Segment-based Path Verification in LEO Satellite Networks

Qian Wu, Yuxuan Weng, Zeqi Lai, Hewu Li
Tsinghua University, China

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Outline

- The emerging LEO Satellite Networks(LSNs).
- Why do we need path verification in LSNs?
- Dose the LSN affect existing path verification methods?
- What design directions should we consider?

The Emerging LSN

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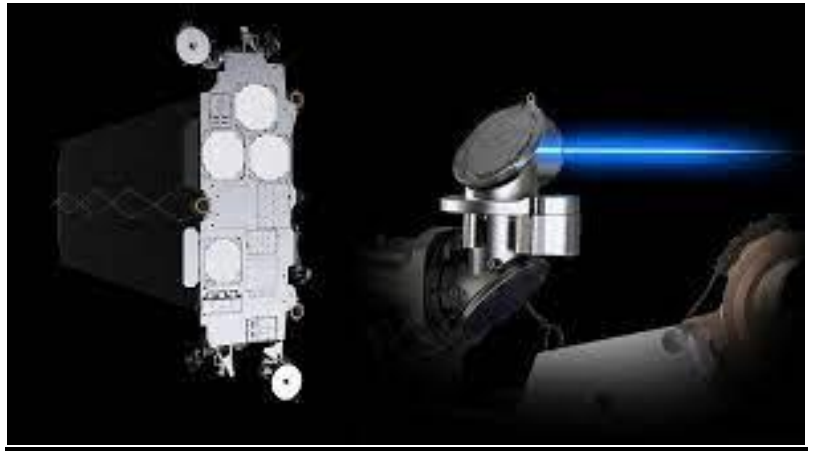
- Low-Earth-Orbit (LEO) Satellite Networks (LSNs) are under construction.
- Inter-satellite links (**ISLs**) are equipped, supporting **long-way traffic**.

10,000+
launched satellites

10,000,000+
global users

155+
countries



LASER MESH NETWORK

Starlink's optical space lasers transmit data throughout the Starlink constellation, providing continuous service in areas far from SpaceX ground stations - providing coverage for your flights over the open ocean and in polar regions.

Starlink's constellation contains 9,000+ lasers transmitting 10Pb+ of daily data traffic. These lasers can sustain a 100Gbps connection per link, can connect up to 3,300+ miles apart, and maintain a mesh network with 99.99% uptime.

LSN Architecture

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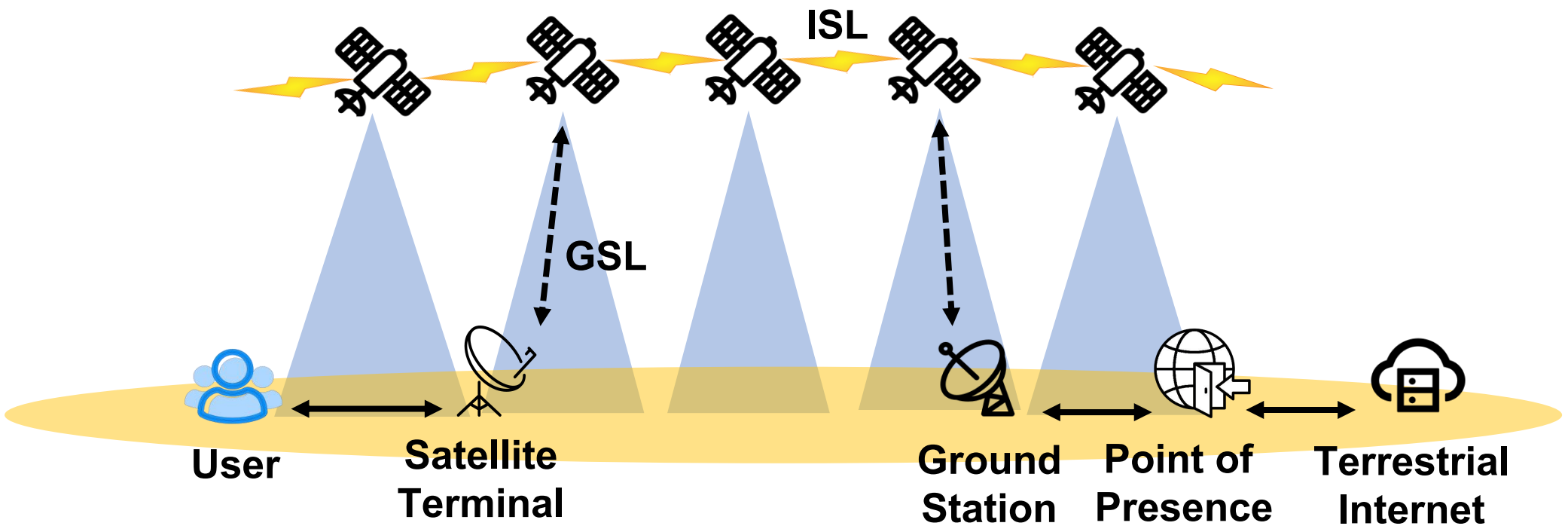
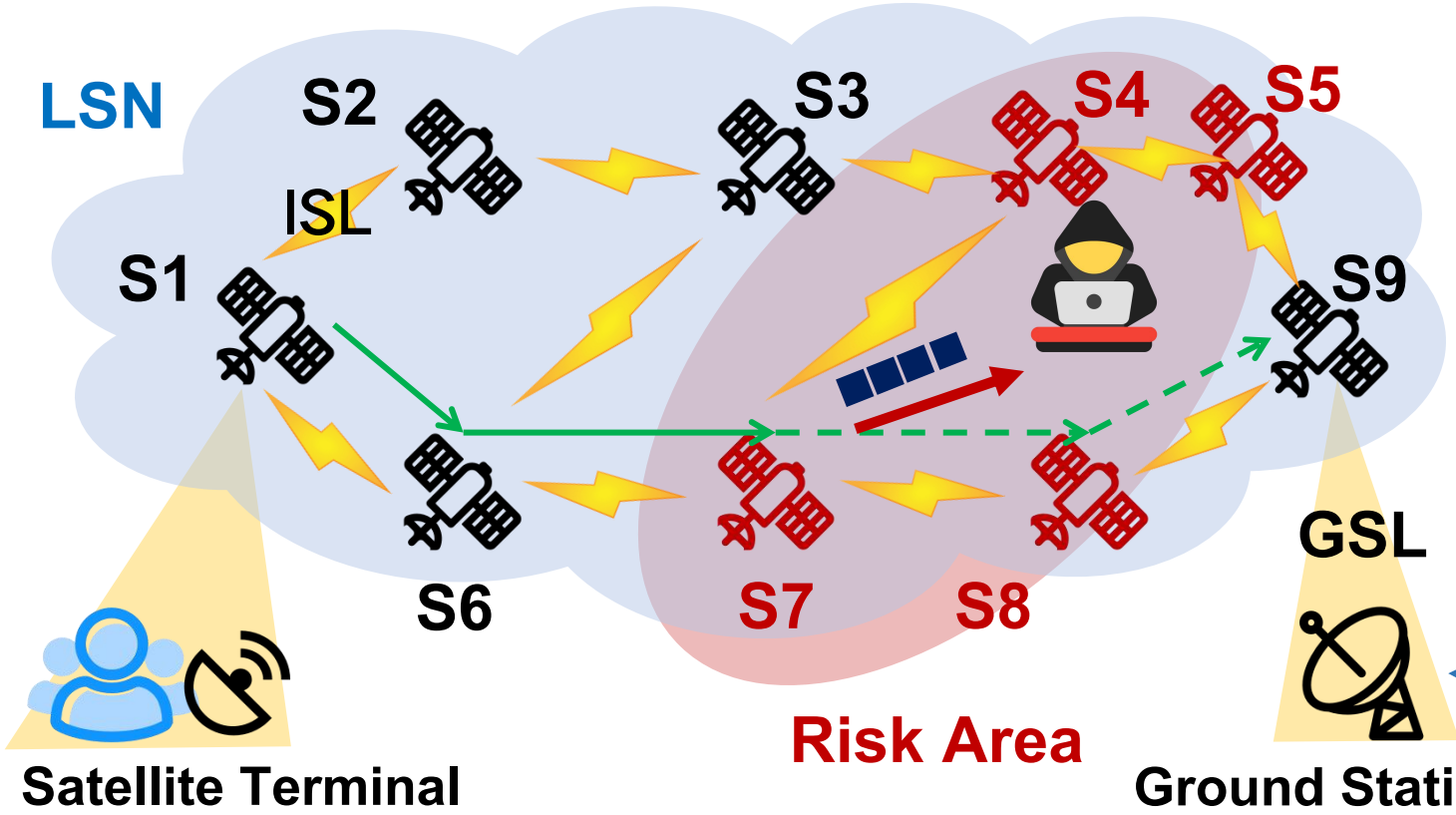
- Terrestrial users can access the Internet via an LSN.
- Space segment achieves **global connectivity** through high-speed **ISLs**.



Routing Threats of LSNs

- LEO satellites are **moving dynamically** around the Earth.
- High dynamics cause satellites to entering ***Risk Areas***, where **natural impact** or **region-specific attacks** may occur.



Information stealing

S7->S8

Traffic hijacking

S7->S4->S5->S9

Routing Threats of LSNs

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- LEO satellites are **moving dynamically** around the Earth.
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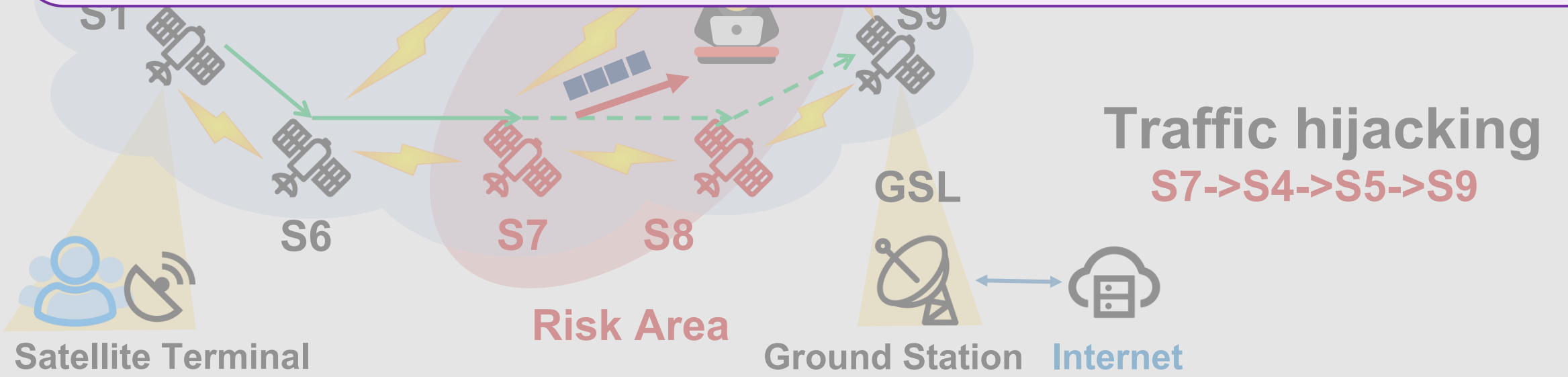
Satellite Network Operator (SNO)

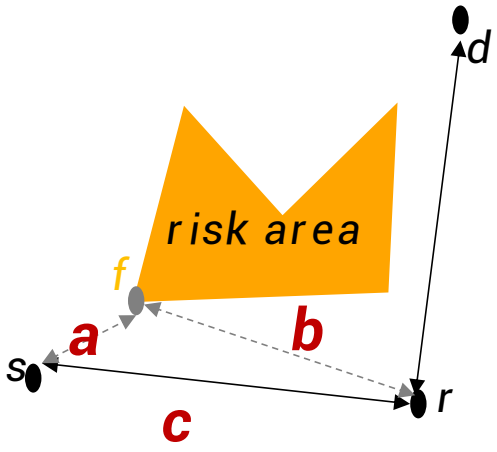
Apply avoidance policies to force traffic to bypass the risk area

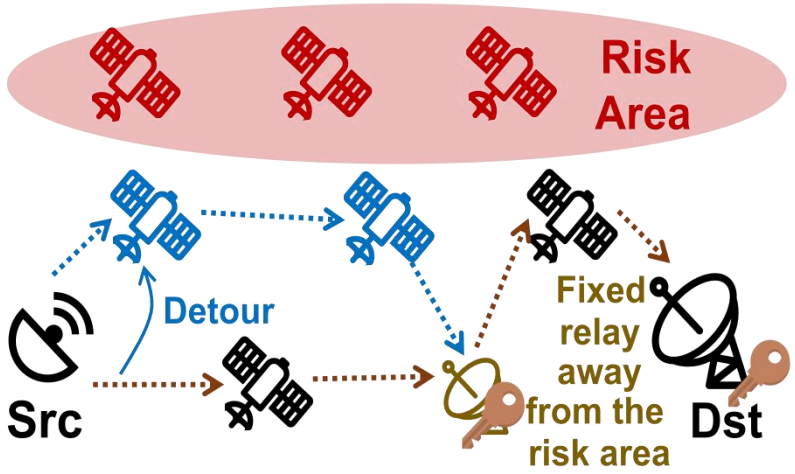
✦ **Verify the practical paths indeed bypass the risk area**

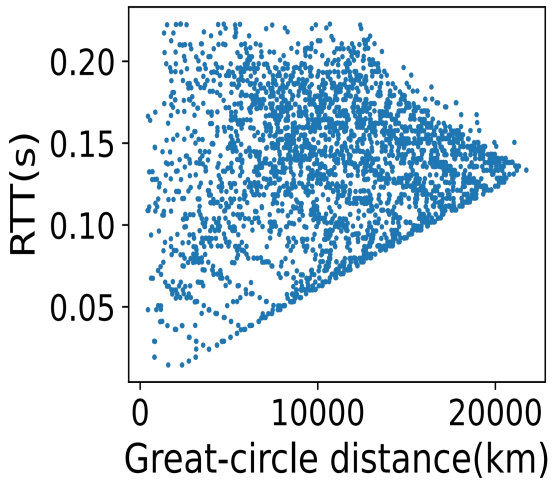


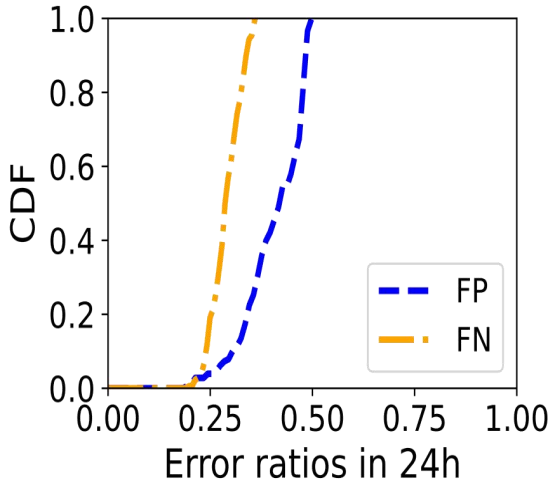
Existing Verification Methods

- **Delay-based method** pre-computes a **remote relay** and enforces the traffic to pass through the relay.
- Taking a detour through the risk area will result in **greater observed end-to-end delay**.





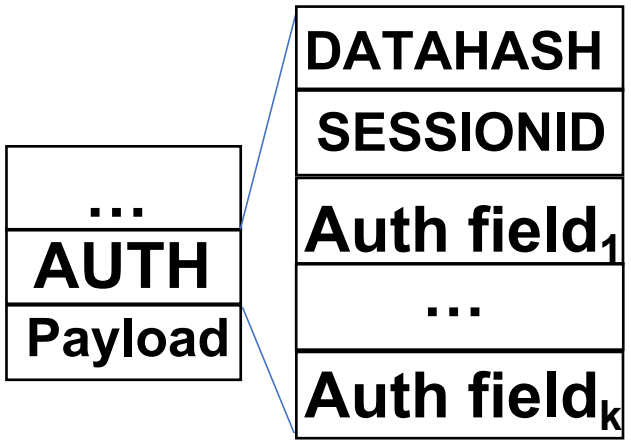


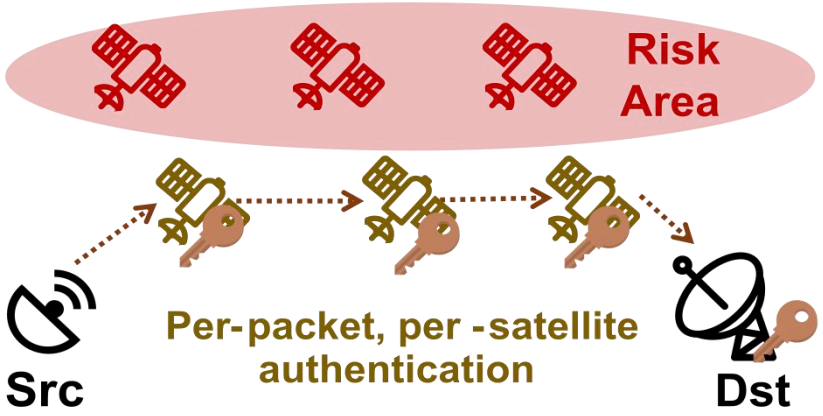


Linear delay-distance relationship doesn't hold in LSNs, leading to low verification accuracy.

Existing Path Verification

- **Crypto-based method** constructs a **verification chain** consisting of nested MACs and checks the chain to verify path.
- The intermediate nodes **verify and update** the verification fields in the packet header **hop by hop**.





Path length N (hops)	ICING	OPT	EPIC
	13+42N	52+16N	24+5N
N=10	433	212	74
N=20	853	372	124
N=30	1273	532	174

Long header length will lead to longer processing delay and limited scalability in mega constellations.

Segment-based Path Verification for LSNs

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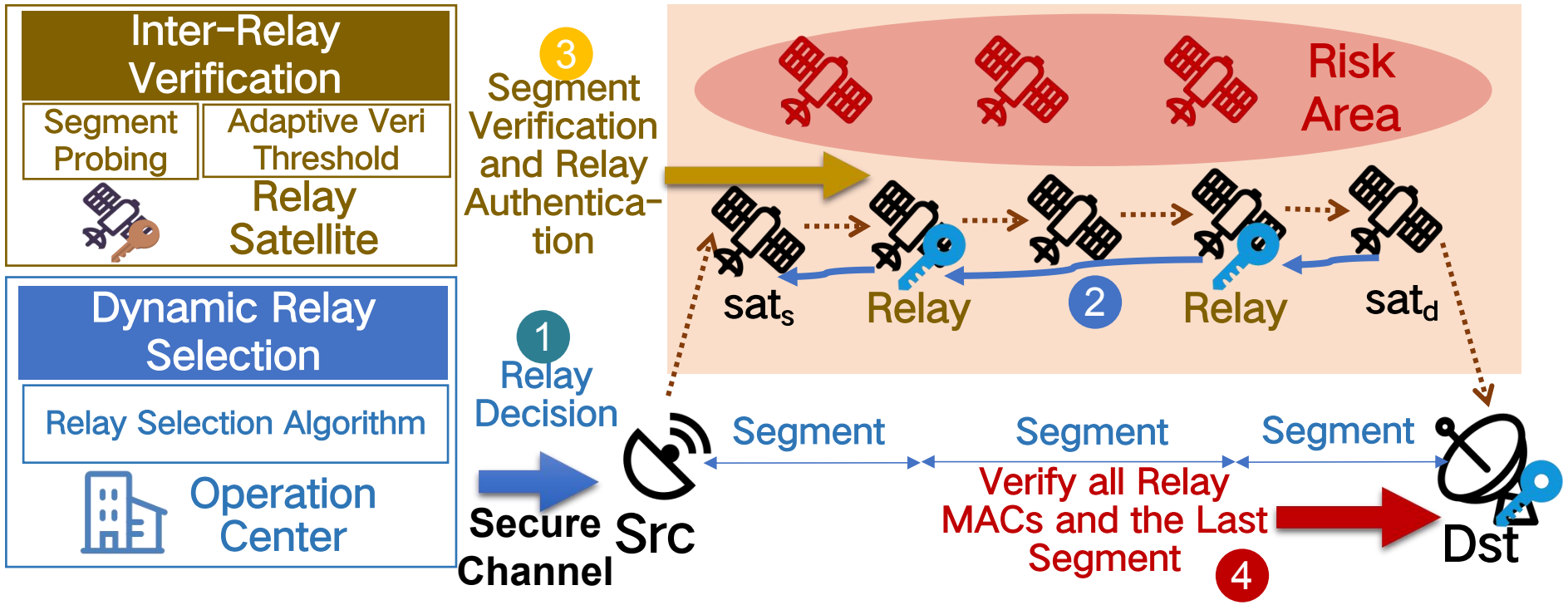
① SNO operation center **selects relays**.
Src **constructs the packet header**, containing authentication and verification fields.
② Relays **probe delay ground truth** of the current segment periodically.
③ Each relay **verifies the segment** and **authenticates paket header**.
④ Dst verifies the last segment path and **makes the final decision**.



Conclusion

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- LSNs are **under heavy construction**.
- LEO satellites are moving dynamically, facing more **routing threats.**
- High-dynamic and large-scale LSNs need a **highly accurate and scalable** path verification method.
- Segment-based path verification transfers from verifying the whole path to **verifying each segment** and only requires **relay authentication**.

THANKS

Q & A

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Qian Wu, Yuxuan Weng, Zeqi Lai, Hewu Li
Tsinghua University, China

wuqian@cernet.edu.cn
wengyx25@mails.tsinghua.edu.cn