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An Efficient Spectrum Assignment for Spatial Division Multiple Access in Millimeter Wave Cellular Network

Thanh Ngoc Nguyen and Taehyun Jeon
Department of Electrical and Information Engineering,
Seoul National University of Science and Technology, 01811 Seoul, Korea

Abstract: The use of millimeter-wave band is a promising candidate for improving performance of 5th generation mobile communication systems because of the vast amounts of available radio resources. However, in the very near future, data traffic is also expected to rapidly increase, due to the explosion of various multimedia services via. mobile communication. In this scenario, spectral efficiency enhancement will become important. In this study, a spectrum utilization for spatial division multiple access is proposed. In the system, the base station uses beamforming antenna array to radiate signal in a particular direction to the desired user for the downlink. Reversely in uplink, a beam is generated toward the desired user to receive the wanted signal as well as to reject the interference. As a result, the base station can serve multiple users separately in the space domain. In this approach, the base station assigns the users which do not interfere with each other in the same radio resource. On the other hand, if users cannot be spatially separated, they will be assigned the disparate channels. The proposed scheme is expected to significantly enhance overall capacity of the network compared to the traditional schemes.

Key words: Millimeter-wave, beamforming, spectral efficiency, small cell, capacity, antenna array

INTRODUCTION

It is the fact that the volume of data traffic in mobile communication increases rapidly in recent years. In addition, the advent of IoT devices leads to increasing number of connections and the data demand. The conventional frequency bands (below 3 GHz) in which the current mobile cellular systems are in operation are expected to be crowded. Various advanced technologies such as MIMO, OFDMA and carrier aggregation are implemented but they will only be the short term solution for the increasing demand. Entering the higher frequencies becomes necessary where abundant spectrum is available. In this scenario, the millimeter-wave band (30-300 GHz) is being considered as the best candidate because of the vast amounts of underutilized frequency. By using user bandwidths of 1-2 GHz at the millimeter-wave frequency bands, capacity of the mobile communication systems can be significantly improved. The high-speed data rate and low latency required by next generation (5G) mobile communication become achievable.

In order to use the millimeter-wave band, the most essential issue is overcoming the high propagation path loss in this band. Fortunately, smart antenna array and beamforming technology provide a useful solution. Beamforming helps to transmit the signal in a particular direction by focusing the radiated power. In the receiver side, nulls can be formed and directed to the direction of interference and receivers obtain only the signals from a desired direction. As a result, the quality of the channel is improved and the interference between users is limited as well. In addition, this effect is magnified by the characteristics of the millimeter-wave which include high straightforwardness, low refraction and diffraction. Furthermore, the very short wavelength of the millimeter-wave band enables the system to integrate the array of antennas in a limited space. For these reasons, significant research effort has been invested in beamforming and millimeter-wave technologies (Sun *et al*., 2014).

In wireless communication systems, multiple access techniques are implemented to increase number of users sharing a limited frequency spectrum. The most common techniques of multiple access include Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), Code Division Multiple Access (CDMA) and Orthogonal Frequency Division Multiple Access (OFDMA). A limitation of these techniques is that the spatial diversity is underutilized which is one of the

Corresponding Author: Taehyun Jeon, Department of Electrical and Information Engineering,
Seoul National University of Science and Technology, 01811 Seoul, Korea

wireless communication resources. The Spatial Division Multiple Access (SDMA) was proposed to take the advantage of spatial diversity by using antenna arrays. The main obstacle of SDMA is the required antenna spacing of array at least a half wavelength which limits the number of the antenna element. However, in the millimeter-wave band, SDMA becomes reliable because the wavelength in this band is very short in order of several millimeters (Berraki *et al*., 2014).

In order to implement SDMA, the base station must have the ability to detect the overlapping of the transmission data streams and to insure the inter-user interference limitation for the detection at every single user. However, in the practical systems, the mobile users are moving and the special separation is not always guaranteed. There might be a case that, users come close to each other and lead to co-channel interference. To solve this issue, the base station must have the ability of detecting interference and re-assigning the radio frequency resource for users.

MATERIALS AND METHODS

System model: In this study, we investigate a single cell scenario in a typical mobile cellular system which is illustrated in Fig. 1. In the limitation of this study, the cell is assumed to be isolated. In other words, we consider only the inter-user interference and neglect the inter-cell interference. Due to the complexity of the adaptive beamforming in the millimeter-wave band system, the switched beamforming is preferred (Maltsev *et al*., 2015) in which the weight vector is chosen from the pre-defined set of code words called codebook. In this study, we adopt the codebook specified in the IEEE 802.15.3c standard which is developed for millimeter-wave system operating in the 57-66 GHz range (Anonymous, 2009). In our system, the base station is equipped with a linear antenna array with N_T elements which are divided into N_A sub-arrays. Each sub-array is controlled by a separated switched beamformer. As a result, the maximum number of beams which can be formed by antenna array is equal to the number of sub-arrays such that the maximum number of mobile users which can be simultaneously served via the same frequency channel is N_A. On the other hand, we assume that the number of mobile users in the cell is K which are distributed randomly in the cell. Each user is equipped with a single antenna. The available spectrum assigned for the system is B_A which is divided into frequency resource blocks with bandwidth BHz.

Let us, consider the transmitted data vector $x = [x_1 x_2, ..., x_k]$ where x_k is the data stream for kth user in the cell.

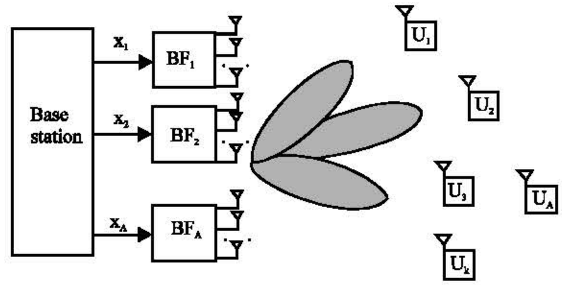

Fig. 1: System model for a typical mobile cellular system

We assume that the data stream x_k is modified by multiplying with a weight vector $w_k \in C^{N\times 1}$ before being transmitted over the channel $h_k \in C^{1\times N}$. Hence, the received signal for kth user can be expressed as:

$$y_k = h_k w_k v_k + h_k \sum_{i=1, i\neq k}^{K} \beta_{(i,k)} w_i x_i + n_k \quad (1)$$

Where:

n_k = The complex Gaussian noise with variance σ^2 and $\beta_{(i,k)}$ = The variable defined as follows

$$\beta_{(i,k)} = \begin{cases} 1, \text{ if i-th user and k-th user are} \\ \text{assigned same channel} \\ 0, \text{ otherwise} \end{cases} \quad (2)$$

Therefore, the received Signal to Interference Plus Noise Power Ratio (SINR) for k-th user is:

$$SINR_k = \frac{|h_k w_k x_k|^2}{|h_k \Sigma^K_{i=1, i\neq k} \beta_{(i,k)} w_i x_i|^2 + \sigma^2} \quad (3)$$

Proposed spectrum assignment: In this study, the proposed frequency assignment scheme will be explained in detail. Figure 2 shows the block diagram of the assignment process for K users in the cell. Here, we denote U is the set of users in the cell, N is the set of not yet scheduled users and the set of scheduled users is S.

Through the process, the base station selects the users who do not interfere with each other and assigns them on the same channel. On the other hand, the interfering users will be moved to the different channel. Finally, the bandwidth for each group will be assigned such that the total capacity of the cell is maximized. Before the process begins, the base station sends the training signal to all users one by one. By calculating the received

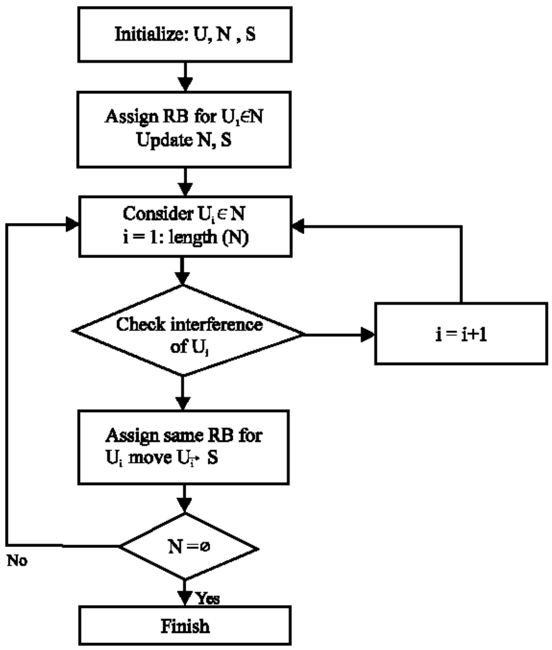

Fig. 2: Proposed frequency assignment procedure

signal power each user can estimate the channel status information. This information is sent back to the base station. Based on the feedback from the user, the base station decides the corresponding beamforming code word. The training process is explained in detail by Wang *et al.* (2013).

RESULTS AND DISCUSSION

In this study, we carry out the simulation to evaluate the performance of the SDMA system with proposed spectrum assignment in the millimeter-wave cellular environment. The system is investigated under the channel environment based on the parameters specified in the standard IEEE 802.11ay (Maltsev *et al.*, 2016) which is popularly applied in millimeter-wave system. The system model discussed in this study is assumed in the simulation with some additional parameters. The base station is assumed to have 8 sub-arrays each of which provides a controllable beam pattern with 30° half power bandwidth. The cell radius is varied from 150-900 m (Fig. 3). A bandwidth of 2 GHz is assigned for the whole system. The performance of the system is evaluated via. the average sum throughput of users which is inferred from the SINR in Eq. 3. The result shows that, the SDMA scheme gives a significant enhancement compared with the conventional OFDM scheme. This gain is the result of allocating the same frequency for multiple users.

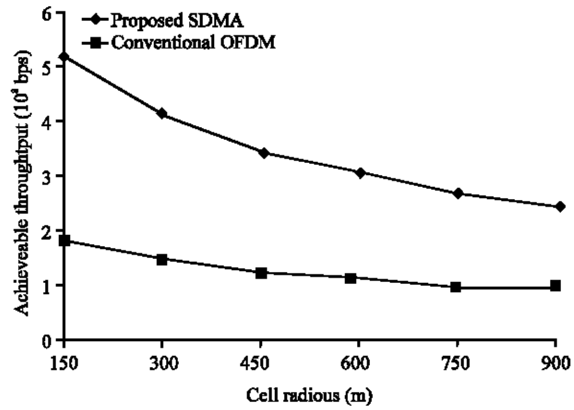

Fig. 3: Throughput enhancement by proposed SDMA scheme

CONCLUSION

In this study, Spatial Division Multiple Access (SDMA) for millimeter-wave is studied and an efficient spectrum assignment for SDMA is proposed as well. The result has proved the viability of SDMA in millimeter-wave cellular system by taking advantage of beamforming and smart antenna array. We also propose a simplified spectrum assignment algorithm for SDMA. This study demonstrated that the combination of beamforming and SDMA in the millimeter-wave band could be a promising solution to for the next generation network.

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