28 GHz Channel Measurements in the COSMOS Testbed Deployment Area

Tingjun Chen[1], Manav Kohli[1], Tianyi Dai[1], Angel D. Estigarribia[1], Dmitry Chizhik[2], Jinfeng Du[2], Rodolfo Feick[3], Reinaldo A. Valenzuela[2], and Gil Zussman[1]

[1]Electrical Engineering, Columbia University, [2]Nokia Bell Labs, [3]Universidad Técnica Federico Santa María

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COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK

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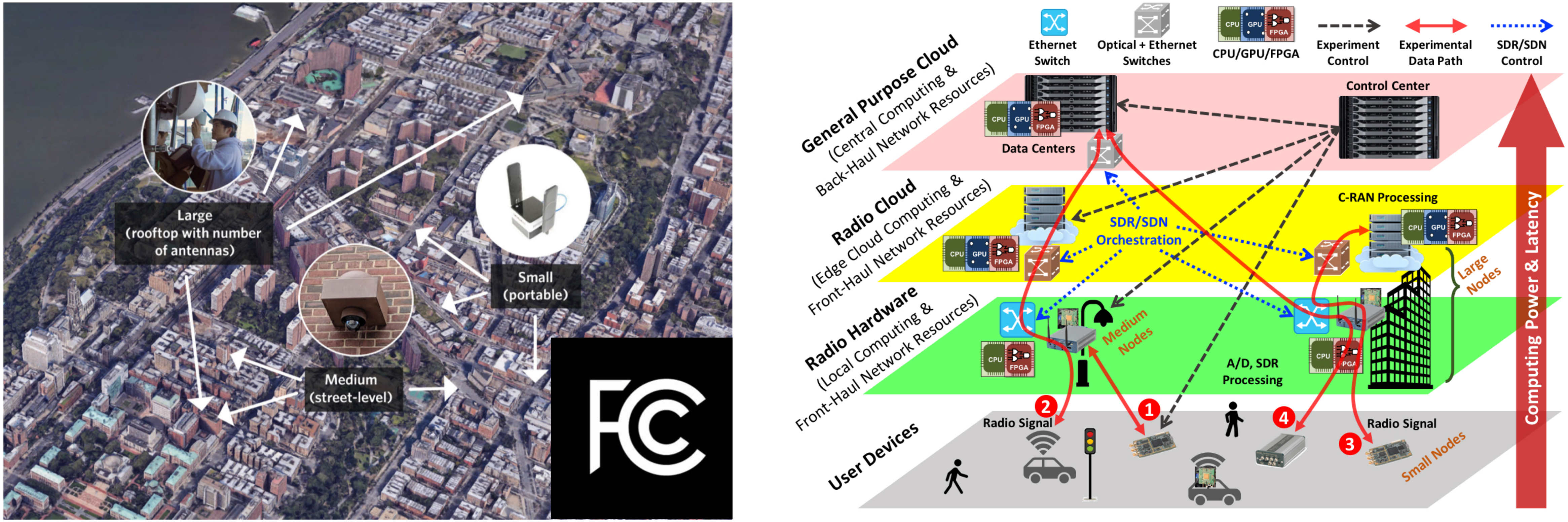
Motivation

- Widely available spectrum at millimeter-wave (mmWave) frequencies compared with sub-6 GHz frequencies can support significantly increased data rates
- Due to the challenging link budget at mmWave frequencies, extensive channel measurements and accurate channel models are needed for the deployment and operation of mmWave networks
    - E.g., what happens if mmWave BSs will be deployed at locations with existing 4G/LTE cells?



The 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 advanced wireless technologies in West Harlem, New York City
- One of the nation's first ***Innovation Zones*** designated by FCC (includes 27.5–28.35 GHz and 38.6–40 GHz)

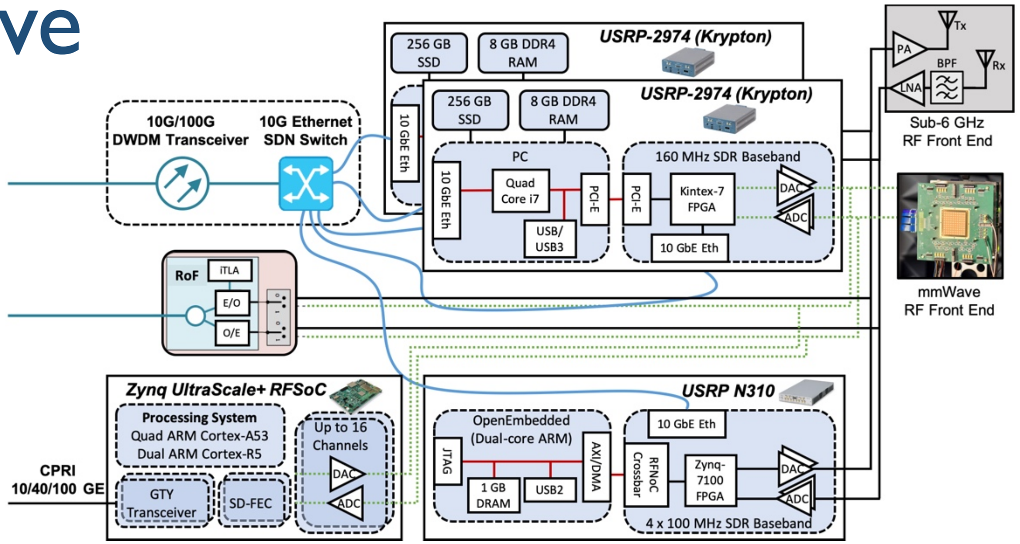


The COSMOS testbed deployment area and its multi-layered computing architecture

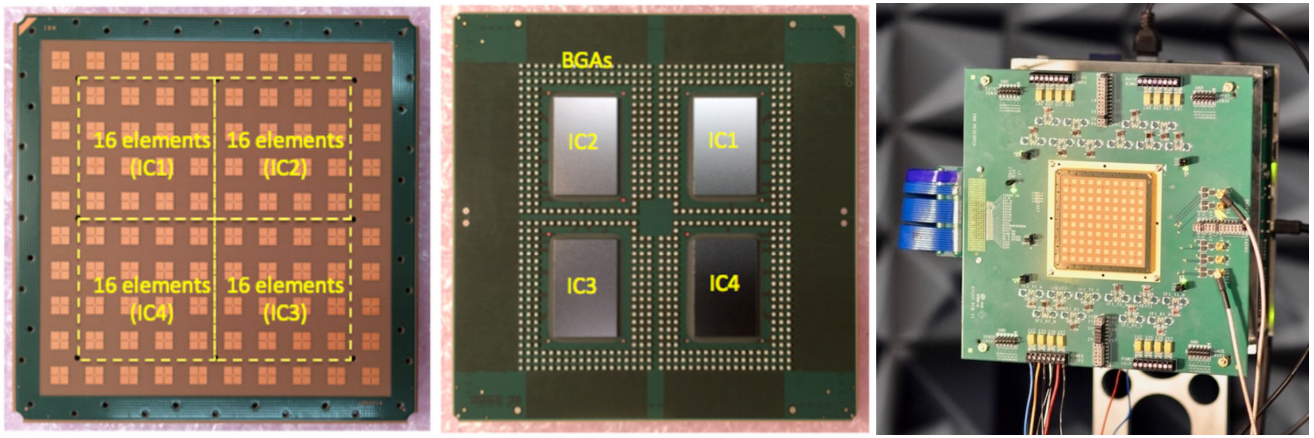
The COSMOS Testbed Deployment Area

COSMOS Key Technology – mmWave

- 28 GHz mmWave phased array modules provided by IBM
  - Experiment with adaptive beamforming and MIMO
- Previous work on mmWave measurements from NYU
  - In NYC downtown and Brooklyn
- 28 GHz channel measurements in the COSMOS testbed area

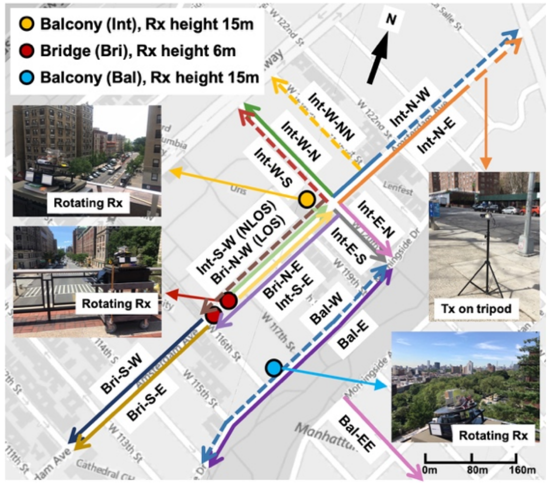


COSMOS large/medium node architecture



mmWave (28 GHz) phased array antenna module from IBM (in collaboration with Ericsson)

NYU (downtown & Brooklyn) channel measurements



Channel measurements in the COSMOS testbed area

Our 28 GHz Measurement Campaign Focus on…

- The COSMOS testbed deployment area as an FCC innovation zone, representative of a ***dense urban street canyon*** environment

- Representative (potential) deployment sites of mmWave BSs (building rooftops, street lightpoles, etc.)

- Extensive measurements on various ***long sidewalks*** (e.g., up to 1,100 m) with ***fine-grained link step size*** (e.g., 1.5/3 m)
  - Over **24 million** power measurements were collected from over **1,500 links** on **13 sidewalks** in **3 different sites** and in different settings during March – June, 2019

A Portable Narrowband 28 GHz Channel Sounder

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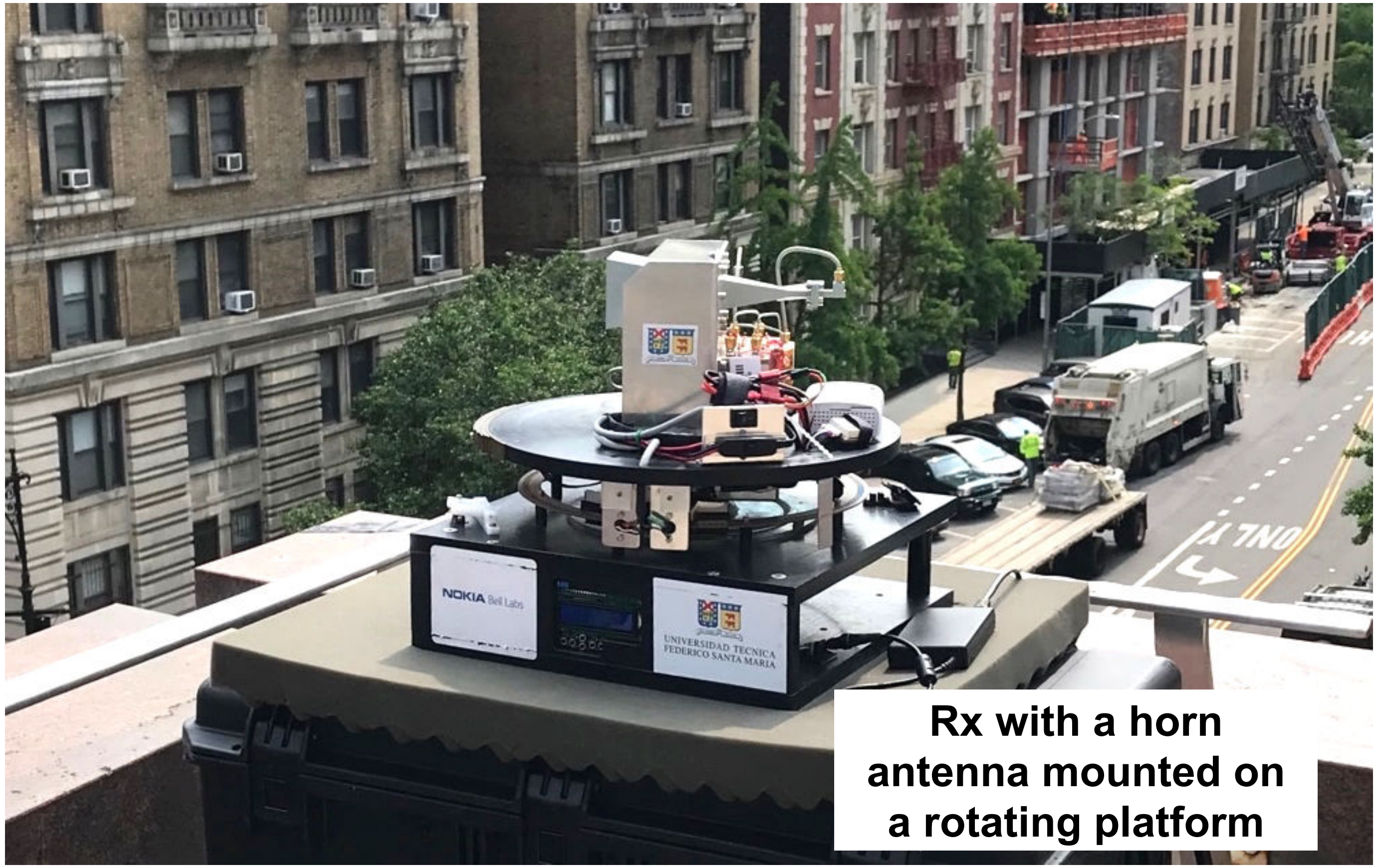
- (Fixed) Tx: battery-powered, +22 dBm Tx power, omni-directional antenna
- (Rotating) Rx: battery-powered, 10 deg horn antenna with +24 dBi gain, up to 300 rpm rotating speed
- Measure up to 161 dB path loss for >10 dB SNR (w/ switchable attenuators/amplifiers) w/ 0.15 dB resolution

Tx with an omni-directional antenna mounted on a tripod



Rx with a horn antenna mounted on a rotating platform

Measurement Environment

- Streets around Columbia Morningside campus

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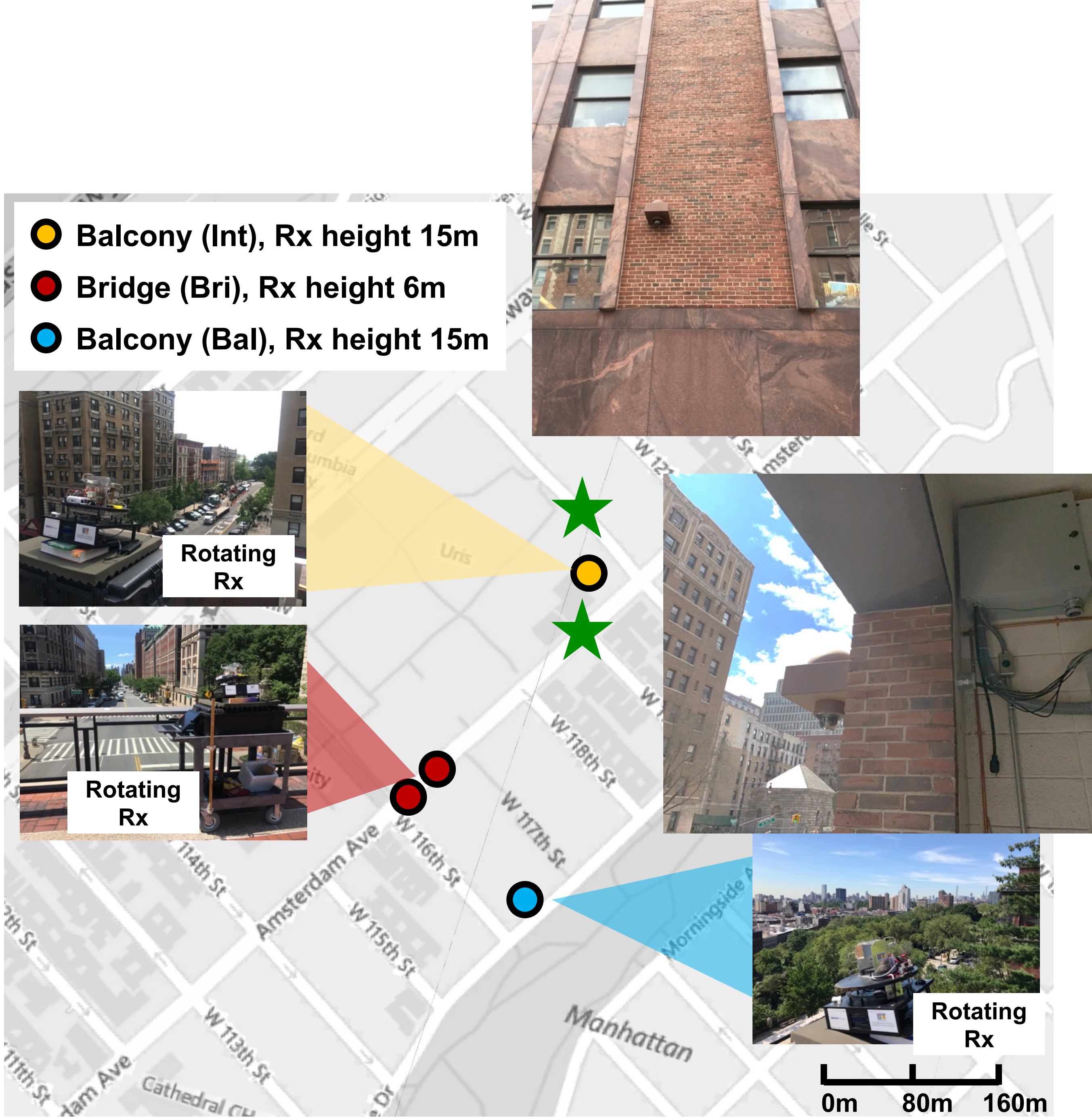
- Three sites representing different deployment scenarios of a mmWave small cell BS:
  - Balcony at a four-way intersection (**Int**): h = 15 m
  - Bridge across a two-way avenue (**Bri**): h = 6 m
  - Balcony overlooking an open park (**Bal**): h = 15 m



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- **Bri**: 4 sidewalks up to 210 m link distance

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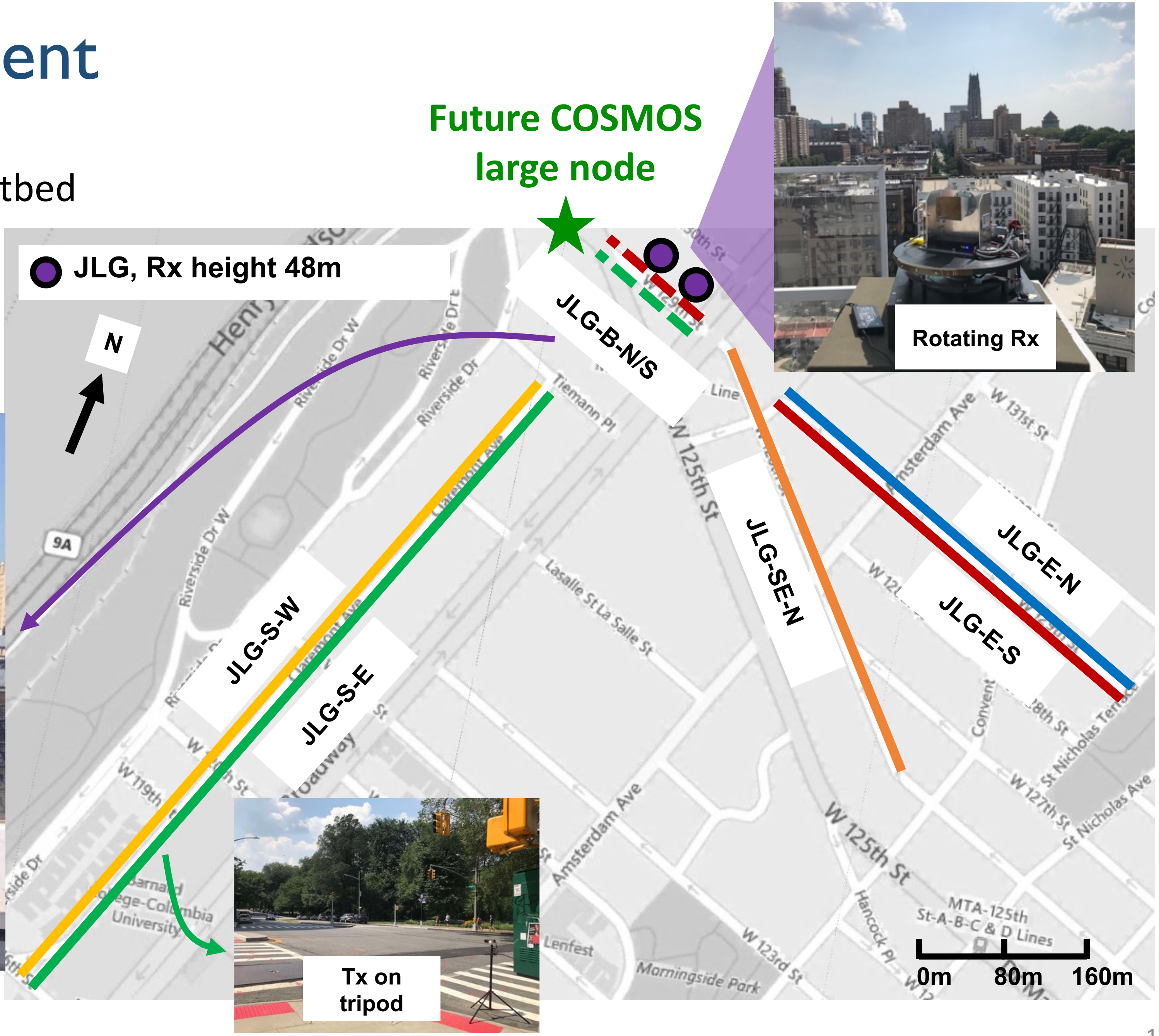
Measurement Environment

- More measurements in the COSMOS testbed deployment area at:
  - The Jerome L. Greene building (**JLG**) at the Columbia Manhattanville campus with **up to 1,100 m** link distance



Performance Metrics

- **Path gain** as a function of the link distance
  - Quantifies loss in signal strength
  - Linear curve-fit: $\mathrm{PG}(d) = 10n \cdot \log_{10}(d) + b + \mathcal{N}(0, \sigma)$ (dB)

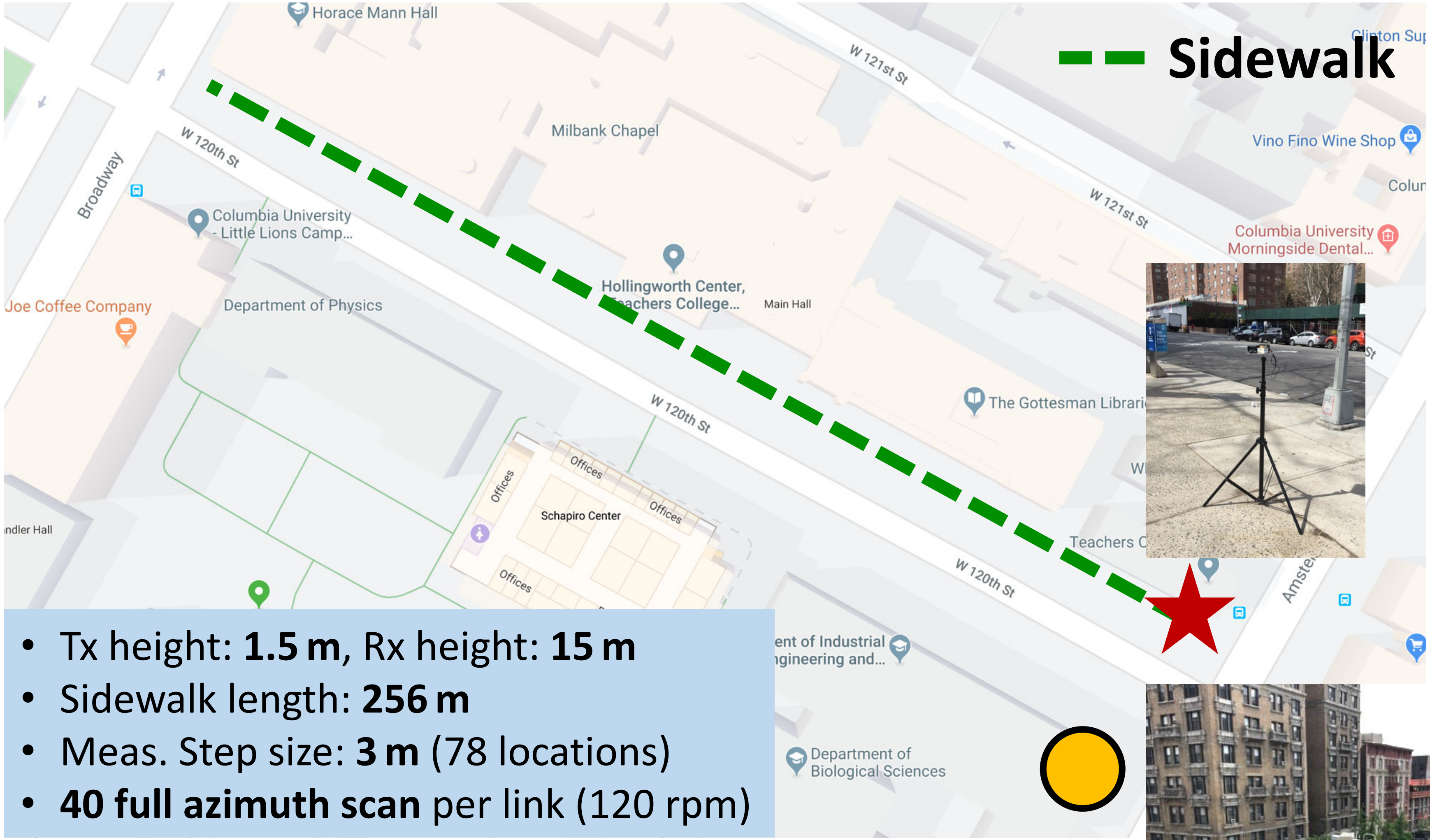
- Effective **azimuth beamforming gain**
  - Quantifies the effects of scattering environments on the signal angular spread, and thus on the beamforming gain
  - Record angular spectrum in the 360 deg azimuth plane

Narrow beam is preserved in "free space"

Narrow beam is widened by scattering/diffusion

- **Signal-to-noise ratio (SNR) coverage** and achievable data rates

An Example Sidewalk: **Int-W-N**



Tx

Rx

- Tx height: **1.5 m**, Rx height: **15 m**
- Sidewalk length: **256 m**
- Meas. Step size: **3 m** (78 locations)
- **40 full azimuth scan** per link (120 rpm)

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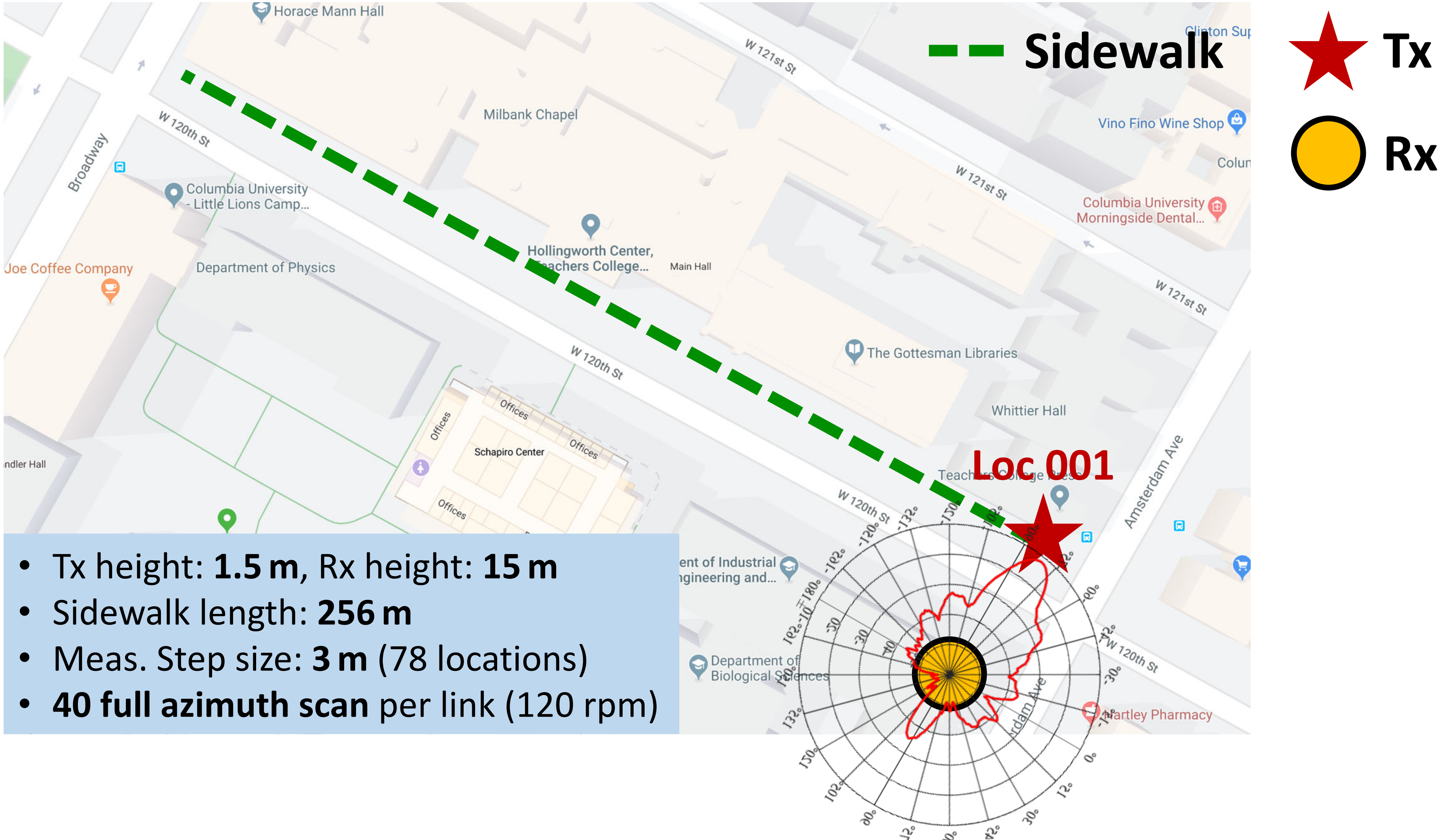

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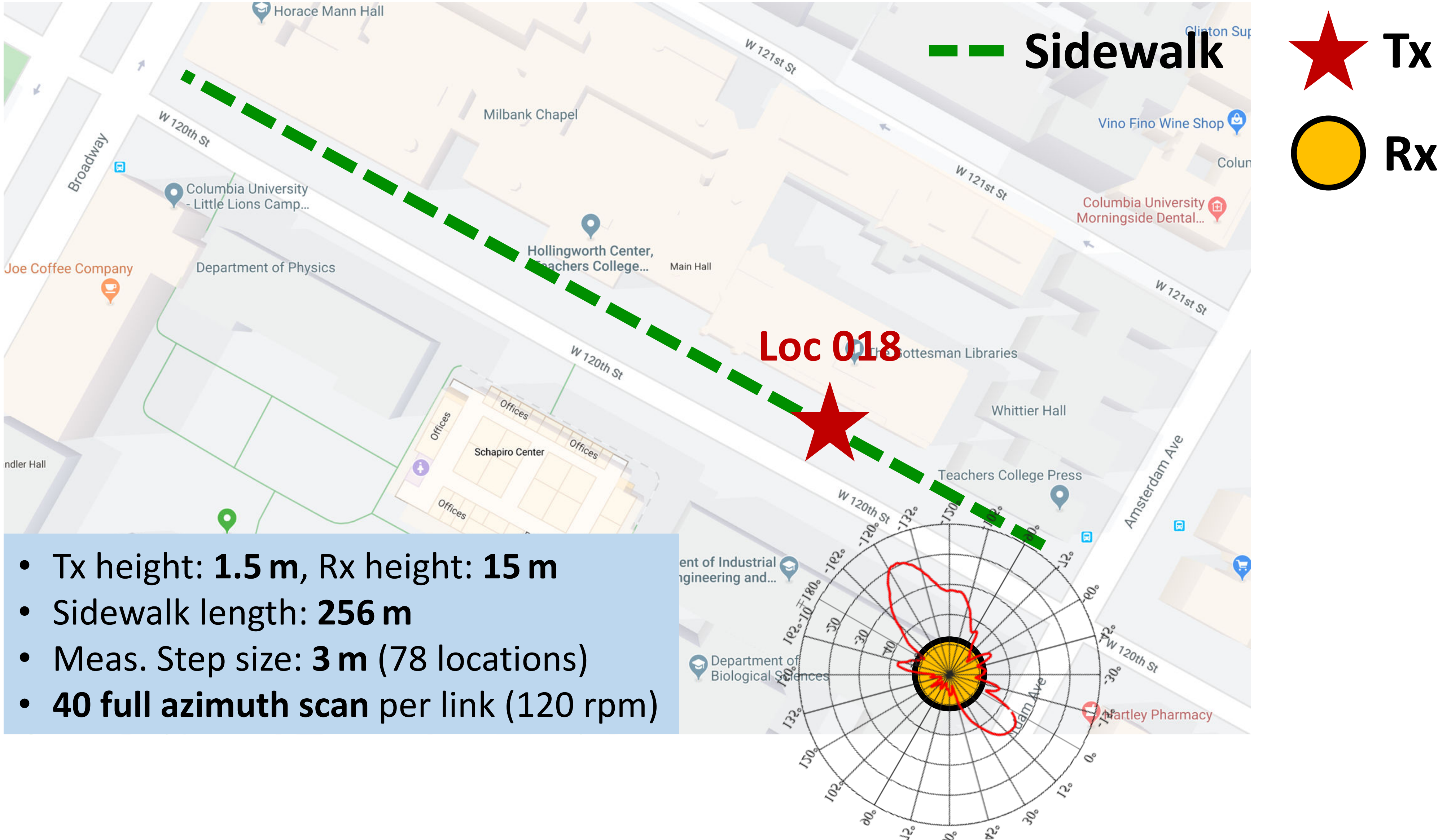

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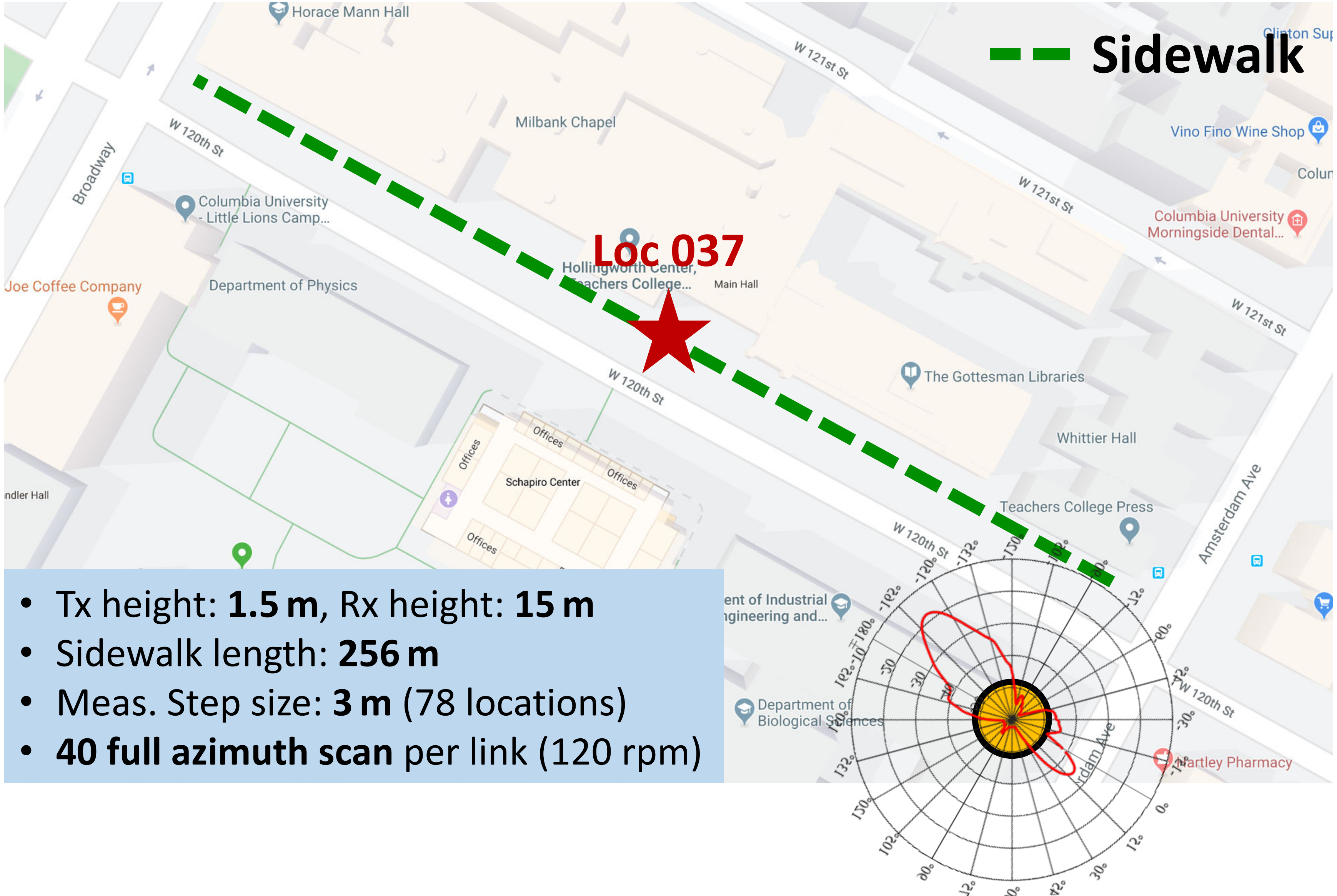

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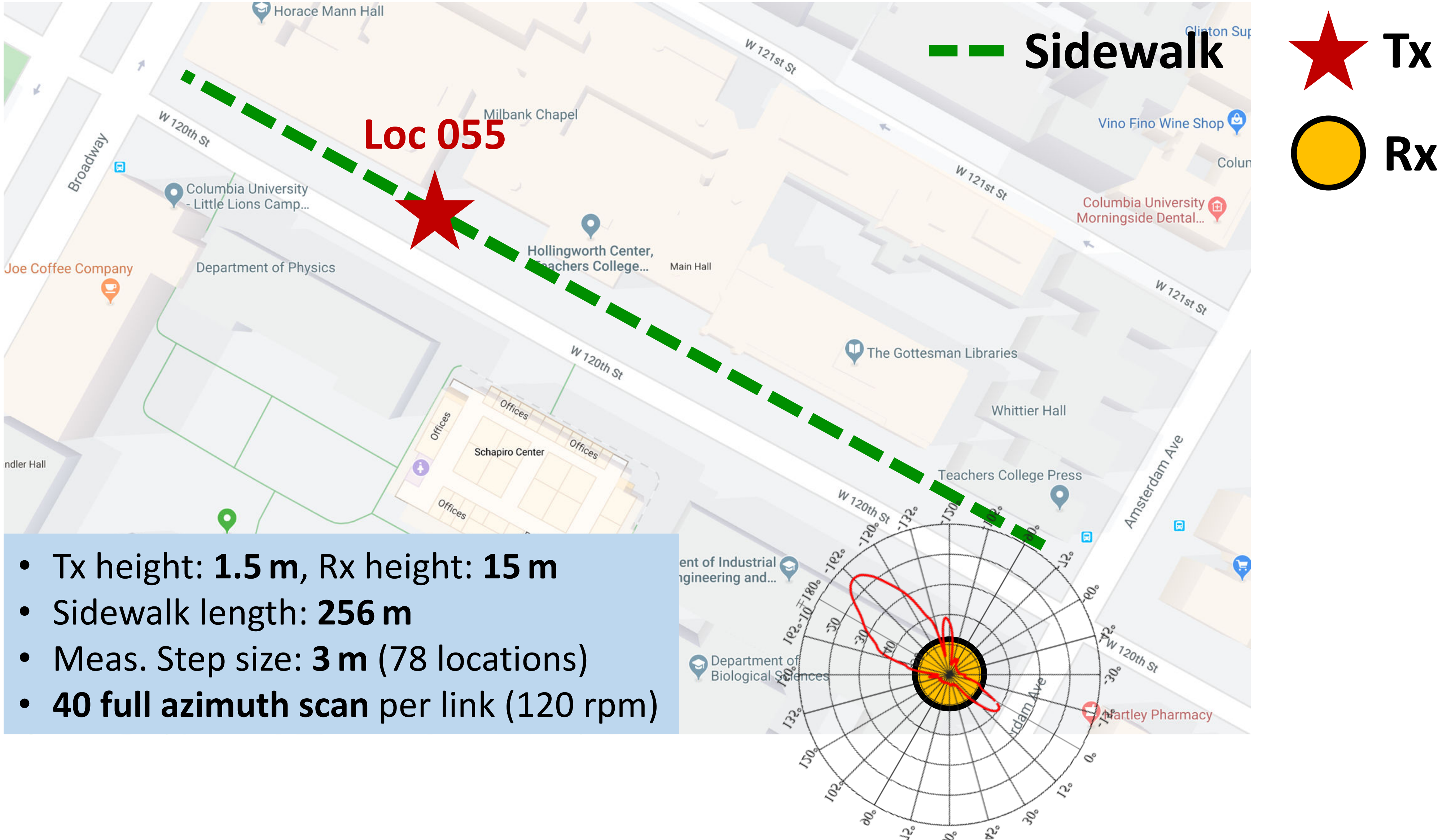

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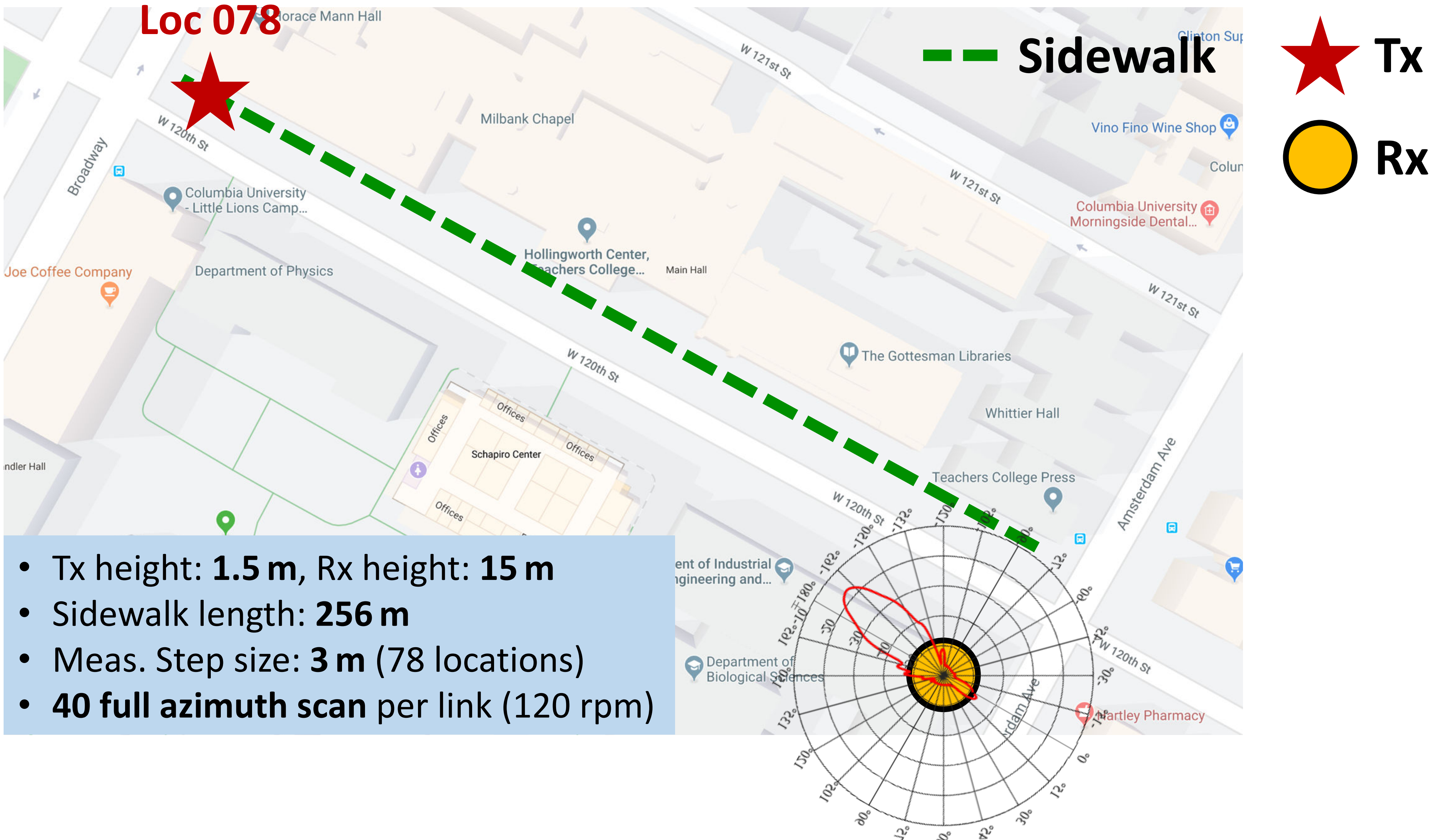

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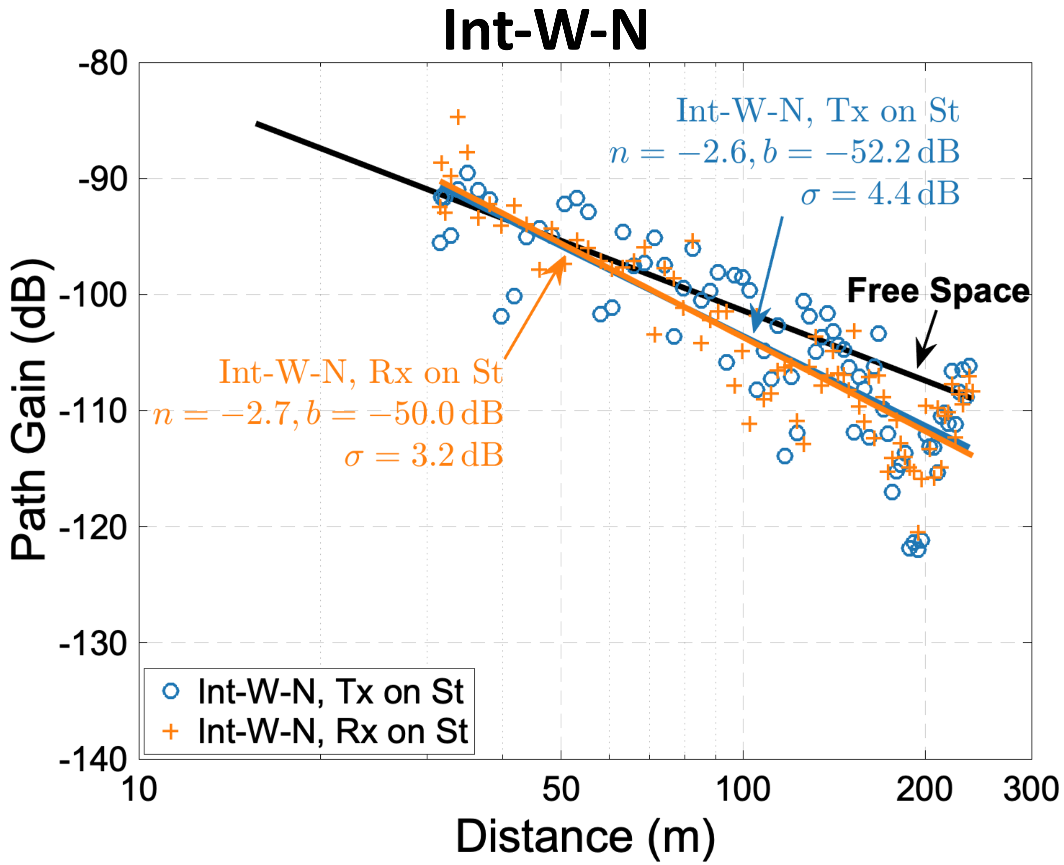
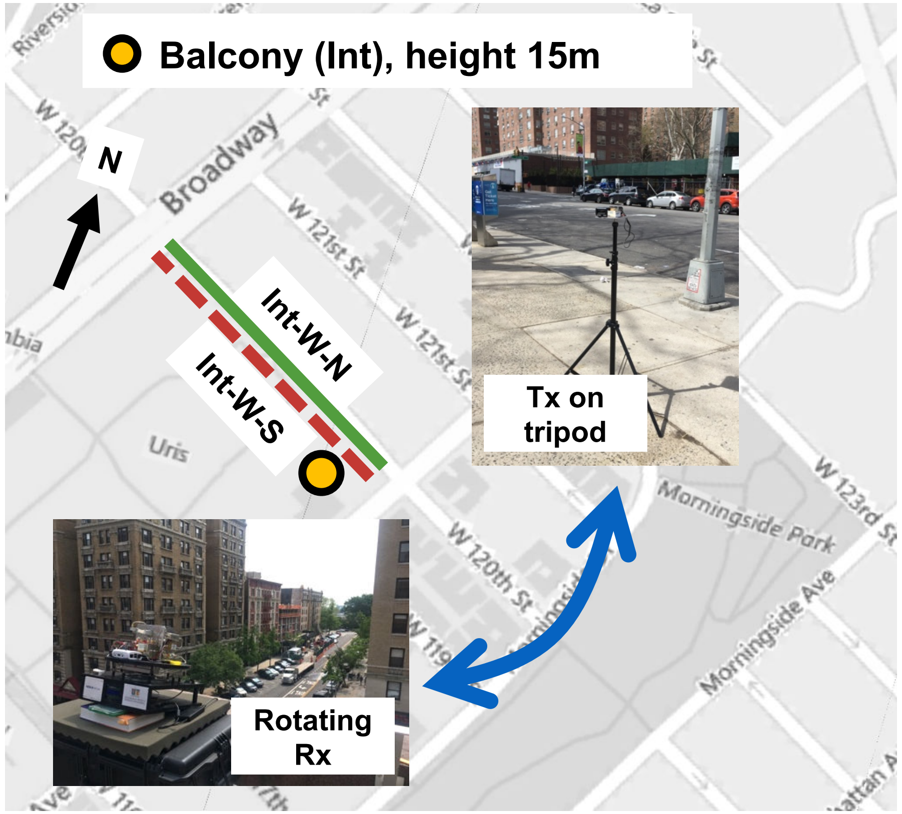
Effects of Setup and Environments – Swapped Tx-Rx

- Swapping the rotating Rx (w/ a directional antenna) and the fixed Tx (w/ an omni-directional antenna)
- Path gain exponents differ only by 0.1/0.2 for **Int-W-N** and **Int-W-S** (LOS vs. NLOS)
- In general, on the same street, the path gain values in the NLOS case are around 5–10 dB lower than that in the LOS case due to more complicated environments





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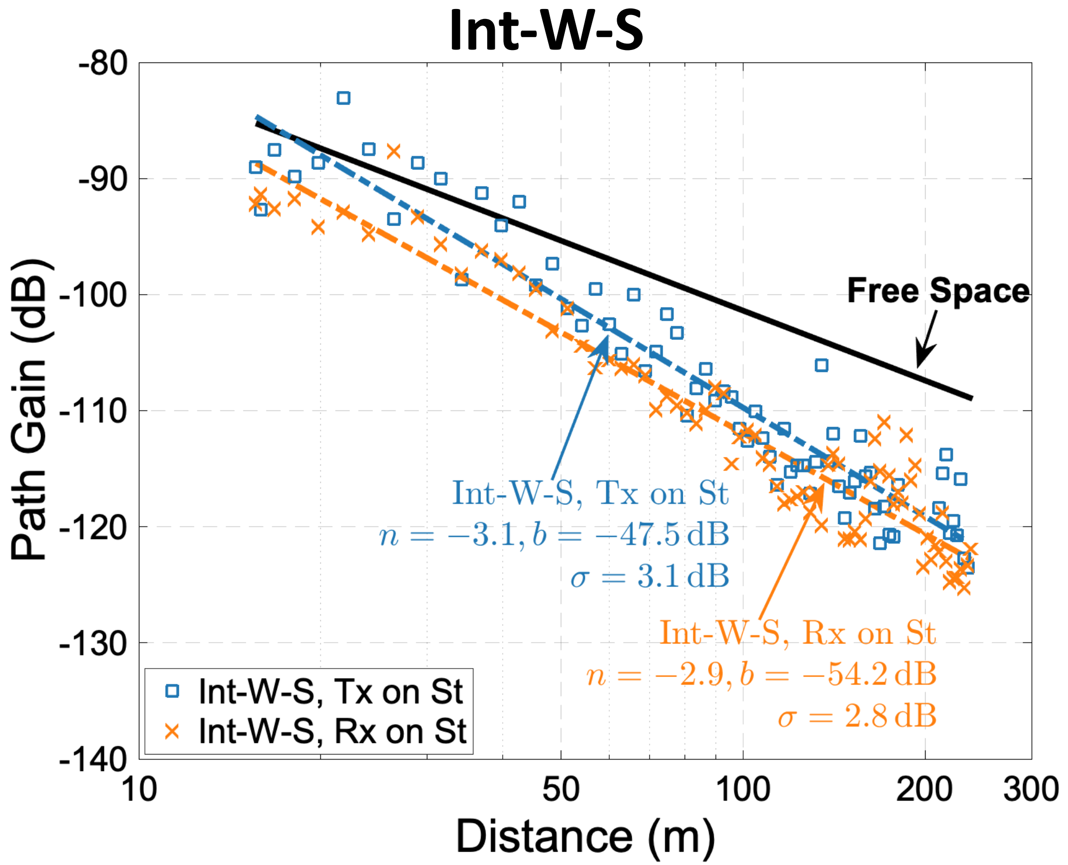
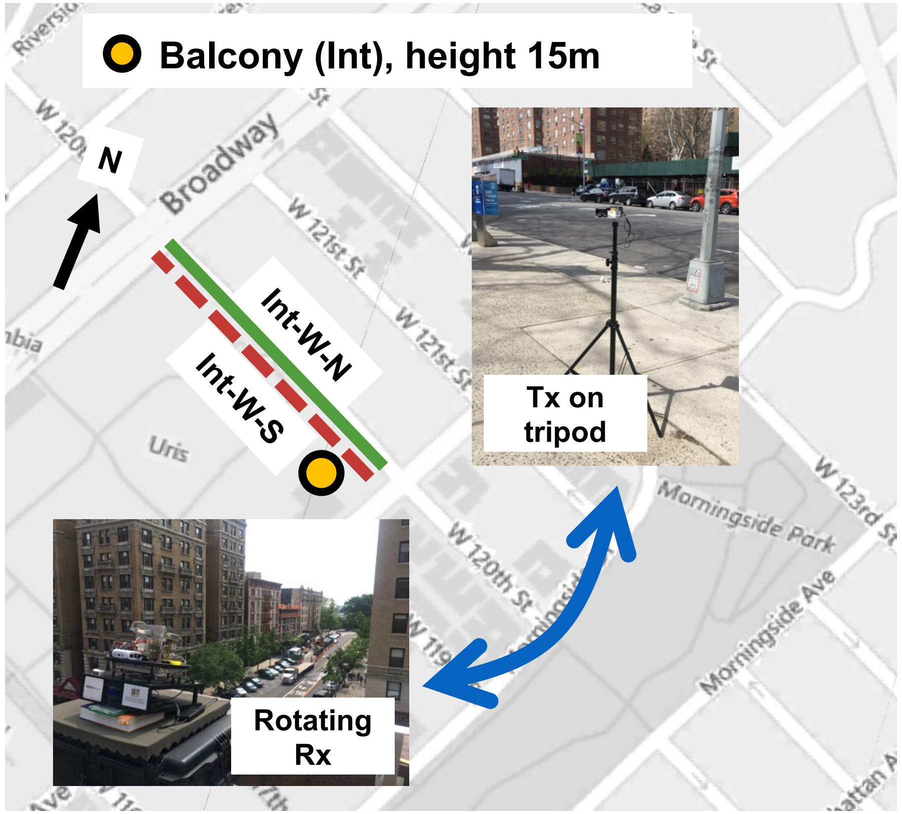
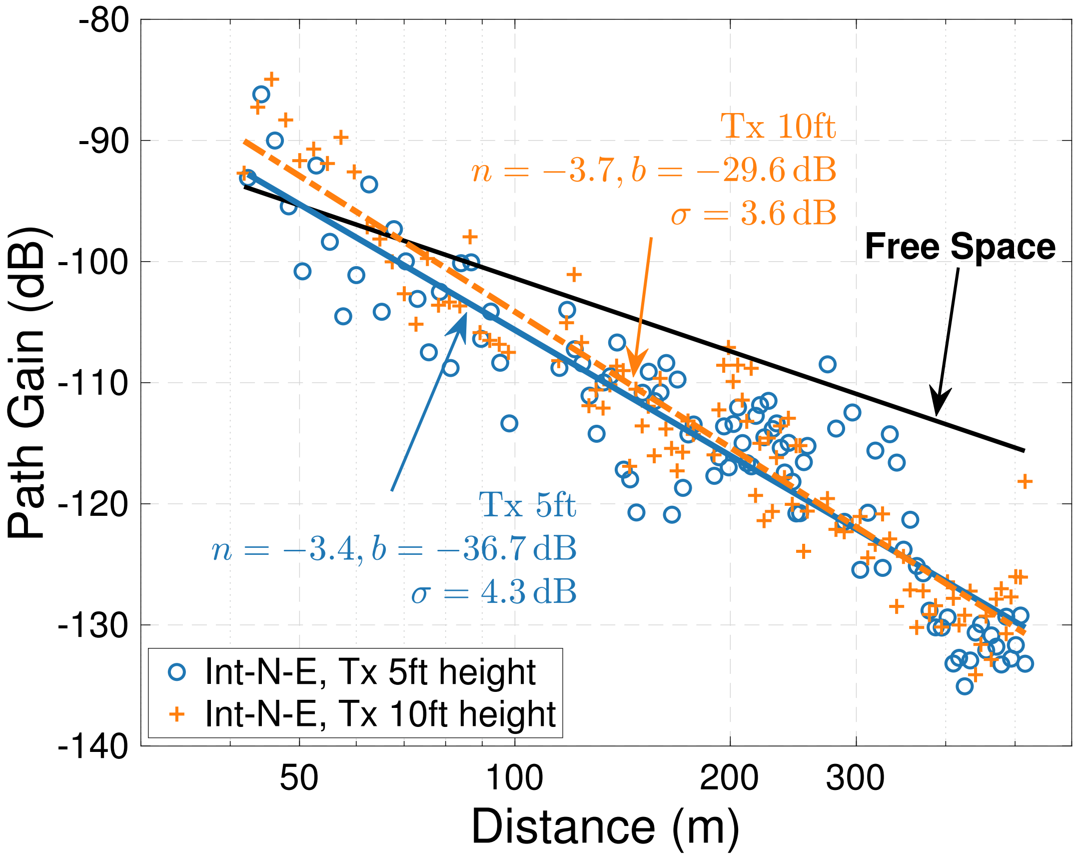
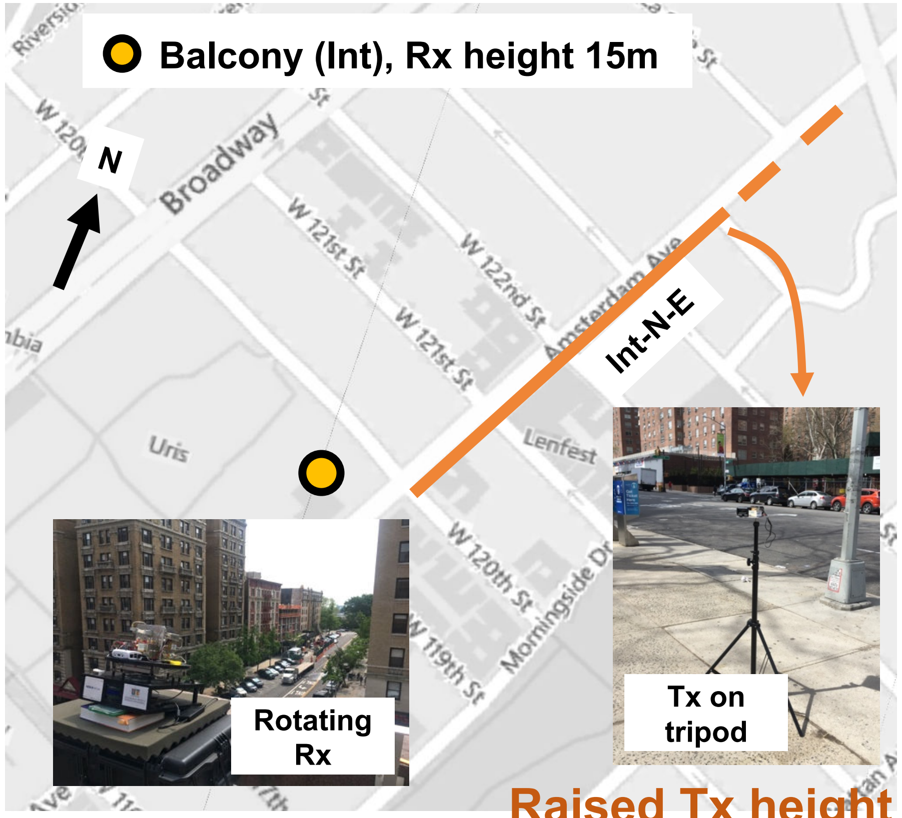




Effects of Setup and Environments – Raised Tx

- Varying Tx heights of 1.5 m/3.0 m (5 ft/10 ft)
- Path gain values differ by only 2.5 dB at the near end (d = 50 m) and by 0.8 dB at the far end (d = 500 m)
- Lower Tx height results in slightly lower path gain values mainly due to foliage blockages

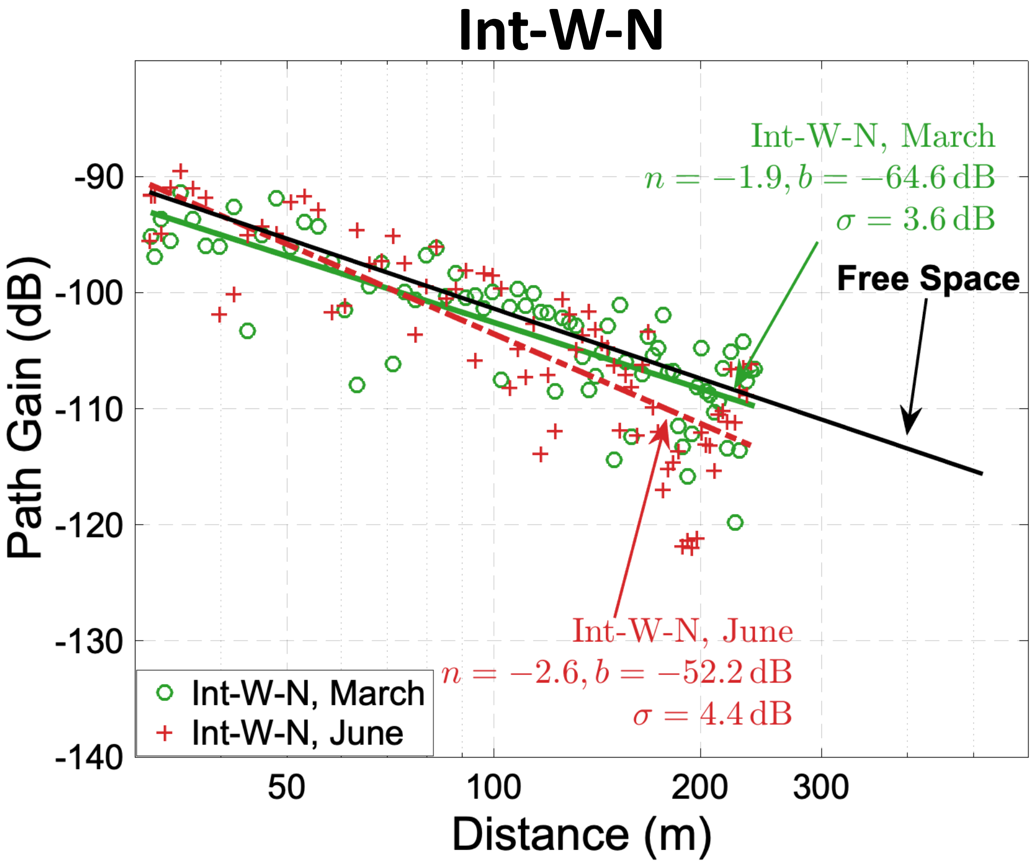


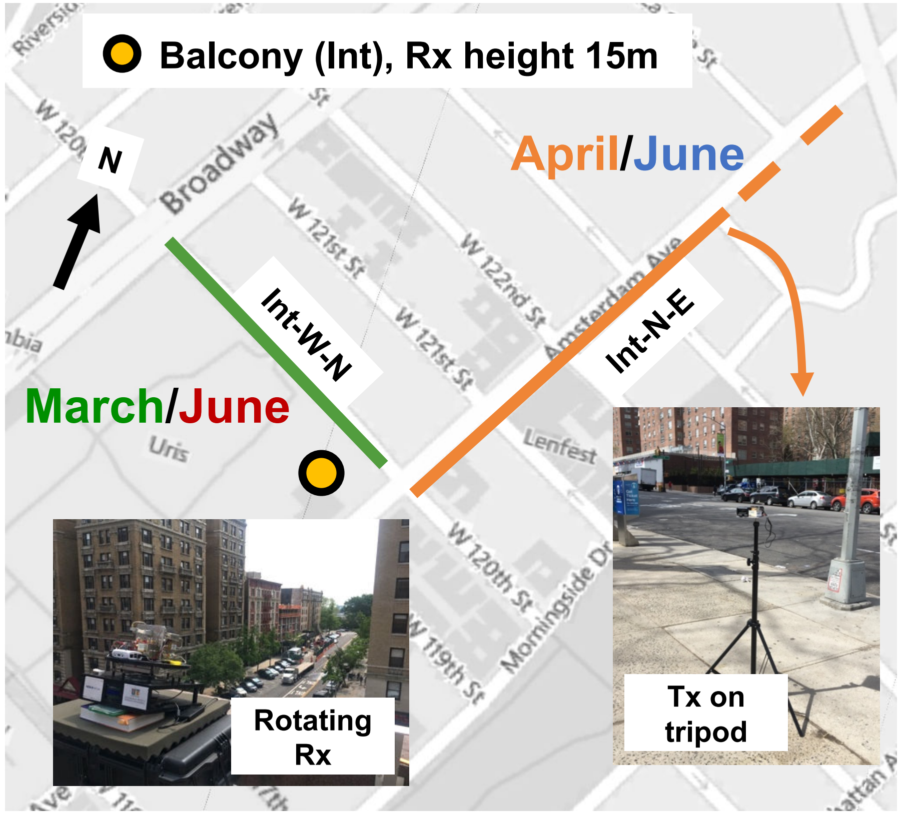


Raised Tx height

Effects of Setup and Environments – Seasonal Effects

- Same measurement campaign throughout March to June, 2019
  - Int-W-N (LOS): March vs. June
  - Int-N-E (LOS @near and NLOS @far): April vs. June
- Path gain drops by up to 10 dB at longer distances, primarily due to thicker foliage on trees





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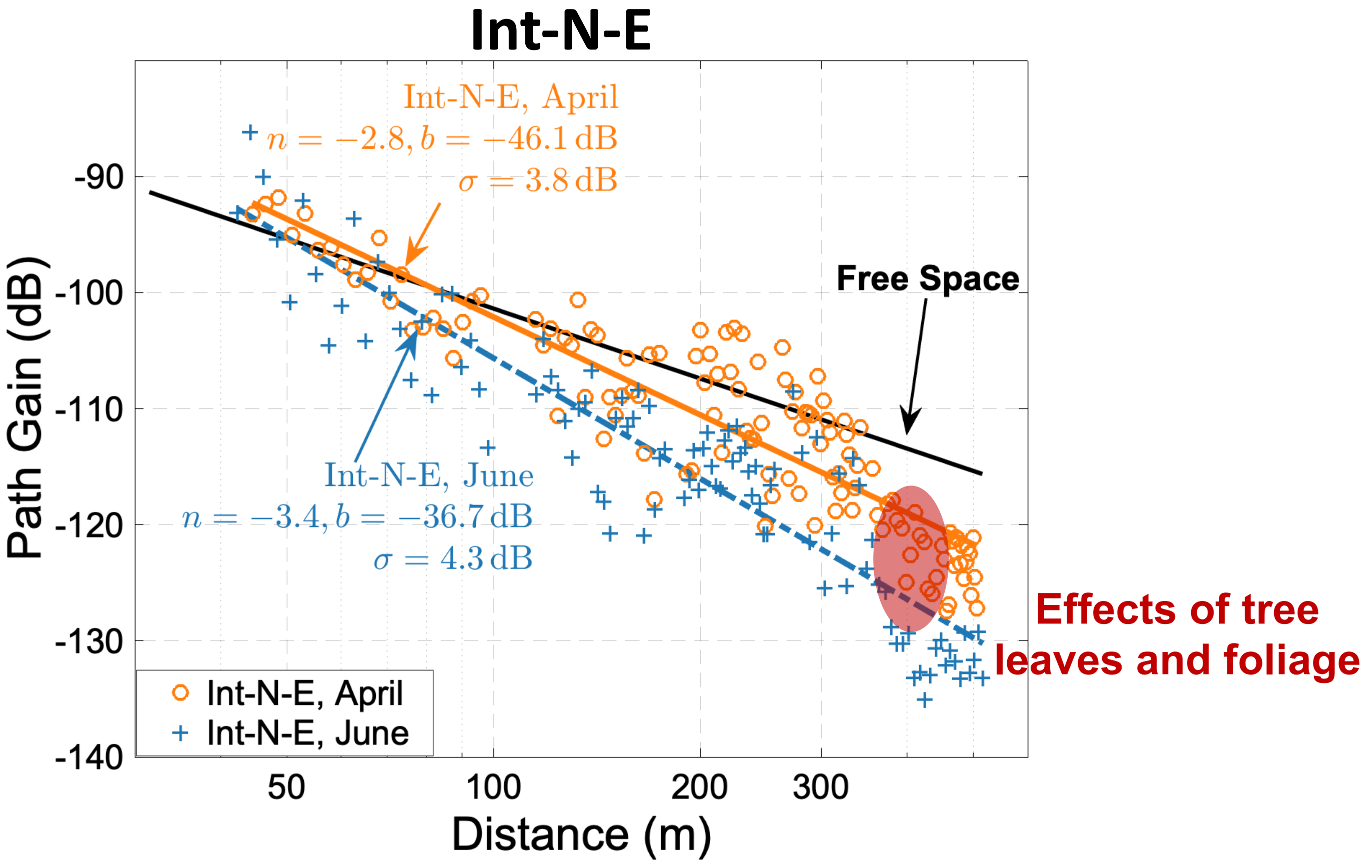
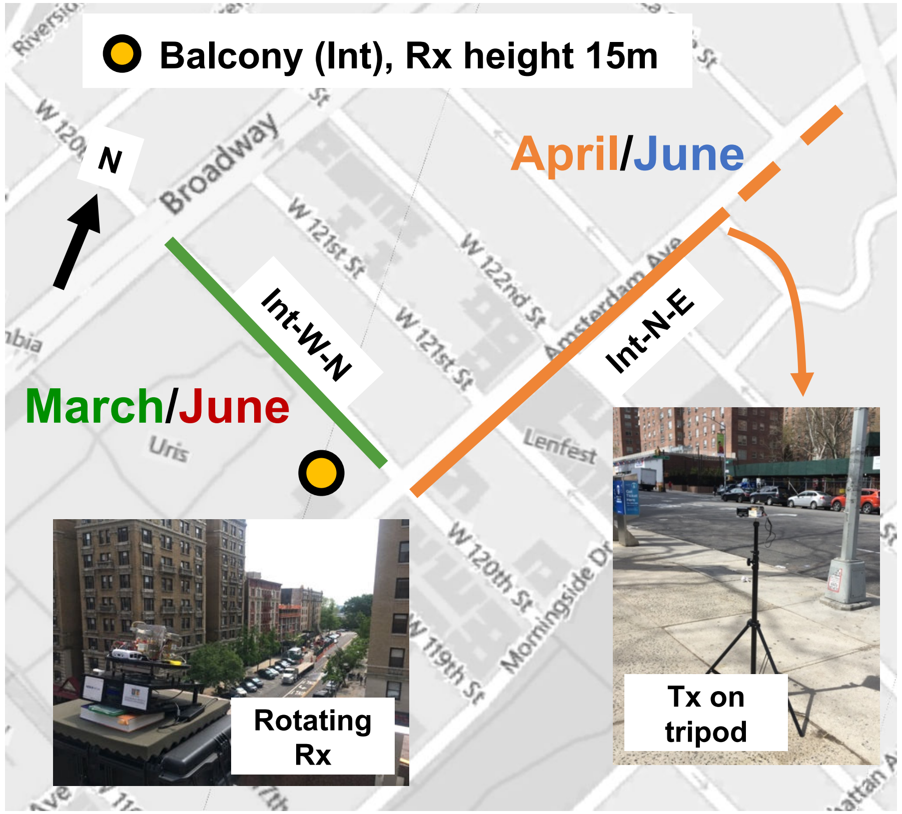
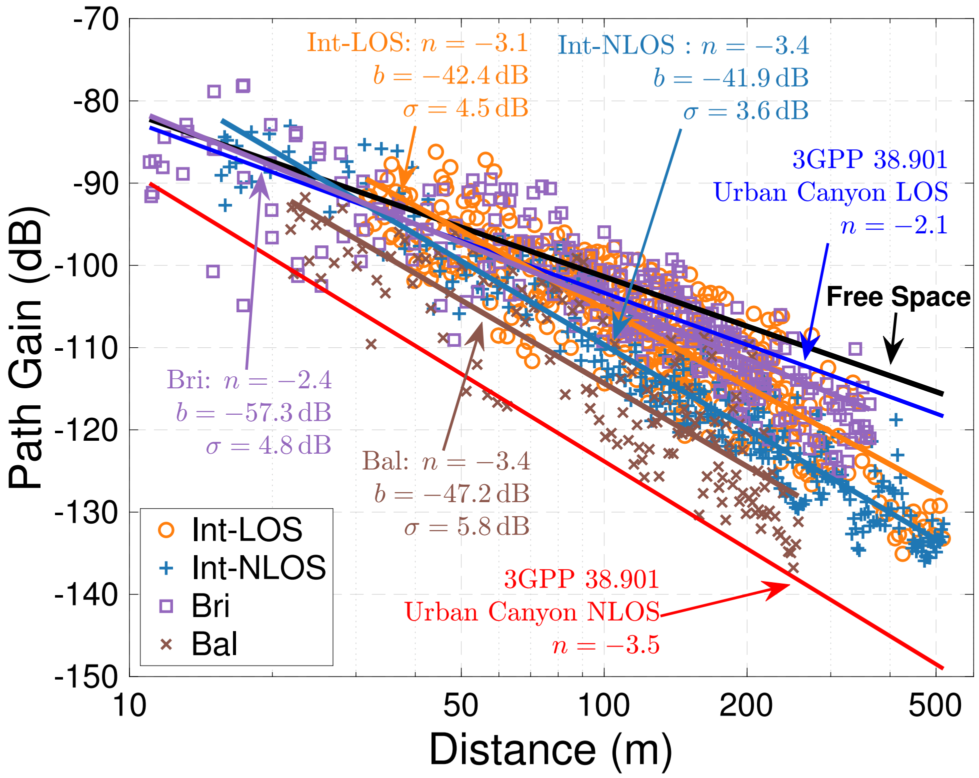
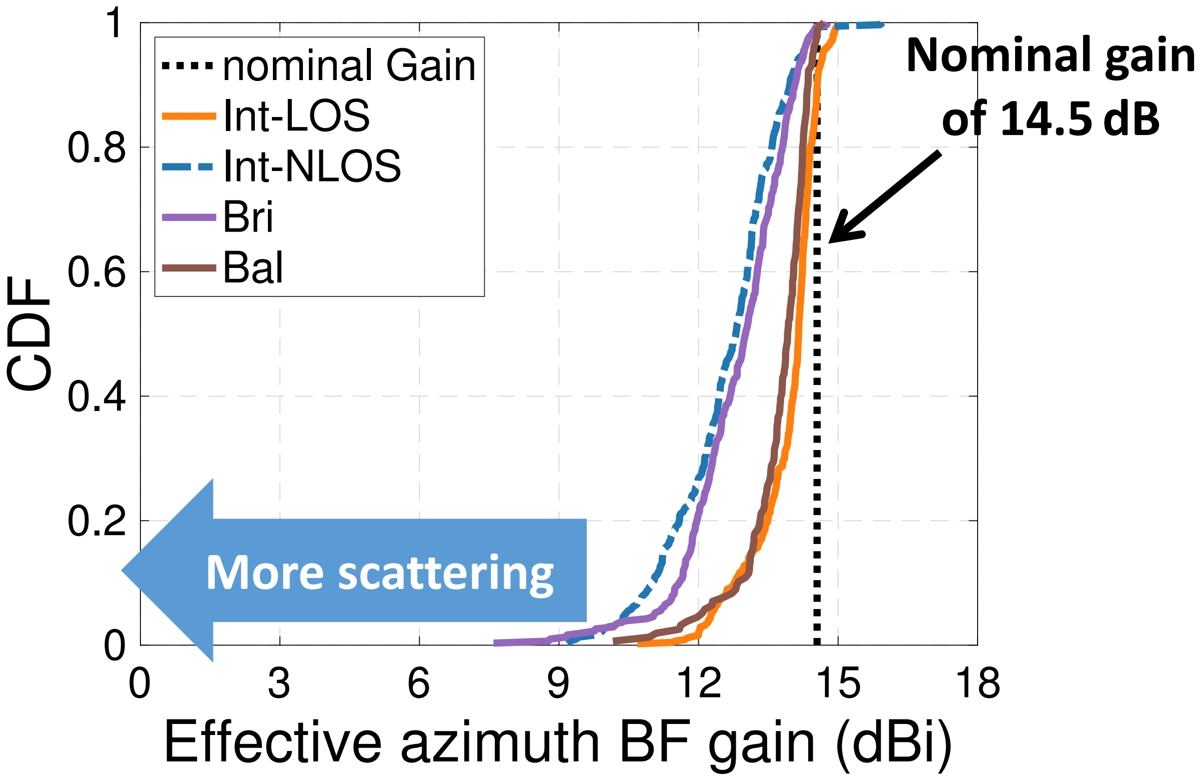




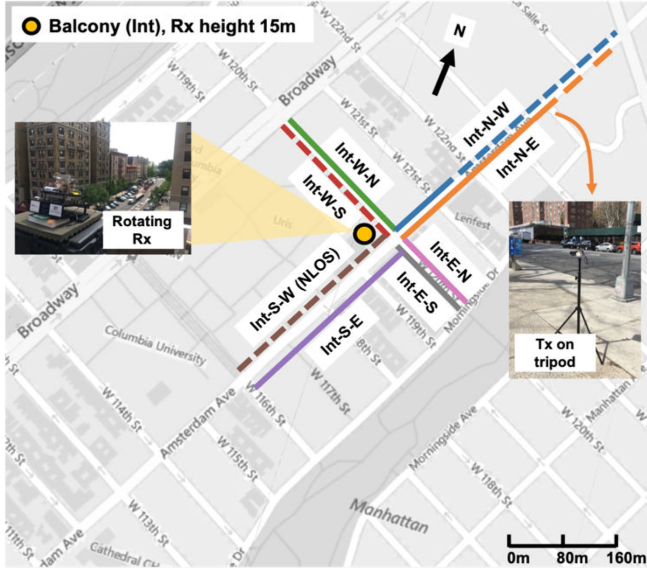
Grouped Sidewalks

- 13 sidewalks categorized into 4 groups:
  - Int-LOS (5), Int-NLOS (3), Bri (4), and Bal (1)
- Most path gains fall b/w the 3GPP urban street canyon LOS and NLOS models
- Street canyon environment “improves” path gains





Individual Sidewalks at Int



- 8 sidewalks at Int:
  - LOS (5) and NLOS (3)
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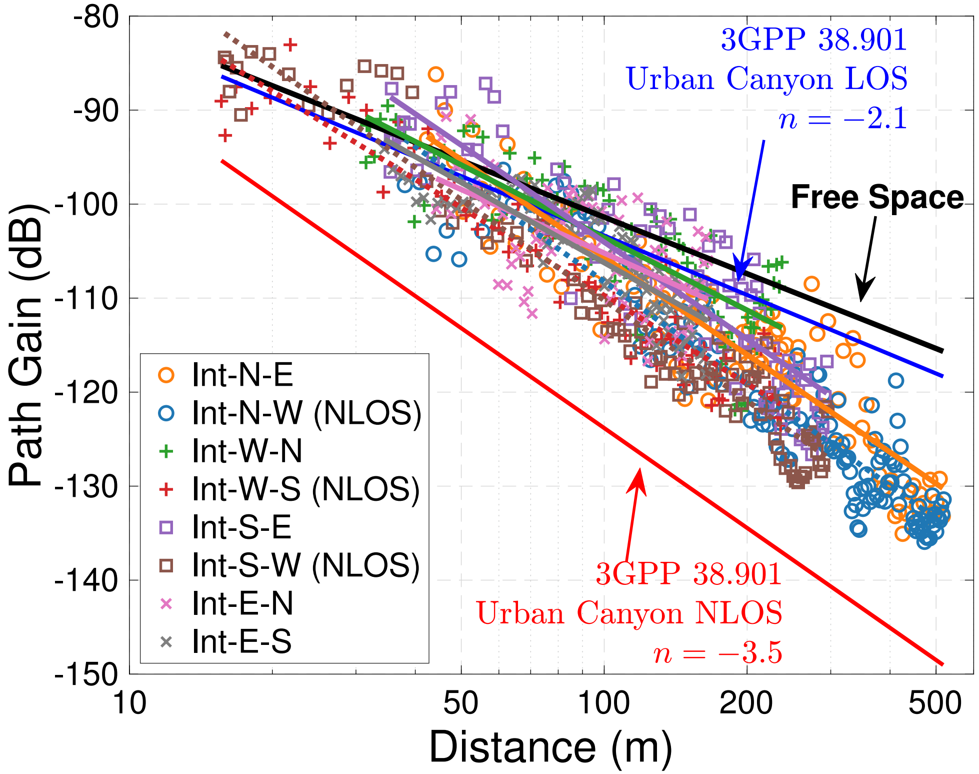

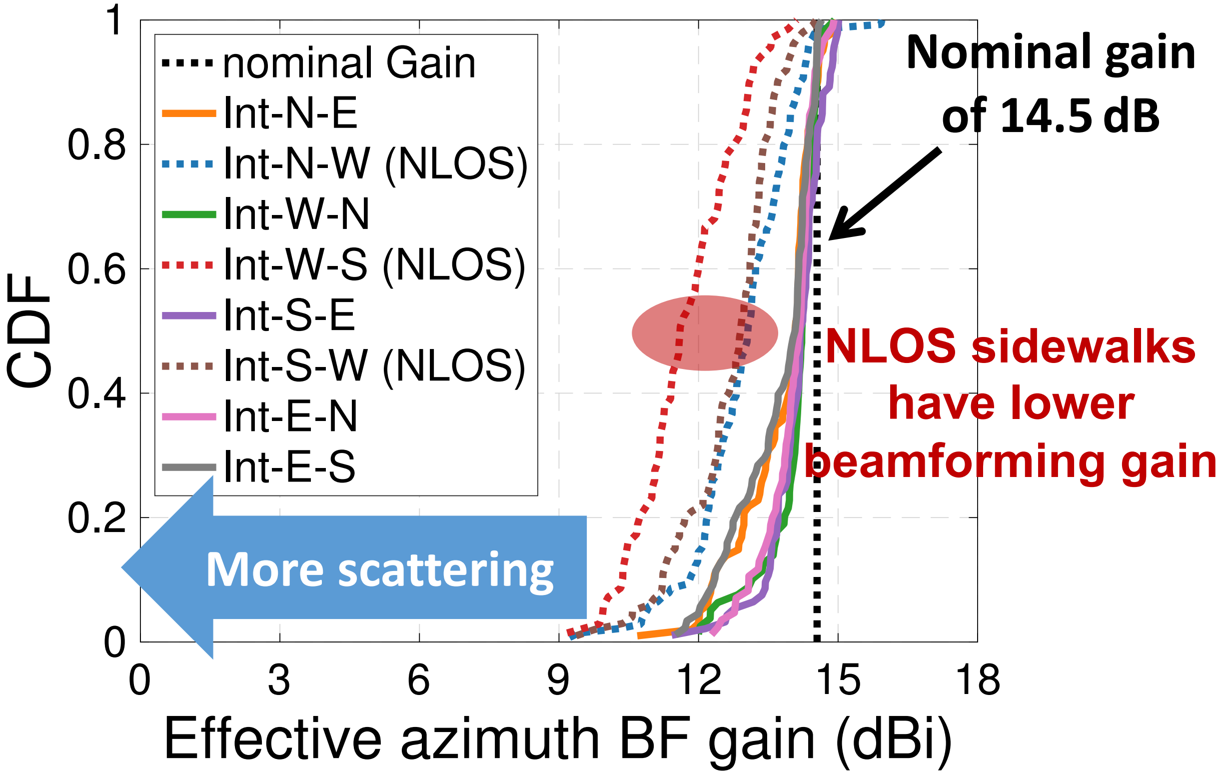

SNR Coverage Map and Achievable Data Rates

- Parameters: P_{Tx} = +28 dBm, G_{Tx} = 23 dB, G_{Rx} = 11 dB, NF_{Rx} = 10 dB, BW = 800 MHz
- Path gains are based on the empirical measurement datasets, and data rates are computed using Shannon's capacity formula (e.g., ~4.0 Gbps @15 dB SNR)
- Minimum data rates can be supported for link distances of at least around 200 meters

Int

Bri & Bal

Summary

- 28 GHz channel measurement campaign
  - Focus on the city-scale COSMOS testbed deployment area as an FCC innovation zone
  - Over **24 million** power measurements were collected from over **1,500 links** on **13 sidewalks** in **3 different sites** and in different settings during March – June, 2019
  - Report and analyze measured path gains, azimuth beamforming gains, and the SNR coverage and achievable rates

- Ongoing work
  - More extensive measurements throughout various COSMOS sites (e.g., Columbia Manhattanville campus, CCNY)
  - More comprehensive studies of seasonal effects in tree-sparse urban street canyons, and wideband channel measurements for obtaining more detailed channel parameters (e.g., power delay profile) in the same environment
  - Measurement-based scheduling and resource allocations in mmWave networks

COSMOS tutorial and testbed tour at ACM SenSys 2019 in Nov. 2019 at Columbia University (IEEE DySPAN 2019 is in the same week in Newark, NJ)

Thank you!

tingjun@ee.columbia.edu

http://www.ee.columbia.edu/~tc2668

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