LEO Satellite vs. Cellular Networks: Exploring the Potential for Synergistic Integration

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Overview

• Background
• Methodology
• Performance
• Coverage
• Multipath
Background

- Low Earth Orbit (LEO) satellite networks
  - e.g., Starlink, Kuiper, OneWeb, …
- Both LEO and cellular networks face challenges
  - *Fail to consistently attain peak network performance*
- Open questions
  - Performance of Starlink under mobility?
  - Starlink and cellular complement each other?
Background

- Satellite and cellular networks have distinct and complementary network performance distribution.
  - *Darker colors indicate periods of higher throughput*
Problems

- Understand the performance and coverage
  - *Compare Starlink and cellular networks*
- Explore the potential of enabling multipath
  - *Leverage their advantages across time and space*
Measurement Methodology

- Hardware and services
  - Satellite: Roam (RM), Mobility (MOB)
  - Cellular: AT&T (ATT), T-Mobile (TM), Verizon (VZ)
  - Smartphones: Samsung Galaxy S21 × 5
Measurement Methodology

- Software measurement tools
  - *iPerf* for TCP/UDP throughput test
  - *UDP-Ping* for latency
  - *5G Tracker [1,2]* for network type, speed, GPS location, signal strength, …

- Data collection: drive tests
  - *5 states in the US*
  - *1239 network tests*
  - *9083 minutes of traces*
  - *3800 km travel distance*

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Starlink-Cellular Performance Comparison

- UDP outperforms TCP in satellite networks due to high packet loss
  - 128 Mbps vs 29 Mbps
Starlink-Cellular Performance Comparison

- “Roam” also works during in motion cases.
- “Mobility” exhibits superior performance than “Roam”
Starlink-Cellular Performance Comparison

- **Latency**
  - RTTs for all networks primarily fall within the range of 50 to 100ms
  - Starlink’s latency is *not significantly worse* than that of cellular networks
    - Only 1.8ms transmission latency one way, theoretically

\[
\text{Latency} = \left( \frac{\text{Distance}}{\text{Speed of light}} \right) = \left( \frac{550 \text{ km}}{299792 \text{ km/s}} \right) = 1.835 \text{ ms}
\]
Potential Factors Affecting Performance

- Moving speed
  - Both satellite and cellular network throughputs have *minimal variation in relation to driving speed*
- TCP parallelism
  - *Increase the number of TCP connections enhances throughput in both networks*

![Graph showing throughput vs moving speed and improvement percentage for different network configurations.](image)
Coverage Study

- Starlink is better in rural areas due to clear sky view.
- Cellular is better in urban areas due to density base station deployment.
- Starlink exhibits the best overall performance.
- Combining different networks improves the overall performance.
Multipath Transport

- Multipath (MPTCP, MPQUIC, …) is popular and proved effective
  - For different combinations of networks
  - For various network applications
- Starlink + cellular MPTCP has been underexplored
  - Take the first step to demonstrate the potential of enabling multipath

* (Some components like PoP omitted)
Multipath Transport

- Experimental setup
  - **Ubuntu 22.04 VM hosts**
  - **MpShell (a variant of Mahi-mahi [1, 2]) for emulation**
  - **iPerf for throughput measurement**

Multipath Transport

- Using MPTCP between Starlink and cellular networks bring benefits
  - *Improve the bandwidth utilization by over 80%*
  - *Maintain decent performance when one service has severe degradation*
- Promising results but room for improvement
  - *Future work: MPTCP scheduler design tailored for LEO networks*
Conclusion

- We conduct a large-scale data collection campaign
- We analyze the performance of satellite and cellular networks
- We explore the potential of multipath on satellite and cellular networks

Thank You!