MaCRo: Mega-Constellations Routing Systems with Multi-Edge Cross-Domain Features

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Abstract

With satellite networks evolving toward gigantic, hybrid, and heterogeneous, non-terrestrial networks (NTN) have become one of the key research topics in 6th Generation (6G) networks. Routing, as the basic technology in NTN, has faced severe challenges. With the continuous increase of satellite constellation, for example, the huge control signaling overhead, frequent link disruption, and multi-mode traffic requirements are problems. In this article, a novel Mega-Constellations Routing (MaCRo) system with multi-edge and cross-domain features is proposed. Control and user plane are separated in order to support flexible network management of multi-layer satellite networks, based on software defined networks (SDN) and multi-access edge computing (MEC) technologies. Cross-domain resources, including communication, storage, computing, conception, and control, are utilized to realize unified scheduling for task-oriented routing. Four typically collaborative modes are discussed and the corresponding functional difference are summarized and compared. Finally, cases are studied and illustrated with key procedures, including intelligent area-segmentation routing and computational power routing. Numerical results show that the hybrid mode proposed in the MaCRo systems outperforms the other routing modes in average end-to-end latency and packet loss rate. The proposed routing system appears to be highly attractive as part of the future 6G NTN networks.

Introduction

Motivation

In recent years, the fifth generation mobile communication technology (5G) has come into people's daily life, expanding the connection between people to the interconnection of everything. However, from a global perspective, the coverage of terrestrial networks is only about 30 percent, limited by the infrastructure restrictions and geographical constrains. Satellite communications, as a natural complementary role, has become a crucial part of 6G NTN systems, due to the flexible networking, wide-coverage capability, high-resilience [1].

With the maturity of design and manufacturing of the Low Earth Orbit (LEO) satellite, a mega-constellation era has come [2]. On the one hand, fast-growing technologies, such as mass and modular production, reusable rockets, and "multiple stars in one arrow," have significantly lowered the cost of production and launch. On the other hand, the progress in integrated circuit, together with laser and microwave inter-satellite link (ISL) technologies, has laid the foundation for higher on-board processing capability and high-capacity inter-satellite networking. By the end of 2022, the global number of on-orbit satellites has reached 7,218, accelerated by the success of commercial satellite communication industry. Starlink, as the leading role, has already provided services to nearly 500,000 users worldwide with 3108 satellites [3].

Routing, as a basic technology to ensure inter-connection among different nodes, has been extensively researched in terrestrial networks. However, it can be hardly adapt to the satellite networks directly, facing new challenges about fast-vary topology, limited resources and network breakdown in complex satellite systems [4]. Routing strategies in small-scale satellite networks also bring a huge number of signaling interactions, intolerant latency and unbearable complexity, severely affecting the performance in mega-constellations. Therefore, in this article, the mega-constellations routing systems (MaCRo) with multi-edge cross-domain features is proposed to cope with the above mentioned shortcomings.

With the support of SDN and MEC technology, the natural characteristics of "multi-edge" networks are utilized, constituted of ground controller center (GCC), LEO, medium earth orbit (MEO) and geostationary earth orbit (GEO) satellites, with control and user plane separated in each layer. Four collaborative modes, including backhaul mode, hosted mode, cluster mode, and hybrid mode, are discussed to integrated the isolated edges in typical scenarios, realizing flexible and low-complexity network management.

In addition, to meet the task-focused requirements, for example, fast target recognition and on-board image processing, the "cross-domain" features are utilized to improve the overall routing performance. So that the calculation of the routing is the combination of both computing and transmission simultaneously in our proposed systems, considering cross-domain capabilities, including communication, storage and computing power.

Related Works

The 3rd Generation Partnership Project (3GPP) has started the specification of NTN since March

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ISSN: 1536-1284
Digital Object Identifier: 10.1109/MWC.006.2300216

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2017 from Release 15, for example, TR 38.811 and 38.821, attempting to extend the air interface, waveform, and protocols of the cellular networks to the satellite systems [5]. Potential solutions are proposed from both academic and industry, for integrating NTN enhancements into 5G NR systems. As an important part of NTN, routing strategy is also in urgent need of innovation.

Based on whether the ISL states are perceived, typical routing algorithms can be divided into static and dynamic routing strategies. Compared with static routing, dynamic routing can adjust routing decisions based on real-time conditions, outperforming in congestion control, fault avoidance, and load balancing. Typically, these dynamic routing can be categorized into virtual topology-based, virtual node-based, and coverage area-based routing algorithms based on the calculation strategy. The virtual topology-based routing algorithm uses the periodic characteristics of the satellite network to slice a dynamic network into multiple time slices, within which the network topology is assumed to remain stable. Thus the routing table is calculated based on the static network topology in each time slot and keeps updating along with time slices [6]. On the contrary, the virtual node-based routing algorithm divides the ground into multiple fixed areas and virtualizes the satellite nodes into fixed nodes, where each fixed node continuously covers an area. This masking successfully shields of network topology varying [7]. The coverage area-based routing algorithm utilizes the regularity of LEO satellite network changes and the periodicity of its topology structure to obtain the status information of the link between the current satellite and its neighbor nodes. Logical address is added to the data packet to mask satellite mobility. Satellites can generate routing decisions based on the obtained link and node information, topology, and logical address information [8].

Although there are lots of satellite routing algorithms as mentioned above, the calculation of routing table is the most essential part to the mega-constellations. Based on where to calculate, routing algorithms can be classified into centralized and distributed routing schemes. The centralized routing algorithm is characterized by requiring the central node to compute and send routing tables to all satellites in the network. This central node is typically the ground control center or a high orbit satellite, for example, the typical Werner's virtual topology routing algorithm [5]. In contrast, the distributed routing algorithms calculate the routing tables independently and make decisions autonomously, achieving better flexibility by sacrificing global optimization and on-board computing power resources.

Characteristic of Mega-Constellations Systems

In this section, the key features of MaCRo are summarized and the threats and opportunities are concluded for large-scale satellite systems.

Key Features of Mega-Constellations

Hybrid and Heterogeneous: The mega-constellation network is hybrid and heterogeneous, consisting of multi-layer satellite nodes with different altitudes, various inclinations, distinctive on-board capability and imbalanced resources. In addition, the satellite network users vary from handheld terminals to very small aperture terminal (VSAT) stations, as well as automotive, train, aircraft (including helicopter), ship and other "on the move" carriers. So the satellites operate on quite different uplink and downlink band, sub-carrier spacing, bandwidth and transmission power, resulting in multiple air interfaces with coexisting protocols, such as 5G new radio (NR) and digital satellite TV system (DVB-S), and so on.

High-Dynamic and Large Load Bearing: Compared with the terrestrial networks, the mega-constellations have significantly high dynamic features. Firstly, the network is a complex communication system with multiple ISLs, where different satellites move periodically according to the rules of ephemeris. The fast-varying locations in space lead to frequent inter-orbit links establishing and interrupting when entering and leaving the polar circle. Also, the constantly changing topology requires frequent updates, resulting in significant signaling overhead. Secondly, factors such as electromagnetic interference in space, man-made destruction, and internal failures caused by the complex outer-space environment, also affect the topology and ISLs. The increase, decease, and update of nodes, have increased the difficulty of management and control of the network.

At last, the mega-constellations have much larger traffic load, taking advantage of the multi-beam and wide coverage characteristics. It is necessary to guarantee the QoS with frequent switching of ISLs and achieve the load balancing while routing.

Diversified Service Requirements: Constrained by the physical available space and consumption power, the on-board processing capabilities, for example, communication, storage, computing and sensing resources, are significantly lower than those in terrestrial networks. The service requirements diverse in spatial, temporary and content domain. For one thing, the distribution of traffic fluctuates temporally and varies geographically affected by the economic, population density and user behavior. For another, the services vary greatly in terms of rate, latency, energy consumption, and reliability. Specifically, the task-oriented services, such as target identification, fast on-board processing, and wide-area internet of things (IoT) communications, have various quality-of-service (QoS) constrains and properties [9].

In conclusion, in terms of networking, capability and requirements, mega-constellations have lots of typical features constituting a complex network with "multi-edge" layers and "cross-domain" resources. The system take the above characteristics into consideration for better network performance.

Threats and Opportunities in Mega-Constellations Routing Systems

In this subsection, based on the above mentioned key features, the routing systems in mega-constellations are discussed from the perspective of both threats and opportunities.

Control Overhead and SDN: Due to the high dynamic changes of topology, ISLs keep switching frequently. The network requires more signaling interactions to gather real-time network status and send the calculated re-routing strategy to the related nodes, bringing huge control overhead on network management and reconfiguration. Because of the expired routing table computation

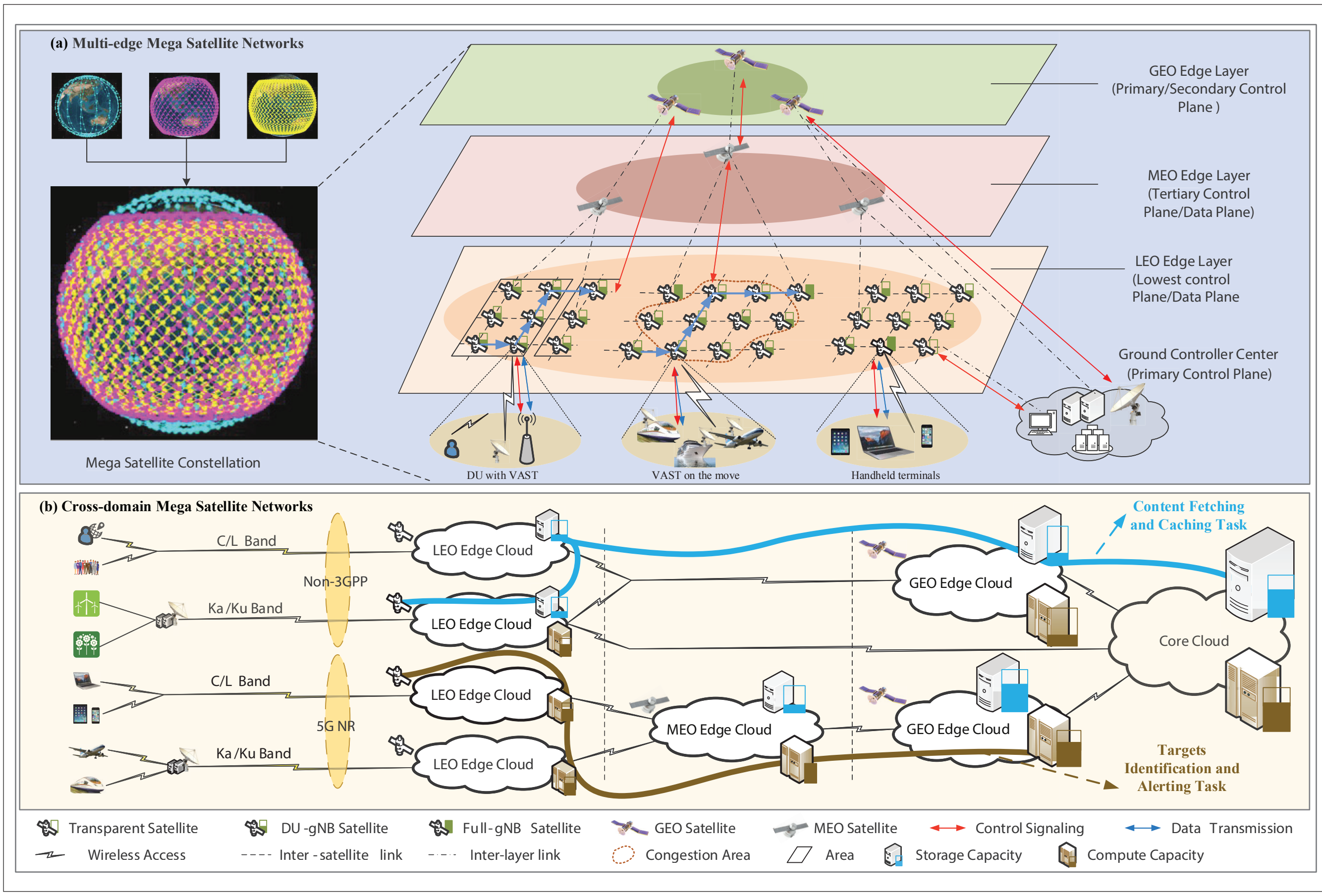

FIGURE 1. Architecture of mega-constellations routing systems: a) Multi-edge architecture of mega-constellations routing systems with control and user plane separated; b) Routing control with cross-domain features for multi-mode traffic requirements.

in mega-constellations, massive packet loss and low QoS are occurred. Fortunately, the locations of satellites are usually predictable, the SDN technology can decouple the control and user plane and be adopted to achieve flexible networking. In this way, the collaborative routing control can help to reduce ISL switching costs and computation, storage and signaling overheads, improving the flexibility and self-adaptation of the network.

Network Failure and Artificial Intelligence: With the scale of satellite networks increases, the routing systems have much higher probability facing the node or link failures, caused by the complicated outer space network environment, traffic congestion, interference, and man-made destruction. Thus the network latency, packet loss and loops are increased, and the reliability and transmission efficiency of satellite routing are substantially reduced. Artificial intelligence (AI) shows a better generalisation capability in satellite routing technology, predicting the network congestion and fault occurrence. The fault monitoring, fault location, fault diagnosis and fault avoidance can be performed during routing calculations when a failure occurs in the network, improving the real-time performance and efficiency of routing and ensuring user QoS.

Multi-Mode Traffic and Computing First Network: The large-scale satellite network bears diverse traffic, including enhanced mobile broadband, wide-area connectivity, delay-tolerant services, synthetic aperture radar (SAR), showing the characteristics of multi-mode. At the same time, the characteristics of different mission requirements show great variability, including tasks such as fast video and picture processing, targets identification and alerting, and contents fetching and caching. Computing first networks (CFN) can be introduced in mega-constellation systems to achieve cross-domain computing resource allocation and orchestration. Multi-edges, for example, LEO, MEO, GEO edges, can be collaborated to make use of the limited computing resources, improving the ability to sense the network state and the flexibility, scalability and performance of routing calculations. With the CFN technologies, the mega-constellation systems can fulfill the massive traffic requirements and task-oriented services to achieve multi-mode, multi-service and multi-capability adaptation.

Architecture of Mega-Constellations Routing Systems

Multi-Edge Architecture of MaCRo

The multi-edge architecture of mega-constellations routing systems (MaCRo) is illustrated in Fig. 1a, which increases the flexibility of the network architecture by separating the control plane (C-plane) and user plane (U-plane). The multi-edge specific components are as below.

GCC Layer: As the primary C-plane in the architecture, it is mainly composed of gateways and control center and connected to the internet cloud. It is taking in charge of the global perception and management of network, collecting the

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information and calculating the routing table, with the functionality of mobility management entity (MME), serving gateway (SGW) and public data network gateway (PGW).

GEO Edge Layer: As a secondary C-plane, it works as the primary control plane when the GCC is out of sight. It can also be responsible for information collection and sensing, control and management of other satellites. It keeps the radio admission control (RAC), radio bearer control (RBC), and connection mobility control (CMC) with MEO and LEO edges. Besides, it can work as lightweight core network with part of the core network element cutting and element function customization, especially in emergency communication routing scenarios.

MEO Edge Layer: As a tertiary C-plane, its main function is multi-LEO grouping control and data forwarding. It is under the control of the upper layer and it also keeps RAC, RBC, and CMC with the LEO satellites in its coverage area. Besides, when faced with network failure or excessive hop transmission, it can assist lower layer to complete the forwarding as a U-plane, alleviate the problems of significant overhead and on-board resource occupation, and achieve load balancing.

LEO Edge Layer: As the lowest C-plane, it keeps the radio resource control (RRC) connection with the terminals of both handheld user and VSAT stations. It can work as the transparent or regenerative nodes. Specifically, it can work as a full-gNB for the users directly connected to it. When cooperate with the terrestrial base stations, it can also work as centralized unit (CU) with the collaboration with the base stations acting as decentralized unit (DU). As the main U-plane, it can complete data transmission, data storage, and task computing processing, and so on.

Due to different network scenes, the edge layers above are not be used all the time and collaborative modes composed of different edges can be generated from the multi-layer architecture, which is explained specifically below. Outperforming single mode with lower signaling overhead and network failure in mega-constellations. In addition, although the satellite network is highly dynamic, it is possible to adopt intelligent methods to face the network failure and reduce the control overhead, taking advantage of the periodical and predicted topology. The goal of this multi-edge MaCRo systems is to realize a saving and intelligent satellite network control mechanism, and the characteristics are as follows.

Lower Cost and Latency: Instead of collecting global link and nodes status and transmitting all these signaling packets back toward the GCC to calculate routing table, the routing strategy in our systems can be more flexible and dynamic depends on different scenarios. For example, the centralized computing for some congested areas are calculated in GCC or GEO edge layer for optimization with higher computing power. Meanwhile, the decentralized routing is conducted by the on-board capability of LEO edge layer. This combination brings lower signaling cost and significantly shorten the latency.

Dynamic Adaption: With the multi-edge collaboration, the perception of hierarchical network is more fast and accurate, taking the advantages of various range of coverage. Routing in MaCRo systems can achieve dynamic adaption by situational awareness. Especially compared with the decentralized routing algorithm, it can solve the locally optimum and loop problem adaptively.

Cross-Domain Routing Control

In MaCRo systems, rather than considering the routing path only from the aspect of wireless bearer networks, it is the integration of three networks utilizing "cross domain" features: satellite wireless access networks, inter-satellite bearer networks and data-center networks, as shown in Fig. 1b. The characteristics of this MaCRo systems are the following.

Supporting Multi-Mode Traffic: This cross-domain architecture of mega-constellations routing systems can efficiently schedule the resources, to support multi-mode service requirement from both VSAT and direct connected users, using frequency bands such as C/L and Ka/Ku band, through Non-3GPP and 5G NR.

Cross-Domain Routing: Based on cross-domain features, the collaboratively control in MaCRo allocates network computing, communication, storage, controlling and sensing resources to complete routing transmission, through proximity calculation and processing of routing decisions. It also performs control management, information awareness and content fetching and caching to relieve the pressure on computing and storage in some clouds or edges and improve network resource utilization. Furthermore, by means of multi-level and multi-layer collaboration, it can effectively adapt to the diversity of service types, ensure the scalability and flexibility of the network, realize unified resource scheduling and management, and integrate transmission and computation.

Collaborative Modes Analysis in MaCRo systems

In the MaCRo systems, the management and control schemes can be categorized into four modes, as shown in Fig. 2, namely "Backhaul Mode," "Hosted Mode," "Cluster Mode," and "Hybrid Mode." In different modes, the functions of network entities are also different. As summarized in Table 1, the functional differences are given for LEO, MEO, GEO edge layers and GCC, from the aspect of communication, perception, computing, and storage in routing procedures.

Backhaul Mode: In backhaul mode, the LEO edge layer plays as "transparent backhaul," which means that the LEO satellites only need to receive, amplify, store and forward the traffic in U-plane. All the LEO edge layer satellites are under the centralized control of GCC on the ground in C-plane. GCC is charge of collecting the state information, calculating routing table and flooding the control messages to the whole networks, as shown in Fig. 2a. However, if the number of LEO satellites is huge, the GCC stations need to be placed globally, which brings large cost to exchange the routing table or handle the network failure, thus this mode is suitable for the small-constellation with strong robust network, to get the optimal solution for each state.

Hosted Mode: With the world-wide coverage of GEO satellites, the hosted mode treats GEO edge layer satellites as centralized host nodes when losing connection with GCC and the MEO satellites monitor the states of the LEO satellites

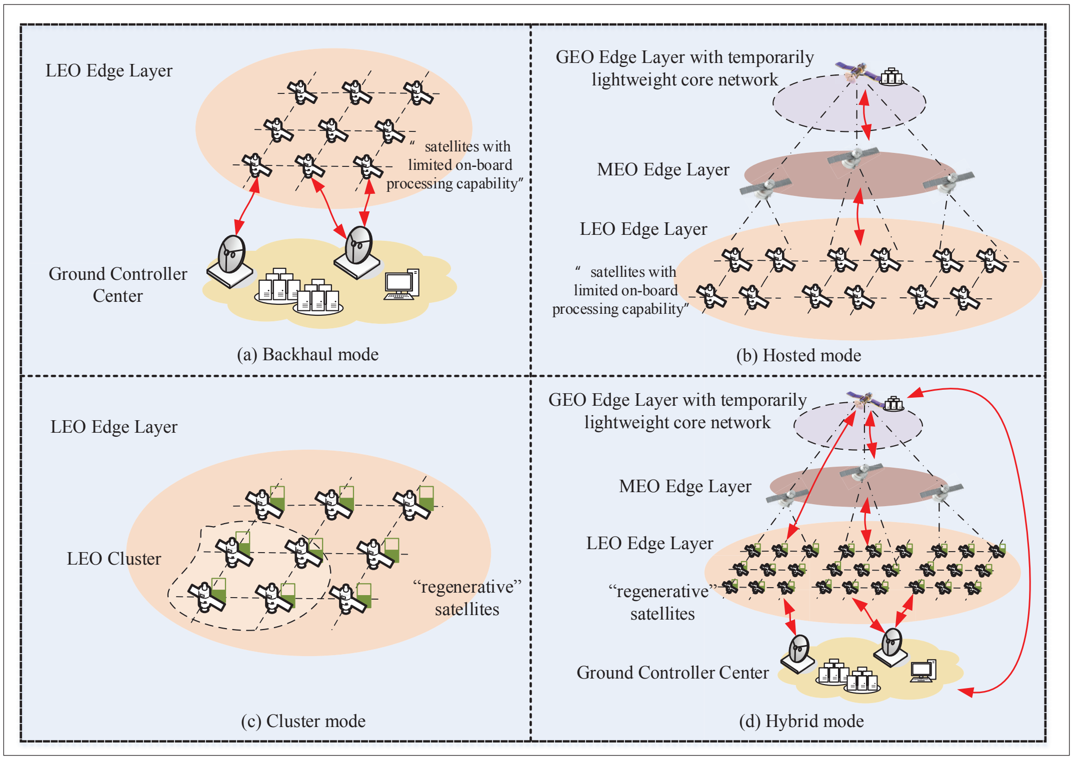

FIGURE 2. The illustration of four collaborative modes in MaCRo systems.

within the coverage area, as shown in Fig. 2b. Without the connection to GCC, the temporarily lightweight core network is formulated in GEO edge layer in C-plane. The GEO satellites formulate control policies and generate control signals for the LEO edge layer networks, eliminating the flooding process. Similar to the backhaul mode, the hosted mode is also able to obtain the optimal control mode for the current state. Compared with backhaul mode, MEO satellites can assist to complete transmission when failures occur.

Cluster Mode: The cluster mode adopts a distributed strategy, in which each "regenerative" LEO satellite exchange the state information with its neighbors. This mode only need to keep C-plane connection with GCC for RRC connection. With the perceptive and computing function on board, the LEO satellites generate control policies, forward the routing table and keep updating individually or by forming " LEO clusters" to cooperate with the nearby intra-cluster nodes, as illustrated in Fig. 2c. In this way, it avoids the collection of network-wide state information and control signaling, which greatly reduces the signaling overhead and communication delay and is suitable for mega-constellations. However, due to the failure occurred in the network, it is easy to cause detour, packet loss and local optimum problems.

Hybrid Mode: As shown in Fig. 2d, multi-edges are all jointly utilized to realize functions in the mega-constellations. With the global-coverage property of the GEO edge layer, signaling overhead can be greatly reduced, but suffering from relatively large latency between GEO and LEO layer simultaneously. In this mode, collaborative control is realized to generate routing strategy, with GCC as the master controller and GEO edge layer as the slave controller. In this way, when the LEO layer loses connection with GCC, the GEO edge layer assists to collect state signals from these satellites. In addition, this mode has relatively stronger computing ability and global perspective, which can adopt intelligent methods such as area-segmentation and traffic prediction enabled by SDN, AI and CFN technologies. Specifically, it can hybrid three mentioned modes above and the jumping among these modes is triggered by the controllers. Four modes can coexist and the satellites in different areas can execute local mode simultaneously. When some areas in the network is robust, it changes to cluster mode in these areas, avoiding routing table flooding. But when the failures occur, such as inter-satellite links break, on-board resources exhausted, the controllers boot up backhaul mode or hosted mode to collect faulty state information and adopt intelligent methods to generate routing recovery strategy of the faulty areas or faulty links, alleviating the network failures. In general, due to the huge number of LEO satellites, backhaul mode and hosted mode need relatively large signaling overhead, compared with other modes. Cluster mode needs the least signaling overhead, but fails to cope with the problems occurred in weak robust network. Although hybrid mode spends more signaling overhead than cluster mode, it can alter to multiple modes in different areas and benefit from the faulty information collection mechanism and intelligent methods, adapting to varied network state dynamically and intelligently.

Cases Study in MaCRo Routing Systems

Intelligent Area-Segmentation Routing Based on Hybrid Mode

As shown in Fig. 3a, a typical hybrid mode scenario is given in mega-constellations, where the GCC and the GEO edge layer to jointly act as the SDN controllers and complete the routing manage-

Mode	LEO Edge Layer	MEO Edge Layer	GEO Edge Layer	GCC	Applicable Scenarios
Backhaul Mode	★ Receive control signals ◦ Store routing table ☐ Read routing table	N/A	N/A	• Collect state signals ☐ Calculate routing table ★ Flood control messages	Small-scale satellite network Good robust network Limited on-board resources
Hosted Mode	★ Receive control signals ◦ Store routing table ☐ Read routing table	• Collect state signals ★ Send control signals ★ Receive control signals	• Collect state signals ★ Send control signals ☐ Calculate routing table	N/A	Small-scale satellite network Poor robust network Limited on-board resources
Cluster Mode	• Exchange state signals ☐ Complete routing decisions	N/A	N/A	N/A	Large-scale satellite network Good robust network Rich on-board resources
Hybrid Mode	◦ Store routing table ☐ Read routing table ★ Receive control signals • Exchange state signals ☐ Complete routing decisions	★ Receive control signals • Exchange state signals ☐ Complete routing decisions	• Collect state signals ★ Send control signals ☐ Calculate routing table	• Collect state signals ☐ Intelligent computation ★ Send control signals ◦ Store historical state signals	Large-scale satellite network Poor robust network Unlimited by on-board resources

★ Communication function • Perceptive function ☐ Computing function ◦ Storage function

TABLE 1. Functional differences in cross domains of multi-edge communication entities under four typical collaborative modes in mega-constellations routing systems.

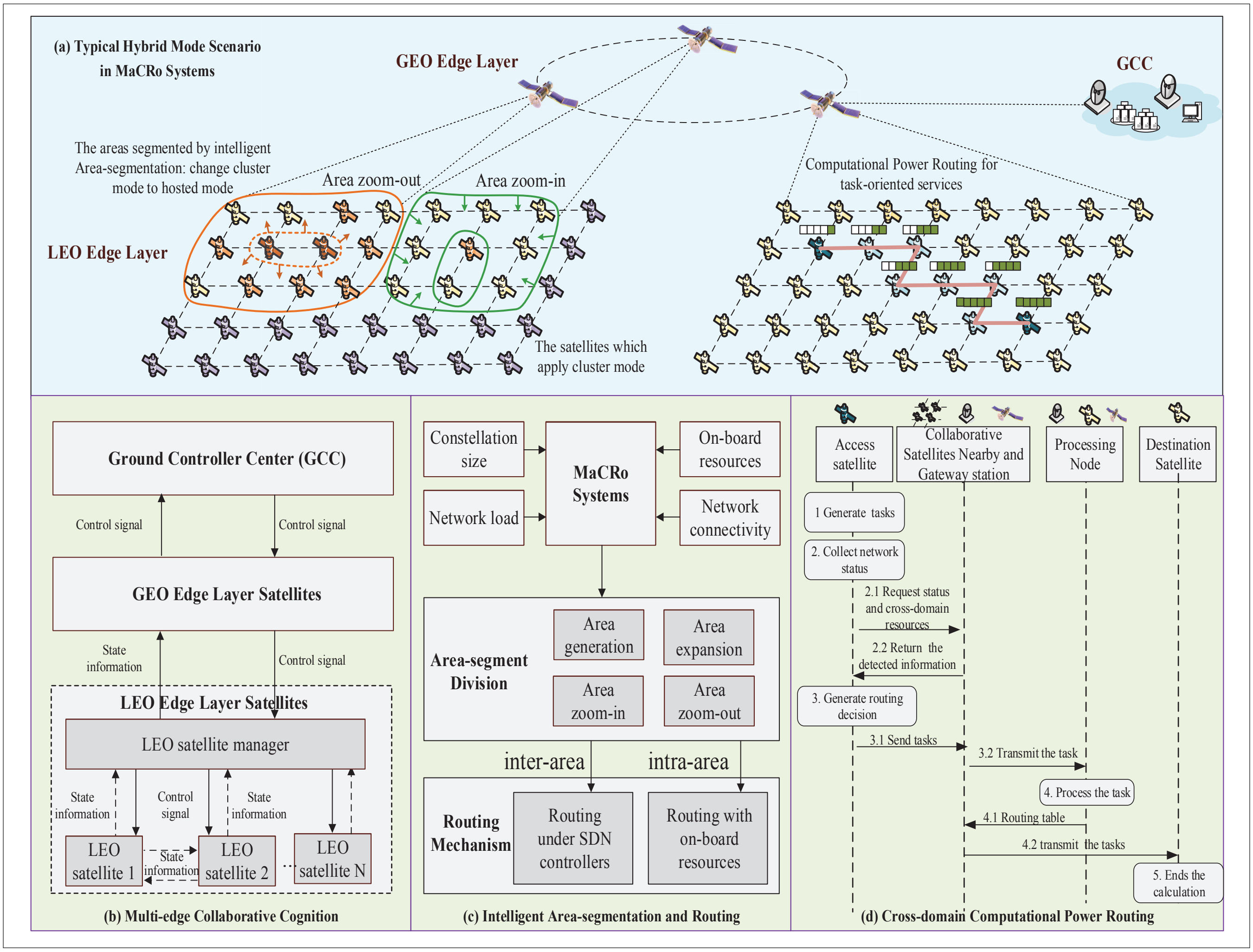

FIGURE 3. Intelligent area-segmentation routing and computational power routing in hybrid mode in MaCRo systems: a) Typical hybrid mode scenario in MaCRo systems; b) Multi-edge collaborative cognition in C-plane with SDN; c) Intelligent area-segmentation and Routing; d) Cross-domain computational power routing method for task-oriented services.

ment of the LEO satellite layer. To deal with the huge signaling overhead cost and intolerant latency, the key procedures of an intelligent area-segmentation strategy in hybrid mode in MaCRo is illustrated in Fig. 3b and c.

In Fig. 3b, the GCC acts as the master controller to complete the intelligent control of the network based on the current state information and the past state information, and establishes the satellite-terrestrial link with the GEO satellites to transmit the control signals. The GEO edge layer plays the role of the slave controller, which can calculate the routing strategy for the LEO satellites according to the control mechanism. The LEO satellite managers establish the inter-orbit link with relative LEO satellites to collect the states and send the control signals. The LEO edge layer focus on communicating with neighbors through ISLs, and report the state information to LEO satellite managers dynamically.

The state of the mega-constellations is affected by factors such as constellation size, on-board resources, network load, and so on. Different network states represent different resilience level of the network, and adaptive routing methods can be realized by the collaborative cognition. In the intelligent area-segmentation routing, the GCC adopts the intelligent area-segmentation division to form the control "areas," as shown in Fig. 3c, includes area generation, area deletion, area zoom-out and area zoom-in. The inter-area and intra-area routing strategy are calculated by GEO edge layer. Specifically, in hosted mode, the satellites inside the areas segmented by intelligent area-segmentation method, forwarding based on the routing table calculated by the SDN controllers. In cluster mode, the satellites outside these areas depend on their on-board resources individually or by clusters in the same layer.

We conduct the simulation in a walker delta constellation with 1800 satellites. The ISL broken ratio is utilized to model the topology changing, link disruption and node crashes, which represent the ratio of the sum of break-up links to the total number of ISLs. In Fig. 4a, the hybrid mode with intelligent area-segmentation shows better adaptability in cope with the link break with relatively small average end-to-end latency. With the increase of link break ratio, cluster mode performs the worst due to the lack of cognition in the LEO edge layer. In Fig. 4b, though all the packet loss rates rise with link break ratio, the hybrid mode also keeps the best performance, improving its high suitability to mega-constellations.

Computational Power Routing Method for Task-Oriented Services

Different from simple transmission, the task-oriented services request for computing and caching resources along with the routing. In the hybrid mode, instead of forwarding the task to the ground, computational routing assigns the tasks to multiple computing resource nodes flexibly based on network and computing resource conditions. Main steps of proposed computational power routing in MaCRo are as follows.

Step 1: LEO satellites generate computational tasks.

Step 2: The source satellite detects the status and available resources of the satellites nearby, such as the computing resources and target recognition capability, determined and dynamically adjusted by the collaboration of GEO and GCC.

Step 3: The satellite makes routing decision based on the size of task, the address of the destination satellite, the distribution of gateway stations, and the current available computing resources, to find suitable computing nodes.

Step 4: The task is conducted along with the path until the process ending, and it comes to Step 1 when new task arrivals.

The simulation platform is built based on the

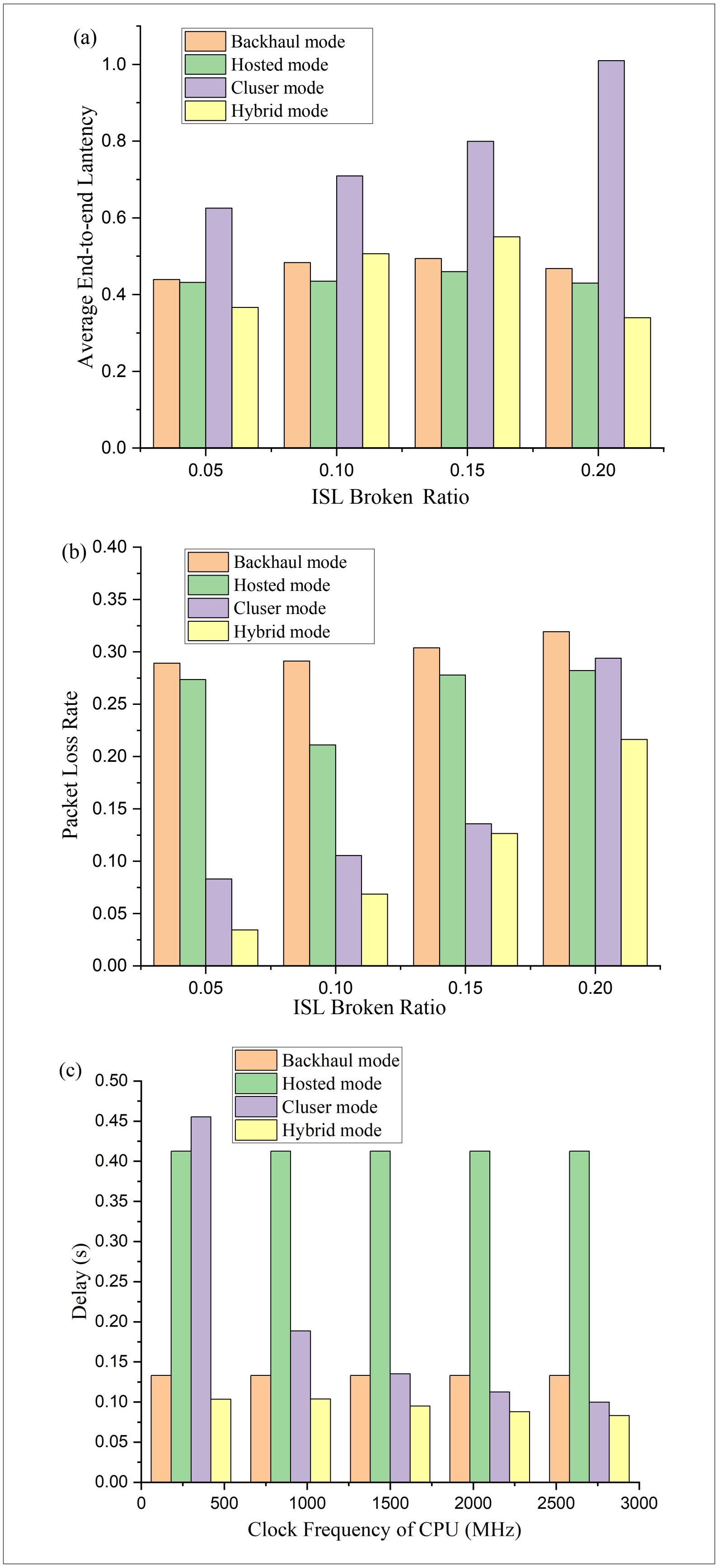

FIGURE 4. Cases studies about end-to-end transmission and task-oriented routing in MaCRo. a) and b) represent the comparison of the average end-to-end delay and packet loss rate of the four collaborative modes respectively with the ISL broken ratio. c) represents the comparison of computational power routing delays in four modes under different satellite CPU clock frequencies.

OPNET platform of the Teledesic constellation, consisting of 3 GEO satellites, 288 LEO satellites and 5 GCC stations. The total task delay includes transmission delay and computation delay. The task computation latency of a satellite is defined as $T_{prop} = Dz/f_{CPU}$ [10], where D represents the size of the task and z is the occupied CPU (Central Processing Unit) cycles to process 1 bit of data. fCPU represents the clock frequency of the CPU. We set z = 200 CPU cycles/bit, D = 0.6 Mb.

As shown in Fig. 4c, simulation results of the computational power routing latency in four modes are given under various LEO layer on-board CPU capabilities f_{CPU}. Compared to the backhaul mode, hosted mode, and cluster mode, the hybrid mode contributes to reduce the overall latency by nearly 28.8 percent, 71.1 percent, and 38.1 percent, respectively. In comparison, the backhaul mode, which offloads the routing task to the limited number of GCC stations, brings multiple transmission hops and lager latency. Similarly, the hosted mode, that offloads to GEO satellites, is suffered from long distance and propagation delay between GEO and LEO layer. In the cluster mode, the satellite selects the appropriate LEO satellite nodes for calculation and routing, so the latency sharply decreases with the increased computing power. In conclusion, the hybrid mode shows the best routing performance for task-oriented services by the intelligent combination of the above modes.

Conclusion and Future Work

In this article, the characteristics of mega-constellations are summarized, pointing out the threats and opportunities of the satellite routing. A SDN-based MEC-enabled architecture of MaCRo is proposed, with muti-layer nodes capability and cross-domain resources are considered toward a flexible and fast-response networks. In addition, four collaborative models are given from the functional differences of each layer. Intelligent area-segmentation routing and task-oriented computational power routing are studied and compared, illustrating that the hybrid mode is the best approach of routing in MaCRo systems. The proposed routing system can be recommended as a highly potential solution for future 6G NTN networks.

Acknowledgment

This work is supported by the National Key Research and Development Program of China 2021YFB2900504 and supported by "the Fundamental Research Funds for the Central Universities"2023ZCJH09.

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Additional Reading

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