COSMOS: Enabling Next-Gen Wireless Research

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Abstract

Next-generation wireless networks will utilize both millimeter-wave (mmWave) frequencies and full-duplex (FD) radios to improve networks through increased data rates, reduced latencies, and more efficient usage of the wireless spectrum. [1,2].

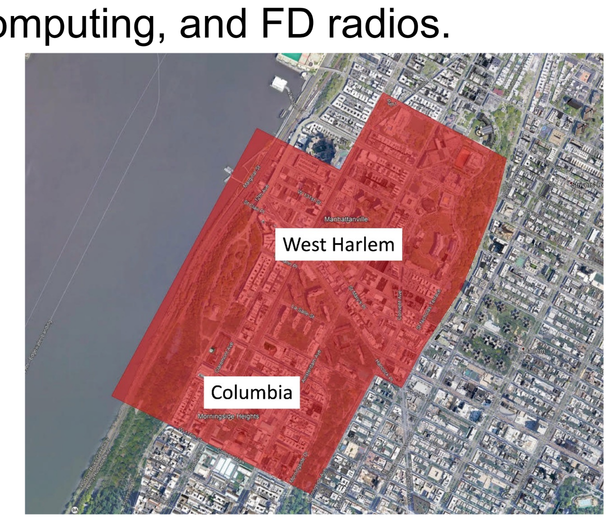
Due to the high path loss at mmWave frequencies, accurate channel measurement and modeling for different deployment sites are required. The most difficult challenge when deploying mmWave antennas is the loss of power when there are obstacles between the transmitter and receiver. In order to evaluate the severity of this difficulty, I participated in an extensive mmWave channel measurement campaign with over 1,500 links on 13 sidewalks which was conducted in the COSMOS testbed deployment area that is located in West Harlem, New York City.

Self-interference cancellation (SIC) is critical to FD wireless communications and takes place across various domains in the transceiver architecture. To enable full-duplex operation, the self-interference (SI) signal leaking from the transmitter to the receiver must be maximally suppressed, as it is often a billion times (> 90dB) stronger than the desired receive signal. A self-interference canceller integrated circuit (IC) operating in the radio frequency (RF) and analog baseband (BB) domains [3] is composed of taps with variable gains and delays that can be adaptively configured to maximize SIC. Finding the optimal canceller configuration is challenging due to the large configuration space and the effects of non-linearities and non-idealities in the physical system. I participated in the implementation of a high bandwidth Gen-3 FD radio which is now being extended to support link-level experimentation.

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 [4,5].
- COSMOS operates in an FCC Innovation Zone which enables greater access to next generation wireless experimentation.
- Technologies on the testbed include software defined radios (SDR), optical networks, mmWave, cloud computing, and FD radios.

COSMOS Testbed Large Nodes



FCC Innovation Zone

References

1. T. Chen, S. Garikapati, A. Nagulu, A. Gaonkar, M. Kohli, I. Kadota, H. Krishnaswamy, and G. Zussman, "A survey and quantitative evaluation of integrated circuit-based antenna interfaces and self-interference cancellers for full-duplex," *IEEE Open Journal of the Communications Society, Special issue on Full-Duplex Transceivers for Future Networks: Theory and Techniques*, vol. 2, pp. 1753–1776, Jul. 2021.
2. T. S. Rappaport, S. Sun, R. Mayzus, H. Zhao, Y. Azar, K. Wang, G. N. Wong, J. K. Schulz, M. Samimi, and F. Gutierrez,, "Millimeter wave mobile communications for 5G cellular: It will work!," *IEEE Access*, vol. 1, pp. 335-339, 2013.
3. A. Nagulu, S. Garikapati, I. Kadota, M. Essawy, T. Chen, A. Natarajan, G. Zussman, and H. Krishnaswamy, "Full-duplex receiver with wideband multi-domain FIR cancellation based on stacked-capacitor, N-path switched-capacitor delay lines achieving >+54dB SIC Across 80MHz BW and >+15dBm TX power handling," in *Proc. IEEE International Solid-State Circuits Conference* (ISSCC'21), 2021.
4. "Cloud enhanced Open Software defined MObile wireless testbed for city-Scale deployment (COSMOS)," https://cosmos-lab.org/, 2019.
5. J. Yu, T. Chen, C. Gutterman, S. Zhu, G. Zussman, I. Seskar, and D. Kilper, "COSMOS: Optical architecture and prototyping," In *Proc. OSA OFC'19 (invited)*, 2019.

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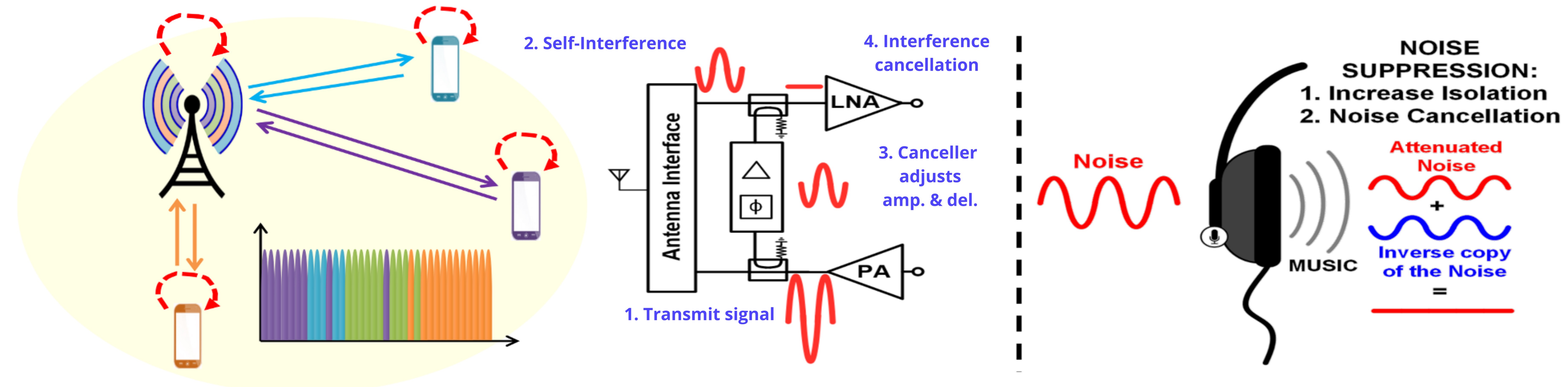
Full-Duplex and Self-Interference Cancellation

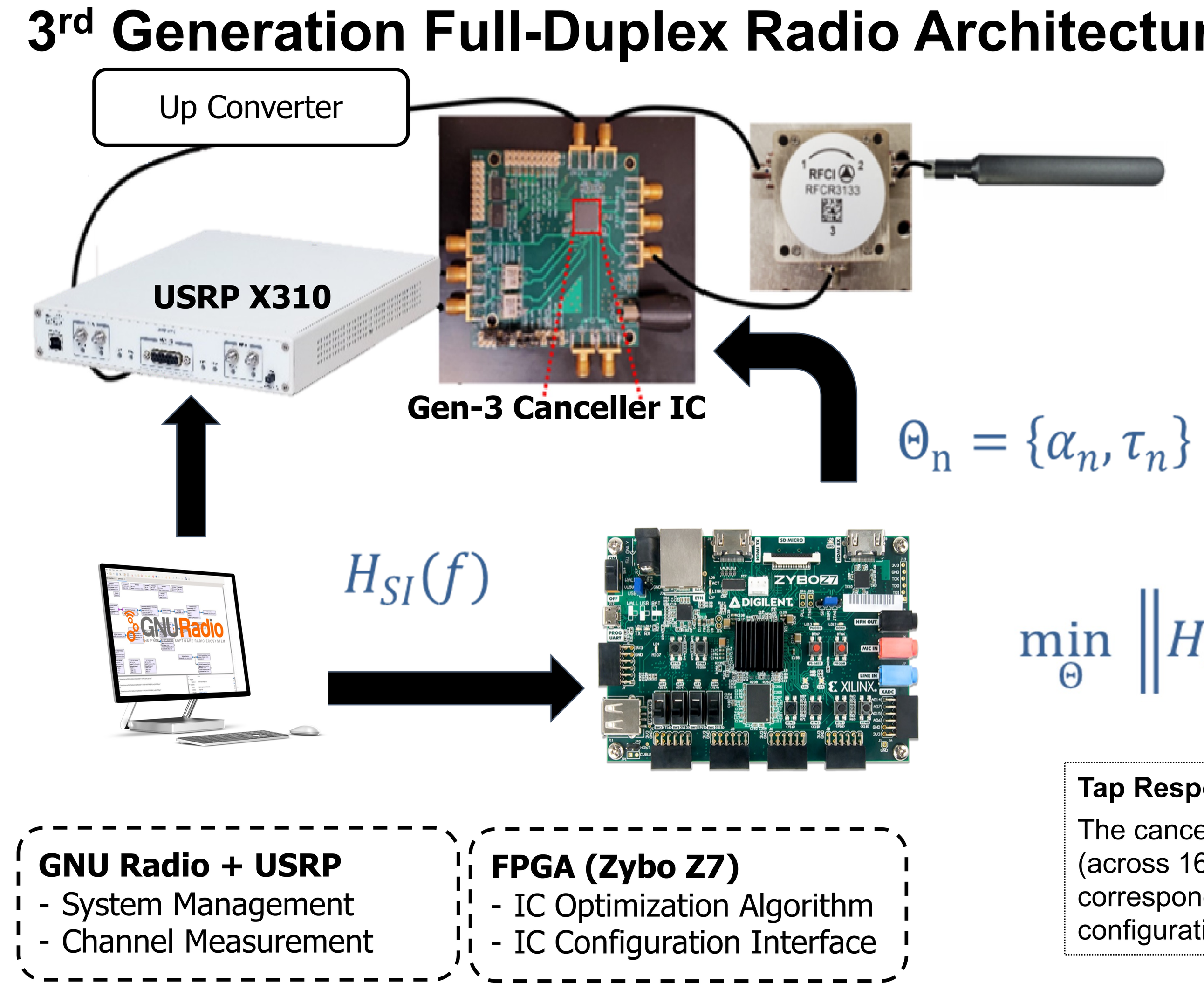


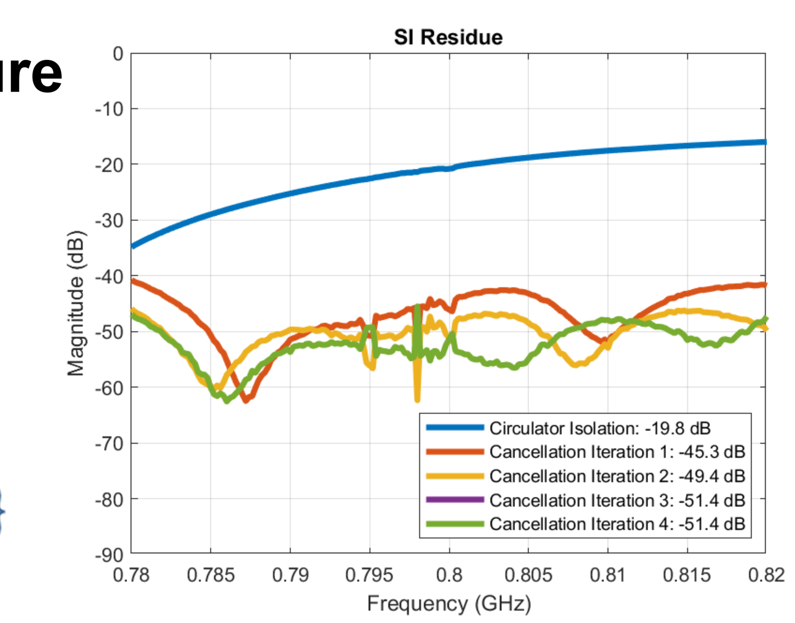
Full-Duplex
- Increase system throughput, decrease latency, more flexible use of wireless spectrum and energy efficient
- Suffers from self-interference (SI) due to transmitter leakage, over a billion times (>90dB) stronger than the receive signal

Self-Interference Cancellation (SIC)
- Operates on the same principles as active noise cancellation in acoustic systems
- Functions across multiple domains including antenna interface isolation, radio frequency (RF) cancellation, analog baseband (BB) cancellation, and digital cancellation

Cancellation Results with 20 MHz Bandwidth
- The initial circulator isolation is 19.8dB. The cancellation after the initialization phase is 45.3dB. After three iterations of gain adjustment, the algorithm reaches a steady state and achieves a cancellation of 51.4dB. Therefore, the RF and BB cancellation alone achieves 31.6dB of self-interference cancellation.

3rd Generation Full-Duplex Radio Architecture

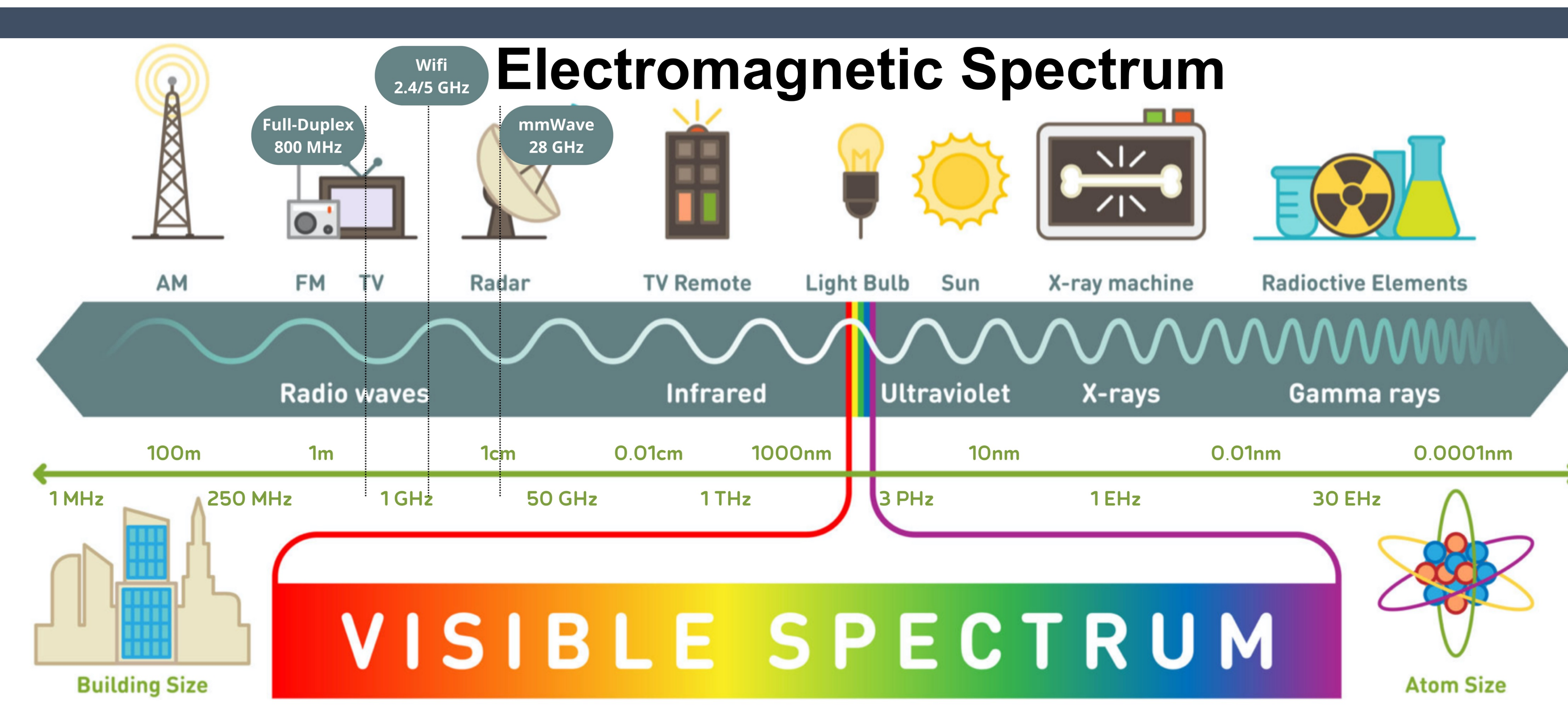




$$\min_{\Theta} \left\| H_{SI}(f) - \sum_n H_n(f, \Theta_n) \right\|$$

Tap Response and Self-Interference Residue Measurements
The canceller IC has a total of 361 possible RF responses (across 16 taps) and 32 possible BB responses (across 8 taps), corresponding to over 10^{19} possible gain and delay configurations

Electromagnetic Spectrum

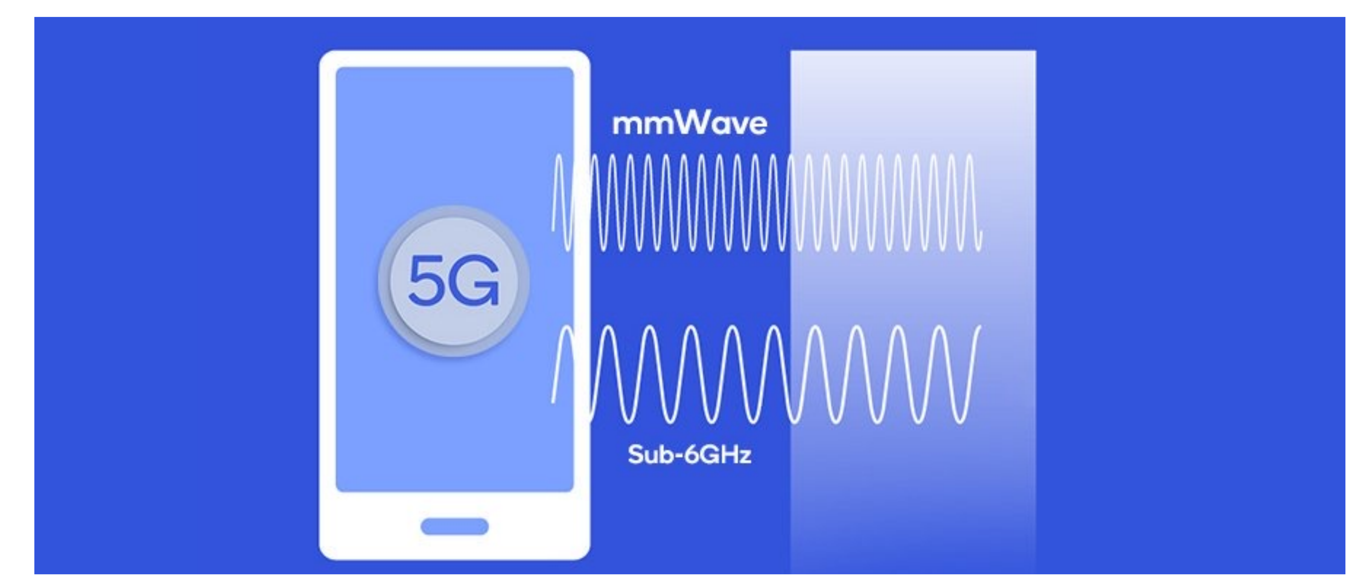


Millimeter Wave Measurement Platform

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

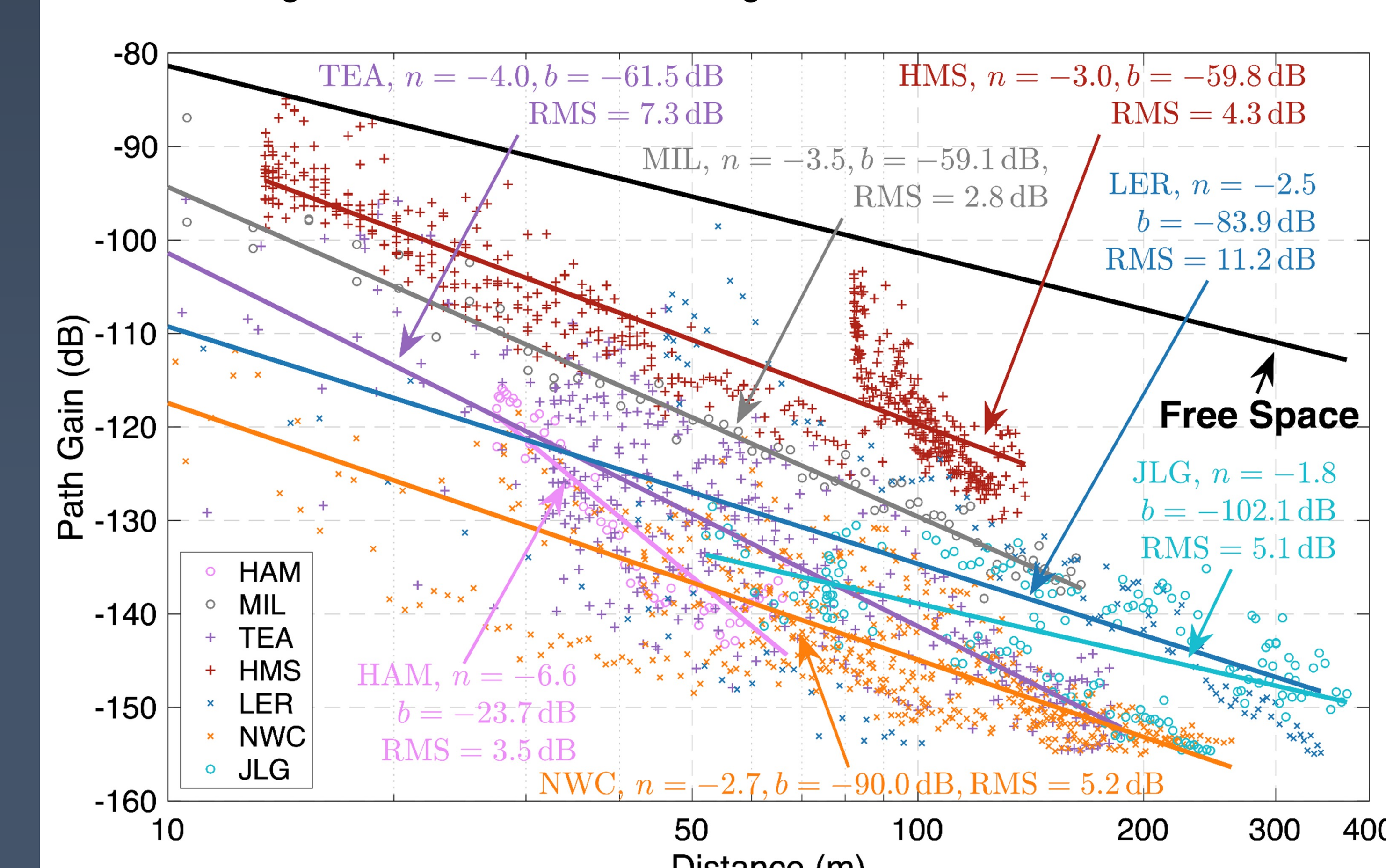
Red – Base and rotating platform
Blue – Power meter and Raspberry Pi
Green – 10 degree horn antenna

- 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.



Results: mmWave – Different Measurement Sites

- Data rates in excess of 2.5 Gbps are achievable for at least 90% of indoor users in typical public school buildings with typical lightpole gNodeB (gNB) deployments.
- Data rates in excess of 200 Mbps are achievable for users in buildings that use modern Low-e glass.



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