

# Power Allocation and User Clustering in Multicast NOMA based Satellite Communication Systems

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**Abstract**—This paper investigates the application of multicast non-orthogonal multiple access (MC-NOMA) schemes to the forward link of a satellite communication system. In multicast transmission each frame contains information of multiple users. To benefit from the theory developed in NOMA, the proposed scheme creates two groups of users within each beam. The analysis conducted in this work reveals that the user grouping has an impact on the performance. In the light of this observation, power allocation and user clustering techniques have been derived to either maximize the sum-rate or achieve max-min fairness. The numerical simulation results show that MC-NOMA outperforms multicast orthogonal multiple access (MC-OMA) schemes, where different groups are served in orthogonal resources. Moreover, the gain of MC-NOMA over the MC-OMA becomes more prominent as number of users per group and the transmit power increases. The results show the minimum-rate and the sum-rate of MC-NOMA can be increased by a factor 2 and 1.45 with respect to MC-OMA, respectively.

**Index Terms**—Multicast NOMA, fairness, sum-rate, clustering

## I. INTRODUCTION

It is well-known that non-orthogonal superposition techniques outperform orthogonal schemes such as time and frequency division multiplexing in some pertinent scenarios. In particular, power domain non-orthogonal multiple access (NOMA) has been proven advantageous for improving the user fairness and the attainable data rate when users to be served present a large signal-to-noise (SNR) imbalance [1]. As a matter of fact, in order to make the most efficient use of satellite resources, the multicast transmission can be used in satellite communication to embed more than one user information into the same frame [2]. In multicast transmission each frame contains information of multiple users. So far, multicast transmission and NOMA have been studied separately. To make progress towards this direction, this paper considers both schemes in satellite communications. The introduction of NOMA alongside with multicast transmission is referred to as multicast NOMA (MC-NOMA). The MC-NOMA applies the superposition coding at the transmitter and successive interference cancellation at the receiver (SIC).

The performance of NOMA in its basic form depends on the power allocation and the SNR imbalance among users. In NOMA, the resource allocation problem has been studied for different performance metrics. In the literature, the sum

rate maximization is the most commonly adopted objective function. The authors in [3], [4] and [6] have studied the optimum power allocation to maximize the weighted sum rate. In [5] and [6], the authors have focused the attention on the optimal power allocation to maximize the sum rate with quality-of-service (QoS) constraints.

Another important measure in NOMA is the fairness among users. The optimization problem is known as the max-min fairness (MMF). Authors in [7] and [8], have investigate the optimum power allocation to guarantee MMF in NOMA, under instantaneous and statistical channel state information (CSI). The weighted MMF has been studied in [9], yet the optimal solution is only derived for the two-user transmission model. By contrast, in [6] the optimum power allocation is derived over multiple channels. Analogously to the sum rate maximization, in the MMF framework the transmission is considered unicast. Note that, the resource allocation in MC-NOMA has not been previously studied and the solutions available for unicast NOMA cannot be straightforwardly applied to the MC-NOMA.

In this paper, the optimum power allocation in the context of MC-NOMA is derived for two groups of users in a single beam. The problems that govern the design are maximum fairness and maximum sum-rate with QoS. In MC-NOMA, users either perform single user detection (SUD) or SIC the decoding strategy has an impact on the clustering. Therefore, an optimum user clustering method is investigated. As for the scope of application, the proposed scheme can be employed on a beam basis to serve two groups of users simultaneously. Using the properties of a strictly increasing function, the MC-NOMA optimization problem can be decoupled into two problems, which allows us to solve the power allocation and the user clustering separately. The derivation shows that the expressions that rule the attainable rates for unicast NOMA are also valid for the MC-NOMA with a slight modification. Upon identifying the user with the worst channel condition, users clustering is performed and the solutions in unicast NOMA are used to find the optimum power allocation.

For user selection, random and ordered clustering are proposed. In random clustering, users are grouped randomly without any supervision. However, in ordered clustering an optimum procedure is derived which maximizes the performance

of MC-NOMA scheme. The simulation results show that MC-NOMA outperforms the multicast transmission combined with orthogonal multiple access (MC-OMA), where different groups are served in orthogonal resources.

The rest of the paper is organized as follows. Section II introduces the system model, various resource optimization problems, and pose the clustering problem. In Section III, the optimum power allocation under a given user clustering is derived. In Section IV, the user clustering methods are evaluated. The performance of the proposed power allocation is evaluated in Section V by simulation and the conclusion is given in Section VI.

## II. PROBLEM STATEMENT

### A. System model

Consider the forward link of a multibeam satellite system that tessellates the coverage area into  $K$  beams. The frequency is reused across the coverage area according to a 4-color pattern. Due to the frequency reuse, each user receives the signals from the other co-channel beams. However, the level of isolation is such that the interference can be treated as a background noise without significant performance degradation. This means that there is no collaboration between beams and each beam can be isolated from the rest. From the information theory it is known that the power domain NOMA can be applied on a beam basis to increase the sum-rate with respect to orthogonal schemes, such as time and frequency division multiplexing. When MC-NOMA comes into play, each beam creates two groups of users which are denoted as A and B for convenience. If we focus the attention on beam  $k$ , the received signal at each group is expressed as follows

$$y_{k,A}^{[j]} = h_{k,A}^{[j]} \left( \sqrt{\alpha_k p_k} s_{k,A} + \sqrt{(1-\alpha_k) p_k} s_{k,B} \right) + I_{k,A}^{[j]} + n_{k,A}^{[j]} \quad j \in \mathbf{I}_A \quad (1)$$

$$y_{k,B}^{[l]} = h_{k,B}^{[l]} \left( \sqrt{\alpha_k p_k} s_{k,A} + \sqrt{(1-\alpha_k) p_k} s_{k,B} \right) + I_{k,B}^{[l]} + n_{k,B}^{[l]} \quad l \in \mathbf{I}_B \quad (2)$$

where  $j$  and  $l$  superscripts refer to the  $j$ -th and the  $l$ -th user in group A and B, respectively.  $\mathbf{I}_A$  ( $\mathbf{I}_B$ ) gathers the indices of those users that form group A (B). The cardinality of each group is  $M$ . Hence, there are  $2M$  users to be served. The coefficients  $h_{k,A}^{[j]}$ ,  $h_{k,B}^{[l]}$  denote the channel associated with the reference beam for users in group A and B, respectively. Hence,  $I_{k,A}^{[j]}$  and  $I_{k,B}^{[l]}$  represent the co-channel interference that comes from the adjacent beams. Note that  $p_k$  is the transmit power of beam  $k$  and  $s_{k,A}$ ,  $s_{k,B}$  are the transmitted symbols that are intended for users in group A and B, respectively. To be concise, symbol indices are omitted. According to the key concept of NOMA, the transmitted signal is formed by the superposition of two signals, i.e.,  $s_k = \sqrt{\alpha_k} s_{k,A} + \sqrt{(1-\alpha_k)} s_{k,B}$ . The term  $\alpha_k \in [0, 1]$  is a variable that controls the power split. Finally,  $n_{k,A}^{[j]}$  and  $n_{k,B}^{[l]}$  are the additive noise terms that contaminate the reception of users in each group. The interference plus noise terms, i.e.,

$I_{k,A} + n_{k,A}$  and  $I_{k,B} + n_{k,B}$  are distributed as  $\mathcal{CN}(0, N_{k,A}^{[j]})$  and  $\mathcal{CN}(0, N_{k,B}^{[l]})$ , respectively.

The Land mobile satellite (LMS) model is used in this paper to model the propagation conditions [10]. The channel is considered constant during a frame transmission. Therefore, the channel is defined as follows

$$h_k^{[i]} = f_k^{[i]} \bar{h}_k^{[i]} \quad (3)$$

where  $f_k^{[i]}$  describes the fading effects. The channel obeys the Loo distribution [10]. The Loo model assumed that the line-of-sight (LoS) components is lognormally distributed, while the multipath component's attenuation is Rayleigh distributed. Therefore, the fading effect is defined as

$$f_k = z_k e^{j\theta_k^{\text{LoS}}} + w_k e^{j\theta_k^{\text{multipath}}} \quad (4)$$

where  $z_k$  is lognormally distributed,  $w_k$  is Rayleigh distributed, and  $\theta_k^{\text{LoS}}$  and  $\theta_k^{\text{multipath}}$  are uniformly distributed between 0 and  $2\pi$ . The mean, the standard deviation, and the average power parameters for the distribution functions are chosen from [11]. The rest of the effects are modeled by  $\bar{h}_k^{[i]}$  that is defined as follows

$$\bar{h}_k^{[i]} = \frac{\sqrt{G_R a_k^{[i]}} e^{j\psi_k^{[i]}}}{4\pi \frac{d_k^{[i]}}{\lambda} \sqrt{K_B T_B B_W}} \quad (5)$$

where  $G_R$  is the receiver antenna gain,  $a_k^{[i]}$  is the gain from  $k$ -th feed to the  $i$ -th user at beam  $k$ . In addition,  $e^{j\psi_k^{[i]}}$  represents the time varying phase due to the beam radiation pattern and radiowave propagation.  $d_k^{[i]}$  is the distance between  $i$ -th user at beam  $k$  and the satellite. Finally,  $\lambda$ ,  $K_B$ ,  $T_B$ , and  $B_W$  are the carrier wavelength, the Boltzmann constant, the receiver noise temperature, and the carrier bandwidth, respectively. Note that the channel is normalized to the noise power. Hence, the noise terms in (1) and (2) have unit variance.

Following the NOMA approach under the assumption that users in group B experience better the channel conditions than those in group A, it follows that for fairness (unlike sum-rate maximization) more power is allocated to users of group A, therefore  $\alpha_k \geq 0.5$ . Therefore, users of groups A and B can perform SUD and SIC, respectively. Without loss of generality, maximum achievable rates under the Gaussian signaling in beam  $k$  are

$$R_{k,A} = \min_{j \in \mathbf{I}_A} \log_2 \left( 1 + \frac{\alpha_k \text{SINR}_{k,A}^{[j]}}{1 + (1-\alpha_k) \text{SINR}_{k,A}^{[j]}} \right). \quad (6)$$

$$R_{k,B} = \min_{l \in \mathbf{I}_B} \log_2 \left( 1 + (1-\alpha_k) \text{SINR}_{k,B}^{[l]} \right), \quad (7)$$

if

$$\min_{l \in \mathbf{I}_B} \log_2 \left( 1 + \frac{\alpha_k \text{SINR}_{k,B}^{[l]}}{1 + (1-\alpha_k) \text{SINR}_{k,B}^{[l]}} \right) \geq R_{k,A}. \quad (8)$$

The rates have been compactly expressed as a function of signal-to-interference-plus-noise ratio (SINR) defined as follows:

$$\text{SINR}_{k,A}^{[j]} = \frac{p_k \left( h_{k,A}^{[j]} \right)^2}{N_{k,A}^{[j]}}, \text{SINR}_{k,B}^{[l]} = \frac{p_k \left( h_{k,B}^{[l]} \right)^2}{N_{k,B}^{[l]}}. \quad (9)$$

### B. Problem formulation

In this paper, we investigate the optimal power allocation and optimal clustering for MC-NOMA systems.

1) *Optimum power allocation*: To optimize the optimal power allocation, we pose two optimization problems for a given user clustering, optimizing the power is equivalent to optimize the alpha.

Maximin fairness: In this case the goal is to maximize the fairness between users of a single beam. The coefficient that controls the power split can be computed by solving

$$\max_{\alpha_k} \min R_{k,A}, R_{k,B}$$

The problem of power allocation to maximize the fairness for a unicast NOMA scheme is known [6]- [9], however it is unknown for a MC-NOMA scheme.

Maximum sum-rate with QoS: The most popular objective in NOMA scheme is to maximize the sum rate (SR) of all users. The SR is maximized if all resources are allocated to a given group of users. However, this power allocation can be avoided by introducing QoS constraint into SR maximization. The problem that governs the power allocation is given by

$$\begin{aligned} \max_{\alpha_k} \quad & R_{k,A} + R_{k,B} \\ \text{subject to} \quad & R_{k,A} \geq R_{k,A}^{\text{minimum}} \end{aligned}$$

where  $R_{k,A}^{\text{minimum}}$  is the QoS threshold of users in group A. This problem has been studied in unicast NOMA scheme in [3]- [5] and [6].

2) *Clustering*: Clustering of users in two group can affect the performance of the system. At each time slot,  $2M$  users should be served, therefore clustering the users in two groups A and B has an impact on the performance of the system. The problem can be defined as follows

$$\max_{I_A, I_B} R_{k,A} + R_{k,B}$$

where two groups A and B have disjoint sets and the union of the these two groups is the whole set and two groups have the same cardinality.

## III. OPTIMUM POWER ALLOCATION IN MC-NOMA

In this section, we seek the optimal power allocation for maximizing the fairness and maximizing the SR with QoS constraints for a fixed user clustering. To find the optimum power allocation in MC-NOMA scheme, first we need to simplify the equations (6) and (7).

It is worth mentioning that if the function  $f(x)$  is strictly increasing for  $x \geq 0$ , then  $\min f(x) = f(\min(x))$ . It can be

verified that functions (6) and (7) are strictly increasing for  $\text{SINR} \geq 0$  if  $0 \leq \alpha_k \leq 1$ . Consequently, we can introduce

$$\Gamma_{k,A} = \min_{j \in I_A} \text{SINR}_{k,A}^{[j]} \quad (10)$$

$$\Gamma_{k,B} = \min_{l \in I_B} \text{SINR}_{k,B}^{[l]}, \quad (11)$$

to compactly express the rates as follow

$$R_{k,A} = \log_2 \left( 1 + \frac{\alpha_k \Gamma_{k,A}}{1 + (1 - \alpha_k) \Gamma_{k,A}} \right), \quad (12)$$

$$R_{k,B} = \log_2 (1 + (1 - \alpha_k) \Gamma_{k,B}). \quad (13)$$

which are formulated under the assumption

$$\log_2 \left( 1 + \frac{\alpha_k \Gamma_{k,B}}{1 + (1 - \alpha_k) \Gamma_{k,B}} \right) \geq R_{k,A}. \quad (14)$$

This inequality guarantees that  $s_{k,A}$  and  $s_{k,B}$  can be decoded by users of group B and it is equivalent to

$$\Gamma_{k,B} \geq \Gamma_{k,A}. \quad (15)$$

If the condition in (15) is not satisfied, then the users of group B can not apply SIC and not decode the signal of interest in the absence of interference. In such a case, the roles should be exchanged so that users belonging to group A and B perform SIC and single-user decoding, respectively. In this paper, it is assumed that the condition in (15) is satisfied and more power is allocated to the users of group A.

In the following subsections the optimal value of  $\alpha_k$  is derived using the Equations (12) and (13). These equations are one of the main contributions of this paper. Exploiting these equations the multicast problem bears resemblance with the unicast problem. Indeed, the performance is governed by the worst users in each group. All the metrics are mapped into a single metric, which allow us to leverage on the solutions available for unicast transmission.

### A. Maximum fairness

The NOMA scheme enables a flexible management of the users achievable rates and provides an efficient way to enhance the user fairness. In this section an optimal power allocation to achieve the maximum fairness between users of a single beam in MC-NOMA scheme is studied. The optimum power allocation of  $p_k$  in beam  $k$  between groups A and B to maximize the fairness is formulated as follows

$$\begin{aligned} \max_{\alpha_k} \quad & \min\{R_{k,A}, R_{k,B}\} \\ \text{subject to} \quad & \alpha_k \in [0, 1], \Gamma_{k,B} \geq \Gamma_{k,A} \end{aligned}$$

Using Equations (12) and (13), the optimization problem turns into the maximum fairness optimization in unicast NOMA. Therefore, the problem is solved using the method proposed in [6]. The optimum  $\alpha_k$  is equal to  $\alpha_k = \alpha_k^*$ , namely,

$$\alpha_k^* = \frac{2\Gamma_{k,A}\Gamma_{k,B} + \Gamma_{k,A} + \Gamma_{k,B} - \sqrt{(\Gamma_{k,A} + \Gamma_{k,B})^2 + 4\Gamma_{k,A}^2\Gamma_{k,B}}}{2\Gamma_{k,A}\Gamma_{k,B}}$$

The optimum  $\alpha_k$  is given in a closed form. In addition, if  $\alpha \neq \alpha^*$ , then it can be verified that the fairness is degraded. Therefore, achievable rates for users of group A and B in beam k are

$$R_k = R_{k,A} + R_{k,B} = 2 \log_2 \left( \frac{\Gamma_{k,A} - \Gamma_{k,B} + \sqrt{(\Gamma_{k,A} + \Gamma_{k,B})^2 + 4\Gamma_{k,A}^2 \Gamma_{k,B}}}{2\Gamma_{k,A}} \right) \quad (16)$$

The Equation (16) shows that the MC-NOMA provides absolute fairness for two group of users in beam k.

### B. Sum-rate with QoS

The sum of Equations (12) and (13) is a strictly decreasing function for  $0 \leq \alpha_k \leq 1$ . Therefore, the minimum of  $\alpha_k$  maximizes the sum-rate without any constraint and it means that all power should be allocated to the users of group B. In order not to shut down weaker users we place a constraint on minimum rate. The SR maximization with constraints in unicast NOMA is studied in [6], [12]. In this case the power allocation problem is given by

$$\begin{aligned} & \max_{\alpha_k} R_{k,A} + R_{k,B} \\ & \text{subject to } \alpha_k \in [0, 1], R_{k,A} \geq R_{k,A}^{\text{OMA}} \end{aligned}$$

It is considered that  $R^{\text{OMA}}$  is equal to the rate that users in group A would achieve if groups are served in an orthogonal multiple access fashion, i.e.,  $R_k^{\text{OMA}} = 0.5 \log_2(1 + \Gamma_{k,A})$ . From the constraint, it can be inferred that

$$\frac{1 + \Gamma_{k,A} - \sqrt{1 + \Gamma_{k,A}}}{\Gamma_{k,A}} \leq \alpha_k^* \quad (17)$$

Note that  $\alpha_k^*$  is always greater than 0.5 and lower than 1, by design because  $\Gamma_{k,A}$  is positive. The optimization problem can be written as follows:

$$\begin{aligned} & \max_{\alpha_k} R_{k,A} + R_{k,B} \\ & \text{subject to } \alpha \in \left[ \frac{1 + \Gamma_{k,A} - \sqrt{1 + \Gamma_{k,A}}}{\Gamma_{k,A}}, 1 \right] \end{aligned}$$

The maximum of sum-rate is achieved by minimum of  $\alpha_k$  and is  $\alpha_k^{**} = \frac{1 + \Gamma_{k,A} - \sqrt{1 + \Gamma_{k,A}}}{\Gamma_{k,A}}$ . Therefore the maximum sum-rate that is maximized subject to the constraint becomes

$$R_k = R_{k,A} + R_{k,B} = \frac{1}{2} \log_2(1 + \Gamma_{k,A}) + \log_2 \left( \frac{\Gamma_{k,A} - \Gamma_{k,B} + \Gamma_{k,B} \sqrt{1 + \Gamma_{k,A}}}{\Gamma_{k,A}} \right) \quad (18)$$

## IV. USER CLUSTERING IN MC-NOMA

In this section the clustering of users in each beam in two groups A and B is studied. For convenience, we consider that all clusters have M users. Generally, the clustering can

be classified into random clustering and ordered clustering. Consider a special partitioning  $P$  over indices:

$$P^t : \mathbf{I}_S \longrightarrow \mathbf{I}_A^t, \mathbf{I}_B^t \quad (19)$$

where,

$$\begin{aligned} \mathbf{I}_S &= \{1, 2M\}, M \geq 2 \\ \mathbf{I}_A^t &= \{i_j^t | i_j^t \in \mathbf{I}_S, \forall j \in [1, M]\} \\ \mathbf{I}_B^t &= \mathbf{I}_S - \mathbf{I}_A^t \\ t &\in \left\{ 1, \frac{(2M)!}{M!^2} \right\} \end{aligned}$$

The partitioning  $t$  is selected such that

$$\mathbf{I}_A^t \subset \mathbf{I}_S, \mathbf{I}_B^t \subset \mathbf{I}_S, \mathbf{I}_A^t \cap \mathbf{I}_B^t = \emptyset, \mathbf{I}_A^t \cup \mathbf{I}_B^t = \mathbf{I}_S,$$

Using the properties of the clustering, in the following two kind of clustering are studied.

1) *Random clustering*: In this category, the set  $\mathbf{I}_S = \{1, \dots, 2M\}$  is divided into two disjoint groups,  $\mathbf{I}_A, \mathbf{I}_B$ , randomly and without any criterion.

In random clustering, the group that has index associated with the lowest SINR is labeled as group  $\mathbf{I}_A$  and the other one as group  $\mathbf{I}_B$ . Therefore, users of group A and B perform SUD and SIC, respectively.

2) *Ordered clustering*: In this section a clustering method is derived to optimize the performance of the MC-NOMA. In this method, at each time the clustering is done based on judicious user selection. The problem can be formulated as follows:

$$\begin{aligned} & \operatorname{argmax}_{\mathbf{I}_A^t, \mathbf{I}_B^t} R_{k,A} + R_{k,B} \\ & \text{s.t. } \mathbf{I}_A^t \cup \mathbf{I}_B^t = \mathbf{I}_S, \mathbf{I}_A^t \cap \mathbf{I}_B^t = \emptyset, \min_{j \in \mathbf{I}_A^t} \text{SINR}_{k,A}^{[j]} \leq \min_{l \in \mathbf{I}_B^t} \text{SINR}_{k,B}^{[l]} \end{aligned}$$

The rates  $R_{k,A}$  and  $R_{k,B}$  are formulated in the equations (12) and (13), respectively. The constraints indicate how the clustering should be made so that (15) is satisfied.

**Proposition 1.** *The optimal clustering which maximizes the sum-rate must satisfy this inequality*

$$\max_{j \in \mathbf{I}_A^t} \text{SINR}_{k,A}^{[j]} \leq \min_{l \in \mathbf{I}_B^t} \text{SINR}_{k,B}^{[l]} \quad (20)$$

*Proof.* Since the sum-rate is strictly increasing for  $\Gamma_{k,A} \geq 0$  and  $\Gamma_{k,B} \geq 0$ , thus the maximum sum-rate is achieved if  $\Gamma_{k,A}$  and  $\Gamma_{k,B}$  are maximized without violating the condition that  $\Gamma_{k,A} \leq \Gamma_{k,B}$ .

Consider two partitioning  $t_{opt}$  and  $t_0$ . We denote  $t_{opt}$  the optimal partitioning, which satisfies (20). for convenience and to be consistent with the notation of the paper, let us assume that  $\mathbf{I}_A^{t_{opt}}$  and  $\mathbf{I}_A^{t_0}$  gather the indices of the weak users, while  $\mathbf{I}_B^{t_{opt}}$  and  $\mathbf{I}_B^{t_0}$  identify the strong users. Now suppose that

$$\begin{aligned} & \min_{l \in \mathbf{I}_B^{t_{opt}}} \text{SINR}_{k,B}^{[l]} \leq \min_{l \in \mathbf{I}_B^{t_0}} \text{SINR}_{k,B}^{[l]} \\ & \min_{j \in \mathbf{I}_A^{t_{opt}}} \text{SINR}_A = \min_{j \in \mathbf{I}_A^{t_0}} \text{SINR}_A \end{aligned}$$

By grouping users differently, it becomes evident that the sum-rate, which is governed by the weakest users, would decrease. This result contradicts the initial hypothesis and thus, (20) must be satisfied. This concludes the proof.  $\square$

TABLE I  
SIMULATION PARAMETERS.

Carrier Frequency	20GHz
Orbit	GEO
G/T	17.68 dB/K
user location distribution	uniform
Beam radiation pattern	Provided by ESA
Beam Radius	140Km

## V. SIMULATION RESULTS

In this section, we present some numerical results of the proposed power allocation and clustering algorithms for a single beam MC-NOMA scheme, according to the different optimization criteria. We consider the forward link of a 4-color frequency reuse satellite communication systems. The simulation model consists of a single beam and the interference from the other beams are considered as the background noise. The parameters of the simulation are given in the table I.

For the LMS channel model, we have used the statistical information provided in [11] for the ka band and the intermediate shadowing. Fig. 1 and Fig.2 compare the performance of MC-NOMA and MC-OMA (groups of users are served in different time slots) in terms of fairness rate when the optimal power allocation is applied to maximize the fairness in MC-NOMA.

Fig. 1 shows the achievable maximum fairness rate in MC-NOMA compared to MC-OMA scheme under two different types of clustering for different number of users per group. The figure shows the results for three different transmit power. As expected, the MC-NOMA outperforms the OMA scheme. In addition, the ordered clustering has much better performance than the random clustering. The simulation result shows that with increasing the number of users per group for a given transmit power the MC-NOMA scheme achieves more gain compared to the MC-OMA scheme. The simulation results shows that the gain increases the other way around, i.e. 20% increases if the number of users increases from 2 to 20 per group.

Fig. 2 demonstrates the achievable maximum fairness rate in MC-NOMA compare to MC-OMA scheme for different total power of the beam ( $p_k$ ) and number of users per group ( $M$ ), when ordered clustering is used. The MC-NOMA achieves more gain than OMA with increasing the number of users. However, the gain of the MC-NOMA over OMA decreases with increasing the power of beams. The reduction in the gain of MC-NOMA over the OMA with increasing the total power is negligible for higher total number of users per group. The gain of MC-NOMA over MC-OMA decreases 15% with increasing the power of the beam from 1 dB to 30 dB if the number of users per group is 2.

Fig. 3 and Fig.4 compare the performance of MC-NOMA and MC-OMA in terms of sum-rate when the optimal power allocation is applied to maximize the sum-rate with some QoS.

Fig. 3 shows the achievable maximum with QoS in MC-NOMA compared to MC-OMA scheme under two different

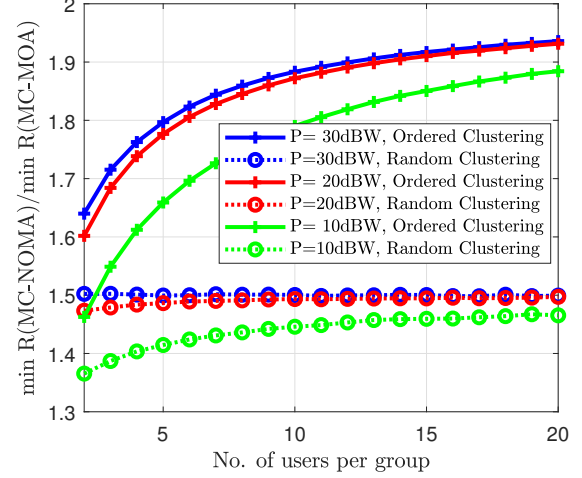


Fig. 1. Comparison of MC-NOMA and MC-OMA fairness rate performance under different kind of clustering for different number of users per group.

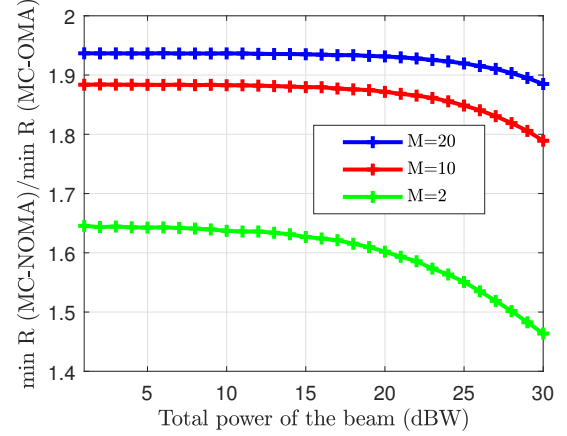


Fig. 2. Comparative NOMA and MC-OMA fairness rate performance under different number of users per group for different power of a beam

types of clustering for different number of users per group. The figure shows the results for three different transmit powers. If ordered clustering is used, then MC-NOMA has better performance compared to OMA and the gain increases with increasing the number of users per group. However, the gain of MC-NOMA compared to OMA decreases in random clustering as the number of users per group increases and MC-NOMA scheme does not achieve any gain compared to MC-OMA. The simulation result shows that the gain increases 7% if the number of users increases from 2 to 20 per group under ordered clustering.

Fig. 4 shows the performance of the MC-NOMA over the OMA under different number of users for different power of the beam. According to the simulation results, the gain of the MC-NOMA over the OMA increases as the power and the number of users per group increase.

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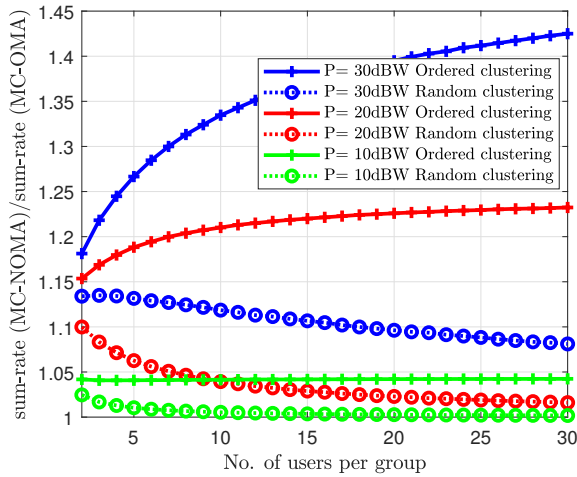


Fig. 3. Comparison of MC-NOMA and MC-OMA sum-rate rate performance under different kind of clustering for different number of users per group.

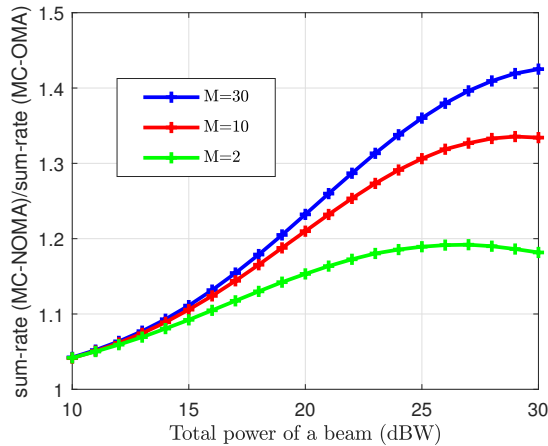


Fig. 4. Comparison of MC-NOMA and MC-OMA sum-rate rate performance under different number of users per group for different power of a beam.

## VI. CONCLUSION

In this paper, the MC-NOMA scheme was investigated in forward link of the satellite communication, with a 4-color frequency reuse pattern. The performance of the NOMA scheme in the multicast transmission was analyzed. It was shown that the attainable data rates are based on the minimum SINR in each group. Therefore, the optimum power allocation for different performance metrics was derived using existing methods. In addition, an ordered clustering was proposed which maximizes the performance. The performance of the system was compared with the multicast orthogonal multiple access scheme. The simulation results show that MC-NOMA outperforms MC-OMA in terms of the minimum rate and sum rate if ordered clustering is used. Moreover, the results show that the performance of the system improves if the number of users per group increases.