Resource Allocation for NOMA Based Space-Terrestrial Satellite Networks

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***Abstract*— Non-orthogonal multiple access (NOMA) has been extensively studied to improve the performance of space-terrestrial satellite networks on account of the shortage of frequency band resources. In this paper, terrestrial network and satellite network synergistically provide complete coverage for ground users. A user association scheme on account of the channel gain and distance between the ground users and the BSs is proposed to identify the users to be associated by the BSs, and there is an upper limit for the number of users associated with each BS. Then calculate the channel condition ratio to select the users served by the satellite. The all BSs provide service for those unselected users, and the NOMA technology is applied to terrestrial network. Then, a user pairing scheme which maximize the minimum the ground user channel correlation coefficient is formulated to match the terrestrial users in a NOMA group. On account of multiple antennas equipped by the BSs and satellite, beamforming is performed among groups of BSs and among satellite users so as to reduce multi-user interference. In the power allocation scheme, we introduce the alternative direction method of multipliers (ADMM) algotithm so as to optimize system energy efficiency. In addition, the objective function is a non-convex function, so the Dinkelbach-style scheme is presented to convert non-convex function into the convex-form function. Eventually, the performance of the presented algorithm is simulated and compared with the existing NOMA-FTPA algorithm. The results indicate that the presented algorithm has high superiority in system energy efficiency and it can be applied to this network.**

***Index Terms*— Energy efficiency, non-orthogonal multiple access, power allocation, alternative direction method of multipliers, space-terrestrial satellite networks.**

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I. Introduction

IN THE wake of the rapid development of the wireless communication technology, the explosive growth of mobile data service demands higher and higher performance of wireless communication system. In the meantime, explosive growth of data traffic has brought enormous challenges to limited spectrum resources [1]. Therefore, the research on new multiple access technologies capable of supporting more users is gaining momentum. In the new multi-access technology research of 5G system, non-orthogonal multiple access (NOMA) technology plays a significant role [2], [3], [8]. It not only meets the needs of spectrum efficiency and number of connections, but also meets heterogeneous requirements of high throughput, low latency and high reliability.

It is the NOMA that is applied to allocate different power to the users based on the user channel quality at the transmitter, which occupies the same time-frequency resource [2], [5]. When NOMA is performed to a single carrier, it is the effective way to realize the spectrum multiplexing that is to apply the power domain [4]. This paper is also based on the above research to apply NOMA technology. The superposition coding is applied at the transmitter while the serial interference cancellation (SIC) [15] technology is applied at the receiver, which is the core technology idea of NOMA. In recent years, many NOMA technologies have been studied in academe and NOMA technology has the following advantages over traditional OMA technology: higher cell edge throughput, lower transmission latency, higher spectral efficiency, and enhanced user fairness. Based on the superiority of NOMA technology, NOMA has become a key technology of current research, especially in order to meet the high spectral efficiency and large connection requirements of future broadband wireless communication technologies [9].

In [16], The downlink NOMA system was considered with only two users, and the system of sum rate maximization problem was studied based on the constraints for the minimum rate requirements of users and the system power of the BSs. On account of the KKT condition for the maximization problem, the optimal power allocation scheme with closed solution was obtained. Under the fixed power allocation, [17] studied the influence of user pairing of single-carrier NOMA system on system performance, and indicated that the larger the difference between the channel conditions for paired users, the higher the capacity of the NOMA system. [10] considered an optimal power allocation scheme based on the MIMO-NOMA transmission system, the total rate maximization algorithm based on MIMO-NOMA for hierarchical transmission was proposed in the case of multiplexing two users. By applying the equal power allocation algorithm among users on each subchannel and comparing with the fractional transmit power allocation (FTPA) algorithm, the performance of the two power allocation algorithms of different system is compared in [11], then the conclusion indicated that applying NOMA are perfectly superior to OFDMA in term of the throughput, latency, fairness and reliability. The authors used DC programming approach to achieve maximization of the energy efficiency and compared with the FTPA algorithm and the equal power allocation algorithm in [5]. And results indicated that proposed algorithm has better performance in the multi-user power allocation.

The above research about the application of NOMA only covers terrestrial networks, however, the satellite plays a significant role in the future communication networks for the vision of building the network that are ubiquitous, in which everything is connected. Because satellites have the advantages of wide coverage, flexible networking, etc, mobile communication can be realized in remote areas, mountainous areas, rivers, seas, and spaces that are not covered by terrestrial networks. At present, according to network function virtualization (NFC), satellites can share the same cloud platform with terrestrial network, so as to coordinate the service provision, spectrum configuration, interference management, user mobility management and other information between them, and realize the collaborative integration of terrestrial network and satellite network to provide services for terminals [18], [34]. Many scholars have studied the space-terrestrial satellite networks [6], [19]and have achieved satisfactory results. In [7], The authors presented the downlink transmission for the NOMA based space-terrestrial satellite networks and applied the Lagrangian multiplier method to formulate a power allocation scheme for two different types of users. By comparing with the distribute suboptimal algorithm and the average power algorithm, the simulation results indicated that the presented algorithm enhance the system capacity. In [19], the authors constructed a terrestrial-satellite networks model, where a satellite and numerous BSs served all users covered, collaboratively. In this model, Lagrange dual method was used to study the power allocation algorithms of terrestrial users and satellite users. Inspired by the authors, in this paper, the space-terrestrial satellite networks model is built, in which satellite as an auxiliary component and terrestrial BSs serve all users under the coverage of the space-terrestrial satellite networks. Then, a power allocation algorithm is designed to resolve the problem of resource allocation and achieve lower delay and higher energy efficiency based on the proposed network.

In addition, some scholars have studied the allocation of space-terrestrial satellite network resources. Numerous subchannel allocation and power allocation algorithms have been applied to the NOMA system [12], [13], in which authors mostly focus on maximizing the system capacity. Communication aiming at energy conservation, emission reduction and consumption reduction has become an inevitable requirement for the sustainable development of the communication industry. This paper is devoted to observing the applicability of resource allocation from the perspective for system energy efficiency. And the maximization of the system energy efficiency for the NOMA based space-terrestrial satellite networks has not been perfectly investigated. In this paper, the architecture based space-terrestrial satellite network for NOMA is investigated, in which both the satellites and BSs provide service for all users covered synergistically, however, NOMA scheme is only performed to terrestrial network. In addition, we investigate the user association scheme and resource allocation algorithms to achieve efficient transmission. Then the main contributions for this paper are described as:

- Firstly, the NOMA framework based on the space-terrestrial satellite networks is established, in which we aim to optimize the system capacity and system energy efficiency. The NOMA scheme is implemented in each group of terrestrial users and satellite network provides extra support for users who exceed the upper limit for users served by BSs. On account of multiple antennas equipped by the BSs and satellite, beamforming is performed among groups of BSs and among satellite users on account of reducing multi-user interference. Then propose an optimization problem for system capacity performance and energy efficiency characteristics, which mainly includes the following three parts: user association, user pairing, BSs and satellites resource allocation scheme.
- A user association scheme is proposed in space-terrestrial satellite networks, in which the channel gain and the distance between the BSs and the user are considered jointly, and there are the maximum number of associations each BS. Then, for user pairing, the channel condition ratio scheme is presented to select satellite users. As far as the terrestrial users are concerned, the maximization of the minimum channel correlation scheme is applied to pair users into groups in order to implementing NOMA. By the bipartite graph, we apply joint hungarian and dichotomy algorithm for terrestrial users pairing.
- On account of optimizing the energy efficiency of the whole system, the suboptimal subchannel allocation algorithm is presented according to the DCA principle. And the power allocation algorithm based on Dinkelbach-style are proposed, in which the Dinkelbach-style process is applied to convert the original non-convex problem into the subtractive convex-form. Meanwhile, the alternative

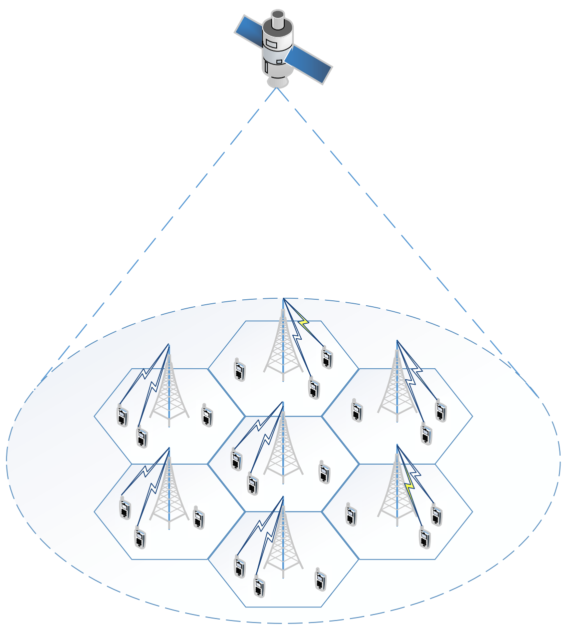

Fig. 1. The system model based the space-terrestrial satellite NOMA networks.

direction method of multipliers (ADMM) method is implemented to resolve objective function optimization problem, which is demonstrated to converge very quickly. The superiority and feasibility of the presented algorithms in NOMA system are demonstrated by numerous simulations.

The rest of the paper is described as follows. Section II presents the NOMA framework based space-terrestrial satellite networks model, and introduces user-associated scheme. Section III formulates the optimization problem. Section IV introduces Dinkelbach-style algorithm and the ADMM technique to solve the optimization problems formulated. In Section V, numerous simulation results demonstrate the superiority of the proposed algorithm in term of system performance. Eventually, We make a summary of this paper in Section VI.

II. System Model and User-Associated Scheme

A. System Model

In this paper, a space-terrestrial satellite network based NOMA is presented, where satellite and BSs provide service to all users under coverage according to the feedback channel state information, cooperatively. For different techniques, different types of satellite could be further considered, however, it beyond the scope of this paper. Therefore, the type of satellite is not specified in this paper. We assume the antennas number for the satellite and each BS are M_T and N_A, respectively. In this paper, as far as we are concerned that the satellite covers R BSs, and terrestrial users served by BSs are divided into groups. Then the NOMA is performed among groups for multi-users applied to the same subchannel by SIC technology [15], [21], [22] in the terrestrial networks. Considering the complexity of system implementation, the study of NOMA generally pairs two users into a group to implement NOMA [16]. As shown in the Fig. 1, within the coverage of each BS, the users of the BS service appear in pairs. The channel conditions for the two users within the NOMA group have quite large difference. Therefore one BS serves N_A groups of users.

$\{U_1, \ldots, U_R\}$ is assumed as the user set, in which each element represents the users covered by the corresponding BS. In general, in current communication networks, terrestrial BSs communications are more efficient and less expensive than satellite communications. Therefore, in space-terrestrial satellite networks, the maximization the energy efficiency of terrestrial BSs is considered as the optimization goal, while satellites provide services to users which cannot be served by the BSs. By applying NOMA technology, we pair two users into a group to share a subchannel in terrestrial networks. We define that the near user and far user set are expressed by $\mu^{\mathrm{h}}_{BN,1}, \ldots, \mu^{\mathrm{h}}_{BN,N_A}$ and $\mu^{\mathrm{h}}_{BF,1}, \ldots, \mu^{\mathrm{h}}_{BF,N_A}$, respectively, in which a near user ($\mu^{\mathrm{h}}_{BN,f}$) and a far user ($\mu^{\mathrm{h}}_{BF,f}$) are paired to implement NOMA. The BS H provides service for S_h users and $S_h > 2N_A$. Therefore, the satellite serves $S_h - 2N_A$ users in the U_h. Then, for all the R BSs, the user number of the BSs is $|U_B| = 2N_A * R$. And the user number of the satellite is $|U_S| = \sum_{\mathrm{h}=1}^{R} S_{\mathrm{h}} - 2N_A$.

B. User Association Scheme

As indicated in the system model, there are S_h users under the coverage of a BS. We propose a user association scheme to identify the users associated with each BS. According to the principle of proximity, the distance between users and each BS is calculated. Then, the users are associated based on the channel gain on the BSs' subchannels. Since the upper limit of the user associated with each BS is S_h, we only take the first S_h users in the sorting. In order to avoid quarrels when the BS associates users, we specify the BS number. And the BS associates the users in order according to the sequence number. The specific steps are as follows:

(1) Number R BSs $\{1, 2, \ldots, r\}$.

(2) According to BS_{radius}, we calculate the distance between each user and each BS as **distance**(h, f), and $h \in R, f \in R * S_h$.

(3) Calculate the channel vector from BS h to user f as $\mathbf{R}(h, f)$, and $h \in R, f \in R * S_h$.

(4) Calculate the channel gain between each user and each BS as $|\mathbf{R}(h, f)|^2$.

(5) If **distance**$(h, f) \leq BS_{radius}$, select users with larger $|\mathbf{R}(h, f)|^2$ to associate BS from $R = 1$, The associated users limit is S_h.

In the process of user association, if the same $|\mathbf{R}(h, f)|^2$ occurs, in order to avoid particularity, the user is randomly associated with a BS.

III. Problem Formulation

As is illustrated in Fig. 1, NOMA are applied to each group for each BS. The superimposed signal transmitted of BS H is

$$\mathbf{X}_H = \sum_{f=1}^{N_A} \mathbf{w}_{H,f} \sqrt{p_{B,H,f}} s_{B,H,f}, \tag{1}$$

in which $s_{B,H,f}$ represents the modulated symbol for the f-th group user in BS H and is presented as follows, $s_{B,H,f} = \sqrt{\beta_{B,H,f}} s_{BN,H,f} + \sqrt{1-\beta_{B,H,f}} s_{BF,H,f}$. $s_{BN,H,f}$ is the signal transmitted to the near user, correspondingly, $s_{BF,H,f}$ is the signal transmitted to the near user. And $E\left[\left|s_{BN,H,f}\right|^2\right] = E\left[\left|s_{BF,H,f}\right|^2\right] = 1$. $\mathbf{w}_{H,f}$ represents the BS beamforming vector and $p_{B,H,f}$ represents the power transmitted in group f. In addition, $\beta_{B,H,f}$ represents the power allocation coefficient.

We formulate transmit signal for satellite as

$$\mathbf{X}_S = \sum_{h}^{R} \sum_{f=1}^{S_h-2N_A} \mathbf{v}_{h,f} \sqrt{p_{S,h,f}} s_{s,h,f}, \tag{2}$$

in which $p_{S,h,f}$ is the transmit power and and $s_{s,h,f}$ is the modulated symbol for fth group users served by the satellite, respectively. $E\left[\left|s_{s,h,f}\right|^2\right] = 1$. Therefore, in group f of BS H, $\mathbf{v}_{H,f}$ represents the satellite beamforming vector, thus superimposed signal received by near user is

$$\begin{aligned} y_{BN,H,F} &= \mathbf{h}_{BN,H,F}^H \mathbf{X}_H + \mathbf{g}_{BN,H,F}^H \mathbf{X}_S + z_n \\ &= \mathbf{h}_{BN,H,F}^H \sum_{f=1}^{N_A} \mathbf{w}_{H,f} \sqrt{p_{B,H,f}} s_{B,H,f} \\ &\quad + \mathbf{g}_{BN,H,F}^H \sum_{h}^{R} \sum_{f=1}^{S_h-2N_A} \mathbf{v}_{h,f} \sqrt{p_{S,h,f}} s_{s,h,f} \\ &\quad + z_n \end{aligned} \tag{3}$$

in which the channel vector for near user of group F by BS H and the channel vector for near user by the satellite are represented as $\mathbf{h}_{BN,H,F}^H$ and $\mathbf{g}_{BN,H,F}^H$, respectively. Meanwhile, we assume the additive White Gaussian noise (AWDN) is represented by z_n. Correspondingly, superimposed signal received for far user is

$$\begin{aligned} y_{BF,H,F} &= \mathbf{h}_{BF,H,F}^H \mathbf{X}_H + \mathbf{g}_{BF,H,F}^H \mathbf{X}_S + z_n \\ &= \mathbf{h}_{BF,H,F}^H \sum_{f=1}^{N} \mathbf{w}_{H,f} \sqrt{p_{B,H,f}} s_{B,H,f} \\ &\quad + \mathbf{g}_{BF,H,F}^H \sum_{h}^{R} \sum_{f=1}^{S_h-2N_A} \mathbf{v}_{h,f} \sqrt{p_{S,h,f}} s_{s,h,f} \\ &\quad + z_n, \end{aligned} \tag{4}$$

the SINR for the far user is

$$\begin{aligned} &\gamma_{BF,H,F} \\ &= \frac{\Gamma_{BF}^K p_{B,H,F}(1-\beta_{B,H,F})}{1+\Gamma_{SF}^K p_{B,H,F}\beta_{B,H,F} + \eta_{BF,H,F} + \eta_{SF,H,F}} \end{aligned} \tag{5}$$

in which $\Gamma_{BF}^K = \frac{\left|\mathbf{h}_{BF,H,F}^H \mathbf{w}_{H,F}\right|^2}{z_n}$,and $\Gamma_{SF}^K = \frac{\left|\mathbf{g}_{BF,H,F}^H \mathbf{v}_{H,F}\right|^2}{z_n}$. $\eta_{BF,H,F}$ indicates the interference for the terrestrial user group F caused by the remaining terrestrial users, and $\eta_{SF,H,F}$ indicates the interference caused by users served by satellite. As follows:

$$\begin{aligned} \eta_{BF,H,F} &= \sum_{f=1,f\neq F}^{N_A} \Gamma_{BF}^K p_{B,H,F} \\ \eta_{SF,H,F} &= \sum_{h=1}^{R} \sum_{f=1}^{S_h-2N_A} \Gamma_{SF}^K p_{S,H,F} \end{aligned} \tag{6}$$

Therefore, the system capacity for the corresponding far user is

$$C_{BF,H,F} = \log_2(1+\gamma_{BF,H,F}), \tag{7}$$

It is by applying SIC that the NOMA scheme is implemented at two users in each group [23], which works by gradually subtracting multiple access interference (MAI) from the optimal user signal. As stated above, The channel condition of near users are superior to far users, and near users can decode and eliminate the signal for far users on account of SIC decoding order. Thus, we can define the SINR for the near user as follows:

$$\gamma_{BN,H,F} = \frac{\Gamma_{BN}^K p_{B,H,F}\beta_{B,H,F}}{1+\eta_{BN,J,K} + \eta_{SN,H,F}}. \tag{8}$$

where

$$\begin{aligned} \eta_{BN,H,F} &= \sum_{f=1,f\neq F}^{N} \Gamma_{BN}^K p_{B,H,f} \\ \eta_{SN,J,K} &= \sum_{h=1}^{R} \sum_{f=1}^{S_h-2N_A} \Gamma_{SN}^K p_{S,H,f} \end{aligned} \tag{9}$$

in which $\Gamma_{BN}^K = \frac{\left|\mathbf{h}_{BN,H,F}^H \mathbf{w}_{H,F}\right|^2}{z_n}$, and $\Gamma_{SN}^K = \frac{\left|\mathbf{g}_{BN,H,F}^H \mathbf{v}_{H,F}\right|^2}{z_n}$.

Therefore, the system capacity for the corresponding near user represents as follows:

$$C_{BN,H,F} = \log_2(1+\gamma_{BN,H,F}). \tag{10}$$

Superimposed signal received for the user served by satellite is

$$\begin{aligned} y_{S,H,F} &= \mathbf{g}_{S,H,F}^H \mathbf{X}_H + \mathbf{h}_{S,H,F}^H \mathbf{X}_S + z_n \\ &= \mathbf{g}_{S,H,F}^H \sum_{h}^{R} \sum_{f=1}^{S_h-2N_A} \mathbf{v}_{H,f} \sqrt{p_{S,h,f}} s_{s,h,f} \\ &\quad + \mathbf{h}_{S,H,F}^H \sum_{f=1}^{N_A} \mathbf{w}_{H,f} \sqrt{p_{B,H,f}} s_{B,H,f} \\ &\quad + z_n, \end{aligned} \tag{11}$$

where $\mathbf{g}_{S,H,F}^H$ and $\mathbf{h}_{S,H,F}^H$ indicate channel vector to satellite users from the satellite and from the BS H, respectively. The SINR for the satellite user represents as follows:

$$\gamma_{S.H,F} = \frac{\Gamma_{SS}^K p_{S,H,F}}{1+\eta_{SS,H,F} + \eta_{BS,H,F}}, \tag{12}$$

where

$$\begin{aligned} \eta_{SS,H,F} &= \sum_{h=1}^{R} \sum_{f=1,[h,f]\neq[H,F]}^{S_h-2N_A} \Gamma_{SS}^K p_{S,H,F} \\ \eta_{BS,H,F} &= \sum_{h=1}^{R} \Gamma_{BS}^K p_{B,H,f} \end{aligned} \tag{13}$$

where $\Gamma_{SS}^{K} = \frac{\left|\mathbf{g}_{S,H,F}^{H}\mathbf{v}_{H,F}\right|^2}{z_n}$,and $\Gamma_{BS}^{K} = \frac{\left|\mathbf{h}_{S,H,F}^{H}\mathbf{w}_{H,F}\right|^2}{z_n}$. $\eta_{SS,H,F}$ represents the interference to the satellite user K caused by the remaining satellite users, and $\eta_{BS,H,F}$ represents the interference caused by BSs. Therefore, the system capacity for the corresponding satellite user represents as follows:

$$C_{S,H,F} = \log_2(1 + \gamma_{S.H,F}). \tag{14}$$

A. Selection of Satellite User

As everyone can see it, due to limitations of BSs placement and the limited service capacity of the BSs, the satellite provide excess service for those users who exceed the BSs service limit. Among all problems that need to be formulated, the first problem is the selection of the satellite users. In (12), it is shown that the satellite users are affected by the BS, in which the channel vector is $\mathbf{h}_{S,H,F}$. We consider that users with better $\mathbf{h}_{S,H,F}$ are served by the BSs, while users with poor $\mathbf{h}_{S,H,F}$ are served by the satellite. Furthermore, satellite channel vector $\mathbf{g}_{S,H,F}$ is also taken into consideration. So the selection scheme for satellite users is presented to select users served by the satellite. Proposed channel condition ratio is $\eta_{H,F} = \frac{|\mathbf{g}_{H,F}|}{|\mathbf{h}_{H,F}|}$ is defined, where $\mathbf{g}_{H,F}$ and $\mathbf{h}_{H,F}$ represent the satellite channel vector and the BS channel vector of users, respectively. The users which have the largest channel condition ratio are selected as satellite users, and the users number is $S_H - 2N_A$. Based on this scheme, satellite users will suffer a little interference from BSs.

B. Joint Hungarian and Dichotomy for Terrestrial Users Pairing Scheme

Except for the satellite users, all the remaining users are served by BSs. In [17], it is shown that pairing users with different channel conditions is ideal when performing NOMA. Since the diversified channel influences of satellites, NOMA technology is only adopted for terrestrial users in this paper to achieve higher spectral efficiency. Then, a terrestrial users pairing scheme is proposed to implement NOMA in terrestrial networks. The channel vector $\mathbf{h}_{B,H,F}$ of the $2N_A$ users is ranked based on the channel condition for every BS H, then select the near users set with N_A larger $\mathbf{h}_{B,H,F}$, and the far users set with N_A smaller $\mathbf{h}_{B,H,F}$. Then, it is shown that the process of pairing.

Firstly, we provide the following definition to represent the correlation coefficients of different channels.

$$Corr(H,p,q) = \frac{\left|\mathbf{h}_{B,H,p}^{H}\mathbf{h}_{B,H,q}\right|}{\left|\mathbf{h}_{B,H,p}\right|\left|\mathbf{h}_{B,H,q}\right|}. \tag{15}$$

The correlation of the two channels is proportional to the above value. If $Corr(H,p,q) = 0$, it means the two channels are uncorrelated. On account of ensuring the user fairness, the optimization of channel correlation coefficients of all groups should be considered. Therefore, we adopt the maximized minimum correlation coefficient scheme, which is a typical strategy of obtaining user fairness. We set the pairing scheme as

$$\max \theta$$
$$C1: \frac{\left|\mathbf{h}_{BN,H,F}^{H}\mathbf{h}_{BF,H,F}\right|}{\left|\mathbf{h}_{BN,H,F}\right|\left|\mathbf{h}_{BF,H,F}\right|} \geq \theta, F = 1,2,\ldots,N_A. \tag{16}$$

The pairing scheme is resolved from following point of view, in which the graph theory is introduced to solve optimization problems. The users served by BS H need be regarded as vertexes of the graph, where N_A vertexes indicate the far users and other N_A vertexes represent the near users. An edge (p,q) is built between the two vertexes, thus the graph $GM(V,E)$ can be regarded a bipartite graph [19]. The pairing scheme of terrestrial users can be converted into the problem of obtaining the maximum matching of the bipartite graph $GM(V,E)$. In the process of solving the maximum matching problem, the $2N_A$ users is arranged in descending order by $|\mathbf{h}_{B,H,F}|$, and it is stipulated that the first N_A users belong to $U_{BN,F} = \{u_{B,H,1},\ldots,u_{B,H,F}\}$ and the last N users belong to $U_{BF,F} = \{\mu_{B,H,1},\ldots,\mu_{B,H,F}\}$. A joint greedy and dichotomy scheme is presented to resolve optimization problem, in which formulation (16) represents the non-convex problem.

So we have Algorithm 1

Algorithm 1 Joint Hungarian and Dichotomy for Terrestrial User Pairing Algorithm

```
Initiate GM(V,E), edge e(p,q) = 0 for all p ∈ U_{BN,F} and q ∈ U_{BF,F}, θ_L = 0, θ_R = 1, ε = ε0
Calculate Corr(H,p,q) = |h^H_{B,H,p} h_{B,H,q}| / (|h_{B,H,p}||h_{B,H,q}|) for all p ∈ U_{BN,H} and q ∈ U_{BF,H}
repeat
  Calculate θ = (θ_L + θ_R)/2
  if Corr(H,p,q) ≥ θ for all p ∈ U_{BN,F} and q ∈ U_{BF,F} then
    Set edge e(p,q) = 1
    Obtain the maximum matching GM by hungarian method
    if |GM| = N_A then
      θ_L = θ
    else
      θ_R = θ
    end if
  end if
until θ_R − θ_L < ε
```

C. Bs and Satellite Beamforming

Each BS covers $2N_A$ users, in which these $2N_A$ users are grouped into N_A groups, then the beamforming is implemented among N groups. On account of the channel states information (CSI) of base stations and satellites, the beamforming precoding technology is proposed to reduce multi-user interference [19]. From the above derivation we can know that the channel correlation for the users in a group is relatively high. Thus we only design the beamforming vector for one user in each group and the BS beamforming vectors based on the near users [19]. For the N_A near users, we apply ZFBF technology, and the constructed beamforming vectors should be satisfied $\mathbf{h}_{BN,H,f}^{H}\mathbf{w}_{H,f} = 0, h \neq f$.

We define $\mathbf{Q}$ as the channel matrix for the near user. If $\mathbf{Q}$ is invertible, ZFBF is the perfect choice. And $\mathbf{Q} = [\mathbf{h}_{BN,H,1}, \mathbf{h}_{BN,H,2}, \mathbf{h}_{BN,H,3}, \ldots, \mathbf{h}_{BN,H,F}]^{\mathbf{H}}$. Therefore, the BS beamforming matrix represents as follows:

$$\mathbf{W} = [\mathbf{w}_{H,1}, \ldots, \mathbf{w}_{H,F}] = \mathbf{Q}^{-1}\Lambda, \tag{17}$$

where Λ is a normalized diagonal matrix, and $\Lambda^2 = diag\{\frac{1}{(\mathbf{Q}^{-\mathbf{Q}}\mathbf{Q}^{-1})_{1,1}}, \ldots, \frac{1}{(\mathbf{Q}^{-\mathbf{Q}}\mathbf{Q}^{-1})_{N,N}}\}$, in which $(\mathbf{Q})_{i,i}$ indicates the i-th element in the main diagonal matrix [34].

However, if $\mathbf{Q}$ is not invertible, the ZFBF will be replaced by the maximum ratio transmission (MRT) beamforming [14]:

$$\mathbf{w}_{H,F} = \frac{\mathbf{h}_{BN,H,F}}{\|\mathbf{h}_{BN,H,F}\|}, \tag{18}$$

Since the satellite channel conditions are more complex, the satellit channel model is considered as a Rician channel in this paper. The same as the terrestrial beamforming scheme, a satellite beamforming scheme is designed.

$\mathbf{D}$ is the channel matrix for the satellite users, and $\mathbf{D} = [\mathbf{g}_{S,H,1}, \mathbf{g}_{S,H,2}, \mathbf{g}_{S,H,3}, \ldots, \mathbf{g}_{S,R,S_h-2N_A}]^{\mathbf{H}}$. If $\mathbf{D}$ is invertible, the beamforming vectors can be calculated the same as (17). If $\mathbf{D}$ is not invertible, the beamforming vectors can be calculated the same as (18).

IV. BS and Satellite Resource Allocation

The iterative algorithm is presented to formulate the optimal powers and subchannels allocations in this section, which has low-complexity and it depended on following steps:

(1) The Dinkelbach-style scheme is proposed to convert proposed non-convex problem into the convex-form problem [25];

(2) The proposed suboptimal subchannel allocation focuses on the heterogeneous user QoS guarantee;

(3) ADMM is applied in power allocation scheme to optimize the objective function.

Firstly, the ratio of the total capacity for the system with the total power consumed by the satellite and BSs represents the system energy efficiency [29], [33]. Hence, the optimization function is designed as follows:

$$max\ \frac{\sum_{H=1}^{R}\sum_{F=1}^{N_A}(C_{BF,H,F}+C_{BN,H,F})+\sum_{H=1}^{R}\sum_{F=1}^{S_h-2N_A}C_{S,H,F}}{\sum_{h=1}^{R}\sum_{F=1}^{N_A}p_{B,H,F}+\xi(\sum_{H=1}^{R}\sum_{F=1}^{S_h-2N_A}p_{S,H,F})} \tag{19}$$

Given the scarcity of satellite resources and the complexity of channel conditions, we define ξ, which represents the importance of satellite power, and for convenience, the system capacity is changed as follows:

$$C_L = \sum_{H=1}^{R}\sum_{F=1}^{N_A}(C_{BF,H,F}+C_{BN,H,F})+\sum_{H=1}^{R}\sum_{F=1}^{S_h-2N_A}C_{S,H,F}. \tag{20}$$

The overall power is changed as follows:

$$P_L = \sum_{H=1}^{R}\sum_{F=1}^{N_A}p_{B,J,K}+\xi(\sum_{H=1}^{R}\sum_{F=1}^{S_h-2N_A}p_{S,H,F}). \tag{21}$$

Dinkelbach-style algorithm is applied to transform non-convex objective functions into convex ones to solve optimization problem.

$$\begin{aligned} F(\lambda) = &\max_{\beta_{B,H,F},p_{B,H,F},p_{S,H,F}} C_L - \lambda P_L \\ &s.t.\ C1: \sum_{H=1}^{R}\sum_{F=1}^{S_h-2N_A} p_{S,H,F} \le P_{S,\max} \\ &C2: \sum_{H=1}^{R}\sum_{F=1}^{N_A} p_{B,H,F} \le P_{B,\max} \end{aligned} \tag{22}$$

As everyone can see it, obtain the solution for the equation $\mathrm{F}(\lambda) = 0$ to resolve the objective function, in which the λ is an adjective variable. Then the algorithm is represented as follows Algorithm 2:

Algorithm 2 Dinkelbach-Style Scheme

1: Initialize: $\beta_{B,H,F}(0)$, $p_{B,H,F}(0)$, $p_{S,H,F}(0)$, $\forall H, F$; $\lambda(1) = \eta(0)$, $\tau = 1$;
2: **repeat**
3: **if** $F(\lambda(\tau)) \neq 0$ **then**
4: Resolve $F(\lambda) = \max_{\beta_{B,H,F},p_{B,H,F},p_{S,H,F},} C_L - \lambda P_L$ for optimal $\{\beta_{B,H,F}(\tau), p_{B,H,F}(\tau), p_{S,H,F}(\tau)\}$, $\forall H, F$;
5: Set $\lambda(\tau+1) = \eta(\tau)$; $\tau{=}\tau+1$
6: **end if**
7: **until** $F(\lambda(\tau)){=}0$

Then, subchannel and power allocation scheme will be formulated according to $\mathrm{F}(\lambda)$.

A. Subchannel Allocation

Because the terrestrial users for BS H have been matched into N_A groups, the number of satellite users is $S_h - 2N_A$. Therefore, we need to match the N_A groups of terrestrial users with the N_A subchannels of the BS H [24]. Thus, the number of satellite matching antenna is $M_T = R * (S_h - 2N_A)$. The Dynamic Channel Allocation (DCA) criterion [36], [37]is taken into account, that is, the channel selected by each user when creating a new link should be the one that can provide the maximum SINR to the current user in the current system. The DCA guidelines have broad applicability, so the following algorithm is proposed based on this criterion. For BS subchannels allocation, Algorithm 3 [32] is as follows:

The similar allocation algorithm as above is applied to satellite subchannels, in which the optimization problem of (24) should be presented in a subtractive-form as follows:

$$\min_{\beta_{B,H,F},p_{B,H,F},p_{S,H,F}} \lambda P_L - C_L, \tag{23}$$

then continue to transform as follows

$$\begin{aligned} &\lambda P_L - C_L \\ &= \lambda(\sum_{H=1}^{R}\sum_{F=1}^{N_A}p_{B,H,F}+\xi(\sum_{H=1}^{R}\sum_{F=1}^{S_h-2N_A}p_{S,H,F})) \\ &\quad -(\sum_{H=1}^{R}\sum_{F=1}^{N_A}(C_{BF,H,F}+C_{BN,H,F})+\sum_{H=1}^{R}\sum_{F=1}^{S_h-2N_A}C_{S,H,F}) \end{aligned}$$

Algorithm 3 BS Subchannels Allocation

Initialization: set the matched list $\mathrm{Q}_{match}(j,n)$ which record users matched on subchannel n.
for $\forall j \in [1,2,\ldots,R]$ and $\forall n \in [1,2,\ldots,N_A]$.
repeat
  for $H=1$ to R **do**
    for $F=1$ to N **do**
      Update the SINR of far user $\gamma_{BF,H,F}$ refering to (5).
      Update the SINR of near user $\gamma_{BN,H,F}$ refering to (8).
      Calculate $\gamma_{B,H,F}=\gamma_{BF,H,F}+\gamma_{BN,H,F}$.
    end for
    Sort the N_A groups users in BS H by $\gamma_{B,H,F}$.
    In descending order, let $\gamma_{B,H,F}$ and $\mathrm{Q}_{match}(j,n)$ correspond one-to-one.
  end for
until $\mathrm{Q}_{match}(j,n)$ is fully matched.

$$=\lambda\sum_{H=1}^{R}\sum_{F=1}^{N_A}p_{B,H,F}-\sum_{H=1}^{R}\sum_{F=1}^{N_A}(C_{BF,H,F}+C_{BN,H,F})$$
$$+\lambda\xi(\sum_{H=1}^{R}\sum_{F=1}^{S_h-2N_A}p_{S,H,F})-\sum_{H=1}^{R}\sum_{F=1}^{S_h-2N_A}C_{S,H,F} \quad (24)$$

where change is as follows:

$$f(X_{BS})=\sum_{H=1}^{R}\sum_{F=1}^{N}(C_{BF,H,F}+C_{BN,H,F})-\lambda\sum_{H=1}^{R}\sum_{F=1}^{N}p_{B,H,F}$$
$$f(X_{sate})=\sum_{H=1}^{R}\sum_{F=1}^{S_h-2N_A}C_{S,H,F}-\lambda\xi(\sum_{H=1}^{R}\sum_{F=1}^{S_h-2N_A}p_{S,H,F}) \quad (25)$$

Furthermore, the ADMM technique of [25] can be applied in each network.

B. Power Allocation

The power allocation scheme includes base stations power allocation and satellite power allocation. For both two parts we introduce the ADMM [28]. The adjective vectors of X_{BS} and Z_{BS} are introduced to solve the presented optimization problem, in which X_{BS} consists of all elements of the BSs power allocation matrix, while Z_{BS} is a global assistant vector, in which each element is corresponding to one in X_{BS}. The indicator function is as follows:

$$g(Z_{BS})=\begin{cases}0 & Z_{BS}\in\phi\\ +\infty & otherwise\end{cases} \quad (26)$$

Meanwhile, the proposed objective function (23) is rewritten as follows:

$$\min_{X_{BS},Z_{BS}} -f(X_{BS})+g(Z_{BS}), \quad (27)$$
$$s.t.\ X_{BS}-Z_{BS}=0. \quad (28)$$

The augmented Lagrangian can be formulated as follows:

$$L_{\rho}^{BS}=-f(X_{BS})+g(Z_{BS})-\frac{\rho}{2}\left\|\mu_{BS}\right\|_2^2+\frac{\rho}{2}\left\|X_{BS}-Z_{BS}^{t}+\mu_{BS}\right\|_2^2, \quad (29)$$

where μ_{BS} and ρ_{BS} are the scaled dual variable and constant penalty parameter, respectively. The iterative process is as follows:

$$\begin{aligned}X_{BS}^{t+1}&:=\arg\min_{X_{BS}}\left\{-f(X_{BS})+\frac{\rho}{2}\left\|X_{BS}-Z_{BS}^{t}+\mu_{BS}\right\|_2^2\right\}\\ Z_{BS}^{t+1}&:=\arg\min_{Z_{BS}}\left\{\left\|X_{BS}^{t+1}-Z_{BS}+\mu_{BS}^{t}\right\|_2^2\right\}\\ \mu_{BS}^{t+1}&:=\mu_{BS}^{t}+(X_{BS}^{t+1}-Z_{BS}^{t+1})\end{aligned} \quad (30)$$

In the Algorithms 4, the BSs power allocation algorithm based on ADMM is presented, and satellite algorithms has same process:

Algorithm 4 Power Allocation for BS

Initialization;
Initialize iteration index $t=0X_{BS}^{0}$, $\xi>0$ and $\mu_{BS}^{0}>0$; $\rho_{BS}=0$ and $Z_{BS}^{0}\in C2$;
while $f(X_{BS})>\xi$ **do**
  According to (30);
  Updates X_{BS}^{t+1}
  Updates Z_{BS}^{t+1}
  Updates μ_{BS}^{t+1}
  $t:=t+1$;
end while

V. Simulation Results and Performance Evaluation

Numerical simulation results is provided to evaluate the presented algorithm and the performance for NOMA based on space-terrestrial satellite networks in this section. We assume that the bandwidth B is 10 MHz, normally, the AWGN power is $\mathrm{n}=\mathrm{BN}_0$, in which $\mathrm{N}_0=-174$ dBm/Hz [35]. It is assumed that the coverage radius of the satellite is 1000 km, in addition, the parameters for the satellite were determined according to the reference [29]. According to the difference of channel condition between the satellite and BSs, the satellite channel and BS channel are assumed the Rician channel [30] and the Rayleigh channel [31], respectively. The maximum BS transmit power is determined as $P_{B,\max}=90$ dBm. In view of the importance of satellite power, we set ξ as 2 and 5 in Fig. 8 and Fig. 9. And in the remaining simulation results, the value of ξ is 1.

Fig. 2 indicates the EE of the presented energy efficiency resource allocation algorithm tends to converge rapidly with the increase of iteration times. It includes BSs energy efficiency, satellite energy efficiency and overall energy efficiency. Assuming that the space-terrestrial satellite networks have 1 satellite and 4 BSs. Each BS have 4 antennas. In a word, L = 4, $M_T=8$, $N_A=4$. Firstly, it is obvious that presented algorithm converges in less than 15 iterations. In addition, the total energy efficiency of BSs and satellite converges to about 0.55 bps/Hz/watt, and the energy efficiency of BSs

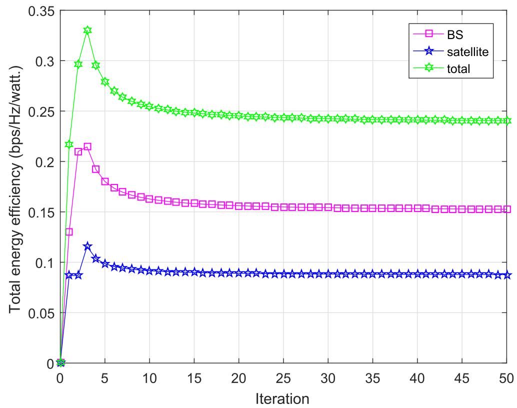

Fig. 2. Convergence in the aspect of the total system energy efficiency.

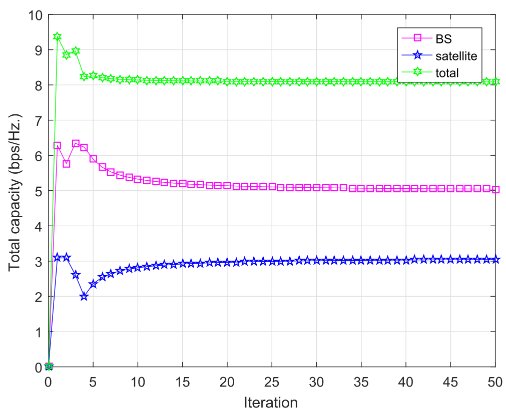

Fig. 3. Convergence in the aspect of the total system capacity.

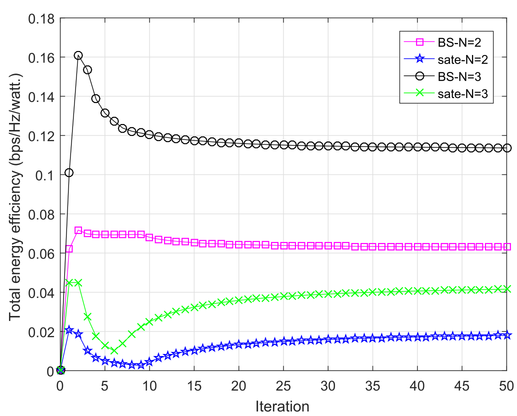

Fig. 4. System Energy efficiency with different number of BS subchannels.

converges to about 0.42 bps/Hz/watt. The energy efficiency of satellite converges to about 0.13 bps/Hz/watt. As everyone can see it, the energy efficiency of BSs is higher than of the satellite. This is because BSs have better channel condition. As comparison, the system capacity is also taken account, just as the Fig. 3 shows. In Fig. 3, all the parameters are same as Fig. 2. For the results obtained Fig. 2, there is a similar trend in Fig. 3.

In Fig. 4, two cases of $N_A = 2$ and $N_A = 3$ are compared and investigated variation of the energy efficiency.

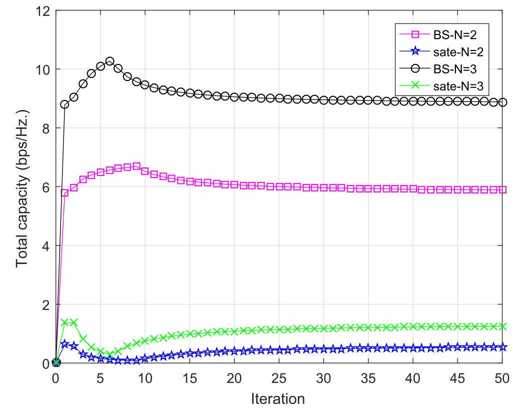

Fig. 5. System capacity with different number of BS subchannels.

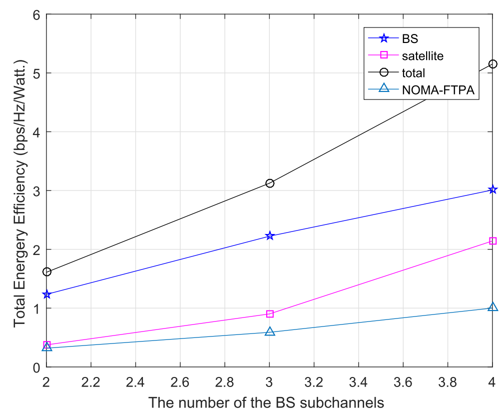

Fig. 6. System Energy efficiency with different number of BS subchannels.

Firstly, when N_A changes from 2 to 3, both BSs energy efficiency and satellite energy efficiency have increased. Due to the higher the value of N_A, the more users the BSs will serve. The channel condition for the BSs is obviously more superior than that for the satellite because of the satellite further distance and higher channel interference. So that as N_A increases, the energy efficiency of the system goes up. So in operation, we prefer more BS subchannels, and satellite services are used as a supplement to serve users who exceed the BSs' service capacity. As comparison, the system capacity is also taken account, just as the Fig. 5 shows. It is obvious that the trend of two is similar. When N_A changes from 2 to 3, energy efficients of the BSs and satellite are growing, and system capacities also have similar trend.

Fig. 6 and Fig. 7 are further demonstration results for Fig. 4 and Fig. 5, respectively. The growth in system energy efficiency for the satellite and the BSs is as N_A increases from 2 to 4 in Fig. 6,. This further proves our predicted results in Fig. 4 and Fig. 5. In the wake of the number of subchannels for BSs increases, the user number served by BSs becomes more. BSs energy efficiency and satellite energy efficiency are also growing. This conclusion also applies to changes in system capacity. In addition, in Fig. 6, the constrast algorithm of FTPA based on NOMA is shown to evaluate the advantages of the algorithm presented in this paper. It is important to note that the constrast algorithm is applied to terrestrial users.

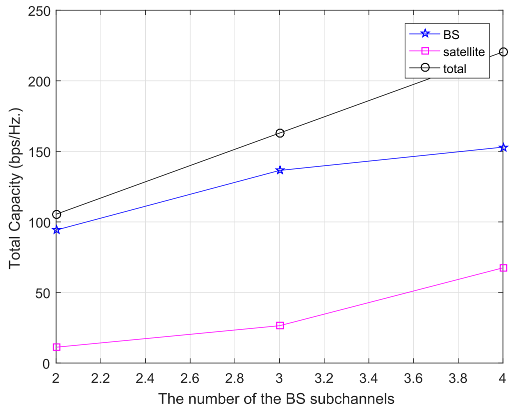

Fig. 7. System capacity with different number of the BS subchannels.

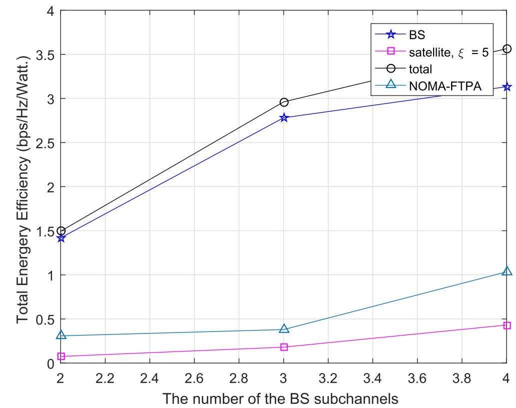

Fig. 9. System capacity with different number of the BS subchannels.

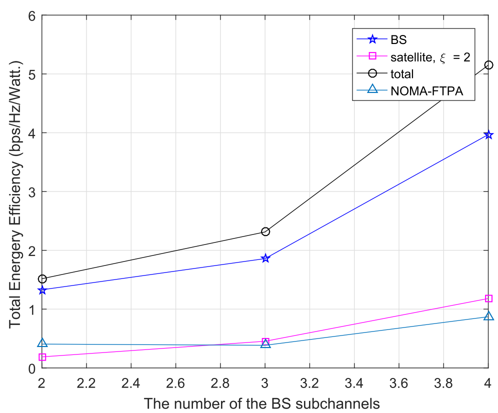

Fig. 8. Energy efficiency with different number of the BS subchannels.

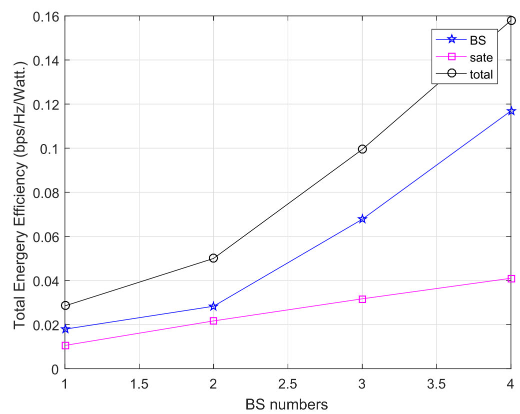

Fig. 10. System Energy efficiency in different numbers of BSs.

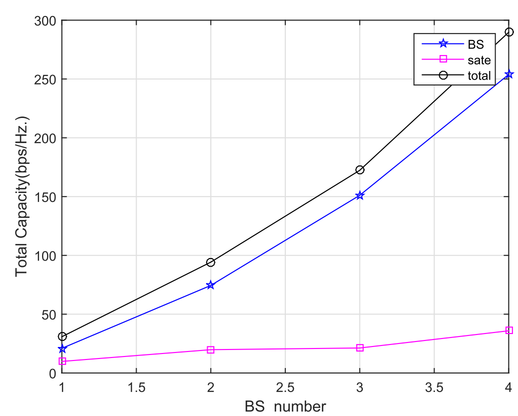

Fig. 11. System capacity in different numbers of BSs.

The line of FTPA is located at the bottom of the figure, although it is also increasing with the increasing of the BS subchannels. From Fig. 6, it is obvious that the line of the BSs in the proposed algorithm can exceed approximately 50%-75% in energy efficiency compared with the line of FTPA.

Given the scarcity of satellite resources and the complexity of channel conditions, we define ξ, which represents the importance of satellite power. In Fig. 8, $\xi = 2$, and the remaining parameter value are similar to those in Fig. 6. At this point, the energy efficiency of the satellite users is reduced compared to Fig. 6, and the total system energy efficiency is also reduced. It is important to note that the constrast algorithm is applied to terrestrial users. The energy efficiency for total system and BSs are still better than those of the comparison algorithm. When $\xi = 5$, the simulation results are indicated in Fig. 9. With the increase of ξ, the energy efficiency for the satellite and the system decreased to a certain extent. However, the advantages of the proposed algorithm can still be demonstrated in in Fig. 9.

Finally, Fig. 10 and Fig. 11 describe changes in system energy efficiency and system capacity for different BS numbers, respectively. From Fig. 10, when the number of the BSs increases from 1 to 4, the energy efficiency for the BSs and the satellites are on the rise. In fact, the terrestrial networks provide high bandwidth service at the low cost. So this trend is in line with the actual situation. Therefore, in the actual situation, we tend to cover more BSs under one satellite, so that under quality of service (QoS) demands, not only the system capacity be improved, but also the system energy efficiency can be enhanced.

VI. Conclusion

In this paper, the NOMA based on space-terrestrial satellite networks is proposed, where BSs and satellites provide services to ground users. Then the channel condion radio is calculated to select satellite users. The users served by

BSs are matched into groups, which are based on bipartite graph theory. And the BS users adopt NOMA technology in each group. Beamforming precoding is used to reduce multiuser interference at the transmitter. The optimization objective problem is formulated for power allocation, then the Dinkelbach-style scheme is applied to convert the proposed non-convex problem into the subtractive convex-form function. Then a subchannel allocation algorithm is presented according to the DCA principle and power allocation is performed by ADMM algorithm. From the simulation results, we simulated the system energy efficiency and system capacity, and compared the data of different subchannels and different numbers of the BSs. Obviously, the system energy efficiency can better reflect the change and has high credibility. By comparing with FTPA-NOMA scheme, simulation results indicate that the presented allocation algorithm for terrestrial users outperforms the FTPA-NOMA algorithm. The presented algorithm in this paper can be applied the space-terrestrial satellite networks well. Precoding is an effective technique that is applied at the transmitter or the receiver to improve system throughput. In our future work, we plan to optimize precoding techniques and apply precoding at the receiver, in which each user is assigned a beamforming vector to reduce interference.

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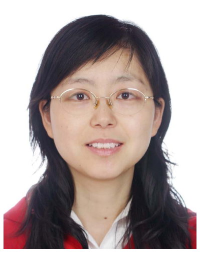

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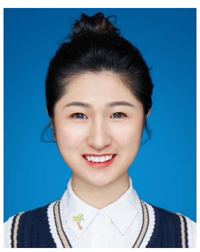

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