Received: 7 February 2023 | Revised: 19 May 2023 | Accepted: 25 June 2023

IET Communications

DOI: 10.1049/cmu2.12653

The Institution of Engineering and Technology WILEY

ORIGINAL RESEARCH

Users' grouping algorithm for fairness improvement of NOMA-based multi-beams satellite networks intended for 5G

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Abstract

Non-Orthogonal Multiple-Access (NOMA)-based Multibeam Satellite Networks (MBSNs) are intended for 5G implementation, and 5G networks set the requirement for both high system capacity as well as high system reliability to all users, which is achieved via high system's fairness. The NOMA network requires a user grouping algorithm (UGA), and most existing UGAs for 2-users NOMA-MBSNs, favor the system's capacity maximization with little regard to the system's fairness. Thus, this paper proposes a UGA that maximizes the fairness of 2-users NOMA-MBSNs. The algorithm seeks to group $2M$ users into M-pairs satisfying three requirements, (i) a minimum channel-gain margin; (ii) high channel-correlation coefficients; and (iii) there is high fairness amongst the resulting pairs, in term of their respective channel-correlation coefficients, to increase the users' fairness of the system. To achieve this, the $2M$ users are split into two sets of M-far and M-near users based on users' channel gains for pairing far and near users with high channel-correlation coefficients. It will turn it into a maximization Bipartite Matching problem (BPMP) of channel-correlation coefficients. The BPMP is addressed by means of the Hungarian Method (HM) to ensure high fairness amongst resulting pairs regarding their channel-correlation coefficients. The proposed UGA demonstrates superior fairness compared to existing UGAs.

1 | INTRODUCTION

Throughout the last decade, the telecommunication industry requires to provide services to new type of users maybe using home automation, industrial internet, smart grids etc. [1]. All these services constitute to Internet of Things (IoT) using which interconnection of millions of devices is possible, which requires reliable, real time better quality of service(QoS) data transfer [2, 3]. This sets the requirement for network performances such as massive-connectivity (i.e. ultra-high density), ultra-reliable (high throughput and high fairness), ultra-low latency, as well as ubiquity (i.e. seamless and large geographical coverage) [4, 5]. These requirements do not seem achievable by the 4G networks currently employed across the globe, as 4G has limitations in supporting these services [6, 7]. For this reason, the international telecommunication union (ITU) has developed standards for the next generation(5G) of wireless regional area networks (WRANs), which should be capable of supporting these services. Some of the 5G performance standards include achieving: i) a minimum connectivity density of 10^6 connections/km^2, ii) an ultra-low end-to-end latency of maximum 1 ms, iii) a user-experienced data rate of 100 Mbps and a peak user data rate of about 10 Gbps; as well as, iv) ultra-high reliability and seamless for all users [8, 9]. As can be seen, achieving high capacity and high reliability to all users (i.e. high users' fairness) are two critical requirements of 5G networks.

In the race to develop networks that meet the 5G requirements, some possible technologies that are considered as a key enabler of 5G network development have already been proposed. These include the NOMA technology, multi-users multiple-input multiple-output (MU-MIMO) technology, as well as the satellite technology as the access-point component to allow ubiquitous coverage [10–12]. Thus, in the field of mobile network development, researchers are currently trending toward developing mobile networks that employ NOMA, MIMO and the satellite to achieve 5G networks. These types of mobile networks are commonly referred to as NOMA-based multi-beam satellite networks (NOMA-MBSNs). In NOMA technology, more than 1-user are served simultaneously by the same antenna while reusing the same frequency, forming what is known as a NOMA beam. As such, NOMA provides increased system capacity and reliability to users; compared to the traditional OMA. Similarly, in the MU-MIMO technology, the access-point is equipped with multiple antennas to serve multiple users simultaneaously. Each antennas reuses the entire frequency spectrum of the access-point to serve its designated user terminal(s). This results in a massive increase of both, the achievable network's capacity, as well as the service reliability to users; when compared to previous networks not employing MU-MIMO. The satellite technology, in turn, allows a wider coverage, compared to terrestrial network; thus, facilitating the achievement of ubiquitous networks. Consequently, a combination of the thee technologies in a network produces a massive network capacity, enhanced service reliability to all users (i.e. increased network's users-fairness), as well as network ubiquity. Thus, such a network delivers the required performance of 5G networks.

Due to serving multiple users in the same beam, to implement a NOMA-based MBSN, a users' grouping algorithm (UGA) is required, in order to group users in NOMA beams. There are two critical design requirements that a UGA must meet, for a NOMA-MBSN. These include: (i) Users who share the same NOMA beam must satisfy a minimum channel-gain margin (C_{gm}) between them to successfully execute the NOMA protocol at the receiver [13, 14]. (ii) These users must also have high channel-correlation coefficient (C_3) between them, in order to optimally mitigate high Inter-Channel-Interference (ICI) due to MIMO technology [15, 16]. Furthermore, limiting to these two requirements could lead to having UGAs that favour the system's capacity maximization, with little regard to the users' fairness of the system. Therefore, in the network's design for high user fairness, a third critical design requirement for UGA is introduced; which is that: (iii) we should not have some groups with very high channel correlation while others have very poor channel correlation; which means that the grouping process should exhibit high fairness across the generated groups, with respect to channel-correlations. A UGA that satisfies these three requirements simultaneously will provide enhanced fairness to the proposed network. If requirement (i) is not met, the successive-interference Cancellation (SIC) will become very difficult at the receiver; making the NOMA process non-implementable. Thus, the increased user-fairness provided by the use of NOMA technology over OMA, will be loss. For the requirement (ii), it must be noted that, only the channel-vector of one user in a beam is used to determine the precoding-weight vector that will be used by all the beam's users; in order for each of them to mitigate the excessive inter-channel interference (ICI) from other beams. So, if requirement (ii) is not met, some users within a given beam will achieve very poor capacity; because, they will not be able to cancel these ICIs by means of the precoding weight-vector used for this particular beam. Subsequently, having some users achieving very poor capacities while others achieve very good capacities, implies a poor users' fairness of the system. The requirement (iii) is an extension of requirement (ii); but at inter-beam level. Basically, we do not want a scenario where, users in some beams have extremely high channel-correlation, while users in other beams have extremely poor correlation. This will favour that only users in some beams achieve good capacity while those in other beams achieve extremely poor capacity. The consequence of this will be a reduced users' fairness of the system. Thus, satisfying requirement (iii) implies that, we try to ensure all beams have relatively good channel-correlations; so that all users in respective beams can achieve relatively good capacity, which subsequently result in improved users' fairness of the system.

This paper will limit itself to investigating UGA for the case of 2-users per NOMA-beam in a MBSN, which we call "2-users NOMA-MBSN". Only a few authors have proposed a UGA for a 2-user NOMA-MBSN. Authors in ref. [15] proposed a UGA based on minimum-Euclidian-norm (*MEN*) technique. The proposed algorithm meets requirement (ii) but with not much considerations of requirements (i) and (iii). Authors in ref. [17] proposed a UGA based on Geographical user's clustering (GUC) technique. This algorithm also meets requirement (ii), but with not much considerations of requirements (i) and (iii). Authors in ref. [18] presented a UGA in which they consider both maximum channel-correlation and channel-gain margin. This algorithm ensures that requirements (i) and (ii) are met; but without considering fairness during pairing, i.e. requirement (iii). Similar to ref. [18], authors in ref. [19] presented a UGA in which they consider both maximum channel correlation and channel-gain margin between users. But yet again, there was not much consideration ensuring fairness between resulting pairs. Therefore, this algorithm also meets requirements (i) and (ii); but without much consideration of requirement (iii). Authors in ref. [20] proposed an optimal User pairing study for downlink non-orthogonal multiple access, which is based on first obtaining the power-allocation, then analyse the pairing problem. While this study may address the requirement of channel-gain margin between users in same pair (i.e. requirement (i)), it does not however, look into addressing requirement (ii) and (iii). In turn, authors in ref. [21] proposed an intuitive UGA which is based on the K-means grouping method. This algorithms seems to ensure that some groups are not marinalized in terms of resulting channel correlation coefficient; thus ensuring both, high channel-correlation and fairness. However, it does not tackle the requirement (i). Finally, authors in ref. [22] proposed a UGA that considers maximum channel correlation and fair grouping. But, there was no specific attention to ensure that all resulting pairs satisfy a minimum channel-gain margin. Therefore, this algorithm ensures that requirements (ii) and (iii) are met; but not much consideration of requirement (i). Thus, to the author's knowledge, no work has proposed a UGA that satisfies all three conditions (i, ii, & iii) for a 2-user NOMA-MBSN. Therefore, this paper suggests closing this gap by providing a UGA that meets all three requirements; and enhances the users' system fairness. The contribution of this paper includes:

- We split the 2 M users into a set of M far-users and M near-users based on the users' channel gains.

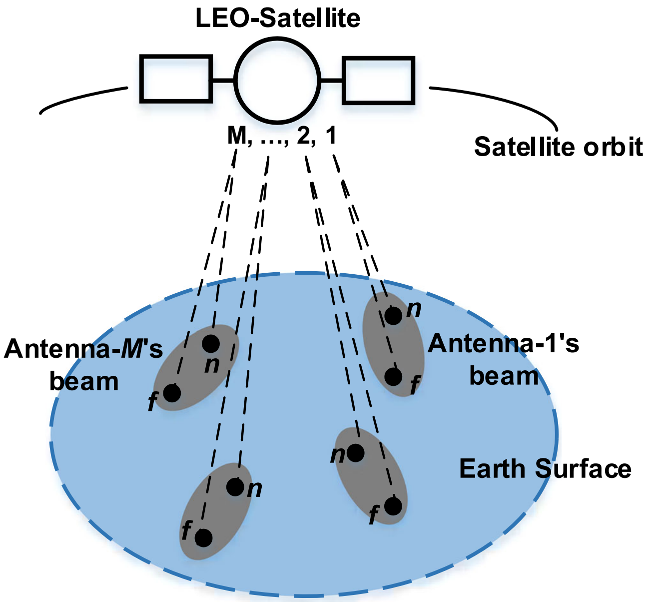

FIGURE 1 Geo-spatial illustration of a 2-users NOMA MBSN (adapted from ref. [6])

- We aim to pair near- and far-users with high C_3, so we formulate the pairing problem as a maximization Hungarian-matrix problem of C_3 between the two sets.
- We introduce restrictions in the original matrix for pairs that do not meet the minimum C_{gm}.
- We solve the restricted Hungarian matrix problem by means of the restricted Hungarian-Method, to ensure fairness amongst the resulting pairs in terms of their C3s. In so doing, the proposed UGA will meet all three requirements.
- In imperfect matching, we iteratively reduce the minimum C_{gm} defined until the restricted Hungarian method provides perfect matching.

The rest of this paper is organised as follows: 1) system description and modelling of "C_3 and C_{gm}"; 2) UGA design process and resulting UGA; 3) UGA implementation and results; 4) conclusion.

2 | SYSTEM DESCRIPTION AND MODELLING

The network consists of an Earth-orbiting satellite used to provide network coverage to mobile users distributed on the ground. The satellite is equipped with M-antennas pointing to the ground and forming M distinct beams on the earth's surface, while each user-terminal is equipped with a single antenna. Each satellite antenna is reusing the entire frequency band, thus resulting in a multi-user MIMO system; or, otherwise, a multi-beam satellite network (MBSN). By means of NOMA technology, each satellite's antenna will be serving two users; which results in a 2users NOMA-MBSN, as illustrated in Figure 1 below. The total capacity of the network is 2 M users. Figure 2 below illustrates the channel link between each user

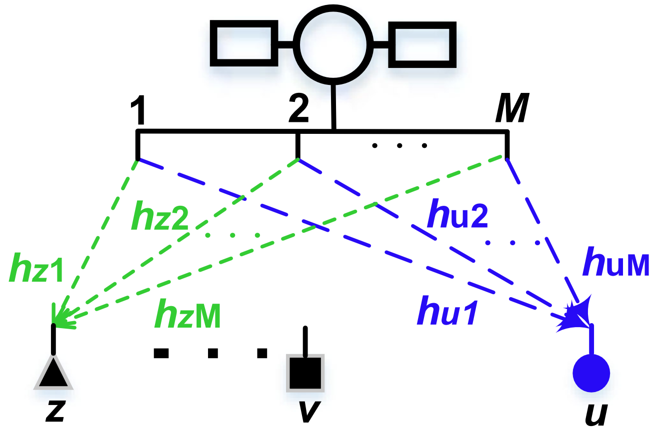

FIGURE 2 Illustration of the channel link between the satellite and users in an MBSN

on the ground and the respective M-antennas on the satellite. Thus, the channel vector of each ground user (u) observed on the satellite can be expressed as:

$$h_u = \begin{bmatrix} h_{u1} \\ h_{u2} \\ \cdots \\ h_{uM} \end{bmatrix} \quad (1)$$

Furthermore, considering that any users (u) and (v) on the ground will have channel vectors (h_u) and (h_v), respectively, the C_3 between the two users can be expressed as:

$$C_3(u, v) = \text{Real}\left(\frac{h_u^H \times h_v}{\|h_u\| \times \|h_v\|}\right) \quad (2)$$

Similarly, the C_{gm} between the two users can be expressed as in Equation (3) or expressed in the form of a channel-gain ratio (C_{gr}) as in Equation (4).

$$C_{gm} = \|h_u\| - \|h_v\| \quad (3)$$

$$C_{gr} = \|h_u\| \,/\, \|h_v\| \quad (4)$$

This work considers that there will be two users per antenna beam (b). One with a better channel condition, referred to as near-user (NU_b), with channel-vector (h_{bn}); and the other one with poorer channel condition, referred to as far-user (FU_b), with channel-vector (h_{bf}). Thus, the C_3 and C_{gr} between the near-user and far-user in a given antenna beam "b", $b = 1, \ldots, M$; can be expressed as:

$$C_3(NU_b, FU_b) = \text{Real}\left(\frac{h_{bn}^H \times h_{bf}}{\|h_{bn}\| \times \left\|h_{bf}\right\|}\right) \quad (5)$$

$$C_{gr}(NU_b, FU_b) = \|h_{bn}\| \,/\, \left\|h_{bf}\right\| \quad (6)$$

Note that, it is assumed in this work that; the satellite has good knowledge of the channel vectors of all the 2 M users at the time of servicing them. Also, in the rest of this study, the C_{gr} will be used in-lieu of the C_{gm}, to express the comparison between the channel-gains of the two users (near and far) in each beam.

3 | USERS' GROUPING ALGORITHM DESIGN

The concept commonly employed for users' grouping in a 2 users-NOMA network is a two-stage process, which implies: (A) to split users into two sets, namely near-users and far-users' sets, based on their respective channel-gains; then, (B) to formulate pairs of far-near users based on channel-correlation coefficients between far users and near users [15, 17–19, 22]. Thus, in this work, to group 2 M users into M-pairs and obtain a set of pairs that satisfies all three requirements (i, ii, and iii) outlined in Section 1 above, we implement the above concept in 5 steps, as follows:

- Step 1: Split the 2 M users into a set of M-near and a set of M-far users; based on the users' channel gains.
- Step 2: Formulate the pairing problem as a channel-correlations maximization bipartite matching problem (BPMP).
- Step 3: Introduce the requirement (iii) (i.e. fair-pairing) into step-2 above, and solve the BPMP using the Hungarian Method (HM), to meet both, the requirement (ii) and (iii) outlined earlier.
- Step 4: Introduce the requirement (i) (i.e. minimum gain-ratio) into the BPMP formulated in step 2″, to yield a "restricted BPMP"; and solve it using restricted-HM.
- Step 5: Introduce the "iteration" of step 4 above; and adjust the "minimum gain-ratio" initially define, until perfect matching is obtained.

3.1 | Step1: splitting the 2 *M*-users into 2 subsets of *M*-users

Since the channel vectors of all the 2 M users are known, we first calculate their respective channel gains. Then we sort them in increasing order. After that, the highest M-gains form the near-users set (NU_1, …, NU_M); while the lowest M-gains make the far-users set (FU_1, …, $\mathrm{FU_M}$).

3.2 | Step2: formulate the users-pairing problem as a bipartite matching problem

After obtaining the set of M-far and M-near users, the aim is to formulate pairs of near and far users with a high C_3. Since one near-user can only be grouped with one far-user, the pairing process becomes a bipartite matching problem (BPMP) of far-

TABLE 1 Illustration of the Hungarian matrix of near-far users' channel-correlation coefficients (C_3)

	$\mathbf{NU_1}$	$\mathbf{NU_2}$	…	$\mathbf{NU_M}$
$\mathrm{FU_1}$	$C_3(\mathrm{NU_1},\mathrm{FU_1})$	…	…	$C_3(\mathrm{NU}_M,\mathrm{FU_1})$
$\mathrm{FU_2}$	…	…		
…	…		…	…
$\mathrm{FU_M}$	$C_3(\mathrm{NU_1},\mathrm{FU_M})$		…	$C_3(\mathrm{NU_M},\mathrm{FU_M})$

and near-users, to maximize the total channel correlation [7, 23]. This optimisation problem (P) can be formulated as:

$$P:\ max\left(\sum_{b=1}^{M} C_3(NU_b, FU_b)\right), \tag{7a}$$

$$\text{s.t. } \mathrm{C_3}\ (\mathrm{NU_b}, \mathrm{FU_b}) \geq \xi; \tag{7b}$$

Where, "ξ" is the minimum C_3 defined.

A few different techniques can be used to solve BPMPs and yield a desired set of pairs, but the outcome is generally influenced by the conditions set. Ideally, if no conditions or restrictions are put between some users of NU-set and FU-set, the pairing process should yield a maximum matching of M-pairs. That is known as perfect-matching [24] and is illustrated by Figure 3(a) below for the case of $M = 4$ antennas. However, if some restrictions are put between users, the paring process could result in a certain number of maximum matching pairs (K), which is less than M. This will mean that some users have not been matched, and is known as imperfect matching [25]. This case is illustrated by Figure 3(b).

3.3 | Step3: solve the BPMB using the HM

If the formulated C_3-maximization BPMP is solved using any arbitrary technique, we could result in a set of M-pairs in which some pairs have excellent C_3, while others have extremely poor C_3. But, such a situation is not acceptable in this application. Because, one of the design requirements for this algorithm is to ensure high fairness between the resulting pairs, in terms of their respective C_3; that is, to avoid having some pairs with extremely high correlations, while others have extremely poor correlations (i.e. requirement "iii"). Therefore, we opt to employ the Hungarian-method (HM) to achieve this high fairness to solve the formulated BPMB. The Hungarian-method is a widely used technique for providing optimal solutions to "maximization-BPMP" (or bipartite graph), while simultaneously ensuring fairness amongst the resulting pairs [26, 27].

To solve our C_3-maximization BPMB using the HM, we generate a Hungarian matrix by calculating the C_3 between all far-and near-users, as illustrated in Table 1 below. Once the matrix is generated, the HM can then be executed.

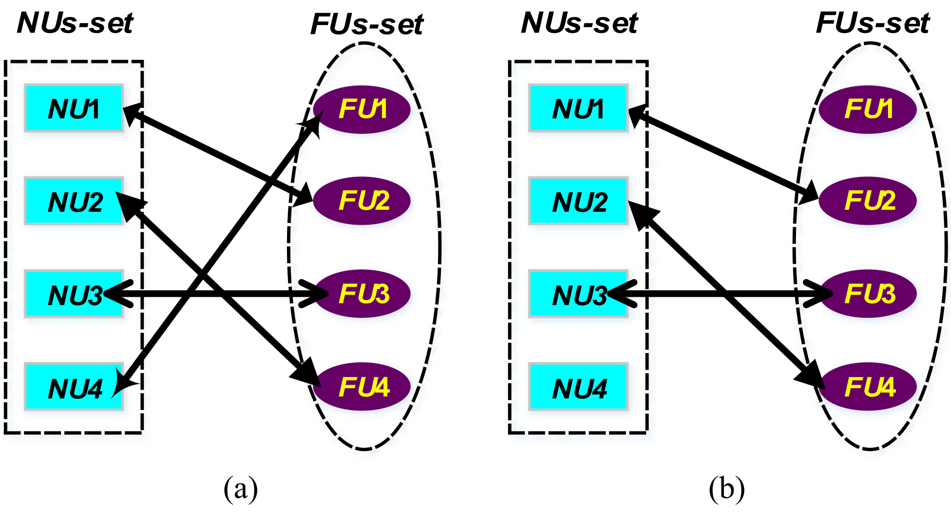

FIGURE 3 Illustration of possible outcomes to the BPMP: (a) perfect matching, (b) maximum (imperfect) matching

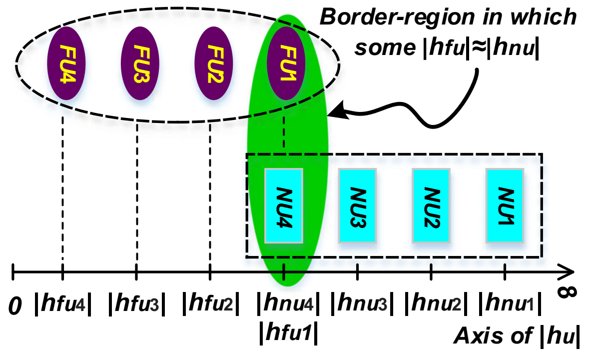

FIGURE 4 Illustration of the border region for far- and near-users' channel-gains

3.4 | Step4: formulate a restricted-BPMB and solve it using the restricted-HM

If the Hungarian matrix formulated in "step-3″" above is solved as it is, without restrictions, we could get scenarios where the highest gain in the far-users set is paired with the lowest gain in the near-user set; while the C_{gr} between the two users is not big enough to satisfy a good NOMA implementation (i.e. requirement "i"). This is illustrated in Figure 4 below. To avoid having this scenario, we introduce into the requirement (i) into the original Hungarian-matrix; that is, the a minimum channel-gain ratio ($C_{\text{gr-min}}$) must be satisfied between far- and near-users that can be paired. Consequently, in the original Hungarian matrix, we restrict all possible far-near users' combinations that do not meet this $C_{\text{gr-min}}$. Thus, we turn the original BPMP into a restricted BPMB, which is solved by the restricted HM thereafter.

3.5 | Step5: introduce the iteration in the pairing process

Generally, when the minimum C_{gr} initially defined (i.e. $C_{\text{gr\_min}}(\text{init})$ is relatively high, this often results in a lot of restricted (FU, NU)-pairs; and subsequently leads to a high probability of having an imperfect-matching outcome from the restricted-HM process. Thus, if such a case arises, we propose reducing the minimum Cgr initially defined and re-executing the restricted-HM process. This will be repeated iteratively until perfect matching is obtained. The decrement step for the $C_{\text{gr\_min}}$ is calculated as:

$$\text{dec\_step} = \frac{C_{gr-min}(\text{init}) - 1}{I_{max}} \tag{8}$$

Where, $I_{\max}$ is the defined maximum number of acceptable iteration. Thus, when imperfect matching is obtained, the new $C_{\text{gr-min}}$ is determined as:

$$C_{gr-min}(\text{new}) = C_{gr-min}(\text{cur}) - \text{dec\_step} \tag{9}$$

$C_{\text{gr-min}}(\text{cur})$ *is* the current $C_{\text{gr-min}}$ at the time of calculating the decrement, and $C_{\text{gr-min}}(\text{new})$ is the new $C_{\text{gr-min}}$ to be used for the next iteration of the restricted HM.

3.6 | Resulting UGA

Considering all the 5 steps discussed above, the proposed users' grouping algorithm for 2-users NOMA-MBSNs, is outlined in Table 2.

4 | TESTING AND DISCUSSION

4.1 | Test setup

To test the proposed algorithm, the network assumptions and specifications listed in Table 3 below were considered.

Since the network's capacity is 2 M users at a given service time slot, we randomly distributed a population of 10 times 2 M users across the network's coverage, from which we then arbitrarily select the 2 M users to serve at a given time slot. The channel vectors of these 2 M users were thereafter, fed to our

TABLE 2 Proposed users' grouping algorithm for 2-users NOMA-MBSNs

Proposed NOMA users' grouping algorithm (UGA) for 2-users NOMA-based MBSNs

Steps	Lines	Actions
Step0:		Initial parameters specification:
(a)	1:	Define M, $C_{gr\text{-}min}$(init), I_{max},
(b)	2:	Calculate $\lvert h_u \rvert$ of each user by evaluating the norm of its channel-vector "h_u,"
Step1:		Split the $2M$-users into 2-subsets of M-users based on their channel gains:
(a)	3:	Classify the users' channel gains from step 1-b, in ascending order;
(b)	4:	Make highest M-channel-gains = (NUs-set); and lowest M-channel-gains = (FUs-set).
Step2&3:		Generate the Hungarian-matrix of C_3(NU, FU):
(a)	5:	Calculate C_3(NU, FU) between every FU and NU, as in (2);
(b)	6:	Then fill the Hungarian-matrix of C_3(NU, FU), as illustrated in Table 1;
(c)	7:	Then discard pairs that have negative channel-correlation coefficients.
Repeat		Repeat:
Step4: A		Execute the restricted-Hungarian-matrix processing
A		Generate the restricted-Hungarian-matrix based on the $C_{gr\text{-}min}$ specified:
(a)	8:	Calculate the C_{gr}(NU, FU) between each NU and FU as in Equation (6); then
(b)	9:	Compare each C_{gr}(NU, FU) calculated to $C_{gr\text{-}min}$; then
(c)	10:	Discard pairs in the Hungarian matrix from "Step 3" for which C_{gr}(NU, FU) $< C_{gr\text{-}min}$.
B		Execute the restricted-HM on the Hungarian matrix from "step4-A".
(a)	11:	Call the restricted-HM Function;
(b)	12:	Obtain the resulting K-pairs
Step5:		Terminate the user-grouping process or reiterate Step4:
(a)	13:	Check for perfect matching by comparing K and M;
(b)	14:	If $K = M$: exit "repeat" = > perfect-matching;
(c)	15:	Else if $K < M$, i.e. = > imperfect-matching:
	16:	Calculate "dec-step" as in Equation (8); then,
	17:	Calculate the new $C_{gr\text{-}min}$ as in Equation (9); then
	18:	Return to Step-4.
Until		Until: perfect-matching is obtained
Step6:		Store final outcome (i.e. resulting M-pairs).

TABLE 3 Multibeam satellite network's parameters specification

Parameter	Specification
Access-point	LEO satellite
Satellite's altitude	Height = 1000 km
Maximum network's ground-coverage	d_{max} = 1000 km from center-beam
Angle-of-arrival span	$-\pi$,$+\pi$, with respect to centre-beam's axis
No of satellite's antennas	$M = 4$ (multi-cast)
Frequency reuse	Full (FFR)
Freq. of operation	F_c = 20 GHz (Ka band)
Channel bandwidth	BW = 500 MHz,
Gain satellite's antenna	G_{tx} = 50 dBi,
No of antennas at the user	1
Gain of user's antenna	G_{rx} = 0 dBi,
Multiple-access technology	NOMA (PD)
No of users per NOMA-beam	r = 2,
Total power-on satellite	$P_{tot\text{-}sat}$ = 60 W (48 dBm),
Maximal antenna's power	$P_{b\text{-}max}$ = 20 W (43 dBm)
K and No	K = 290 Kelvin, No = −174 dBm/Hz

TABLE 4 Channel vectors of the selected 8 users to be served

h_1	h_2	h_3	h_4
+0.006 + 0.041i	+0.014 − 0.0148i	−0.000 + 0.012i	+0.028 − 0.048i
−0.008 + 0.040i	+0.010 − 0.0174i	−0.005 + 0.011i	+0.015 − 0.054i
−0.037 − 0.016i	−0.009 − 0.0184i	−0.008 − 0.009i	−0.047 − 0.029i
+0.024 − 0.033i	−0.020 − 0.0021i	+0.012 − 0.003i	−0.042 + 0.037i
h_5	**h_6**	**h_7**	**h_8**
+0.041 + 0.023i	+0.030 + 0.034i	+0.008 + 0.001i	+0.006 + 0.010i
+0.038 + 0.028i	+0.022 + 0.039i	+0.008 + 0.001i	+0.003 + 0.011i
+0.013 + 0.045i	−0.024 + 0.038i	+0.008 + 0.002i	−0.010 + 0.006i
−0.017 + 0.044i	−0.045 − 0.002i	+0.007 + 0.004i	−0.008 − 0.008i

proposed UGA; to generate the desired pairs. To calculate the respective channel vectors of the 2 M users, the Frii's equation was used for the path loss, the log-normal model was used for the shadowing; and the Rician model was used for the multipath fading, which best describes the multipath fading of a satellite-to-earth link [28–30].

4.2 | Test results for the case of 4 satellite antennas

For the case of $M = 4$ satellite's antennas, there are 8 users to be served; and, therefore, to be grouped into 4 pairs by the UGA. Table 4 below lists the respective channel vectors of the 8 users. For the purpose of simulation, in the scenario presented in this study (a Satellite-to-Earth link), channel-vectors (CSI) of respective users were estimated by means of existing analytical channel

TABLE 5 The restricted Hungarian matrix of far-near users' C_3, for case of $M = 4$, with the 4 generated pairs highlighted

FU\NU	3	7	4	6
8	0.8631	0.1428	0	0.3223
1	0.4510	0.2075	0	0.9085
5	0.2058	0.3714	0.8943	0.6413
2	0.2016	0.6178	0	0.1554

TABLE 6 The channel-gain ratios (C_{gr}) of the 4 generated pairs

Pair No	[NU-FU]	$\lvert h_{nu}\rvert$	$\lvert h_{fu}\rvert$	Cgr = $\lvert h_{nu}\rvert / \lvert h_{fu}\rvert$	Cgr-min
1	[3-8]	0.1126	0.0410	2.7470	1.5
2	[6-1]	0.0831	0.0256	3.2455	
3	[7-2]	0.0954	0.0170	5.6025	
4	[4-5]	0.0912	0.0243	3.7512	

TABLE 7 The channel-correlation coefficients (C_3) of the 4 generated pairs

Pair No	[NU-FU]	Channel-correlation coefficient (C_3)	Jain's FM of C_3-s
1	[3-8]	0.8634	0.9796
2	[6-1]	0.9085	
3	[7-2]	0.6178	
4	[4-5]	0.8943	

models, after assuming the distance and angle-of-arrival of each user with-respect-to the access-point (i.e. the satellite). In this regard, the following models were used to obtain each channel vector: the Frii's free-space model (for the path-loss), the log-normal model (for the shadowing), and the Rician model (for the multipath fading); and the distance as well as AoA of each user were randomly defined within the boundaries specified in the Table 3 above. These channel vectors were thereafter fed to the proposed UGA, which executed and generated the 4 pairs desired. Table 5 shows the restricted Hungarian matrix of channel-correlation coefficients (C_3) between far and near users; and highlights the generated pairs by the UGA. Table 6 displays the respective channel-gain ratios (C_{gr}) of the generated pairs, as well as the minimum channel-gain ratio ($C_{gr\text{-}min}$) defined. Table 7 shows the respective C_3 of the generated pairs; as well as Jain's fairness index of the UGA, based on the C_3-s of generated pairs. Figure 5 below finally illustrates the respective beams of 4 generated pairs, within the network coverage.

Observing Table 6, it can be seen that the C_{gr} of each generated pair is all greater than the $C_{gr\text{-}min}$ defined (i.e. 1.5); which indicates that the UGA satisfies the requirement (i). Also, Table 7 shows that the C_3 of each generated pair is relatively high (>0.6), which indicates that the UGA satisfies requirement (ii). Lastly, Table 7 also shows that the resulting fairness metric of the UGA is extremely high (0.9796); which indicates that the UGA ensures high fairness amongst generated pairs; and thus satisfies requirement (iii). In sum, the proposed UGA satisfies all three design requirements (i, ii, and iii), for the case of 4-antennas on the satellites.

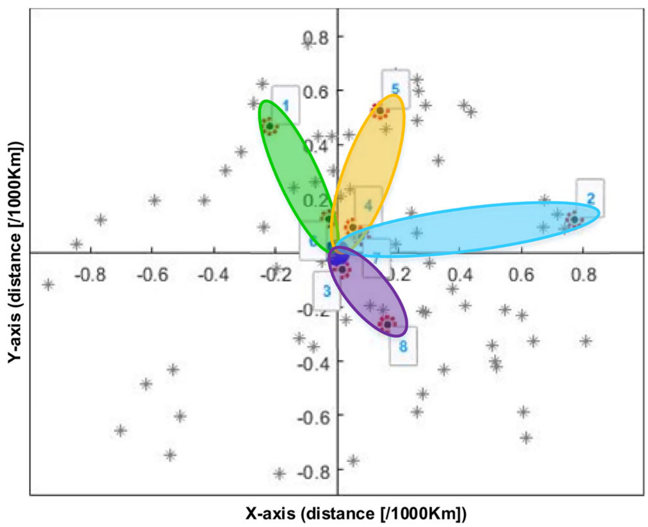

FIGURE 5 Highlight of the 4 generated pairs on the top-view of Network's spatial distribution

After satisfaction of the results from the UGA, for the case of 4-antennas, the UGA was tested for different satellite antennas at the time. The results summarised below are for the case of $M = 5$ and $M = 6$, respectively. For the case of $M = 5$, Table 8 lists the respective channel vectors of the 10 users to be served. These channel vectors were fed to the proposed UGA, which executed and generated the 5 pairs desired. Table 9 below shows the restricted Hungarian matrix of C_3 between far and near users, produced from the users' channel vectors. It also highlights the 5 generated pairs by the UGA. Table 10 then lists the C_{gr} of each pair; while Table 11 lists the C_3 of each pair and the resulting Jain's fairness metric (FM) of the UGA. Finally, Figure 6 illustrates the beams for these respective pairs within the network coverage. Looking into Table 10, the C_{gr} of each pair is greater than the defined $C_{gr\text{-}min}$ (i.e. 1.5). Also, looking at Table 11, all the pairs have a relatively high C_3 (>0.6), and the resulting Jain's fairness metric is very high (0.9572). Thus, for the case of 5-antennas, the UGA still satisfies all three design requirements (i, ii, and iii) set. Similarly, for the case of $M = 6$, Table 12 below lists the respective channel vectors of the 12 users to be served. These channel vectors were fed to the proposed UGA, which executed and generated the 6 pairs desired. Table 13 shows the restricted Hungarian matrix of C_3 between far and near users, produced using the users' channel vectors. It also highlights the generated pairs by the UGA. Table 14 then lists the C_{gr} of each pair; while Table 15 lists the C_3 of each pair and the resulting Jain's fairness metric (FM) of the UGA. Finally, Figure 7 below illustrates the beams for these respective pairs within the network coverage. Looking into Table 14, the C_{gr} of each pair is still greater than the defined $C_{gr\text{-}min}$ (i.e. 1.5). Also, looking at Table 15, all the pairs still have a relatively high C_3

TABLE 8 Channel vectors of the selected 10-users to be served

h_1	h_2	h_3	h_4	h_5
0.010+0.003i	−0.012−0.027i	0.012−0.007i	+0.041−0.038i	−0.006−0.008i
0.010+0.003i	−0.024−0.018i	0.011−0.009i	+0.033−0.045i	−0.009−0.003i
0.008+0.007i	0.008+0.029i	0.003−0.014i	−0.017−0.053i	0.008+0.005i
0.005+0.009i	0.010−0.028i	−0.006−0.013i	−0.053−0.017i	−0.006−0.008i
0.002+0.011i	−0.025+0.016i	−0.013−0.007i	−0.045+0.033i	0.004+ 0.009i
h_6	h_7	h_8	h_9	h_{10}
0.030+0.034i	0.032+0.018i	−0.012−0.027i	0.006+0.010i	−0.026+0.032i
0.022+0.040i	0.029+0.022i	−0.024−0.018i	0.003+0.012i	−0.039+0.013i
−0.024+0.038i	0.010+0.035i	0.008+0.029i	−0.010+0.006i	0.033−0.024i
−0.045−0.002i	−0.013+0.034i	0.0108−0.028i	−0.008−0.008i	−0.024+0.033i
−0.020−0.040i	−0.032+0.019i	−0.025+0.016i	0.006−0.010i	0.0128−0.039i

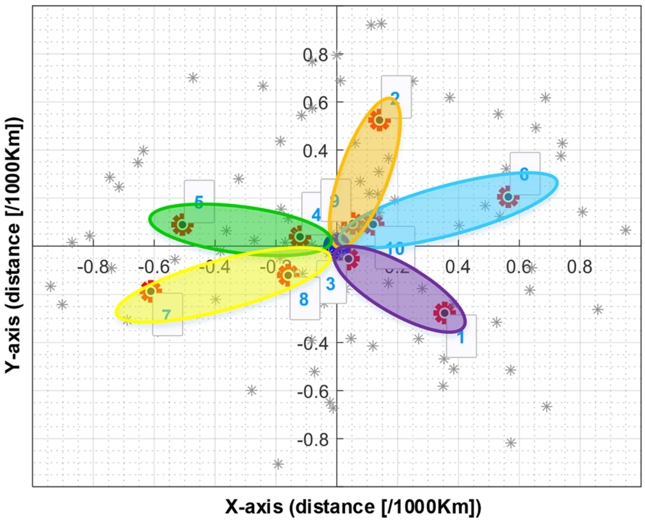

FIGURE 6 Highlight of the 5 generated pairs on the top-view of network's spatial distribution

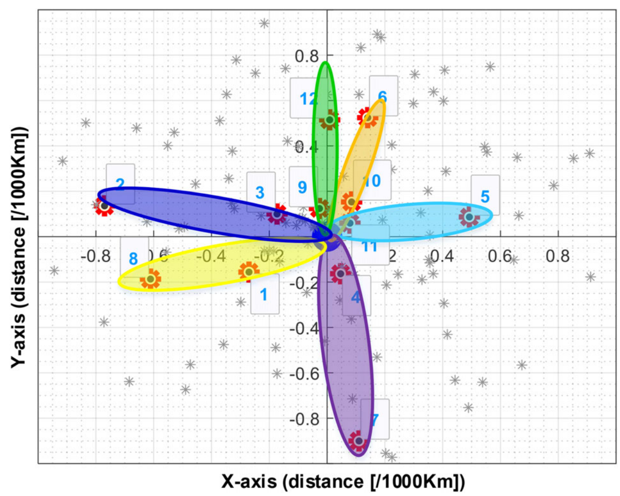

FIGURE 7 Highlight of the 6 generated pairs on the top-view of network's spatial distribution

TABLE 9 The restricted Hungarian-matrix of far-near users' C_3, for case of $M = 5$, with the 5 generated pairs, highlighted

FU∖NU	3	9	4	10	8
1	0.7784	0	0.2879	0	0
5	0.4026	0	0.9424	0.2494	0.2981
2	0.2176	0.8273	0	0.1206	0.4035
6	0	0	0.0621	0.7522	0.2060
7	0	0.4026	0	0.2879	0.6681

TABLE 10 The channel-gain ratios (C_{gr}) of the 5 generated pairs

Pair No	[NU-FU]	$\lvert h_{nu} \rvert$	$\lvert h_{fu} \rvert$	Cgr = $\lvert h_{nu} \rvert / \lvert h_{fu} \rvert$	Cgr-min
1	[3-1]	0.1258	0.0326	3.8650	1.5
2	[10-6]	0.0833	0.0247	3.3741	
3	[8-7]	0.0671	0.0232	2.8925	
4	[4-5]	0.0929	0.0286	3.2455	
5	[9-2]	0.1020	0.0272	3.7512	

TABLE 11 The C_3 of the 5 generated pairs

Pair No	[NU-FU]	Channel-correlation coefficient (C_3)	Jain's FM of C_3-s
1	[3-1]	0.7784	0.9572
2	[10-6]	0.7522	
3	[8-7]	0.6681	
4	[4-5]	0.9414	
5	[9-2]	0.8273	

(>0.5), and the resulting Jain's fairness metric is still very high (0.9080). Thus, for the case of 6-antennas, the UGA still satisfies all three design requirements (i, ii, and iii) set. In sum, all these results indicate that the proposed UGA satisfies all three design

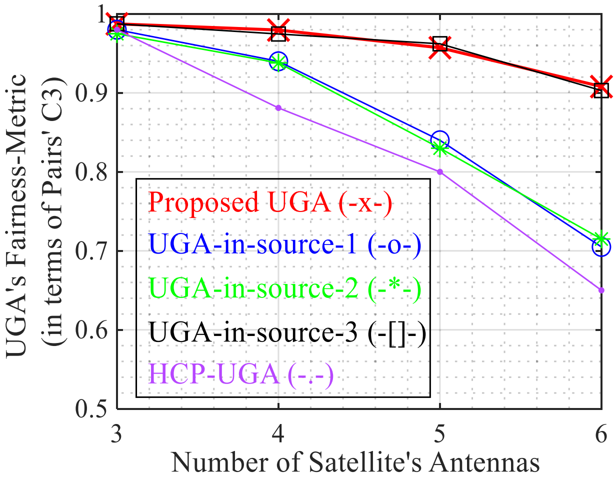

FIGURE 8 Fairness-metrics of various users-grouping algorithms for different number of satellite's antennas

requirements of 2-users NOMA-MBSN for different numbers of satellite antennas.

Following the satisfaction of results from the proposed UGA for different numbers of antennas, its fairness performance was compared to that of some existing UGAs for 2-users NOMA Multicast networks. These include: (A) the UGA called "Algorithm" in ref. [19], which we called here "UGA-in-source-1″;" (B) the UGA called "Algorithm-1″" in ref. [18], which we call here "UGA-in-source-2″;" (C) the UGA called "Algorithm-2″" in ref. [22], which we call here "UGA-in-source-3″;" and (D) a UGA that automatically put together far and near users with highest C_3, which we called here "HCP-UGA". While using the same set of users' channel-vectors for each UGA, the fairness metrics obtained from each UGA for different antennas are displayed in Figure 8 below. The results demonstrate that our proposed UGA outshines other UGAs in terms of resulting fairness amongst generated pairs. They further indicate that, the "proposed-UGA" and the "UGA-in-source-3″" present similar performance in terms of fairness. This is because both algorithms employ the Hungarian-method to solve the pairing problem. But, the superiority of the "proposed-UGA" is that, it avoids the problem of pairing near and far users whose channel-gains are very close to each other's, as illustrated by Figure 3 above; and which subsequently will not implement NOMA protocol satisfactorily. This problem is not

TABLE 13 The restricted Hungarian matrix of far-near users' C_3, for case of $M = 6$, with the 6 generated pairs highlighted

FU\NU	11	9	4	10	3	1
5	0.5581	0.0285	0.1031	0	0	0
12	0	0.7787	0	0.2218	0	0
6	0	0.2581	0	0.7464	0.1086	0
8	0	0	0.0621	0	0	0.7787
2	0	0.0497	0	0	0.5278	0
7	0	0	0.8897	0	0	0.0379

TABLE 14 The channel-gain ratios (C_{gr}) of the 6 generated pairs

Pair No	[NU-FU]	$\|h_{nu}\|$	$\|h_{fu}\|$	Cgr = $\|h_{nu}\|$ / $\|h_{fu}\|$	Cgr-min
1	[11-5]	0.1168	0.0322	3.6236	1.5
2	[10-6]	0.0816	0.0298	2.7393	
3	[4-7]	0.0834	0.0180	4.6265	
4	[9-12]	0.1017	0.0313	3.2455	
5	[1-8]	0.0502	0.0254	1.9741	
6	[3-2]	0.0735	0.0209	3.5257	

TABLE 12 Channel vectors of the selected 12 users to be served

h_1	h_2	h_3	h_4	h_5	h_6
0.006+0.010i	0.041+0.023i	0.013+0.002i	−0.015+0.026i	0.003−0.006i	0.006+0.041i
0.003+0.012i	0.038+0.028i	0.013+0.002i	−0.026+0.015i	0.001−0.007i	−0.008+0.040i
−0.010+0.006i	0.013+0.046i	0.012+0.004i	0.015−0.026i	−0.007−0.002i	−0.038−0.017i
−0.008+0.08i	−0.017+0.044i	0.011+0.006i	0.000+0.030i	−0.002+0.007i	0.024−0.033i
0.006−0.010i	−0.040+0.025i	0.010+0.008i	−0.015−0.026i	0.006+0.003i	0.028+0.031i
0.012+0.003i	−0.047−0.004i	0.008+0.010i	0.026+0.015i	0.004−0.006i	−0.036+0.021i

h_7	h_8	h_9	h_{10}	h_{11}	h_{12}
0.004+0.012i	0.022+0.025i	−0.006+0.006i	0.017−0.029i	−0.010−0.017i	−0.006−0.008i
0.000+0.013i	0.016+0.029i	−0.008+0.001i	0.009−0.032i	−0.017−0.010i	−0.010−0.003i
−0.013+0.000i	−0.018+0.028i	0.008−0.003i	−0.029−0.018i	0.010+0.017i	0.008+0.006i
−0.001−0.013i	−0.033−0.002i	−0.007+0.004i	−0.025+0.023i	0.000−0.020i	−0.006−0.008i
0.013−0.001i	−0.014−0.030i	0.006−0.005i	0.015+0.030i	−0.010+0.017i	0.004+0.009i
0.001+0.013i	0.019−0.027i	−0.005+0.006i	0.033−0.006i	0.017−0.010i	−0.001−0.010i

TABLE 15 The C_3 of the 6 generated pairs

Pair No	[NU-FU]	Channel-correlation coefficient (C_3)	Jain's FM of C_3-s
1	[11-5]	0.5581	0.9080
2	[10-6]	0.7464	
3	[4-7]	0.8897	
4	[9-12]	0.7787	
5	[1-8]	0.7585	
6	[3-2]	0.5278	

however avoided in the algorithm "UGA-in-source-3″". Thus, our proposed UGA maximises the network's fairness in terms of achiveable capacities of respective users.

5 | CONCLUSION

In this paper, a UGA for a 2-users NOMA-MBSN was proposed. The design goal of the proposed algorithm was to ensure that: (i) all pairs satisfy a minimum channel-gain margin (C_{gm}), expressed in this work in form of channel-gain ratio (C_{gr}); (ii) all pairs have a high channel-correlation coefficient (C_3), and (iii) there is high fairness amongst the pairs in terms of their respective C_3. The performances of the proposed UGA were tested for the different number of satellite's antennas. In each case, the results demonstrated that the algorithm satisfies all three requirements. The results also showed that, the proposed UGA provides superior performance to some existing UGAs, in terms of ensuring fair pairing amongst the resulting pairs, with regard to pair's C_3. Thus, this proposed UGA is a more suitable grouping concept, for applications that aim at maximizing the fairness of 2users-NOMA-MBSNs.

AUTHOR CONTRIBUTIONS

Joel Biyoghe: Conceptualization; Formal analysis; Investigation; Methodology; Validation; Visualization; Writing—original draft; Writing—review & editing. Vipin Balyan: Conceptualization; Formal analysis; Funding acquisition; Project administration; Resources; Software; Supervision; Writing—original draft; Writing—review & editing

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study will be used for ongoing research and is not available.

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How to cite this article: Biyoghe, J., Balyan, V.: Users' grouping algorithm for fairness improvement of NOMA-based multi-beams satellite networks intended for 5G. IET Commun. 17, 1780–1790 (2023). https://doi.org/10.1049/cmu2.12653