A Global Perspective of 5G Network Performance

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SiGNALS Research Group

Key Highlights

- 5G is providing meaningful capacity gains to LTE networks on a global basis with LTE extending the coverage, reliability and speeds of high bit rate transmissions
- Millimeter wave signals are far more resilient than generally perceived, including indoors, with additional performance gains coming
- 5G capacity gains can have a meaningful impact on the user experience
  - Application downloads
  - Video streaming
- Although the comparisons are nuanced, 5G can be just as energy efficient as LTE, with a full day of battery easily achieved with most scenarios

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Today's Agenda

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- Indoor deployments of 5G millimeter wave are already occurring with favorable results
- 5G capacity gains improve the user experience, especially in capacity-constrained environments
- The energy efficiency of 5G can exceed that of LTE while delivering a full workday's worth of smartphone usage

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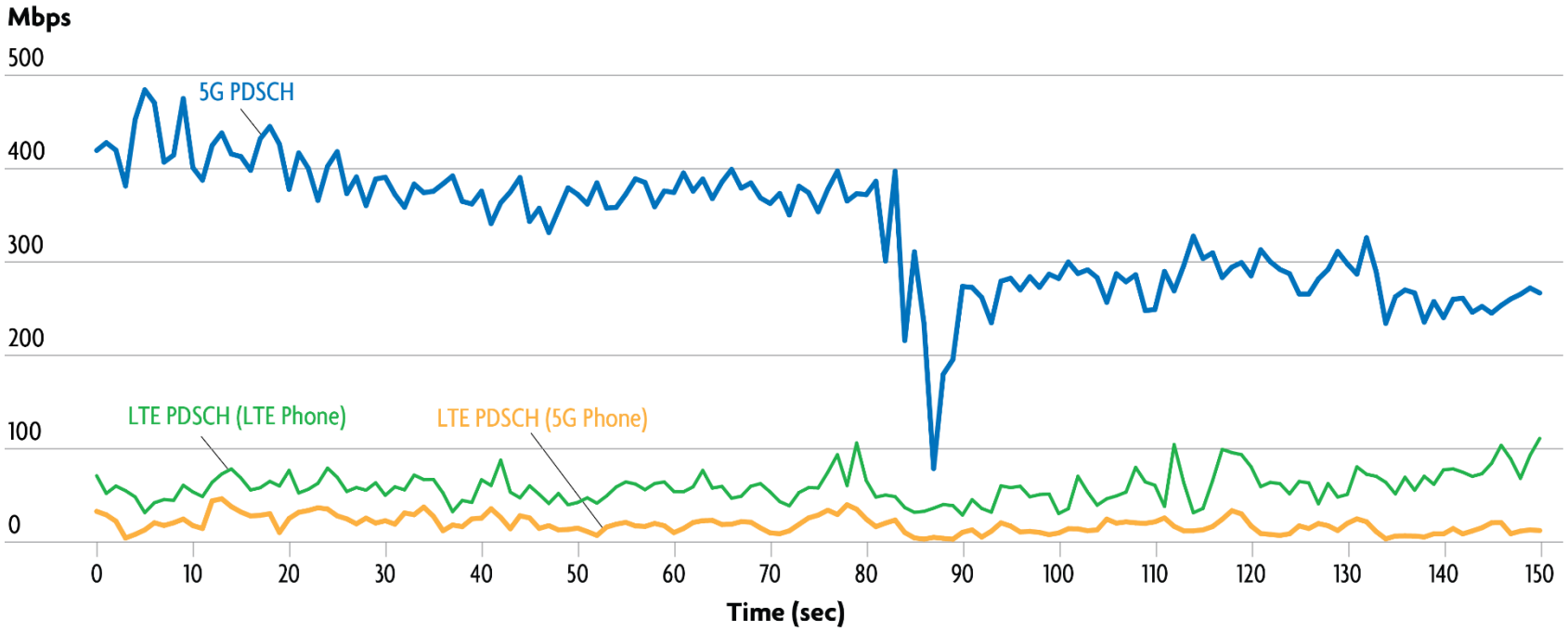
5G Performance in Seoul (Gangnam)



- ~4.6 km walk test near COEX in Gangnam
- LTE-only and 5G-capable LG V50 phones operating in parallel
- 192.8 GB of transferred data

COEX Walk Test

5G Availability

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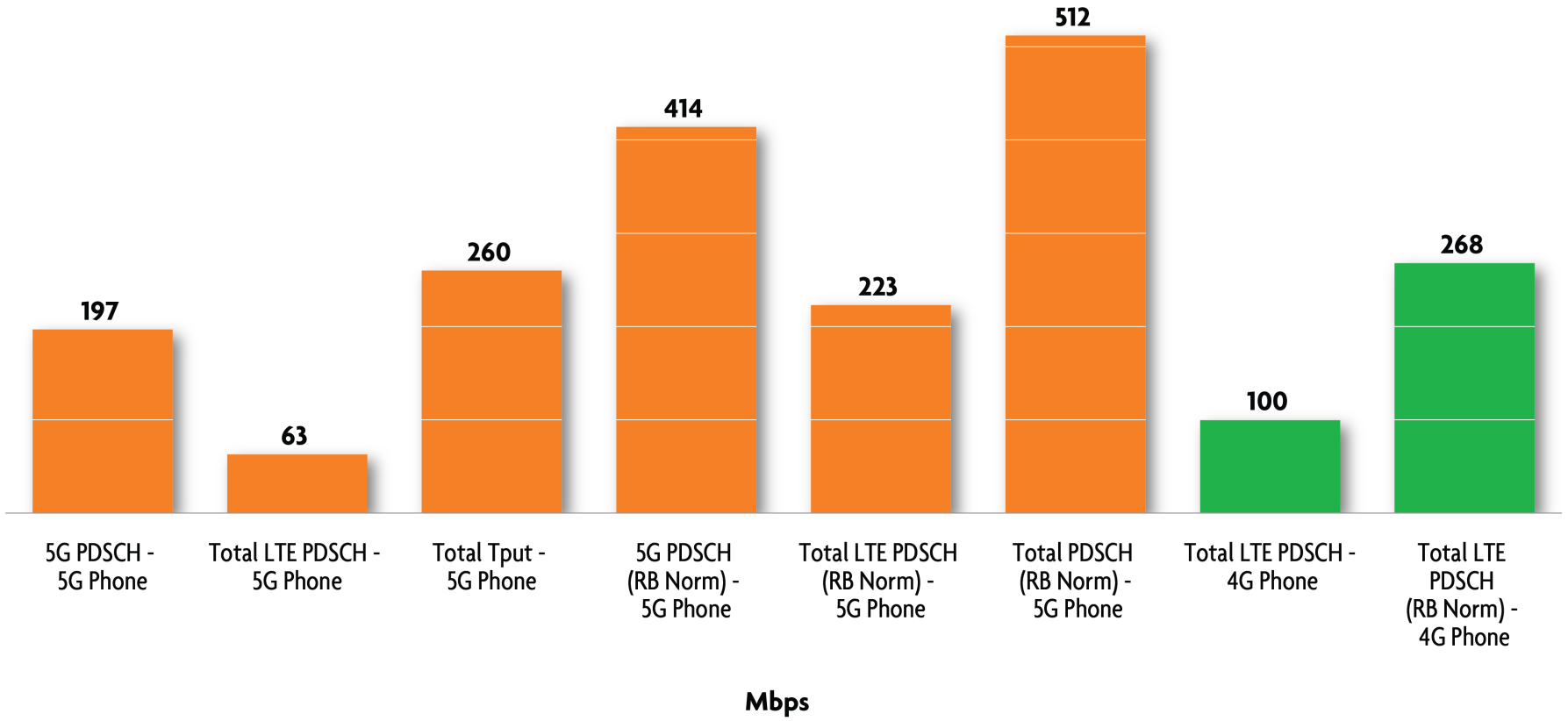
5G Performance in Seoul (Gangnam)

Median Throughput (Measured and Normalized)



- 5G-capable phone was 2.6x faster than the LTE-only phone
- With RB normalized results, the gain was 1.9x.

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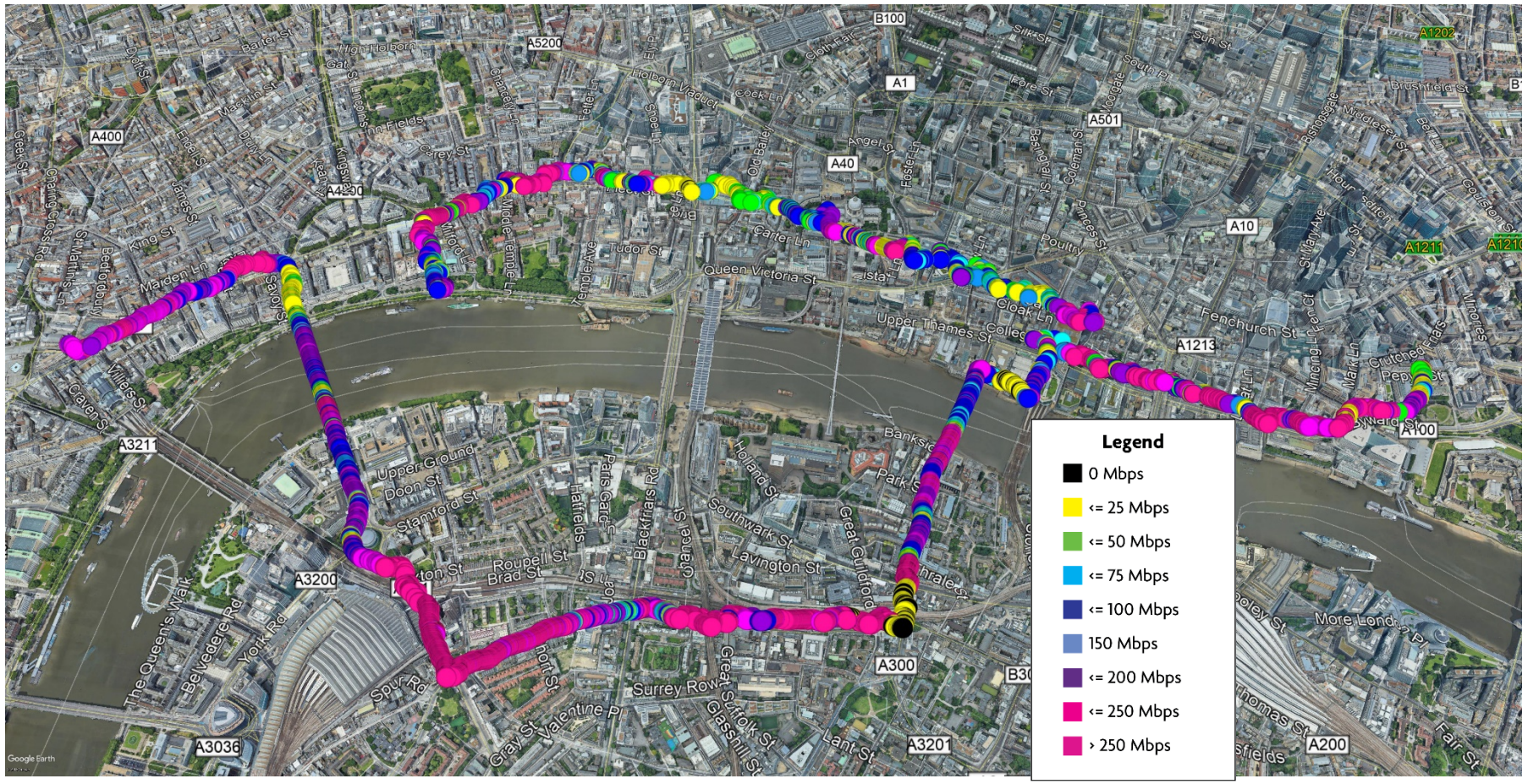
5G Performance in Central London

EN-DC Throughput (5G + LTE)



- EE has LTE 5CCA (BW=95 MHz)
- 5G deployed at 3.5 GHz (BW = 40 MHz)
- ~135 GB of transferred data
- 6.75 km

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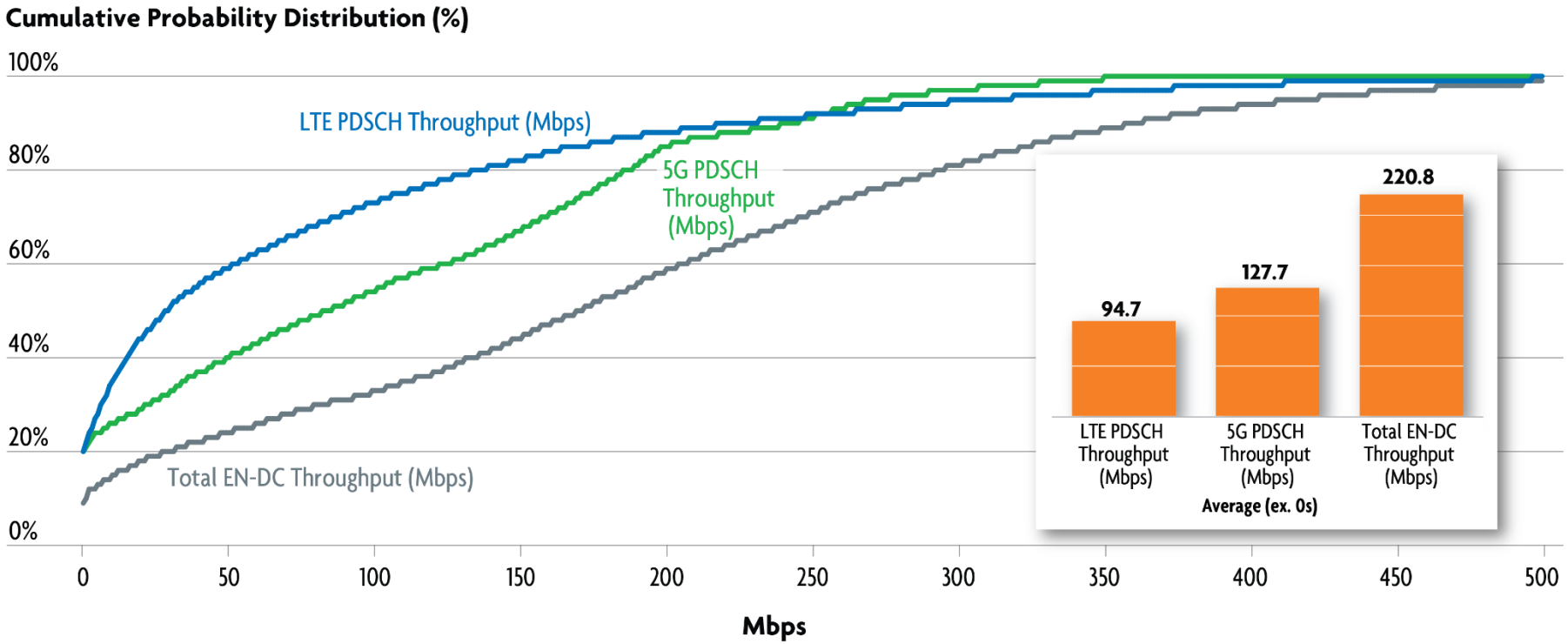
5G Performance in Central London

LTE and 5G Throughput Contributions



- OnePlus 7 Pro smartphone
- Average speeds @ 220 Mbps
- Peak speeds @ 600 Mbps
- Testing leveraged common applications (Google Drive, etc.)

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5G Performance in Bern Switzerland

EN-DC Throughput (5G + LTE)

- Swisscom has LTE 4CCA (BW=70 MHz)
- 5G deployed at 3.5 GHz (BW = 100 MHz)
- ~45.8 GB of transferred data
- ~8 km^2 area

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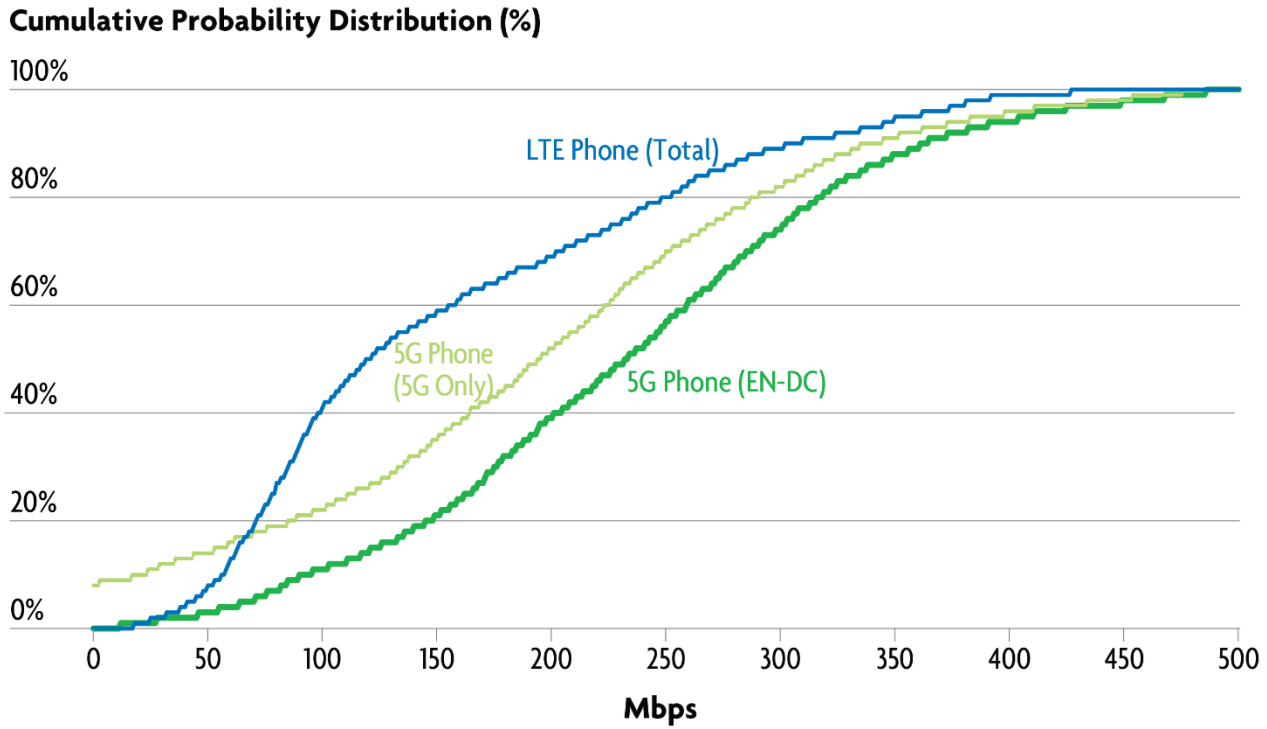
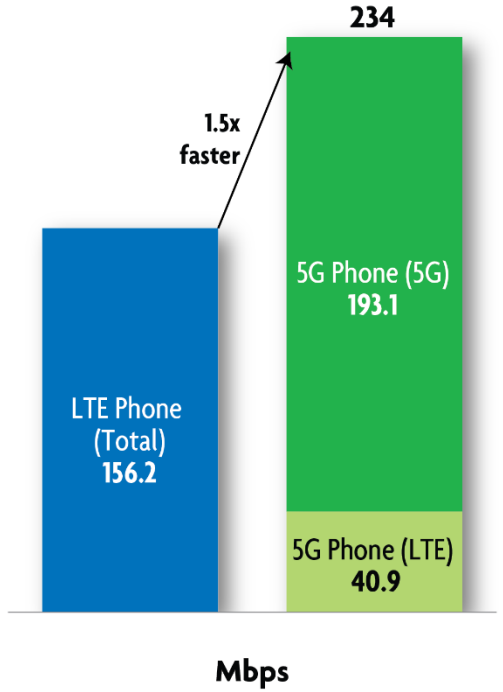
5G Performance in Bern Switzerland

5G-Capable versus LTE-Only Smartphones





- Two OPPO Reno 5G smartphones running in parallel
- 5G-capable phone was 1.5x faster than the LTE-only phone
- LTE contributed ~17% to the overall speed of the 5G phone

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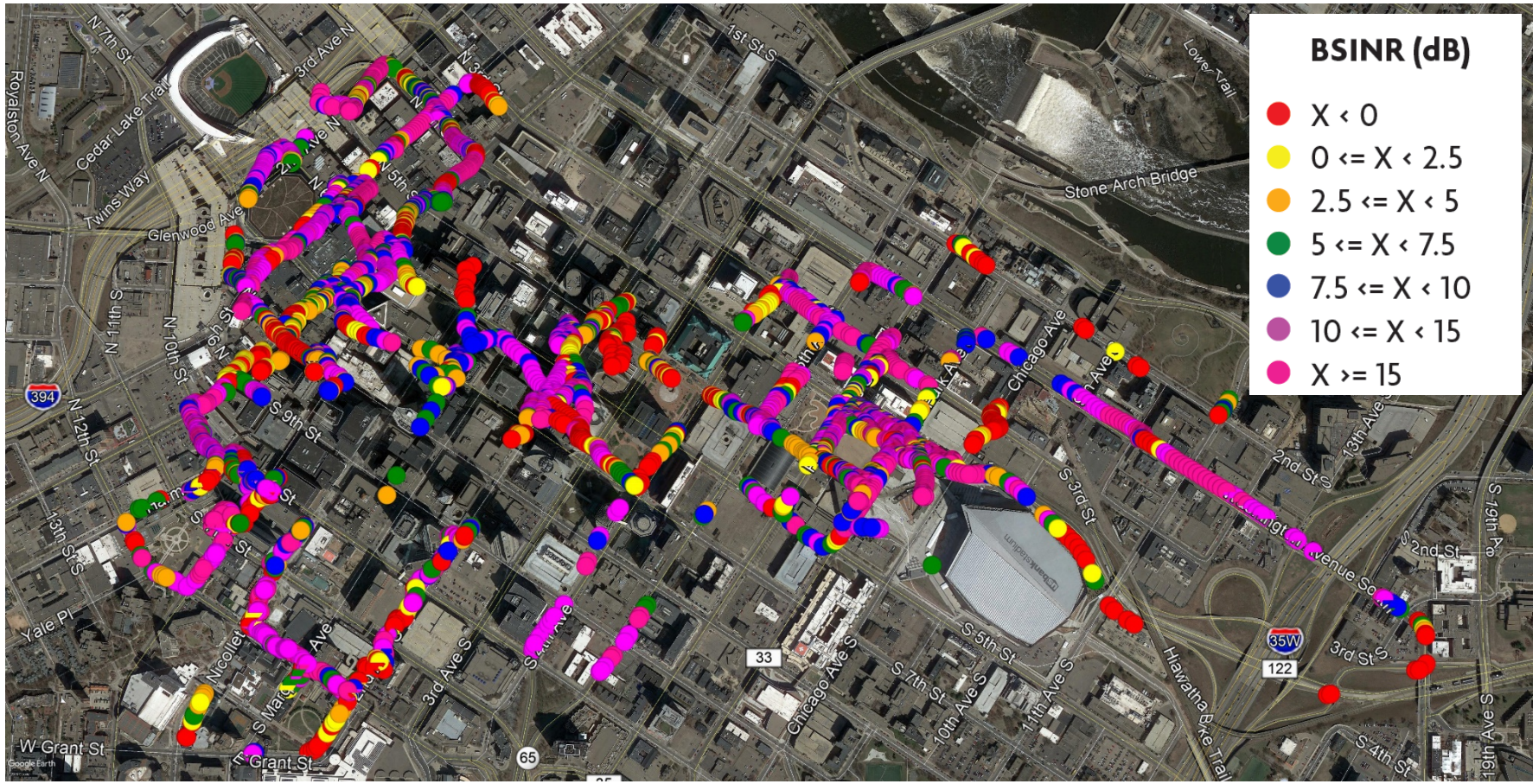
5G Millimeter Wave Performance in Minneapolis, MN (April 2019)

Geo plot of Measured Signal Quality (BSINR)



- Testing done just after Verizon launched commercial 5G services
- Figure shows signal quality (BSINR), as reported by the Motorola Moto Z3 smartphone with 5G module

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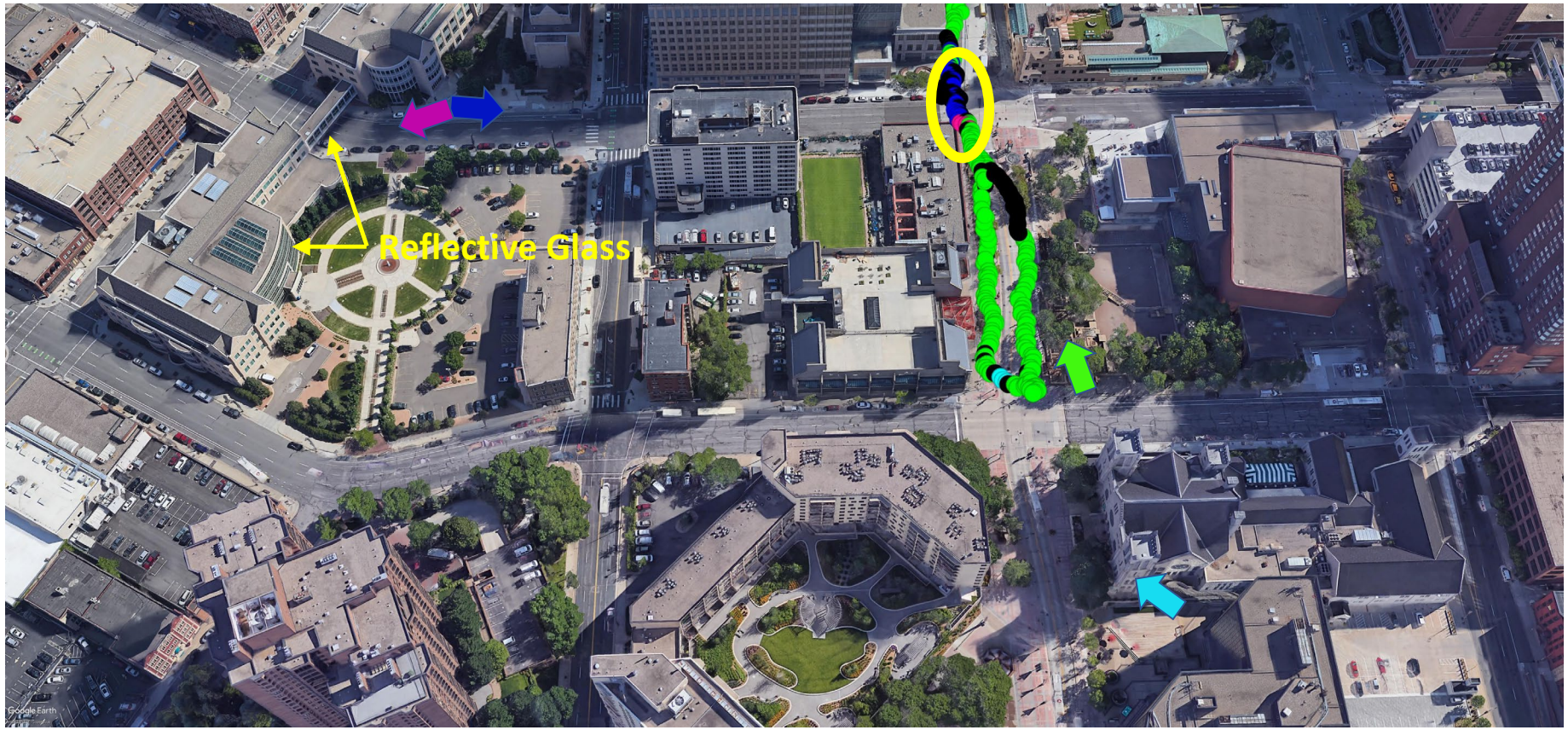
5G Millimeter Wave Performance

Geo plot of Nicollet Mall Walk Test



- Four 5G cell sites (PCIs) provide coverage over the ~1 block walk
- Highlighted intersection served by three 5G sites, including reflected beams from 1.5 blocks away

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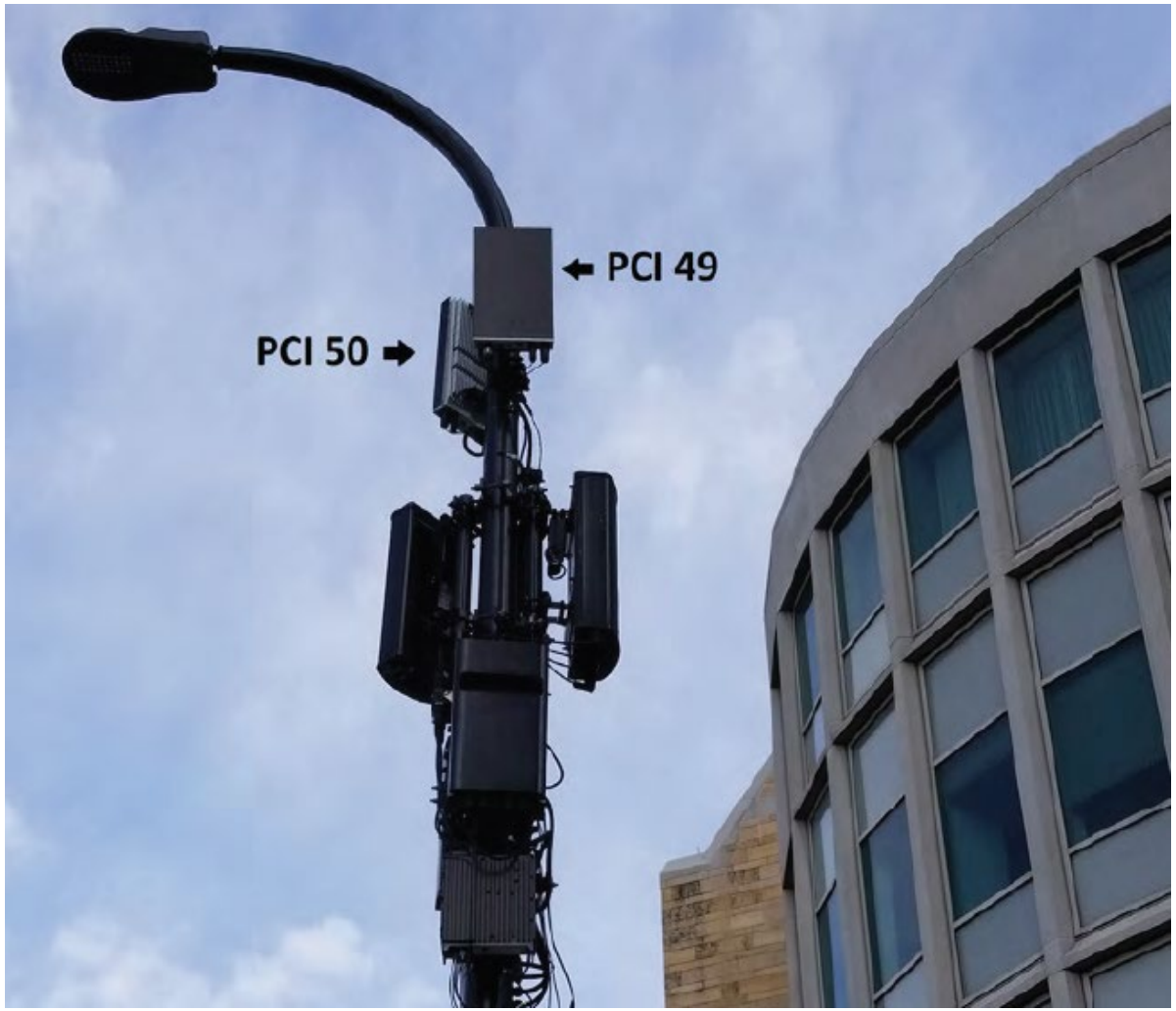
5G Millimeter Wave Performance

5G Cell Site Along 11th Avenue



- PCI 49 points down 11th avenue and toward the highlighted intersection
- PCI 50 points ~135 degrees away and toward a building and Skyway, which crosses 11th avenue

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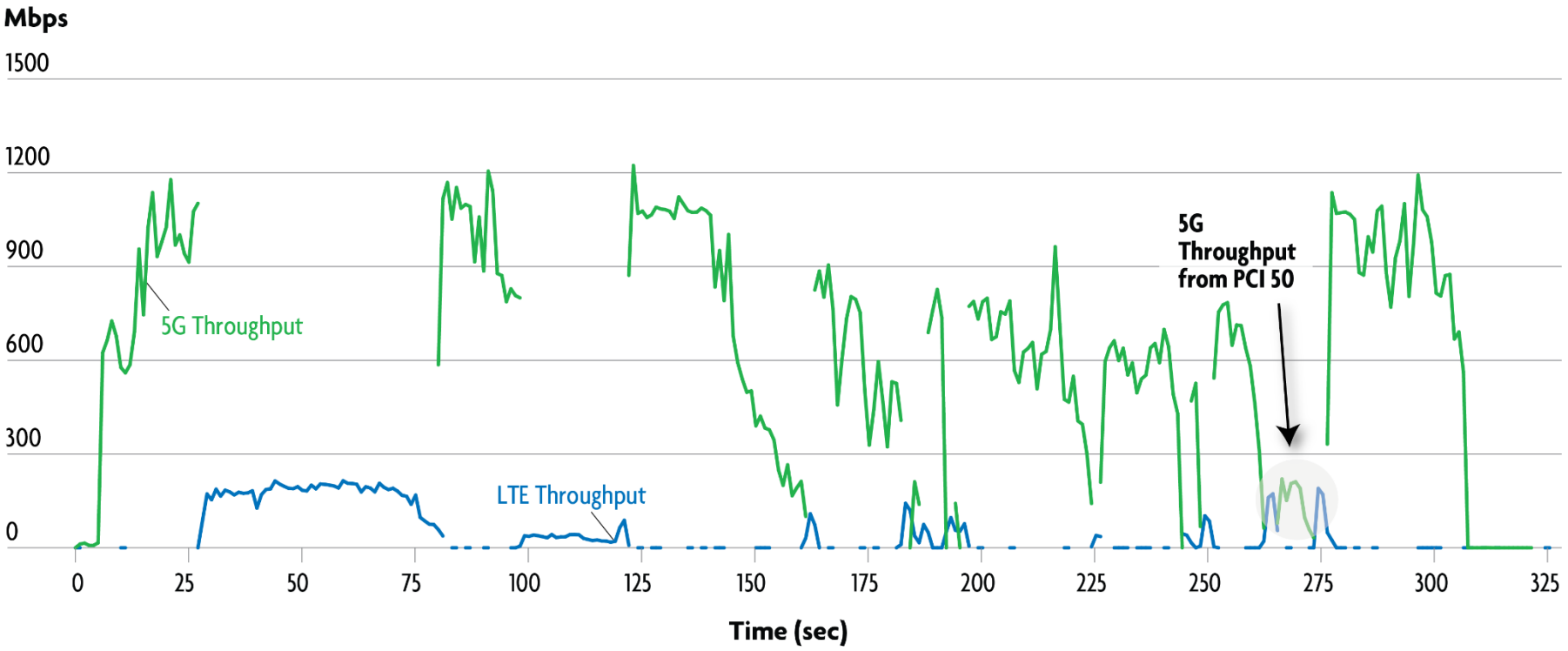
5G Millimeter Wave Performance

5G and LTE Throughput



- Although EN-DC wasn't supported, LTE provided meaningful throughput when 5G wasn't available
- Reflected signals generated data speeds approaching 200 Mbps

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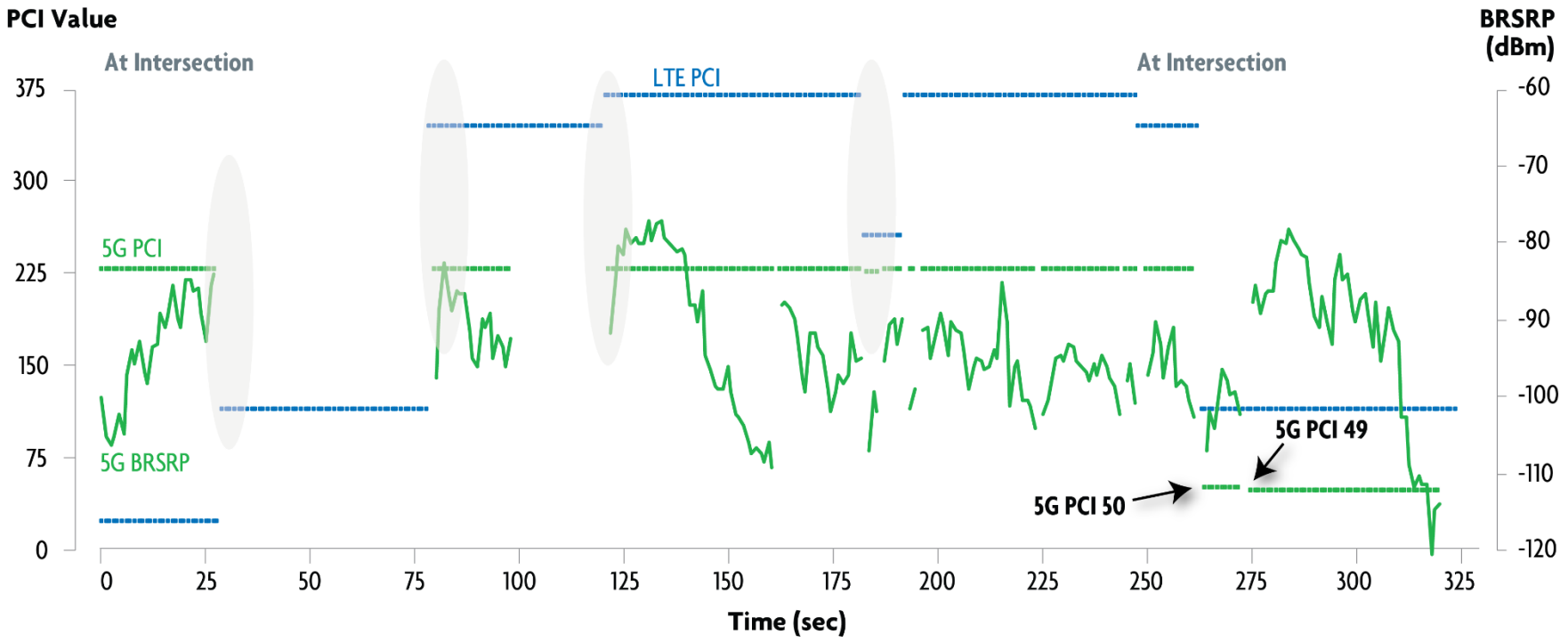
5G Millimeter Wave Performance

5G and LTE Cell Sites and 5G Signal Strength



- Time series plot in which the start and end of the figure occurs at the highlighted intersection
- Loss of 5G signal corresponds with a change in the LTE anchor cell (strong 5G signal throughout)

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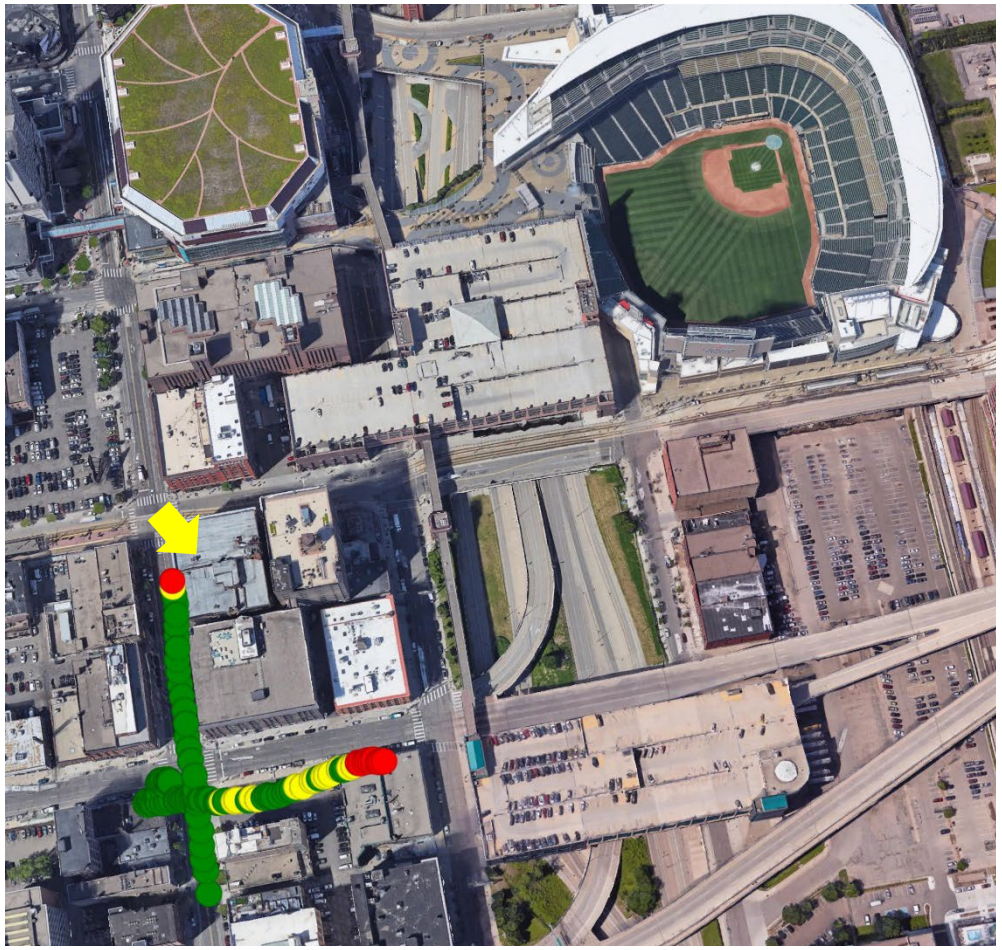
5G Millimeter Wave Performance

5G NLOS Coverage Based on Signal Strength (BRSRP)



- 5G PCI 99 points into the 3rd floor of a multi-floor office building
- Millimeter wave signals somehow extend around the corner at the nearby intersection
- Captured with Motorola phone

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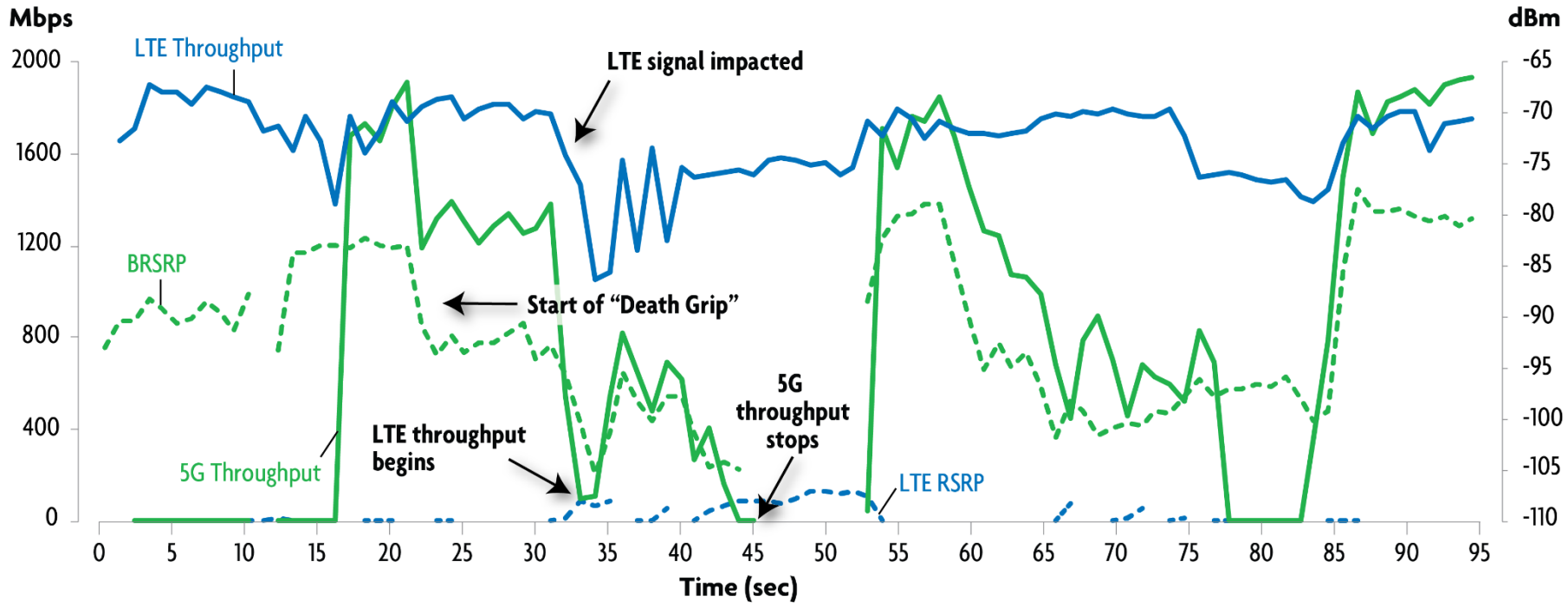
5G Millimeter Wave Performance

Performance Differences with the "Grip of Death"



- With considerable effort (and two hands) it is possible to significantly impact millimeter wave RF performance – also degrades LTE
- With normal hand placement the impact should be manageable

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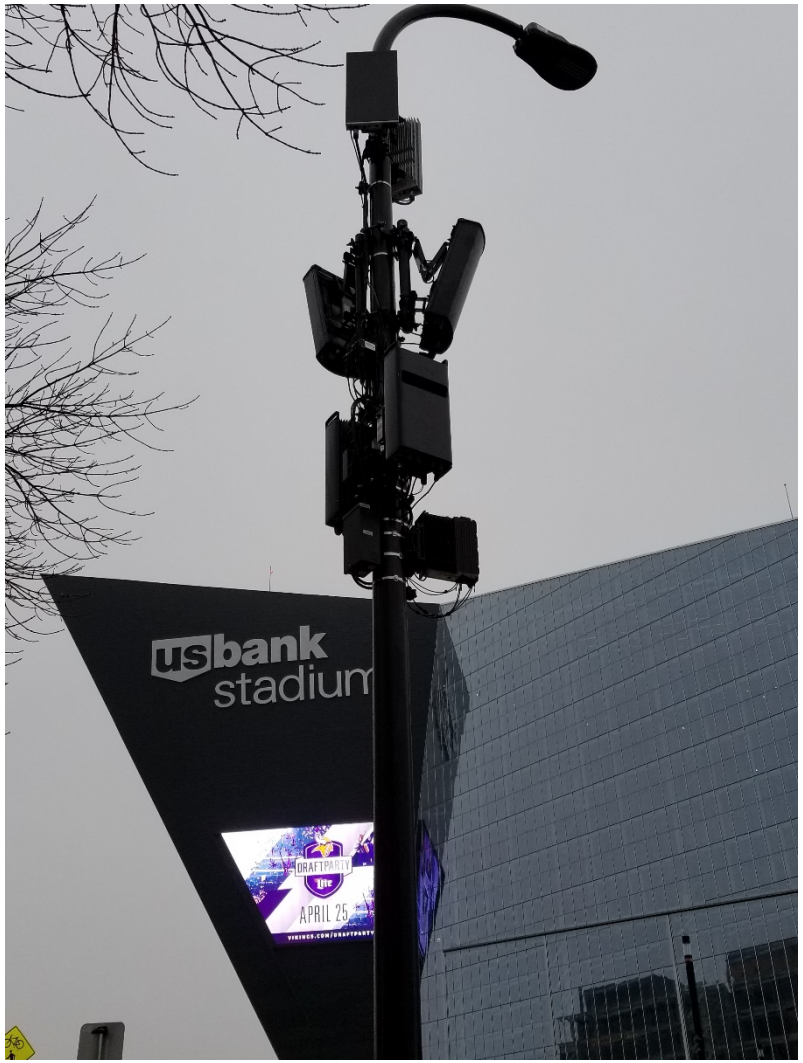
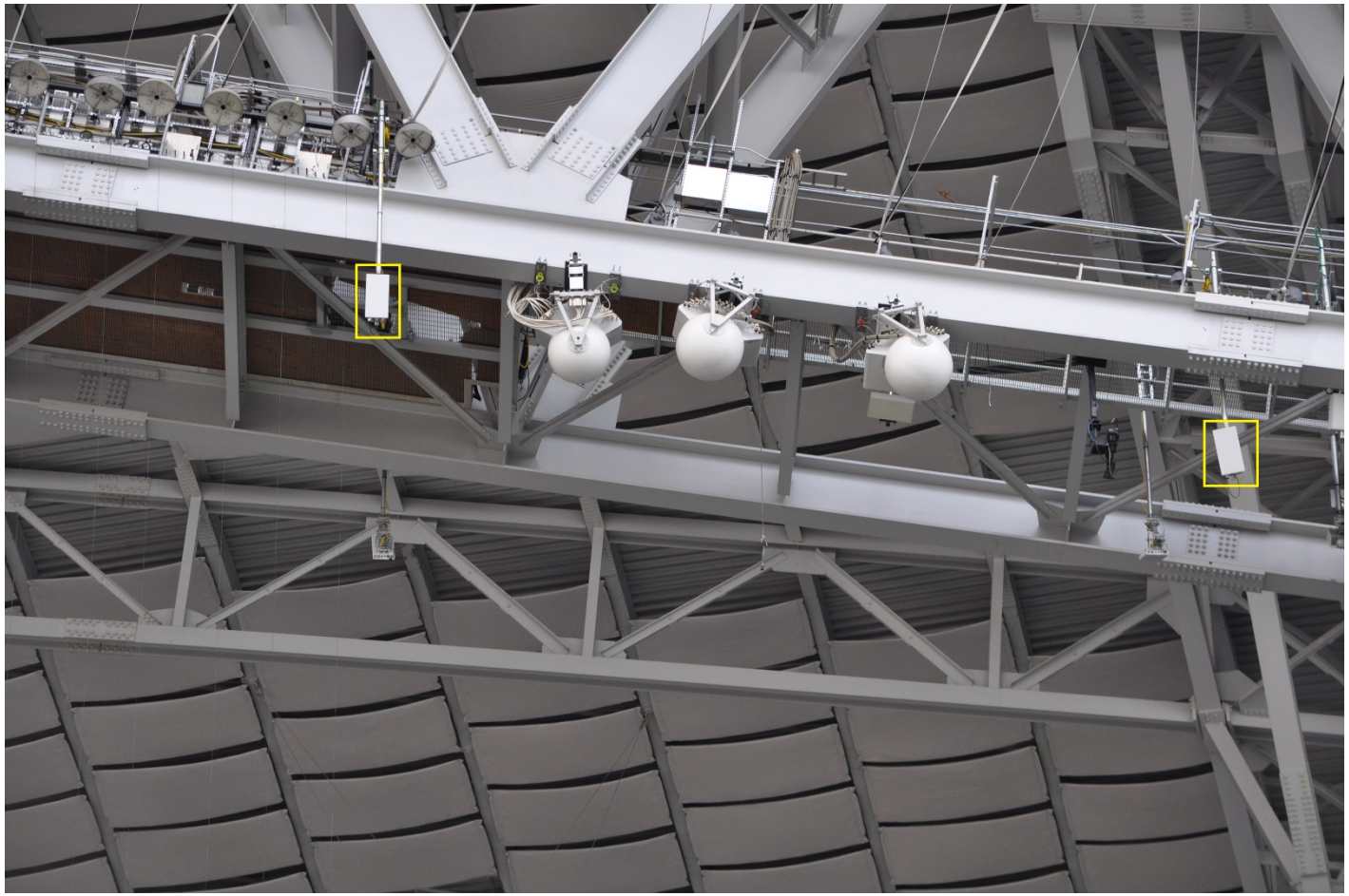
US Bank Stadium – Minneapolis, MN

Commercial 5G Outdoors (April 2019)



Commercial 5G INDOORS (September 2019)



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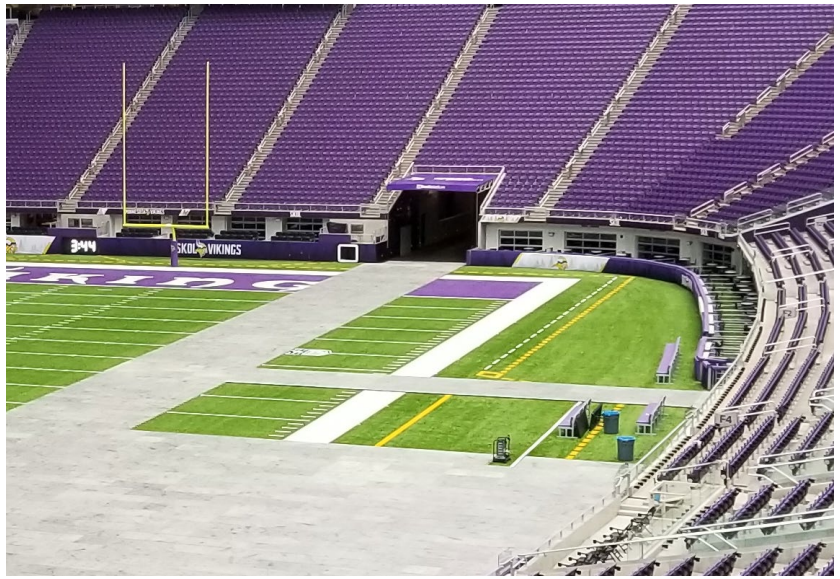
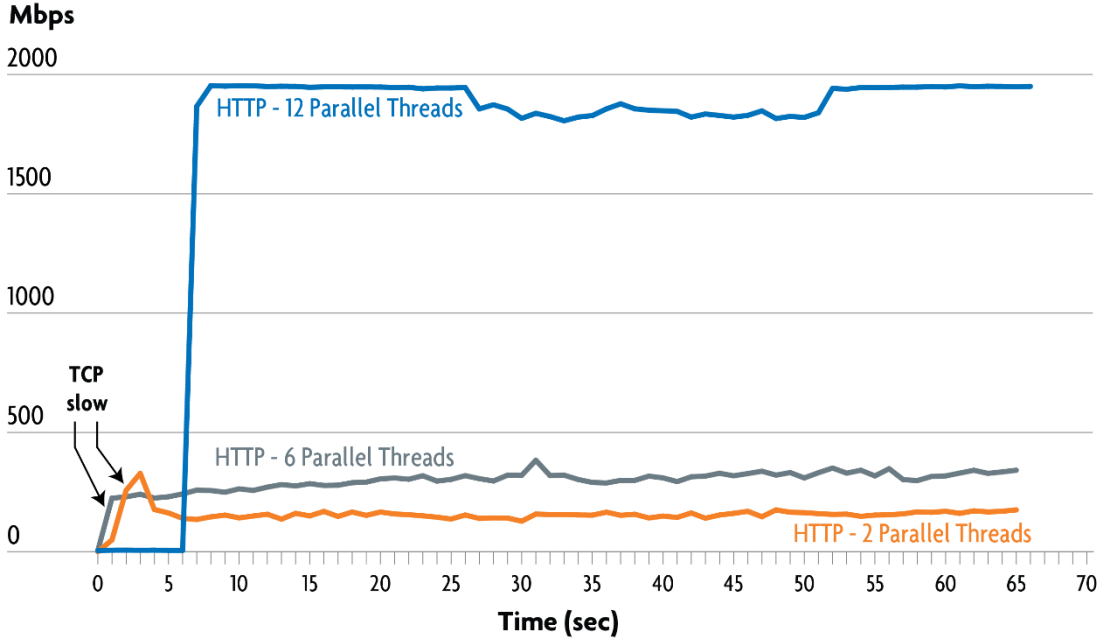
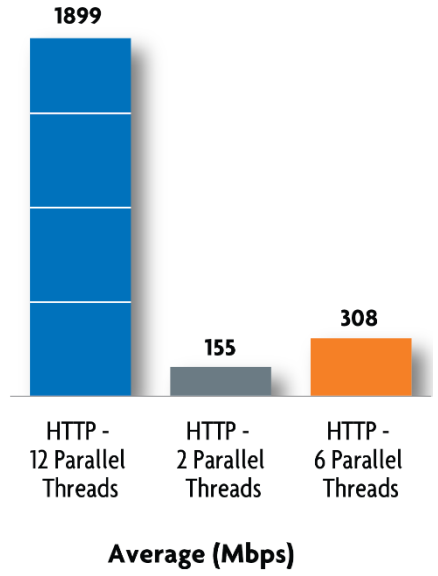
US Bank Stadium – Minneapolis, MN

My View



My Data Speeds





My Seat

- ~1.9 Gbps PHY Layer Throughput in my seat
- But protocol behavior can limit the user experience

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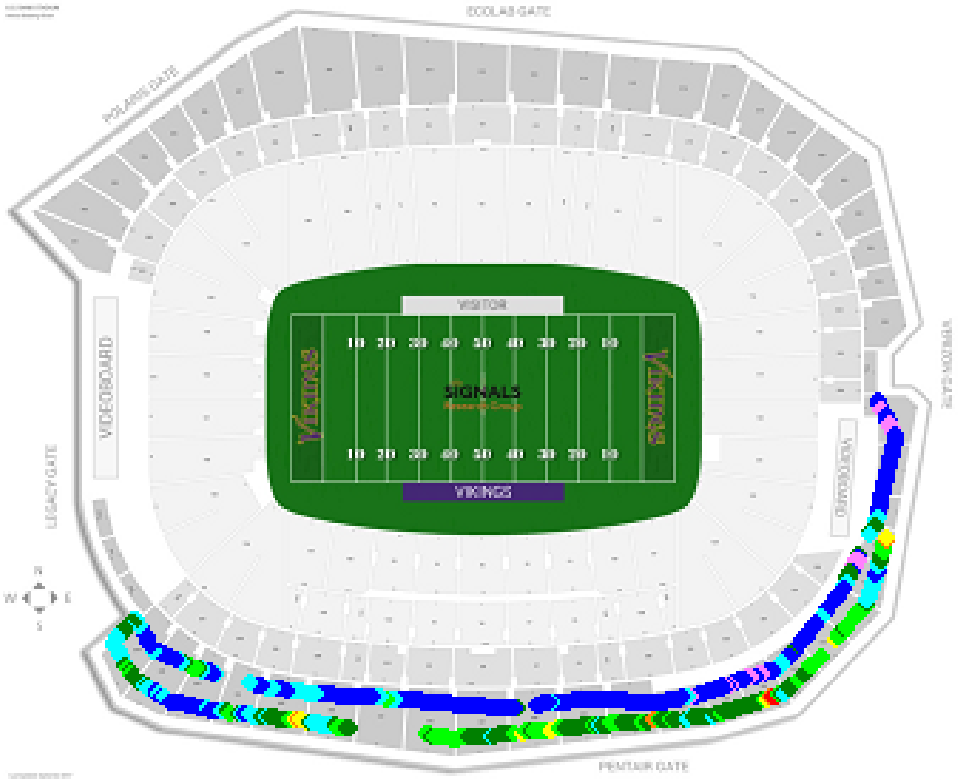
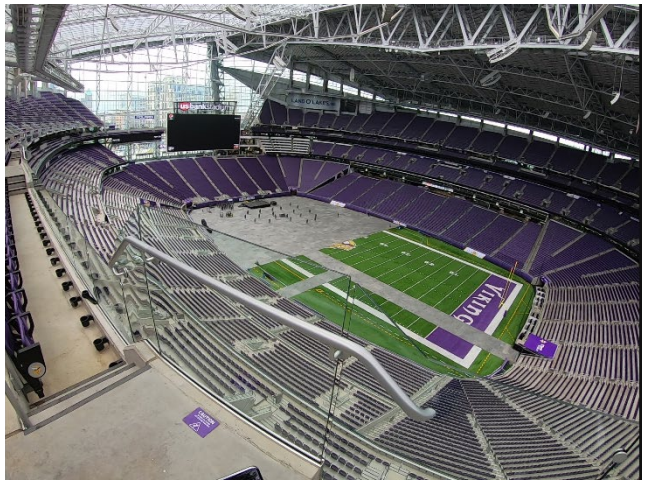
US Bank Stadium – Minneapolis, MN





BRSRP

- -80 <= x < -75 (3.58%, 20)
- -85 <= x < -80 (42.22%, 236)
- -90 <= x < -85 (17.89%, 100)
- -95 <= x < -90 (21.11%, 118)
- -100 <= x < -95 (12.52%, 70)
- -105 <= x < -100 (1.61%, 9)
- -110 <= x < -105 (0.72%, 4)
- x < -110 (0.36%, 2)

- Sample results show near ubiquitous coverage on the upper level
- Results extend to virtually all areas within the stadium

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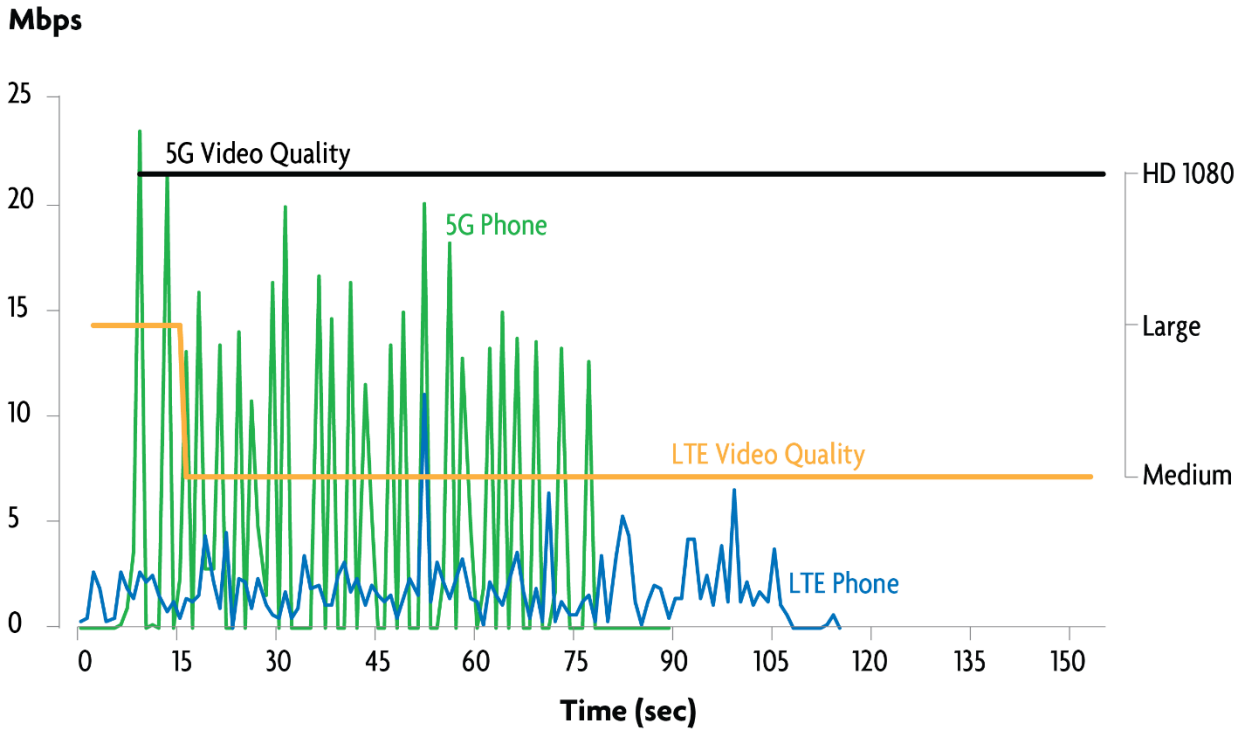
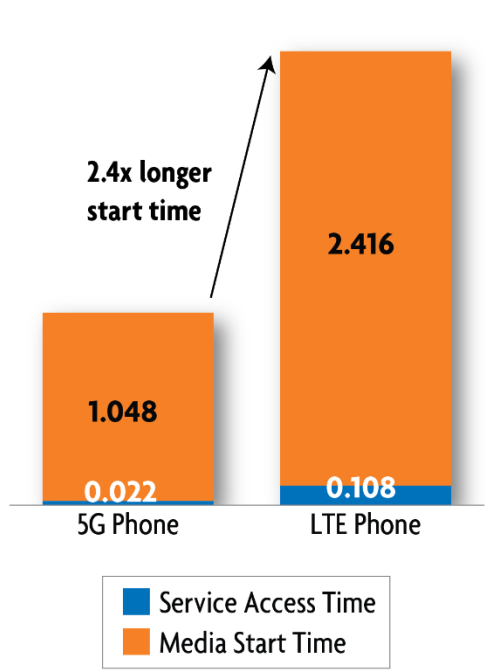
YouTube Playback

Real Time Throughput and Reported Video Quality





- Due to capacity constraints in the LTE network, the LTE-only smartphone reverted to a lower resolution format while the video playback took slightly longer

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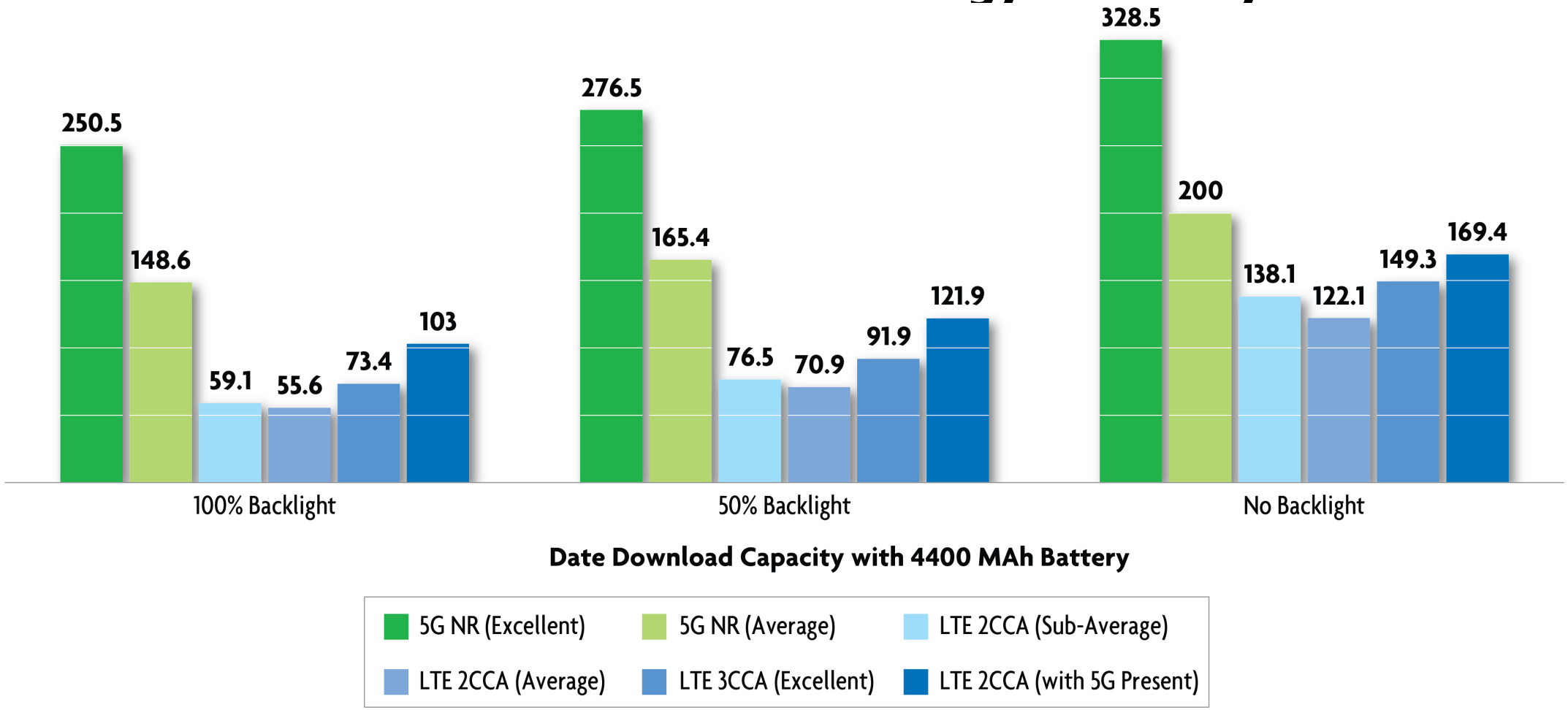
5G Millimeter Wave and LTE Energy Efficiency



- Higher energy efficiency translates into an ability to download more data for a given battery life (4400 mAh)
- Results depend on backlight display setting

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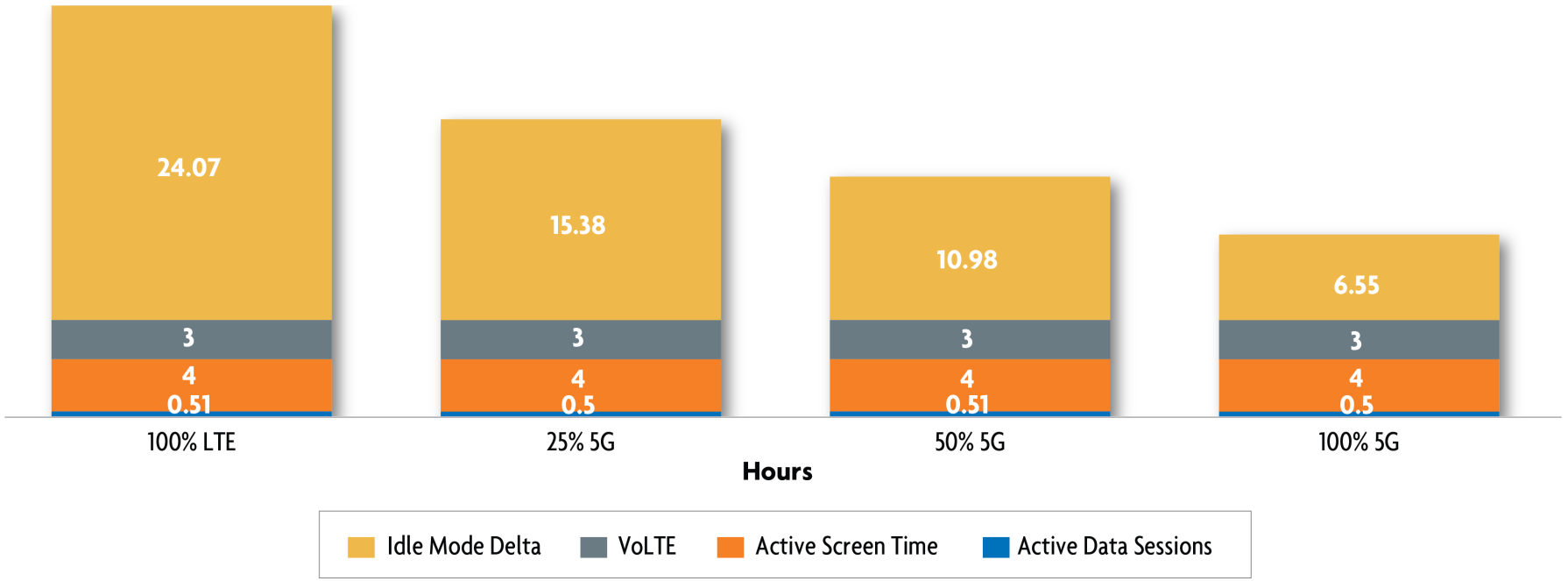
5G Millimeter Wave and a 12-Hour Workday



KEY ASSUMPTIONS

- 1.5 GB of transferred data
- 80% of data sent at 5 Mbps; 10% at 30 Mbps and 10% at max speed (measured)
- 50% display brightness
- 3 hours of VoLTE (5G present)
- 4 hours of other activity which requires the backlight
- Idle time reflects excess energy divided by current requirements

- Energy consumption due to data connectivity has little bearing on overall battery life
- Even with very conservative assumptions, a 5G smartphone can last a full workday

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Our Test Methodology and Partners

SPIRENT

PCTEL® Performance Critical

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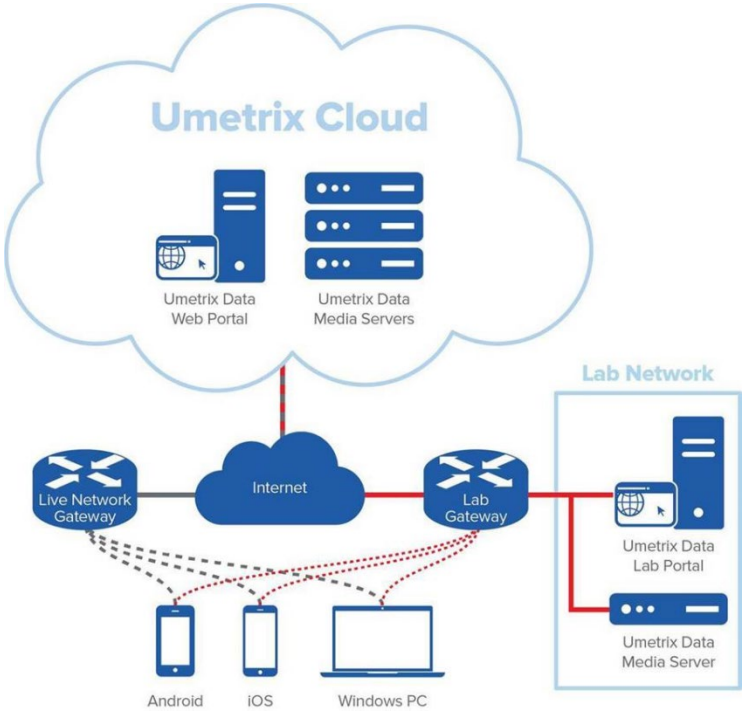

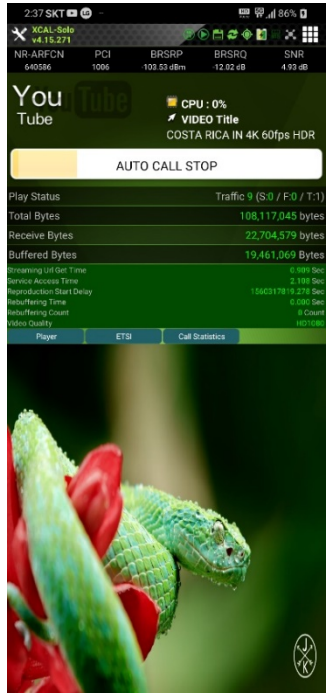

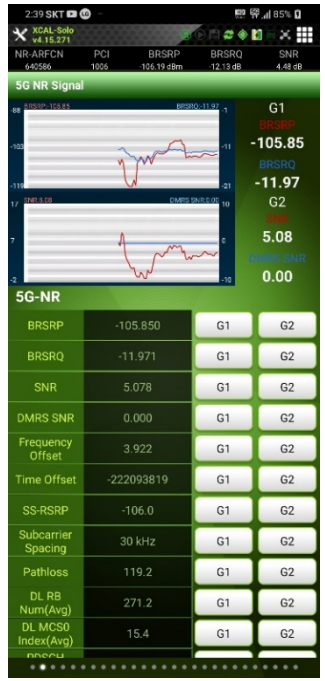

- Dedicated and highly-reliable data connectivity services, combined with real-time measurements of network and device/chipset parameters

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Final Thoughts

- Since the first commercial launch six months ago, 5G performance has continued to improve
  - Support for EN-DC (5G + LTE throughput)
  - Cell handovers (between 5G cell sites and beam indices)
- Consumers [and mobile operators] are already benefiting from the new capacity layer
- Continued improvements are in the works
  - Better utilization of 5G and LTE (EN-DC)
  - More concurrent 5G channels in millimeter wave (wider bandwidth)
  - Sub 6 GHz FDD deployments with DSS and chipset support
  - Leveraging NR-NR DC to improve coverage and increase data speeds / capacity

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