Vertical Beamforming Influence on Cellular Networks

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ABSTRACT

This paper proposes a vertical beamforming concept to a cellular network employing fractional frequency reuse technique. The reference antenna utilized in this paper is the one currently employed at base station. The idea of using two different vertical beams is proposed for cell-center and cell-edge regions, separately. The proposed concept is validated through computer simulation in terms of SINR and channel capacity. The obtained results indicate that the proposed concept can improve the performance of the cellular networks comparing with the ones employing horizontal beamforming and one spot beam covering cell sector.

Keywords: Beamforming, Fractional Frequency Reuse, OFDMA, Linear Array, Cellular System.

1. INTRODUCTION

Several occurring standards for cellular broadband networks, such as WiMax or Long-Term Evolution (LTE), are based on Orthogonal Frequency Division Multiple Access (OFDMA) [1]. The OFDMA allows the distribution of subcarriers among users thus all users can transmit and receive at the same time within a single channel. Consequently, it can reduce multipath interference. However, the OFDMA technique cannot provide full benefits due to the problem of Inter-Cell Interference (ICI) from neighboring cells. In cellular networks, the users staying in cell-center area exploit high signal strength as they are close 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 experience interference signal coming from neighboring cells. To tackle the problem, the frequency resource is divided and differently allocated between cell-center and cell-edge area, so called Fractional Frequency Reuse (FFR) [2].

From the work presented in [3], a novel FFR scheme for multi-cell OFDMA systems has been proposed. In this scheme, each cell in cellular networks is divided into three sectors. The subcarriers are partitioned into two groups in each cell. One is called super group employed at cell-center and another one is called regular group. The regular group is divided into three parts corresponding to the boundary region of three sectors in the cell-edge. Therefore, the intra-cell interference from cell-edge to cell-center can be decreased and the number of ICIs can be reduced. Furthermore, the concept of beamforming has been proposed to tackle ICI problem. However, the problem still remains when the direction of ICI signal from neighboring cells is the same as the one of desired signal in the cell. Moreover, several antenna types have been proposed to steer their beam to desired direction such as the work presented in [4] which has presented inter-cell interference reduction using vertical beamforming scheme for fractional frequency reuse technique. In this work 7×7 planar array antenna is utilized. This scheme can reduce ICI and improve performance of the cellular networks. Nevertheless, this concept is considerably not practical as there are some difficulties in installation planar array at BS. In addition, system level analysis of vertical sectorization for 3GPP LTE and self-optimization of coverage and capacity in LTE using adaptive antenna systems have been presented [5-6]. In these works, performance with various vertical half-power beamwidths and electrical tilt angles have been observed to obtain the optimized space of the overlap between two vertical sectors and the gain in terms of cell capacity. From these schemes, capacity of the system can be improved. However, the schemes proposed in [5-6] cannot reflect the true performance for cellular network as a real antenna currently employed at BS has not been taken into account. In addition, the work presented in [7] has revealed the performance of vertical beam formation applied to a commercial active antenna. In the mentioned work, a min-norm technique has been proposed to accomplish beam formation which is considerably complicated to be implemented at BS, thus the hardware is costly. Therefore, this paper presents the concept of vertical beamforming suitable for BS antennas as they are currently linearly stacked in vertical manner. This vertical beamforming technique is simple and practical to be installed at BS. The performance of proposed concept is validated through computer simulation comparative with the ones currently utilized at BS.
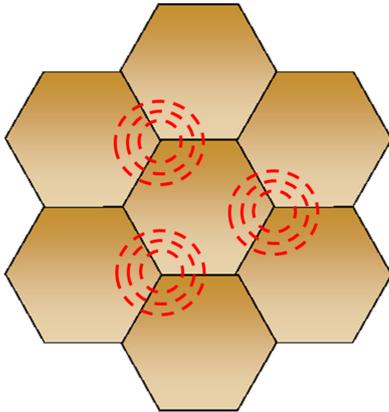
Fig.1: *Interference scenario from neighboring cells.*

(a) Top view

(b) Side view
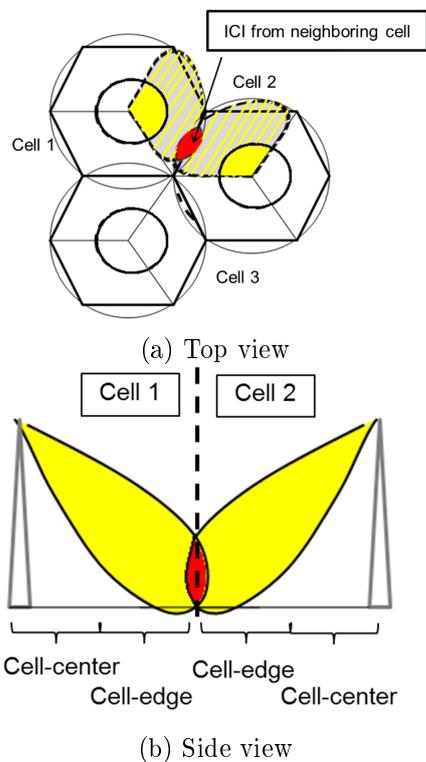
Fig.2: *ICI from neighboring cell viewing at (a) top (b) side.*

The rest of this paper is as follows. After brief introduction, the problem formulation of this paper is discussed including an approach to tackle the problem in Section II. Then, the concept of FFR is presented in Section III. Next, both horizontal and vertical beamforming at BS are discussed in Section IV. Afterwards, the proposed concept is properly applied to one commercial antenna currently utilized at BS in Section V in order to see its real performance. In this section, some simulation results in terms of Signal-to-Interference plus Noise Ratio and channel capacity reveal the performance of vertical beamforming for cellular networks. Finally, Section V concludes the paper.
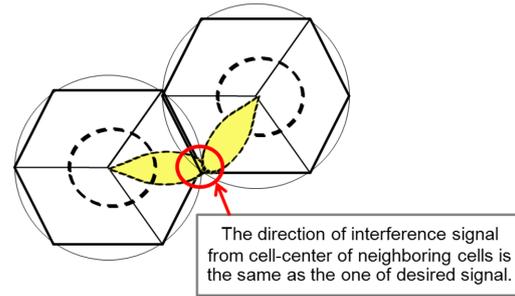
Fig.3: *Interference from neighboring cell when performing horizontal beam formation.*

2. PROBLEM FORMULATION

In cellular networks, all subcarriers are used for full benefits when they are utilized in every cell. However, this causes interference signal between neighboring cells as shown in Fig. 1. To cope this problem, the FFR for OFDMA technique is utilized in cellular networks [8-9]. The users staying in cell-center use different subcarrier from the users located in cell-edge. However, the users in cell-center still suffer from the interference from cell-center of neighboring cells as illustrated in Fig. 2. From literatures [10-13], several ideas when performing beam formation in azimuth have been proposed to tackle the problem. Nevertheless, interference from cell-center of neighboring cells still remains when the direction of interference signal from cell-center of neighboring cells is the same as the one of desired signal in the cell as shown in Fig. 3. In addition, several concepts to form beam towards desired direction using several antenna designs have been proposed for utilizing in cellular networks. Notwithstanding, those concepts are relatively complicated to be set up at BS. Therefore, this paper proposes a simple vertical-beamforming technique to reduce interference signal from neighboring cells. The antenna array commercially utilized at BS is also adopted to see the true performance for cellular systems.

3. FRACTIONAL FREQUENCY REUSE

Fractional Frequency Reuse (FFR) technique can provide full benefit to utilization of frequency bandwidth. Fundamental of FFR technique is the separation of coverage area (or cell) into two parts: cell-center and cell-edge regions. All available subcarriers are used at cell-center region and some of subcarrier groups are used at cell-edge as shown in Fig. 4 (a). Furthermore, FFR technique can be adapted into several allocation subcarrier groups as presented in [14-17]. All available subcarriers are divided into four parts: one part is used at cell-center area while other parts are used at cell-edge area in different cells as shown in Fig. 4 (b). For Fig. 4 (c), all available subcarriers are separated to two groups: cell-center and
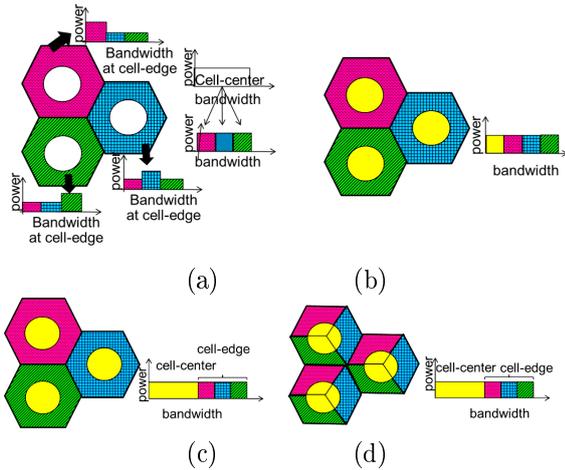
Fig.4: *Example of FFR technique with different frequency allocation scheme.*
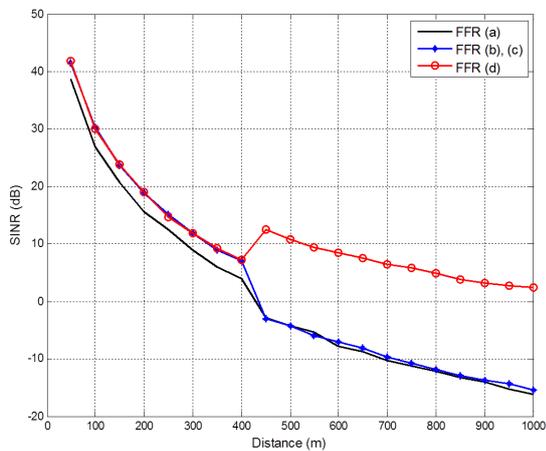
Fig.5: *SINR vs. distance between BS and MT for different kind of FFR.*

cell-edge groups. The cell-edge group is separated into three groups employed at cell-edge for different neighboring cells. In addition, to improve its capacity and reduce ICI, FFR technique is utilized including with cell sectorization as shown in Fig. 4 (d) in which each cell is divided into three sectors. All available subcarriers are separated to two groups. One is called cell-center group employed at cell-center area and another one is called cell-edge group. The cell-edge group is divided into three groups where each group is employed at different sectors.

The performance in terms of Signal-to-Interference plus Noise ratio (SINR) employing different FFR techniques is shown in Fig. 5. Please note that FFR technique used in Fig. 5 is referred to the one shown in Fig. 4. As a result, FFR cooperating with cell sectorization provides maximum performance. This is because it provides full benefit of frequency reuse in every cell. Therefore, the concept of FFR plus

cell sectorization is adopted for the rest of this paper. Please note that SINR shown in Fig. 5 is rapidly changed at distance of 400 meters as this distance is initially given being a threshold distance between cell-center and cell-edge regions.

Next, beamforming performance when the antennas are vertically and horizontally stacked is discussed. Computer simulation is performed to show the performance in terms of SINR for both scenarios.

4. HORIZONTAL AND VERTICAL BEAMFORMING

Although, interference signal coming from neighboring cells is reduced using FFR, it cannot cope the problem of ICI. This problem is due to the subcarrier from neighboring cells interfering the one in the cell, so called ICI problem. To handle this problem, several researchers have proposed the beamforming techniques when the beam pattern is steerable in horizontal plane as shown in Fig. 6 (a). As we can see that different beams are employed in different azimuth directions. Consequently, it cannot only reduce interference signal transmitted from the neighboring cells but also enhance the signal in desired direction. Nevertheless, the mentioned concept does not work very well for the case having ICI signal coming from the same direction of the desired signal for the cell of interest. In addition, the beam coming from cell-center introduces high level of interference to the neighboring's cell- center. Therefore, this paper proposes an idea to reduce ICI problem using vertical beamforming concept as shown in Fig. 6 (b). 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. The performance comparison of vertical and horizontal beamforming is shown in Fig. 7. The parameters given in the simulation are listed in TABLE I [3]. As we can see, utilizing vertical beamforming provides higher SINR to the systems. This is because interference from cell-center to the neighboring's cell-center can be reduced.

The vertical beamforming mentioned above can be accomplished using a linear array arranged in vertical lattice [18]. The characteristic of beam steering for linear array is given by [19]

$$AF = \sum_{n=1}^{N} e^{j(n-1)(kd cos\theta + \beta)} \qquad (1)$$

where N stands for the number of antenna elements and k is the propagation constant, with $k = 2\pi/\lambda$. The antenna elements are equally spaced by d. The angle represented by θ is measured from the z-axis in spherical coordinate as shown in Fig. 8. Also, β is the phase shift between adjacent elements which can be expressed by

$$\beta = -kd \, cos\theta_0 \qquad (2)$$
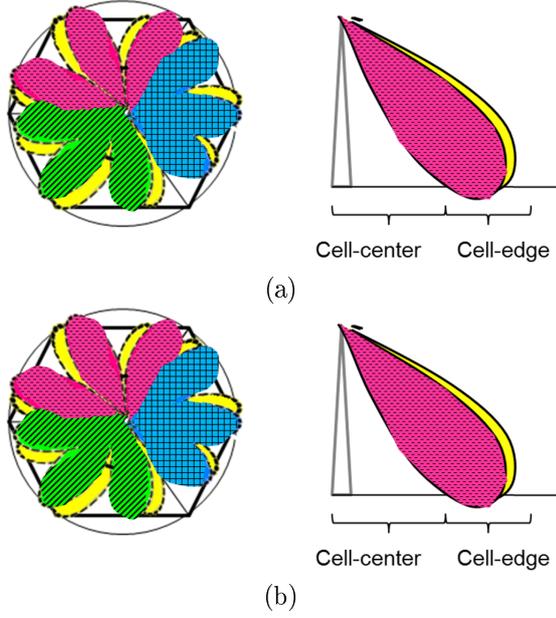
Fig.6: *(a) Horizontal and (b) vertical beamforming when viewing at top and side.*
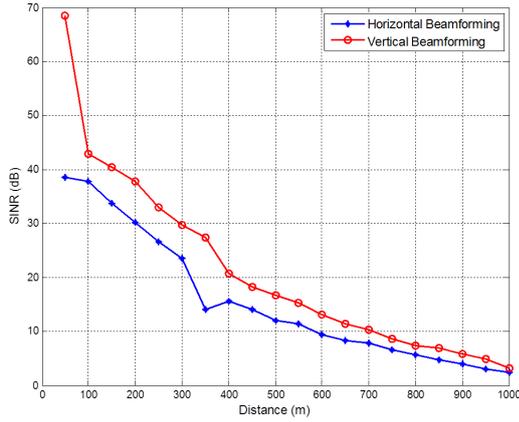
Fig.7: *SINR vs. distance between BS and MT when performing horizontal and vertical beamforming.*

where angle represented by θ_0 is the direction of maximum radiation.

For the computer simulation, the hexagonal cellular system is assumed. The wireless channel between BS and users is assumed to experience effects from propagation path loss and shadowing fading as follows. The propagation path loss can be given by [3]

$$PL = 120.9 + 37.6 \log R \qquad (3)$$

where R is the distance between user and BS in kilometers. As the shadowing fading values are assumed to be correlated, then we consider the following correlation model for shadowing [3].

$$S_n = X(d) \cdot S_{n-1} + \sqrt{1 - X(d)^2} \cdot N(0, \sigma) \qquad (4)$$
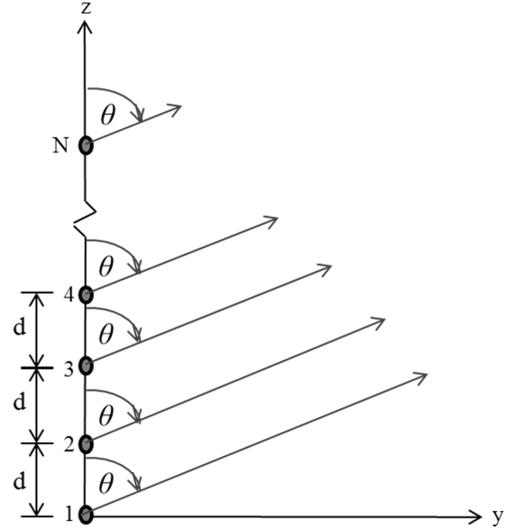
Fig.8: *Geometry of N-element array positioned along the z-axis.*

Table 1: *Parameters given in simulation.*

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

$$X(d) = 2^{\frac{-d}{d_{corr}}} \qquad (5)$$

where $X(d)$ is normalized autocorrelation function, 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 (4) 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 ith user can be expressed by [3]

$$H_i = \sum_{l=0}^{L-1} h_{i,l}(T_s) e^{-j2\pi k \Delta f \cdot \tau_1} \qquad (6)$$

where $h_{i,l}$ is the wide-sense stationary narrow band complex amplitude Gaussian process of the Lth path. The T_s stands for the OFDM symbol period and Δf is the neighboring 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 [3]

$$G_i = 10^{\frac{-PL_i}{10}} \cdot S_i \cdot |H_i|^2 \cdot g_i \qquad (7)$$

Fig.9: *Cellular structure of OFDMA systems and interference at cell-edge.*

where g_i is gain of the linear array when transmitting the signal from BS towards the ith user.

The frequency allocation utilized in the computer simulation for this paper is illustrated in Fig. 9. An OFDMA cellular environment with two-tier 19 cells is assumed. When the ith user is located in cell 1, the number of ICI at the cell- center from neighboring cells is 18 (cell 2 to 19). At the cell-edge area, the interference signal is coming from 7 cells. For example, when the ith user is in cell 1, the ICI signal is coming from cell 6, 7, 15, 16, 17, 18, and 19. The received SINR of the ith user can be expressed by [3]

$$SINR_i = \frac{G_i P_i}{N_0 \Delta f + \sum_{j=1}^{q} G_{i,j} P_j} \tag{8}$$

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. The P_i and P_j are 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 neighboring subcarrier spacing.

The channel capacity of ith user can be expressed by [19]

$$C_i = \left(\frac{m}{M}\right) log_2(1 + SINP_i) \tag{9}$$

where m is the number of subcarrier groups utilized at desired area and M is all available subcarrier groups. In this paper, the all available subcarriers are separated into two groups.

In next section, simulation results of BS antenna utilized nowadays though CST Microwave Studio are revealed. Then, the performance in terms of SINR and channel capacity using simulation results from CST Microwave Studio through the computer simulation is discussed.

5. VERTICAL BEAMFORMING IN CELLULAR NETWORK

In this paper, the antenna created in simulation according to the one appeared in [20] is currently employed at cellular BS. The photograph of the reference antenna is shown in Fig. 10 (a). It includes 9-elements antenna array where the inter-element spacing is 0.83λ [20]. From simulation results, half power beamwidth in azimuth plane is narrower when the number of array elements decreases. Therefore, it cannot cover all of the sector area. On the other hand, half power beamwidth in azimuth plane is wider than $65°$ when the number of array elements increases. This may cause an intra-cell interference. In addition, in case of the spacing between adjacent elements is less than 0.83λ, half power beamwidth in azimuth plane is wider than $65°$ while half power beamwidth in azimuth plane of antenna is less than $65°$ when the spacing between adjacent element is more than 0.83λ. Moreover, there is large upper sidelobe causing an inter-cell interference to neighboring cells when the spacing between adjacent antennas is more than 0.83λ. The simulation results obtained from CST Microwave Studio are compared with the commercial data from Commscope Company. The photograph of reference antenna is compared with the one created in CST Microwave Studio as shown in Figs. 10 (a) and (b), respectively. The horizontal pattern of commercial data and simulation results are shown in Figs. 11 (a) and (b), respectively. Also, the vertical pattern of commercial data and simulation results are shown in Figs. 12 (a) and (b), respectively. In addition, some parameters given in simulation are compared with the ones from commercial data as shown in Table II. As we can see, the simulation results have a good agreement with the ones from commercial data. Also, the obtained half-power beamwidth in horizontal and vertical planes and also beam tilt are similar. Also, gain and front to back ratio of antenna are moderately comparable.

The performance of cellular networks is shown in terms of SINR and channel capacity using the proposed scheme through the computer simulation. Please note that the parameters given in the simulation are listed in TABLE I [3]. The antenna gain values employed in (7) in case of cell-center and cell-edge are obtained from own developed computer program using CST Microwave studio. Please note that the linear array antenna operating at 900 MHz is employed [20]. The choice of mainbeam direction can be chosen by adjusting the phase shift between the antenna elements of the array. In the cell-center area, the inference signal is assumed to be coming from 18 cells. At the cell-edge area, the interference signal is coming from 7 cells (cell 6, 7, 15, 16, 17, 18 and 19) as demonstrated in Fig. 9. The threshold distance is assumed to be 400 meters. This distance is the criteria to switch the utilized beam. The beam at

Fig.10: *Photograph of reference antenna (a) and the one created in simulation (b).*

Fig.11: *Radiation pattern in azimuth of reference antenna [20] obtained from (a) commercial data and (b) simulation.*

Fig.12: *Radiation pattern in elevation of reference antenna [20] obtained from (a) commercial data and (b) simulation.*

cell-center is utilized when the distance between user and serving BS is less than 400 meters, otherwise the beam at the cell-edge is exploited.

In case of one spot beam, the coverage area is all over the sector hence the cell-center and cell-edge uti-

Table 2: *Parameters given in simulation.*

Parameters	Commercial data	Simulation results
Frequency (MHz)	870 - 960	900
Horizontal, Half power beamwidth (degree)	65	64.1
Gain (dBi)	17.8	18.7
Vertical, Half power beamwidth (degree)	7	7
Beam tilt (degree)	6	6
Upper sidelobe suppression (dB)	18	13.1
Front to Back Ratio at 180° (dB)	30	30.95
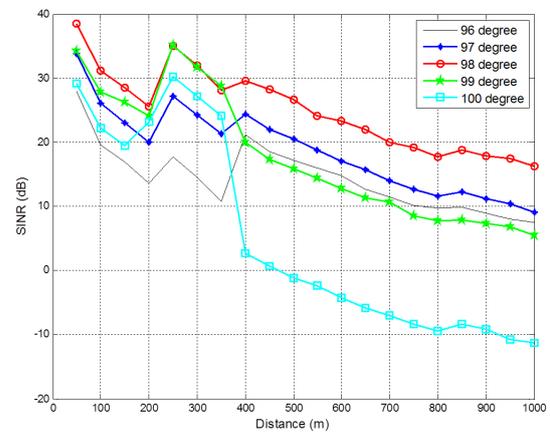
Fig.13: *SINR vs. distance between BS and MT when varying tilted-angle of mainbeam for cell-edge area.*

lize the same beam pattern. The different mainbeam directions are assumed in order to give variety of simulation cases. From simulation, mainbeam direction of 98° seems to provide the maximum SINR to the systems as shown in Fig. 13. However, SINR is relatively low in the cell-center region (0 to 400 meters) when mainbeam direction is small from 96, 97 to 100 degrees. This is due to that the half-power beamwidth in vertical plane of antenna cannot cover all of the sector area. However, the SINR can be improved when applying the proposed concept utilizing vertical beamforming, two beams for cell-center and cell-edge.

Next, an appropriate angle of mainbeam direction covering cell-center area is discussed. Some different angles of mainbeam directions have been utilized in simulation to improve performance of cell-center area as its outcome is shown in Fig. 14. As we can see, mainbeam direction of 106° seems to provide the maximum SINR at cell-center area. Nevertheless, it cannot provide maximum performance in the
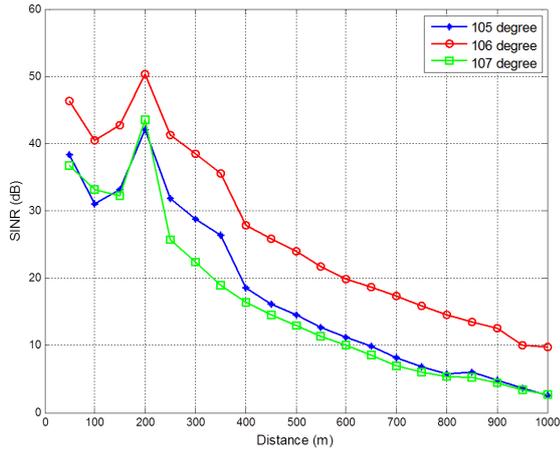
Fig.14: *SINR vs. distance between BS and MT when varying tilted-angle of mainbeam for cell-center area.*
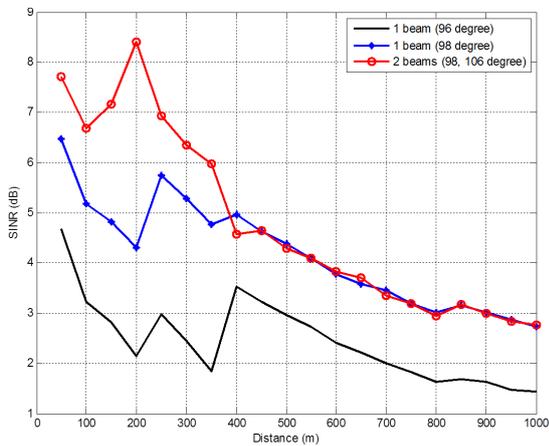
Fig.15: *SINR vs. distance between BS and MT for 3 cases: single beam, 1-beam vertical beam and 2-beam vertical beam.*

cell-edge region (from 400 to 1000 meters) comparing with utilizing main beam direction of 98°. This is because the half-power beamwidth in vertical plane of antenna cannot cover the cell-edge area. Furthermore, the users at the cell-edge area suffer from high level of interference coming from neighboring cells. Therefore, this paper proposes utilization the different beams in cell-center and cell-edge area separately. The mainbeam direction of 106° is used for covering cell-center area and 98° is used for covering cell-edge area. Latter, the proposed concept is validated comparing with single beam scheme providing one spot beam covering all over the sector, hence the cell-center and cell-edge utilize the same beam pattern. The obtained comparison is shown in Fig. 15. Two assumed cases provide similar performance in the cell-edge region (after 400 meters). In addition, SINR is relatively low in the cell-center region (0 to 400 me-

ters) when applying single beam scheme. However, in this area, the SINR can be improved when applying the proposed concept utilizing vertical beamforming, two separate beams for cell-center and cell-edge.

Next, the channel capacity of two cases is described in Fig. 16. As we can see, case of vertical beamforming, two beams utilized for cell-center and cell-edge separate can improve the capacity system. However at 350 meters, the capacity of proposed scheme is lower than the capacity of one spot beam scheme. This may be caused by changing beam from cell-center to cell-edge. However, the proposed vertical beamforming enhances performance of cellular networks.

The results discussed earlier have been obtained by assuming the region in one-dimensional from 0 to 1000 meters. Anyway it cannot illustrate the overall performance throughout the sector. Therefore, the SINR throughout the sector is revealed in Fig. 17. As we can see, the area having higher SINR in case of utilizing the proposed concept is wider comparing to the one employing single beam, particularly at the cell-center. This means that the vertical beamforming enhances the performance of cellular networks.
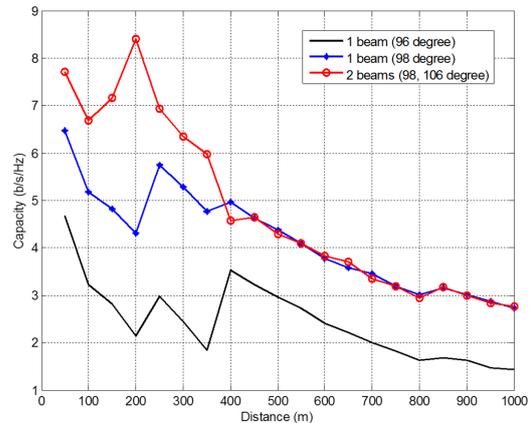
Fig.16: *Capacity vs. distance between BS and MT for 3 cases: single beam, 1-beam vertical beam and 2-beam vertical beam.*

(a)   (b)
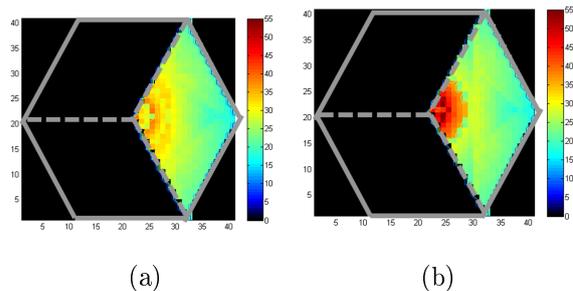
Fig.17: *Contour plot of SINR over the sector for (a) single beam and (b) vertical beamforming.*

6. CONCLUSION

This paper has investigated into a vertical beamforming concept for the cellular networks utilizing fractional frequency reuse. Beam patterns are simulated according to the BS antenna currently utilized nowadays. Two separate beams are utilized for cell-center and cell-edge. The proposed concept is validated using computer simulation in terms of SINR and channel capacity comparing with single beam concept. The results show that mainbeam directions of 106° and 98° provide the maximum SINR at cell-center and cell-edge, respectively. This results in reduction of the inter-cell interference coming from neighboring cells. The obtained results have indicated that the vertical beamforming concept can improve the performance of the cellular networks comparing with the one employing one spot beam.

7. ACKNOWLEDGEMENT

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