Provisioning Uninterrupted Satellite Communication Services by Preset-Satellite-Chain (PSC)-Based Seamless Handover

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Abstract: A novel preset-satellite-chain (PSC)-based seamless handover scheme is proposed based on satellite ephemeris. Results show that the proposed scheme can eliminate service outages caused by periodic disconnection of inter-satellite links.

1. Introduction

With the increasing demand for broadband, global coverage and real-time of satellite networks, the optical satellite network (OSN) is going to be an indispensable part of B5G/6G and internet of satellites (IoSat) [1, 2]. Provisioning uninterrupted satellite communication services is critical to an effective OSN. However, due to the rapid change of satellite network topology, the problem of 1) limited service duration, and 2) the service outage occurs on a large scale and frequently [3]. As shown in Fig.1 (a), one disconnection of inter-satellite links (ISLs) can cause multiple service outages. The traditional rerouting-based hard handover scheme can indeed realize the service restoration. However, it causes intolerable service outage latency, and the latency is significantly exacerbated in satellite network scenarios with longer distances and more frequent topology changes compared with the terrestrial networks. Therefore, we need an effective scheme to deal with the common service outages behaviors and provision uninterrupted satellite communication services.

Due to the predictability of satellite motion and topology changes, the satellite chain lifetime and the ISL that is about to disconnect can be calculated in advance. Therefore, in satellite network scenarios, the reaction against service outage can be executed in advance. In this paper, we propose a novel preset-satellite-chain (PSC)-based seamless handover scheme. Based on satellite ephemeris, the proposed scheme can preset and handover the backup satellite chain (BSC) before the ISL is disconnected (as shown in fig. 1 (b)). The simulation result shows that service outages caused by periodic ISL disconnections can be eliminated in the simulation scenario where only one ISL disconnection is considered.

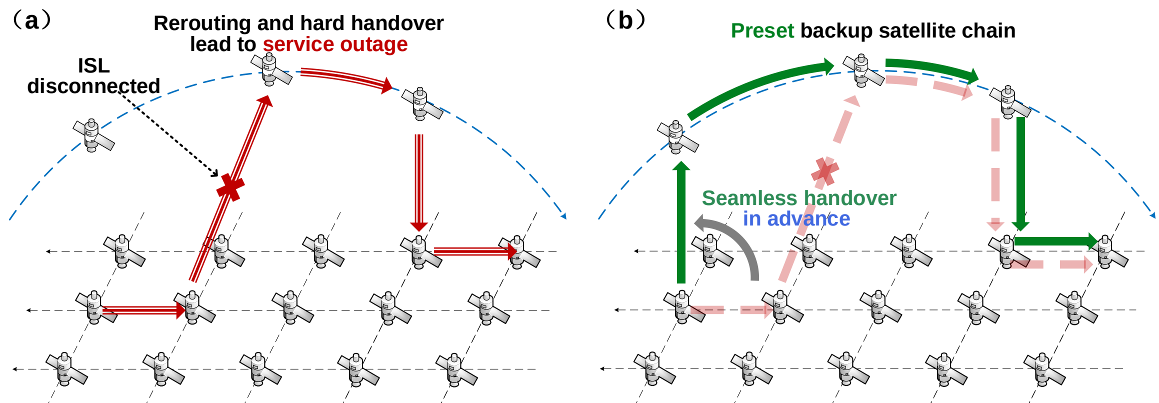

Fig. 1. Schematic diagram of (a): multiple service outages for the disconnection of ISLs; (b) PSC-Based seamless handover scheme.

2. Description of PSC-Based seamless handover scheme

The PSC-Based seamless handover scheme consists of a series of processes such as the calculation and preset of working satellite chain (WSC) and backup satellite chain (BSC), and seamless satellite chain handover, etc. Fig. 2 demonstrates the workflow of the PSC-Based seamless handover scheme. At the time of the service request arriving, the WSC for the service request has been calculated and provided based on the current network topology. Meanwhile, the duration of this WSC and the earliest disconnected ISL are calculated based on satellite ephemeris. If the duration of this WSC is insufficient to complete the service, the BSC preset process is be executed. When the remaining lifetime of the WSC is below a certain threshold, the seamless satellite chain handover process is be executed before the ISL is disconnected. At this point, the entire scheme has completed a round of execution and will be repeated until the service is complete.

Using appropriate routing algorithms, the PSC-Based seamless handover scheme can provide optimal WSCs and BSCs based on satellite ephemeris. We establish an integer linear programming (ILP) model of the routing and wavelength assignment (RWA) for WSC and BSC when an ISL is disconnected [4]. We assume that the network topology and a demand matrix are given. We also assume that the set of alternate WSCs and BSCs between each node-pair is pre-computed and given. Mathematical formulations of the ILP model are shown as follows.

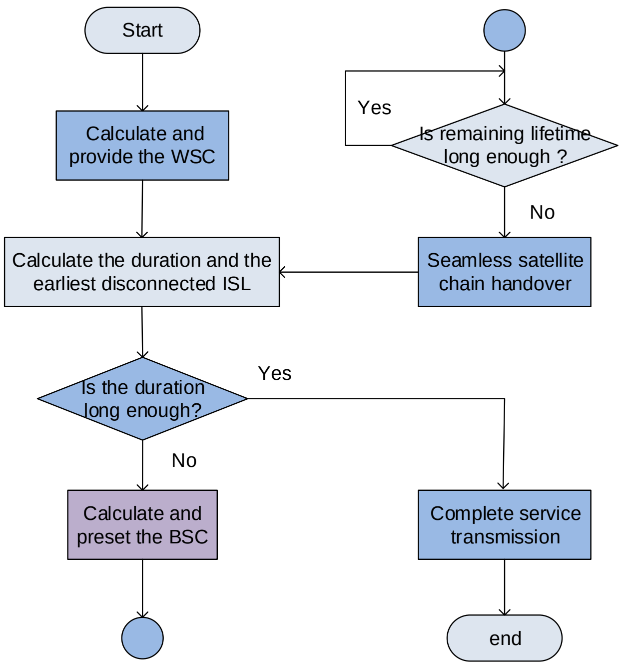

Fig. 2 Workflow of the PSC-Based seamless handover scheme

Given

N: Satellite nodes in the network (numbered 1 through N).

Node-pairs are numbered 1 through $N \times (N-1)$.

E: ISLs in the network (numbered 1 through E).

W: Maximum number of wavelengths on a ISL.

R^i: Set of alternate WSCs for node-pair i.

$M_i = |R^i|$: Number of alternate WSCs between node- pair i. Let M be the maximum number of alternate WSCs between any node-pair, i.e., $M = Max(M_i),\ 1 \le i \le N(N-1)$.

R_k^i: Set of eligible alternate BSCs between node-pair i after ISL k is disconnected.

d_i: Demand for node-pair i, in terms of number of lightpath requests.

k: the disconnected ISL.

Variables

s_j^k : Number of spare wavelengths used on ISL j when ISL k is disconnected.

w_j: Number of wavelengths used by WSCs on ISL j.

$\gamma_w^{i,r}$ takes on the value of 1 if the r^{th} WSC between node-pair i utilizes wavelength w before any ISL is disconnected; 0 otherwise.

$\beta_{w,k}^{i,r}$ takes on the value of 1 if the BSC r between node-pair i utilizes wavelength w when ISL k is disconnected; 0 otherwise.

Optimization

$$\text{Minimize} \sum_{j=1}^{E} (w_j + s_j^k) \quad (1)$$

Constraints

$$(w_j + s_j^k) \le W \qquad 1 \le j \le E \quad (2)$$

$$d_i = \sum_{r=1}^{M_i} \sum_{w=1}^{W} \gamma_w^{i,r} \qquad 1 \le i \le N(N-1) \quad (3)$$

$$w_j = \sum_{i=1}^{N(N-1)} \sum_{r \in R^i, j \in r} \sum_{w=1}^{W} \gamma_w^{i,r} \qquad 1 \le j \le E \quad (4)$$

$$s_j^k = \sum_{i=1}^{N(N-1)} \sum_{r \in R^i, j \in r} \sum_{w=1}^{W} \beta_{w,k}^{i,r} \qquad 1 \le j \le E \quad (5)$$

$$\left[\sum_{i=1}^{N(N-1)} \sum_{i'=1}^{N(N-1), i \neq i'} \left(\sum_{r \in R^i, j \in r} \gamma_w^{i,r} + \sum_{r \in R_k^{i'}, j \in r} \beta_{w,k}^{i',r} \right)\right] \le 1 \quad (6)$$
$$1 \le j \le E, 1 \le w \le W$$

$$\sum_{r \in R^i, j \in r} \sum_{w=1}^{W} \gamma_w^{i,r} = \sum_{r \in R_k^{i'}, j \in r} \sum_{w=1}^{W} \beta_{w,k}^{i,r} \quad (7)$$
$$1 \le j \le E, j \neq k, 1 \le i \le N(N-1)$$

The objective in (1) is to minimize the total capacity. Equation (2) bounds the number of wavelength links on each ISL. Equation (3) satisfies the demand between each node-pair i. Equation (4) defines the number of WSC lightpaths traversing each ISL. Equation (5) defines the number of BSC lightpaths traversing each ISL. Equation (6) constraints wavelength-continuity, i.e., only one WSC or BSC lightpath can use a wavelength w on ISL j. Equation (7) meets link handover demands after ISL k is disconnected for each wavelength w.

3. Emulation results and discussions

To evaluate the performance of proposed PSC-Based seamless handover scheme, we simulate a two-layer satellite network topology consisting of 48 Low-Earth orbit (LEO) satellites and 12 Medium-Earth orbit (MEO) satellites. The primary parameters of the satellite constellations are shown in table 1. Based on the satellite network topology, the satellite ephemeris is calculated. For simplicity, we ignore 1) the inter-orbital ISL between satellite nodes in opposite orbit directions and 2) the ISL disconnection in polar regions. We assume the inter-orbital ISL length as its maximum value and the Inter Layer Link (ILL) length as a fixed value (difference in orbital altitude). In order to simplify connection requests, we assume that all demands, i.e., number of lightpath requests, are 1 ($d_i = 1$). The WSCs and BSCs are calculated using *Dijkstra* algorithm based on the network topologies of current time and next time respectively in the satellite ephemeris.

Table 1. Primary parameters of the satellite constellation

Parameters	LEO	MEO
Orbit inclination	90°	55 °
Orbit altitude	1621.86 km	3621.86 km
Orbit period	7121.08 sec	9952.01 sec
Number of orbits	6	3
Number of satellites per orbits	8	4
Intra-orbital ISL distance	6122.93 km	7071.07 km
Inter-orbital ISL distance	≤ 4140.10 km	——

Fig. 3 shows the histogram of the reduced outage time between PSC-Based seamless handover scheme and the traditional rerouting-based hard handover scheme. We select one ISL disconnection for observation. In PSC-Based seamless handover scheme, since BSCs are preset in advance, the outage time only includes the handover delay time. We assume that the handover delay time is 50ms. Since the propagation delay account for most of the outage time in the long-distance satellite network scenario, we ignore the other delays in rerouting-based hard handover scheme. It can be seen that the proposed PSC-Based seamless handover scheme can reduce the outage time by 59-196ms.

Fig. 4 compares the instantaneous link resource occupation between traditional rerouting-based hard handover scheme and PSC-Based seamless handover scheme. 8 ISL disconnections and 2 ISL connections occur within 400 seconds of simulation time. It can be seen that the preset BSCs result in a temporary increase in wavelength link occupancy. The number of occupied wavelength links increases by 9.47% at some time before the ISL disconnected, and the average number of occupied wavelength links increases by 0.1% throughout the simulation time.

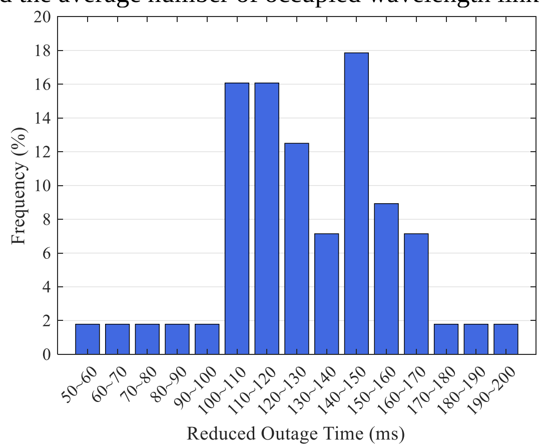

Fig. 3. Histogram of the reduced outage time

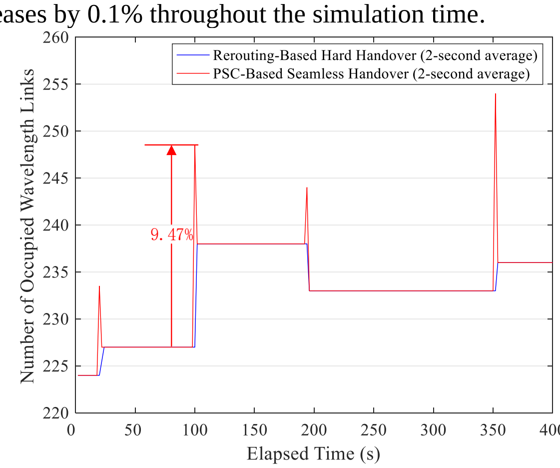

Fig. 4. Instantaneous link resource occupation

4. Conclusion

We propose a novel PSC-Based seamless handover scheme for provisioning uninterrupted satellite communication services. Through the preset BSC and seamless satellite chain handover, the services outage caused by periodic disconnection of ISLs can be eliminated. In addition, we demonstrate a workflow and an ILP model for our scheme, and evaluate the uninterrupted transmission performance in the simulation scenario where only one ISL disconnection is considered. For more dynamic OSNs, more efficient handover schemes may be required against multiple and irregular ISL disconnections.

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5. References

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