Performance Analysis of Fractional Frequency Reuse Factor For Interference Suppression In Long Term Evolution

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Abstract— **In cellular system the downlink performance is strongly limited by inter-cell interference. In order to mitigate this interference, a number of frequency reuse schemes have been proposed in literature. The current paper presents a novel fractional frequency reuse scheme combined with interference suppression for orthogonal frequency division multiple access network which are used in LTE-A and WiMAX IEEE 802.16M standardization process.FFR technique partitions each cell into two regions. Inner region and Outer region to allocate different frequency bands to each region. Since the user set inner region are less exposed to the inter cellular interference. The frequency resource in each inner region can be universally used. Based on this frequency band allocation. FFR may reduce channel interference and offer large system capacity. The entire mechanism is simulated through existing scenario.**

***Keywords-** long term evolution; fractional frequency reuse; orthogonal frequency division multiple access*

I. INTRODUCTION

The 4th Generation (4G) of wireless mobile systems is characterized by Long Term Evolution (LTE) and WiMAX technologies which continue to evolve with higher data rates and improved Quality of Service (QoS) even for the cell edge users as the main targets. In order to achieve these, MIMO antenna techniques have been incorporated in these standards. The capacity promised by MIMO systems may not be fully realizable by conventional cellular architectures without additional control of inter-cell interference which limits throughput, in particular for cell-edge users.

Several techniques with different degrees of complexity can be considered for out-of-cell interference mitigation in OFDMA systems. OFDMA provides a degree of freedom by allowing dynamic assignment of channels/subcarriers to different users at different time instances, to take advantage of the channel response variations among different users on different channels. Sub-channelization implies that a significant fraction of the power is used on only a portion of the bandwidth used to serve the weak user even though universal reuse.

Nevertheless, neighboring sectors should assign orthogonal subcarriers to cell edge users and it is important to consider interference when assigning subcarriers to users.

One of the key characteristics of a cellular network is the ability to reuse frequencies in order to increase both capacity and coverage. Fractional Frequency Reuse (FFR) is discussed in the OFDMA-based network, such as the Long Term Evolution (LTE), to overcome the Co-Channel Interference(CCI) problems. In FFR the cell space is divided into two regions: inner, which is close to the Base Station (BS) and outer, which is situated to the borders of the cell. The whole frequency band is divided into several sub-bands, and each sub band is differently assigned to inner and outer region of the cell respectively. As a result of FFR, intra-cell interference is eliminated, and inter-cell interference is substantially reduced. At the same time the system throughput is enhanced. Various reuse factors and interference mitigation levels can be achieved by adjusting either the bandwidth proportion assigned to each region or the transmission power of each band.

Main goal of this paper is to propose and evaluate an interference management FFR mechanism for OFDMA macro cell networks. The mechanism calculates the optimal FFR scheme based on two parameters: user throughput and user satisfaction. The proposed mechanism successively checks the inner cell radius and the inner cell frequency and calculates the per-user Signal to Interference plus Noise Ratio (SINR), capacity and throughput. These values are then used in order to calculate the cell mean throughput and the user satisfaction. Finally, the mechanism selects the optimal FFR scheme that either maximizes the cell mean throughput or the user satisfaction. The paper also presents several simulation scenarios in order to evaluate the proposed FFR mechanism.

II. PROPOSED FFR AND SYSTEM MODEL

We consider the downlink of an OFDMA cellular system in which users are assigned a set of subcarriers at specific time slots for transmission of packets. As already discussed, the OFDMA system supports FFR by division of subcarriers into sub bands. Fig. 1 shows the traditional FFR for LTE whereas fig. 2 shows the proposed FFR.

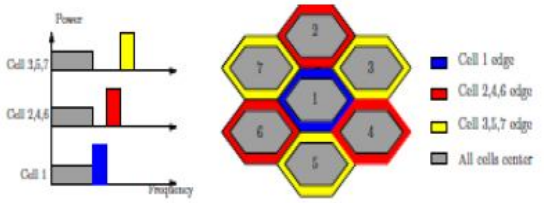

Fig 1.FFR in LTE. Frequency reuse factor is 3.

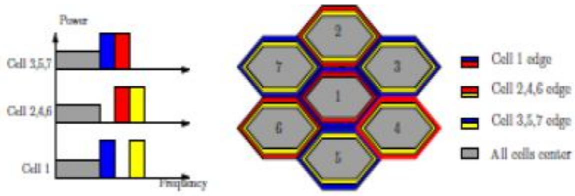

Fig 2.Proposed FFR in LTE. Only one interference is ensured in the worst case scenario. Frequency reuse factor for cell edge user is 1.5

From now on, we only focus on the outer part of spectrum which is reserved for the cell edge users. Traditional FFR ensures orthogonal allocation of sub bands in neighboring cells for cell edge users leading to zero interference for the cell edge users. However the frequency reuse factor for cell edge users increases to 3 which leads from the simple calculation $1/[(3(\frac{1}{3})+3(\frac{1}{3})+\frac{1}{3})/7]$. On the other hand, proposed FFR ensures maximum of one interference for the cell edge users and the frequency reuse factor subsequently reduces to 1.5 leading from the calculation $1/[(3(\frac{2}{3})+3(\frac{2}{3})+\frac{2}{3})/7]$. This leads to an improvement of spectral efficiency by 33%. Basing on the proposed FFR, we now discuss the system model. Suppose we have K cells (sectors) $k \in \kappa = 1..,K$, and J sub-bands for the cell edge users $j \in J = 1, ..., J$, in the system. Time is slotted, so that transmissions within the network is synchronized. The BSs employ bit interleaved coded modulation (BICM) based OFDMA system using antenna cycling i.e. the antenna used by a particular stream at a BS is randomly assigned per dimension so that each stream sees all the degrees of freedom of the channel.

A transmission in a cell, assigned to a subcarrier, causes interference to only one user in the neighboring cells that is assigned to the same subcarrier. So the received signal by use *i* in cell *k* on subcarrier *j* is written as

$$y_{k,i,j} = h_{k,i,j} + h_{k',i,j}x_{k',i',j} + z_{k,i,j} \quad (1)$$

We assume that the subcarriers are narrowband and model each subcarrier as a frequency flat fading channel so $h_{k,i,j} \in \mathbb{C}^{n_r}$ is the vector characterizing flat fading channel response from *k*-th BS to *nr* receive antennas of *i*-th user at *j*th subcarrier. This vector has complex-valued multivariate Gaussian distribution with zero mean and unit variance. Each subcarrier corresponds to a symbol from a constellation map. $x_{k,i,j} \in X_{k,i,j}$ is the desired symbol where $X_{k,i,j}$ denotes QAM constellation. $y_{k,i,j}, z_{k,i,j}, \in \mathbb{C}^{n_r}$ are the vectors of received symbols and circularly symmetric complex white Gaussian noise of double-sided power spectral density $N_0/2$ at *nr* receive antennas. $h_{k',i,j}$ is the channel from the interfering k-th BS to *i*-th user whereas $x_{k',i',j} \in X_{k',i',j}$ is the interfering symbol. The complex symbols $x_{k,i,j}$ and $x_{k',i',j}$ are assumed to be independent. The max log MAP bit metric for *p*-th bit for bit value *b* of the desired symbol $x_{k,i,j}$ in its full form is given as

$$\lambda^p(y_{k,i,j}, b) \approx \min_{x_{k,i,j} \in X^{p,b}_{k,i,j}, x_{k',i',j} \in X_{k',i',j}} \left\| y_{k,i,j} - h_{k,i,j}x_{k,i,j} - h_{k',i,j}x_{k',i',j} \right\|^2 \quad (2)$$

$X^{p,b}_{k,i,j}$ denotes the subset of the signal set $x_{k,i,j} \in X_{k,i,j}$ whose labels have the value $b \in \{0,1\}$ in the position *p*. A low complexity max log MAP detector was proposed in where it was shown that we can reduce one complex dimension in (2) i.e. the cardinality of the search space reduces form $|X^{p,b}_{k,i,j}| |X_{k',i',j}|$ to $|X^{p,b}_{k,i,j}|$. So by using this low complexity detector, the complexity of detection remains unchanged even with the introduction of one interference.

III. MECHANISM DESCRIPTION

A. Throughput and user satisfaction calculation

In this section we evaluate a methodology for calculating the SINR, throughput and user satisfaction.

Let us assume that the overall network consists of M adjacent cells. Each cell contains a number of users seeking to share a group of sub carriers. We distinguish the two cases in this, i.e., a user found within the inner region of the cell or the user being found outside the region. In a typical OFDMA cellular network, for a user *y* who is served on a base station *a* on a subcarrier m, the related SINR is given by the following equation

$$SINR_{y,m} = \frac{G_{a,y}P_{a,m}h_{a,y,m}}{\sigma_m^2 + \sum_j^k G_{j,y}P_{j,m}h_{j,y,m}}$$

In the above equation, the term $G_{a,y}$ represents the path loss associated with the channel between the user *y* and the base station *a*, $P_{a,m}$ is the transmit power in the base station on subcarrier *m* , $h_{a,y,m}$ represents the exponentially decaying channel fast fading power and σ_m^2 is the noise power of the Additive White Gaussian Noise channel. k and j represent the set of all interfering base stations. In the current analysis, we assume that the transmit power applied is equal i.e., $P_{a,m}$ =P for all base stations.

The coefficient $h_{a,y,m}$ is replaced by its mean value $h_{a,y,m}$=1.

The interference that occurs comes from the disjoint sets of downlink in the inner and the outer regions. The transmission in a cell inner region that is assigned a specific band causes interference only to inner users of other cells that are assigned the same band. It is essential to distinguish two types of base stations. The first type consists of all interfering base stations transmitting to cell inner users on the same sub-band as user *y* and the second type consists of all interfering base stations transmitting to cell edge users on the same sub band as user *y* .

Once the SINR is calculated, we evaluate the throughput. The capacity of user *y* on sub carrier *m* can be evaluated as

$$C_{y,m} = \Delta f. log_2(1 + SINR_{y,m})$$

Where Δf stands for available bandwidth for each subscriber divided by the number of users that share the specific subcarrier. Similarly, the throughput of the user y can be expressed as

$$T_y = \sum_{m} \beta_{y,m} C_{y,m}$$

Where $\beta_{y,m}$ corresponds to macro user *y*. when $\beta_{y,m}$=1, it represents a case when m is assigned to the macro user *y*, else $\beta_{y,m}$=0.

We define the term user satisfaction (US) as the sum of the users throughput divided by the product of the maximum users throughput and the number of users (Y).

$$US = \frac{\sum_{y=1}^{Y} T_y}{\max_{user_{throughput}} * Y}$$

The values of US range between 0 and 1. When US approaches 1, all the users in the corresponding cell experience similar throughput, whereas when US approaches 0, there is a big difference in the throughput of various users achieved in the cell.

```
% Mechanism for the optimization of FFR
generate network cell &users()
for r = 0:R    % inner cell radius
        for n = 0:26    % inner cell subcarriers
                for x = 1:X    % users
                        calculate sinr(x)
                        calculate_capacity(x)
                        calculate throughput(x)
                end
        calculate mean throughput(r,n)
        calculate_user_satisfaction(r,n)
        end
end
calculate ffr for max mean throughput()
calculate_ffr_for_max_ user_satisfaction()
```

The mechanism assumes a number of multicast users that are uniformly distributed in the topology. In order to find the optimal FFR scheme, the mechanism divides each cell into two regions and calculates the total throughput and US for the following 26 Frequency Allocations (FA), assuming Frequency Reuse 1 and 3 for the inner and the outer region respectively:

- FA1: All (25) subcarriers are allocated in inner region.

  No subcarriers are allocated in outer region.

- FA2: 24 subcarriers are allocated in inner region.

1/3 subcarrier allocated in outer region.

• FA25: 1 subcarrier allocated in inner region.

24/3 subcarrier allocated in outer region.

• A26: No subcarriers allocated in inner region.

25/3 subcarriers allocated in outer region.

For each FA, the mechanism calculates the per-user throughput and the mean throughput and US. This procedure is repeated for successive inner cell radius (0 to *R*, where *R* is the cell radius). Finally, the mechanism selects the optimal FFR schemes that maximize the mean throughput and US.

The pseudo-code of the proposed FFR mechanism is presented above. The complexity and the running time of the algorithm are proportional to the number of users multiplied by the number of cells in the topology. This means that that the complexity can be expressed as O(#*users*∗ # *cells*) .

IV. SIMULATION RESULTS

The simulation parameters used in the current paper are presented in the following table. We consider a system with bandwidth of 10MHz for an LTE system with 25 subcarriers each having a bandwidth of 375KHz. The path loss model considered is the Okumura model.

Table 1: Simulation parameters

Parameter	Units	Value
System bandwidth	MHz	10
Sub carriers		25
Sub carriers bandwidth	KHz	375
Carrier frequency	MHz	2500
Cell radius	m	300
Correlation distance	M	40
Channel model		3GPPLTE
Path loss	dB	Okumura
BS transmit power	dBm	43
Noise power density	dbm / Hz	-174

The simulation result in figure 3, reveals that when we intend to optimize the throughput, the maximum throughput is observed around cell radius of 90m and figure 4 reveals that the maximum user satisfaction is optimum till 60m however the user satisfaction declines as the cell radius is approaching 90 m cell range. Similarly, when we wish to optimize the user satisfaction, maximum throughput is observed around 100m range which is observed in figure 5, however the maximum satisfaction is observed at raound 150m range. On the similar lines, the figures 7 and 8 illustrate the comparative projection of throughput and user satisfaction. Figures 9 and 10 show a comparative plot of bandwidth allocation and inter cell area based on whether throughput is optimized or user satisfaction is optimized.

V. CONCLUSION

In this paper, we demonstrated the Fractional Frequency Reuse mechanism to mitigate the Inter cell Interference in Long Term Evolution using the per user SINR, capacity, throughput values to calculate the optimum cell mean throughput and user satisfaction.

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