Distributed FFR as the Novelty Solution of the Integration Femtocell and Macrocell in Cellular Network

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***Abstract*— LTE-Advanced and Femtocell are deployed by cellular operators to improve the coverage and capacity to respond the demand for higher data rates in wireless networks. Integration of femtocell into cellular network faced interference between femtocell and macrocell. Several scenarios based on Fractional Frequency Reuse (FFR) methods have been proposed to mitigate this interference, including integer fractional fraction reuse (FFR), soft frequency reuse (SFR), frequency frequency reuse orde-3 (FFR-3) and optimal static fractional frequency reuse (OSFFR). The study proposes Distributed Fractional Frequency Reuse scenario to mitigate interference and improve performance simultaneously. Distributed fractional Frequency reuse (DFFR) is an improvement of OSFFR by allocating sub-bands proportional and it is reused for each sector.**

Keywords—femtocell; Interference mitigation; LTE; LTE-Advanced; FFR; fractional frequency reuse; cellular network

I. INTRODUCTION

Long-Term Evolution (LTE) allows operators to use new and wider spectrum and 3G network complements with higher data rates, lower latency, and a flat IP-based architecture. The improvement of capacity and coverage is driven by customers needed to better access data-internet experience in cellular network.. LTE supports heterogeneous network using a mix of macrocell, picocell, femtocell and relay base station to improve spectral efficiency per unit area. [10].

It is generally known that increase capacity can be done with micro-ization of cellular networks [1], splitting a cell into a number of smaller cells. However this approach is not easy to implement because of expensive CAPEX and site acquisition issue, especially in the urban area. femtocells also called home base stations, which are short range, low cost and low power base stations, are installed by the consumer for better indoor voice and data reception. The key advantage of femtocells is that there is a very little upfront cost to the service provider. However, the another argument (1) better coverage and capacity, (2) improved macrocell reliability, (3) cost-benefit, (4) reduced subscriber turnover [1]. A femtocell is the best solution to overcome indoor blank spot and to serve unreachable customers as long as fixed broadband available as well as to improve the quality of service (QoS) delivered to customers [10].

Femtocell utilizes the same frequency allocation as macrocell that raises cross-tier interference. Several FFR methods have been proposed to mitigate this interference, such integer fractional fraction reuse (FFR), soft frequency reuse (SFR), frequency frequency reuse orde-3 (FFR-3) [3], optimal static fractional frequency reuse (OSFFR)[10]. Those methods are known as inter-cell interference coordination (ICIC) aimed at managing spectrum-frequency allocation to improve spectral efficiency with the final goal of boosting capacity and throughput.

This study is aimed at improving the distribution of sub-band allocation based on previous work [3]. This distribution aims to mitigate interference and improve performance simultaneously. Improvement of performance will be focused on macrocell because previous work just only allocates a few sub-band or about one-ninth of total spectrum allocation. Although improvement of macrocell has to compensate with the decrease of femtocell performance, but it is rationale because femtocell still has one-third allocation.

The rest of this paper is organized as follows. section II will present proposed modeling of DFFR that will be used to simulate this research, including mathematical equations. Section III will describe proposed framework. Section IV will describe result and discussion. Finally, Section V will conclude the paper from the analysis of the simulation and the future work

II. MODELING AND FORMULATION

This chapter will describe proposed improvement of a novel FFR method called FFR-6 or OSFFR [3] by using the newest method, where distributed sub-band allocation is implemented to achieve better macro user performance. Proposed FFR will be started with formulation and modeling. It consists of mathematical equations used to calculate the formula for modeling and followed by how to distribute and allocates spectrum for inner and outer region between macrocell and femtocell.

Frequency allocation aimed at ensuring the interference not to happen between macrocell and femtocell and improve performance by reuse sub-band. Frequency allocation can be described as follows:

A. *Frequency Allocation*

In Previous FFR [3], OSFFR only allocates a few sub-band for macrocell. Consequently, the performance gap between macrocell and femtocell is high. OSFFR allocate sub-band for macrocell strictly. On the other hand, proposed FFR will allocate sub-band higher for macrocell and reuse it. Accordingly, macrocell has more sub-band to increase performance.

The spectrum frequency is divided into two equal parts as illustrated in figure 1 (a). The first part of this total frequency band is given to the inner region with a reuse factor of one and the frequency band is denoted as A, while the rest frequency band is equally divided into six sub-bands, with a reuse factor of three and the frequency bands are denoted as B, C, D, E, F and G respectively.

The Cell is divided two regions, the inner region, and the outer region. Each region is divided again into six sub-regions (sectors). Totally there are twelve sectors for each cell and each sector is allocated for some different sub-bands with the adjacent regions as illustrated in figure 1 (b). This condition avoids interference between the sectors significantly. Distributed in terms of DFFR is the allocation of spectrum in all regions of fractional frequency reuse which is spreaded evenly, for the macro user and femto user. In another word, DFFR increases fairness between users, both macro- users and femto- users.

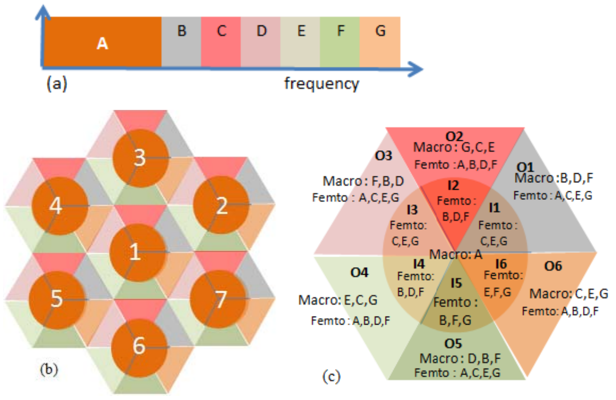

Fig. 1. DFFR Scheme

Plotting sub-band into sectors can be explained as follows: First sub-band (notated as "A") is allocated in the inner region for a whole macro user in this area. The macro user in the outer region uses the rest of the spectrum that is not used by adjacent region both in the same cell or neighbored cell. proposed FFR allocates one-third of the total spectrum to each the outer region-sector consisting of three sub-band. Each sub-band is used for some of outer region-sectors that do not intersect repeatedly, commonly known as "reuse". For example, sub-bands {B,D,F} reuse for outer region-sector 1, outer region-sector 3 and outer region-sector 5. Sub-bands {C,E,G} reuse for outer region-sector 2, outer region-sector 4 and outer region-sector 6. The previous work of OFFR only allocates one sub-band for each outer macro region-sector while DFFR allocates three sub-bands.

The femtocell will be allocated spectrum that is not used by macrocell in the current sector. Figure 1 (c) illustrates spectrum allocation for femto users in the inner region-sector 1 consisting of three sub-bands {C, E, G} that can be reused for inner region-sector 3 and inner region-sector 5. Sub-bands {C, E, G} are not used by macrocell in current sectors, i.e. sub-bands {A, B, D, F}. Similarly, inner region-sector 2 consists of three sub-bands {B, D, F} and it can be reused for inner region-sector 4 and inner region-sector 6. Sub-bands {B, D, F} is not used by macrocell in current sectors, i.e sub-bands {A, C, E, G}. Using of different sub-band between femtocell and macrocell in current sector mitigate cross-tier interference, significantly.

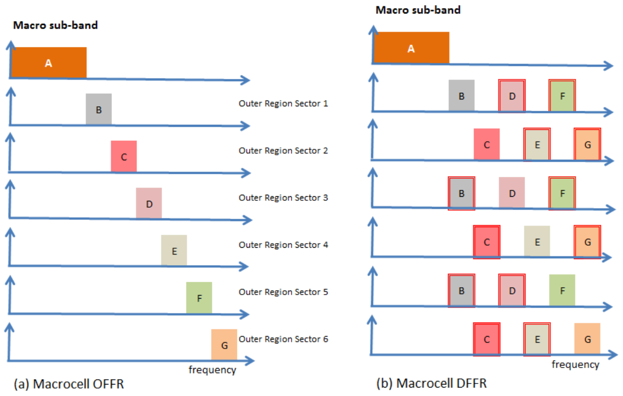

Fig. 2. OFFR and DFFR Scheme

Figure 2 illustrates comparison spectrum allocation for macro users in the outer region-sector between (a) OFFR and (b) DFFR. For example, outer region-sector 1 consisting of three sub-bands {B, D, F} that can be reused for outer region-sector 3 and outer region-sector 5. OFFR just allocate one subband for each Outer region-sector, while DFFR allocate three subbands.

B. Calculation of Metrics.

Mathematical equations begin with path loss which is a function of the distance between user to serviced base station plus another loss caused walls, floors or distance between building. The resulting path loss will generate channel gain which is used to find SINR. Besides channel gain, SINR is influenced by serviced power base station and interference from adjacent/ neighboring base station plus white noise power spectral density. Based on SINR result, we can calculate the capacity of each user and the total throughput, both femtocell and macrocell. Furthermore, the mathematical equations can be written as follows.

Path loss (or path attenuation) is the reduction in power density (attenuation) of an electromagnetic wave as it propagates through space. In this simulation, the path loss for the first case and for a macro user roaming outdoor in an urban area can be determined as follows [2]:

$$PL(Db) = 15.3 + 37.6 \log_{10} R \qquad (1)$$

Path loss for macro- user which is located indoor is:

$$PL(Db) = 15.3 + 37.6 \log_{10} R + L_{ow} \qquad (2)$$

where L_{ow} is the penetration loss of an outdoor wall. As well, path loss between femtocell base station and femto-user can be calculated as:

$$PL(Db) = 38.46 + 20 \log_{10} R + L_{ow} + 0.7d_{2D,indoor} + 18.3\, n^{((n+2)/(n+1)-0,46)} + q.L_{iw} \qquad (3)$$

where n is a number of penetrated floor, q is the number of walls separating apartments or rooms between the femtocell BS and the femto-user, and L_{aw} is the penetration loss of the wall separating apartments or rooms. The term $0.7d_{2D,indoor}$ takes account of penetration loss due to walls inside an apartment and is expressed in m. And $d_{2D,indoor}$ representing the distance in the house. Pathloss for femto-user at outdoor and served by femtocell, consider the outdoor wall loss, can be calculated as bellows:

$$PL(Db) = \max(15.3 + 37.6 \log_{10} R,\ 38.46 + 20 \log_{10} R) + L_{ow} + 0.7d_{2D,indoor} + 18.3\, n^{((n+2)/(n+1)-0,46)} + q.L_{iw} + L_{ow} \qquad (4)$$

Estimated SINR of macro-user *m* on subcarrier *k,* when interfered with another macrocell and adjacent femtocell can be calculated as bellows [4][8]:

$$SINR_{m,k} = \frac{P_{M,k} G_{m,M,k}}{N_0 \Delta f + \sum_{M'} P_{M',k} G_{m,M',k} + \sum_{F} P_{F,k} G_{m,F,k}} \qquad (5)$$

Where $P_{M,k}$ and $P_{M',k}$ are transmitted power from macrocell *M* and neighboring macrocell *M'* on subcarrier *k*. Notation of $G_{m,M,k}$ describe channel gain between macro-user *m* and macrocell *M* on subcarrier *k* and while for neighboring macrocell denoted by $G_{mM'k}$. Similarly, $P_{F,k}$ is transmitted power from adjacent femtocell *F* on subcarrier *k.* And $G_{m,F,k}$ is channel gain between macrocell user *m* and femtocell *F* on subcarrier k.. And N_0 is white noise power spectral density and Δf is subcarrier spacing.

In case of a femto user f on subcarrier k interfered by all macrocells and adjacent femtocells, the received SINR can be similarly given by:

$$SINR_{f,k} = \frac{P_{F,k} G_{f,F,k}}{N_0 \Delta f + \sum_{M} P_{M,k} G_{f,M,k} + \sum_{F'} P_{F',k} G_{f,F',k}} \qquad (6)$$

Channel Gain *G* can be calculated from path loss value and can be reviewed as equation:

$$G = 10^{-PL/10} \qquad (7)$$

Having estimated the SINR from (5) and (6), we can calculated capacity The mathematical capacity of macro-user *m* on subcarrier *k* can be formulated as [3]:

$$C_{m,k} = \Delta f.\log_2(1+\alpha.SINR_{m,k}) \qquad (8)$$

Similarly, capacity of femto-user *f* on subcarrier *k* can be expressed by:

$$Cf,k = \Delta f.\log2(1+\alpha.SINR_{f,k}) \qquad (9)$$

where α is targeted Bit Error Rate (BER) and defined by $\alpha = -1.5/\ln(5.BER)$.

Throughput is an accumulation of capacity each user. Throughput macrocell and femtocell can be expressed as respectively:

$$T_M = \sum_m \sum_k \beta_{m,k} C_{m,k} \qquad (10)$$

$$T_F = \sum_F \sum_k \beta_{f,k} C_{f,k} \qquad (11)$$

Where $\beta_{m,k}$ describe allocated subcarrier for macro user and $\beta_{f,k}$ is an equation to describe allocated subcarrier for femto-user.

III. PROPOSED FRAMEWORK

Based on the equation in chapter 2 above, we can calculate performance network with consideration of interference between femtocell and macrocell. Performance calculation uses simulation with defined parameter.

Proposed FFR will be compared with OSFFR (optimal static fractional frequency reuse) and previous FFR. One of the major parameters to compare between methods is throughput. Modeling will be simulated with one cell and number of users that determined all around the cell. Based on redistribution of sub-band, the simulation will describe the improvement of performance for proposed FFR.

Simulation method to find capacity and throughput is derived from estimated SINR from behavior users. This simulation goal is getting best performance for cellular operators and can be represented by diagram block as follows:

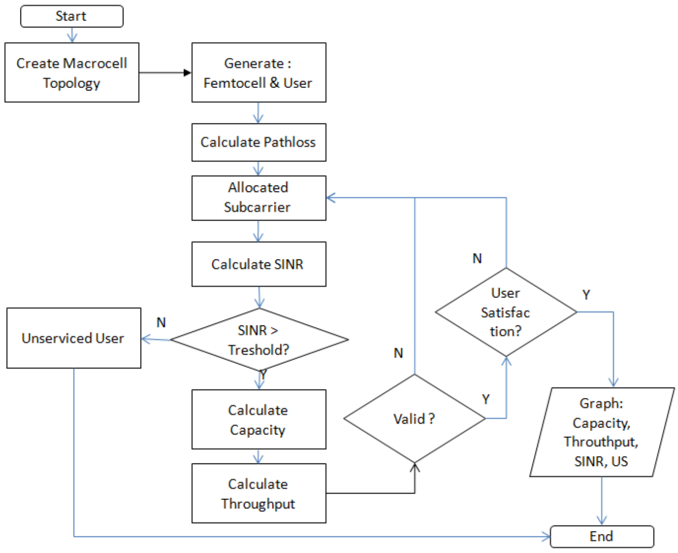

Fig. 3. Simulation flow chart

Network's parameter values for simulation can be summarized as bellows:

Parameter	Value	Unit
Macrocell Radius	250	Meters
Femtocell Radius	20	Meters
Frequency	2.000	Mhz
Macro BS Power	46	dBm
Femto BS Power	10-20	dBm
Outdoor Wall Loss	20	dB
Indoor Wall Loss	5	dB
White Noise Power Density	-174	dBm/Hz
Network Size	1	Macro
SINR at MU Device	10	dB

Several parameters above can be changed as operator design needed or based on real environment.

IV. RESULT AND DISCUSSION

Based on the experiment can be used to evaluate the performance of throughput for proposed DFFR and previous FFR

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A. Throughput for macrocell

Based on figure 4, SFR has the best performance for the macro inner region. It is because SFR allocates the majority of the spectrum or two-third of the total spectrum for the macro inner region. It is in line with FFR-3 that allocates a half of the total spectrum. There is no difference between DFFR and OSFFR for the inner region. Both DFFR and OSFFR allocate just one-third of the total spectrum.

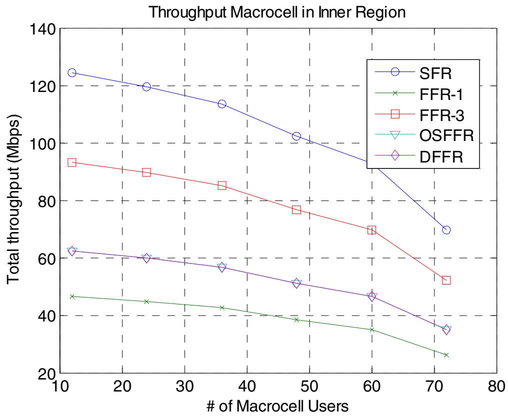

Fig. 4. Inner region comparison of macrocell

Figure 5 shows that the best performance for macrocell in outer region is obtained by DFFR. The performance of DFFR increases significantly because besides DFFR allocates one-third spectrum per region, DFFR also reuses sub-band until three times. Total spectrum for the outer region with DFFR scheme is equal to one-third multiplied by six sectors. Another scheme which is close to DFFR is OSFFR, although the total just one-ninth multiplied by six and it is still far from DFFR.

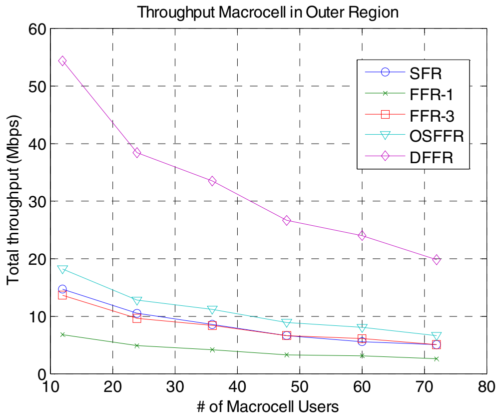

Fig. 5. Outer region comparison of macrocell

In this experiment, throughput performance is affected by sub-band allocation. The performance will increase proportionally by increasing of sub-band that will be allocated. Therefore, besides the allocated number of sub-bands, reuse factor also affects the performance significantly.

B. Throughput for femtocell

Figure 6 describes there is no difference between DFFR and OSFFR of the inner region for the femtocell. Both DFFR and OSFFR lead in performance compared to previous schemes. It is because of the reuse factor that implemented to different sectors.

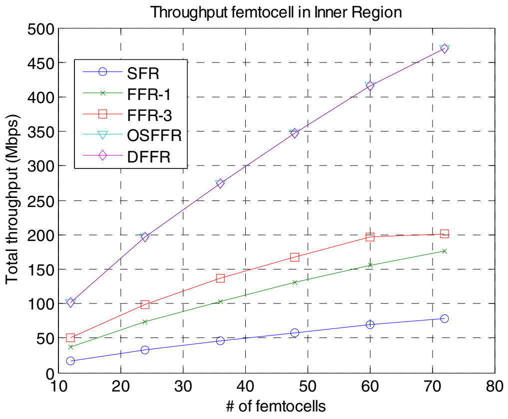

Fig. 6. Inner region comparison of femtocell

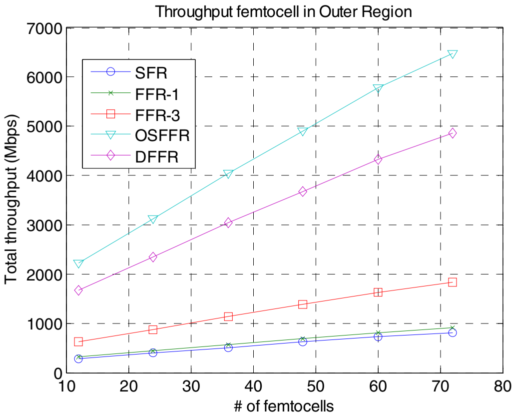

Fig. 7. Outer region comparison of femtocell

Trade-off DFFR scheme caused relocation of sub-band from the femtocell to the macrocell in outer regions, performance outer region is 25% lower than OSFFR. But, if it is compared to another scheme, DFFR is still better.

V. CONCLUSION

DFFR increases outer macro performance, at least 200% as OSFFR or previous scenarios as a result of adding two-ninth sub-band allocation and reusing it to each sector are not intersecting. This is compensated (trade-off) by decreasing outer femto around minus 25% as an impact of relocation of two-ninth of sub-band from the femtocell to macrocell. DFFR is proper for the spread of users distributed uniformly on the whole cell and DFFR is improper for clustered users in partial of sectors only.

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