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Performance Enhancement Employing Vertical Beamforming for FFR Technique

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***Abstract*—**This paper proposes a vertical beamforming concept to a cellular network employing Fractional Frequency Reuse technique including with cell sectorization. Two different beams are utilized in cell-center and cell-edge, separately. The proposed concept is validated through computer simulation in term of SINR and channel capacity. Also, comparison when utilizing horizontal and vertical beam formation is in focus. The obtained results indicate that the proposed concept can improve the performance of the cellular networks comparing with the one using horizontal beamforming.

***Keywords*—**Beamforming, Fractional Frequency Reuse, Inter-Cell Interference, cell sectorization.

I. Introduction

NOWADAYS, the Orthogonal Frequency Division Multiple Access (OFDMA) [1] technique has been utilized in several standards for cellular broadband networks, such as Long-Term Evolution (LTE) or WiMax. The OFDMA deployed the OFDM technology for multiple user access. The OFDMA allows the distribution of subcarriers among users thus all users can transmit and receive simultaneous time within a single channel. Therefore, it can reduce multipath interference. However, all subcarriers are utilized for full benefits when they are used in every cell. This is because of the problem of Inter-Cell Interference (ICI) from neighbor cells. In cellular networks, the users staying in cell-center area exploit high signal strength as they are nearby to the base station (BS). On the other hand, the signal strength is degraded when users are moving close to the cell-edge. Moreover, the users located at cell-edge also suffering inferring signal coming from neighboring cells. To tackle the problem, the frequency resource is divided and differently allocated between cell-center and cell-edge area, this technique is called Fractional Frequency Reuse (FFR) [2].

Fundament of FFR technique is division of the cell area into two regions: cell-center and cell-edge region. All available subcarriers are separated into two groups. One is used for cell-center region and another one is used for cell-edge region. Therefore, the intra-cell interference from cell-edge to cell-center can be ease and the number of ICI can be reduced. Furthermore, the concept of horizontal beamforming has been proposed to improve performance of FFR technique. However, it cannot provide full benefit due to the direction of ICI signal from neighboring cells is the same as the one of desired signal in the cell. Therefore, this paper proposes a vertical beamforming technique to reduce ICI from neighboring cells. The vertical beamforming concept proposed in this paper is two difference beams are utilized in cell-center and cell-edge separately. The horizontal and vertical beamforming are simulation to comparative performance when utilized different FFR technique.

The rest of this paper is as follows. After brief introduction, the concept of FFR is presented in Section II. Then, horizontal and vertical beamforming are discussed along with computer simulation results to show the performance of proposed concept in Section III. The results obtained using the proposed concept are also compared with the ones employing horizontal beamforming utilized different FFR technique. Finally, Section IV concludes the paper.

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II. Fractional Frequency Reuse

FFR is a technology that splits coverage cell into two regions: cell-center and cell-edge region. All available subcarriers are divided into two groups to allocate for cell-center and cell-edge region separately as shown in Fig. 1. Moreover, FFR technique can be remodeled into several type by allocation subcarrier groups [3]–[6]. All available subcarriers are used at cell-center area. At cell-edge area, all available subcarriers are divided into three groups to use at each cell-edge area in different cell as shown in Fig. 2 (a). For Fig. 2 (b), all available subcarriers are separated to four groups. Users at cell-center region use one subcarrier group while users at cell-edge region use the other subcarrier group. Furthermore, all available subcarriers are divided into two groups. One is called cell-center group and another one is called cell-edge group. The cell-center group is used at cell-center area. The cell-edge group is separated to three subgroups, each subgroup is utilized at cell-edge for different neighboring cells as shown in Fig. 2 (c). For Fig. 2 (d), the cell-edge area is separated to three sectors to reduce ICI and improve its capacity. All available subcarriers are divided into two groups. One is cell-center group employed at cell-center area. Another one is cell-edge group which is divided into three subgroups, each subgroup is employed at each sector.

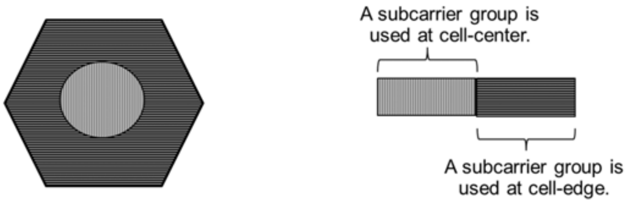


Fig. 1 Fundament of FFR technique

Next, each type of FFR (FFR (a) to FFR (d)) technique is discussed along with horizontal and vertical beamforming. Computer simulation is performed to show the performance in term of SINR and channel capacity for both beamforming with different FFR technique.

III. Horizontal And Vertical Beamforming

The intra-cell interference from cell-edge to cell-center can be ease and the number of ICI can be reduced by using FFR technique. However, the problem of subcarrier from neighboring cells interferer to the one in the cell still remains. This impairment is due to radiation pattern of antenna is used to covering all of a sector area. To handle this problem, several researchers have proposed the beamforming technique when the beam pattern is steerable in horizontal plane. Consequently, it cannot only reduce interference signal transmitted from the neighboring cells but also enhance the desired signal. Nevertheless, the mentioned concept does not work very well for the case having ICI signal coming from the same direction of the desired signal at the cell. Therefore, this paper proposes an idea to reduce ICI problem using vertical beamforming concept as shown in Fig. 3. As we can see, the FFR technique is utilized along with the concept of different subcarriers in different beams. This is full utilization of parameters in both frequency and space domains. According to this, the users at cell-center receive higher signal strength while the ICI signal from neighboring cells is decreased. As a result, the overall signal quality can be improved.

The vertical beamforming mentioned above can be accomplished using a linear array [7]. The characteristic of beam steering for linear array is given by [8].

(1)

where N stands for a number of antenna elements and k is the propagation constant, with $k=2\pi/\lambda$. The antenna elements are equally spaced by d. Also, β is the phase shift between adjacent elements. The angle represented by θ is measured from the z-axis in spherical coordinates.

For the computer simulation in this paper, the hexagonal cellular system is assumed. The wireless channel between the base station and the user is assumed to have effects from

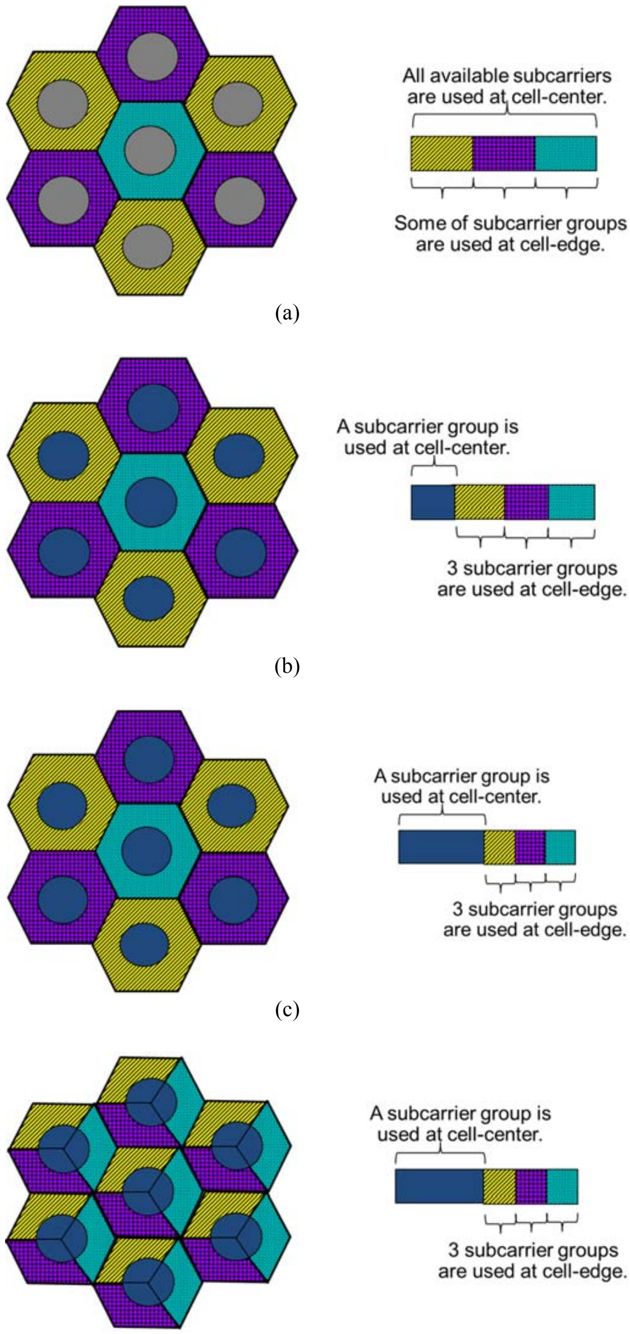
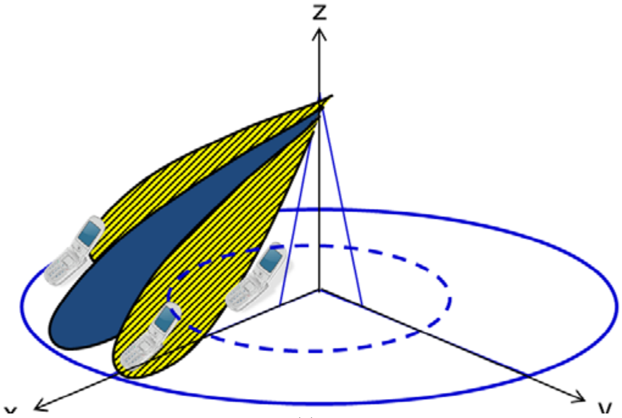
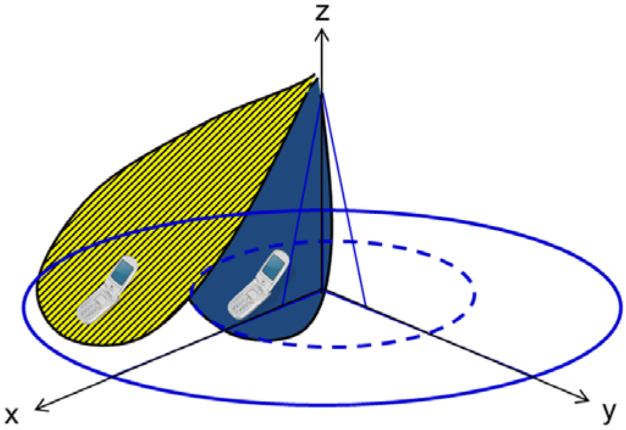


Fig. 2 Cell structure utilizing FFR technique



(a)



(b)

Fig. 3 (a) Horizontal and (b) vertical beamforming

propagation path loss and shadowing fading as follows. The propagation path loss can be given by

$$PL = 120.9 + 37.6 \log R \tag{2}$$

where R is the distance between the user and the BS in kilometers. As the shadowing fading values are assumed to be correlated, then we consider the following correlation model for shadowing

$$S_n = X(d) \cdot S_{n-1} + \sqrt{1 - X(d)^2} \cdot N(0, \sigma) \tag{3}$$

$$X(d) = 2^{-d / d_{corr}} \tag{4}$$

where d_{corr} is decorrelation length and d is the moving distance of the mobile station after the last calculation of shadowing. The $N(0,\sigma)$ presented in (3) is a Gaussian random variable with zero mean and standard deviation of σ. The S_n and S_{n-1} are the shadowing values at the two consecutive calculations.

The sampled channel frequency response of i^{th} user can be expressed by

$$H_i = \sum_{l=0}^{L-1} h_{i,l}(nT_s) e^{-j2\pi k \Delta f \cdot \tau_1} \tag{5}$$

where $h_{i,l}$ is the wide-sense stationary narrow band complex amplitude Gaussian process of the L^{th} path. The T_s stands for the OFDM symbol period and Δf is the neighbor subcarrier spacing, with $\Delta f = 1/T_s$. Also, τ_1 is the corresponding delay. The channel gain between the serving BS and i^{th} user is G_i, which can be expressed by

$$G_i = 10^{\frac{-PL_i}{10}} \cdot S_i \cdot |H_i|^2 \cdot g_i \tag{6}$$

where g_i is gain of the linear array when transmitting the signal from BS toward the i^{th} user.

The structure allocation utilized in the computer simulation for this paper is illustrated in Fig. 4. An OFDMA cellular environment with two-tier 19 cells is assumed. When the i^{th} user is located in cell 1, the number of ICI at the cell- center from neighbor cells is 18. At the cell-edge area, the interference signal is coming from 7 cells as shown in Fig. 4. The received SINR of the i^{th} user can be expressed by

(7)

where G_i is gain between i^{th} user and serving cell 1. In addition, $G_{i,j}$ is the gain between i^{th} user and j^{th} cell j. The P_i and P_j are the transmitted power by serving 1st cell and j^{th} cell respectively. The parameter q is the number of ICI cells. Also, N_0 is the power spectrum density of AWGN, and Δf is the neighbor subcarrier spacing.

The performance in term of SINR using horizontal and vertical beamforming with different FFR technique through the computer simulation is shown in Fig.5. The parameters given in the simulation are listed in TABLE I [6]. Please note that, a threshold distance between cell-center and cell-edge area is 400 meters. As we can see, when FFR technique including with cell sectorization (FFR (d)) is utilized, it can provide higher SINR to the system. Furthermore, case of vertical beamforming with FFR (d) technique can be provided the maximum SINR of the system due to interference from cell-center to neighboring's cell-center is reduced. Moreover, the average channel capacity is calculated [2] as shown in TABLE II. This result can confirm that the vertical beamforming with FFR (d) enhances performance of cellular network.

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TABLE I
SIMULATION PARAMETERS

Parameters	Values
subcarrier spacing	15 kHz
white noise power density	-174 dBm/Hz
inter-cell distance	2 km
base station transmit power	43 dBm
carrier frequency	900 MHz
d_{corr}	5 m
standard deviation	8 dB
channel model	Pedestrian B

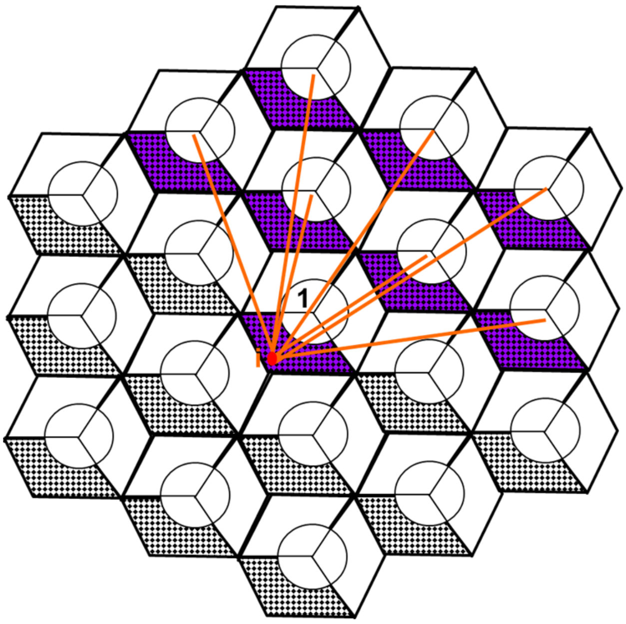

Fig. 4 Cellular structure of OFDMA system and interference at cell-edge

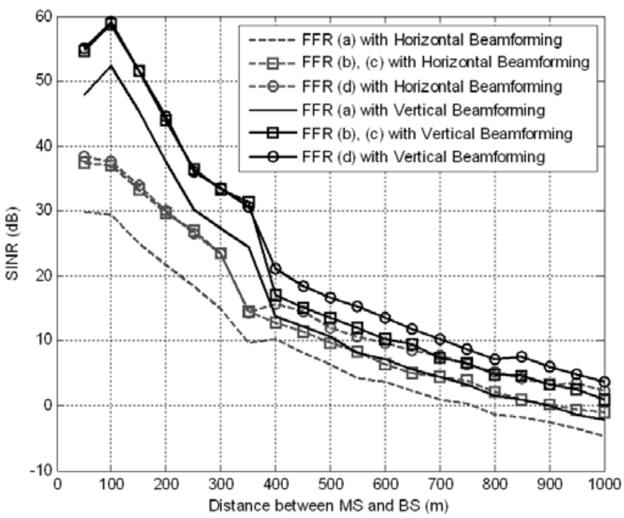

Fig. 5 SINR vs. distance between base station and mobile terminal

TABLE II
CHANNEL CAPACITY

Type of FFR	Channel Capacity (b/s/Hz)	
	Horizontal Beamforming	Vertical Beamforming
a	2.0374	3.4905
b	1.1913	1.7837
c	1.9880	3.0009
d	2.6542	3.8388

IV. CONCLUSION

This paper has proposed a vertical beamforming concept for the cellular networks utilizing fractional frequency reuse including with cell sectorization. Two beams are utilized for cell-center and cell-edge separately. According to this, the inter-cell interference from neighboring cell can be ease by utilizing vertical beamforming. Moreover, the capacity can be improved when FFR technique is used including with cell sectorization. The proposed concept is validated using computer simulation in term of SINR and channel capacity. The obtained results have indicated that the vertical beamforming with cell sectorization FFR concept can improve the performance of the cellular networks comparing with the one using horizontal beamforming concept.

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