X-TCP: a Cross Layer Approach for TCP Uplink Flows in mmWave Networks

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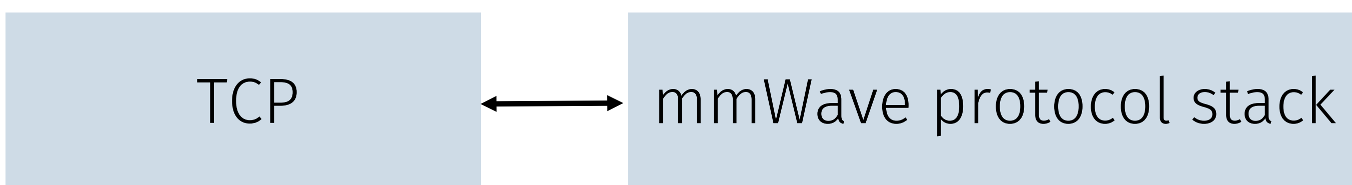
Outline

- Introduction
- TCP and TCP for mmWave
- Proposal: cross layer approach
- Performance evaluation
  - Random scenario
  - Outage scenario
- Conclusions

Introduction

- TCP is one of the most used transport protocols
- mmWave links will be probably used in next generation cellular networks

The end-to-end performance depends on the interaction between different layers

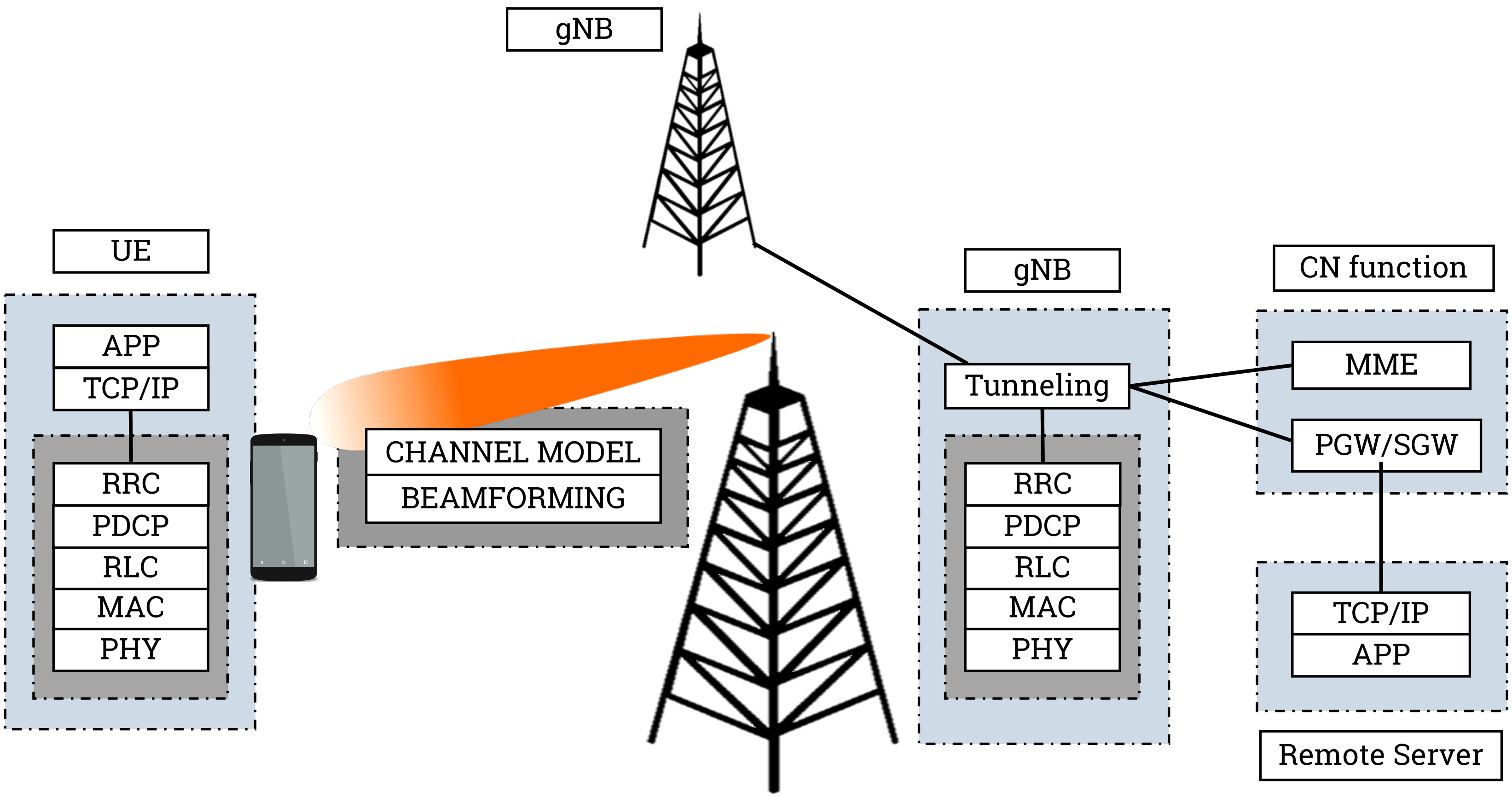


TCP issues in mmWave

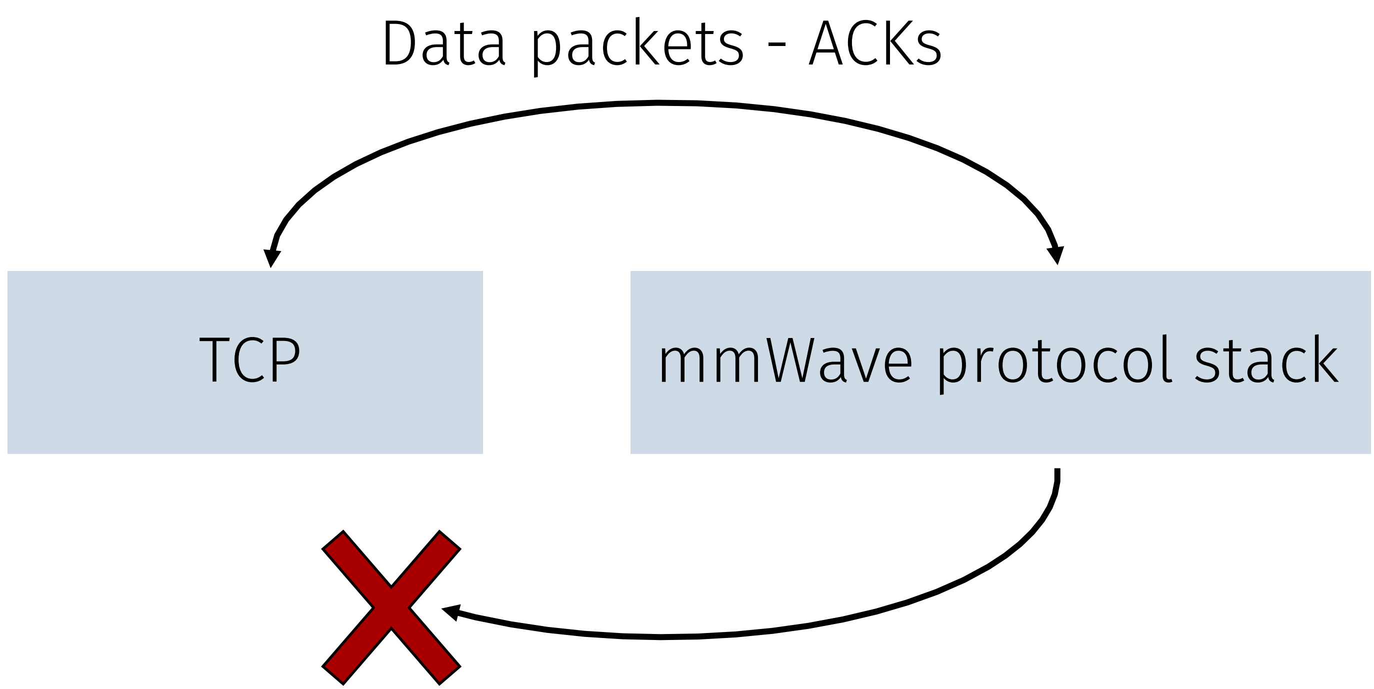
- mmWave links
  - **blockage** and **link disruption**
  - bandwidth **fluctuation** in LOS/NLOS transitions
- **TCP suffers**: suboptimal performance and waste of resources
  - Long time to recover full throughput after an outage
  - Very high RTT in NLOS + bufferbloat

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

mmWave network

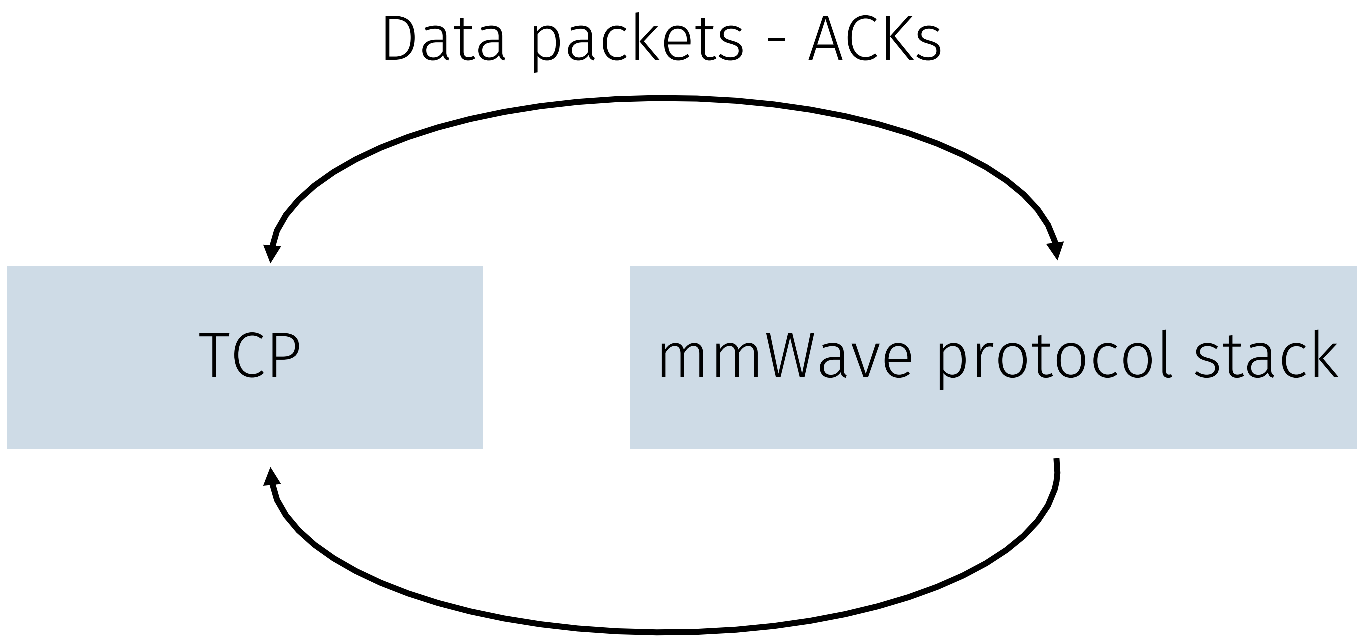


Traditional approach



TCP can only infer the state of the mmWave link from "information" in ACKs

Cross layer approach



TCP directly knows the state of the mmWave link

- Direct knowledge is feasible only for local links
- Uplink approach

Information needed

- Assumption
  - **3GPP-like** protocol stack (PHY, MAC, RLC, PDCP)
  - TDD physical layer
- Transport block size at MAC layer + slot duration
  - Scaled to account for higher layer headers

➡ Estimation of available data rate $\hat{e}_{\mathrm{datarate}}$

- Round trip time (with ACK timestamps) $\hat{e}_{\mathrm{rtt}}$
  - Consider minimum RTT in an interval rtt_{min}
  - Avoid adding buffering delays

Algorithm

Algorithm 1 Cross layer congestion window update

initialization
$rtt_{\text{min}} \leftarrow \infty$
cwnd $\leftarrow$ Maximum Segment Size (MSS)

for every received ACK
  estimate RTT $\hat{e}_{\text{rtt}}$
  from the mmWave stack:
    estimate mmWave data rate $\hat{e}_{\text{datarate}}$
    get SINR value Γ
  if $\hat{e}_{\text{rtt}} < rtt_{\text{min}}$
    $rtt_{\text{min}} \leftarrow \hat{e}_{\text{rtt}}$

  if $\Gamma \geq 0$ and $\hat{e}_{\text{rtt}} \leq rtt_{\text{min}} + \epsilon$
    cwnd$\leftarrow \hat{e}_{\text{datarate}}\, rtt_{\text{min}}$
  else
    cwnd$\leftarrow \lambda\, \hat{e}_{\text{datarate}}\, rtt_{\text{min}}$

Considerations

- Retransmissions at MAC and RLC layers may occupy the transport block
- There may be congestion in other links

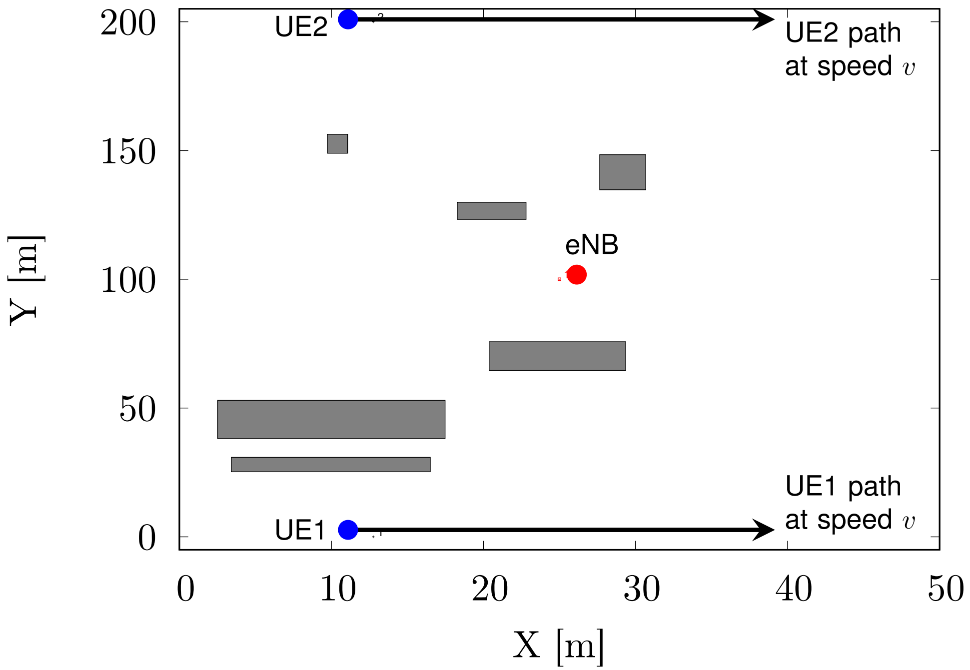
→ Apply scaling factor λ if

- SINR below threshold
- Estimated RTT >> $rtt_{\min}$

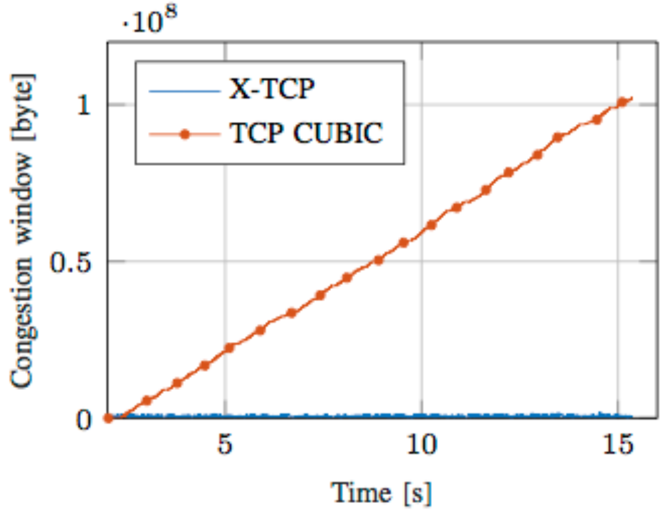
- Empirical value
  - Scenario-based optimization left for future work

Random scenario

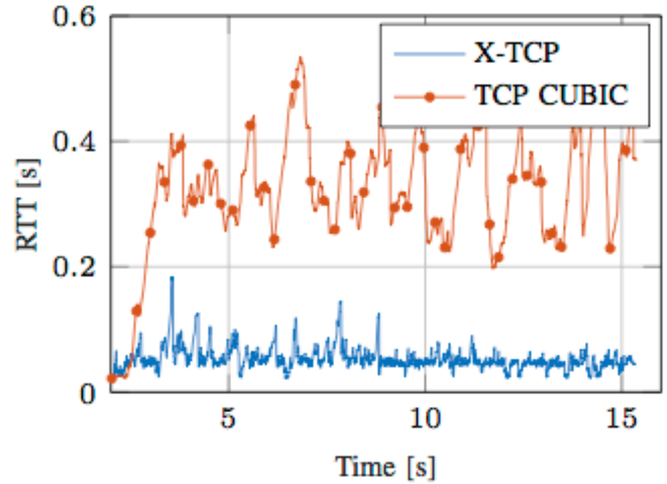
- ns-3-based simulation
- End-to-end detailed protocol stack
- NYU statistical channel model
- Randomly generated obstacles



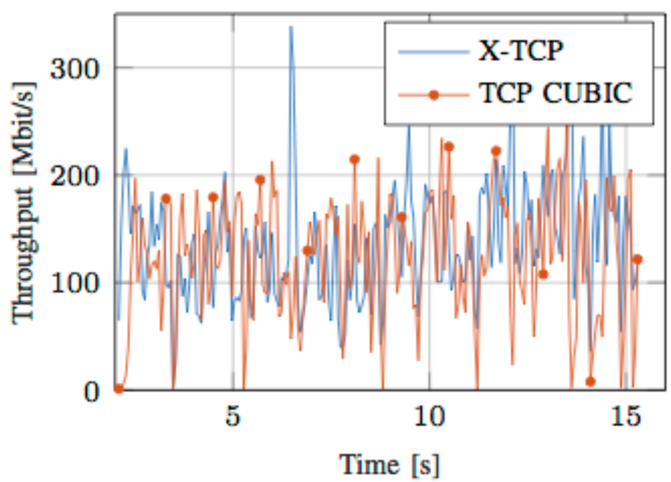
Example in NLOS



(a) Window

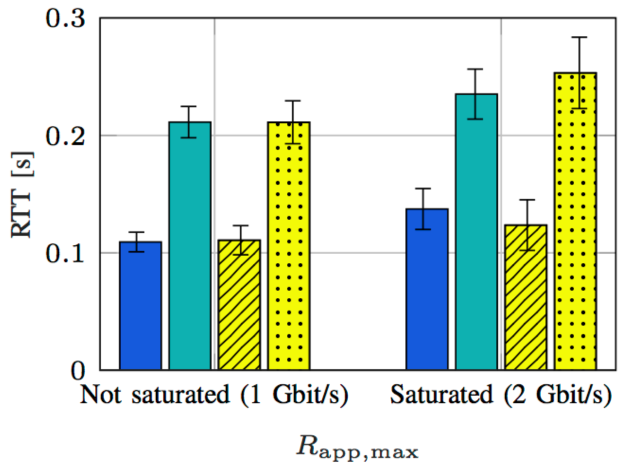


(b) RTT

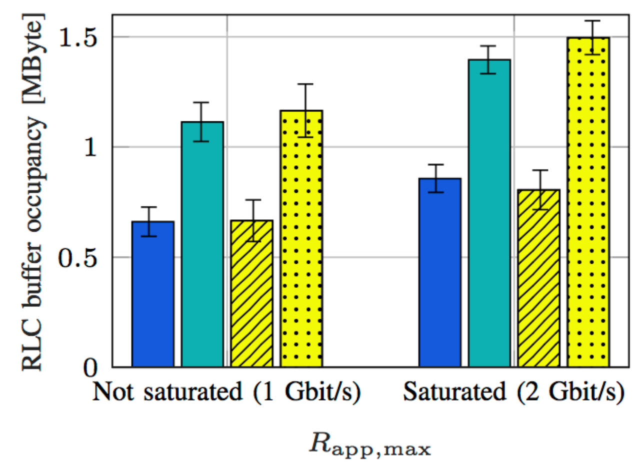


(c) Throughput

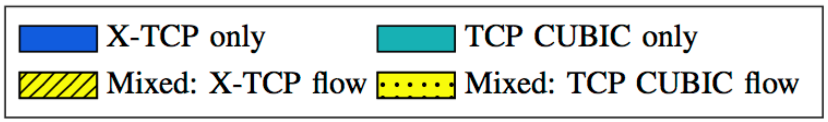
Average results

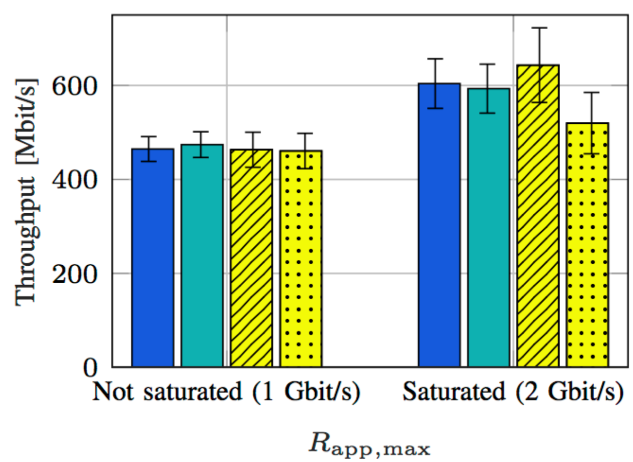


(a) Average RTT



(b) RLC buffer occupancy

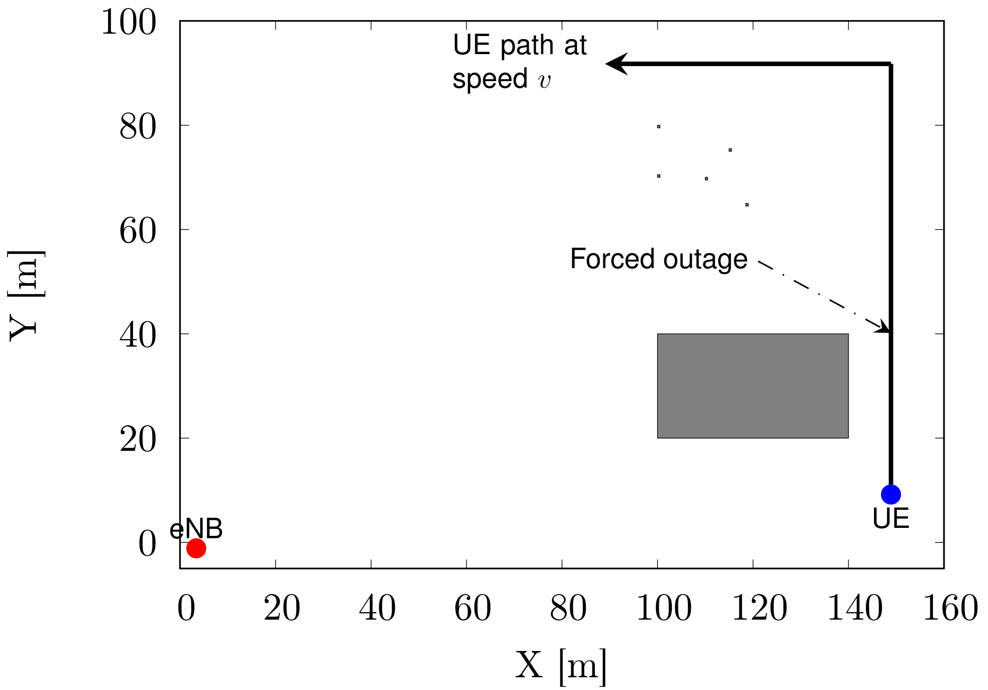




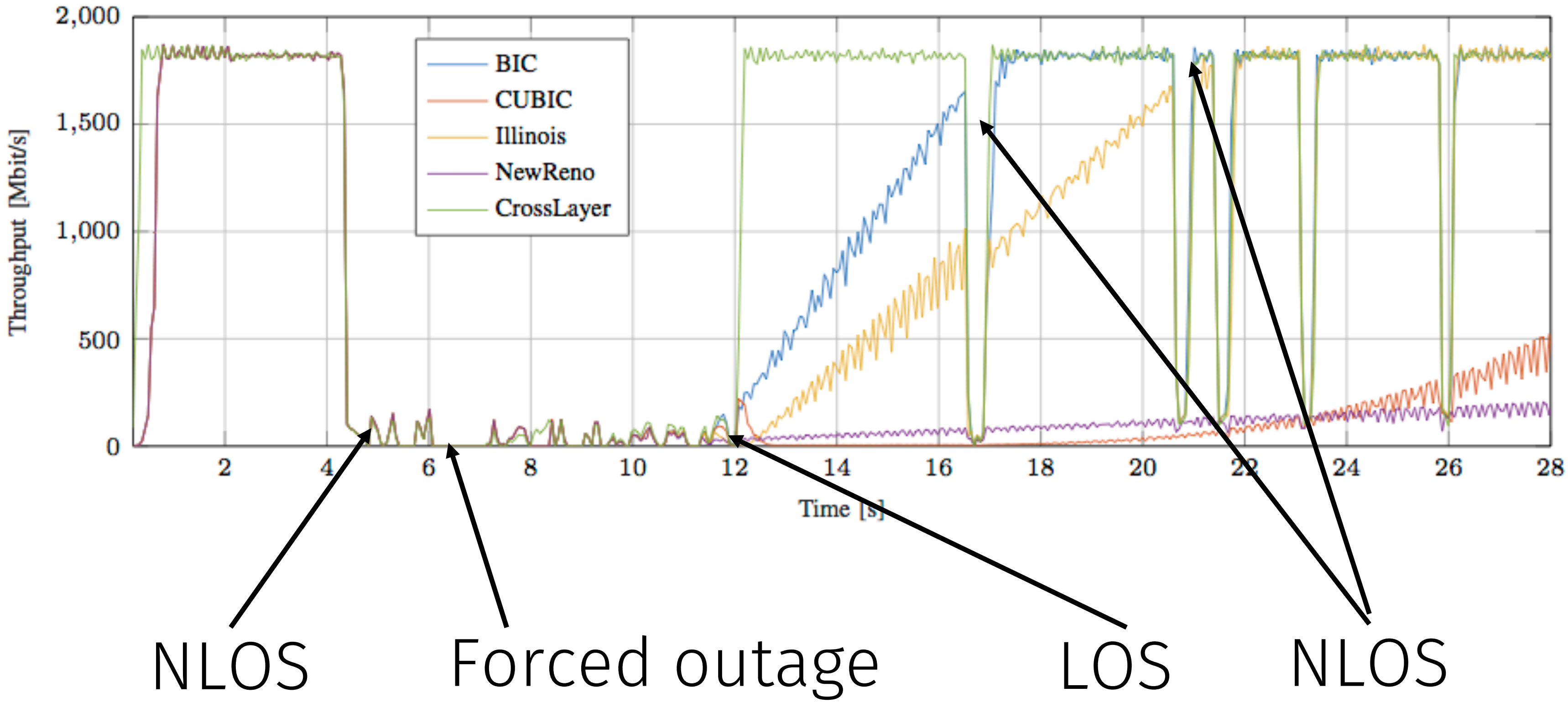
(c) Average throughput

Outage scenario

- Random channel realizations
- Fixed obstacles
- Forced outage



Example



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Average results

TCP flavor	Average throughput [Mbit/s]
X-TCP	1225.21 ± 15.81
TCP BIC	1051.32 ± 10.42
TCP Illinois	949.87 ± 10.78
TCP CUBIC	342.79 ± 8.46
TCP NewReno	342.46 ± 10.33

Conclusions

- Proposed a cross layer approach for uplink TCP
- Performance evaluation over different scenarios
  - Randomly generated
  - Forced outage

- Future works
  - Optimization of scaling factor λ
  - TCP split approach

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