Evaluating The Interference Potential in 6 GHz: An Extensive Measurement Campaign of A Dense Indoor Wi-Fi 6E Network

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SPECTRUMX

INTRODUCTION

- The Federal Communications Commission (FCC) has allocated the 6 GHz band (5.925 - 7.125 GHz) for unlicensed, shared use in the US.
- Incumbents in the band are protected via Low Power Indoor (LPI) rules that do not require the use of an Automatic Frequency Control (AFC) mechanism and Standard Power (SP) rules which do.

Table 1: Unlicensed Operation over 6 GHz.

Band	Incumbents	Use Cases	Chann. No.	Freq. (MHz)
U-NII-5	Fixed, Satellite Uplink	LPI, SP	1-97	5925-6425
U-NII-6	Satellite uplink, BAS, CTRS	LPI	101-117	6425-6525
U-NII-7	Fixed, Satellite uplink/downlink	LPI, SP	121-185	6525-6875
U-NII-8	Fixed, Satellite, BAS	LPI	189-233	6875-7125

Table 2: Max. Tx Power for 6 GHz LPI.

Device Type	Maximum TX Power				
	20 MHz	40 MHz	80 MHz	160 MHz	320 MHz
STA	12 dBm	15 dBm	18 dBm	21 dBm	24 dBm
AP	18 dBm	21 dBm	24 dBm	27 dBm	30 dBm

Deployment:

- University of Michigan (UMich), Ann Arbor, Michigan, USA has deployed the world's largest Wi-Fi 6E network. The campus network includes more than 16,000 Wi-Fi 6E LPI APs deployed across 225 buildings.

Objective:

- The aim of this study is to evaluate, in an unbiased manner, the potential for interference to outdoor fixed links from a real-world, densely deployed 6 GHz LPI network.
- A first-of-its-kind, extensive measurement campaign undertaken on the main campus of UMich.
- Generating heat-maps at ground level of outdoor Received Signal Strength Indicator (RSSI) measured on the 20 MHz beacon frames transmitted by LPI APs, using measurements obtained by walking and driving on the main campus area (MCA) and the nearby residential area (RA).
- Drone measurements around buildings near the path of 6 GHz fixed links to assess outdoor RSSI levels at higher altitudes where these links are deployed.

TOOLS & METHODOLOGY

(a) Wi-Fi deployment at UMich. Green Pins: Buildings with Wi-Fi 6E LPI APs. (b) Driving and walking meas. in the MCA. Red Pins: Driving, Blue Pins: Walking. (c) 6 GHz fixed links. Orange: drone meas. locations, Blue: Tx locations, Red: Rx location.

Figure 1: The main campus area (MCA) and the residential area (RA) in UMich.

- Fig. 1(a) shows the Wi-Fi 6E deployments in the MCA and the RA of UMich. The majority of the buildings in the MCA have double-pane low-E windows. Only 227 APs are deployed in the RA, which is a less dense deployment compared to the MCA which has a few thousand deployed APs.

Table 3: Measurement tools and devices.

Tool	Wi-Fi Parameters	Devices
SigCap	Time-stamp, location, frequency, RSSI, BSSID, SSID, #STA, Channel Utilization	1 × Google Pixel 6, 1 × Samsung S21 Ultra, 3 × Samsung S22+
Wireshark	Source/Destination, SSID, BSSID, Frequency, RSSI, Tx Power, beacon and data packets	Laptop: ThinkPad P16 Gen 1, Wi-Fi Card: Intel(R) Wi-Fi 6E AX211 160 MHz, OS: Ubuntu 22.04 LTS

Methodology:

- **Driving Measurements** were conducted in the MCA as shown in Fig. 1(b) at a speed of 20 miles per hour. Data was collected with SigCap running on the five smartphones listed in Table 3.
- **Walking Measurements:** The center of the campus, where Wi-Fi 6E is densely deployed, offers only pedestrian access. Hence RSSI measurements were collected in this area by walking (Fig. 1(b)).
- **Drone Measurements:**
  - There are five active, fixed links in the MCA, as shown by the black lines in Fig. 1(c).
  - Nine buildings, indicated by the orange pins in Fig. 1(c), were chosen for drone measurements due to their proximity to Links 1 and 2, operating at center frequencies 7037.5 MHz and 6212.065 MHz with bandwidths of 25 MHz and 56 MHz, respectively.
  - As shown in Fig. 2, a Samsung S22+ smartphone with SigCap was tied to the drone for data collection.
  - The drone moved vertically up and down, parallel to the wall of a given building.
- **Fixed Location :** The measurement area is a classroom on the first floor of a building, shown in Fig. 4.

Table 4: Building information for drone measurements.

Building Name	Height (ft)	No. of AP/BSSIDs
Building 1 (BLD1)	58	43/86
Building 2 (BLD2)	40	184/368
Building 3 (BLD3)	45	44/88
Building 4 (BLD4)	47-65 wrt. upper and lower levels	400/800
Building 5 (BLD5)	58	39/78
Building 6 (BLD6)	65-85 wrt. upper and lower levels	46/92
Building 7 (BLD7)	75	40/80
Building 8 (BLD8)	70	40/80
Building 9 (BLD9)	70	40/80

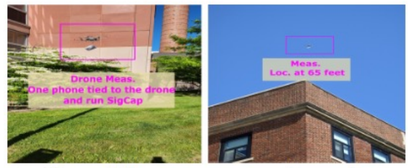
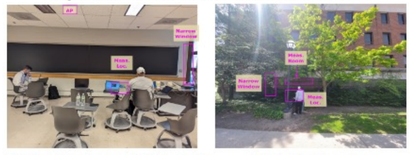


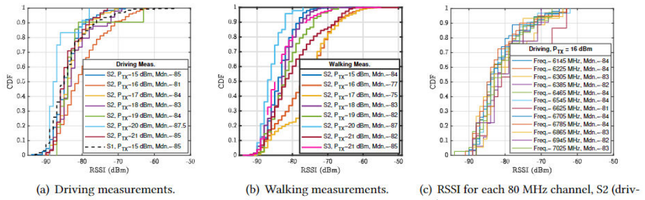
Figure 2: Drone measurement scenario.



(a) Indoor locations and Wi-Fi 6E AP (b) Outdoor locations

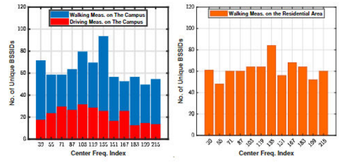
Figure 3: Measurement and AP locations for FL2.

RESULTS & DISCUSSIONS



(a) Driving measurements. (b) Walking measurements. (c) RSSI for each 80 MHz channel, S2 (driving).

Figure 4: CDF of outdoor RSSI, driving and walking. S1: MCA in Jan., S2: MCA in May, S3: RA in May.



(a) Main campus area (MCA). (b) Residential area (RA).

Figure 5: Number of unique BSSIDs at MCA and RA.

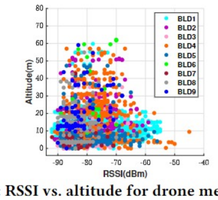
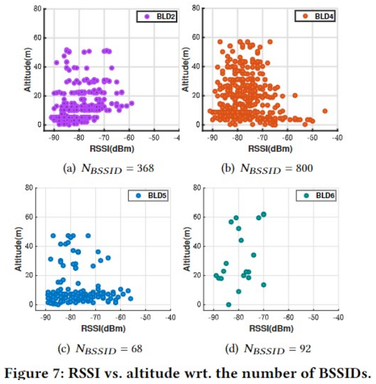
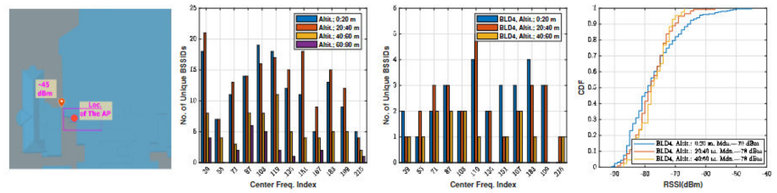


Figure 6: RSSI vs. altitude for drone measurements.



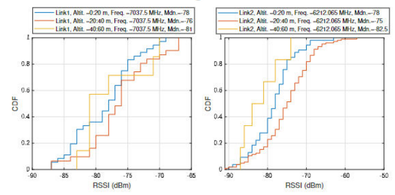
(a) $N_{BSSID} = 368$ (b) $N_{BSSID} = 800$ (c) $N_{BSSID} = 68$ (d) $N_{BSSID} = 92$

Figure 7: RSSI vs. altitude wrt. the number of BSSIDs.



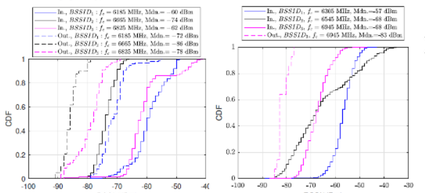
(a) -45 dBm RSSI outdoor. (b) All nine buildings. (c) BLD4. (d) CDF of RSSI.

Figure 8: Number of unique BSSIDs vs. altitude.



(a) Link 1: RSSI on Channel 215. (b) Link 2: RSSI on Channel 55.

Figure 9: CDF of drone RSSI measurements on channels overlapping Links 1 and 2.



(a) Double-pane low-E window. (b) Solid brick wall.

Figure 10: BEL for fixed locations FL1 and FL2.

- All channels are used relatively uniformly, thus reducing the probability of interference to an outdoor fixed link that overlaps with a particular 80 MHz channel.
- It is important to note, however, that not all APs will contribute to significant signal emissions outdoors.
- In addition to the number of APs within a given building, the likelihood of these APs to LOS conditions through nearby windows plays a vital role in the resulting outdoor RSSI levels, and hence potential for interference.
- In Fig. 10(b) two BSSIDs were not detected outside due to the solid brick wall. $BSSID3$ was observed outside since it is associated with the AP located in the adjacent room, which has a window pointing out towards the outdoor measurement location.

CONCLUSION

- We conducted an extensive measurement campaign via drone, driving, walking, and indoor-outdoor measurements at the world's largest indoor Wi-Fi 6E deployment on the Umich campus, investigating the interference potential of densely deployed LPI APs.
- To the best of the authors' knowledge, this is the first such measurement campaign conducted on a real-world Wi-Fi 6E deployment.
- In-depth analyses of the relationship between outdoor RSSI levels and factors such as the number of APs, the positioning of the APs in relation to nearby windows, and altitude is provided.
- Most LPI Aps within a building cannot be received outdoors, but a few Aps with LOS through windows can result in high outdoor RSSI levels in a very small number of locations, e.g. only 5% of the indoor BSSIDs in one building are observed outdoors in a location near a solid brick wall.
- The BEL near double pane low-E windows was 12 - 16 dBm

REFERENCES

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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 Proceedings of the 17th ACM Workshop on Wireless Network Testbeds, Experimental Evaluation & Characterization, ser. WiNTECH '23, 2023, p.56–63.

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