Precoding and Scheduling in Multibeam Multicast NOMA based Satellite Communication Systems

Sareh Majidi Ivari*, Marius Caus†, Miguel Angel Vazquez†
M. Reza Soleymani*, Yousef R. Shayan*, and Ana I. Perez-Neira† ‡
* Concordia University, Montreal, Canada
† Centre Tecnologic de Telecomunicacions de Catalunya (CTTC/CERCA), Castelldefels, Barcelona, Spain
‡Dept. Signal Theory and Communications - Universitat Politecnica de Catalunya (UPC), Barcelona, Spain,
Emails: {m_sareh,msoleymani,yshayan}@encs.concordia.ca, {marius.caus,mavazquez,aperez}@cttc.es

***Abstract*—In this paper, we propose a multibeam multicast non-orthogonal multiple access-based (MB-MC-NOMA) scheme for satellite communication systems. Building upon the multibeam transmission, we exploit precoding and NOMA techniques to deal with inter-and intra-beam interference, respectively. Combining these two techniques in the multicast transmission is not trivial as both scheduling, and the precoding design shall be reconsidered. Indeed, it is shown there is a contradiction between criteria for efficient user scheduling in MC-NOMA and MC-linear precoding: while the first one requires a strong channel gain imbalance between user terminals, the latter seeks user channel vector similarities. To tackle this problem, we propose a user scheduling in MB-MC-NOMA, which provides a good balance between these two criteria. Besides, the MC-linear precoding is designed with aid of a mapping function that deals with the lack of spatial degrees of freedom. The numerical simulation results show that the performance of the MB-MC-NOMA scheme is improved by using the proposed user scheduling and a novel precoding design based on the singular value decomposition (SVD). Moreover, the MB-MCNOMA scheme outperforms its orthogonal version scheme. In particular, we observe that the throughput of the MB-MC-NOMA is increased a 25% with respect to MB-MC-OMA scheme under certain fair conditions.**

***Index Terms*—Multicast NOMA, linear precoding, fairness, user scheduling**

I. Introduction

Precoding in multibeam satellite systems has been identified as a critical element of next-generation systems for both geostationary and non-geostationary orbits. Indeed, the bandwidth increase resulting from aggressive frequency reuse among beams substantially augments the user segment throughput. In this context, precoding can revert the inter-beam interference generated by the co-located beams employing the same frequency. The deployment of the precoding system will require an update of both ground and user segments. While the ground equipment shall include the operations involved in the precoding procedure (i.e., precoding matrix computation and multiplication, channel state information feedback processing,...), user segment shall also be updated as user equipment must perform new synchronization and channel feedback activities not included in non-precoding systems. This hardware upgrade supposes an excellent opportunity to enhance the satellite system capacity with other promising techniques.

This is the case of non-orthogonal multiple access (NOMA) techniques thoroughly developed for terrestrial systems. This technique's key idea is to simultaneously transmit more than one symbol, assuming that certain users perform successive interference cancellation (SIC) and decode the superimposed symbols. Under certain conditions of power imbalance, it is known that NOMA offers a throughput increase compared to orthogonal multiple access (OMA) techniques. In addition, it has been shown that the spectral efficiency is increased by combining NOMA with multiple-input multiple-output (MIMO) transmission [1]. Ding et al. [2] validate, again via simulation, that MIMO-NOMA has a better outage performance than MIMO-OMA. In [3], it is proved analytically that MIMO-NOMA outperforms MIMO-OMA in terms of both sum rate and ergodic sum rate.

NOMA application in satellite systems has been studied in the recent years [4]- [7]. In all cases, the use of NOMA shows a potential theoretical gain compared to former OMA schemes currently implemented. The precoding design in NOMA forward link satellite systems is reviewed in [8]- [10]. Remarkably, NOMA precoding systems require additional attention compared to OMA. It is required that users receiving different frames have orthogonal channel vectors, but it is also necessary to have a certain power imbalance to achieve NOMA gains.

In contrast to the mentioned papers, this work focuses on an unexplored aspect of NOMA precoding techniques in satellite systems: the multicast transmission. In this work, this scheme is referred to as multibeam multicast NOMA-based (MB-MC-NOMA) scheme. Note that multicast is an important aspect of satellite systems [11] whose long codewords and a huge number of simultaneous users demands require to embed more than one user data in a single frame.

In this paper, user scheduling, MC-linear precoding and MC-NOMA are designed for the MB-MC-NOMA scheme in the forward link of the satellite communication system. The user scheduling is designed to improve the performance of

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both MC-linear precoding and MC-NOMA scheme. The performance of the MC-NOMA scheme is improved if groups of users have the maximum signal to interference plus noise ratio (SINR) imbalances. However, the performance of the MC-linear precoding technique is improved if channel vectors have minimum Euclidean distance and users have similar SINRs, as the rates are dictated by the user with minimum SINR. These two criteria contradict each other. In this paper, we are able to find a good compromise between SINR imbalance and the colinearity of channel vectors.

In the MC-linear precoding, the precoding matrix is obtained from a unicast design by computing the composite channel matrix, which is a virtual channel that does not necessarily have a physical meaning. The idea is to follow the same rationale as unicast precoding. To this end, the users' channel vectors to be served in a given beam are mapped into a single vector to deal with the lack of spatial degrees of freedom. In this paper, we present three different mappers. The mappers are governed by singular-value-decomposition (SVD), signal-to-noise-ratio (SNR), and averaging. In addition, using the results presented in [12] the MC-NOMA is designed by optimizing the user grouping and power allocation in each beam.

The simulation results show that the MB-MC-NOMA scheme using the proposed user scheduling outperforms the MB-MC-OMA scheme. In addition, the results show that the SVD mapper achieves a higher data rate compared to the other mappers in both: MB-MC-NOMA and MB-MC-OMA.

The rest of the paper is organized as follows. Section II introduces the system model. Section III presents the user scheduling. In Section IV, the design of the MC-linear precoding is discussed. Section V tackles user grouping and power allocation in MC-NOMA. The performance of different precoders and user scheduling algorithm in MB-MC-NOMA and MB-MC-OMA schemes evaluated in Section V by simulation and finaly, the conclusion is given in Section VI.

II. System Model

Consider the forward link of a multibeam satellite communication system that tessellates the coverage area into K beams. The full frequency reuse pattern is used across the coverage area. Due to the frequency reuse, each user receives the signals from the other beams. Therefore, interference mitigation techniques shall be used to cancel the inter-beam interference. In this context, linear precoding is used in the multibeam satellite communication to revert the inter beam interference [13].

Note that, as reported in the other works, multibeam satellite precoding techniques shall consider a multicast transmission for each beam as information from different users is embedded at each codeword. Moreover, to increase the system capacity, we explore the possibility of performing the MC-NOMA scheme in the power domain within each beam [12]. The combination of MC-NOMA with precoding leads to MB-MC-NOMA.

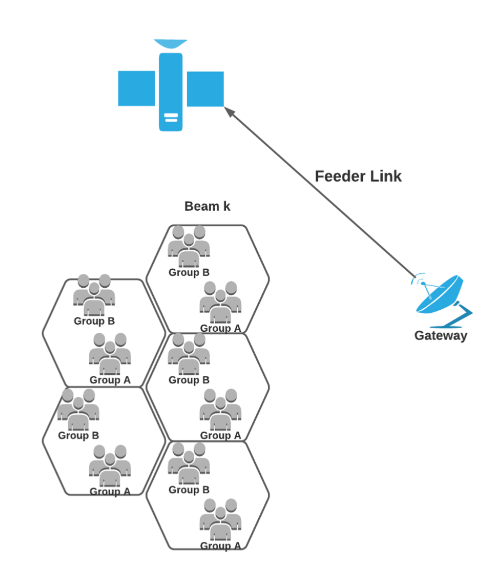

Fig. 1: System model of the proposed MB-MC-NOMA scheme

We consider that each beam provisions service to two groups of users, group $\mathcal{A}$ and group $\mathcal{B}$. Without loss of generality, we will consider a fixed number of users, i.e. M for each time instant and for each group. Therefore, there are $2M$ users per beam. The user indices are gathered in $I_{k,S}$. At each time instant $I_{k,S}$ is selected from a bigger set of users coined as $\mathcal{U}$. In this paper, this user selection is called user scheduling which is studied in Section IV. The MC-NOMA divides $I_{k,S}$ into two groups of users indices $I_{k,\mathcal{A}}$ and $I_{k,\mathcal{B}}$, $k \in \{1,...,K\}$. The division within beams is called user grouping. Figure 1 shows the system model of the proposed MB-MC-NOMA scheme.

As reported in the literature, there exist different options when combining linear precoding and NOMA; beamformer-based structure and cluster-based structure [14]. In the beamformer-based structure, each beamformer serves a single group of users, and in the cluster-based structure, each beamformer serves multiple groups of users. In this paper, we consider the cluster-based structure in which there is a single precoding vector per beam rather than two. Therefore, the transmitted signal in the proposed MB-MC-NOMA scheme is

$$
\begin{aligned}
x &= \sum_{k=1}^{K} \sqrt{p_k}\mathbf{w}_k(\sqrt{\alpha_k}s_{k,\mathcal{A}} + \sqrt{1-\alpha_k}s_{k,\mathcal{B}}) \\
&= \sum_{k=1}^{K} \sqrt{p_k}\mathbf{w}_k s_k. \qquad (1)
\end{aligned}
$$

Let symbol $s_{k,\mathcal{A}}(s_{k,\mathcal{B}})$ conveys information intended for users of group $\mathcal{A}(\mathcal{B})$ in beam k, and α_k controls the fraction of power devoted to the users of group $\mathcal{A}$ and $\mathcal{B}$ in beam k. The vector $\mathbf{w}_k \in \mathbb{C}^{K\times 1}$ precodes the symbol that is intended to users in beam k. In addition, p_k corresponds to the available power in beam k. In this paper, we assume that the power is equally split between beams. Therefore, the transmitted signal is constrained to

$$p_k||\mathbf{w}_k||^2 \leq \frac{P_\text{T}}{K}, \quad k = 1, \cdots, K, \tag{2}$$

where P_T is the maximum available power in the satellite payload. If we focus the attention on the k-th beam, then it follows that the received signal by the j-th user in group $\mathcal{A}$ and the l-th user in group $\mathcal{B}$ are expressed as follows

$$\begin{aligned} y_{k,\mathcal{A}}^{[j]} &= \mathbf{h}_{k,\mathcal{A}}^{[j]}\mathbf{w}_k\sqrt{p_k}(\sqrt{\alpha_k}s_{k,\mathcal{A}} + \sqrt{1-\alpha_k}s_{k,\mathcal{B}}) \\ &+\mathbf{h}_{k,\mathcal{A}}^{[j]}\sum_{n=1,n\neq k}^{K}\mathbf{w}_n\sqrt{p_n}s_n + n_{k,\mathcal{A}}^{[j]}, \quad j \in I_\mathcal{A} \end{aligned} \tag{3}$$

$$\begin{aligned} y_{k,\mathcal{B}}^{[l]} &= \mathbf{h}_{k,\mathcal{B}}^{[l]}\mathbf{w}_k\sqrt{p_k}(\sqrt{\alpha_k}s_{k,\mathcal{A}} + \sqrt{1-\alpha_k}s_{k,\mathcal{B}}) \\ &+\mathbf{h}_{k,\mathcal{B}}^{[l]}\sum_{n=1,n\neq k}^{K}\mathbf{w}_n\sqrt{p_n}s_n + n_{k,\mathcal{B}}^{[l]}, \quad l \in I_\mathcal{B}. \end{aligned} \tag{4}$$

As for the notation, $\mathbf{h}_{k,\mathcal{A}}^{[j]} \in \mathbb{C}^{1\times K}$ and $\mathbf{h}_{k,\mathcal{B}}^{[l]} \in \mathbb{C}^{1\times K}$ denote the channel vector associated to the j-th and the l-th user of group $\mathcal{A}$ and group $\mathcal{B}$, respectively. Finally, $n_{k,\mathcal{A}}^{[j]}$ and $n_{k,\mathcal{B}}^{[l]}$ are the additive noise terms that contaminate the reception of users in each group.

To model the propagation conditions, we consider the land mobile satellite (LMS) channel [15]. As for the mobility, it is assumed that the channel is constant during the frame transmission. The channel vector is defined as

$$\mathbf{h}_{k,Y}^{[i]} = f_{k,Y}^{[i]}\overline{\mathbf{h}}_{k,Y}^{[i]} \tag{5}$$

where $i \in I_{k,Y}$, for $Y = \{\mathcal{A}, \mathcal{B}\}$ and $k = 1, ..., K$. The vector $\overline{\mathbf{h}}_{k,Y}^{[i]}$ is given by

$$\overline{\mathbf{h}}_{k,Y}^{[i]} = \frac{\sqrt{G_R}[a_1^i e^{j\Phi_1^i}, ..., a_K^i e^{j\Phi_K^i}]}{4\pi\frac{d_k^{[i]}}{\lambda}\sqrt{K_B T B_W}} \tag{6}$$

where G_R is the receiver antenna gain, $a_l^{[i]}$ is the gain from the l-th feed to the i-th user. Besides, $e^{j\Phi_l^{[i]}}$ represents the time-varying phase due to the beam radiation pattern and radio wave propagation and $d_k^{[i]}$ is the distance between the i-th user at beam k and the satellite. Finally, λ, K_B, T, and B_W are the carrier wavelength, the Boltzmann constant, the receiver noise temperature, and the carrier bandwidth, respectively. The fading effect is modeled by $f_k^{[i]}$ and obeys the Loo distribution. Therefore, the $f_{k,Y}^{[i]}$ is defined as

$$f_{k,Y}^{[i]} = z_{k,Y}^{[i]}e^{j\theta_{k,Y}^{[i],\text{LoS}}} + w_{k,Y}^{[i]}e^{j\theta_{k,Y}^{[i],\text{MP}}} \tag{7}$$

where $z_{k,Y}^{[i]}$ is the line-of-sight component, which is log-normally distributed, and $w_{k,Y}^{[i]}$ is the multipath component, which is Rayleigh distributed. Moreover, $\theta_{k,Y}^{[i],\text{LoS}}$ and $\theta_{k,Y}^{[i],\text{MP}}$ are uniformly distributed between 0 and 2π. Note that the channel is normalized to the noise power. Hence, the noise terms $n_{k,\mathcal{B}}^{[l]}$ and $n_{k,\mathcal{A}}^{[j]}$ are distributed as $\mathcal{CN}(0,1)$. In addition, we assume the availability of perfect channel state information at the transmitter (CSIT).

In this paper, we consider the maximum of sum-rate constrained to the fairness within beams. The problem is defined as

$$\begin{aligned} &\max_{p_k,\alpha_k,\mathbf{w}_k,I_{k,S},\{I_{k,\mathcal{A}},I_{k,\mathcal{B}}\}} \sum_{k=1}^{K} R_k \\ &\text{subject to} \\ &R_{k,\mathcal{A}} = R_{k,\mathcal{B}} \quad k = 1, \ldots, K \\ &\alpha_k \in [0,1] \quad k = 1, \ldots, K \\ &p_k\|\mathbf{w}_k\|^2 \leq \frac{P_\text{T}}{K} \quad k = 1, \ldots, K \end{aligned}$$

where $R_{k,\mathcal{A}}$ ($R_{k,\mathcal{B}}$) is the maximum achievable rate by users in group $\mathcal{A}$ ($\mathcal{B}$). Hence, $R_k = R_{k,\mathcal{A}} + R_{k,\mathcal{B}}$. The maximum achievable rates depend on the decoding strategy. We will bring back this issue later on. As the joint optimization of the precoder, the power allocation and the user grouping is too complex, we propose to decouple the original problem into separate subproblems, which are easier to solve. Algorithm I explains the steps that are followed.

Algorithm 1: User scheduling and resource allocation in the MB-MC-NOMA scheme

Inputs: $\mathcal{U}, P_\text{T}$
Outputs; $I_{k,S}$,$\mathbf{w}_k$,$I_{k,\mathcal{A}}$,$I_{k,\mathcal{B}}$,p_k,α_k
User scheduling ($I_{k,S}$)
Design MC-linear precoding ($\mathbf{w}_k$)
User grouping ($I_{k,\mathcal{A}}$,$I_{k,\mathcal{B}}$)
Power allocation (α_k)

In the following section, we thoroughly analyze each subproblem.

III. User scheduling

User scheduling in the MB-MC-NOMA scheme boils down to selecting $2M$ users out of a set of N, where $2M << N$. The user scheduling is not straightforward in the MB-MC-NOMA scheme because the criteria for user scheduling in the MC-NOMA and MC-linear precoding are in contradiction to each other.

The MC-NOMA scheme has been proven advantageous for improving the user data rate when groups of users to be served present a large SNR imbalance [4]. The SNR of the i-th user in beam k with channel vector $\mathbf{h}_k^{[i]} = [h_{k1}^{[i]}, h_{k2}^{[i]}, ..., h_{kK}^{[i]}]$ is

$$\text{SNR}_k^{[i]} = \|h_{kk}^{[i]}\|^2. \tag{8}$$

Therefore, the SNR imbalance between the i-th and the t-th user in beam k is $|h_{kk}^{[i]}|^2/|h_{kk}^{[t]}|^2$. Nevertheless, the MC-linear precoding technique works better if channel vectors have low Euclidean distance [16]. The Euclidean distance between the i-th and the t-th user in beam k is calculated as

$$d_k^{it} = \|\mathbf{h}_k^{[i]} - \mathbf{h}_k^{[t]}\|^2, \{i,t\} \in I_{k,S}. \tag{9}$$

Essentially, the Euclidean norm and the SNR imbalance trade-off each other, thus we have to find a compromise. In the proposed method, the N users are divided into two sets according to the SNR, so that users that experience good and bad channel conditions are grouped separately. Hence, the sets can be labeled as weak users and strong users. At each time, M users with the lowest Euclidean distance are selected from each set of users. It is important to remark that we do not perform an exhaustive search, but the first user in each set is selected randomly and the rest are added one by one. Therefore, on each set there are M users that have channel vectors with a high degree of co-linearity. However, the sets are created so that the SNR imbalance between users of different sets is as high as possible. The Algorithm 2 explains the user scheduling procedure.

Algorithm 2: User scheduling

Inputs: Users terminals (N), Channel coefficients
Outputs; $I_{k,S}$
Calculate the SNR of N users
Based on the resulting SNRs divide N users into two sets: set of strong users and set of weak users
Choose M users with the lowest Euclidean distance from set of strong users
Choose M users with the lowest Euclidean distance from set of weak users
Gather the indices of the $2M$ selected users in $I_{k,S}$

IV. MC-linear precoding

In unicast transmission, the precoding matrix, $\mathbf{W} = [\mathbf{w}_1 \mathbf{w}_2 ... \mathbf{w}_K]$, is a function of the composite channel matrix, $\mathbf{H} = [\mathbf{h}_1^T, ..., \mathbf{h}_K^T]$. In the MC-linear precoding, the procedure is not so straightforward as in the unicast linear precoding. In MC transmission, each beam is not identified with a channel vector, but it is characterized by the matrix that gathers the channel vectors of all users to be served. That is, $\mathbf{C}_k = \left[(\mathbf{h}_k^{[1]})^T, ..., (\mathbf{h}_k^{[2M]})^T\right]$. With the objective of mimicking the unicast design, it is necessary to define the function f, which maps $\mathbf{C}_k$ into the vector $\mathbf{g}_K$ namely,

$$f : \mathbf{C}_k \longrightarrow \mathbf{g}_k. \tag{10}$$

After performing the mapping on a beam basis, the composite channel matrix becomes $\mathbf{G} = \left[\mathbf{g}_1^T \mathbf{g}_2^T ... \mathbf{g}_K^T\right]^T$. It is important to mention that the complexity in the MC-linear precoding is finding an optimum mapper.

Upon building $\mathbf{G}$, the minimum mean square error (MMSE) criterion is selected to generate the precoder. The MMSE has low computational complexity and good sum-rate performance for the diverse multibeam satellite systems [16]. The precoding matrix is given by

$$\mathbf{W}_{\mathbf{MMSE}} = 1/\sqrt{\gamma_{\mathbf{MMSE}}} \left(\left(\mathbf{G}^H \mathbf{G} + \frac{K}{P_{\mathrm{T}}} \mathbf{I}_K \right)^{-1} \mathbf{G}^H \right). \tag{11}$$

where $\mathbf{I}_K$ is the K-dimensional identity matrix. To control the power and satisfy the power constraints, the precoding matrix should be divided by,

$$\gamma_{\mathbf{MMSE}} = \max_n \left(\mathrm{diag} \left(\mathbf{W}_{\mathbf{MMSE}} \left(\mathbf{W}_{\mathbf{MMSE}} \right)^H \right) \right). \tag{12}$$

In the next subsections, we present three mappers to construct the composite channel matrix.

A. Mapping by SNR

In [17], the channel of the strongest users in the MIMO-NOMA are chosen to generate beamforming vectors. Using this result, we propose a mapper which chooses the user with highest SNR in each beam. Then, the channel vector associated with the selected user is used to construct $\mathbf{g}_k$. The SNR of i-th user in beam k is given by (8).

B. Mapping by SVD

This mapper is governed by the SVD. First we compute the SVD of $\mathbf{C}_k^H \mathbf{C}_k$ yielding

$$\mathbf{C}_k^H \mathbf{C}_k = \mathbf{U}_k \mathbf{\Sigma}_k \mathbf{V}_k^H, \tag{13}$$

where $\mathbf{\Sigma}_k$ is the singular value matrix and $\mathbf{U}_k$ ($\mathbf{V}_k$) gathers the left-singular vectors (right-singular vectors). Then the mapper chooses right or left singular vector associated with the highest singular value. The selected singular vector in beam k is considered as $\mathbf{g}_k$. With this approach we intend to maximize the energy that is spread over the users.

C. Mapping by averaging

In this method, the mapper finds the average of the user channel vectors [13]. Therefore, $\mathbf{g}_k$ is computed as

$$\mathbf{g}_k = \frac{\sum_{i \in I_{k,S}} \mathbf{h}_k^{[i]}}{2M}. \tag{14}$$

In the next section, we investigate the MC-NOMA scheme which includes user grouping and power allocation.

V. MC-NOMA scheme

Following the MC-NOMA approach, the weak users perform single user detection (SUD), and strong users perform SIC. In this paper, the group of weak and strong users are labeled as groups $\mathcal{A}$ and $\mathcal{B}$, respectively. Therefore, maximum achievable rates under the Gaussian signaling in beam k are written as

$$R_{k,\mathcal{A}} = \min_{j \in I_{k,\mathcal{A}}} \log_2 \left(1 + \frac{\alpha_k \mathrm{SINR}_{k,A}^{[j]}}{1 + (1-\alpha_k)\mathrm{SINR}_{k,A}^{[j]}} \right) \tag{15}$$

$$R_{k,\mathcal{B}} = \min_{l \in I_{k,\mathcal{B}}} \log_2 \left(1 + (1-\alpha_k)\mathrm{SINR}_{k,B}^{[l]} \right). \tag{16}$$

It is important to remark that the user grouping satisfies

$$\min_{l \in I_{k,\mathcal{B}}} \log_2 \left(1 + \frac{\alpha_k \mathrm{SINR}_{k,B}^{[l]}}{1 + (1-\alpha_k)\mathrm{SINR}_{k,B}^{[l]}} \right) \geq R_{k,A} \tag{17}$$

Expression (17) will drive the grouping strategy. To get (15),(16) and (17), we resort to SINR, which is defined as

$$\text{SINR}^{[j]}_{k,\mathcal{A}} = \frac{p_k|\mathbf{h}^{[j]}_{k,\mathcal{A}}\mathbf{w}_k|^2}{1+\sum_{n=1,n\neq k}^{K} p_n|\mathbf{h}^{[j]}_{k,\mathcal{A}}\mathbf{w}_n|^2} \quad (18)$$

$$\text{SINR}^{[j]}_{k,\mathcal{B}} = \frac{p_k|\mathbf{h}^{[l]}_{k,\mathcal{B}}\mathbf{w}_k|^2}{1+\sum_{n=1,n\neq k}^{K} p_n|\mathbf{h}^{[l]}_{k,\mathcal{B}}\mathbf{w}_n|^2}. \quad (19)$$

The achievable data rates in equations (15) and (16) are strictly increasing for SINR $\geq$ 0. Therefore, using the following expressions

$$\Gamma_{k,\mathcal{A}} = \min_{j\in I_{k,\mathcal{A}}} \text{SINR}^{[j]}_{k,A} \quad (20)$$

$$\Gamma_{k,\mathcal{B}} = \min_{l\in I_{k,\mathcal{B}}} \text{SINR}^{[l]}_{k,B}, \quad (21)$$

the achievable data rate can be written as

$$R_{k,\mathcal{A}} = \log_2\left(1+\frac{\alpha_k\Gamma_{k,\mathcal{A}}}{1+(1-\alpha_k)\Gamma_{k,\mathcal{A}}}\right) \quad (22)$$

$$R_{k,\mathcal{B}} = \log_2\left(1+(1-\alpha_k)\Gamma_{k,\mathcal{B}}\right). \quad (23)$$

Note that the condition (17) is equivalent to

$$\Gamma_{k,\mathcal{B}} \geq \Gamma_{k,\mathcal{A}}. \quad (24)$$

Therefore, in this paper it is assumed that the user grouping satisfies the condition (24) and has the following properties:

$$I_{k,\mathcal{A}} \subset I_{k,S}, I_{k,\mathcal{B}} \subset I_{k,S}$$
$$I_{k,\mathcal{A}} \bigcap I_{k,\mathcal{B}} = \emptyset, I_{k,\mathcal{A}} \bigcup I_{k,\mathcal{B}} = I_{k,S}. \quad (25)$$

According to [12], the user grouping is optimized if the imbalance between $\Gamma_{k,\mathcal{A}}$ and $\Gamma_{k,\mathcal{B}}$ is maximized. To maximize the imbalance between $\Gamma_{k,\mathcal{A}}$ and $\Gamma_{k,\mathcal{B}}$ the condition $\max_{j\in I_{k,\mathcal{A}}} \text{SINR}^{[j]}_{k,\mathcal{A}} \leq \min_{l\in I_{k,\mathcal{B}}} \text{SINR}^{[l]}_{k,\mathcal{B}}$ should be satisfied. Taking into account this condition and following the guidelines reported in [12], it is straightforward to create the groups. Due to the lack of space, we address the reader to [12] for further details. The next step is to tackle the power allocation in the MC-NOMA scheme, which is governed by α_k. The optimum α_k in terms of fairness is given by

$$\alpha_k^* = \frac{2\Gamma_{k,\mathcal{A}}\Gamma_{k,\mathcal{B}}+\Gamma_{k,\mathcal{A}}+\Gamma_{k,\mathcal{B}}-\sqrt{(\Gamma_{k,\mathcal{A}}+\Gamma_{k,\mathcal{B}})^2+4\Gamma^2_{k,\mathcal{A}}\Gamma_{k,\mathcal{B}}}}{2\Gamma_{k,\mathcal{A}}\Gamma_{k,\mathcal{B}}} \quad (26)$$

This value guarantees that

$$R_{k,\mathcal{A}} = R_{k,\mathcal{B}} = 2\log_2\left(\frac{\Gamma_{k,\mathcal{A}}-\Gamma_{k,\mathcal{B}}+\sqrt{(\Gamma_{k,\mathcal{A}}+\Gamma_{k,\mathcal{B}})^2+4\Gamma^2_{k,\mathcal{A}}\Gamma_{k,\mathcal{B}}}}{2\Gamma_{k,\mathcal{A}}}\right), \quad (27)$$

where $\Gamma_{k,\mathcal{A}}$ and $\Gamma_{k,\mathcal{B}}$ are given in (20) and (21), respectively.

VI. SIMULATION RESULTS

In this section, we evaluate the proposed MB-MC-NOMA scheme. The parameters of the simulation are given in the Table I. We have used the statistical information provided in [18] to model the LMS channel for the ka band and the intermediate shadowing. As a benchmark, we consider an OMA scheme consisting of two time slot transmission, serving $I_{k,\mathcal{A}}$ and $I_{k,\mathcal{B}}$ separately. In other words, we consider two different precoded multicast transmission attending in an orthogonal fashion $I_{k,\mathcal{A}}$ and $I_{k,\mathcal{B}}$. This results into the computation of two different precoding matrices considering both users sub-sets. Remarkably, the same precoding technique has been used for the OMA case.

Carrier Frequency	20GHz
Orbit	GEO
G_R/T	17.68 dB/K
user location distribution	uniform
Beam radiation pattern	Provided by ESA
EIRP/beam	63dBW
B_W	500MHz
Number of beams	7

TABLE I: Simulation parameters.

Figure 2 shows the performance of the MB-MC-NOMA scheme under different MC-linear precoding designs and user scheduling methods considering a variable number of users per beam M. It is depicted that for all precoding methods, the proposed scheduling technique behaves better to the pure random user scheduling. This difference is specially notorious for the maximum SNR mapping and average mapping.

Attending to the precoding design, our proposed approach based on the SVD yields to the highest sum-rate values for all M. In particular, SVD offers a sum-rate gain with respect to the maximum SNR and average of at least 15% and up to 50% for certain M values.

Figure 3 compares the performance of the MB-MC-NOMA and MB-MC-OMA. The results show the sum-rate ratio between MB-MC-NOMA and MB-MC-OMA schemes employing the different precoding techniques and considering the proposed scheduling technique. According to the results, the MB-MC-NOMA outperforms the MB-MC-OMA schemes when SVD is used as the mapper with the proposed scheduling. In light of the numerical evaluation, we observe that using the maximum SNR precoding alternative NOMA presents substantially lower sum-rate values compared to OMA. However, channel averaging precoding technique shows certain sum-rate gain for reduced number of users M. Indeed, for $M > 6$ the OMA becomes the best technique in terms of sum-rate. Note that precoding in NOMA has to simultaneously attend twice the number of user terminals compared to OMA and; therefore, its performance decrease is highlighted as M increases. In other words, NOMA suffers from a stronger impact the number of users per beam compared to OMA.

In any case, our proposed scheme based on SVD is able to cope with the mentioned effect. As reported in Figure 3, this alternative yields to larger sum-rates compared to OMA for

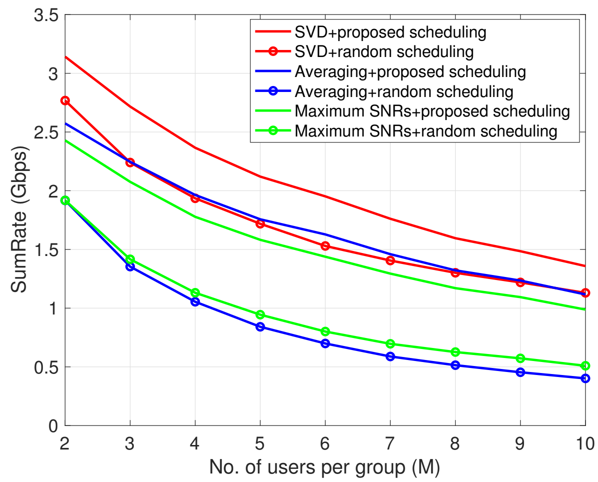

Fig. 2: Performance of MB-MC-NOMA under different mappers and number of users per group

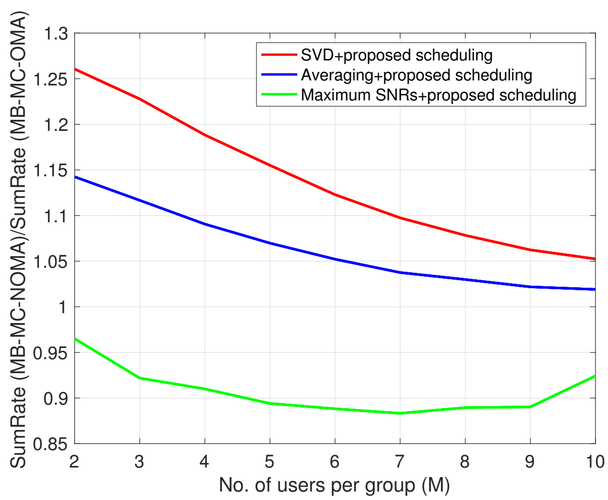

Fig. 3: Comparison of performance of MB-MC-NOMA and MB-MC-OMA schemes under different mappers and number of users per group

all considered M values. In particular, for $M = 2$, NOMA shows a 25% sum-rate gain.

VII. Conclusion

In this work, the MB-MC-NOMA scheme is presented in the forward link of the multibeam satellite communication systems. For the proposed scheme, the user scheduling is designed to optimize the performance of both the MC-linear precoding and MC-NOMA. In addition, it is shown that the linear precoding needs a mapper to deal with the lack of spatial degrees of freedom in the MC transmission. Therefore, we present three different mappers. Next, the user grouping and power allocation are designed to optimize the performance of the NOMA scheme. The results show that the MB-MC-NOMA scheme outperforms the MB-MC-OMA scheme by using the SVD as the mapper and the proposed user scheduling.

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