A Comprehensive Real-World Evaluation of 5G Improvements over 4G in Low- and Mid-Bands

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SPECTRUMX

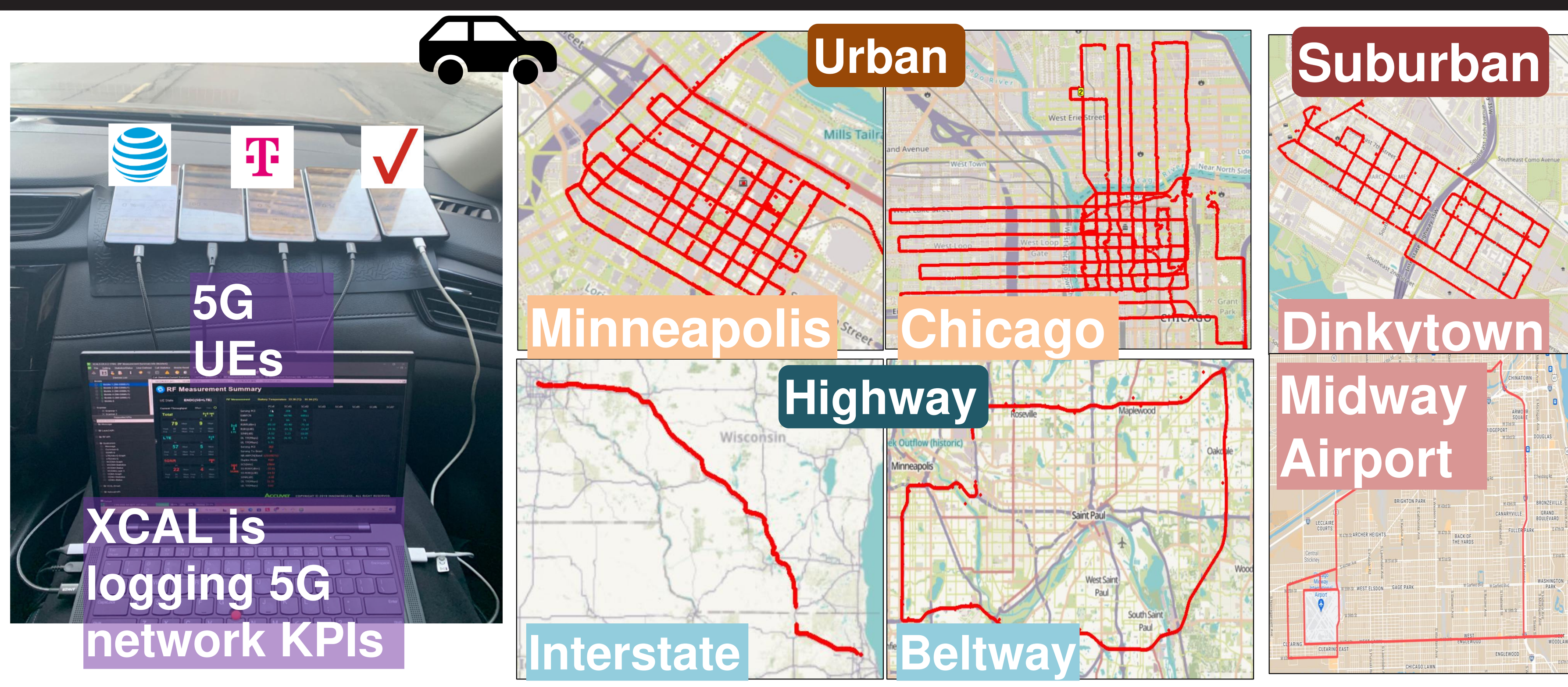

Fig. 1: Setup of the 5G probes and driving routes of our measurements.

BACKGROUND

- Initial 4G networks primarily used low (<1 GHz) and mid (1-6 GHz) frequency bands, while early US 5G focused on mmWave (>24 GHz) bands. 5G mmWave offers high throughput but faces limitations from propagation loss, body blockage, foliage, and thermal effects [1,2,3].
- Current 5G deployments emphasize the mid-band, striking a balance between coverage and performance. 5G's novel features (bandwidth, modulation, code rate, MIMO layers) theoretically offer throughput gains.
- However, some advanced 5G technologies (e.g., MU-MIMO, 1024-QAM) may be under development or omitted due to cost considerations. Earlier research lacks data on recent 5G deployments in the BRS (n41, 2.5-2.7 GHz) and C-band (n77, 3.7-4.2 GHz).

RESEARCH QUESTIONS

Quantifying 5G spectrum usage is crucial to determine if additional broadband allocation is needed.

To this end, we conducted extensive in-field measurements in two major metropolitan areas in the US, Minneapolis and Chicago, along with the highways connecting them.

TOOLS AND METHODOLOGY

TABLE I: Statistics of 4G/5G dataset.

Mobile Operators	AT&T, T-Mobile, Verizon
Radio Technologies	4G, 5G
Measurement Venues	Minneapolis, Chicago
Cumulative Data Traces	1200+km; Around 14 hours
XCAL Key Perf. Indicators	PCI-Beam idx; Freq.; SCS; RSRP; RSRQ; CQI; RI; BLER; MCS; #RBs; #MIMO layers; MIMO modes; PHY-layer throughput;

- To cover a large area, data are collected while driving. Fig. 1 shows the measurement setup and driving routes. Table 1 shows statistics of data collected over the campaigns: Chicago in December 2022, Minneapolis in April, May, November 2023.

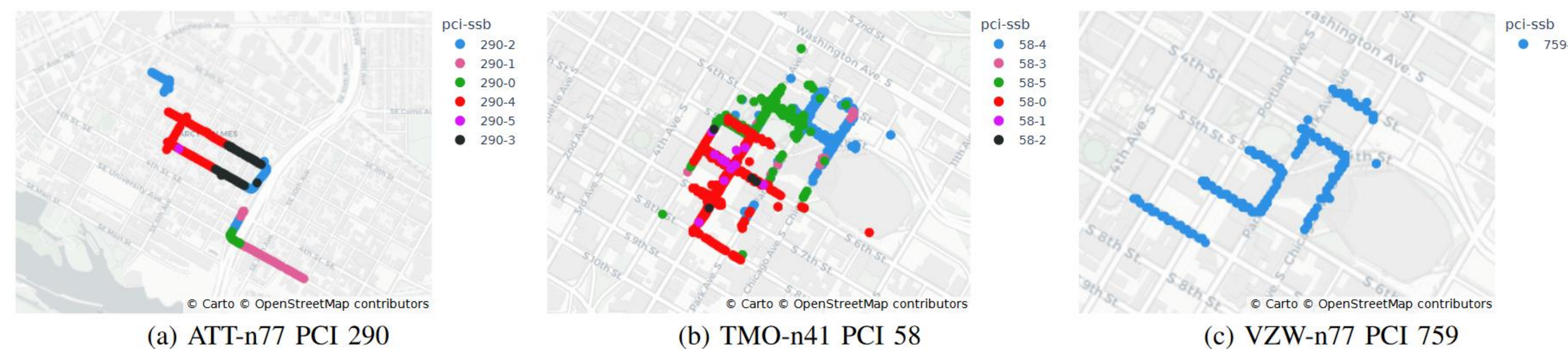

Fig. 2: PCI-SSB index maps of mid-band channels.

- Three S22+ phones were utilized, equipped with three major US operators' SIMs: AT&T (**ATT**), T-Mobile (**TMO**), and Verizon (**VZW**). The phones were connected to a Lenovo ThinkPad X1 Carbon laptop running Accuver XCAL to capture various 4G and 5G signal parameters, along with generating DL traffic for throughput measurements.

RESULTS

- **5G modes:** ATT and VZW only deployed NSA (non-standalone) while TMO deployed both SA (standalone) and NSA. We did not observe NR aggregation in NSA.
- **4G and 5G Physical Cell Indicator (PCI):** TMO has the densest mid-band (n41) deployment (464 unique PCIs) compared to ATT and VZW (n77) and other 4G bands.
- **Low- and mid-band NR beams:** The number of synchronization signal block (SSB) indices per PCI indicates beam count. Fig. 2 shows ATT and TMO use up to 6 beams per PCI in mid-band, while VZW uses just one. 5G low-band deployments consistently use a single beam.
- **Throughput and normalized throughput:** Fig. 3a shows the downlink throughput comparison between select NR and LTE low- and mid-band channels. We observe the highest median on TMO-n41 (100 MHz). Therefore, we normalize the throughput by the bandwidth and MIMO layers. Fig. 3b shows ~2 bit/s/Hz/stream like QPSK, except for TMO-n41 with the median of ~3.14 bit/s/Hz/stream.
- **Impact of RSRP and CQI on normalized throughput:** Reference Signal Receive Power (RSRP) indicates coverage, while Channel Quality Index (CQI) indicates channel conditions from UE's perspective. Fig. 3c and 3d shows the comparison of these respective parameters on various 4G and 5G low- and mid-band channels. We observe higher correlation between CQI and normalized throughput, compared to RSRP and normalized throughput.
- **MIMO analyses**: Rank Index (RI) is the MIMO channel rank as calculated by UE for MIMO layer decision. Fig.4 shows higher report of RI 3 and 4 in NR mid-bands. All NR low-bands only utilizes 2x2 MIMO, while the 4G channels only report RI up to of 3. We did not observe MU-MIMO deployments.

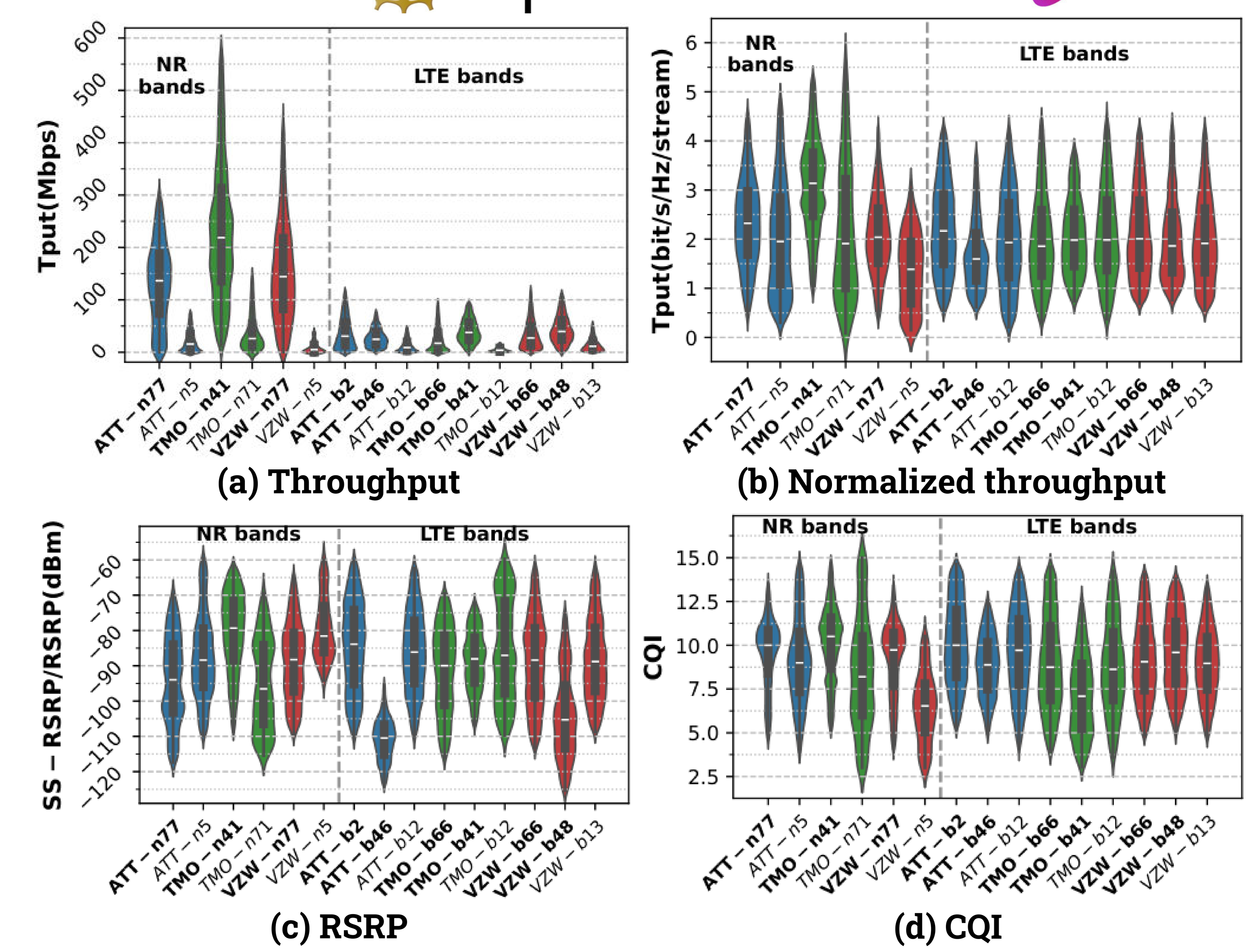

Fig. 3: Comparison between NR and LTE channel parameters (mid-band channels in bold).

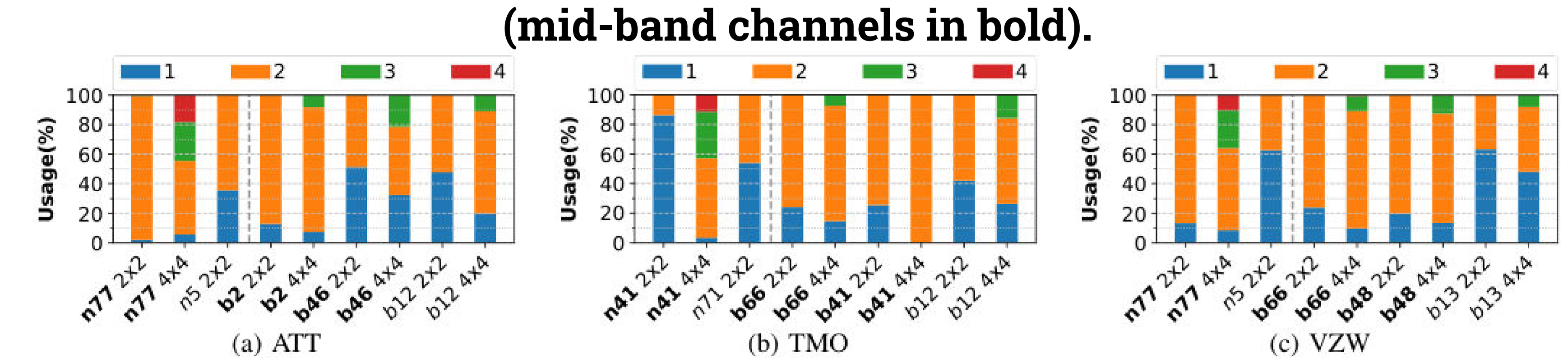

Fig. 4: Comparison of RI in various MIMO modes. (mid-band channels in bold).

CONCLUSION

We observe improvements in 5G over 4G due to the higher bandwidth of mid-band 5G, with dense deployment and multiple beams. While there is a marginal increase in the usage of the full capability 4x4 MIMO with 4 layers in NR, we observe a lack on the implementation of new 5G features, *i.e.*, 1024-QAM, MU-MIMO.

ACKNOWLEDGEMENTS

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