

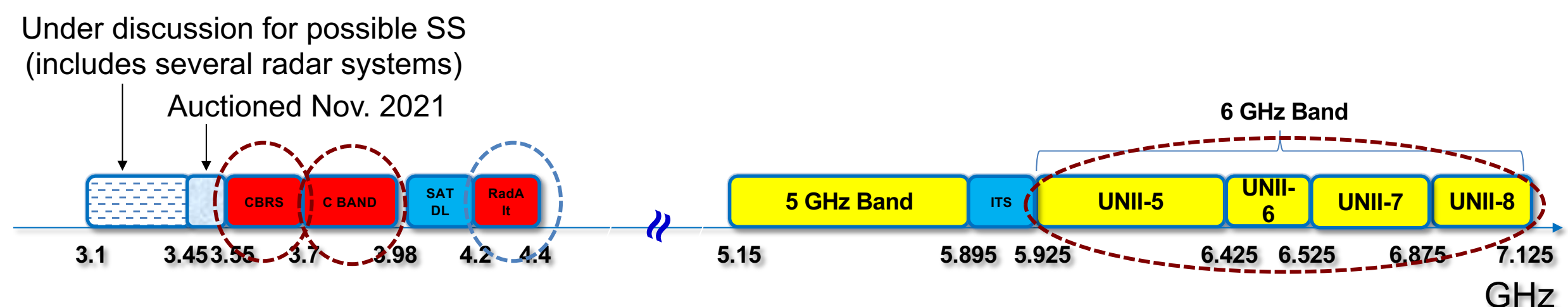
Collaborative Research: SWIFT: Coexistence and Interference Mitigation in the Mid-Band Spectrum: Analysis, Protocol Design, and Experimentation

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BACKGROUND & MOTIVATION



Significance of mid-bands: Good tradeoff between coverage and capacity

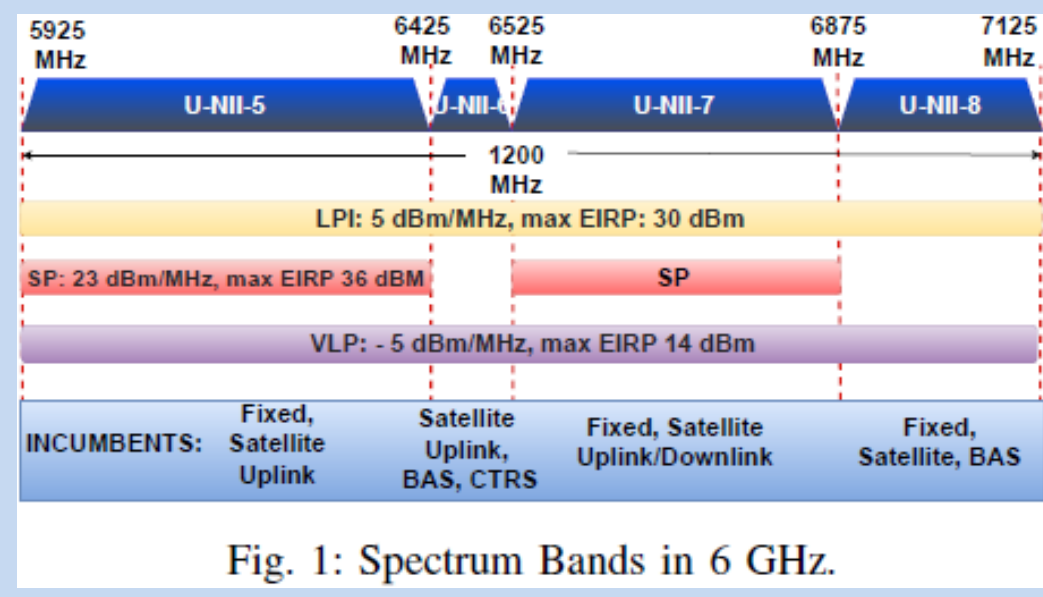
Highly valuable to operators (e.g., C-band auction generated \$80.9B net revenue, compared to \$7.5B for Upper 37 GHz, 39 GHz, & 47 GHz bands combined)

Our project deals with coexistence challenges related to three specific mid-bands: CBRS, C-band, and the Unlicensed 6 GHz.

COEXISTENCE & INTERFERENCE CHALLENGES in the 6 GHz BAND

FCC's 6 GHz ruling

Unlicensed Operation	Env.	Band	Max EIRP	Control Mec.	R&L, FNPRM	Status
SP	Indoor	U-NI-5, U-NI-7	AP: 36 dBm, STA: 30 dBm	AFC	1st R&O	Approved
LPI	Indoor/Outdoor	U-NI-5, U-NI-6, U-NI-7, U-NI-8	AP: 30 dBm, STA: 24 dBm	No	1st R&O	Approved
VLP	Indoor/Outdoor	U-NI-5, U-NI-7	14 dBm	No	2nd R&O	Approved
VLP	Indoor/Outdoor	U-NI-6, U-NI-8	14 dBm	No	3rd R&O	Approved
Geofenced VLP	Indoor/Outdoor	U-NI-5, U-NI-6, U-NI-7, U-NI-8	21 dBm	Geofencing Req.	2nd FNPRM	Proposed
CIC	Indoor	U-NI-5, U-NI-6, U-NI-7, U-NI-8	For LPI Devices	Enabling Signal Level	2nd FNPRM	Proposed

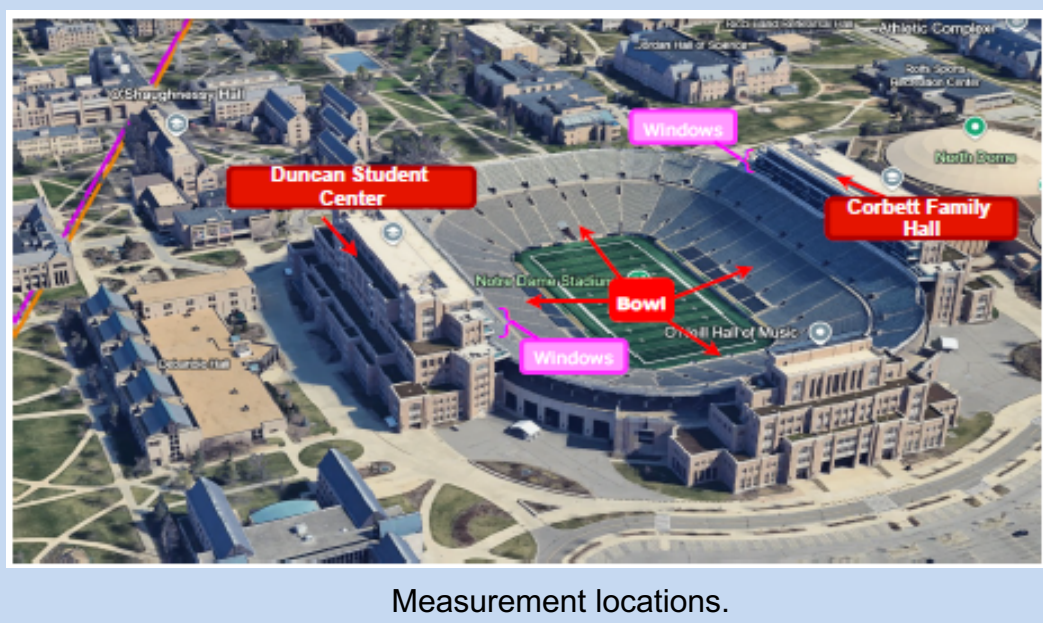


Objectives

- Evaluation of Indoor/Outdoor Sharing in the Unlicensed 6 GHz Band:** Detailed analyses of coexistence of outdoor SP with indoor LPI under different conditions: fully occupied stadium and empty stadium.
- A first of its kind detailed data set of indoor and outdoor measurements of SP and LPI APs.
- Comparison of 6 GHz usage and 5 GHz usage when the stadium is at full capacity with 80,000 attendees.
- Spectrum analyzer measurements quantifying the increase in aggregate interference when the stadium is at full capacity.

Deployment

- The ND stadium consists of an open bowl area and three adjacent buildings anchored to the south, east, and west sides.
- About 900 SP Wi-Fi 6E APs (Aruba AP-634) are installed outdoors in the stadium bowl: two SP APs are placed within a case and mounted on the handrail that splits the stadium section.



Measurement locations.

Measurement Tools and Campaigns

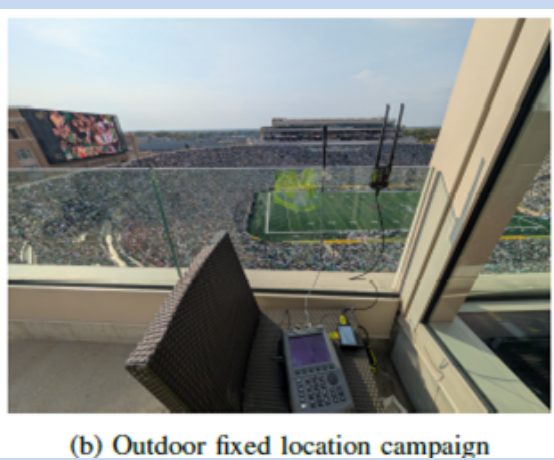
- Smartphones with **SigCap**.
- All RSSI measurements were on the 20 MHz beacon channel.
- Outdoor walking measurements were conducted in the bowl using phones equipped with SigCap. Indoor Measurements were conducted using SigCap phones, in floors 7 - 9 of Corbett and floors 1, 2, 7 - 9 of Duncan.
- The spectrum analyzer, with an antenna designed for 4- 8 GHz, was placed on the balcony of the 9th floor of Duncan Student Center.

Measurement tools and features.

App/Tool	Features	Devices
SigCap	BSSID, Tx power, # of connected clients, frequency, channel utilization, RSSI, GPS, Tx and Rx link-speeds when connected	3 x Google P8, 2 x Samsung S22, 1 x Samsung S24
SA	Spectrum power captured over 100 kHz bins	1 x Keysight FieldFox, Model N9951A Handheld SA



(a) Outdoor walking campaign



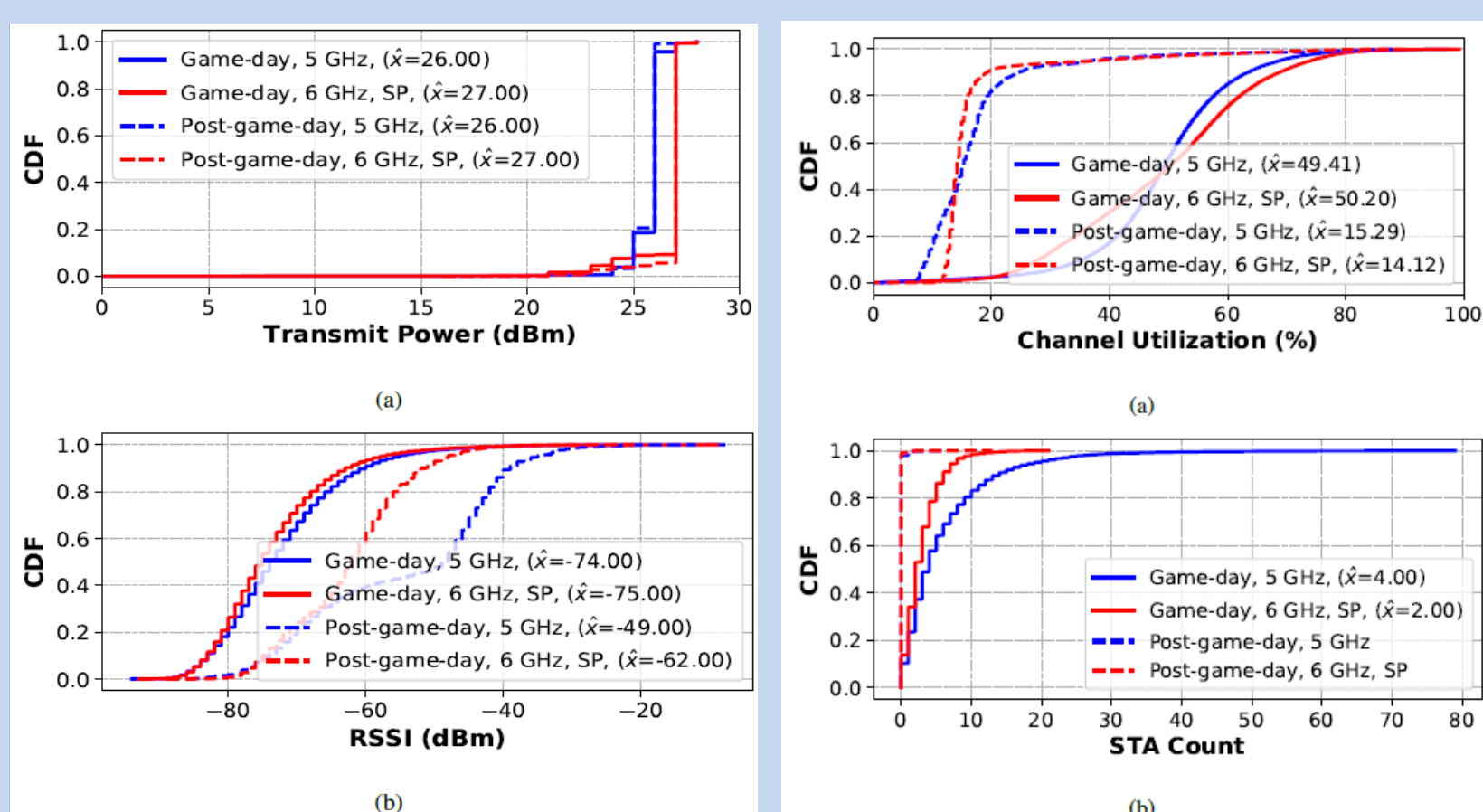
(b) Outdoor fixed location campaign



(c) Indoor walking campaign

Measurement campaigns.

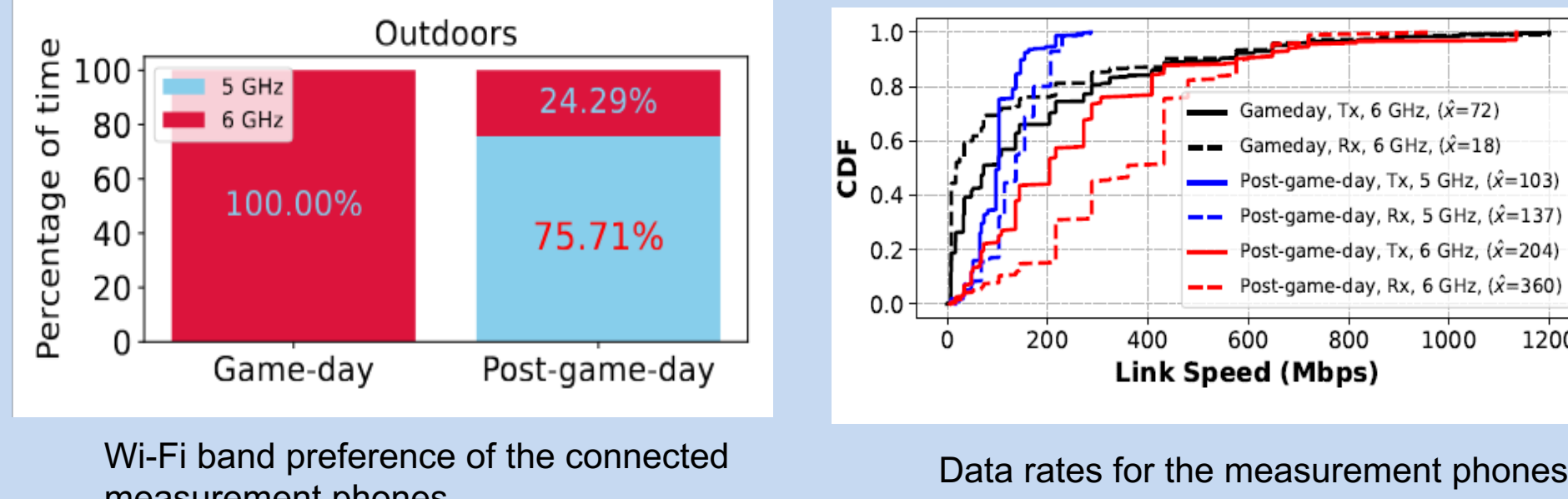
Results: 5 GHz vs 6 GHz



- Measured Tx power < the maximum 36 dBm EIRP permitted, both by the AFC in 6 GHz and by FCC regulations in 5 GHz: Since the deployment is extremely dense, lower Tx power allows better frequency reuse.
- We see similar channel utilization for 5 GHz and 6 GHz SP APs, on both game-day and post-game-day, since primary channel utilization is mainly due to the transmission of beacons

Tx power, RSSI levels, channel utilization, and STA Count for 5 GHz and 6 GHz SP outdoors on game-day.

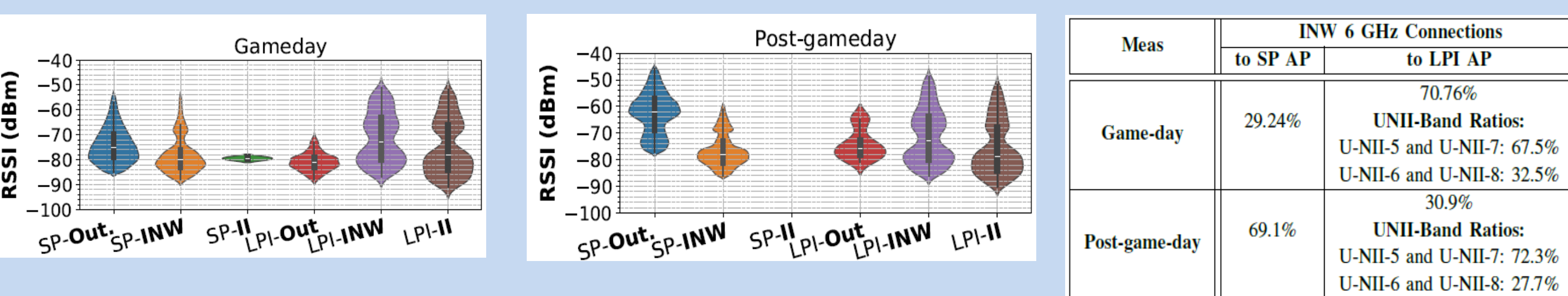
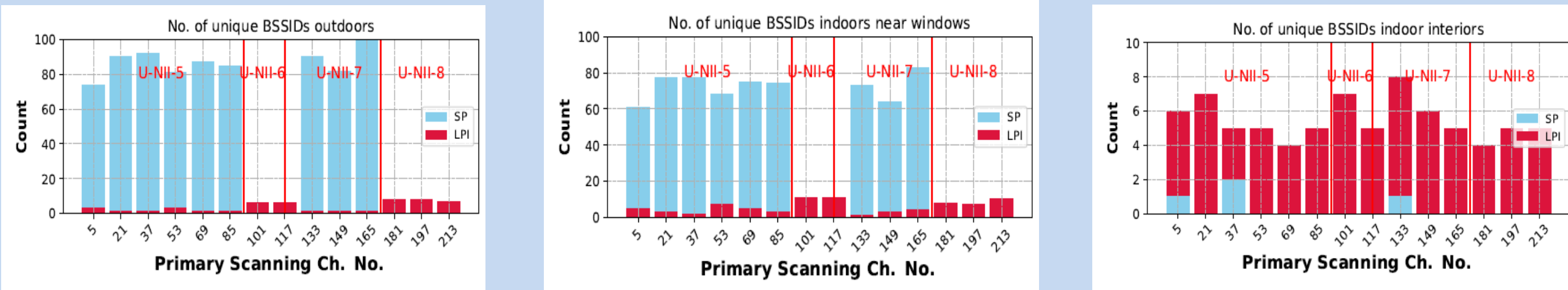
Results: 5 GHz vs 6 GHz –Wi-Fi Usage vs Link Speed



Key takeaway: The 6 GHz band is crucial for improving connectivity in dense deployments: the 5 GHz band is almost completely saturated on game-day.

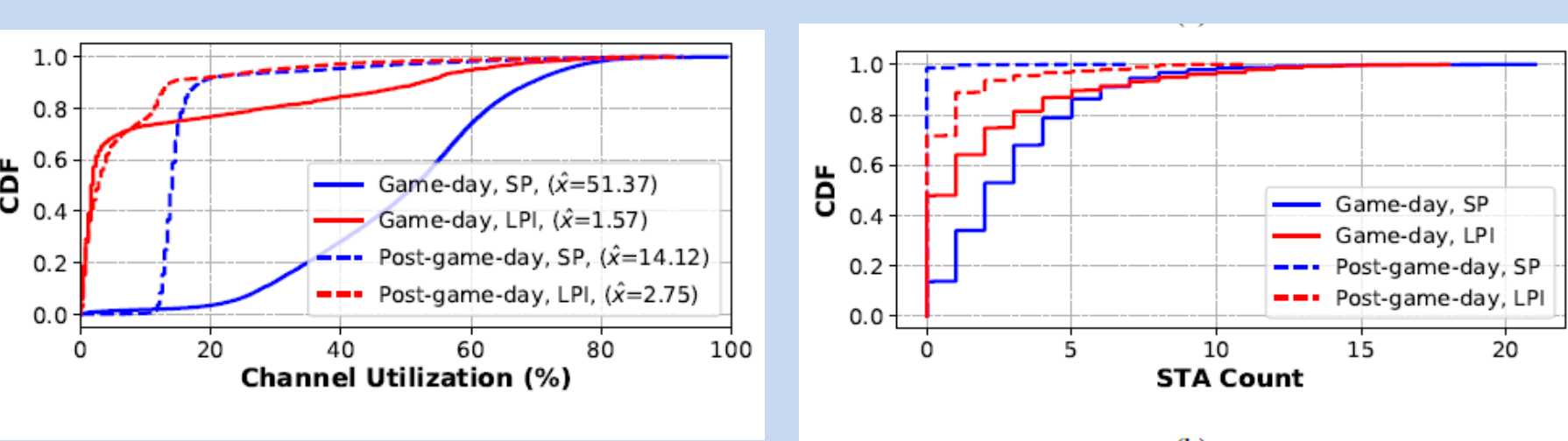
By the Notre Dame Office of Information Technologies: 14% of client connections in the stadium on game-day were over the 6 GHz band- this rate of adoption is fairly high since only the newer phone models incorporate Wi-Fi 6E.

Results: Number of Unique BSSIDs, RSSI, and Connection Ratios for SP and LPIs



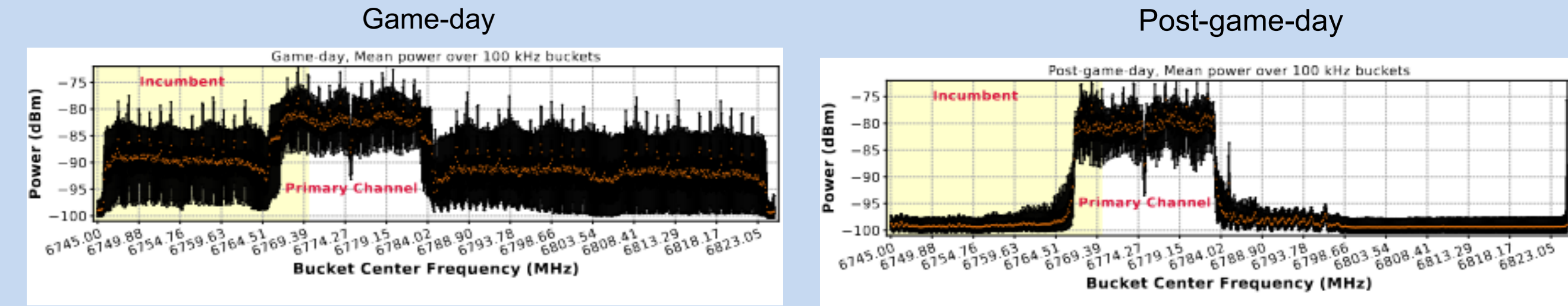
- Key takeaway:** SP operations outdoors and LPI operations indoors will affect each other in the INW environment- further highlighting the importance of careful channel assignments
- Key takeaway:** Indoor interior environments, with their physical separation, are well insulated from outdoor SP operations, enabling outdoor and indoor interior deployments to operate simultaneously without negatively impacting each other's performance.

Results :Channel Utilization and STA Count



CDF plots of channel utilization and STA count on game-day and post-game-day.

Results : Aggregate Interference in 6 GHz



- The 30 MHz incumbent with center frequency 6755 MHz is also shown in yellow in the figure.
- Key takeaway:** The 20 MHz primary channel, Channel 165 (6765 - 6785 MHz) has an elevated power level due to beacon transmissions.
- Key takeaway:** AFC systems are not designed to account for aggregate interference, a significantly higher aggregate interference measured on game-day: 10 dB higher in mean power compared to post-game-day.

Conclusions & Future Work

- The first-of-its-kind, comprehensive measurements and analyses presented in the paper clearly indicate that the entire 6 GHz band is crucial for dense deployments:
- Frequencies used with high power outdoors may be unavailable for LPI use indoors, especially near windows: The hybrid sharing proposed by Ofcom [4] where the outdoor deployment is 5G with much higher power than LPI.
- AFC does not consider aggregate interference while calculating allowed power, our spectrum analyzer measurements indicate a rise of about 10 dB in aggregate signal strength during game-day: The deployment studied was extremely dense with approximately 100 BSSIDs on each channel.

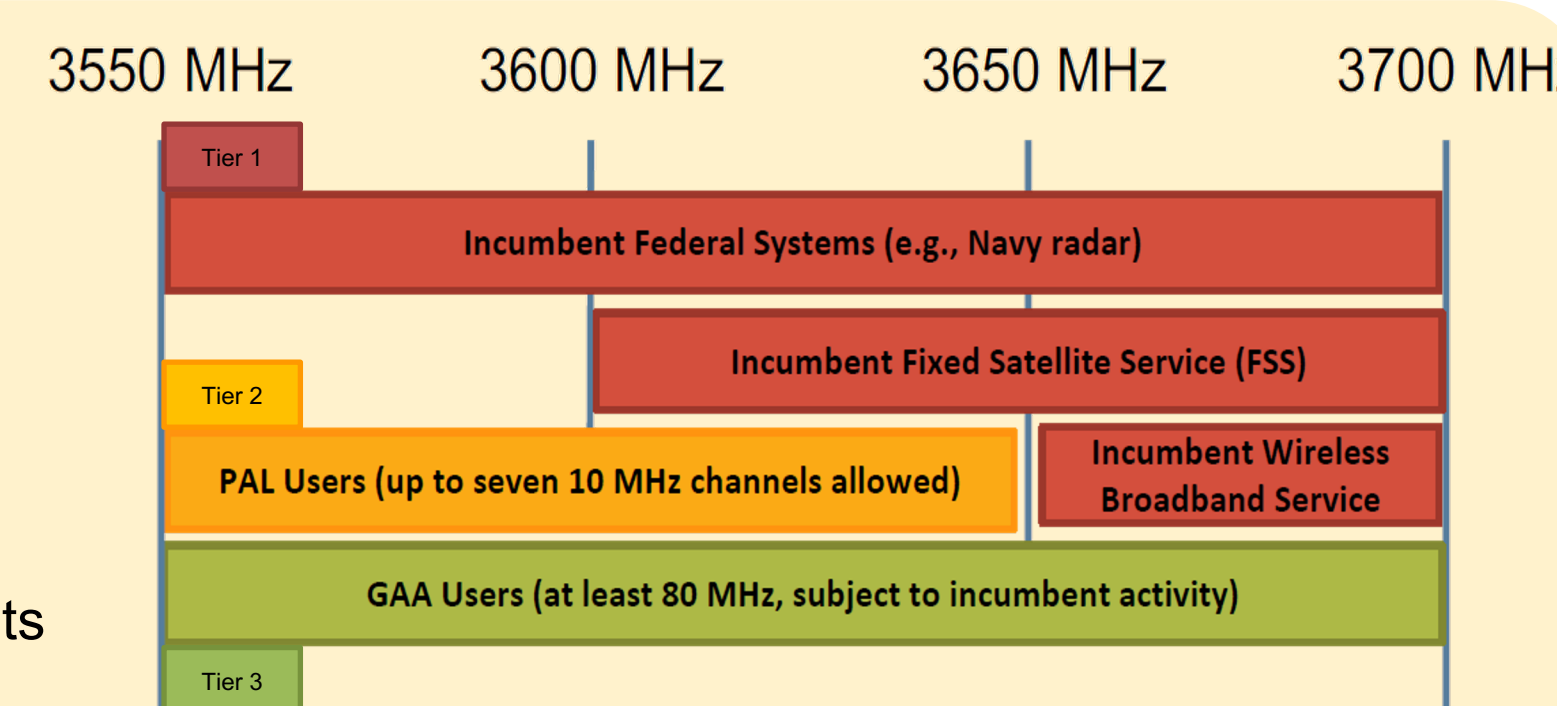
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- [1] S. Dogan-Tusha, A. Tusha, M. I. Rochman, H. Nasiri, J. R. Palathinkal, M. Atkins, and M. Ghosh, "Evaluation of indoor/outdoor sharing in the unlicensed 6 GHz band," arXiv preprint arXiv:2505.18359, 2025.
- [2] S. Dogan-Tusha, A. Tusha, M. I. Rochman, H. Nasiri and M. Ghosh, "Spectrum Sharing Characterization Using Smartphones: Exploring 6 GHz Sharing Through Large-Scale Wi-Fi 6E Measurements," in IEEE Communications Magazine, vol. 63, no. 2, pp. 70-76, February 2025.
- [3] [S. Dogan-Tusha, M. I. Rochman, A. Tusha, H. Nasiri, J. Helzerman, and M. Ghosh, "Evaluating the interference potential in 6 GHz: An extensive measurement campaign of a dense indoor Wi-Fi 6E network," in "Proc. ACM WINTech '23", 17th ACM Workshop on Wireless Network Testbeds, Experimental Evaluation & Characterization, Oct. 2023, pp. 56-63.

COEXISTENCE AND INTERFERENCE ANALYSIS IN THE CBRS BAND

Background

- 3-tier architecture
- 15 channels, each 10 MHz
- GAA/GAA coexistence issue
- No limit on # of aggregated channels
- GAAs are LTE (band 48); 5G NR soon
- TDD operation
- Spectrum inquiry and grant in 5 MHz units



GAA/GAA Coexistence Issues

- Co-channel interference (CCI), Adjacent channel interference (ACI), Unsynchronized TDD configurations

→ High DL/UL interference

Objectives:

- A Generalized Deep Learning Model for Signal Coverage Prediction in the CBRS Band
- A comprehensive evaluation and comparison of empirical/analytical channel models, RT, and DL methods for RSS prediction using measurements collected from a real-world CBRS deployment in the city of South Bend, IN.
- We compare the predicted RSS with the measured RSS as a metric to assess the performance of each method.

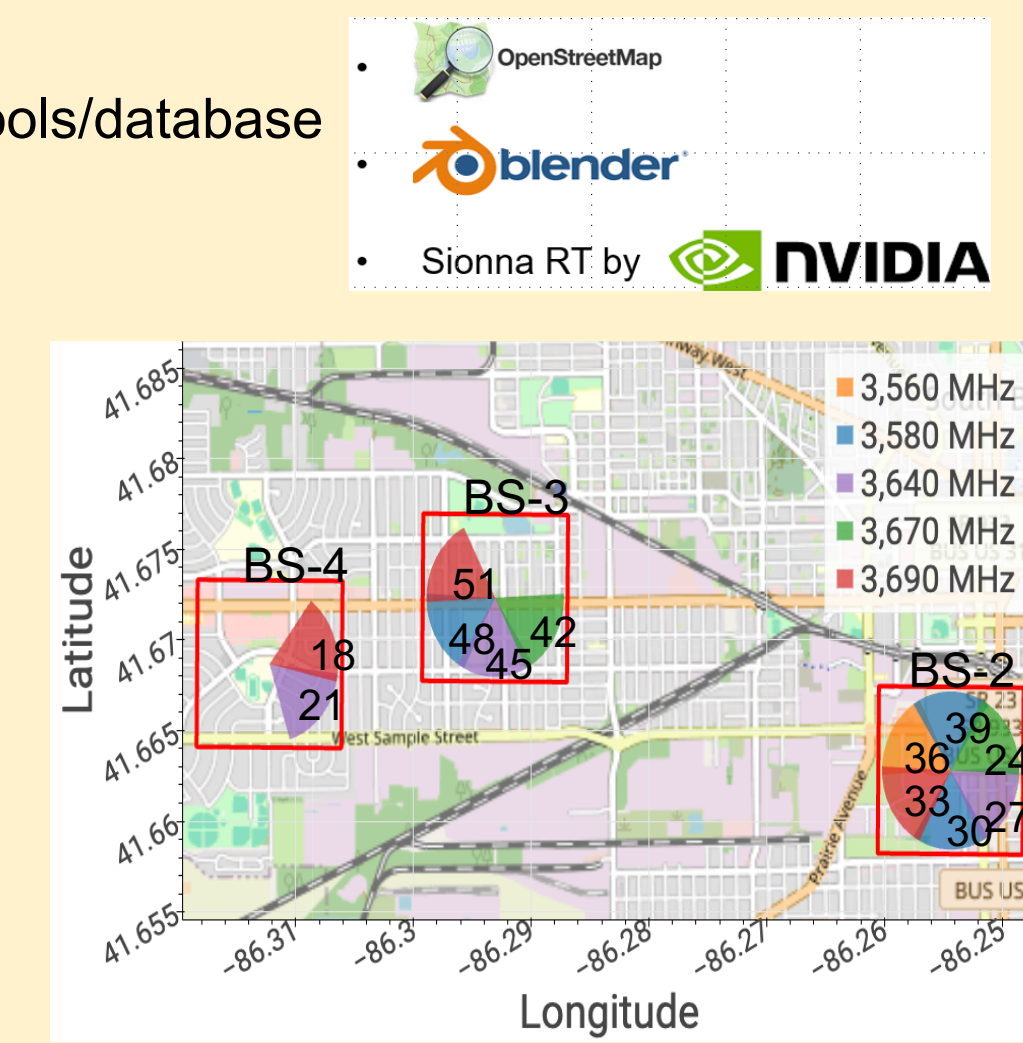
Methodology: Geo2SigMap

- First ML signal mapping model using pure publicly available tools/database

- Massive real-world raytracing dataset by automotive pipeline: 27,176 areas, 135,800 ray tracing results
- ML propagation model tested by real measurements: 45,156 measurements on six CBRS stations
- Three different kinds of measurement devices

Real-world Measurements

- Private CBRS LTE cells
- 10 cells in the South Bend school district
- CBRS band (3.5 GHz)
- 20 MHz bandwidth

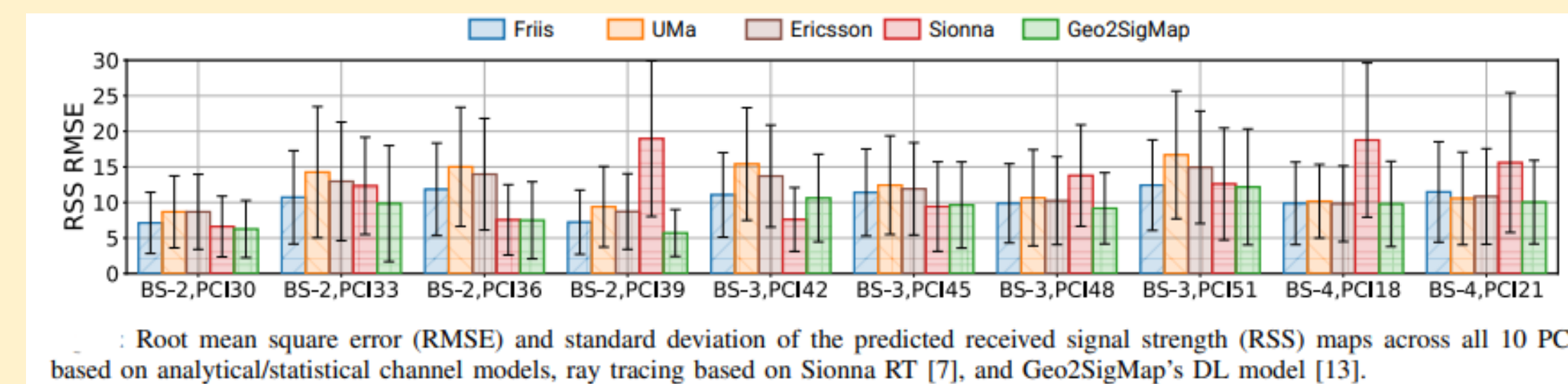
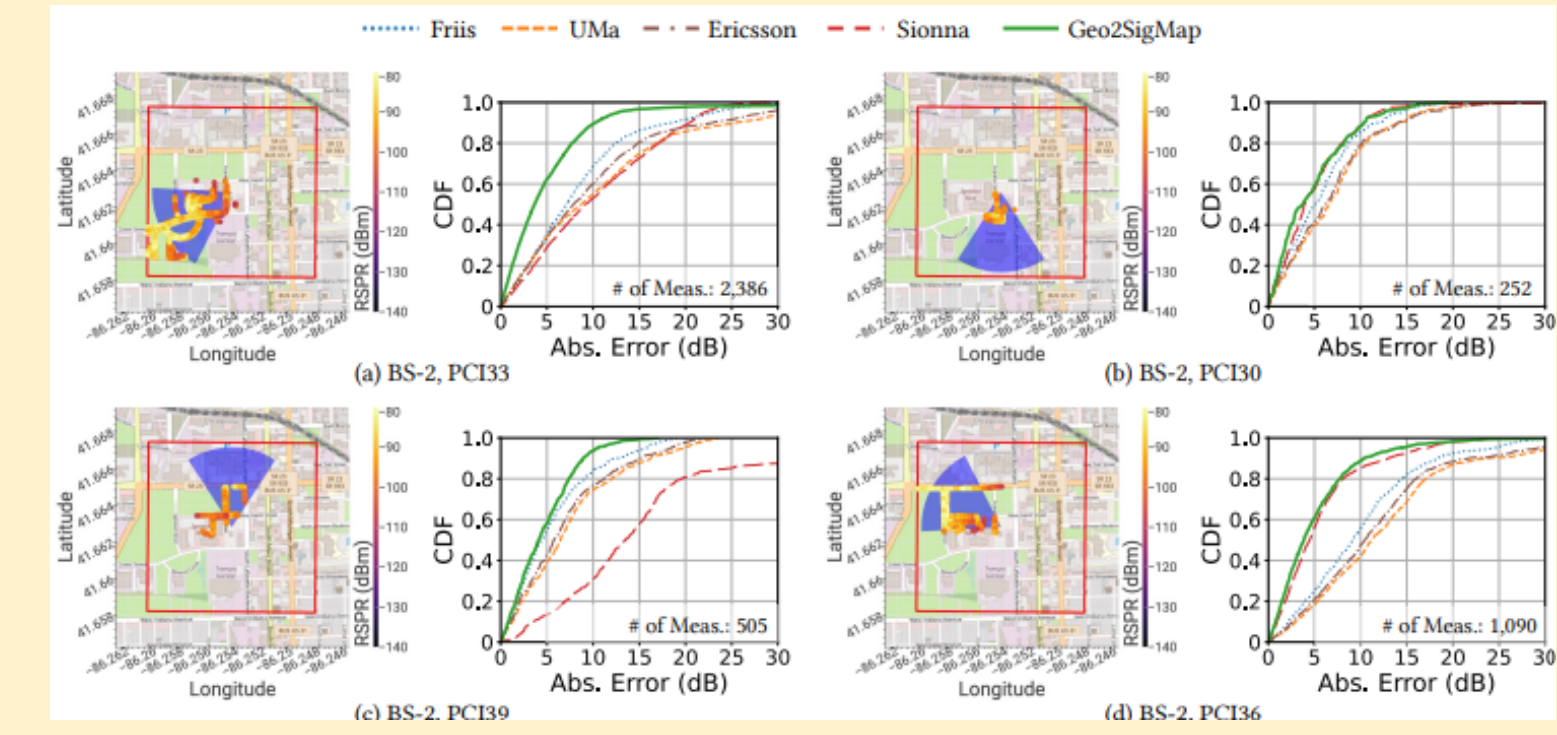


Specifications of CBRS LTE cells

BS	Height t	Down tilt	PCI	Carrier Frequency	Azimuth Orientation	Number of Meas.
BS-2	44 m	-4 °	30	3.58 GHz	180 °	252
			33	3.69 GHz	240 °	2,386
			36	3.56 GHz	300 °	1,090
			39	3.58 GHz	0 °	505
BS-3	12 m	-4 °	42	3.67 GHz	120 °	1,747
			45	3.64 GHz	180 °	3,579
			48	3.58 GHz	240 °	1,687
			51	3.69 GHz	300 °	2,982
BS-4	33 m	-1 °	18	3.69 GHz	70 °	5,524
			21	3.64 GHz	130 °	1,077

Evaluation: Compare with Baseline

- Measurements overlaid on target areas with the base station at the center and CDF of absolute errors for each prediction methods.
- Across all 10 PCIs, the proposed model always has a **top-3** performance on both the median error and the 90th percentile



Conclusions & Future Work

- We re-trained the original DL model from our previous work, Geo2SigMap, using a new synthetic multi-dimensional dataset to enable the model to accommodate various spatial scale inputs.
- Despite challenges such as the geographically uneven distribution of measurement data and missing building information compared to the measurements in our previous work, the results demonstrate that the improved Geo2SigMap consistently outperforms the baseline models in most scenarios.

[5] . Li, Z. Gao, J. R. Palathinkal, M. Ghosh and T. Chen, "A Generalized Deep Learning Model for Signal Coverage Prediction in the CBRS Band," 2025 IEEE International Symposium on Dynamic Spectrum Access Networks (DYSPAN), London, United Kingdom, 2025, pp. 1-5
[6] A. Tusha et al., "A Comprehensive Analysis of Secondary Coexistence in a Real-World CBRS Deployment," in IEEE Transactions on Cognitive Communications and Networking, vol. 11, no. 3, pp. 1397-1409.