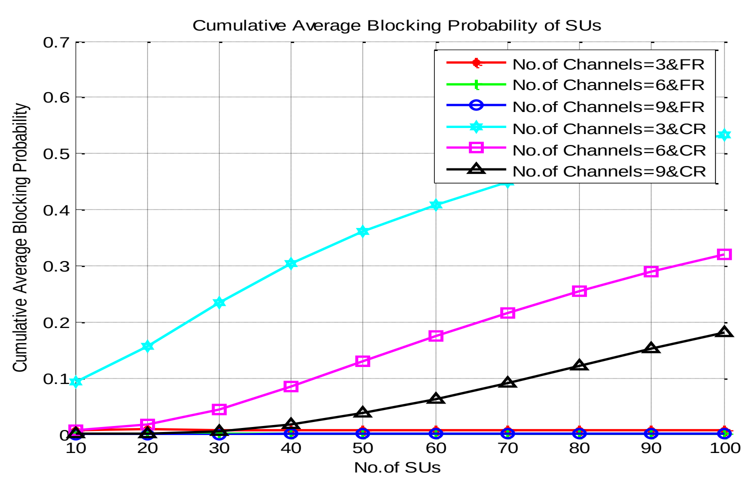


Figure 5.8. Average Number of SU Requests for Medium SU Demand Scenario

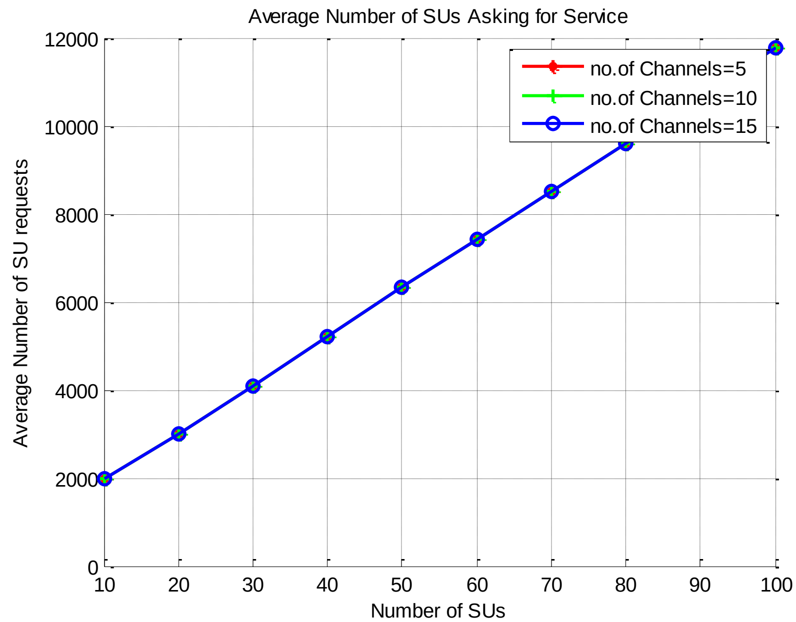


Figure 5.9. Cumulative Average Blocking Probability of SUs for Medium PU Occupancy and Medium SU Demand Scenario

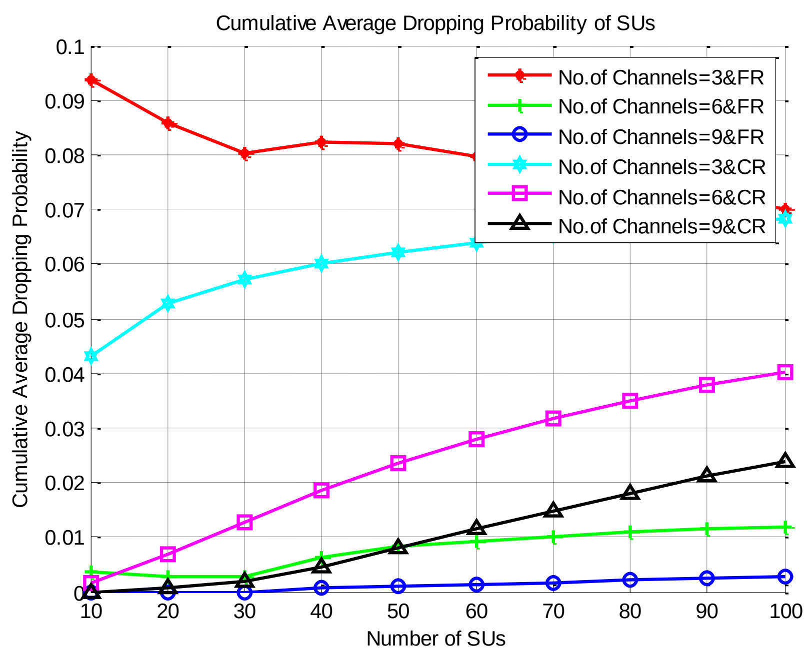


Figure 5.10. Cumulative Average Dropping Probability of SUs for Medium PU Occupancy and Medium SU Demand Scenario

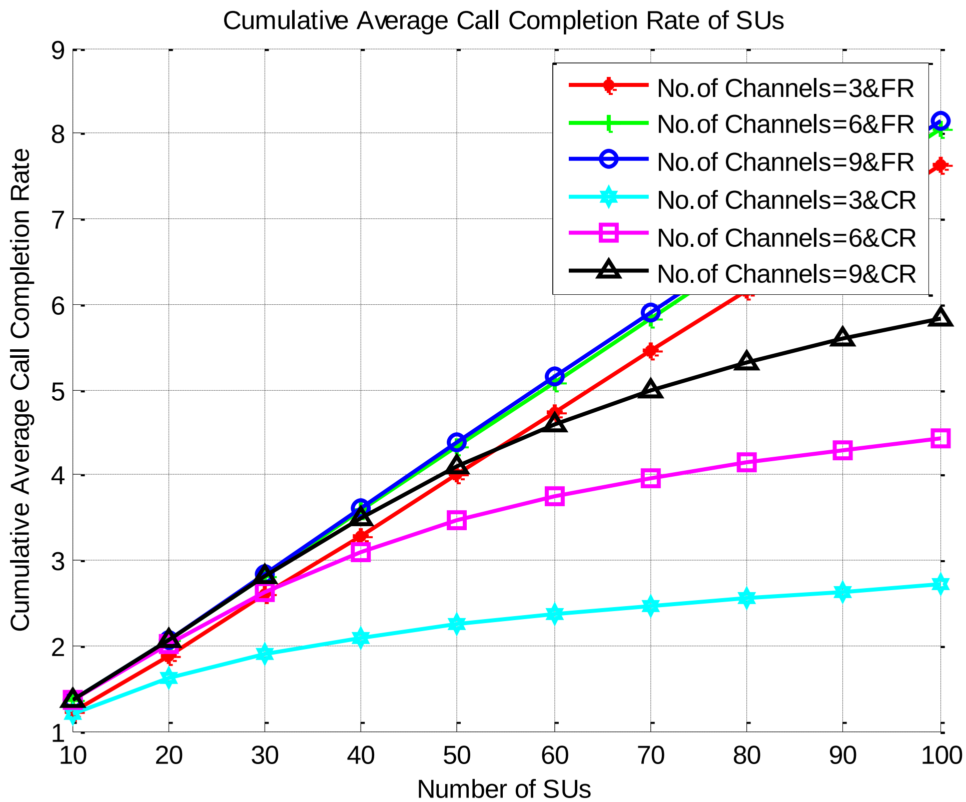


Figure 5.11. Cumulative Average Call Completion Rate of SUs for Medium PU Occupancy and Medium SU Demand Scenario

### 5.6. Summary

The proposed frequency reuse mechanism is compared with existing channel reservation method. Due to frequency reuse, call blocking is reduced as number of offered channels available to secondary users is more when compared to channel reservation methods. However, a negligible, instead of significant increase in call dropping probabilities is observed, due to the provision of frequency reuse during spectrum handoffs also. Finally call completion rate, which represents successful completion of calls, is improved in frequency reuse method when compared to channel reservation methods.

Frequency reuse is more advantageous when there is more demand from SUs and PUs' occupancy is high. The only care that needs to be taken is that frequency reuse should be applied such that there is no co-channel interference. In general, the users/devices that are using the same frequency are considered as co-channel users. The co-channel interference that is considered here is slightly different from the co-channel aspect considered in cellular communication systems. In cellular communications, non-adjacent cells that are allotted with the same channel frequencies are called as co-channel cells (or co-channel users). However, in the context of cognitive radio networks, the mechanism of 'opportunistic access' is nothing but using the same frequencies of the PUs in the same area by SUs, during the absence of PUs. Co-channel interference here refers to the aspect of being present in the same area, without causing interference to others. It includes the aspect of underlay mechanisms of 'opportunistic access' also, where the power levels and distances between PUs and SUs (or even between multiple SUs that use the same frequency channel) decide the interference levels.

.