Congestion Avoidance Geographic Routing in a Large-scale Multiple Shell Low Earth Orbit Satellite Constellation

Cheng-Yu Chen[1], Yu-Hua Liao[2], Jen-Yeu Chen[2]
[1]Department of Electronic Engineering, Chung Hua University
[2]Department of Electronic Engineering, National Dong Hwa University

ID: J240562

Abstract

With the research and prospects of 6G technology, large-scale low-earth orbit satellite networks will play a crucial role in future communication frameworks. In this study, we proposed the congestion avoidance geographic routing algorithm, utilizing an online algorithm to dynamically adapt to changes in network topology and solve the network congestion problem. The algorithm not only determines the forwarding satellites based on the distribution of neighboring satellites but also employs traffic thresholds to avoid heavily loaded satellites. Compared to traditional geographic routing protocol, our method achieves lower end-to-end delay.

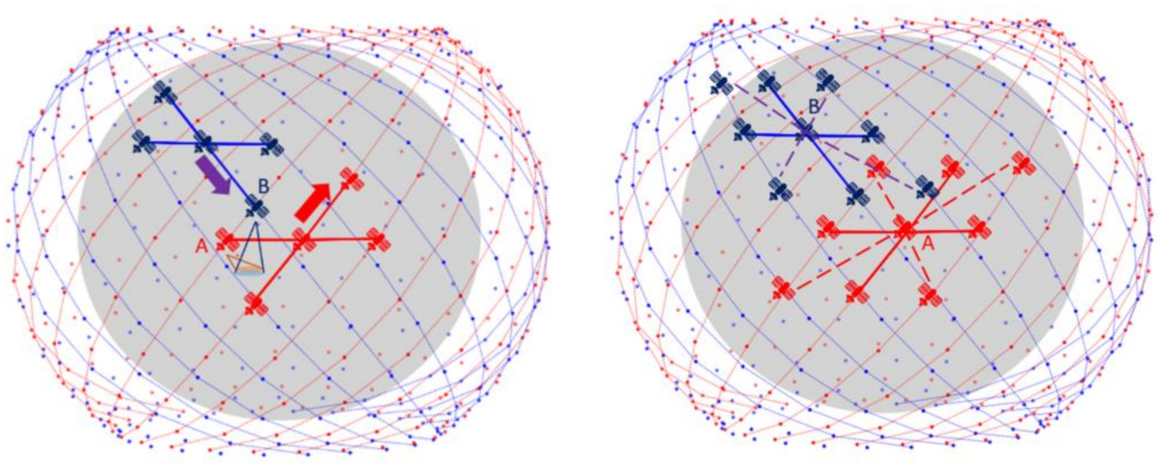
Introduction

In satellite networks, if many users access the same satellite simultaneously, it can lead to high load and energy consumption on that satellite, potentially causing packet loss and excessive delays, thereby degrading the overall network performance. Therefore, it is essential to consider the congestion state of satellite networks, efficiently utilize the resources of satellites, and balance the network load. Our goal is to establish a routing path that can effectively avoid congestion. As a result, we set appropriate traffic thresholds for users' requirements and disregard links where traffic utility exceeds a specific value, thereby achieving global satellite network load balance while meeting user demands. We proposed a decentralized 3D congestion avoidance geographic routing (CAGR) algorithm with load awareness based on Greedy Perimeter Stateless Routing (GPSR), which dynamically and effectively avoids satellites with relatively high loads through inter-satellite communication.

	Upper shell	Lower shell
Orbit altitude	550km	340km
Number of orbit planes	72	72
Number of satellites plane	22	22
Orbit inclination	53°	53°
Total number of satellites	1584	1584

Network Environment

1) As shown in Fig. 2, we consider a two-shell Walker Delta constellation network topology structure.
2) We consider two types of inter-satellite links (ISL) between single-shell satellites. Fig. 3 (a) shows the communication method submitted by Starlink to the FCC; each satellite has 4 ISLs. Fig. 3 (b) shows our predicted future communication method; each satellite has 8 ISLs.
3) Inter-satellite links are bidirectional and symmetric. Assuming satellite A can receive packets from one of its neighboring satellites, satellite B, then satellite A can also send packets to satellite B.
4) Each satellite can know its own and its neighbors' location information and packet load and can determine the location information and movement direction (ascending or descending) of the target satellite being served, with only minimal overhead.
5) Each satellite can identify the position of the movement direction switching point (Mountain point) of its orbit, as shown in Fig. 4(a).
6) Each satellite can only communicate with other satellites moving in the same direction, and satellites in different shells only choose to communicate with the nearest satellite, as shown in Fig. 4(b).



(a) (b)

Fig. 3 (a) 4 ISLs for each satellite; (b) 8 ISLs for each satellite.

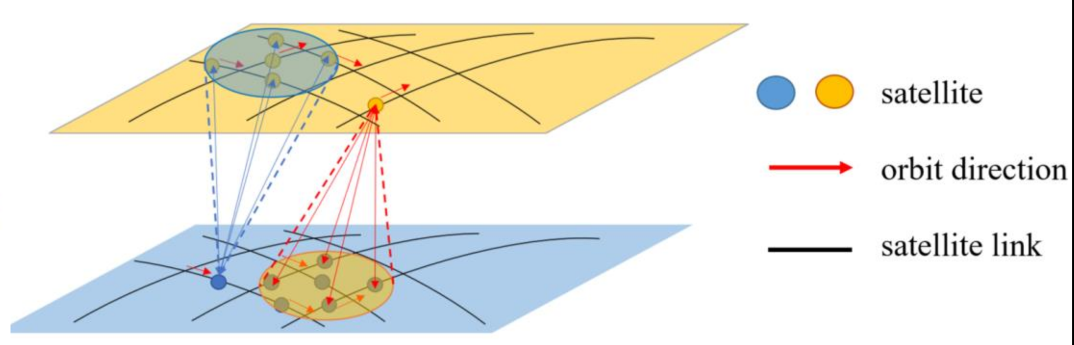
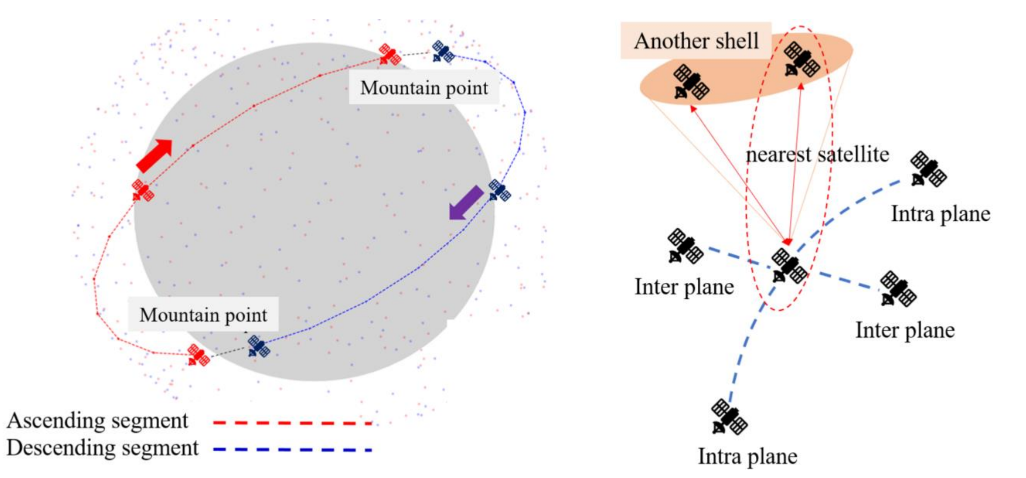
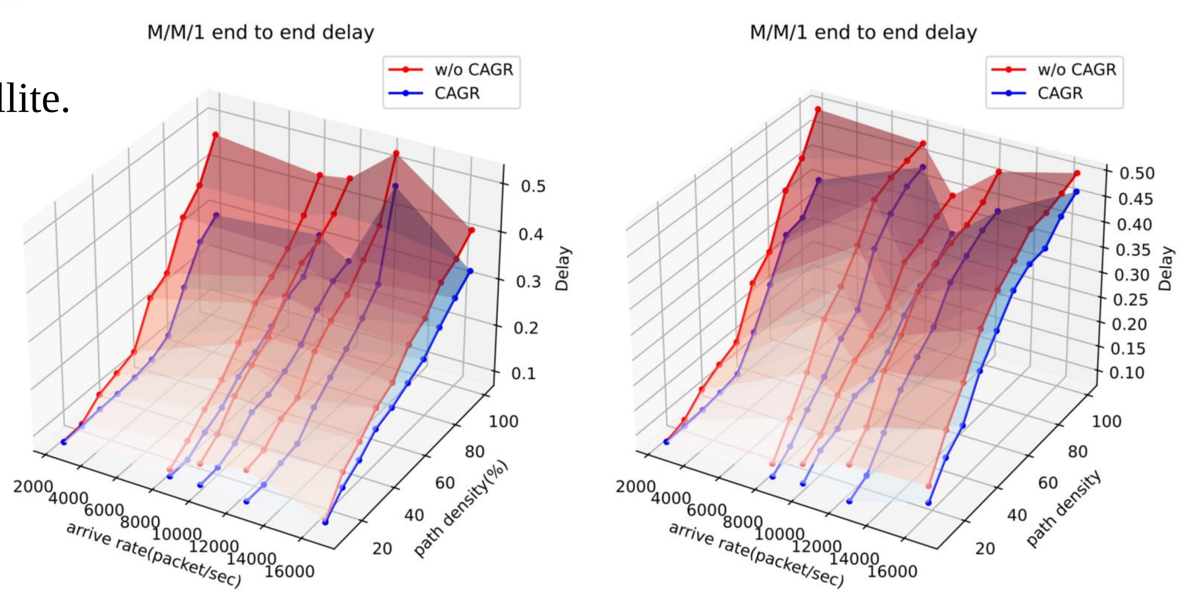


Fig. 2 Two shell walker delta constellation topology.



(a) (b)

Fig. 4 (a) Mountain point; (b) satellites in different shells.



(a) (b)

Fig. 7 M/M/1 end-to-end delay (a) with 4 ISLs; (b) with 8 ISLs.

Simulation Results

We compared the differences between end-to-end delay with the CAGR algorithm and the traditional geographic routing method (w/o CAGR) in the scenarios of satellites having different numbers of single-layer ISLs (4 and 8) and using the M/M/1 queueing model.

As shown in Fig. 7, our algorithm's advantages become more pronounced as the overall load on the satellite network increases.