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Optimal Relay Placement Schemes In OFDMA Cellular Networks

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ABSTRACT

The Wireless services such as Skype and other multimedia teleconferencing require high data rate irrespective of user's location in the cellular network. However, the Quality of Service (QoS) of users degrades at the cell boundary. Improvement in capacity and increase in coverage area of cellular networks are the main benefits of Fixed Relay Nodes (FRNs). These benefits of FRNs are based on the position of relays in the cell. Therefore, optimal placement of FRNs is a key design issue. We propose new schemes optimal FRN placement in cellular network. Path-loss, Signal to Interference and Noise Ratio (SINR) experienced by users, and effects of shadowing have been considered. Our analysis give more emphasis on supporting users at the cell-boundary (worst case scenario). The results show that these schemes achieve higher system performance in terms of spectral efficiency and also increase the user data rate at the cell edge.

Keywords - FRN deployment, OFDMA, multi-hop, outage probability, Sectoring.

1. INTRODUCTION

Increase in capacity, coverage and throughput are the key requirements of future cellular networks. To achieve these, one of the solutions is to increase the number of Base Stations (BS) with each covering a small area. But, increasing the number of BSs requires high deployment cost. Hence, a cost effective solution is needed to cover the required area while providing desired Signal to Interference plus Noise Ratio (SINR) to the users so as to meet the demand of the future cellular networks. To achieve the high data rate wireless services, Orthogonal Frequency Division Multiple Access (OFDMA) is one of the most promising modulation and multiple access techniques for next generation wireless communication networks. In OFDMA, users are dynamically allocated sub-carriers and time-slots so that it is possible to minimize co-channel interference from neighboring cell by using different sub-carriers. Therefore, OFDMA based multi-hop system offers efficient reuse of the scare radio spectrum.

We consider an OFDMA-based cellular system in which users arrive and depart dynamically. Each arriving user demands rate $\bar{r}$. If the required rate can be provided, only then a user is accepted, otherwise it is blocked. Depending on the SINR experienced by an arriving user, the BS computes the subcarriers that need to allocate to the user so as to provide the required rate. If the required sub-channels (i.e., a group of subcarriers) are available, then the user is admitted. Note that the SINR decreases as the distance between the BS and the user increases. Thus, the users at the cell boundary can cause blocking probability to be high. Since the number of admitted users is directly proportional to the revenue of the service provider, it is imperative to design solutions that allow accommodating a large number of users. This motivates us to propose a Fixed Relay based cellular network architecture that is well suited to improve the SINR at the cell boundary, and thus can possibly increase the number of admitted users. Relaying is not only efficient in eliminating coverage holes throughout the coverage region, but more importantly; it can also extend the high data rate coverage range of a single BS. Therefore bandwidth and cost effective high data rate coverage may be possible by augmenting the conventional cellular networks with the relaying capability.

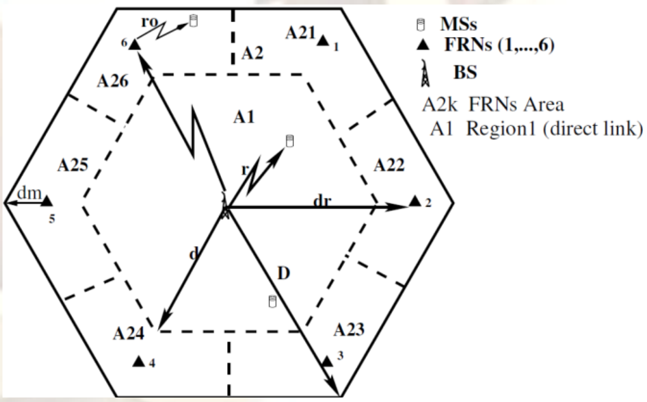

Fig.1 Layout of FRN based Cellular system

We consider a cellular system with six fixed relay nodes (FRNs) that are placed symmetrically around the BS as shown in Fig. 1. Mobile stations (MSs) in outer regions AR1 to AR6 can use relaying to establish a better path than the direct link to BS. The key design issues in such systems are the following: (1) How sub-channels should be assigned for (a) direct MS to BS links, (b) FRN to BS links, and (c) MS to FRN links. Algorithm for this is referred to as the channel partitioning scheme. (2) How sub-channels can be used across various cells.

Algorithm for this is referred to as channel reuse scheme.

Effective channel partitioning maximizes utilization of every channel in the system, and thus obtains high spectrum efficiency in cellular systems [3]. For a cellular system enhanced with FRNs, the main idea of channel partitioning is to optimally assign the resources to the MS-BS, FRN-BS, and MS-FRN links. Such intra-cell spectrum partitioning along with the channel reuse scheme not only grant the data rate demanded by each user, but also manages the inter-cell interference by controlling the distance between any pair of co-channel links.

The concept of channel partitioning for FRN based cellular system has been discussed in [4], [5], [2], [8], [7], [14]. In [4], full frequency reuse scheme was proposed. The authors divided the cell in to seven parts and allocated six sets of subcarriers to FRN link and the remaining to BS. The authors aimed at exploiting the multiuser diversity gain. However, sectoring the inner region can further reduce the co-channel interference. In [5], frequency reuse scheme was proposed based on dividing the outer region in to six and also sectoring the inner region. In [2], a preconfigured relay channel selection algorithm is proposed to reuse the channels that are already used in other cells on the links between FRNs and MSs. This scheme may suffer from high co-channel interference on FRN-MS links. In [7], [14], frequency partitioning and reuse schemes for cellular WLAN systems with mobile relay nodes are proposed. Relays are mobile as the MSs themselves act as a relay for other MSs. Since the relay is mobile, the channel between relay and the BS can change, which will result in a large number of inter-relay handoffs. Furthermore, MSs acting as relays may not be cooperative because of the power consumption and the security issues. In [8], a coverage based frequency partitioning scheme is proposed. The scheme assumes that the relay nodes are placed at a distance equal to the two-third of the cell radius, and does not consider optimal relay placement. Some other proposals for frequency management include the use unlicensed spectrum [12], and the use of directional antennas [1].

In our paper [6], we proposed a channel partitioning and a channel reuse scheme for increasing system capacity to support some preceding standards like Global System for Mobile Communications (GSM). In this paper, we extend the channel partitioning and channel reuse scheme for OFDMA cellular networks which results in increased system capacity and spectral efficiency. We also consider the optimal relay placement based on different parameters. We show that with the appropriate relay placement, the system performance can be improved significantly. As a result, the number of users that can be accommodated in the system can be maximized while providing each user with its required rate.

The paper is organized as follows. In Section 2, we describe our system model. In Section 3, we propose our relay placement schemes based Path-loss, SNR and Shadowing. In Section 4, we evaluate the performance of the proposed schemes using numerical computations and simulations. In Section 5, we conclude the paper.

2. SYSTEM MODEL AND DESCRIPTION

2.1 System Configuration

We consider a cellular system consisting of regular hexagonal cells each of edge length D. Each cell has a BS and certain number of FRNs situated symmetrically around the BS at a distance d_r from the center and dm from the cell edge as shown in Fig.1. Let the total bandwidth available for the downlink be W units. Let the minimum SNR/SIR experienced by the user at furthest location from BS/FRN be γ_1. Similarly, let the minimum SNR/SIR experienced by FRN at furthest location from BS be γ_2, i.e, both MS and FRN are placed at a location that they experienced minimum SNR or SIR. Therefore, these locations are the effective boundary for each link (i.e MS-BS, FRN-BS and FRN-BS). For a given MS position, let the distance from BS be d^* and nearest FRN be d^*_m. If $d^* \leq d$, then MS communicates with the BS directly; otherwise it communicates through the nearest relay using two hop route. Because of the specified routing scheme, a cell can be partitioned into seven regions as shown in Fig.1. We define the region covered by BS as the inner region (A_1) and the region covered by FRNs as outer region (A_2). Outer region is further divided into A_{2k}, for k=1, ..., 6. All the MSs in region A_1 communicate directly to the BS, and the MSs in k^{th} A_2 region communicate to BS through relay k^{th} FRN. Both the number of FRNs (K) and the size of each region in a cell (d^*_m and D) are determined by the optimal relay placement algorithm.

2.2 Channel Partitioning and Reuse Scheme

The channel partitioning scheme, partitions the downlink bandwidth into 2K+1 orthogonal segments, viz. W_1, $W_{2,k}$ and $W_{3,k}$ for k = 1, . . . ,K. The band W_1 is used by the MSs in region A_1, the band $W_{2,k}$ is used by k^{th} FRN to communicate with the BS, and the band $W_{3,k}$ is used by the MSs in k^{th} A_2 region to communicate with k^{th} FRN. Let $W_2 = \sum_{k=1}^{6} W_{2,k}$ and $W_3 = \sum_{k=1}^{6} W_{3,k}$. Because of the channel partitioning, there is no intra-cell interference, and the system performance is mainly determined by inter-cell co-channel interference.

For channel reuse scheme, we assume that the frequency reuse distance is 1, i.e., each cell uses the complete bandwidth W for the downlink communication [11]. In each cell, inner region uses the same band W1. While k^{th} FRN uses band W_{2k} to communicate with BS and MS in k^{th} A_2 region uses W_{3k} band to communicate with k^{th} FRN.

2.3 Propagation Model

Wireless channel suffers from fading. Fading is mainly divided into two types, slow and fast. Slow fading is due to path-loss and shadowing, while fast fading is due to multi-path. In this paper, we assume that the code lengths are large enough to reveal the ergodic nature of fast fading. Hence, we do not explicitly consider multi-path effect. We focus on the path-loss and shadowing in the analysis. Because of the path-loss, the received signal power is inversely proportional to the distance between the transmitter and the receiver. In general, the path-loss P_L between a transmitter and a receiver is given as,

$$P_L = \frac{P_T}{P_R} G_T G_R = \left(\frac{4\pi f}{c}\right)^2 \left(\frac{d^*}{d_0}\right)^\gamma \qquad (1)$$

where P_T is the transmitted power; P_R is the received power, G_T and G_R are the antenna gain of transmitter and receiver respectively; f is the carrier frequency, c is the speed of light; d^* is separation between the transmitter and receiver; d_0 is the reference distance, and $\gamma > 0$ is the path-loss exponent [11].

3. RELAY PLACEMENT SCHEMES

Improvement in capacity and increase in coverage area are the main benefits of FRNs. These benefits of FRNs are based on the position of relays in the cell. Deploying FRNs around the edge of the cell help the edge users. However, when they are placed at inappropriate locations, may cause interference to the edge users of the neighboring cell. Therefore, optimal placement of FRNs is a key design issue. Consider the downlink scenario where the BS encodes the message and transmits it in the first time slot to nearby MSs and FRNs. FRNs transmits the message to MSs at the cell boundary in the second time slot. FRNs are either Decode-and-Forward (DF) type, which fully decodes and re-encodes the message, or Amplify-and-Forward (AF) type, which amplifies and forwards the Message to MSs in the second hop. Note that the reverse will be for uplink scenario. In downlink scenarios, we consider non-transparent type relays, i.e., MSs in the first hop communicate to BS while MSs in the second hop communicate only to FRNs [15].

In this section, we propose two types of Relay placement schemes to deploy FRNs optimally in the cell. We analytically determine the position of FRNs within the cell so that the QoS requirement of each user is satisfied. In each scheme we evaluate the signal strength on the three links (BS-MS, BS-FRN, and FRN-MS links). The term "three links" denote the "BS-MS, BS-FRN and FRN-MS links", henceforth, we use both terms interchangeably. On these three links, we assume that each link has minimum SNR requirement (threshold). When the received SNR exceeds a threshold, the message is correctly decoded. The distance of user from BS/FRN, where the received SNR equals the threshold is defined as the effective radius of BS/FRN; it inturn determines the optimal FRN location. In the next subsections, we describe our proposed methods to deploy FRNs optimally based on path-loss and SNR.

3.1 Relay Placement based on Path-loss

In this subsection, we propose a simplified relay placement algorithm that depends on the path-loss. Path-loss is signal attenuation between a source (BS/FRN) and a receiver (MS) which depends on the propagation distance.

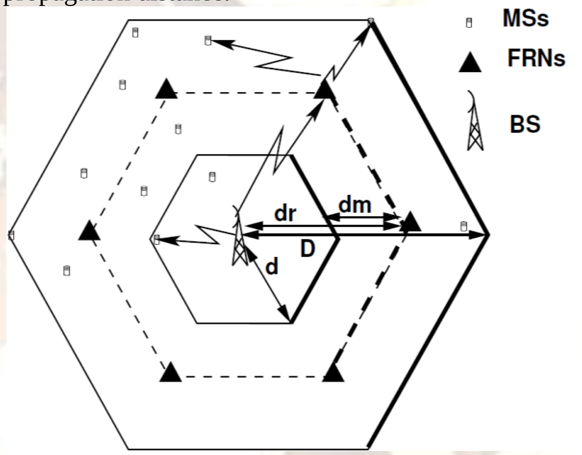

Fig.2 Layout of FRN enhanced Cellular system illustrating the coverage of MS-BS, FRN-BS and MS-FRN regions.

We consider a simplified cellular configuration consisting of BS and FRNs as shown in Fig.2. Initially, FRNs are placed at random position in a cell. MS moves from BS towards the cell boundary along a straight-line trajectory. Determination of optimal position is based on the received signal strength and distance measurements along the path. MS evaluates the received signal strength till the signal strength becomes equal to the preset threshold value.

As the MS moves away from the BS/FRN, if the received signal strength decreases below a threshold value and the MS is not able to communicate with the BS. At this position where the received signal strength is too weak, appropriately placed FRN can enhance the signal quality of the MS.

Now, we describe our path-loss based FRN placement algorithm as follows: Referring to Fig.2, let P_{BS} and P_{FRN} be the power transmitted by BS and FRN respectively. Let P_b be the power received by

MS located at the distance (d) from BS; P_r be the power received by FRN located at the distance (d_r) from BS; P_m be the power received by MS located at the distance (d_m) from one of FRNs. When MS follows straight line trajectory, then BS, MS and FRN are collinear and the radius of the cell D is computed as $D = d + 2d_m$ and also $d_r = d + d_m$. Assume that the threshold $P_b = P_m$ and $P_b \neq P_r$, the path-loss (1) is redefined for the three links as:

$$P_b = K_1 P_{BS} \left(\frac{d_0}{d}\right)^{\gamma_b} \quad (2)$$

$$P_r = K_2 P_{BS} \left(\frac{d_0}{d_r}\right)^{\gamma_r} \quad (3)$$

$$P_m = K_3 P_{FRN} \left(\frac{d_0}{d_m}\right)^{\gamma_m} \quad (4)$$

where K_1, K_2 and K_3 are constants; γ_b, γ_r and γ_m are the path-loss exponent on BS-MS, BS-FRN and FRN-MS links respectively. Based on (2), (3), (4) and simple algebraic manipulation, the ratio

$$\frac{P_{BS}}{P_{FRN\,m}} = \frac{d^{\gamma_b}}{d_r^{\gamma_r}} \quad (5)$$

$$\frac{P_b}{P_r} = \frac{d_r^{\gamma_r}}{d_m^{\gamma_b}} \quad (6)$$

remain constant. Based on these expressions, we define the optimal radius for BS-MS link or direct link ($\hat{d}$) and that of FRN-MS link or relaying link ($\hat{d}_m$) as,

$$\hat{d} = \max_{d>0}\{d\},$$
$$s.t \quad satisfying\ the\ constraints\ in\ Equ. (5) and\ (6) \quad (7)$$

$$\widehat{d_m} = \underset{d_m \in (0,\ d_r - \hat{d})}{\operatorname{argmax}} \{d_m\},$$
$$s.t \quad satisfying\ the\ constraints\ in\ Equ. (5), (6)\ and\ (7) \quad (8)$$

We choose threshold greater than the minimum signal strength below which call drops. Thus all admitted calls never drop. Since the effects noise, shadowing and interference from neighboring cells are not considered in this model, this algorithm provides the simplified estimate of FRN placement scheme. In the next subsection, we propose a scheme that considers the effect of noise and shadowing.

3.2 Relay Placement based on SNR and Shadowing

Relay placement algorithm based on SNR and shadowing considers the case of isolated cell, where interference from neighboring cells is not considered. In addition to signal attenuation due to path-loss, we consider the effects of noise and shadowing. Shadowing effects happen when a transmitted signal is diffracted due to a tree or the top of a building along the path of propagation. Let Γ^b_{BM}, Γ^b_{BR} and Γ^b_{RM} be the SNR experienced by the user on BS-MS, BS-FRN and FRN-MS links respectively. In this paper the term SNR is used to denote the effects of noise and shadowing, henceforth, we use SNR to represent the effect of SNR plus shadowing. This algorithm is based on evaluation of SNR on three links as follows,

$$\Gamma^b_{BM} = P_{BS} - 10\gamma_b \log(d) + \xi_b - N_b \quad (9)$$
$$\Gamma^b_{BR} = P_{BS} - 10\gamma_r \log(d_r) + \xi_r - N_r \quad (10)$$
$$\Gamma^b_{RM} = P_{FRN} - 10\gamma_m \log(d_m) + \xi_m - N_m \quad (11)$$

Note that we use subscript *b*, *r* and *m* in this paper to refer to the three links BS-MS, BS-FRN and FRN-MS respectively. ξ_b, ξ_r and ξ_m are Gaussian random variable with standard deviation of σ_b, σ_r and σ_m on the three links mentioned above. Similarly, N_b, N_r and N_m denote the thermal noise.

This algorithm evaluates the SNR of each link. We consider SNR as a decision parameter for the success/failure of a transmission on a link; the received message is correctly decoded when the SNR experienced by MS on each link exceeds a threshold SNR. Hence, the effective radius of the three links can be obtained from the threshold SNR on the three links. Let the threshold SNR on BS-MS, BS-FRN and FRN-MS links are denoted as Γ_b, Γ_r and Γ_m respectively. Accordingly, the probability of successful decoding with direct transmission over BS-MS (Pr_b) is given as,

$$\begin{aligned} P_{r_b} &= Pr(\Gamma^b_{BM} > \Gamma_b) \\ &= Pr(P_{BS} - 10\gamma_b \log(d) + \xi_b - N_b > \Gamma_b) \\ &= Pr(\xi_b > 10\gamma_b \log(d) + N_b + \Gamma_b - P_{BS}) \quad (12) \\ &= Q\left(\frac{10\gamma_b \log(d) + N_b + \Gamma_b - P_{BS}}{\sigma_b}\right) \end{aligned}$$

We consider that for a given user position, if probability that the received SNR above the threshold is 95%, then the user has good link with the BS. Therefore such users do not require relaying support. The effective radius for direct link ($\hat{d}$) is the maximum distance where the above criteria is satisfied. Hence, optimum value of effective radius for direct link ($\hat{d}$) is given as,

$$\hat{d} = \max_{d>0}\{d\},$$

$$= max\left\{10^{\left(\frac{10\gamma_b \log(d) + N_b + \Gamma_b - P_{BS}}{\sigma_b}\right)}\right\} \quad (13)$$
$$s.t \quad d > 0;\ P_{r_b} \geq 0.95,$$

Similarly, the probability of successful decoding on BS-FRN link (P_{r_r}) and on FRN-MS link (P_{r_m}) can be expressed as,

$$P_{r_r} = Q\left(\frac{10\gamma_r \log(d) + N_r + \Gamma_r - P_{BS}}{\sigma_r}\right) \quad (14)$$

$$P_{r_m} = Q\left(\frac{10\gamma_m \log(d) + N_m + \Gamma_m - P_{FRN}}{\sigma_m}\right) \quad (15)$$

The equivalent SNR over two-hop transmission depends on the type of relaying scheme. In this paper we consider Decode and Forward Relaying (DF) and Amplify and Forward Relaying (AF) relaying schemes.

3.2.1 Decode and Forward Relaying

Consider a downlink scenario, where each FRN decodes the signal received from BS-FRN link and re-transmits to MS on the FRN-MS link. In this scheme, the end to end rate achieved from BS to MS is determined by the minimum rate achieved among the rates of BS-FRN and FRN-MS links, i.e., if the required rate for this scheme is R_{DF}, then

$$2R_{DF} \le min\{\log_2(1+\Gamma_{BR}^b), \log_2(1+\Gamma_{RM}^b)\} \quad (16)$$

If the required rate is not achieved on either of the link, then user is said to be in outage. Let the outage probability in DF scheme be Γ_{out}^{DF}, it can be expressed as

$$P_{\text{out}}^{DF} = \Pr(min\{\log_2(1+\Gamma_{BR}^b),\ \log_2(1+\Gamma_{RM}^b)\} \le 2R)$$
$$= 1 - \Pr(min\{\log_2(1+\Gamma_{BR}^b), \log_2(1+\Gamma_{RM}^b)\} \ge 2R)$$
$$= 1 - P_{\text{suc}}^{DF} \quad (17)$$

If user does not go into outage, this means there is successful transmission on BS-FRN and FRN-MS links. Let the P_{suc}^{DF} be the probability of successful transmission on DF scheme, then it can be computed as [9],

$$P_{\text{suc}}^{DF} = Pr(\Gamma_{BR}^b > \Gamma_r).Pr(\Gamma_{RM}^b > \Gamma_m)$$
$$= Q\left(\frac{10\gamma_m \log(d_m) + N_m + \Gamma_m - P_{FRN}}{\sigma_m}\right). Q\left(\frac{10\gamma_r \log(d_m) + N_r + \Gamma_r - P_{BS}}{\sigma_r}\right)$$
$$= P_{r_r} P_{r_m} \quad (18)$$

We consider the criterion $P_{\text{suc}}^{DF} \ge 95\%$ for deploying FRNs in cellular networks. Therefore, the effective radius ($\hat{d}_m$) for relaying link (FRN-MS) will be optimal distance which 5% outage probability is satisfied, i.e., $P_{\text{out}}^{DF} \ge 0.05$. Hence, the optimum radius for FRN-MS link is given as,

$$\hat{d}_m = \underset{d_m \in (0,\ d_r - \hat{d})}{\text{argmax}} \{d_m\},$$

$$= \underset{d_m \in (0,\ d_r - \hat{d})}{\text{argmax}} \left\{10^{\left(\frac{P_{FRN} - N_m - \Gamma_m - \sigma_m . Q^{-1}(P_{r_m})}{10\gamma_m}\right)}\right\}$$

$$s.t \quad P_{\text{suc}}^{DF} \ge 0.95\ ;\ P_{r_b} \ge 0.95. \quad (19)$$

3.3.2. Amplify and Forward Relaying

In amplify and forward relaying scheme, the AF relay amplifies the analog signal received from the BS and transmits an amplified version of it to the MSs [14]. Let the experienced SIR for this scheme be Γ^{AF}, then it is computed as follows.

$$\Gamma^{AF} = \frac{\Gamma_{BR}^b \Gamma_{RM}^b}{\Gamma_{BR}^b + \Gamma_{RM}^b + 1} \quad (20)$$

Let Γ be the threshold SIR. If the experienced SIR falls below the threshold, the user is said to be in outage and outage probability is given as P_{AF}^{out} out for AF scheme [14].

$$P_{AF}^{out} = Pr\left(\frac{\Gamma_{BR}^b \Gamma_{RM}^b}{\Gamma_{BR}^b + \Gamma_{RM}^b + 1} \le \Gamma\right) \quad (21)$$

It is difficult to obtain the exact closed-form solution for outage probability of (21) [10]. However, several literatures give the closed-form lower bound and upper bound. We are interested in upper bound solution to compute the effective radius of relaying link. Accordingly, the optimum radius for relaying link ($\tilde{d}_m$) due to AF relay is given as:

$$\hat{d}_m = \underset{d_m \in (0,\ d_r - \hat{d})}{\text{argmax}} \{d_m\},$$

$$= \underset{d_m \in (0,\ d_r - \hat{d})}{\text{argmax}} \left\{10^{\left(\frac{P_{FRN} - N_m - \Gamma_m - \sigma_m . Q^{-1}(P_{r_m})}{10\gamma_m}\right)}\right\}$$
$$s.t \quad P_{\text{suc}}^{AF} \ge 0.95\,, \quad (22)$$

3.3 Optimal Number of FRNs

Assume that users are distributed uniformly in the cell. Hence, the approximate number of FRNs required in a cell can be obtained by computing the area of inner region A_1 and that of outer region A_2. After simple mathematical steps, the number of FRN required in a cell is also computed as $N_{FRN} = \left\lceil 4(\frac{d}{d_m} + 1) \right\rceil$. Since the entire cell radius is defined as D = d + 2dm, the number of FRN that can support the users in outer region depend on optimal value of d and d_m. We choose optimal value of d and d_m that minimizes the number of FRN used in the cell. The optimization equation is described as,

$$\widehat{N}_{FRN} = \arg\min\{N_{FRN}\},$$
$$s.t \quad \hat{d},\ \hat{d}_m \text{ and } \tilde{d}_m \text{ satisfying Equ.} (19 \text{ and } 22),$$
$$\hat{d} \text{ and } \hat{d}_m \text{ satisfying Equ.} (8) \quad (23)$$

3.4 Outage performance analysis

Co-channel interference and shadowing effects are among the major factors that limit the capacity and link quality of a wireless communications system. In this section, we use Gauss-Markov model to evaluate the statistical characteristics of SIR in Multihop communication channels. By modeling SIR as log-normally distributed random variable, we investigate the performance of relay placement schemes discussed in Subsection 3.1 and 3.2. We make a comparison between the above models in terms of performance evaluation where outage probability is a QoS parameter. Further more the result is used to find the more realistic way of channel partitioning and relay FRN placement schemes.

The co-channel uplink interference to the BS/FRN of interest is assumed to be from MSs or FRNs that links to first tier or upper tier cells ($MS_{i's}$ or $FRN_{K's}$). Including the shadowing effect on the three links, the SIR on each link can be described as;

$$\Gamma^b_{BM} = \frac{10^{\xi b/10}}{d^{\gamma b}}\left[\sum_{i=1}^{N}\frac{1}{d_i^{\gamma b}\,10^{\xi bi/10}}\right]^{-1} = \left[\sum_{i=1}^{N}\left(\frac{d}{d_i}\right)^{\gamma b} 10^{\frac{\xi bi-\xi b}{10}}\right]^{-1} \quad (24)$$

$$\Gamma^b_{BR} = \frac{10^{\xi r/10}}{d_r^{\gamma r}}\left[\sum_{i=1}^{N}\frac{1}{d_{ri}^{\gamma r}\,10^{\xi ri/10}}\right]^{-1} = \left[\sum_{i=1}^{N}\left(\frac{d}{d_{ri}}\right)^{\gamma r} 10^{\frac{\xi ri-\xi r}{10}}\right]^{-1} \quad (25)$$

$$\Gamma^b_{RM} = \frac{10^{\xi m/10}}{d_m^{\gamma m}}\left[\sum_{i=1}^{N}\frac{1}{d_{mi}^{\gamma r}\,10^{\xi mi/10}}\right]^{-1} = \left[\sum_{i=1}^{N}\left(\frac{d}{d_{mi}}\right)^{\gamma m} 10^{\frac{\xi mi-\xi m}{10}}\right]^{-1} \quad (26)$$

where d and d_r are the location of desired MS and FRN from the BS_0 on direct link, d_m is the location of desired MS from desired FRN under the second hop. Similarly, d_i and d_{ri} are the location of co-channel interferer MS and FRN from the BS_0, while d_{mi} denotes the location of co-channel interferer MSs from FRN that is associated to BS_0. Shadowing for the desired links are denoted as ξ_b, ξ_r and ξ_m For interfering links shadowing is expressed as ξ_{bi}, ξ_{ri} and ξ_{mi} to denote the interfering link of MS-BS, FRN-BS and MS-FRN; in all cases, i∈ {1, ..., 18}.

Basically, the outage probability analysis for the three links (MS-BS, FRN-BS and MS-FRNs) is similar to the expression given in Section 3.2. However, interference from neighboring cells is considered here. We compute the mean and standard deviation of both desired and interference signal based on Fenton-Wilkinson′s and Schwartz-Yeh′s method [13]. Shadowing is usually represented by i.i.d. log-normal model in wireless multi-hop models. However, shadowing paths are correlated. Hence, we consider correlation among interferers and also the correlation that may exist between interferer and desired signals

4. RESULTS AND DISCUSSION

In this section, we present the analytical and simulation results to illustrate the performance of our proposed FRN placement algorithms. We use Matlab simulation for modeling cellular networks under varying channel conditions. We analyze the performance of relay placement schemes based on path-loss and SNR as described in previous section. The list of simulation parameters are mentioned in Table 1.

Table 1. List of the simulation parameters.

Parameters	**Values**
Carrier Frequency	5GHz
System Bandwidth (W)	25.6MHz
Standard Deviation ($\sigma d, \sigma r$ and σm)	8, 5, 8 dB
Correlation Coefficient	0.5
Path-loss Exponent ($\gamma d, \gamma r$ and γm)	3.5, 2.5, 3.5
BS Transmit Power (P_{BS})	40dBm
FRN Transmit Power (P_{FRN})	20dBm
MS transmit Power (P_{MS})	2dBm
Threshold (Γ)	-10dBm
Thermal Noise (N)	-100dBm

The optimal FRNs placement results are summarized in the Table 2.

Table 2. Results of optimal FRNs placement based on path-loss and SNR.

Parameters	Based on Path-loss	Based on SNR
d_r	2120m	2076m
d	1611m	1522m
d_m	509m	554m
N_{FRN}	6	6

Fig. 3 illustrates the outage probability of downlink cellular network where the optimal FRN placement scheme is based on path-loss. This figure compares the outage probability of relay enhanced cellular system of direct link and relay link along with the scheme without FRNs. Furthermore, Fig. 3 demonstrates that outage probability is significantly improved in relay enhanced cellular system with optimal FRN placement. As it can be shown in this figure, at SIR threshold of 0 dB, the outage probability of the scheme without FRNs is 40%. But, the outage probability of our proposed scheme for FRN-MS link is nearly 0%. This means that due to optimal placement of FRNs, outage probability at cellular boundary improves by 40%. Since the users at the cell boundaries dominate the system performance, our optimal relay placement scheme significantly improves the outage probability of MSs of second hop link.

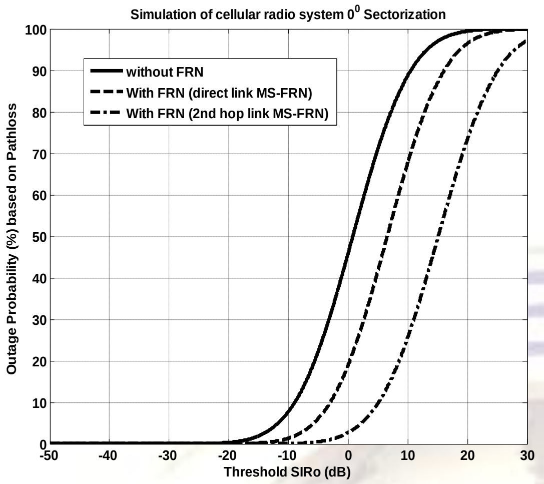

Fig. 3. Outage probability versus SIR threshold of DF relay enhanced cellular system with no sector in the inner region; optimal FRN placement is based on path-loss.

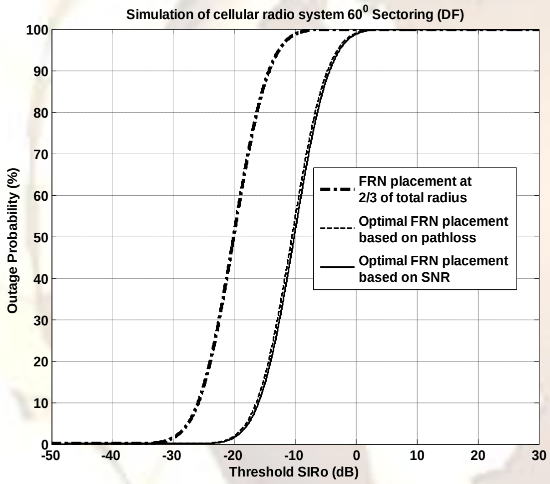

Fig. 4. Outage probability versus SIR threshold of DF relay enhanced cellular system with 60^0 sectoring in the inner region; proposed optimal FRN placement schemes are compared with FRNs location at 2/3rd of cell radius.

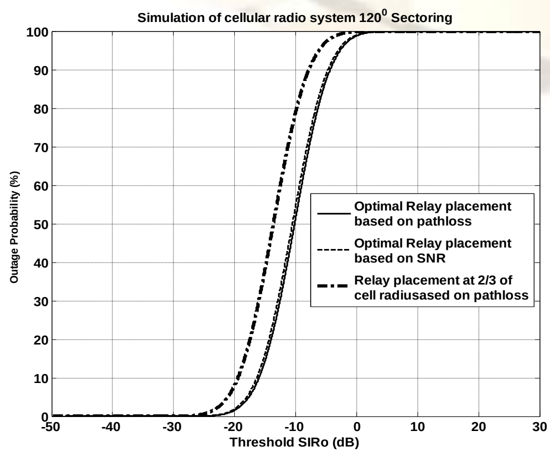

Fig. 5. Outage probability versus SIR threshold of DF relay enhanced cellular system with 1200 sectoring in the inner region; proposed optimal FRN placement schemes are compared with FRNs location at 2/3rd of cell radius.

Fig. 4 illustrates the outage probability versus SIR threshold for DF relay where the inner region of the cell is sectored in to 60^0 sectoring (refer Fig.1). We compare our proposed optimal FRN placement schemes with a scheme that places FRNs at 2/3rd position of the cell radius. The results show that our proposed schemes achieve significant improvement on the performance of the cellular network. In Fig.4, at SIR threshold of -20 dB, the outage probability of a system when FRNs are placed at 2/3rd of cellular radius is 50% whereas, the outage probability of our proposed scheme for FRN-MS link is only 2%. However, there is no significant difference in performance among our proposed schemes. As can be shown in Fig.4, Fig.5 and Fig.6, comparing the performance of our two proposed schemes, the outage probability of optimal FRNs placement scheme which depends on path-loss and that of the scheme which depends on SNR are nearly equal. Hence, either of the two proposed schemes can be implemented for optimal FRNs placement to achieve the same QOS requirement.

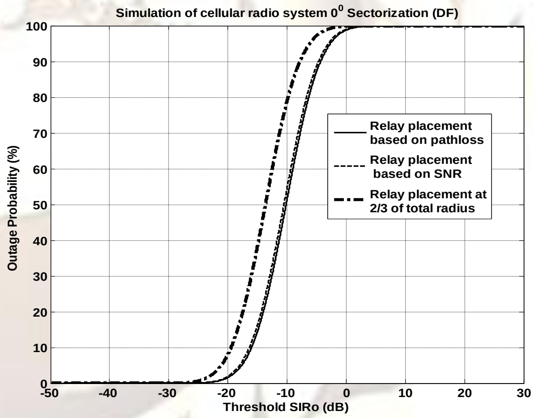

Fig. 6. Outage probability versus SIR threshold of DF relay enhanced cellular system with no sectoring in the inner region; proposed optimal FRN placement schemes are compared with FRNs location at 2/3rd of cell radius.

Fig.4, Fig.5 and Fig.6 also illustrate that sectoring the BS-MS direct link of the cell significantly improves the outage performance of the cell in which FRNs are placed at 2/3rd of the cell radius while sectoring has no significant effect on the cellular networks that use the proposed optimally FRNs placement schemes. Even though sectoring lowers the effect of co-channel interference, it also degrades system capacity.

Fig.7 shows the performance of path-loss based optimal FRNs placement schemes for 6 and 18 co-channel interferers. We evaluate the performance of the two hop cellular network with AF and DF relay. Since AF relay scheme amplifies the required signal and noise, the cellular network performance decreases with the increase in number of co-channel cells. We also observe that, outage probability of the system at -20 dB SIR threshold is improved by 80% when the co-channel decreases from two tire (18 cell) to one tier (6 cells) cell. However such effect is not significantly observed in DF relaying scheme.

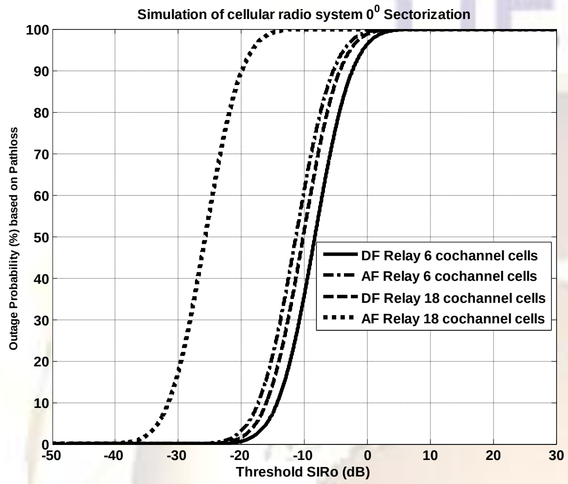

Fig.7. Outage probability versus SIR threshold of AF and DF relay enhanced cellular system with one tier and two tier co-channel cells; Optimal FRNs placement is based on path-loss

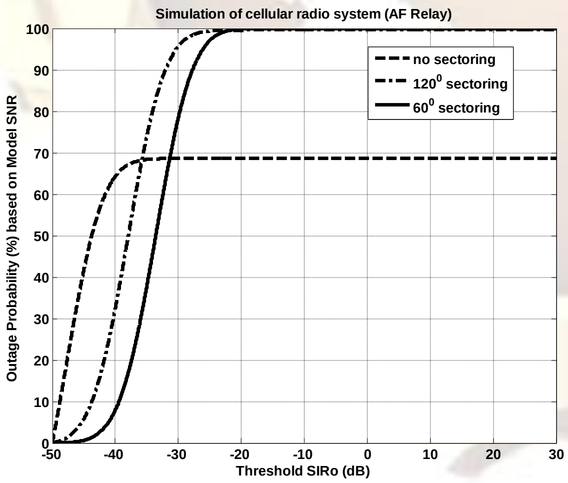

Fig.8. Outage probability versus SIR threshold of AF relay enhanced cellular system with 0^0, 60^0 and 120^0 sectors in the inner region of the cell; optimal FRNs placement is based on SNR.

Fig.8 shows the effect of sectoring on AF relay in which the optimal FRNs placement is based on SNR. Similar to above results, sectoring can improve the outage probability of users by lowering the effects of co-channel interference, but decreases system capacity.

5. CONCLUSION

This research work proposed two optimal FRNs placement schemes which are based on path-loss and SNR. The proposed schemes also compute optimal number of FRNs that are required to enhance the QoS of cellular system. Our schemes also investigate effects of sectoring the inner region of the cell on optimal FRN placements. Sectoring the inner region for improves the outage probability. Our optimal relay node placement schemes significantly reduce the outage of the cellular system and provide better QoS for users at cell boundaries.

6. ACKNOWLEDGMENT

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