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A Conditional Clustering Scheme for Hybrid NOMA in Millimeter Wave Communication System

Thanh Ngoc Nguyen* and Taehyun Jeon**

**Ph.D. Student, Department of Electrical and Information Engineering, Seoul National University of Science and Technology, Korea*
***Professor, Seoul National University of Science and Technology, Korea*
E-mail: {thanh.nguyen, thjeon}@seoultech.ac.kr

Abstract

Millimeter-wave (mmWave) and Non-orthogonal multiple access (NOMA) are expected to be the major techniques that lead to the next generation wireless communication. NOMA provides a high spectrum efficiency by sharing of spatial resources among users in the same frequency band. Meanwhile, millimeter-wave gives a huge underutilized bandwidth at extremely high frequency band (EHF) which covers 30GHz to 300GHz. These techniques have been proven in several recent literatures to achieve high data rates. The combination of NOMA and millimeter-wave techniques further improves average sum capacities, as well as reduces the interference compared to conventional wireless communication systems. In this paper, we focus on hybrid NOMA system working in millimeter-wave frequency. We propose a clustering algorithm used for a hybrid NOMA scheme to optimize the usage of wireless resources. The proposed clustering algorithm adds several conditions in grouping users and defining clusters to increase the probability of the successful superposition decoding process. The performance of the proposed clustering algorithm is investigated in hybrid NOMA system and compared with the conventional orthogonal multiple access (OMA) scheme.

Keywords: *Millimeter-wave, Beamforming, Spectrum efficiency, Small cell, Capacity*

1. Introduction

Because of the rapid development of information technology especially in machine-to-machine (M2M) communications, sensor networks and internet-of-things (IoT) areas which are expected to grow to billions in the next few decades, the number of wireless connection keeps increasing exponentially. In addition, the data traffic demand of mobile phones, mostly related to multimedia, is also expected to rise up to 10 times more than nowadays [1, 2]. These demands require innovation of the current wireless communication networks to enhance the capacity and data rate. In this scenario, millimeter-wave (mmWave), non-orthogonal multiple

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Corresponding Author: Taehyun Jeon (thjeon@seoultech.ac.kr)
Tel: +82-2-970-6409, Fax: +82-2-978-2754
**Professor, Seoul National University of Science and Technology, Korea

access (NOMA), and massive multi-input-multi-output (massive MIMO) used in large-scale antenna system had attracted a lot of attention both in academia and industry [3].

Millimeter-wave band, also known as the extremely high frequency (EHF) refers to the frequency band from 30 to 300GHz. With huge underutilized frequency band, millimeter-wave gives the solution for the lacking of bandwidth as in the conventional frequency bands. Moreover, the short wavelength of millimeter-wave enables the large-scale antenna system due to the small required space of the antenna. While millimeter-wave gives the new and unused band, non-orthogonal multiple access or NOMA was proposed to improve the spectrum efficiency (SE) [4]. NOMA takes advantage of the superposition coding to transmit data of multiple users in the same frequency, code and time domain. However, the implementation of NOMA requires more complexity in both the transmitting and receiving process. The receiver has to implement successive interference cancellation (SIC) to eliminate the strong inter-user interference, while the base station must have the ability to organize the users in groups (clusters) and assign the resource (transmit power) for each group as well as each user in a group. One of the main obstacles for implementing NOMA is that the channel gain difference between users should be maintained to guarantee the successful SIC process. Fortunately, the high path loss of the millimeter-wave propagation enhances the channel gain differences among users. As a result, the inter-users interference in a NOMA-based network can be reduced significantly. This is the main reason that many efforts have been done to combine the NOMA scheme with the millimeter-wave system [5].

In this paper, the NOMA is implemented in millimeter-wave system to optimize the usage of wireless resources. In this system, the base station transmits data to multiple users via sharp beams generated by the large antenna array. Each beam is utilized to transmit the data for two users in a cluster. The multiple streams are separately transmitted to the users in the manner of spatial division multiplexing. However, it is difficult to design a beamforming vector for multiple users in a cluster. Therefore, a hybrid NOMA scheme was proposed [6, 7]. This scheme implements NOMA among the users within each group, and conventional OMA among clusters in the network. In this case, the system complexity is reduced and the inter-cluster interference decreases. As a drawback, the spectrum efficiency is lower compared to the optimal NOMA scheme [8-10]. In this paper, we provide a user clustering scheme for the hybrid NOMA by adding several conditions in grouping users and defining clusters. The performance of the proposed scheme is investigated in terms of summation capacity and compared with the conventional Orthogonal Multiple Access scheme.

The remaining parts of this paper are organized as follows. In section 2, the system model of a typical cellular system will be briefly described. The mathematical model of the transmitted signal is also given in this part. In section 3, the proposed scheme is explained. In section 4, simulation assumption is described and the results will be provided along with the discussion of the system throughput performance. Finally, in section 5, several conclusions will be given to close our work.

2. System Model

In this section, a millimeter-wave NOMA downlink scenario is considered. The system consists of one base station with a large array of antennas and K single antenna users. It is assumed that the antennas array of base station performs MIMO transmission with M beams. Practically, the number of users in a cell is much greater than the number of beam ($K \geq 2M$). The RF beamforming is preferred in the recent research [5] because of the low complexity compared to the full adaptive beamforming. At the base station, the large antenna array is divided into sub-arrays which are separately controlled by an RF beamformer. Mobile users are randomly distributed in the cellular network in which the base station is located at the center. The overall system scenario is illustrated in figure 1.

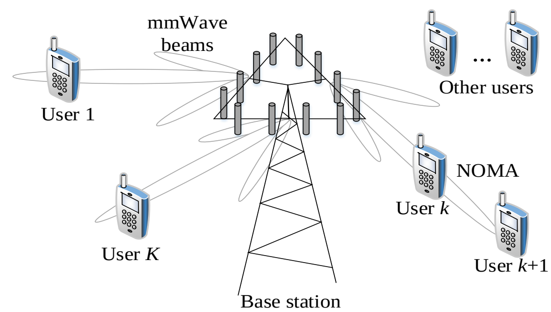

Figure 1. System model for a typical mobile cellular system

For simplicity, in this paper, we adopted the path loss models for millimeter-wave cellular network proposed in [5]. The calculation of the propagation path loss, $L_{mm}(r)$, is given as follows:

$$L_{mm}(r) = \rho + 10\alpha \log(r) + \chi_{mm} \tag{1}$$

where r is the distance between the BS and the UE, χ_{mm} is the zero mean log normal random variable which represents the effects of shadow fading for the millimeter-wave link. The factor ρ is the fixed path loss which is dependent on the carrier frequency f_c: $\rho = 32.4 + 10\log(f_c)$. The path loss exponent is denoted by α. The received power at the user from the BS is defined as [3]:

$$P_r(r,\theta) = \left(\frac{\lambda_c}{4\pi}\right)^2 \frac{P_t G(\theta)}{L(r)} \tag{2}$$

where P_t is the transmit power, λ_c is the wavelength of the carrier frequency and $L(r)$ is the path loss, respectively. $G(\theta)$ is the transmit antenna gain at the azimuthal angle of the BS. All users are assumed to have the single omni-directional antenna. The signal to interference plus noise ratio SINR of the k-th user is given as [3]:

$$SINR_r = \frac{P_t G(\theta_k)}{\sum_{i=1,i\neq k}^{K} P_t G(\theta_i) + \left(\frac{\lambda_c}{4\pi}\right)^2 \sigma^2 L(r)} \tag{3}$$

where the first term of the denominator represents the effect of the inter-user interference which can be compressed by simple beamformers such as zero-forcing or MMSE beamforming. The noise power is denoted as σ^2.

In the conventional OMA scheme, the available bandwidth B is divided into K sub-bands which are assigned to each user in the cell. Consequently, the data rate (in bits per second) of the user served by the BS is given as [3]:

$$R_k = \frac{B}{K}\log_2(1 + SINR_k) \tag{4}$$

3. Proposed Conditional Clustering Scheme

As discussed in the previous section, many research works related to NOMA have been carried out to enhance the spectrum efficiency compared to the conventional OMA scheme [4, 5]. Due to the complexity of the optimal NOMA, hybrid schemes were considered. In this section, details on the proposed clustering scheme are discussed which is based on the hybrid NOMA scheme proposed in [6]. The proposed scheme targets for the improvement of the system spectrum efficiency by adding several critical conditions in the process of defining clusters.

We consider a NOMA system in which the base station is connected with multiple users in the cell. According to the clustering procedure of NOMA in [3], the base station collects the SINR feedback signal from users. Based on this information, the base station detects the user's channel gain and calculates channel correlation among users. These are the key factors to select the users for cluster in NOMA system. The base station continues to consider the remaining users to form other NOMA clusters until all users are assigned in clusters. The base station implements NOMA among the users within each group, and conventional OMA among clusters in the network. This scheme is known as hybrid NOMA which is adopted in [6].

Different from the hybrid NOMA in [6], in the proposed scheme, not all of users are firmly grouped in clusters. In order to guarantee the successful SIC, the base station calculates the difference of the channel gain among users and makes sure it is higher than the SIC threshold (13dB). The base station only uses NOMA for users which satisfy the condition to ensure the data is encoded successfully at the receiver. The other users are served in the manner of the conventional OMA scheme. In this case, the number of users in each cluster is not fixed and it depends on the channel condition of the users. By guaranteeing the channel correlation and the SIC threshold in grouping users, the transmission data is secured to be decoded correctly at the receiver. In the case that the number of users in each cluster is predefined, there would be a situation in which the user cannot decode the superposition encoded signal and the performance of all system degrades.

4. Performance Evaluation

In this section, some simulation results are presented to evaluate the performance of the proposed clustering scheme. We assume the millimeter wave environment which is specified in the standard IEEE802.11ay [8]. The system model in section 2 is used in the simulation with several additional parameters. The base station is equipped with beamforming antenna arrays which provide the beam pattern with 30 degrees half power bandwidth. The cell radius is set to 250m to 500m while keeping the same number of users in cell to evaluate the effect of the user density on the performance of the system. The performance of the system is evaluated via the total data rate of users which is inferred from the SINR in (4). The result in figure 2 shows that the proposed hybrid NOMA scheme gives a significant enhancement in term of spectrum efficiency compared to the conventional OMA scheme. This gain is the result of using NOMA cluster to share the same frequency bandwidth for multiple users. Especially, when the user density (number of users in an area) increases, the gain is significant. The result also shows that the proposed scheme works better in higher user density.

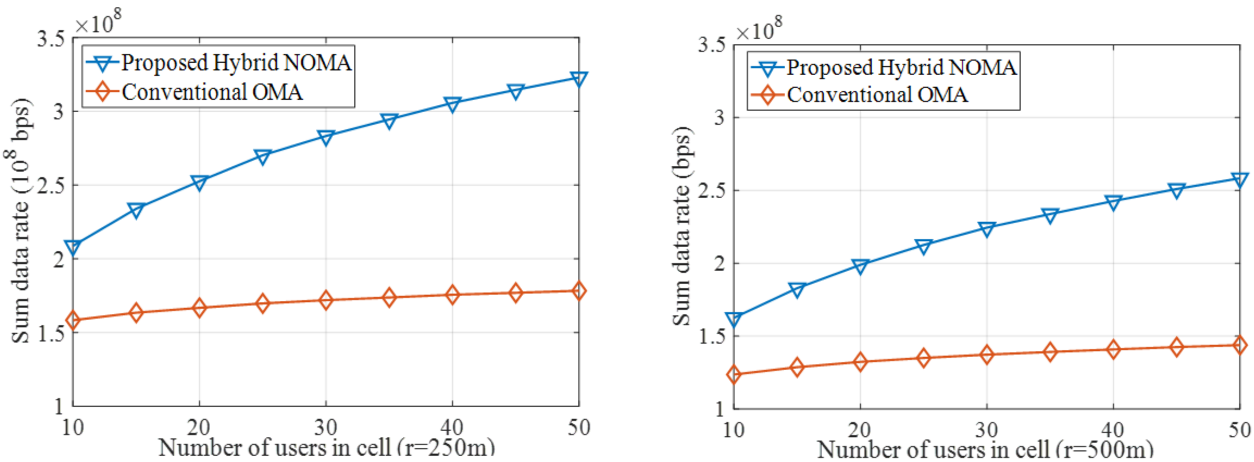

Figure 2. Data rate enhancement by proposed clustering scheme

5. Conclusion

Combination of NOMA and mmWave transmission techniques is expected to help wireless system meet the demands of high data rate and massive connectivity in the next generation wireless communication. In this paper, we proposed and evaluated a conditional user clustering scheme in hybrid NOMA system for millimeter-wave communication system. The proposed clustering is expected to help the hybrid NOMA system to optimize the usage of a huge underutilized frequency in the millimeter-wave frequency band. The proposed scheme attempts to reduce the probability that the user cannot decode the superposition encoded signal by adding acceptance conditions of the channel correlation and the SIC threshold for the cluster members. In other words, the proposed scheme puts a high priority on the balance between the spectral efficiency and the quality of the transmission. Simulation results show that the sum rate of hybrid NOMA system adopting the proposed clustering algorithm is increased compared to the conventional OMA system.

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