Indonesian Journal of Science & Technology

Journal homepage: http://ejournal.upi.edu/index.php/ijost/

Managing the Interference for Down-Link in LTE Using Fractional Frequency Reuse

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ABSTRACTS

Long Term Evolution has developed a new radio technology called femtocell or Femto Base station; which is well-suited to improve cellular network capacity and mobile coverage to indoor user's areas. Providing additional capacity and coverage expansion through FBSs could lead to large interference in a cellular radio communication network. In this paper; we proposed an efficient resource allocation scheme based on Fraction Frequency Reuse (FFR) for interference mitigation; where the entire spectrum is shared among network entities. FFR mechanism aims to reduce co-tier and cross-tier downlink interferences by allocating non-overlapping sets of bands to the user equipment at different geographic locations. The main purpose of this work is to compare two main types of FFR schemes; respectively; Strict FFR and Soft Frequency Reuse with the proposed scheme. The three types of FFR schemes were explained and evaluated with Monte-Carlo simulation based on some performance metrics; namely; sum-rate; spectral efficiency; and outage probability. Simulation results showed that the impacts of the proposed scheme are significantly high in comparison with two other methods. The proposed scheme proved to enhance spectral efficiency; reduced the outage probability; and increased the sum rate for all the users.

ARTICLE INFO

Article History:
Received 01 Sep 2019
Revised 18 Jan 2020
Accepted 25 May 2020
Available online 20 June 2020

Keywords:
LTE;
FFR;
SFR;
Femtocell;
Femto Base Station;
Resource Allocation;
Inter-cell interference (ICI).

1. INTRODUCTION

Long Term Evolution (LTE) and LTE-advanced give operators the potential to achieve higher peak data rates throughout systems with higher spectrum bandwidths. Work on LTE began in 2004; and an official work item began in 2006. A complete specification of LTE was developed in early 2009 (Krause; 2012). The initial deployment of LTE started in 2010 with release 8. LTE-advanced was introduced by release 9 and beyond) started in 2011. According to the 3rd Generation Partnership Project (3GPP) specifications; LTE offers a significant improvement in spectral efficiency; latency; and multi-user flexibility; compared to older mobile standards. It supports heterogeneous cellular networks; including macrocells or macro-base stations (MBSs); picocells; Femto Base Stations (FBSs); and relays. FBS was first introduced by IEEE 802.16 SDD (System Description Document) to provide an advanced radio interface operate in licensed bands. Researches showed that 66% of calls and over 85% of data services occur indoors. Some surveys showed that 43% of households and 34% of businesses experience poor indoor coverage problems (Cullen; 2008).

An FBS is a very small base station that operates in a licensed spectrum to connect standard mobile devices to the service provider's network via broadband connections (such as Digital Subscriber Line (DSL); cable; or fiber) (Chandrasekhar *et al.*; 2008). Small base stations can be put in a residential setting. Thus; the FBS allows the mobile operator to extend mobile network coverage into the home by using the consumer's internet connection; it can improve the macrocells capacity and coverage simply and economically. Inefficient deployment of the FBS may lead to a degradation of the overall performance of the cellular system. One example of this performance degradation is coverage holes for indoor Macrocell User Equipments (MUEs) due to interfering transmissions by nearby FBSs. As FBSs are embedded inside a macrocell; both macro and FBSs should operate on a certain frequency. The operators need to specify the allocated frequency range for the macro and FBSs. This frequency allocation is a tedious job. A little mismanagement can lead to various levels of interference problems in a two-tier network (Chandrasekhar *et al.*; 2009).

The network topology of a cellular network changed when the FBS is added. Therefore; the most important challenge to the deployment of FBSs is the problem of interference. The issue of interferences could occur from interferences related to Macrocell to FBS; FBS to Macrocell; or FBS to FBS. Many studies found that it is important to choose the location of FBSs carefully to have the greatest possible coverage area with the least positive number of FBSs entities (Bennis *et al.*; 2011). Using this approach; it leads to a reducton of interference to acceptable levels at a lower implementation cost. While many other studies considered transmission power as a way of Interference Mitigation Technique; a dynamic power control algorithm was proposed by several researchers (Claussen; 2007; Shin & Choi; 2012) to reduce the interference probability in Maximizing Indoor Coverage Availability. In contrast; a decentralized resource allocation for the Hybrid wireless networks was proposed by Chu *et al.* (2010). In this scheme; the available spectrum is divided into two separate classifications based on time and frequency domains. All the spectral resources can be selected and utilized by the Macrocell. At the same time; only a subset of frequency bands is allowed to connect randomly to the FBS when it wants to transmit.

On the contrary; Mahmud and Hamdi (2014) have shown that FBSs can achieve

higher capacity and enhance indoor coverage at a lower cost. The distance between the transmitter and the receiver is shortened; in which the interference probability minimizes. Meanwhile; Fractional Frequency Reuse (FFR) mechanism has been proposed as an InterCell Interference Coordination (ICIC) technique in the Orthogonal Frequency Division Multiple Access (OFDMA) based network; to improve the communication systems spectral efficiency with low complexity; since it can efficiently employ available sub-bands.

There are several pieces of papers (Chang *et al.*; 2009; Hassan & Assaad; 2009) that focus on optimizing the FFR mechanism through the use of advanced methods such as the graph theory (Chang *et al.*; 2009) and the convex optimization technique (Hassan & Assaad; 2009) to maximize network performance. Additional work by Han *et al.* (2008) found the optimal resource allocation method to reduce Co-Channel Interference (CCI) and increase spectral efficiency. In this paper; a new frequency partitioning approach and sub-bands allocation scheme has been proposed to improve the system performance and increase system capacity using FFR.

In the next section; we explained the challenges to mitigate the interference in two-tier LTE femtocell systems and the basics of the FFR mechanism for interference management in the OFDMA based LTE femtocell system. Later; in the next step we presented a literature review of the main types of FFR methods. The proposed scheme was then presented and it was followed by the results of a comparative performance evaluation of the different FFR schemes. Finally; the conclusion was given.

2. INTERFERENCE OF MANAGEMENT AND FRACTIONAL FREQUENCY REUSE (FFR).

Due to the radio resource limitations; a two-tier macrocell and FBS network have to share the frequency spectrum; rather than splitting frequency between tiers (Chu *et al.*; 2010). The sharing could lead to signal interference; especially in the dense deployment of FBSs. This interference arises because of the duplication of resources in the neighboring cells. It has the effect of degrading the service quality of the end-users. Hence; the two types of interference in two-tier Macrocell and FBS networks are (Chandrasekhar *et al.*; 2009): Co-tier interference (Femto to Femto or macro to macro); and Cross-tier interference (Femto to macro or macro to Femto). **Figure 1** depicts two scenarios of downlink co-tier and cross-tier interference.

In Co-Tier Interference; this type of interference occurs between elements in the same tier within a network. In this case; co-tier interference occurs between neighboring FBSs that belong to the same tier. As shown in **Figure 1**; both uplink (UL) and downlink (DL) interferences exist. In UL interference; Femto user equipment (FUE) interferes with another FBS. While in downlink interference; the FBS interferes with another FUE in Co-tier interference.

Regarding Cross-Tier Interference; this type of interference occurs between elements in the two-tier network. The interference occurs between macrocells and FBSs in different tiers as shown in **Figure 1**. In UL interference; an FUE close by to the macrocell base station (MBS) interferes with it other than MUE. While in DL interference; an MBS close by to the FUE interferes with it other than FBS in cross-tier interference.

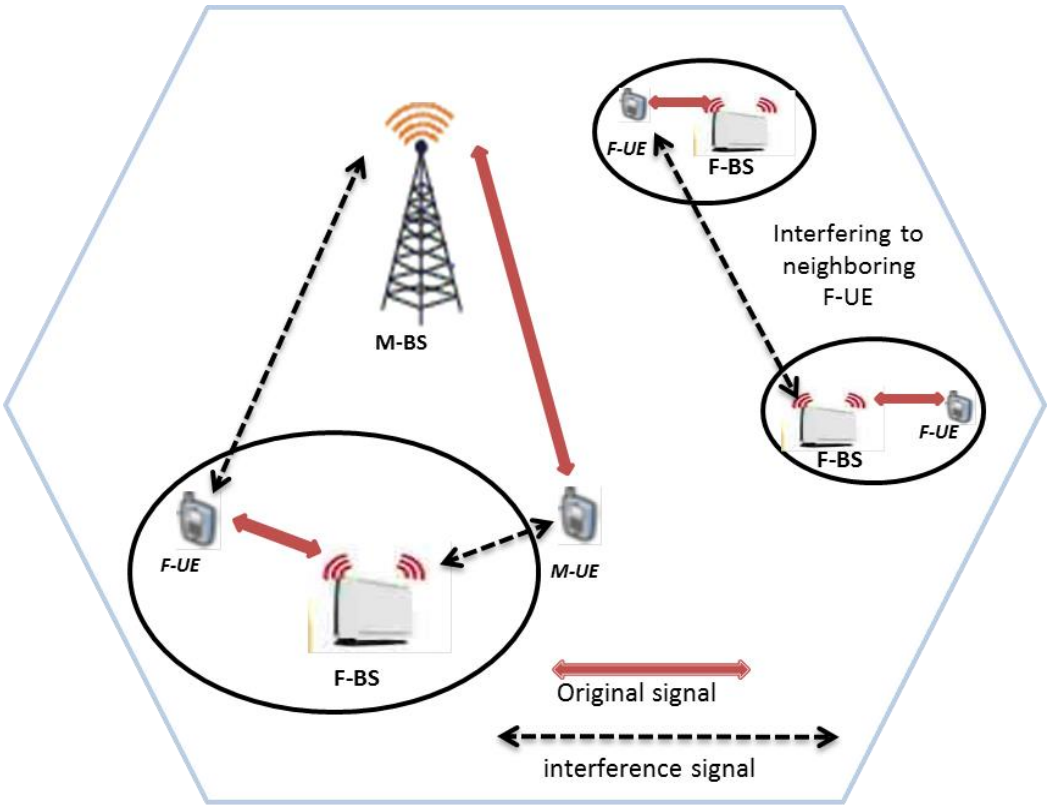

Figure 1. Interference in a two-tier network

The maximization of the network throughput with the consideration of cross-tier and co-tier interference has become a big challenge. Researchers presented different schemes for interference mitigation in two-tier macrocells and FBSs. These schemes considered uplink or downlink to be transmission. A resource allocation scheme aiming to reduce the co-tier interference is discussed and evaluated by Madan *et al.* (2010). Chandrasekhar *et al.* (2009) developed an algorithm based on power control to mitigate the cross-tier interference and increase system performance. Much work has been done based on cognitive radio technology; shared spectrum usage; partitioned spectrum usage; and modified FFR schemes to mitigate the interference in the cellular network.

In this paper; we evaluated the main types of FFR schemes proposed for mitigating interference in the two-tier Femtocell network; namely soft FFR; strict FFR; as well as a new FFR scheme; which is referred to as the proposed scheme. We performed a broad comparison of all these schemes; considering some performance metrics; including sum-rate; spectral efficiency; and outage probability in a two-tier LTE Femtocell system.

2.1. Fractional Frequency Reuse

FFR is an interference management technique to overcome the CCI and inter-cell interference (ICI) problems. The cell is logically divided according to distance into inner and outer regions; and the different regions are allocated different frequency reuse factors (FRF). Hence; the users are differentiated as cell-Centre users and cell edge ones. Cell-Centre region uses universal frequency reuse. However; the cell edge zone is divided into N FFR regions; and different frequency sub-bands are allocated to each region. By doing this; the neighboring cells' edges operate at different sets of sub-bands. This technique helps to mitigate cross-tier interference.

Figure 2 shows deployments with 3 cell-edges reuse factor. **Figure 2(a)** is the strict FFR; and **Figure 2(b)** is the Soft Frequency Reuse (SFR) deployments with 3 cell-edges reuse factor.

2.1.1.Soft Frequency Reuse

SFR has been established as a standard technique to control CCI in cellular systems. The cell area is divided into two regions; a central region where the major frequency band is available and a cell edge area where only a small fraction of the spectrum is available. The spectrum dedicated to the cell edge may also be used in the central region if it is not being used at the cell edge (Chandrasekhar *et al.*; 2008). A lack of spectrum at the cell edge may result in much-reduced capacity in that region. This is overcome by allocating high power carriers to the users in this region; thus improving the SINR and the capacity**. Figure 2(b)** represents the SFR deployment with a Reuse-3 on the cell-edge zone.

SFR divides the available spectrum into three sub-bands; f_1; f_2; and f_3; assigned to the cell edge-zone. The cell-edge regions are confined to utilize only the cell edge band. The cell-center users have access to the cell-edge band; consequently; the center zone is allowed to use the same sub-bands used by adjacent cell-edge users. For example; if sub-band f_1 is assigned to the cell-edge zone. Then the cell center zone is allowed to use sub-bands f_2; and f_3.therefore; SFR is more bandwidth efficient than strict. According to the FBSs location in the macrocell coverage area; FBSs can be divided into two main categories; namely center FBSs and edge FBSs. FBSs at any center zone are not allowed to use sub-bands allocated to the cell-edge zone of the same cell. Center FBSs are allowed to use only one sub-band; whereas edge FBSs will operate on the other two sub-bands. For instance; if sub-band f_1 is allocated to the edge zone; then edge FBSs will use either sub-bands f_2; f_3.

SFR allows the base station to use the same sub-bands used by the adjacent cell edge-users to serve the cell-center users. The dominant interfering downlinks originate from the tier-1 macrocells. Consequently; cell-center users and cell-edge users will experience interference from the first tier. Therefore; a power control factor (β) is introduced for cell-edge users to reduce inter-cell interference (Chandrasekhar *et al.*; 2008). To accomplish this; the transmit power will be $P_{center} = P$ for users located in the center-zone; and $P_{edge} = \beta P$ for users located in the edge-zone; where $\beta \geq 1$. This significantly reduces the cross-tier interference except for users near the boundary of the center and the edge zone. However; the co-tier interference would be reduced due to low FBS power.

2.1.2. Strict FFR

Strict FFR is an interference management technique. It splits one cell into two concentric regions according to distance and allocated different FRF to each region. The inner sub-cell uses universal frequency reuse. Outer sub-cell is divided into N FFR regions; and separate frequency is allocated to each region. By doing this; the neighboring cells' edges operate on different sets of sub-channels. This technique helps in the mitigation of cross-tier interference.

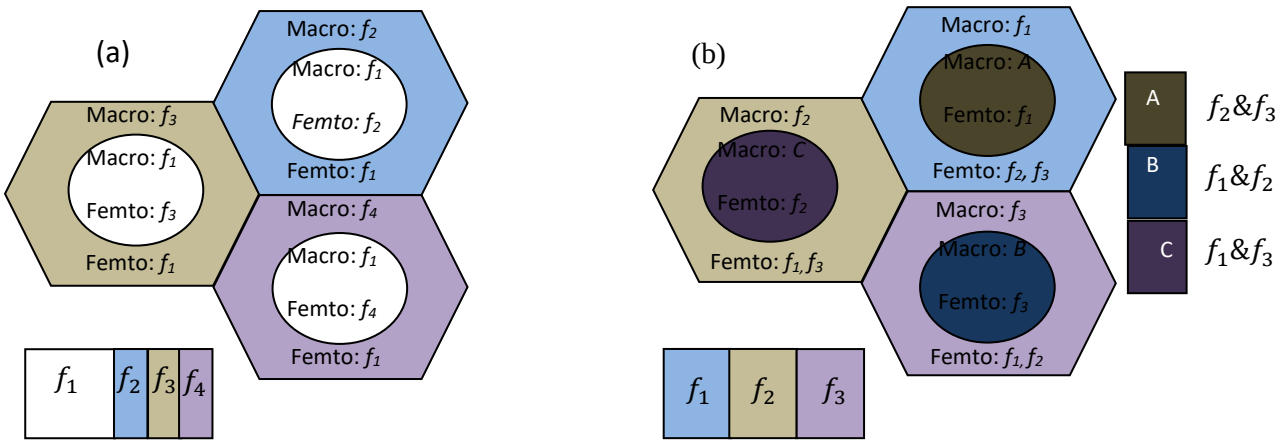

Figure 2. (a) Strict FFR and (b) SFR deployments with 3 cell-edges reuse factor.

In Strict FFR; the available bandwidth is divided into two parts; one part of them denoted by f_1 is assigned to the center-zone; whereas the second part is divided equally into several sub-bands according to FRF of the edge zone. Therefore; the total number of sub-bands equal (N+1). **Figure 2(a)** represents the Strict FFR deployment with a cell-edge reuse factor of N =3. The reuse factor of 1 is reserved for center-zone; and with N=3; sub-bands f_2; f_3; f_4 are applied to the edge-zone. The interference between inner and outer users is mitigated; due to the cell-edge users do not share any spectrum with cell-center user

In adddition; in Strict FFR; FBSs can be divided into two main categories; center FBSs and edge FBSs. FBSs are allowed to use two sub-bands per cell. Center FBSs will operate on the same sub-bands that are allocated to the cell-edge zone. Likewise; Edge FBSs occupied the same sub-bands used by macrocells in the center-zone. For example; if sub-band f2 is allocated to the edge zone; edge FBSs will operate on sub-band f1. Only one sub-band is selected by edge FBSs; and three sub-bands are excluded to mitigate cross-tier interference.

However; co-tier interference between the FBSs may become sharp; especially in the edge zone since all the adjacent cell-edge FBSs use a limited number of sub-bands. Additionally; cross-tier interference would be severe near the transition areas of the center and edge zones in a macrocell. The frequency allocation scenario between Macrocell and FBS entities comes at the expense of network spectral efficiency.

3. PROPOSED SCHEME

We propose frequency allocation schemes for hybrid macrocell- Femto networks by exploiting popular macrocell frequency allocation schemes. Our proposed allocation schemes enhance the coexistence of both types of networks. These proposed allocation schemes are assumed to be fixed as they require no coordination and no signaling between macrocells and FBSs. We compare the different proposed schemes in different FBS deployment densities using metrics such as spectral efficiency; outage probability; and average network sum-rate.

In this study; we consider that the network includes Macrocell and FBSs in the LTE system. The Macrocell is located at the center zone; and MUEs are uniformly distributed in the Macrocell. We also assumed that a large number of FBSs are deployed and configured. The number of FBSs varies between 0; and 40 and FBSs are uniformly distributed in the Macrocell. FUEs can only be located inside the coverage area of FBS. We finally assume that the available

spectrum is shared between Macrocell and FBS.

In the proposed FFR scheme; the coverage of Macrocell is divided into two parts; namely one is the center zone; and the other one is the edge zone; each containing three sectors. The center cells are denoted by Z_1; Z_2; Z_3; and the edge cells are denoted by X_1; X_2; and X_3. In order to achieve segmentation of outer regions X_1; X_2; and X_3; the Macrocell should use three sectorized antennas; each of which with a sector width of $2\pi/3$.

The available spectrum band is separated into two equal parts. The first part is denoted by SA and the other part is further divided into three subsets denoted by SB; SC; and SD. The center zone (Z1; Z2; and Z3); will be assigned to the sub-band of the SA with reuse factor 1; whereas in the edge zone; reuse factor 3 is used. The sub-bands SB; SC; and SD are applied in X1; X2; and X3 regions**.**

Figure 3 describes the distribution of frequency sub-bands for the full band into the Macrocell and FBS.

More specifically; as shown in **Figure 4**; when FBS starts working and estimated the received signal strength indication (RSSI) for all the sub-bands (S_u). If RSSI value for sub-band S_A is the highest then FBS is located in the center region. FBS excludes not only the sub-bands which are occupied by the Macrocell in the center zone; but also the ones which are occupied by the Macrocell in the same sector. When the RSSI value for sub-band S_A is not the highest; then the FBS is located in the edge zone. The FBS selects the sub-bands; which are not occupied by the Macrocell in the same region. For instance; if FBS is in sub-area X_2; it can use only the sub-bands S_A; S_B; and S_D. And the sub-band S_C is used by the Macrocell. However; if the FBS is present in the center cell; then only sub-band S_B and S_D can be used.

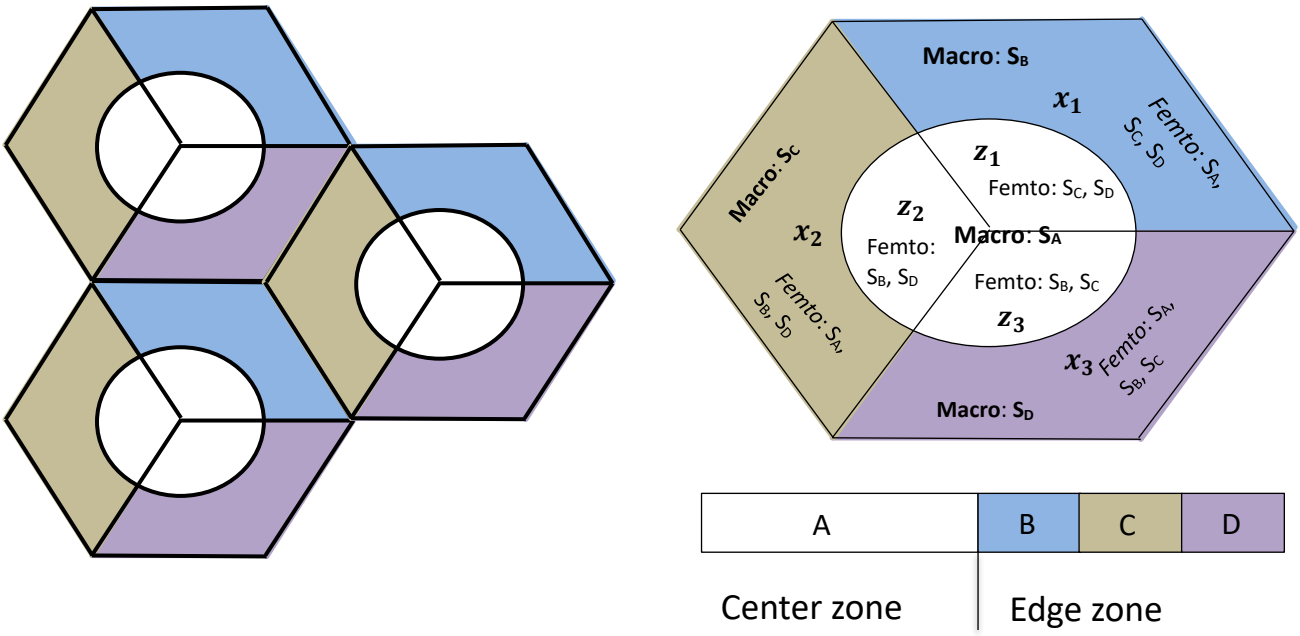

Figure 3. Proposed scheme

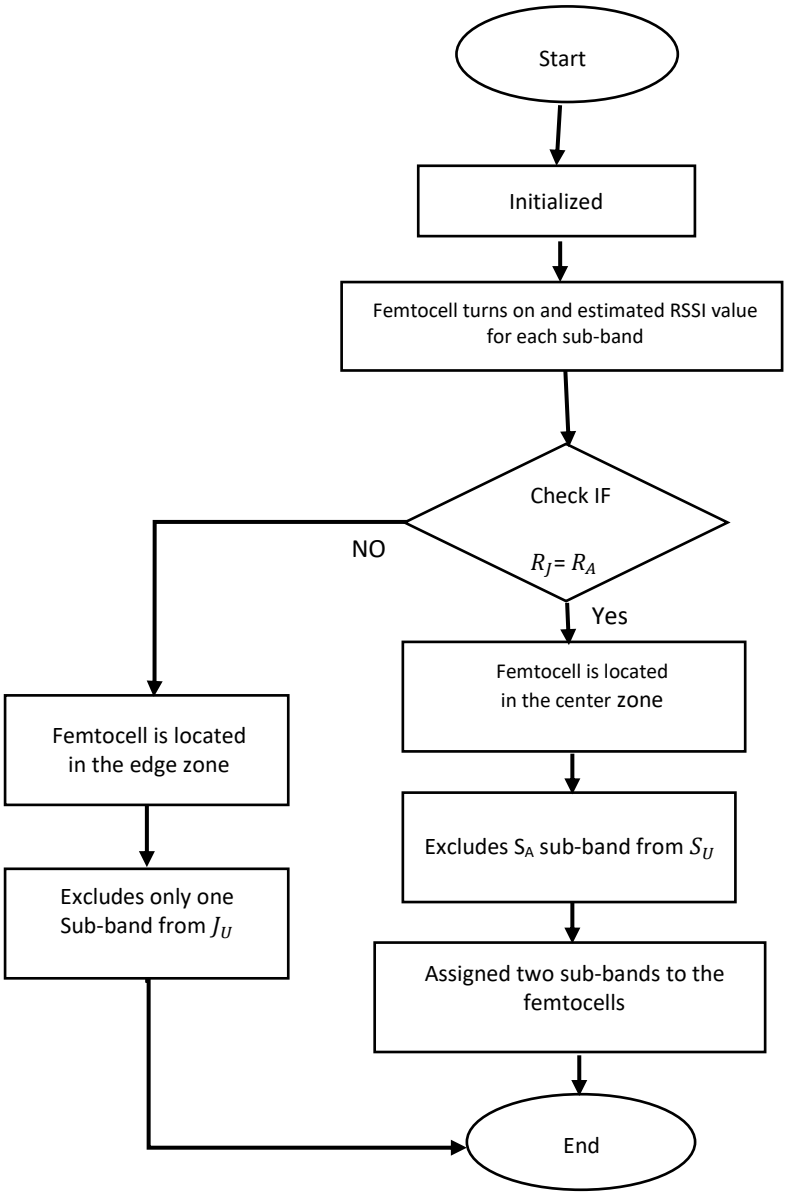

Figure 4. Flowchart of the proposed method

Due to the typical feature of OFDMA; the Macrocell is intervening with ICI. FFR is used to mitigate that interference. To prevent interference from macrocells; FBSs utilize different sub-bands. The FBS reused bands in the coverage of macrocells as much as possible. As FBS has very small transmitting power; the interference among macrocells and FBSs is considerably reduced. In order to increase the throughput of consumers in the edge region; a larger number of sub-bands are allocated to the FBSs in that region. In our scheme; with a decreased MBS coverage area; wider parts of the spectrum are available to select from. Therefore; co-tier interference is significantly decreased in comparison with other schemes. Additionally; the cross-tier interference to an FUE may only be possible on the transition region around cell boundary or from an MUE in the center-zone sub-area. The cross-tier interference-limited only by 2 adjacent macrocells.

4. PROPOSED MODEL

Consider a cellular network consisting of a number of macrocells and many FBSs. MUE is interfered with by all neighboring cells and the adjacent FBSs. Due to small transmit power; only FBSs within a certain distance to the MUE are considered adjacent. The

received SINR of a macro user m on sub-carrier x is expressed as (Lee *et al.*; 2010).

$$SINR_{m;x} = \frac{p_x^k G_{m;x}^k}{N_o \Delta f + \sum_{x` \epsilon X`} p_{x`}^k G_{m;x`}^k + \sum_{f \in F} P_f^k G_{m;f}^k} \quad (1)$$

where p_x^k *and* $p_{x`}^k$ are the transmit power of serving macrocell *x* and the neighboring macrocell *x`* respectively on sub-carrier *k*. The set *x`* represents all the interfering base stations; i.e.; base stations that are using the same sub-band as user m; which depends on the location of the MUEs and the specific FFR scheme used. *F* is the set of interfering FBSs. Here; the adjacent FBSs are defined as those FBSs which are inside a circular area of radius 60 m centered at the location of MUE m. N_o is the noise power spectral density; and Δf represents the sub-carrier spacing. $G_{m;x}^k$Is the channel gain between macro user m and serving macrocell x on sub-carrier k; which is dominantly affected by path loss; the path loss for outdoor is modeled as Ho and Claussen (2007):

$$PL_{outdoor} = 28+35 log_{10}(d) \text{ dB} \quad (2)$$

where *d* is the distance from a base station to a user in meters. The channel gain G can be expressed as

$$G_{m;x}^k = 10^{-PL_{outdoor}/10} \quad (3)$$

Similarly; $G_{m;f}^k$ is affected by both indoor and outdoor path-loss. In this case; *d* would be the Euclidean distance between an FBS *f* and the edge of the indoor wall in the direction of MUE *m*. The path loss for indoor is modeled as

$$PL_{indoor} = 38.5+20 log_{10}(d) + L_{Walls} \text{ dB} \quad (4)$$

where L_{walls} values are 7; 10; and 15 dB for light internal; internal; and external walls; respectively (Ho & Claussen; 2007). After the wall; the path-loss will be based on an outdoor path-loss model. The practical capacity of macro user *m* on sub-carrier *k* can be given by.

$$C_{m;x}^k = \Delta f . \log_2(1 + \lambda SINR_{m;x}^k) \quad (5)$$

where Δf represents sub-carrier spacing and λ is the constant referring to the target bit error rate (BER) with $\lambda = \frac{-1.5}{\ln(5BER)}$. Here we set BER to 10-6 (Santos *et al.*; 2007).

For an FUE u_f communicating with the FBS f on sub-band *K*; the received SINR of FUE u_f on sub-band *K* is similarly given by

$$SINR_{u_f;f}^k = \frac{p_f^k G_{u_f;f}^k}{N_o \Delta f + \sum_{x \epsilon X} P_x^k h_{u_f;x}^k G_{u_f;x}^k + \sum_{f` \in F`} P_{f`}^k G_{u_f;f`}^k} \quad (6)$$

where *F`* is the set of all interfering (or adjacent) FBSs and *X* is the set of interfering MBS. Here; $G_{u_f;f}^k$ represents indoor channel gain for distance d between the FUE and its serving FBS. On the other hand; $G_{u_f;x}^k$ corresponds to both indoor and outdoor path-loss model. Since the interfering signal is coming from the MBS; in the denominator; we include fading. Due to the fact that the transmission radius of the interfering FBS is small; fading is not considered for indoor propagation. Again; note that only FBSs within a certain range are considered as interference sources.

For evaluation; the average network sum-rate; spectral efficiency; and outage probability are considered.

In the Sum-Rate; The maximum achievable capacity for FUE y_f is given by

$$C_{yf;f}^k = \Delta B \cdot \log_2\left(1 + \lambda SINR_{y_f;f}^k\right) \quad (7)$$

Accordingly; the average network sum-rate R_{avg} is defined as.

$$R_{avg} = \frac{\sum_{x_m \in X_m} \sum_{k \in K} P_{x_m;m}^k C_{x_m;m}^k}{MUE_{total}} + \frac{\sum_{f \in F_A} \sum_{y_f \in Y_f} \sum_{k \in K} P_{y_f;f}^k C_{y_f;f}^k}{FUE_{total}} \quad (8)$$

where $P_{x_m;m}^k$ and $P_{y_f;f}^k$ refer to the binary sub-bands. When $P_{x_m;m}^k = 1$; it

represents that the *n*th sub-bands are assigned to the *m*th users belongs to MUE. When $P^k_{y_f;f} = 1$; it represents that the *n*th sub-bands are assigned to the *m*th users belongs to FUE.

In the spectral efficiency; The spectral efficiency is defined as the average data rate per unit spectrum. With the spectral efficiency defined as $S^k_{x_m;m} = \log_2(1 + \lambda\, SINR^k_{x_m;m})$ and $S^k_{y_f;f} = \log_2(1 + \lambda\, SINR^k_{y_f;f})$ for MUE x_m and FUE y_f; respectively; the average network spectral efficiency; Sis gave by.

$$S_{\text{avg}} = \frac{\sum_{x_m \in \mathbf{X_m}} \sum_{k \in \mathbf{K}} \Gamma^k_{x_m;m} S^k_{x_m;m}}{K_{band}} + \frac{\sum_{f \in \mathbf{F_A}} \sum_{y_f \in \mathbf{Y_f}} \sum_{k \in \mathbf{K}} \Gamma^k_{y_f;f} S^k_{y_f;f}}{K_{band}} \quad (9)$$

In the Outage Probability; outage probability affects network performance. It affects the data rate and throughput of the network. To find out the outage probability; we need a threshold value. If the outage probability is small; then the throughput increases; if the throughput increases; then the data rate increases. The outage probability P_{out} is given by Lee *et al.* (2010).

$$P_{out} = \frac{\sum_m \sum_k \delta_{m;k}\, SINR_{m;k}}{\sum_m \sum_k \delta_{m;k} SINR_{m;k}} \quad (10)$$

Where $\delta_{\text{m;k}}$ indicates failed sub-carrier assignment for user m on sub-carrier *k*. If$\delta_{\text{m;k}} = 1$; then SINR of that sub-carrier is under the SINR threshold ($\text{SINR}_{\text{m;k}} < \text{SINR}_{\text{threshol}}$).

5. SIMULATION PARAMETERS

Simulations are done with the assumption that the network consists of 7 macrocells. In order to provide adequate variation in the simulation environment; we have varied the number of FBSs from 0 to 40. The simulated scenario considered is depicted in **Figure 5**. Here a regular layout with 7 sites is designed. The dots; in **Figure 5**; are the MUEs (red color) and the FUEs (blue color) that assumed to be randomly distributed; and the different colors indicate the different sectors. We assume that the FBS formed are non-hexagonal and operate in closed access mode (only registered FUE devices will be able to access the FBS).

All the network parameters (in **Table1**) will remain constant during a simulation run. To make the results accurate; the numbers of FBSs are increased from 0 to 40 in each simulation run. The simulation parameters that will be used are summarized in **Table 1**.

When FFR is applied; the Macrocell uses a part of the frequency bands given to the central zone; and the rest is given to the edge region. A two-dimensional antenna pattern is considered by the simulation. Both are omnidirectional; and sectorized antennas are set up on MBS. Each station uses three sectorized antennas with 22 W for the edge region and an omnidirectional antenna with 15 W transmit power for the center zone. For all the FBSs; the transmitting power is 100 mW.

Table 1. Simulation Parameters

Parameters	Values	
	Macro	**Femto**
Cellular layout	Hexagonal grid	a circular area
Number of cells	7	0-40/macro
Cell coverage	280 m	30 m
BS transmit power	FFR: 15; 22 W	13dBm (100mW)
Number of users in one macrocell coverage	50	40
Channel Bandwidth	10MHz	
FFT size	1024	
Number of taken sub-carriers	600	
Sub-carrier spacing	15kHz	
White noise spectral density	-174dBm/Hz	
Size of the center zone	0.63 of macro coverage	
Channel model (Path loss; *PL*)	$PL_{outdoor}$= 28+35$log_{10}(d)$ dB	
	PL_{indoor} = 38.5+20$log_{10}(d)$+L_{walls} dB	

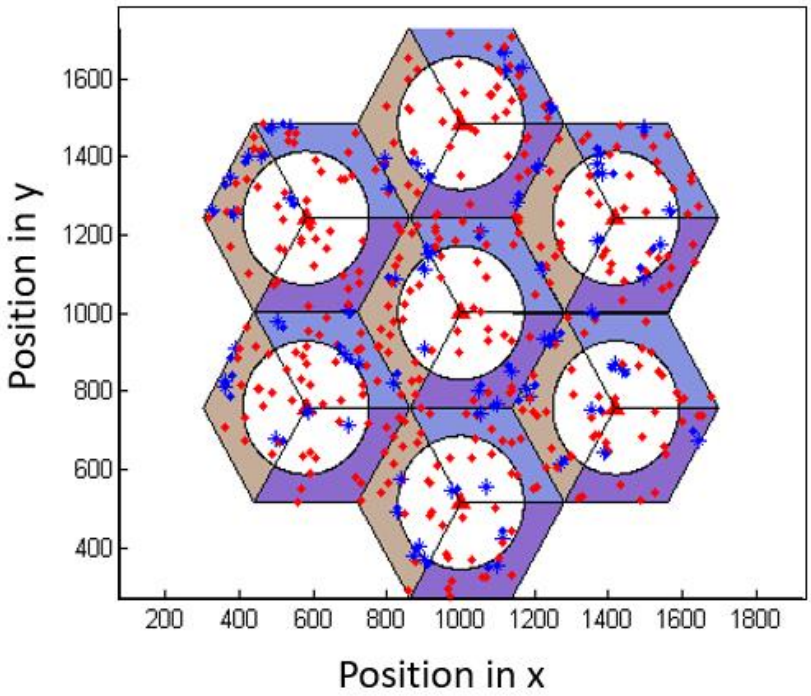

Figure 5. The considered network scenario

6. SIMULATION RESULTS

Allocating more resources to edge users than interior users is optimal in terms of a sum-rate maximization. Therefore; it is intuitive that; if users are distributed uniformly; a smaller interior radius equates to classifying more users as cell-edge users; which provides them with the benefits of interference avoidance via FFR. Also; with the proposed scheme; the usable number of sub-bands per unit area increases when compared to the other FFR schemes; and consequently; the spectral efficiency increases.

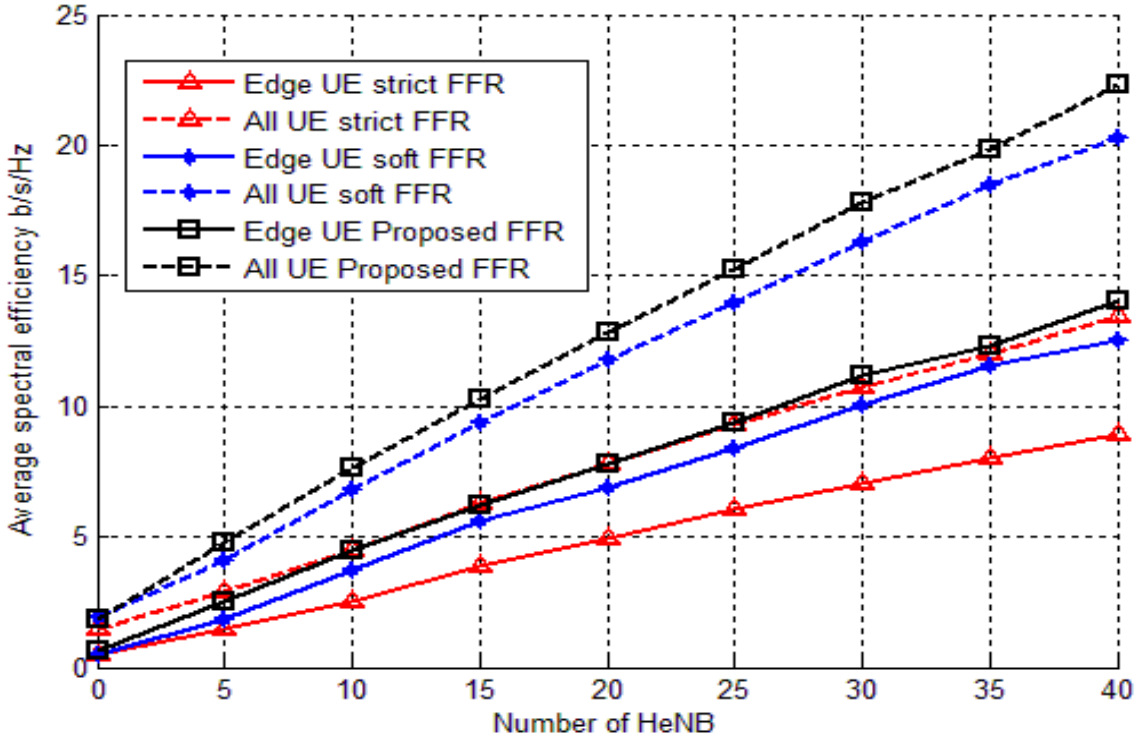

Figure 6. Average spectral-efficiency for different FFR schemes.

As shown in **Figure 6**; the average spectral efficiency for both edge UEs and all UEs improve if more FBSs are deployed within the network. The average spectral efficiency of all UEs is significantly higher than of edge UEs. In resource allocation terms; focusing on resource efficiency means optimization to the peak throughput of the cell; so the ability to allocate the sufficient number of sub-bands to users in high rate requirements can be achieved. Note that in the figure; a comparison of the spectral efficiency for the three schemes shows a higher reuse factor is used in the cell edge zone than the center zone. Results showed that; among the three schemes; for cell edge-zone UEs; the proposed scheme has higher spectral efficiency gains; coming at 41%; and 49% for strict FFR; and soft FFR schemes; respectively. In addition; for UE located in the center and edge zone; the average spectral-efficiency gains for the proposed scheme increases as the number of FBSs grows per macrocell coverage area; coming at 43% and 51% when compared to strict FFR; and soft FFR schemes; respectively.

The average sum rates of the network for different FFR schemes are given in **Figure 7**. For the proposed scheme; as the number of FBSs increased; the overall average sum-rate grow since frequency bands are reused many times repeatedly. It is due to decreasing cross-tier and co-tier interference; thereby the SINR achieved by the proposed scheme is much higher than other schemes. However; for MUEs; the sum-rate becomes worse; because of the interference introduced by FBSs. Among the three frequency reuse schemes; the proposed FFR offers the best overall average sum-rate; approximately 20-30 kbps higher than soft FFR. In contrast; Strict FFR provides the worst performance; where the gap between strict FFR and soft FFR becomes wider if the number of FBSs increases. For MUE; strict FFR consistently has the worst performance. However; soft FFR outperforms proposed FFR; as shown in **Figure 8**.

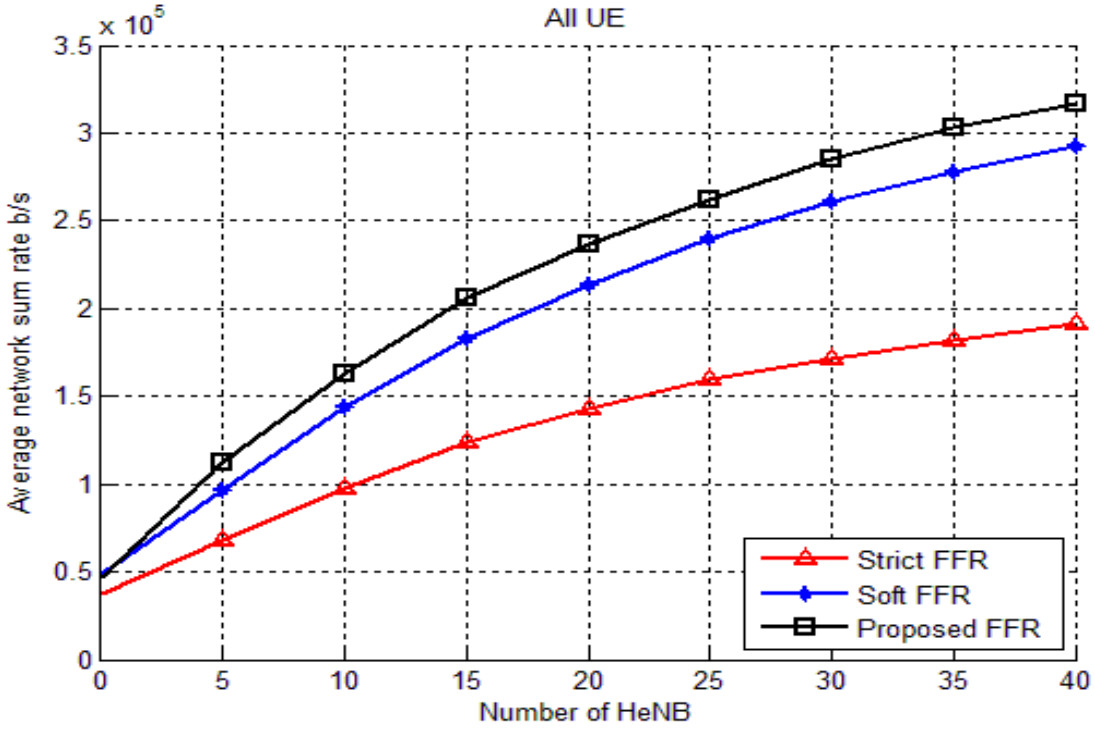

Figure 7. Average sum rate of the network for different FFR schemes.

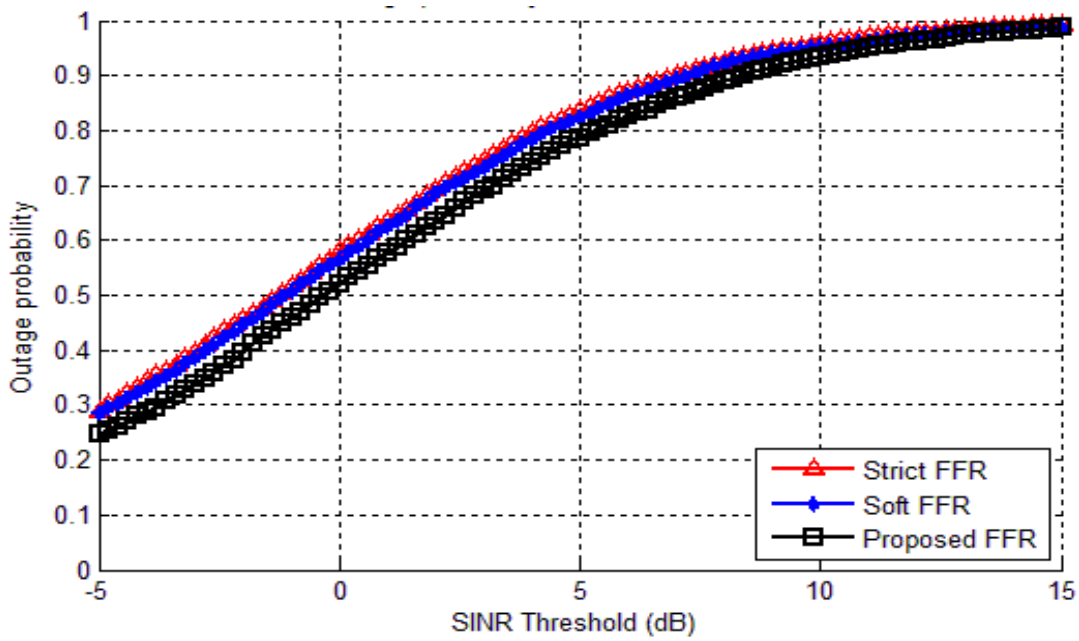

Figure 8. Outage probability for different FFR schemes.

Figure 9 shows the outage probability for three types of FFR schemes placed on the two-tiers LTE system. For a given SINR threshold; the proposed scheme indicates a lesser outage probability than the schemes under comparison. It is due to; for the proposed scheme; inter-cell interference on cell-edge UEs is limited by two neighboring MBSs. While for soft FFR schemes; inter-cell interference is caused by 6 MBSs.

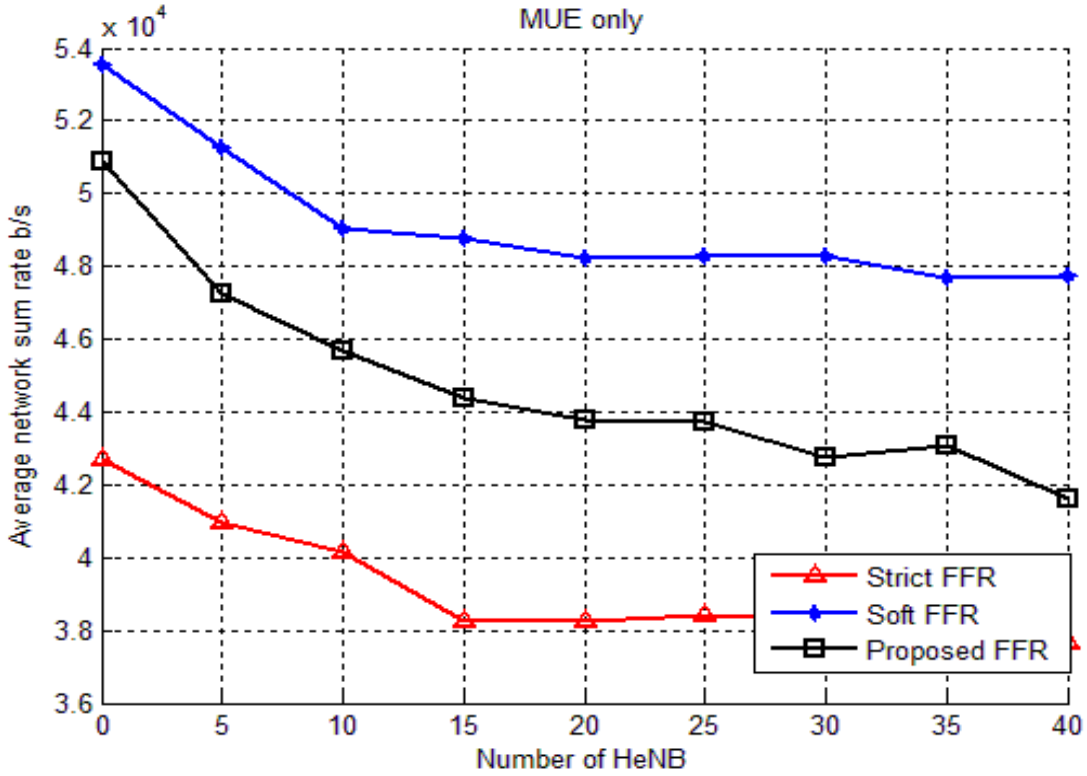

Figure 9. Average network sum-rate (MUE) of the three schemes.

When the sinr threshold increases; the outage probability becomes higher and reaches close to the other schemes. This means that the proposed scheme enables support to more users efficiently; regardless of the interference. Soft FFR and strict FFR have almost the same outage probability and higher than the outage probability of the proposed FFR. The gap closes when the sinr threshold is higher. It may also be noted that the proposed scheme decreases the outage probability even at a lower sinr threshold. Signal to interference noise ratio concerning outage probability shows that link performance is better.

7. CONCLUSIONS

LTE networks have become rapidly growing technologies in the 4th Generation (4G) cellular system; due to its high performance with respect to the data rate; delay; latency; spectral efficiency; and large coverage. However; it suffers from the ICI problem; especially for cell-edge users. Different methods are implemented to mitigate this type of interference. Interference mitigation using various fractional frequency reuse schemes is addressed in this work. We propose an FFR Technique to mitigate inter-Cell interference in the LTE femtocell system using fractional frequency reuse. Simulation results confirm that the proposed scheme is effective against co-tier and cross-tier interferences in two-tier macrocells and Femto networks. The proposed scheme proved to enhance spectral efficiency; reduce the outage probability; and increase the sum rate for all users.

8. AUTHORS' NOTE

The author(s) declare(s) that there is no conflict of interest regarding the publication of this article. The authors hereby confirm that the data and the paper are free of plagiarism.

9. REFERENCES

Bennis; M.; Giupponi; L.; Diaz; E. M.; Lalam; M.; Maqbool; M.; Strinati; E. C.; De Domenico; A.; & Latva-aho; M. (2011). Interference management in self-organized femtocell networks: The befemto approach. In *2011 2nd International Conference on Wireless Communication; Vehicular Technology; Information Theory and Aerospace & Electronic Systems Technology (Wireless VITAE)* (pp. 1-6). IEEE.

Chandrasekhar; V.; Andrews; J. G.; & Gatherer; A. (2008). Femtocell networks: a survey. *IEEE Communications Magazine*; *46*(9); 59–67.

Chandrasekhar; V.; Andrews; J. G.; Muharemovic; T.; Shen; Z.; & Gatherer; A. (2009). Power control in two-tier femtocell networks. *IEEE Transactions on Wireless Communications*; *8*(8); 4316–4328.

Chang; R. Y.; Tao; Z.; Zhang; J.; & Kuo; C. C. (2009). A graph approach to dynamic fractional frequency reuse (FFR) in multi-cell OFDMA networks. In *2009 IEEE International Conference on Communications* (pp. 1-6). IEEE.

Chu; X.; Wu; Y.; Benmesbah; L.; & Ling; W. K. (2010). Resource allocation in hybrid macro/femto networks. In *2010 IEEE Wireless Communication and Networking Conference Workshops* (pp. 1-5). IEEE.

Claussen; H. (2007). Performance of macro-and co-channel femtocells in a hierarchical cell structure. In *2007 IEEE 18th International Symposium on Personal; Indoor and Mobile Radio Communications* (pp. 1-5). IEEE.

Cullen; J. (2008). Radio frame presentation; Femtocell Europe 2008. *London; UK; June*.

Han; S. S.; Park; J.; Lee; T.-J.; Ahn; H. G.; & Jang; K. (2008). A new frequency partitioning and allocation of subcarriers for fractional frequency reuse in mobile communication systems. *IEICE Transactions on Communications*; *91*(8); 2748–2751.

Hassan; N. U.; & Assaad; M. (2009). Optimal fractional frequency reuse (FFR) and resource allocation in multiuser OFDMA system. In *2009 international conference on information and communication technologies* (pp. 88-92). IEEE.

Ho; L. T.; & Claussen; H. (2007). Effects of user-deployed; co-channel femtocells on the call drop probability in a residential scenario. In *2007 IEEE 18th International Symposium on Personal; Indoor and Mobile Radio Communications* (pp. 1-5). IEEE.

Krause; J. (2012). Future 3GPP RAN standardization activities for LTE. *Wireless World Research Forum*; *29*; 10.

Lee; P.; Lee; T.; Jeong; J.; & Shin; J. (2010). Interference management in LTE femtocell systems using fractional frequency reuse. *2010 The 12th International Conference on Advanced Communication Technology (ICACT)*; *2*; 1047–1051.

Madan; R.; Sampath; A.; Bhushan; N.; Khandekar; A.; Borran; J.; & Ji; T. (2010). Impact of coordination delay on distributed scheduling in LTE-A femtocell networks. *2010 IEEE Global Telecommunications Conference GLOBECOM 2010*; 1–5.

Mahmud; A.; & Hamdi; K. A. (2014; April). On the co-channel femtocells exclusion region in

fractional frequency reuse macrocells. In *2014 IEEE Wireless Communications and Networking Conference (WCNC)* (pp. 2306-2311). IEEE.

Santos; R. B.; Lima; F. R. M.; Freitas; W. C.; & Cavalcanti; F. R. P. (2007). QoS based radio resource allocation and scheduling with different user data rate requirements for OFDMA systems. In *2007 IEEE 18th International Symposium on Personal; Indoor and Mobile Radio Communications* (pp. 1-5). IEEE.

Shin; D.; & Choi; S. (2012). Dynamic power control for balanced data traffic with coverage in femtocell networks. In *2012 8th International Wireless Communications and Mobile Computing Conference (IWCMC)* (pp. 648-653). IEEE.