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SATELLITE NETWORK SLICE PLANNING

Architecture, Performance Analysis, and Open Issues

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For beyond-5G and 6G communications, the satellite-terrestrial integrated network (STIN) is expected to provide diverse services with global coverage. The first step in implementing a successful STIN is to make the satellite network capable of functioning seamlessly with its terrestrial counterpart. However, as satellites rotate around Earth at very high speeds and are connected over very long wireless links, it is almost impossible to use terrestrial schemes without modification.

In this article, network virtualization with network slicing, which is actively investigated in terrestrial networks, is analyzed for satellites. Satellite network slice planning (SNSP) methods are proposed to reserve the network resources for the virtual network (VN) during the required service time. The process is modeled with VN requests (VNRs) as the purpose is to embed the VNRs efficiently and to maintain the VN until the end of its required service time. Candidate methods for SNSP over megaconstellated satellite networks are presented and then evaluated with diverse metrics to find an appropriate method. Key parameters and the system bottleneck of SNSP are also identified. Finally, system efficiency, the tradeoff relation of SNSP, and open issues are discussed based on simulation results.

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Introduction

For 5G/6G networks, satellite communication is expected to be an essential component of future nonterrestrial

IN THIS ARTICLE, NETWORK VIRTUALIZATION WITH NETWORK SLICING, WHICH IS ACTIVELY INVESTIGATED IN TERRESTRIAL NETWORKS, IS ANALYZED FOR SATELLITES.

networks (NTNs) owing to their inherent advantages of global coverage and independence from natural/man-made disasters. Satellites can be the service providers of new applications that are not served by terrestrial links, such as urban air mobility (UAM). Satellites are required to offer a quality of service (QoS) as stringent as the terrestrial networks for various applications [1].

Megaconstellated satellites, such as SpaceX Starlink and Amazon Kuiper, will form a large network in space because intersatellite links (ISLs) are used for global broadband communications. With ISLs, end-to-end propagation delays and the number of ground gateways are lower than those achieved with bent-pipe satellite nodes (SNs). Furthermore, if satellites have their computational capabilities, a megaconstellated satellite network with ISLs can function as a wireless core network floating in space [2]. With this trend, satellite network slicing has attracted the interests of researchers/developers, and it is one of the key techniques in 5G networks. Network slicing provides each slice customer with a dedicated service by virtually creating an independent VN from a physically shared common network infrastructure. The independent VN is called a *network slice* and corresponds one-to-one to the service.

Satellite network slicing enables a substrate satellite network to support diverse services similar to terrestrial network slicing. Because the satellite network is expected to serve various new emerging applications on a global scale and can be integrated with a terrestrial network, satellite network slicing is an essential technology for the expanded vertical convergence of 6G networks with ultra-3D coverage.

In a previous study [3], a satellite network with onboard computing capability was presented with satellite edge computing (SatEC) architecture and network slices. The SatEC architecture with offloading was proposed, and the multiple objectives of end-to-end latency and transmission/computation power were optimized. Furthermore, the scheduling policy of access satellites was proposed based on satellite network slicing, assuming that end-to-end slices were adequately embedded and managed as the satellites moved. Realizing this assumption is one of the critical challenges for sliced satellite networks and thus constitutes the core topic of this article.

Challenges in realizing network slicing in satellite networks are unique because the network is constructed over long wireless links, and each node moves at very high speeds. For the given locations of ground network slice requests, access satellites should perform frequent handovers to serve the slice during the required service time. In addition, the ISL connectivity and link distances may vary over time.

The implementation of network slicing can be divided into scheduling and planning [4]. As illustrated in Figure 1, during scheduling, a schedule for the VNs in the shared substrate SNs is determined, and during planning, network resources are reserved for a VN during its service time so that the slice provider ensures that the VN can provide reliable support for the desired service. The planning part for satellite network slicing is far more critical than that in terrestrial networks because slice management with handovers is essential for fast-moving satellites. The management of embedded VNs

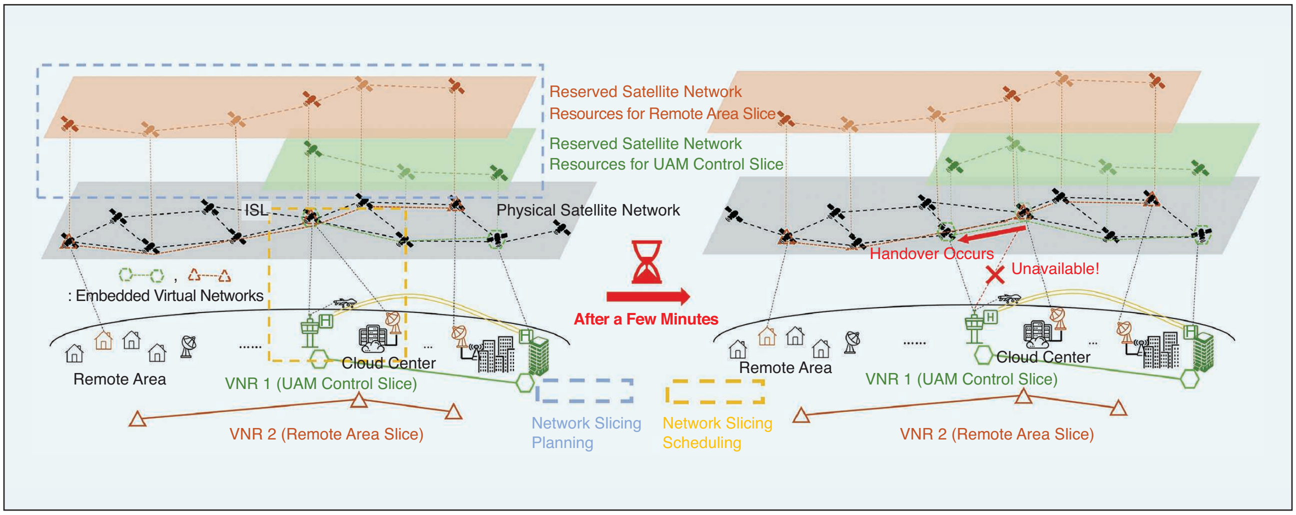

FIGURE 1 An illustration of SNSP: satellite network slice planning as an embedding problem of VNRs with satellite–ground handovers in time.

during the service time with satellite handovers should be contemplated for the successful deployment of the network. Thus, SNSP is a key challenge and is the most fundamental step in implementing satellite network slices. The intuition resulting from SNSP can be crucial for the management of deployed satellites as well as the global network design prior to launch.

As depicted in Figure 1, the SNSP under consideration includes embedding the VNRs that have arrived and managing the embedded VNs during the required service time with handovers, if necessary, to handle the mobility of satellites. The SNSP is modeled as a VN-embedding (VNE) problem for VNRs. The embedded virtual nodes of each slice are illustrated in darker colors. Handovers occur when the embedded SNs are no longer available. Because the VNE problem is known to be NP-hard, it is divided into node embedding and link embedding [5]. There has been little research on SNSP. In [6], a satellite VNE algorithm was proposed, assuming frequent switching of ISLs using a simple simulation.

In this article, basic methods for VNE are introduced, and then handover strategies are proposed. To reduce the computational burden of the VNE process and investigate the effectiveness of splittable path link embedding, an additional step before link embedding, named *prelink embedding*, is also proposed. SNSP performances are evaluated with simulations for the acceptance ratio; the number of handovers; end-to-end latency; data throughput; and cost. In addition, the system bottleneck and key parameters for the system efficiency of SNSP are discussed. To the best of our knowledge, this work is the first attempt to propose various potential SNSP methods with handover management in joint accounts and discuss the key challenges for SNSP based on realistic simulations and performance assessments.

6G Satellite Network

Satellites provide global Internet services and diverse future applications as a network. In other words, megaconstellated satellites are interconnected over wireless ISLs to create a large network in the sky. The 6G satellite network with ISLs can be both a network operating independently of the terrestrial network and a part of the 3D network that is integrated with its terrestrial counterpart.

A noticeable distinction between satellite and terrestrial networks is that a satellite network has wireless connections among its moving nodes. In fact, this can be a unique advantage of satellite networks. Dynamic link connectivity over time can be exploited based on the mobility of satellites and different types of services. For example, if a user requires low-latency service, the ISLs should be updated frequently based on a visible matrix to find the shortest path connection [7]. On the other hand, if a service demands reliable end-to-end connectivity for a long period, it would be better not to change the ISL connectivity, for example, by deploying a bidirectional Manhattan Street Network (MSN) whose link connectivity is maintained permanently [8].

SATELLITE NETWORK SLICING IS AN ESSENTIAL TECHNOLOGY FOR THE EXPANDED VERTICAL CONVERGENCE OF 6G NETWORKS WITH ULTRA-3D COVERAGE.

ISL Connections for Satellite Network Slicing

Currently, SpaceX plans to provide four low-Earth orbit (LEO) satellite ISLs per satellite [9]. Figure 2 conceptually shows possible link connections, where gray links represent the MSN connecting the four neighbor links. For example, the blue satellite in Figure 2 is connected to green satellites using the MSN protocol. The MSN links remain connected to the same satellites, regardless of their mobility. However, because the relative locations of satellites change and other visible satellites can be connected with wireless ISLs, it is possible to deploy a time-varying link connection protocol. For example, the blue lines in Figure 2 represent the possible interorbital plane link connections of the blue satellites in a snapshot and after a few minutes. As the purpose of SNSP is to reserve the network resources of the satellite network for VNRs, MSN connectivity is feasible for sliced services.

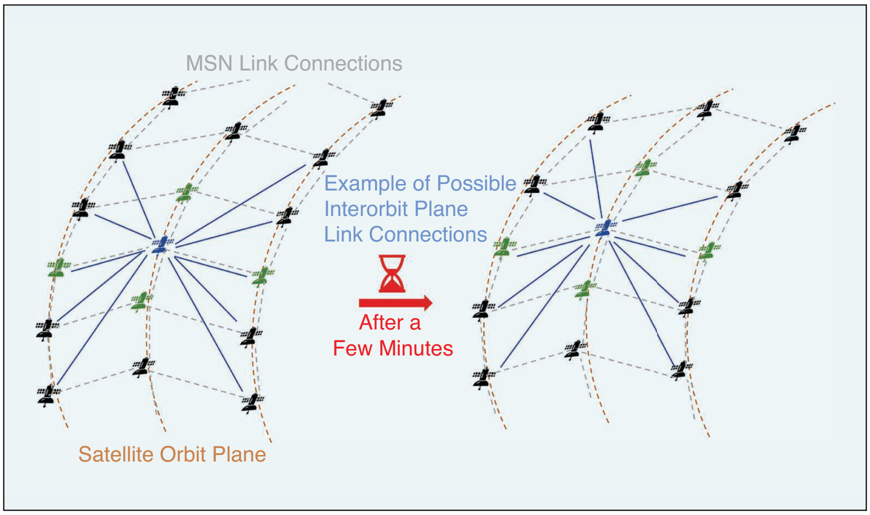

FIGURE 2 A description of ISLs: an illustration of ISL connectivities over time for megaconstellated satellites with the same altitude and inclination angle.

If a time-varying link connection protocol is used for a sliced service, ISL handovers should occur frequently, in addition to satellite-to-ground link handovers. This dynamically increases the workload required to maintain the VNs and is not realistic for the slice scenario. Therefore, for the 6G satellite network, a sensible solution will be to combine the network slice implemented by the MSN link protocol with additional temporary link connections based on a time-varying visible matrix-based protocol for random access and delay-sensitive services.

Possible Satellite VNE Methods

Assuming an MSN link connection, an SNSP strategy is proposed as a VNE problem with VNRs to reserve satellite network resources. The VNRs are composed of virtual nodes and virtual links, and the purpose of the VNE is to embed the VNRs in the substrate network efficiently [10]. The satellite network and VNRs are represented using flow graphs. Furthermore, as satellites move, handovers should be incorporated to properly manage the embedded VNRs. As in a terrestrial network, in a satellite network, VNE is divided into virtual node and link embedding [5]. In addition, a prelink-embedding step is proposed prior to the link embedding for the satellite network. Figure 3 shows the VNE process using the proposed embedding methods.

Virtual Node Embedding

The basic constraints for virtual node embedding are in the distance and node capacity. The embedded SN should be chosen from satellites whose ground service coverage contains a VNR location. An SN should also support a sufficient data rate that is at least larger than the requested capacity of the virtual node. As described in Figure 3 with a red outline, two possible

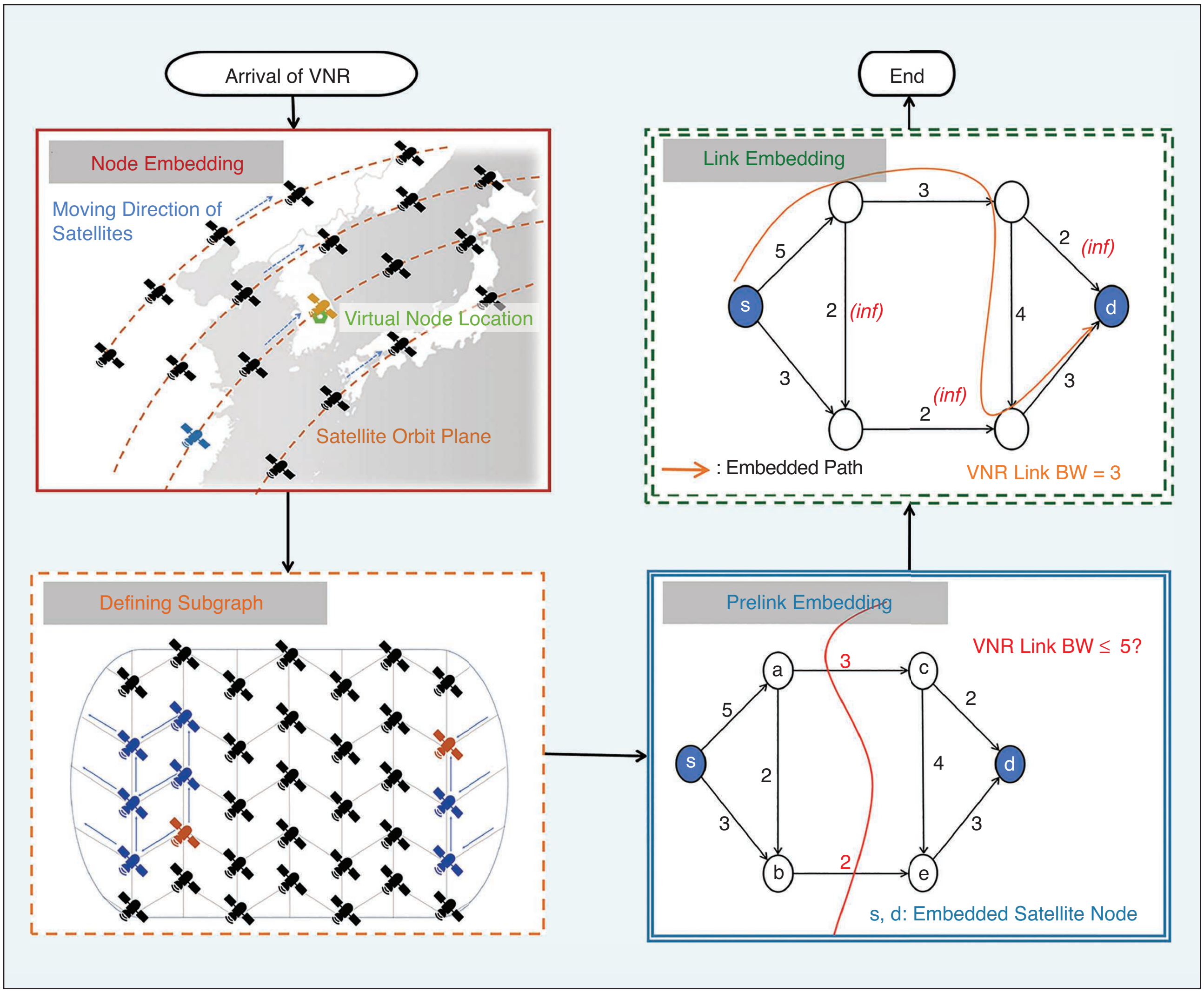

FIGURE 3 The VNE process and its embedding methods with simple examples. Virtual nodes are embedded to the SNs first, and virtual links are embedded afterward by defining a subgraph and deciding whether the request is acceptable.

node-embedding methods are introduced, based on SNs that satisfy the constraints. The green marker in the map represents the virtual node location of the VNR, and the yellow and blue satellites are the SNs embedded with the proposed methods.

The first method, the most intuitive, is to select the closest SN, which reduces the estimated propagation delay and is represented by the yellow satellite in the node-embedding example. The delay difference, which can be significant, depends on the selection of SNs. For example, assuming an elevation angle of 10°, satellites at an altitude of 1,000 km should be able to communicate with ground users up to approximately 2,700 km away. In other words, depending on the node selection, up/downlink propagation delays can vary by up to 5.6 ms, which will not be negligible in 6G networks.

The second method is to select the longest service available SN, the blue satellite in the node-embedding example. This reduces the number of handovers, and eventually, the number of executions of reembedding the VN. Thus, this method can improve the stability of slice service with a low amount of computation.

There can be many other node-embedding methods, such as randomly selecting an SN within the available satellites and selecting an SN with the maximal residual node capacity. However, the two proposed methods will be analyzed because each can achieve low latency and slice service stability, which are the two fundamental requirements for the 6G satellite network.

Virtual Link Embedding

After the virtual nodes of the VNR are embedded, subgraphs of the satellite network are introduced. Because the megaconstellated satellites are deployed globally in a circulation structure, a subgraph should be defined to reduce the search space for the remaining VNE process. The subgraph has a pair of embedded satellites whose virtual nodes are linked with a virtual link in the direction of the minimum number of hops. For example, in Figure 3, with an orange dashed outline, the orange satellites represent a pair of embedded satellites that are used to define the subgraph, and the blue satellites and blue links construct the defined subgraph for the embedded satellite pair.

Prelink embedding reduces the computational burden of the satellite network as, when implemented, the path-finding-based link-embedding algorithm for VNRs does not have to be used where embedding is not feasible. The prelink-embedding step finds a bottleneck in the subgraph by using the max-flow min-cut theorem [11]. By comparing the network bottleneck and the required link capacity, the prelink-embedding step decides not to proceed to the next VNE step; instead, it declares failure for embedding VNR if the VNR link capacity is greater than the network bottleneck. Figure 3, with blue double outlines, shows a simple example of the prelink-embedding step. A network bottleneck is identified as a red cut with a flow value of five; if the VNR link capacity is less than this value, the process can proceed to the next step of link embedding. This step can be implemented using a simple merge-based algorithm, whose computational burden is much lower than that of path-finding-based algorithms for link embedding.

SNSP IS A KEY CHALLENGE AND IS THE MOST FUNDAMENTAL STEP IN IMPLEMENTING SATELLITE NETWORK SLICES.

Under the link-embedding constraint, all the residual link capacities in the embedded routing path should be greater than the capacity of the VNR link. In the same manner as the node-embedding methods, the two link-embedding methods for latency and stability are introduced, as illustrated in Figure 3 with green double-dashed outlines.

To reduce the propagation delay, the first method finds the shortest path in the subgraph by satisfying the constraint of making all residual link capacities sufficient for the embedded path. This method can be implemented with the shortest path algorithms by setting the link weights to infinite values if they are less than the VNR link capacity and to the physical distances otherwise. In Figure 3, assuming the same subgraph of the prelink-embedding example and a VNR link capacity of three, a link distance graph can be given with infinite values in red.

The second method for stability embeds the virtual link request into the maximum flow path. Because the embedded path can be found in the subgraph, the link propagation delay can be guaranteed to some extent. The purpose of this method is to determine the maximum flow path. The maximum flow method is applied for the same example of prelink embedding in Figure 3. Unlike the conventional maximum flow problem, the purpose here is to find the maximum flow path, not the maximum flow value in the network. The method can be implemented using the shortest path algorithms with a different algorithm objective instead of the typical maximum flow algorithms. For example, as shown in Figure 3, the Dijkstra algorithm can construct the maximum flow path by finding the maximum link in the neighborhood and updating the path weight to the minimum link capacity in the obtained path.

The two methods can also be implemented for the splittable path-embedding scenario by iterating the link-embedding methods until the virtual link request is fulfilled. However, this article focuses on the single-path scenario to compare the utility of splittable path

In this article, basic methods for VNE are introduced, and then handover strategies are proposed.

embedding in a satellite network environment with a realistic simulation setup taken into account.

Handover Strategies

For satellite–ground handover strategies, LEO satellites with ISLs and steerable antennas are considered such that fixed beams are assumed on the ground, which is one of the 3rd Generation Partnership Project (3GPP) NTN reference scenarios [12]. Once a VNR is embedded in a satellite network, the VN can be served for only a few minutes at the longest because of the mobility of the embedded LEO SNs. This can be problematic if the usual service time of a VNR is in the order of hours, such as for the control of Regional Air Mobility (RAM) with a longer flight range than UAM; global live streaming services; and Internet services for remote areas. Thus, the SNSP should include the execution of service handovers. Because the MSN link protocol is used for slice services, handovers are required only between the ground and satellites.

The handover strategy decides not only when to hand over links but also how to hand over VNs. There are two representative methods for the latter: adding new links to the VN and reembedding with the handover SN. The first approach can reduce the computational burden for handovers, but the end-to-end performance degrades with handovers because the number of end-to-end hops increases and the satellite link distances of the embedded VN may change over time. In addition, a new scheme for this handover step is required to add new links between previously and newly embedded SNs. The second approach gives opposite results because end-to-end performance can be guaranteed, but the computational burden increases. The reembedding strategy can be a viable option for the 6G network to meet service requirements even though the computational burden for SNSP increases.

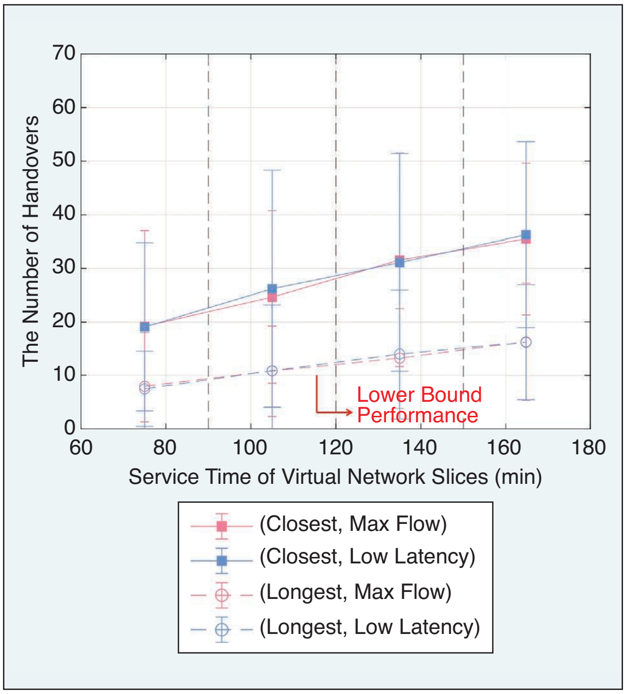

FIGURE 4 The number of handovers of a VN.

Satellite handover should occur when the satellite is no longer available or when service requirements are violated. Because the VNR requires the data rate for virtual nodes and links, there may be additional requirements for the end-to-end delay, QoS, quality of experience (QoE), etc., which are challenging to meet owing to the mobility of satellites and channel conditions. Thus, a satellite handover may be needed to satisfy demands, although links are still available. There are various open issues for handover strategies, such as the updating frequency of link connections and criteria of handover execution time in terms of QoS, QoE, and delay.

Performance Analysis

In this section, the SNSP performance is analyzed with respect to diverse evaluation metrics by evaluating the proposed methods. For the VNR embedding process, four different methods are simulated: the method of "closest, max flow" (Figure 4) for the closest node and capacity with the max-flow link; the method of "closest, low latency" for the closest node and low-latency link; the method of "longest, max flow" for the longest service node and capacity with the max-flow link; and the method of "longest, low latency" for the longest service node and low-latency link. The handover is assumed to be executed when one of the access links of the VN is unavailable by reembedding the VN with the same embedding method.

The simulation specifications are listed in Table 1. The Walker–Delta model of a total of 1,600 satellites at an altitude of 1,000 km is used, and the state-of-the-art data rates of Starlink are adopted [13]. The minimum elevation angle of the satellites is set to 10°, which is the same value as in the technical report of 3GPP [14]. The VNRs for the slice services are assumed at two levels. Low-level VNR requests require relatively small data rates, including massive Internet of Things or remote area emergency services. On the other hand, high-level VNRs demand higher data rates, such as data/video streaming or real-time UAM/RAM controlling. The statistical numbers of the low- and high-level requests are set to be the same. The requested service time of the simulated VNRs is assumed to be between 1 and 3 h. Satellite location data for

12 h are used to simulate the SNSP in a steady state, and the time unit is set to one minute.

The satellite location data were obtained by using the MATLAB-based simulation code [15], and all the simulations were conducted in Python with the NetworkX library by implementing our proposed methods on the satellite flow graph. The VNRs are modeled to arrive according to the Poisson process with 10 VNRs/min (1.2 gigabits/min = 20 megabits/s) on average. The VNR locations are assumed to be in the continental United States. Considering the practical model of commercial satellite networks, ground stations are assumed to be deployed sufficiently to support the required services in the service area, for example, within the continental United States. All simulations are repeated five times, and the average values are obtained. The optimal algorithms of the proposed methods converged rapidly within the network update interval for dynamic embedding. In general, the system will be in a steady state, except for after rare events of the initial deployment or large-scale network recovery.

Evaluation Metrics

The proposed SNSP methods are evaluated with respect to the VNR acceptance ratio; the number of handovers per VN; end-to-end latency; data throughput; and the ratio between data throughput and cost for SNSP. The acceptance ratio represents the statistical ratio of the successfully accepted VNRs over the arrived VNRs. Because the end-to-end latency can be time varying, the initial latency, maximum latency, minimum latency, and average latency of a VN are analyzed during the required service time. The data throughput is given as the sum of the node capacities and link capacities of all embedded VNs. The cost for SNSP is defined as the penalty of the network for the slice service; thus, weights for the number of nodes and hops over ISLs are added to the data throughput.

Simulation Results

Figure 4 shows the simulation results for the number of handovers according to the service time of the VNs. The resulting points are obtained by averaging the data during a service time of equal duration, and the error bars represent the standard deviations. It is shown that the closest node-based methods, which are represented as solid lines, perform handovers for approximately twice as long as the longest service node-based methods. In addition, the dotted lines, which are the results for the longest service node-based methods, represent the lower bound of the number of handovers needed to serve the satellite network slice.

Table 2 lists the simulation results of the acceptance ratio and end-to-end latency. The expired VNs include only those that were successfully served during the required service time. The acceptance ratio after link

THE HANDOVER STRATEGY DECIDES NOT ONLY WHEN TO HAND OVER LINKS BUT ALSO HOW TO HAND OVER VNS.

TABLE 1 ***Simulation specifications.***

	Model (Altitude)	***Total Number of Satellites***	***Number of Orbit Planes***	***Inclination Angle***
Constellation Specifications	Walker–Delta (1,000 km)	1,600	32	53.8°
Satellite specifications	***SN capacity***		***ISL Capacity***	
	17–23 Gbps		20 Gbps	
VNR specifications	***VNR Node Capacity***		***VNR Link Capacity***	
	Low level	High level	Low level	High level
	30–50 Mbps	100–300 Mbps	30–50 Mbps	100–300 Mbps
VNR arrival rates	***Number of Requests***		***Data Rate***	
	10/min		1.2 gigabits/min	

Mbps: megabits per second.

TABLE 2 ***Simulation results for acceptance ratios and end-to-end latencies.***

		Closest, Max Flow	***Closest, Low Latency***	***Longest, Max Flow***	***Longest, Low Latency***
The number of embedded VNs		1,193.8	1,195.6	1,190.2	1,214.8
The number of expired VNs		5,715.2	5,615.2	5,812.2	5,854.6
Acceptance ratio	After prelink embedding	0.9507	0.9508	0.9740	0.9788
	After link embedding	0.9507	0.9508	0.9740	0.9788
End-to-end latency (s)	Initial	0.06192	0.05823	0.06231	0.05960
	Minimum	0.02220	0.02144	0.02622	0.02587
	Maximum	0.1151	0.1044	0.1280	0.1232
	Average	0.06483	0.06002	0.06133	0.05910

BASED ON THE SIMULATION RESULTS, MOST OF THE EVALUATION METRICS WERE MAINLY AFFECTED BY THE NODE SELECTION METHODS AND HANDOVER STRATEGIES.

embedding is derived by dividing the sum of the numbers of embedded VNs and expired VNs by the total number of arrived VNRs. The longest service-available node-based methods outperform the others because the numbers of handovers with the longest available node-based methods are approximately half those with the closest node-based methods, as shown in Figure 4, and the trials for reembedding are significantly reduced. The prelink-embedding step determines the bottleneck of a flow and permits the splittable flows, whereas the link-embedding step assumes single-path link embedding.

Because the acceptance ratios after prelink embedding and after-link embedding are exactly identical for all proposed methods, we can see that end-to-end path splitting has no impact on our scenario. For further analysis, additional heuristic simulations were conducted by changing the satellite and VNR parameters to determine when it is meaningful to split the flow. Multiple path embedding takes effect when the average requested link capacity of a VNR reaches approximately one-tenth of the satellite network resource as the acceptance ratio after prelink embedding becomes different from that of after-link embedding. Thus, in the future, if newly provisioned services require extremely high data rates, the use of splittable path embedding may improve the network performance.

The results of the initial end-to-end latencies in Table 2 reveal that the best performance was achieved with the “closest, low latency” method, and the worst was achieved with the “longest, max flow” method. The minimum and maximum end-to-end latencies tend to be affected more by the node choice method; more precisely, they are affected by the frequency of handovers. As handovers occur more often, the ISL link routes are more updated, and thus, there is less performance degradation. At this point, the following observation can be made; fewer executions of handovers make for more reliable connections with higher acceptance ratios but relatively longer latencies in the worst/best cases. On average, it is better to use the “longest, low latency” method, but if the slice requires a stringent latency constraint, for example, fewer than 0.11 s in the worst case, the “closest, low latency” method is a more sensible option.

Figure 5 shows the simulation results for the data throughput and its ratio to the cost of assessing the network slice performance. In the data throughput results, all four methods achieved similar performance with the original simulation parameter settings, SN = 20 gigabits/s (Gbps) and ISL = 20 Gbps. To determine the system bottleneck of the SNSP, additional simulation results are compared by changing the SN and ISL capacities to 2 Gbps, respectively. In Figure 5(a), the performance degradation with the ISL capacity change is greater than that with the other cases, which suggests that ISLs can be a system bottleneck. Conventionally, ISLs are connected to only four links for a satellite, but approximately 50 available satellites can be observed in a fixed ground location for LEO megaconstellations. When the ISL capacity becomes much smaller than the SN capacity, the max-flow link-based methods plotted in red show a higher data throughput than the low-latency path methods.

Because the ISL utilization ratio in a small box at the bottom-right corner shows that the max-flow-based methods use more ISLs than the low-latency-based methods, the maximum flow path methods have an advantage in terms of system fairness over the low-latency path methods. When the SN capacity is much smaller than that of the ISL, as shown in the second and third groups of the bar graphs, the performances show significant differences according to the node-embedding methods. The longest service node methods have higher data throughputs than the closest node methods, as shown by the hatched bars, because of better stability with fewer handovers. In Figure 5(b), for the ratio between data throughput and cost, a performance difference is observed in the original simulation setup according to the method. The longest service-available node-based methods outperform the others. This result implies that the cost of the satellite network slice system is greater with the closest node-based methods, which tend to embed network slices to a greater number of ISLs than the longest node-based method. This is because more handovers occur, which eventually have a similar effect to embedding more VNs.

The red line with dots in Figure 5(b) shows the change in the average ratio for each simulation setup, with the same assumed ISL capacity. The average decreases with the SN capacity, while the SN capacity itself affects the ratio that represents the system efficiency. Thus, it can be said that node selection methods, handover strategies, and even the SN capacity specifications are more critical for making the satellite network slice system more effective than the link choice methods.

Conclusion

In this article, SNSP for 6G integrated networks was analyzed, and open issues for satellite network slicing were presented. With the unique characteristics of satellite networks, including the dominance of wireless links and the relative location change of SNs in time, SNSP is an extremely important issue for satellite networks. The SNSP was modeled as a problem of VNE and satellite-to-ground handover decisions. The VNE problem was divided into node embedding, link embedding, and prelink embedding, and then candidate methods were proposed. Potential handover strategies and open issues with them were introduced.

Based on the simulation results, most of the evaluation metrics were mainly affected by the node selection methods and handover strategies; thus, an optimized design was imperative to satisfy the slice user demands and augment the system efficiency. Sizable ISL capacities were necessary to increase the overall network throughput because the system bottleneck was on the ISL, while sufficient SN capacities were useful for the system efficiency, represented by the throughput and cost ratio of the network.

In conclusion, for network slice services in a satellite network, it is important to secure the capacity of the ISLs

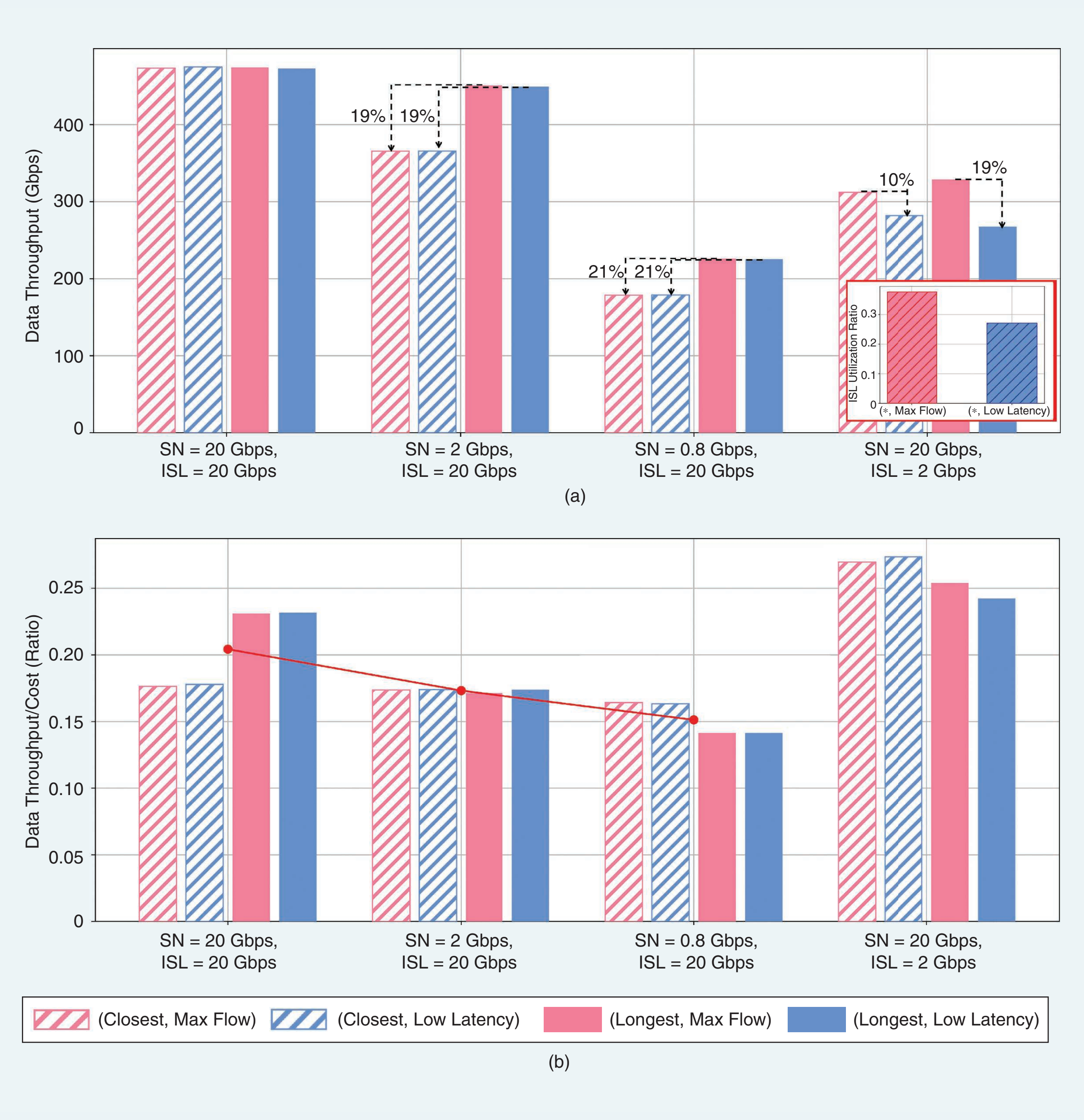

FIGURE 5 Simulation results of (a) data throughput and (b) its ratio to cost. Gbps: gigabits/s.

and to select the virtual SN efficiently according to the purpose of the slice. This work can lay the first cornerstone for SNSP and guide further research and hardware development with a proliferation of newly emerging future network applications. To implement the proposed methods, a centralized satellite network controller based on satellite software-defined networking should be deployed first. Because the logically centralized controller must provide an ultralow delay for the management of SNSP, future work may include a detailed strategy of how and when to execute handovers, possibly in a proactive way, and a slice design with moving users by combining intelligent schemes such as reinforcement learning or federated learning with the proposed SNSP methods in a distributed manner.

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