Dynamic Satellite Optical Communication Networks

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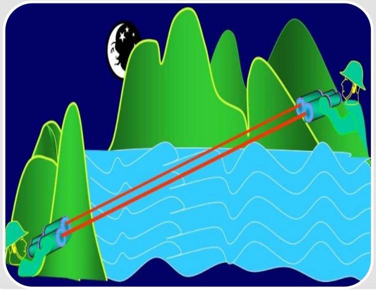
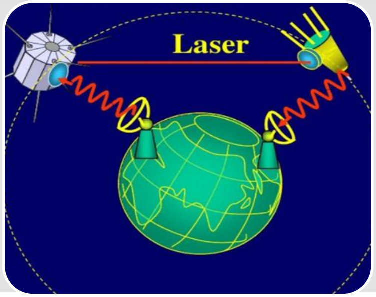
Satellite Optical Communications

Laser advantages

Microwave

- L/S —— No resources
- C/Ku —— Saturated
- Ka —— Fierce competition
- Q/V —— Authenticate
- W/THz —— Immaturity

➡ **laser communication**

More coverage	Lower attenuation	Larger capacity

Satellite laser communication developments

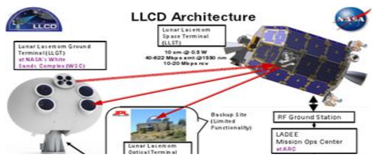
International

2008	2014	2016	2019
US：LEO NFIRE Inter-satellite link Distance：4900km Traffic rate：5.6Gbps	**Japan：LEO small terminal** Satellite-Ground link Distance：1000km Traffic rate：10Mbps	**Europe：European Data Relay System** Inter-satellite link Distance：45000km Traffic rate：1.8Gbps	**US：LEOSat** Inter-satellite link Distance：2700km Traffic rate：**10Gbps**

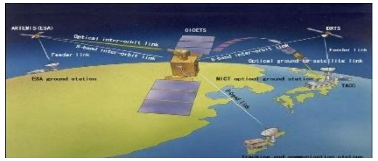
Comparison

Domestic

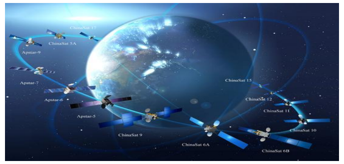
2012	2016	2018	2020
Chinese HY-2 satellite Satellite-Ground link Distance：2000km Traffic rate：504Mbps	**Tiangong-2 space lab** Satellite-Ground link Distance：350km Traffic rate：1.6Gbps	**BDS-3 M11,M12** Inter-satellite link Distance：~km Traffic rate：1Gbps	**SJ 20** Satellite-Ground link Distance：32000km Traffic rate：**10Gbps**



US: LLCD



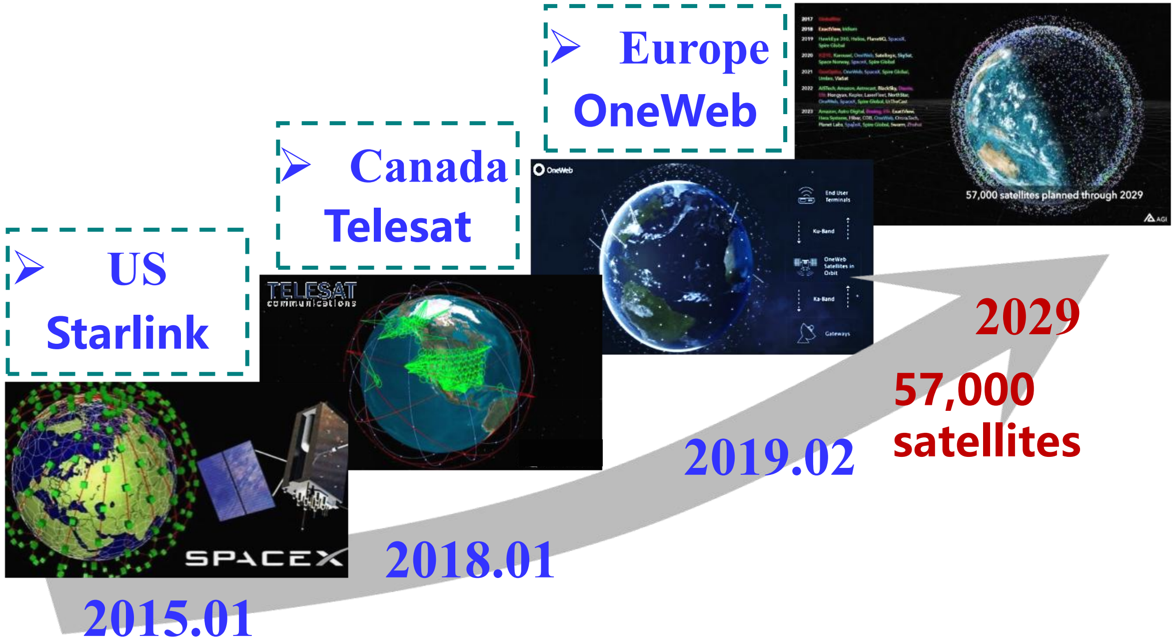
Europe: OICETS



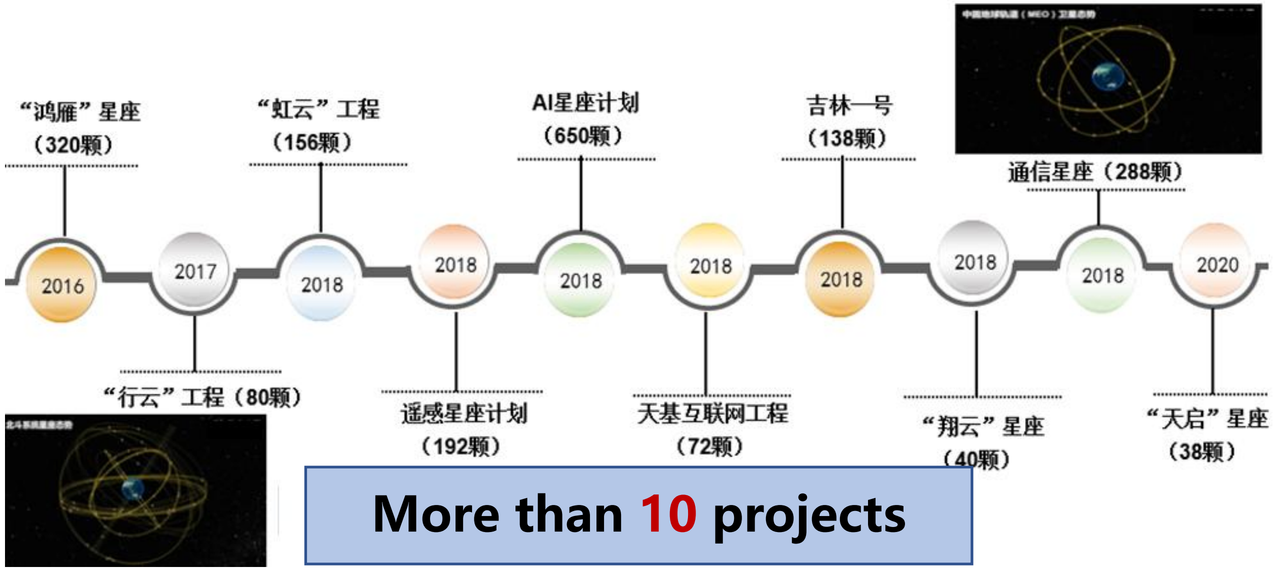
China: SJ-20

Development of Globe Satellite Networks

Foreign satellite constellations



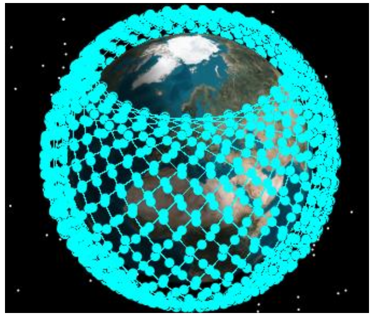
Domestic satellite constellations



More than **10** projects

Latest research progresses

Space Exploration Technologies Corp. (SpaceX)

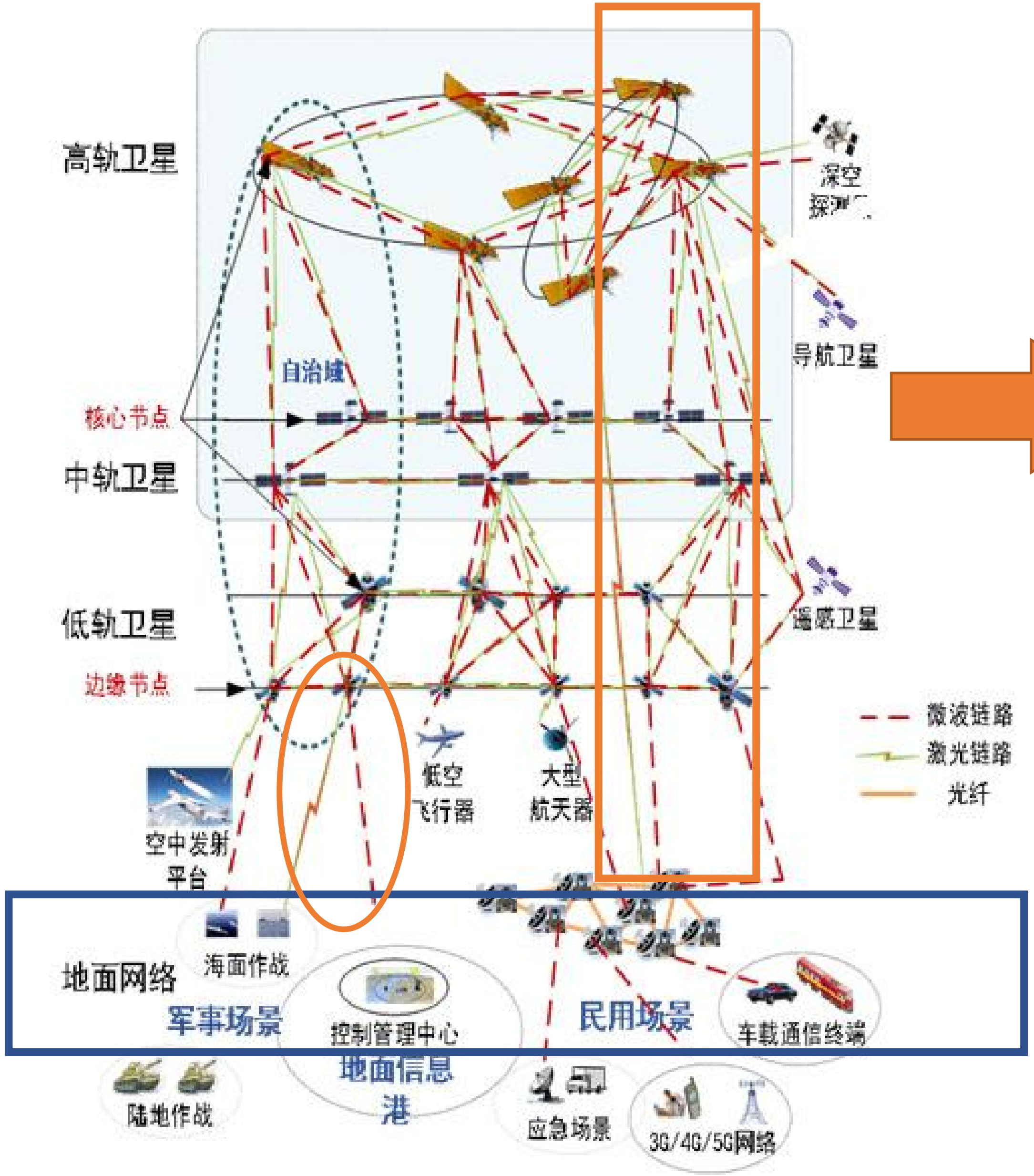


	Amount
The first stage (2024)	12k
The second stage	30k
Sum	**42k**

China Satellite Network Group Co., Ltd

	Amount
The first stage	6.1k
The second stage	6.9k
Sum	**13k**

Typical Features of Optical Satellite Networks (OSNs)



Large scale

High dynamic

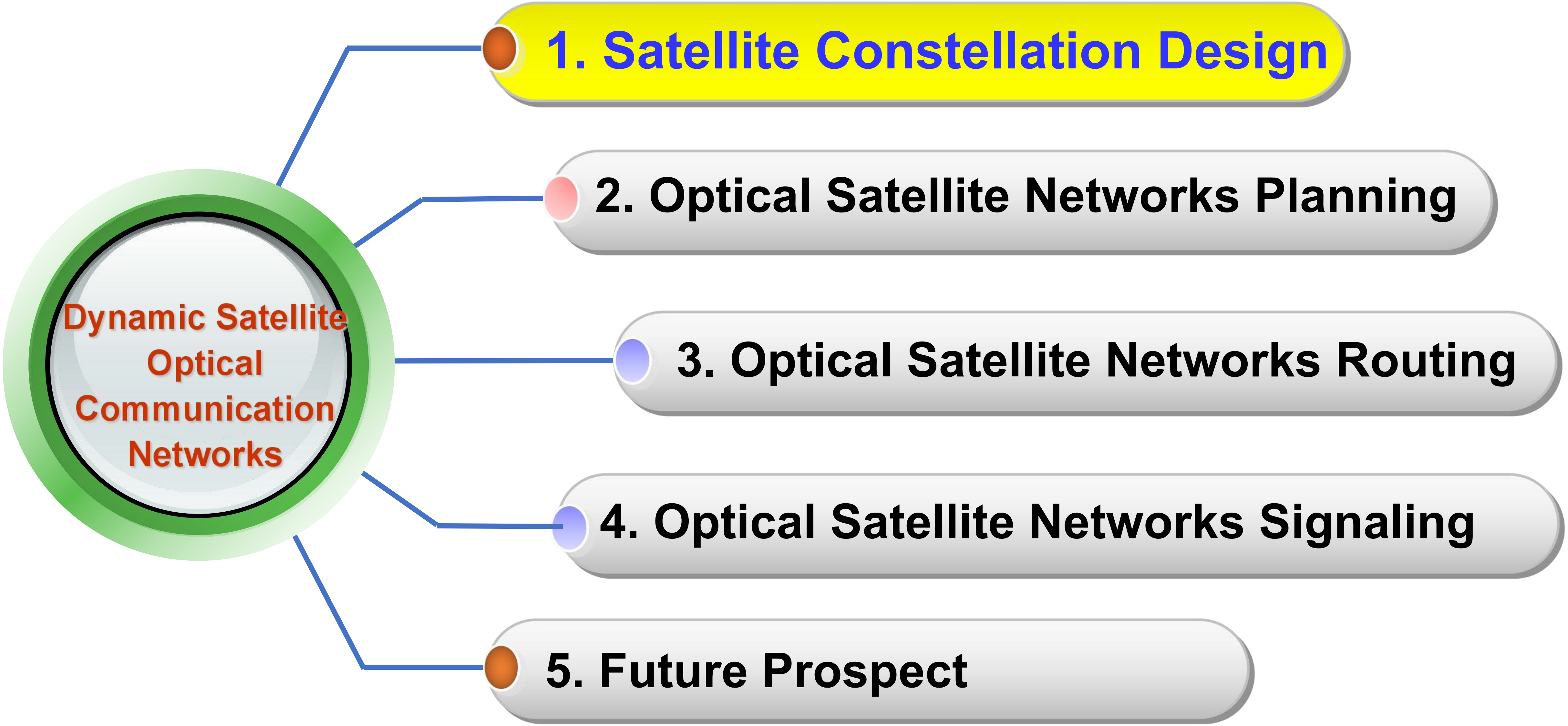
Long ISL distance

Frequent switchover

Unbalanced traffic distribution

High service concurrency

Content



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1. Satellite Constellation Design
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Satellite Constellation Design

- **Problem:** How to **maximize the number of satellite-ground links** and **improve the connection duration of satellite-ground links** under a given number of satellites.
- **Solution:** According to the **single satellite coverage model**, a complete constellation design method is proposed.
- **Effect:** The global coverage of 1,152 satellites has reached **100%**, and satellite-ground links has been increased by **10** links on average.

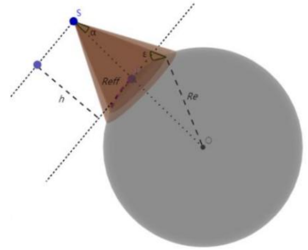


Fig.1 Single star coverage

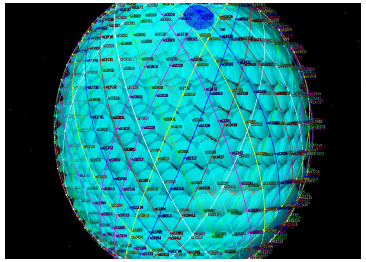
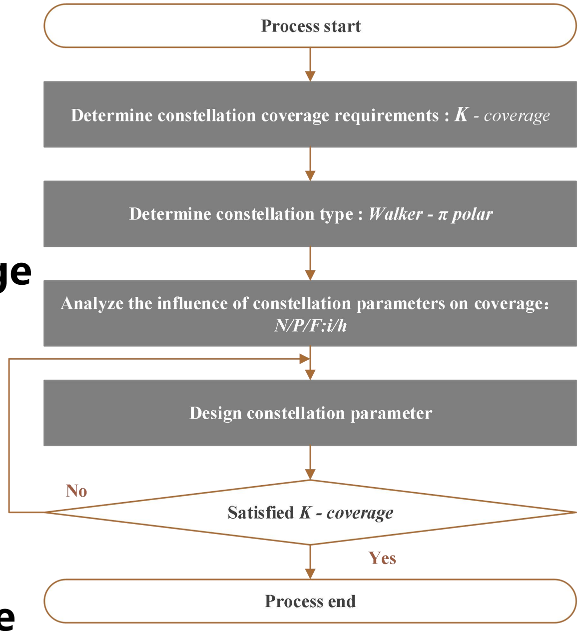


Fig.2 Network coverage



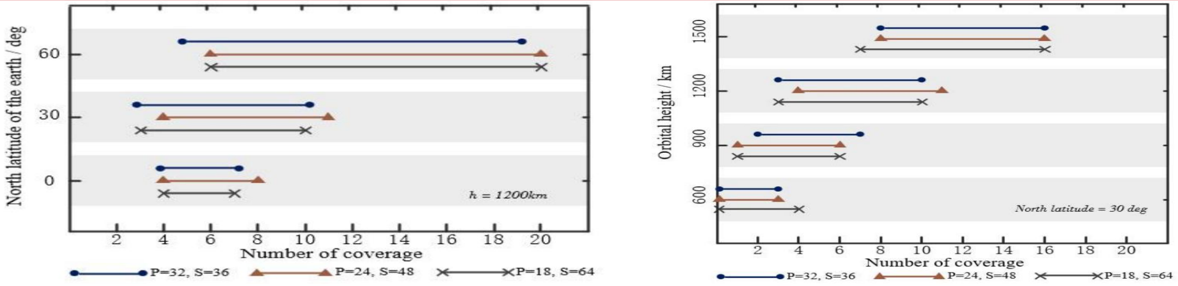


Fig.3 Ground coverage at different heights and track surfaces

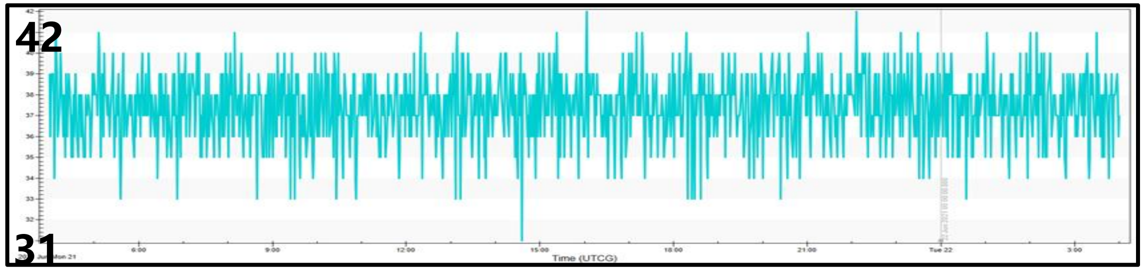
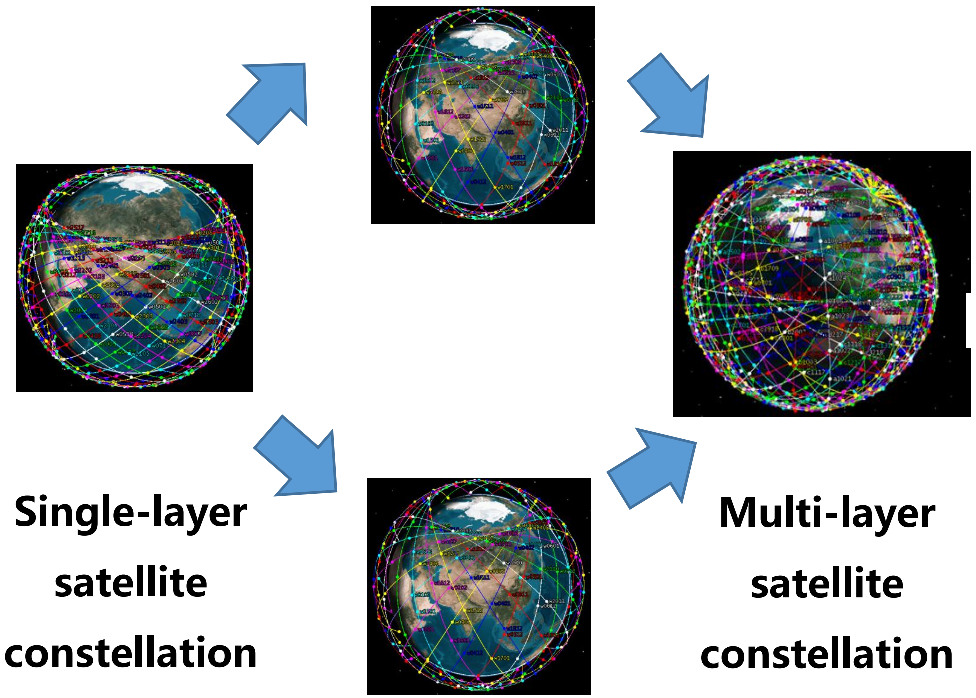


Fig.4 The number of satellite-ground links was optimized

Yang M, **Zhao Y***, He X, Wang W, et al. Constellation design method for large scale satellite optical networks[C]//2021 19th (ICOCN). IEEE, 2021: 1-3.

Multi-layer Satellite Constellation Design

- **Problem:** What are the advantages and disadvantages of single-layer satellite constellation and multi-layer satellite constellation, and how to further expand the network capacity?
- **Solution:** Single-layer satellite constellation is **split into multi-layer satellite constellation.**
- **Effect:** By using our 144*2 dual-layer satellite constellation, the network capacity can be increased by **10%-40%** (compared with a single-layer 288 constellation).



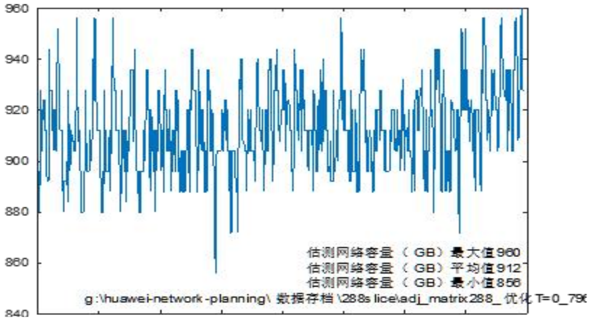


Fig.1 288 constellations capacity

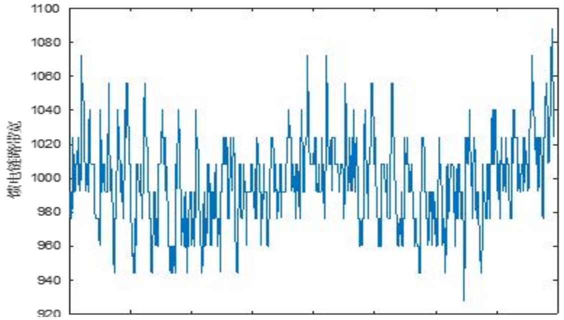


Fig.2 # of 288 Feeder link

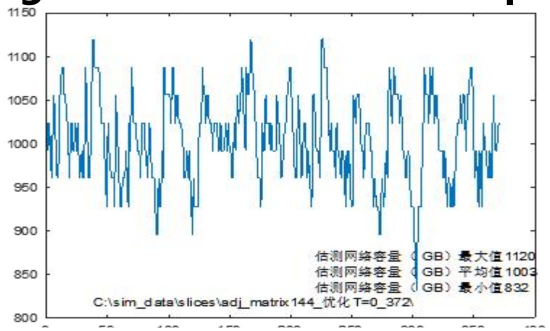


Fig.3 144*2constellations capacity

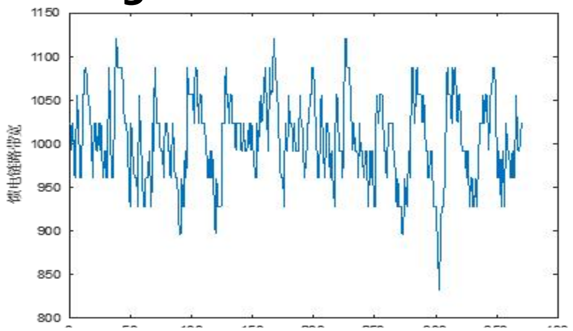


Fig.4 # of 144*2 Feeder link

[1]] H. Dang, **Y Zhao***, et al., Link Planning Schemes for Uninterrupted Inter-layer Communication in Dual-layer LEO Optical Satellite Networks

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Optical Satellite Networks Topology Planning

- **Problem:** The high dynamic nature of satellite networks leads to frequent construction and disconnection of satellite-ground links, which directly leads to frequent network snapshot update, service transmission interruption, and frequent network convergence.
- **Solution: The snapshot partition strategy based on time window** is studied to reduce the number of snapshots and increase the duration of snapshots.
- **Effect:** The results show that the number of snapshots can be reduced by **54.5%** to **97.6 %** and the network capacity can be guaranteed by **99.3%.**

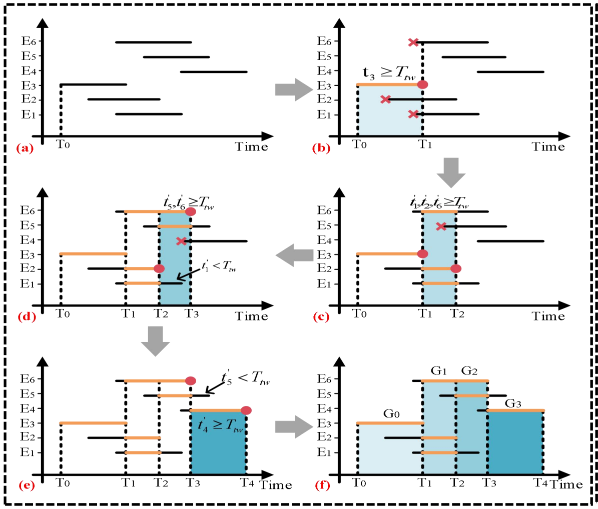

Fig.1 Technical solution

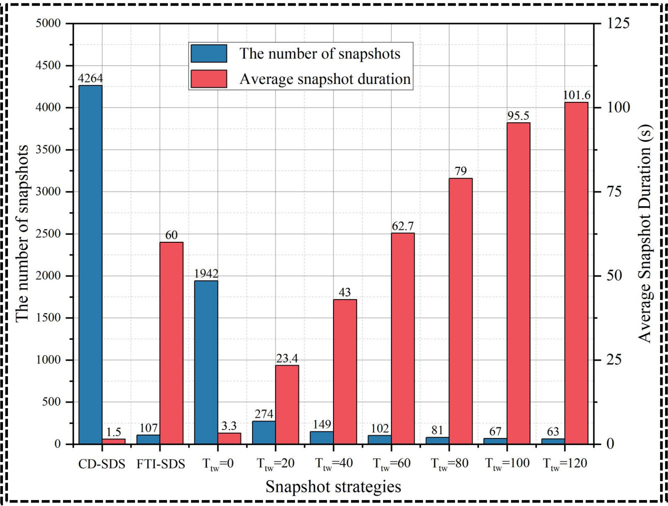

Fig.2 Quantity and average duration of snapshots

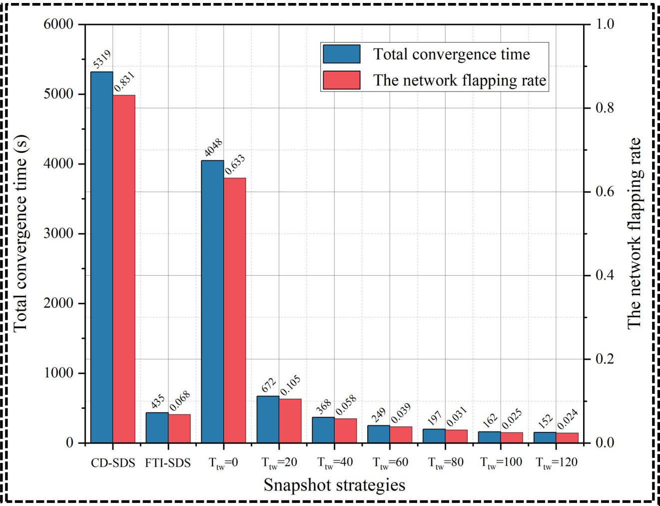

Fig.3 Network convergence duration and flapping rate

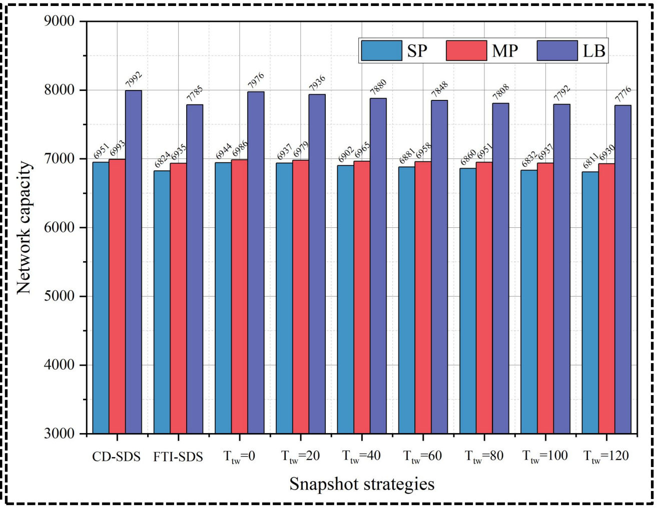

Fig.4 Network Capacity Statistics

[1] H. Dang, **Y Zhao***, et al., "A Snapshot Division Strategy Based on Time Window in Optical Satellite Networks"

Adaptive OSN **Link Planning**

- **Problem:** The capacity of the satellite channel varies widely (channel physical damage). Currently, the satellite channel uses the fixed (minimum) channel capacity as the service path to provide the basis, and the channel resource is seriously wasted.
- **Solution:** Design an **adaptive planning algorithm for satellite-ground channel**, combined with the capacity change of satellite-ground link .
- **Effect:** The satellite network service bearing capacity is increased by **30.2%**. The utilization rate of network bandwidth resources is increased by **50%**. But additional network resource convergence time and packet overhead are incurred.

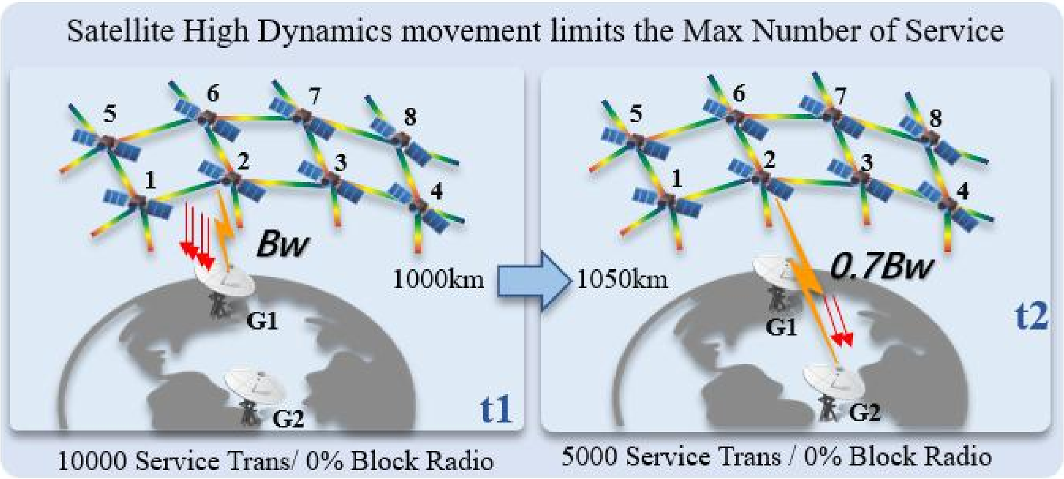

Fig.1 Capacity changes of satellite-ground links

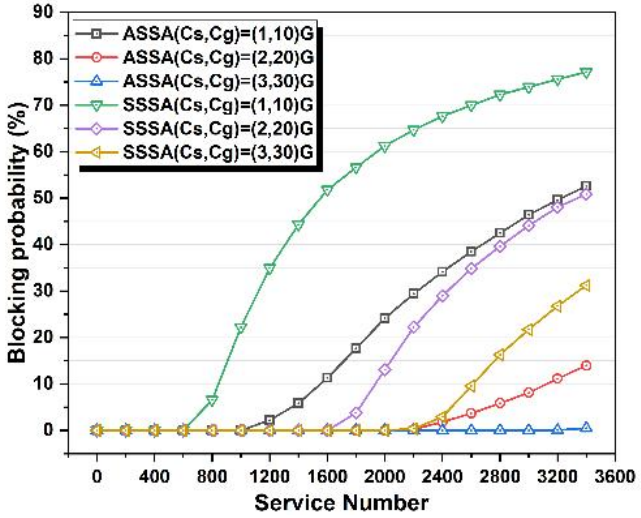

Fig.2 Algorithm performance

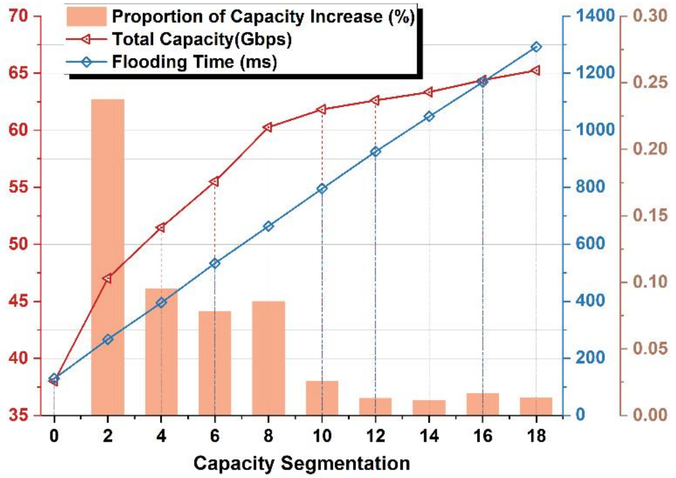

Fig.3 Algorithm cost

[1] P Zheng, **Y Zhao***, et al., Adaptive Service Scheduling for Satellite-Ground Downlink Capacity in Optical Satellite Networks

Optical Satellite Networks **Traffic Planning**

- **Problem:** Due to the dense deployment of ground gateways, the link load of space segment is highly uneven, which becomes the bottleneck for network throughput improvement.
- **Solution:** Design a **traffic planning algorithm based on satellite-ground cooperation** to optimize the service forwarding path and solve the low network throughput caused by the bottleneck of space segment link resources.
- **Effect:** In the 288-satellite constellation, the service throughput is improved by **68.4%** and the resource utilization is improved by **6.11%.**

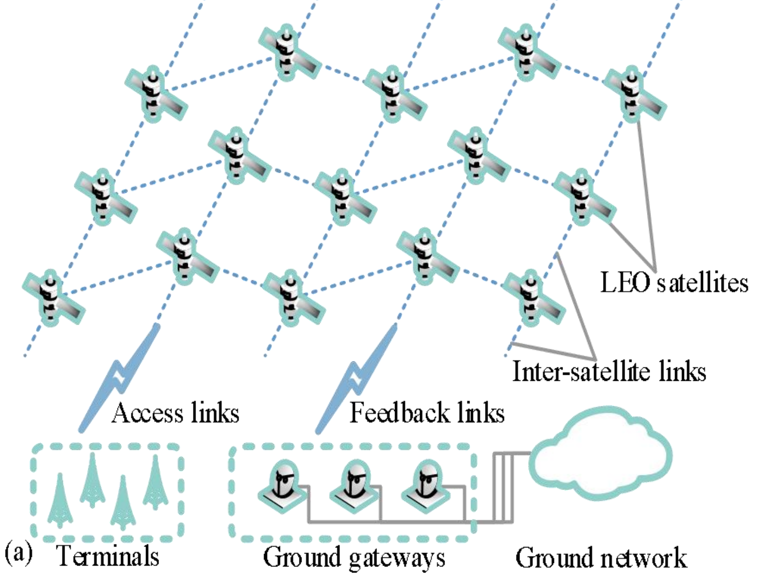

Fig.1 Satellite network architecture

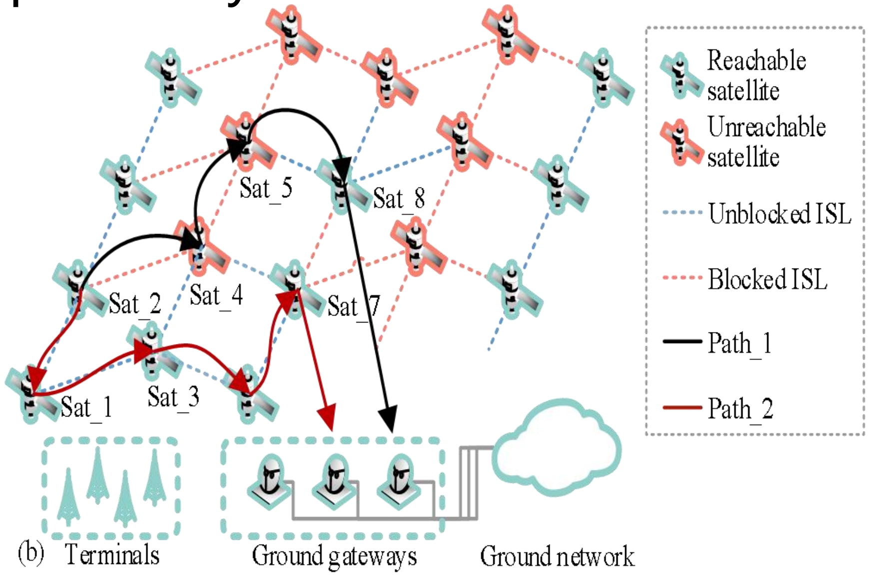

Fig.2 Service transmission path

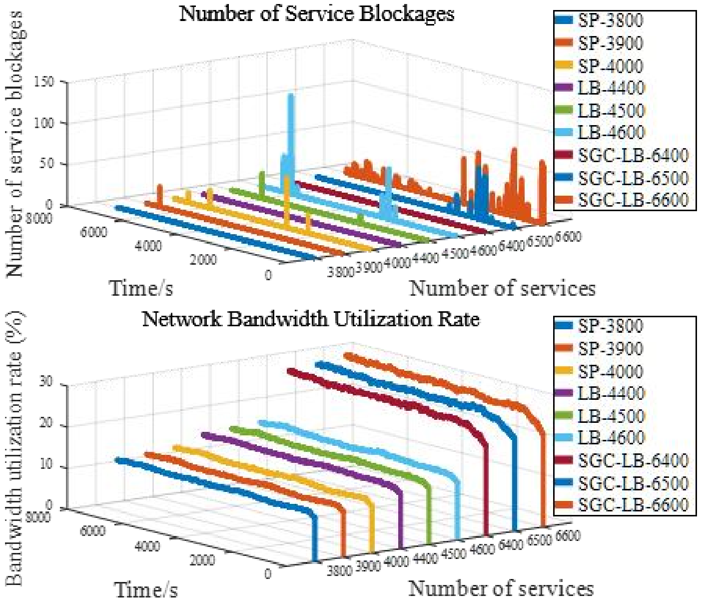

Fig.3 Traffic blocking rate and resource utilization

[1] Y. Ning, **Y. Zhao***, X. Li, S. Rahman, H. Zhang, and J. Zhang, "Load-Balancing Routing Algorithm Against Inter-Satellite Link Congestion in LEO Satellite Optical Networks," in Optical Fiber Communication Conference (OFC) 2022

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Optical Satellite Networks Routing Convergence

- **Problem:** Satellite-ground link switching leads to frequent topology changes, slow convergence speed, and high cost of traditional flooding, and the accuracy of the routing table is reduced in the large-scale and dynamic networking environments.
- **Solution:** The network topology is divided into inter-satellite links and satellite-ground up/down links. **The change of satellite-ground up/down links adopts the orbit based directional flooding method.**
- **Effect:** In one satellite cycle, the overhead is reduced by nearly **50%**, and the convergence time is reduced by **100s**; The performance will fluctuate due to inter-satellite link failure.

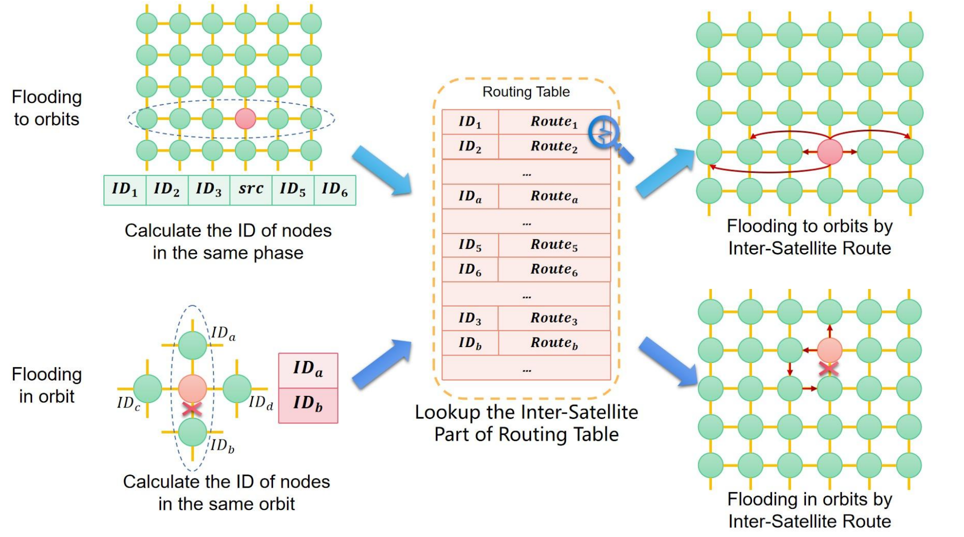


Fig.1 Directional flooding method based on track

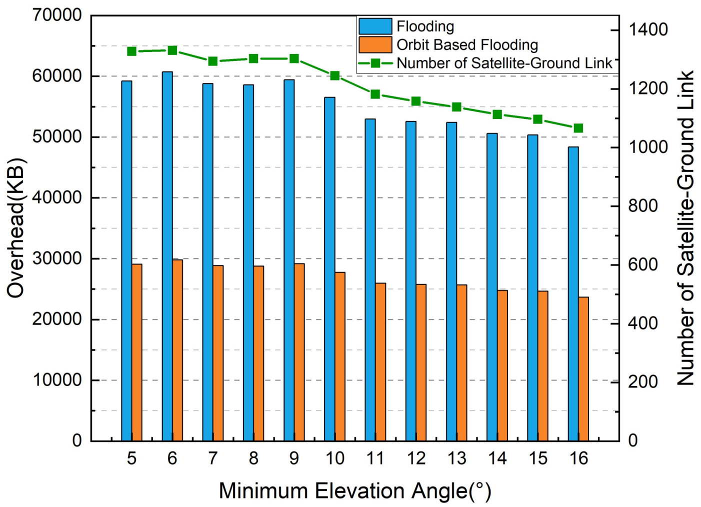


Fig.2 Convergence cost

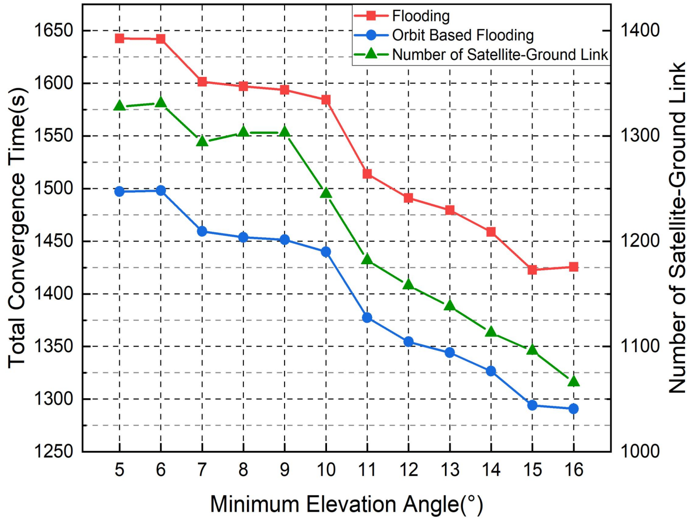


Fig.3 Total convergence time

[1] Z.Q. Wang, **Y. L. Zhao***, et al., Orbit Based Flooding Scheme for Convergence of Satellite-Ground Link Handover in satellite laser networks

Optical Satellite Networks Routing with Traffic Prediction

- **Problem:** The spatial and temporal distribution of flow is unbalanced, and differences in transmission performance of ISLs and SGLs lead to high concurrent traffic convergence.
- **Solution:** Through **traffic prediction**, the service path is planned in advance to reduce the probability of high concurrent service conflicts.
- **Effect:** Compared with the lowest blocking rate algorithm in theory, the blocking rate of this algorithm is reduced by **5%** and the transmission delay is reduced by about **5ms**.

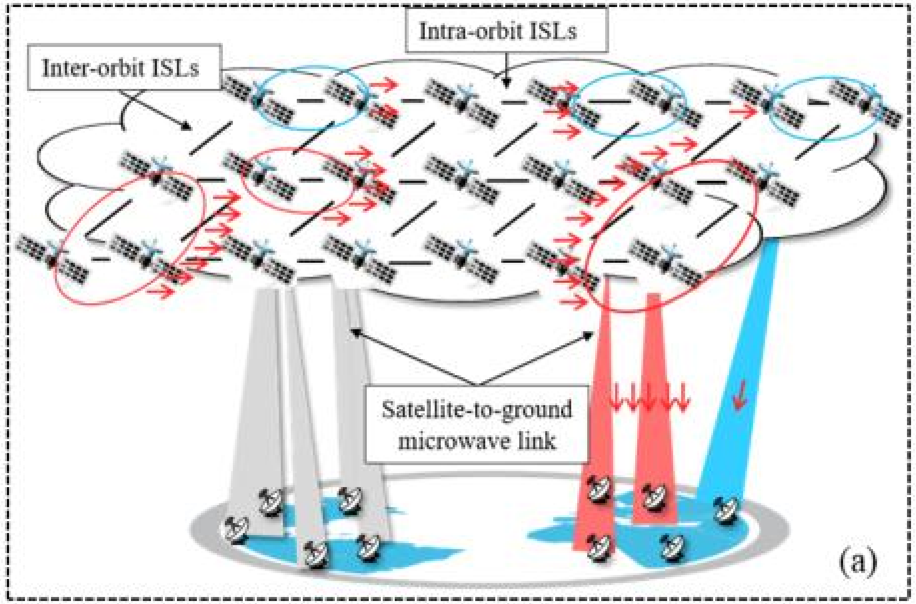


Fig.1 Scenario of high concurrent traffic convergence

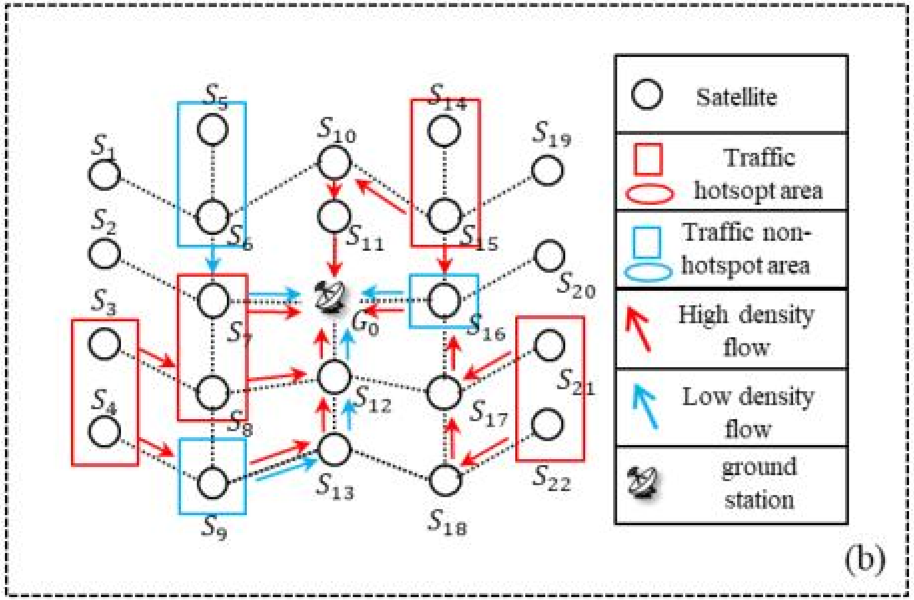


Fig.2 Problem abstraction of high concurrent traffic convergence

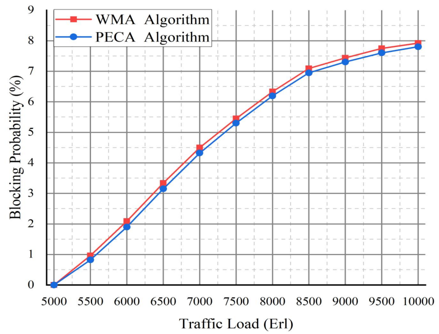


Fig.3 Blocking rate

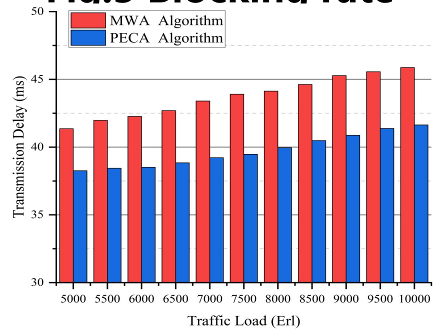
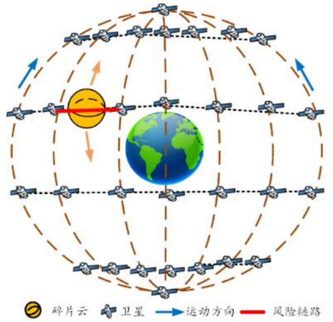


Fig.4 Delay

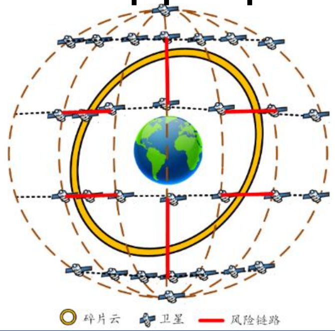
[1] L. Li, X. He, H. Wang, W. Wang, **Y. Zhao*,** and J. Zhang, "Reducing Concurrent Traffic Request Routing Conflict in Satellite Optical Networks," in Asia Communications and Photonics Conference 2021.

Optical Satellite Networks Routing with Debris

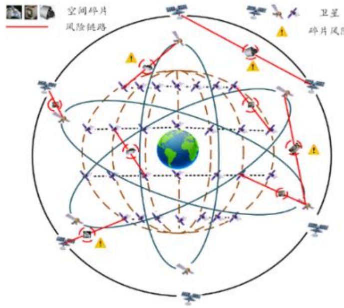
- **Problem:** There is a large number of debris in space and some of them may move between two satellites, which may cause the transmission interruption.
- **Solution:** **The risk assessment model** and **the corresponding perception method** are constructed according to the physical characteristics of space debris in different periods.
- **Effect:** The prediction accuracy of space debris within 10s is **95%**, and the service success rate is increased by about **5%** with an appropriate learning rate.



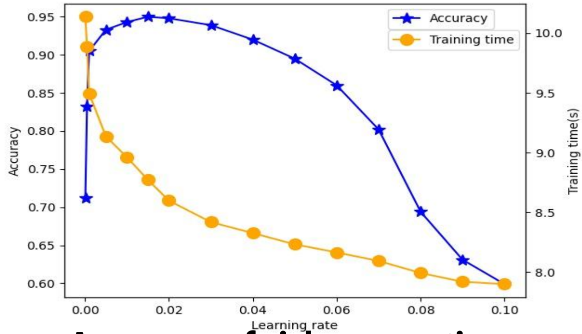
Spherical stage
Initial debris cloud



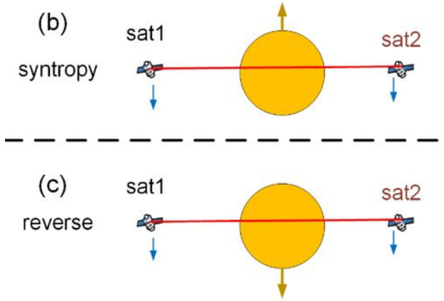
Circular stage
The fragment density is half spherical

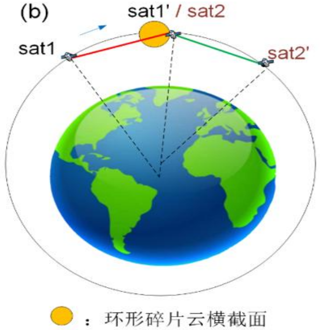


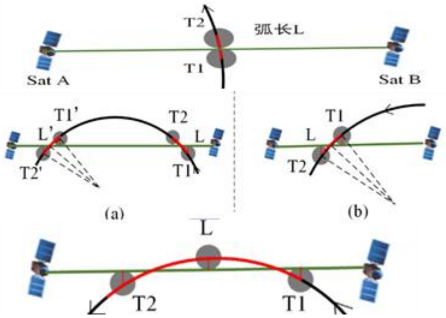
Omnidirectional diffuse stage
Fragments are relatively independent

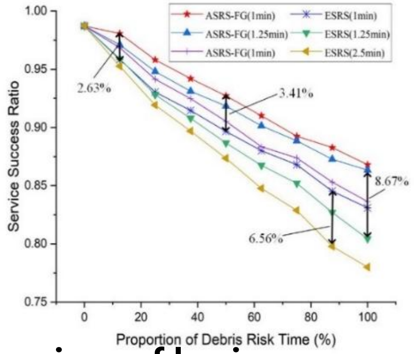


Accuracy of risk perception









Comparison of business success rate

[1] Ma Zhuangzhuang,"Research on the routing strategy based on space debris risk perception in satellite optical networks ", Thesis for Master Degree,2022
[2] Ma, Zhuangzhuang, **Yongli Zhao***, Wei Wang, Xiangjun Xin, and Jie Zhang. "Adaptive Snapshot Routing Based on Space Debris Risk Perception in Satellite Optical Networks." In 2021 International Conference on Optical Network Design and Modeling (ONDM), pp. 1-6. IEEE, 2021.

Optical Satellite Networks Routing with Survivability

- **Problem:** The high dynamic satellite optical network is in a harsh and fragile space environment, and the switching of links leads to the switching of working path and protection path. **How to improve the sharing degree of protection resources is a key problem to be solved.**
- **Solution:** A service sharing protection method based on time window matching is proposed, by which the switching times of the working path are reduced and the sharing degree of the protection path is improved.
- **Effect:** Compared with the benchmark algorithm, the switching times of working paths are reduced by **38.7%**, and the sharing degree of protection paths is increased by **35.7%**.

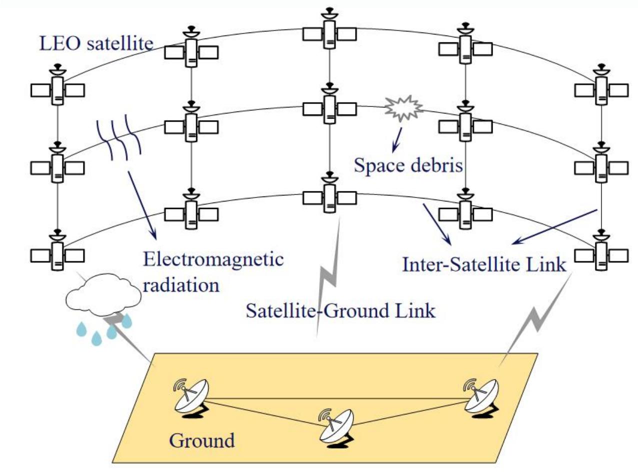


Fig.1 Fault diagram of the OSN

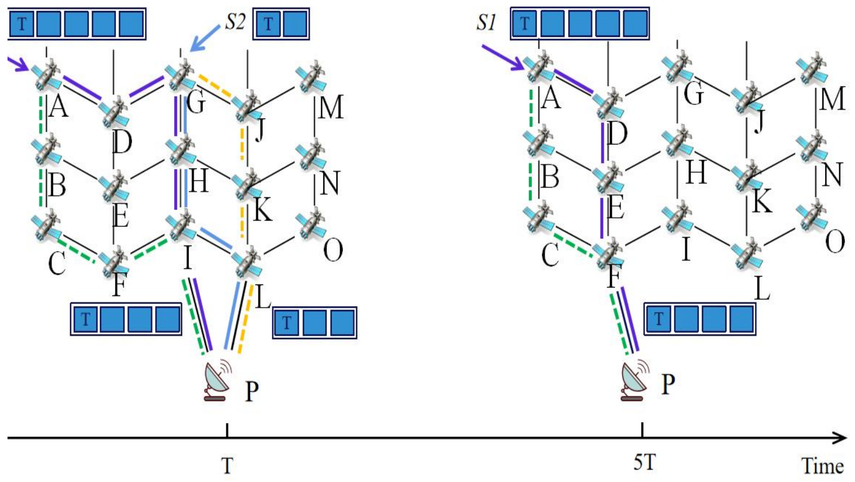


Fig.2 Problem description

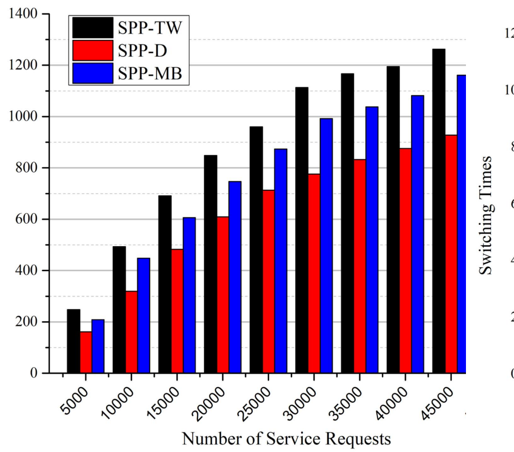


Fig.3 Average link sharing

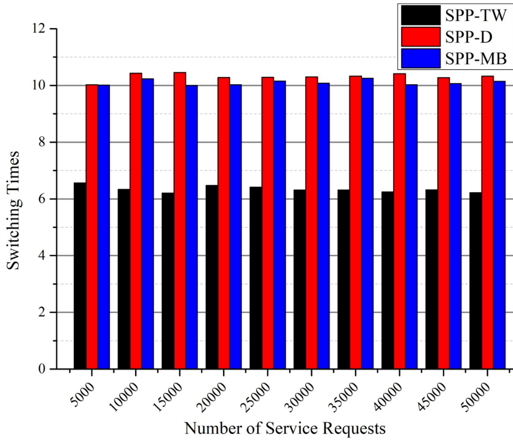


Fig.4 Switching times

[1] X.C. Yan, **Y. L. Zhao*,** et al., Time Window- Based Shared Path Protection in satellite laser networks

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Optical Satellite Networks Signaling with Segment Routing

- **Problem Description:** In a satellite optical network, an optical path needs to be established before service transmission. **The key to realize fast provision of services is how to realize fast signaling.**
- **Solution: A fast service provision scheme based on extended SR** (segment routing) is proposed, which includes two steps: signaling path acquisition and signaling provision.
- **Effect:** The blocking rate is reduced by up to **8.6%,** the maximum label compression rate is **46%**, and the cross-domain end-to-end signaling delay is reduced by up to **964ms**

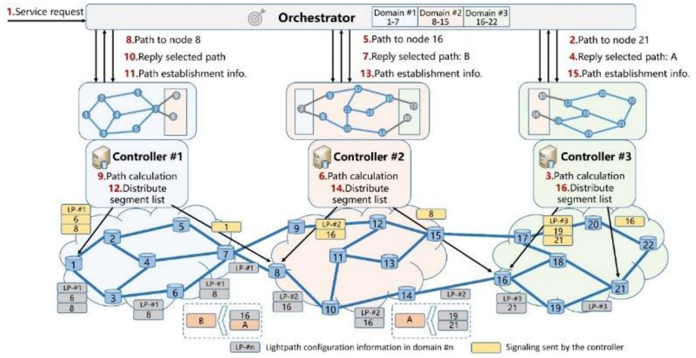

Fig. 1 Service provision process

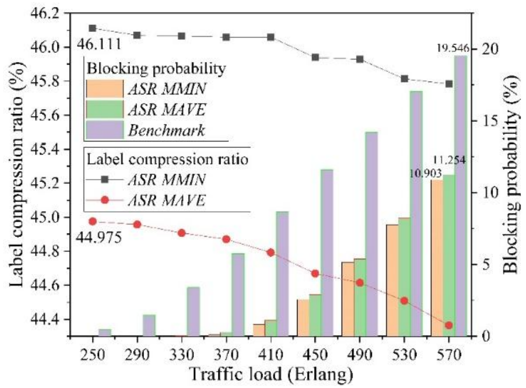

Fig. 2 Service blocking rate and label compression rate

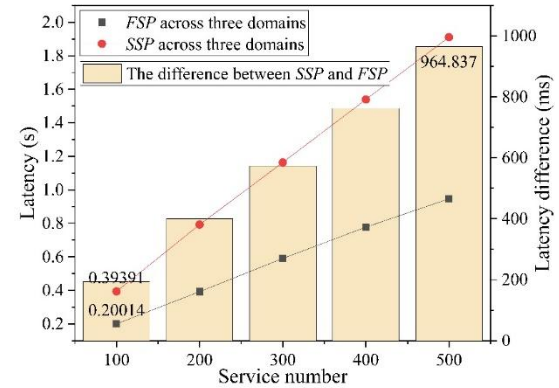

Fig. 3 End-to-end service provisioning delay

[1] X. Li, **Y Zhao***, et al., “End-to-end service provisioning based on extended segment routing in multi-domain optical networks of F5G,” JOCN, 2022
[2] X. Li, **Y Zhao***, et al., "Experiment of Segment Routing based Service-Oriented Fast Path Construction for F5G," OECC 2021, pp. W1A.2.
[3] X. Li, **Y Zhao***, et al., "Experiment of Extended Segment Routing Enabled Fast End-to-End Service Provisioning in Multi-Domain for the Fifth Generation Fixed Network (F5G)," ACP 2020, pp. 1-3.

Optical Satellite Networks Signaling with Deterministic

- **Problem Description:** When signaling data is transmitted in the satellite optical network data communication network, the delay is uncertain. **It is important to accomplish the deterministic transmission of signaling.**
- **Solution:** A deterministic signaling scheduling scheme based on delay awareness is proposed, and **signaling is divided into hard real-time signaling and soft real-time signaling considering the demand of different service**.
- **Effect:** The scheduling failure rate is reduced by up to **11.58%**, the resource utilization rate is increased by up to **3.6%**, and the end-to-end delay is reduced by up to **15.8ms.**

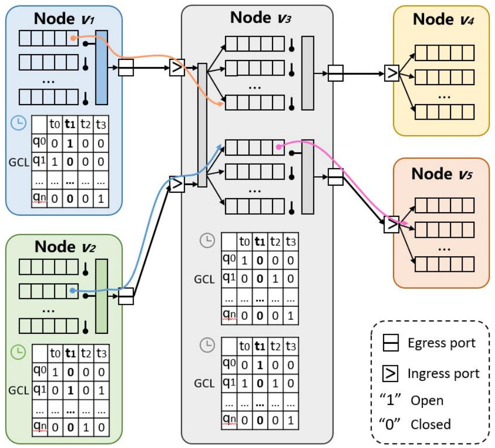

Fig.1 Deterministic signaling scheduling architecture

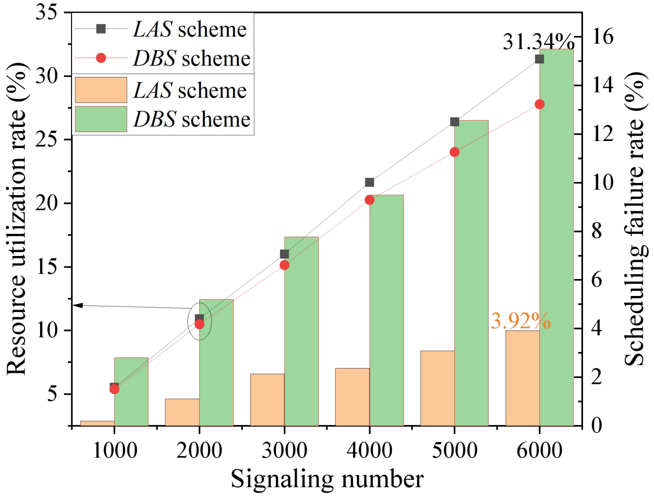

Fig. 2 Hard real-time signaling scheduling failure rate and resource utilization

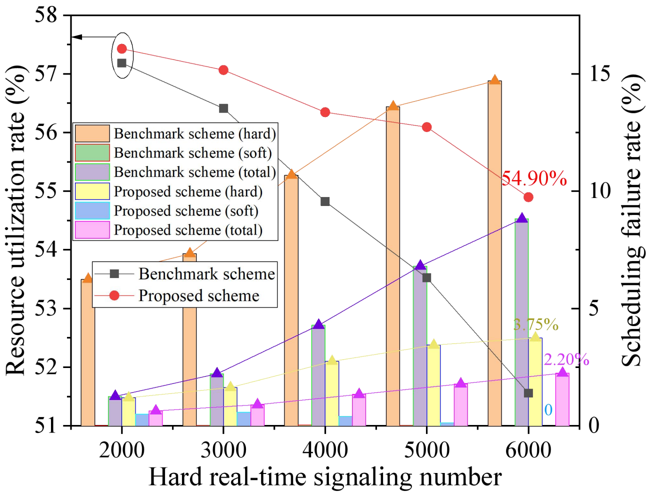

Fig. 3 Deterministic signaling scheduling failure rate and resource utilization

[1] X. Li, **Y Zhao***, et al., "Latency-Aware Scheduling Scheme for Deterministic Signaling in F5G"

Content

Dynamic Satellite Optical Communication Networks

1. Satellite Constellation Design
2. Optical Satellite Networks Planning
3. Optical Satellite Networks Routing
4. Optical Satellite Networks Signaling
5. Future Prospect

Future Prospect:

1. How to shield the dynamism of optical satellite networks?

- The distance between satellites in adjacent orbits changes all the time. The basic problem is how to shield the dynamism of satellites to improve the performance of satellite networks.

2. How to improve the network robustness in complex spatial environment?

- The space debris, solar transit, etc., will affect the OSNs. How to improve the robustness of the network is the basis for maintaining the stable operation of the satellite optical network.

3. How to manage and control a large-scale satellite network?

- With the rapid development of large-scale OSNs, how to effectively manage and control the large-scale satellite network is of great significance.

4. How to ensure the consistent life of satellites in orbit?

- Different satellite launch times and different degrees of on-orbit consumption lead to inconsistent satellite life. The life of satellites may be extended by methods such as satellite energy-saving routing.

Thank You!

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