Content Caching and Multi-hop Routing in Low Earth Orbit Satellite Networks

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Abstract— There are many efforts to provide telecommunications services to rural areas where Internet service is not available, making Internet connectivity available worldwide. In addition to Internet provision, content can be provided through satellite networks, and propagation delay can be reduced by caching content on the satellite. In such contexts, efficient content delivery to users within suitable time frames relies on effective inter-satellite routing. This paper discusses the significance of content caching and multi-hop routing strategies in low Earth orbit satellite networks.

Keywords— Content Caching, Inter-Satellite Link, ISL Routing, Multi-hop Routing, LEO Satellite Networks

In reality, several companies, including SpaceX, Telesat, Amazon, and OneWeb, are actively engaged in numerous initiatives to provide global Internet access using LEO satellites. Inter-satellite link (ISL) enables faster service than terrestrial networks, and SpaceX is working to deploy LEO satellites equipped with ISL links in the near future. The ISL has a speed about 47% higher than that of a terrestrial optical fiber link. As a result, in the next generation, it becomes possible to significantly reduce data transmission delays through the utilization of ISL links. To accomplish this, the implementation of a suitable multi-hop routing strategy between ISL becomes indispensable.

Internet services will be provided through LEO satellite, and 8k video services and next-generation applications such as Digital Replica and High-Fidelity Mobile Hologram will also be provided in the near future. The servers providing these services are usually located on the ground. To transmit data from origin servers, it is necessary to route the data through satellites that cover the respective server locations. However, satellites serving terrestrial origin servers can often experience high traffic loads due to service transmission. Consequently, two congestion conditions may arise: (i) congestion in the satellite-terrestrial link and (ii) congestion in the satellite node with respect to the corresponding area. The former can be solved by caching content to satellites, and the latter can be mitigated through traffic distributed control measures. In the next-generation network operating within the low-orbit satellite environment, timely delivery of content cannot be guaranteed when data is transmitted through congested nodes. Therefore, it becomes essential to balance the traffic load, ensuring timely content delivery in such a network.

ZHU, Xiangming, et al. [1] makes content placement decisions to reduce content delivery time in an integrated satellite-terrestrial networks environment with three BS-Satellite-GW layers each with cache. However, when delivering content to users through multiple satellites, the routing strategy was not considered at the delivery time, and the dynamic mobility characteristics of the satellites and ISL distance were not considered. In addition, when content is placed on the same number of hops, it is not decided which satellite to place among them. Similarly, when delivering content to users, it does not consider which satellite node will deliver the content.

DENG, Xia, et al. [2] proposed improved back-pressure routing by redesigning the backlog based on distance between satellites. This is a new design of the existing backpressure routing algorithm by reflecting the mobility characteristics of the satellite, and through this, it is possible to reduce the delivery time and guarantee the stability of the network. However, this paper does not consider the energy consumed in content delivery and routing.

Lai, Zeqi, et al. [3] proposed techniques for achieving rapid and effective routing recovery while maintaining low latency and high bandwidth service capability in the space environment where failures occur frequently due to various factors. They suggest an adaptive routing technique by collaboratively combining two methods: addressing predictable failures and swiftly responding to unforeseeable failures in a dynamic satellite environment.

ACKNOWLEDGMENT

This work was supported by **Institute of Information & communications Technology Planning & Evaluation (IITP)** grant funded by the Korea government(MSIT) **(No.2022-0-00704)**

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