A Data-Firmware Aggregated Transmission Mechanism for Efficient Firmware-Over-The-Air of Low Earth Orbit

Na-Hyun Kim[1*], Yeon-Ji Lee[1], and Il-Gu Lee[1]
[1] Sungshin Women's University
cselab.nhk@gmail.com, cselab.lyj@gmail.com, iglee@sungshin.ac.kr

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Abstract

Low Earth Orbit (LEO) satellite transmission systems serve as critical infrastructure across industrial and public sectors; however, they are environmentally constrained by high channel noise, transmission delays, and limited bandwidth. In such environments, transmitting an entire firmware file within a single frame increases the probability of transmission failure and degrades service availability due to large-volume transfers. Conventional approaches transmit data and firmware independently, exchanging separate acknowledgment (ACK) for each, thereby increasing transmission overhead. This paper proposes a data-firmware aggregated transmission technique that simultaneously ensures real-time performance and integrity in mission-critical environments. Experimental results demonstrate that the proposed technique improves transmission efficiency by up to 3.12 times compared to conventional methods.

1 Introduction

Low Earth Orbit (LEO) satellite networks are key infrastructure for providing high-speed internet and low-latency transmission services to users worldwide [1]. However, environmental constraints such as the satellites' continuous orbital mobility and high channel noise make it difficult to maintain stable transmission quality [1,2]. Therefore, there is a growing need for highly reliable and efficient transmission mechanisms specifically tailored to the low-orbit satellite environment. In this environment, conventional wireless firmware update technology has separated general and firmware data, transmitting them independently and exchanging individual acknowledgment (ACK) per data type [2]. This structure requires separate transmission and acknowledgment procedures for each data segment, which increases the frequency of protocol control messages. Consequently, transmission efficiency decreases, transmission overhead increases, and the utilization efficiency of limited channel resources declines. This inefficiency accumulates particularly in resource-constrained and latency-sensitive satellite transmission environments, leading to increased transmission failure rates and reduced service availability [3]. Therefore, developing new firmware transmission techniques that simultaneously ensure transmission efficiency and data integrity is essential. Accordingly, this study proposes a data-firmware aggregated transmission technique that simultaneously secures real-time performance and integrity in mission-critical environments.

* Corresponding author

2 Data-Firmware Aggregated Transmission Mechanism

Figure 1 shows the overall operation procedure of the proposed data-firmware aggregated transmission technique and the simulation-based performance evaluation results comparing the total transmission count with changes in packet loss rate. This experiment calculates the average transmission count through 10,000 iterations, assuming the transmission and reception of 70 operational data packets and a 60KB firmware file. First, during the operational data transmission process, the ground station divides the firmware update file into fixed size blocks. It then aggregates each block with existing data packets and transmits them to the satellite. Subsequently, when transmitting the ACK for the operational data, the satellite effectively reduces the number of control message exchanges by consolidating the ACK information for the firmware blocks and transmitting it block-by-block.

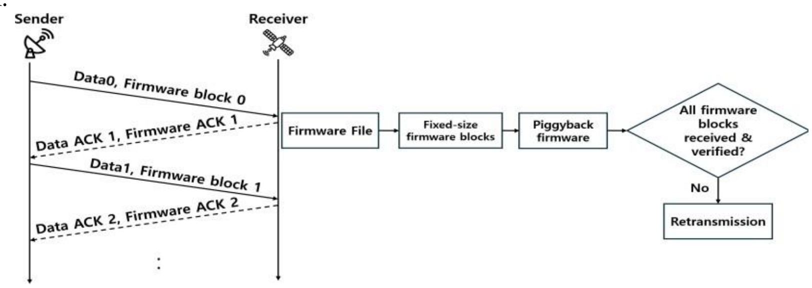

Figure 1: Flowchart for the proposed data-firmware aggregated transmission mechanism

Figure 2 shows the performance comparison between the conventional and proposed methods based on the number of transmissions as the packet loss rate increases. The proposed method can selectively retransmit only the lost firmware blocks even when packet loss occurs, effectively eliminating unnecessary redundant transmissions. As a result, it demonstrated up to 3.12 times fewer transmission numbers compared to the conventional method.

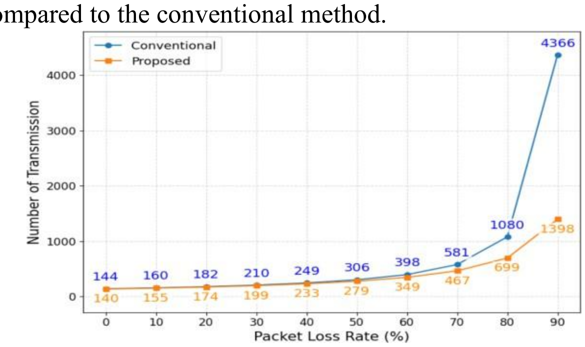

Figure 2: Comparison of total transmission counts with increasing packet loss rate

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