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Interaction of Frequency Allocation Schemes and Beam Forming on the Performance of Cellular Communication Systems Based on OFDM

R. Gholami and N. Neda
Department of Electrical and Computer Engineering, University of Birjand, Birjand, Iran

Abstract: In this study, the interaction of Beam Forming and frequency allocation schemes on an OFDM-based system such as LTE or WiMAX is investigated in order to support the maximum capacity and minimum outage probability. The results of simulation show that rank1 precode scheme based on MISO channel, according to what considered in LTE standard, along with the cell region division in order to allocate OFDM frequency carriers lead to a Considerable interest in the total capacity of the network in different traffics.

Keywords: Beam Forming, closed loop spatial multiplexing, frequency allocation, LTE system

INTRODUCTION

Expansion of demand in the mobile networks to support data applications with high spectral efficiency and output leaded to the Development of fourth generation networks based on OFDM including WiMAX and LTE (Prasad, 2004). The Long Term Evolution (LTE) standard is a radio interface with very high flexibility that the investigation of it was started from early 2005 by the 3rd Generation Partnership Project (3GPP) and was completed (Astély *et al*., 2009; Dahlman *et al*., 2007; Khan, 2009). Of course this system which is presented with the aim of supporting the data transmission rate to 100 Mbps for Downlink and 50 Mbps for Uplink requires wide bandwidth and also effective efficiency of this bandwidth. Thus, one of the important aims in designing a LTE network is to improve the performance in the cell edge in order to maximize the capacity and thereupon the management of frequency resources in these systems is very vital. The downlink radio transmission in LTE is performed by using OFDM modulation but in uplink radio transmission because of PAPR problem (Peak to Average Power Ratio) using SC-FDMA (Single Carrier FDMA) is suggested (Astély *et al*., 2009; Myung *et al*., 2006; Elayoubi and Haddada, 2007).

We know that the frequency reuse leads to the resources efficiency in the cellular systems. Of course this technique will cause the increase of interference in the cell edges and the reduction SINR and also capacity in these regions (Adhikari, 2009). Although applying appropriate clustering and sectoring in the present cellular systems (e.g., GSM) partially causes the increase of channel capacity and the reduction of interference between cells, but according to the high transmission rate in modern systems, more need of reusing the frequencies is felt to be able to support traffic increase, high rate and desired service quality. Thus it is required that the new schemes of the OFDM frequency carriers allocation in different regions of the cell be studied and also the effect of modern facilities predicted in an OFDM-based system like LTE or WiMAX on the performance of these schemes be investigated more precisely (Elayoubi *et al*., 2008; Tso and Viswanath, 2005; Son and Lee, 2006). An example of these facilities is supporting MIMO channels in the above systems which in this study will be studied from aspects its effect in controlling of the intercell interference.

Applying MIMO is one of the most important technological developments in the scope of modern digital communication. MIMO system which was first presented by Telatar in 1995, today is widely considered in OFDM-based standards like LTE and WiMAX and in order to increase transmission rate, coverage and capacity of cell (Adhikari, 2009; Gesbert *et al.*, 2003; Khan, 2009; Kuhn, 2006).

An important technique in these systems is simultaneous transmission of a string of data on multiple antennas with appropriate preceding weights which leads to Beam Forming (Adhikari, 2009). In this method if the weighting of antennas is done with suitable coefficients (which depends on the user's location in the cell) can cause the increase of signal power especially in cell edges, although it may increase the interference effect on adjacent users.

The investigation of the effect of different frequency allocation schemes in combination with the rank 1 precoding on capacity and outage probability in an OFDM-based cellular network like LTE is the main aim of this study.

FREQUENCY ALLOCATION SCHEMES

A certain radio spectrum (bandwidth) can be divided into a series of discrete radio channels. Such channels can be received simultaneously while

Corresponding Author: R. Gholami, Department of Electrical and Computer Engineering, University of Birjand, Birjand, Iran

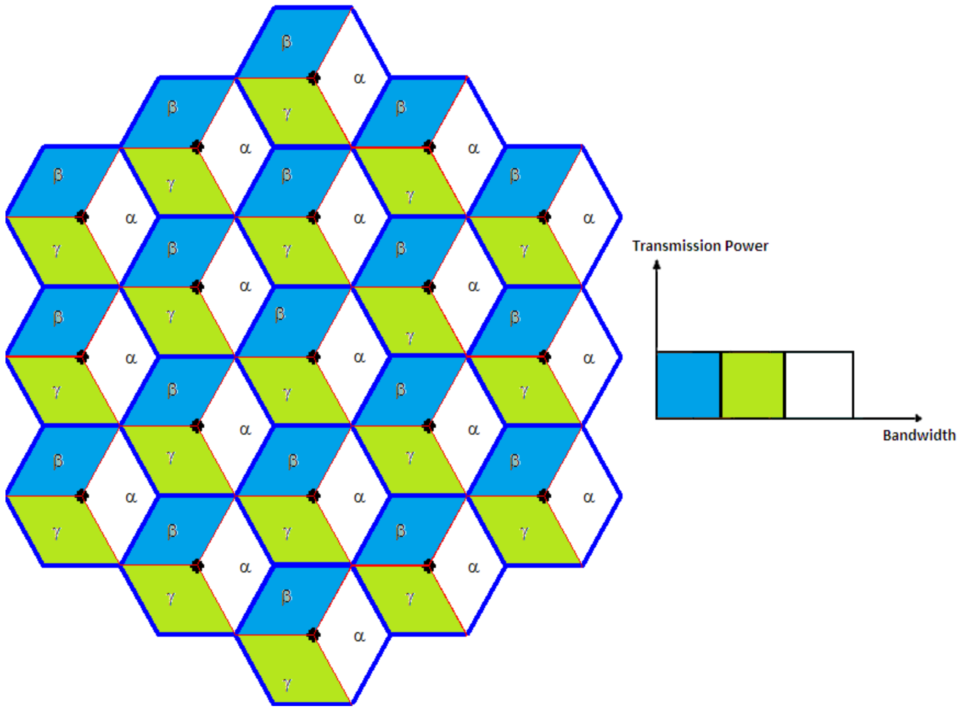

Fig. 1: 120° sectoring

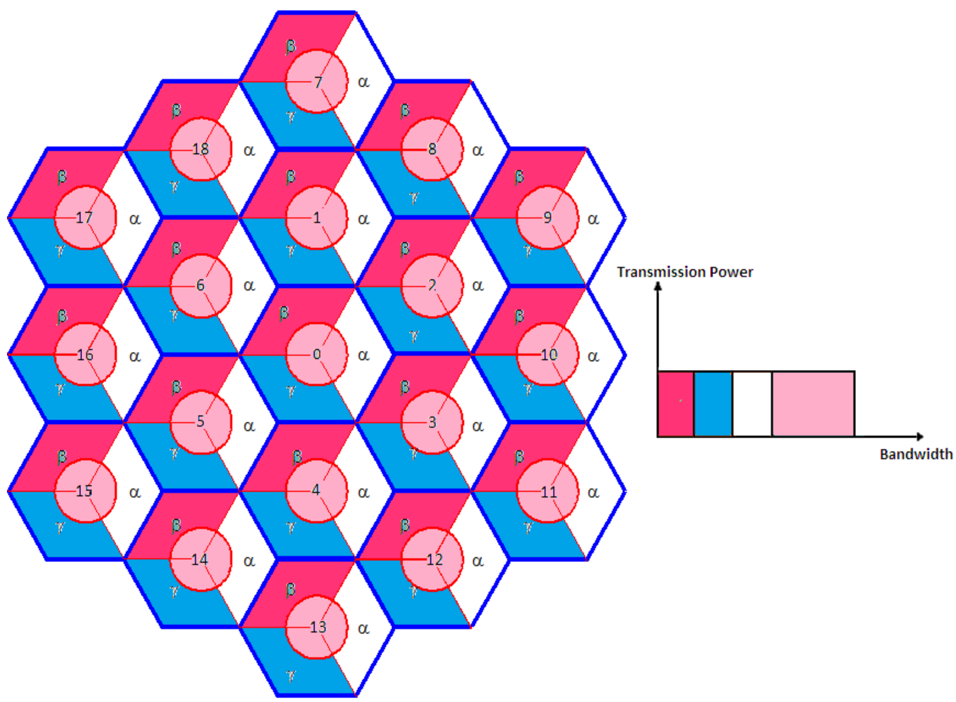

Fig. 2: Cell region division

maintaining acceptable radio signals are used. To divide a given radio spectrum into such channels many techniques can be used such as Frequency Division (FD), Time Division (TD), or Code Division (CD). In FD, the spectrum is divided into separate frequency bands. While in the TD, the separation of channel is done with division of the spectrum to the time periods that call the time gap. In CD, the channel separation is derived using different modulation codes. In addition, with combination of techniques mentioned above can design sophisticated techniques for radio spectrum division into discrete channels. For example, the combination of TD and FD use in GSM systems. The major factor to determine the numbers of channels with a certain quality that can be used for a specified mobile spectrum is the Received signal quality level that can be achieved in each channel (Atzela and Naghshineh, 1996). Available frequency spectrum is a limited and rare. Therefore, it is a very valuable resource that should be used effectively. The aim of cellular systems is an efficient utilization of available frequencies in order to increase capacity. Frequency reuse is a key technique for this work. In the below parts, two frequency allocation schemes including cell sectoring and cell Region division are introduced.

Cell sectoring: The co-channel interference in a cellular system can be reduced by substituting an Omni-directional antenna at the base station with several directional antennas that each radiate in a specific sector. In this scenario, while each cell practically uses all frequency band it will interfere with only a part of adjacent cells. This technique which leads to interference reduction and also the increase of system performance is named cell sectoring (Rappaport, 2009). In this plan as shown in Fig. 1, the existing bandwidth is divided into 3 parts and each part is allocated to one sector.

Cell region division: In this scheme (Son and Lee, 2006, 2007), the area covered by each cell and the entire bandwidth (the total OFDM carriers) is divided into two outer and inner sections. As shown in Fig. 2, the inner band is allocated to the inner region of each sector, but the outer band is divided into tree sub-bands and each sub-band is allocated to one sector. Depend on the location of each user is assigned one or more channels of the outer or inner band to it. For example, the layout shown in Fig. 2 is composed of 19 cells which such for inner region of the α sector in the 0^{th} cell (the reference cell), are interfere inner region 7α sectors belonging to number of cells {5, 6, 14, 15, 16, 17, 18}, inner region 6β sectors belonging to number of cells {3, 4, 10, 11, 12, 13}, inner region 6γ sectors belonging to number of cells {1, 2, 7, 8, 9, 10}. Since cell centers in the network, are always away from each other, users in these areas will experience a high SIR and therefore can be considered a set carriers for them to reuse factor 1.

Also for outer region of the α sector in the 0^{th} cell (the reference cell), are interfere outer region 7α sectors belonging to number of cells {5, 6, 14, 15, 16, 17, 18}. The Geographical division of each area is as function of the radius 'r' of inner region and also is done the bandwidth divided according to areas ratio. Then, W_{in} = (W.Q) /3 and W_{out} = (1 - Q) W/3 is the bandwidth allocated to inner and outer region of each sector. In the upper equation, Q is area ratio inner region to total region.

Transmit Beam Forming with rank 1: As was said, MIMO technologies widely to use in OFDM-based systems such as LTE and WiMax has been proposed. In LTE, the Closed Loop Spatial Multiplexing (CLSM) includes sending one or two streams of data simultaneously by two antennas of the base station to mobile (Adhikari, 2009). Sending 1 data stream is known as Rank 1 CLSM and sending 2 data streams is known as Rank 2 CLSM, which of course use each depends on the channel conditions. In this study we review only Rank 1 CLSM as gain will create that in controlling SIR in each of these frequency allocation schemes.

Rank 1 CLSM implements transmit by Beam Forming. Two transmission symbols on each antenna and each channel OFDM are transmitted with certain phase difference to be together. Phase difference between two data sent can be 0, 90, -90 or 180°, respectively. These phase differences can lead to the formation of four different beams in the base station, which each mobile depending on its position (angle than the main beam antenna), can choose one of four radiation. This phase difference is created by selecting one of four precoder matrix as Table 1.

Can easily show that power received by the remote user, by vector sum the total published electric field by both antennas and including the phase difference caused by published difference in signal path and also the phase difference caused by imposed precodes defined as follows:

$$P(i) \propto G^2(\alpha)\left(1 + Cos(2\pi kSin(\alpha) + \varphi(i))\right)^2 \quad (1)$$

where,

- i : Type of precoder matrix
- kλ : The distance between antennas (λ is transmission wavelength and k is constant)
- α : The angle between the main beam antenna and user location

Also, G(α) shows the antenna gain at angle α to the main beam and φ(i) express the phase difference created by the precoder matrix.

As can be seen to be received power by each user on each OFDM carrier frequency is depend to the user location and also precoding type used for the user. Note that the beam pattern is very sensitive to the distance between two transmit antennas at base stations. If the inter-antenna distance is small (say 0.5λ) then the transmitted signals are more correlated (k = 0.5) and the radiation pattern power can change depending on α will be slow.

View of the angular power distribution pattern for a low distance between two transmitter antennas and introduced in four precoder in Table 1 is shown in Fig. 3. Also, Table 2, is shown number each precoder and angular range around the bisector of each sector that the radiation power it caused, is more from the other precoders. The mobile can select the best

Table 1: Rank 1 precoder matrix in LTE

Precoder matrix	Phase difference φ(i)	Matrix index (i)
$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\1\end{bmatrix}$	0°	1
$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-1\end{bmatrix}$	180°	2
$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\j\end{bmatrix}$	90°	3
$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-j\end{bmatrix}$	-90°	4

Table 2: Angular range for most power for each precoders introduced in Table 1

Angular range to the middle beam (°)	Matrix index (i)
-60 to -48	2
-48 to -15	3
-15 to 15	1
15 to 48	4
48 to 60	2

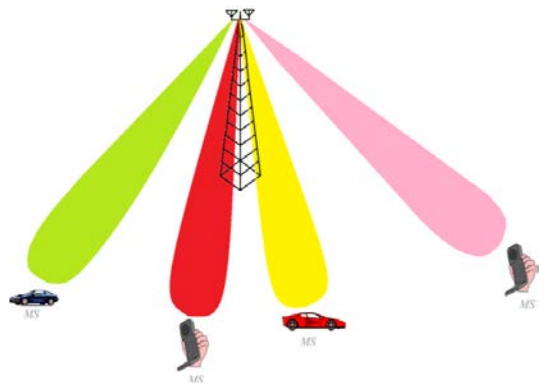

Fig. 3: Transmit Beam Forming depending on the angle of each user (Rank 1 CLSM)

precoder matrix with calculate the SIR and reporting precoding matrix desired and quality channel to base station.

If the best gain power region that achieved by a specific precoding, is high (As Table 2 for half the wavelength distance between two transmitter antenna), then a mobile even in high speeds also had the best coverage and will be received good strength. So the rank 1 closed loop spatial multiplexing mechanism in LTE, is applicable in the high correlated environment (low distance between the transmitter antennas), in a wide range of user speed even with a low rate feedback.

COMPARISON CRITERIA

Signal to Interference Ratio (SIR): The path loss between an mobile is located in "s" position of the base expressed as follows:

$$L = d^{-n} 10^{\xi/10} = d^{-n}\chi \tag{2}$$

where,

n : A path loss exponent (n∈[2, 4])

d : The distance between the base station to user

ξ : A Gaussian distributed random variable with zero mean and standard deviation

σ : The shadowing

χ : A lognormal random variable

As shown in Fig. 2, two cases can be considered relying on the location of the user. In the first case, the user is located in the inner region of sector, for example α and the second case, the user is located in the outer region of α sector. Quantity E_b/I_0 (bit energy to interference power for the mth user on the network) in two cases, are expressed by Eq. (3) and (4), respectively:

$$\left(\frac{E_b}{I_0}\right)_m = \frac{P.L_{(s,i)}/R}{\left[\sum_{j=1}^{K} n_j P.L_{(s,j)}.Block\_Source\right]/W_{in}} \geq \delta \tag{3}$$

And similarly, for second case:

$$\left(\frac{E_b}{I_0}\right)_m = \frac{P.L_{(s,i)}/R}{\left[\sum_{j=1}^{K} n_j P.L_{(s,j)}.Block\_Source\right]/W_{out}} \geq \delta \tag{4}$$

In the above equations, Block_Source represents the number of allocated subcarriers to the user, P is power allocation to each OFDM channel frequency, n_j is the number of interfering users in the jth interfering cell, $L_{(s,i)}$ is the path loss between user at "s" position and the ith base station and $L_{(s,j)}$ is the path loss between user at "s" position and the jth interfering base station. Also R is the transmission rate on each OFDM channel and δ is threshold desired signal to interference (E_b/I_0).

Outage probability: Considering the Eq. (3) and (4), the outage probability in the inner and outer region identified are as follows:

$$P_{\text{outage}_{\text{in}}} = P\left[\left(\frac{E_b}{I_0}\right)_m \leq \delta\right] \times P[x \in R_i] \tag{5}$$

And

$$P_{\text{outage}_{\text{out}}} = P\left[\left(\frac{E_b}{I_0}\right)_m \leq \delta\right] \times P[x \in R_o] \tag{6}$$

where, R_i and R_o represents inner region area outer region area thus the total capacity and outage probability system are defined in Eq. (7) and (8) respectively. In this equations, C (r) and P (r) represents the capacity place and outage probability place of the system based on the distance from the base station, respectively:

$$\begin{cases} C_i = \sum_{r \in R_i} C(r).\dfrac{2\pi r}{R_i}.\Delta r \\ C_o = \sum_{r \in R_o} C(r).\dfrac{2\pi r}{R_o}.\Delta r \end{cases} \Rightarrow \quad C_{\text{overal}} = C_i.\frac{W_{\text{in}}}{W} + C_o.\frac{W_{\text{out}}}{W} \tag{7}$$

And also:

$$\begin{cases} P_i = \sum_{r \in R_i} P(r).\dfrac{2\pi r}{R_i}.\Delta r \\ P_o = \sum_{r \in R_o} P(r).\dfrac{2\pi r}{R_o}.\Delta r \end{cases} \Rightarrow \quad P_{\text{overal}} = P_i + P_o \tag{8}$$

THE RESULTS OF SIMULATION

We first consider a LTE cellular network with 19 cells and compare the methods Introduced in the frequency allocation and interference control. Assumed that all mobile phones are distributed on the cellular networks with a uniform probability density distribution and each base station assign a same power to all users. Also assumed that is available 1024 the OFDM channel and traffic load per cell is considered 50% of total traffic.

In this simulation, we consider the frequency bandwidth of 10 MHz, transmission rate on OFDM each channel is R = 15 kbps and threshold is $\delta = 4dB$. we consider the radius normalized by the inner region and the antenna gain, r = 0.5 and G (α) = 1, respectively. Also, is assumed that the standard deviation of ξ is 8 dB for the interfering signals from adjacent cells and for the Reference cell signals is 2.5 dB.

Initially, we compared the cell sectoring scheme (Fig. 1), cell region division (Fig. 2) and cell region division with the transmit Beam Forming (Fig. 3) according to the distance of the user to base station and then will be evaluated the overall performance of each scheme according to the increased traffic load.

In Fig. 4 and 5 are shown, the outage probability and average capacity (average over all regions and users) in terms of percentage of network traffic load, respectively. As will be seen, in all schemes increase outage probability with increasing network traffic, but is obvious slow growth the outage probability in composition cell division and cell sectoring schemes into the appropriate precoding technique. Here, separately for each user is selected the best code according to mobile user location and data in Table 2.

Of course, seen that the precoder offers the most gain in the intermediate traffics, Because in the very busy network, the centralized base antenna beam can cause to increase interference for users that are in line with the desired user.

In Fig. 5 is given, the average capacity gain network based on percentage of traffic load. Clearly seen that if we consider the capacity of the whole

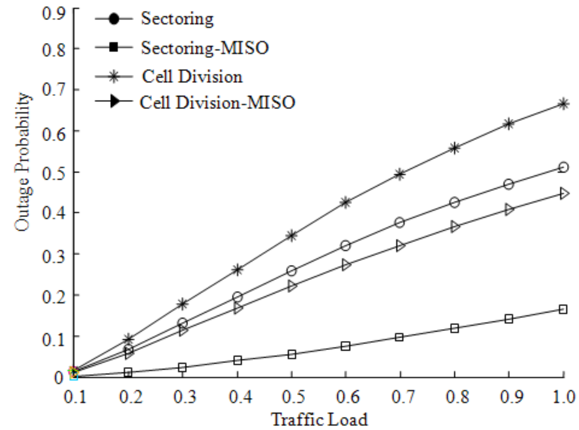

Fig. 4: Overall outage probability in each cell based on the traffic load

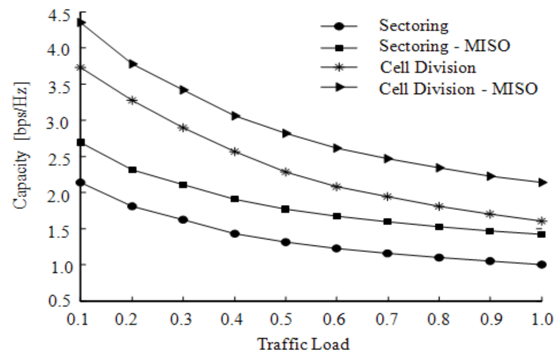

Fig. 5: Overall capacity in each cell based on the traffic load

system, cell division scheme lead to a significant gain than sectoring scheme and also using rank 1 CLSM will create a similar gain in all the traffic loads to cell division scheme. In Fig. 5, we observed that the capacity of the whole system into the region division scheme, according to the better efficiency of frequency (bandwidth shared in the inner area), an average of about 18.5% compared to sectoring increases. In addition, the combined this scheme with transfer precoding technique, can be increase the average capacity of the total network about 14% compared to conventional cell division region scheme (single antenna).

CONCLUSION

In this study, we investigated the performance of the schemes of cell sectoring and cell region division in an OFDM-based network such as LTE in the case of capacity and interference. It was observed that the use of multiple antenna transmissions with appropriate precoding, causes more efficiency of frequency spectrum and better servicing quality compared with the previous cellular systems and combination of this structure with the frequency allocation schemes can lead to considerable increase in capacity and quality of servicing especially in intermediate traffics.

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