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Femtocell Interference Alleviation using Cluster-based Frequency Reuse Technique

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ABSTRACT

For satisfying the need of increasing number of users, their demands for the services and to provide enhanced indoor coverage, Long Term Evolution (LTE) has reveal small cellular base stations called Femtocells. These home base stations can dramatically improve voice and data coverage for the indoor subscribers. In spite of limited spectrum availability in the cellular networks subjects severe interference issues in the neighboring femtocell users use same radio band for transmission. Hence issue of interference can be raised. One of the best solutions on it is proposed methodology used in this paper that assigns distinct set of Resource Blocks (RBs) to each interfering femtocells. At first this scheme checks interference level of the Femtocell User Equipment (FUE) to identify the interfering femtocells. It then form a cluster of all interfering femtocells and apply Cluster Aware Soft Frequency Reuse (CASFR) algorithm to partition area of each femtocell into cell-center and cell-edge regions then assign non-interfering unique sets of RBs to the cell-center and cell-edge users of all the interfering femtocells. This method achieves improvement in the performance for the overall femtocell network by efficiently alleviating the uplink and downlink interference.

Keywords: LTE, Femtocell, RB, SFR, CASFR

1. INTRODUCTION

By considering the growing demands for wireless services from users, 3rd Generation Partnership Project(3GPP) evolved Universal Mobile Telecommunication Services (UMTS) into the Long Term Evolution (LTE) that is a fourth generation wireless communication standard. LTE exploited in mobile phones to achieve high ubiquitous data rate and coverage in large areas during mobility with the Orthogonal Frequency Division Multiple Access (OFDMA) transmission technique providing great benefits in handling Inter-Symbol Interference (ISI), Intra-Cell Interference also high flexibility in resource allocation can be reaped.

Due to the requirement for extensive coverage, high spectral efficiency and to improve mobile network coverage in small areas LTE has developed small low-power cellular base stations called Femtocells [1] that can be installed inside a home as a single stand-alone device or in clusters, and can significantly improve voice, data coverage and the system capacity for the indoor subscribers by effective reuse of resources in a cellular system. The femtocells are linked to the main core network using the mobile backhaul scheme this will be helpful to offload fraction of user traffic from Macro Base Station (MBS) by channeling it through the internet service provider of the user in addition to high performance and better coverage,. This freed-up capacity can be used to accommodate more users entering the network.

Since, limited spectrum availability in the cellular networks causes severe interference issues in the neighboring femtocell users and between the femtocell and Macro cell transmitting using the same resources, most User Terminals (UTs) are seriously get affected with heavy Inter Cell Interference (ICI) especially in the border areas of cells. And this causes low cell coverage and inferior system capacity. Conventional method to Figure out this problem is by increasing the cell-cluster-order to avoid the reuse of the same frequency bands in neighboring cells, which can mitigate the ICI efficiently, nonetheless at the cost of a decrease in available bandwidth for each cell. This would result in reduced cell capacity and lower system spectrum efficiency in general, and would worsen in the case of unbalanced traffic distribution among cells also not suitable for femtocell networks since the position of the femtocells is random depending on the users' service requirement. Thus, it is desirable to combat the ICI by other means.

The Cluster-Aware Soft Frequency Reuse (CASFR) scheme that effectively alleviating the downlink and uplink interference within the femtocells and the main contributions of this scheme are in contrast to other Soft Frequency Reuse (SFR) scheme, CASFR divides the bandwidth in each cell based on the number of interfering femtocell Base Stations (FBSs). Then allocate unique set of Resource Blocks (RBs) to each interfering FBS. This flexible resource allocation guarantees complete extinction of Inter Cell Interference in the LTE femtocell networks. Initially the CASFR algorithm gets knowledge about the current interference level of the Femtocell User Equipment (FUE) and then proceeds to reduce it. Hence it improves the Signal-to-Interference-and-Noise Ratio (SINR) values, which results in higher throughput for the users also increases spectrum efficiency of the network. The proposed methodology not only increases the resource efficiency but also reduced interference between Co-channel cells.

The remainder of his paper is organized as follows. Section II presents System model to be used. Proposed methodology is introduced and explained in detail in section III. In section IV simulation results are shown and discussed. Finally section V concludes this paper.

2. SYSTEM MODEL

2.1 Mathematical Equations

We consider a system with bandwidth B that is divided into N RBs. The signal power observed by receiver r from transmitter t on RB n is given by:

$$Y_n^r = P_n^t G_n^{r,t} \qquad (1)$$

Where, P_n^t is the transmit power per PRB n and $G_n^{r,t}$ is the channel gain between r and t.

2.1.1 Interference

Since the macro and femtocells share the same available resources in both time and frequency domain, the interference received at any receiver r is the aggregated interference from both. Thus I_n^r is given by:

$$I_n^r = \sum_{i \in M'} P_n^m G_n^{r,i} + \sum_{j \in F'} P_n^f G_n^{r,j} \qquad (2)$$

Where, P_n^m denotes the Macro User Equipment (MUE) transmit power in the uplink and MBS transmit power in the downlink. Likewise, P_n^f denotes uplink FUE and downlink Femto Base Station (FBS) transmit power respectively. The sets of interfering macro and femto base stations are denoted by M' and F' respectively. $G_n^{r,i}$ is the channel gain between the FBS and interfering MUE in the uplink and FUE/MUE and interfering MBS in the downlink. Similarly, $G_n^{r,j}$ is the channel gain between the FBS and interfering FUE in the uplink and FUE/MUE and interfering FBS in the downlink.

2.1.2 Signal to Interference plus Noise Ratio

The Signal-to-Interference-and-Noise-Ratio (SINR) can be determined from Equation (1) and (2) as follows:

$$SINR = \frac{P_n^t G_n^{r,t}}{\sum_{i \in M'} P_n^m G_n^{r,i} + \sum_{j \in F'} P_n^f G_n^{r,j} + \eta} \qquad (3)$$

Where, η is the thermal noise per RB n.

2.1.3 Throughput

Throughput is given by Shannon's equation that determines the achievable data rate of a channel:

$$Thp_r = B_{RB}.\log(1 + SINR_n^r) \qquad (4)$$

Where, B_{RB} is the bandwidth of a RB. From Equation (4), the total throughput of a cell can be expressed as:

$$ThP_{total} = \sum_{u=1}^{U} \sum_{n=1}^{N} Thp_{u,n} \ \frac{bits}{s} \qquad (5)$$

Where, U is the total number of users of a cell and N is the total number of PRBs assigned to the users of that cell.

2.1.4 Uplink Power Control

Uplink power control is given by:

$$P_n^t = \min\left\{p^{max}, max\left[p^{min}, p^{max}\left(\frac{L}{\alpha}\right)^{\varepsilon}\right]\right\} \qquad (6)$$

Where, p^{max} and p^{min} are the maximum and minimum transmit power per PRB. The k-percentile path loss value α determines the critical path loss above which the UE transmits with maximum power. The balancing factor ε determines how steeply the transmit power increases with increasing path loss.

2.1.5 Channel Model

Channel model is given by below equation:

$$G_n^{r,t} = 10^{\left(-\frac{LS}{10}\right)} \qquad (7)$$

Where, LS is path loss between the transmitter t and receiver r on RB n.

2.1.6 Path Loss Model

This paper uses the path loss models described in [6]. The models represent the indoor, outdoor and indoor-to-outdoor (and vice versa) channel environments and are very suitable for dense deployment of femtocells.

a) FUE or MUE to FBS:

$$LS = 15.3 + 37.6\ log_{10}\left(\frac{d}{1000}\right) \quad dBm \qquad (8)$$

Where, d is the distance between the transmitter and the receiver.

b) Indoor UE to MBS:

$$LS = 15.3 + 37.6\ log_{10}(d) + L_w \quad dBm \qquad (9)$$

L_w represents the penetration loss when signals travel through walls from indoor to outdoor (or outdoor to indoor). All above equations used are taken from reference paper [10]-[14].

3. PROPOSED SCHEME

The main objective of this proposal is to mitigate Co-channel interference between the femtocells present in the cell edge areas. Interference occurs when two or more closely located FBSs with overlapped regions transmit using the same RB. This has severe degrading affects to the SINR values of both the FBSs and the FUEs; thereby reducing their throughput to a great extent. One way to solve this issue is by allocating distinct set of sub-carriers to the users at the cell edge of each cell.

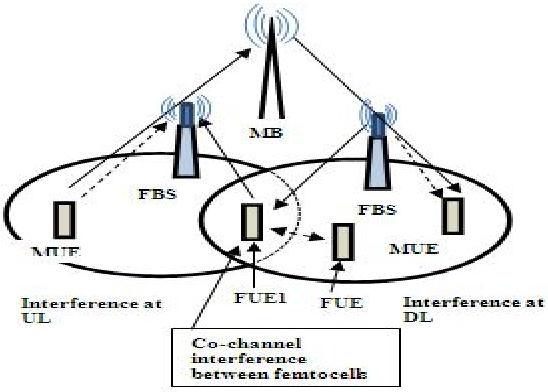

Figure 1 Interference Scenarios [11]

3.1 Downlink Interference

In the downlink, FUEs suffer interference from neighboring FBSs and the overlaying MBS. FUEs also suffer interference from neighboring MBS if it's serving FBS is located at the edge of the Macrocell. Figure 1 shows a typical downlink interference scenario in an overlaid Macro-Femtocell network. On the other hand, MUEs suffer from interference due to neighboring MBS and FBS.

3.2 Uplink Interference

As seen in Figure.1 MUEs in the transmission range of FBS cause interference in the uplink. FUEs of the neighboring cell also cause uplink interference if transmitting on the same RB.

3.3 Cluster-Aware Soft Frequency Reuse Scheme (CASFR)

This section presents CASFR algorithm for femtocell network.

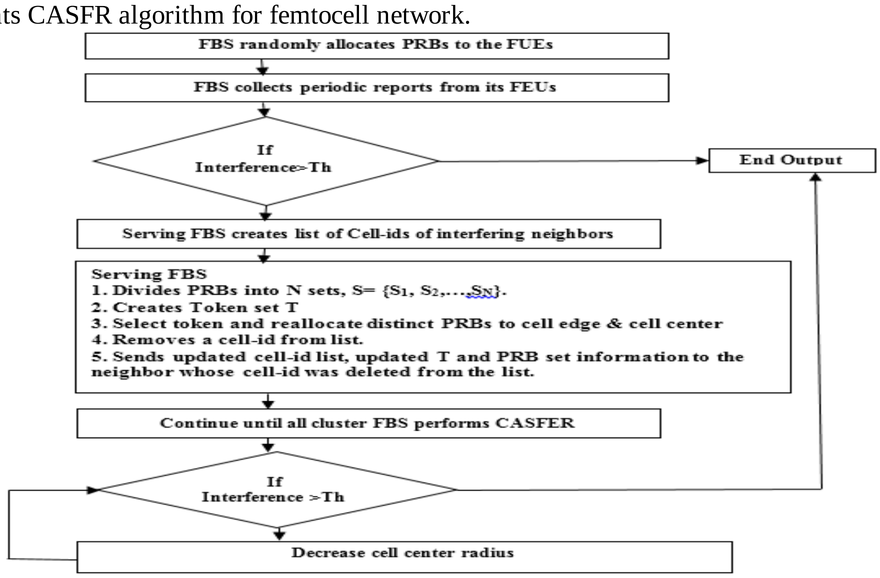

Figure 2 Cluster-Aware Soft Frequency Reuse Algorithms[11]

Algorithm consists of three main stage 1) Detection of Interference 2) Cluster formation 3) Application of soft frequency reuse. Since our aim is to mitigate ICI between the femtocells, the interference from the Macro network has been taken as a constant throughout. As per algorithm initially, every FBS uses all the available RBs and randomly allocates them among its UEs using one-to-one matrix mapping. Matrix P contains the list of RBs and matrix F contains the list of UEs. This guarantees complete avoidance of intra cell interference. Then FBS will listen to surrounding transmissions and collect information about the interference level from users attached to it with very high periodicity. If the interference experienced by any of its FUE is above a certain threshold, the serving FBS exchanges load information messages across the X2 interface with its neighbors and collects physical cell identity of the interfering FBSs to form a cluster of them. Once the cluster has been defined, the serving FBS then divides the RBs into N unique sets, S= $\{S_1, S_2, \ldots, S_N\}$, where N is the total number of interfering FBSs. Since a RB is the smallest element of resource allocation assigned by the base stations scheduler, it can be safely assumed that there will be enough RBs for creating the N sets. However, if the number of RBs is less than the number of interfering FBS, then algorithm can be applied in the same manner considering the available sub-carriers. In the next step, the serving FBS creates a Token set, T= {1, 2, …, N}, to ensure that distinct set of RBs are selected by each cell of the cluster for their cell edge. The serving FBS then selects a token ti, and a set of RB Si, for its cell edge users. The cell center RB sets are selected using the equation $\{\{\{i+j\}mod\ N\}+1\}$, j= {0, 1, 2… (N-2)}}. The cell center radius is the distance of the affected FUE from its FBS. In the final step, the serving FBS first deletes the token ti from T and randomly deletes a cell-id from the list. Then it sends out a high-interference-indicator (HII) to the neighbor with the deleted id containing the updated cell-id list, the updated token list and the information about the RB sets. This process continues until all the cells in the cluster have selected their RB sets for the cell center and the cell edge. The FBSs can further reduce their cell center radius if other FUEs experience interference above the threshold value. Also, if there is shortage of RBs in the cell center, the cell center users can borrow RBs from the cell edge only if they are not in use by the cell edge FUEs. However, the cell edge users are never allowed to borrow RBs from the cell center to ensure ICI. This ensures interference mitigation in the cluster using SFR, as illustrated in [8]. Thus the CASFR algorithm learns about the interference level of the FUEs periodically, and adjusts the cell center radius based on the observed interference level. The algorithm will start again if a FBS joins or leaves the cluster. A FBS that do not take part in any cluster enjoys the full bandwidth of the system.

4. RESULTS AND DISCUSSION

Here LTE-based femtocell network is generated for analysis purpose where femtocells are placed randomly within the macrocell. This dense femtocells environment is generated so as to form an overlapping femtocells region and all parameters taken for design of network and simulation are as per mentioned in Table1. Here in between macrocell and femtocells shared spectrum allocation technique is used where femtocells can be use same set resources as that of macrocells as per availability of them, hence there may be more chances of interference scenario is expected. Also frequency reuse factor for every femtocell is kept one so as to obtain better spectrum efficiency but that may be again lead to interference. Resource block is the smallest unit of resource has been used in LTE which has both time and frequency dimensions. Closed loop access method is used in between femtocell base station and its user's means access will be provided to authorized users.

Table 1 Design and Simulation Parameters

Parameters	Values
Macrocell Layout	3 sectors per MBS
Femtocell Layout	1 sector per FBS
Bandwidth	20MHz
Max FUE Femtocell	5
Macrocell Radius	500m
Femtocell Radius	10m
Operating frequency	2.5GHz
MBS Txp.	38dBm
FBS Txp.	20dBm
Max MUE Txp.	24dBm
Max FUE Txp.	20dBm
Min Txp.	30dBm
Cluster Size	3

Now if any femtocell user equipment which falls under the overlapping area of two femtocell may get affected by interference by neighboring FBS at downlink while FBS will suffer from neighboring FUE which is in the transmission range of that FUE at uplink. The main objective of this paper is to reduce ICI occurred at cell edge by allocating distinct set of resource blocks. Hence as interference level rise above certain threshold CASFR will be implemented. The simulation results are as shown below which are analyzes the downlink interference, SINR and throughput of the femto users as well as uplink interference, SINR and throughput of FBS. In this paper femtocell of cluster size 3 is considered.

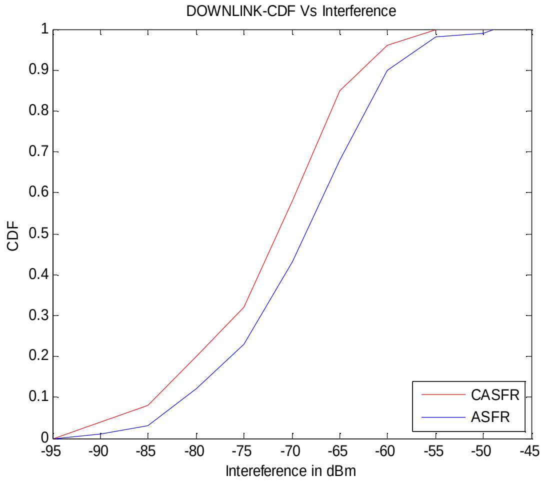

Figure 3 Downlink User Interference

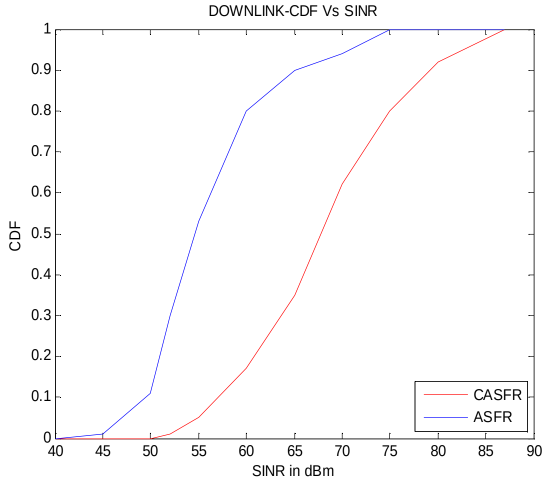

Figure 4 Downlink User SINR

For knowing about the performance of CASFR algorithm here it is compared with the previously developed Adaptive Frequency Reuse (ASFR) algorithm. All plots are plotted versus Cumulative Distributive Function (CDF) as this function is useful to study and understand random signal also its behavior. Figure.3 compares CDF of Downlink Interference of CASFR and ASFR for FUEs. The graph clearly shows that CASFR can efficiently reduce the interference than ASFR. The threshold interference level set is -45dBm, CASFR managed to reduce the interference up to -55dBm whereas ASFR reduced it up to -49dBm. Figure.4 shows graph of CDF vs. SINR of CASFR and ASFR for downlink FUEs. As interference decreases received signal strength increases which improve the system performance.

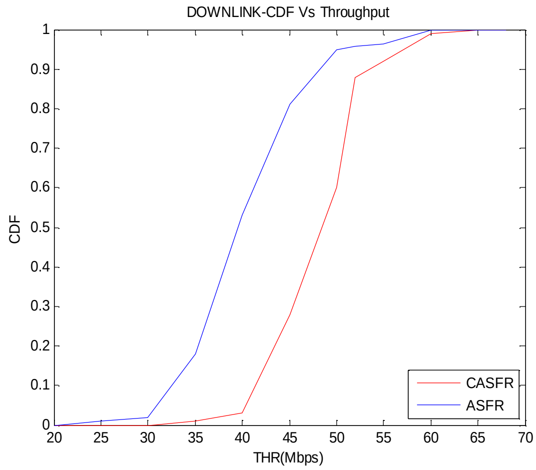

Figure 5 Downlink User Throughput

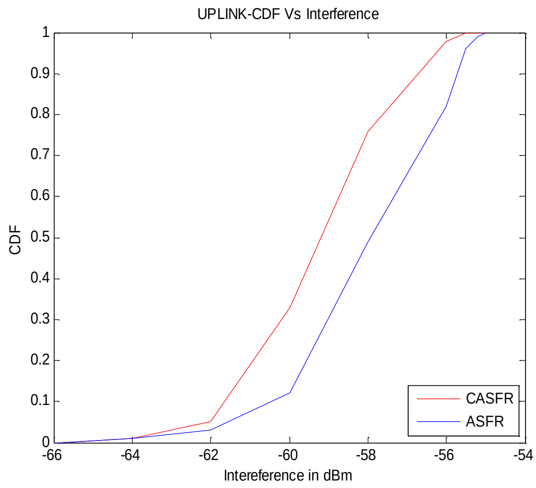

Figure 6 Uplink FBS Interference

Figure.5 shows graph comparing throughput results for CASFR and ASFR. The throughput obtained for the downlink by CASFR is around 64 Mbps whereas for ASFR is 60 Mbps. So CASFR gives greater throughput compared to ASFR, which can prove CASFR is excellent method than ASFR for Inter-cell- Interference reduction between femtocells located in dense environment. Somewhat Similar results are obtained for Uplink Femtocell Base Station (FBS). Figure.6 shows graph comparing uplink interference of CASFR and ASFR for FBSs. For Uplink CASFR is able to reduce Interference up to -55.8 dBm whereas ASFR reduces interference up to -55dBm as shown in graph above.

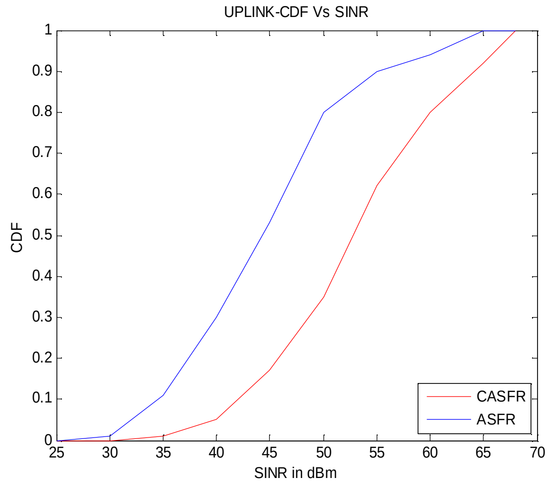

Figure 7 Uplink FBS SINR

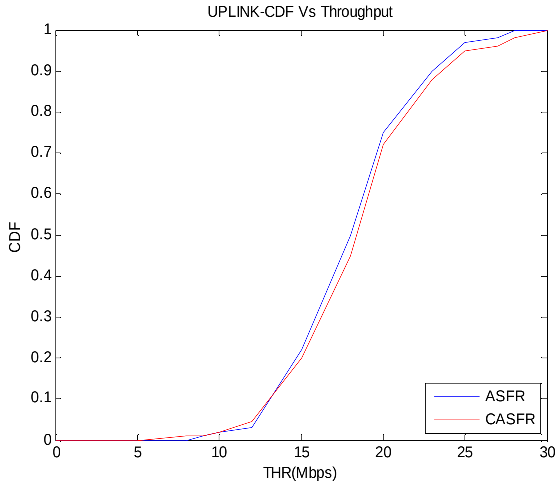

Figure 8 Uplink FBS Throughput

Figure.7 shows graph of SINR for uplink FBSs. Figure.8 shows comparison between CASFR and ASFR for throughput of FBSs. Results indicates also for uplink CASFR perform effectively as compared to ASFR. Throughput obtained by CASFR is up to 30 Mbps whereas by ASFR is 27 Mbps. Finally conclusion drawn is CASFR algorithm perform well to increase the perforce of the overall femtocell network.

5. Conclusion

In this paper a Cluster Aware Soft Frequency Reuse scheme is proposed for the 3GPP LTE femtocell networks. The scheme is triggered every time a FUE experiences strong interference from its neighboring femtocells. By allocating distinct set of RBs to the cell edge users this scheme considerably reduces the interference which automatically increases the throughput of the cell. The simulation results show the benefits of applying scheme. CASFR improves system performance significantly.

For future work, If still interference is present than we can make provision to change the RB with the neighboring cell RB present in non-interfering zone, also with the condition if this RB is not in use with this cell. So this can increase efficiency of the system.

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