ICI Reduction in Femtocell Network with CASFR Algorithm

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ABSTRACT
To provide enhance indoor coverage, Long Term Evolution (LTE) has been developed small cellular base stations called femtocells that can dramatically improve voice and data coverage for the indoor subscribers. Nevertheless, limited spectrum availability in the cellular networks causes severe interference issues in the neighboring femtocell users transmitting on the same sub-carriers. This paper proposed a Cluster-Aware Soft Frequency Reuse (CASFR) algorithm that assigns distinct set of Physical Resource Blocks (PRBs) to each interfering femtocells. According to algorithm first Femtocell Base Station (FBS) uses periodic messages from the femto user Equipment (FUE) to identify the interfering femtocells. It then divides each femtocell area into cell-center and cell-edge. Finally, it uses the CASFR algorithm to assign un-interfering sets of PRBs to the cell-center and cell-edge users of all the interfering femtocells. This is a very simple and efficient technique to mitigate uplink and downlink interference without wasting network resources thus improves performance for the overall femtocell network.

Key words
Femto-cell, LTE, SFR, CASFR.

1. INTRODUCTION
The 3rd Generation Partnership Project (3GPP) has been developed Long Term Evolution (LTE) [1] to achieve high ubiquitous data rate, high spectral efficiency and coverage in large areas during mobility with the Orthogonal Frequency Division Multiple Access (OFDMA) transmission technique. Though the system capacity is enhanced, issue of indoor coverage is still continued due to propagation path loss. Also as per the survey more than 60% traffic is generated at the indoor, Hence an alternative concept of femtocell for OFDMA system has been developed [2], [3] to get better indoor voice and data coverage. Femtocell is a low-power, low cost cellular home base station that can improve the system capacity for the indoor subscribers. The femtocells are linked to the main core network using the mobile backhaul scheme that uses the user's Digital Subscriber Line (DSL) or other internet connections. It helps to reduce load from Macro Base Station (MBS) and accommodate more users entering the network It is known that effective reuse of resources in a cellular system can highly enhance the system capacity. With a smaller frequency reuse factor (FRF), more available bandwidth can be obtained by each cell. Frequent reuse of same available spectrum in the cellular networks causes severe interference issues in the neighboring femtocell users and between the femtocell and macro cell transmitting in the same radio band. Even deployment of femtocells within macrocell is in unplanned (random) manner so often they form an overlapping region which result in frequency collision especially between neighboring cell edge users using Same PRBs or same sub-carriers while data transmission. Most User Terminals (UTs) are seriously affected with heavy Inter Cell Interference (ICI), and this causes low cell coverage and inferior system capacity. Now in order to efficiently figure out this ICI problem whilst not drastically reduce the utilization of the scarce frequency spectrum various ICI mitigation techniques has been proposed [4]-[7] in literature survey. But this conventional methods would result in reduced cell capacity and lower system spectrum efficiency in general, and would worsen in the case of unbalanced traffic distribution. Different Soft Frequency reuse (SFR) schemes successively proposed in [8]-[11] are considered most representative approach due to its flexibility and effectiveness for coordination of ICI. In this paper Cluster-Aware Soft Frequency Reuse (CASFR) algorithm is proposed that more effectively mitigates the downlink and uplink interference within the femtocells as compared to earlier schemes.

The remainder of this paper is organized as description for the system model then discussed the proposed algorithms for interference mitigation in the downlink and the uplink of the femtocells, then presented result analysis and discussion. Finally conclusions are drawn.

2. SYSTEM MODEL
In the LTE downlink the sub-carriers are split into PRBs and distributed among their UEs by the respective base stations. Thus the basic unit of resource in LTE is a PRB that has both time and frequency dimension. We consider a system with bandwidth B that is divided into N PRBs. The signal power observed by receiver r from transmitter *t* on PRB 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 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.

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 PRB n.

2.2 Throughput

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

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

Where, B_{PRB} is the bandwidth of a PRB. 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.

2.3 Uplink Power Control

Uplink transmit power 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.

2.4 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 PRB n.

2.5 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.

2.5.1 FUE or MUE to FBS:

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

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

2.5.2 Outdoor MUE to serving and interfering MBS:

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

This model represents the path loss between an MUE and its serving MBS as well as interfering channels between a MUE and an interfering MBS.

2.5.3 Indoor UE to MBS:

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

L_w represents the penetration loss when signals travel through walls from indoor to outdoor (or outdoor to indoor).

3. METHODOLOGY

3.1 Cluster-Aware Soft Frequency Reuse Scheme (CASFR)

The main objective of this proposed algorithm 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 transmits using the same PRB. This has severe degrading affects to the SINR values of both the FBSs and the FUEs thereby reducing their throughput to a great extent.

3.2 Interference Scenario at Down-Link and Up-Link

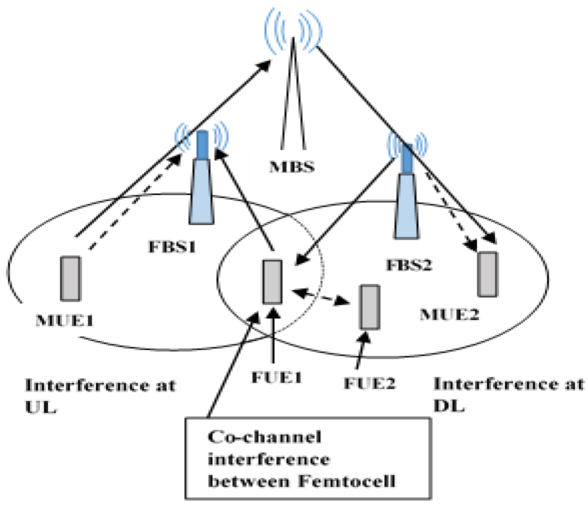

Fig.1: Interference Scenario [12]

Fig. 1, shows a typical interference scenario in an overlaid macro-femtocell network. 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. On the other hand, MUEs suffer from interference due to neighboring MBS and FBS. Whereas at uplink 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 PRB.

3.3 Interference Avoidance Scheme

Since our aim is to mitigate ICI between the femtocells, the interference from the macro network has been taken as a constant throughout in this paper.

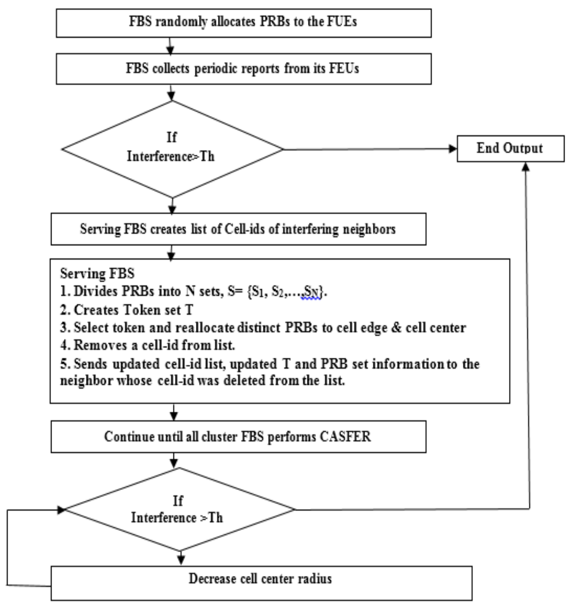

Fig. 2: Cluster-Aware Soft Frequency Reuse Algorithm

Fig.2 explains the outline of the CASFR algorithm. Initially all femtocells randomly allocate PRBs to their users by performing one-to-one matrix mapping. This will assure complete avoidance of intra cell interference. In LTE each FBS with very high periodicity collects information about the current interference level from its FUEs. 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 identify the cell-ids of the interfering FBS ds to form a cluster of them. After formation of cluster, the serving FBS divides the PRBs into N unique sets, S= $\{S_1, S_2, \dots, S_N\}$, where N is the total number of interfering FBSs. A PRB is the smallest element of resource allocation assigned by the base stations scheduler, hence it can be safely assumed that there will be enough PRBs for creating the N sets. However, if the number of PRBs 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 PRBs are selected by each cell of the cluster for their cell edge. The serving FBS then selects a token ti, and a set of PRB Si, for its cell edge users. The cell center PRB sets are selected using the equation $\{\{\{i + j\} mod\ N\} + 1\}$, j={0, 1, 2,…, (N-2)}. The distance of the affected FUE from its FBS is known as cell center radius. 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 which include information about the deleted id, the updated cell-id list, the updated token list and the information about the PRB sets. The same process get continue till all FBS in the cluster assign distinct set of PRBs to their cell center and edge. If other FUEs experience interference above the threshold value then FBSs can further reduce their cell center radius. If shortage problem of PRBs occur in case of cell center users then they can borrow PRBs from the cell edge only if they are free in that time. However, the cell edge users are never allowed to borrow PRBs from the cell center to ensure ICI.

In this way the CASFR algorithm gives us assurance of ICI mitigation between the femtocells as per [8]. 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 ANALYSIS AND DISCUSSION

Table 1: 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

The simulation environment has been designed in MATLAB and consists of around 90 MBS each having FBS in their coverage area. The value of FBS varies depending on its requirement and here it is taken only 4 for demo purpose. The MUEs are uniformly dropped in the MBS cells. The FBSs are dropped within a predetermined area of the MBS to ensure femto cell overlap. Each FBS can serve up to 4 FUEs while each MBS can serve multiple MUEs at a time for simulation purpose maximum 10 FUEs are considered and accordingly system performance is checked. We consider a closed-access FBS system where only registered users have access to a FBS. The simulation parameters are summarized in Table 1.

However, in reality, the femtocells are deployed by home users without network planning. Here a dense femto cell environment is generated where multiple FBSs are randomly deployed. Since a FBS only serves its registered users, any unregistered user located in its coverage area will suffer from interference. Along with FBS and FUE, MBS and MUE get affected by Interference but this paper only focus on interference mitigation between the femto cells users. The rest of this section analyzes the downlink interference and user throughput of the FUEs and uplink interference and throughput of FBS. We consider femtocell cluster of sizes 3. The femtocells that do not participate in a cluster are not considered. The graphs represent the performance of CASFR in all types of FUEs. That is, we consider all the FUEs irrespective of whether they lie in or out of the interference zones.

Fig. 3 shows the cumulative distribution function (CDF) of downlink interference of CASFR for high traffic region. After utilization of CASFR, the average interference of the FUEs are calculated which shows that even though numbers of users are increased the system performance is significantly better.

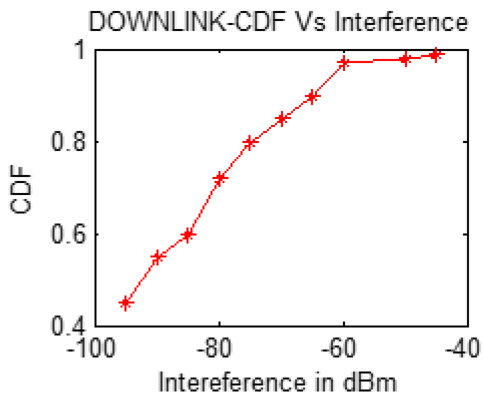

Fig 3. Downlink user Interference

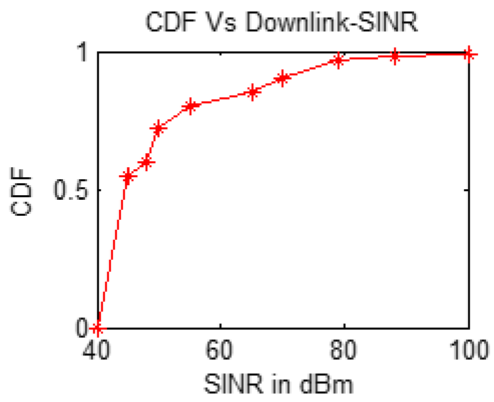

Fig. 4: Downlink user SINR

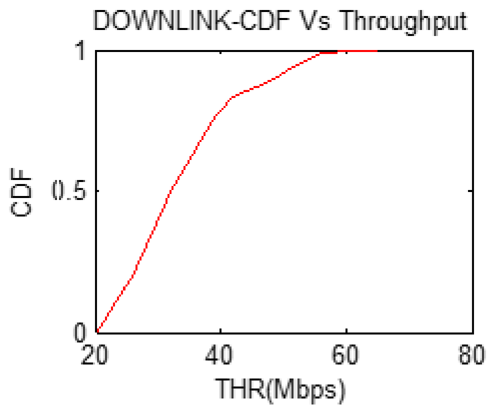

Fig. 5: Downlink user Throughput

Fig.4 shows the graph presenting the improved SINR which is effect of reduction in interference for FUEs. Fig. 5 shows the average downlink throughput of the users achieved by CASFR. Also even with low bandwidth in the cell edge area, CASFR still shows an improvement in the throughput.

Similarly Fig. 6, 7and 8 show signal behavior of uplink interference, SINR and throughput of FBS. This can mostly be attributed to the fact that CASFR reduction in interference increases the SINR values, which results in higher throughput for the users.

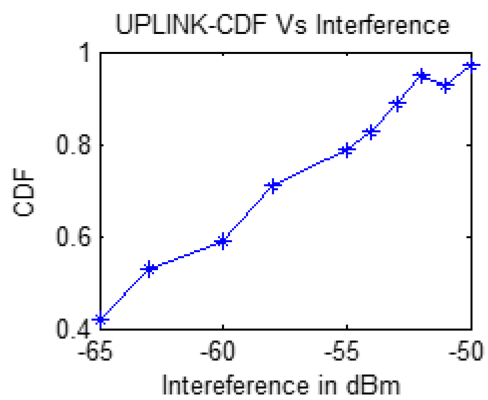

Fig. 6: Uplink Interference of FBS

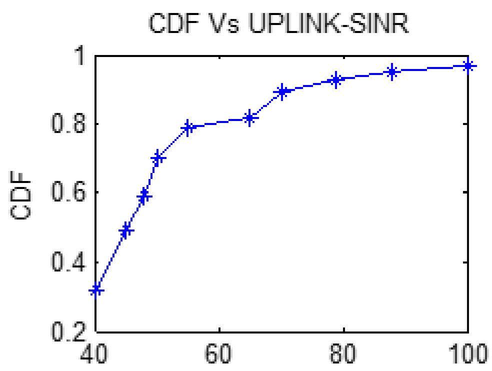

Fig.7: SINR at the Uplink of FBS

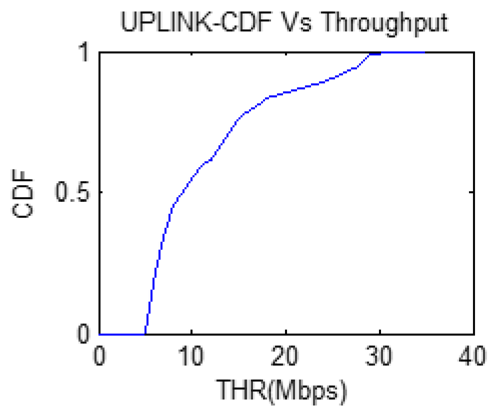

FIG.8 Uplink Throughput of FBS

5. CONCLUSION

The Cluster-Aware Soft Frequency Reuse algorithm used in this paper effectively mitigate the downlink and uplink ICI between two neighboring femtocells. This the algorithm learns about the interference level of the Femtocell User Equipment (FUE) and the fact is that it increases the Signal-to-Interference-and-Noise-Ratio (SINR) values, which results in higher throughput for the users also increases spectrum efficiency of the network. This guarantees complete obliteration of ICI in the downlink of LTE femtocell networks. The simulation results show the benefits of applying this algorithm in dense environment.

For future scope plan is to address the ICI interference reduction between femtocells for their different access mode.

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