Spectrum Efficiency of Beamspace MIMO NOMA for mmWave Communication with Imperfect Knowledge of Channel Estimates

Ubaid M. Al-Saggaf [1,2], Muhammed Ahsan Shaikh[3], Abdulrahman U. Alsaggaf[1,2] and Muhammad Moinuddin[1,2]

[1]Department of Electrical and Computer Engineering, King Abdulaziz University, Jeddah, Saudi Arabia

[2]Center of Excellence in Intelligent Engineering Systems (CEIES), King Abdulaziz University, Jeddah, Saudi Arabia

[3]Department of Electrical Engineering, Faculty of Engineering Sciences and Technology, Hamdard University, Karachi, Pakistan

Abstract

As mobile technology advances, it is becoming a crucial part of our daily life. The number of mobile and IoT devices is rising exponentially, creating enormous challenges for large connectivity. The conventional multiple-access technique depends on the orthogonal multiple-access technique, which has a limited number of orthogonal resources and is not suitable for large connectivity. The researchers are investigating the non-orthogonal multiple access technique, which is a suitable solution for large connectivity. Further, the limited bandwidth in the microwave is resolved by the use of mmWave, which enables the service provider to give large bandwidth. The performance of wireless communication depends mainly on the knowledge of the channel at the BS. This paper evaluates spectral efficiency for the beamspace MIMO NOMA in mmWave communication with imperfect knowledge of the channel estimates. The results show that the spectral efficiency decreases drastically with a slight increase in the channel estimate imperfectness.

Keywords: Beamspace, MIMO NOMA, mmWave, power allocation,

1 Introduction

The number of mobile devices is increasing drastically daily and is expected to increase further. The current wireless communication system would not be able to support the massive connectivity, large data rate, and latency problem. Wireless communication and its upcoming generation need to provide low latency and very large connectivity by the fast rise in the number of mobile users and IoT devices [1]. The operators must consider strategies to tackle these challenges through heterogeneous networks, spectrum sharing, leasing network slicing on the domain, etc. As per the authorities, as compared to the 5G, the 6G will need stricter requirements [2]. It is expected that the current NR, mmWave, and sub-6 bands won't be able to provide the necessary required QoE and QoS. Therefore, it is estimated that for the upcoming network, greater frequency spectrum bands, such as 73 GHz, 140 GH, and 3 THz are necessary. A high peak data rate is required for applications that uses high data rate such as immersive multimedia [3]. The end-to-end delay should be less than 1 ms, and the latency to be zero. For example, the required latency is close to zero for the XR services to increase the QoS [4]. The latency requirement in telepresence should be lower than in the sub-millisecond [2]. In the development of the communication system, multiple access techniques are an essential part, and it is also important in the upcoming generation as previous generations [5]. The dominant multiple access technique for the 6G cellular network will be a NOMA technique instead of the OMA technique. The NOMA has also been proposed for the 5G/B5G in early years and it also shows improvement with respect to secrecy capacity, user fairness and security [6]. The different techniques utilize by the NOMA such as user's decoding order and successive interference cancellation (SIC). The efficient spectrum utilization and allocation of resources made NOMA important for the current and future mobile networks [7]. The huge connectivity and large spectral efficiency is also supported by the NOMA. The multiple users and devices are not constrained by the available orthogonal resource instead they are allocated different power co-efficient. Thus allows, large number of connectivity in NOMA system. There are two main categories of NOMA, code domain and power domain NOMA[8], [9]. The NOMA in power domain assigned different power different according to the channel condition of that user. However, in case of the code domain NOMA, users are allocated with different code and multiplexed over the same resource and time [10]. Another technique proposed in recent works is beamspace NOMA [11,12,13,14,15,16,17,18]. These works provide various beamforming techniques for beamspace NOMA. More recently, a statistical beamforming technique was introduced for beamspace MIMO-NOMA [18] which utilizes statistical measures only for designing the beamforming weights. In our work, we used the same model of beamspace MIMO-NOMA defined in [15] and [18]. However, the aim of our work is to investigate the spectrum efficiency of the beamforming techniques given in [15] in the scenario of imperfect channel estimates.

The rest of the paper structured as below, system model is discussed in section 2, and power allocation algorithm is described in section 3. The results and analysis are discussed in section 4 and section 5 conclude the paper.

2 Beamspace MIMO NOMA System Model

In this paper, downlink single cell for mmWave communication system is considered. There are N_{RF} Radio Frequency (RF) chains at the base station and it consists of N transmit antennas, and BS serves K single antennas users simultaneously [11]. One of the most commonly used mmWave channel is used in this system model which is known as Saleh- Valenzuela channel model [12].

$$\boldsymbol{h}_k = \beta_k^{(0)}\boldsymbol{a}(\theta_k^{(0)}) + \sum_{l=1}^{L} \beta_k^{(l)}\boldsymbol{a}(\theta_k^{(l)}) \tag{1}$$

The LoS component of k^{th} is represented as $\beta_k^{(0)}\boldsymbol{a}\left(\theta_k^{(0)}\right)$ in which $\boldsymbol{a}\left(\theta_k^{(0)}\right)$ is the spatial direction and complex gain is denoted as $\beta_k^{(0)}$. The NLoS component of k^{th} user is expressed as $\beta_k^{(l)}\boldsymbol{a}\left(\theta_k^{(l)}\right)$ where the range of l is $1 \leq l \leq L$. The total figure of the NLoS factor is L. The steering vector with dimension $N \times 1$ is denoted as $\boldsymbol{a}(\theta)$ the steering vector and based on the fundamental ULA [13] expressed as below

$$\boldsymbol{a}(\theta) = \frac{1}{\sqrt{N}} \left[e^{-j2\pi\theta m}\right]_{m\in J(N)} \tag{2}$$

The symmetric set of directories which is placed about zero is represented as $J(N)$. In this model, the spatial domain of the channel in (1) is changed to a beamspace channel through the use of a lens antenna array [12]. The exact realization of the lens antenna array is with the spatial discrete conversion with the steering vector of N dimension covering the complete space in the N × N transform matrix U [14].

$$\boldsymbol{U} = [\boldsymbol{a}(\overline{\theta_1}), \boldsymbol{a}(\overline{\theta_1}), \cdots, \boldsymbol{a}(\overline{\theta_N})]^H \tag{3}$$

The pre-determined spatial directions in

$$for\; n = 1,2,\cdots,N \text{ and } \overline{\theta_n} = \frac{1}{N}\left(n - \frac{N+1}{2}\right) \tag{4}$$

The beam space channel matrix $\overline{\boldsymbol{H}}$ is defined as

$$\overline{\boldsymbol{H}} = \boldsymbol{U}\boldsymbol{H} = [\boldsymbol{U}\boldsymbol{h_1}, \boldsymbol{U}\boldsymbol{h_2}, \cdots, \boldsymbol{U}\boldsymbol{h_k}] = \left[\overline{\boldsymbol{h_1}}, \overline{\boldsymbol{h_2}}, \cdots, \overline{\boldsymbol{h_K}},\right] \tag{5}$$

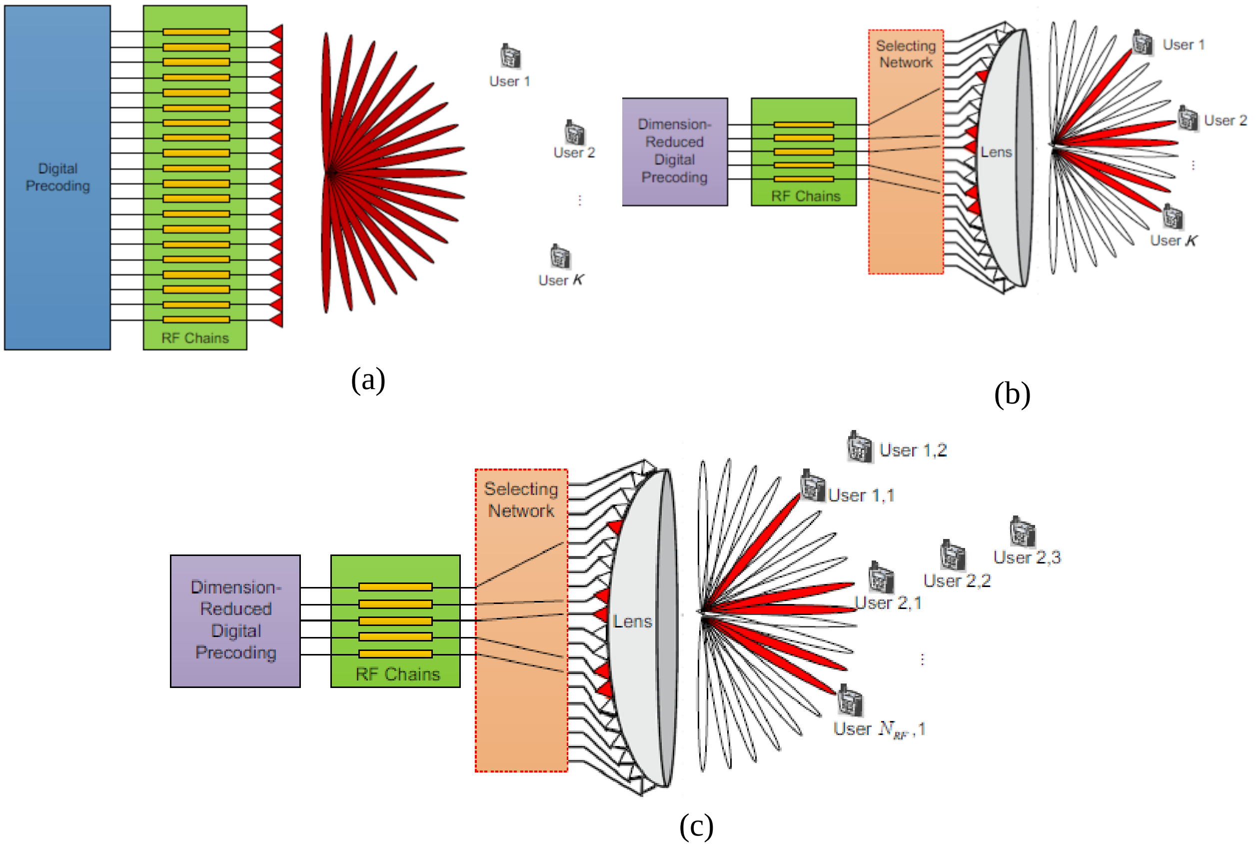

Figure 1: (a) Conventional MIMO; (b) beamspace MIMO; (c) beamspace MIMO-NOMA [15].

As can be seen in Fig. 1 (a), in conventional MIMO schemes, $N_{RF} = N$, whereas in case of mmWave large MIMO system large quantity of antennas are required at the BS such as $N_{RF} = N = 256$ or even higher [14]. As a result, the straight deployment of mmWave with massive MIMO is impractical because of the high cost of the hardware and the energy utilization that RF chains cause [13] e.g, each

RF chain uses almost 250 mW, while a large MIMO mmWave system with 256 antennas needs 64 W [16] . Beamspace MIMO, a recently proposed solution to this problem, can use lens antenna arrays to drastically minimise the quantity of radio frequency chains needed in mmWave large MIMO scheme without obviously sacrificing performance. As seen in Fig. 1. (b), the spatial domain channel (2) can be converted to the beamspace channel by using a lens antenna array. [17].

The number of users severed at the same time may be larger than the N_{RF} . However, the nominated beams are equivalent to N_{RF}. Let S_n total quantity of users served by the n^{th} beam. The $\boldsymbol{h}_{m,n}$ is the channel vector of the m^{th} user located in the n^{th} beam and $\boldsymbol{w}_n$ is the precoding vector of the n^{th} with the dimension of $N_{RF} \times 1$ [15]. For the m^{th} user located in n^{th} beam ($m = 1, 2, \cdots, |S_n|$ and$n = 1, 2, \cdots, N_{RF}$), received signal can be represented as follows

$$y_{m,n} = \boldsymbol{h}_{m,n}^H \sum_{j=1}^{N_{RF}} \sum_{i=1}^{|S_j|} \boldsymbol{w}_j \sqrt{p_{i,j}}\, s_{i,j} + v_{m,n}$$

$$= \underbrace{\boldsymbol{h}_{m,n}^H \boldsymbol{w}_n \sqrt{p_{m,n}} s_{m,n}}_{desired\ signal} + \underbrace{\boldsymbol{h}_{m,n}^H \boldsymbol{w}_n \sum_{i=1}^{m-1} \sqrt{p_{i,n}}\, s_{i,n} + \boldsymbol{h}_{m,n}^H \boldsymbol{w}_n \sum_{i=m+1}^{|S_n|} \sqrt{p_{i,n}}\, s_{i,n}}_{Intra-beam\ interferences}$$

$$+ \underbrace{\boldsymbol{h}_{m,n}^H \sum_{j \neq n} \sum_{i=1}^{|S_j|} \boldsymbol{w}_j \sqrt{p_{i,j}}\, s_{i,j}}_{Inter-beam\ interferences} + \underbrace{v_{m,n}}_{Noise} \quad (6)$$

2.1 EXPRESSION OF SINR

In this system model we take into account the three key terms in (6) to get the SINR equation. The initial term is the m^{th} user's wanted signal in the n^{th} beam, and the second term is intra beam interference, where all other users in the n^{th} beam are taken into account except the m^{th} user. All users of all beams are considered in the case of the final term, which is an inter beam interference, except the n^{th} beam and (6) can be further expressed as follows.

$$y_{m,n} = \underbrace{\boldsymbol{h}_{m,n}^H \boldsymbol{w}_n \sqrt{p_{m,n}} s_{m,n}}_{desired\ signal} + \underbrace{\boldsymbol{h}_{m,n}^H \boldsymbol{w}_n \sum_{i=1}^{m-1} \sqrt{p_{i,n}}\, s_{i,n}}_{Intra-beam\ interferences} + \underbrace{\boldsymbol{h}_{m,n}^H \sum_{j \neq n} \sum_{i=1}^{|S_j|} \boldsymbol{w}_j \sqrt{p_{i,j}}\, s_{i,j}}_{Inter-beam\ interferences} + \underbrace{v_{m,n}}_{Noise} \quad (7)$$

Then, (7) can be written in the form of SINR for m^{th} user in n^{th} beam as below

$$\gamma_{m,n} = \frac{\left\| \boldsymbol{h}_{m,n} \boldsymbol{w}_n \right\|_2^2 p_{m,n}}{\xi_{m,n}} \quad (8)$$

$$\xi_{m,n} = \left\|\boldsymbol{h}_{m,n}^{H}\boldsymbol{w}_n\right\|_2^2 \sum_{i=1}^{m-1} p_{i,n} + \sum_{j\neq n}\left\|\boldsymbol{h}_{m,n}^{H}\boldsymbol{w}_j\right\|_2^2 \sum_{i=1}^{|S_j|} p_{i,j} + \sigma_{m,n}^2 \quad (9)$$

3 Spectral Efficiency and the Proposed Work

Spectral Efficiency (SE) is a key performance measure for a communication system. It is defined as the ratio of channel capacity per bandwidth, that is,

$$SE = \frac{C}{B} = \log_2(1 + SINR) \quad (10)$$

In this work, we analyze the SE in beamspace MIMO NOMA system under random uncertainty in the channel. More precisely, we consider the following random walk model for the beamspace channel:

$$\widehat{\boldsymbol{h}}_{m,n} = \boldsymbol{h}_{m,n} + \boldsymbol{q}_{m,n}\,, \quad (11)$$

where $\boldsymbol{q}_{m,n}$ is the random uncertainty in the channel of m^{th} user in n^{th} beam. Thus, the SE for m^{th} user in n^{th} beam is given by

$$SE_{m,n} = \frac{C_{m,n}}{B} = \log_2\left(1 + \gamma_{m,n}\right)$$

After substituting the expression for $\gamma_{m,n}$ with the aid of Equations (8), (9), and (11) in the above, we achieve the following:

$$SE_{m,n} = \frac{C_{m,n}}{B} = \log_2\left(1 + \frac{\left\|\widehat{\boldsymbol{h}}_{m,n}\boldsymbol{w}_n\right\|_2^2 p_{m,n}}{\left\|\widehat{\boldsymbol{h}}_{m,n}^{H}\boldsymbol{w}_n\right\|_2^2 \sum_{i=1}^{m-1} p_{i,n} + \sum_{j\neq n}\left\|\widehat{\boldsymbol{h}}_{m,n}^{H}\boldsymbol{w}_j\right\|_2^2 \sum_{i=1}^{|S_j|} p_{i,j} + \sigma_{m,n}^2}\right) \quad (12)$$

The aim of this work is to investigate the impact of random uncertainty $\boldsymbol{q}_{m,n}$ on the behavior of SE. For this purpose, $\boldsymbol{q}_{m,n}$ is modeled as zero mean Gaussian random vector with correlation matrix $\boldsymbol{R}_q = \sigma_q^2\boldsymbol{I}$, where σ_q^2 is the variance.

4 Results and Discussion

In this analysis, spectral efficiency is evaluated with perfect of knowledge of the channel and imperfect knowledge of the channel with factors 0.01, 0.05 and 0.1. The knowledge of the channel determine the overall performance of the wireless communication. The curves show that the spectral efficiency with perfect knowledge of the channel is higher for any number of user in the system. the worst spectral efficiency is achieved with imperfect channel with factor 0.1 and the performance of imperfect channel with factor 0.05 is in between two other factors. Thus, the spectral efficiency of beamspace MIMO NOMA for mmWave communication severely affected by the poor knowledge of the channel.

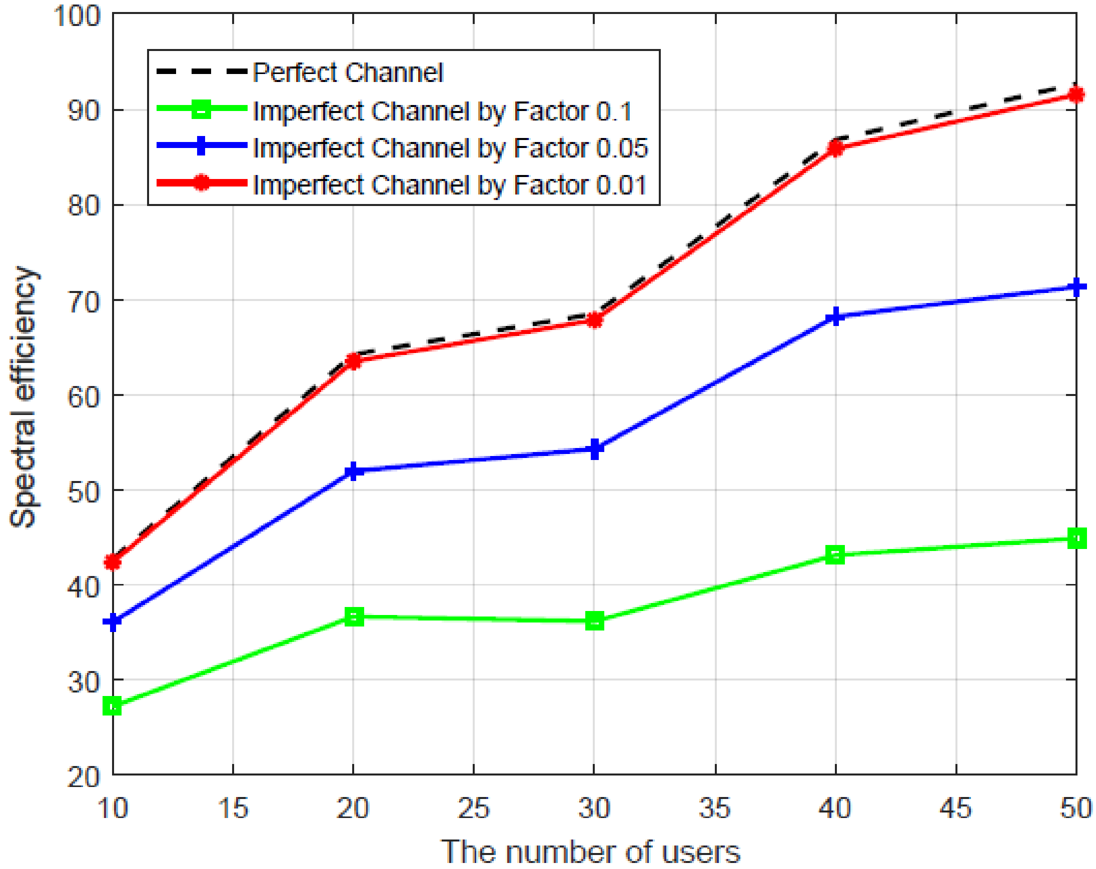

Figure 2: Spectral efficiency comparison with knowledge of the perfect channel and imperfect channel with factors 0.01, 0.05, and 0.1.

5 Conclusion

The use of NOMA overcomes the inadequacy of conventional OMA, such as the limited number of resources. The NOMA can be used with different technologies such as beamspace MIMO which results in further enhancement in the performance by exploiting the advantages of both techniques. In this work, spectral efficiency of the beamspace MIMO NOMA for mmWave communication is analyzed with both perfect and imperfect knowledge of the channel. The results show that the spectral efficiency of the system is drastically affected by imperfect channels. In future work, beamforming can be optimized to deal with this issue.

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