On the Performance of Multiple Region Reverse Frequency Allocation Scheme in a Single Cell Downlink Heterogeneous Networks

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***Abstract*—The need for small-sized and low-powered home base stations such as femtocells has increased with an escalated data demand. Since the downlink traffic is larger in magnitude than the uplink, use of femtocells provides a good solution. Femtocells not only increase the throughput but also the overall capacity of the system while operating in the same licensed spectrum. Because of their operation in the same spectrum, interference becomes a major problem. In this paper, we study the downlink performance of a heterogeneous network by proposing a Reverse frequency allocation (RFA) scheme by dividing the cell service area into multiple regions and assign frequencies to various cell entities in such a way that the major interference is avoided. RFA scheme not only improves the spectral efficiency by utilizing the complete spectrum within one cell but also eliminates the strong interference due to macro base station on femto users. We analyze and evaluate the achievable performance of this technique for the downlink scenario. Using simulations, we show that under reasonable signal-to-interference plus noise ratio (SINR) values, multiple regions enhance the performance of users by decreasing the overall system outage probability. It is shown that a 4-region RFA scheme provides almost double performance gain over a 2-region RFA scheme for the same set of parameters.**

***Index Terms*—Reverse frequency allocation, interference, frequency reuse.**

I. INTRODUCTION

Femtocell is a low complexity, low-powered, and small-sized base station (BS) that enables communication with an improved quality of service. These base stations are placed inside user's premises but operate in licensed spectrum. As the demand for cellular services can originate from indoor environment significantly, hence it is desirable to provide good coverage to the indoor users. According to [1], by the start of 2011, approximately 2.3 million femtocells were globally deployed, and it is expected to reach approximately 50 million by 2014. Another study claims that 30% business and 45% home users are unsatisfied with their indoor coverage [2]. Because of an increase in the data demand, femtocells are gaining attention from mobile operators. The main purpose of the femtocells is to provide better indoor coverage while offloading traffic from the main macro base station (MBS), which indeed is an expensive radio resource.

While deploying a homogenous femto-cellular network, interference is one of the main problems since femtocells use the same spectrum as being utilized by overlaid macro-cellular network. These interferences are generally categorized as co-tier and cross-tier interference [3]. Co-tier interference occurs when transmission of one femtocell (aggressor) obstruct the on-going transmission of another femtocell and its user (victim). Cross-tier interference, on the other hand, adds extra degree of complexity. In cross-tier, the transmission between MBS (aggressor) and macro user equipment (MUE) interferes with the ongoing transmission between the femtocell access point (FAP) and femtocell user equipment FUE (victim) and vice versa. Cross-tier interference in femto-cellular environment is different from traditional interference. In closed-access mode of the femto-cellular network, the MUE would not be able to access femtocell's services. This would lead to a strong interference from MUE to FAP in the uplink operation and from FAP to MUE in the downlink operation.

For interference cancellation or avoidance, many schemes have been proposed that focus on different frequency allocation schemes. Selection of those allocation schemes is dependent upon femtocells density. One of the strategies is *static frequency-reuse* scheme in which the bands for macrocell and femtocell are dedicated separately [4]. In *shared frequency band* scheme, the total spectrum can be utilized by both macro and femtocell, while in sub-frequency band scheme; the whole spectrum is allotted to macrocell while a portion of the whole band is fixed for the femtocells. In this paper, we use the shared frequency allocation scheme and propose a variant of this scheme known as Reverse frequency allocation (RFA). In RFA, we divide the complete cell in non-overlapping regions and frequency band is distributed in such a way that spectral efficiency can be improved. Due to partitioning of cell, the number of interferers, i.e., users operating on the same frequency can also be reduced.

In the next section, we briefly discuss the previous work. In Section III, system model will be described. We discuss the interference modeling and optimal region selection in Section IV. After that, simulations and results will be discussed, which

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is followed by conclusion in Section VI.

II. Related Work

A complete introduction about femtocells including all types of interference scenarios is presented in [5], along with other papers such as [6]-[9]. Regarding interference avoidance in femtocells, many researchers proposed different frequency planning techniques. Initially, it was proposed to assign different orthogonal frequencies to the base stations of different cells [10]. Authors in [11] proposed another elegant scheme of *fractional frequency reuse* (FFR). In FFR, whole of the spectrum is divided into multiple frequency bands. These bands are distributed among cluster such that the users that are present in the middle of the cell are allocated with a separate band from the users that are present at the edge. Although this schemes allocates different frequency bands to the edge-users and the users present in the center of the cell, but still it is spectrally inefficient as the available resources may not be used efficiently.

The authors of [12] proposed *soft fractional frequency reuse* scheme. This schemes also partitions the whole frequency spectrum but allows the center-cell users to use more than one frequency bands. It is spectrally more efficient as compared to previous scheme because femto users can also utilize the same band that is assigned to the macro users. The whole band is utilized within a single cell, which also makes it spectrally more efficient. The drawback of this scheme is that part of band is still statically dedicated for femto users and also like the previous schemes, this scheme does not take account of user's traffic distribution. The authors of [13] proposed a simple algorithm which provides more preference to the MUEs by controlling the power of the FAP. The fundamental assumption is that, MBS provides the information of MUEs to all the FAPs. Once the MUEs is under significant interference, the nearby FAP will reduce its transmit power. This approach leads to the performance degradation of FUEs. Another approach which is used to avoid the interference in OFDMA based femtocells is discussed in [9]. In this approach, each FAP initially sense the surrounding radio environment for specific sub-channel. Each user equipment requires a certain number of sub-channels depending upon the QoS criteria. If a particular sub-channel is free, FAP then allocate the sub-channel to that user, subject to low level of interference.

The authors of [14] proposed a *dynamic frequency reuse* scheme that considers the overall traffic load. The spectrum allocation for both the macro and femto regions changes dynamically depending upon the traffic load pattern. However, the drawback of this scheme is that it is highly dependent upon current information about geographical locations of the users. Technique that is analyzed in [15] is *reverse frequency allocation* scheme (RFA). Reverse Frequency allocation scheme divides the complete region into two non-over-lapping regions named as inner region and outer region. It is spectrally most efficient among all the schemes because it not only utilizes whole frequency band among single cell but also the frequencies used for the uplink and the downlink transmissions of MBS to MUE are being utilized as the downlink and uplink frequencies of FAP to FUE, respectively. In this paper, we extend this approach by allowing multiple regions in a cell. Specifically, we demonstrate a 4-region RFA scheme and compare its performance with the 2-region RFA as discussed in [15].

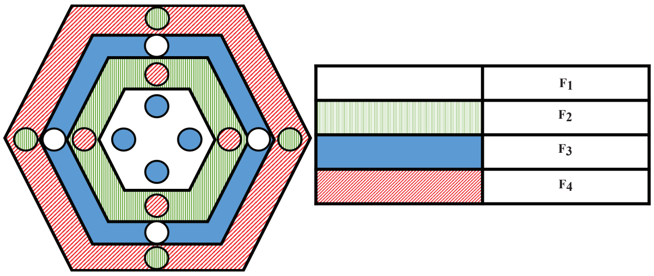


Fig. 2: Frequency distribution for 4 regions.

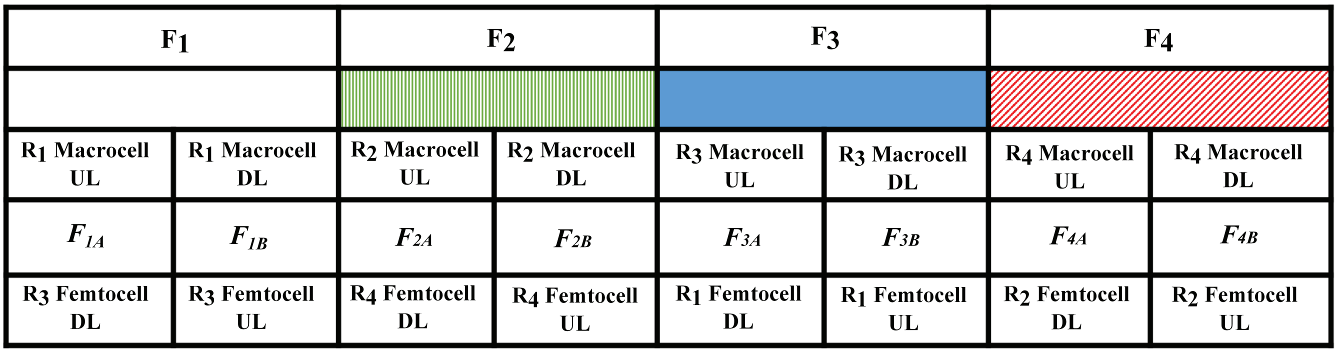
III. System Model

We consider a reverse frequency allocation (RFA) scheme for a single cell in which the entire region of a macrocell is divided into k disjoint regions. Furthermore, the allocated frequency spectrum, F, is divided among k orthogonal sub-bands, such that $F = \bigcup_{i=1}^{k} F_i$, where $\bigcap_{i=1}^{k} F_i = \phi_i$; ϕ denotes a empty set.

For every i^{th} region, we assume frequency division duplexing (FDD), i.e., each sub-band is further divided into its uplink and downlink frequency bands, such that
F_i = $\left[F_{iA}+F_{iB}\right]$; $i = \{1, 2, ...k\}$.

For a fair usage of frequencies in the RFA scheme, we assume
$k = 2^M$,where $M \in Z^+$ = $\{1, 2, ...\}$.

In the following, we consider k=4 and provide a complete spectral decomposition of the network for a 4-region RFA scheme. As mentioned earlier, the basic aim of the RFA scheme is to divide a cellular region in such a way that least amount of interference scenarios are produced; thereby decreasing the overall outage of the system. For that as shown in Fig. 1, the available region is divided into four non overlapping regions, i.e., R_1, R_2, R_3, and R_4, respectively. The available spectrum F for the single cell is also divided into 4 bands namely F_1, F_2, F_3, and F_4 and each region is assigned a frequency band. Each band contains the uplink and downlink frequency carriers. Frequency carriers F_{1A} and F_{1B} are used by MUEs in R_1, F_{2A} & F_{2B} for MUEs in R_2 for uplink and downlink operations, and so on. It can be observed that the MBS have relatively high transmit power as compared to FAPs, hence the femto users receive large amount of interference from MBS on the same frequency channel. Thus it is desired to allocate the frequencies in such a way that a femto user receives no interference from the downlink of MBS. Hence if F_{1A} is used for downlink FUEs in R_3, it is desired to reuse this frequency for one of the uplinks



F1		F2		F3		F4	
		▥		🟦		▨	
R1 Macrocell UL	R1 Macrocell DL	R2 Macrocell UL	R2 Macrocell DL	R3 Macrocell UL	R3 Macrocell DL	R4 Macrocell UL	R4 Macrocell DL
F_{1A}	F_{1B}	F_{2A}	F_{2B}	F_{3A}	F_{3B}	F_{4A}	F_{4B}
R3 Femtocell DL	R3 Femtocell UL	R4 Femtocell DL	R4 Femtocell UL	R1 Femtocell DL	R1 Femtocell UL	R2 Femtocell DL	R2 Femtocell UL

Fig. 1: Reverse frequency allocation of 4 regions.

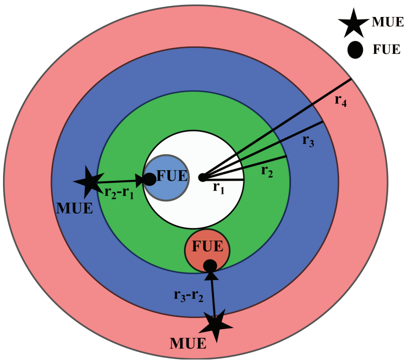


Fig. 3: Worst-case scenario in 4-region RFA. The direction of arrows shows the interference direction.

of MUEs in R_1, and interference is minimal if these two interfering regions are as far as possible. Hence we make two sets of interfering regions; R_1 & R_3, and R_2 & R_4. Hence this implies that R_1-FUE in downlink uses the same frequency as the uplink MUE in R_3.

Since our focus for this study is the downlink receiver (mobile users either MUEs or FUEs), hence the interference arrives from R_3-FAP to R_1-MUE. As FAPs are low powered and large path loss exists between these nodes this interference is not significant. On the other hand, the R_1-MUE in uplink uses the same frequency as that of the downlink FUE in R_3. In this case, the downlink FUE receives interference from MUE uplink, which is again low-powered and feeble because of the path loss between R_1 and R_3. Hence minimal interference is observed using this scheme for both downlink users, i.e., R_1-MUE and R_3-FUE. Same procedure is done for R_2 and R_4. In summary, the frequencies are allocated to the femtocells in such a way that the femtocells that are contained in R_1 will use F_{3A} and F_{3B} frequency carriers for their downlink and uplink operations, respectively. Similarly, R_2 femtocells will use F_{4A} and F_{4B} frequency carriers for downlink and uplink operations, respectively. In the same way, R_3 and R_4 femtocells will utilize F_{1A}, F_{1B} and F_{2A}, F_{2B} frequency carriers for their downlink and uplink operations, respectively.

IV. INTERFERENCE MODELING AND REGION SELECTION

As described earlier, the interference in this particular case of 4-region RFA arrives from only one interfering region. For example, communication going on in R_1 will be interfering the communication of R_3 as they are operating on the same partitioned frequency, i.e., F_1. Interference, on the other hand, will be significantly reduced because in the 4-region case the area under each region is minimized. As the area is reduced the number of interferers will also be reduced on the average. Although the RFA scheme offers more vulnerability to interference, however, interference either co-tier and/or cross-tier both will have their impact on the downlink users performance metrics. These performance metrics can be throughput and coverage etc. In heterogeneous networks a designer must, due to different channel conditions, prioritize these performance metrics. For example, in an environment of high user density the system must optimize its spectral efficiency so that greater number of users can be adjusted. While on the other hand a system that ensures high data rate must optimize to certify high SINR. In each case the other performance metric can be sub-optimized. We now model the various types of interferences present in our system. As described, the FUEs encounter interference not only from uplink MUEs in the distant region but also from the neighboring FAPs in the same region that are operating at the same frequency. As this paper studies the outage aspects of the network, which means that the SINR is the performance metric that will be used in this type of system. The SINR at a receiver j can be calculated as

$$SINR(dB) = \frac{P_{des}}{d_{des}^{\beta}}\mu_{mj} - \sum_{i\in\,\mathbb{I}}\frac{P_i}{d_{ij}^{\beta}}\mu_{ij} \tag{1}$$

where P_{des} is the power received from the intended transmitter m, while P_i is the interfering power from the ith transmitter, which can be co-tier or cross-tier interferer. The set $\mathbb{I}$ denotes the set of all interferers. The path loss exponent is represented as β, while the distances of the receiver from the interferers and desired transmitter are represented as d_{ij} and d_{des}, respectively. The flat fading channel gain from the desired and interfering transmitter to the jth receiver is denoted by μ_{mj} and μ_{ij}, respectively, where μ_{mj} , μ_{ij} $\in$ μ and the

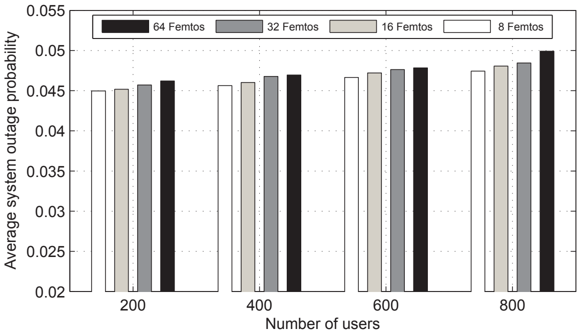


Fig. 4: Average system outage probability of 2-region RFA.

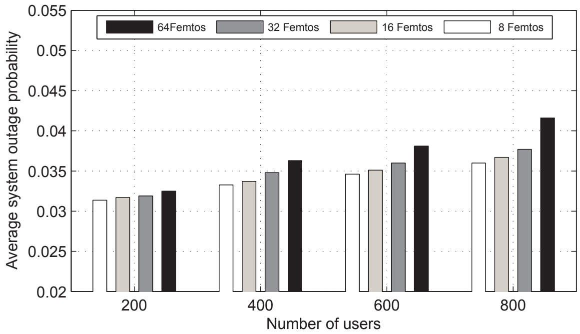


Fig. 5: Average system outage probability of 4-region RFA.

set μ consists of independently and identically distributed (i.i.d) random variables, which are drawn from an exponential distribution with the parameter σ_μ^2 =1. Hence we are interested in finding the $\mathbb{P}\{SINR \leq P_{th}\}$ and average this outage probability for all users of the system.

A. Optimal Partitioning of Regions

The multiple regions in the RFA must be partitioned in such a way that the impact of the interference should be minimized. For example, in Fig. 3, 4-region RFA is implemented in a cell with radius r, which is further divided into four non-overlapping regions. To find the optimal distance for each region, we consider a worst-case scenario, i.e., we want to calculate the optimal region lengths, when the interference in the system is maximum. As it is already been shown that the in a 4-region RFA, R_1 and R_2 are the interfering regions with R_3 and R_4, respectively. The femto users (FUEs) are placed at the region boundaries while their interfering macro users (MUEs) are placed at their nearest interfering region's boundary. This is the worst-case scenario because the interference from each MUE to its respective FUE is maximum in this situation. As the co-tier interference is one of the major contributing factors towards the total interference in this RFA scheme and will have a significant impact in R_1. This is due to the fact that the density of the femtocells with respect to this area is highest in this region. So for a certain fixed threshold, P_{th}, through extensive simulations, it is observed that r_1 should be at least $0.6r$ so that the SINR of this particular region should be above an acceptable value. As in the worst-case, SINR should be at least equal to the P_{th} to get success, therefore, our optimization problem becomes the following;

$$maximize \ \ \{SINR\}$$
$$s.t$$

$r_1 = 0.6r$, $r_1 \leq r_2 \leq r_3 \leq r_4$ and $r_4 = r$, where r_1, r_2, r_3 and r_4 are the radius of R_1,R_2, R_3 and R_4 regions, respectively. To explain this approach, let us again consider the example of 4-region RFA. From Fig. 3,

$$SINR_{opt} = \frac{(r_2 - r_1)^2}{\delta_{FUE}} = P_{th}, \tag{2}$$

$$SINR_{opt} = \frac{(r_3 - r_2)^2}{\delta_{FUE}} = P_{th}, \tag{3}$$

where δ_{FUE} is the maximum distance of FUE from its intended FAP. From (2) and (3),

$$r_2 = \frac{(r_1 + r_3)}{2}. \tag{4}$$

As, $r_3 \leq r_4$ then $r_2 \leq 0.8r$. Now r_3, due to fairness, is taken equal between r_2 and r_4. So, $r_3 \leq \ 0.9r$.

V. SIMULATION RESULTS AND PERFORMANCE ANALYSIS

In our simulation environment, we randomly distribute circular-shaped femtocells within a hexagonal macrocell. Open access mode is simulated in our simulations for the femtocells. Macrocell base station (MBS) and femto access points (FAPs) are assumed to have omnidirectional antennas. Transmission power of MBS and FAP is fixed to be 20 and 0.2 Watts, respectively, while the transmit power of both MUE and FUE is fixed to 0.2 Watts. The users are uniformly placed in the macrocell, where at least one user is placed in each femtocell. Parameters used for the simulations are shown in Table 1. User outage for 2-region and 4-region RFA is analyzed.

Fig. 4 and 5, shows the outage probability in a 2-region RFA scheme with the 4-region RFA. These graphs analyze the overall system outage for a macrocell having a radius of 1 Km with varying number of users and with varying total number of femtocells. The path loss exponent, β, is taken to be 2 in this case. It can be observed that as the number of users increases, the average system outage probability also increases. This increase in the system outage is due to the cross-tier interference, i.e., interference from MUEs to FUE in the uplink direction. Also with the increasing number of femtocells,

TABLE I: Simulation Parameters

Parameter	Value
Power of MBS	20 Watts
Power of MUE	0.2 Watts
Power of FAP	0.2 Watts
Power of FUE	0.2 Watts
Femto Radius	50 meters
Macrocell radius	1 to 4 Km
P$_{th}$	-50dB

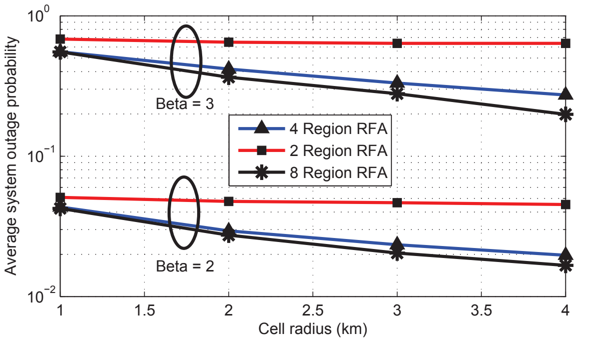


Fig. 6: Average system outage probability at different cell radius.

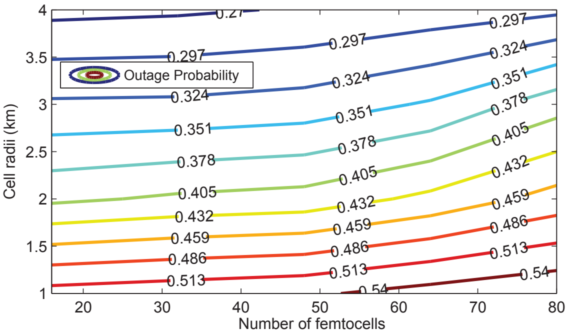


Fig. 7: Average system outage probability for various femtocells and cell radius with 600 users in 4-region RFA

the co-tier interference also increases, i.e., interference from FAPs to FUEs in the downlink direction. Therefore, in both cases, i.e., either increasing number of users and/or femtocells, the system outage probability increases. In Fig. 4, 2-region RFA scheme is analyzed. It divides the complete cell in 2 regions. Simulations were performed on different number of femtocells. For example, when 8 femtos are considered then each region contains 4 femtocells. Similarly, for 64 femtos, every region has 32 femtocells each and so on. From Figs. 4 and 5, we can see that 4-region RFA scheme outperforms 2-region RFA in terms of system outage probability. This reduction in system outage is due to the fact that 4-region RFA divides the complete single cell in such a way that each region has less number of interferers.

Fig. 6 analyzes different RFA schemes i.e., 2-region, 4-region, and 8-region RFA, at different cell radii and different path loss exponents. 800 users and 64 femtocells were randomly distributed in the cell. In 8-region RFA, total area is divided among 8 regions. Frequency spectrum is divided in such a way that any region, at maximum, can have no more than 2 interfering regions. For example, R_3 will have R_1 and R_5 as its interfering regions. Similarly, R_4 has R_2 and R_6 as its interfering regions. On the other hand R_1, R_2, R_7, and R_8 will have only one interfering region. As the cell radius increases, the distance between the FUE (victim) and the MUE and interfering FAPs (aggressor) also increases, alleviating the SINR of FUE. This improvement in performance is not as significant in 8-region RFA as it is in 4-region RFA scheme. This is due to the fact that as the number of regions increases for a fixed cell radius, not only the interfering regions come close but also the size of each region decreases, yielding higher co-tier and cross-tier interferences. Hence at smaller cell radii 8-region RFA performs almost equal to the 4-region RFA scheme.

On the other hand, it can also be seen that as the cell radius increases, the difference between the performance of 2-region and 4-region RFA also increases. For larger cell radii, the 4-region RFA significantly improves the performance in terms of outage probability. For example, at the cell radius of 4 Km with 800 users and $\beta = 2$, the 2-region RFA scheme provides an average system outage probability approximately equal to 5%, but in the 4-region RFA with same parameters, the average system outage probability decreases to 2%. Hence large number of users will be in coverage. Similarly, for the larger path loss exponents, β, it can be seen that the 4-region RFA outperforms the 2-region RFA. For example, the difference in system outage probability for two schemes at a radius of 4Km with $\beta = 2$ is 3%. While at $\beta = 3$, this difference is increased up to approximately 40%. So, we can say that for larger cell radius or larger path loss exponent, the 4-region RFA completely outperforms the 2-region RFA.

Fig. 7 shows the contour plot that provides the average system outage probability that will be faced in any cell with a particular radius and varying number of femtocells for a 4-region RFA. These simulations were done with 600 users and β is taken to be 3. It can be observed that at a radius of 2 Km, the outage probability for 80 femtocells is around 46%. If this outage probability needs to be reduced for same number of cell users to 40%, then the maximum number of allowed femtocells should not be greater than 30. Hence an upper bound on the number of femtocells can be evaluated for varying cell radii.

VI. CONCLUSION

Dense deployment of femtocells provides high data rates to the indoor users. It also enables the network operators to offload the traffic from macro base station. In order to achieve a good QoS and coverage, co-tier and cross-tier interferences are the major problems among the femto-femto and femto-macro networks, respectively. The reverse frequency allocation scheme is one of the robust techniques in term of interference mitigation and spectral efficiency, particularly in downlink traffic. We have proposed an RFA scheme in the downlink by dividing the cell into multiple regions. Specifically, we studied the 2, 4, and 8-region RFA schemes. The simulation results show that the 4-region RFA with optimal cell radii provides a reduced average system outage probability as compared to the 2-region RFA in terms of a certain number of users and femtocells. Moreover, by increasing the cell radius, 4-region RFA outperforms the 2-region RFA in term of system outage for certain values of path loss exponent. The analysis of RFA scheme with higher multiple regions, its spectral efficiency, and complexity analysis is left as a future work.

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