Analysis for the Adverse Effects of LEO Mobility on Internet Congestion Control

draft-lai-ccwg-lsncc-00

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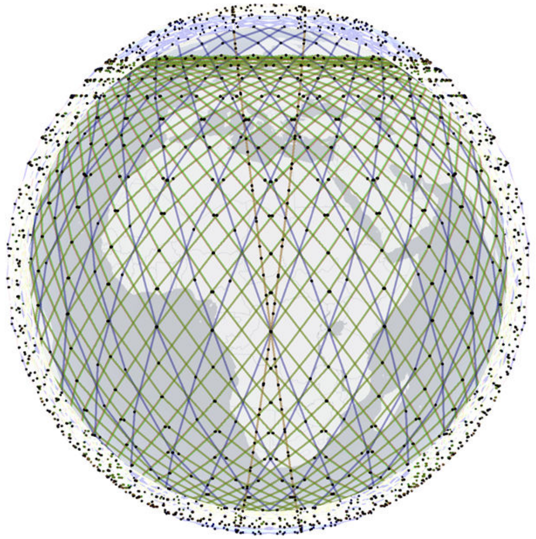
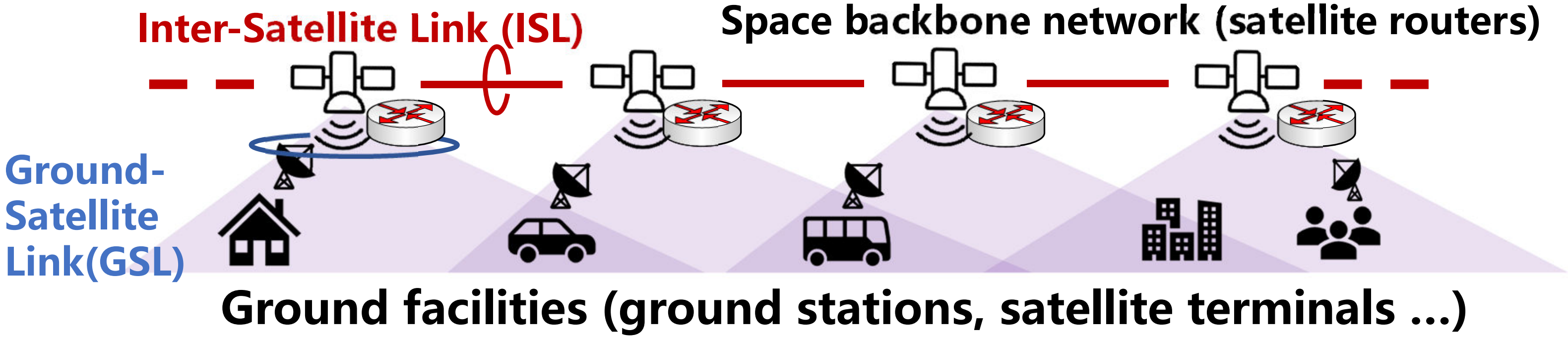
Outline

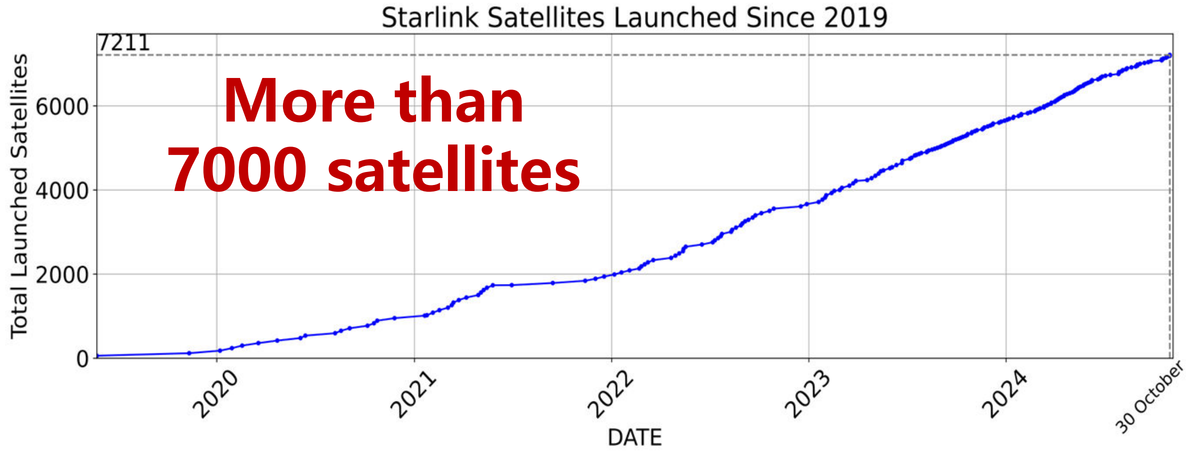
- **Background**
- **Impacts of LEO Mobility on Internet Congestion Control**
- **Potential Mitigations**
- **Conclusion and Future Work**

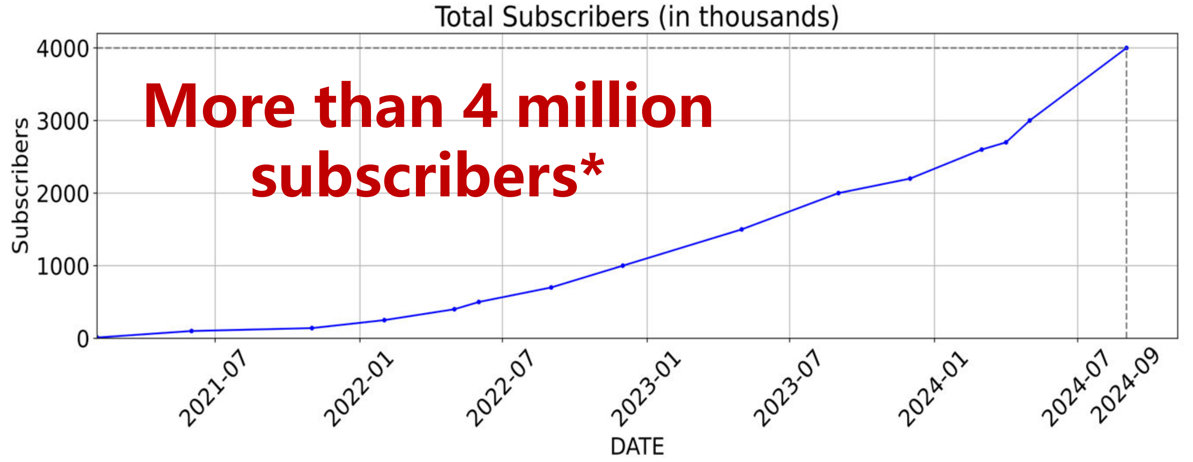
Background: LEO Satellite Networks (LSN)

- **Providing Internet services from space**
  - Through **a network of low-earth orbit (LEO) satellites**
  - Leading players: Starlink, OneWeb, Amazon Kuiper, Qianfan … …





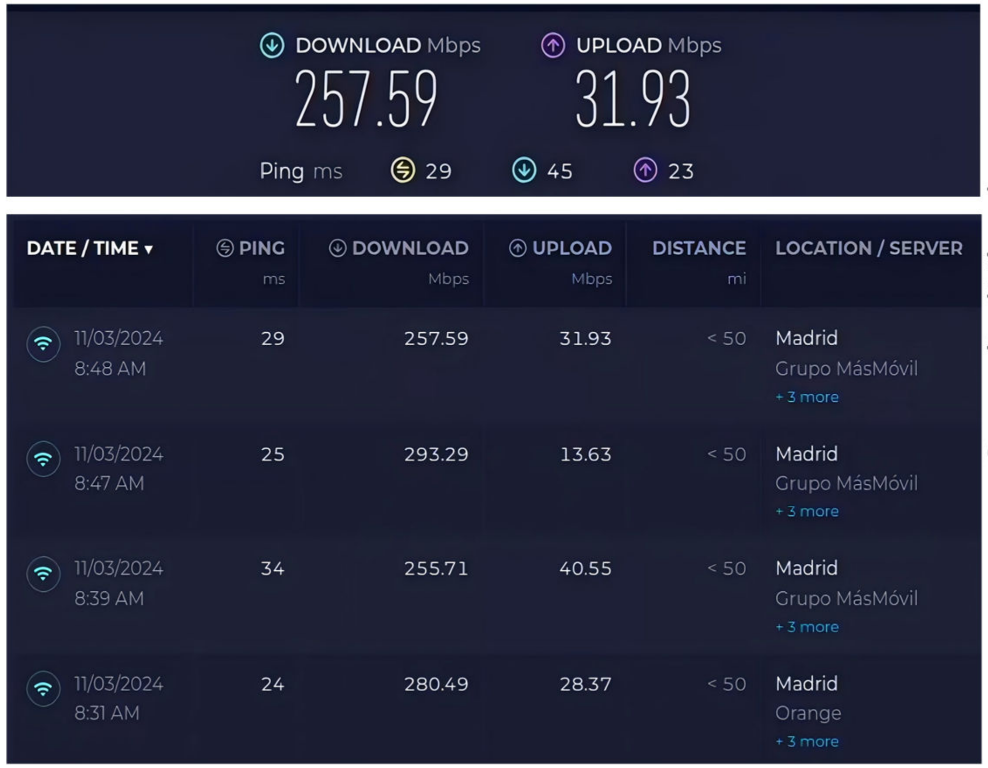


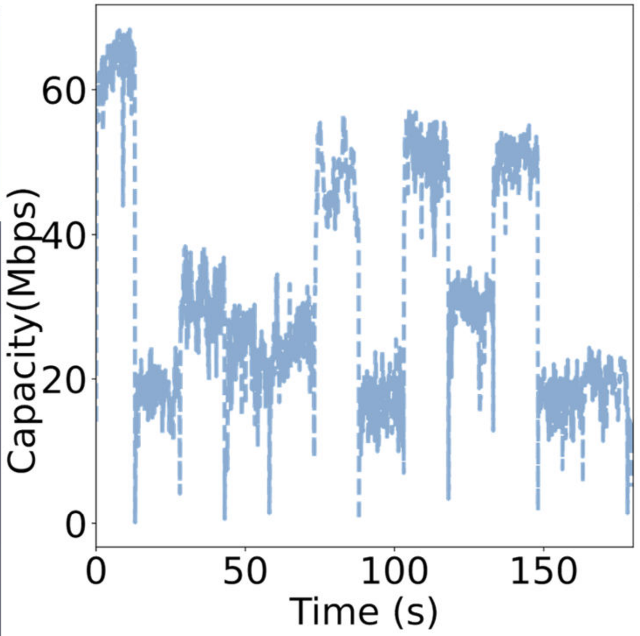


*source: https://x.com/Starlink/status/1839424733198344617

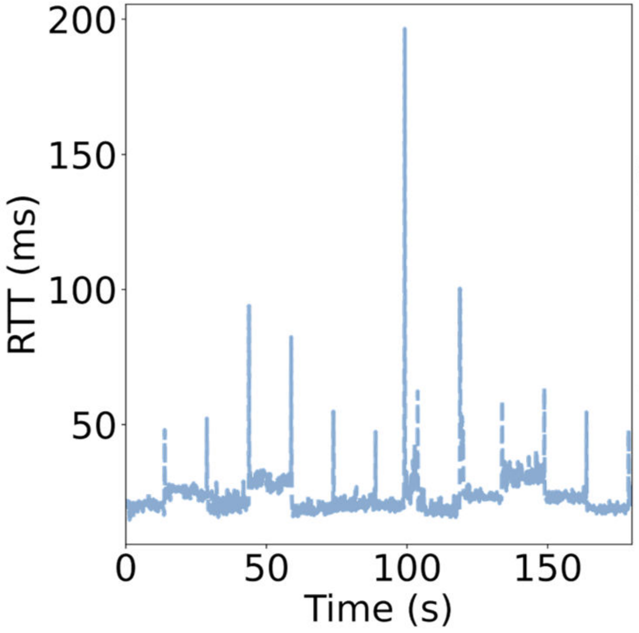
Network Characteristics of LSNs

- **Starlink as an LSN case (the largest operational LSN today)**
  - From an average view: low latency and high speed
  - From a fine-granularity view: **drastic network variations**

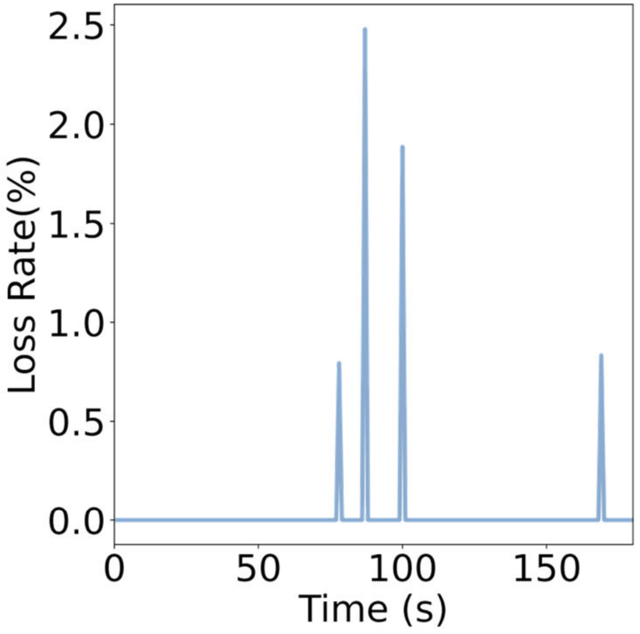




Link Capacity Variations



Non-congestion RTT Variations



Non-congestion Loss Variations

Due to the LEO mobility, the network performance of end-to-end connection over an LSN changes drastically over time!

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A Real Check for CCAs over LEO Links

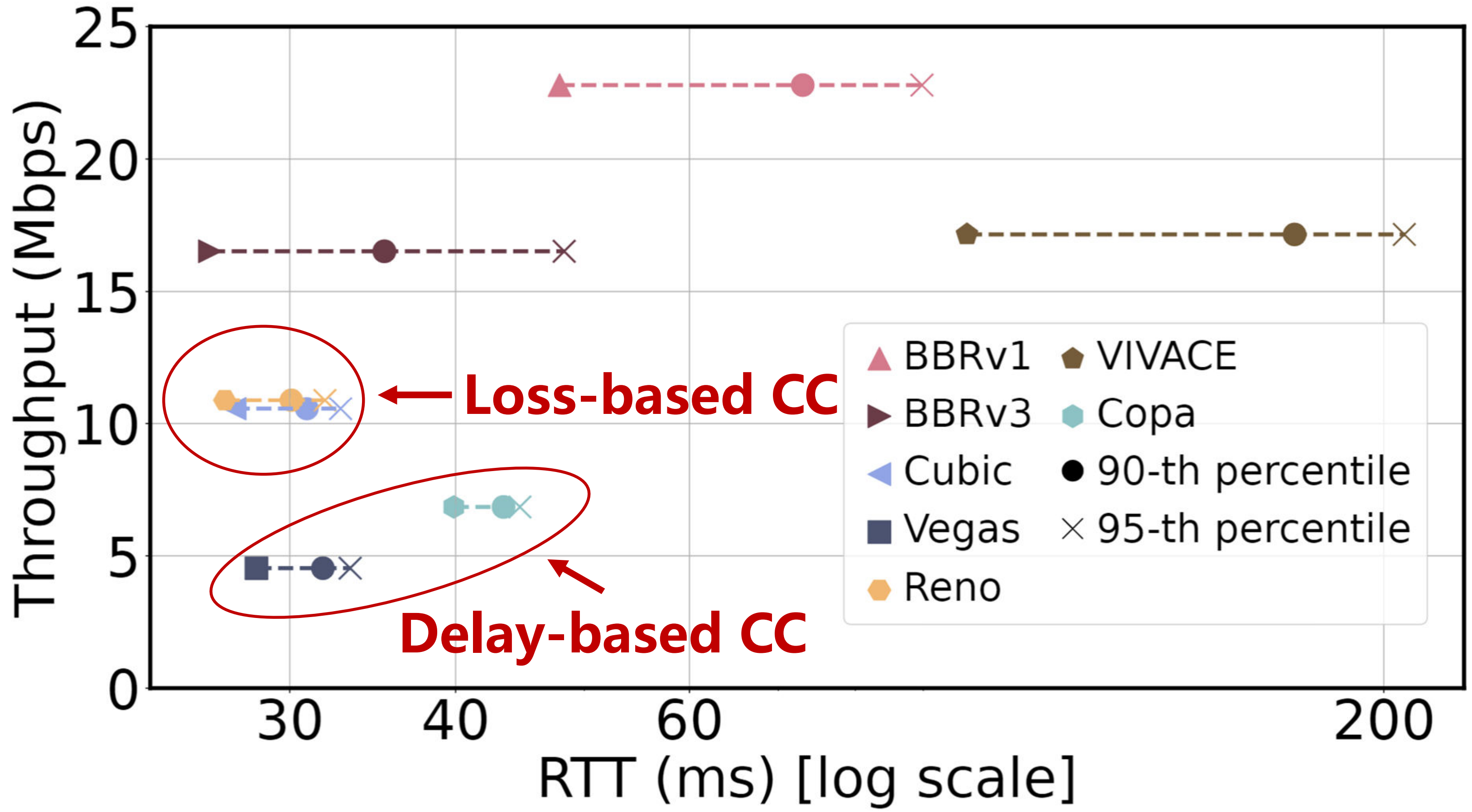
- **Benchmarking various congestion control algorithms (CCAs)**
  - Based on a satellite terminal deployed in Madrid

CCA comparison

- **Loss-based:** TCP-Reno, TCP-Cubic
- **Delay-based:** TCP-Vegas, Copa
- **Model-based:** BBRv1, BBRv3
- **Learning-based:** PCC-VIVACE

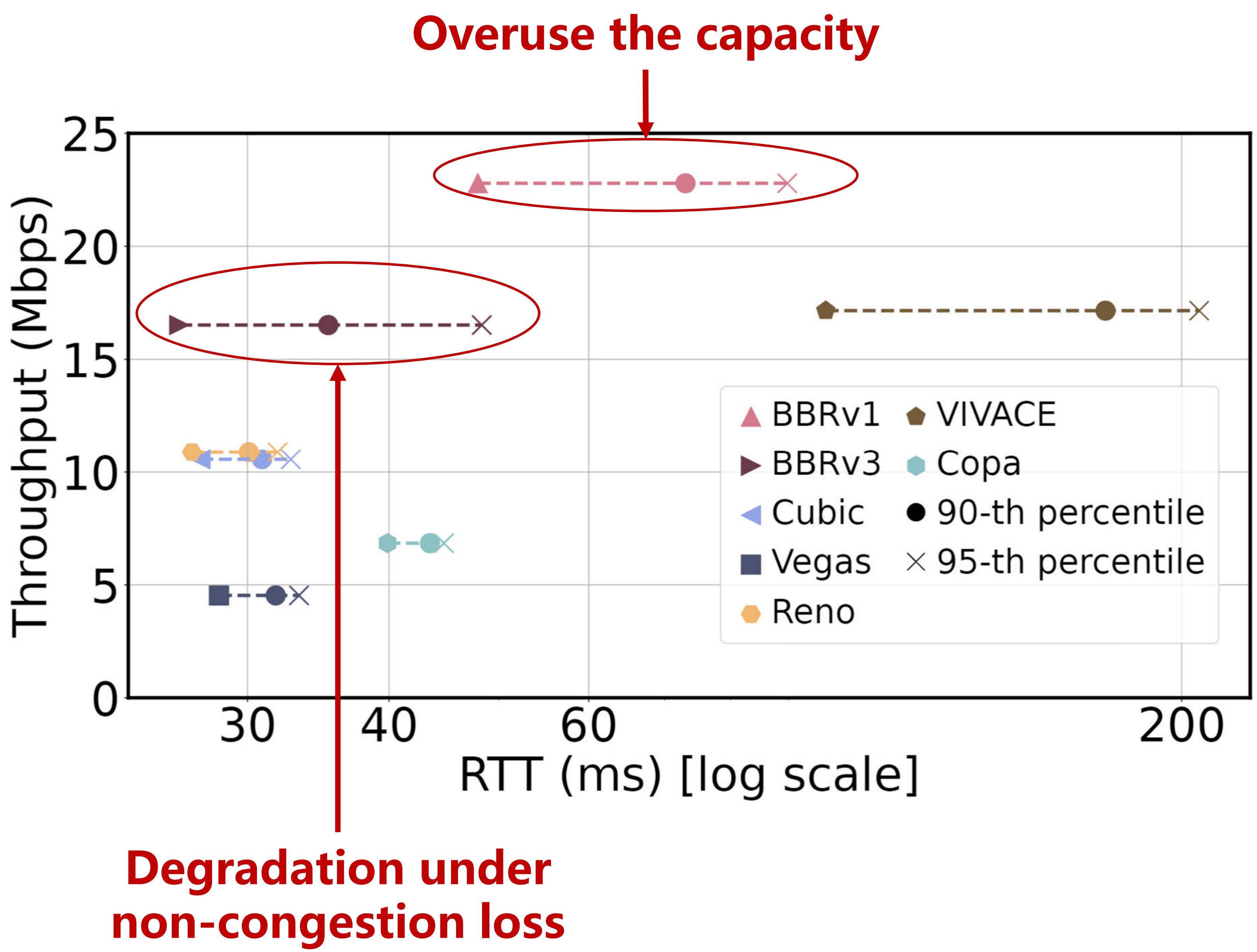
For each CCA we run more than 30 tests to obtain the statistic results

RTT against Throughput (1/3)



- **Loss-based CC**
  - **Low throughput** due to non-congestion packet loss
  - E.g. packet loss due to satellite handovers
- **Delay-based CC**
  - **Low throughput** due to non-congestion delay jitter
  - E.g. LEO mobility changes the path, and thus the delay

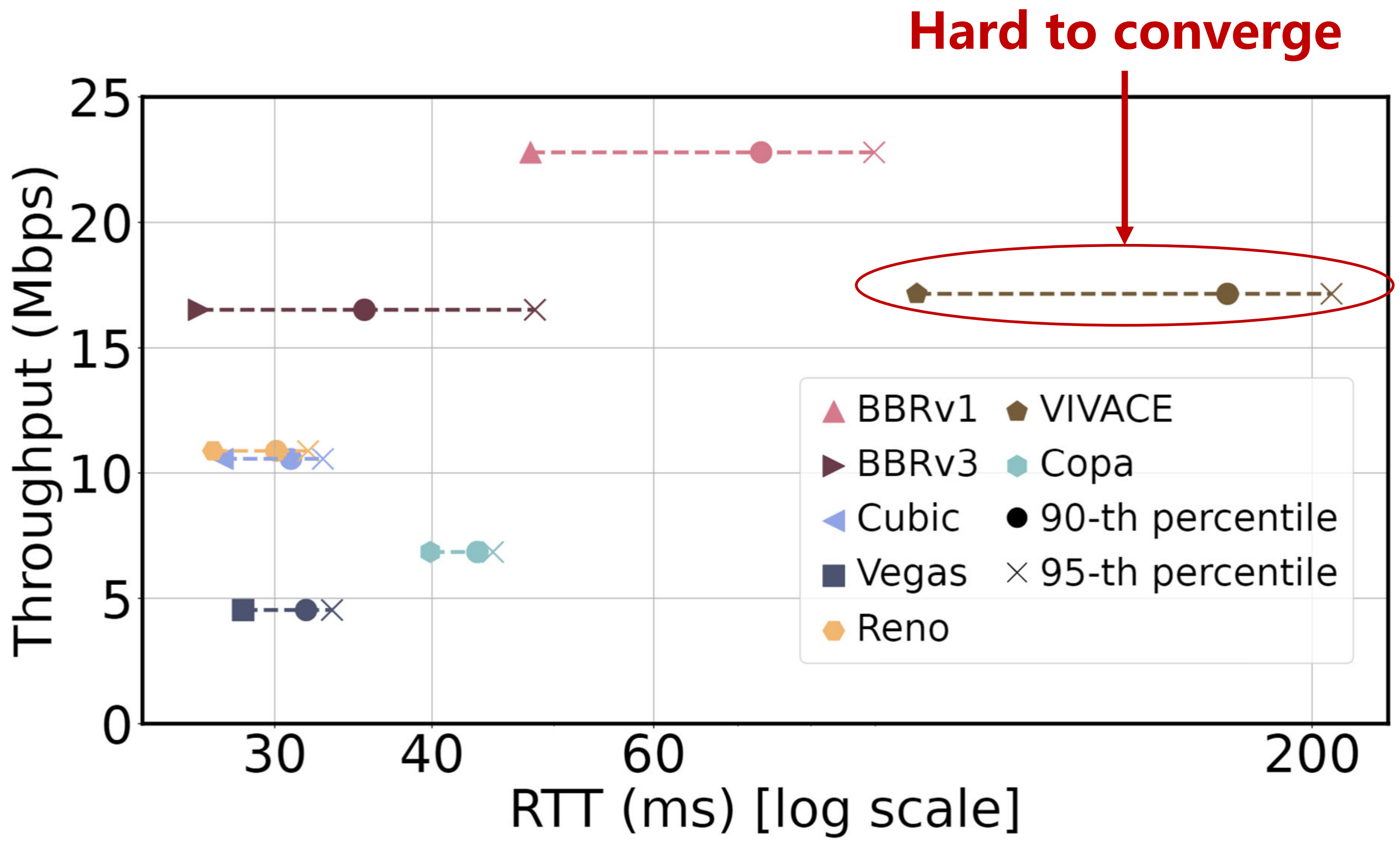
RTT against Throughput (2/3)



- **BBRv1**
  - Frequently overuse the dynamic link capacity
  - The **Max_BW filter** over-estimates link capacity
  - **High delay and delay tail**

- **BBRv3**
  - **Throughput degradation** due to the non-congestion packet loss
  - Lower delay than BBRv1

RTT against Throughput (3/3)



- **Learning-based CC**
  - Utility function
  - Sending rate contribution
  - Latency penalty
  - Loss penalty

  - LSN conditions change rapidly over time
  - **It is challenging to learn and converge the sending rate to the correct value**
  - **High delay**

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Changes Brought by LEO Mobility

- **The fundamental assumptions in current CCAs**
  - Existing Internet congestion control leverages **performance changes observed on the sender** to estimate network congestion
  - **Existing assumptions:** packet loss indicates congestion, delay increase indicates congestion, maximum throughput indicates link capacity

- **The unique LEO mobility breaks these assumptions**
  - Packet loss might be caused by satellite handovers
  - Consistent delay increase might be caused by LEO path changes
  - Max_BW filter might over-estimate the drastically changing link capacity

Potential Mitigations

- **The mixture of congestion and non-congestion signals creates big challenges for Internet congestion control!**

- **Potential mitigations**
  - Explicit notifications for discriminating network variance
  - Cross-layer optimization
  - Multi-path enhancement

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Conclusion and Future Work

- **Internet paths with LEO links** are carrying an increasing amount of network traffic
- The unique **LEO mobility** causes **drastic end-to-end variations**, involving new challenges on Internet congestion control
- We performed a **performance study** on various CCAs in a real LSN, and we hope it provides insights for future CCA standards
- As our future work, we will explore improvements for CCAs in LSNs

THANKS

Comments & Questions

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