Power Allocation for Dynamic Fractional Frequency Reuse (DFFR) in Downlink LTE-A System

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Abstract— **Network MIMO is a feasible technique that can significantly improve the performance of wireless communication systems by canceling the Inter-cell Interference (ICI). Dynamic Fractional Frequency Reuse (DFFR) is the technique to mitigate ICI in LTE-Advanced system, which improve throughput and capacity, especially for the cell-edge users (CEUs). Recent research has shown that the impact of DFFR scheme on system performances has already studied and can provide significant gains in term of outage probability and network sum rate throughput. This paper presents a performance investigation of a DFFR scheme in a Network MIMO configuration based on an LTE-A downlink transmission environment. This paper also aims to enhance cell edge throughput and capacity by improving water filling algorithm for power allocation (PA). The proposed PA strategy is to maximize the performance of CEUs which commonly incur considerable ICI. Furthermore, the proposed method has been compared to the Frequency Reuse, Fractional Frequency Reuse (FFR) and other conventional DFFR schemes. Results show that the proposed scheme present superior performances of the throughput by 60% and capacity by 42% compared to the other schemes.**

Keywords— DFFR, FFR, Network MIMO, water filling algorithm

I. INTRODUCTION

The Long Term Evolution-Advanced (LTE-A) is the prominent candidate for 4G network that has been proposed by the 3rd Generation Partnership Project (3GPP). To continue an evolution, they aim to improve the overall systems in terms of increasing the data rates and resource utilization efficiency of the wireless communications. Orthogonal frequency division multiple access (OFDMA) is adopted in the LTE-A downlink to achieve high throughput and improve spectrum efficiency. The subcarriers in OFDMA systems are orthogonal to each user of the same cell, therefore the intra-cell interference is avoided. On the contrary, ICI becomes a significant performance bottleneck in 4G networks when the size of each cell is becoming smaller. Network MIMO has been identified as a capable technique that can exploit inter cell interference [1]. Network MIMO, also known as Coordinated Multipoint (CoMP) in LTE-Advanced systems, where base stations (BSs) are connected with high-capacity backhaul links and share the data and the channel state information (CSI) relating to each of its users.

Frequency reuse (FR) is one of the methods that adopted in LTE-A to mitigate ICI and allows the given frequency band to reuse fully for each cell of the network. However, frequency bands intersecting between adjacent cells and cause ICI, mostly at the cell edge of the network. To overcome this problem, Fractional Frequency Reuse (FFR) scheme was introduced in the 3GPP LTE-A system [2,3] and the Dynamic Fractional Frequency Reuse (DFFR) scheme presented in [4]. The key idea of FFR scheme deployment is to avoid the CEUs of neighboring cells interfere with each other, where the total bandwidth divided between neighboring cells. However, it still may incur even severe ICI to some of the cell edge users, because of the offered low throughput compared to DFFR scheme.

DFFR scheme was proposed as a mean to mitigate ICI and improve the overall performance of FFR in terms of coverage and capacity in wireless cellular networks. According to the development of DFFR, users and subcarriers within a cell are divided into two groups, (i) super groups cover all the cells and the subcarriers are allocated and given to any user in the cell and (ii) regular groups, which is further partitioned into three sectors. CEUs only can access to the cell-edge band, but not to the cell-center users (CCUs). In fact, it can use both of the cell-center band and the cell-edge band simultaneously. Besides, in contrast to the power allocated to CEUs, the power level is decreased for CCUs for transmission through the use of the frequency band.

Most studies have focused on the combination of FFR schemes and power allocation. One of the FFR schemes for the previous study is Soft Frequency Reuse (SFR) scheme. For instance, in [5], re-allocation algorithms have been proposed, so that, the effectiveness of the throughput in the system can be improved. However, the equal power allocation approach is used in these articles. Besides that, the power control or resource limitation cannot provide the significant performance improvement of throughput in the system. Hence, the numerous problem should be tackled by introducing some algorithms that combine on both resource and power allocations.

Since, the power allocation has never been addressed in DFFR, hence, a power allocation algorithm for water filling (WF) algorithm is proposed in this paper, which can resolve the problem in LTE-A network. In certain circumstance, the water filling (WF) algorithm is developed to improve the performance of cell edge users such as throughput, capacity and to mitigate the interference. This is because, considerable ICI usually occurred in the CEUs. The combination of network MIMO and FFR, have been considered in the works [6], [7]. However, the study of DFFR and Network MIMO is not seen in the literature. Hence, the dynamic scheme in Network MIMO is proposed to improve the performance of FFR scheme. In this work, the WF algorithm will be introduced for zero-forcing based network MIMO with the target to increase the performance of throughput and achieve the capacity of the users in a cellular network. By combining the Network MIMO and DFFR scheme, the throughput to both CCUs and CEUs can be improved due to the increase in the received signal-to interference-plus noise ratio (SINR) and also can be quite powerful in terms of capacity enhancement. The rest of the paper is organized as follows: Section II described the system model and the problem is formally stated. Section III provides LTE-A simulation parameters and performance analysis. Lastly, Section IV concludes the paper.

II. SYSTEM MODEL

The proposed DFFR sectorization for Network MIMO model is shown in Figure 1. The model includes 7 cell sites where the center cell has two tier neighboring cells. A regular DFFR scheme combined with sectorization is fully used the spectrum in each cell and to cancel ICI.

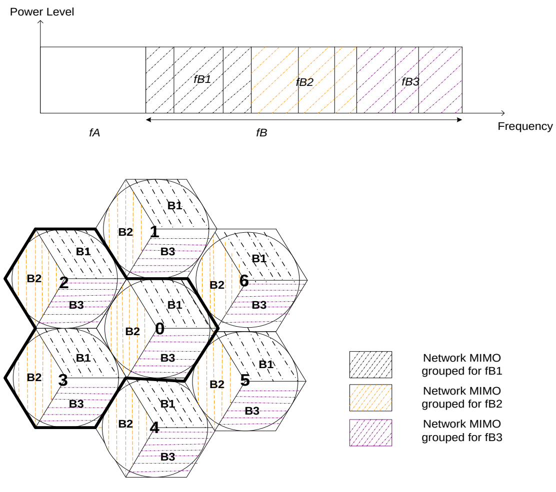

Fig. 1. DFFR sectorization for Network MIMO.

The cellular network is represented by a hexagonal cell. Fig. 1, shows the dynamic frequency allocation, where each cell is divided into three sectors and three 120° sectors at the cell edge that are served by sectorial antennas. The distribution of users is randomly scattered across the cell and stationary over the plane. The frequency partition between sectors can be either regular or rearranged [6]. For the regular partition, all the sectors with the same main-beam direction are allocated the same frequency band. Each user assumes to establish communication via the nearest base-station.

A. Network MIMO

In this work, we consider a cellular network with M cells in the transmitting antenna N_T for each base station antenna, serving K users with each receiving antenna N_R. In the simulation, two number of MIMO antennas is assumed. Both base station and the user have two transmit and receive antennas. The received signal vector of the system can be written as:

$$Y_{sys} = H_{sys} * X_{sys} + n_{sys} \quad (1)$$

$Y_{sys} = vec([Y_1, Y_2, \ldots Y_M])$ is the system received signal vector where Y_m is the received signal vector at the m-th cell. $X_{sys} = vec([X_1, X_2, \ldots X_M])$ is the system transmitted signal vector where X_m is the transmitted signal vector at m-th cell. n_{SYS} is the circularly symmetric complex additive Gaussian noise vector at the user's receiver. The random channel matrix H_S is given by

$$H_{SYS} = \begin{bmatrix} H_1 H_{2\to 1} \ldots\ldots H_{M\to 1} \\ H_{1\to 2} H_{2} \ldots\ldots H_{M\to 2} \\ \vdots \\ H_{1\to M} H_{2\to M} \ldots H_{n\to M} \end{bmatrix} \quad (2)$$

H_M represents the random channel matrix from m-th BS to all of its served user, while $H_{n\to M}$ represents the random channel matrix from n-th BS to all of K users in the m-th cell. Thus, we can represent the received signal of k-th user at the m-th cell as

$$y_{m,k} = H_{m,k} x_m + \sum_{n\neq m}^{M} H_{n\to m,k} x_n + n_{m,k} \quad (3)$$

$H_{m,k}$ is the channel between the m-th BS and the k-th user, while, $H_{n\to m,k}$ is the channel matrix between the n-th BS and the k-th user in the m-th cell and $n_{m,k}$ is the noise vector of the k-th user in the m-th cell.

B. Channel Model

$G_{t,r}$ represents the channel gain and split by the distance *(d)* between a transmitter *t* and receiver *r* is expressed as below

$$G_{t,r} = |H_{t,r}|^2 10^{\frac{-L(d)+X_\sigma}{10}} \quad (4)$$

$H_{t,r}$ depicts as the channel transfer function between transmitter t and receiver r. The log-normal shadowing (X_σ) with standard deviation σ and value is in dB. L represents the path loss (dB) and the expression is denoted as

$$L(d) = 15.3 + 37.6 \log_{10}(d) \quad \text{[dB]} \quad (5)$$

C. Problem Formulation

For the DFFR scheme, where a user u is served by Base Station b, the SINR is expressed as the following equation:

$$SINR = \frac{P_{b,u} h r^{-\alpha}}{\sigma^2 + P_{i,u} I_r} \quad (6)$$

According to (3), $P_{b,u}$ represent the power transmitted by the Base Station b on user u, α is the path loss exponent, σ^2 is the noise power, r is the distance between the user and base station,h denotes to the small scale fading and shadowing and random variable, I_r refers to the power interference, where R_i is the distance and g_i is the statistical distribution that include fading value, shadowing and any other desired random effect between the interfering base station and the user. Thus, the I_r is expressed as follows:

$$I_r = \sum_{i \in \phi / b_o} \left(g_i R_i^{-\alpha} \right) \quad (7)$$

D. Acceptable Rate

The probability of acceptable rate is each user achieve Shannon bound for their instantaneous SINR. The average rate has been expressed by using the SINR equation that can figure out the relative performance of non-uniform cell traffic. The average rate for CEUs equation is written as follows

$$\tau(\beta_{FFR}) = E[\ln(1 + SINR)] = \int_{r>0} e^{-\pi r^2} E\left[\ln\left(1 + \frac{P h_{b,u} G_{b,u}}{\sigma^2 + P I_r}\right)\right] 2\pi r dr \quad (8)$$

where the vectors b and u is the base station and user, respectively. The average rate equations can be derived by integrating SINR distribution and $ln\ (1+SINR)$ is a positive random variable, so (5) can be represented as

$$E\left[\ln\left(1 + \frac{P h_{bu} \hat{G}_{bu}}{\sigma^2 + P I_r}\right)\right] = P_r\left[\ln\left(1 + \frac{P h_{bu} \hat{G}_{bu}}{\sigma^2 + P I_r}\right)\right] \rangle \left| \frac{P h_{bu} G_{bu}}{\sigma^2 + P I_r} \langle \beta_2 \right| \quad (9)$$

E. Allocation of Center and Edge Type Users

The allocations of center and edge users are done on the basis of strongest and weakest SINR values. The users that are close to the serving base station and falls below a certain threshold SINR value are assigned as center users and are allocated all center subcarriers whereas, the users that lie beyond the required SINR limit were assigned as edge type.

F. Network MIMO: Zero-Forcing (ZF)

ZF precoding is known as to eliminate the interference from other users completely. The ZF applies to invert the channel to obtain $hW = I_N$. I_N is an N x N identity matrix. Weight matrix (W) is the pseudo-inverse of the channel matrix [6]. Hence, the received signal model is found to be

$$y_n[m] = h_n x_n[m] + w[m] = hWs + w = s + w, \quad n = 0,1,\ldots.N\text{-}1 \quad (10)$$

where $x_n[m]$ is the input in each subchannel, $y_n[m]$ is output and $w[m]$ represents the noise of signals in each subchannel. h_n, the channel matrix from the base station to users.

The ZF precoding may limit the utilization of the maximum power available at each base station as this could result in the violation of the per sub carrier power constraint. In order to overcome this problem, WF algorithm is proposed. This algorithm is optimal when CSI is recognized at the transmitter.

Equal power is a simple power allocation scheme, where equal power is optimal when the CSI is not recognized at the transmitter. Therefore, equal power allocation can be written as

$$P_u = P_{total} / N \quad (11)$$

G. Water Filling (WF) Algorithm

WF is one of a technique where, by adjusting the channel gain for the power of the spatial channels. Power become greater when the gain and signal to noise ratio (SNR) are higher in the channel. In all subchannels, the sum of data rates can be maximized when having more power. The Shannon's Gaussian Capacity formula is applied to the data rate that related to the power allocation as expressed below

$$C = B \log(1 + SNR) \quad (12)$$

An accurate power allocation is not responding with the data rate, because the capacity equation represents a logarithmic function of power [8]. Therefore, the power allocation scheme uses the WF algorithm as to achieve the optimal value. The basic WF algorithm is expressed below

$$Capacity = \sum_{i-1}^{n} \log(1 + Powerallocated * G_n) \quad (13)$$

III. SIMULATION SETTINGS AND PERFORMANCE ANALYSIS

MATLAB simulation is developed to investigate the performance of the achieved throughputs and capacities of the DFFR with water filling algorithm scheme, and it is compared against three other schemes: FR, FFR and DFFR.

A. Simulation Parameters

In the topology, we consider a 7-cells that represented in Fig. 3 and the performance of the CEUs and CCUs in terms of throughput and capacity are analyzed. Each cell is distributed with an equal number of users in the cell that are randomly located.

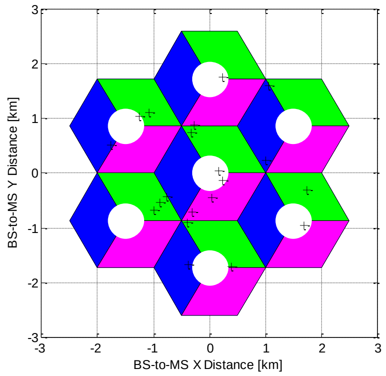

Fig. 3. Hexagonal Cell

The main simulation parameters are listed in Table I and the achievement of rate and capacity are produced and compared against the aforementioned techniques.

TABLE I. SYSTEM PARAMETERS FOR THE URBAN EVALUATION ENVIRONMENT [9]

Cell Parameters	
Grid Layout	3-sectored hexagonal 7 cells
Cell Radius	1 km
Distribution of Users	Uniformly distributed 15 to 20 [10]

Channel Model	
Channel Bandwidth	10 MHz
Carrier frequency	2 GHz
Number of Subcarriers	1200
Frequency Spacing	15 kHz
Path loss exponent	4 (urban area)
Noise Density	-174 dBm
SINR Threshold Checked (γ)	0 to 50 dB

Power Allocation	
Total Power Constraint at each BS	43 dBm
Algorithm	WF

B. Results and Discussions

The Rate threshold, R_{th} is used to assign cell center users and cell edge users. That is, if the instantaneous acceptable rate is above the given R_{th}, the performance is assigned as cell edge users. Otherwise, the acceptable rate is considered to cell center users.

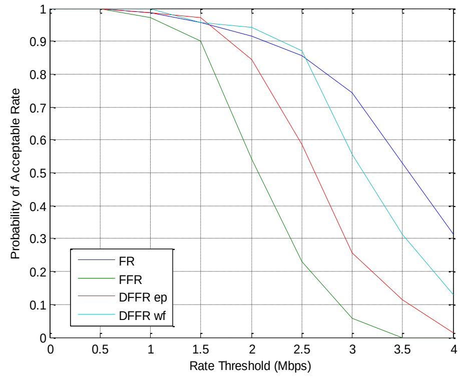

Fig. 4. Probability of acceptable rate cell center users

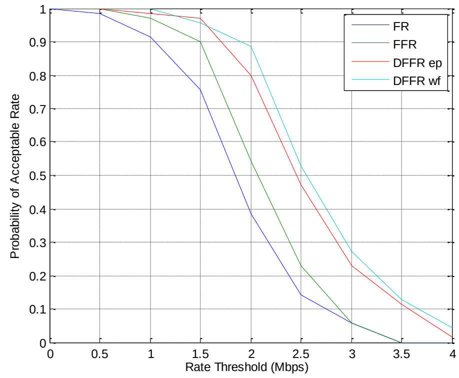

Fig. 5. Probability of acceptable rate cell edge users

Fig. 4 and Fig. 5 illustrate the probability of achievable rate CCUs and CEUs for FR, FFR, DFFR and DFFR-WF scheme. The implemented scheme in Fig. 4, tends to approach towards FR scheme, but still performs much better as compared to other schemes for all center users. The center users in DFFR are more prone to interference from the neighboring cells since they all use the Reuse-1 scheme as a result the throughput for center users decreases for all center bandwidth limited users. The edge user in Fig. 5 suffers a negligible loss with respect to the implemented scheme because of band borrowing and added interference from borrower's center users and performs much better as compared to other schemes. The curves in Fig. 5 shows a slight decrease in edge users losses with increasing values of the rate with the overall implemented scheme. In DFFR scheme, users at the edge yield more throughput since they are less prone to interference due to the higher the frequency reuse factor of three. Due to the graph present, it shows that by adopted the power allocation scheme obtained a better improvement of CEUs throughput than DFFR scheme in [10] by 80%. When R_{th} = 2 Mbps, the performance of DFFR-WF outperforms DFFR significantly. This is because when the R_{th} is higher, more power can be allocated to cell edge users without co-channel interference.

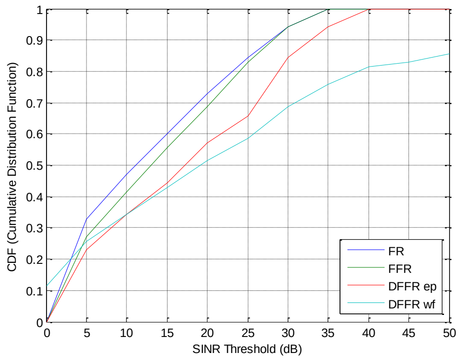

Fig. 6. CDF of Capacity cell center users

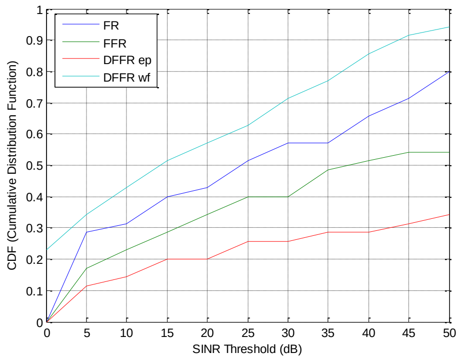

Fig. 7. CDF of Capacity cell edge users

Fig. 6 and Fig. 7 show the CDF (Cumulative Distribution Function) of transmission capacity for both cell center users and cell edge users as a function of the SINR threshold, γ_{th}. The value of γ_{th} is 1 dB, which provides the best SINR performance for the considered FFR based cellular network [2]. A lower value of γ_{th} may push too many users from cell edge to cell center resources, while a higher γ_{th} value may increase the number of cell edge users. Fig. 6 depicts a drastic increase in FR scheme center users capacity as the UE moves towards the base station in FR scheme, but at the same time the edge users of FR scheme suffer due to increasing order of interference received by the edge users from neighboring base stations from the set of same frequency bands used all over the system. On the other hand, the graph representing FR shows a tremendous increase in capacity of center users, but at the same time a decreasing capacity behavior is seen as the UE moves to the base station which creates problems for bandwidth center users. As can be seen in Fig. 7, the DFFR-WF scheme achieves better capacity compared with other schemes. Moreover, when compare to the power transmitted to the CEUs of DFFR scheme and DFFR-WF scheme, the power is very limited in the DFFR scheme because with a fixed total power, so the channel capacity become worst. Despite of DFFR-WF scheme increases the performance of users at the edge, it also imposes a capacity decrease for its center users due to allocating the bandwidth system into the center and edge respectively since a part of the center bandwidth is sacrificed to recover edge users decreasing capacity loss in FR scheme.

IV. CONCLUSION

A power allocation solution is proposed in this paper to improve the throughput and capacity performance. A WF algorithm has been adopted into the DFFR sectorization scheme for 3 cell Network MIMO. The proposed scheme determines to reduce the inter cell interference problem in LTE-A downlink. According to the simulation results, the DFFR with proposed power allocation outperforms the fixed frequency allocation schemes in terms of throughput and capacity.

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