

I. Introduction

Satellite communication systems play a pivotal role in the evolution of B5G and 6G, offering expansive coverage and seamless connectivity, particularly in regions lacking terrestrial infrastructure. LEO satellites, which operate at the height between 500km to 2000km, has several advantages for transmission, like smaller propagation delay and less power attenuation compared to GEO satellite.

II. Motivation and Contribution

MIMO transmission, or multi beam transmission, transmit signal to users simultaneously, which results in interference. Therefore, technique like precoder is designed to eliminate the inference, or increase signal-to-interference-and-noise ratio(SINR). However, most of the precoder design requires instantaneous channel state information(iCSI), which is very hard to correctly estimate in satellite communication system caused by long propagation delay. In contrast, antenna array response is easier to estimate. Hence, we first implement the system in [1], and try to extend the technique from iCSI to array response. Here is our contribution,

- Implemented the communication system in [1].
- Propose a user grouping algorithm based on array response vector.
- Proposed hybrid precoder based on array response vector.
- Performance analysis of zero-forcing, maximum ratio precoder.

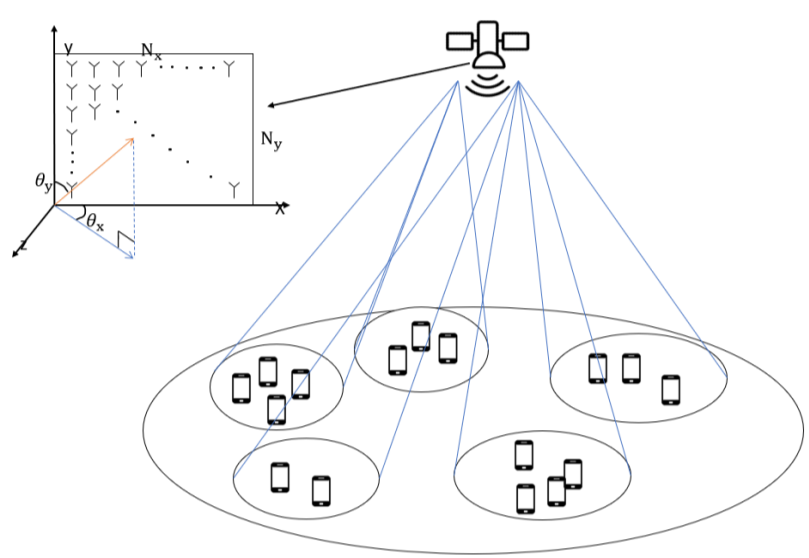


Figure 1 : system model

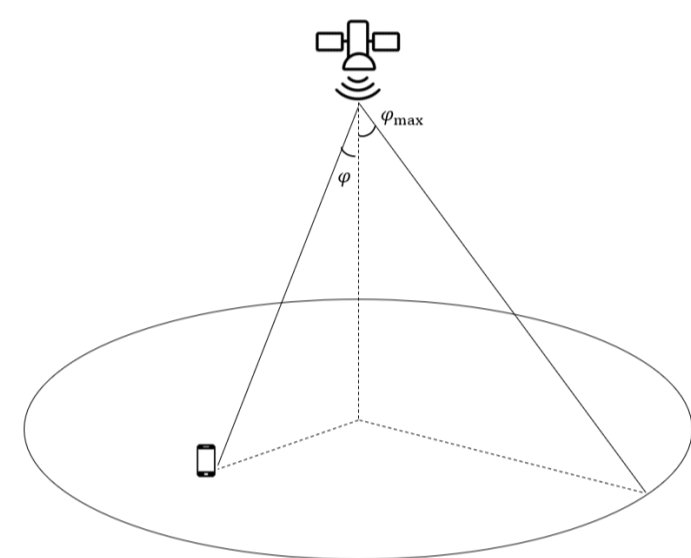


Figure 2 : elevation angle definition

III. System Model

In our system model, LEO satellite transmitted signals to the users in its coverage area. The LEO satellite uses uniform planar antenna array (UPA) for transmitting. We simply choose the distance between each single antenna as half of wavelength, which is the minimum requirement. There are N_x antennas on x axis and N_y antennas on y axis. The total number of antennas is $N_t = N_x N_y$. Users in the coverage area is grouped depending on the user grouping algorithm. We separate the user into β groups, which is equal to number of RF chains.

a. Channel model

$$\mathbf{h}_k(t, f, \theta_k^x, \theta_k^y) = \mathbf{v}_k(\theta_k^x, \theta_k^y) g_k(t, f)$$

We use the channel model in [2]. The channel is separated into array response vector(first term) and channel response(second term). Channel response is modeled by Rician fading model. And array response vector is defined as below.

$$\mathbf{v}_k(\theta_k^x, \theta_k^y) = \mathbf{v}_k^x(\theta_k^x) \otimes \mathbf{v}_k^y(\theta_k^y), \quad \otimes: \text{Kronecker product}$$

$$\mathbf{v}_k^x(\theta_k^x) = \frac{1}{\sqrt{N_x}} \cdot [\mathbf{1} \quad \exp\{-j\pi\theta_k^x\} \quad \dots \quad \exp\{-j\pi(N_x - 1)\theta_k^x\}]^T$$

$$\mathbf{v}_k^y(\theta_k^y) = \frac{1}{\sqrt{N_y}} \cdot [\mathbf{1} \quad \exp\{-j\pi\theta_k^y\} \quad \dots \quad \exp\{-j\pi(N_y - 1)\theta_k^y\}]^T$$

b. Signal model

$$y_{gi} = \sqrt{p_{gi}} \mathbf{h}_{gi}^H \mathbf{A} \mathbf{d}_g s_{gi} + \mathbf{h}_{gi}^H \mathbf{A} \sum_{g' \neq g} \mathbf{d}_{g'} \sqrt{p_{g'i_{g'}}} s_{g'i_{g'}} + n_{gi}$$

This is received signal. The first term is desired signal, second term is interference from other users and third term is additive white gaussian noise, which follow $CN(0, N_0)$. \mathbf{A} is the analog part of hybrid beamforming, and \mathbf{d}_g is the digital part.

c. Problem formulation

We simply apply equal power to every user. From the signal model, we can write out SINR and sum rate. And then the optimization problem.

$$\gamma_{gi} = \frac{p \|\mathbf{h}_{gi}^H \mathbf{A} \mathbf{d}_g\|_2^2}{\sum_{g' \neq g} \|\mathbf{h}_{gi}^H \mathbf{A} \mathbf{d}_{g'}\|_2^2 p + N_0}$$

$$\max_{\mathbf{A}, \mathbf{d}_g} \sum_{g=1}^{\beta} \sum_{i \in \Gamma_g} \log_2(1 + \gamma_{gi})$$

$$\text{s. t. } \|\mathbf{A} \mathbf{d}_g\|_2^2 = 1 \quad \text{for all } g$$

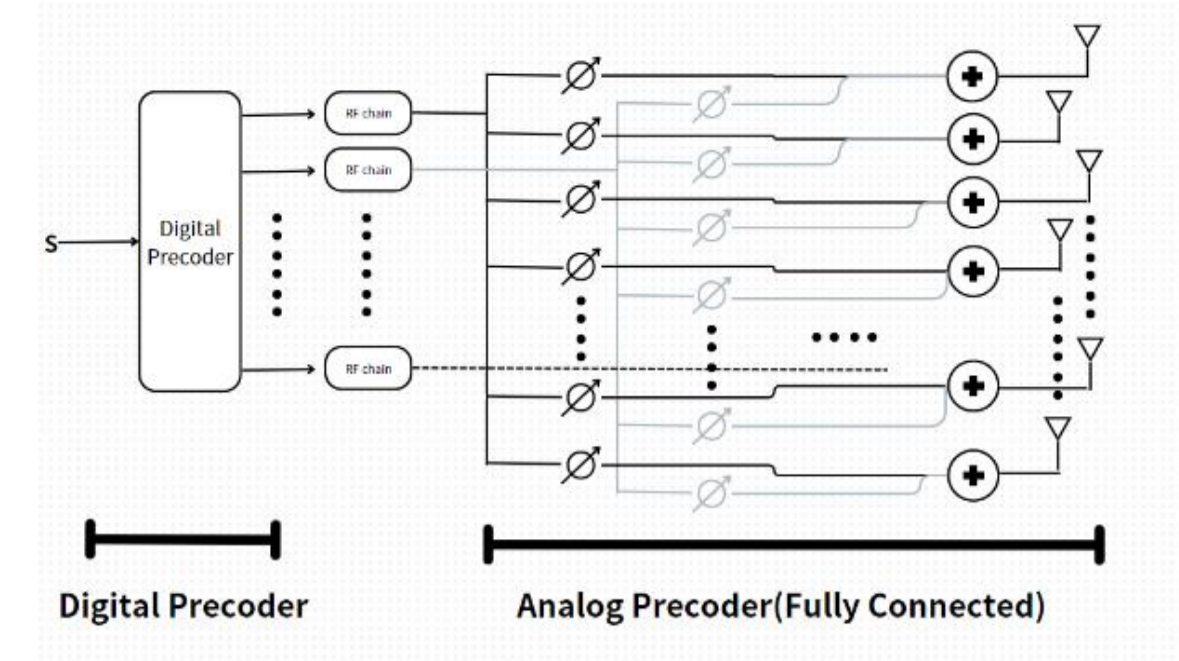


Figure 3 : hybrid beamforming

IV. Research Method

a. Hybrid Precoder and User Grouping Based on iCSI

1. Group Center Selection

In the proposed algorithm in [1], cluster centers are chosen based on correlation and channel gain. Users with correlation less than threshold are classified as candidates. Cluster centers are the candidate with largest gain.

2. Fair User Grouping

For the rest of users, we assign every user to a group which has largest correlation with them.

3. Hybrid beamforming

For analog part, precoder simply compensate the phase change of array response and channel. For digital part, we first define an equivalent channel combined with channel response and analog beamforming. And then, we apply zero forcing and maximum ratio to analyze the performance.

b. Hybrid Precoder and User Grouping Based on array response

Hybrid beamforming is the same as previous part. We focus on user grouping.

1. 1st clustering

In this step, users with correlation larger than threshold are grouped.

2. No-user group selection

We assign the user with low correlation with everyone to no-user group

3. Fair user grouping

For the rest of users, we assign every user to a group which has largest correlation with them.

4. Group center selection

We choose centers by maximizing the total sum of correlation with centers.

And we use the grouping result to do hybrid beamforming.

V. Result and Conclusion

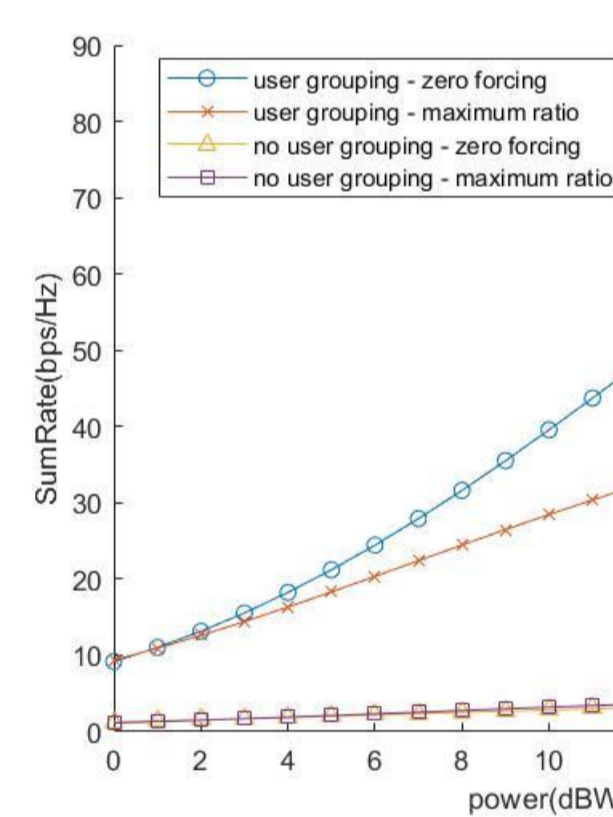


Figure 4 : performance analysis (1)

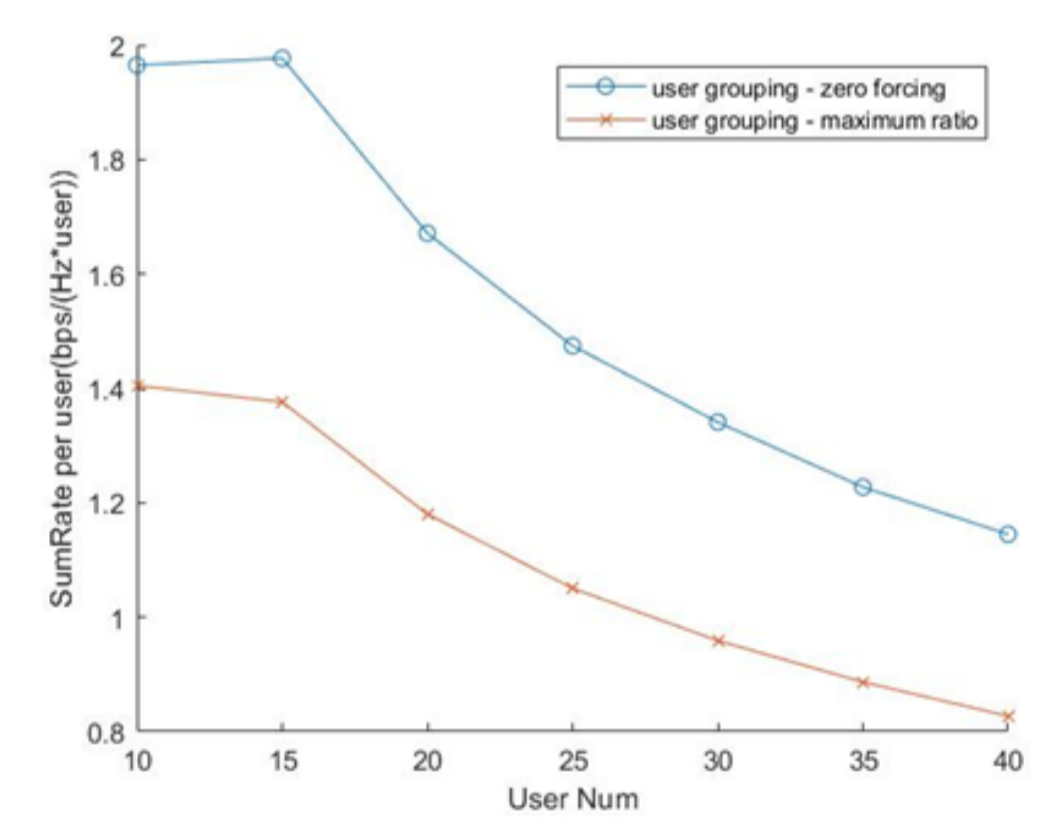


Figure 5 : performance analysis (2)

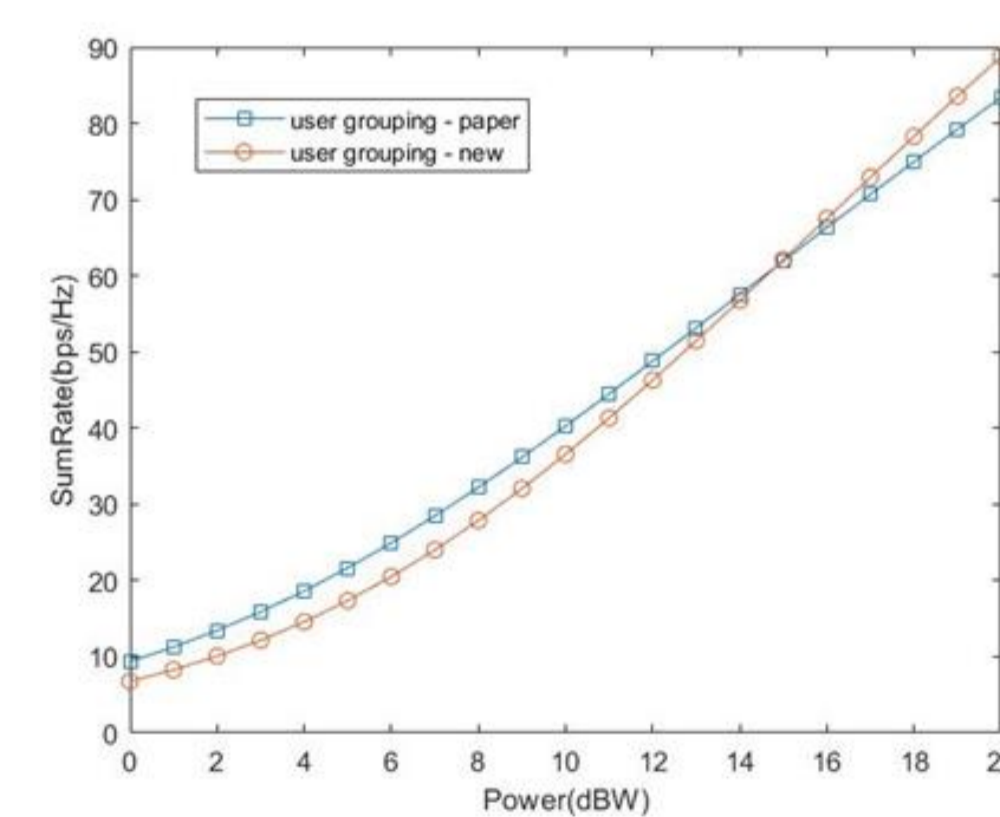


Figure 6 : performance analysis (3)

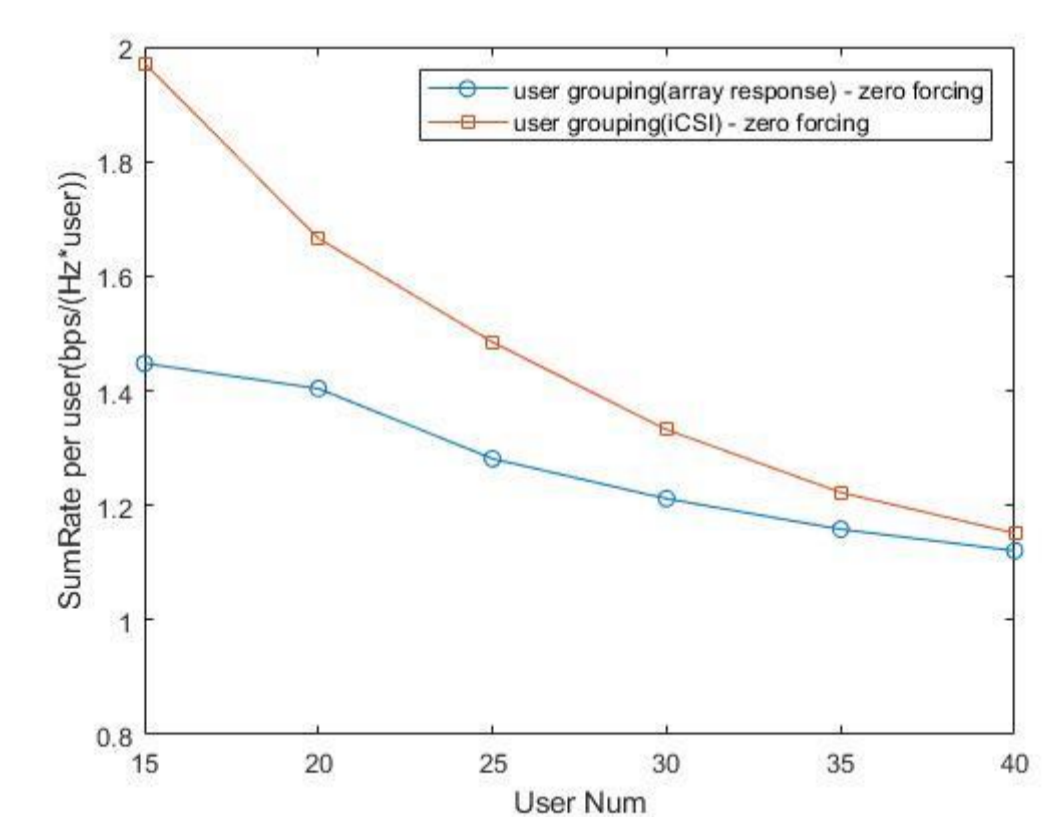


Figure 7 : performance analysis (4)

From the result, we can conclude that user grouping is indispensable in MIMO system design. In addition, zero forcing outperform maximum ratio. However, no matter which digital precoder is chosen, the performance decreases as user number increases. To deal with the difficulty of obtaining iCSI in satellite communication system, we proposed a user grouping and hybrid beamforming technique that only use array response. From the result, we can see that the performance is slightly less than the algorithm proposed in [1]. The result follow our expectation. However, the performance of our proposed algorithm is not well when user number is small. The reason is that when user number is small, channel gain is the main factor, which we don't take into consideration. But, because of the large cover area, user number is rarely small.