Performance Analysis of Femtocell on Channel Allocation

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Abstract. Femtocell channel assignment is an important design criteria in cellular systems. In femtocell, access mechanisms are classified in to three classes: open access, closed access and, hybrid access. Additionally, the subscribers in the femtocell network are divided into two groups: subscriber group (SG) and non-subscriber group (NSG). Normally, some channels are reserved for SG. In this paper, five channel assignment models are briefly discussed and analyzed. The performance parameters such as blocking probability for each case is derived and analyzed. Furthermore, other parameters such as bit error rate (BER), the capacity for different path loss condition are also analyzed. We also identified the optimum reserved percentage of channel for SG so that performance remains the highest. The results show that the increase in offered traffic increases the blocking probability. Also, as the base stations increase, BER decreases and the capacity increases.

Keywords: Femtocell · Hybrid access · Channel allocation · Blocking probability · SG · NSG

1 Introduction

Femtocell [1] is a low powered base station that is placed in homes to increase the signal strength of the macro base station near cell edge areas. By using this femtocell, the coverage of the signal can be increased and the number of users also increased, giving the better quality of service (QoS) [2]. Femtocell base stations (also called as femto access point (FAP)) being plug and play devices [2], provided by the network operator; enhances the throughput of the macro base station coverage.

The different aspects of femtocell are access modes [3] and the channel allocation [4, 5]. The access modes differentiate the subscribers to access the femto network. For example, under open access, any user is given access to the network. Channel allocation is one of the most important aspects in the femtocell. In this, the channels are allocated to femtocell to give access to the subscribers. The channel allocation also increases the capacity. Additionally, the macrocell reliability is increased. The channel allocation is accomplished in two ways [6, 7]: (i) one being from macrocell to femtocell and (ii) from femtocell to the user. Placing a macro cell base station at the cell edges to increase the

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signal strength is proven to be a costlier than placing a suitable femtocell base station network. This induces cost benefit for the user as well as the network provider.

The channels which are existing in macrocell can be given to the femtocell to increase the QoS and coverage at the edges of the macrocell region where the signal strength of the macrocell is less. When the set of channels are allocated to the femtocell, then there will be interference between the femtocell and macrocell which degrades the macrocell QoS. The interferences exist between the femtocell to femtocell or femtocell to macrocell. There are two types of interferences [5]: (i) the co-channel interference and (ii) the adjacent channel interference. Co-channel interference is the interference between the femtocell and macrocell whereas the adjacent channel interference is the interference between the femtocell and the femtocell. As the same set of channels is allocated to macrocell and femtocell, there will be co channel interference between the femtocell and macrocell. This is one of the main challenges in the channel allocation of femtocell. However, allocation of channels follows different methods for different users (subscribers).

The subscribers of the femtocell are divided into the two groups: subscriber group (SG) and nonsubscriber group (NSG) [8, 9]. The numbers which are stored in the FAP are the customers as SG and the user numbers which are not stored at FAP are customers as NSG. The total service rate is considered as 3-min. The different models are analyzed for the blocking probability and number of occupied channels. In this paper, parameters like blocking probability [8], BER, capacity [10, 11] for the femtocell network is investigated and the corresponding results are presented. The result obtained in this work is different from the existing work and suitable conclusion is drawn. We have also found the optimum reserved channels for the SG users. It is observed that if assignment of reserved channel is varied, the QoS varies. Therefore, it becomes necessary to identify the optimum number of SG users. As per our knowledge, such study and results are not available in the literature. Other performance parameters like bit error rate (BER), capacity is also analyzed and discussed.

Contents of the rest of the paper is as follows. Section 2 presents the system configuration and architecture of femtocell network. Section 3 discusses the methodological model overview where models for most of the methods are described. Results are presented and discussed in Sect. 4 examines and analyses the results. Section 5 presents the conclusion and future scope.

2 System Configuration

This section describes a brief explanation of the architecture of femtocell network.

Architecture of Femtocell Network

The architecture of the femtocell network [8] is as shown in the Fig. 1. The architecture defines how the femtocell is placed in the macrocell region and how it works in the region without any problem.

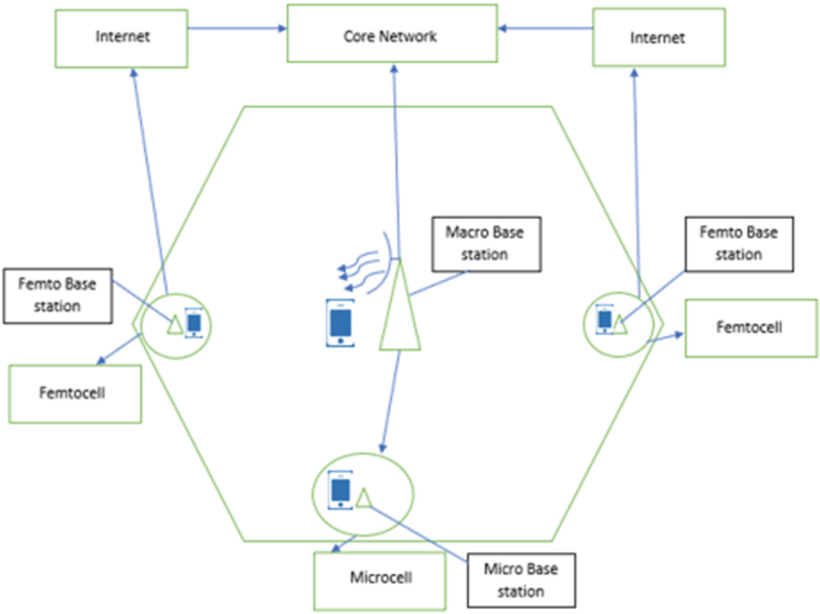

Fig. 1. Architecture of the femtocell network

Normally, the femtocell base station is placed at the edge of the macrocell region. There can be one or many femtocell base stations along the cell edge of the macrocell. This femtocell base station is also known as the Femto Access Points. These FAP's are connected to the core network of a provider by using the Internet broadband connection. These FAP's can be accessed by the users as they are plug and play devices. The main contribution is of these FAPs are to increase the signal strength near macrocell edge areas and improve the QoS. FAP's can use the same frequency set that of macrocell or other set of frequencies. Normally, they use less power transmission and therefore, coverage area of FAP is small. However, there are few challenges like interference, blocking probability, etc.

The characteristics and performance depends on various factors such as number of FAPs, number of channels allocated and so on. To understand the performance, we should understand the models. In the next section, we analyze various models for the channel allocation and derive for the some of these performance parameters.

3 Design and Analysis

In this section, we discuss the mathematical model of different channel allocation techniques of femtocell network. Most of the models are based on Markov chain.

3.1 Models and Their Blocking Probabilities

The models proposed are based on Markov chain as shown in Fig. 2 which is a stochastic process describing a sequence of possible events in the channel allocation. In this process, the present event is dependent on the state (occupancy of the channel) of the previous event. If the present state is occupied then the user will move to the next event (allocation of the next channel).

Consider, '*n*' is one of the channels in total of '*s*' number of channels. The occupancy of 'nth' channel depends upon whether $(n-1)^{th}$ channel is occupied or not and it is independent on the $(n-2)^{th}$ channel.

The channel models discussed in the next sections are based on two strategies [8]: (i) with equal priority for SG and NSG and (ii) percentage of reserved channels for SG. They are equal channel sharing (ECS), reserved channel sharing (RCS), variable channel sharing (VCS), reserved and variable channel sharing (RVCS), switching of reserved and variable channel sharing (SRVCS). These models are briefly discussed below. We have also found and the blocking probability for the each model.

A. **Equal channel sharing**

Equal channel sharing model is the basic model for every model which is proposed. In this model, there is no priority for the SG and NSG group. As they have equal priority, the blocking probability is the same for SG and NSG. The Markov chain model for the ECS is as shown in the Fig. 3.

For the analysis of ECS model, total *s* number of channels is considered which are for SG and NSG group together. There is no priority for the groups. To find the total probability, we need to know the zeroth probability and state probability. Zeroth probability is defined as P_o and state probability is mentioned as P_j and is given by:

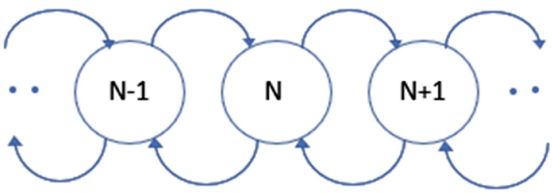

Fig. 2. Markov chain model

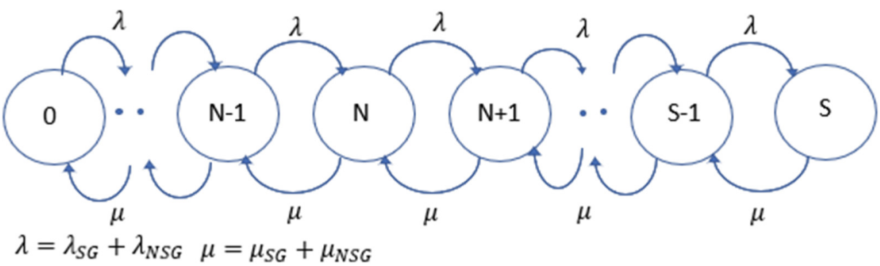

Fig. 3. Markov chain model for ECS

$$P_j = \frac{\left(\frac{\lambda_{SG} + \lambda_{NSG}}{\mu_{SG} + \mu_{NSG}}\right)^j}{j!} p_o \tag{1}$$

where

$$\lambda_{SG} = \rho * \mu_{SG} \tag{2}$$

$$\lambda_{NSG} = \rho * \mu_{NSG} \tag{3}$$

ρ is defined as the offered traffic and is given by the total number of channels in the femtocell, μ_{SG} and μ_{NSG} is the service rate for the user (SG and NSG). Its value is considered as 3 min. As we know that total probability is always equal to 1 by using that property we find the zeroth probability and total state probability:

$$\sum\nolimits_{j=0}^{s} P_j = 1 \tag{4}$$

From the Eqs. (1) and (4), the zeroth probability is calculated and it is given as:

$$p_o = \frac{1}{\sum\nolimits_{i=0}^{s} \frac{\left(\frac{\lambda_{SG} + \lambda_{NSG}}{\mu_{SG} + \mu_{NSG}}\right)^i}{i!}} \tag{5}$$

Now, solving (1) and (5), the blocking probability is calculated. Replacing ***j*** by *s,* the blocking probability is given by P_s:

$$p_s = \frac{\frac{\left(\frac{\lambda_{SG} + \lambda_{NSG}}{\mu_{SG} + \mu_{NSG}}\right)^s}{S!}}{\sum\nolimits_{i=0}^{s} \frac{\left(\frac{\lambda_{SG} + \lambda_{NSG}}{\mu_{SG} + \mu_{NSG}}\right)^i}{i!}} \tag{6}$$

The blocking probability is the same for SG and NSG subscribers as there is equal priority for both categories of subscribers and it is given by:

$$p_{bSG} = p_{bNSG} = p_s \tag{7}$$

B. **Reserved channel sharing**

In the reserved channel sharing, some channels are reserved for the SG users. Even the reserved channel is unused, they will not be offered to NSG users. The Markov chain model for the RCS is as shown in Fig. 4.

Consider again that there are total of ***s*** number of channels in these (n + 1) to ***s*** number of channels is reserved for the SG users. That is, 0 to ***n*** channels are occupied by both SG and NSG users whenever they want the service. The remaining (n + 1) to ***s*** channels are for SG users. If the reserved channels are occupied and if more SG users

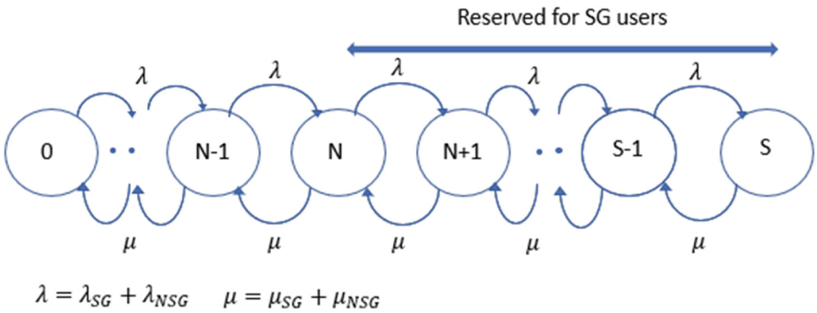

Fig. 4. Markov chain model for RCS

needed the service, then from the remaining channels it can be allocated to the SG user. The blocking probability is then calculated.

The state probability for reserved and unreserved channels are:

$$p_j = \frac{\left(\frac{\lambda_{SG} + \lambda_{NSG}}{\mu_{SG} + \mu_{NSG}}\right)^j}{j!} p_o \quad (0 < j \le n) \tag{8}$$

$$p_j = \frac{(\lambda_{SG})^{(i-n)} (\lambda_{SG} + \lambda_{NSG})^n}{i!(\mu_{SG} + \mu_{NSG})^i} P_o \quad (n < j \le s) \tag{9}$$

And, the total state probability is given as:

$$p_s = \frac{\left(\frac{\lambda_{SG} + \lambda_{NSG}}{\mu_{SG} + \mu_{NSG}}\right)^s}{s!} + \frac{(\lambda_{SG})^{(s-n)} (\lambda_{SG} + \lambda_{NSG})^n}{s!(\mu_{SG} + \mu_{NSG})^s} P_o \tag{10}$$

The zeroth probability is given as:

$$P_o = \frac{1}{\sum_{i=0}^{n} \frac{\left(\frac{\lambda_{SG} + \lambda_{NSG}}{\mu_{SG} + \mu_{NSG}}\right)^i}{i!} + \sum_{i=n+1}^{s} \frac{(\lambda_{SG})^{(i-n)} (\lambda_{SG} + \lambda_{NSG})^n}{i!(\mu_{SG} + \mu_{NSG})^i}} \tag{11}$$

Therefore, the blocking probability can be expressed as:

$$p_s = \frac{\frac{\left(\frac{\lambda_{SG} + \lambda_{NSG}}{\mu_{SG} + \mu_{NSG}}\right)^s}{S!} + \frac{(\lambda_{SG})^{(s-n)} (\lambda_{SG} + \lambda_{NSG})^n}{S!(\mu_{SG} + \mu_{NSG})^s}}{\sum_{i=0}^{n} \frac{\left(\frac{\lambda_{SG} + \lambda_{NSG}}{\mu_{SG} + \mu_{NSG}}\right)^i}{i!} + \sum_{i=n+1}^{s} \frac{(\lambda_{SG})^{(i-n)} (\lambda_{SG} + \lambda_{NSG}g)^n}{i!(\mu_{SG} + \mu_{NSG})^i}} \tag{12}$$

The blocking probability for each categories (subscriber) in RCS is:

$$p_{bSG} = p_S \text{ and } p_{bNSG} = \sum_{n}^{S} p_j$$

The disadvantage of this model is that sometimes no channel may remain for the NSG in the reserved channels.

C. Variable channel sharing

In this model, all the channels are variable. That is, all channels are shared among the SG and NSG users. There is no priority for the SG and NSG users. The variable channel sharing depends upon the value ***c***, the presence of NSG users whose value is considered between the 0 and 1. Here, 0 implies no NSG user while 1 implies NSG user. The Markov model for the VCS is shown in the Fig. 5.

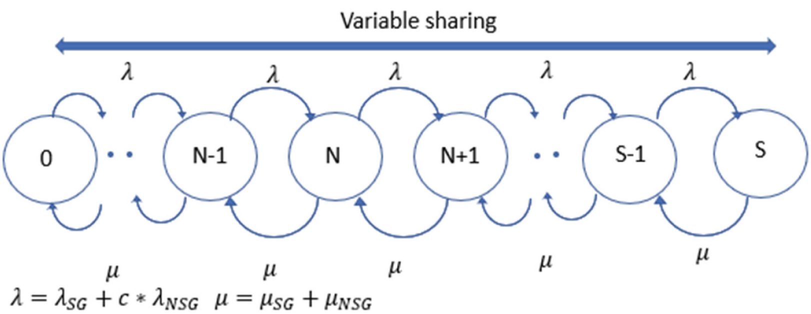

Fig. 5. Markov chain model for VCS

For variable channel sharing let us again consider that a total ***s*** number of channels are present. The variable ***c*** defines the presence of NSG user, when c = 0, then there is no NSG user and c = 1 defines the presence of NSG user with equal priority. So, when the variable c = 1, the variable channel sharing is equal to equal channel sharing model. The blocking probability is then calculated.

The state probability for ***s*** channels is given as:

$$p_j = \frac{\left(\frac{\lambda_{SG} + C\lambda_{NSG}}{\mu_{SG} + \mu_{NSG}}\right)^j}{j!} P_o \tag{13}$$

For zeroth probability and replacing *j* by *i,* it follows:

$$p_o = \frac{1}{\sum_{i=0}^{s} \frac{\left(\frac{\lambda_{SG} + c\lambda_{NSG}}{\mu_{SG} + \mu_{NSG}}\right)^i}{i!}} \tag{14}$$

The total state probability is defined as:

$$p_s = \frac{\frac{\left(\frac{\lambda_{SG} + c\lambda_{NSG}}{\mu_{SG} + \mu_{NSG}}\right)^s}{s!}}{\sum_{i=0}^{s} \frac{\left(\frac{\lambda_{SG} + c\lambda_{NSG}}{\mu_{SG} + \mu_{NSG}}\right)^i}{i!}} \quad (15)$$

The SG blocking probability is given as:

$$p_{bSG} = p_S$$

The NSG blocking probability when the channels are variable when c = 0, there will be the maximum blocking probability for NSG.

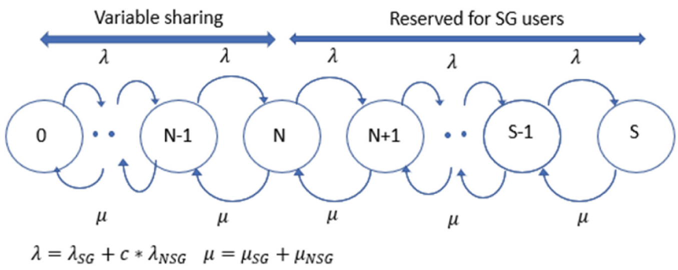

Fig. 6. Markov chain model for RVCS

D. **Reserved and variable channel sharing**

This model is improved version of the VCS model. It is a combination of RCS with high priority for the SG users so that SG users do not want their QoS to be affected. In this model, some channels are reserved for the SG users and remaining channels are available for SG and NSG users with the variable sharing. The Markov chain model for the RVCS is as shown in Fig. 6.

Let us consider, ***s*** be the total number of channels. In this total (n + 1) to ***s*** channels are reserved for SG users. From 0 to ***n*** channels are variable and these channels can be occupied by the SG and NSG users. The blocking probability for RVCS is calculated as below.

The state probability for the (0 to n) channels is:

$$p_j = \frac{\left(\frac{\lambda_{SG} + c\lambda_{NSG}}{\mu_{SG} + \mu_{NSG}}\right)^j}{j!} P_o \quad (0 < j \leq n) \quad (16)$$

The state probability for (n + 1) to ***s*** channels is given as:

$$P_j = \frac{(\lambda_{SG})^{(i-n)}(\lambda_{SG} + c\lambda_{NSG})^n}{i!(\mu_{SG} + \mu_{NSG})^i} P_o \quad (n < j \leq s) \tag{17}$$

The total state probability for ***s*** channels is:

$$P_s = \frac{\left(\frac{\lambda_{SG} + c\lambda_{NSG}}{\mu_{SG} + \mu_{NSG}}\right)^s}{s!} + \frac{(\lambda_{SG})^{(s-n)}(\lambda_{SG} + c\lambda_{NSG})^n}{s!(\mu_{SG} + \mu_{NSG})^s} P_o \tag{18}$$

The zeroth probability is calculated as:

$$P_0 = \frac{1}{\sum_{i=0}^{n} \frac{\left(\frac{\lambda_{SG} + C\lambda_{NSG}}{\mu_{SG} + \mu_{NSG}}\right)^i}{i!} + \sum_{i=n+1}^{s} \frac{(\lambda_{SG})^{(i-n)}(\lambda_{SG} + C\lambda_{NSG})^n}{i!(\mu_{SG} + \mu_{NSG})^i}} \tag{19}$$

The blocking probability for RVCS is:

$$p_{bSG} = \frac{\frac{\left(\frac{\lambda_{SG} + C\lambda_{NSG}}{\mu_{SG} + \mu_{NSG}}\right)^s}{S!} + \frac{(\lambda_{SG})^{(s-n)}(\lambda_{SG} + C\lambda_{NSG})^n}{S!(\mu_{SG} + \mu_{NSG})^s}}{\sum_{i=0}^{n} \frac{\left(\frac{\lambda_{SG} + C\lambda_{NSG}}{\mu_{SG} + \mu_{NSG}}\right)^i}{i!} + \sum_{i=n+1}^{s} \frac{(\lambda_{SG})^{(i-n)}(\lambda_{SG} + C\lambda_{NSG})^n}{i!(\mu_{SG} + \mu_{NSG})^i}} \tag{20}$$

whereas, $P_{b,NSG} = \sum_{n}^{s} Pj$ is the blocking probability for the RVCS model.

E. **Switching based reserved and variable channel sharing**

The SRVCS is an extension of model's VCS and RVCS. It states the switching capability to provide channels to NSG users or not. There are two cases which exist in this model; the one is c = 0 and $c \neq 0$.

For the case c = 0, this model works normally as VCS and RVCS where as for $c \neq 0$, SRVCS completely turns into SG mode where all NSG users are blocked. So, $P_{bNSG} = 1$ and blocking of SG users will be minimum. The blocking probability for SG users is as then calculated.

The blocking probability for SRVCS when c = 0 using VCS model is:

$$P_s = \frac{\frac{\left(\frac{\lambda_{SG}}{\mu_{SG} + \mu_{NSG}}\right)^s}{s!}}{\sum_{i=0}^{s} \frac{\left(\frac{\lambda_{SG}}{\mu_{SG} + \mu_{NSG}}\right)^i}{i!}} \tag{21}$$

The blocking probability for SRVCS when c = 0 using RVCS model is given as:

$$P_S = \frac{\frac{\left(\frac{\lambda_{SG}}{\mu_{SG}+\mu_{NSG}}\right)^s}{s!} + \frac{(\lambda_{SG})^{(s-n)}(\lambda_{SG})^n}{S!(\mu_{SG}+\mu_{NSG})^s}}{\sum_{i=0}^{n}\frac{\left(\frac{\lambda_{SG}}{\mu_{SG}+\mu_{NSG}}\right)^i}{i!} + \sum_{i=n+1}^{s}\frac{(\lambda_{SG})^{(i-n)}(\lambda_{SG})^n}{i!(\mu_{SG}+\mu_{NSG})^i}} \tag{22}$$

The above blocking probability completely blocks NSG users when c = 0. When c = 1, SRVCS will act as VCS or RVCS model.

3.2 Other Performance Parameters

A. Signal to interference plus noise ratio (SINR)

This is one of the most important quality of service parameters. The mathematical form for the SINR [12,13] is given as:

$$SINR = \frac{P_{fbs}G_{fbs}}{\sigma + \sum P_{fbs} + \sum P_{mbs}} \tag{23}$$

where, P_{fbs} is the transmission power of femtocell station; P_{mbs} is the transmission power of macrocell station; G_{fbs} is the channel gain and σ = noise power.

B. Path Loss (P_L)

Path loss is defined as the obstacles between the transmitter and receiver and it is different for the indoor and outdoor.

Case I: Pathloss [14, 15] between the macro base station and an user equipment is:

$$P_L = 15.3 + 37.6\log(d) + L_{OW} \tag{24}$$

where d is the distance between the transmitter and receiver and L_{ow} is outer walls for the case of outdoor it is set to zero.

Case II: Pathloss between the femto base station and an user equipment is:

$$P_L = \max(15.3 + 37.6\log(d), 38.46 + 20\log(d)) + 0.2d_{indoor} + 18.3n^{\left(\frac{n+2}{n+1}\right)-0.46} + qL_{iw} + L_{ow1} + L_{ow2} \tag{25}$$

where n = number of penetrated floors

q = number of walls separating apartments between the femto base station n and the user equipment.

d_{indoor} = distance inside the house.

L_{ow} and L_{iw} penetration loss of an outdoor and indoor wall which are set to 20 dB and 5 dB respectively.

C. Bit error rate (BER)
The BER of Shannon channel capacity is expressed as:

$$BER = 0.2exp\left(\frac{1.5SINR}{2^k - 1}\right) \tag{26}$$

where SINR is the signal to interference plus noise ratio, and k is the number of users.

D. Capacity or throughput
Capacity [16, 17] is the tight upper bound on the rate at which information can be reliably transmitted over a communication channel.

To calculate the capacity, we use:

$$C = B * \log_2(1 + \alpha SINR) \tag{27}$$

where $\boldsymbol{B}$ is the bandwidth, and $\alpha = \frac{-1.5}{\ln(5\text{BER})}$

4 Results and Discussion

In this section, we summarize the results obtained for the different models for different performing parameters. For all the simulation of models mentioned in the Sect. 3 parameters that are considered are total number of channels are 50, offered traffic is equal to total number of channels considered, total service rate is set to the 3 min. For RCS and RVCS 70% of channels are reserved for the SG users. For the simulation of SINR, BER the parameters considered are micro transmit power is 43dBm, femtocell transmit power is 10dBm, noise power −174dBm/Hz, number of femtocell and microcell considered as 10 and 1.

Figure 7 illustrates the blocking probability for the equal channel sharing model for both categories of users. It is seen that the blocking probability for ECS model is same for SG and NSG because in this model there is no priority for SG or NSG users. In the figure, we also have RCS SG when 70% of the channels are reserved for SG. From the Fig., we see that out of 40 number of channels, when 5 channels are occupied; the blocking probability for the ECS is less that is performance is better. As the number of channel's occupation increases, the blocking of another user also increases. 70% of reserved channel in case of RCS is considered because, it is found to be approximately optimum. If, we reserve more percentage of channels, there is very small increment in the performance.

The result of VCS and RVCS is as shown in Fig. 8. The plot is drawn for the two cases, when c = 0 and c = 0.5. When c = 0, most of the NSG users will be blocked while SG users will experience minimum blocking (as can be seen in the Fig.). However, when c = 0.5, VCS and RVCS of both categories of user experience the almost same blocking.

Figure 9 illustrates the blocking performance for RVCS model for different values of c with 70% channel reservation for SG users. We have used c values from 0 to 0.8. As stated, c = 0 implies no NSG user while c = 1 implies presence of NSG user. It is seen that for smaller value of c, the blocking for SG users is minimum.

The performance of SRVCS is shown in Figs. 10 and 11. Figure 10 shows the performance for different values of ***c*** using VCS model for only SG blocking. It can be seen that when c = 0, blocking for SG users is minimum, as no NSG users are present. While, c = 0.5, the blocking of SG user increases since there will be presence of NSG users.

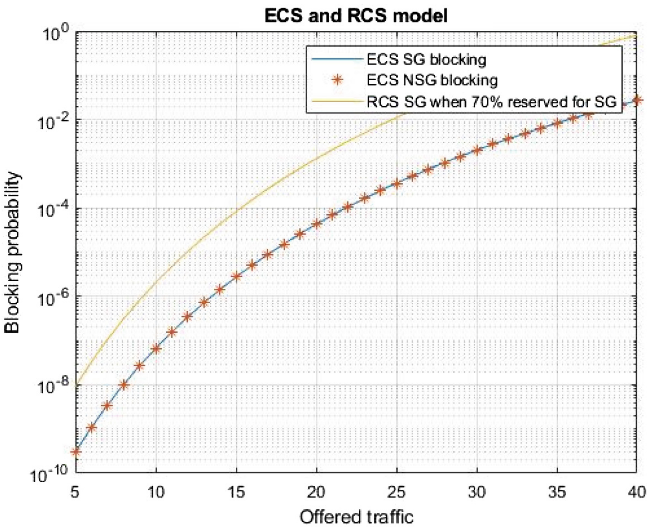

Fig. 7. Blocking probability of ECS and RCS (70%)

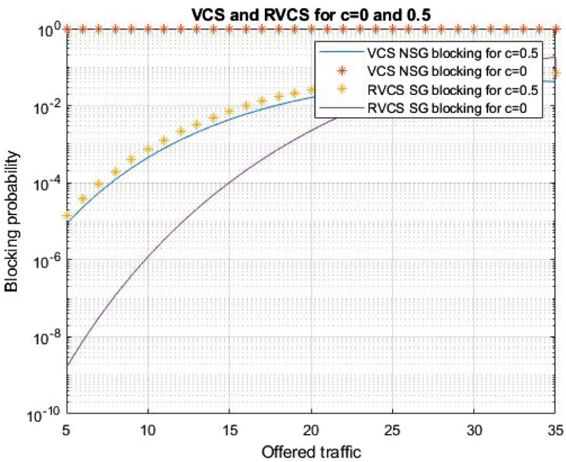

Fig. 8. Blocking probability of VCS and RVCS

Figure 11 shows the blocking probability for SRVCS using RVCS model when 70% of the channels are reserved for SG users in both cases (c = 0 and c = 0.5). It is seen that the performance in both cases are almost same except that when offered traffic is less, the SRVCS blocking performance for c = 0 is slightly better.

Figure 12 shows the BER performance over the number of femtocells. We considered some fixed value of path loss that is 0.2 and 0.5. It is seen that as the number of femtocell base station increases, the BER is decreased and it is slightly poorer when path loss is higher (0.5).

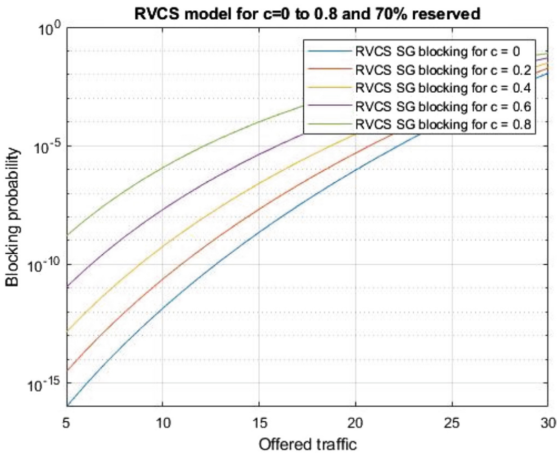

Fig. 9. Blocking probability of RVCS for different ‘c’

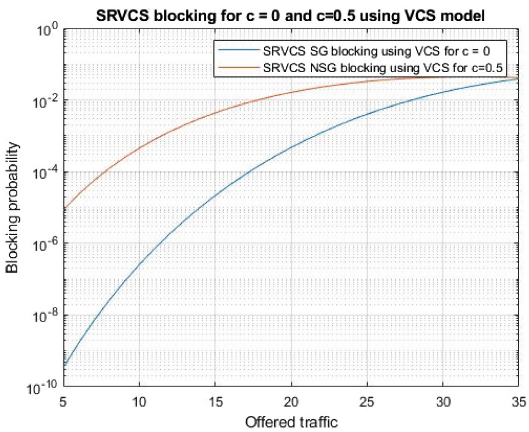

Fig. 10. Blocking probability for SRVCS using VCS for c = 0 & c = 0.5

Figure 13 shows the relation between the number of femtocells and the capacity (bit/Hz). It is seen that as the number of femtocell base station increases the capacity also increases. Of course, that seems obvious. However, when number of FAPs is less the difference in the capacity between path loss of 0.2 and 0.5 is small. But this difference in performance increases when FAPs are more.

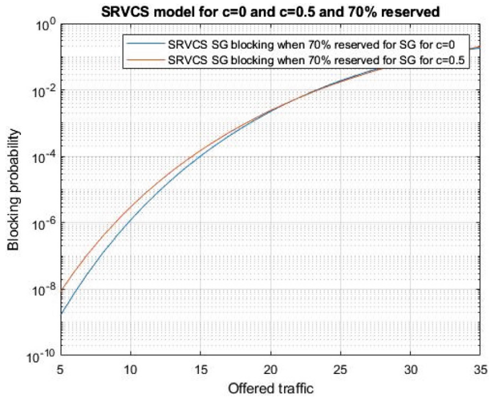

Fig. 11. Blocking probability for SRVCS using RVCS for c = 0 & c = 0.5

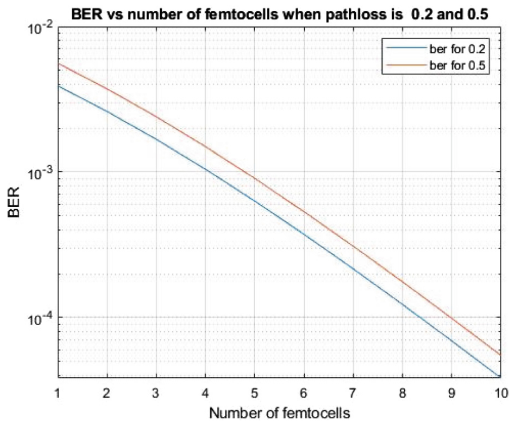

Fig. 12. BER vs Number of femtocells for pathloss 0.2 and 0.5

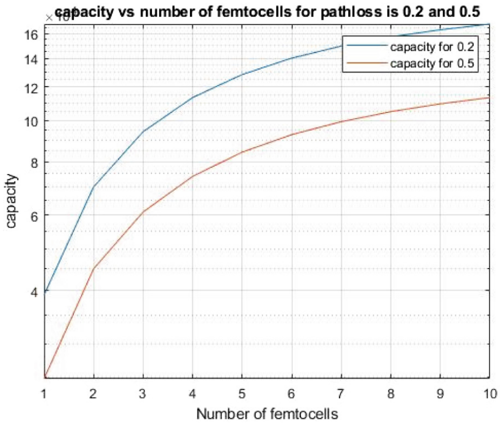

Fig. 13. Capacity vs Number of femtocells for pathloss 0.2 and 0.5

5 Conclusion

In this work various models of channel allocation for femtocell is studied and investigated for different cases like, presence of NSG users, percentage of reserved channel of SG and so on. It is found that 70% of reserved channel for SG is optimum. If we reserve more channel than 70%, the performance does not change significantly. It is also observed that when number of femtocell base stations is increased, the capacity as well as bit error performance is increased. However, interference is a limiting factor in this performance. The exact amount of limitation or effect by interference is not studied, but can be undertaken to observe the performance between QoS and number of FAPs which cause interference. Deployment of FAPs is another area of investigation which might be macrocell dependent and coverage area of it after actual field measurement.

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