Faculty of Electrical Engineering, University Teknology Mara, Malaysia

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Fractional Frequency Reuse Interference Mitigation in LTE Femtocell Network

Wan Nurdiyana binti Wan Mat
Faculty of Electrical Engineering,
Universiti Teknologi MARA (UiTM),40450 Shah Alam, Selangor Darul Ehsan, Malaysia

Abstract- The demand of wireless services through the cellular networks is ever-increasing. Femtocell has a strong potential for increasing the efficiency, improvements of cell coverage and network capacity of next-generation mobile networks. In Long Term Evolution (LTE) technology has developed a femtocell for indoor coverage extension. Both these problems can be solved by deploying femtocells in LTE networks. Interference occurs between newly added femtocell and pre existing macrocell as macrocell and femtocell share same frequency band. Macrocell-femtocell interference management is biggest issue when talk about LTE femtocell networks. Effective frequency allocation scheme should be used for macrocell-femtocell interference management in LTE femtocell network. Various frequency allocation schemes used for interference management in LTE femtocell networks are discussed in this paper.

Keywords: Fractional Frequency Reuse (FFR), Long Term Evolution (LTE), femtocell,

I. Introduction

In modern societies the demand for higher data rates is quite intense and users expect to achieve comparable data rates in both wired and mobile networks. This has triggered the design and development of new data-minded cellular standards of which the Third Generation Partnership Project's (3GPP's) Long Term Evolution (LTE) appears to be the most promising candidate. The LTE is technologically based on Orthogonal Frequency Division Multiple Access (OFDMA) to achieve higher data rates and enhanced spectral efficiency. Knowing that radio spectrum is limited and becoming insufficient nowadays, it is inevitable to use precious spectrum resource wisely. The integrated femtocell/macrocell environments comprise of a conventional cellular network overlaid with shorter-range self-configurable base stations (BS), called femtocells [1]. These kinds of networks offer an efficient way to improve cellular system capacity. The limiting factor in such networks is the interference between macrocells and femtocells that can suffocate the capacity due to the near-far problem. This means that femtocells should use a different frequency channel than the one of the potentially nearby high-power macrocell users (MUs). Fractional Frequency Reuse (FFR) techniques are discussed in Long Term Evolution (LTE) networks to overcome the Co-Channel Interference (CCI) problems, i.e., interference from transmitters located in neighbor cells with the same frequency bands as the reference cell of interest, and Inter-Cell Interference (ICI) problems, i.e., interference from neighboring cells. In FFR techniques the cell space is divided into two regions: inner, which is close to the macrocell BS and outer, which is situated to the cell borders.

Femtocell can be operated in three different access modes - open access mode, close access mode and hybrid access mode. In open access mode every users in femtocell coverage area is allowed to access femtocell. In close access mode only users subscribed to femtocell in femtocell coverage area are allowed to access femtocell. In hybrid access mode all users in femtocell coverage area are allowed to access femtocell but priority is given to users subscribed to femtocell. Femtocell network area are low cost, short-range BSs and low power installed by the consumer .Femtocells are small, short-ranged (10m-30 m), low powered (10mW-100 mW) access points to developed for provide the high bandwidth.

This paper proposes a dynamic mechanism that selects the optimal FFR scheme based on the relative throughput of a user compared to the throughput of the users in the same cell. This custom metric is called User Satisfaction (US) throughout this work. The proposed mechanism uses an algorithm that divides the cell into two regions (inner and outer) and calculates the US metric for successive combinations of the inner region radius and inner region frequency allocation. For each combination, besides the US metric, the algorithm calculates the per-user throughput and the cell total throughput. After these calculations, the mechanism selects the FFR deployment that maximizes the US metric.

II. FRACTIONAL FREQUENCY REUSE

In FFR, in order to ensure that the mutual interference between users and BSs remains below a harmful level, adjacent cells use different frequencies. In fact, a set of different frequencies is used for each cluster of adjacent cells. Cluster patterns and the corresponding frequencies are reused in a regular pattern over the entire service area. The closest distance between the centres of two cells using the same frequency (in different clusters) is determined by the choice of the cluster size and the layout of the cell cluster. This distance is called the frequency reuse distance.

One of the main objectives of LTE is to achieve high spectral efficiency, meaning the use of the whole of the system's bandwidth in all cells. This approach is called Frequency Reuse1 and is considered as the simplest frequency reuse scheme: all sub-bands of the available bandwidth are allocated to each cell. In Frequency Reuse 3, the system bandwidth is divided into 3 equal sub-bands; each one of these is allocated to cells in a manner that no other surrounding cell is using the same sub-band. Full frequency reuse in each cell can exempt the necessity of advance frequency planning among different cells, and the frequency reuse patterns can be dynamically adapted on a frame-by-frame basis in each cell. In this work a sub-case of these approaches is studied and analysed below.

Our main objective is to apply optimal FFR in order to improve the throughput of a user compared to the throughput of the users in the same cell and in detail, the proposed mechanism divides the cell into two regions, the inner and outer region, and selects the optimal size as well as the optimal frequency allocation between these regions with main target to maximize the user satisfaction metric.

III. PROPOSED INTERFERENCE MITIGATION METHOD

In this study, all the process is carried on by performing the steps describe in proposed algorithm. The frequency allocation is examined in terms of RBs, the minimum allocation unit in LTE both for protocol side and system resource allocation. In order to find the optimal FFR deployment (inner region radius and inner region frequency), the mechanism uses an algorithm which divides each cell into two regions and calculates the total throughput and US for the following 26 Frequency Allocations (FAs), assuming 25 RBs and that Frequency Reuse 1 and 3 are applied in the inner and the outer region respectively:

- FA_1: All (25) RBs are allocated in inner region.
  No RBs are allocated in outer region.
- FA_2: 24 RBs are allocated in inner region.
  1/3 RBs allocated in outer region
- ...
- FA_{25}: 1 RB allocated in inner region.
  24/3 RBs allocated in outer region.
- FA_{26}: No RBs allocated in inner region.
  25/3 RBs allocated in outer region.

The general case of the frequency allocation for the proposed mechanism is graphically presented in Figure 1. The cell is divided in two regions: inner and outer. In Figure 2b, N refers to the total number of RBs. This means that for the case of N = 25 RBs, there are 26 FAs in total. In the first place the proposed mechanism takes as input the network configuration, i.e. the amount of cells that will be generated per row and per column, the number of total network users, the network's bandwidth and the transmitting signal power of macrocells. Then the mechanism generates the network's deployment according to these parameters.

For each frequency allocation, the proposed mechanism calculates the per-user throughput, the cell total throughput and US. This procedure is repeated for successive inner region radius (0 to R, where R is the cell radius). After the above calculations, the mechanism selects the FFR scheme that maximizes the US.

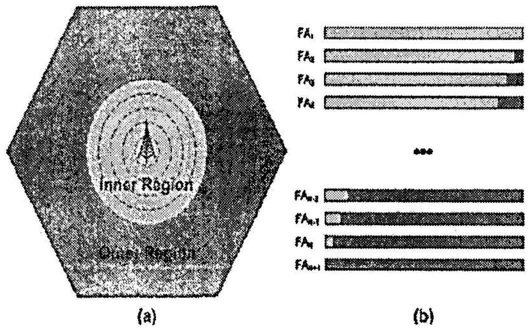

Figure 1 (a) Cell division and (b) frequency allocations of the mechanism

IV. CALCULATION

It describes the theoretical approach to calculate the SINR, throughput and US metric. It assumes that the overall network is composed of N adjacent cells. Each cell contains a number of users seeking to share a group of subcarriers. It distinguish the case where a user is found in the inner or in the outer region of the cell. In a typical OFDMA cellular network, for a user x who is served by a base station b on subcarrier n, the related SINR is given by the following equation.

$$SINR_{x,n} = \frac{G_{b,x} \cdot P_{b,n} \cdot h_{b,x,n}}{\sigma_n^2 + \sum_{j=1}^{k} G_{j,x} \cdot P_{j,n} \cdot h_{j,x,n}} \quad (1)$$

Where Gb,x refers to the path loss associated with the channel between user x and base station b, Pb,n is the transmit power of the base station on subcarrier n, hb,x,n is the exponentially distributed channel fast fading power and $\sigma 2n$ is the noise power of the Additive White Gaussian Noise (AWGN) channel. Symbols k and j refer to the set of all the interfering BSs (i.e. BSs that are using the same sub-band as user x). In detail, j is the cell index and k the number of co-channel cells. In the analysis, it assume that equal transmit power is applied, $Pb,n = P$ for all BSs. The coefficient hb,x,n is replaced by its mean value ($hb,x,n = 1$).

After the SINR estimation, it proceed with the throughput calculation. The capacity of user x on subcarrier n can be calculated by:

$$C_{x,n} = \Delta f \cdot \log_2(1 + SINR_{x,n}) \quad (2)$$

Where Δf refers to the available bandwidth for each subcarrier divided by the number of users that share the specific subcarrier. Moreover, the throughput of the user x can be expressed as follows:

$$T_x = \sum_n \beta_{x,n} \cdot C_{x,n} \quad (3)$$

Where, $\beta x,n$ represents the subcarrier assigned to user x. When $\beta x,n = 1$, the subcarrier n is assigned to user x. Otherwise, $\beta x,n = 0$.

Moreover, in order to evaluate the simulation experiments it define the metric User Satisfaction (US) as the sum of the users' throughput divided by the product of the maximum user's throughput and the total number of users (X) in the cell. This metric expresses the relative throughput of a user compared to the throughput of the users in the same cell and it physically presents how close the user's throughput is to the maximum throughput in the area.

$$US = \frac{\sum_{x=1}^{X} T_x}{\max\_user\_throughput \cdot X} \quad (4)$$

US range between 0 and 1. When US approaches 1, all users in the corresponding cell experience similar throughput, while when US approaches 0, there are big variations in the throughput achieved by the users in the cell. US has been selected as performance metric since it leads to a fairer overall network behaviour.

V. SIMULATION RESULT AND ANALYSIS

The simulation parameters that are necessary for the conduction of the experiment are presented in Table 1. Since it examine an LTE-based cellular environment all the performance requirements, link and system simulation parameters (BS transmit power, Power Noise Density, Cell radius) are in accordance with the 3GPP specifications [2]. In detail, we consider a system with 5MHz of bandwidth (i.e. LTE) divided into 25 RBs. Each RB has 12 subcarriers of 15 KHz each [3]. The scenario assumed is urban macro, which exists in dense urban areas, served by macrocells BS of 2,000 MHz frequency. In addition, we calculate the path loss according to Cost 231 Hata Model, which illustrates the highest path loss in urban areas [4,5]. Since the correlation in shadowing can significantly affect the mobility behavior and the received power, and has impact on the overall system performance, we also consider the correlation distance of shadowing, which for our modelling is set to 40 m [2].

Parameter	Value
System bandwidth	5MHz
Resource blocks #	20dBm
Subcarriers #	300
Subcarriers' bandwidth	15Hz
Carrier frequency	2000MHz
Cell radius	250m
Correlation distance	40m
Channel model	3GPP Typical urban
BS transmit power	46 dBm
Power noise density	−174 dbm/Hz

Table 1. Simulation parameter proposed

The scenario assumes that 360 static users are distributed uniformly in the topology, which consists of 16 cells (Figure 2). We will focus on one cell of the topology that is highlighted in Figure 2. The specific cell contains 24 users. As depicted in Figure 1, the selected FFR scheme that maximizes the US for the examined cell consists of two regions. The inner region (yellow) has 131 m radius and contains 6 users while the remaining cell area (red) constitutes the outer region and contains 18 users. In addition, the optimal bandwidth allocation for the inner region is 2 RBs. For the facilitation of the description of the experiments that follow, in Figure 1 number the users that are located in the examined cell.

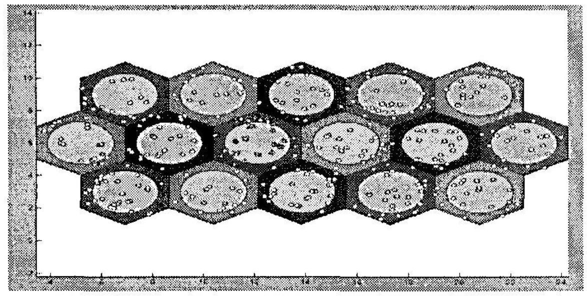

Figure 2 Optimal FFR scheme selected by the mechanism (inner region radius = 131 m)

Figure 3 presents the user satisfaction (US) for the three distinct scenarios. Many interesting observations arise from this figure. As far as the US metric is concerned, the selected FFR scheme results in higher values compared to the other two schemes. Indeed, IFR1 achieves a maximum US value equal to 0.3867 while IFR3 results in 0.5639 US. On the other hand, the selected FFR scheme achieves a maximum US value equal to 0.7116, i.e. 84.02 % increment compared to IFR1 and 26.19 % increment compared to IFR3. These percentages indicate the improved performance of the selected FFR scheme, and consequently of the proposed mechanism, in terms of US.

In order to further compare the three schemes, Figure 3 also depicts the cell total throughput that each scheme achieves. IFR1 achieves the highest cell total throughput value (9.69 Mbps), IFR3 results in 8.3Mbps cell total throughput while the selected FFR scheme achieves 8 Mbps for the selected inner region radius and frequency allocation. However, the fact that it achieves the highest US indicates that all users experience close throughput values and therefore avoids to distinct between "high-throughput" and "low-throughput" users.

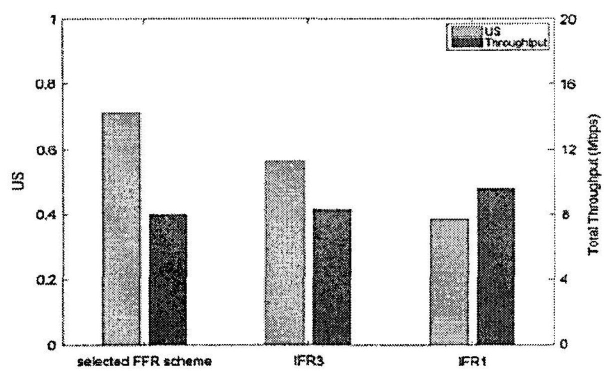

Figure 3 Comparison of IFR1, IFR3 and selected FFR scheme for the static users' scenario

In order to reveal the impact of the US maximization and in order to further compare the three frequency reuse schemes, it examine the maximum, average, and minimum user throughput that each scheme achieves (Figure 4a,b,c, respectively). As Figure 4 a, b depict, IFR1 achieves the highest values for the maximum and average user throughput throughout the simulation, while the selected FFR scheme achieves lower maximum and average values, which are close to the ones achieved by the IFR3. According to Figure 4c, the selected FFR scheme achieves the highest minimum user throughput among the three frequency reuse schemes. It is very interesting to observe, that the curves that correspond to the maximum, average and minimum throughput of the FFR scheme that is selected by the proposed mechanism are very close. This means that the mechanism assigns similar values of throughput to the users irrespectively of the region that they are located (inner or outer).To sum up, the proposed mechanism may lead to lower average cell total throughput values compared to the other two schemes; however, it allocates the available bandwidth between the two regions of the cell (inner and outer) in a "fairer" way so that all users in the cell experience similar throughput.

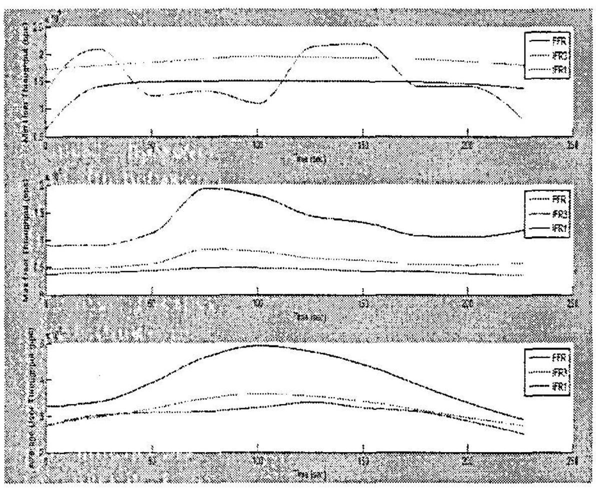

Figure 4 a Maximum, b average and c minimum user throughput versus time for the three schemes

The above observations are clearly depicted in Figure 5 that shows the throughput of the 24 users of the cell for the initial distribution (also see Figure 3). This figure also corresponds to time slot 0 s in Figure 5. According to Figure 5, the selected FFR scheme ensures that all users will experience similar values of throughput regardless of their location in the cell. More precisely, it achieves the lowest throughput for the 2nd user (0.24 Mbps) and the highest for the 15th user (0.47 Mbps).

On the other hand, IFR1 allocates the available bandwidth in a quiet "unfair" way. In this case, as Figure 5 shows, eight users (users 2,4,10,11,17 and 23) experience high throughput values, while the rest of them obtain lower values. The combination of Figure 3 and 6 reveals that these users are located close to the base station. Therefore, IFR1 favours the users that are located close to the base station (1.12 Mbps throughput for user 17 that is closest to the base station) while the users are the cell edge experience lower throughput values (0.16Mbps for user 9).

IFR3 allocates the available bandwidth in a similar way. Indeed, users 2, 4, 10, 11, 17 and 23, which are close to the base station, obtain the highest throughput values (0.59 Mbps for user 17), while user 8 that is at cell borders achieves the lowest (0.21 Mbps). To summarize, the "fairest" throughput assignment is achieved by the proposed mechanism due to the RBs' allocation between the inner and outer cell region. The mechanism ensures that all the users will experience comparable values of throughput irrespective of their location in the cell.

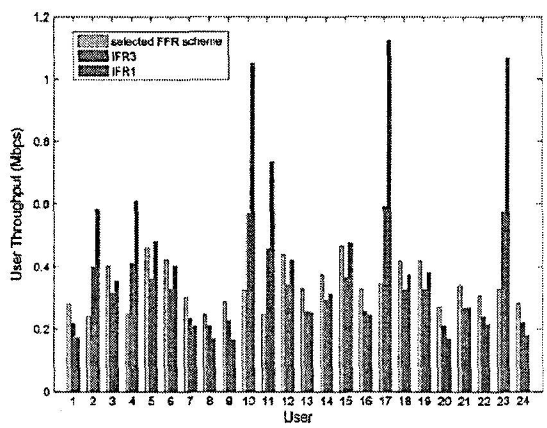

Figure 5 Per-user throughput of the three schemes for the initial distribution at 0 s.

VI. Conclusion

For the performance evaluation of the proposed mechanism, we distinguished two scenarios: one for a topology with static users and one for moving users. In the case of static users the cell total throughput and US were examined against network parameters such as inner region radius and bandwidth. Moreover, a comparison between IFR1, IFR3 and the FFR scheme that is selected by the proposed mechanism and was performed. According to the results the proposed mechanism achieves the maximum US value and therefore avoids to distinct between "high-throughput" and "low-throughput" users.

In the moving users' scenario, initially we compared the cases where the mechanism performs the adaptation process or not. The results indicated that the adaptation process leads to improved performance since it allows the update of inner region radius and frequency allocation and therefore can reflect the users' mobility. Moreover, we compared the performance of the FFR scheme that is selected by the proposed mechanism with the IFR1 and IFR3 schemes. The comparison showed that the selected FFR scheme leads to lower cell total throughput values; however, it results in higher US vales. The overall observation is that the proposed mechanism allocates the available bandwidth between the two regions of the cell (inner and outer) in a more fair way, ensuring that all users in the cell will experience similar throughput.

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