Characterizing Performance and Power for mmWave 5G on Commodity Smartphones

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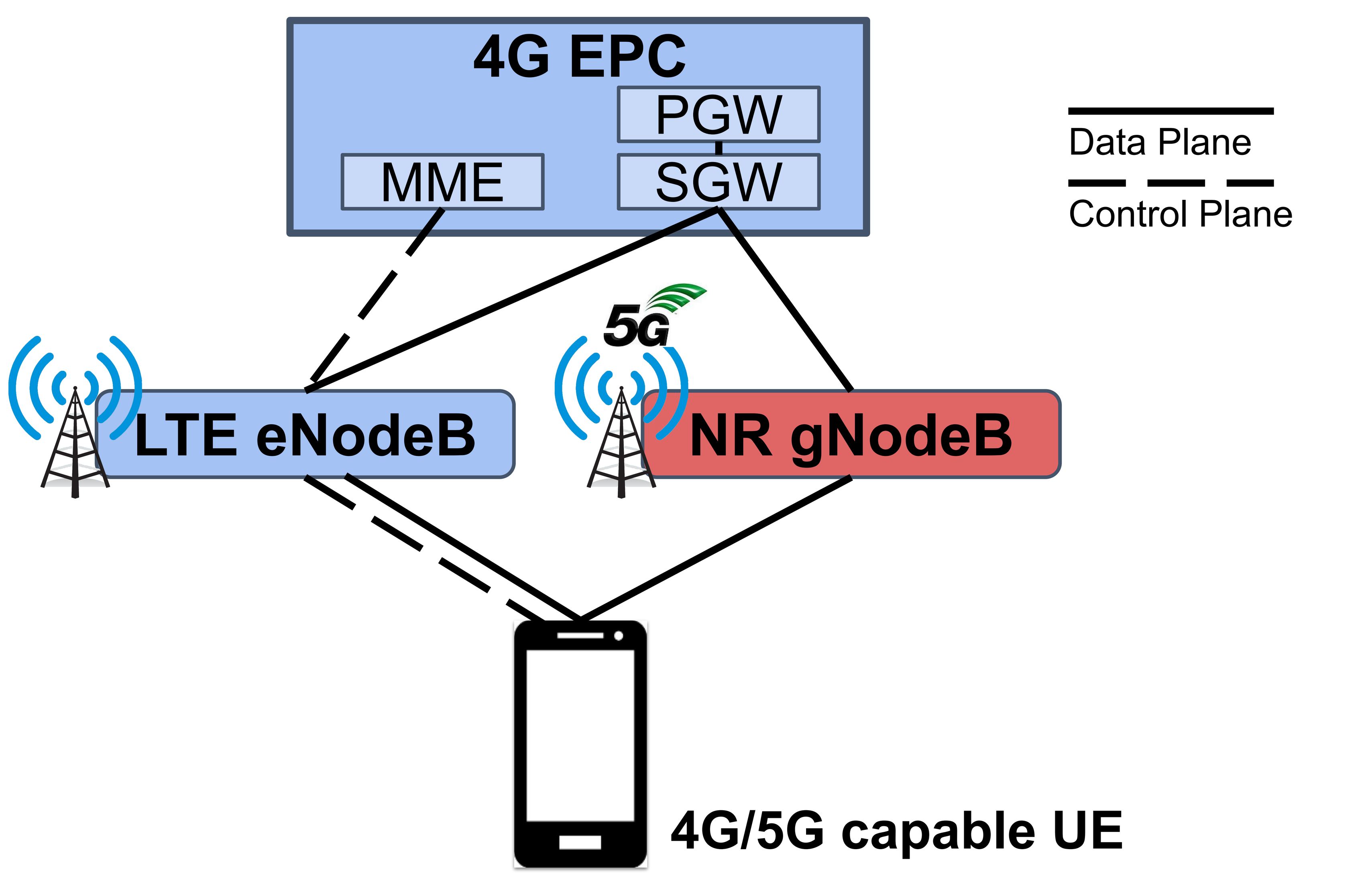
1. Introduction and Motivation

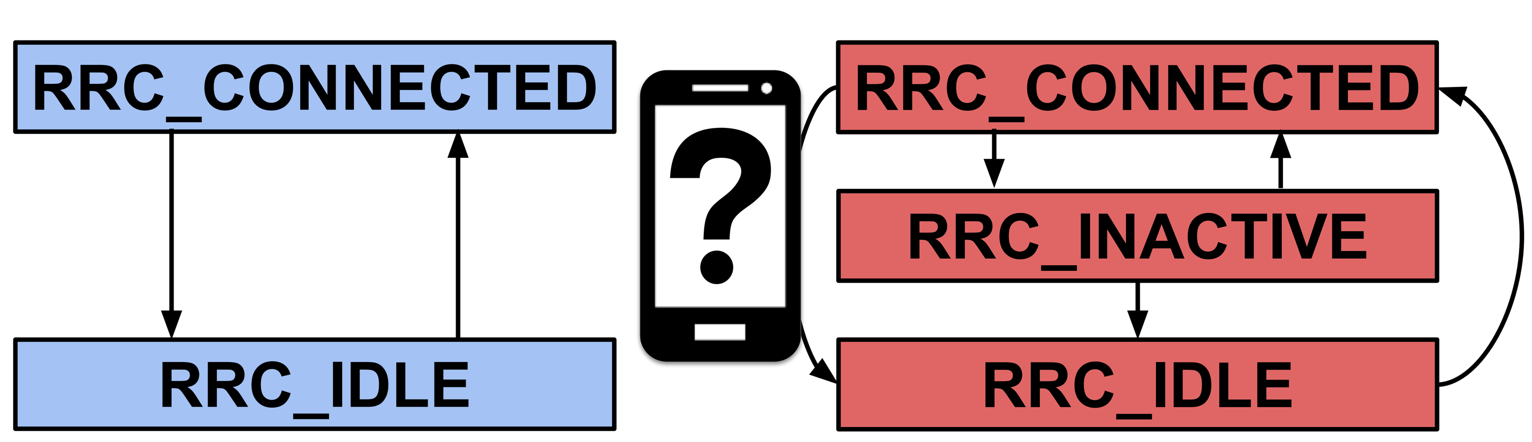
During the first half of this year, four major operators in the US announced their **5G** deployment, which indicates the advent of next generation networks. Three of them use millimeter wave technology for ultra high bandwidth.

Carrier	**Verizon**	**T-Mobile**	**AT&T**	**Sprint**
Frequency range	mmWave 28/39 GHz	mmWave 28/39 GHz	mmWave 24/39 GHz	mid-band 2.5 GHz

Non-standalone (NSA) architecture utilizes 5G for data plane operations while retaining 4G core for control plane operations.



Dual Connectivity (EN-DC) is a core technology of NSA 5G which supports 5G services under 4G infrastructure, which enables a UE to connect to LTE and NR at the same time. In this case, the UE will have only single RRC state machine.



RRC state transitions in LTE

RRC state transitions in NR

2. Challenges and Solutions

We aim to **explore network and power characteristics for NSA 5G** which introduces a high data rate and low latency. To achieve this goal and identify potential issues in 4G-5G interworking, we are faced with numerous problems:

- Potentially complex control plane
- mmWave's sensitivity to environment and attenuation
- Heterogeneous performance across locations/operators

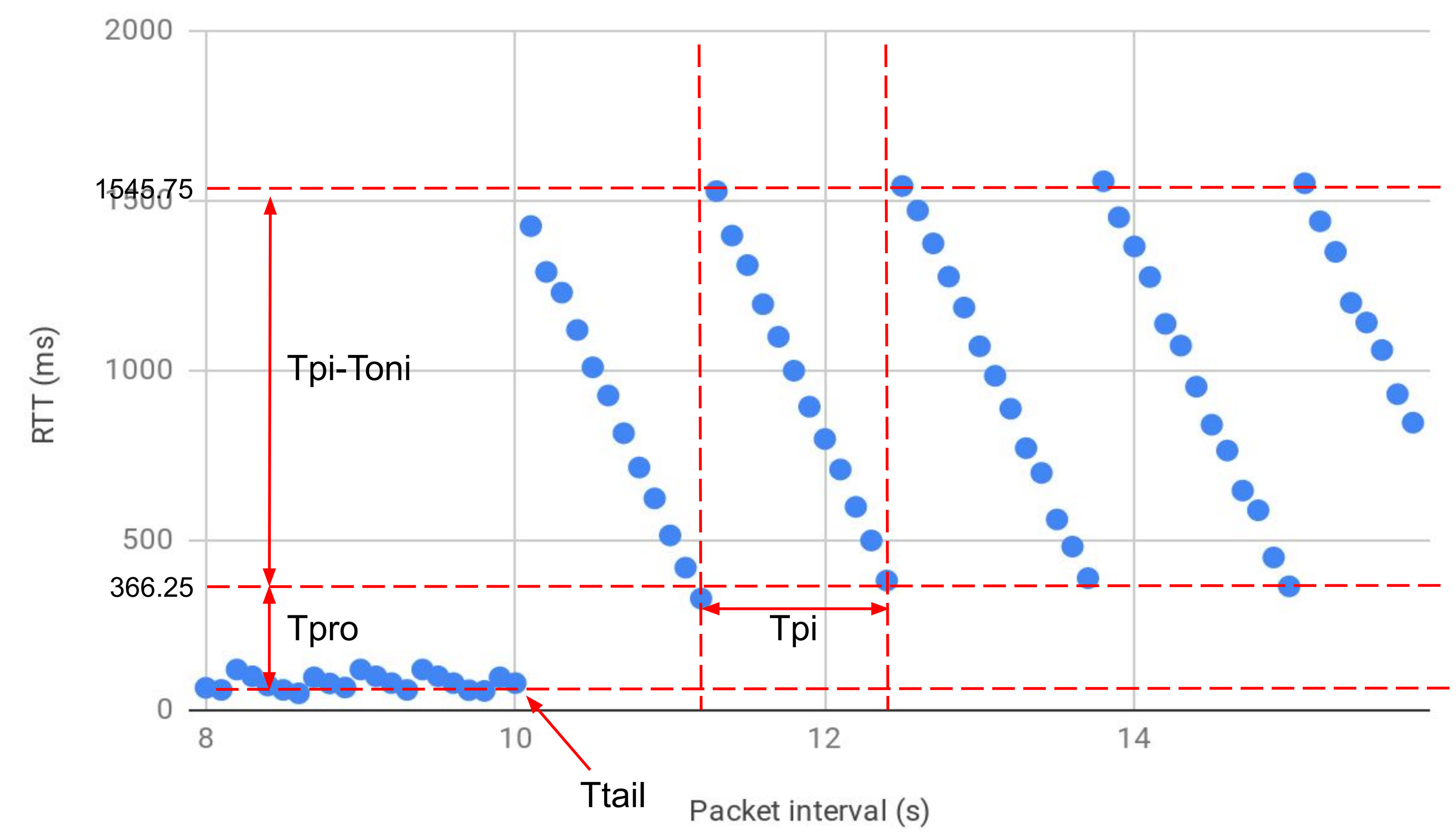
Proposed steps to unveil these problems:

- Network-based parameter probe
- Power model construction
- Environmental factor analysis
- Crowdsourcing

3. Preliminary results

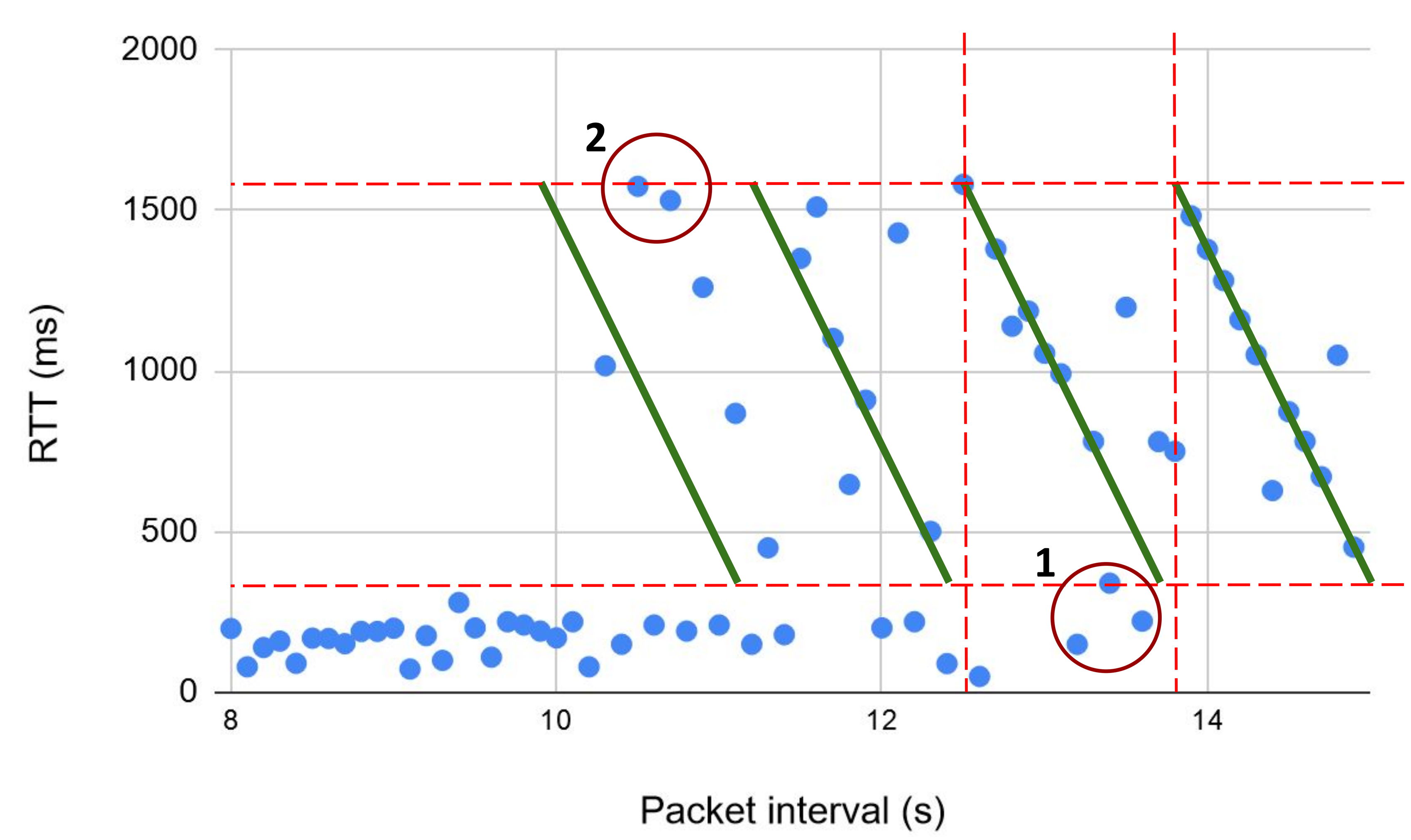
LTE RRC state probing results (AT&T)

- T_{pi}: RRC_IDLE DRX cycle. (1.27 s)
- T_{oni}: RRC_IDLE On Duration timer. (90 ms)
- T_{tail}: RRC inactivity timer. (306 ms)
- T_{pro}: LTE promotion delay. (10 s)



NR RRC state probing results (Verizon)

- 4G-5G handover observed even without moving.
- Background traffic interference leads to bad points:
  - Case 1: UE never enter the idle mode.
  - Case 2: Packet interval > Real UE idle time.



4. Crowdsourcing

Crowdsourcing is expected to collect experimental data while benefiting users (e.g., report real-time performance) without sacrificing little user data.

Bandwidth estimation

- Brute-force speed tests is data consuming. A single test over 5G consumes 1987/86.4 MB of downlink/uplink data. Reported DL/UL bandwidth: 1154/57.8 Mbps.
- Traditional lightweight solutions perform badly over cellular networks (e.g., packet pair/train). Base station scheduling eliminates the gap between probe packets.

Context-aware measurement

- Tagging measurement conditions facilitate analysis.