A Novel Spectrum Assignment Technique for Interference Mitigation in 4G Heterogeneous Networks

Vikram Santhanam, Mahasweta Sarkar, Santosh Nagaraj and Christopher Paolini

Abstract— **This paper proposes a novel frequency reuse scheme in a hierarchical cellular network using the long-term evolution (LTE) technology. Universal frequency reuse (UFR) is targeted for future generation multi-cellular wireless networks. However, current research has shown that implementation of UFR may lead to intolerable interference levels experienced by user equipments in the vicinity of the cell edge. In this paper, we specifically address this issue. In the proposed frequency reuse framework, the available subcarriers are partitioned into three bands and the cell is divided into two major parts- cell center and cell edge. The edge of the cell is further divided into three regions Interior Edge Band (IEB), Intermediate Band (IB) and Exterior Edge Band (EEB). The cell center uses all three frequency bands with low power and cell edge uses only one of three bands. As the proposed architecture contains well defined boundaries for the sub-bands, it is easy to deploy more femtocells at the cell edge and exploit all other frequency sub-bands that are not used. The proposed frequency reuse scheme is an effective inter-cell interference coordination (ICIC) technique for next generation wireless networks. Simulation results shows that the proposed scheme can perform better on cell edges, reduce transmission power, improve network capacity and cell throughput when compared with commonly used techniques like Soft Frequency Reuse (SFR) and Partial Frequency Reuse (PFR).**

Keywords: Long-term evolution (LTE), femtocell, macrocell, orthogonal frequency division multiplexing (OFDM), single-carrier frequency division multiple access (SC-FDMA).

I. Introduction

Of late, 3GPP standards such as Long Term Evolution (LTE) and LTE Advanced (LTE-A) are gaining popularity to fulfill the growing demand in the cellular world. Future cellular systems are expected to use orthogonal frequency division multiplexing (OFDM) techniques to meet increasing demands on wireless networks for reliable high speed data services, better throughput than conventional systems and high spectral efficiencies [3].

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With OFDM, frequency selective fading commonly encountered on wireless channels is mitigated as the multicarrier technique divides the wide band signal into narrowband subcarriers. As the subcarriers are orthogonal to each other in OFDM, intra-cell interference and ISI are also mitigated in a single cell. However, in a multi-cell environment will frequency reuse, inter-cell interference (ICI) is inevitable.

To mitigate ICI, inter cell interference coordination (ICIC) techniques have been considered by many researchers. The main approaches for the ICI mitigation are inter-cell interference cancelation, randomization and coordination. ICI cancellation focuses on interference suppression at the user equipment (UE) rather than exploiting the processing gain. ICI randomization focuses at randomizing the interfering signal(s) and suppresses interference at the UE due to the processing gain. ICI co-ordination/avoidance focuses on downlink resource management between neighboring cells by imposing restrictions on time/frequency utilization and resource management or for transmit power at a certain time/frequency. This can provide better SINR, coverage and data-rates [4].

Recent studies have shown that introduction of femtocells can greatly improve capacity even though they provide coverage over a smaller area than traditional macrocells. Multiple femtocells can be deployed at the edges of the cell to provide coverage to the so-called dead zones in a cost-efficient way. Deployment of Femtocells has potential for improved network capacity, better coverage and higher frequency reuse for future cellular networks. Femtocells aim at co-channel deployment with macrocell users, resulting in efficient frequency utilization. This will introduce co-channel interference between femtocell and macrocell users that could degrade the system data rate, capacity and throughout [2].

Interference in femtocells mainly depends on access modes. There are two types of access modes: Open Access and Closed Access. Closed access femtocells work only with a group of UEs that are subscribed to it and are allowed to connect to the femtocell base station. The macrocell UE which is near to the closed access femtocell base station will suffer high interference, whereas in open access mode the macrocell UE can handoff to the femtocell base station without any subscription and helps to improve the network coverage and capacity. Although femtocells can be placed at the cell edge to exploit the frequencies, there could be severe inter cell interference with the neighboring cells without an effective resource allocation technique.

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In this paper, we propose a technique that enhances capacity by using well defined sub-bands, reusing the frequencies at the edge of the cell and consequently deploying more femtocells at the cell edge. In the proposed architecture, the allotted spectrum is divided into three sub-bands. The cell is divided into cell center and cell edge. The cell center uses all the available bands. The edge of the cell is again further divided into three regions as interior edge band (IEB), intermediate band (IB) and exterior edge band (EEB). The frequency band is divided into three subbands so that in high interference conditions, it could be allocated with nine different combinations at the cell edge. Every band is allocated at the cell edge in such a way that the neighbor cells do not overlap in frequency. This technique will increase the data rate, capacity and reduce interference.

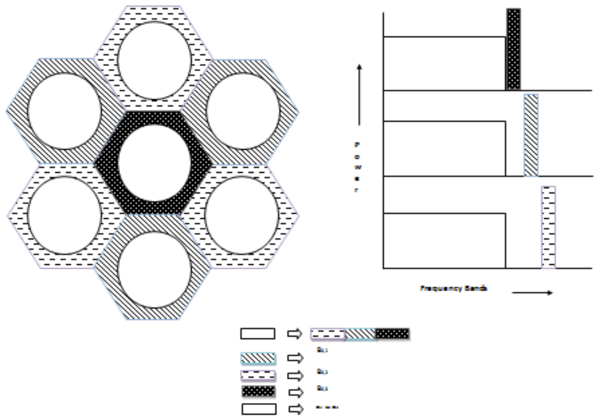

Figure 1. Power and Frequency allocation for Partial Frequency Reuse

The rest of the paper is organized as follows. In Section II, existing frequency reuse techniques are discussed. The assumptions and system model for the inter-cell interference coordination problem in LTE-A networks is explained in Section III. In Section IV, an SFR-based ICIC technique that increases frequency reuse, data rate and capacity is proposed. Simulation results are presented in Section IV and concluding remarks are drawn in Section V.

II. Existing Frequency Reuse Techiniques

In ICIC techniques, communication between neighboring cells is required to configure the architecture. These techniques are segregated into two categories, static and semi-static interference co-ordination. Static reconfiguration is done in a time scale of days whereas in semi-static, reconfiguration happens in a time scale of few seconds [4].

Some popular static inter-cell coordination techniques are Ericsson's proposal and Alcatel's proposal.

A. Ericsson's Proposal

In Ericsson's proposal, only a portion of the spectrum is used at the cell edge while the entire spectrum is used at the center of the cell. Cells use a different band than their neighbor at the edge of the cell to control interference. The frequency reuse factor is 1/3 at the cell edge [11].

B. Alcatel's Proposal

In Alcatel's proposal, the available spectrum is divided into several frequency bands called sub-bands, specifically into 7 or 9 sub-bands. The cell center uses all the bands with a low transmit power and cell edge uses any three sub-bands, such that the sub-bands will not used in the adjacent cells. The edge of the cell is divided into three sectors that are 120 degree apart from the origin. The three sub-bands are allocated individually to each sector such as sub-bands 6, 1, 2 are used in one cell, sub-bands 3, 7, 2 in the adjacent cell, and so on such that there could be 7 different combinations that can be used in the adjacent 7-cell architecture. The frequency reuse factor is 3/7 at the edge of the cell [11].

Some of the semi-static inter-cell interference techniques are Siemens' proposal, partial frequency reuse and soft frequency reuse.

C. Siemens' Proposal

In Siemens' proposal the available spectrum is divided into X number of sub-bands. Y sub-bands are utilized at the cell

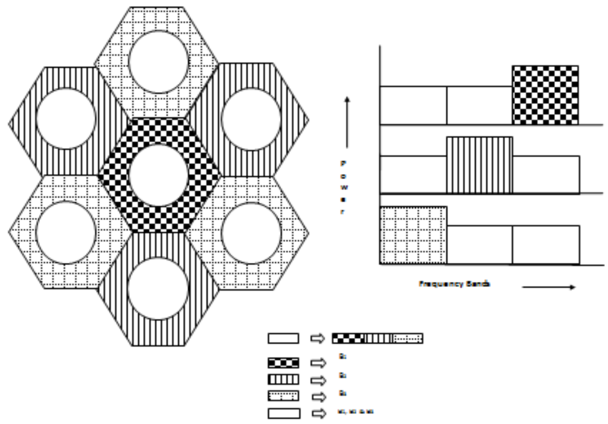

Figure 2. Power and frequency allocation scheme for Soft Frequency Reuse

edge where Y is the subset of *X* ($Y \subseteq X$) while adjacent cell edges are orthogonal to each other and *X-3Y* sub-bands are used for the cell center. The cell center can use only a portion of the available spectrum however; the cell edge can use multiple sub-bands depending upon the network load [11].

D. Partial Frequency Reuse (PFR)

In PFR, the available spectrum is divided into two-thirds and one-third of the band as shown in figure 1. The larger portion (two-thirds) of the spectrum is allocated to the cell center and the remaining one third of the spectrum is further subdivided into three parts and allocated to each adjacent cell edge. Thus, orthogonality is maintained at the cell edge and interference is reduced.

E. Soft Frequency Reuse (SFR)

In SFR, the available spectrum is divided into two bands: cell-edge and cell-center, as shown in figure 2. User equipments are classified into interior cell and exterior cell UEs, based on their location. Cell edge UEs are limited to use

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only a portion of the available bands while cell center UEs can use all available bands. One third of the available spectrum is allocated to the adjacent cell edges so that cell edge traffic have non-overlapping frequency bands and are therefore orthogonal to each other. The base station (eNB) transmits with a non-uniform power whereas, high-power is preferably assigned to UEs located at the cell edge to increase SINR and throughput and low power is assigned to cell-center UEs. The SFR schemes outlined in [5], [6] and [7] are bandwidth-efficient ICIC techniques, effective for evenly distributed traffic.

III. Proposed Frequency Reuse Techinique

We consider a heterogeneous network with a 7-cell architecture such that a set of Cells={$Cell_1$,$Cell_2$,..,$Cell_i$}, consists of a set of macro-cells $MC=\{MC_1,MC_2,..,MC_j\}$ and a set of femtocells $FC=\{FC_1,FC_2,..,FC_k\}$ that share a common set of resource blocks (PRB) $F= \{F_1,F_2,..,F_m\}$ with the user equipments $UE= \{UE_1,UE_2,..,UE_n\}$. In the proposed technique, the cell is divided linearly into cell center and cell edge. The cell edge is further divided into three equal areas namely, IB, IEB and EEB. Initially users are assumed to be equally distributed.

The entire available band B is divided into three different bands namely B_1, B_2 and B_3. Two bands (say B_1 and B_2) are used within the center of the macro-cell with low power and the third band B_3 is further divided into three sub bands (say $B_{3,1}$, $B_{3,2}$ and $B_{3,3}$) and used at the edge of the macro-cell with high power. Let us assume B_1, B_2 and B_3 are the center bands (CB) , $B_{1,1}$, $B_{2,1}$ and $B_{3,1}$ be interior edge band (IEB), $B_{1,2}$, $B_{2,2}$ and $B_{3,2}$ be intermediate band (IB) and $B_{1,3}$, $B_{2,3}$ and $B_{3,3}$ be exterior edge band (EEB) as shown in the figure 3.

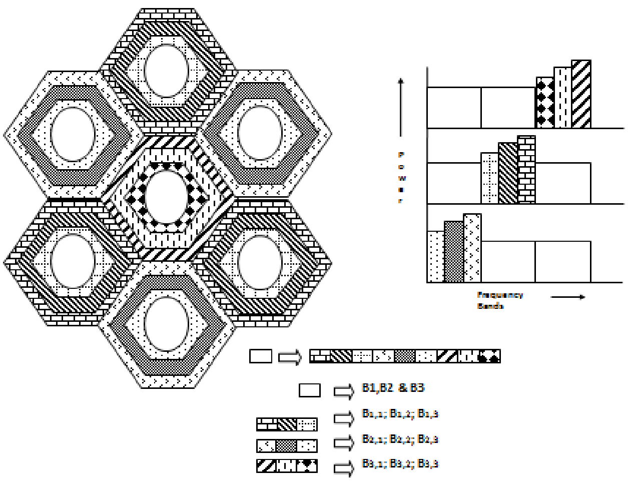

Figure 3. Power and frequency allocation scheme for Proposed Frequency Reuse Technique

Let UE_n be the user equipment of interest and it uses the same set of PRBs for both uplink and downlink. Let P_1 denote the low power band and P_2 denote a power higher than P_1. Similarly P_3 and P_4 uses higher transmit powers than P_1 and P_2. The center cell uses the edge cell bands provided they are not used in the cell edge. In the proposed algorithm, a frequency reuse factor of 1 is achieved at the cell edge.

The frequency reuse scheme is adopted in the proposed system model by deploying femtocells in the network. Femtocells are equally deployed at the cell center and at the edge of the cell. Femtocells at the cell center share the frequency bands and at the cell edge it reuses the sub-bands that are used at the center of cell so the frequency reuse factor of 1 is attained.

A. Radio Resource Allocation Algorithm

In the proposed algorithm, there are two different radio resource allocation methods that are used for HeNB and eNB. The HeNBs can share the available bandwidth with the eNB at the center of the cell. The edge has a different allocation algorithm to avoid the interference and to increase the frequency reuse. The proposed radio resource algorithm is explained as below

Proposed Radio Resource Allocation Algorithm

```
Initialize Cell_i , MC_j, FC_k and UE_n
For each UE_n
  Compute the distance from eNB's and HeNB's
  If distance (FC_k , UE_n) < 20 m
      Register with best HeNB
        If UE_n in CB
          Share CB, IB, IEB and EEB bands with other UE_n-1
        Elseif UE_n in IB
          Share CB, IB and IEB and dedicatedly use EEB sub-band other UE_n-1
        Elseif UE_n in IEB
          Share IB and EEB and dedicatedly use CB bands other UE_n-1
        Elseif UE_n in EEB
          Share CB, EEB and dedicatedly use IEB and IB sub-bands other UE_n-1
  Else
    Register with best eNB
    If band (UE_n) is CB
      Transmit at P_1
    Elseif band (UE_n) is IB
      Transmit at P_2
    Elseif band (UE_n) is IEB
      Transmit at P_3
    Elseif band (UE_n) is EEB
      Transmit at P4
End
```

- The MC_j, FC_k are initialized in the $Cell_i$ .When the UE_n is switched on, UE_n searches for the MC_j, FC_k and selects the best FC_k, ,if a HeNB is available within the 20 meters radius. If the UE_n is not able to find the better HeNB, it will camp with one of the best eNB, MC_j.

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- If the FC_k service the UE_n which is placed in the cell center, the *CB*, *IB*, *IEB* and *EEB* bands are shared between eNB and HeNB's. If FC_k is placed at the IB, *CB, IB* and *IEB* are shared and FC_k can use *EEB* dedicatedly. If FC_k service the UE_n which is placed at the *IEB* and shares the *IB* and *EEB* and dedicatedly uses *CB*. If FC_k is placed at *EEB*, it shares *CB*, *EEB* and dedicatedly use *IEB* and *IB* sub-bands.
- When the UE_n is at CB and connected to the MC_j, the UE_n transmits with a maximum power of P_1. When UE_n is moved to IB, the network instructs the UE_n to transmit at a higher power than P1 based on the distance, where maximum transmit power within IB is P2. Similarly when UE_n is moved to IEB, then the network instructs to transmit with a power higher than P2 and within the range of P3. When UE_n is moved to EEB, then UE_n can transmit to the maximum power class of P4 which is higher than P3.

IV. Simulation Results And Analysis

A. Experiental Setup

Femtocells are deployed in an area of 600m by 600m which is covered with a single macrocell. The houses are assumed to be circular with radius of 10m and it has been considered that all the houses in the cell have the same layout. It has been assumed that the pedestrian pathway is 1m away from the edge of the house and the total width of the road between the houses is 10m which includes the pedestrian pathways. Therefore the distance between the centers of the houses along one axis is 30m and it has been assumed that on the other axis perpendicular to the street, the gap between two houses is 3m thereby providing a distance of 23m between the centers of the houses along that axis.

We assume that this is a high traffic area with an increase in the number of users within the cell during peak hours. As the femtocell placement is random, femtocell location is also chosen randomly within the 10 meters of each house. It has been assumed that femtocells are approximately 30 to 40 meters apart and maximum of 8 users can be accommodated at a time if bandwidth is available.

B. Simulation Model

Simulations were run on MATLAB. As the number of users increases in the network, the macrocell would not be able to support them all. Simulations show that those users can be accommodated by the femtocell network. As the number of users increases significantly during peak hours, this simulation shows how the users are serviced in the network using the femtocells and how interference is avoided to a great extent. As the users are mobile, the location, path-loss, transmit power and received signal strength (RSS) also vary depending upon the distance from the base station. When a femtocell user experiences a very low RSS, the user is handed over to the less interfered PRB's in the next cycle or to a neighboring femtocell or to the macrocell.

C. Simulation Parameters

TABLE I. Simulation Parameters

Simulation Parameters	
Parameter	***Value***
Macrocell antenna gain (γ_{Macro})	11dBi
Macrocell output power ($Pout_{Macro}$)	50 dBm EIRP
Femtocell antenna gain (γ_{Femto})	-3dBi
Femtocell maximum Tx power	+21dBm
Adjacent channel level at UE receiver	-36 dBm
UE receiver adjacent channel Selectivity	+28 dB
Noise level at UE receiver from adjacent channel (σ)	-66 dBm
Coding gain (C_G)	25dB
EbNo	2-7 dB
Receiver signal strength at $\text{UE}_{\text{Required}}$ ($\Gamma_{Required}$)	-82 dBm
Macrocell radius (R_{max})	300 m
Femtocell Radius (r_{max})	20 m
Path Loss (PL)	83 dBm
Maximum no. of users per Femtocell	8
Maximum macrocell transmit power ($Pmax_{Macro}$)	+41 dBm
TTI duration	0.5ms
System bandwidth	20 MHZ

D. Problem Formulation

The power, Γ_{Required}, required by the UE is given by the following equation,

$$\Gamma_{Required} = \sigma - C_G + E_b N_o \quad (1)$$

where, C_G is the coding gain, $E_b N_o$ is the required signal to noise ratio and σ is the noise at the UE's receiver (including interference from the adjacent channel). The noise and interference at the UE's receiver is calculated as,

$$\sigma = Pout_{Macro} - PL - \gamma_{Femto} \quad (2)$$

where, $Pout_{Macro}$ is the Macrocell output power, γ_{Femto} is Femtocell antenna gain and PL is the path loss calculated from

$$PL = 38 + 20 * log_{10}(d_{Macro}) + L_O \quad (3)$$

with path loss component d_{Macro} that denotes the distance of each user from the eNB and the L_O represents the other losses due to the reflections from buildings. The output eNB power, $Pout_{Macro}$ is computed as,

$$Pout_{Macro} = Pmax_{Macro} + \gamma_{Macro} \quad (4)$$

where, $Pmax_{Macro}$ is the maximum eNB transmit power and γ_{Macro} denotes the macrocell antenna gain.

Area Spectral Efficiency is defined as a "measure of the quantity of users or services that can be simultaneously supported by a limited radio frequency bandwidth in a defined geographic area [1, 10]". The ASE is computed as

$$\text{ASE} = \eta / (\text{A} * \text{W}) \quad (5)$$

where, η is the sum of maximum throughput of all users, A is the geographic area and W is the frequency Bandwidth.

The radio resource block can be viewed as a frequency-time grid. The available spectrum is divided into sub-carriers where each sub-carrier (SB) occupies 15 kHz. There are 14 OFDM symbols (OS) for every 1 ms, or 14 K symbols/sec. Time domain is divided into slots of each 0.5ms duration. Each sub-frame contains two time slots and is of duration 1ms. Each frame consists of 10 sub-frames and thus it spans for 10ms (10 * 2 * 0.5ms). For bandwidth *W*,

$$\frac{\mathrm{Symbol}}{\mathrm{sec}} = \left(\frac{\mathrm{W}}{\mathrm{SB}}\right) * \mathrm{OS} \qquad (6)$$

The data rate (DR) is calculated for the above system as Obtained symbol/sec to the number of bits transmitted per symbol. For the LTE system the number of bits transmitted per symbol is six. DR is computed as,

$$\mathrm{DR} = \mathrm{Obtained}\,\frac{\mathrm{Symbol}}{\mathrm{sec}\,*}\,\mathrm{No\ of\ bits\ per\ symbol} \qquad (7)$$

For our system, 16.8 M sym/sec x 6 bits/sym = 100.8 M bit/sec. The modulation technique is assumed to be 128 QAM for the obtained maximum data rate.

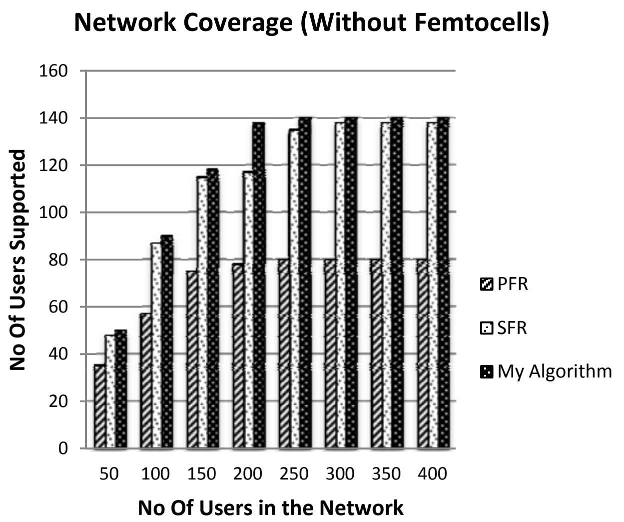
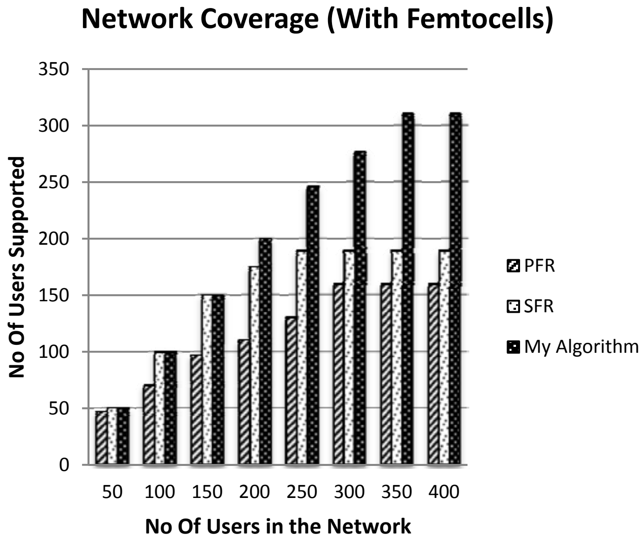


Figure 4. Datarate vs No. of Users without Femtocells

E. Simulation Results

In order to evaluate the performance of the proposed technique, the proposed techinque was simulated and the results are compared with the existing schemes.

Figure 4 shows the maximum number of users supported in the network as a function of the number of users. The proposed scheme is compared with PFR and SFR. The graph shows the maximum number of users supported by the network slowly increases and saturates at a point. This shows that the network with PFR technique cannot support more than 80 users whereas the proposed algorithm is able to support 140 users which is on par with SFR that supports 130 users without femtocells.



The above figure shows the maximum number of HeNB and eNB users supported by the network. The proposed scheme is compared with PFR and SFR with femtocells. From Figure 5, we can observe that the network is able to support 310 with the proposed scheme whereas SFR supports 180 users and PFR supports 135 users.

Figure 5. Datarate vs No. of Users with Femtocells

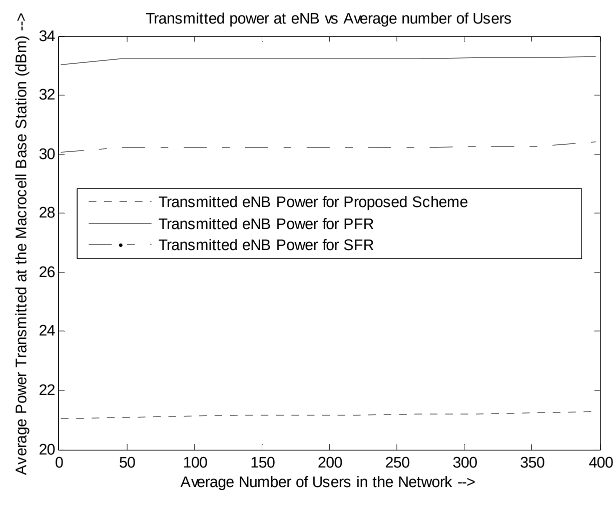


Figure 6. Average HeNB Transmit power vs Average No. of Users in the Network

The above figure shows the average transmit power of eNB. The simulation was run 10 times, each with a different user number (randomly generated) and uniformly distributed user locations. The base station transmit power is calculated based on *UEn*'s distance, noise and path-loss as explained in Section IV-C. The average of the 10 simulations is graphed and compared with SFR and PFR as shown in figure 6. With the

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proposed scheme, the transmit power is varied for the center band and each edge subband separately. Hence the average transmit power is reduced.

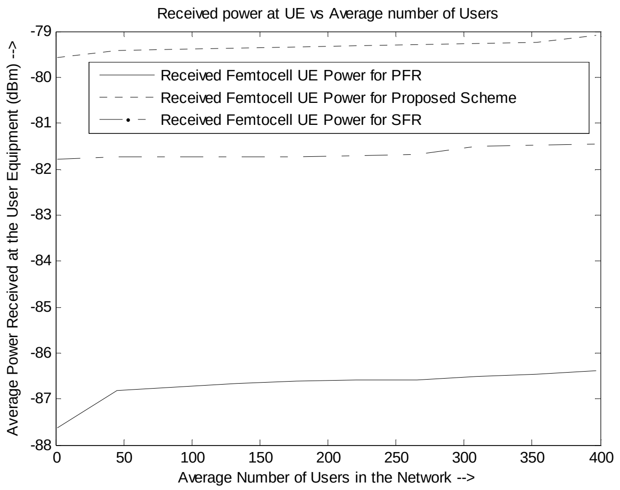

Figure 7. Average Received power at UE vs Average No. Users in Network

Figure 7 shows the average received power at the UE. The simulation was run 10 times, each with a different user number (randomly generated) and uniformly distributed user locations and each time, the corresponding UE received power was calculated. The average value is graphed and compared with PFR and SFR. The power transmitted from the HeNB is lower than eNB, however the power should be sufficient to receive the signal at the UE receiver as the receiver is closer. With the proposed scheme, even though the power is reduced in different bands as well as in the HeNB, the UE is able to receive the signals within the range -80 dBm to -79 dBm.

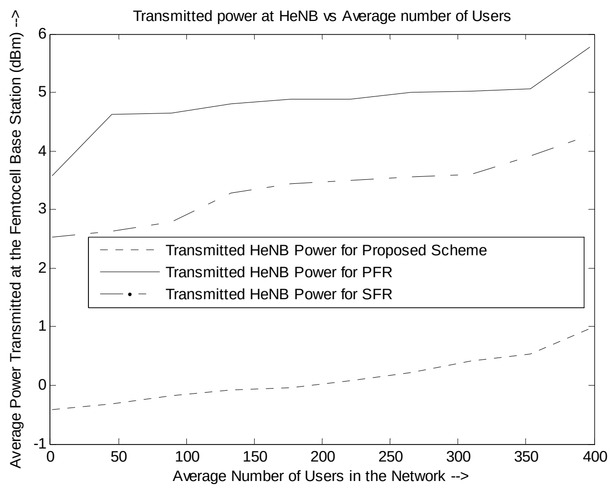

Figure 8. Average HeNB Transmit power vs Average No. of Users in the Network

Figure 8 shows the average power transmitted by the HeNB. Simulation is run for uniformly distributed user locations and the base station's transmit power is calculated. The average value is plotted and compared with PFR and SFR. In the proposed technique, the HeNBs are placed 40 meters apart, so the frequency spectrum can be reused and capacity can be increased. The power transmitted from the HeNB is lower than the eNB. When femtocells are used, more users fall within range of a femtocell base station and therefore transmission occurs over shorter ranges and with lower power. The average HeNB transmit power is arounds 1 dBm.

V. CONCLUSIONS

In this paper, we proposed a novel frequency reuse technique to mitigate inter-cell interference for future OFDMA based cellular networks. The new frequency and power allocation methods were discussed. This technique provides an efficient spectrum allocation strategy at the cell edge and center to co-ordinate with femtocells and macrocells for better overall network performance. It has been observed from our simulations that the proposed technique with femtocells guarantees significantly increased data-rate, reduced network power consumption, frequency reuse factor of 1 throughout the cell, reduced inter-cell interference and increased network capacity with a simple design to meet the service requirements of the users.

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