Dynamic User Association for Resilient Backhauling in Satellite–Terrestrial Integrated Networks

Cui-Qin Dai, Junfeng Luo, Shu Fu, Jinsong Wu, and Qianbin Chen, *Senior Member, IEEE*

***Abstract*—The satellite–terrestrial integrated networks (STINs) have gradually become a new class of effective ways to satisfy the requirements of a higher capacity and stronger connection in the future communications. In contrast with terrestrial networks, the fast periodic motion of satellites results in the dynamic time-varying features of STIN, which further leads to frequent changes in the connectivity of satellite–terrestrial links and the backhaul capacities of satellite networks. To balance the accessible capacity of STIN under the intermittent connectivity and dynamic backhaul capacity, an effective user association mechanism is needed. In this article, a dynamic user association (DUA) mechanism with task classification is proposed to meet the requirements of load balancing and the user task processing. First, a STIN model is constructed with low earth orbit satellites and the three types of base station, which are a macro base station, small cell base station, and low earth orbit based base station. After that, the optimization problem is formulated via jointly considering the task classification, the load condition of base stations, and the backhaul capacity of low earth orbit based base stations. Then, the DUA mechanism is proposed to find the most suitable base station serving each user. In DUA, a dynamic cell range extension algorithm is developed to adjust the load of STIN in terms of the resilient backhaul capacity, and a greedy-based user-centric user association with task classification algorithm is proposed to find the base station, which has the maximum rate and minimum load for each user and to meet the requirements of user task processing. The simulation results show that the proposed DUA can enhance the load balance and guarantee the task processing demand of STIN compared with the reference signal receiving power association and the max-sum rate association algorithms.**

***Index Terms*—Resilient backhaul capacity, satellite–terrestrial integrated network (STIN), task classification, user association (UA).**

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I. Introduction

THE satellite–terrestrial integrated networks (STINs) have been envisioned to extend the coverage area and increase the throughput via integrating the satellite-based networks and the terrestrial networks [1]–[3]. In contrast with terrestrial heterogeneous networks (HetNets) [4], satellite-based networks and terrestrial networks are being integrated to provide more effective solutions for backhauling in STIN. It is helpful to break the transmission bottleneck caused by ultradense (UD) and heavy traffic between the end users and the core network. However, the orbital movement of satellites generally results in dynamic network topologies and interrupted link connectivity. It leads to the dynamic change of the backhaul links, which further affects the accessible capacity of STIN. Therefore, it is a nontrivial task to balance the accessible capacity of STIN under the dynamic backhaul capacity [5]–[7].

In STIN, the satellite link was treated as a backup connection for critical cell sites to supplement the limited capacity in its terrestrial links during peak time or even replace the terrestrial connection in the cases of total or partial failure and maintenance in [8] and [9]. Since the backhaul capacity strictly limits the access capacity of STIN, more and more research works have focused on improving the backhaul capacity. In [10] and [12], the backhaul capacity was enhanced through spatial multiplexing, spectrum sharing, and beam sharing technologies, respectively. To solve the backhaul bottleneck, the caching function was added for backhauling in [13], and the codesign solution of the radio access network (RAN) and backhauling was provided in [14]. However, the above studies for the backhauling of STIN have only considered how to support the proliferation of data traffic but ignored the effects caused by the time-varying topology and links in STIN.

User association (UA) is a way to coordinate backhauling and RAN due to its key role in enhancing load balancing, spectrum, and energy efficiency [15]. The original UA rule was based on the received power [16], where a user will associate with the specific base station (BS), which provides the maximum received signal strength (max-RSS). With the development of multitier heterogeneous cellular networks, the max-RSS UA may lead to serious load imbalance. To achieve better load balance, cell range expansion (CRE) schemes [17] have been proposed to add a positive bias to the small-cell BSs such that each user is associated to the BSs with the highest biased signal-to-interference-noise ratio (SINR). With CRE, more users can be served by small cells with weaker signal strengths yet with smaller load and, thus, with more resources available than the

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macro BSs (MBSs), taking the advantage of enhanced spatial reuse. Moreover, driven by the growing number of bandwidth-hungry applications, the uplink traffic is generated more than that in the downlink. In order to solve the above problems, it is necessary to consider the network capacity and the load of nodes in designing UA rule, when studying the combination of RAN and backhauling [18]–[21]. In [18] and [19], heuristics-based UA algorithms were presented to address the backhaul load balancing with the constraints of the cell load and backhaul throughput. In [20], a distributed UA scheme was proposed to balance the network load while taking into account the backhaul delay and reliability constraints. Han *et al*. [21] considered the coupling relationship between the UA and resource allocation in view of the backhaul constraint. Recently, the UA and resource allocation have been considered jointly to improve the network utility [22]–[24]. In [22], Wang *et al*. investigated the problem of joint UA and bandwidth allocation with backhaul constraints for two-tier HetNets. Jang *et al.* [23] studied the problem of joint UA and resource block allocation with backhaul constraints for small cells. Lee *et al*. [24] addressed UA problem for quality of service (QoS) provisioning and backhaul load balancing with equal resource allocation in HetNets. Although designed to optimize the network performance, the aforementioned UA schemes, nonetheless, operate in cell-centric fashion and fail to account for the diverse QoS requirements of users. In fact, for uplink, the user is the main part for manufacturing traffic and using network. Keeping in view the dominant role of users' requirements, a novel user-centric backhaul scheme was proposed in [25] to jointly exploit the diversity in user requirements and backhaul constraints. However, the random mobility of users will make the resource utilization of static UA unreasonable. Therefore, dynamic user association (DUA) is emerging to solve the problem of resource utilization. Users can associate with BS, while users within BS's coverage make coverage and resource utilization strongly related. Therefore, some research articles on CRE are underway to adjust the coverage by the amount of dynamic changes in the scene, which includes traffic load [26] and the number of users [27].

All the above works have made good contributions to the UA approaches in terrestrial HetNets. However, the backhaul capacity in STIN will change dynamically due to the intermittent connectivity of satellite–terrestrial links. In addition, the delay due to using a satellite network as backhauling is quite different from that of the traditional terrestrial backhauling. As an effort to address both of the aforementioned problems, in this article, a DUA mechanism is proposed via jointly considering the requirements of load balancing and the user task processing. First, we construct a STIN model, which consists of the low earth orbit (LEO) satellites and the three types of BS, viz., MBS, small cell BS (SBS), and LEO-based BS (LBS). Then, the space-time graph (STG) [28], [29] is introduced to express the dynamic contact relationship between the LBSs and LEOs, where the transmission links are modeled in the light of the time-varying topology and the interrupted links of STIN. After that, the DUA mechanism is presented to address the problem of load balancing and task processing requirements. As two essential components of DUA, dynamic cell range extension (DCRE) is developed to change the coverage and transmit power of LBSs according to the backhaul capacity, and greedy-based user-centric user association with task classification (GUUAT) was employed to find the most suitable BS in the alternative BS set according to their own requirements. Our main contributions are:

1) *Analyze the characteristics of terrestrial nodes and the dynamic contact relationship of transmission links for STIN:* On the one hand, a STIN model with satellite backhaul links is designed to break the bottleneck of terrestrial backhaul capacity. On the other hand, the dynamic contact relationship is analyzed with STG by means of the spatial nodes' trajectories, and the transmission model is constructed to transfer data via considering intercell and intersatellite interferences. On the basis of the above analysis, the UA problem for resilient backhauling is formulated.
2) *Design DUA mechanism for STIN:* To solve the problems of load balancing and task processing in STIN, the DUA mechanism is proposed. As two essential components of DUA, DCRE is developed to balance the load between the satellite and terrestrial networks, and GUUAT is given to guarantee the task processing demands.
3) *Solve the DUA problem and reduce the complexity of DUA with the greedy algorithm:* Through the introduction of the greedy algorithm, the DUA problem in STIN is solved and the complexity of DUA is reduced. It is worth noting that the DUA problem is NP-hard. Thus, we transform it into subproblems. In order to further reduce the complexity of the algorithm, we initialize the target solution set before seeking the optimal solution for each subproblem.

The rest of this article is organized as follows. In Section II, we construct the STIN model, analyze the dynamic contact relationship between the nodes based on the STG, and describe the system diagram of DUA. In Section III, we provide the transmission models of both the terrestrial and terrestrial–satellite communications and define the UA problem in STIN. A specific DUA mechanism for STIN is designed in Section IV. Simulation results are presented in Section V, and finally, we conclude the article in Section VI. For convenience, we summarize all nonstandard abbreviations in Table I.

TABLE I
NONSTANDARD ABBREVIATION

Abbreviation	Paraphrase
MC	Macro cell
TSC	Traditional small cell
LSC	LEO-based small cell
SBS	Small cell base station
LBS	LEO-based base station
TST	Terrestrial-satellite terminal
UD	Ultra-dense
STIN	Satellite-terrestrial integrated networks
DCRE	Dynamic cell range extension
GUUAT	Greedy-based User-centric user association algorithm with task classification
DUA	Dynamic user association mechanism

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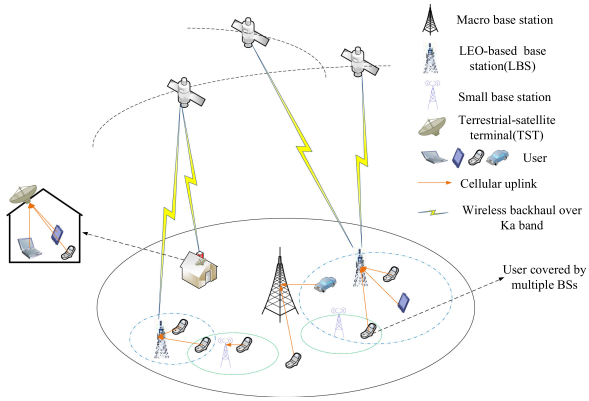

Fig. 1. Model of the STINs.

TABLE II
CHARACTERISTICS OF THE TERRESTRIAL NODES

Entities	MBS	SBS	LBS
Propagation delay (ms)	<1	<1	20-25
Coverage radius (km)	1-3	0.1-0.3	Dynamic changes
Backhaul link	Fiber links	Multi-hop wired links	Wireless links over Ka-band
Access link	Wireless links over C-band	Wireless links over C-band	Wireless links over C-band
Backhaul capacity	Fixed	Fixed	Dynamic changes

II. SYSTEM MODEL

In this section, we first construct the STIN model. Afterward, STG is introduced to analyze the dynamic contact relationship between the time-varying nodes. Finally, the system diagram of the DUA mechanism is given and described.

A. Network Model

A STIN model consisting of a terrestrial layer and satellite layer is shown in Fig. 1. The satellite layer consists of LEOs that periodically move at high speed along the orbit. Intersatellite links can be established between the satellites in the visible range, and then data can be transmitted to each other. The terrestrial layer consists of users, macrocells (MCs), traditional small cells (TSCs), and LEO-based small cells (LSCs). Each LBS at the center of each LSC is equipped with terrestrial–satellite terminal (TST) [30], which integrates the traditional BS functions and partial earth station functions, in other words, TST supports both the high-quality TST-satellite backhaul links over Ka-band and the user-TST links over C-band. Moreover, equipped with multiple independent antenna apertures [31], [32], each TST can be connected with multiple satellites simultaneously, which further improves the backhaul capacity of the LSCs. However, the fast periodic motion of satellites results in a dynamic time-varying feature of STIN, which further leads to frequent changes in the connectivity of satellite–terrestrial links and the backhaul capacity of satellite networks. For intercell interference management, we assume that the satellite operator and the traditional terrestrial operator cooperate to serve the users in a centralized manner. For the convenience of understanding, we have compiled the characteristics of the three types of BSs, as listed in Table II.

The propagation delay listed in Table II is the period during which the user sends data to the core network from the BS. It can be calculated by

$$T_{\text{trip}} = \frac{L_{\text{channel}}}{V} \tag{1}$$

where T_{trip} represents the propagation time, L_{channel} represents the channel length, and V represents the propagation rate of the electromagnetic wave on the channel. Therefore, the propagation delay of the data transmitted via using the terrestrial backhaul and the satellite backhaul is different. In addition, as can be seen from the Table II, users can access the core network in following three ways: 1) the MC with large backhaul capacity is supported by fiber links from the MBS directly to the core network; 2) the TSCs with very limited backhaul capacity are connected with the core network through multihop wired links; 3) the LBSs transmit user data to the satellite network over a dynamically changing wireless backhaul links, and then the satellite network forwards it to the core network.

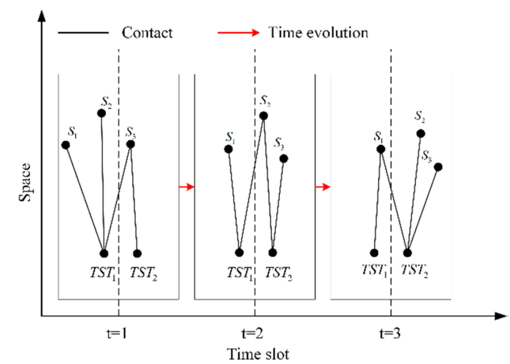

Fig. 2. Dynamic contact relationship between TSTs and LEOs.

B. Dynamic Network Analysis

As shown in Fig. 1, due to the periodic motion of satellites, the network topology and contacts of spatial links are time varying and intermittent. Moreover, users also move within the scene. In view of the above, a sequence of chronological static graphs is needed to model the time-evolving STIN topology. As shown in Fig. 2, each static graph is a snapshot of nodes and their interactions observed at a certain time slot, and the red arrow indicates the motion of the node in the interval between two time slots. Then, a dynamic network topology with a sequence of snapshots describes the evolution of contact between the nodes over a period of time.

In this article, the mobile BS is out of our considerations. Thus, we exhibit the dynamic contact relationship between the TSTs and LEOs with two fixed TSTs and three moving satellites as an example. With the rapid movement of satellites, the position of satellites in each snapshot will change, which will affect the connections in the satellite–terrestrial links.

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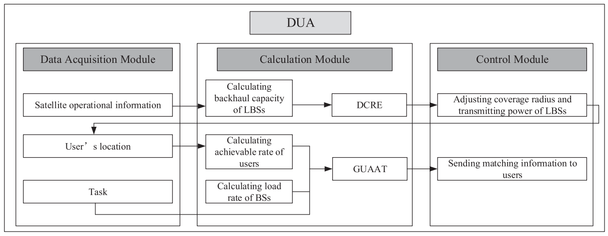

Fig. 3. System diagram of DUA.

C. System Diagram

In STIN, the complementary ground components are used as a relay to connect the satellite network and users [33]. Similarly, this relay is represented as LBS in the scene we proposed. Therefore, whether users use the terrestrial network as backhauling or the satellite network as backhauling, it must be related to the BS set. In view of this, DUA works on BSs.

Fig. 3 shows the system diagram of DUA, which is mainly composed of a data acquisition module, calculation module, and control module. At the beginning of each time slot, the data acquisition module determines the association relationship among the LBSs and satellites, the user's location, and the type of tasks generated by the user. Among them, since the satellite operates periodically, we can know the time when the satellite covers the BS through the constellation management company. According to the information provided by the data acquisition module, the calculation module will calculate the backhaul capacity of LBSs and the achievable rate of users. Moreover, the implementation of DCRE is based on the backhaul capacity of LBSs, while the implementation of GUAAT is based on the achievable rate of users, the load rate of BSs, and the type of tasks. Among them, DCRE will affect the user–BS association relationship because the user must be within the coverage of the BS to be associated with the BS. The main tasks of the control module include two aspects: 1) adjusting the coverage radius and transmitting power of LBSs based on the DCRE; 2) sending the matching information calculated by GUAAT to users.

III. Transmission Model and Problem Formulation

In this section, we first construct the transmission model of terrestrial communications and terrestrial–satellite communications by referring to [21] and [30]. Then, we analyze the characteristics of STIN and formulate the optimization problem.

A. Transmission Model for Terrestrial Communications

Denote the set of BSs and users as $\mathbf{B} = \{b_1, \ldots, b_j, \ldots, b_B\}$ and $\mathbf{U} = \{u_1, u_2, \ldots, u_U\}$, respectively. The MBS is denoted by $j = 1, 2 \leq j \leq J$ denotes SBSs, and $J + 1 \leq j \leq B$ denotes LBSs. Range_j represents the coverage radius of cell $b_j \in \mathbf{B}$, whose coordinate is (x_j, y_j). The coordinate of user $u_i \in \mathbf{U}$ is (x_i, y_i). Then the sight distance $d_{i,j}$ of u_i and b_j at time t can be expressed as

$$d_{i,j}(t) = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}. \tag{2}$$

To describe the relationship between the position of users and the coverage of each cell at time t, a binary coverage matrix $\mathbf{A}(t)$ of size $B \times U$ is introduced, where $a_{i,j}(t) = 1$ indicates that u_i lies within the coverage of b_j at time t, and $a_{i,j} = 0$ otherwise

$$\mathbf{A}(t) = \begin{array}{c} \\ b_1 \\ b_2 \\ \vdots \\ b_B \end{array} \begin{array}{c} \begin{array}{cccc} u_1 & u_2 & \cdots & u_U \end{array} \\ \begin{bmatrix} a_{11}(t) & a_{12}(t) & \cdots & a_{1U}(t) \\ a_{21}(t) & a_{22}(t) & \cdots & a_{2U}(t) \\ \vdots & \vdots & \ddots & \vdots \\ a_{B1}(t) & a_{B2}(t) & \cdots & a_{BU}(t) \end{bmatrix} \end{array} \tag{3}$$

where

$$a_{i,j} = \begin{cases} 1, & d_{i,j} \leq \mathrm{Range}_j \\ 0, & \text{otherwise.} \end{cases} \tag{4}$$

For cell b_j, the number of users in its coverage is $\sum_{i=1}^{U} a_{i,j}(t)$, which should satisfy $0 \leq \sum_{i=1}^{U} a_{i,j}(t) \leq U$. Similarly, for user u_i, the number of BSs that can be associated is $\sum_{j=1}^{B} a_{i,j}(t)$, which should satisfy $0 \leq \sum_{j=1}^{B} a_{i,j}(t) \leq B$.

At a certain moment, user u_i may have multiple accessible BSs but it can only be connected with one of the BSs at most, as shown in (6). In contrast, the BS b_j can access multiple users at the same time. In order to describe the association relationship between the users and BSs, a binary matrix $\mathbf{X}(t)$ of size $B \times U$ is introduced, where $x_{i,j}(t) = 1$ indicates that user u_i is served by cell b_j, and $x_{i,j}(t) = 0$ otherwise

$$\mathbf{X}(t) = \begin{array}{c} \\ b_1 \\ b_2 \\ \vdots \\ b_B \end{array} \begin{array}{c} \begin{array}{cccc} u_1 & u_2 & \cdots & u_U \end{array} \\ \begin{bmatrix} x_{11}(t) & x_{12}(t) & \cdots & x_{1U}(t) \\ x_{21}(t) & x_{22}(t) & \cdots & x_{2U}(t) \\ \vdots & \vdots & \ddots & \vdots \\ x_{B1}(t) & x_{B2}(t) & \cdots & x_{BU}(t) \end{bmatrix} \end{array} \tag{5}$$

$$\sum_{i=1}^{U} x_{i,j}(t) \leq 1 \quad \forall 1 \leq j \leq B. \tag{6}$$

The received signal of BS b_j sent by user u_i is then given by [30]

$$y_{i,j} = \sqrt{p_u} h_{i,j} x_{i,j} \delta_i + \underbrace{\sum_{i' \neq i} \sum_{j' \neq j} \sqrt{p_u} h_{i,j'} x_{i',j'} s_{i'}}_{\text{intercell interference}} + N_j \tag{7}$$

where p_u is the transmit powers of user, δ_i is the transmitted signal of user u_i, and the corresponding channel coefficient is $h_{i,j}$. The additive complex white Gaussian noise (ACWGN) at BS is denoted by $N_j \sim CN(0, \sigma^2)$, and σ^2 is the noise variance

$$h_{i,j} = g_{i,j} \beta_{i,j} (d_{i,j})^{-\alpha} \tag{8}$$

where $g_{i,j}$ is a complex Gaussian variable representing Rayleigh fading, $\beta_{i,j}$ follows log-normal distribution representing shadowing fading, and α represents the path loss exponent.

In the uplink environment, all cells operate in the same frequency resource pool and have a frequency reuse factor of one. The bandwidth of the terrestrial network is taken as W, and the channel takes a Rayleigh fading channel with an average of one. Thus, the SINR on the uplink of user u_i to BS b_j at time t can be expressed by [21]

$$\mathrm{SINR}_{i,j}(t) = \frac{p_i |h_{i,j}|^2}{\sigma^2 + \sum_{i' \in \mathbf{U}/i} x_{i',j}(t) p_{i'} |h_{i',j}|^2}. \tag{9}$$

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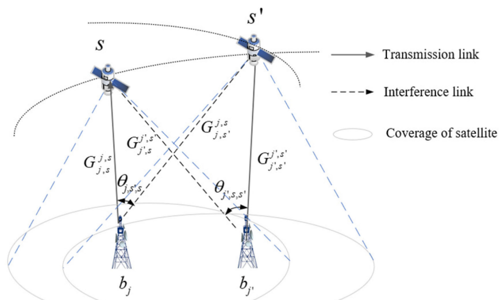

Fig. 4. Illustration of each LBSs antenna gain.

The achievable rate of each user u_i served by BS b_j at time t can be expressed by

$$C_{i,j}(t) = W\log_2(1+\mathrm{SINR}_{i,j}(t)). \tag{10}$$

Hence, the total capacity of each cell b_j at time t can be obtained by

$$C_j^{\mathrm{Access}}(t) = \sum_{i=1}^{U} x_{i,j}(t)C_{i,j}(t). \tag{11}$$

B. Transmission Model for Terrestrial–Satellite Communications

Denote the set of LEOs as $\mathbf{S} = \{1, 2, \ldots, S\}$.To describe the connection relationship between the LBSs and LEOs, a binary matrix $\mathbf{Q}(t)$ of size $(B - J + 1) \times S$ is introduced, where $q_{j,s}(t) = 1$ indicates that LBS b_j is connected with LEO s, and $q_{j,s} = 0$ otherwise. The transmit power of the TST b_j to the satellite s is set to be fixed, denoted as $p^L_{j,s}$. Thus, the received signal of satellite s sent by TST b_j is then given by [30]

$$\begin{aligned} y_{j,s} = {} & \sqrt{p^L_{j,s}G^{j,s}_{j,s}}h_{j,s}\delta_{j,s}q_{j,s} \\ & + \underbrace{\sum_{j\in[J+1,B}\sum_{s'\neq s}\sqrt{p^L_{j',s'}G^{j',s'}_{j',s}}h_{j',s}s_{j',s}b_{j',s} + N_s,}_{\text{intersatellite interference}} \\ & \forall J+1 \le j \le B, \quad s \in \mathbf{S}, \quad s' \in \mathbf{S} \end{aligned} \tag{12}$$

where $\delta_{j,s}$ is the transmitted signal of TST b_j to satellite s. The channel gain of the TST b_j-satellite s link is denoted by $h_{j,s}$, with both the large-scale fading and the shadowed-Rician fading [29]. As shown in Fig. 4, $G^{j,s}_{j,s}$ is the antenna gain of TST b_j toward satellite s and $G^{j',s'}_{j',s}$ is the off-axis antenna gain of TST $b_{j'}$ toward the direction of satellite s'. Denote the angular separation between the TST $b_{j'}$-satellites' link and the TST $b_{j'}$-satellite s link as $\theta_{j',s,s'}$. The item $G^{j',s'}_{j',s}$ is a function of $\theta_{j',s,s'}$, as shown in [34, Attachment III, Appendix 8]. ACWGN at satellite$s$ is $N_j \sim CN(0, \sigma^2)$.

The achievable rate of LBS b_j served by LEO s over Ka-band at time t can be expressed by

$$\begin{aligned} C_{j,s}(t) = {} & W^{Ka}\log_2 \\ & \times \left(1 + \frac{q_{j,s}(t)P^LG_{j,s}|h_{j,s}|^2}{\sum_{j'\in\{J+1,B\}/j} q_{j',s}(t)P^LG_{j',s}|h_{j',s}|^2 + \sigma^2}\right) \\ & \forall J+1 \le j \le B \end{aligned} \tag{13}$$

where W^{Ka} is the transmission bandwidth using the Ka-band.

We assume that satellite networks cover the earth seamlessly for the whole day; in other words, each LBS can connect with at least one LEO for backhaul, as shown in (14). Among them, N_r represents the number of antennas equipped with LBS for backhauling, that is, the maximum number of satellites that can be connected, which can be adjusted with the development of satellite networks

$$1 \le \sum_{s\in\mathbf{S}} q_{j,s}(t) \le N_r, \quad \forall J+1 \le j \le B. \tag{14}$$

Then, the total backhaul capacity of each LBS b_j at time t can be obtained by

$$\begin{aligned} & C_j^{\mathrm{Backhaul}}(t) = \sum_{s=1}^{S} q_{j,s}(t)C_{j,s}(t), \quad \forall J+1 \le j \le B \\ & \text{s.t. (14).} \end{aligned} \tag{15}$$

For the convenience of writings, in this article, we denote the backhaul capacity C_j^{Backhaul} is fixed when $b_j (1 \le j \le J)$.

C. Problem Formulation

Through the modeling analysis of STIN, the several characteristics of STIN can be obtained: 1) the backhaul capacity of the LBSs will dynamically change with the number of connected satellites; 2) the delays for uploading tasks in the terrestrial network and satellite network are different; 3) overlapping coverage between the cells. In fact, the accessible capacity of the cell is limited by the backhaul capacity. When the TST is connected with multiple satellites, the backhaul capacity increases and the accessible capacity also increases. Our goal is to find a UA scheme to balance the accessible capacity and the backhaul capacity in STIN.

In the uplink network, a common method is to maximize the network capacity as an optimization target to find an optimal UA strategy, as shown in the following:

$$\max f(\mathbf{X}(t)) = \sum_{j=1}^{B} C_j^{\mathrm{Access}}(t)$$

s.t. (6)

$$x_{i,j}(t) \le a_{i,j}(t) \quad \forall 1 \le i \le U, \quad 1 \le j \le B \tag{16a}$$

$$C_j^{\mathrm{Access}}(t) \le C_j^{\mathrm{Backhaul}}(t) \quad \forall 1 \le j \le B \tag{16b}$$

$$x_{i,j}(t) \in \{0, 1\} \tag{16}$$

where the constraint (16a) indicates that the user u_i is within the coverage of BS b_j, and (16b) indicates that the data rate accessed of BS b_j is not higher than the backhaul capacity.

In order to avoid local node congestions, the load balancing between the BSs is also considered. Denote the load rate [26] as ϕ, and the user will select the BS, which has the lowest load rate. At this point the optimization model is modeled as

$$\max\ f(\mathbf{X}(t)) = \sum_{i\in\mathbf{U}}\sum_{j\in\mathbf{B}}\frac{C_{i,j}(t)}{\phi_j(t)}$$

s.t. (6)

$$x_{i,j}(t) \le a_{i,j}(t) \quad \forall 1 \le i \le U, \quad 1 \le j \le B \tag{17a}$$

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$$C_j^{\text{remain}}(t) + C_j^{\text{Access}}(t) \le C_j^{\text{Backhaul}}(t)$$
$$\forall 1 \le j \le B \tag{17b}$$
$$x_{i,j}(t) \in \{0,\ 1\} \tag{17}$$

where $\phi_j(t)$ is the load rate of BS b_j at time t, $C_j^{\text{remain}}(t)$ is the load state of BS b_j at time t, and the constraint (17b) indicates that the total data rate of BS b_j is not higher than the backhaul capacity. It is worth noting that $C_j^{\text{remain}}(t)$ is provided by the BS b_j itself, which also represents the unprocessed capacity

$$\phi_j(t) = \frac{C_j^{\text{remain}}(t)}{C_j^{\text{Backhaul}}(t)}. \tag{18}$$

Assume that the processing rate of BS is v, the interval of time slot is *T*. Thus, the amount of data that BS can process is vT in a time slot t. The load state of BS j at time t can be obtained by

$$C_j^{\text{remain}}(t) = \begin{cases} C_j^{\text{Access}}(t-1) - vT, & C_j^{\text{Access}}(t-1) > vT \\ 0, & C_j^{\text{Access}}(t-1) < vT. \end{cases} \tag{19}$$

IV. DUA Mechanism in STIN

In this section, we first propose the DUA mechanism in general. Then, DCRE and GUUAT algorithms are proposed in detail.

A. DUA Mechanism

Listing all the possible values of $\mathbf{X}$ by exhaustive attack method requires $O(B^U)$ computational complexity, which is obviously undesirable for the network with a large number of BSs and users. Thus, the idea of a greedy algorithm is introduced and the original optimization problem is transformed into U user-centric subproblems. Each user only needs to find a BS that satisfies its own optimal utility function. Through traversing all users, the optimal $\mathbf{X}$ can be solved.

The network topology is constantly changing, which leads to dynamic changes on the user accessing and backhauling. Therefore, we first divide the network according to the STG to ensure that the network topology remains unchanged at time t. On this basis, DCRE is proposed to solve the utilization problem of different backhaul capacities caused by different connections in each snapshot. DCRE algorithm changes the coverage and transmits power of LBSs dynamically under different backhaul capacities, so as to flexibly adjust the number of associated users to achieve the purpose of load control. However, there is another problem, the requirements of task processing must be considered in STIN. The delay for using satellite network as backhauling will be much larger than that for ground network because of the high orbit and fast running speed of satellites. To solve this problem, we propose GUUAT, which considers the requirements of task processing requirements. In GUUAT, the optional BS set is first initialized for each user, and then each user selects the optimal BS to be associated in the set. And the optimal evaluation consists of rate, load, and task type. The optimal UA matrix $\mathbf{X}$ can be obtained by traversing all users. After that, users associate BSs according to $\mathbf{X}$, then the data is transmitted. Finally, in the next snapshot, all of the above is repeated.

Algorithm 1: Dynamic Cell Range Extension.

Input: LBS set $\{J+1, \ldots, B\}$, R, C_j^{single}, Range^*, P^*
Output: $\text{Range}_j(t)$, $P_j(t)$
while $\{J+1, \ldots, B\} \neq \emptyset$ **do**
  Calculate the backhaul capacity of LBS $b_j (J+1 \le j \le B)$ at time t.
  if $[\frac{C_j^{\text{backhaul}}(t)}{C_j^{\text{single}}}] \neq 0$ **then**
    $\text{Range}_j(t) \leftarrow \text{Range}^* + R[\frac{C_j^{\text{backhaul}}(t)}{C_j^{\text{single}}}]$
    $P_j(t) \leftarrow P^* \cdot (\frac{\text{Range}_j(t)}{\text{Range}^*})^{-\alpha}$
  end if
  $\{J+1, \ldots, B\} \leftarrow \{J+1, \ldots, B\} - j$
end while
return $\text{Range}_j(t)$, $P_j(t)$

The whole process of the scheme is shown in Fig. 5, which is divided into the following main steps.

Step 1: Calculate the backhaul capacity of LBSs at time t.
Step 2: Execute DCRE.
Step 3: Calculate the accessible BSs set $\mathbf{Z}_i(t)$ for each user.
Step 4: Execute GUUAT.
Step 5: Users associate BSs according to the association matrix $\mathbf{X}$ and transmit data.
Step 6: $t = t + 1$. Repeat all above steps.

The calculation of the first step is given in Section III-B. Then, DCRE (Step 2) is completed on the basis of the first step. The detailed process of DCRE is described in Section IV-B. Step 3 is the initiation of Step 4. They will be described in detail in Section IV-C. As two essential components of DUA, DCRE can balance the load of ground and satellite networks, and GUUAT can guarantee the requirements of the user task processing.

B. Dynamic Cell Range Extension

The integration of satellite networks and the terrestrial networks not only increases the choice of users to access the core network but also expands the overall capacity of the network. However, the fast periodic motion of satellites results in the dynamic time-varying feature of STIN, which further leads to frequent changes in the connectivity of satellite–terrestrial links and the backhaul capacity of satellite networks. In practice, the accessible capacity is limited by the backhaul capacity. This further creates a new problem. When the satellite network can access a large amount of capacity, there are not enough users in the coverage of LBSs, which results in wasting resources. To adapt to the difference of backhaul capacity among different LBSs, cell-specific CRE bias in which each small cell is assigned a distinctive CRE bias value [27] is needed to optimize the cell ranges more accurately and further promote the system performance. Hence, to balance the accessible capacity of STIN under the intermittent connectivity and dynamic backhaul capacity, an effective mechanism is needed. Hence, we design the DCRE according to the resilient backhaul capacity, as shown in Algorithm 1.

The precondition for the user to associate the BS is within the coverage of the BS. Therefore, in order to increase the number of

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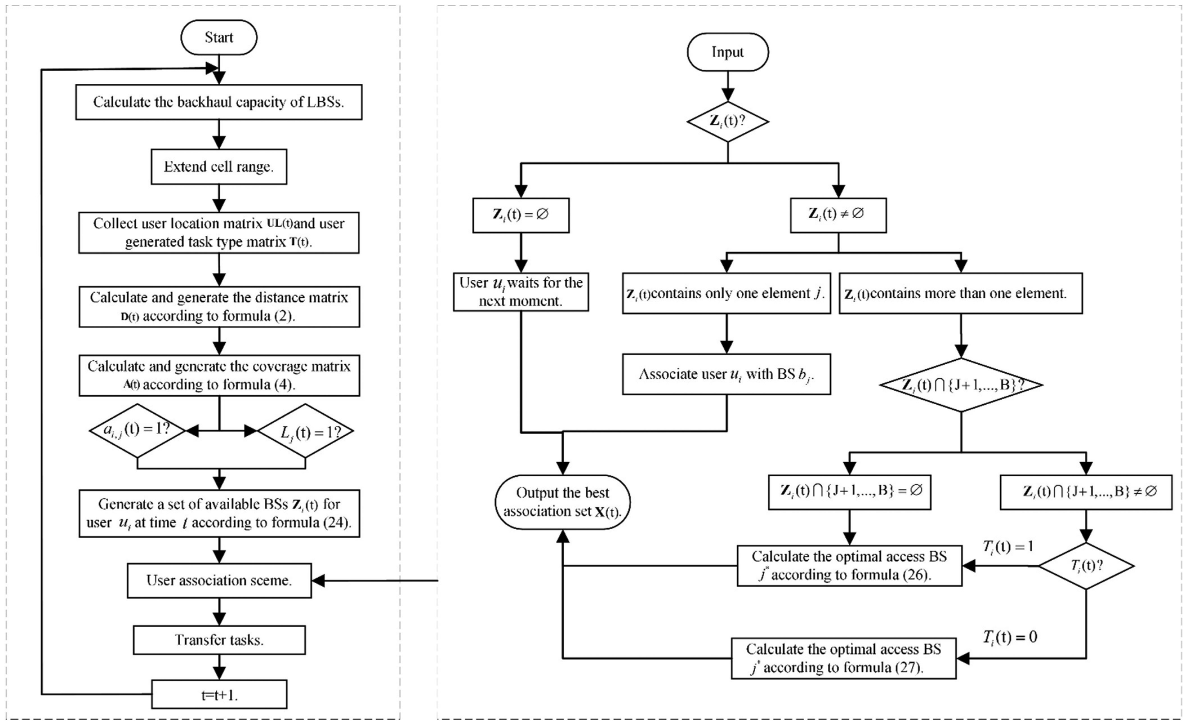

Fig. 5. Flowchart of DUA mechanism.

users, which associate with the BS, the coverage of the BS must be increased. In addition, due to the seamless global coverage of UD satellite constellations, LBSs can be associated with at least one satellite. Based on the above reasons, the coverage radius expansion with the dynamic change of LBSs backhaul capacity is calculated in the following:

$$\mathrm{Range}_j(t) = \begin{cases} \mathrm{Range}^* + R\left[\dfrac{C_j^{\mathrm{Backhaul}}(t)}{C_j^{\mathrm{single}}}\right], & \left[\dfrac{C_j^{\mathrm{Backhaul}}(t)}{C_j^{\mathrm{single}}}\right] > 1 \\ \mathrm{Range}^*, & \left[\dfrac{C_j^{\mathrm{Backhaul}}(t)}{C_j^{\mathrm{single}}}\right] = 1 \end{cases} \quad \forall J+1 \le j \le B \tag{20}$$

where [.] represents the rounding function, Range^* represents the given coverage radius of the BS $b_j(J+1 \le j \le B)$, *R* represents the step size, and C_j^{single} indicates the backhaul capacity of BS $b_j(J+1 \le j \le B)$, which is associated with a single satellite.

Simply the number of users covered increases with the increase of the coverage area of the BS but users in the extended area may not decide to access the BS due to the utility function of the UA algorithm. A common UA decision is that the user chooses the BS with the best channel quality. Channel quality is affected by power and fading. Therefore, we use equal boundary road loss to satisfy the QoS of edge users and then get the power update

$$P_j(t) = P^* \cdot \left(\frac{\mathrm{Range}_j(t)}{\mathrm{Range}^*}\right)^{-\alpha} \quad \forall J+1 \le j \le B \tag{21}$$

where P^* is the given transmit power of BS $b_j(J+1 \le j \le B)$.

C. Greedy-Based User-Centric UA Algorithm With Task Classification

Different from the ground network, the high orbit of the satellite network results in a long propagation delay, which makes it conditional to use the satellite network as backhauling. Thus, the data to be transmitted must meet the condition to make this method reasonable. In fact, the types of tasks generated by users are different, and the delay requirements of task processing are also different. To sum up, in order to meet the needs of users, task classification must be considered when choosing the backhaul network. In other words, after the implementation of DCRE, with the increase of the backhaul capacity of LBSs, the transmit power and coverage increase to absorb more users into the satellite network but forwarding data to the core network through the satellite network may result in longer delays, which is not in line with the demand of users who wish to process tasks faster. Similarly, the delay-tolerant tasks may access the terrestrial network due to the faster transmission rate, which will occupy the network resources of the delay-sensitive tasks. Therefore, in order to meet the requirements of task processing, we introduce task classification which is represented by a binary matrix $\mathbf{T}$, where $T_i = 1$ indicates that the user u_i generates delay-sensitive task, in contrast, $T_i = 0$ indicates that the user u_i generates delay-tolerant task

$$T_i = \begin{cases} 1, \text{delay} - \text{sensitive task} \\ 0, \text{delay} - \text{tolerant task.} \end{cases} \tag{22}$$

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The task classification is added to the optimization procedure, as shown in the following:

$$\max\ f(\mathbf{X}(t)) = \sum_{i=1}^{U}\sum_{j=1}^{B}\frac{C_{i,j}(t)}{\phi_j(t)}$$

s.t. (6)

$$x_{i,j}(t) \le a_{i,j}(t),\quad \forall 1 \le i \le U,\quad 1 \le j \le B \tag{23a}$$

$$C_j^{\text{remain}}(t) + C_j^{\text{Access}}(t) \le C_j^{\text{Backhaul}}(t)\ \forall 1 \le j \le B \tag{23b}$$

$$j \in \begin{cases}\{1,\ldots,J\}, & \text{if } T_i = 1\\ \{J+1,\ldots,B\}, & \text{if } T_i = 0\end{cases} \tag{23c}$$

$$x_{i,j}(t) \in \{0,\ 1\} \tag{23}$$

where the constraint (23c) indicates that delay-sensitive tasks access to the terrestrial network and delay-tolerant tasks access to the satellite network.

Using the idea of the greedy algorithm, we transform the problem of solving the optimal association matrix $\mathbf{X}$ into the problem of solving the optimal association BS for each user, as shown in the following:

$$j_i^*(t) = \text{argmax}\sum_{j\in\mathbf{Z}_i}\frac{C_{i,j}(t)}{\phi_j(t)},\quad i \in \mathbf{U}$$

s.t. (6)

$$x_{i,j}(t) \le a_{i,j}(t),\quad \forall 1 \le i \le U,\quad 1 \le j \le B \tag{24a}$$

$$C_j^{\text{remain}}(t) + C_j^{\text{Access}}(t) \le C_j^{\text{Backhaul}}(t)\ \forall 1 \le j \le B \tag{24b}$$

$$j \in \begin{cases}\{1,\ldots,J\}, & \text{if } T_i = 1\\ \{J+1,\ldots,B\}, & \text{if } T_i = 0\end{cases} \tag{24c}$$

$$x_{i,j}(t) \in \{0,\ 1\}. \tag{24}$$

To reduce the computational complexity, we first initialize the alternative BS set for each user. In the STIN scenario, the user u_i must satisfy two conditions to access the BS b_j: 1) the user u_i is within the coverage of the BS b_j; 2) the BS b_j is not overloaded. The case that both conditions are satisfied at the same time can be characterized by (25). The user u_i can access the BS b_j and is represented by $\text{Count}_{i,j} = 1$, and $\text{Count}_{i,j} = 0$ otherwise

$$\text{Count}_{i,j}(t) = A_{i,j}(t)L_j(t) \tag{25}$$

where L_j represents the load status of the BS b_j at the current moment, and

$$L_j = \begin{cases}1,\ \text{C}_j^{\text{remain}} < C_j^{\text{Backhaul}}\\ 0,\ \text{C}_j^{\text{remain}} \ge C_j^{\text{Backhaul}}\end{cases} \tag{26}$$

where $L_j = 1$ indicates that the load has not overflowed, and $L_j = 0$ otherwise.

Denote $\mathbf{Z}_i(t)$ as the set of all accessible BSs of the user u_i at the current time t. So, $\mathbf{Z}_i(t)$ is a set of all b_j that satisfy condition $\text{Count}_{i,j} = 1$. By determining the accessible BS set $\mathbf{Z}_i(t)$ to avoid traversing all BSs causing unnecessary processing delays. For each user u_i, the optimal associated BS $j_i^*(t)$ in $\mathbf{Z}_i(t)$ can be solved by (27) or (28), and the optimal association matrix $\mathbf{X}(t)$ at time t can be obtained by traversing all users. The process of GUUAT is described in Algorithm 2.

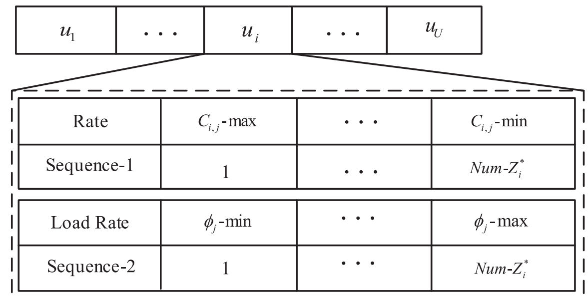

Fig. 6. Solution process based on sorting.

Algorithm 2: Greedy-Based User-Centric UA Algorithm With Task Classification.

Input: $\mathbf{B}$, $\mathbf{U}$
Output: $\mathbf{X}$
while $\mathbf{U} \ne \emptyset$ **do**
  Calculate the accessible BSs set $\mathbf{Z_i}(t)$ of user u_i at time t.
  if $\mathbf{Z_i}(t) \ne 0$ **then**
    $x_{i,j} \leftarrow 0,\quad j \in \mathbf{B}$
  else
    if $\mathbf{Z_i}(t) \cap \{J+1,\ldots,B\} = \emptyset$ **then**
      $j_i^*(t) = \text{argmax}\frac{C_{i,j}(t)}{\phi_j(t)},\quad j \in \mathbf{Z_i}(t)$
      $x_{i,j_i^*} \leftarrow 1$
      $x_{i,j} \leftarrow 0,\quad j \in \mathbf{B}/j_i^*$
    else
      if $T_i = 1$ **then**
        $j_i^*(t) = \text{argmax}\frac{C_{i,j}(t)}{\phi_j(t)},\quad j \in \{\mathbf{Z_i}(t) \cap \{J+1,\ldots,B\}\}$
        $x_{i,j_i^*} \leftarrow 1$
        $x_{i,j} \leftarrow 0,\quad j \in \mathbf{B}/j_i^*$
      else
        $j_i^*(t) = \text{argmax}\frac{C_{i,j}(t)}{\phi_j(t)},\quad j \in \{\mathbf{Z_i}(t) \cap \{1,\ldots,J\}\}$
        $x_{i,j_i^*} \leftarrow 1$
        $x_{i,j} \leftarrow 0,\quad j \in \mathbf{B}/j_i^*$
      end if
    end if
  end if
  $\mathbf{U} \leftarrow \mathbf{U} - i$
end while
return $\mathbf{X}$

The detailed process is as follows. If $\mathbf{Z}_i(t) = \emptyset$, which means that there is no BS that satisfies the condition for the user access, so the user needs to wait for the next moment. If $\mathbf{Z}_i(t) = \emptyset$ and contains only one element b_j, the element b_j is the optimal connection BS of the user. The $\mathbf{Z}_i(t) \ne \emptyset$ and contains more than one element, which means that the user can access more than one BS, including terrestrial network access points and satellite network access points. At this time, in order to avoid the delay-sensitive tasks access to the satellite network, we will judge whether it can access the satellite network. The judgment method is $\mathbf{Z}_i(t) \cap \{J+1,\ldots,B\}$. If

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$\mathbf{Z}_i(t) \cap \{J+1,\ldots,B\} = \emptyset$, which indicates that the satellite network cannot be accessed, the optimal access BS j^* of user u_i is calculated according to

$$j_i^*(t) = \operatorname{argmax} \frac{C_{i,j}(t)}{\phi_j(t)}, \quad j \in \mathbf{Z}_i(t). \tag{27}$$

If $\mathbf{Z}_i(t) \cap \{J+1,\ldots,B\} \neq \emptyset$, which indicates that the user u_i can access the satellite network, the type of user-generated task needs to be detected. If $T_i = 1$, which indicates that the user u_i wants to access the terrestrial network to complete the task quickly, the optimal association BS j^* of user u_i is calculated according to (27). If $T_i = 0$, it indicates that the user u_i has a higher tolerance for task processing time. Thus, it is now necessary for the user to connect the satellite network to reduce the load of the terrestrial network and release the terrestrial network resources for delay-sensitive tasks. Therefore, the optimal association BS of user u_i is calculated according to

$$j_i^*(t) = \operatorname{argmax} \frac{C_{i,j}(t)}{\phi_j(t)}, \quad j \in \{\mathbf{Z}_i(t) \cap \{J+1,\ldots,B\}\}. \tag{28}$$

To obtain the solutions of (27) and (28), $C_{i,j}(t)$ are sorted [35] from large to small, and the ordinal numbers are from small to large, starting from one, as shown in Fig. 6. Similarly, $\phi_j(t)$ are sorted from small to large, and the ordinal numbers are sorted from small to large, starting from one. $\mathbf{Z}_\mathbf{i}^*$ is a set of eligible BSs, and $\mathbf{Z}_\mathbf{i}^* = \mathbf{Z}_i(t) \cap \{1,\ldots,J\}$ in (27) and $\mathbf{Z}_\mathbf{i}^* = \mathbf{Z}_i(t) \cap \{J+1,\ldots,B\}$ in (28). The number of eligible BSs is denoted as $\mathrm{Num}-\mathbf{Z}_\mathbf{i}^*$. Adding two ordinal numbers about BS $j \in \mathbf{Z}_\mathbf{i}^*$ to get a new ranking, the smallest one is the optimal solution.

In order to analyze the time complexity of DUA, Lemma 1 is defined in the following.

Lemma 1: Assume that the number of BSs is n, the number of LBSs is m, and the number of users is u. During T time slots, the time complexity of the DUA is $\mathrm{O}(mT + Tun\log(n))$.

Proof: The complexity of the DUA consists of the complexity of DCRE and GUAAT. The time complexity of DCRE is $\mathrm{O}(m)$ because we only need to compute m times backhaul capacity. During the operation of GUAAT, we need to traverse u users. And traversing each user, we need to execute three times sorting algorithms. For getting the achievable rate sorting and load rate sorting of BS set covering users, we need to do two sorting algorithms. In addition, we need to do a sorting algorithm for selecting the most suitable BS for the user. Assume that we use fast sorting whose complexity is $\mathrm{O}(n\log(n))$. Thus, the time complexity of GUAAT is $\mathrm{O}(un\log(n))$. To summarize, the time complexity of DUA is

$$\mathrm{O}(T(m + un\log(n))) = \mathrm{O}(mT + Tun\log(n)). \tag{29}$$

V. Simulation Results

A. Parameters Setting

To verify the effectiveness of our proposed DUA mechanism, MATLAB is used as the simulation environment. The envisioned STIN consists of the LEOs and the three types of BS, viz., MBS, SBS, and LBS. The layout of BSs is a 1000×1000 m area covered by an MBS, including 1 MBS, 10 SBSs, 5/10/15 LBSs, and 500 users. The location of MBS is in the middle, while SBSs and LBSs are distributed uniformly in the coverage area, and users are randomly generated in the coverage area. We set ideal backhaul for the MC, and all TSCs and the backhaul capacity interval of LBSs are obtained from the simulation results in [30]. Since the LBSs we set are generated within the coverage of MC, for satellites with the orbital heights of several hundred kilometers or even more than 1000 km, the elevation angle change in a small range is negligible and, thus, the backhaul capacity of LBSs in the scene is the same. We suppose that the backhaul capacity of LBS associated with a single satellite is 20 megabits per second (Mb/s). The small-scale fading over C-band is modeled as Rayleigh fading. All simulation parameters are listed in Table III.

TABLE III
Major Simulation Parameters

Parameter	Value
Cover radius of MBS	1000m
Cover radius of SBS	150m
The number of SBSs	10
The number of LBSs	5/10/15
Number of users	500
Transmit power of user	23dBm
Transmit power of MBS	46dBm
Transmit power of SBS	33dBm
Road loss index	3.76
C-band bandwidth	20MHz
Backhaul capacity of MC	150Mbps
Backhaul capacity of each TSC	20Mbps
Noise density	-174dBm/Hz
Step size R	50m
The given coverage radius of LBSs	150m
The given Transmit power of LBSs	33dBm

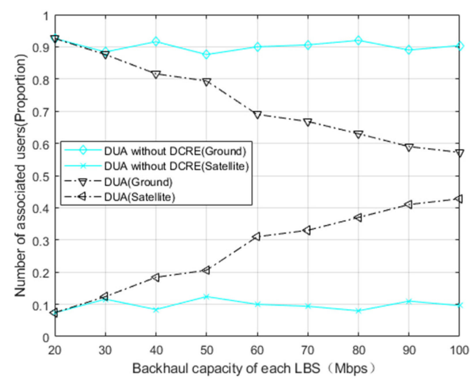

Fig. 7. User access proportion distribution of DUA with or without using DCRE.

B. Result Analysis

In order to verify the impact of the proposed DCRE on the effect of load balancing, we made two comparisons: 1) the user access proportion distribution of DUA using DCRE or not using DCRE, as shown in Fig. 7; 2) the user access proportion distribution of the three algorithms using DCRE or not using DCRE is simulated by using the proposed DUA, the classic RSRP association algorithm, and the max-sum rate association algorithm, as shown in Fig. 7. Assuming that DCRE is not used, the coverage radius and transmitting power of LBSs are set to be the same as SBS. Moreover, the configuration set

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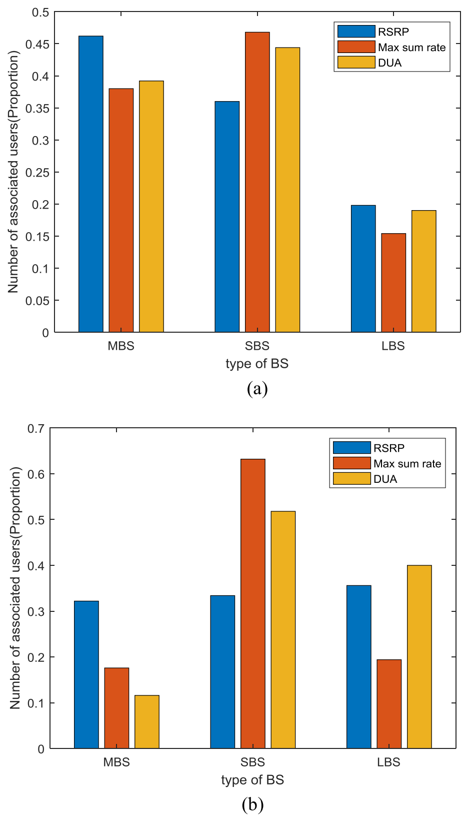

Fig. 8. (a) Proportional distribution of user accessing without using DCRE. (b) Proportional distribution of user access with using DCRE.

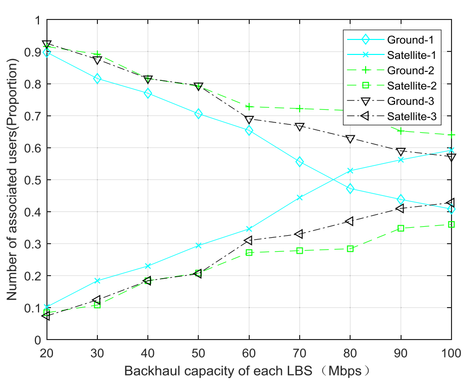

Fig. 9. Impact of backhaul capacity on UA.

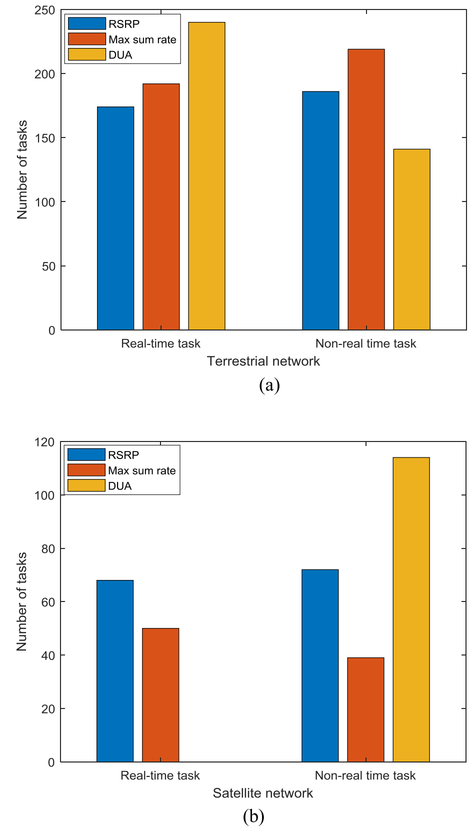

Fig. 10. (a) Task distribution of terrestrial network accessed. (b) Task distribution of satellite network accessed.

of BSs is 1 MBS, 10 SBSs, and 5 LBSs. It is worth noting that Figs. 7–10 all adopt this configuration set. In Fig. 7, with the increase of the backhaul capacity of LBSs, the user access proportion of DUA without DCRE tends to be stable, and the fluctuation is caused by the random movement of users. On the contrary, due to the use of DCRE, the user access proportion of satellite network will increase with the increase of the backhaul capacity of LBSs. The reason is that DCRE has expanded the coverage area of LBSs, which will result in an increase in the number of users within LBSs coverage. Thus, DCRE can ensure the reasonable utilization of satellite backhaul resources. To demonstrate the universality of DCRE, the second comparison is performed. The backhaul capacity of LBSs is set as 50 Mb/s. By comparing Fig. 8(a) with (b), it can be seen that DCRE enables the three algorithms to achieve balancing the load of the terrestrial network and the satellite network, and our proposed algorithm performs the best in the current state. In fact, RSRP is mainly affected by the transmit power of BS, DUA is mainly affected by the coverage of BS, and max-sum rate-based UA is only affected by the user's transmit power and interference from other users in the cell, so, the DCRE has a greater impact on RSRP and DUA due to the enhancing coverage and transmit power of BS.

The dynamic backhaul capacity of LBSs will impact the load balancing of the whole network. Hence, to verify this impact, we compare the RSRP association algorithm, the max-sum rate association algorithm, and the proposed DUA. We set the backhaul capacity of each LBS to gradually increase from 20 to 100 Mb/s, as shown in Fig. 9. In particular, here, we used the DCRE. In Figs. 1–3 and 9, represent the RSRP association algorithm, the max-sum rate association algorithm, and the DUA, respectively. As can be seen from the figure, with the increase of backhaul capacity, the effect of DCRE on load balancing becomes more and more significant. Among them, the RSRP association algorithm is the best, the max-sum rate association algorithm is the worst, and the DUA is between the two algorithms. Thus, the dynamic backhaul capacity will affect the UA strategy.

Since the backhaul time of the satellite network is much longer than that of the terrestrial network, we must consider the processing requirements of tasks. As shown in Fig. 10, we

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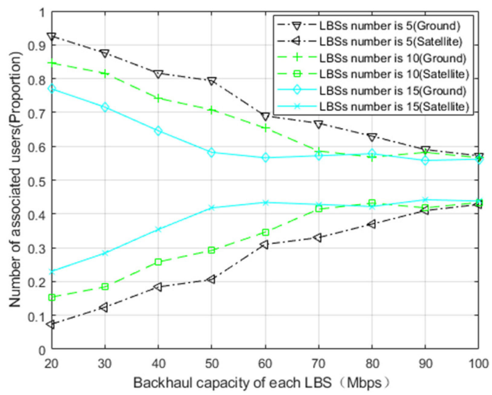

Fig. 11. Impact of the number of LBSs on UA.

have compared the task types accessed by three UA algorithms. The results show that the DUA supports the most real-time tasks and the least nonreal-time tasks compared with the RSRP association and the max-sum rate association algorithms in the tasks of ground network accessed. On the contrary, in the tasks of satellite network accessed, the RSRP association and the max-sum rate association algorithms not only have accessed nonreal-time tasks but also have accessed a large number of real-time tasks. However, tasks by DUA accessed are all nonreal-time tasks, which ensure the QoS of users is covered by both satellite networks and terrestrial networks. Similarly, this also demonstrates the effectiveness of the DUA.

The number of LBSs is related to the coverage of LBSs, and the change of coverage will affect the user access. Therefore, we simulate based on the different configuration sets of LBSs (the number of LBS is 5/10/15), and the result is shown in Fig. 11. When the number of LBSs is 15 and the backhaul capacity of LBSs is more than 60 Mb/s, the user access proportion tends to be stable. The reason is that, at this time the coverage area of LBSs and MBS basically overlaps. Thereby, as long as the conditions are met, all users can choose to access the satellite network. Similarly, when the number of LBSs is ten and the backhaul capacity of LBSs is more than 80 Mb/s, the user access proportion tends to be stable. Moreover, when the number of LBSs is five, the impact of backhaul capacity on user access will be from the beginning to 100 Mb/s. Therefore, the DUA mechanism is more applicable to a limited number of LBSs, which will provide a reference for laying such network infrastructure in the future.

VI. Conclusion

In this article, we have proposed the DUA mechanism to deal with the problem of UA affected by resilient backhauling in STIN. Compared with the traditional UA, our proposed DUA mechanism well addresses the problems of load balancing and meets user's task processing requirements in STIN. We have analyzed the characteristics of terrestrial nodes and the dynamic contact relationship for STIN. To address the problem of load balancing and task processing requirements, the DUA mechanism has been proposed. As two essential components of DUA, algorithms of DCRE and GUUAT are used to optimize the load balance and guarantee the task processing demands separately. Simulation results have demonstrated several results as follows: 1) dynamic backhaul affects UA strategy; 2) our proposed DCRE algorithm can effectively adjust the network load; 3) compared with RSRP association and max-sum rate association algorithms, our proposed DUA mechanism can effectively adjust the network load and guarantee the task processing demand in STIN; and 4) through the simulation comparation of different parameter sets, we find that we can maximize the network performance by setting up LBS reasonably. Some promising avenues for future research are to extend our results to a more complex STIN scenario, e.g., the satellite layer is a multilayer satellite network, or the ground layer is a complex HetNets.

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