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A Literature Review on Dynamic LEO Satellite Communication Network

KADAPALA ANJAIAH[1]
[2]***Research scholar in computer science and engineering, Osmania University Hyderabad Telangana state***
mobile number:9618455781
email: kadapala.anjaiah@gmail.com

Dr. K. Sagar[2]
[2]***professor***
cse department, Chaitanya Bharathi institute of technology, Hyderabad Telangana state
mobile:9849400136
email: kadapasagar@cbit.ac.in

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Abstract:

To support the explosive growth of wireless devices and applications, various access techniques need to be developed for future wireless systems to provide reliable data services in vast areas. With recent significant advances in dynamic low Earth orbit (LEO) satellite network, we present comprehensive study about architecture, communication, key technologies, resource allocation strategies, routing algorithm, mobility management for LEO satellite networks. To identify the gaps, the current state of dynamic LEO satellite communication network is summarized and the challenges facing future LEO satellite communication network are discussed. Worthy research directions are recommended. This article is providing a road map for researchers and industry to shape the future of LEO Satellite Communication Network.

Keyword: Low-Earth Orbit (LEO) satellites, Internet of Thing (IoT), Edge Computing, Fifth generation (5G) network, terrestrial network, Software Defined Network (SDN),

1. Introduction:

In recent years, with the development of wireless communication technology, the terrestrial cellular network is facing the explosive growth of data traffic. Although the terrestrial cellular network has the advantages of short delay and large bandwidth, it still has some limitations [1]. Due to the limit of geographical environment and economy, it is difficult for cellular networks to cover special areas such as oceans, deserts, forests, and islands. Ocean navigation, geological exploration, environmental emergency rescue, and other scenarios rescue require an all-weather, wide-coverage, highly reliable communication mode. Satellite communication can solve the above problems well by virtue of wide coverage, small geographic limitation, and large system capacity. Satellite communication can provide swift and stable service for multiuser on land, sea, and in the sky [2]. Furthermore, they are indispensable for emergency communication to rescue in natural calamities such as earthquakes, floods and tornadoes [3]. Satellite networks are playing an increasingly important role in observation, surveillance and reconnaissance an efficient manner over long distances with dramatic growing of the demand for such services [4-6]. The satellite communication system has experienced the development of global beams, regional beams, and spot beams. Flexible resource allocation between spot beams can further improve system performance.

According to the different orbital altitudes, satellites can be classified into geostationary orbit (GEO), satellites, medium-earth orbit (MEO)satellites, and low-earth orbit (LEO) satellites. Among various types of satellites, LEO satellites have gained more popularity from the last two decades [7] because of having the characteristics of low path loss, short communication delay, and flexible orbital position [8]. Voice services, broadband Internet access, and data broadcast services are delivered in a convenient and reliable manner that results in lower propagation delay and smaller path loss. The reason lies in the fact that LEO satellites generally fly on tracks of 200 to 2000 km and provide wireless coverage with mesh topology [9].

The Internet of Things (IoT) is a burgeoning paradigm that changes our lives greatly and has taken our society one step closer to ubiquitous communication, such as smart home, intelligent gateway, intelligent society and so on. With evolution of IoT, tremendous growth in user traffic has been experience. Terrestrial let alone cannot handle such high user traffic due geographical and economical constraint which led to increase the demands for satellite-terrestrial network integration [10]. Low Earth Orbit (LEO) mega-constellation systems, which involve hundreds of satellites, are gaining increased attention in achieving the integration with terrestrial technologies [11]. Given the renewed interest towards LEO mega-constellations, an interesting research topic is the design of a suitable network management model using Software Defined Networking (SDN). Leveraging the benefits coming from both systems, this model has the potential to achieve a more flexible control and management of the traditional satellite systems, as well as to enable a future hybrid satellite/terrestrial network.

Although the terrestrial communication is about to enter the 5G era, terrestrial communication systems are unlikely to achieve global seamless coverage for the constraints of geographical conditions and economic development level [12]. However, LEO satellite communication networks can provide full-time communication services without blind zones, which is an incomparable advantage over ground communication networks. With the increasing demand for Internet access, LEO satellite communication networks will play a more important role in the fifth-generation (5G) and the upcoming sixth-generation (6G) mobile communication networks. Nowadays, a new round boom of the LEO satellite constellation system has risen and become a hotspot of commercial investment, including OneWeb [13], SpaceX [13], Telesat [14], and other satellite-related companies that have put forward their commercial LEO satellite constellation systems. The introduction of LEO satellite communication in 5G provides more possibilities for the future IoT applications [15]. Compared with the traditional Geosynchronous Earth Orbit (GEO), the LEO has the most important advantages such as low loss, low delay, wide coverage, and large orders of magnitude [16]. The LEO satellite based IoT is ideal for applications such as monitoring of short data, remote or long-distance moving objects, and sensor data acquisition. However, due to the high-speed movement of LEO satellites and the variety of business, terminals are scattered in various areas, which makes the business analysis of LEO satellite based IoT relatively difficult [17]. Therefore, it is necessary to analyse the law and characteristics of traffic, and guide the design the architecture of LEO satellite based IoT.

Low earth orbit (LEO) constellation network having an important role in the future space-air-ground integrated communication network. In the LEO constellation, each satellite can provide communication services for the terminals within its coverage [18]. If the communication target is not in the coverage region, cross-domain communication can be realized through the inter-satellite link (ISL). However, with the development of intelligent terminals, communication data is no longer just voice and text, but images and video, probably using VR and AR technologies. Moreover, the increasing number of special function terminals, such as unmanned aerial vehicles (UAV) and intelligent sensors, makes the demand for real-time data processing impending. Data transmission between the terrestrial command centre and LEO satellite has been difficult to meet the low latency computing of terminals [19]. The main requirement is to improve the fast data computing ability of LEO satellites when massive terminals accessing. Therefore, the fusion of LEO constellation and the edge computing paradigm has gradually attracted attention to enhance the real-time management for intelligent terminals.

Edge computing is an emerging computing model, which possesses sufficient computing and storage resources on the edge of the Internet that very close to intelligent terminals [20]. So, the data processing can be performed at the edge server, and the terrestrial command center is more responsible for storing processing results and further big data analysis [21]. The edge server can be deployed in the LEO satellite, making LEO satellites become edge computing satellites (ECSs), where the data processing module for terminals are installed. Terminals utilize the computing resources of ECSs to realize data analysis and accept the unified scheduling of ECSs. Computing resources of ECS can be split into KVM-based virtual machines with different specifications to implement data processing for various terminals [22]. Meanwhile, ECSs can also form a collaborative network to achieve information sharing and unified cross-regional terminal scheduling [23]. However, since LEO satellites are moving at a relatively high speed, its topology and coverage area in the next time slot may change, leading to the reconfiguration of the resources in ECSs. The resources and time spent on reconfiguration may impact the ability of ECS for real-time data processing. The routing strategies of resource scheduling and information sharing for ECS network are also problems when facing emergency [24]. Therefore, a dynamic resource scheduling scheme in ECS network is needed to help the ECS realize real-time data processing for intelligent terminals.

For the timely transfer of messages from sender to receiver, communication delay is one of the critical factors in determining service satisfaction. For instance, short and stable delay means high quality of service (QoS) [25]. Traditional shortest path algorithms, such as the Dijkstra algorithm and the Bellman-Ford algorithm, have been used to decide optimal routing scheme by comparing delay without delay variation. In addition to satellites in motion, there are hot spots due to intensive population and economic prosperity. All of these issues suggest potential optimization of the satellite network [26]. As a result, traditional routing algorithms could be further optimized. If there is no practically executable routing scheme, the QoS that satellite systems can provide will be lower when network congestion occurs. Routing analysis based on graphical evaluation and review technique (GERT) can be conducted in a comprehensive view of both delay and its variation. Indefinite information in the satellite network is quantitatively characterized as well. GERT can be used to present the transitive relation in a stochastic process system. For example, value in an input output table can be easily measured in a GERT network by mean and standard deviation, which contributes to analyse dynamic input–output process clearly [27]. Routing analysis based on graphical evaluation and review technique (GERT) can be conducted in a comprehensive view of both delay and its variation. Indefinite information in the satellite network is quantitatively characterized as well. GERT can be used to present the transitive relation in a stochastic process system. For example, value in an inputoutput table can be easily measured in a GERT network by mean and standard deviation, which contributes to analyse dynamic input–output process clearly [27].

Satellite communication systems have been considered as a potential solution for complementing terrestrial networks by providing coverage in rural areas as well as offloading and balancing data traffic in densely populated areas [278]. With the emergence of LEO satellite mega-constellations, which involve hundreds to thousands of satellites [29], the concept of satellite networks is evolving rapidly and gaining increased attention. It is expected that satellite networks will be an integral part of the future universal communication network, which is not only on Earth but also in its surrounding space and even extends to reach the Moon and other planets. 3GPP introduced a number of satellite use cases in 5G networks (3GPP TR 22.822 Release 16) which discuss the role of satellites in future networks [30]. For example, 3GPP introduced Internet of Things with a Satellite Network and Global Satellite Overlay use cases that both emphasize the future role of satellite networks. However, to realize such use cases there are still several challenging matters to address. A major challenge that faces future satellite networks is mobility management.

Mobility management is a quite mature research topic in communication networks; however, this is not the case for the next generation of satellite networks. Many recent surveys and tutorial on future SatNets focused on discussing communication and networking related issues. For example, Radhakrishnan et al. [31] focused on inter-satellite communications in small satellite constellations from the perspectives of physical to network layers, and the Internet of remote things applications of satellite communication were reviewed in [32]. However, only a few reviews were published on the mobility management related issues in next generation satellite networks. In [33] Miao et al. discussed the challenges facing SDN-based integrated satellite-terrestrial networks. In [34], Xu et al. explored the challenges that software-defined next generation satellite networks may encounter and provided some potential solutions. In [35] Hossain et al. discussed the survivability and scalability of space networks. Mobility management, in these protocols, consists of two main components, which are handover management and location management.

The reminder of this paper is organized as follows. Section II describes and review, several typical application scenarios for LEO satellite constellation and compare the existing studies under each approach and point out the important points that should be considered in the context of future LEO Satellite Communication Network. Section III present challenges, and opportunities with future perspective for LEO Satellite Communication Network Finally, Section IV concludes this work and looks forward to the future research directions.

2. Literature Review

In this section we present related work about architecture, communication, key technologies, resource allocation strategies, routing algorithm, mobility management for LEO satellite networks.

2.1. LEO Satellite Communication System

The size of the LEO satellite constellation is becoming larger and larger due to the advantages of technology and cost. A large-scale constellation can better achieve global coverage and greatly expand the system capacity [36]. In highly complex and frequently changing systems, it is critical to consider the load on the underlying network components due to user behaviour. The massive traffic loads also challenge the quality of service (QoS) of LEO Satellite communication systems [37]. The satellite system is different from the terrestrial network, so researchers adopt some special frames and protocols according to the particularity of satellite systems, including data relay satellite (DRS) system, delay-tolerant network (DTN), and performance enhancement system (PES). However, these satellite communication protocols based on TCP/IP have poor mobility, high overhead, and high complexity [38]. Further, most of the existing satellite network protocols are only applicable to medium Earth orbit (MEO) geosynchronous Earth orbit (GEO) satellites. Therefore, network architecture and resource management system are particularly important for LEO satellites.

2.2 LEO satellite Network architecture

Due to the LEO satellite connectivity and mobility characteristics, future LEO SatNets will introduce two unprecedented architecture in which satellite will be working as a mobile BS, a router, and a terminal.

2.2.1 LEO satellite-based mobile BSs: In future networks, it is expected that satellites, especially LEO satellites, will provide wide coverage and support the communication network capacity in densely populated areas, as shown in Figure 1. In this situation, a LEO satellite-based mobile BS will be serving thousands of users. This will be empowered by the integration of reconfigurable intelligent surfaces with LEO satellites as well [39].

Fig. 1: LEO satellite based mobile BS serving thousands of users.

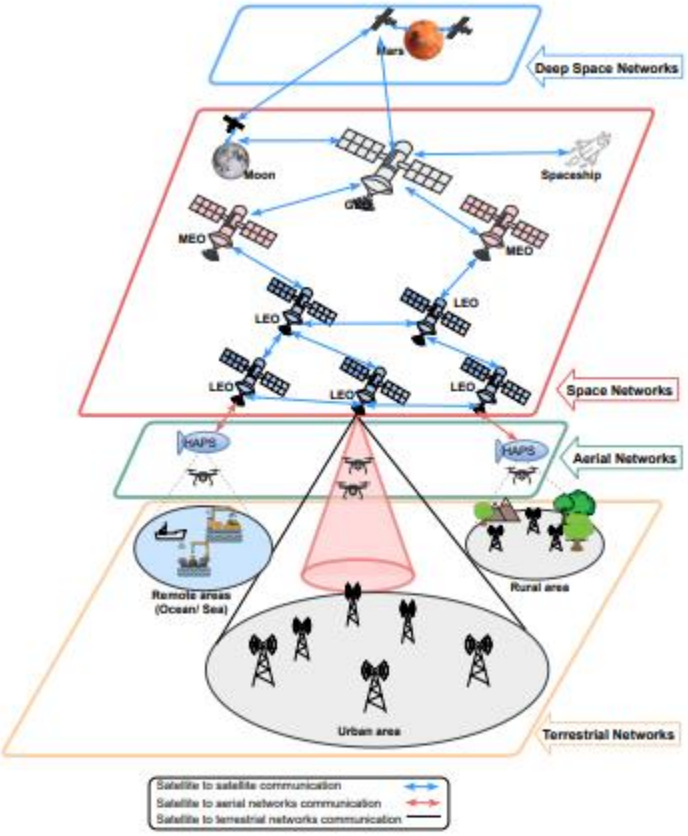


Fig. 2: LEO satellites connected to multiple networks.

2.2.2 LEO satellite integrated Terrestrial, and Aerial networks: To provide worldwide communication and Internet services, there is a need for the development of IP-based satellite networks which can be easily integrated into terrestrial and aerial IP networks. In future integrated networks, besides being part of the network of satellite mega-constellations, LEO satellites will be also connected to terrestrial networks, aerial networks, or space network, as shown in Figure 2.

Recently, the construction of commercial LEO satellite systems is active all over the world, but it is hard to avoid some challenges in the network architecture and resource management. The architecture of the O3b system in the MEO satellite network and the OneWeb system adopts a transparent forwarding mechanism. These two systems have no inter-star networking, outing, and switching function, and the system resource utilization is low when business is highly dynamic [40]. The architecture of Iridium and SpaceX relies on ISL to achieve intersatellite networking, but their networking technologies are relatively backward, the control plane and forwarding plane are highly coupled, and the resource scheduling mechanism requires more human intervention, which all reduce the resources utilization efficiency [41]. To solve the above problems, researchers have made a lot of efforts on LEO satellite network architecture and corresponding resource allocation scheme.

2.3 LEO Satellite Resource Allocation and resource management Scheme.

The satellite resource allocation scheme will directly affect the user's QoS and system performance. In [42] Wang et al. considers the trade-off between the maximum total system capacity and inter-beam fairness to obtain the optimal allocation scheme by a subgradient algorithm. In [43] Colavolpe et al. optimizes the allocation strategy by calculating and comparing user transmission rates under different transmission modes and strong interference. In [44] Ivanov et al. explains the physical layer structure of a multibeam satellite system, simplifies the three-dimensional coordinate system of the ground user to the two-dimensional coordinate system in the equatorial plane. Further, researchers calculate the maximum channel capacity according to the satellite beam coverage area and transmission power. In [45] Zhang et al. proposes a beam-hopping algorithm, which adjusts the beam size according to the business distribution. In [46] Zuo et al. uses a heuristic algorithm to achieve frequency band selection and beam allocation and adopts Lagrangian dual algorithm and water-filling-assisted Lagrangian dual algorithm to achieve power allocation. In [47] Chang et al. proposes a channel allocation scheme of mixed random access and on-demand access, which reduces system delay within the throughput threshold. This scheme provides effective solutions for services with different delay sensitivities. The above satellite resource allocation scheme improves the system performance in some aspects. However, they only focus on the instantaneous performance of the system and ignore the time correlation in the resource allocation process. The allocation result of the previous time will indirectly lead to the subsequent allocation effect, which will undoubtedly affect the system resource utilization. The satellite channel allocation can be regarded as a sequential decision problem, and a decision is made on the arriving user request within each interval T. RL is a good way to adapt to this decision-making problem. In [48, 49] uses augmentation learning to solve channel allocation and congestion control in satellite Internet of things (SIoT). Compared with traditional algorithms, RL can improve performance in terms of energy consumption and blocking rate. In [50] Hu extends single-agent deep reinforcement learning (DRL) to multiagents and propose a collaborative multiagent DRL method so as to improve transmission efficiency and achieve the desired goal with lower complexity. In [51] Deng et al. discusses a scheme of combining RL and resource allocation in different heterogeneous satellites and multiple service requirements and demonstrates the application effect of DRL in heterogeneous satellite networks (HSN). However, there are few researches on LEO satellite resource allocation. Most of the research has focused on MEO and GEO satellites.

As a resource management unit that is widely used in the terrestrial wireless network, a resource pool can realize resource sharing and dynamic scheduling according to service requirements and improve spectrum efficiency. In [52] Wang et al. proposes a design scheme of EGS based on resource pool architecture. By integrating digitizing, the resource pool can achieve signal processing and baseband processing functions, the utilization of high-speed data communication resources can be effectively improved in satellite networks. In view of the problems existing in the "chimney" architecture of EGS, [53, 54] propose architectures based on resource pool to solve the instability of EGS systems. The researchers compare the two architectures with and without resource pooling and found that the resource pooled system architecture is more reliable while improving the efficiency and flexibility of device resource use. In [55] Zhai et al. analyses the contradiction between resource constraint and business demand in satellite networks and proposes the concept of "on-board resource virtualization". Further, researchers construct a mission-oriented satellite network resource management model and conduct on-board resource allocation by means of resource sharing and collaborative management. At the present stage, satellite communications are creating suitable operational control systems for different functions and different series of satellites in order to achieve efficient utilization of resources [56]. In [57] Zheng et al. proposes a LEO satellite network architecture based on a satellite resource pool. The system manages channel resources through a centralized resource pool to adapt to the traffic difference between beams. They adopt the Q-learning algorithm in RL for dynamic channel allocation and analyses the system performance and time complexity of FCA, LACA, and Q-DCA schemes in different scenarios. The corresponding network architecture, on-board resource pool and channel allocation mapping under a single satellite is shown in Figure 3.

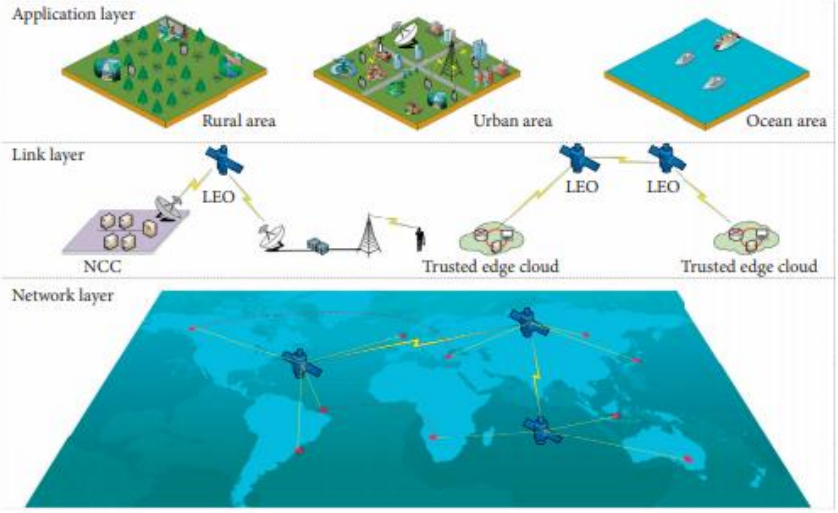


Fig.3(a): LEO satellite network architecture

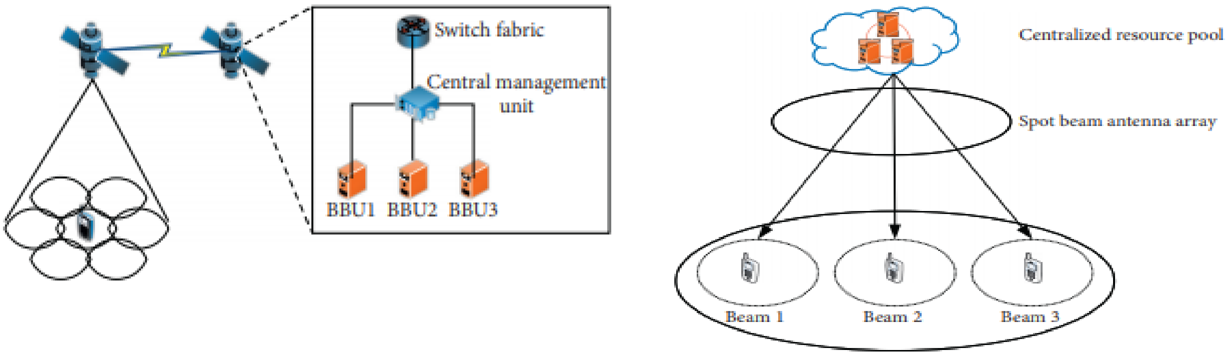


Fig. 3(b): Structure of on-board resource pool.

Fig. 3(c): Channel allocation mapping under a single satellite.

Fig. 3 LEO Satellite Channel Allocation Scheme Based on Reinforcement Learning

2.4 Mobility Management in LEO satellite network

Future integrated terrestrial, aerial, and space networks will involve thousands of Low Earth Orbit (LEO) satellites forming a network of mega-constellations, which will play a significant role in providing communication and Internet services everywhere, at any time, and for everything. Due to its very large scale and highly dynamic nature, future LEO satellite networks (SatNets) management is a very complicated and crucial process, especially the mobility management aspect and its two components location management and handover management.

2.4.1 Location Management: IETF IPv6 mobility management standards including Mobile Internet Protocol version 4 (MIPv4) and later followed by MIPv6 [58], Proxy Mobile Internet Protocol version 6 (PMIPv6) [59], Fast Handovers for Mobile Internet Protocol version 6 (FMIPv6) [60], and Hierarchical Mobile Internet Protocol version 6 (HMIPv6) [61] that addressed the location management issue in terrestrial networks. Although some research attempted to employ the location management techniques of IPv6 mobility management standards [62-64], such techniques have many limitations when applied to satellite networks. To overcome the limitations of IETF IP-based location management, one of three approaches was followed by the existing studies on LEO SatNets location management. The first approach attempted to enhance or extend the IETF IP-based location management techniques [65-66]. The second approach is based on the split of the two roles of IP addresses (i.e., locator/identifier split) [67-68]. The third approach focuses on utilizing Software Defined Network (SDN) for the purpose of topology (location) management [69-70]. The taxonomy of LEO SatNets Location management [71] is shown in Figure 4.

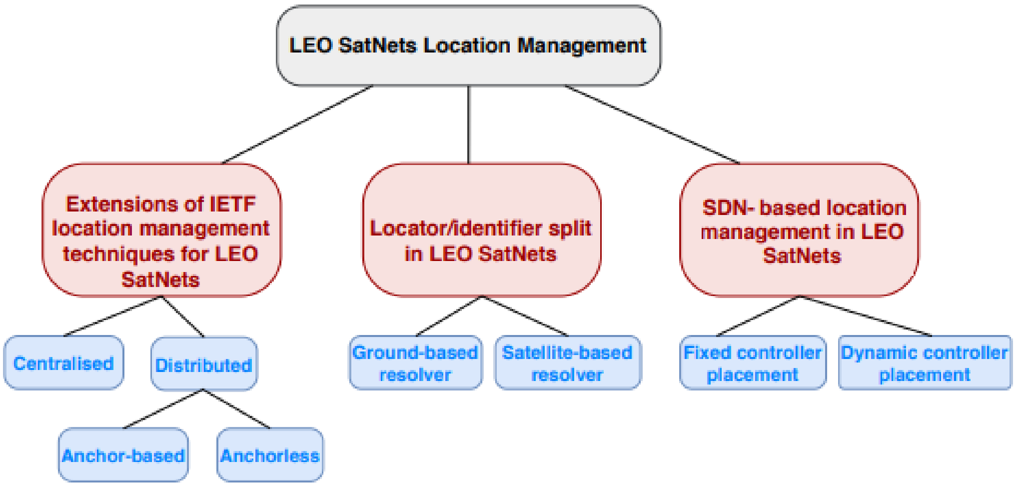


Fig.4 LEO SatNets Location management classification

2.4.1.1 Extensions of IETF location management techniques for LEO SatNets: To enhance the performance of the IETF location management techniques, a number of extensions were proposed solutions for satellite network location management in two categories where the location management is done in either a distributed or centralized manner. The distributed IETF location management techniques' extensions can be either anchor-based or anchorless, as described in Figure 4. In anchor-based location management [72], the responsibilities of location management are permanently assigned to certain network entities. In contrast, anchorless location management role is shifted from one network entity to another based-on network topology changes. A virtual mobility management scheme called VMIPv6, which is an enhancement of MIPv6 protocol, is proposed in [65]. VMIPv6 adopts the anchorless concept of location management and the distributed architecture introduced in the IETF's DMM requirements document (RFC 7333) [73]. However, this approach has two main drawbacks, first is ground stations are fixed and do not move with satellites, which makes it hard to communicate with the home agent when the satellite is not in line-of-sight; and second is, ground stations deployment is bounded by Earth geography. In addition, fixed home agents on satellites will require several hops to complete binding updates when the satellite is not in line-of-sight, which increases the update delay and consumes ISLs bandwidth. To overcome such problems, [66] proposes to use a flexible agent placed on LEO satellites, where the home agent functionality is relayed from one satellite to another (i.e., the satellite that is closer to the MN) in a flexible manner.

2.4.1.2 Locator/identifier split in LEO SatNets: Since the IP dual-role (i.e., locator and identifier) is regarded as the main cause of inefficient location management. In terrestrial networks, many research works are investigating the separation of the locator and identifier roles of IP such as Identifier Locator Network Protocol (ILNP) [74].

2.4.1.3 SDN-based location management in LEO SatNets: The SDN concept was introduced to add programmability and flexibility to network management [75]. Since the centralized nature of SDN limits the network scalability, several works have integrated SDN with a Distributed Mobility Management (DMM) architecture to adapt to the large scale of LEO SatNets.

2.4.2 Handover management: The satellite handover can be regarded as a procedure in which multiple mobile terminals compete for satellite resources. In a low earth orbit (LEO) satellite network, handover management across satellite spot beams needs to be addressed to decrease handover times while using network resources efficiently since the speed of LEO satellites is much higher than that of mobile nodes. The satellite handover can lead to many problems, such as delay, transmission loss and signalling overhead. Besides LEO, GEO, and MEO, there are another two satellite handovers, i.e., spotbeam handover and intersatellite link (ISL) handover. Spotbeam handover refers to the satellite handover between multiple beams when the satellite uses multiple beams. The solutions for spotbeam handover are relatively mature [76-77]. ISL handover refers to the fact that, when a satellite approaches the polar region gradually, it will lose connection with another satellite in adjacent orbit.

The satellite handover problem is a hot issue in academia and industry. Duan et al. [78] proposed a handover control strategy combined with multihop routing. Syed Umer Bukhari et al. [79] used fuzzy c-mean clustering based on LEO satellite handover. They overlooked the call quality. Hu et al. [80] proposed a velocity-aware hand overprediction in LEO satellite communication networks. Remmy et al. [81] analyzed the performance of correlated handover service in LEO satellite systems. Gervais et al. [82] proposed adaptive handoff for multiantenna mobile satellite systems with an ancillary terrestrial component. Liao et al. [83] provided analysis of maximum traffic intensity under the preset quality of service requirements for fixed-channel reservation with a queuing handover scheme. Wu et al. [84] proposed an architecture called the software-defined satellite network (SDSN) and a seamless handover mechanism for LEO satellite based on this architecture. Compared with hard and mixed satellite handovers, the algorithm has greater advantages of delay and throughput. All of the above methods can only minimize the number of satellite handovers. However, the call quality cannot be guaranteed, and the handover time is not considered. In [85] Wu et al. propose a software-defined satellite network (SDSN) architecture with novel satellite handover strategy using bipartite graph based on the potential game for mobile terminals in a LEO satellite communication network. The LEO satellites serve as the nodes for data transmission in the SDSN architecture. Figure 5. represent SDSN architecture for LEO satellite resource-sharing and Figure. 6 shows the bipartite graph for handover management. A bipartite graph framework for handover maximizes the benefits of mobile terminals and a terminal random-access algorithm based on the target of user space maximization are proposed to solve the two problems in the LEO satellite resource-sharing model.

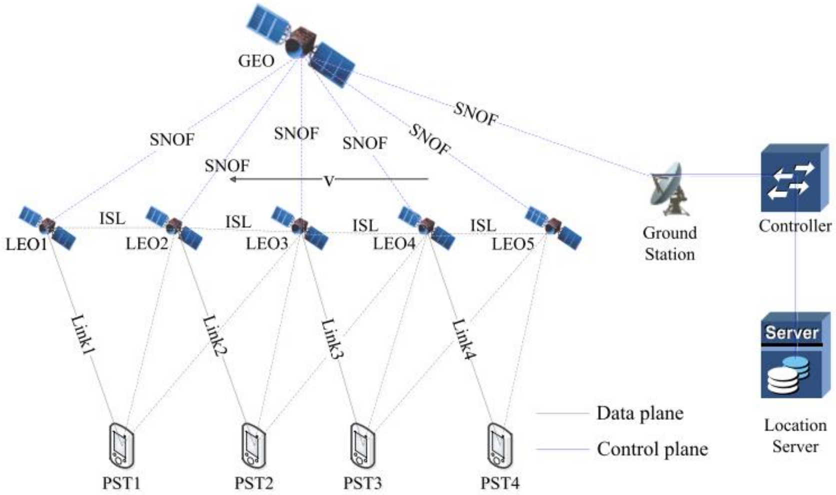


Fig.5. A LEO satellite resource-sharing model based on an SDSN architecture.

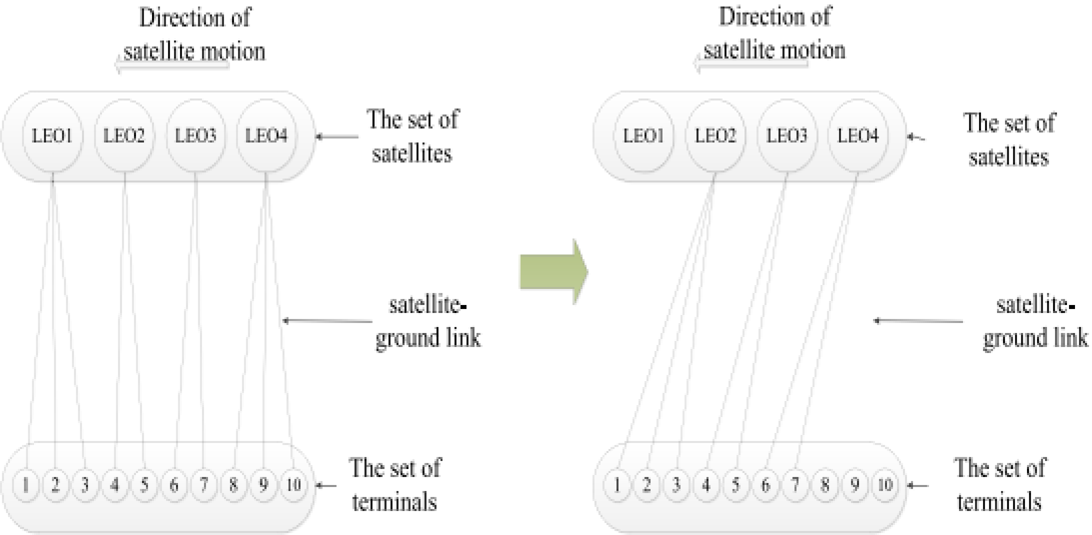
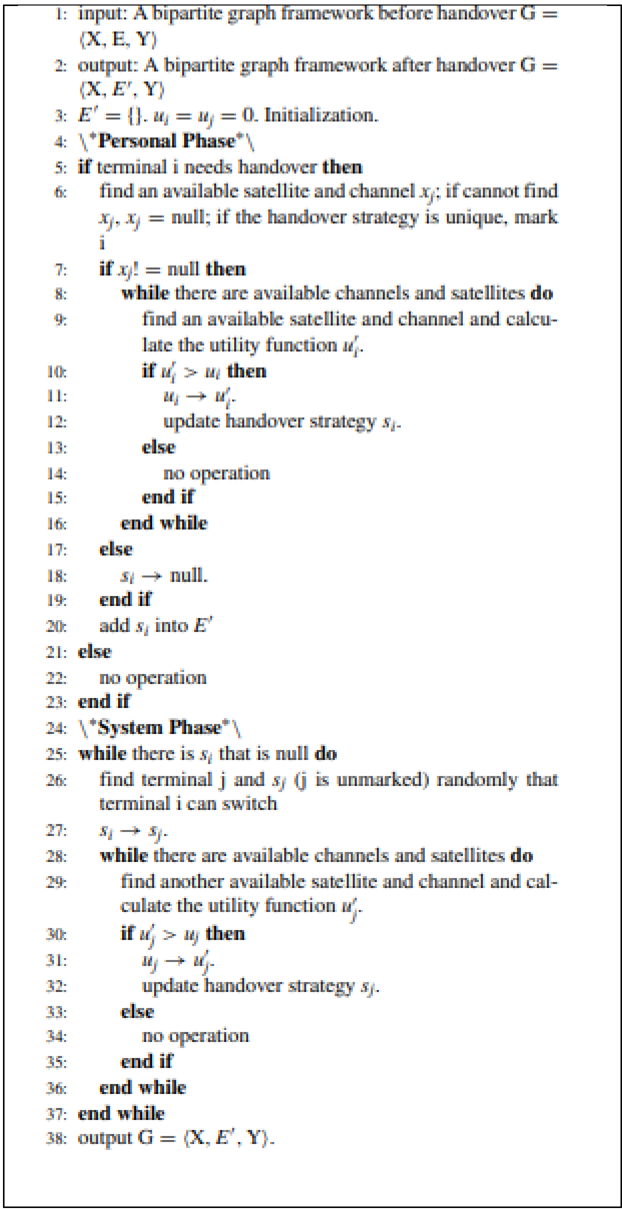


Fig.6. The bipartite graph of the connection relationship between satellites and terminals.

When the mobile terminals need to switch, the handover algorithm 1 based on the potential game to maximize the benefits of mobile terminals is used. When mobile terminal wants to access the LEO satellite network, algorithm 2 is used. Algorithm 1 shows the handover algorithm that maximizes the benefits of mobile terminals. It consists of two phases: the personal phase and system phase. In the personal phase, when LEO satellites orbit around the Earth or mobile terminals move, mobile terminals select the satellite with the maximum benefits to switch according to their own utility functions. In the system phase, there may not be any available channels or available satellites for some mobile terminals. The corresponding satellites and channels shall be vacated for them. Then, the disconnected mobile terminals switch again according to algorithm 1.

Algorithm 1 Handover Algorithm to Maximize the Benefits of Mobile Terminals	**Algorithm 2 Terminal Random Access Algorithm Based on the Target of User-space Maximization**



```
input: A bipartite graph framework before handover G = $\langle X, E, Y \rangle$
output: A bipartite graph framework after handover G = $\langle X, E', Y \rangle$
$E' = \{\}$. $u_i = u_j = 0$. Initialization.
\*Personal Phase*\
if terminal i needs handover then
    find an available satellite and channel $x_j$; if cannot find $x_j$, $x_j$ = null; if the handover strategy is unique, mark i
    if $x_j$! = null then
        while there are available channels and satellites do
            find an available satellite and channel and calculate the utility function $u_i'$.
            if $u_i' > u_i$ then
                $u_i \rightarrow u_i'$.
                update handover strategy $s_i$.
            else
                no operation
            end if
        end while
    else
        $s_i \rightarrow$ null.
    end if
    add $s_i$ into $E'$
else
    no operation
end if
\*System Phase*\
while there is $s_i$ that is null do
    find terminal j and $s_j$ (j is unmarked) randomly that terminal i can switch
    $s_i \rightarrow s_j$.
    while there are available channels and satellites do
        find another available satellite and channel and calculate the utility function $u_j'$.
        if $u_j' > u_j$ then
            $u_j \rightarrow u_j'$.
            update handover strategy $s_j$.
        else
            no operation
        end if
    end while
end while
output G = $\langle X, E', Y \rangle$.
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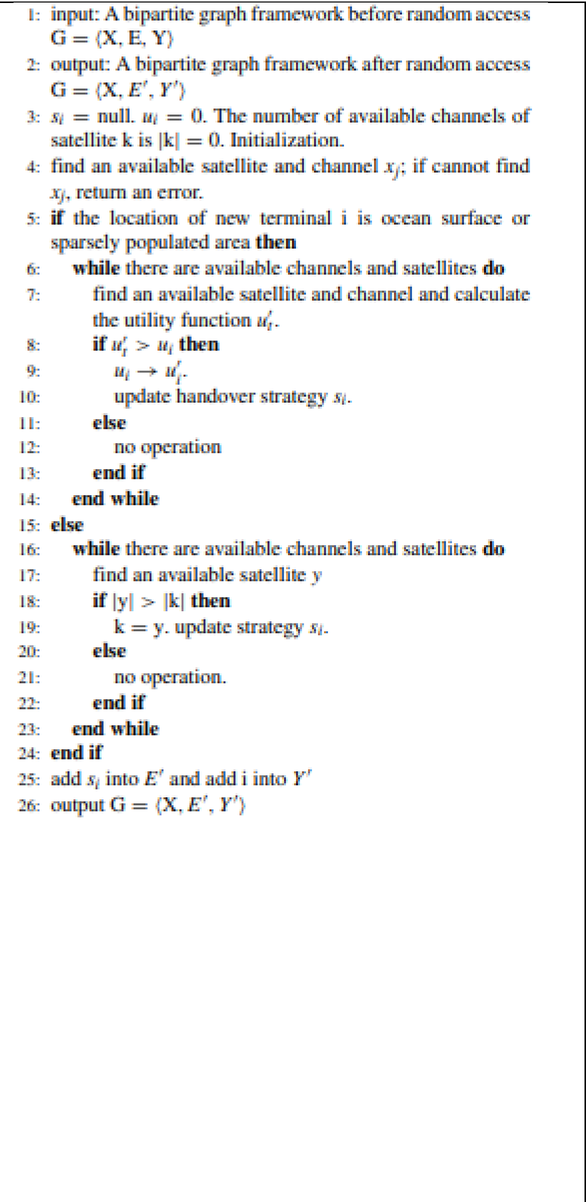

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input: A bipartite graph framework before random access G = $\langle X, E, Y \rangle$
output: A bipartite graph framework after random access G = $\langle X, E', Y' \rangle$
$s_i$ = null. $u_i = 0$. The number of available channels of satellite k is $|k| = 0$. Initialization.
find an available satellite and channel $x_j$; if cannot find $x_j$, return an error.
if the location of new terminal i is ocean surface or sparsely populated area then
    while there are available channels and satellites do
        find an available satellite and channel and calculate the utility function $u_i'$.
        if $u_i' > u_i$ then
            $u_i \rightarrow u_i'$.
            update handover strategy $s_i$.
        else
            no operation
        end if
    end while
else
    while there are available channels and satellites do
        find an available satellite y
        if $|y| > |k|$ then
            k = y. update strategy $s_i$.
        else
            no operation.
        end if
    end while
end if
add $s_i$ into $E'$ and add i into $Y'$
output G = $\langle X, E', Y' \rangle$
```

2.5 Routing Algorithm for LEO Satellite Network

Many routing algorithms for LEO satellite networks are proposed in recent years. Most of them focused on how to minimize end-to-end propagation delay [86]. With the explosive growth of satellite applications, however, queuing delay becomes more and more non-negligible. Consequently, in [87] Li et al. adopted expected queuing delay to avoid congestion. Furthermore, an "Orbit Speaker" based scheme [88] collects queuing delay of each neighbour link and delivers them to all satellites in its orbit. In many routing algorithms, virtual topology is widely used to control the dynamical satellite networks. In these schemes, satellite operation period can be divided into multiple slots, in which the topology is considered stable. Queuing delay is collected at the beginning of each slot and then static shortest path algorithm is used to calculate routing table. Under high traffic load, however, the queuing delay collected in these schemes may be outdated due to their long convergence time.

With a point-to-multipoint architecture, Dijkstra algorithm [89] is designed to look for the shortest path in increasing order of path length. The one for bus ad-hoc network [90] addressed sparse distribution issue in software-defined bus ad-hoc network. Satellite network topology is predictable and thus connectivityaware algorithms can form an effective class of solutions. The Connectivity-aware routing framework [91] developed a centralized unicast routing that satisfies the needs of strong stability and low delay. Time complexity of the framework is largely lower compared with the traditional Dijkstra algorithm. Different from terrestrial devices, satellite energy efficiency should be an important concern when designing routing algorithms. Balanced and Energy Efficient Multi-Hop (BEEMH) algorithm [92] minimized the amount of energy cost in wireless sensor networks. Spending too much time is the setback of this algorithm. Minimum weight link disjoint paths restricted upper bound common nodes problem [93] that minimizes the link weights upon request of nodes number is raised. The authors introduced the L-Link Bellman-Ford Algorithm, which adopted the framework of dynamic programming to search for shortest path within link number specified in a weighted directed graph. Transmission security is also an important issue in satellite network routing. In the existence of randomly scattered eavesdroppers, Secure Routing algorithm [94] modifies the traditional Bellman-Ford algorithm to maximize confidentiality of data transmission in multihop wireless networks. Interval multicast algorithm (IMA) [95] is intended for participants to receive messages within the specified time interval. IMA is designed with interval multicast subgraph in collaborative and competitive applications.

Pritsker [96] explained a common process of the GERT. GERT network of crisis evolution [97] introduced the natural evolution of resource crisis based on a GERT network. The GERT method extended by a characteristic function [98] addressed the issue of schedule risk for new-product development. In order to eliminate the defects in the traditional project schedule models (critical path method [99] and project evaluation and review technique [100]), the extended GERT method is proposed. Edward et al. [101] proposed the queuing graphical evaluation and review technique (Q-GERT) in reliability analysis. For LEO satellite communication network, Geng et al. in [102] introduces an optimal delay routing algorithm (DQGERTMPS) considering delay variation in the LEO satellite communication network. On account of complex structure and random service, the LEO satellite DQ-GERT network is designed by DQ-GERT model for the first time. Then, delay evaluation index is constructed. The delay queuing graphical evaluation and review technique minimal path (DQGERT-MPS) algorithm can effectively deal with uncertain information and vividly characterize the movement of LEO satellites. The algorithm flow descriptions is shown in are as follows and its corresponding flow graph is shown in Figure 7.

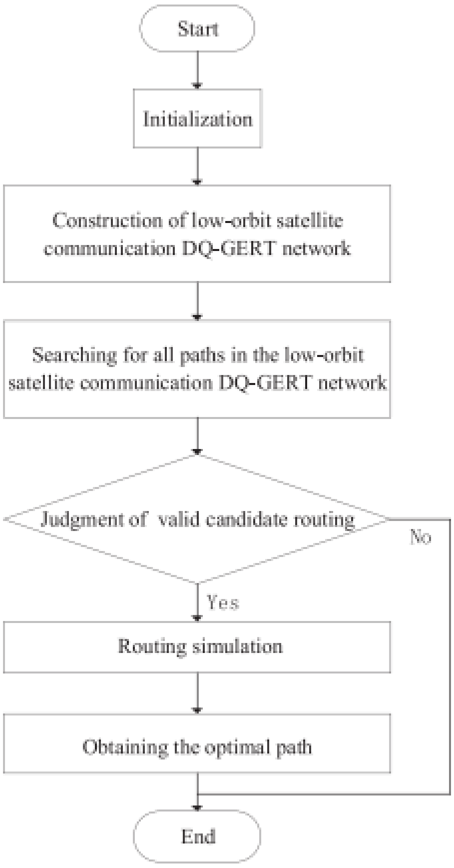

Fig.7. Flow graph of the DQGERT-MPS algorithm.

(1) Initialization: Topology structure and delay parameters in the LEO satellite communication network in current time slot are given.

(2) Construction of LEO satellite communication DQ-GERT network: After link relationships are determinate within definition 1 and definition 2, a LEO satellite communication DQ-GERT network is established.

(3) Searching for all paths in the LEO satellite communication DQ-GERT network: This phase is to find minimum path sets from the source node to the destination node in the satellite network. After that, discover the distribution of processing delay, queuing delay, and propagation delay in all paths.

(4) Judgment of valid candidate routing: A path that satisfies four constraints including input and output flow constraint, channel load constraint, antenna access constraint, and antenna rotation constraint is regarded as a valid candidate path. Eliminate redundant paths. The existence of invalid paths greatly increases computational complexity of proposed algorithm.

(5) Routing simulation: Service process is simulated for 1000 times in the LEO satellite network. Delay parameters (mean and standard deviation) produced by each valid candidate path are gained. It is worth noting that the realization probability of irrelevant links is zero when simulating a path.

(6) Obtaining the optimal path: Compare the delay evaluation index of all valid candidate paths, the optimal delay path is selected in the LEO satellite communication DQ-GERT network.

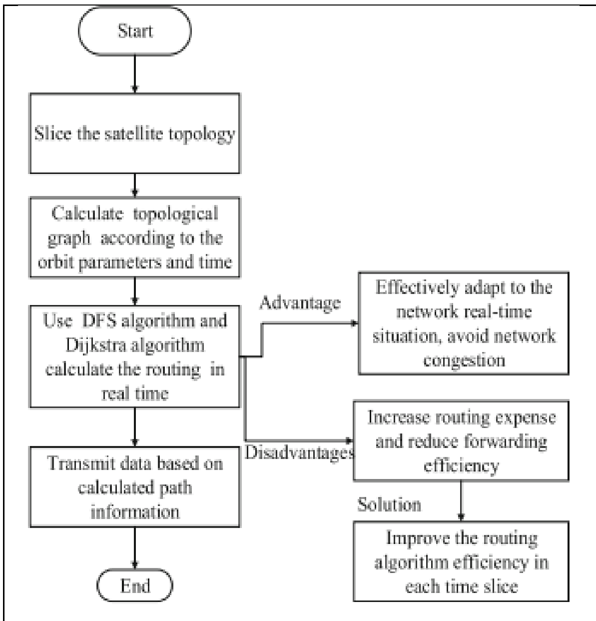

Fig.8. Advanced routing algorithm based on virtual topology

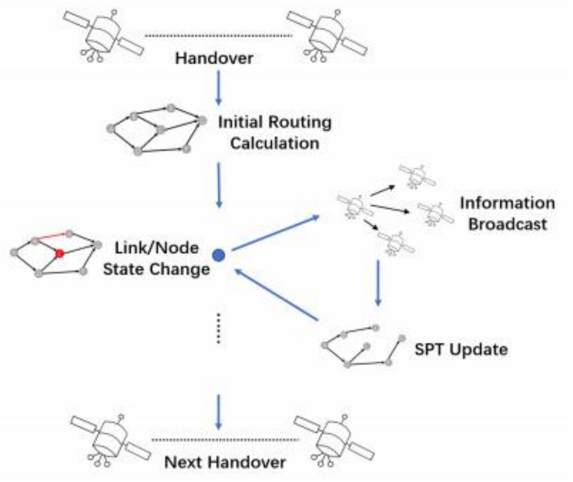

Fig. 9. State-aware load-balanced routing in LEO satellite networks

In [103] Jia et al. use routing algorithm based on the idea of virtual topology [104,105] shown in Figure 7, which is widely used for routing calculation in the LEO satellite network. In [106] State-Aware and Load-Balanced (SALB) routing model shown in Figure 9 is proposed for LEO (low earth orbit) satellite networks.

2.6 Advance technological integration with LEO satellite network

2.6.1 LEO Satellite based IoT: The LEO satellite based IoT is an important complement and extension of the terrestrial IoT and the only way to address global coverage. In [107] Jin et al. proposed the framework architecture for LEO satellite based IoT for traffic analysis which is divided into space segment, ground segment and user segment as shown in Figure 10. Since the terminal of LEO satellite based IoT is far away from the satellite, the terminal's transmission power is required to be larger, and the terminal's signalling interaction process should be minimized to accommodate frequent route switching between satellites [108]. Finally, through the modular integrated design, it can support the IoT business needs of different scenarios.

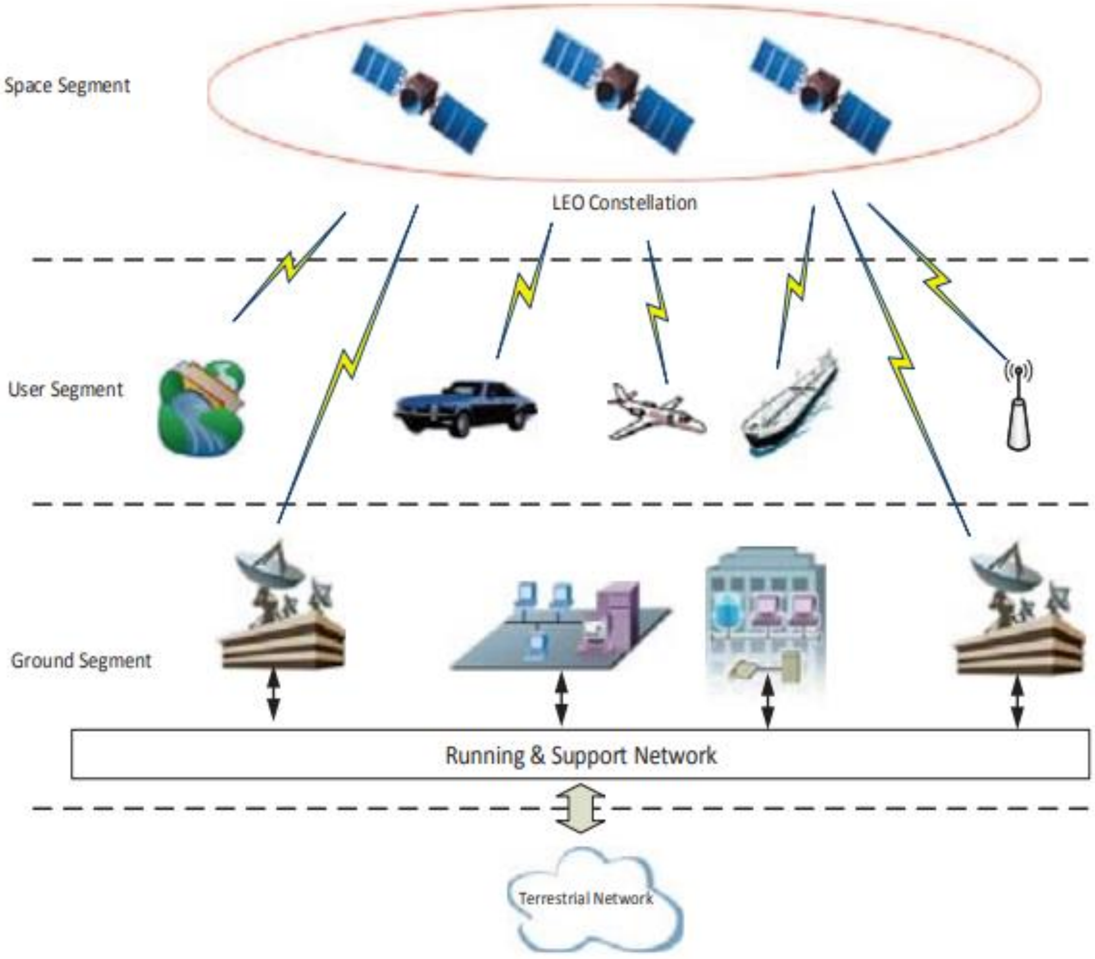

Fig. 10. Architecture of LEO Satellite based IoT System

2.6.2 Edge computing satellite network architecture: The LEO satellite network has been a valuable architecture due to its characteristics of wide coverage and low transmission delay. Utilizing LEO satellites as edge computing nodes to provide reliable computing services for access terminals will be the indispensable paradigm of integrated space-air-ground network. However, the design of resource division strategy in edge computing satellite (ECS) is not easy, considering different accessing planes and resource requirements of terminals. Moreover, network topology, available resources and relative motion need to be analysed comprehensively to establish ECS collaborative network for emergency situations. To address these problems, ECS network architecture utilizing the SDN paradigm is proposed in [108] to achieve the global coverage, especially in remote areas (e.g., desert, ocean, forest, etc.), where a terrestrial network is impossible or impractical to reach. The GEO satellites with wide coverage are used as the SDN controller to achieve real-time control of the LEO constellation. The edge servers deployed in ECSs are mainly responsible for data processing of intelligent terminals in the coverage region. the edge computing satellite network architecture to exhibit data interaction in different layers and the framework of mobile edge computing servers in ECS, as shown in Figure. 11. The right half of the figure expresses a three-layer space-air-ground integrated network, which are GEO satellite layer, LEO satellite layer, and air ground layer. In this work the advanced K-means algorithm (AKG) and breadth-first-search-based spanning tree algorithm (BFST) is provided to realize ECS resource division and ISL construction respectively.

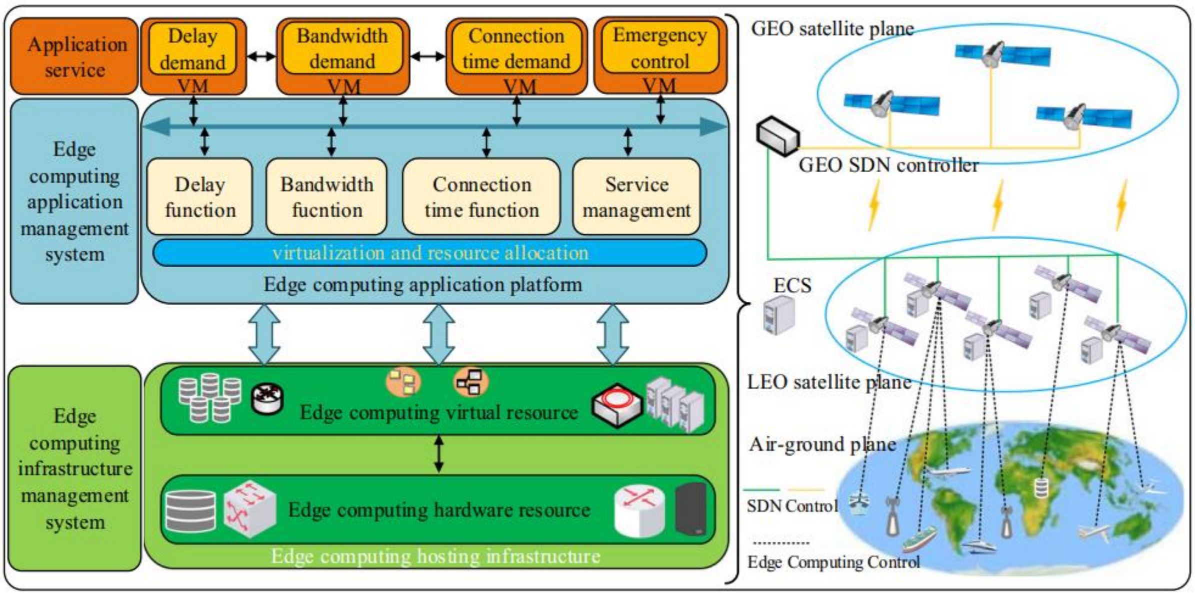

Fig. 11 The edge computing satellite network architecture

2.6.3 LEO satellite integration with 5G technology: 5G's new technology can meet more complex application scenarios and services, and its new transmission technology with higher spectrum utilization can be used in the new 5G LEO satellite mobile communication system. With the recent rapid development of low Earth orbit (LEO) satellites, the LEO satellite access network (SAN) has shown its potential as an expansion of terrestrial networks to address the above issues. Several companies have announced their plans to launch thousands of LEO satellites by 2022 or so [110,111], including SpaceX, OneWeb, Kepler, and SPUTNIX. These projects aim to provide seamless and high-capacity global communication services by constructing an ultra-dense LEO constellation, cooperating with terrestrial operators. To utilize the high-frequency band in space, a terrestrial-satellite terminal (TST) equipped with phase antenna arrays acts as the access point (AP) for users. Each TST supports both the user, TST links over C-band, and the TST-satellite links over Ka-band, enabling terrestrial small cell coverage for users. Benefiting from high altitudes, broad operating spectrum, and ultra-dense topology, LEO satellite networks can support a massive number of users with their high-capacity backhaul, vast coverage, and more flexible access technique, which is less dependent on instantaneous radio environments [112]. The typical architecture of ultra-dense 5G LEO-satellite access network is shown in Figure. 12.

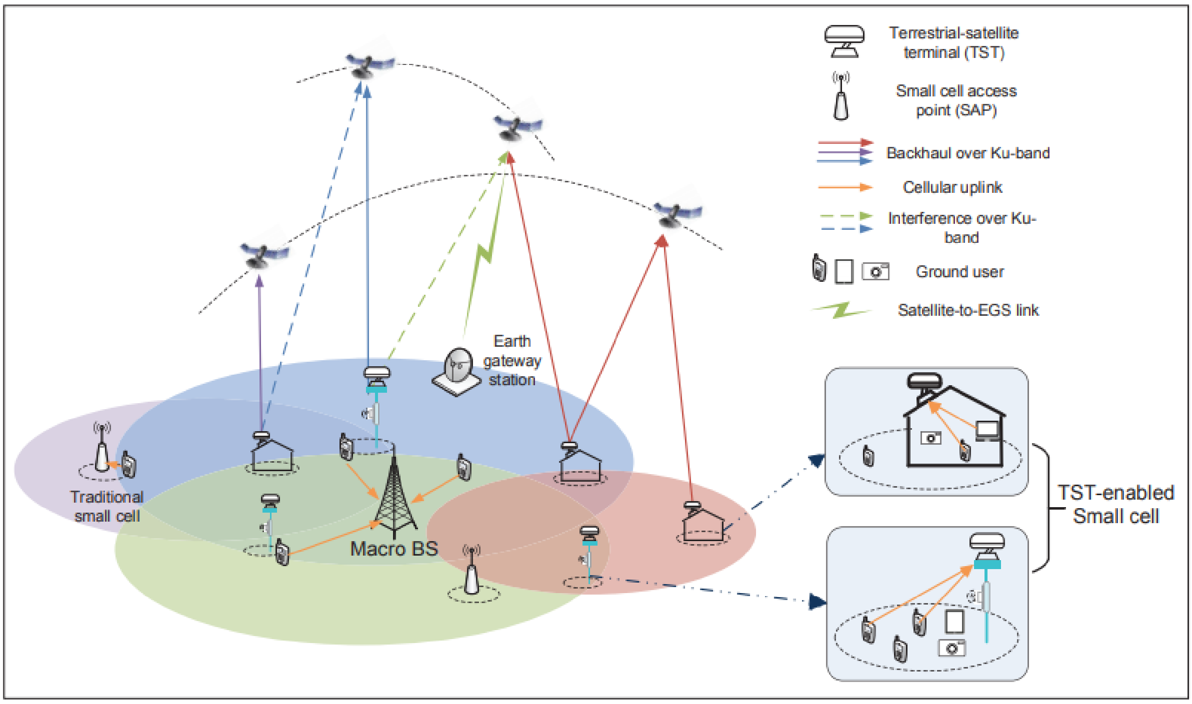

Fig.12 System model of an ultra-dense 5G LEO-satellite access network.

3. Open Challenges and opportunities in LEO Satellite network communication

As of the great coverage and flexibility, the next generation LEO mega constellations will be capable to provide services for various communication application scenarios, for both traditional telecommunications and Internet access and upcoming IoT, M2M and 5G services. However intensive research is required to overcome the obstacles and unlock the potentials of future LEO SatNets to providing continuous connectivity everywhere, for everything, and in the required QoS. This section highlights some critical points that require further investigation and recommends future research directions.

- In future LEO SatNets, there will be several megaconstellations with different orbital parameters. Such parameters will have an effect on a number of variables including propagation delays, handover frequency and duration, footprints, and density of satellites. Such variables affect the performance of location management algorithms. Thus, for different orbits/constellations, location management might be different. In addition, the diversity in required QoS for user devices/applications should be taken into consideration while designing location management solutions for future LEO SatNets.
- The main causes of the current Internet's problems are the so-called triple bindings, namely user/network binding, control/data binding, and resource/location binding. The author proposed a collaborative Internet architecture that completely cancels the restrictions imposed by the triple bindings. Although this approach applicability in future LEO SatNets was not discussed, it worths the investigation as it may add flexibility to network topology management.

- Blockchain technology is well known for managing its ledgers in a secure and distributed nature. This feature of blockchain might be advantageous in managing the flow tables in SDN-based LEO SatNets.
- With booming development in IoT environment, as a powerful supplement to terrestrial systems, LEO constellation-based IoT is worth being focused and studied. To make this topic become a reliable cost-benefit solution, further researches are needed to be done including transmission scheme, system security and low power consumption design.
- Low earth orbit mobile satellite system (LEO-MSS) is the major system to provide communication support for mobile terminals beyond the coverage of terrestrial communication systems. However, the quick movement of LEO satellites and the propagation delay of LEO-ground links bring not only great challenges to radio resource management, but also difficulties in handover management. Thus, improved handover strategies should be introduced in future works.
- the DQGERT-MPS algorithm can effectively deal with uncertain information and vividly characterize the movement of LEO satellites. Besides, the QoS of the optimal routing is better in terms of delay variation. Future work will set up QoS evaluation index system. As satellites provide multiple services, the key drivers of service satisfaction are also different.
- For the LEO satellite IoT system, its traffic distribution is very sudden and versatile, both in time and space. When the business suddenly increases, there is a possibility of access blocking, and when the traffic is small, it is a great waste for satellite resources. Therefore, it is particularly important to study the resource management strategy that changes with the traffic volume.
- The LEO satellite IoT is not trying to replace the terrestrial IoT, but the complement and extension, which can greatly expand the coverage of the former and promote the development of IoT. This paper describes the simulation method of LEO satellite IoT traffic for the special application scenarios and business types. The simulation results show that the distribution of LEO satellite system business has great burstiness and variability in time and space. This non-uniformity is not conducive to the stability of system performance. Therefore, when designing the LEO satellite IoT system, we must first estimate the distribution characteristics and laws of the business, and then guide the determination of satellite communication capacity and constellation design.
- Potential research directions for 5G integrated LEO satellite network include integrated traffic modelling, adaptive spectrum sharing scheme design, and energy-efficient cross-platform protocol design.

4. Conclusions and Future Aspects

Broadband LEO satellite communication has been a hot topic recently. A comprehensive overview has been presented in this article on methods, technologies and algorithm for LEO systems including system architectures, resource allocation and resource management methods, mobility management, routing algorithm, and integration of LEO satellite with advance technologies including IoT, edge computing and 5G network. In general, the design of broadband LEO satellite communication systems is much more challenging than that of GEO. There are still many open issues in this area such as optimal routing strategies with dynamic network topology, coordination of multiple constellations, especially with GEO systems, and adaptive frequency and bandwidth usage for minimizing the interference. In the future, the terrestrial network and the space network will complement each other and eventually realize network convergence. It will provide stable, convenient, and low-cost broadband access services for anyone at any time and any place. Achieving LEO satellite communication network compatibility with other networks, seamlessly switching, resource coordination, and interference reduction between networks are further challenges that we need to face.

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