Optimal Relay Placement and Resource Allocation in LTE Networks

THESIS

submitted by

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THESIS CERTIFICATE

This is to certify that the thesis entitled **Optimal Relay Placement and Resource Allocation in LTE Networks**, submitted by **Sanjay Ghosh (Roll No. EE11M018)**, to Indian Institute of Technology, Madras, for the award of the degree of **Master of Technology**, is a bonafide record of the research work done by him under my supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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-Sanjay Ghosh

ABSTRUCT

To meet the increasing demand for high data rate services, one solution being employed in next generation cellular systems, LTE is to deploy low-cost relay stations in each cell. In order to achieve maximum enhancement in throughput and coverage probability, it is required to determine optimal positions of the Relay Stations. This research proposes two novel Relay placement strategies and two Resource (Frequency) allocation strategies for the various links in the cotext of LTE frequency planning i.e Soft Frequency Reuse (SFR) and Fractional Frequency Reuse (FFR). We have studied the performance of the proposed schemes in terms of Coverage Probability and Throughput for both Uplink and Downlink and have compared with the system using conventional LTE frequency planning without Relay Stations. This non-overlapping frequency allocation between Relay assisted links (i.e BS- RS link and RS-MS link) enables half-duplex one-way (HD-OW) relaying to achieve the spectral efficiency same as full-duplex one-way (FD-OW) relaying.

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Abbreviations

AWGN: Additive White Gaussian Noise.
BS : Base Station.
CCDF : Complementary Cumulative Distribution Function.
CN : Complex Normal distribution.
Des: Design.
DL : Downlink.
FD-OW : Full Duplex One Way.
FFR : Fractional Frequency Reuse.
FRF : Frequency Reuse Factor.
FRN : Fixed Relay Node.
HD-OW : Half Duplex One Way.
LTE : Long Term Evolution.
MRS : Max-Rate Scheduling.
MS : Mobile Station.
N : Nornal distribution.
PFS : Proportional Fair Scheduling.
RS : Relay Station.
SFR : Soft Frequency Reuse.
SINR : Signal to Interference plus Noise Ratio.
SIR : Signal to Interference Ratio.
SNR : Signal to Noise Ratio.
RA : Resource Allocation.
UL : Uplink.

Chapter 1

Introduction

Fourth generation (4G) cellular systems are required to support high-quality broadband services, supporting voice and video applications in addition to data services. One of the main challenges faced by the developing standard is providing high throughput at the cell edge. Technologies like multiple input multiple output (MIMO), orthogonal frequency division multiplexing (OFDM), and advanced error control codes enhance per-link throughput but do not inherently mitigate the effects of interference. One solution to improve coverage is the use of fixed relays, pieces of infrastructure without a wired backhaul connection, that relay messages between the base station (BS) and mobile stations (MSs) through cooperative communication (Fig 1.1).

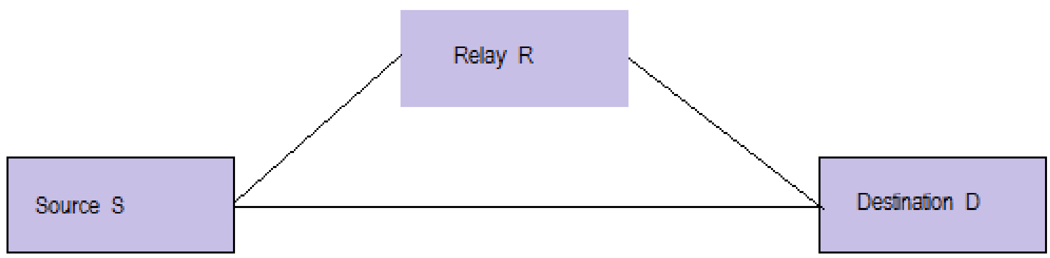


Figure 1.1: Typical Cooperative Communication.

There are two different approaches for cooperative transmission, according to the role played by the relaying terminal: the amplify and forward (AF) scheme and the decode and forward scheme (DF). The most simply approach is the AF approach which is a non-regenerative approach where the relay amplifies and retransmits the signal received from the source. It is also non as non-regenerative relay. The most complex approach is the DF scheme where the relay station decodes the received signal and retransmits the decoded and regenerated symbols. It is also known as regenerative approach. The DF relaying introduces more delay in transmission than AF relaying, but it gives better performance than the counter one.

Relaying is viewed as an energy saving technique because it can reduce the transmit power by breaking one long range transmission into several short range transmissions. Among various relaying technique from spectral efficiency point of view, half-duplex one-way (HD-OW) and full-duplex one-way (FD-OW) relaying have been considered (Fig 1.2).

Figure 1.2: Network model for HD-OW and FD-OW relaying.

In HD-OW relaying, all nodes operate in half-duplex mode and it will take four channel uses to achieve bi-directional communication. In the first channel phase, node A transmits its data signal to the relay node R in only one direction at the time. Subsequently, in the second channel phase, the relay node R transmits the processed signal to node B. In the third and fourth channel phases, node B transmits the signal to node A by relaying node R. Such HD-OW relaying suffers from a substantial loss in terms of spectral efficiency due to the pre-log factor 1/2, which dominates the capacity at high signal-to-noise ratio (SNR).

On the other hand, FD-OW relaying also has been proposed in where all the nodes operate in full-duplex mode. Therefore, it will take two channel uses or each bi-directional communication. Although the number of required channel uses for FD-OW relaying is the same as that of HD-TW relaying, the spectral efficiency of FD-OW relaying may decrease due to self-interfering signal at node R.

To meet the increasing demand for high data rate services, one solution being employed in next generation cellular systems is to deploy low-cost relay stations in each cell. An RS placed close to the cell edge, will result in low received SNR on the BS-RS link and will also cause higher interference to the neighboring cells. On the other hand, placing the RS away from the cell edge, results in a low SNR on the RS-MS link, causing cell edge users to be more prone to outage. Thus in order to achieve maximum enhancement in throughput and coverage probability, it is required to determine optimal positions of the Relay Stations.

Thesis Outline:

The rest of the thesis is structured as follows.

★ In second chapter, Literature Review has been discussed. It consists a summary on the research works done in context Relay Placement in Cellular System.

★ Third chapter presents the System Model which has been considered as the backbone over which improvement has been intended.

★ In fourth chapter, we first have formulated the problem and Proposed Solutions have been explained. It included both the relay placement and frequency allocation one by one.

★ Chapter 5 includes the definition of Coverage Probability. Also two scheduling algorithms have been defined; which has been used to calculate system throughout.

★ In chapter 6, we show the simulation results for various combinations of proposed placements and resource allocations.

★ Finally, thesis ends with the conclusion and the scope for the future work in chapter seven.

Chapter 2

Literature Review

There have been done a lot of research works mainly focussed on signal processing at relay node or on the whole relay-assisted system; but very few on the placement issue in the wireless network. In wireless system, distance between transmitter and receiver plays a crucial role in the performance of the system; which could be enough to motivate towards this relay station(s) placement problem. This chapter presents a brief overview of related work on relay placement and frequency allocation.

Review 1:

In this subsection, we will discuss about the approach given in [1]. They proposed a channel partitioning and relay positioning schemes where we have taken the objective function as to maximize the number of users admitted in a cell while providing each user with required data rate. In other words, the blocking probability of users has been minimized. A user is said to be blocked if the required rate cannot be provided to it.

They have considered the scinario where the users are admitted and departed dynamically. Depending on received SIR by an access-seeking user, the minimum bandwidth required to be allocated is calculated and if the required bandwidth is not available, the user is blocked.

The system model along with the relays is shown in the following figure. Each regular hexagonal cell has a BS at centre; six Fixed Relay Nodes (FRN) placed symmetrically around the BS at a distance d_r. In routing issue, they have divided each cell into 7 sections as shown. The users in the region A_1 (smaller hexagon with radius d) are supposed to communicate directly to the BS. The users in outer regions AR_1 to AR_6 can use relaying (FRN_k in region AR_K for k=1,. . 6)to establish a better link over direct link.

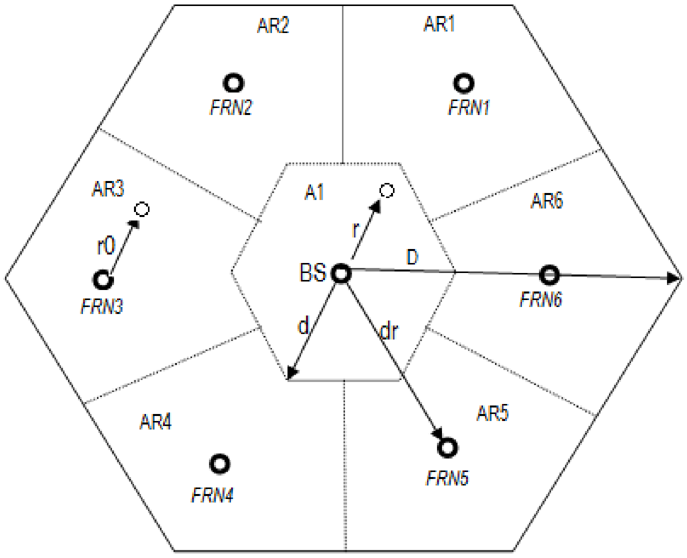


Figure 2.1: Layout of FRN enhanced Cellular system.

In resource partitioning issue, the authors have proposed to divide the whole band W into thirteen orthogonal segments, as W_1, $W_{2,k}$ and $W_{3,k}$ for $k = 1, ..6$. The band W_1 is allocated to be use by the users in region A_1, the band $W_{2,k}$ is allocated to be used by FRN_K to communicate to with BS, and the band $W_{3,k}$ is assigned to to be used by the users in the region AR_K to communicate with FRN_K. The worst case SIR scinario has been considered and only for downlink case.

Let Γ_{BM}, Γ_{BR} and Γ_{RM} be worst case SIR of BS-MS, BS-FRN and FRN-MS link respectively. Define:

$$\Delta = \frac{(\frac{d}{D})^2}{1 - (\frac{d}{D})} \frac{\log_2(1 + \Gamma_{RM})}{\log_2(1 + \Gamma_{BM})} + \frac{\log_2(1 + \Gamma_{RM})}{\log_2(1 + \Gamma_{BR})} + 1. \tag{2.1}$$

$$W_1 = \frac{\log_2(1 + \Gamma_{RM})}{\log_2(1 + \Gamma_{BM})} \frac{W}{\Delta}; \tag{2.2}$$

$$W_2 = \frac{W}{\Delta}; \tag{2.3}$$

$$W_3 = \frac{\log_2(1 + \Gamma_{RM})}{\log_2(1 + \Gamma_{BR})} \frac{W}{\Delta}. \tag{2.4}$$

Let λ be the avegrage active user density per unit area in a cell.

Objective: maximize λ
subjected to W_1, W_2 and W_3 satisfy (2.2), (2.3) and (2.4)

The main drawback is that they have employed 6 FRNs in each cell. But from economic point of view, it is always better to deploy less numbers of low-cost relay stations in order to minimized both the maintainence and installation cost. So number of relays should be reduced. Also they have not clearly showed the performance improvement over the conventional cell.

Review 2:

In this subsection, the approach given in [2] and [3] has been presented. The Authors have defined Coverage Radius after the introduction of Relay. Then with the help of that definition, they have proposed the relay placements in order to maximize Coverage Radius and estimate the the minimum number of required relays.

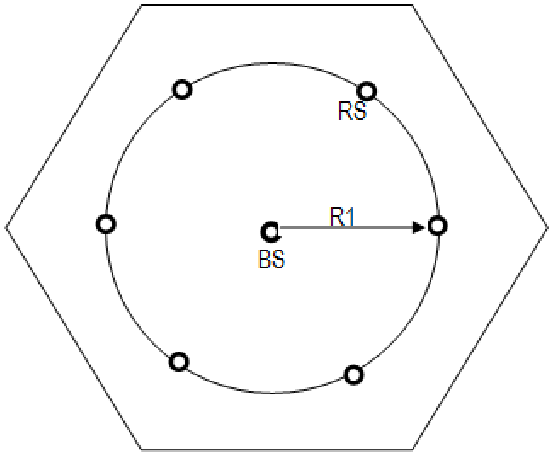


Figure 2.2: Topology with $N_R = 6$ RSs placed symmetrically around the BS.

The authors have considered a topology with N_R non-transparent Relay Stations (RS) placed symmetrically at radial distance R_1 around every BS as shown in above figure. Log-nornal shadow fading channel has been taken in account and optimal RS placements from a long term coverage perspective has been evaluated.

Let P_R: downlink transmit power of the BS.
P_R: downlink transmit power of RS.
η: pathloss exponent.
d: point-to-point distance from BS to Mobile Station (MS) when there is no relay.
N: background thermal noise.
ξ: log-normal shadowing random variable, $N(0, \sigma)$.
T: Thresold of the minimum SNR required for correct decoding of the received signal .

So received SNR at SNR, $SNR_{BS-MS} = P_B - 10\eta \log d - N + \xi$.

Probability of correct decoding,

$$\begin{aligned} p_c &= Pr(SNR_{BS-MS} > T) \\ &= Q(\frac{T + N - P_B + 10\eta \log d}{\sigma}) \end{aligned} \tag{2.5}$$

In the relay-assisted cellular system shown in the following, when an MS moves outside the coverage area of the BS, it is handed over to one of RSs and unhold the direct link with the BS. So, the probability of correct decoding is,

$$p_c = p_{pc1} p_{c2}$$
$$= Pr(SNR_{BS-RS} > T) + Pr(SNR_{RS-MS} > T)$$
$$= Q(\frac{T + N - P_B + 10\eta \log R_1}{\sigma}) Q(\frac{T + N - P_R + 10\eta \log R_2}{\sigma}) \quad (2.6)$$

where p_{c1} and p_{c2} are the probabilities of correct decoding on the BS-RS and RS-MS links respectively, R_1 is the relay placement radius and R_2 is the distance from the RS to the MS.

For given relay placement radius R_1, R_{cov} is the maximum distance from the BS at which both $E(SNR_{BS-RS})$ and $E(SNR_{RS-MS})$ are greater than threshold T. So $R_{cov} = R_1 + R_2$, when the BS, RS and MS are collinear. For fixed p_c there can be a tradeoff between R_1 and R_2. So there can be an optimum value of R_1 which maximizes the coverage radius $R_{cov} = R_1 + R_2$ as follows,

$$R_1^* = \underset{R_1 = \in (0, R_1^{max})}{\text{argmax}} \; R_1 + R_2 \qquad s.t. \qquad p_c = 0.5.$$

Where R_1^{max} is maximum possible RS placement radius. The value of R_1^{max} depends on p_c. Now, for a fixed value of p_c in equation (2.6), R_2 can be expressed as a function of R_1 $i.e$ $R_2 = f(R_2)$. So it can be written as following

$$R_1^* = \underset{R_1 = \in (0, R_1^{max})}{\text{argmax}} \; R_1 + f(R_1) \quad (2.7)$$

The way, the minimum number of required RSs has been chosenis shown in fig(2.3).It makes sure that the coverage discs of two consecutive RSs just touch without over-lapping. Such placement introduces some coverage holes, which can be reduced by increasing the number of RSs. The number of required RSs is given by

$$N_R = \lceil \frac{\pi}{sin^{-1}(\frac{R_2^*}{R_1^*})} \rceil \tag{2.8}$$

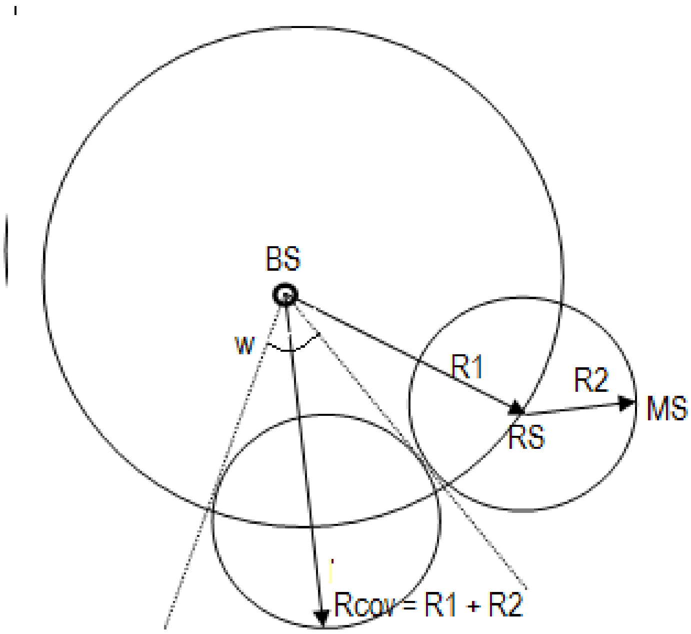


Figure 2.3: Layout of Cellular system with FRN.

The main drawback of this approach is the requirement of more number of RSs to maintain minimal coverage hole. More precisely, for higher value of p_{c_2}, the situation will be worse. They have talked about coverage extension. Also they have not mentioned about frequency allocation explicitly, which is one important resource whose distrbution should be clarified clearly.

■ ■

In this **subsection**, the summary of some more research works, relevant to this topic has been presented. The authors in [4] have analyzed the RS placements problem in cooperative dual-relaying Mobile Multi-hop Relay (MMR) networks. They have formulated the problem with an objective of minimizing the numbers of RSs to satisfy the traffic demands, minimum rate requirement of MS, interference and cell bandwidth constraints of the network and have proposed an algorithm to select the two best RS locations from the set of predefined set of candidate positions.

In paper [5], relay channel partitioning and reuse schemes for two-hop OFDMA fixed relay-enhanced cellular architecture has been studied. The authors have talked about four fixed resource allocation schemes different partitions and reuse factors *i.e* 7-part partitioning (PF7), 4-part partitioning (PF4), partial reuse (PR) and full reuse (FR) schemes. Among them two schemes PR and FR improve throughout by relay-channel partitioning as well as reuse; whereas other two mitigate co-channel interferences by relay-channel partitioning only.

In [6], the authors have explored the single RS placement problem with the objective of increasing system capacity rather than coverage extension in IEEE 802.16j network. They formulated and solved the single RS placement problem in multi-MS model in order to yield the optimal deployment and resource allocation for each single RS regarding a given set of MSs. They have taken into consideration both the optimal RS location and relay time allocation in a single stage by incorporating an cooperative relay strategy of Decode-Forward (DF) or Compress-Forward (CF).

In the paper [7], the authors have focussed on the planning of Ad-hoc Relay Network (ARN) to improve cellular coverage. There an iterative RS placement algorithm is proposed which divides all points in the cell into good and bad coverage points and places RSs at the good points whose neighbors have bad coverage. The problem, authors have considered, is about how to improve the SINR of the received signal in a spot with poor coverage by relaying data from a spot with good coverage.

Chapter 3

System Model

3.1 Soft Frequency Reuse

The Soft Frequency Reuse (SFR) is considered to be one of the most effective frequency planning strategies to mitigate inter-cell interference in cellular systems. In SFR, the available spectrum is divided into two reserved parts: a edge-cell band and a inner-cell band. Users within each cell are also divided into two groups, inner-cell users and edge-cell users, based on their distance to BS. Edge-cell users are restricted to the reserved edge-cell band while inner-cell users have exclusive access to the inner-cell band. The layout of the SFR [8] frequency planning applied, in a seven-cell hexagonal system along with power distortion is shown in Fig 3.1, where the inner-cell users can use two-third of the frequency band and the edge-cell users only use remaining frequency band non-overlapping with adjacent cell-edges. So the per-cell Frequency Reuse Factor (FRF) is 1.

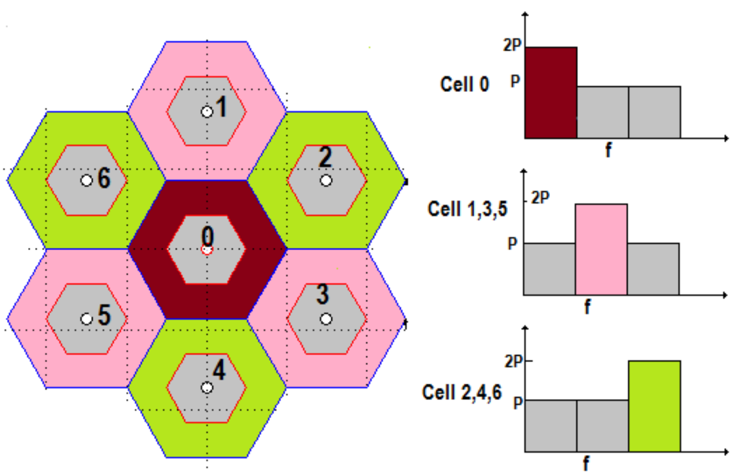


Figure 3.1: The frequency planning and power allocation for the SFR scheme.

3.2 Fractional Frequency Reuse

Fractional frequency reuse (FFR) is an interference management technique well-suited in cellular Networks. In FFR [9], like SFR users within each cell are divided into two groups. The entire bandwidth is divided into four segments $i.e$ $f0$, $f1$, $f2$ and $f3$. The idea is to apply $f0$ for inner-cell regions for all cells, whereas $f1$, $f2$ and $f3$ are used for an FRF of 1/3 configuration for the edge-cell regions only. The system layout and power distribution is shown in Fig 3.2. Since in each cell inner-cell users are assigned with same frequency band, all neighboring cells cause interferences ;whereas in edge-cell there are less numbers of interferers . So the per-cell FRF is 1/2.

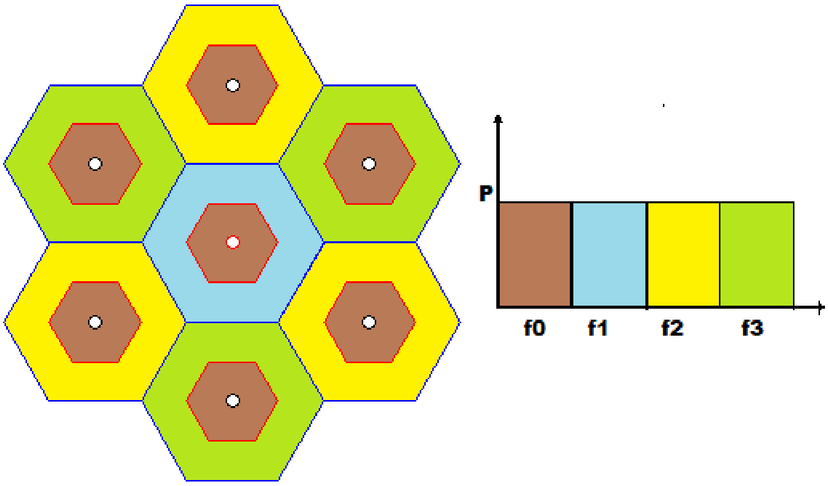


Figure 3.2: The frequency planning and power allocation for the FFR scheme.

Chapter 4

Problem Formulation And Our Apporach

4.1 Problem Formulation

In the cell with RS, the users which are not directly served by the BS, need to send their data over BS-RS link and RS-MS link respectively. So the data rate ($R2$) of BS-RS link must be greater or equals to the data rate ($R3$) of RS-MS link.

$$R2 = B_2 log_2(1 + \Gamma_{RM}) \tag{4.1}$$

$$R3 = B_3 log_2(1 + \Gamma_{BR}) \tag{4.2}$$

Constraint:

$$R_2 \geq R_3. \tag{4.3}$$

where B_2 and B_3 are the bandwidth of RS-MS link and BS-RS link respectively. Γ_{RM} and Γ_{BR} are SINR of RS-MS link and BS-RS link respectively. In our Resource Allocation strategies, we have kept aside enough bandwidth for the BS-RS link, which is equal of the bandwidth allocated for the RS-MS link to fulfill this requirement (eq 4.3).

Our analysis is based on worst case SINRs. The worst case SINR is obtained by considering the scenario in which all possible inter-cell interferers are present and they are placed at the shortest possible distances from the receiver. The worst case SINR of a link provides a lower bound on its actual SINR. Thus, to guarantee the required rate on a link, it suffices to guarantee the rate for the worst SINR on the link. We have considered Rayleigh fading channel coefficeients and AWGN background noise .

The received signal y at any node (BS, RS or MS) in a cell can be written as

$$y = hx + n + \sum_{i \in Z} h_i x_i \tag{4.4}$$

Where Z represents set of indices of all interferers in the system; x is the desired transmitted signal; h_i and x_i are the channel coefficient and the transmitted signal from the i-th interferer respectively. We have assumed $n \sim N(0, \sigma_n^2)$; $h \sim CN(0, \sigma^2)$ and $h_i \sim CN(0, \sigma_i^2)$.

So the expression of the SINR is defined as follows:

$$\Gamma = \frac{\frac{PH}{r^\gamma}}{\sigma_n^2 + \sum_{i \in Z} \frac{P_i H_i}{r_i^\gamma}} \tag{4.5}$$

Where γ is the pathloss exponent of the wireless channel; r is the distance of the receiver from the source of the message signal (distance from serving RS/BS to MS in case of downlink); r_i is the distance from the i-th interferer to the receiver; P is the transmit power of the message signal and P_i is the transmit power of i-th interferer respectively; H and H_i are exponentially distributed channel fading power correspond to h and h_i respectively.

The aim of Resource partitioning and relay positioning schemes is to maximize the average throughput per-cell while keeping the same FRF per-cell. Since throughput is a function of SINR, the problem implies to improve the avegrage SINR for each users. We have proposed the following Relay Placement and Resource Allocation strategies, which can solve our purpose.

4.2 Proposed Relay Placement

Each cell has a BS and three Fixed RSs situated symmetrically around the BS at a distance (from BS) d, where d is also the radius of the inner-cell (Fig 4.1). The remaining part of the cell is called as 'edge-cell'.

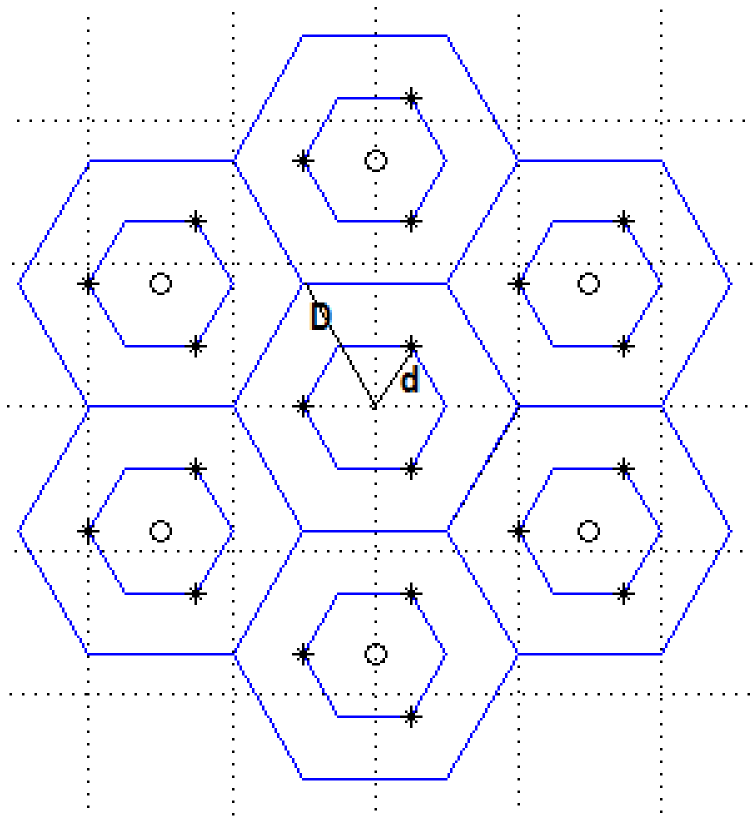
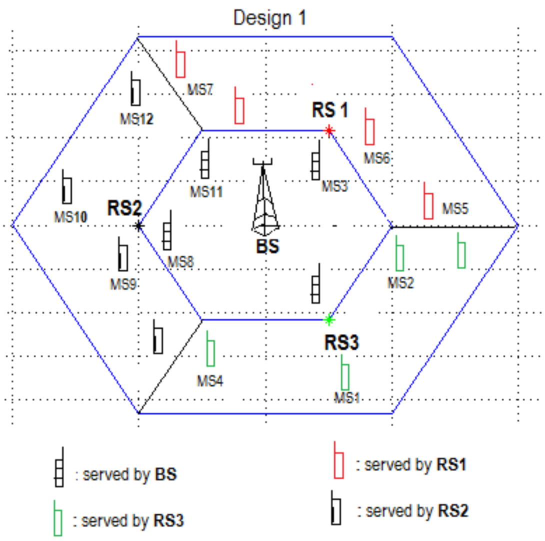


Figure 4.1: Proposed Relay Placements in hexagonal cell.

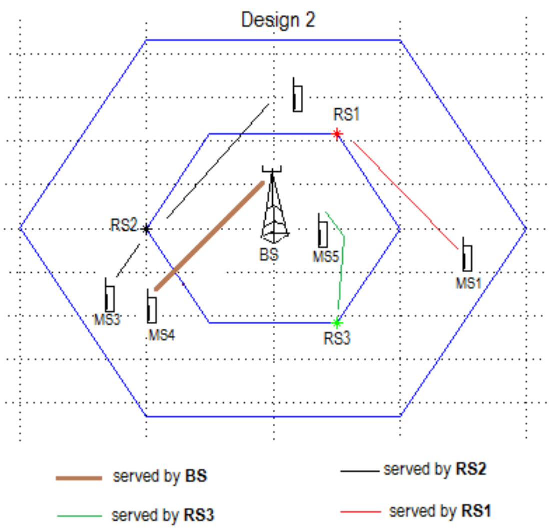
So eventually our placement problem is nothing but to vary d in the range $(0, D)$ and find the value which maximize the throughtput in each cell.

We have proposed the following two strategies of serving MS in a cell.

Design 1 (Des1): All the users in inner-cell are served by the BS irrespective of the locations. And each edge-users is served by the nearest RS.



Design 2 (Des2): Each user is served one of the RSs or BS, which has the best channel response; irrespective of either it belongs to inner-cell or edge-cell or the nearest station.



4.3 Proposed Frequency Planning

Inclusion of RS needs to assign a dedicated band for the BS-RS link which is not directly used to serve any MS. Also it reduces the effective available bands for direct links (BS-MS or RS-MS) data transmission. We have proposed two strategies to assign the total band for the above mentioned the links.

Resource Allocation 1 (RA1): For both the cases of SFR (Fig 4.2(a)) and FFR (Fig 4.3(a)), the band which is assigned (conventional) for edge-cell is divided into two parts: one is user for BS-RS link and another is for RS-MS link. We have maintain consistancy in colors for convenience.

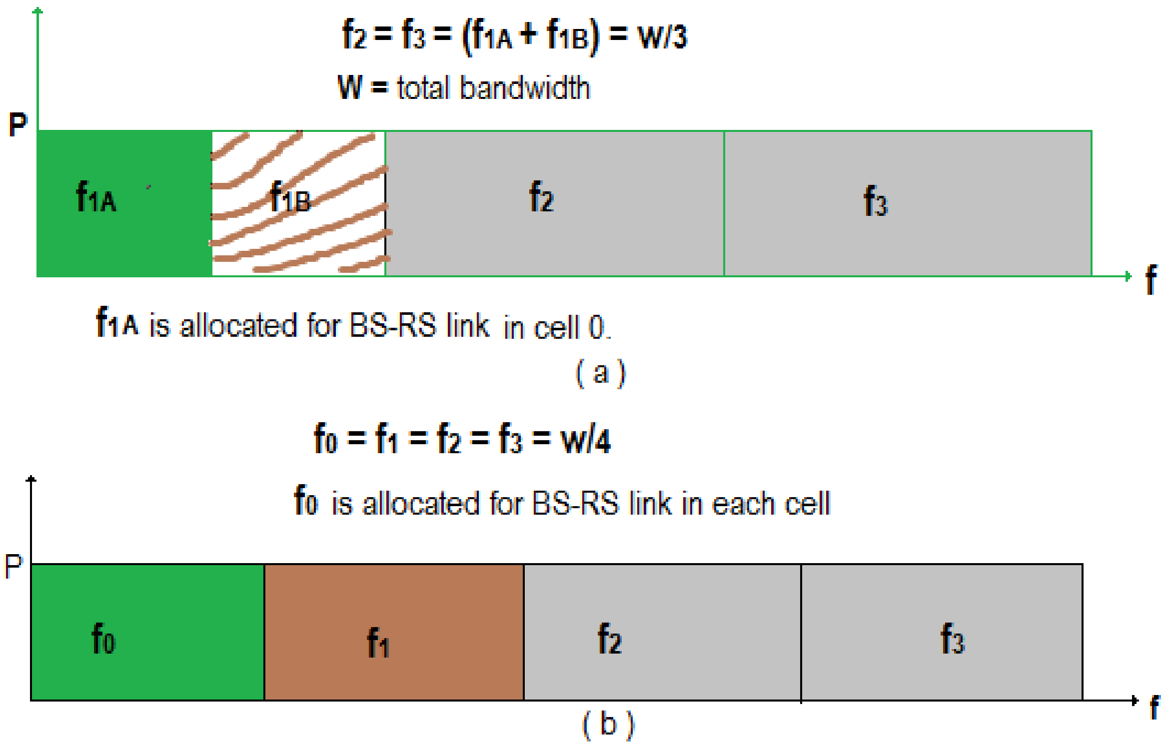


Figure 4.2: Proposed frequency allocation strategies for SFR with Relays.

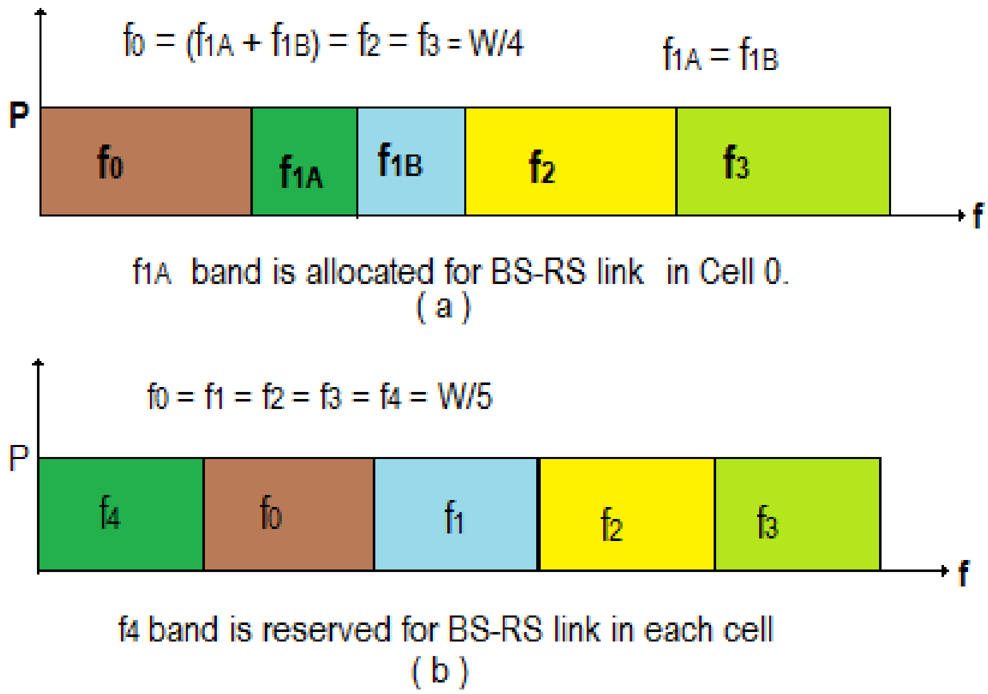


Figure 4.3: Proposed frequency allocation strategies for FFR with Relays.

Resource Allocation 2 (RA2): In this case, a certain part of the whole band is kept aside for the BS-RS link and each cell uses the same band for the BS-RS links. In SFR (Fig 4.2(b)), the whole band divided into four parts instead of three (conventional SFR); one part is kept dedicated for the BS-RS link and remaining three parts are used like conventional SFR. In FFR (Fig 4.3(b)), the whole band is first divided into five parts; one of them is assigned for BS-RS link for each cell and the remaining four parts are used like conventional FFR.

Chapter 5

Performance Parameters

We have considered following two parameters to measure performance improvement by the above designs compared to the scenario when there is no RS in the system: Coverage Probability and Throughput per cell.

5.1 Coverage Probability

Coverage Probability [10] is defined as the probability that a user's instantaneous SINR is greater than a fixed thresold SINR value, T :

$$P_c = P_r(SINR > T) \tag{5.1}$$

which is equivalently the complementary cumulative distribution function (CCDF) of the SINR. Here T (in dB) is the threshold of the minimum SNIR required for correct decoding of the received signal. So it is convenient to indicate SINR improvement in terms of Coverage Probability. The definition of Coverage Probability is conditioned on the locations of the user and the serving and interfering stations.

5.2 Throughput

Throughput improvement is the main aim of our disegn. We know that throughput is a monotone increasing function of SINR (since $C = Wlog_2(1 + SINR)$). Also SINR is directly proportional to received signal strength, which decays exponentially with the distance from the transmitter ($P_{received} \propto r^{-\gamma}$, where γ is the pathloss exponent of the wireless channel). So it more likely that there will be huge gap of SINR between inner-cell and edge-cell. Optimal relay placement along with proper frequency allocation can solve this problem. To calculate the average throughput of inner-cell and edge-cell, we implemented the following two Scheduling algorithms [11], [12], [13] : Max Rate Scheduling (MRS) and Proportional Fair Scheduling (PFS).

5.2.1 Max-Rate Scheduling

The Max-Rate Scheduling is used to maximize the sum throughput of a network. It does not maintain any fairness among the users. MRS selects user j by:

$$j = \underset{1 \leq i \leq n}{\operatorname{argmax}} R_i(k) \tag{5.2}$$

where $R_i(k)$ is the individual throughput of i^{th} user during k^{th} time-slot. If there are multiple available channels, it selects the users in decending order of their individual throughputs. So the weak users very rarely get access of the network.

5.2.2 Proportional Fair Scheduling

Proportional Fair Scheduling (PFS) provides fairness among the users in the network. It ckecks whether a user has got access during the previous time-slot or not. It gives more priority to the users which were idle during the previous time-slot. PFS selects user j by:

$$j = \underset{1 \leq i \leq n}{\operatorname{argmax}} \frac{R_i(k)}{R_{ei}(k)} \tag{5.3}$$

The average throughput, R_{ei} is obtained by the following exponential weighted moving average of the instantaneous data rate R_i :

$$R_{ei}(k+1) = \begin{cases} (1-\alpha)R_{ei}(k) + \alpha R_i(k) & \text{if i served in slot k ,} \\ (1-\alpha)R_{ei}(k) & \text{otherwise .} \end{cases} \tag{5.4}$$

where $0 < \alpha < 1$ is a weighting factor, whose value may be chosen as 0.01.

When $\alpha \rightarrow 0$, equ(5.3) will provide equal air time to all mobile users. In such cases, the denominator in equ(5.3) is computed by a simple arithmetic mean of the throughput:

$$R_{ei}(k) = \sum_{i=1}^{n} \frac{R_i(k)}{n} \tag{5.5}$$

When there are multiple available channels, it selects the users in decending order of the ratio $\left(\frac{R_i}{R_{ei}}\right)$.

Chapter 6

Simulation Results

In this section, we discuss the simulation results done by using MATLAB to study the performance of proposed schemes. We consider the interferences caused by upto 2^{nd} of the neighboring cells (6 in 1^{st}-tier and 12 in 2^{nd}-tier) and neglect the interference caused by the other higher order tier cells.

Simulation parameters:
Cell Radius(R)=1Km.
Pathloss exponent (γ)=3.
σ^2=1.
σ_i^2=1 for $\forall i \in Z$.
σ_n^2= -100dBm.
Total Bandwidth= 20MHz.
Bandwidth per channel= 200KHz.

6.1 Coverage Probability Improvement

Coverage Probability can be improved by installing Relays and how this improvement varies with various d. In our simulations we have considered all of the following scenarios : SFR Downlink, SFR Uplink, FFR Downlink and FFR Uplink for both the Designs (i.e Design 1 and Design 2). For all the cases, we got significant improvement over the system without Relays. Some of the plots are shown as following.

6.1.1 Coverage Probability Improvement with Des1

SFR Downlink

We know Coverage Probability depends on received SINR, which is a strong function of the distances of the interferers (eqn 4.5). Also in case of downlink, the source of inter-cell interference is Base Stations in LTE cellular network. When there is no relay stations deployed in the network, under worst case SINR scenario, it may happen that all the neighboring cell BSs are the sources of interference. But in presence relay, if any of the proposed non-overlapping frequency planning is employed, many sources of the interference get replaced by Relay Station, which transmits signal with power half of the previous case and also RS might be at far distance than of BS . Thus, there is a significant improvement in received SINR level, which casues enhanced Coverage Probability.

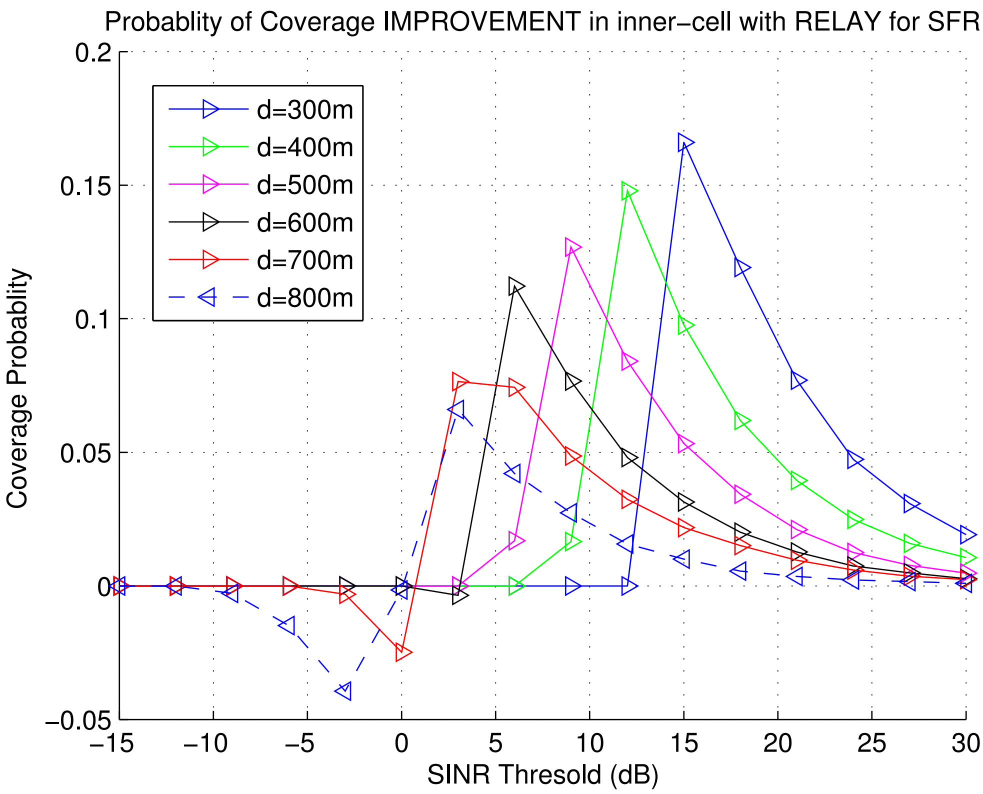


Figure 6.1: Coverage Prob. Improvement with Relay in inner-cell for SFR DL with Des1.

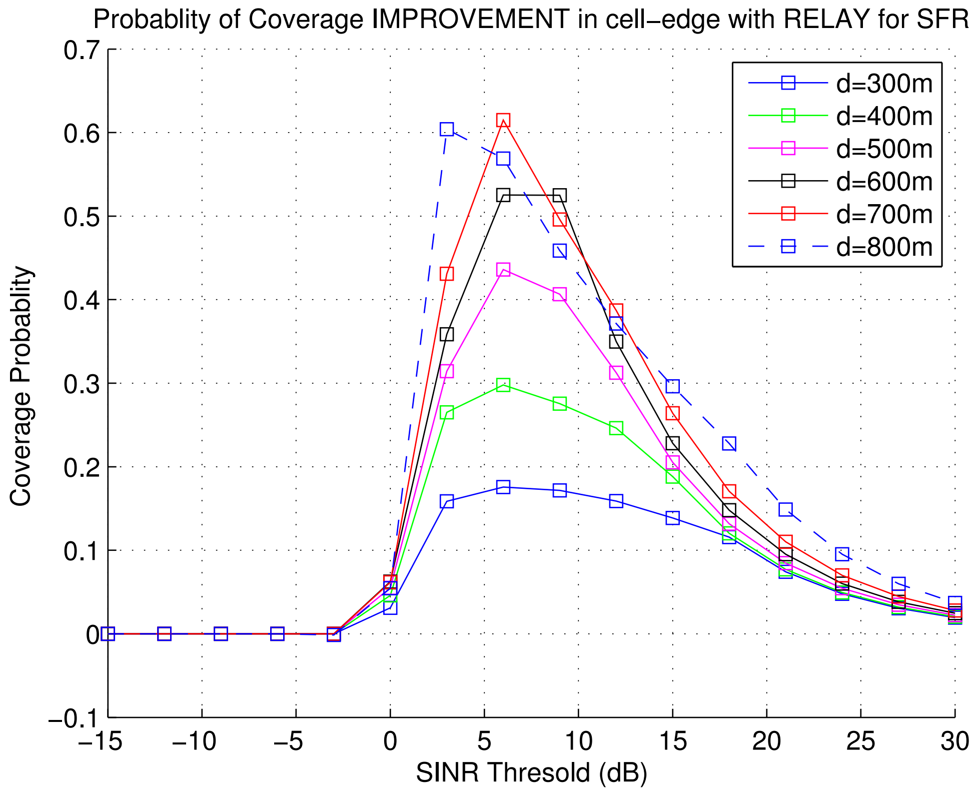


Figure 6.2: Coverage Prob. Improvement with Relay in edge-cell for SFR DL with Des1.

The above two figures (Fig 6.1 and Fig 6.2) compare the improvement of coverage probability by Relay for various values of d in inner-cell and edge-cell, respectively. This improvement in inner-cell is maximum for d=300m and it gets reduced with increment of d (Fig 6.1). But in edge-cell, the coverage probability improvement changes in opposite manner of inner-cell (Fig 6.2). The miminum improvement is achieved for d=300m and it increases with d. So, in order to show maximum coverage probability at edge-cell only d should lie in the range around 700-800m. It is also clear that the improvement in edge-cell dominance the improvement in inner-cell.

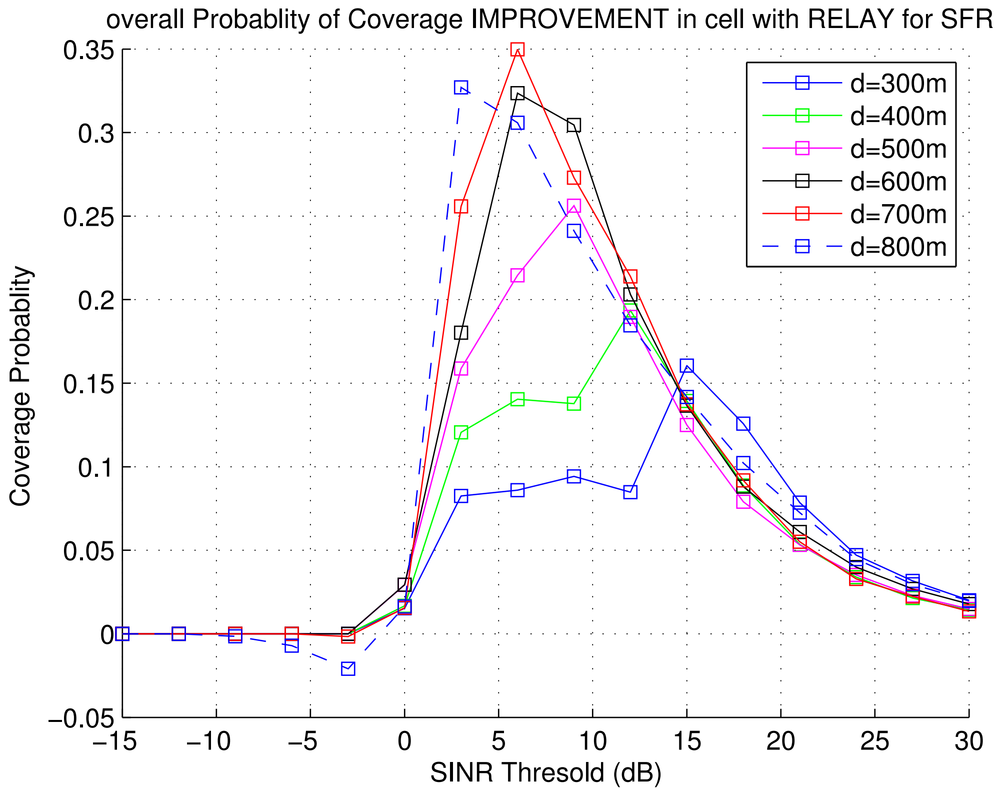


Figure 6.3: Overall Coverage Prob. Improvement with Relay for SFR DL with Des1.

The above plot (Fig 6.3) gives the overall Coverage Probability improvement which is the average the improvements in edge-cell and inner-cell. So to get optimum coverage improvement the d should lie in the range 600m-800m.

The optimal d always depends on the power allocation to BS and Relays. We may get little different plots for different power allocation. But for any of the case there will be positive improvement of Coverage Probability.

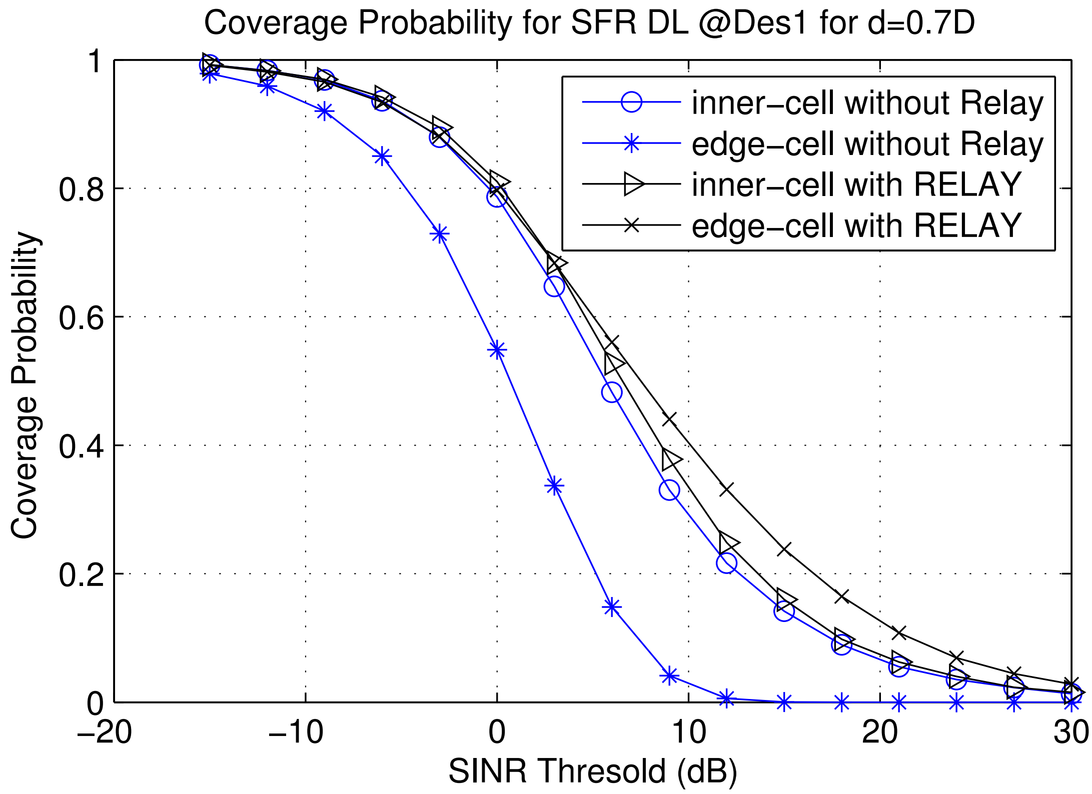


Figure 6.4: Coverage Probability for SFR Downlink with Des1 .

The above (Fig 6.4) shows the Coverage Probabilities for SFR Downlink for Design 1 including edge-cell and inner-cell seperately a fixed value of d=0.7D. It implies that under proposed relay deployment with proposed frequency planning edge-cell coverage probability enhancement outperforms inner-cell.

FFR Downlink

This section discusses about the improvements of coverage probability because of using Relay in inner-cell, edge-cell and overall (average) for various d for FFR downlink with Des1 .

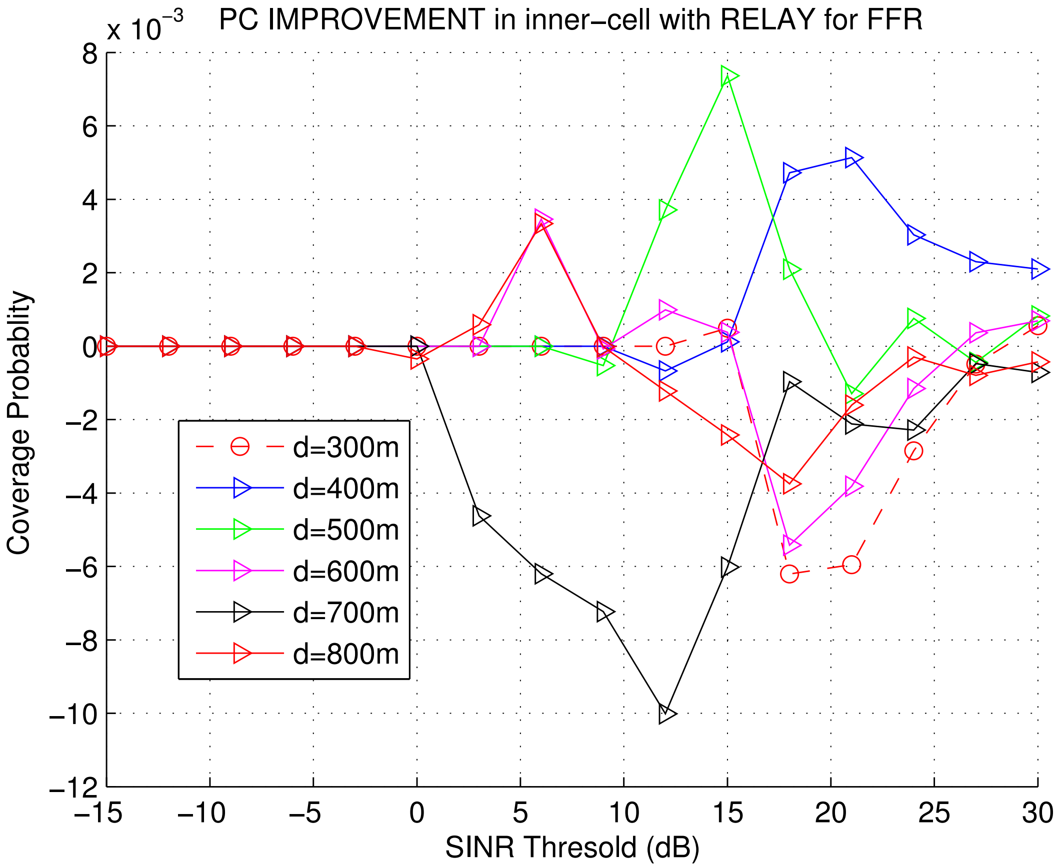


Figure 6.5: Coverage Prob. Improvement with Relay in inner-cell for FFR DL with Des1.

Figure 6.5 gives the improvement of Coverage Probability in inner-cell due to the addition of Relay. It is clear from this plot that there is very small change in improvement of coverage probability for various d. So, it is not strong enough to comment on the optimal d from this figure.

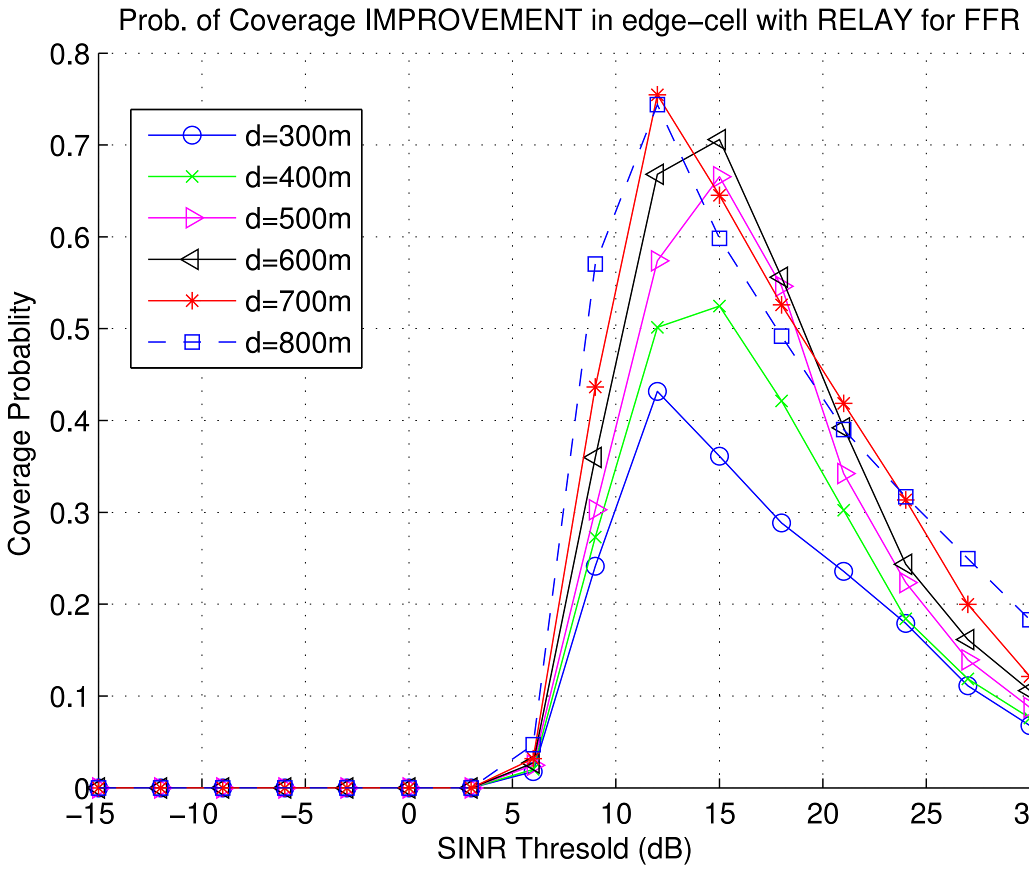


Figure 6.6: Coverage Prob. Improvement with Relay in edge-cell for FFR DL with Des1.

The improvement in edge-cell (Fig 6.6) increases with d with the help of Relay. So, only from the edge-cell coverage point of view the optimal d should lie in the range 500m-800m. As similar with FFR case, here also edg-cell coverage improvement dominance over inner-cell improvement.

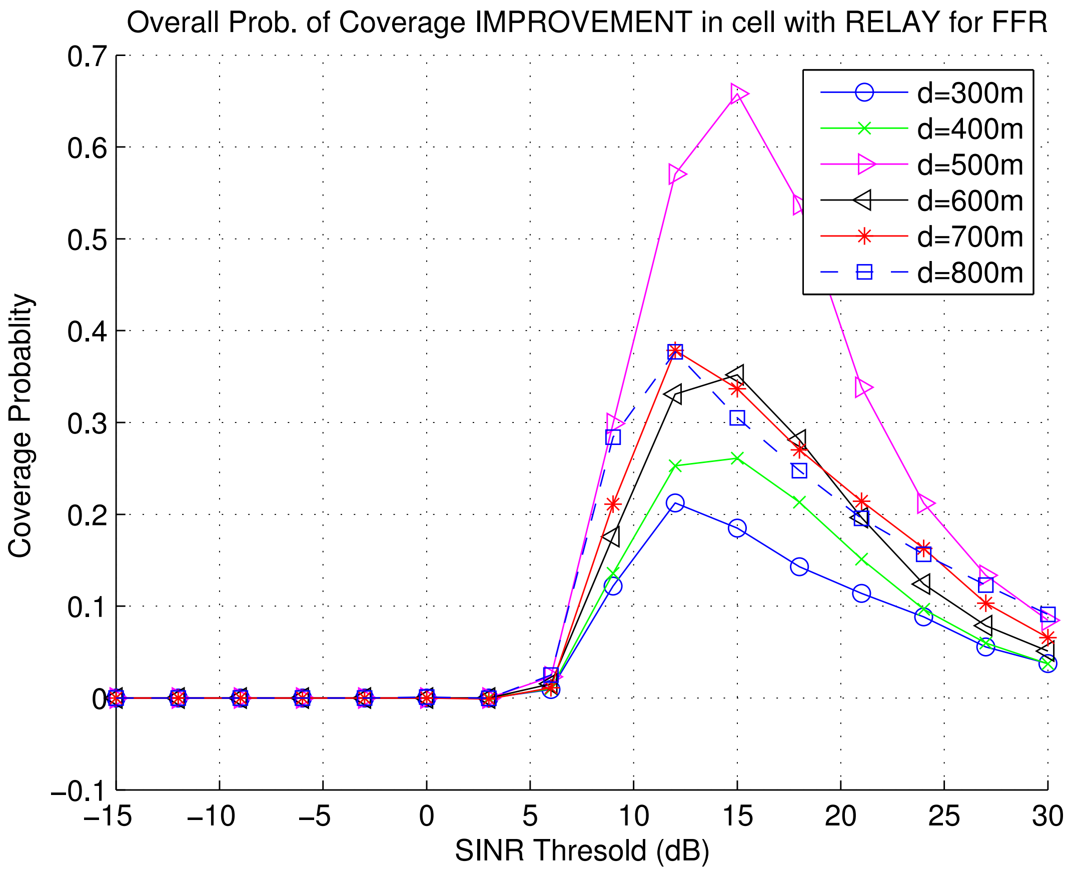


Figure 6.7: Overall Coverage Prob. Improvement with Relay for FFR DL with Des1.

The above figure (Fig 6.7) shows how the overall improvement(average of 'edge-cell improvement' and 'inner-cell improvement') of "coverage probability" vary for various d. So, the optimal d is 500m.

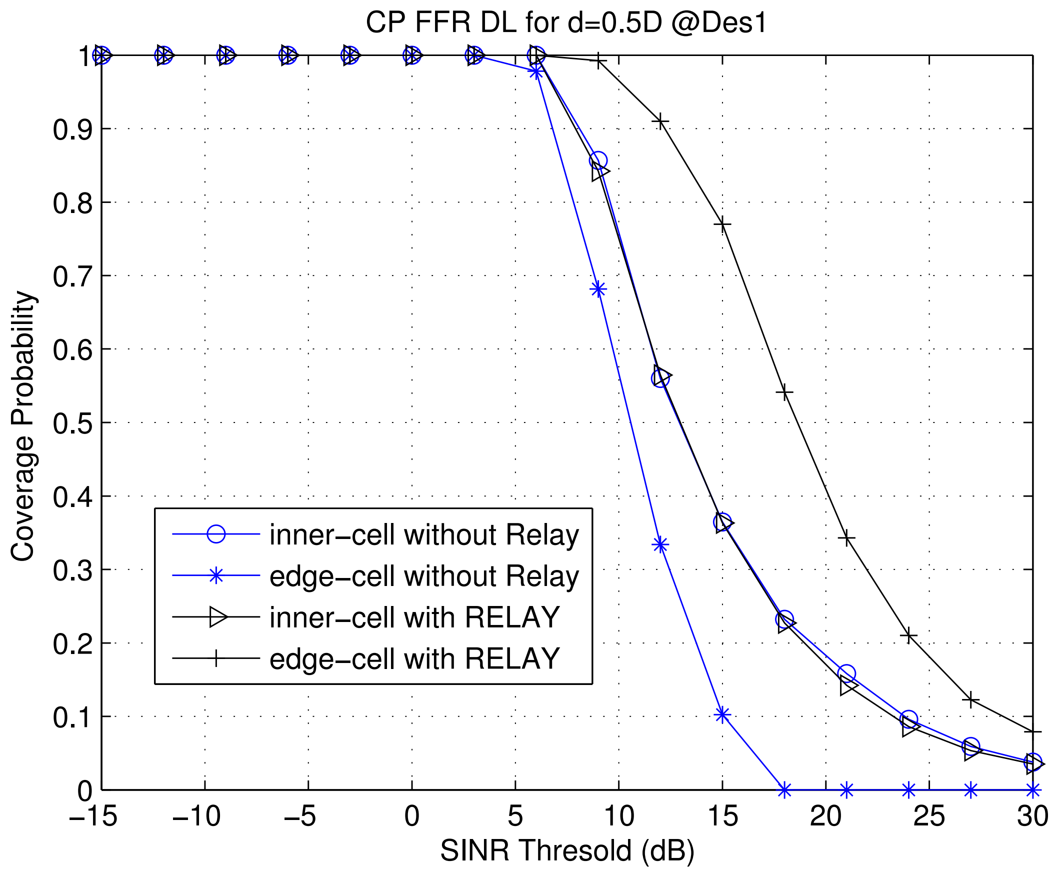


Figure 6.8: Coverage Probability for FFR Downlink with Design 1.

The above figure (Fig 6.8) corresponds to the variations of Coverage Probability with threshold SINR in inner-cell and edge-cell regions in absence and presence of Relay for FFR DL with Des1. It shows that there is no enhancement in inner-cell. Because, our proposed resource allocation strategies do not influence the received SINR level in inner-cell region. But there is a huge gain in the level of received SINR level in edge-cell region.

FFR Uplink

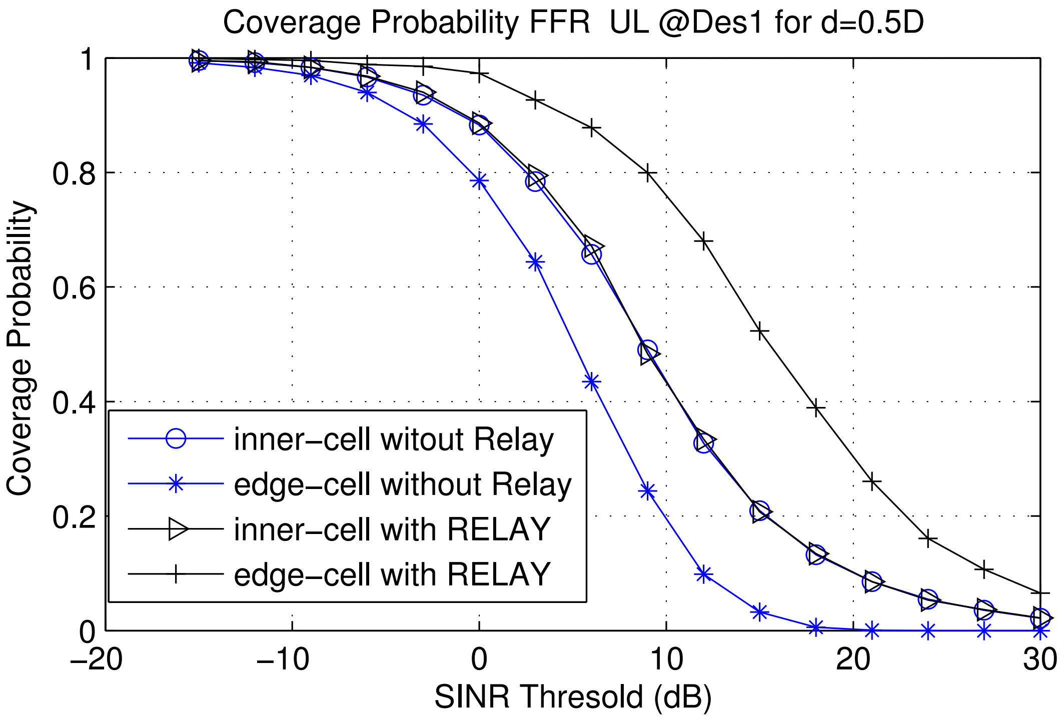


Figure 6.9: Coverage Probability for FFR Uplink with Design 1.

It shows the Coverage Probabilities for Design 1 at fixed d for FFR Uplink (Fig 6.9). Like the previous one, the graphs corresponds to inner-cell region without Relay and with Relay overlap and there is an improvement for the users in edge-cell region.

6.1.2 Coverage Probability Improvement with Des2

SFR Downlink

In Des2 downlink each user is linked with either the BS or any one of the RS depending on the best channel quality. Since distance between transmitter and receiver plays a crucial role in wireless communication, the value of d in our design influences a lot in performance of the Relay-assisted network. The following plot corresponds to coverage Probability enhancement for SFR downlink with Des2 in inner-cell region.

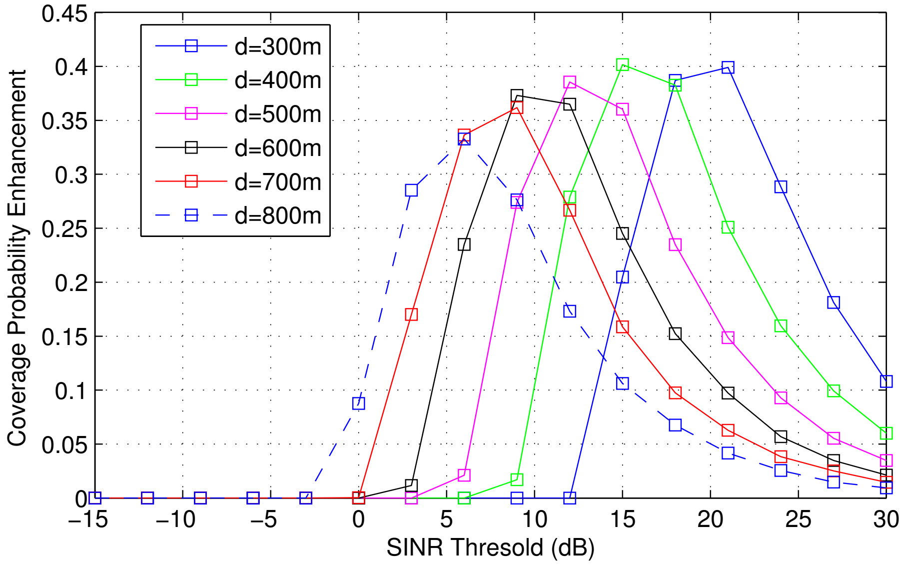


Figure 6.10: Coverage Prob. Improvement with Relay in inner-cell for SFR DL with Des2.

It (Fig 6.10) reveals that there is minor effect of d on Coverage Probability enhancement . And it slightly diminishes with increasing d. So it's better to have smaller d in our design.

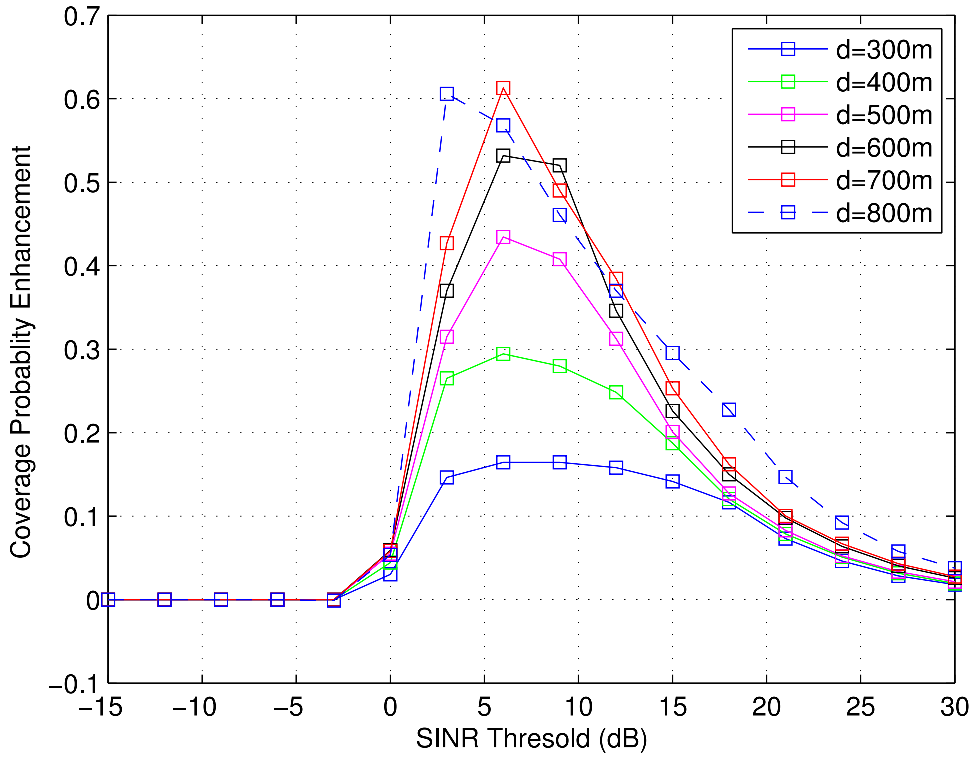


Figure 6.11: Coverage Prob. Improvement with Relay in edge-cell for SFR DL with Des2.

The above one (Fig 6.11) gives the coverage probability enhancement in edge-cell region for SFR downlink with Des2 . Here we see, performance improves for higher values of d. So there is a tradeoff between performance enhancement in inner-cell and edge-cell for fixed d. It needs higher d for better performance in edge-cell and lower d for better performance in inner-cell. So to conclude on optimal d, it's necessary to maximize the overall enhancement.

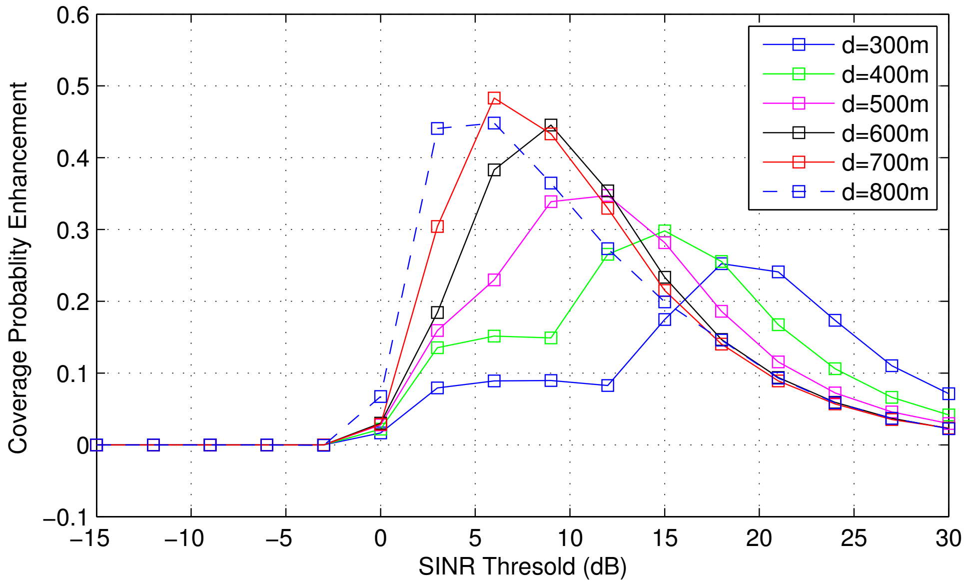


Figure 6.12: Overall Coverage Prob. Improvement with Relay for SFR DL with Des2 .

This figure (Fig 6.12) shows the same for overall enhancement. From the plot it clear that the d should be choosen in the range 600m-800m.

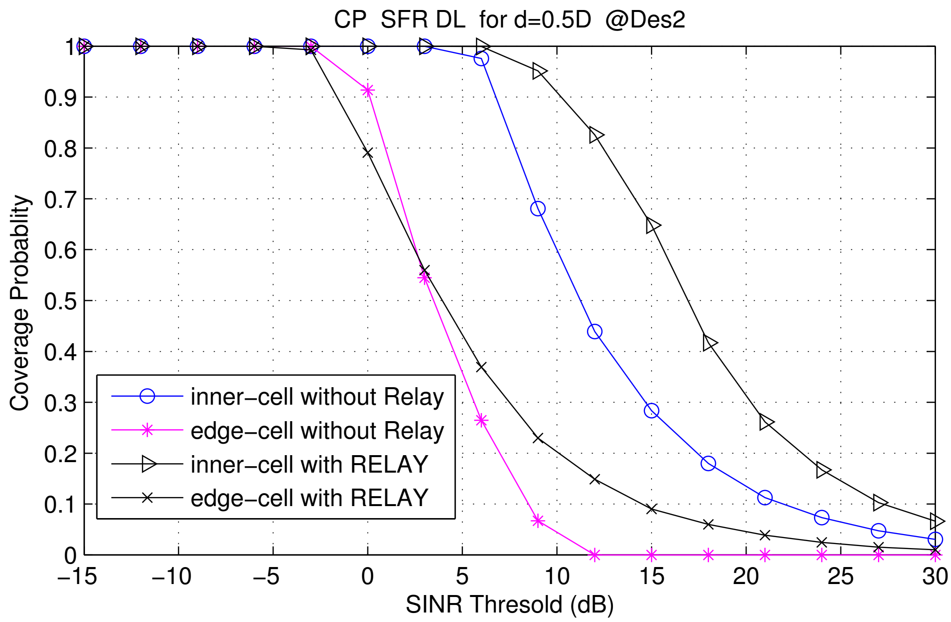


Figure 6.13: Coverage Probability for SFR Downlink with Design 2.

The above (Fig 6.13) shows the Coverage Probabilities for SFR Downlink for Des2 including edge-cell and inner-cell seperately a fixed value of $d = 0.7D$.

SFR Uplink

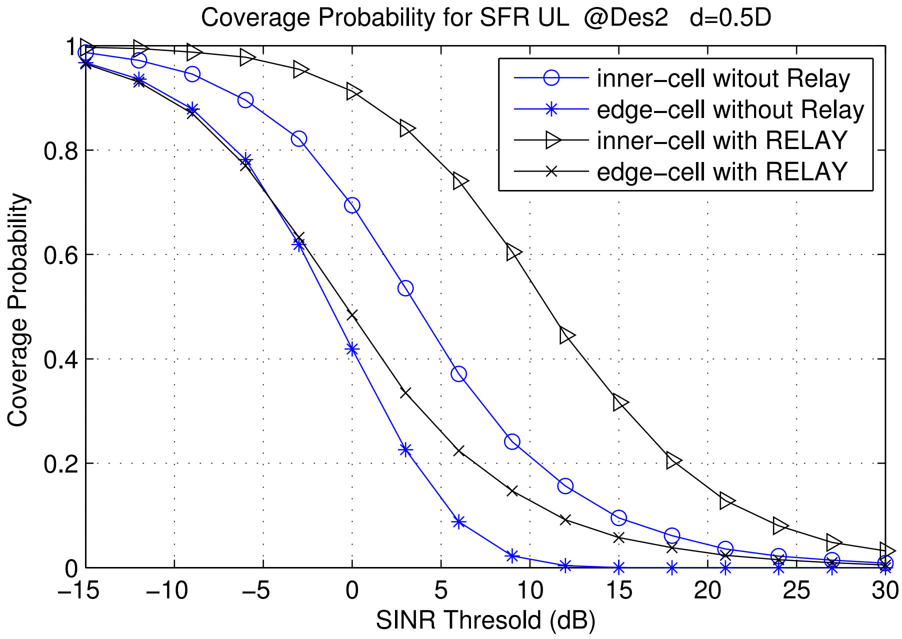


Figure 6.14: Coverage Probability for SFR Uplink with Design 2.

FFR Uplink

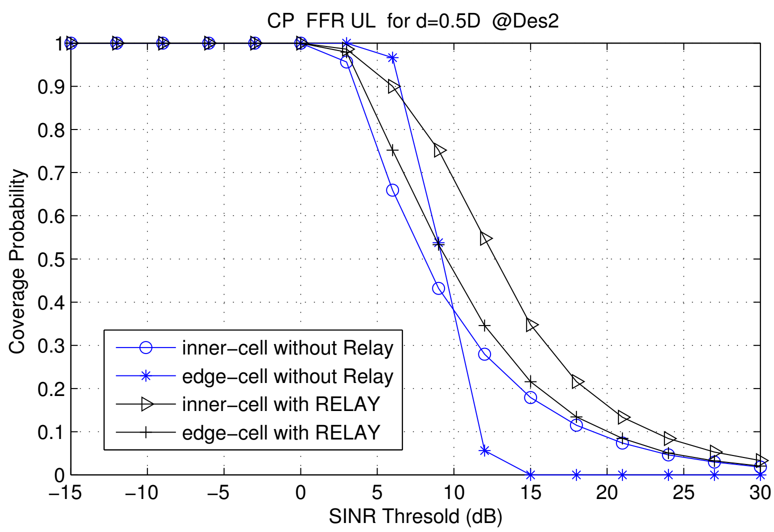


Figure 6.15: Coverage Probability for FFR Uplink with Design 2.

FFR Downlink

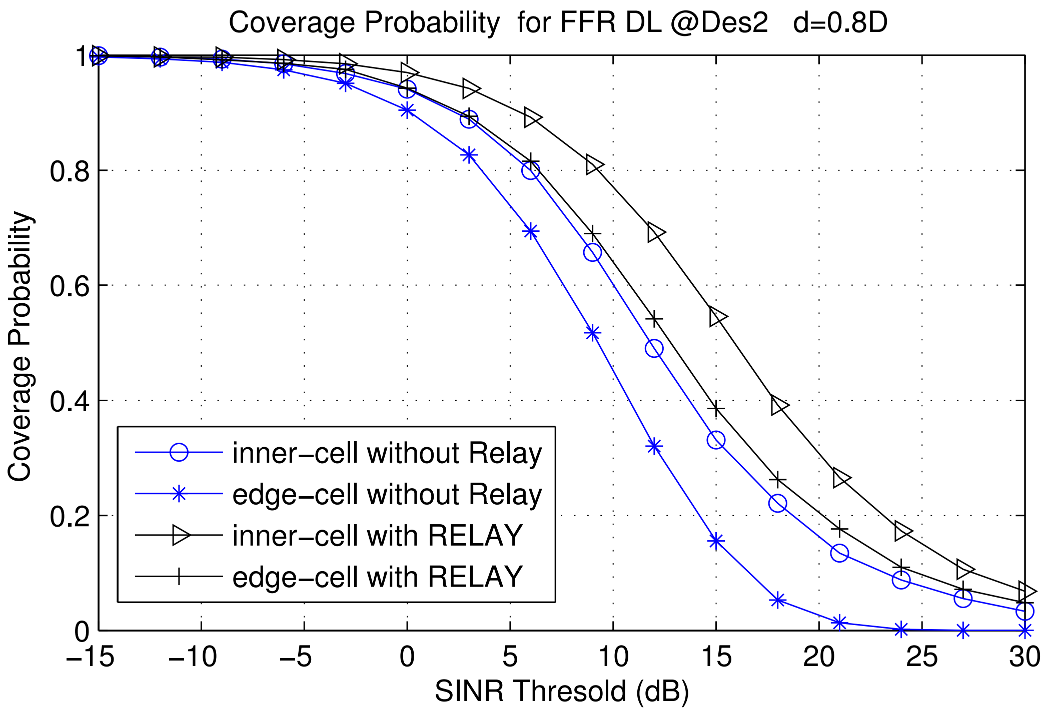


Figure 6.16: Coverage Probability for FFR Downlink with Design 2.

The improvements by Design 2 for FFR Uplink and FFR downlink have been shown in Fig 6.15 and Fig 6.16 respectively.

From simulation results, it's clear that **Design 2** outperforms **Design 1** for most of the scenarios. So inclusion of Relay Station has very good impact in terms of increasing the SINR level in a cell.

6.2 Throughput Improvement

We calculate the average system Throughput for all combinations of proposed Designs (Design1 and Design2) and Resource Allocations (RA1 and RA2) for all of the above mentioned four scenarios. Also we have done with both of the scheduling algorithms. So there total **16** possible combinations of plots we have got. Some of the results are shown as following.

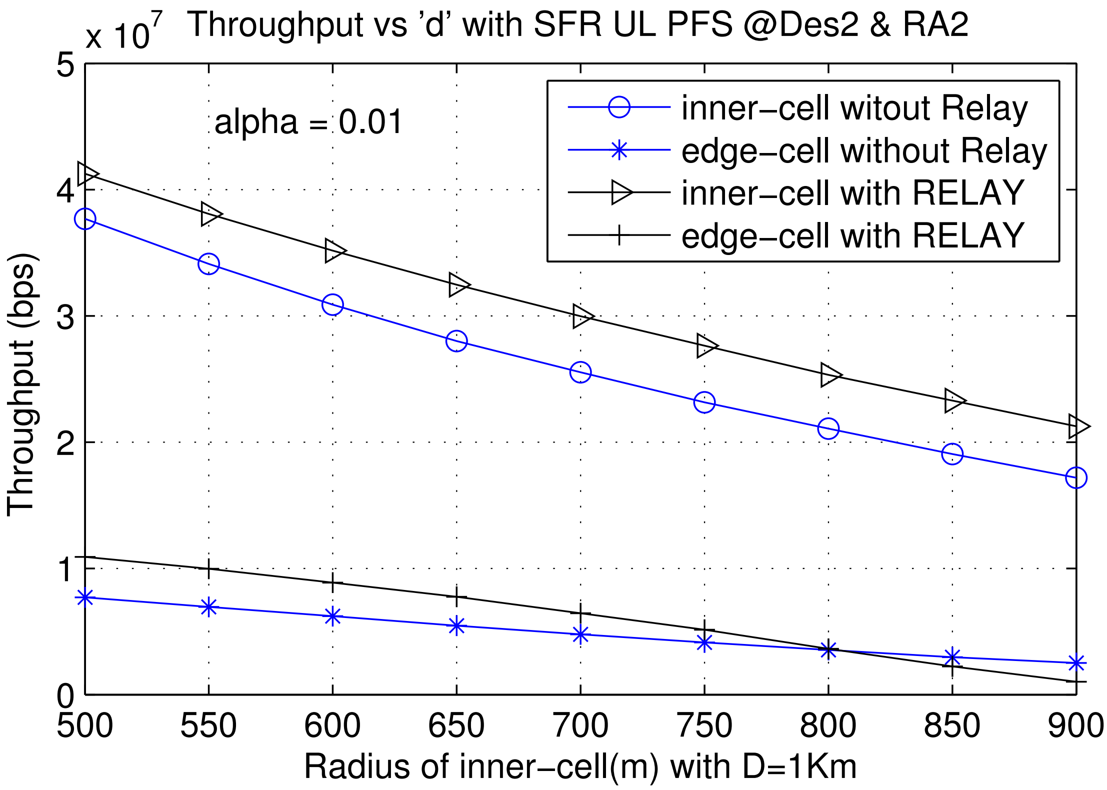


Figure 6.17: Throughput vs d for SFR UL with PFS @Des2 and @RA2.

The Fig 6.17 corresponds to SFR Uplink with Proportional Fair Scheduling with Design2 and Resource Allocation2, shows that we can get increased throughput for both inner-cell and edge-cell if the d is kept within $0.8D$.

The following figure (Fig 6.18) corresponds to FFR Downlink with Proportional Fair Scheduling for same Design rule and resource allocation strategy as the previous one. In this case there is minor improvement in the inner-cell region since there is small change in SINR level. In edge-cell region we get a significant upliftment in throughput.

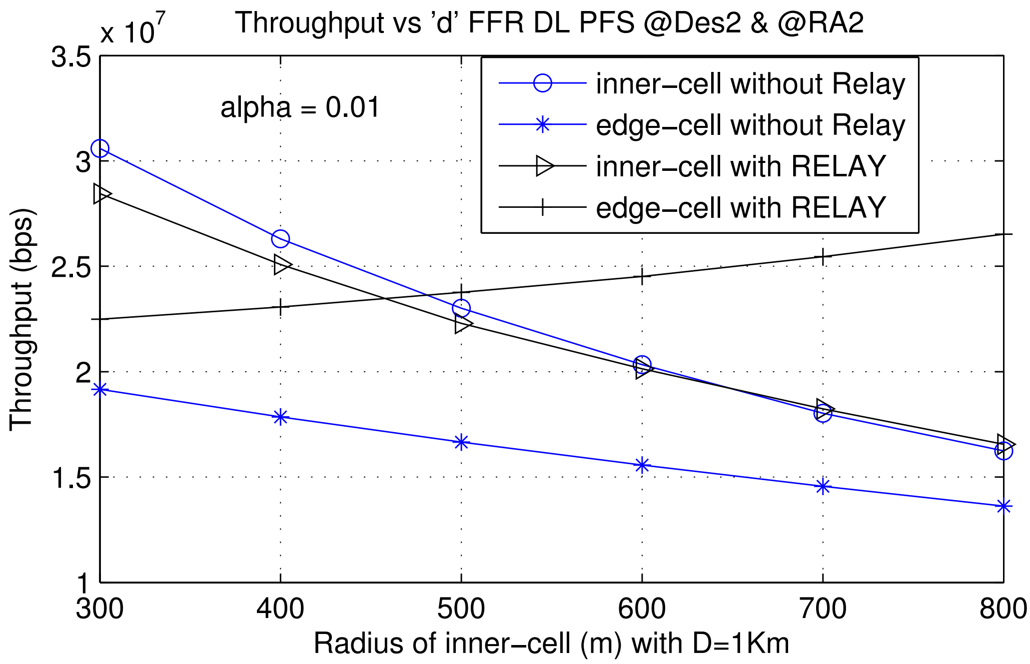


Figure 6.18: Throughput vs d for FFR DL with PFS @Des2 and @RA2.

We also have implemented the Max-Rate Scheduling algorithm in our simulations. Figure 6.19 shows the throughput corresponds to FFR Uplink with Max-Rate Scheduling Design1 and Resource Allocation1. As similar with FFR downlink, in inner-cell, the throughput of the network without relay is same as the throughput with relay. And there is a huge improvement in edge-cell in presence of relay.

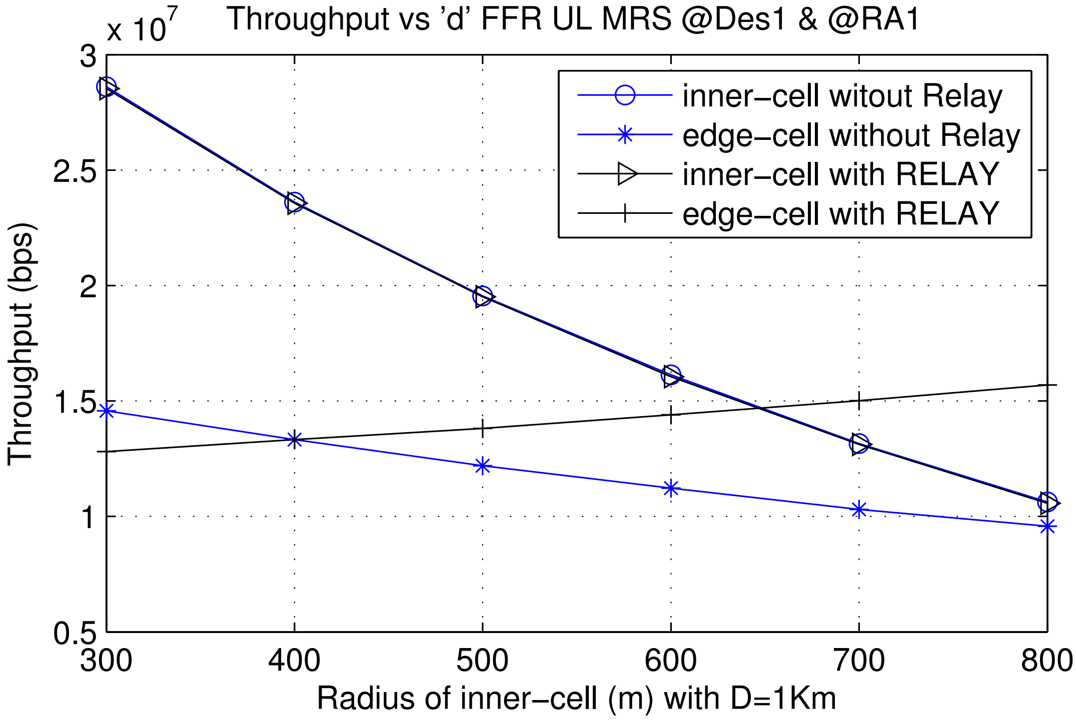


Figure 6.19: Throughput vs d for FFR UL with MRS @Des1 and @RA1.

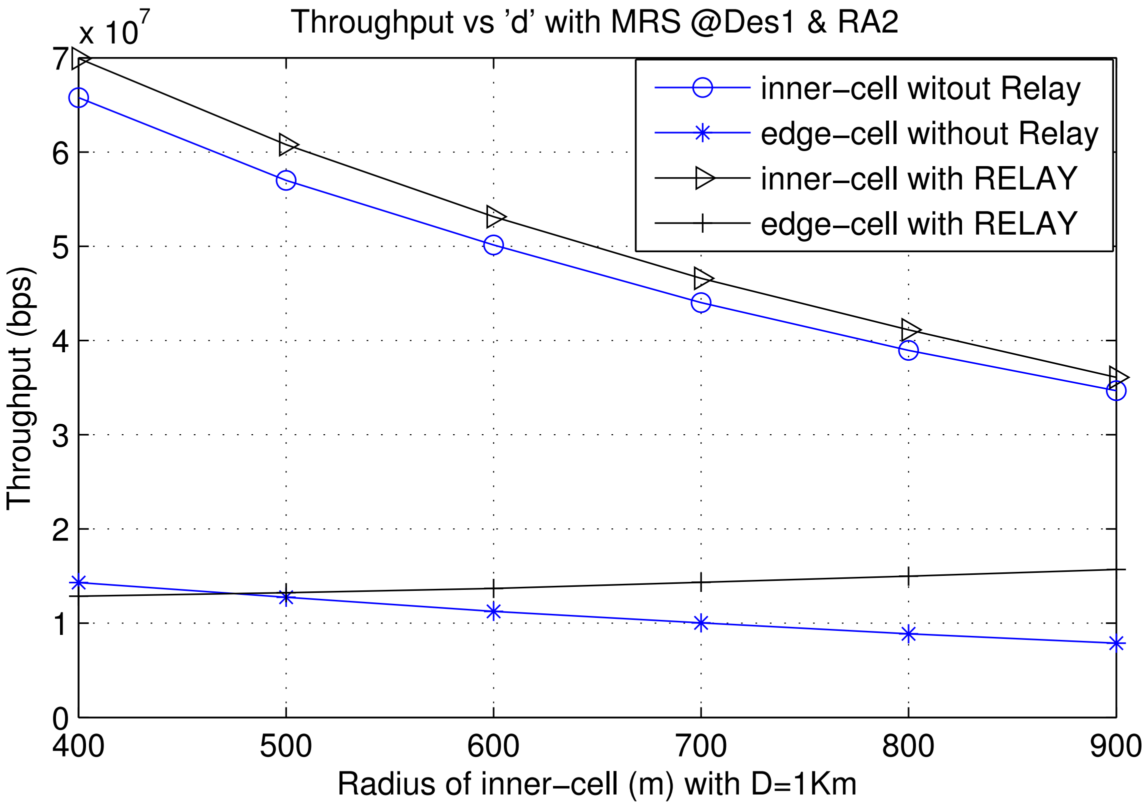


Figure 6.20: Throughput vs d for SFR DL with MRS @Des1 and @RA2.

The last figure (Fig 6.20) corresponds to SFR Downlink with Max-Rate Scheduling for Design1 and Resource Allocation2. For this scenario, we can achieve the improved performances for both inner-cell region and edge-cell region with the help of relay.

The following **table** brings the summary of Throughput improvements in Relay-assisted network.

Scenario	Design Strategy	Resource Allocation	Throughput in edge-cell	Throughput in inner-cell
SRF Downlink	Des1	RA1	Minor degradation	Enhancement
		RA2	Enhancement	Enhancement
	Des2	RA1	Minor degradation	Enhancement
		RA2	Minor Enhancement	Enhancement
SFR Uplink	Des1	RA1	Minor Degradation	Major Enhancement
		RA2	Enhancement	Major Enhancement
	Des2	RA1	Enhancement	Minor Degradation
		RA2	Minor Enhancement	Major Enhancement
FFR Downlink	Des1	RA1	Minor Degradation	Same
		RA2	Enhancement	Minor Degradation
	Des2	RA1	Minor Enhancement	Enhancement
		RA2	Major Enhancement	Same
FFR Uplink	Des1	RA1	Enhancement	Enhancement
		RA2	Enhanced	Same
	Des2	RA1	Enhancement	Enhancement
		RA2	Enhancement	Same

Chapter 7

Conclusion And Future Work

7.1 Conclusion

This thesis proposes a modified LTE cellular network architecture that simultaneously uses new channel partitioning and three Fixed Relay Stations placements schemes. The object of our work is to achieve throughput improvement of the network with the help of optimal Relay placement and resource allocation. First we have shown the SINR upgradation with the help of relay stations and then throughput improvements with two different channel partitioning strategies.

We have studied for both Uplink and Downlink cases for worst case SINR assumption (i.e all possible interferers are present at possible nearer distances). Also we have considered both SFR and FFR as the backbone frequency planning for LTE network and showed the average system throughput improvement. In throughput calculation, two scheduling algorithms - Proportional Fair Scheduling and Max-Rate Scheduling have been employed.

For both of the frequency allocation strategies, a dedicated band has been reserved aside for the BS-RS link (bachhaul link) with the assumption that it is enough to satisfy eqn(4.3). It is known that FD-OW relaying outperforms HD-OW relaying in terms of spectral efficiency [14]. But the complexity for both signal detection and channel estimation in FD-OW relaying is more than HD-OW relaying. So the above resource allocation allows us to get the advantage of FD-OW relaying with simple HD-OW relaying signal processing.

We propose to deploy only three fixed relay stations in each cell unlike few of the previous researchers have proposed. It quite obvious that if there are more the number of relay stations, more will be the overall link budget (included installation cost, maintainence ans so on). So it's better to use less number of relay stations.

The optimal relay placement and the enhanced coverage along with throughput calculated in this paper can be practically used as a system design parameter in cellular systems.

7.2 Future Work

The uniqueness of our resource allocations is the assignment of non-overlapping frequency bands between BS-RS link and RS-MS link. The main objective behind this is to make sure that the instantaneous BS-RS link throughput should be atleast the instantaneous RS-MS link throughput as given in equ(4.3). Even though throughput also a function of received SINR; we have assign the same amount of bandwidth for the mentioned links.

Inspite of having the above mentioned advantages of such resource allocation, the main disadvantage is that it reduces the useful bandwidth. Mainly, there are two significant extension can be done over.

Firstly, we can jointly optimize the minimum required bandwidth for BS-RS link (backhaul link) to maximize total throughput ($R_1 + R_2 + R_3$) under the constraint to satisfy equ(4.3).

Secondly, directional antenna can be deployed for the transmission over the backhaul link (BS-RS link) in place of omni-direction antenna. Since in the proposed Relay placements there are only three fixed RSs and they are symmetrically situated with respective BS (i.e BS is placed at the centroid of the equilateral triangle whose vertices are the RSs). In case downlink, if possible we can employ such a directional at BS to provide very narrow directive beam towards the three Relay Stations only or we can use three high gain unidirectional antennas each for each BS-RS link. For uplink, the only option is to use very high gain unidirectional antenna at each relay station towards the BS.

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