Analysis of Low-Latency Virtual Network Resource Reservation for LEO Satellite Network

Taeyeoun Kim *, Jeongho Kwak *, and Jihwan P. Choi †

*Dept. of Electrical Engineering and Computer Science, Daegu Gyeongbuk Institute of Science & Technology, Korea

†Dept. of Aerospace Engineering, Korea Advanced Institute of Science & Technology, Korea

{kim77ty, jeongho.kwak}@dgist.ac.kr, jhch@kaist.ac.kr

***Abstract*—For beyond 5G and 6G communications, the satellite terrestrial integrated network (STIN) is expected to provide diverse services with seamless coverage. The first step for implementing the STIN is to make the satellite network capable of supporting advanced functions that the terrestrial counterpart is providing. In this paper, network virtualization with network slices, which is actively studied in the terrestrial network, is analyzed for the satellite network. The main difference between satellite and terrestrial networks is the mobility of satellites. Since the slice services require end-to-end connectivity, the satellite network topology change due to the mobility of satellites can give a huge impact to the slices. The latency is analyzed with time-varying satellite topology with an assumption that the virtual network resource for slice is reserved for low latency. For simulations, the minimum number of handovers is assumed and the end-to-end latency is analyzed for its initial latency, average latency, minimum latency, and maximum latency during the service time of slices in the satellite network.**

***Index Terms*—Satellite network, satellite network slicing, low latency connectivity**

I. Introduction

In recent years, the satellite terrestrial integrated network (STIN) is one of the attracting issues for 6G networks with global coverage, low latency, and ultra reliable services. To realize the STIN, satellite networks should be able to provide functionalities, such as edge computing, software-defined networking (SDN), and network slicing technologies. With this future direction, there have been various research outcomes on satellite server edge computing architecture [1], satellite SDN controlling [2], and network slice scheduling for satellite networks [3]. Especially, satellite network slicing is expected to be an enabler for diverse and user-customized services with different service requirements.

In this paper, virtual network resource reservation for satellite network is analyzed. With a global trend of non-geostationary orbit (non-GEO) satellite internet services, a low earth orbit (LEO) satellite network-based slice planning scenario is assumed. To reserve the network resources for the virtual network (VN) during the required service time, the virtual network embedding (VNE) process in satellite networks is modeled as virtual network requests (VNRs) arrive in every time unit. Fig. 1 shows our scenario as the VNRs represent various slice requests. For example, a request for remote area services and urban air mobility (UAM) control is illustrated. The VNRs consist of virtual nodes and virtual links, which are embedded to the satellite nodes and inter-satellite links (ISLs), respectively. The main purpose of VNE is how to effectively embed the multiple VNs onto the shared substrate networks with limited resources [4], and an additional VNE issue for the satellite network is to maintain the mapped VNs with the changing satellite topology. As the VNE problem is known to be an *NP-hard* problem [5], the VNE process is divided into the sub-problems of virtual node and link embedding.

As the LEO satellites orbit the Earth in high speed, the satellite network topology and serviceable satellites for a fixed location on the Earth change dynamically. Thus, the latencies of end-to-end slices change over time during the service time for network slices under dynamic satellite networks unlike the terrestrial network. To numerically analyze the end-to-end propagation delay of the satellite network slice, low latency virtual node and link embedding methods are proposed, and the end-to-end latency varying over time is analyzed with simulation.

The VNE process is then simulated in a realistic environment, with the constellation specification of Starlink. To analyze the latency, the minimum number of handovers is assumed with handover occurring when the embedded virtual network is no more available. The end-to-end propagation delay is analyzed for the initial latency, average latency, maximum latency, and minimum latency, and the challenges for the satellite network slice are discussed.

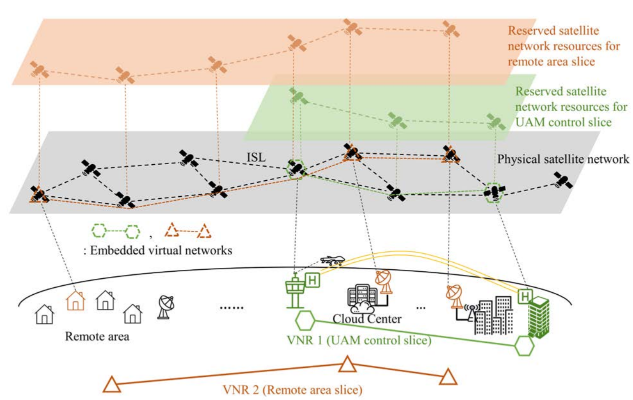

Fig. 1. Satellite network resource reserve for network slicing.

II. Virtual Network Embedding (VNE)

In this section, the VNE process for reserving the network resources of slices is introduced. Since the purpose of this paper is to analyze the slices embedded in the satellite network for the latency, low latency methods for the virtual nodes and links are proposed at the moment of the reserve. Also, an adequate handvoer strategy is proposed for management of the embedded satellite network slices.

Firstly, *virtual node embedding* is a process which finds a satellite node for the fixed ground location of the VNR node. Thus, a satellite node has to be chosen among the service available satellites of the location of the VNR node. As the purpose of embedding is the low latency, the virtual node embedding method in this paper finds the minimum propagation delay satellite node with more residual node capacity than the VNR node capacity, in other words, the closest satellite node in the satellite network constellation.

For *virtual link embedding*, the process executes routing path decisions with an assumption of single path embedding. Similarly to the virtual node embedding method, the virtual link embedding method finds the minimum propagation delay routing path, that is, the shortest path. The path can be determined with the Dijkstra shortest path algorithm whose graph nodes are satellites and edges are ISLs.

For the management of the embedded VNs, a simple handover strategy is assumed. Since satellites move and the expected LEO satellite service time of fixed ground users is about 10 minutes, satellite-ground handovers for satellite network slices are essential. In this paper, handovers occur by re-embedding the VN when one of the embedded satellite nodes is out of the service area.

III. Simulation results

Fig. 2 shows simulation results for the latency. The simulations are conducted every 1 minute for 12 hours of mega-constellated 1,600 satellite locations with about 7,000 successfully embedded and managed VNs. The service time of the VN is assumed to be bounded in 1 to 3 hours. The end-to-end delays in Fig. 2 show statistical results, which indicates average delays of a VN.

In Fig. 2, the initial delay and average delay are similar. This means that the expected end-to-end delay of the embedded VN is roughly the same as its initial delay in the embedded time. However, comparing these delays with the minimum and maximum delays, a large performance deviations are observed in Fig. 2. This is mainly because of the mobility of satellites, the ISL distances and satellite-ground access link distances that change dynamically over time. These results show that satellite network slicing is vulnerable to ensuing end-to-end latency jitter.

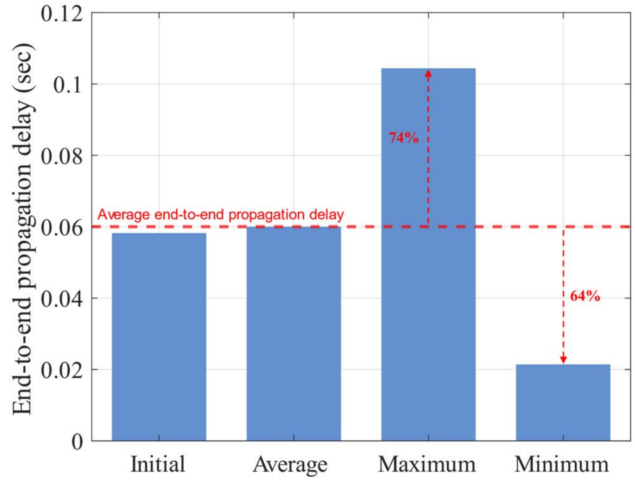

Fig. 2. End-to-end latency simulation results.

IV. Conclusion

In this paper, the latency problem in the virtualized satellite network due to the mobility of satellites was addressed. An satellite network resource reservation method for low latency was proposed with the VNE problem composed of virtual node embedding and virtual link embedding. With simulations, the end-to-end propagation delay for satellite network slice was analyzed considering the management of VNs with handovers. The results showed that the average latency is similar with the initial latency, but a large latency jitter, which means the performance difference between the minimum and maximum latency, was observed. Thus, reducing the jitter with less frequent handovers of the embedded slice becomes one of the challenges in satellite network slicing. Based on the results, the unique characteristic of satellite network reservation is observed, so that the advanced schemes of satellite network resource reservation and its handover will be suggested for the future work.

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