A Framework for End-to-End Evaluation of 5G mmWave Cellular Networks in ns-3

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September 14, 2016

Outline

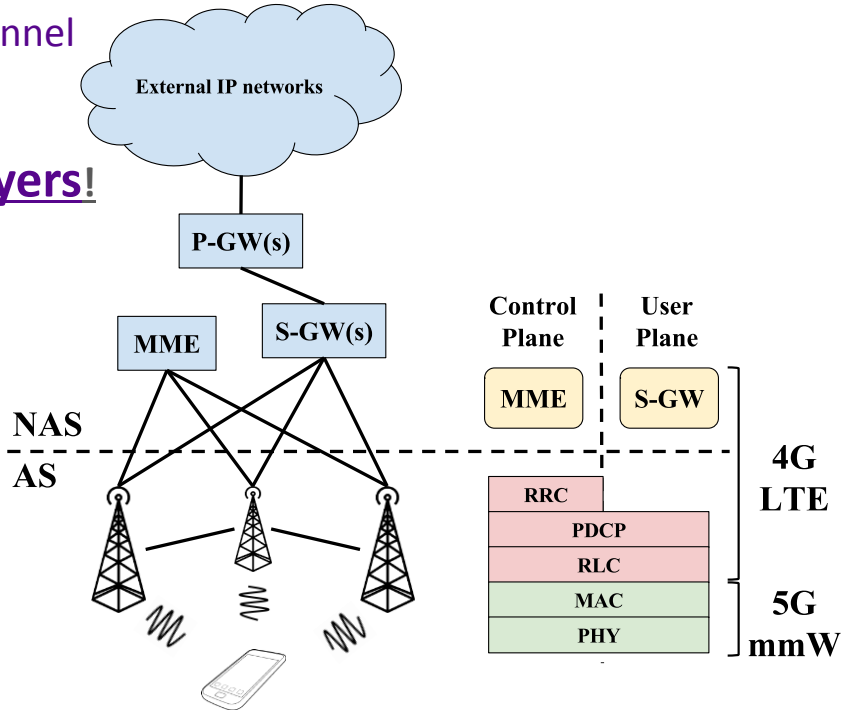
- ❑ Motivations
- ❑ Overview
- ❑ mmWave Channel
- ❑ Custom PHY/MAC implementation
- ❑ TCP performance evaluation
- ❑ Direct Code Execution
- ❑ Tight integration LTE-mmWave
- ❑ Potential New Areas

Motivations

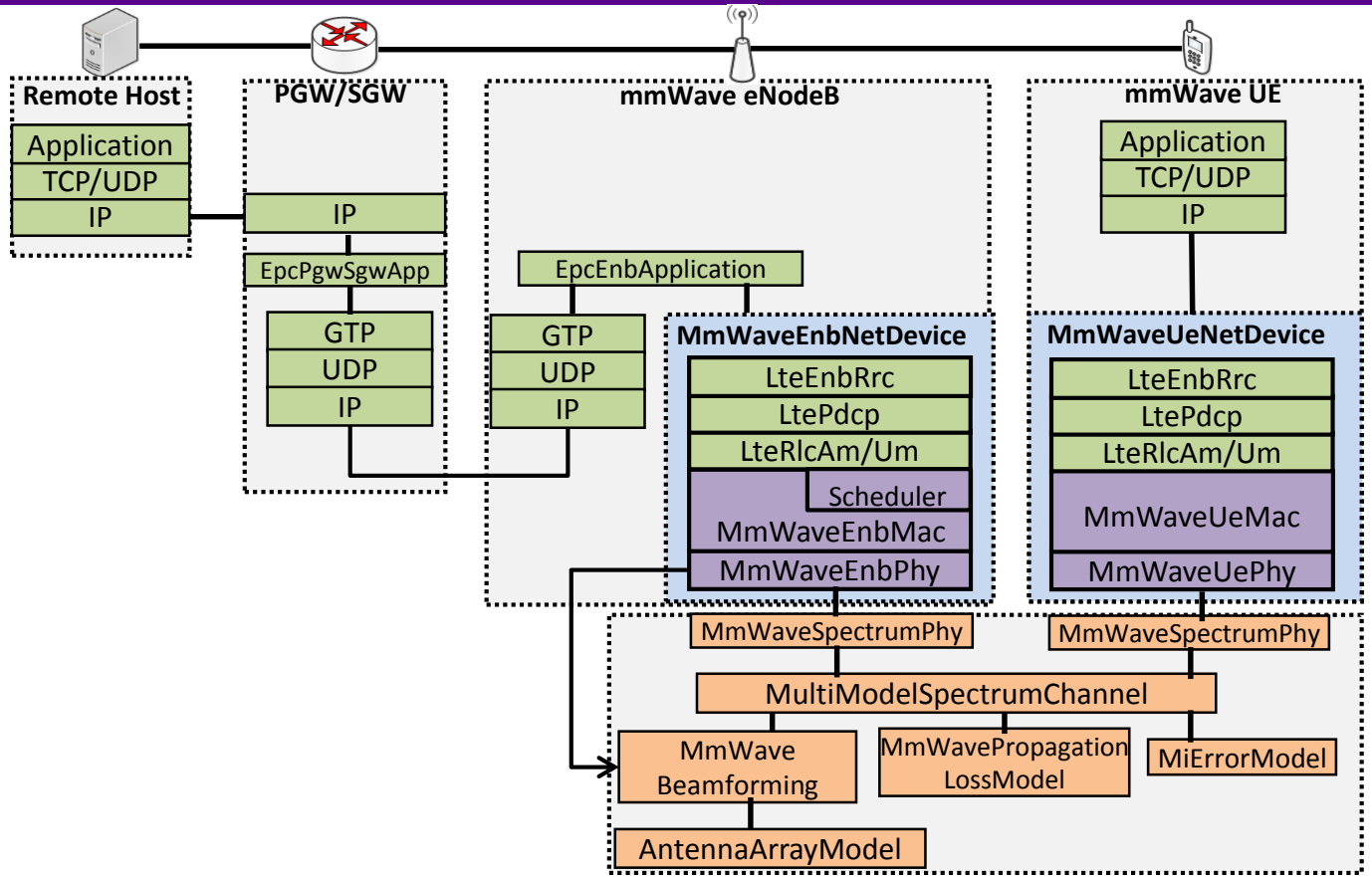
- Recent interest in mmWave as candidate 5G technology
- Lots of effort in characterizing the complex mmWave channel
- Lack of simulation tools for **E2E** performance evaluation

Realizing 5G requirements will require innovations at all layers!

- Event-driven network simulation [1, 2, 3]
  - Full-stack E2E
  - Customizable, modular framework
  - Open-source



Overview



ns3/LENA built-in

custom mmW PHY/MAC

custom mmW channel model

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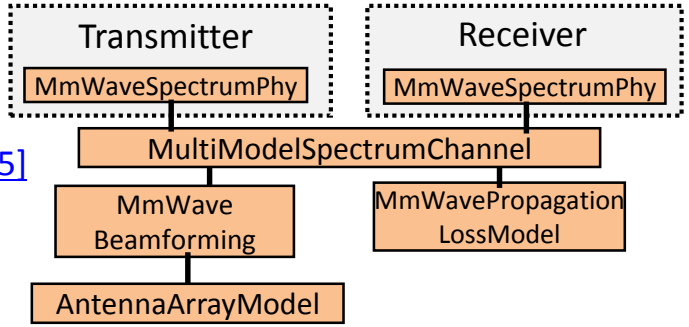
mmWave Channel

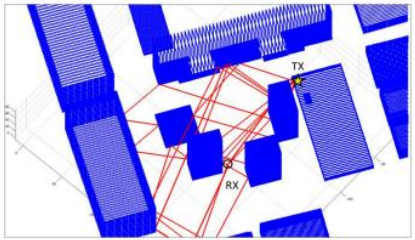
Statistical models

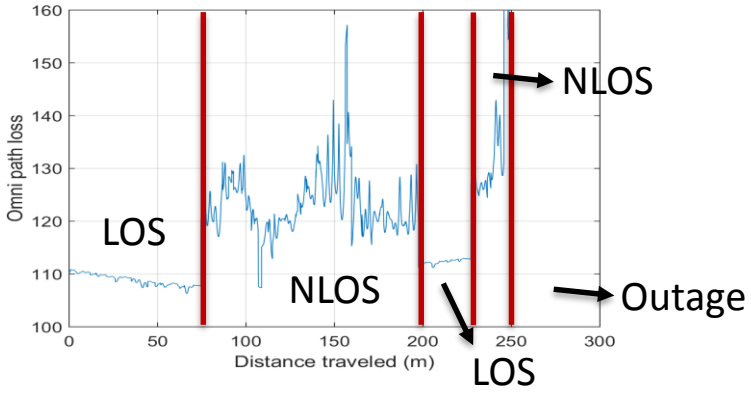
- NYU Measurements of 28 and 73 GHz channel [4]
- NYUSIM: The Open Source 5G Channel Model Simulator Software [5]
- QUADRIGA channel model [6] obtained within mmMAGIC [7]



Traces

- Obtained through **sounding** and/or **ray-tracing** [8]





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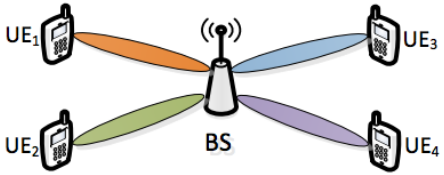
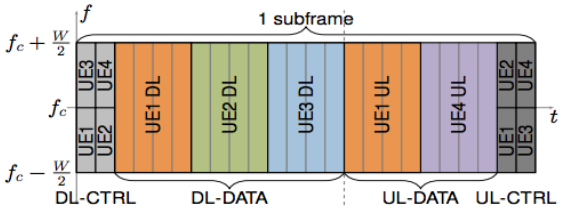
Example: Sub-frame structure

- Analog beamforming for data transmission
- OFDM with time division access
- Huge amount of data transmitted on each symbol

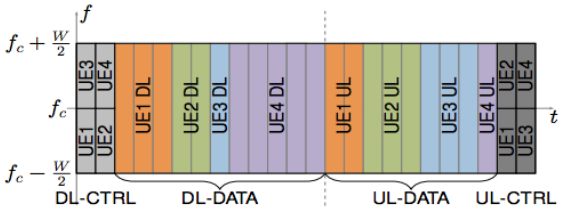
- Variable Transmission Time Interval (TTI) data slots [9, 10]
- Dynamic TDD [11]
- Short sub-frames enable fast scheduling, HARQ turnaround

- **Better radio utilization**
- **Lower latency**





(a) Fixed TTI subframe

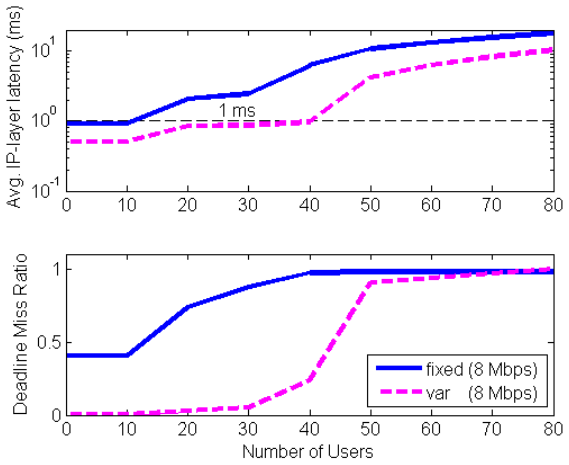


(b) Variable/Flexible TTI subframe

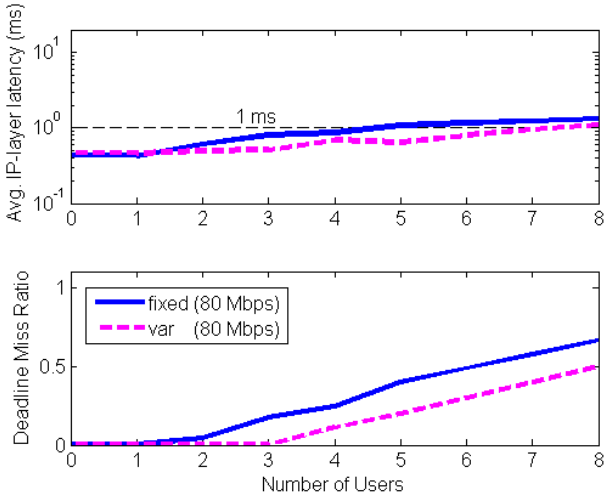
Latency for Fixed and Variable TTI

Quantify radio-link latency for Variable over Fixed TTI [12]

- 100 µs sub-frame (24 symbols --1 DL control, 1 UL control symbol)
- HARQ with target maximum 10% Block Error Rate
- UEs move at vehicular (25 m/s) speed

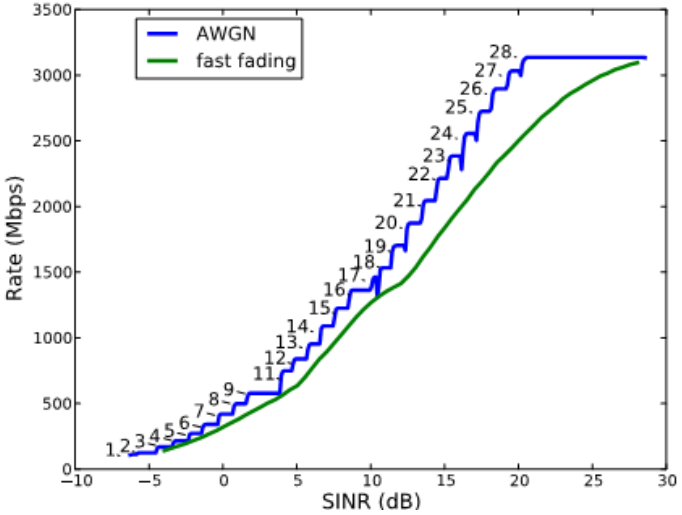


Many UEs, Low-rate



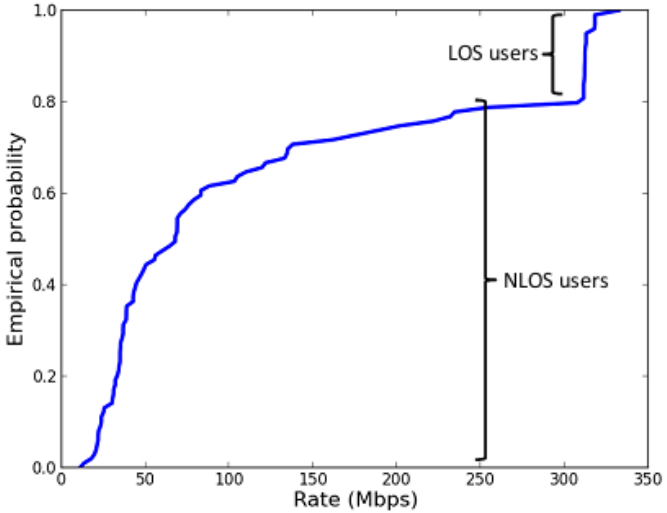
Few UEs, High-rate

IP-layer Throughput



Performance of AMC + CQI feedback model for 1 GHz mmW

SINR gradually increased to show transitions between Modulation and Coding Scheme (MCS) levels



Multi-user capacity

10 drops of 10 users - uniform(10,200m)

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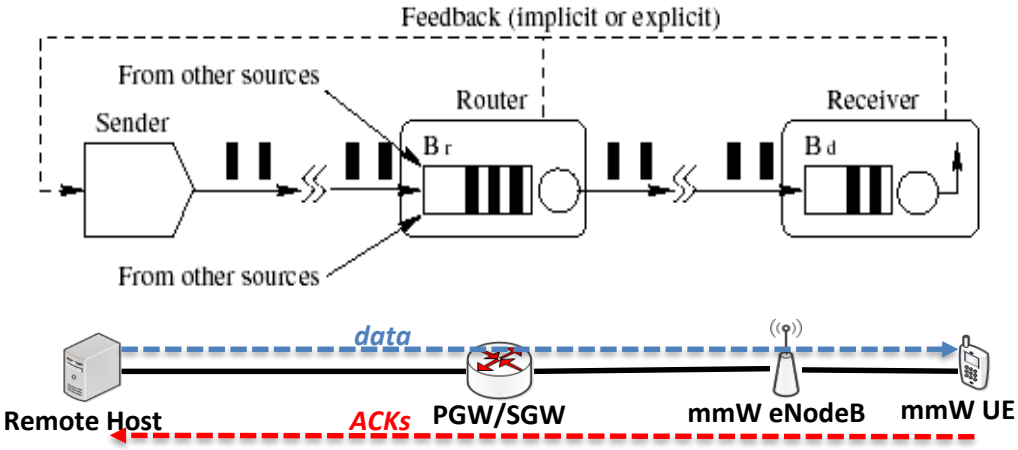
Transport Layer Challenges



mmWave links

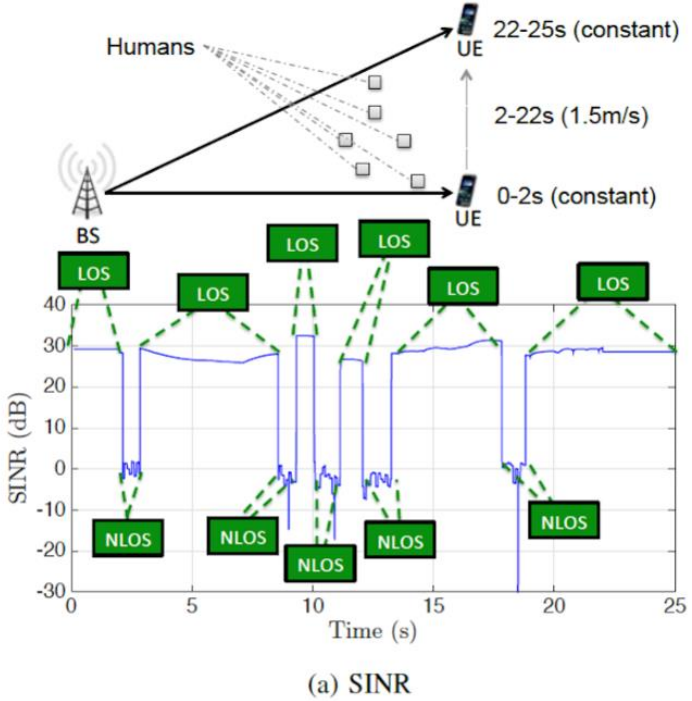
- ❑ Intermittent
- ❑ Very high peak data rates

Questions

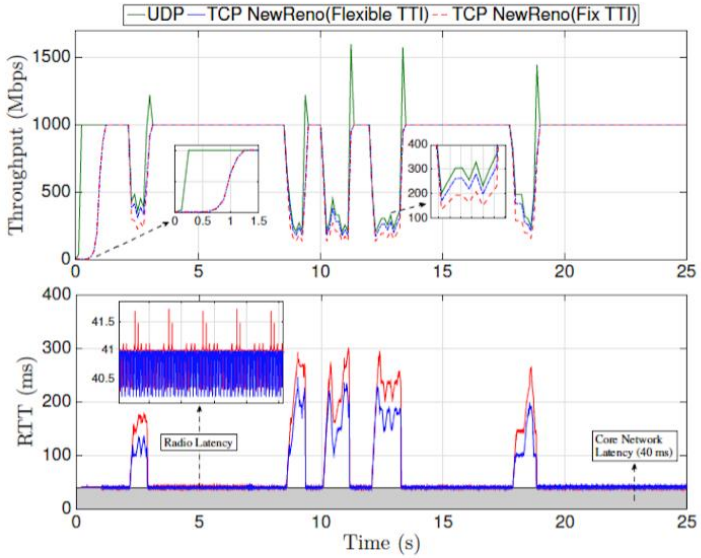
- ❑ Can current TCP adapt?
- ❑ If not, how do we fix TCP?
- ❑ Should the core network evolve?

TCP Performance over mmWave [8]

Scenario 1



(a) SINR



(b) TCP performance

UDP vs. TCP

- Ramp-up times
- Utilization

Flexible TTI

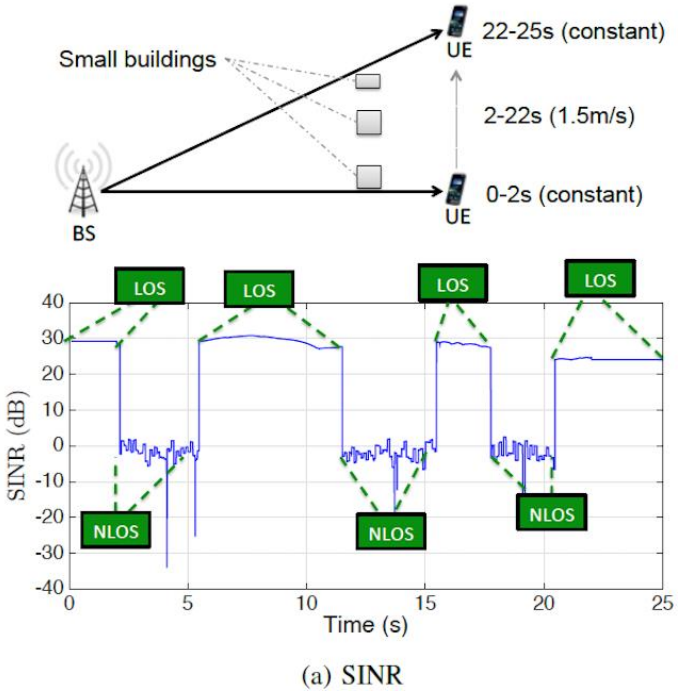
- Higher Throughput
- Lower latency

Latency

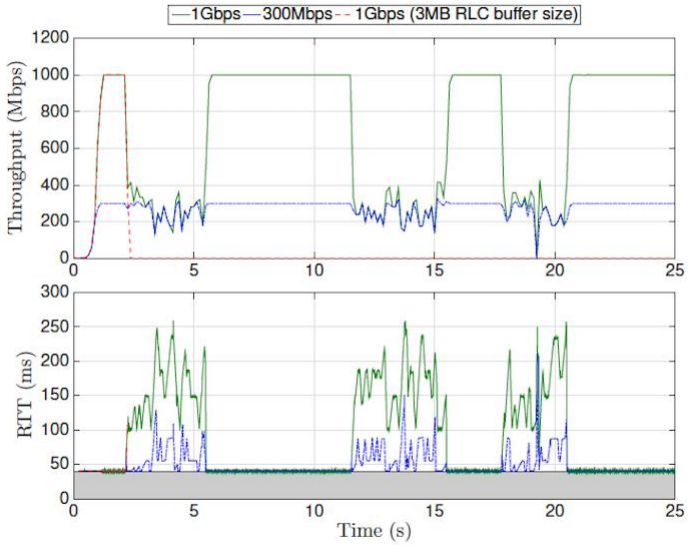
- Core Network *(40ms)*
- High latency in *NLOS* regimes

TCP Performance over mmWave [8]

Scenario 2



(a) SINR



(b) TCP performance

Bufferbloat

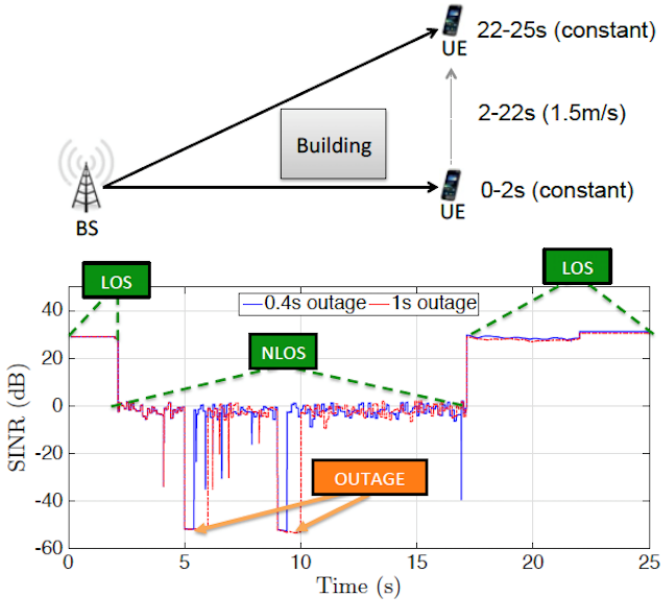
- Buffering too much data resulting in *latency increase*

Buffer overflow

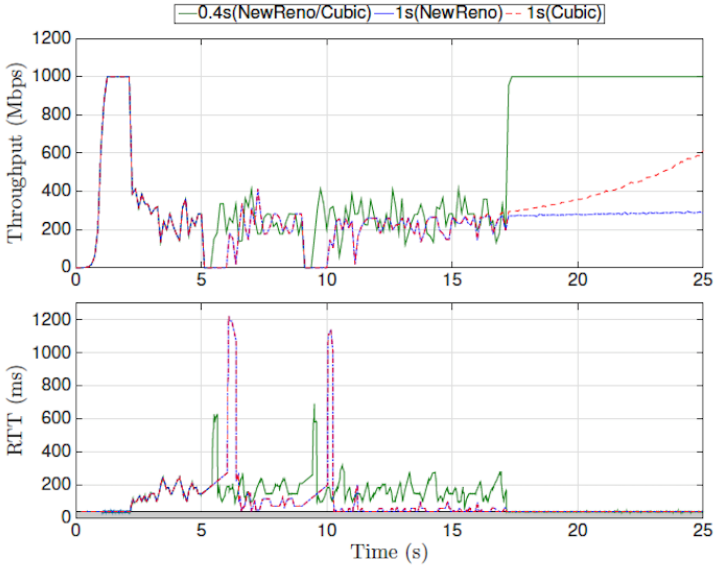
- TCP *Fast Retransmit* inefficiency

TCP Performance over mmWave [8]

Scenario 3



(a) SINR



(b) TCP performance

Short outage (0.4s)

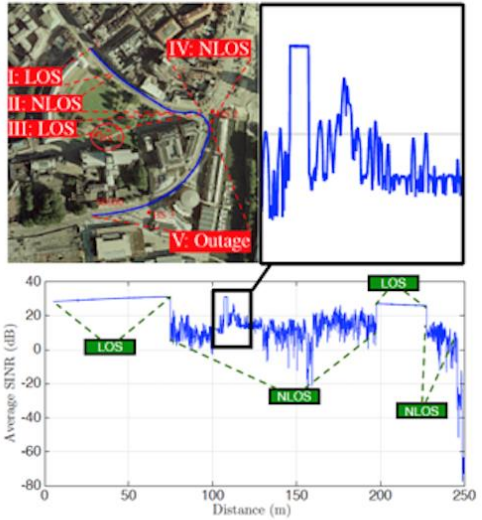
- No TCP retransmissions
- Fast *ramp-up* to capacity in *LOS*

Long outage (1s)

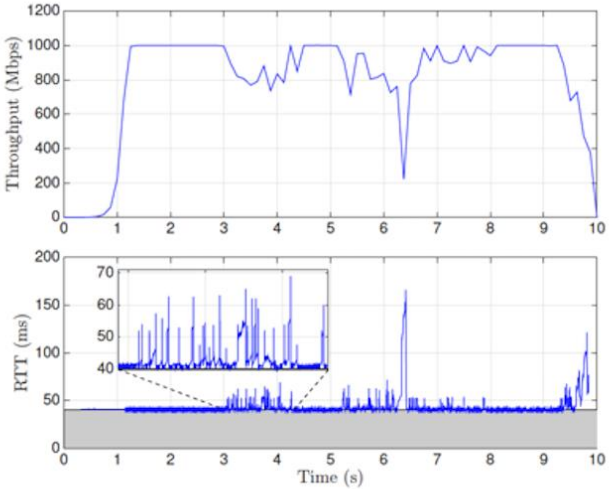
- TCP retransmissions
- *Slow ramp-up* to capacity in *LOS*

TCP Performance over mmWave [8]

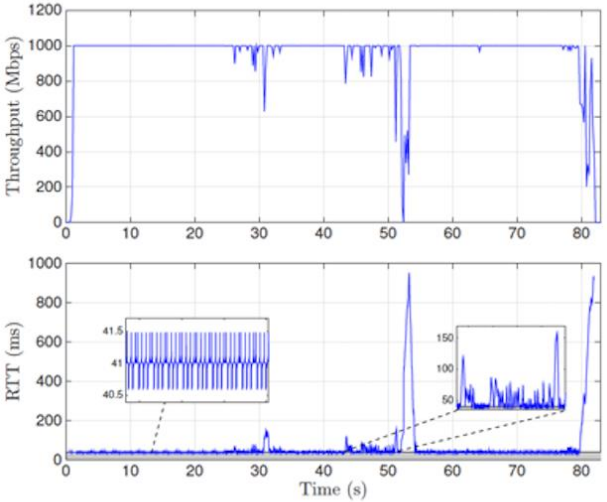
Real traces



(a) SINR



(b) TCP performance (25 m/s)



(c) TCP performance (3 m/s)

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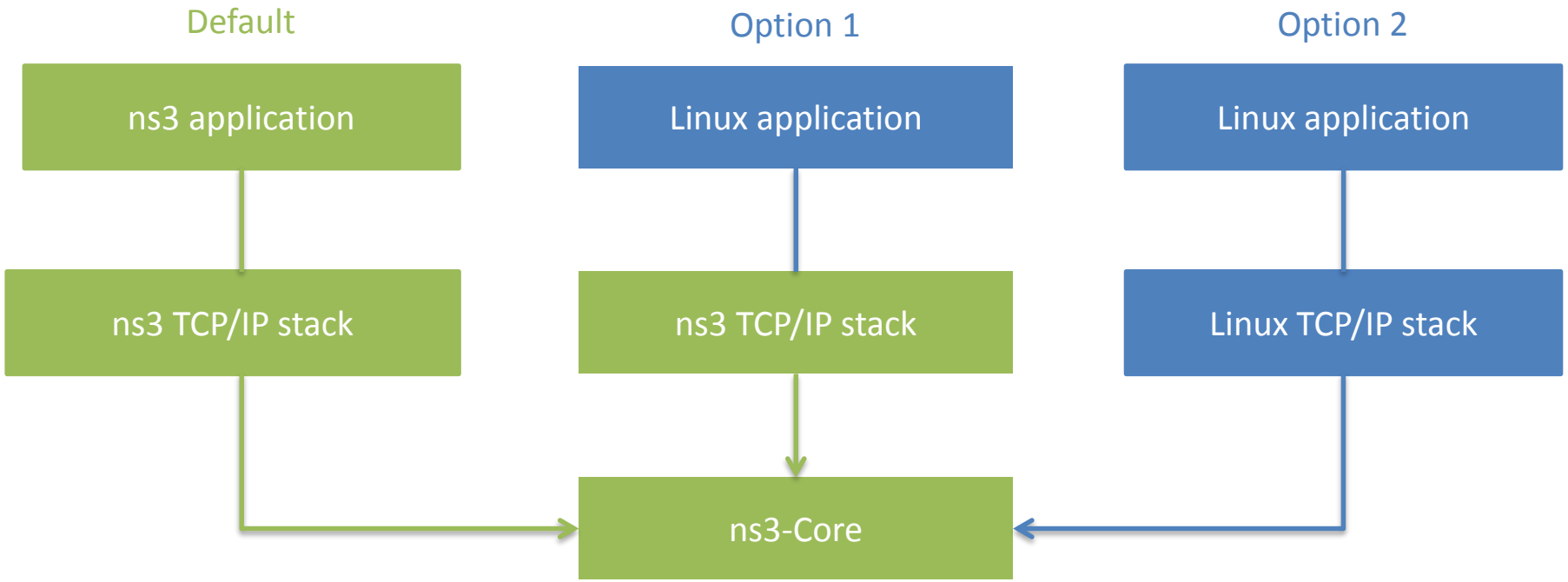
Direct Code Execution



Use case: We can run a **real implementation** of any TCP version (*Cubic*, *Vegas*, *MultiPath*, ..) over our end-to-end mmWave framework!

GOAL

TOP CS Conference
(NSDI, SIGCOMM, MOBICOM, ..)

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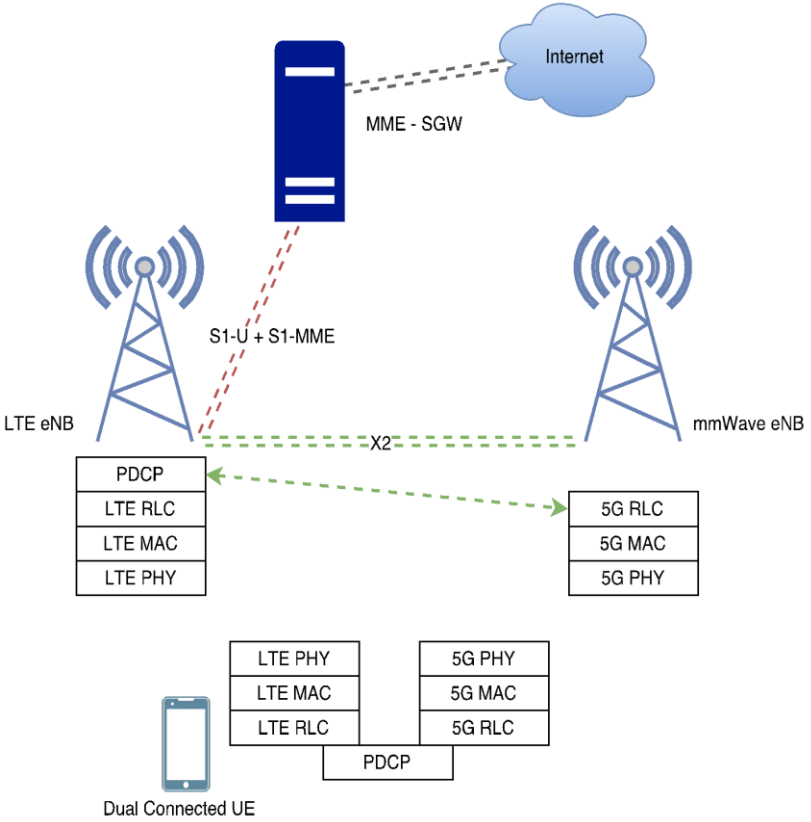
- **Tight integration LTE-mmWave**
- Potential New Areas

LTE-mmWave Tight Integration

Non-Standalone 5G mmWave

- RRC procedures
  - SINR-based initial access
  - Secondary cell HO
  - Fast switching between RATs
- X2
  - **Seamless** (RLC UM) and **lossless** (RLC AM) HO
  - PDCP-RLC forwarding
- References: [13, 14, 15]



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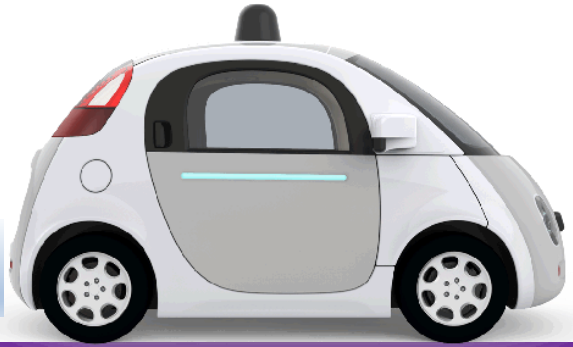
Potential New Areas

We can also exploit our end-to-end simulation framework for…

Key actions

- ❑ Integrate a traffic simulator (SUMO)
- ❑ Capture and integrate mmWave vehicular traces

Vehicular networks



Key actions

- ❑ Record 360 video
- ❑ Integrate a video quality evaluation tool-set (EvalVid)

Immersive Video

References

[1] ns-3 mmWave module: https://github.com/mmezzavilla/ns3-mmwave

[2] Marco Mezzavilla, Sourjya Dutta, Menglei Zhang, Mustafa Riza Akdeniz, Sundeep Rangan, *5G mmWave Module for ns-3 Network Simulator*, MSWiM '15 Proceedings of the 18th ACM International Conference on Modeling, Analysis and Simulation of Wireless and Mobile Systems

[3] Russell Ford, Menglei Zhang, Sourjya Dutta, Marco Mezzavilla, Sundeep Rangan, Michele Zorzi, *A Framework for End-to-End Evaluation of 5G mmWave Cellular Networks in ns-3*, in Proceedings of the Workshop ns-3 (WNS3)

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[5] NYUSIM: The Open Source 5G Channel Model Simulator software

[6] QUADRIGA: The Next Generation Radio Channel Model

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[9] Sourjya Dutta, Marco Mezzavilla, Russell Ford, Menglei Zhang, Sundeep Rangan, Michele Zorzi, *Frame Structure Design and Analysis for Millimeter Wave Cellular Systems*, submitted to IEEE Transactions for Wireless Communications

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[15] Michele Polese, *Performance Comparison of Dual Connectivity and Hard Handover for LTE-5G Tight Integration in mmWave Cellular Networks*,
Master's Thesis carried out by Mr. Michele Polese under the supervision of Dr. Marco Mezzavilla and Prof. Michele Zorzi

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