Study Group

2023/09/14

Molly Yu

Overview

- **Understanding Operational 5G: A First Measurement Study on Its Coverage, Performance and Energy Consumption**
- **Experiments and Observations of 5G NSA Reliability and Latency Performance in Metro Train Environment**

Understanding Operational 5G: A First Measurement Study on Its Coverage, Performance and Energy Consumption

Introduction

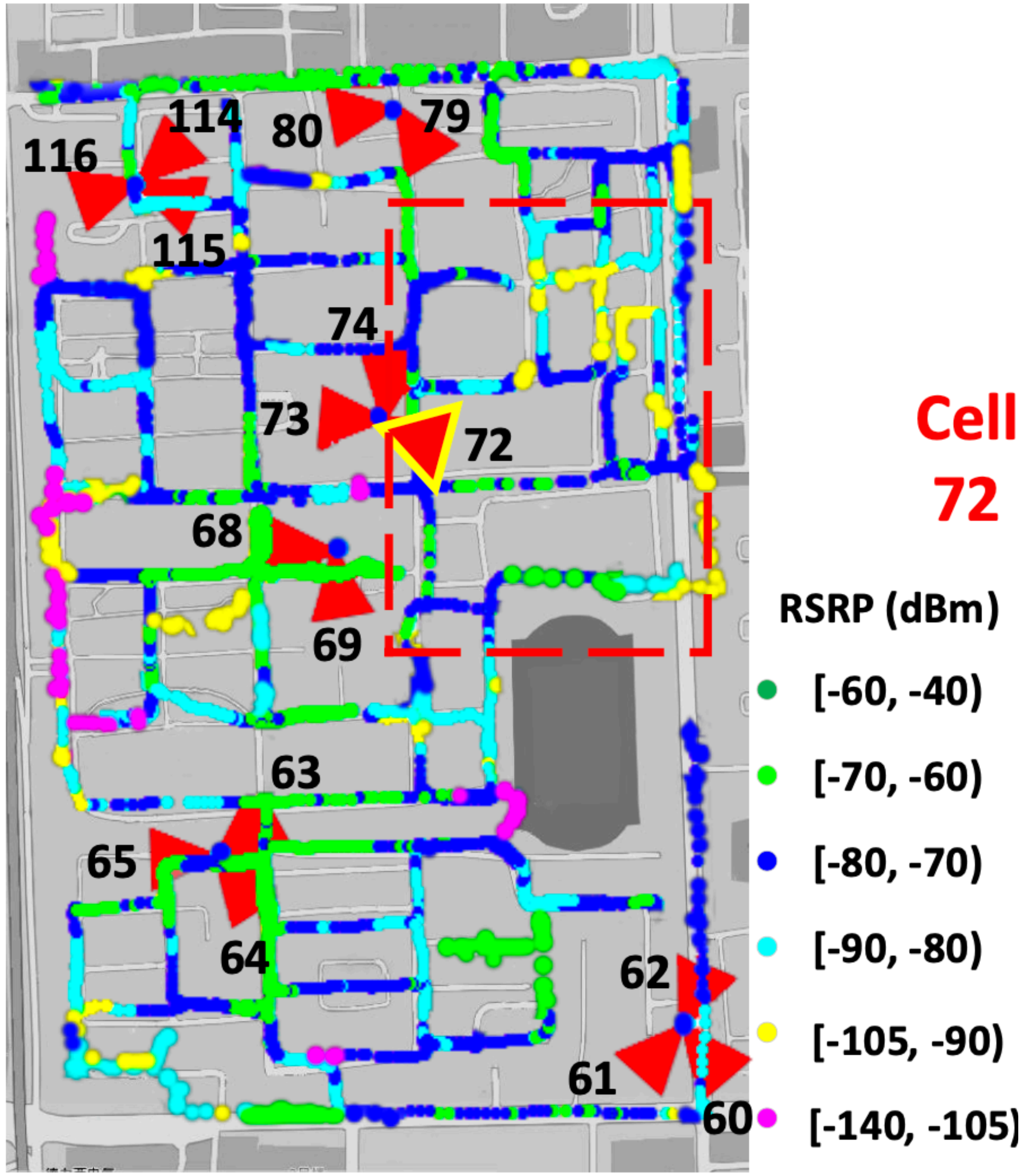
Introduction

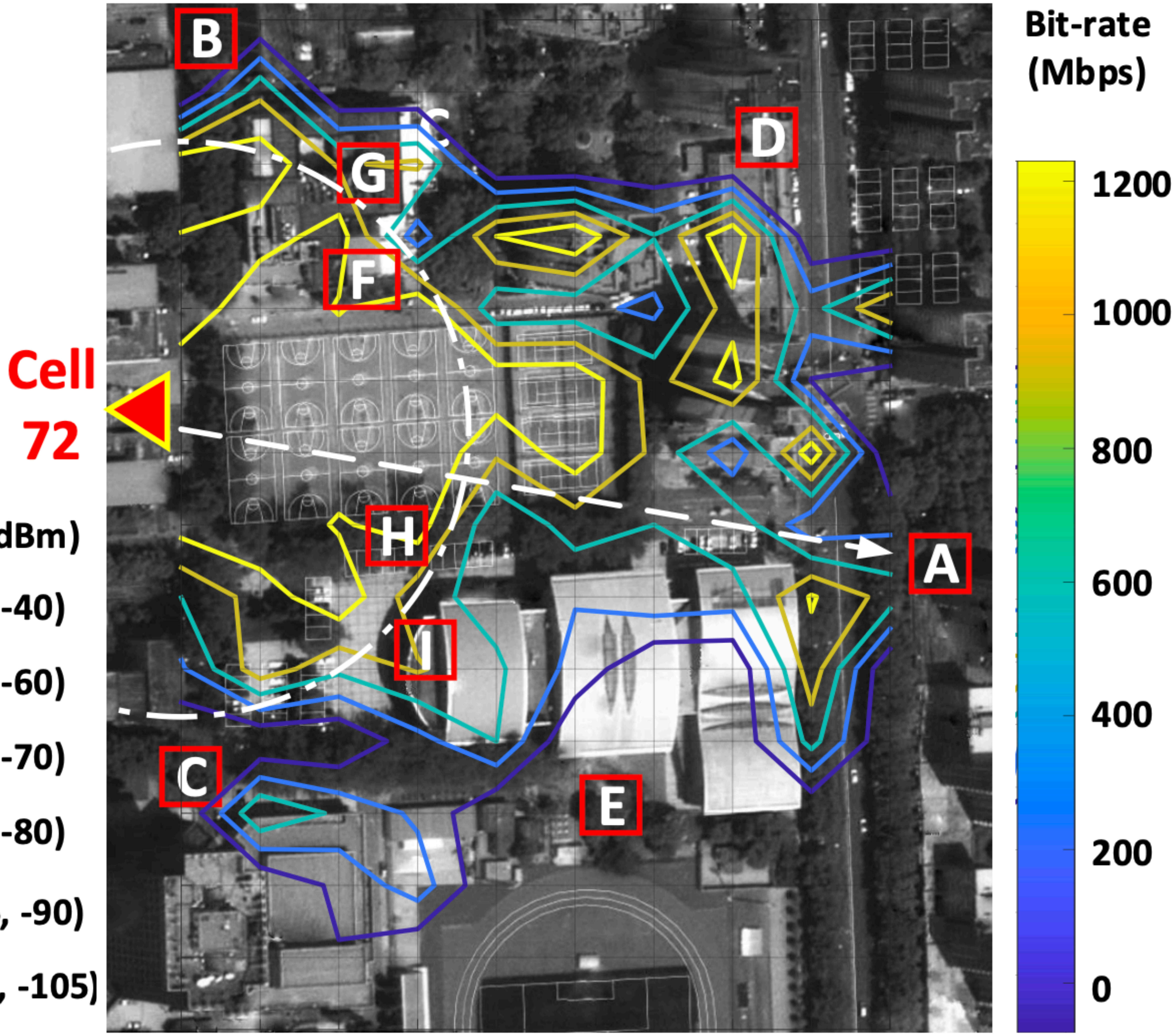
Measurement perspectives

- **Physical layer signal quality, coverage, and handover (HO)**
    - XCAL-Mobile based 5G analytics tool
- **End-to-end throughput and latency**
    - How attrition factors affect in practice
- **Quality of experience (QoE) of 5G's niche applications**
    - Investigate the inter-play between communication and computing factors
- **Energy consumption on smartphones**
    - pwrStrip: energy profiling tool

5G Coverage

5G Coverage


116
114
80
79
115
74
73
72
68
69
63
65
64
62
61
60
RSRP (dBm)
[-60, -40)
[-70, -60)
[-80, -70)
[-90, -80)
[-105, -90)
[-140, -105]


Cell
72
B
G
F
D
H
A
I
C
E
Bit-rate
(Mbps)
1200
1000
800
600
400
200
0

5G Coverage

Cell coverage

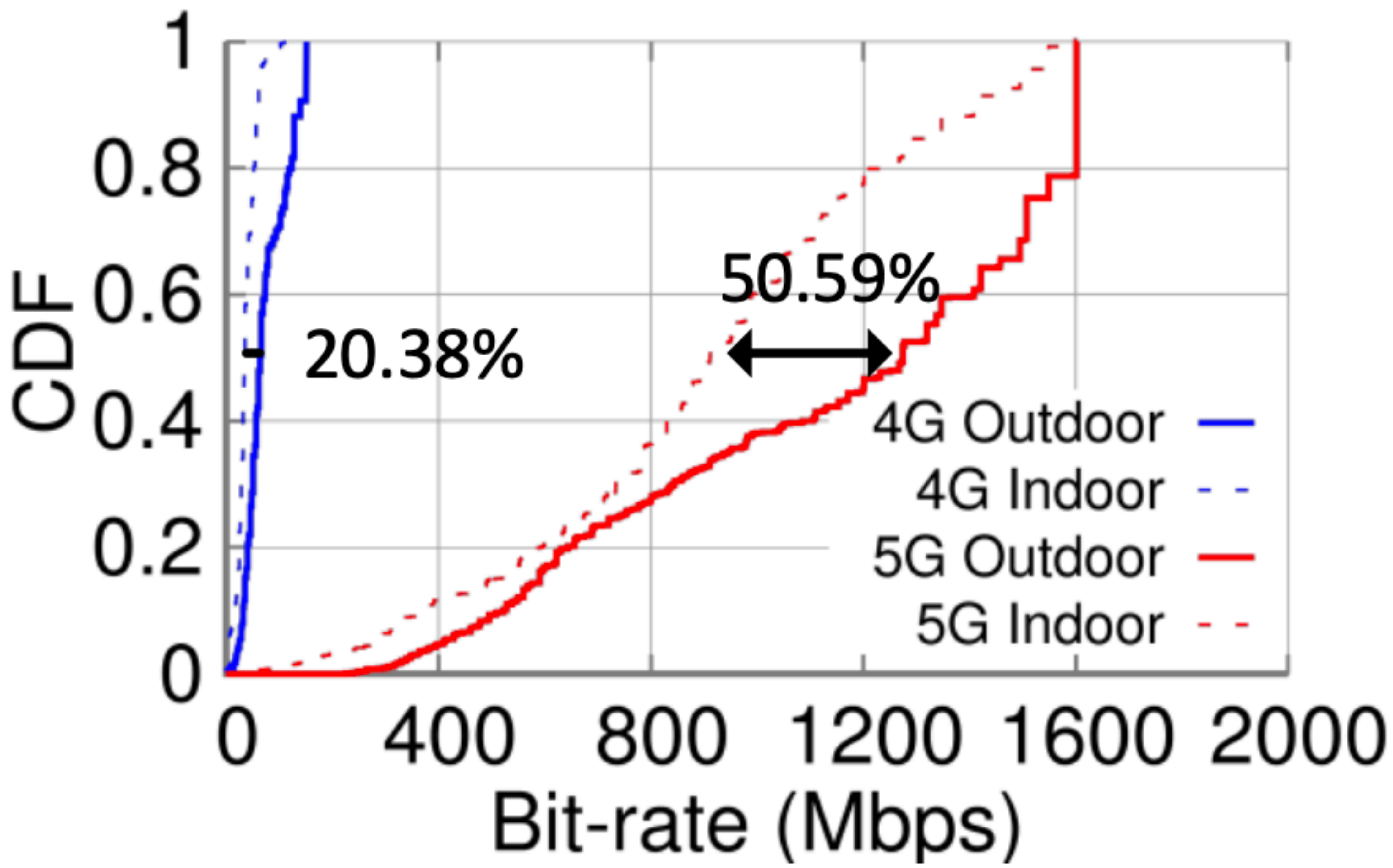
- Since **building blockage** and **multi-path reflections**, the contour lines obviously deviate from the ideal sector shape.
- Walk along a line-of-signal (LoS) path and finds that **coverage radius of one gNB is approximate 230m**, while typical 4G link distance is at around 520m.
- The gNBs commonly use sectionalized antennas with a **fan-shaped** gain pattern, and hence a **narrow field-of-view (FoV)**.

=> A deliberate arrangement of the gNB locations may help maximize the coverage with minimum cost.

5G Coverage

Indoor-outdoor gap

- Due to the poor indoor 5G coverage
- In-outdoor bit rate



5G Coverage

Handover across cells

- Due to smaller coverage, **5G HO is expected to become more frequent**.
  - 80 minutes measurement at a walking/bicycling speed of 3 ~ 10 km/h:
    - Horizontal HO (5G-5G)：387
    - Vertical HO (4G-5G, 5G-4G)：20

5G Coverage

Handover across cells - HO latency

- HO latency：
  - **5G-5G: 108.40 ms**
  - 4G-4G: 30.10 ms
  - 4G-5G: 80.23 ms

=> Root cause：**NSA** architecture

=> Long latency can be resolved in the future 5G SA architecture.

End-to-End Throughput and Delay

End-to-End Throughput and Delay

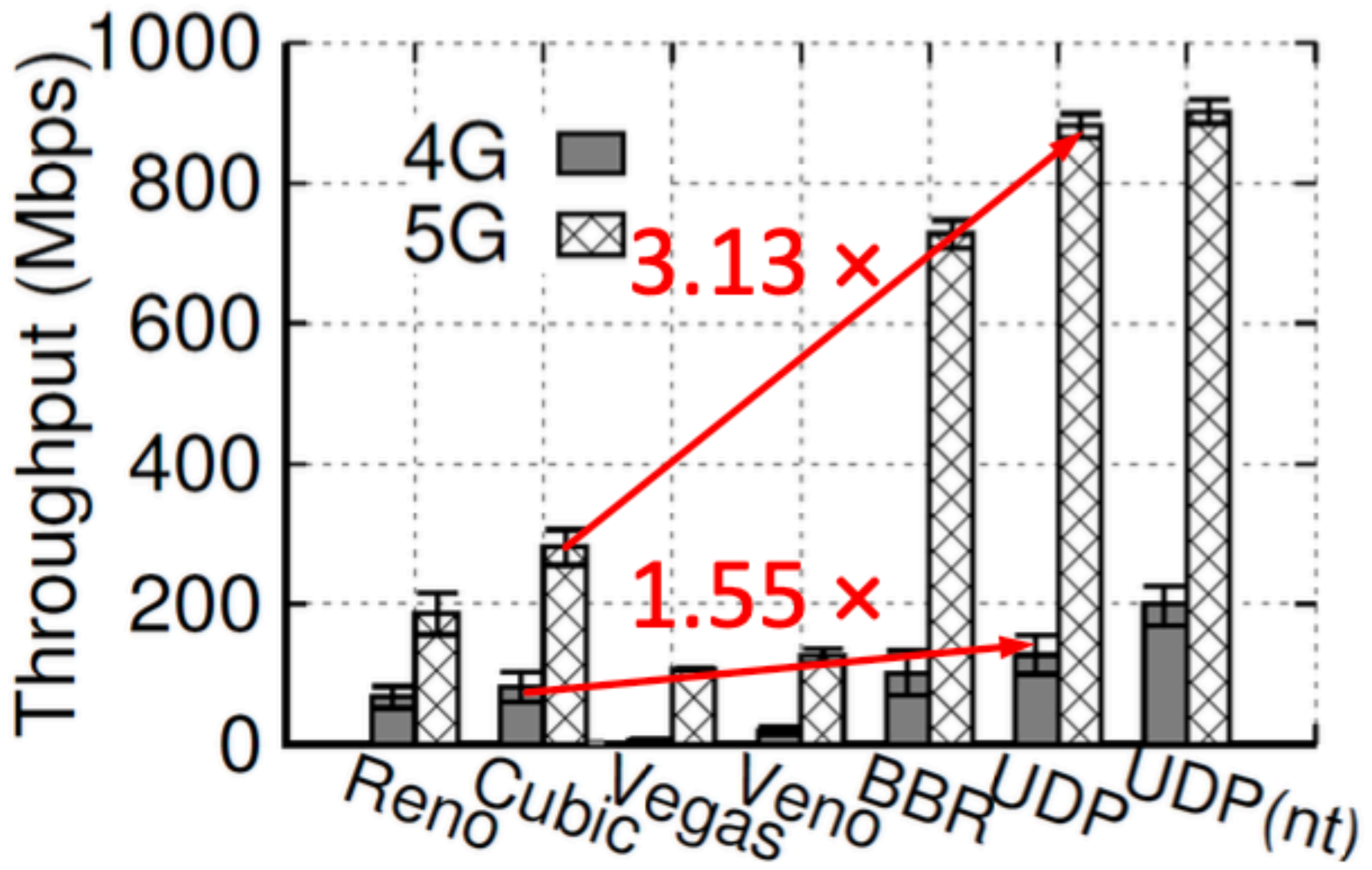
Transport layer throughput - UDP throughput baseline

- Gradually increase the UDP sending rate, and use the **peak UDP throughput** measured at the receiver side as the baseline.
- During the **late-night**, the **5G DL increases slightly** while that of 4G DL increases dramatically.
  - Limited number of 5G users, so there's a small day-night variation.

End-to-End Throughput and Delay

Transport layer throughput - TCP throughput anomaly

- UDP and TCP throughputs
  - Loss-based TCP：Reno, Cubic
  - Delayed-based TCP： Vegas, Reno



End-to-End Throughput and Delay

Locating the performance bottleneck - Packet loss in the RAN

- **Packet losses are inevitable in the RAN**.
- MAC/LLC layers usually adopt **error checking/correction**, and **retransmission** mechanism.
- All retransmissions eventually succeed far below the re-transmission threshold.
- Packet loss is **irrelevant to MAC-layer resource allocation** inside the gNBs.
- Packet loss **bottleneck is not on the 5G wireless link**.

End-to-End Throughput and Delay

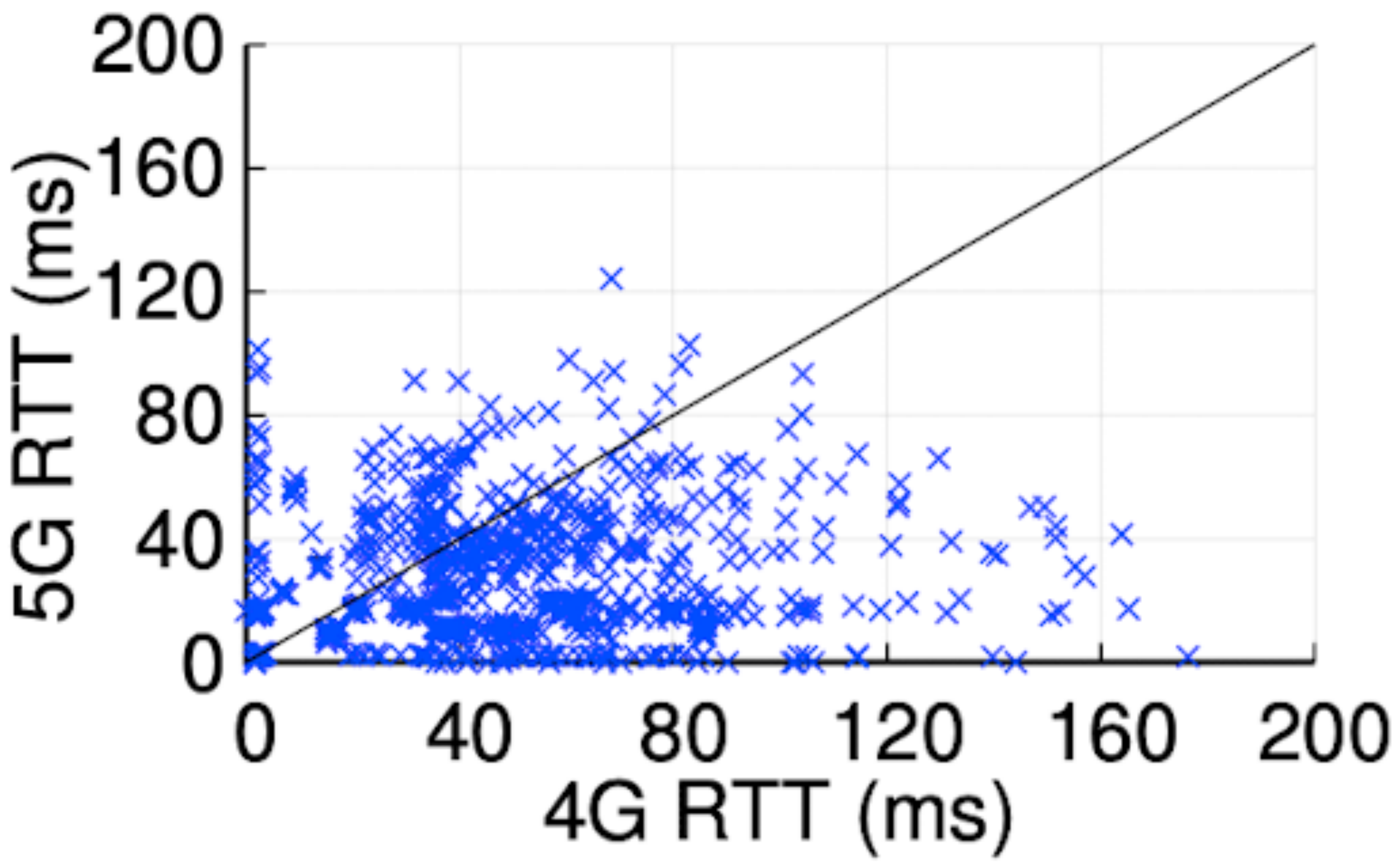
TCP throughput during handover

- 5G-4G and 5G-5G HO suffer **significant throughput degradation** in contrast to 4G-4G HO.
- Because **large HO latency** which interrupts the normal TCP transmission.
- Confirms the limitations of 5G NSA architecture again.

End-to-End Throughput and Delay

End-to-end latency - Overview

- Measure the RTTs of 80 random paths crossing the 4G and 5G network.
    - 5G network paths achieve a network latency of 21.8ms on average
    - 5G paths still **reduce RTT** by 22.3ms (31.86%) on average, compared to 4G.



End-to-End Throughput and Delay

End-to-end latency - Delay vs. path length

- Re-arrange the RTTs according to the geographical distance of each path.
  - The **RTTs of both 4G and 5G increase with path length**.
  - The **ratio** between the **gap** and the **absolute RTT value becomes smaller** as path distance increases.

=> Wireline networks also need to be retrofitted.

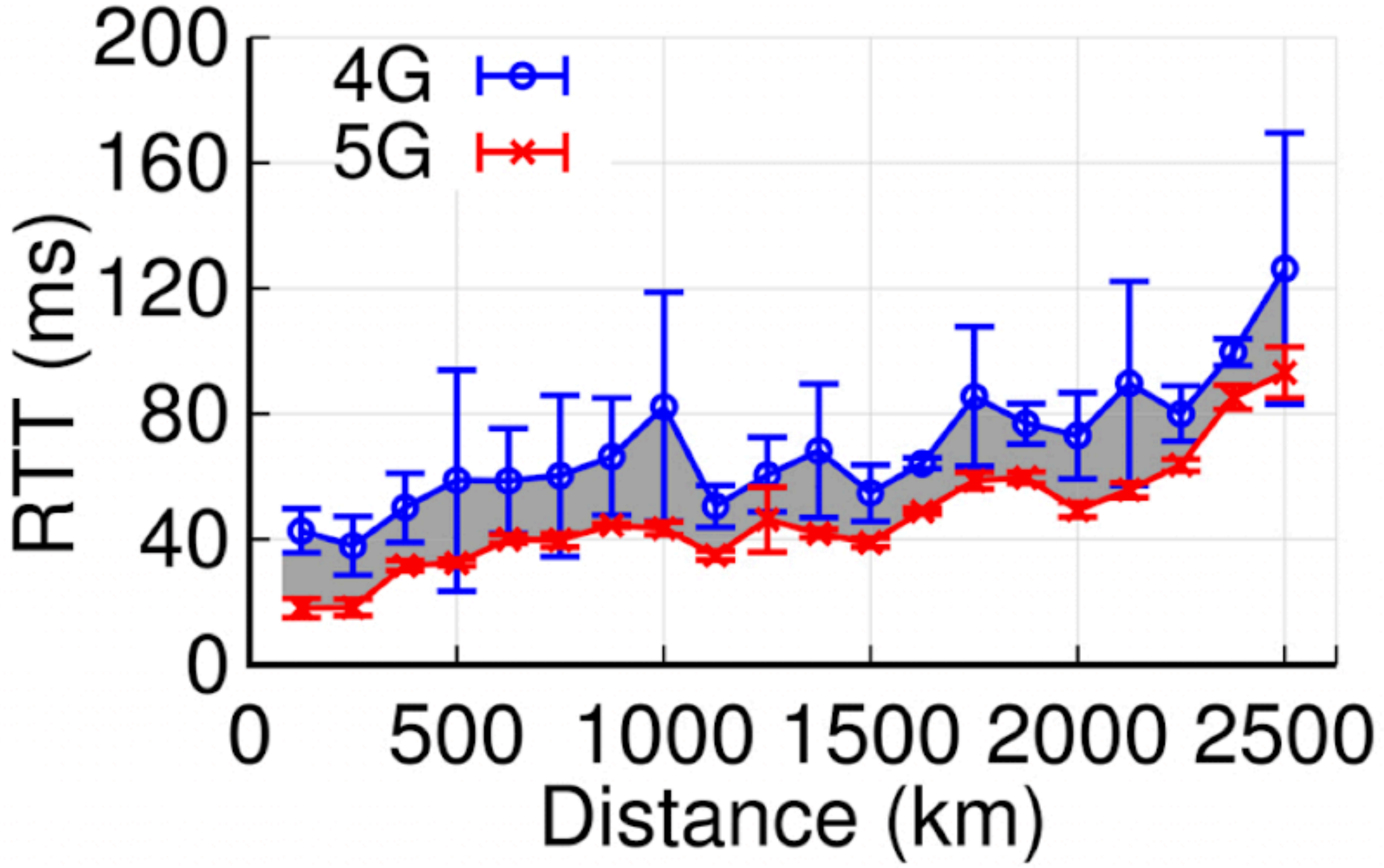


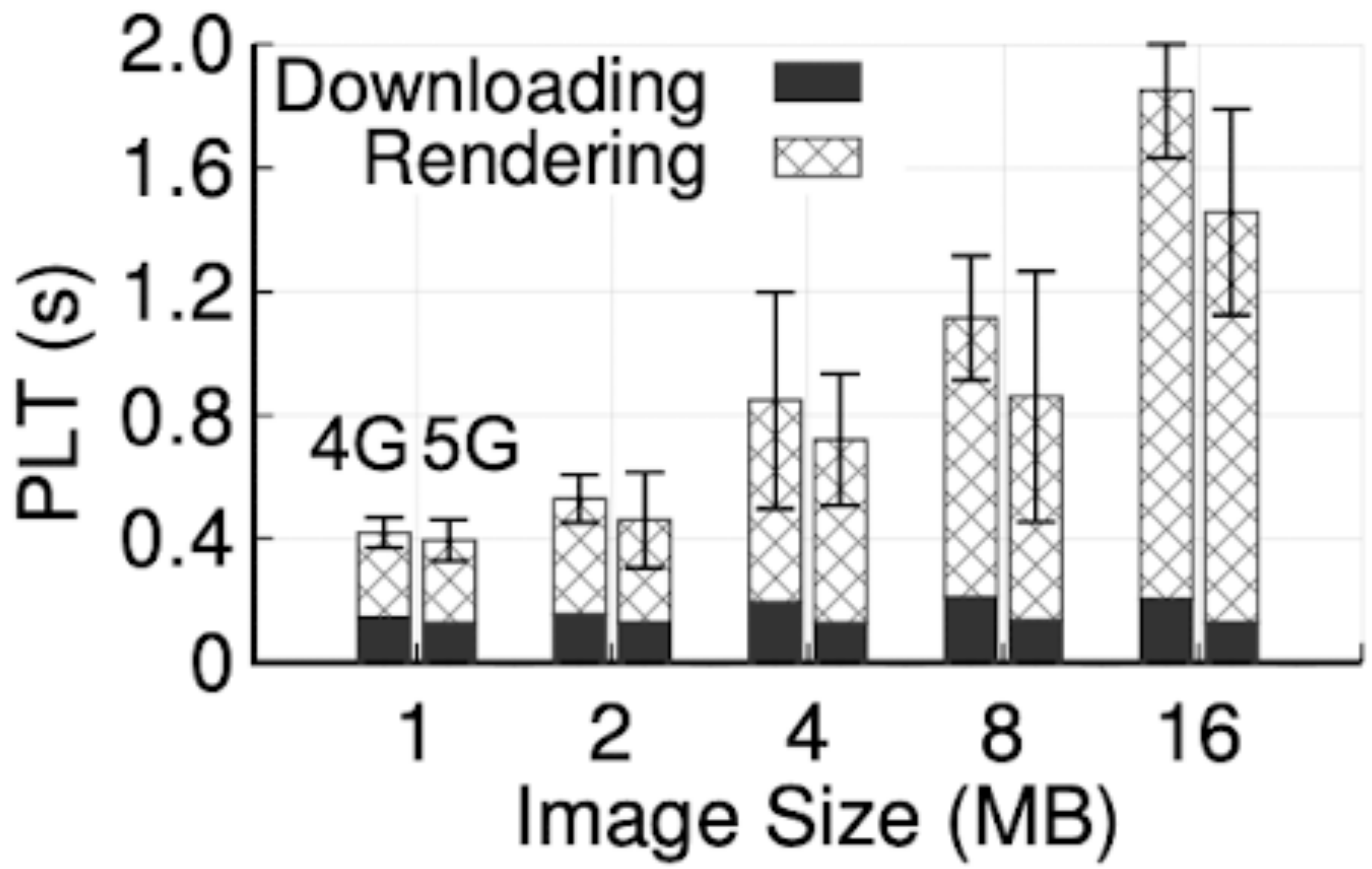
Figure 15: RTT vs. path length.

Application Performance

Application Performance

Web browsing

- **PLT：Page loading time**
- PLT of different images



Application Performance

Web browsing

- Two causes of PLT latency：
  - The **rendering** time takes a dominant fraction in PLT
  - 5G only provides a smaller reduction on average
    - Already **finished downloading before TCP converges**, which heavily underutilizes the 5G bandwidth.

Application Performance

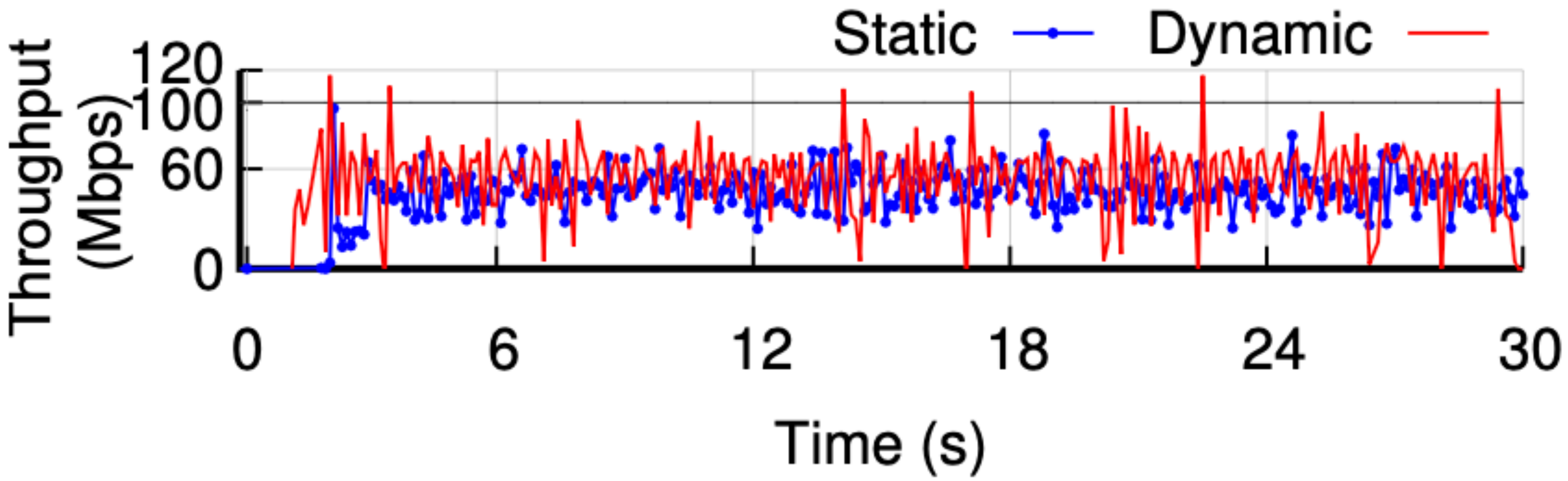
UHD Panoramic Video Telephony

- Mobile UHD panoramic video telephony poses a high demand on network capacity and stability, especially for the **uplink (UL)**.
- 4K telephony produces heavy traffic load with unpredictable **fluctuations** making it unaffordable for 4G networks.
- It is anticipated that 5G may resolve this issue.

Application Performance

UHD Panoramic Video Telephony - Tolerance on video throughput fluctuation

- Measure the UL video throughput.
  - all HD resolution videos (720P, 1080P, 4K and 5.7K) does not exceed the 5G UL capacity while 4G networks cannot support a 5.7K video.
- Despite enough bandwidth of 5G UL, the **fluctuation** of video streams may still cause **low QoE**, which escalates the video traffic and thus causes frame freezing.
- Received 5.7K video throughput fluctuation under 5G networks

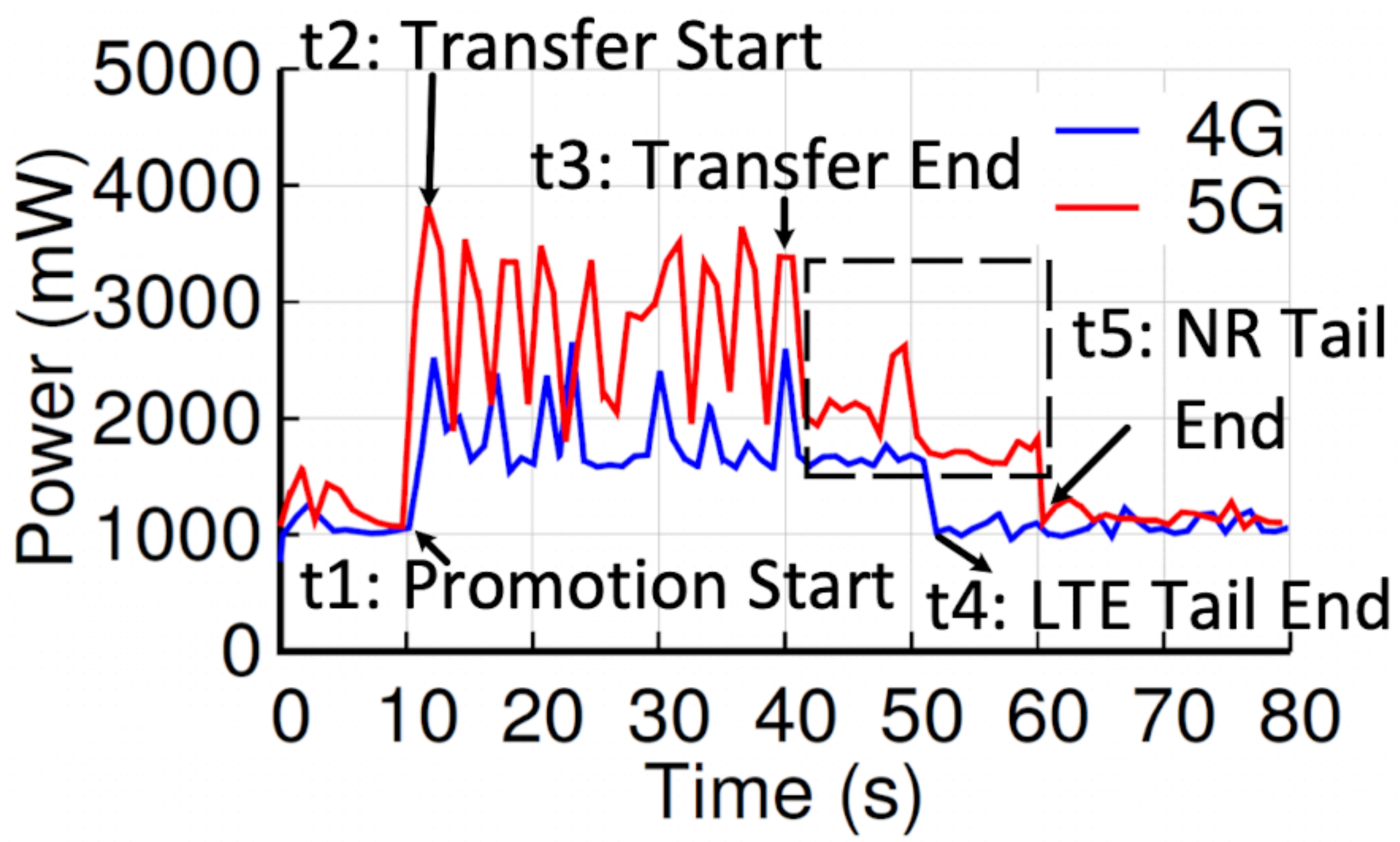


5G Smartphone Energy Consumption

5G Smartphone Energy Consumption

A Showcase of 5G energy management

- The **5G module dominates the energy cost.**
- A Showcase of 5G energy management



5G Smartphone Energy Consumption

Optimizing the 5G power management

- Adopt a **dynamic mode selection scheme**, which turns on the energy-hungry 5G module only when necessary.
- Dynamic mode switching saves a remarkable amount of energy.

Conclusion

Conclusion

- **End-to-end** measurement study spanning multiple interacting networking layers.
- **Low bandwidth utilization** can be solved through proper network resource provisioning or more intelligent protocol adaptation.
- **Long latency** and **high power consumption** need long-term co-evolution of 5G with the legacy Internet infrastructure and radio/computing hardware.

Experiments and Observations of 5G NSA Reliability and Latency Performance in Metro Train Environment

Introduction

Introduction

- Conducted measurement in the **Taipei MRT**.
- Observe the correlation between **packet loss, excessive latency**, and **HO events.**

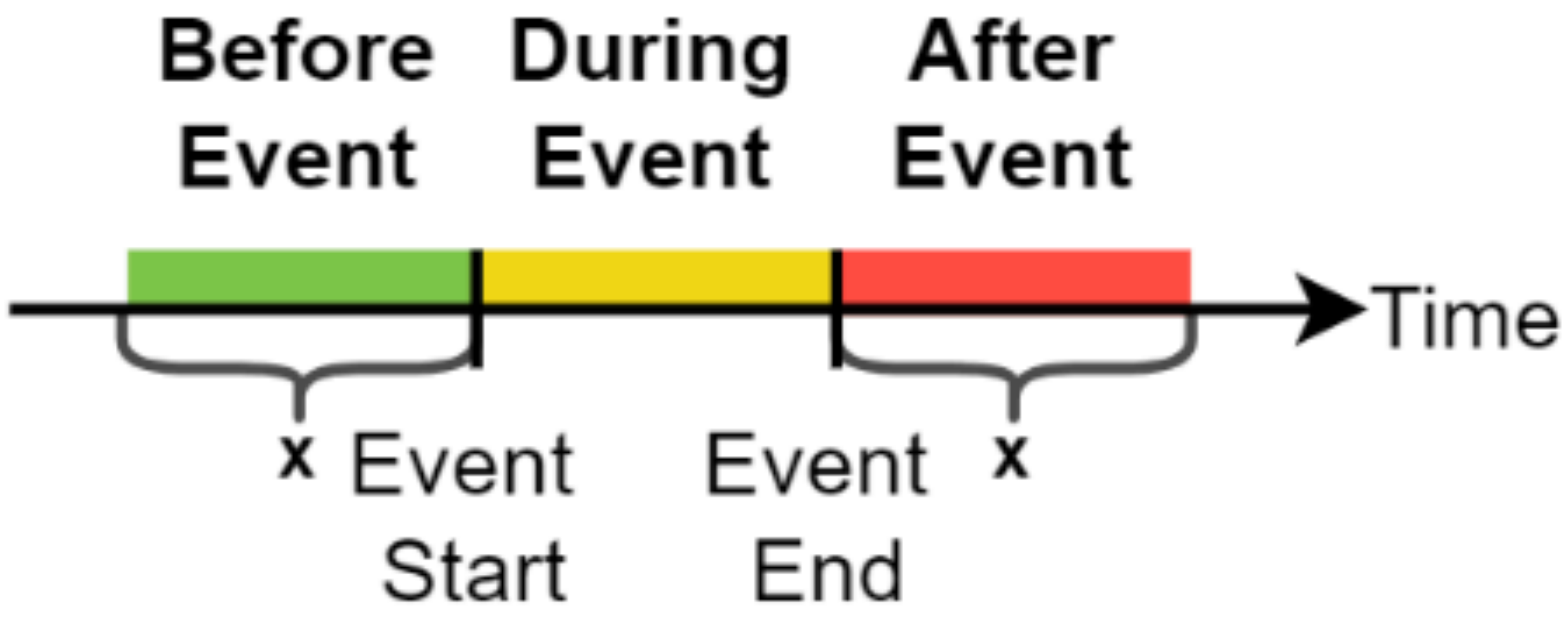
Handover Events in 5G NSA

Handover Events in 5G NSA

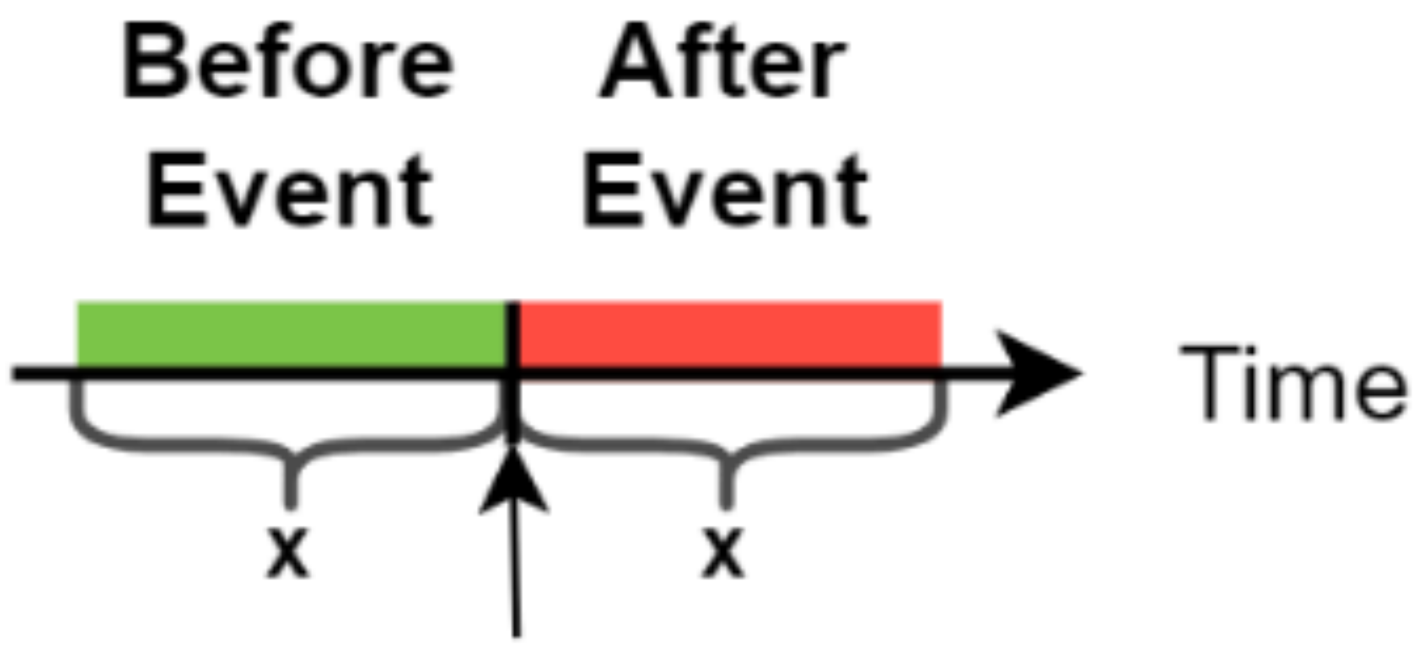
DESCRIPTION FOR DIFFERENT HANDOVER EVENT TYPES

Event type	Description
eNB handover	(eNB1) $\rightarrow$ (eNB2)
Inter-Master Node (MN) handover without Secondary Node change	(eNB1, gNB1) $\rightarrow$ (eNB2, gNB1)
Secondary Node (SN) addition	(eNB1) $\rightarrow$ (eNB1, gNB1)
Secondary Node (SN) change	(eNB1, gNB1) $\rightarrow$ (eNB1, gNB2)
Secondary Node (SN) removal	(eNB1, gNB1) $\rightarrow$ (eNB1)
Inter-Master Node (MN) handover with Secondary Node (SN) change	(eNB1, gNB1) $\rightarrow$ (eNB2, gNB2)
eNB to Master Node (MN) change	(eNB1) $\rightarrow$ (eNB2, gNB1)
Master Node (MN) to eNB change	(eNB1, gNB1) $\rightarrow$ (eNB2)

Handover Events in 5G NSA



Successful Handover Events



Handover Failure Event

Methodology

Methodology

- Route A：辛亥 - 動物園 -> 19 times
- Route B： 中原 - 十四張 -> 22 times
- UEs have both UL/DL data traffic with the server simultaneously.

Results

Results and Insights of Measurement

Locations, packet losses, and handovers

(d) Locations of uplink packet losses (red dots) and handovers (blue dots) on the route from Xinhai station to Zoo station

Results and Insights of Measurement

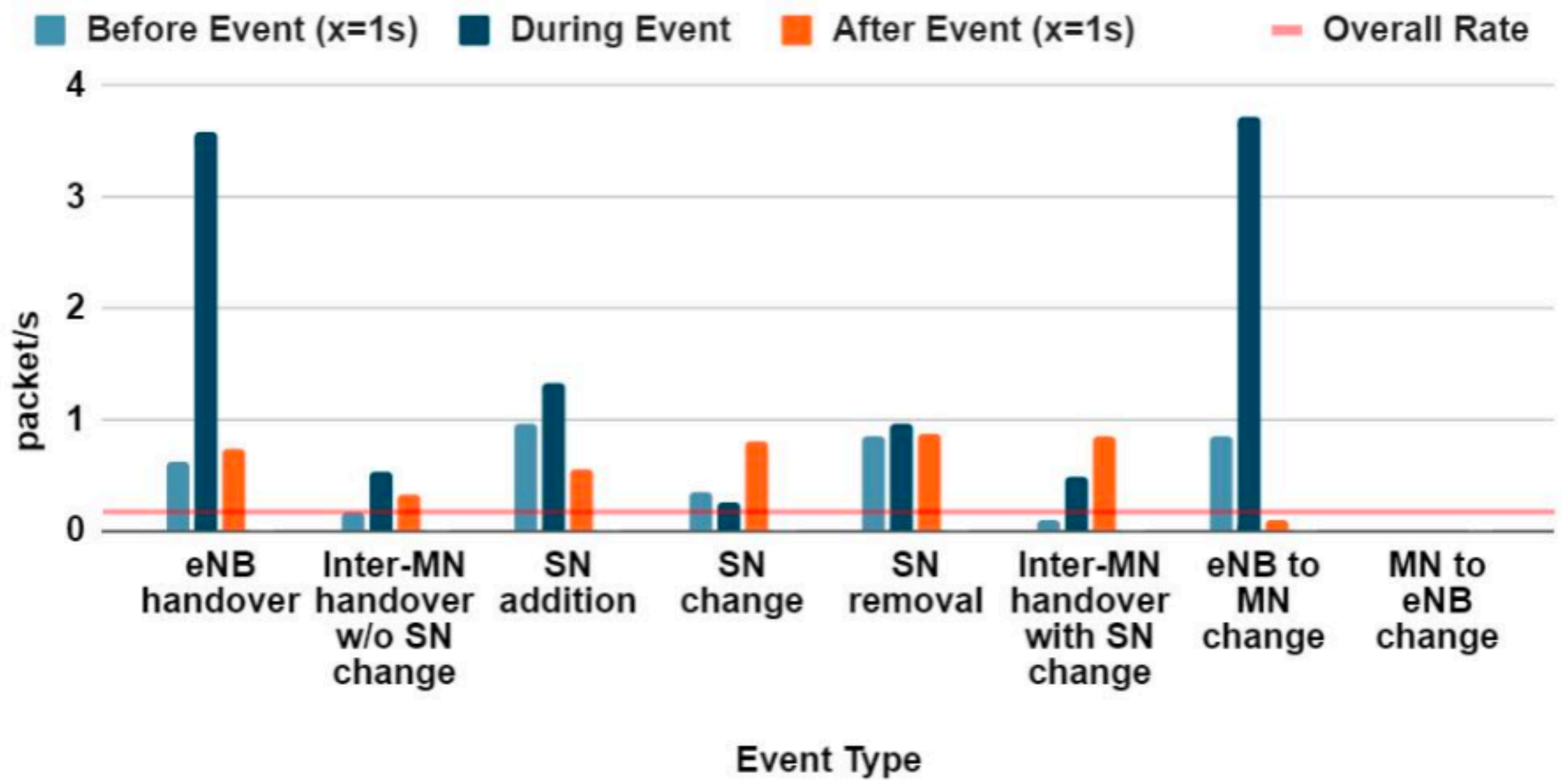
Locations, packet losses, and handovers

- Most of the dense packet loss locations are close to **MRT stations**.
- Packet loss and HO events occur at **similar places**. Many of the places that have frequent HOs are close to MRT stations.
- Packet losses in forward direction and reverse direction occur in **correlated but shifted location**.

Results and Insights of Measurement

Handovers and packet losses

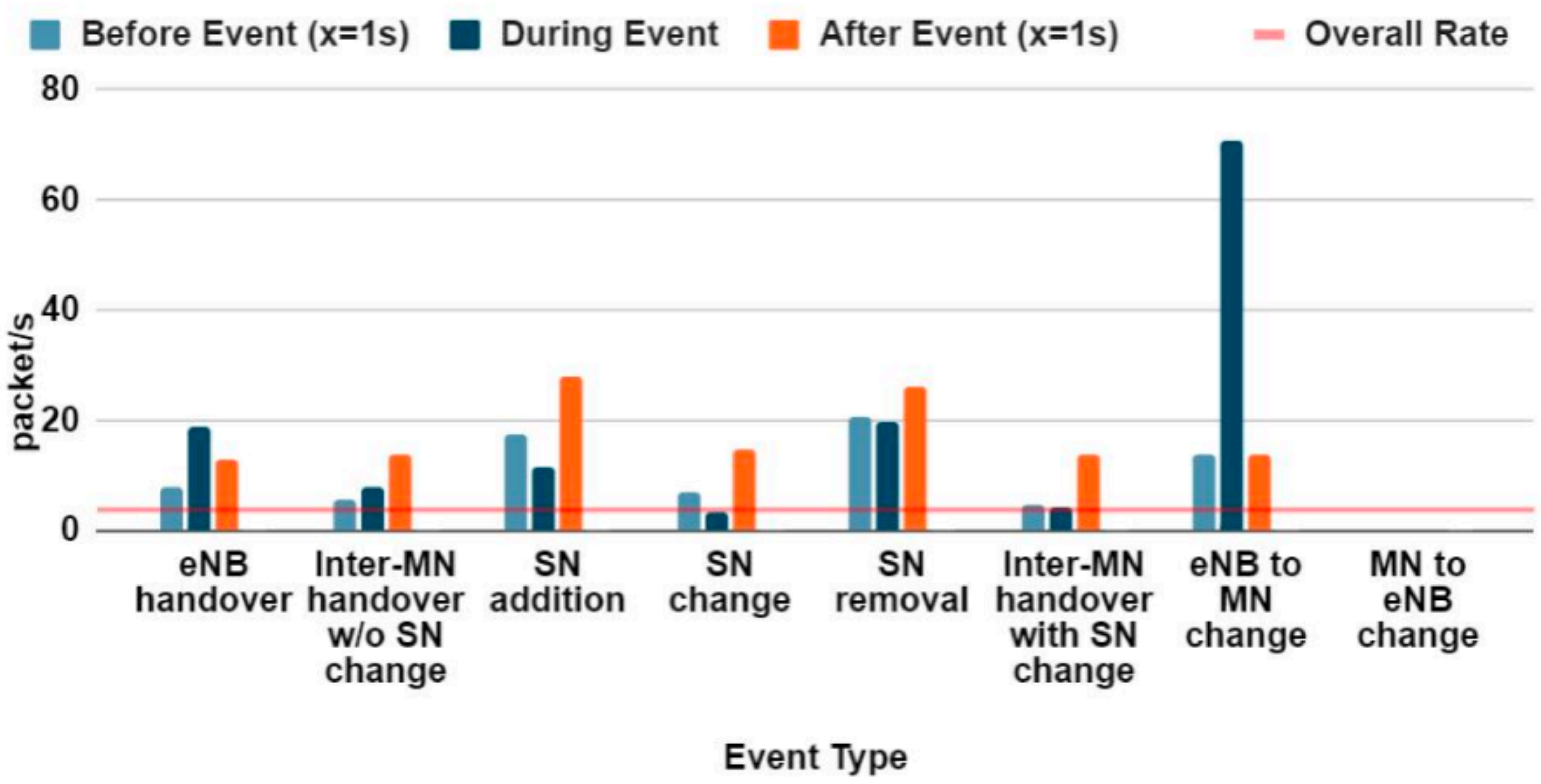
- A **strong connection between handover events and packet loss**.
  - PLRs in handover-related intervals are much higher than the overall PLR, and most packet losses are also in handover-related intervals.



Results and Insights of Measurement

Handovers and excessive latency

- **Handover events and excessive latency are highly relevant.**
  - Excessive latency rates in handover-related intervals are much higher than the overall excessive latency rates.
- There may be **other factors that can trigger excessive latency**.



Results and Insights of Measurement

Necessity of handover

- 1.3% of the handovers have a single **neighboring target cell**.
- 54.2% of the LTE handover executions can be potentially **deferred** by at least 5 seconds.
- 6.36% of the LTE handovers where the **original serving cell is still qualified** for service.

=> There are **unnecessary handovers**.

Conclusions

Conclusions

- On MRT routes, **packet loss** and **excessive latency** occur in similar locations, where **handover** usually occurs.
- **Some handovers are unnecessary** and cause additional packet losses.
- **5G handover algorithm** can still improve for better reliability.