Access Point Selection based on Regular Coding in Walker-delta Satellite Optical Networks

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Abstract: In this paper, a mobile-side access satellite selection algorithm based on regular coding is proposed. Simulation results show it can effectively reduce the connection latency and blocking ratio in walker-delta satellite optical networks. © 2023 The Author(s)

1. Introduction

With the demand for connection between mobile terminals (MTs) increasing exponentially, Starlink is preparing to allow 5G users to access satellite networks through smartphones. In the latency-sensitive fields (i.e., financial), huge losses would be incurred by even one-millisecond delay or blocking. Therefore, Starlink has started the deployment of inter-satellite laser links. Research shows the reduction of latency in terminal-to-terminal (T2T) communication for the geosynchronous orbit system[1]. The adoption of T2T strategy will be an important issue and the connection between MTs has been regarded as a hot topic. Researchers investigate the protocol for mobility management (including location and handover management) and predicted future research directions[3]. Meanwhile, a novel mobile core network architecture that loads the mobility management function on the satellite is proposed to optimize the network delay[4]. However, most of the existing studies ignore the feature that some constellations with inter-satellite laser links may have negative influence on the performance of T2T communications.

Walker constellation is a popular satellite constellation and Walker-delta constellation (WDC) is a circular orbit geometries constellation with orbit inclination. In some satellite optical network using WDC (e.g., Starlink), the orbit is much inclined and multiple satellites are available for terminals (MTs and ground stations). In such situation, different access satellites for MTs results in different paths. Some Researchers focus on the hop estimation of terminals in satellite optical networks and find that the hop difference in Starlink caused by the difference of paths may be up to 45 hops[2]. Thus, it is necessary to study the access satellite selection issue for MTs to avoid the above situations that reduce the T2T performance.

We introduce a regular satellite coding method by analyzing the fundamental origin of the different paths caused by different access satellites. Based on regular coding, we can estimate the hop between access points effectively and propose an access point selection (APS) algorithm. Simulation results show that the access point selection algorithm based on regular coding (APS-RC) can reduce the latency by 39% (26.7ms) compared with the random selection case (random access point selection, RAPS) using the shortest hop routing algorithm. While compared with the minimum case (terrestrial-side access point selection, TAPS) the proposed algorithm is only 3% (1.2ms) more latency. TAPS algorithm chooses the access satellite considering the whole topology including all terminals and satellites to minimize the latency.

2. Problem Statement and Solution

2.1 Problem statement

In the Walker-star constellation or Walker-delta constellation with a small inclination, the topology is related to the location in geographical coordinates. However, in the Walker-delta constellation with larger inclination (e.g., Starlink), the topology is not related to the geographical location as Fig.1 shows. If the mobile terminals select the access satellites randomly, the access satellites may be the closest in geographical coordinates but not in topology. In this situation, the latency of the connection will be much larger than the minimum case because the connection path may be much longer although the satellites are close in geographical coordinates. By analyzing the feature of the satellite in WDS with larger inclination, we can find that the satellites that are close in geographical coordinate but far in topology are running in the opposite direction like the satellites in the reverse seam. For fixed terminals like satellite ground stations, they have enough processing ability to calculate the whole topology including constellation and ground terminals to choose the access satellite able to build a minimum latency path. While for mobile terminals, it is impossible for them to consider the whole topology to choose access satellites. And this may lead to a latency increase in the above situation. For the example in Fig.1, user A has four available satellites (two red and two blue) while the access satellite of user B is the purple one. All of the available satellites of user A are close to the purple node in geographical coordinates. But if user A chooses the red one as access satellite, there will be 13 hops more than choosing the blue one.

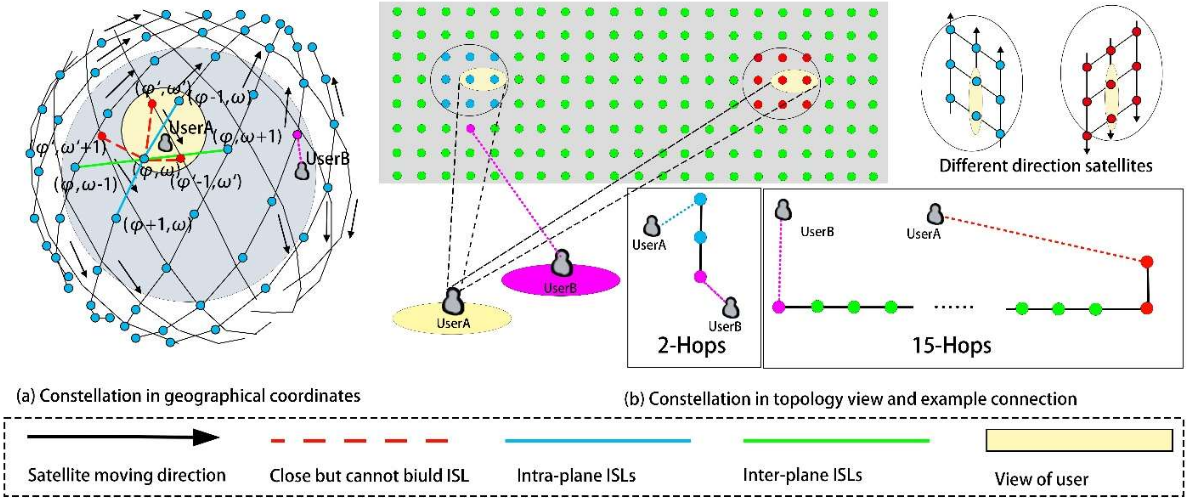

Fig. 1. (a) Geographical satellite location, (b) topology satellite location.

2.2 APS-RC

Although some hop estimate algorithms [2] have a good performance (relative error ~5%), it is still too complex for a mobile terminal to estimate the hop counts when setting up the connection. These algorithms use satellite direction and location to estimate the number of hops between two terminals. In this problem, we only need to exclude those paths whose hops are much more than others. In WDC with a larger inclination and inter-satellite laser link, although some satellites are close in geographical coordinate but far in topology with each other, the constellation is still a regular constellation. Therefore, we can simply determine the topology location of a satellite by regular coding which contains its orbit and its number in the orbit. If we get the regular code of several satellites, we can exclude those satellite pairs that are too far from each other in topology.

Given a WDC with the number of satellites *N* and the number of orbit planes *P*, we can define the satellites' code I_j:$(\varphi_j, \ \omega_j)$ where φ_j is the orbit id and ω_j is the satellite id in the orbit. Because the satellite in WDC has two inter-orbit satellite links (ISLs) and two intra-orbit ISLs as Fig.1(a) shows, the hop number h of shortest paths between two satellites $h = |\varphi_j - \varphi_2| + |\omega_j - \omega_2|$. So, if we get the access satellite of two terminals, we can estimate the hop between them. In this way, we can separate the satellites available to the mobile terminals into two groups in which one is close in topology and the other is far in topology as Fig.1(b) shows. Above all, when a mobile terminal M_1 starts to connect another mobile terminal M_2, M_1 will inquire the access satellite S_2 of M_2 whose id is I_2 from its own access satellite S_1 and inquire the satellites' id from available satellites set $\{S_n\}$ to build the available satellites' id set $\{I_n\}$. For each I_j in $\{I_n\}$, estimate the hop number H_j between S_j and S_2 by $H_j = |\varphi_j - \varphi_2| + |\omega_j - \omega_2|$ and get the hop number set $\{H_n\}$. Finally, we select the available satellite S_k from $\{S_n\}$ as the access satellite instead of S_1 and start to build the connection between M_1 and M_2. With this method, satellites and MTs need to interact and store the code of satellites instead of the whole network including satellites and terminals. The detailed procedures of the satellite selection algorithm are as follows.

Scheme: APS-RC
Input: Target mobile terminal M_2
Output: Access satellite S_k

1: Search the access satellite S_2 of M_2 and its id I_2 from the default access satellite S_1 of M_1;	5: Build the hop number set $\{H_n\}$;
2: **for** each available satellite in available satellite set $\{S_n\}$ of M_1:	6: **for** each H_j in $\{H_n\}$,
3: Obtain the id I_j:$(\varphi_j, \ \omega_j)$;	7: select the lowest one H_k;
4: Calculate the hop number H_j between S_j and S_2 : $H_j = |\varphi_j - \varphi_2| + |\omega_j - \omega_2|$;	8: Change the access satellite S_1 of M_1 to the satellite S_k having the lowest hop number H_k;

3. Simulation Result and Discussion

To evaluate the proposed APS-RC, we conduct shortest length algorithm (SLA) and shortest hop algorithm (SHA) to allocate T2T requests, which are randomly generated between 1000 terminals. The satellite constellation is set as Starlink. SLA is the routing algorithm that calculates the shortest path in terms of the distance of links while SHA is the one that calculates the path in terms of the hop of links. Other simulation settings are shown in Table 1.

Parameter	Value	Parameter	Simulation Indicator
Number of LEO satellite	1584	ToS	Dynamic (1-80Mbps)
Number of Orbital Planes	72	Number of MTs	1000
Orbital Altitude	530km	Src&Dst Node	Random MT
Orbital Inclination Angle	53°	Number of	100000
Satellite Ground Link Capacity	16Gbps	Arrival Mode	Index distribution (70/s in average)
Inter Satellite Link Capacity	10Gbps	Service Duration	Index distribution(100s in average)

Table 1. Simulation Network and Request Parameters

We choose one of the snapshots of the network topology sampled according to the switching of the satellite-to-earth link for the following simulation. We choose the RAPS and TAPS algorithms as the baseline.

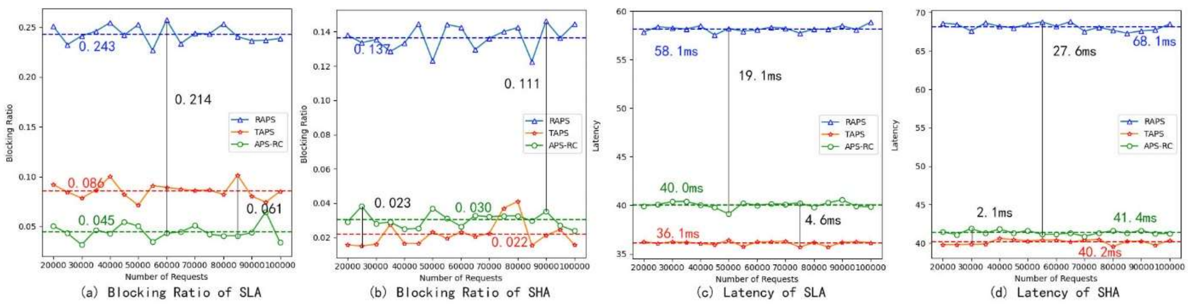

Fig. 2. (a), (b)Requests blocking ratio, (c), (d)requests latency

As shown in Fig.2, we sample result at every 5000 requests in average from the 20000th to the 100000th in order to present the results more clearly. Fig.2 (a) and (b) mainly show the blocking ratio performance of SLA and SHA. We can see that the blocking rate of the APS-RC algorithm is about 20% lower than the RAPS algorithm and even 4% lower than the TAPS algorithm in average in SLA. In SHA, the blocking rate of the APS-RC algorithm is about 10% lower than RAPS and 1% higher than TAPS in average. In Fig.2 (c) and (d), the latency of APS-RC is about 18ms lower than RAPS and 4ms higher than TAPS in SLA while the latency of APS-RC is about 26ms lower than RAPS and 1ms higher than TAPS in SHA. These results above show that the performance of APS-RC has a significant improvement over RAPS and it is also very close to the ideal situation, i.e., TAPS. As expected, the performance of APS-RC algorithm is much closer to TAPS in SHA than that in SLA because the APS-RC algorithm improves the performance of service by estimating the hops instead of length.

4. Conclusions

In this paper, we propose an access point selection (APS) algorithm to reduce the latency of T2T service, considering the limit of communication and storage ability of satellites and MTs. Using software simulation, we concluded that APS-RC has an improvement over the RAPS algorithm (blocking ratio 10%, latency 26.7ms) and the performance of the APS-RC algorithm is close to the ideal situation (TAPS) especially in SHA(blocking ratio 0.8%, latency 1.2ms).

5. Reference

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