TCP in 5G mmWave Networks: Link Level Retransmissions and MP-TCP

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Outline

- Contribution
- ns-3 simulator
- Interaction with **lower-layer retransmissions**
- **Multipath TCP** (MP-TCP):
  - The protocol
  - LTE or mmWave as secondary path?
  - Coupled or uncoupled congestion control?
- Conclusions

TCP in mmWave networks

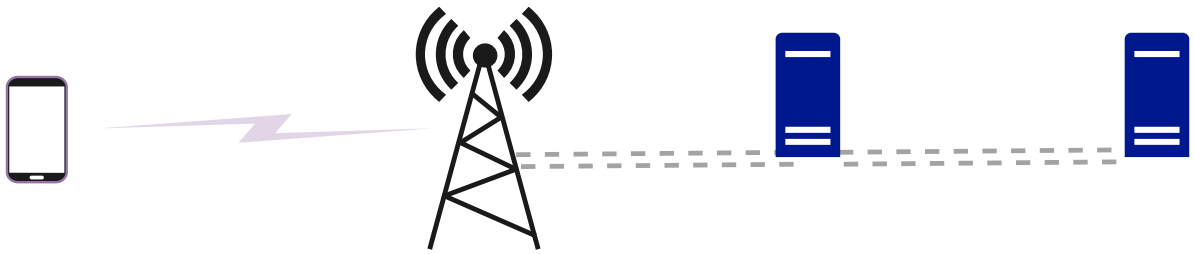
- mmWave links
  - **blockage** and **link disruption**
  - bandwidth **fluctuation** in LOS/NLOS transitions
- **TCP suffers**: suboptimal performance and waste of resources
  - Long time to recover full throughput after an outage
  - Very high RTT in NLOS + bufferbloat

[3] Zhang et al., ***Transport Layer Performance in 5G mmWave Cellular***
[4] Zhang et al., ***The Bufferbloat Problem over Intermittent Multi-Gbps mmWave Links***

Contribution

Use the **Linux kernel** TCP/IP stack and the NYU **mmWave** module to:

1. Measure how different lower-layer **retransmission** mechanisms (HARQ, RLC) impact TCP throughput and latency
2. Study the performance of **MP-TCP** on combined **mmWave** and **LTE** links

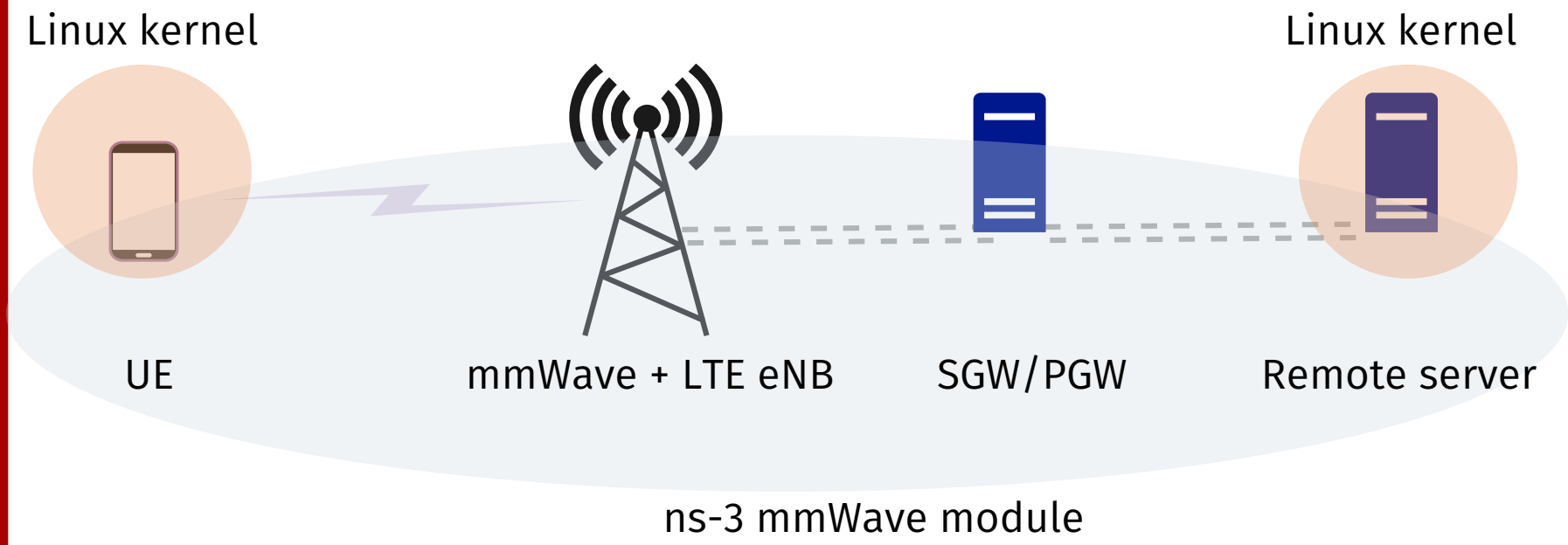


ns-3 simulator

- ns-3 NYU mmWave module
- **Dual Connectivity** extension from [5]
- Integration with **DCE**
  - It allows to connect ns-3 to the Linux TCP/IP stack
  - LibOS provides the Linux kernel (4.0) as a library
  - Use applications such as iPerf, wget

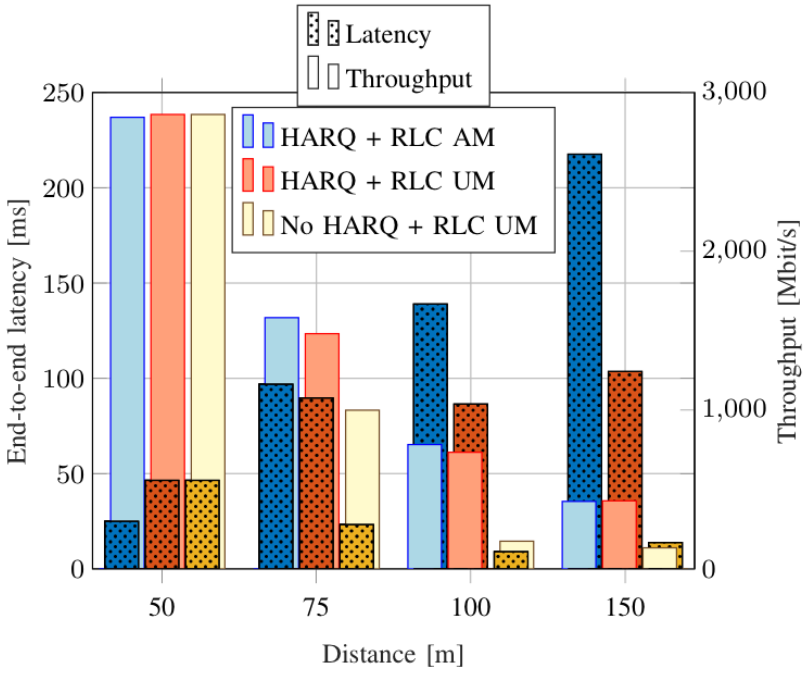
[5] Michele Polese, Marco Mezzavilla and Michele Zorzi, ***Performance Comparison of Dual Connectivity and Hard Handover for LTE-5G Tight Integration***, 2016 EAI International Conference on Simulation Tools and Techniques (SIMUTools), Prague, Czech Republic, 2016

ns-3 simulator



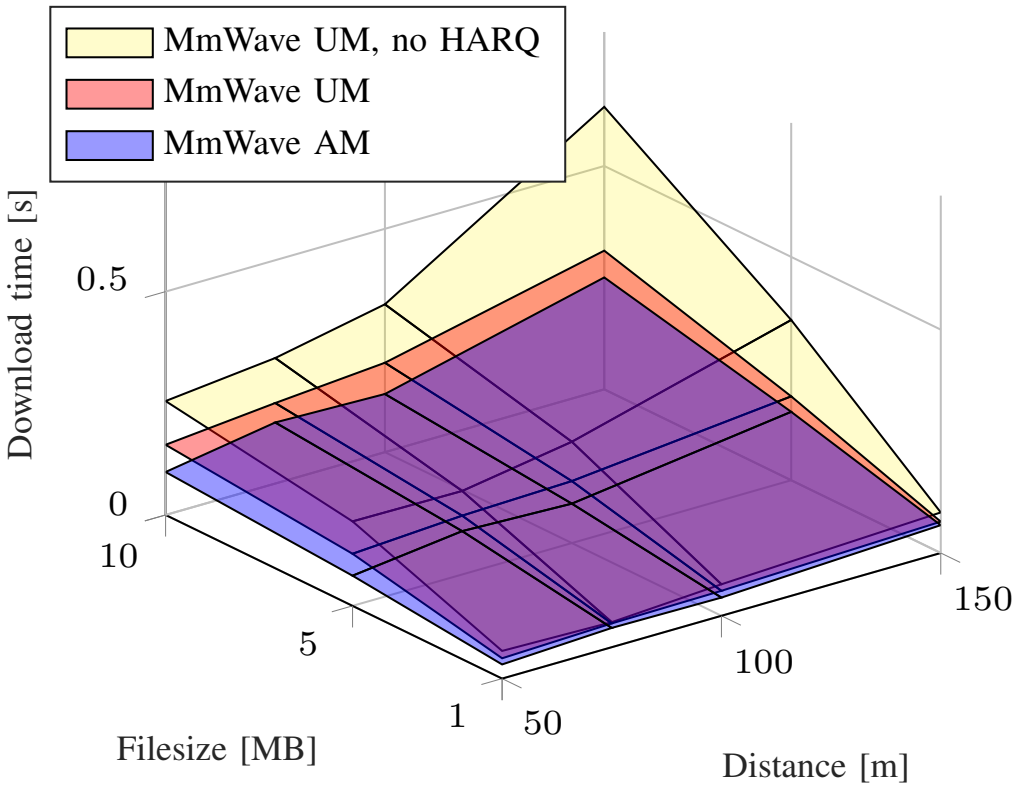
Lower-layer retransmissions

- Typical throughput-latency **trade-off**
  - MAC and RLC layer retransmission mechanisms avoid packet loss –> increase TCP throughput
  - Retransmissions -> increase latency
  - For long flows **HARQ** is the most effective retx mechanism



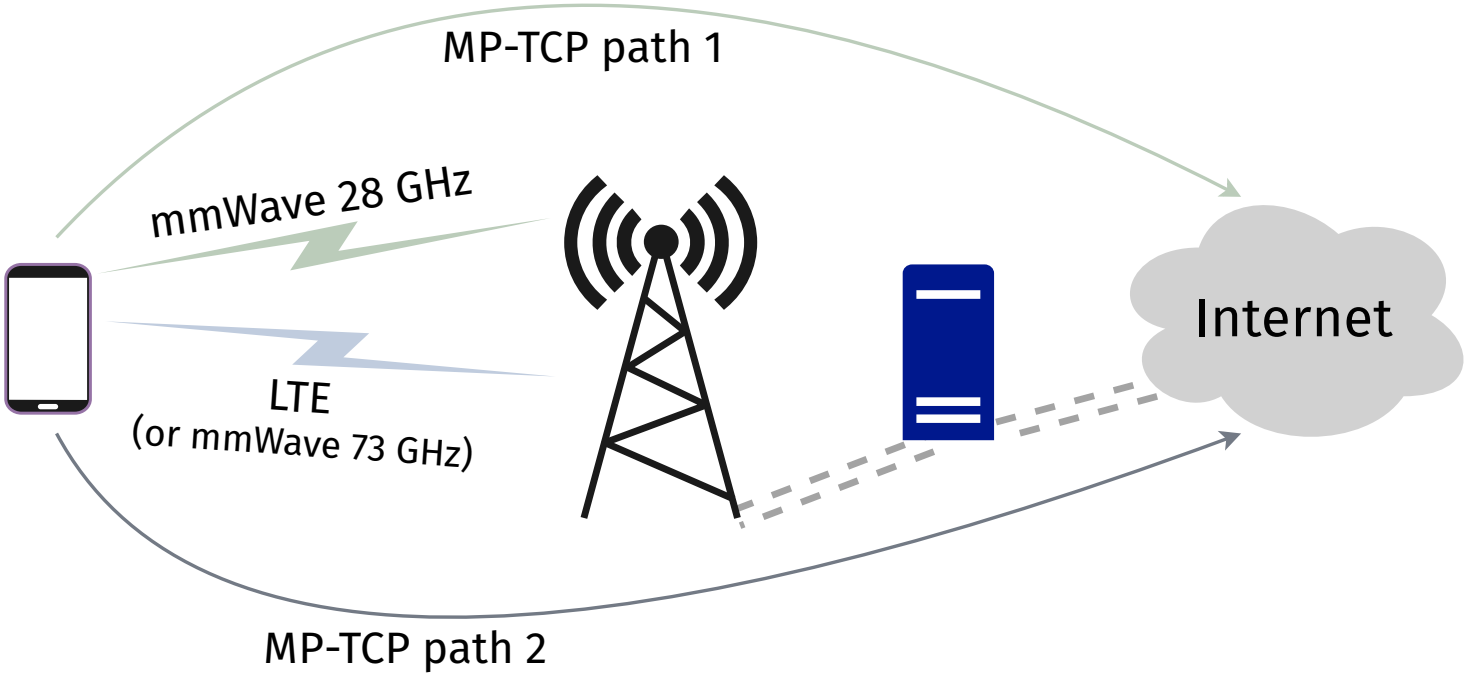
Lower-layer retransmissions

- Retransmissions help also for **short flows** (i.e., download time of a small file)



Multipath TCP (MP-TCP)

- Modern devices have **multiple network interfaces**
- MP-TCP allows seamless vertical handover
- We use it to provide ***path diversity*** in LTE + mmWave cellular networks

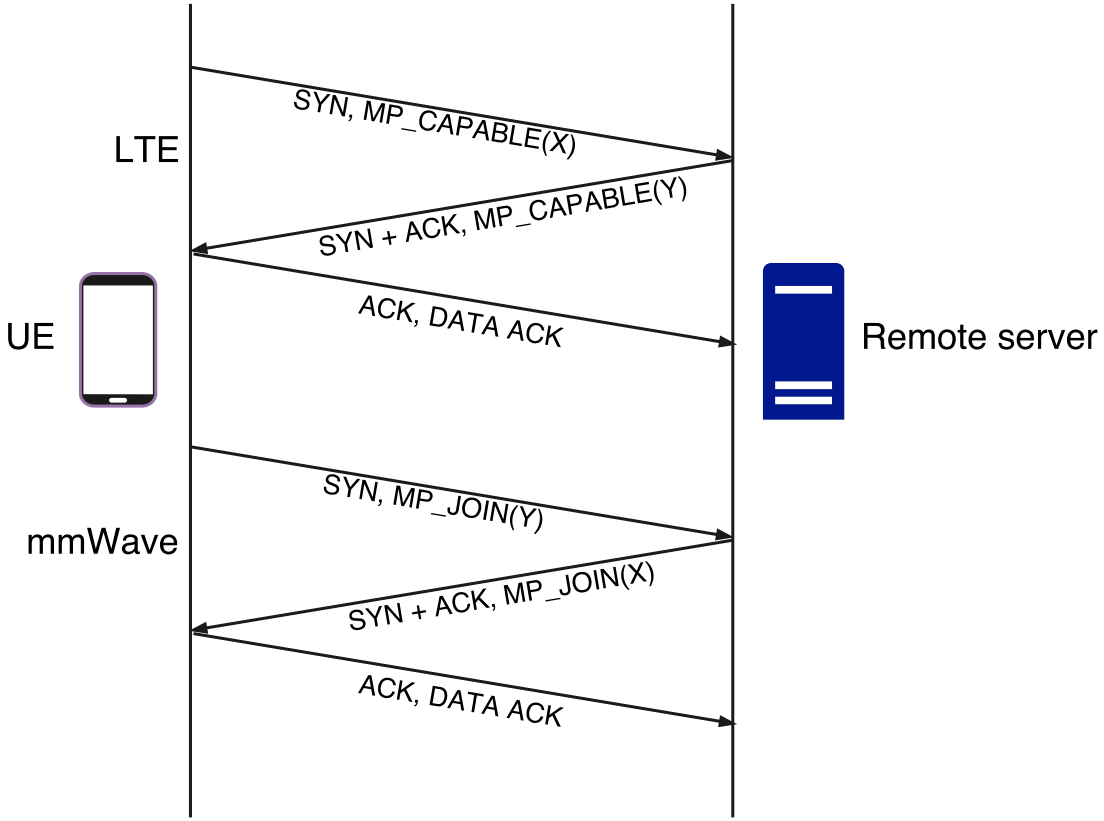


Multipath TCP design

- Design goals
  - **Improve throughput** – perform at least as well as the best single path TCP (SP-TCP) flow
  - **Be fair** – on shared links, do not get more resources that SP-TCP flows
  - **Avoid congestion** – prefer less congested paths among the available ones
- **Transparent** to the application (TCP socket)

Multipath TCP flow setup

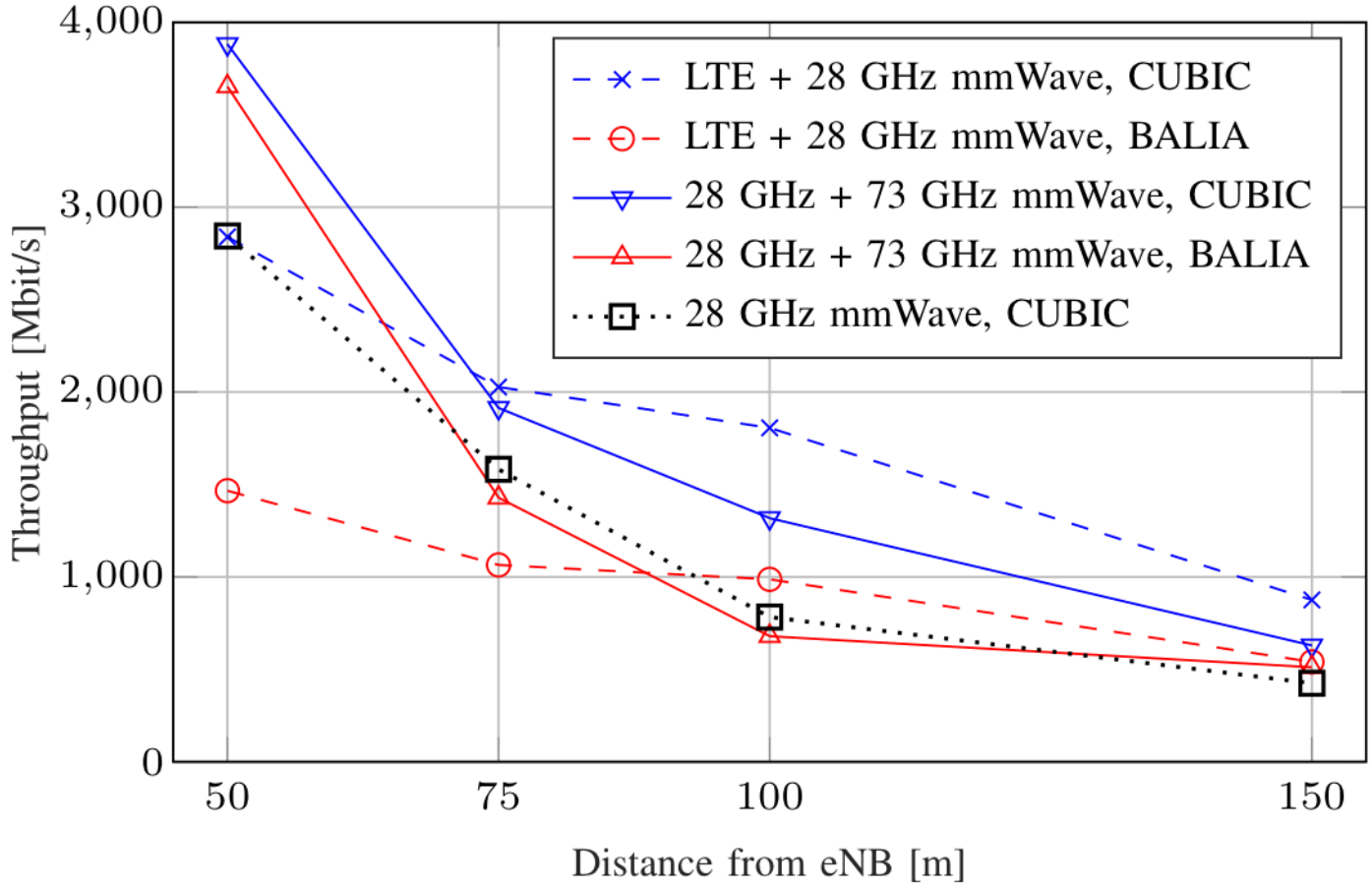
- Different IP addresses signal the presence of multiple interfaces
- An additional three-way handshake is needed because of **middleboxes**



MP-TCP congestion control

- Coupled vs uncoupled CC:
  - **Coupled** -> congestion on one flow has impact also to the other ones
  - **Uncoupled** -> each flow is independent (e.g., it can run any SP-TCP CC, like **CUBIC**)
- We will consider:
  - Uncoupled with TCP CUBIC
  - Coupled with **BALIA** – the state of the art CC algorithm for MP-TCP, but based on the design of NewReno (AIMD)

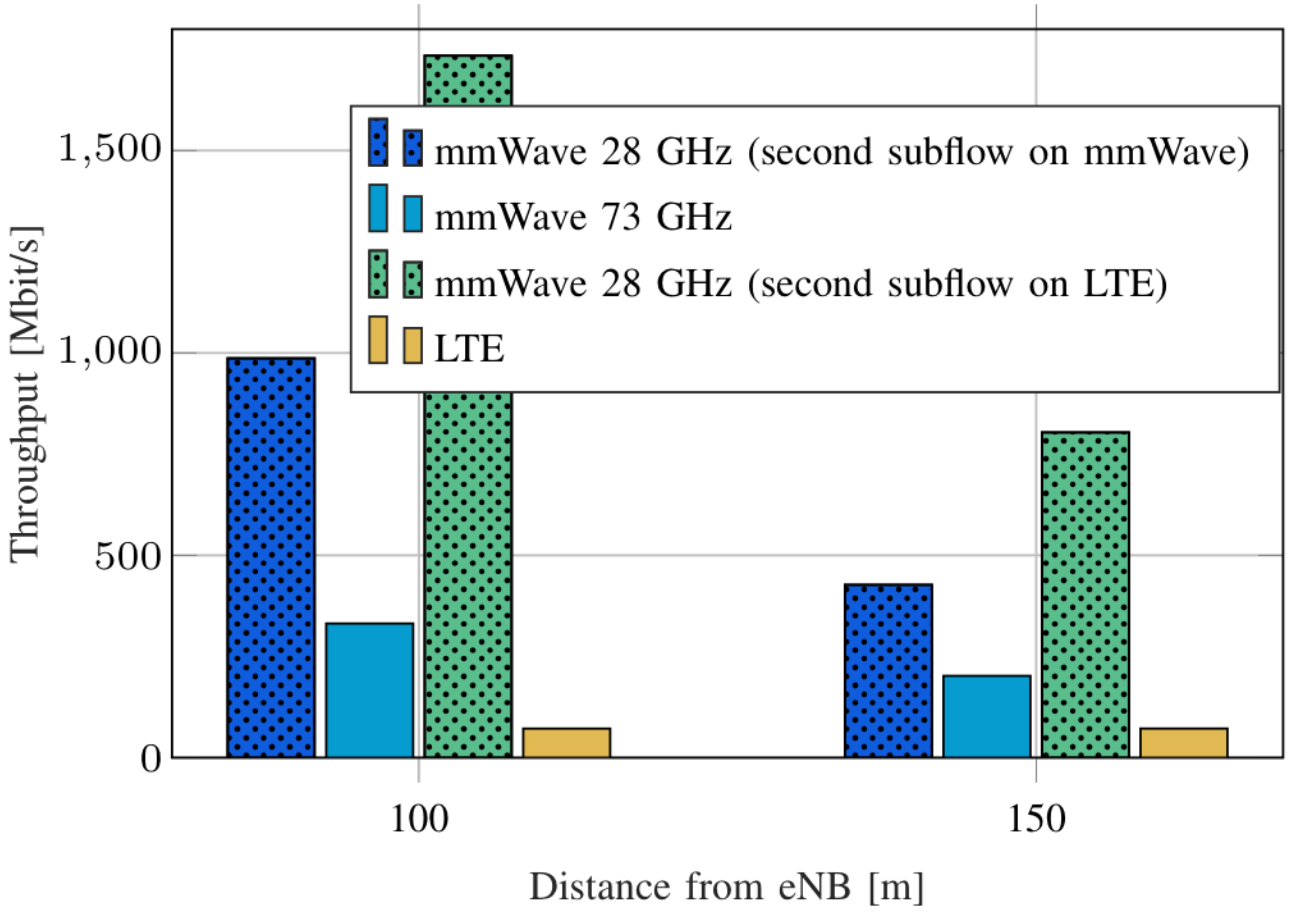
Secondary path: LTE or mmWave?



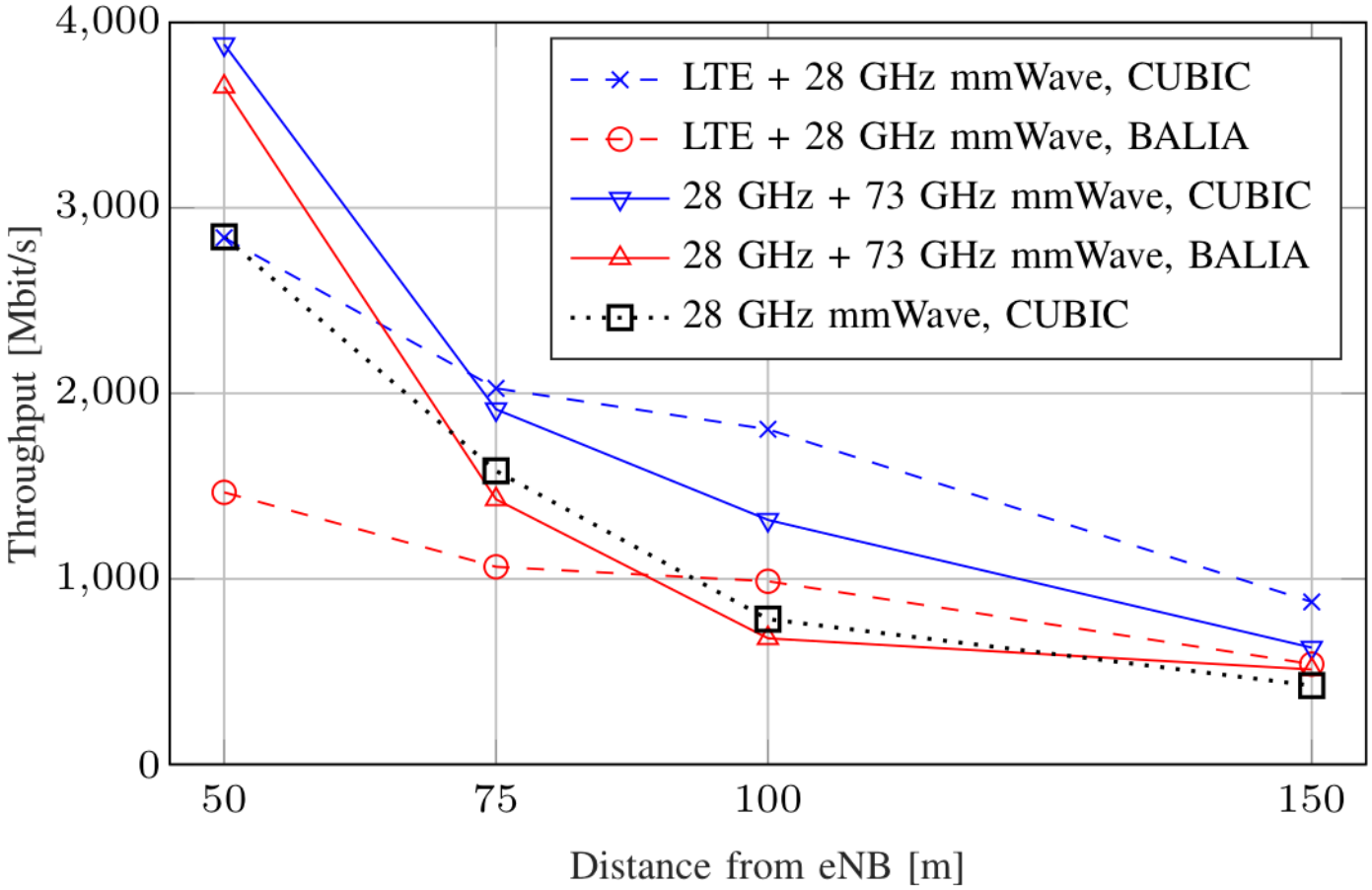
Dashed -> 28 GHz mmWave + LTE
Solid -> 28 GHz mmWave + 73 GHz mmWave
Dotted -> 28 GHz mmWave single path

Secondary path: LTE or mmWave?

Contribution of the two paths to the total throughput

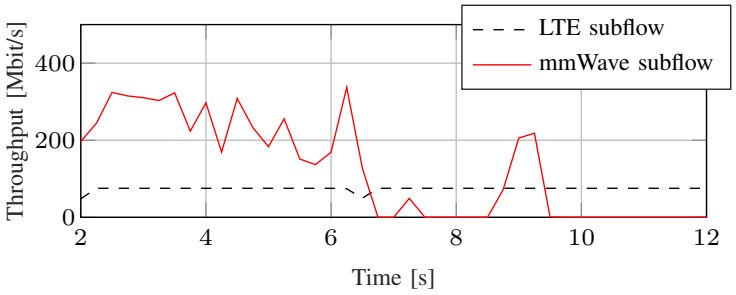


CC: coupled or uncoupled?

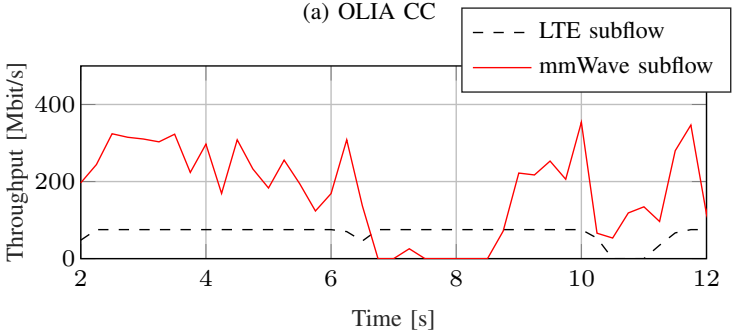


Blue -> CUBIC uncoupled CC
Red -> BALIA coupled CC
Black -> SP-TCP (CUBIC)

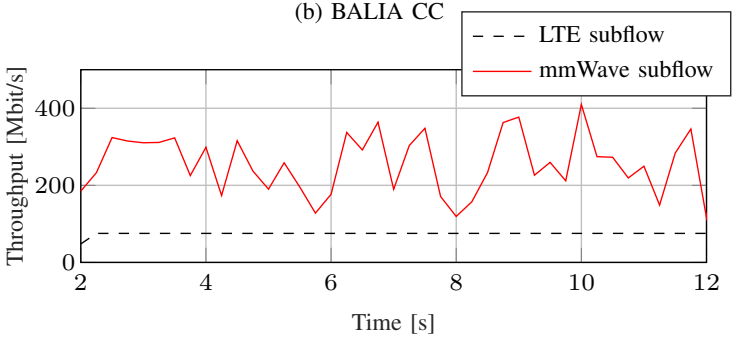
CC: coupled or uncoupled?



(a) OLIA CC



(b) BALIA CC



(c) CUBIC uncoupled CC

- Evolution of the two paths over time, d = 150 m
- t = 7 s -> OLIA and BALIA steer all the traffic to the LTE link (already saturated)
- Similar behavior observed in [6] in a wired network

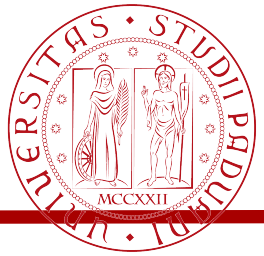
[6] Peng et al., ***Multipath TCP: Analysis, Design and Implementation***

MP-TCP takeaways

1. At large distance, **LTE** is better than mmWave as secondary flow
   - TCP performance is boosted by a **stable** LTE link
2. The currently available **CC algorithms** do not respect MP-TCP design goals
   - Uncoupled **harms** SP-TCP flows on shared bottlenecks
   - BALIA coupled has **smaller throughput** than SP-TCP in some cases

Conclusions

- Realistic simulations with **Linux TCP/IP** stack
- Lower-layer retransmissions increase **throughput** – and **latency**
- **MP-TCP** could provide end-to-end **path** diversity but the current **CC** algorithms are **not suited** for mmWave links



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