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Modeling of Inter-Satellite Link Protocol for Satellite Constellation

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***Abstract*—This paper presents simulation results of Inter-Satellite Link (ISL) protocol for satellite constellations. The 4-satellite trail ISL model simulated by NS-3 provides results of quantitative packet throughput and amounts of packet loss on the ISL protocol based on the IEEE 802.11 standard. Based on transmission control protocol/internet protocol (TCP/IP) with increased inter-frame parameters, four-way handshake message signaling brings packet re-transmission to cope with packet loss. The simulation results show a correlation between the slot time, the uplink data rate, and the ISL throughput in the satellite topology.**

Keywords—Satellite constellation, inter-satellite link, TCP/IP, IEEE 802.11, NS-3

I. Introduction

Legacy communication satellite services, which rely on a single low/medium earth orbit (L/MEO), experience limited coverage and shorten connection establishment times with ground stations or users. Therefore, traditional services have numerous challenges in providing diverse premium communication services.

Therefore, in recent years, the current communication satellite industry paradigm, led by industrial companies such as Starlink, OneWeb, Kuiper, etc., has been shifting from single satellites to satellite constellations. The shift aims to provide global coverage services and support reduced communication delays. These companies plan to construct satellite constellations by deploying multiple thousands of communication satellites to overcome limitations in the current communication satellite services.

There also has been extensive research regarding satellite constellations in low earth orbit, which incorporate inter-satellite links (ISLs) to achieve enhanced data throughput and reduced communication delays. These LEO satellite constellations are highly anticipated to serve as a primary infrastructure for delivering global coverage across a range of 6G communication services [1]. Next-generation communication satellites will likely perform data processing and data packet routing through their onboard processing (OBP) subsystem, minimizing dependency on the ground system and human intervention. To achieve the functionalities, ISLs with an optimized protocol, adaptability, short latency, and high reliability are essential, but these are still opened issues.

This paper examines the optimal slot time length of the inter-frame space of a four-way handshake for ISL communication by refining the inter-frame parameters of the IEEE 802.11 Standard. Furthermore, we establish a numerical correlation between data rate and protocol reliability in designing ISL communication networks by investigating changes in the length of the Physical Layer's slot time and data transmission rate.

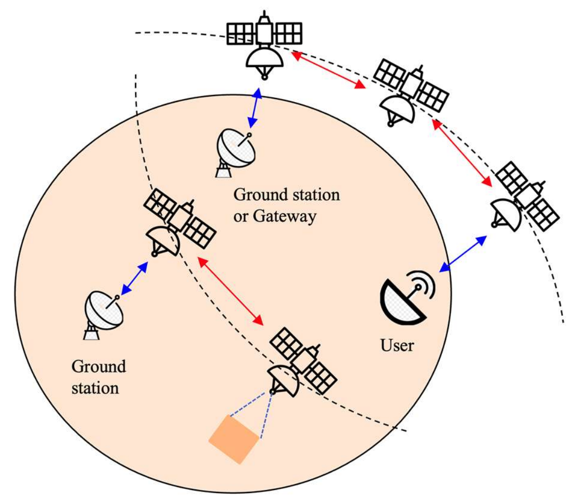

Fig. 1. Satellite constellation with inter-satellite link

II. ISL Protocol

The IEEE 802.11 Standard has its own inter-frame timing parameters, which are the standard for the physical and media access control (MAC) layers of wireless local area networks (WLANs). Fig. 2 (a) presents 4-way handshaking message signaling between a transmitter and a receiver. Fig. 2 (b) also shows their inter-frame parameters. There are multiple inter-frame timings in the protocol, and these must be adjusted to adapt to the ISL communication satellite environment. Especially, short interface space (SIFS) and distributed coordination function space (DIFS) timing parameters are directly correlated with propagation delay. Each inter-frame timing unit has a time unit called slot time that defines other timing parameters. To constitute an ISL protocol based on the IEEE 802.11 standard, it is essential to adjust the values of inter-frame parameters suitable for ISL communication environments [2].

This paper presents simulation results of data throughput and a number of packet losses with respect to the change of slot time value and uplink data rate from a ground user, which shows detailed data flows with monitoring data transmissions

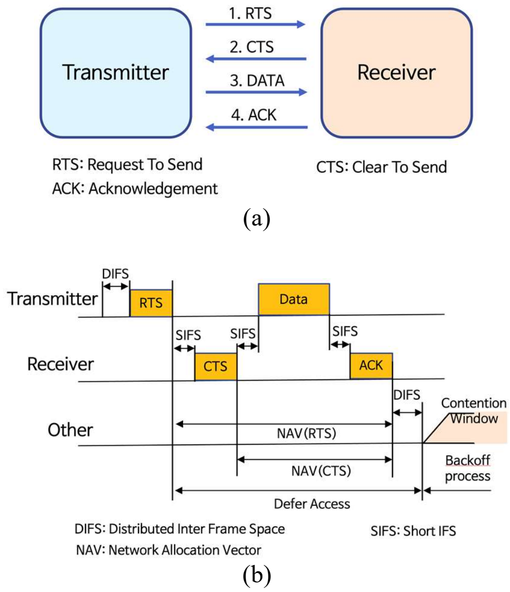

Fig. 2. IEEE 802.11 Standard signaling. (a) Four-way handshaking message transmission and (b) RTS-CTS-DATA-ACK timing parameters.

and collisions. We model the transmission control protocol/internet protocol (TCP/IP) based ISL protocol with slot time adjustment.

III. Simulation Result

We use the network simulator NS-3 for modeling the ISL protocol through a four-satellite trail formation. Additionally, we define each ISL terminal as having an 8 Mbps data rate with a 6 ms propagation delay, and the satellite downlink as having a 5 Mbps data rate with a 3 ms propagation delay. Fig. 3 shows packet input/output throughputs captured in the satellite trail. In the simulation, a ground user transmitted 536-byte size packets, the same as TCP segment size, for 7 seconds (start-stop time is 2 to 9 seconds), and the total simulation duration is 10 seconds.

Fig. 3 (a) presents the throughput with respect to the 300 μs slot time value and the 448 kb/s user uplink data rate. The figure shows there are very few TCP data collisions. On the other hand, Fig. 3 (b) shows the throughput and the increased packet loss with a 10 times increased slot time of 3,000 μs, which is the cause of data retransmission. Data re-transmission, therefore, does not ended until final duration 10. Fig. 3 (c) depicts the throughput with a 3,000 μs slot time and a decreased uplink data rate of 120 kb/s. The decreased uplink data rate results in reduced re-transmission, which minimizes data transmission delay and processing overheads.

IV. Conclusion

In the next study, we will simulate and present the optimized data throughput with respect to the data packet size and inter-frame parameters to cope with the satellite constellation delay and satellite formation for the communication service reliability.

Acknowledgment

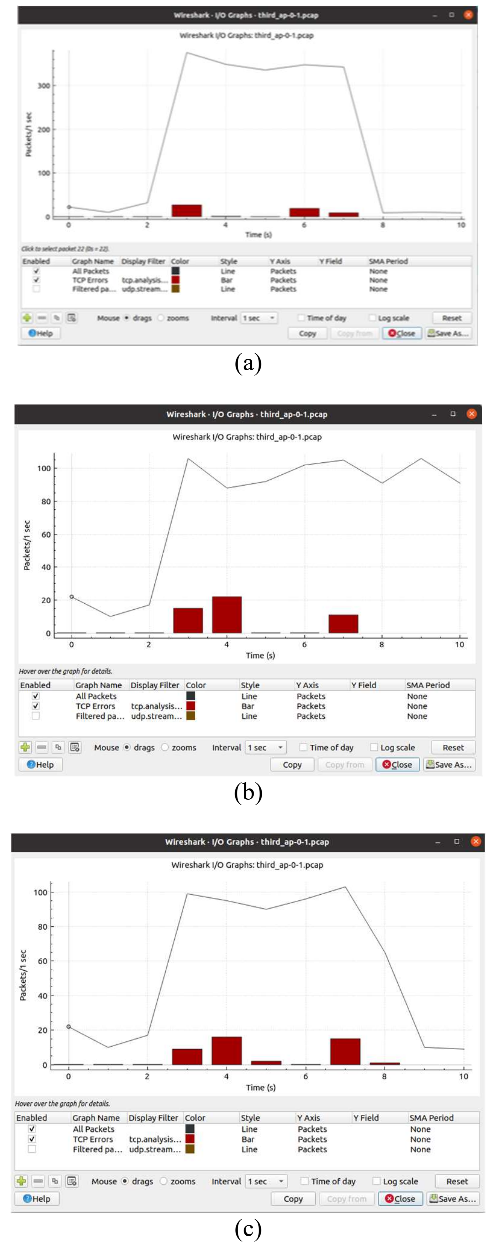

Fig. 3. Packet Input/Output Graphs captured by Wireshark. (a) Slot time is 300 μs and data rate is 448 kb/s. (b) Slot time is 3,000 μs and data rate is 448 kb/s. (c) Slot time is 3,000 μs and data rate is 120 kb/s

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