Outdoor-to-Indoor 28 GHz mmWave Measurements in the COSMOS Testbed Deployment Area

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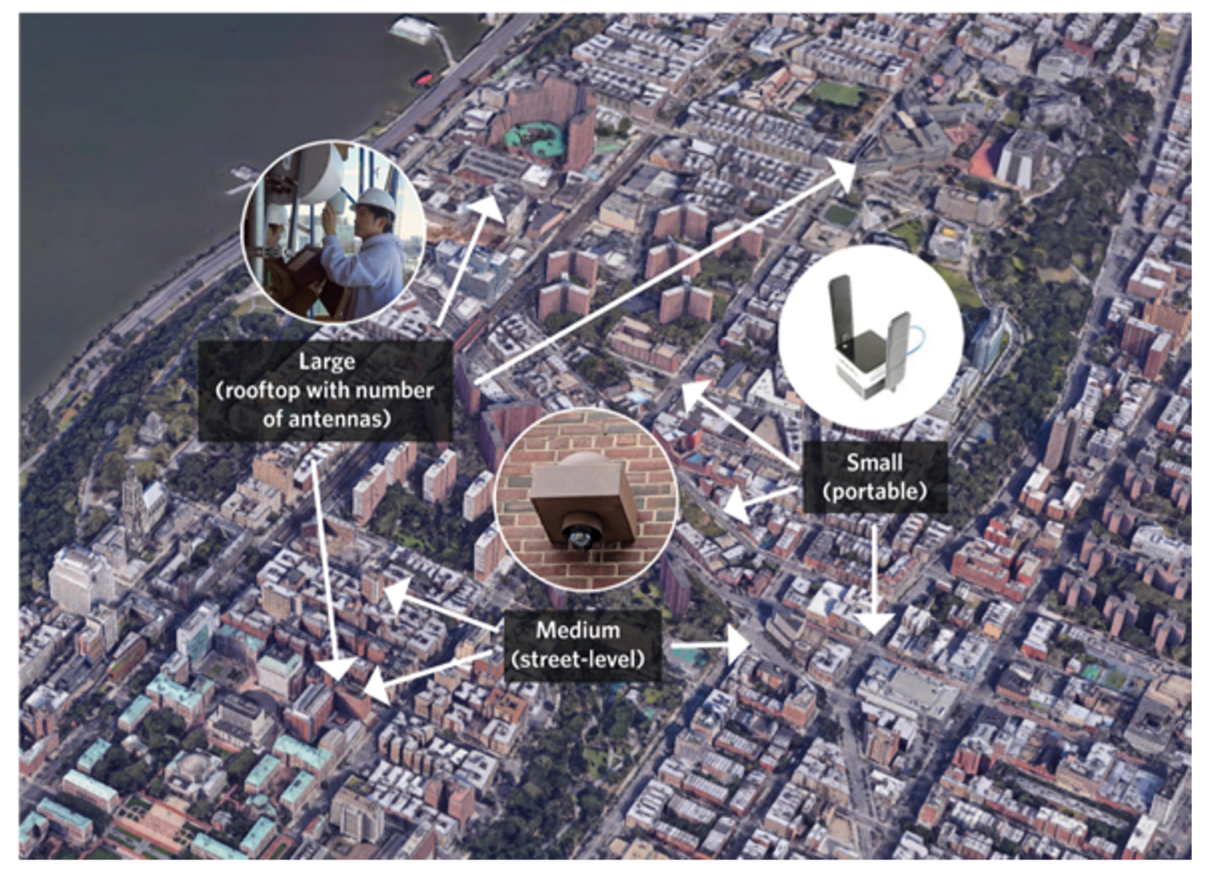
Abstract

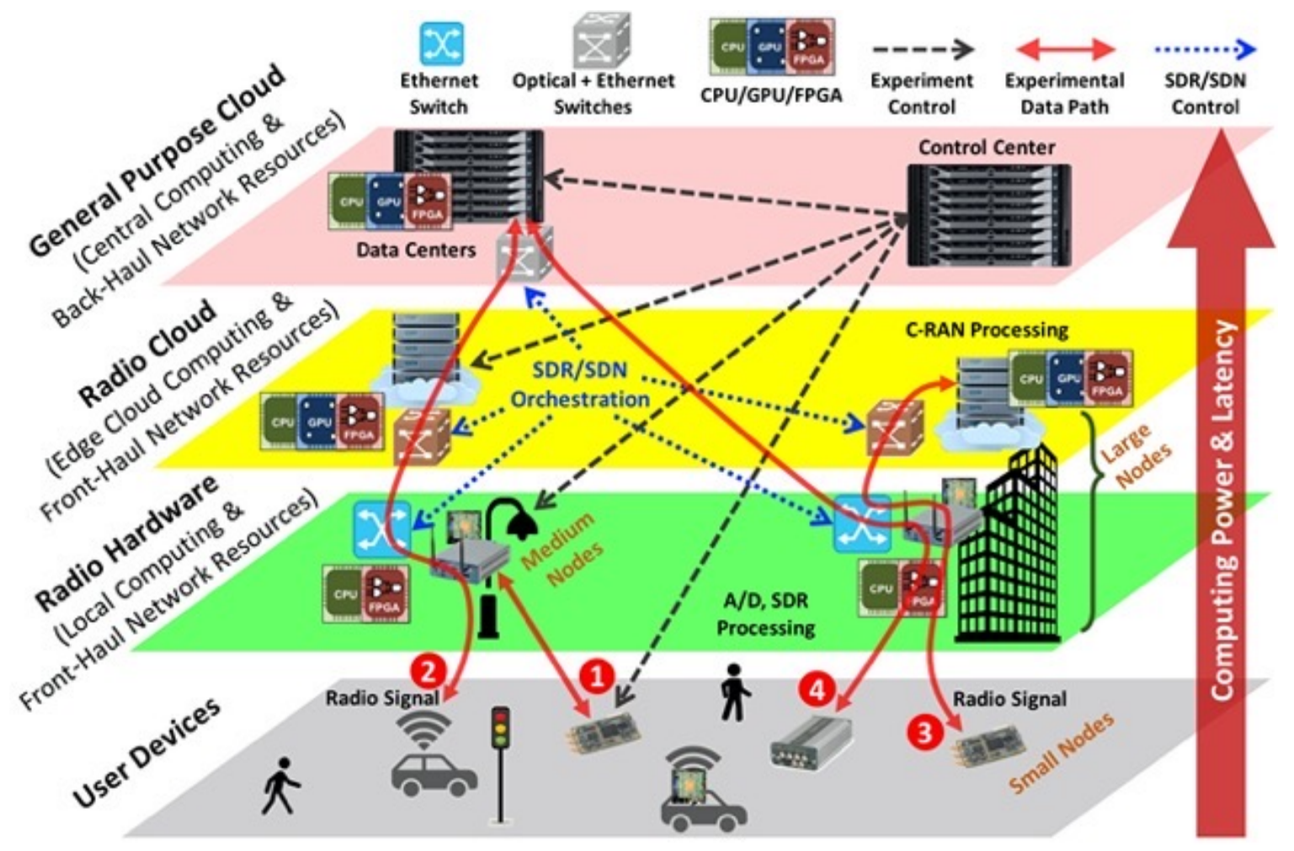
- 5G-and-beyond wireless networks will utilize millimeter-wave (mmWave) frequencies to achieve significantly higher data rates [1].
- The mmWave radio frequency signal experiences high path loss especially into buildings.
- Following from prior outdoors measurements [2, 3], to quantify and understand building penetration by a 28 GHz mmWave signal, a street-based measurement campaign in the deployment area of the PAWR COSMOS testbed in New York City was conducted. Results for two distinct types of common buildings are presented; newer buildings primarily constructed with glass and metal, and older buildings primarily constructed with brick.
- Path gain values with their fitted lines and the effective azimuthal beamforming gains are computed.
- Results can inform COSMOS testbed development, including the deployment of IBM 28 GHz phased array antenna modules [4] as well as indoor 5G/6G wireless access in locations such as public schools.

COSMOS Testbed

- *Cloud Enhanced Open Software Defined Mobile Wireless Testbed for City-Scale Deployment* (COSMOS) is a city-scale programmable testbed for advanced wireless technologies in West Harlem, New York City [5, 6].
- The COSMOS Team includes Rutgers, Columbia, NYU, University of Arizona and CCNY, alongside city, community and industry collaborations with New York City, Silicon Harlem, and IBM.

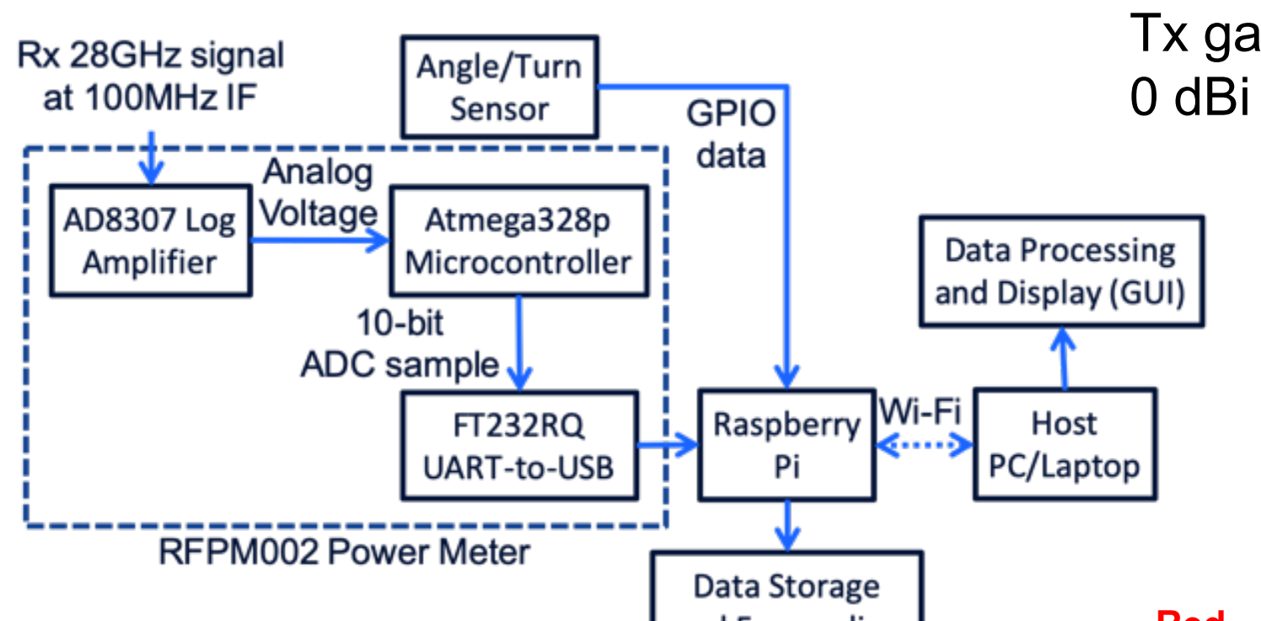


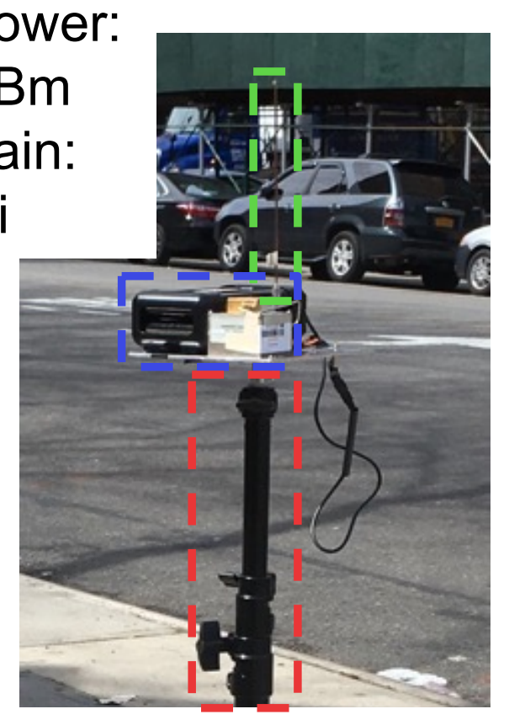
Deployment area of the COSMOS testbed



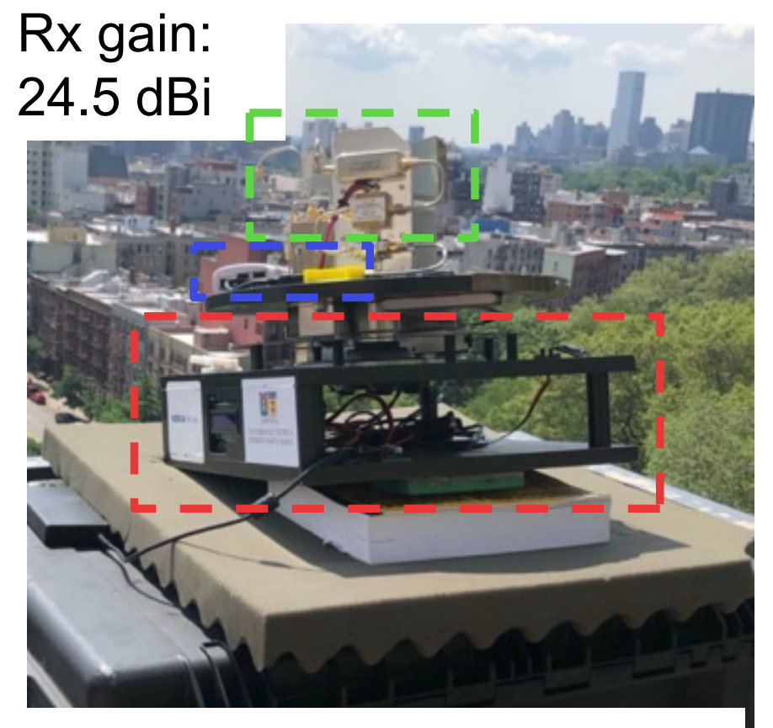
COSMOS' multi-layered computing architecture

Measurement Platform





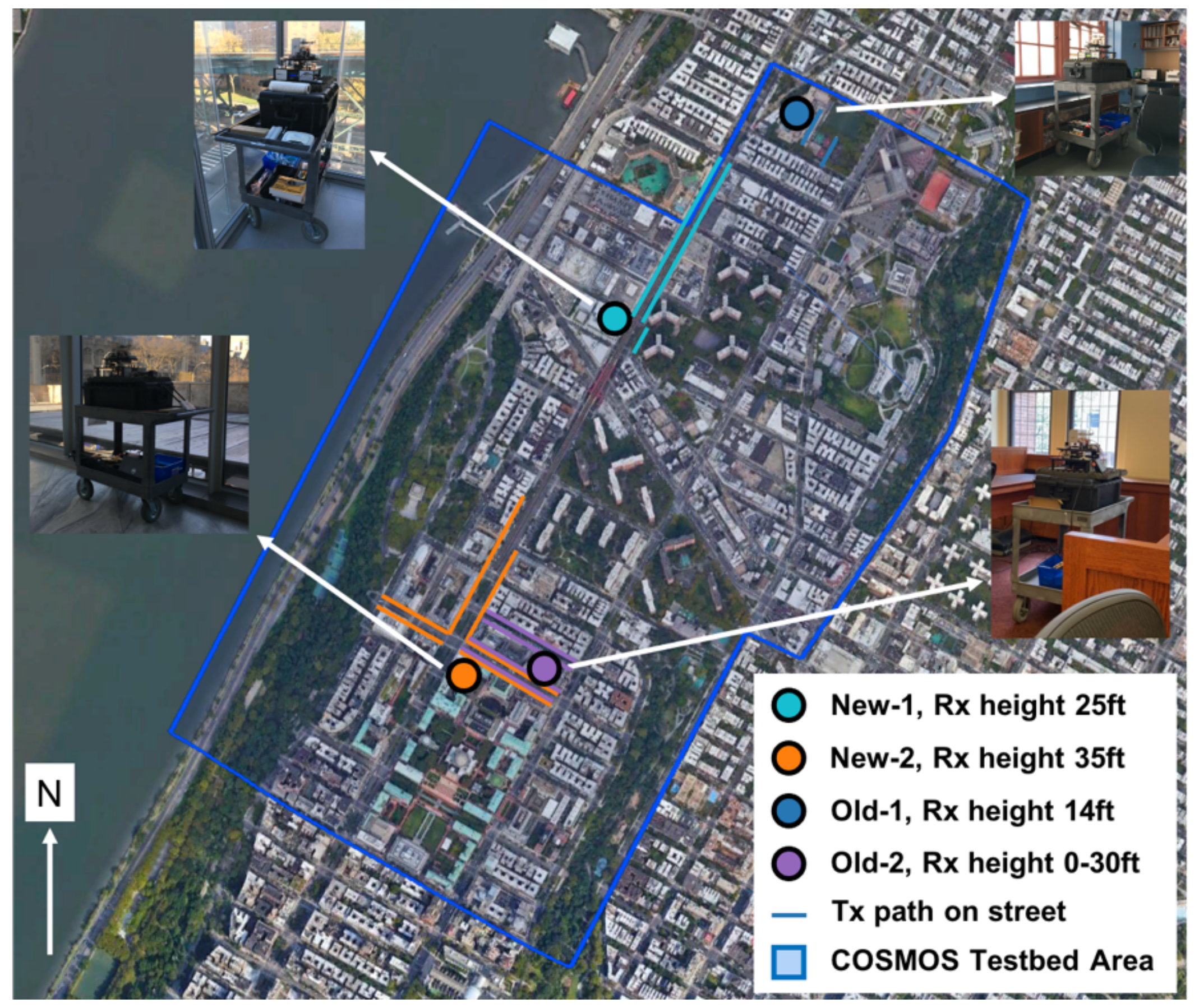
Red – Tripod for mounting Tx
Blue – Battery and RF circuits
Green – Omni-directional antenna



Red – Base and rotating platform
Blue – Power meter and Raspberry Pi
Green – 10 degree horn antenna

- We use a 28 GHz portable narrowband channel sounder.
- The transmitter (Tx) is equipped with an omni-directional antenna, and the receiver (Rx) is equipped with a 10-degree horn antenna with 24.5 dBi gain mounted on a rotating platform.
- Rx records power measurements at a rate of 740 samples per second using an onboard Raspberry Pi that is wirelessly controlled by a PC.

Measurement Environment and Locations



- Over 1,100 links measured across four different measurement sites, emulating different indoor environments and building types:
  - **New-1** – Corner office in modern building
  - **New-2** – Coffee shop in modern building
  - **Old-1** – Classrooms in older public school
  - **Old-2** – Library and cafeteria in older university
- **New-1** and **New-2** are modern buildings with predominantly glass and metal construction.
- **Old-1** and **Old-2** are older buildings with predominantly brick and concrete construction.
- Each measurement location except **Old-1** is in an urban street canyon. Measurements taken at **Old-1** are performed in the grounds of a middle school where the surrounding buildings are further away.
- These four deployment scenarios are common throughout NYC and other northeast US cities.

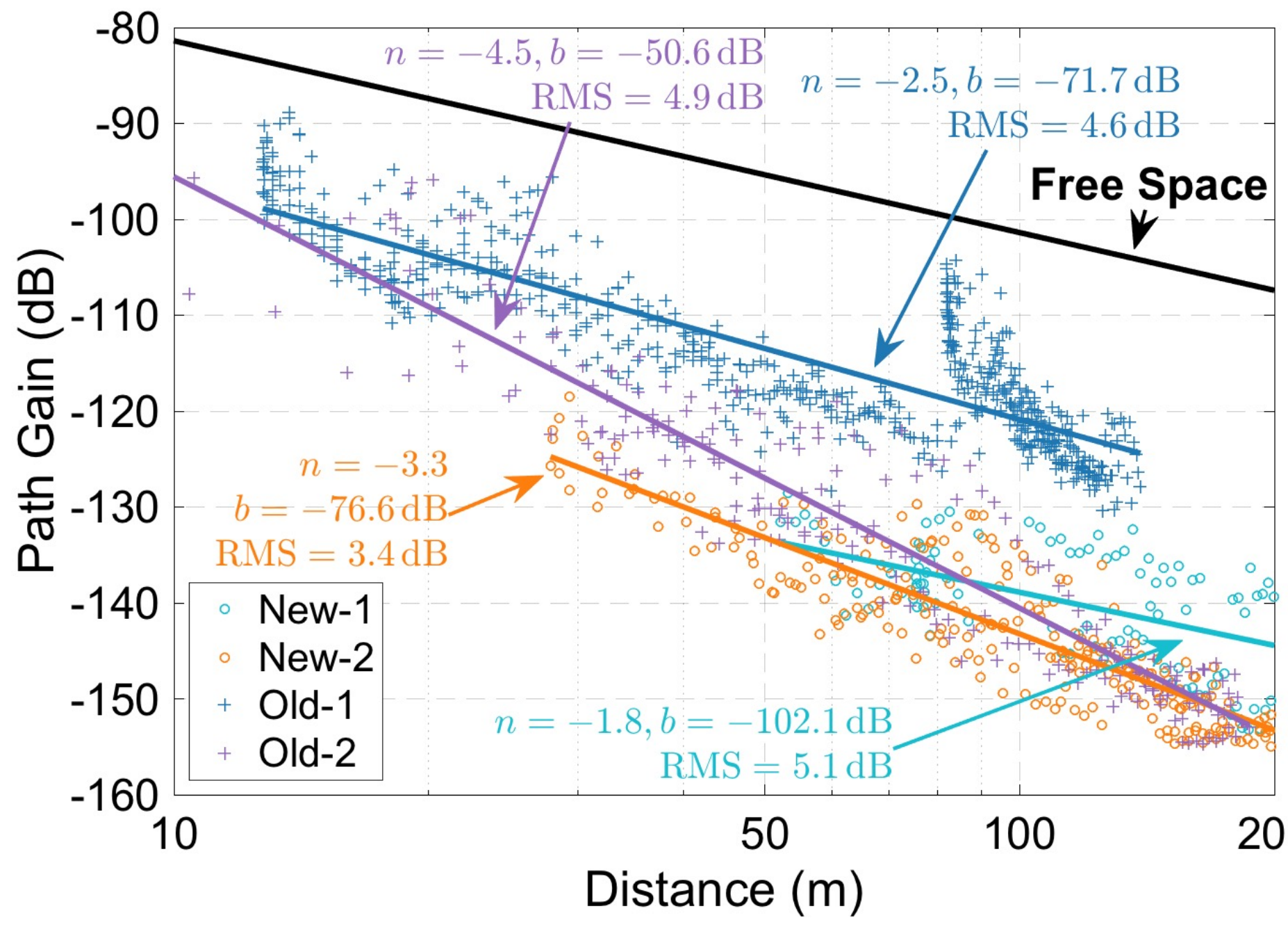
Results – Different Measurement Sites

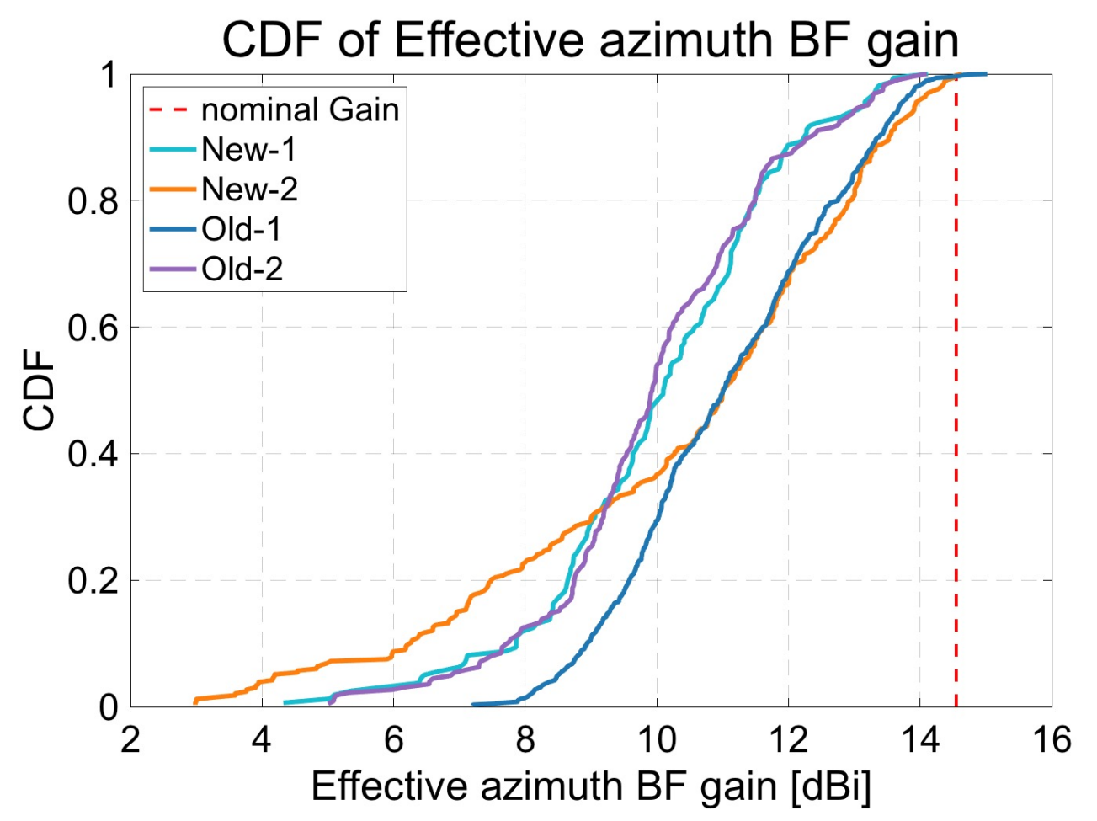
Path gain: $PG(d)=\overline{P_{horn}}(d)/(P_{Tx}\cdot G_{el})$

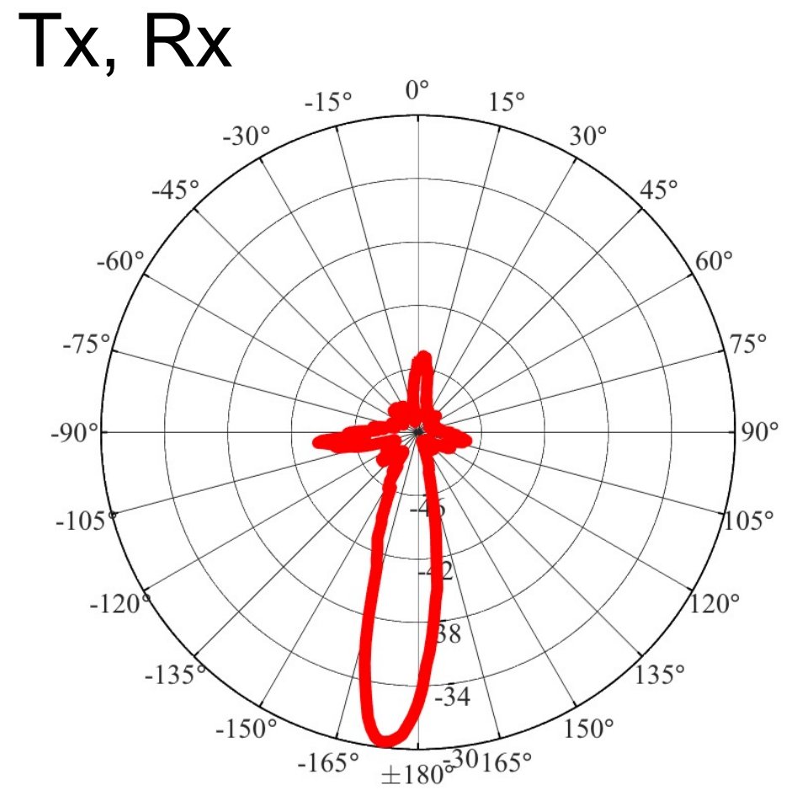
$\overline{P_{horn}}(d)$ = Average received power at link distance d

P_{Tx} = Tx power (22 dBm)

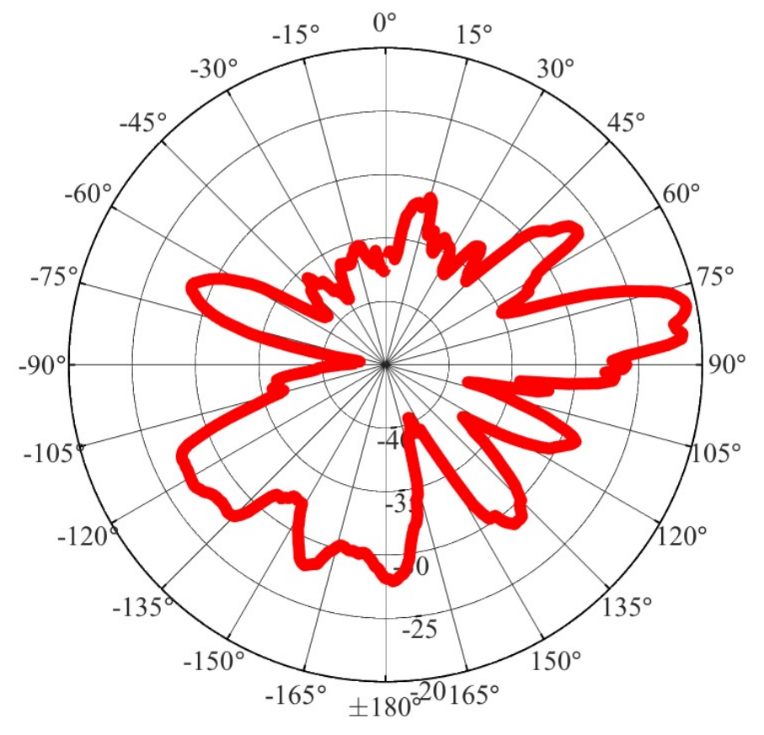
G_{el} = Elevation gain between Tx, Rx







Low scattering

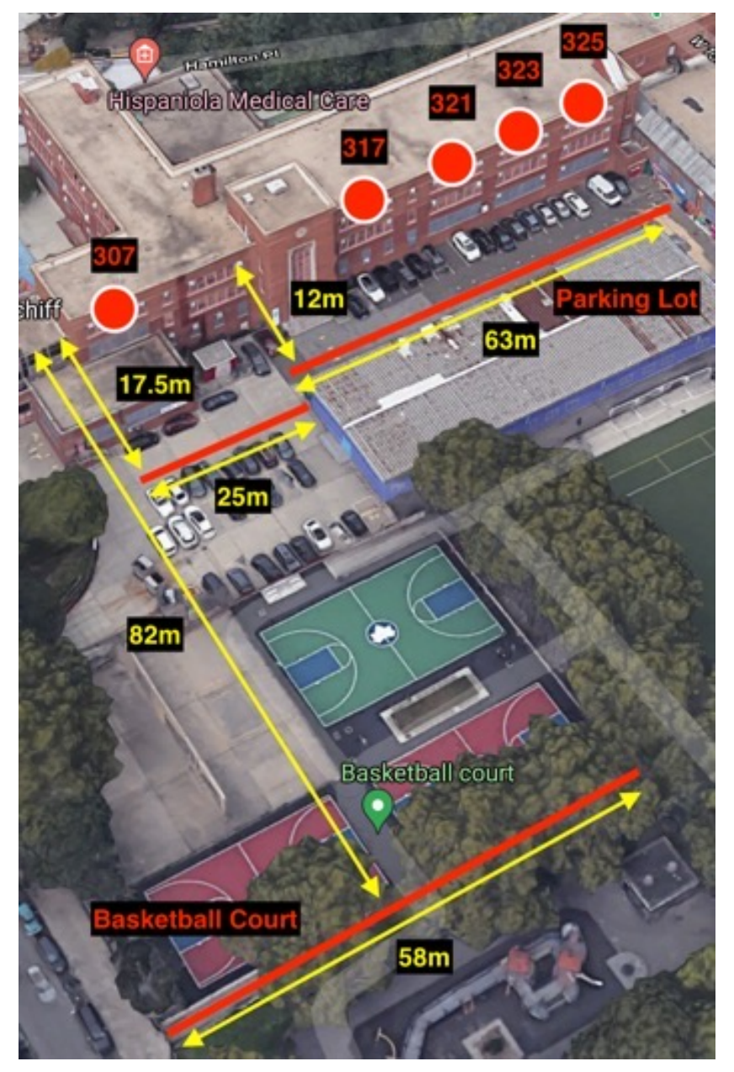


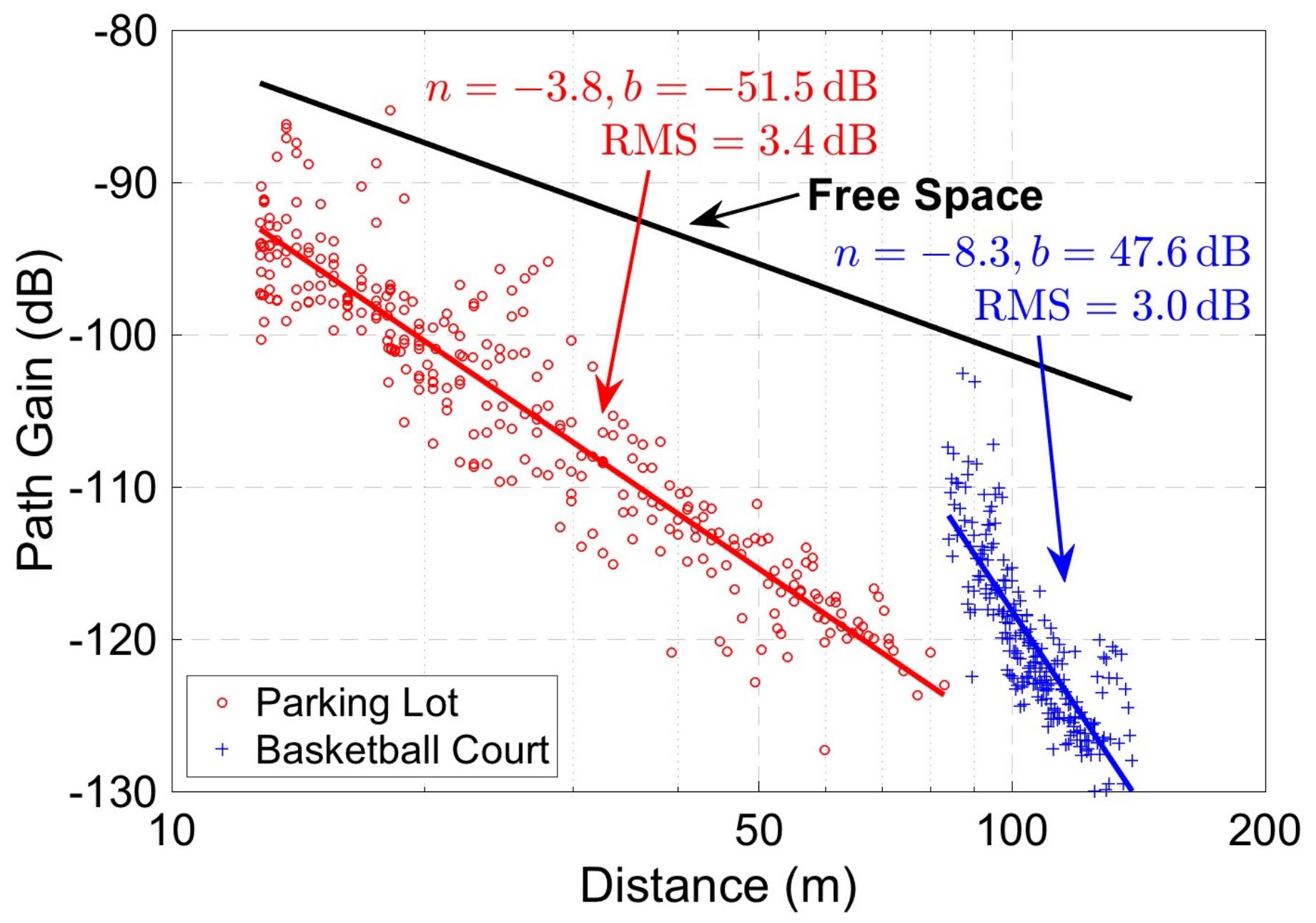
High scattering

- Effective azimuth beamforming (BF) gain is computed by taking the peak of the angular spectrum and dividing by the average: $G_{az}(d)=\max_{\phi}\{P(d,\phi)\}/\overline{P_{horn}}(d)$.
- In general at shorter distances, links measured from **Old-1** and **Old-2** experience lower path loss than links measured from **New-1** and **New-2**.
- Measurements at **Old-1** experience a much lower path loss than other locations. This is possibly due to the thin windows of the older building construction.
- All locations suffer 4-5 dB median beamforming gain loss due to scattering.

Case Study – Hamilton Grange Middle School at Old-1

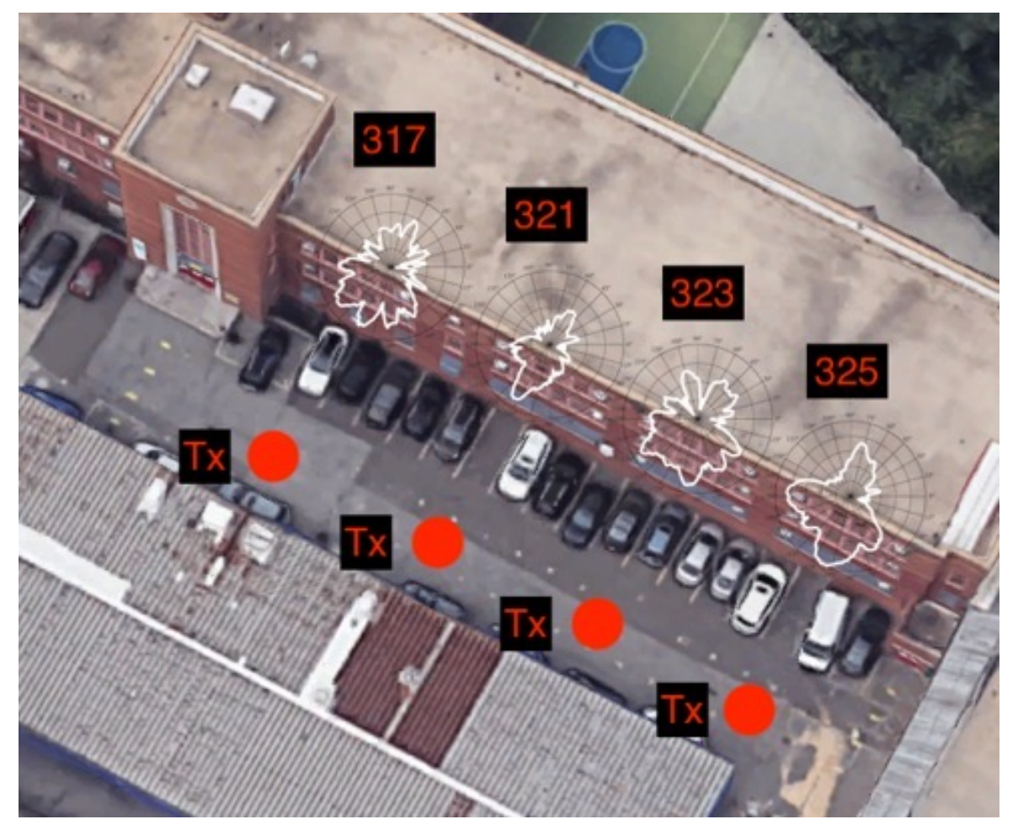
- Noticeable difference when moving Rx along red paths at Parking Lot (PL) and Basketball Courts (BC).
- 10dB difference in path loss at ~85m distance demonstrates the impact of the angle of incidence.
- ~85m distance at BC is at a low angle of incidence, ~85m distance at PL is at high angle of incidence.
- Implications on base station deployments: may need to avoid high angles of incidence.



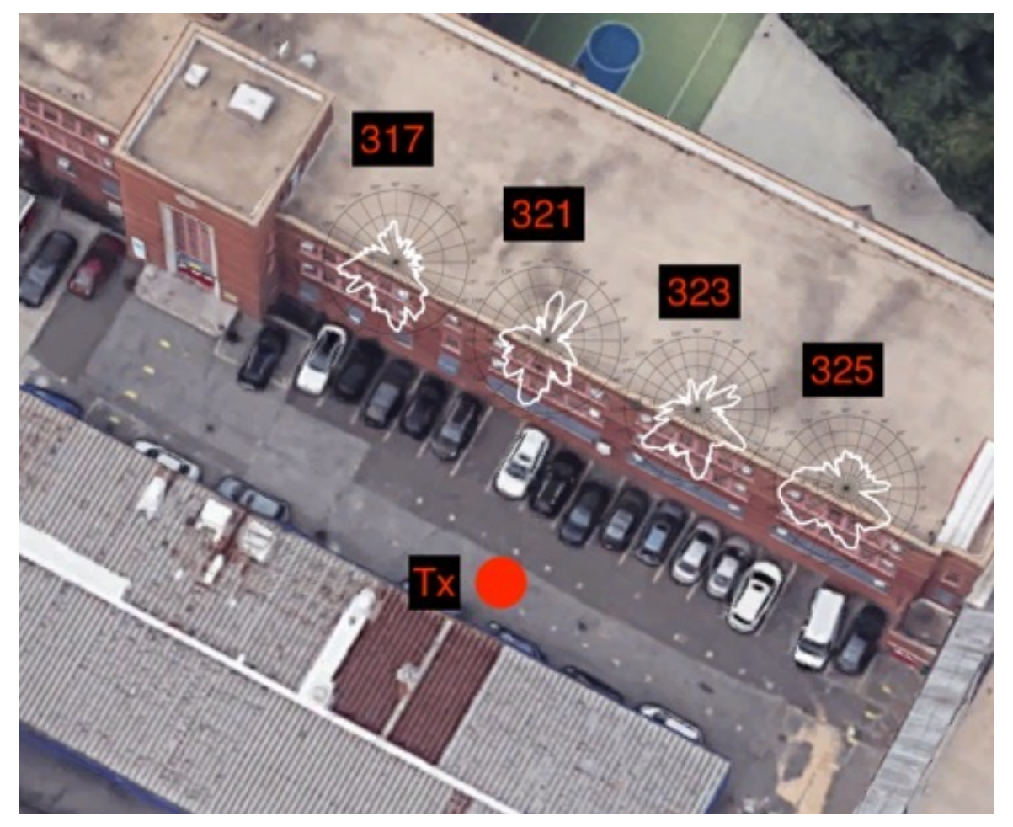


Angle of Arrival (AoA) for Classrooms at Old-1

- Angular spectra can also be analyzed to understand AoAs; the directions power is received from.
- Understanding AoA can help optimize location of outdoor mmWave nodes to provide maximum coverage indoors.
- Whether transmitter is placed in front of each classroom, or a single transmitter is placed in the middle of the classrooms, the peak power received is in the straight-line direction from Tx to Rx.
- Angular spectra in general show a large amount of scattering.
- This will reduce the beamforming gain achievable in such links, but also lessens the need for ultra-precise beamforming and beamsteering.
- Define typical values for a mmWave link: Tx power P_{Tx}= 28 dBm, Tx gain G_{Tx}= 23 dBi, Rx gain G_{Rx}= 9 dBi, Rx noise floor N_{Rx}= -90 dBm. With worst-case measured path gain of -130 dB, a signal-to-noise ratio (SNR) of 20 dB is achieved. At 200 MHz bandwidth, indoor data rates would be in excess of 1.3 Gbps.



Angular spectra for transmitter placed in front of each classroom

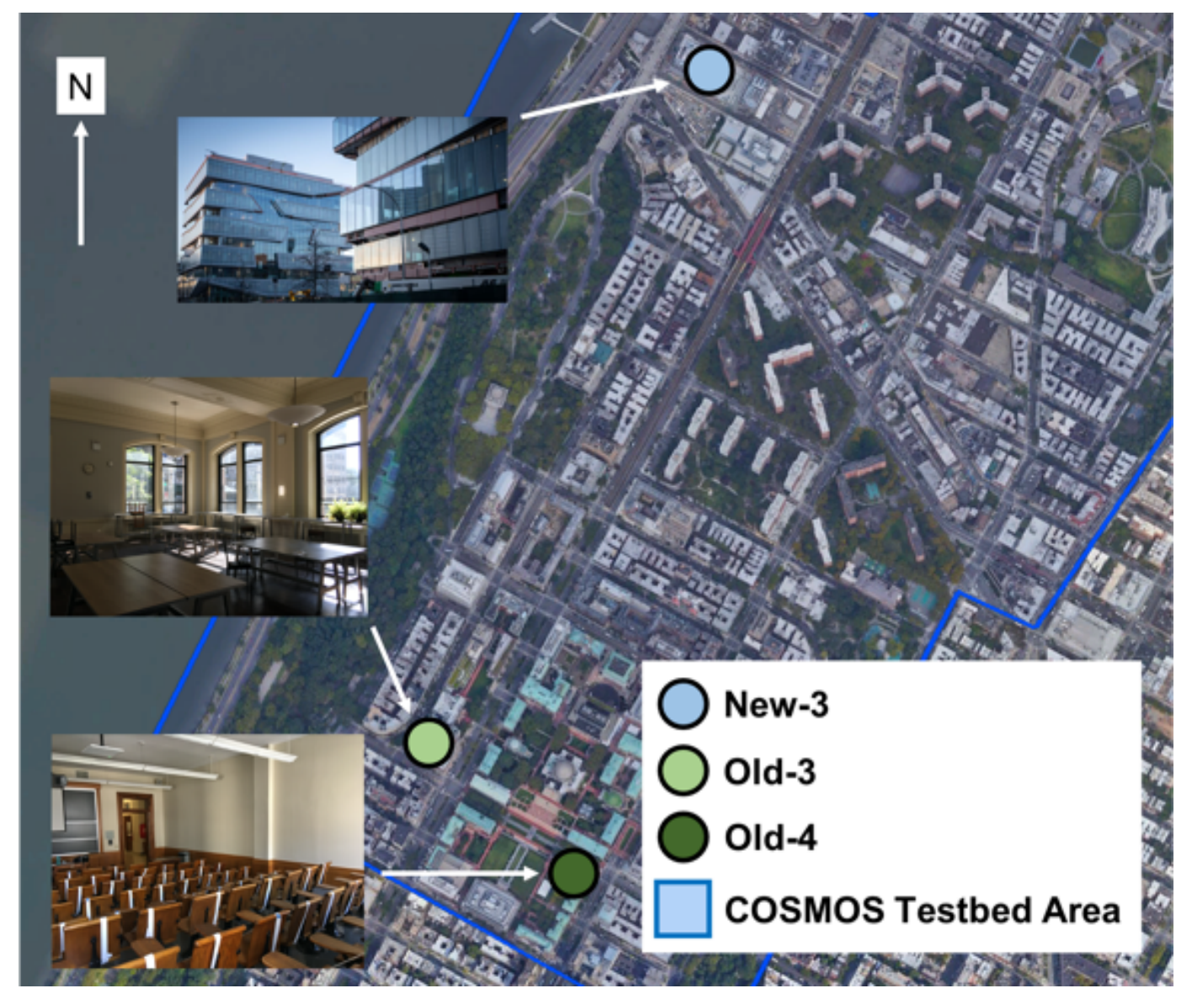


Angular spectra for single transmitter location in middle of classrooms

$$SNR=P_{Tx}+G_{Tx}+PG+G_{Rx}-N_{Rx}$$

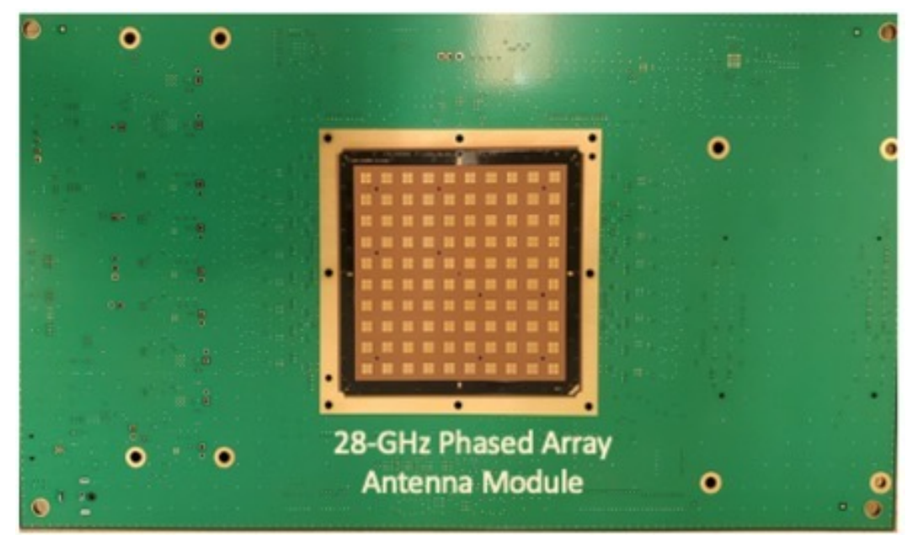
Ongoing & Future Work

- More extensive measurements in the current locations, as well as new ones in the COSMOS testbed area.
- Deployment of IBM phased arrays into COSMOS medium nodes [4].
- Utilize measurement data to analyze performance of IBM phased arrays when used in a fixed-wireless access (FWA) deployment [7].

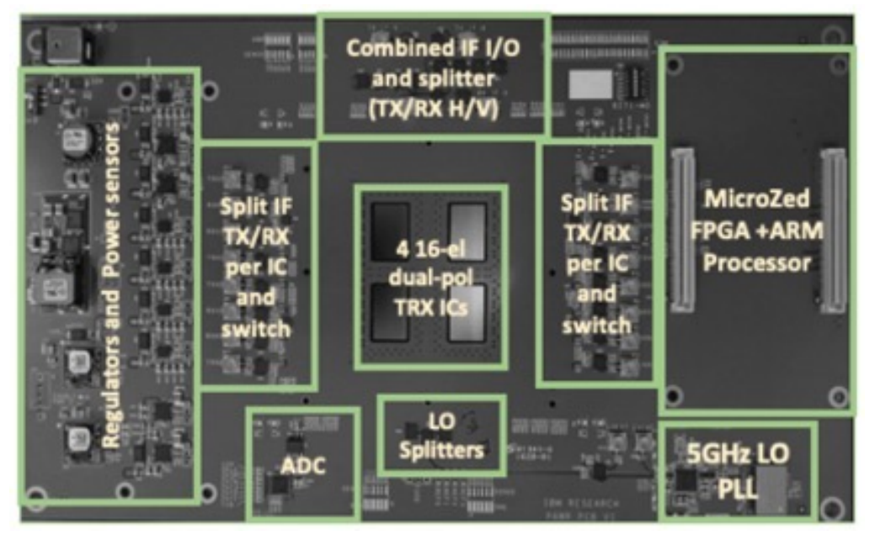


Future measurement locations

Medium Node



IBM Phased Array



IBM Phased Array Electronics

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