28 GHz Channel Measurements in the COSMOS Testbed Deployment Area*

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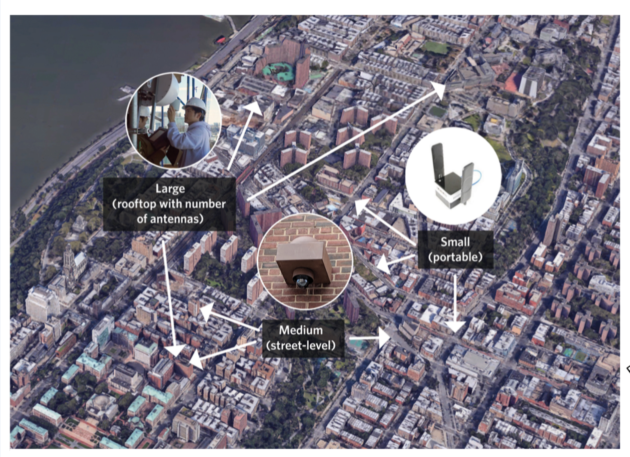
Abstract

Next-generation wireless networks will utilize millimeter-wave (mmWave) frequencies to achieve significantly higher data rates [1]. However, due to the high path loss at mmWave frequencies, accurate channel measurement and modeling for different deployment sites is required. We conducted an extensive mmWave channel measurement campaign with over 2,800 links on 24 sidewalks in the COSMOS testbed deployment area in West Harlem, New York City between March and August 2019, and Fall 2020.

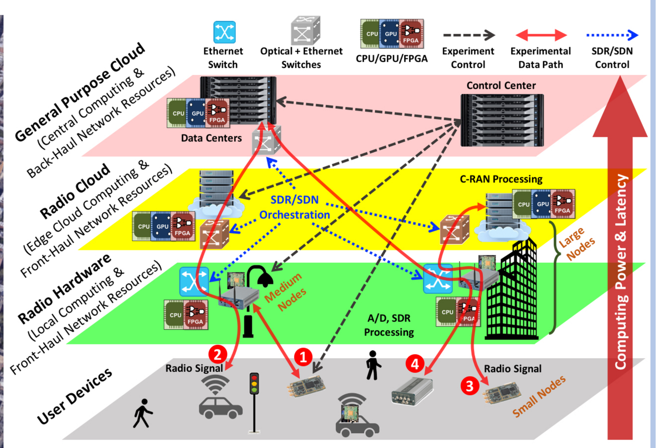
Results on the measured path gains, the effective azimuth beamforming gains, and the signal-to-noise ratio (SNR) coverage are presented for various locations and settings. These results can inform future COSMOS testbed development, including the deployment of IBM 28 GHz phased array antenna modules [2] and provide a benchmark for other deployments in dense urban environments.

COSMOS Testbed

- ***C**loud enhanced **O**pen **S**oftware defined **MO**bile wireless testbed for city-**S**cale deployment* (COSMOS) is a city-scale programmable testbed for experimentation with advanced wireless technologies in New York City [3, 4].
- COSMOS is a joint project involving Rutgers, Columbia, and NYU along with several partner organizations including New York City, CCNY, University of Arizona, Silicon Harlem, and IBM.

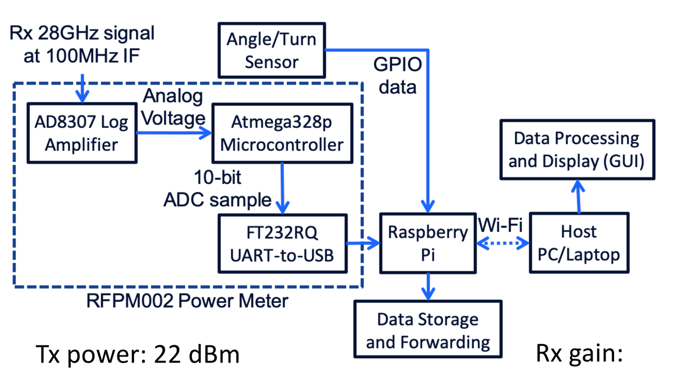


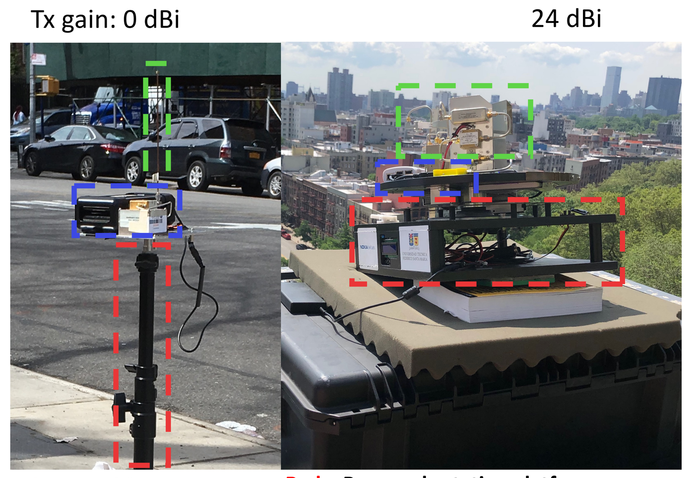
COSMOS testbed deployment area



COSMOS' computing architecture

Measurement Platform





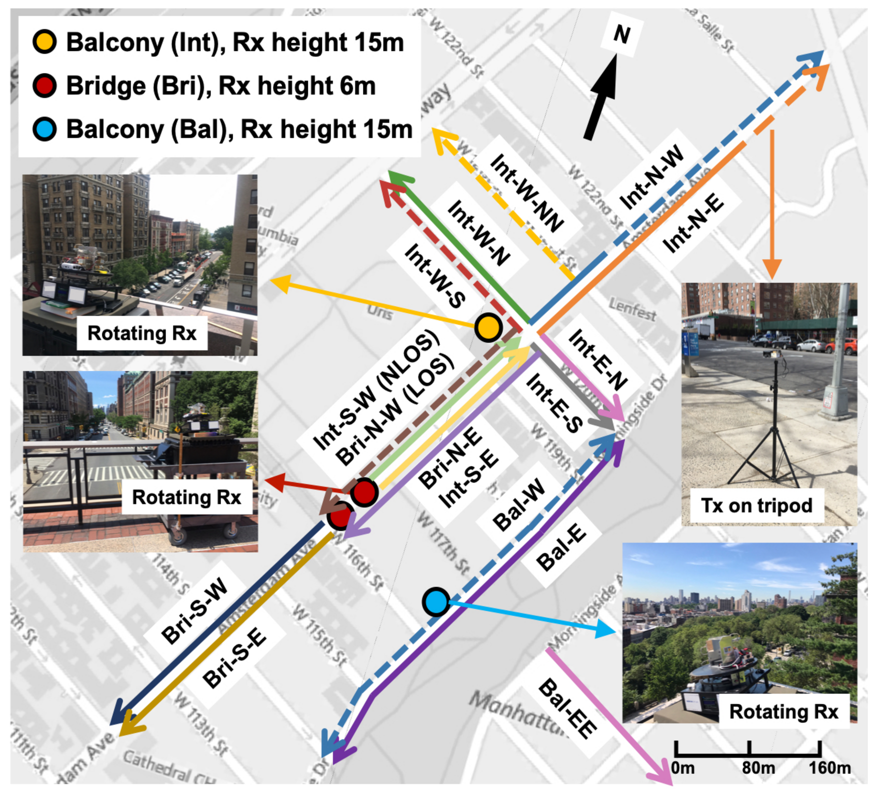
Red – Tripod for mounting Tx
Blue – Battery and RF circuits
Green – Omni-directional antenna

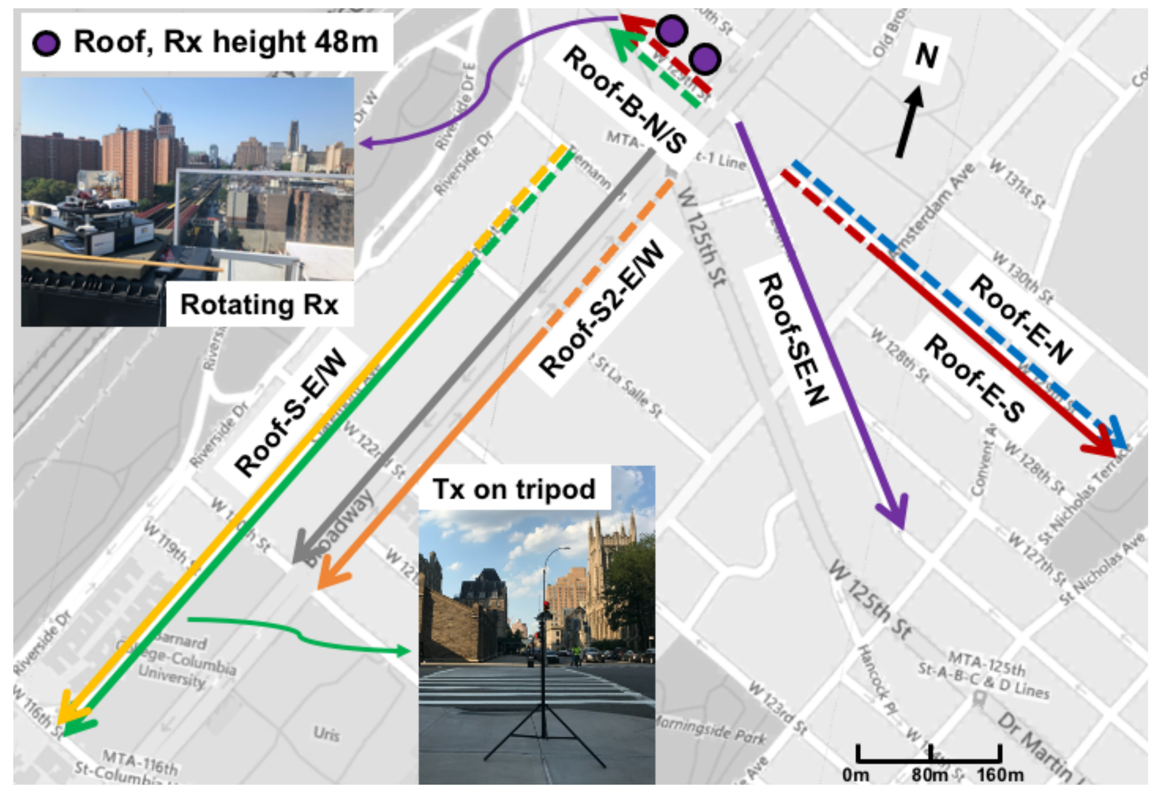
Red – Base and rotating platform
Blue – Power meter and Raspberry Pi
Green – 10 degree beam width rotating horn antenna

28 GHz channel sounder and its block diagram

- We utilize a custom-built 28 GHz portable narrow-band channel sounder for measurements.
- The transmitter (Tx) is equipped with an omni-directional antenna.
- The receiver (Rx) is equipped with a 10° horn antenna and is mounted on a rotating platform spinning at 120 RPM.
- The Rx records power measurements at a rate of 740 samples/sec using a Raspberry Pi controlled wirelessly by a laptop.

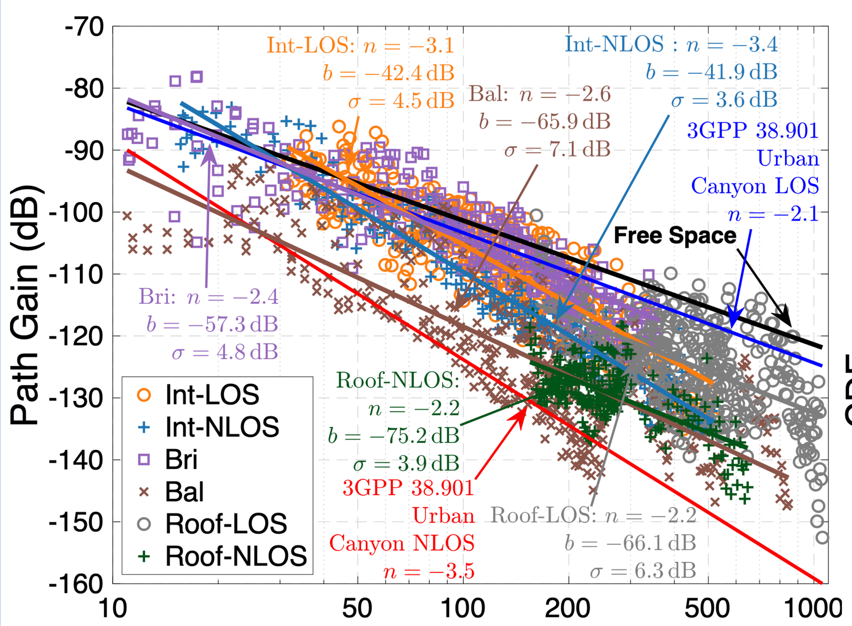
Measurement Sites and Environments





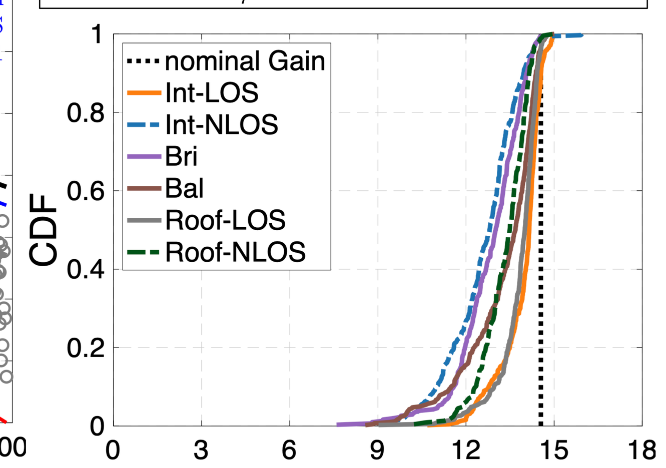
- Over 2,800 links measured across four different measurement sites, emulating different deployment scenarios for a mmWave base station (BS):
  - **Int**, overlooking a four-way intersection
  - **Bri**, a bridge overcrossing a two-way avenue
  - **Bal**, a balcony overlooking a city park
  - **Roof**, overlooking an overground subway track
- These four deployment scenarios represent common BS deployment sites in Manhattan and other cities.
- The measurement areas have sparse thin trees on both sides on the city streets, with 5-10 story concrete buildings, representative of Northeast U.S. cities.

Results – Different Measurement Sites

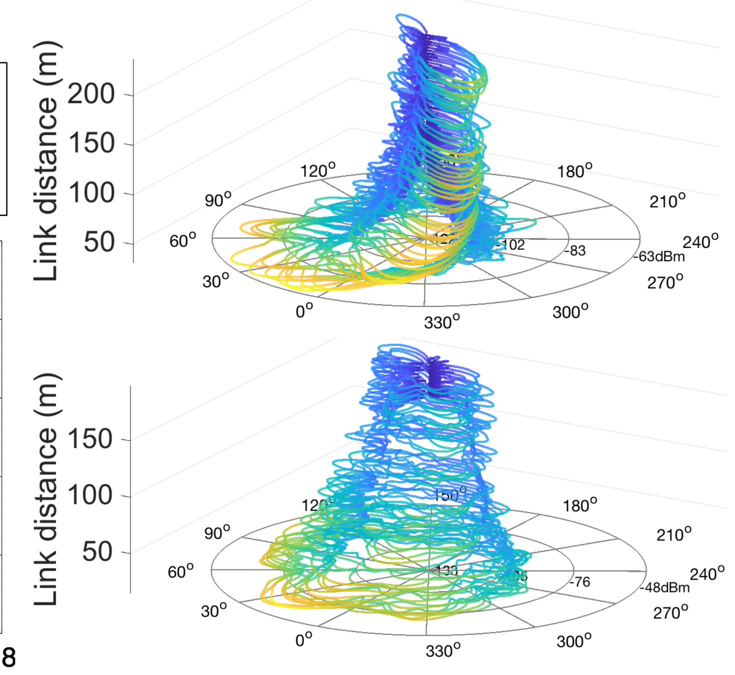


Aggregated path gain models for each deployment scenario

Path gain: $PG(d) = \overline{P_{\text{horn}}}(d)/(P_{\text{Tx}} \cdot G_{\text{El}})$
Effective beamforming gain:
$G_{\text{az}}(d) = \max_{\phi}\{P(d,\phi)\}/\overline{P_{\text{Horn}}}(d)$

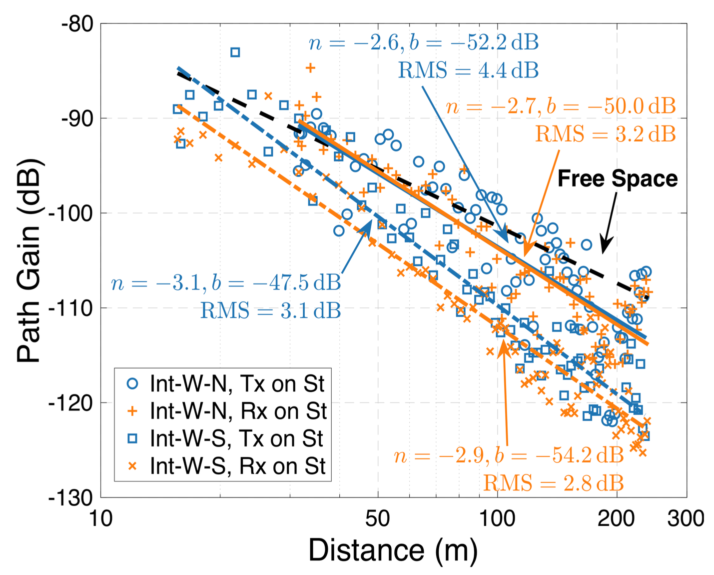


CDF of effective beamforming gain for each deployment scenario

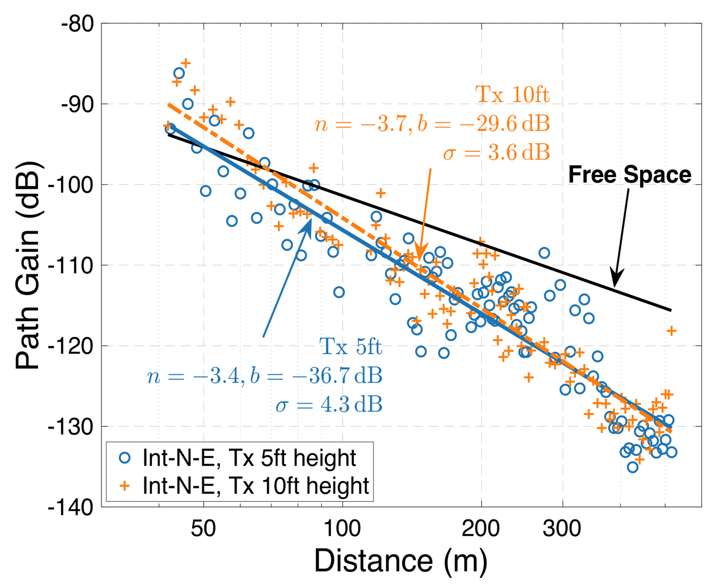


Top: power angular spectra for a LOS sidewalk
Bottom: power angular spectra for NLOS sidewalk

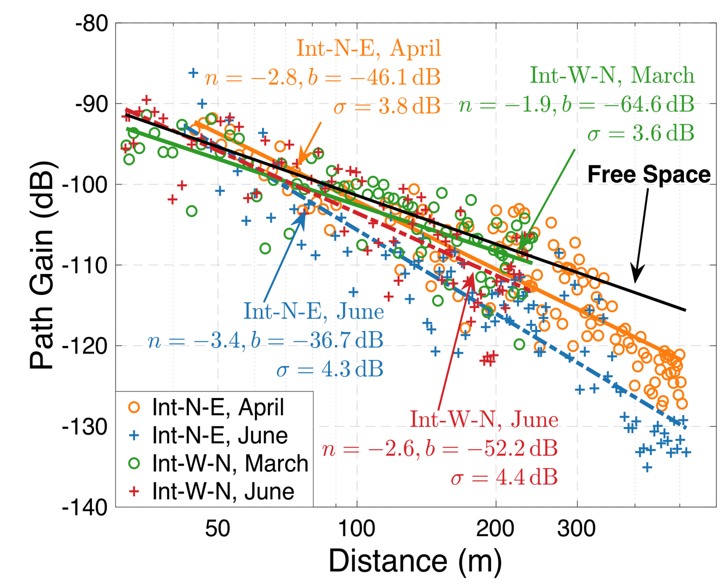
- Measurement results show that (i) **Int-LOS** (line-of-sight), **Bri** and **Roof-LOS** have comparable path gains, and (ii) **Int-NLOS** (non-LOS), **Bal** and **Roof-NLOS** have lower path gains.
- The majority of link path gain values fall within 3GPP urban canyon LOS and NLOS models [5].
- Effective azimuth beamforming (BF) gain is computed as the ratio between the maximum power and the average power over all angles. A lower azimuth BF gain value implies greater environmental scattering.
- Links measured in **Int-NLOS** and **Roof-NLOS** experience higher scattering due to blockage in the NLOS cases, and possible reflections in **Bri** case, caused by two rows of buildings parallel to the link direction.



Effects of swapping the Tx and Rx



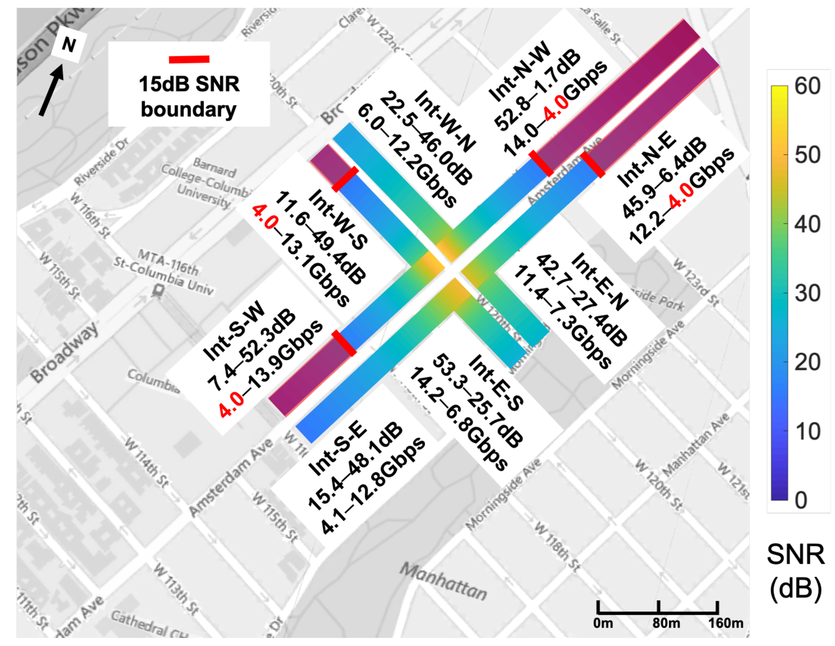
Effects of raising the height of the Tx



Effects of different seasons

- We conduct further sets of measurements to better understand three possible effects on the results.

Signal-to-Noise Ratio (SNR) Coverage Heatmap



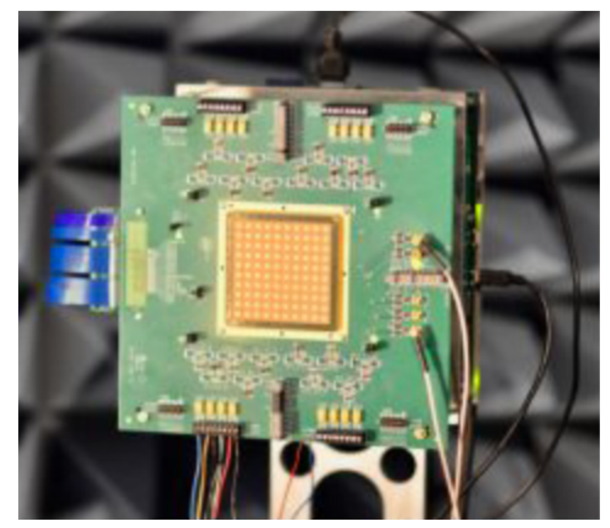
Heatmap annotated with achievable data rates for Int

P_{Tx} = Tx power = 28 dBm
G_{Tx} = Tx gain = 23 dBi
G_{Rx} = Rx gain = 11 dBi
P_{NF} = Noise Figure = 10 dB
$PG_{\text{Med}}(d)$ = Median path gain, computed from our empirical path gain models.

- Using Tx and Rx gains and Tx power typical for a 28 GHz mmWave BS and user equipment, we can compute the SNR with: $SNR(d) = P_{\text{Tx}} + G_{\text{Tx}} + PG_{\text{Med}}(d) + G_{\text{Rx}} - P_{\text{NF}}$
- Results can provide insights into the deployment of the IBM 28 GHz phased array antenna modules (PAAMs) [2] that will be integrated in the COSMOS testbed.
- Sufficient SNR coverage (>15 dB) up to ~160 m link distance for all sidewalks.

Ongoing & Future Work

- More extensive measurements in the COSMOS testbed area, near Manhattanville and CCNY [6].
- Conduct measurements to understand the effect of sidewalk clutter, such as vegetation, parked cars and pedestrians.
- Outdoor-to-indoor measurements to investigate building penetration loss and indoor angular spread.
- Use the angular spectra recorded by the equipment to investigate how the direction of maximum power changes as a user moves along a street.
- Development and simulation of link and network-level algorithms for beam steering and scheduling, using power angular spectra data.
- Measurements of wideband channel characteristics and channel dynamics using IBM's 28 GHz PAAMs [2].



IBM phased array antenna module (PAAM)

CCNY COSMOS testbed area view

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*Based upon the results presented in T. Chen, M. Kohli, T. Dai, A. D. Estigarribia, D. Chizhik, J. Du, R. Feick, R. Valenzuela, and G. Zussman, "28GHz channel measurements in the COSMOS testbed deployment area," in *Proc. ACM MobiCom'19 Workshop on Millimeter-Wave Networks and Sensing Systems (mmNets)*, Oct. 2019.

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