



SigCap: A Crowdsourcing Platform for Wireless Broadband Mapping and Analysis

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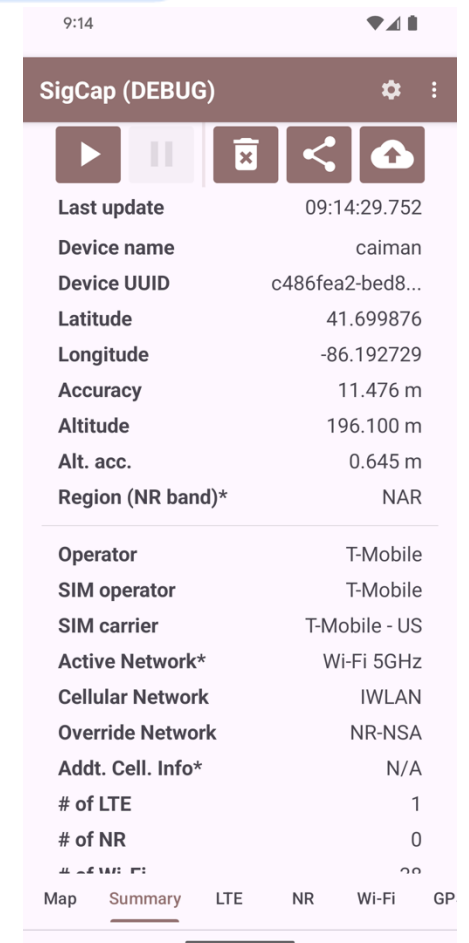
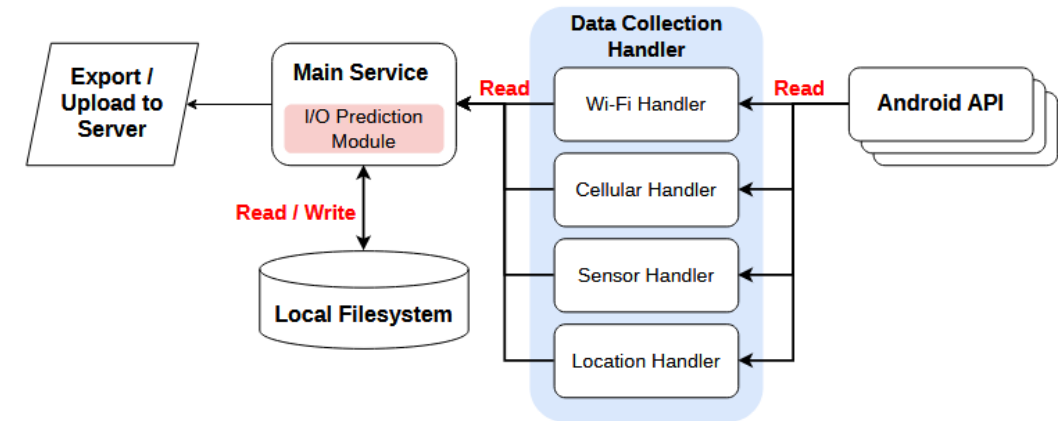
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Outline

- Overview and Motivation
 - Wireless broadband data is essential for consumers and policymakers.
 - SigCap as a crowdsourced platform for measurement and analysis of cellular and Wi-Fi signals.
- Summary of Data Collected by SigCap
 - New tool: **SigCap Data Platform** built by Center for Research Computing at Notre Dame
(<https://sigcap.crc.nd.edu>)
- Case Studies

SigCap Overview

- Developed in the University of Chicago since 2019.
- Collects various signal and sensor data through Android API, along with GPS location.
- Easy mapping and exporting through SigCap Data Platform (<https://sigcap.crc.nd.edu>).
- No root capability required.
- **Disadvantage:** depends on Android API which sometimes broken on new update.



Summary of Captured Parameters

- **Overview:** timestamp, device UUID, GPS coordinate, operator name, currently active network (e.g., LTE, NR-SA, NR-NSA, Wi-Fi).
- **Traffic statistics:** number of packets, total size of packets, and throughput for TX and RX.
- **4G LTE:** PCI, frequency, RSRP, RSRQ, RSSI, bandwidth.
- **5G NR:** PCI, frequency, SS-RSRP, SS-RSRQ.
- **Wi-Fi:** BSSID, primary frequency, center frequency, RSSI, bandwidth, operating standard, link speed, channel utilization, number of STA, transmit power.
- **GPS/GNSS satellite:** satellite ID (SVID), constellation type (e.g., GPS, GNSS, GLONASS, Galileo, Beidou), frequency, carrier to noise ratio (CNR).
- **Temperature sensor:** CPU, GPU, Skin temperatures.
- **Battery sensor:** battery temperature, level, current discharge
- **iperf:** application layer throughput
- **ping:** round trip latency
- **HTTP GET:** application layer throughput
- **Further info:** <https://people.cs.uchicago.edu/~muhiqbalcr/sigcap/docs/>

Extracting SigCap Data

- After SigCap data have been uploaded, you can access it through the data platform page (<https://sigcap.crc.nd.edu>).
- Before accessing the data, please log in to your account or create one.
 - When creating the account, please state clearly your reason for requesting an account on the “note box”.



Login / Sign Up

Wireless Signal

n, powered by an

Password (again)

Note*

Please provide a reason for requesting an account

Sign Up

<https://sigcap.crc.nd.edu>

[SigCap Data Platform Live Demo]

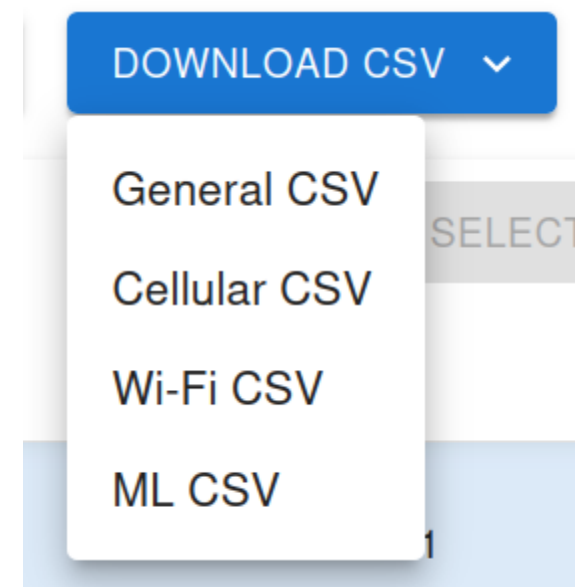
Extracting SigCap Data, cont.



- On the cellular map display, you can filter the map based on operator, technology, band (frequency range), statistics (maximum or mean of data), and bin size in meters.

Extracting SigCap Data, cont.

- For the CSV creation, there are four different types:
 - **General CSV:** Each row in this CSV represents a single data capture with multiple cellular and Wi-Fi entries.
 - **Cellular CSV:** This CSV presents only the cellular entries.
 - **Wi-Fi CSV:** This CSV presents only the Wi-Fi entries.
 - **ML CSV:** Similar to the General CSV, this CSV summarizes cellular and Wi-Fi entries within a row but with statistics such as average, std. dev., minimum, and maximum, to use as a machine learning input.



Contributing to SigCap
Empirical data is important to
have a ground truth of
wireless broadband coverage
in the U.S.

The ARA platform is uniquely situated in a rural setting, where
Mobile Network Operators (MNOs) give less focus for deployments.

SigCap install link:

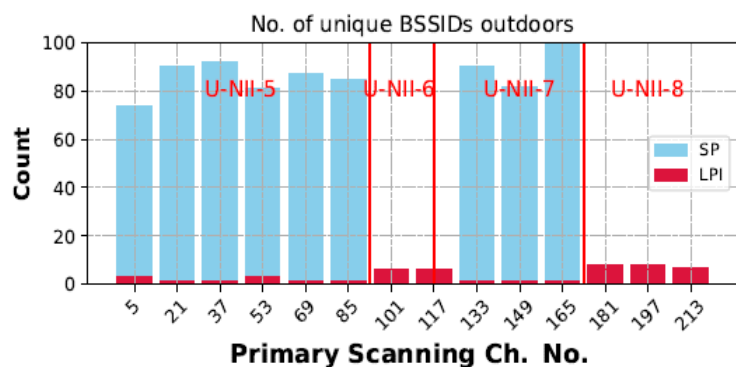
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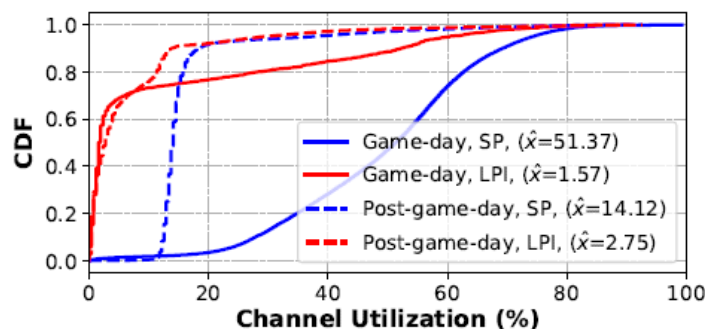
SigCap Install Link

Case Study 1: 6 GHz Wi-Fi Deployments at the Notre Dame Stadium [1]

- Goal: to compare the performance of Wi-Fi in 5 and 6 GHz (under Standard Power/SP and Low-Power Indoor/LPI), as well as cellular MNOs.
 - 6 GHz spectrum can be utilized for unlicensed use under two power regimes: Standard Power (SP) and Low-Power Indoor (LPI).
 - Study the performance of Wi-Fi and cellular MNOs to serve the stadium with full capacity of 77k attendees.
- Methodology: passive measurements using SigCap as well as active measurements using Ookla Speedtest.
 - Focusing on outdoor bowl and indoor locations (concourse, VIP areas)



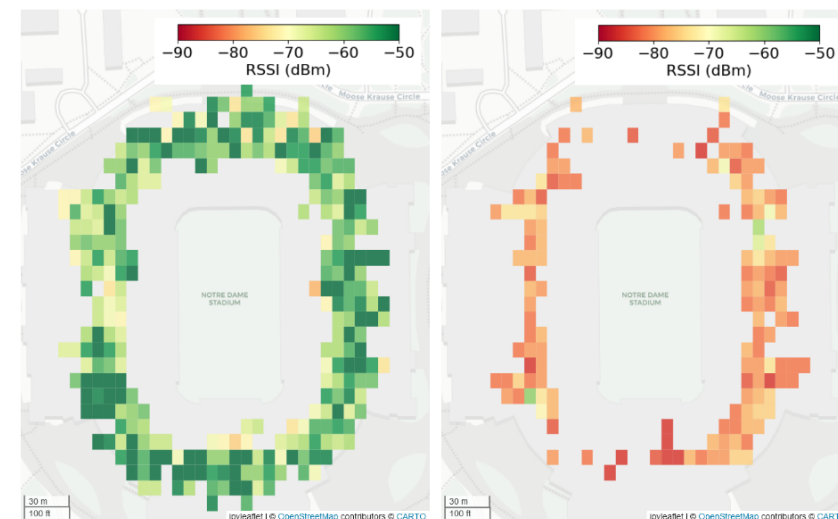
Number of Unique BSSID in the 6 GHz Deployment at ND Stadium



Channel utilization of 6 GHz APs at ND Stadium



6 GHz Fixed Links at ND Stadium



(a) SP APs

(b) LPI APs

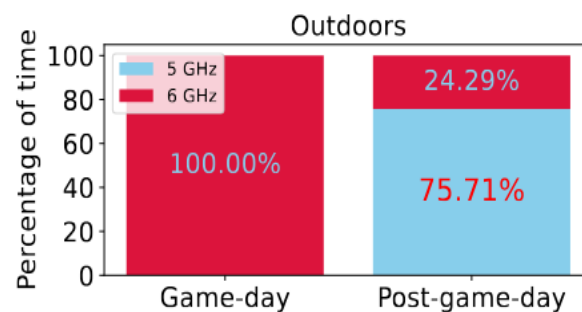
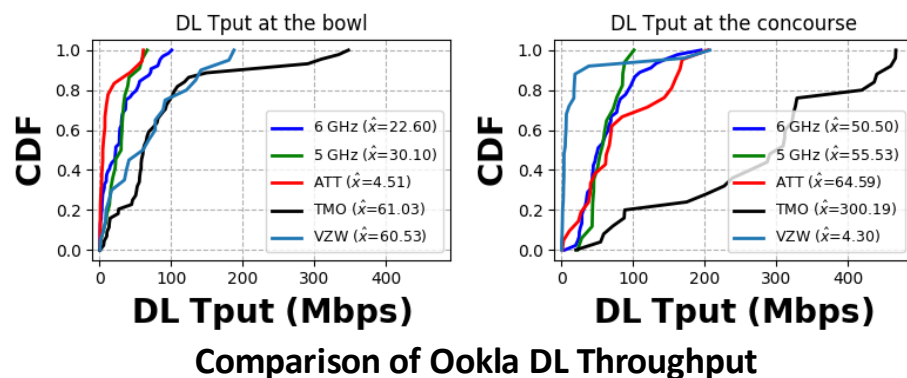
Heatmap of Wi-Fi RSSI Captured Outdoors at ND Stadium

[1] Dogan-Tusha, S., Tusha, A., Rochman, M.I., Nasiri, H., Palathinkal, J.R., Atkins, M., and Ghosh, M. *Evaluation of Indoor/Outdoor Sharing in the Unlicensed 6 GHz Band. To be published in IEEE DySPAN 2025.*

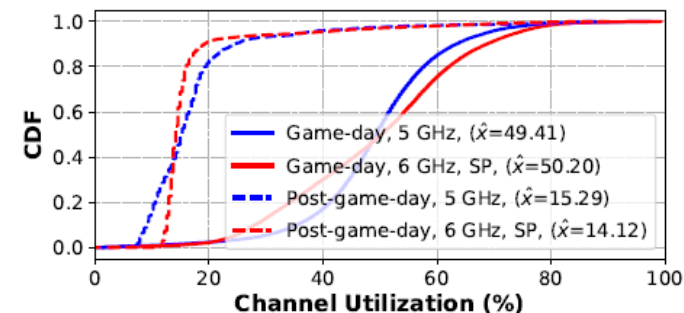
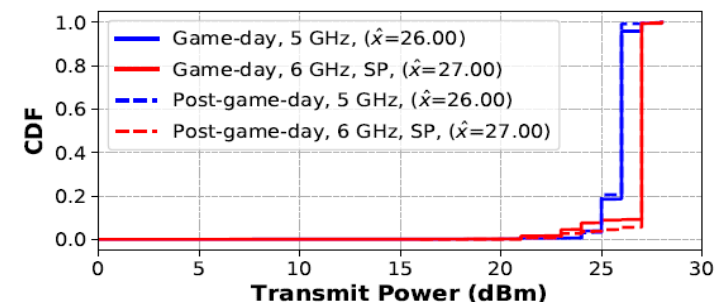
Case Study 1: 6 GHz Wi-Fi Deployments at the Notre Dame Stadium [1], cont.

• Results:

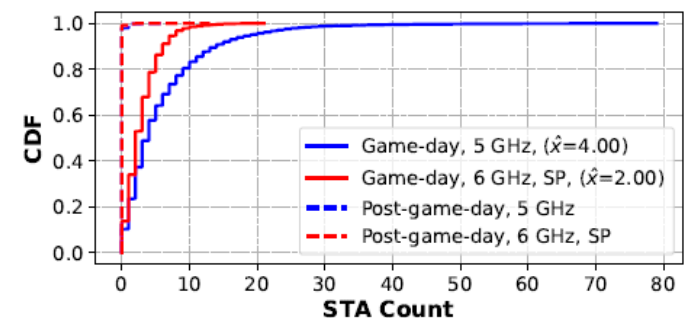
- Since the stadium is not in direct path of any fixed links, it can use the maximum 36 dBm for SP. However, we discovered that SP APs use TX power lower than the permitted 36 dBm.
- The 5 GHz band is almost completely saturated on game-day, highlighting the importance of the 6 GHz deployment.
- We did preliminary throughput measurements using Ookla, and it shows comparable performance between 5 & 6 GHz Wi-Fi: further analysis needed.



Wi-Fi Band Preferences of Measurement Phones



(a)

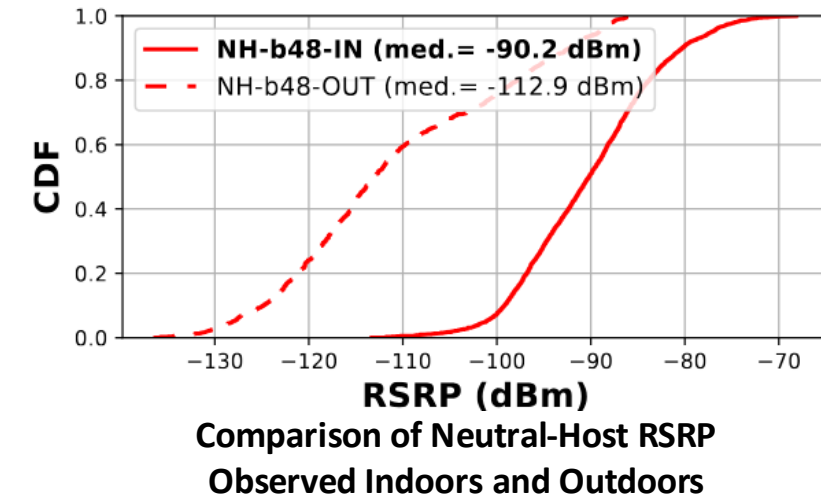
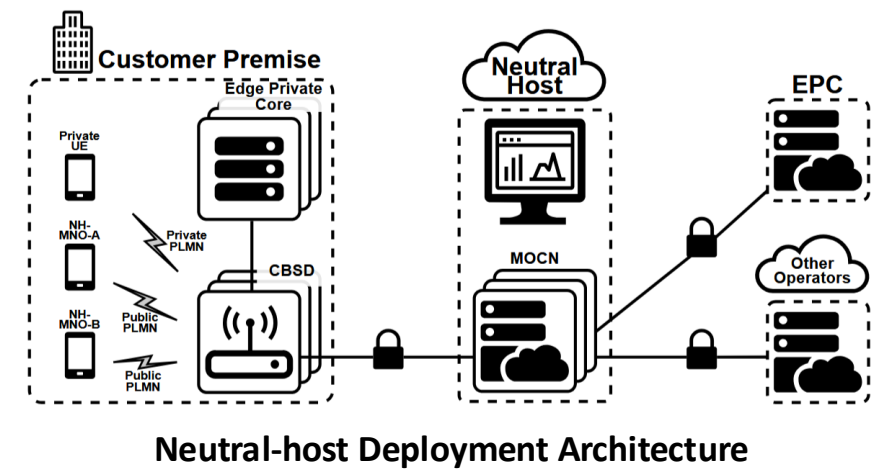


(b)

Comparison of Transmit Power, Channel Utilization, and STA Count

Case Study 2: CBRS Neutral-Host Deployment Performance [2]

- Goal: to compare the performance of CBRS neutral-host and cellular MNOs .
 - Neutral-host concept enables seamless handoff from cellular MNOs outdoors to the private CBRS network indoors.
 - This enables spectrum sharing between high-power outdoor macros and low-power indoor CBRS devices (CBSDs).
- Methodology: passive measurements using SigCap as well as detailed passive and active measurements enabled by QualiPoc (root-enabled app).
 - Deployment at a healthcare facility.
 - Comparing MNO A and MNO B, both served by the CBRS network indoors through neutral-host.
- Results:
 - There is a 22 dB median difference between neutral-host RSRP received indoors and outdoors, highlighting the indoor isolation of the low-power CBSDs for spectrum sharing.

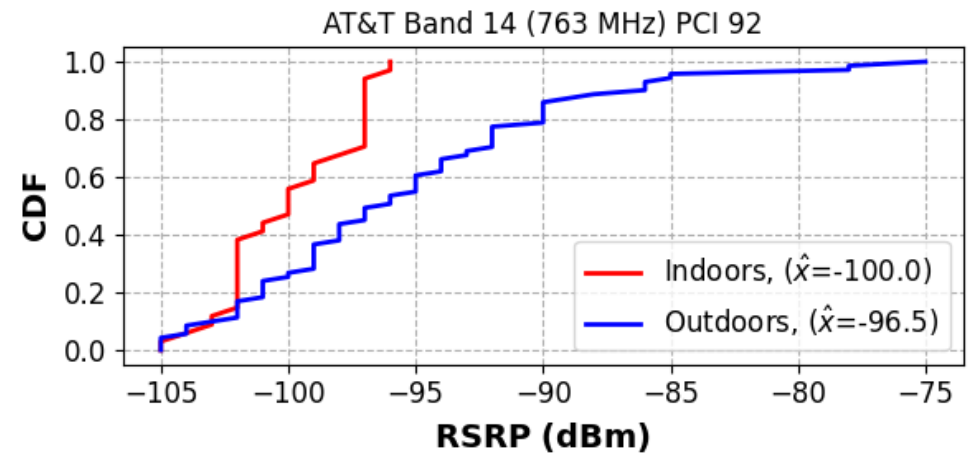
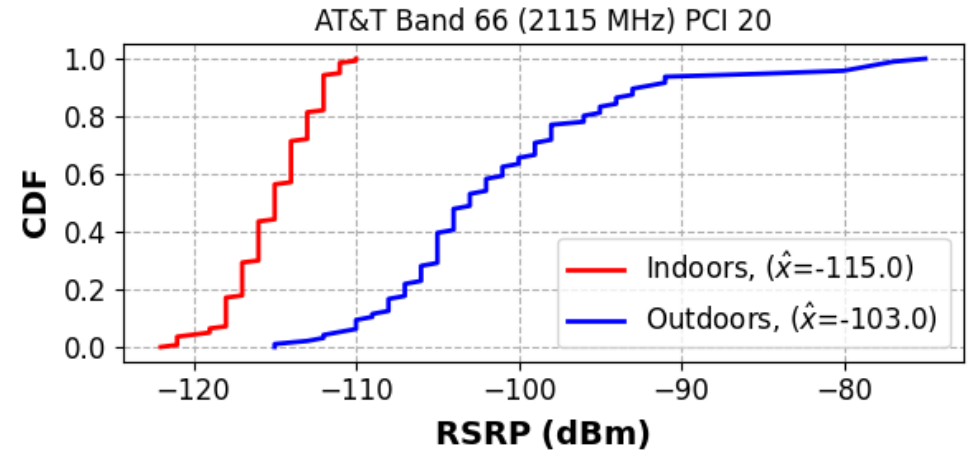


[2] Rochman, M.I., Palathinkal, J.R., Sathya, V., Yavuz, M., and Ghosh, M. **Neutral-Hosts In The Shared Mid-Bands: Addressing Indoor Cellular Performance.** *To be published in IEEE DySPAN 2025.*

A bit of side tangent...
We did SigCap

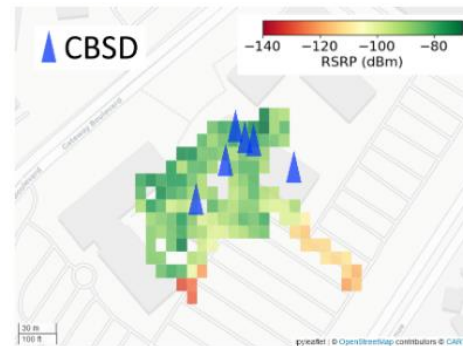
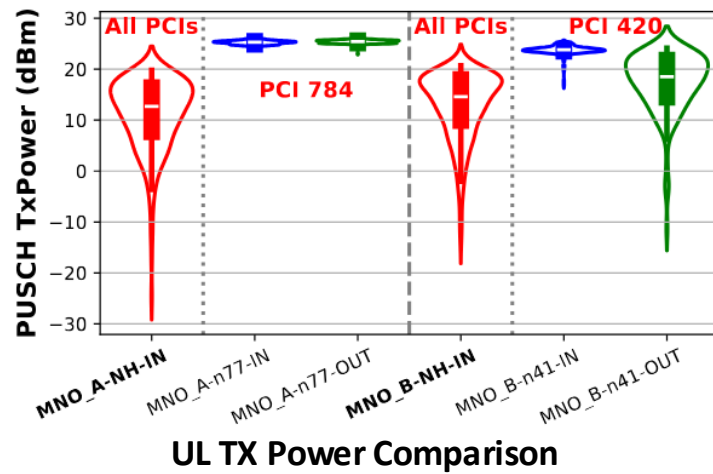
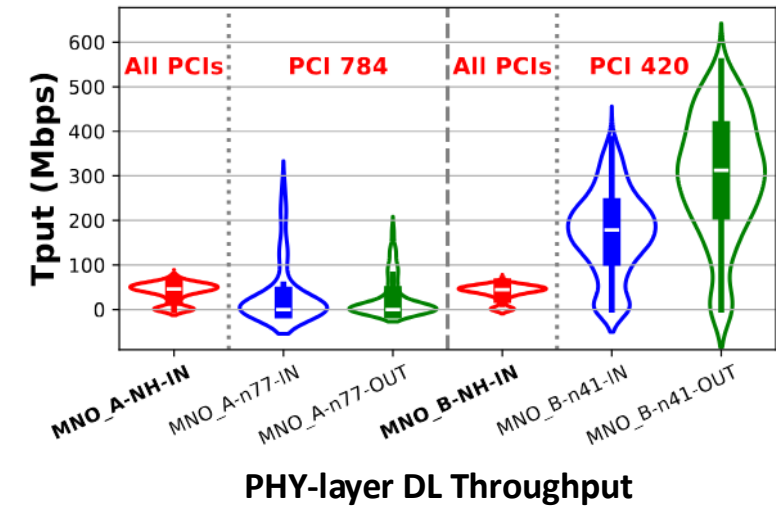
measurements this morning
around ISU campus to
measure building loss of
outdoor macros.

Comparing RSRP from the
same PCI, we observe
higher building loss from
the higher frequency Band
66



Case Study 2: CBRS Neutral-Host Deployment Performance [2], cont.

- Results, cont.:
 - MNO-A shows poor throughput and coverage indoors, which can be assisted by the indoor neutral-host.
 - Neutral-host enabled phones uses lower transmit power due to the proximity to CBSDs.



RSRP Heatmaps of Neutral-Host and MNOs' 5G deployments

Case Study 3: I/O Prediction [3]

- Goal: Predicting device location (indoor/outdoor) based on cellular, Wi-Fi, and GNSS/GPS signal captured in phones.
 - FCC introduces 6 GHz unlicensed usage with indoor limitation: no weatherization and battery power.
 - This limitation can be easily bypassed, and some operators need weatherized APs in their indoor deployments.
- Methodology:
 - Collect indoor/outdoor-labelled SigCap data from various phones and environments, within and outside the U.S.
 - Offline training to build models: threshold-based, SVM, random forest, and decision tree.
 - Testing using data captured from *both known environments and new locations (Scenario 1)* and *only new locations not included in the training (Scenario 2)*.
- Results:
 - Indoor accuracy is lower since more than 50% of indoor dataset was collected near windows.
 - Models trained on GNSS features generally perform better than those trained with Wi-Fi features. Combining both GNSS and Wi-Fi features lead to notable improvements.

Method	Scenario 1		Scenario 2	
	I	O	I	O
Th-B	72	79	67	86
SVM	60	100	69	100
RF	78	95	78	100
DT	72	95	70	100

Comparison of Accuracy (%) for Models

Method	only GNSS		only Wi-Fi		GNSS + Wi-Fi	
	I	O	I	O	I	O
SVM	60	100	54	84	69	99
RF	78	95	72	95	80	98
DT	72	95	70	95	80	98

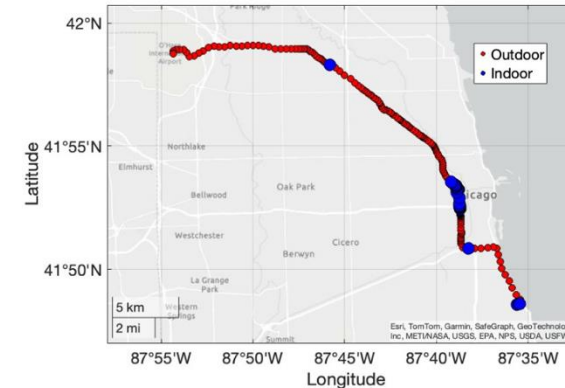
Comparison of Accuracy (%) for Models with GNSS and Wi-Fi features.

[3] Nasiri, H., Rochman, M.I., and Ghosh, M.
Indoor/Outdoor Spectrum Sharing Enabled by GNSS-based Classifiers. *To be published in IEEE MILCOM 2025.*

Case Study 3: I/O

Prediction [3], cont.

- Containment instead of indoor/outdoor:
 - Common definition of indoor/outdoor may not fit in the context of electromagnetic (EM) isolation.
 - Outdoor locations may be shielded from interference due to surrounding structures, while indoor locations may be highly exposed to outdoor EM signals.
- We define two focused measurements to illustrate containments:
 - **Measurement 1:** Driving measurements from a residential location to O'Hare Airport in Chicago, during which the vehicle passed under several bridges.
 - **Measurement 2:** Stationary measurement inside a grocery store in South Bend, near large windows and in the interior aisles.
- Results:
 - Well-contained environments show lower average GNSS signal strength and number of observed satellites, and vice versa.
 - Our GNSS-based models generally predicts "indoor" for well-contained environments, while poorly-contained environments are not so straightforward: particularly for data captured in a "grocery store near large windows".



Measurement 1



Measurement 2

Containment Level	Outdoor (Driving)	Indoor (Grocery Store)
Well-Contained	"Under the Bridges" Num. of samples: 130 Avg. CNR (dB/Hz): 19.8 Avg. Num. of Observed Sat.: 22.8 % Predicted Outdoor : 10	"Interior Sections" Num. of samples: 53 Avg. CNR (dB/Hz): 22.8 Avg. Num. of Observed Sat.: 19 % Predicted Indoor : 96
Poorly-Contained	"Not Under the Bridges" Num. of Samples: 1100 Avg. CNR (dB/Hz): 26.4 Avg. Num. of Observed Sat.: 32.8 % Predicted Outdoor : 100	"Near Large Windows" Num. of Samples: 45 Avg. CNR (dB/Hz): 24.8 Avg. Num. of Observed Sat.: 29.7 % Predicted Indoor : 56

Comparison of Well- and Poorly-Contained Environments in Terms of GNSS Features

Thank you for your attention!

For further questions, feel free to email me at mrochman@nd.edu.

SigCap Data Visualization: <https://sigcap.crc.nd.edu>

References:

- [1] Dogan-Tusha, S., Tusha, A., Rochman, M.I., Nasiri, H., Palathinkal, J.R., Atkins, M., and Ghosh, M. **Evaluation of Indoor/Outdoor Sharing in the Unlicensed 6 GHz Band**. *To be published in IEEE International Symposium on Dynamic Spectrum Access Networks (DySPAN) 2025.*
- [2] Rochman, M.I., Palathinkal, J.R., Sathya, V., Yavuz, M., and Ghosh, M. **Neutral-Hosts In The Shared Mid-Bands: Addressing Indoor Cellular Performance**. *To be published in IEEE International Symposium on Dynamic Spectrum Access Networks (DySPAN) 2025.*
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