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

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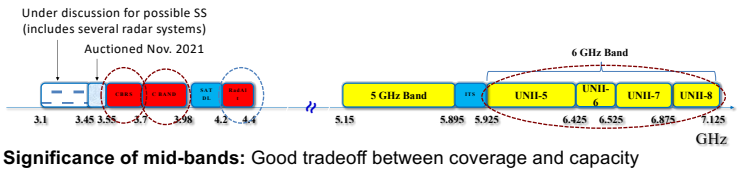
BACKGROUND & MOTIVATION



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:

- Different power masks for different UNII bands
- Two classes of unlicensed devices (LPI and SP)
- SP operation limited to UNII-5 & UNII-7 (with AFC)

Table 1: Unlicensed Operation over 6 GHz.

Band	Incumbents	Use Cases	Chann. No.	Freq. (MHz)
U-NII-5	Fixed, Satellite Uplink	LPI, SP	1-93	5925-6875
U-NII-6	Satellite uplink, BAS, CCTS	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

Objectives:

- Evaluate potential for interference to outdoor fixed links from a real-world, densely deployed 6 GHz net
- A first-of-its-kind, extensive measurement campaign undertaken on the main campus of Umich
- Generating heat-maps: Transmitted by LPI APs by walking and driving: Main campus area (MCA) and 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

Methodology:

- **Driving Measurements:** Conducted in the MCA as shown in Fig. 1(b) at a speed of 20 miles/hour. Data was collected with SigCap running on the five smartphones listed in Table 3

Table 3: Measurement tools and devices.

Tool	Wi-Fi Parameters	Devices
SigCap	Time stamp, location, frequency, RSSI, BSSID, SSID, #SS, Channel Utilization	3 × 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 Yoga Gen 3, Wi-Fi 6 Card: Intel(R) Wi-Fi 6 AX211 160 MHz, OS: Ubuntu 22.04 LTS

- **Walking Measurements:** Campus center where Wi-Fi 6E is densely deployed offers only pedestrian access ➔RSSI measurements were collected in this area by walking (Fig. 1(b))

Drone Measurements:

- 5 active fixed links in the MCA, as shown by the black lines in Fig. 1(c)
- 9 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

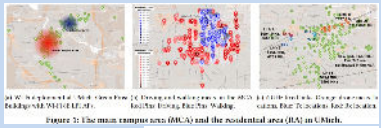


Figure 1: The main campus area (MCA) and the residential area (RA) in UMich.

Table 4: Building information for drone measurements

Building Name	Height (ft)	No. of AP/BSSIDs
Building 1 (BLD1)	55	45/86
Building 2 (BLD2)	43	156/265
Building 4 (BLD4)	41	41/56
Building 4 (BLD4)	55 w/o roof, upper and lower levels	69/160
Building 5 (BLD5)	55	23/78
Building 6 (BLD6)	65-85 w/o roof, upper and lower levels	9/60
Building 7 (BLD7)	75	40/88
Building 8 (BLD8)	70	40/88
Building 9 (BLD9)	70	40/88

Results:

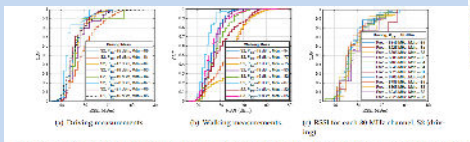


Figure 4: CDF of nonlinear RSSI, driving and walking, S1: MCA in Jan., S2: MCA in May, S3: RA in May.

Figure 2: Drone measurement scenario.

Figure 3: Measurement and AP locations for FL2.

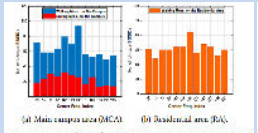


Figure 5: Number of unique BSSIDs at MCA and RA.

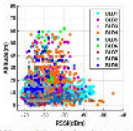


Figure 6: RSSI vs. altitude for drone measurements.

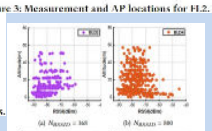


Fig. 7: RSSI vs altitude w.r.t the number of BSSIDs

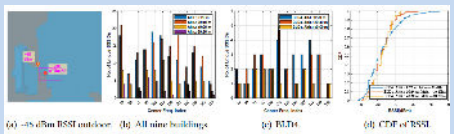
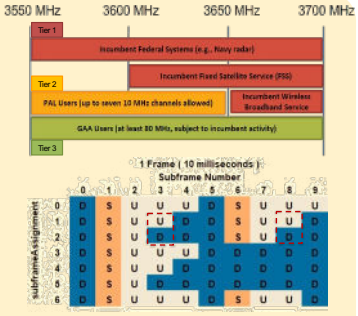


Figure 8: Number of unique BSSIDs vs. altitude.

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

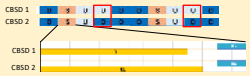


GAA/GAA Coexistence Issues

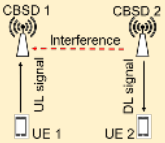
- Co-channel interference (CCI)
- Adjacent channel interference (ACI)
- Unsynchronized TDD configurations

➔ **High DL/UL interference**

Unsynchronized frame time



Different TDD config.



Objectives:

- Evaluate ACI between GAA users with various TDD configurations, distances, and transmit powers
- Design protocol-based and ML-based methods for GAA coexistence to minimize interference while maximizing spectrum utilization

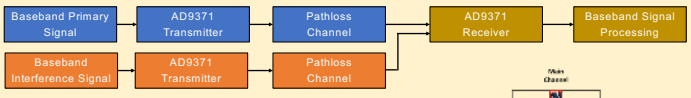
Tasks:

- Evaluate & predict EVM under interference ➔ **Spectrum allocation**
- Infer TDD of interferer ➔ **TDD selection**

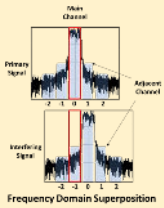
Methodology:

Model interference between multiple CBSDs and UEs using Matlab Simulink to produce CCI and ACI. Use data as input to GAA coexistence algorithms for channel and TDD assignment

Simulation Setup:



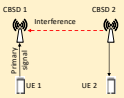
UL signal	Single frame lteRMCUL ('A3-5', 50 RB, QPSK, R=1/3)
DL signal	Single frame lteRMCDL ('R.3', 50 RB, 16-QAM, R=1/2)
TDD format	TDD Config 1, SSC 7 (one example)
Bandwidth	10 MHz
Transmission Bandwidth	9 MHz
UTRA Chip Rate	3.84 Mcps
Sampling Rate	122.88 MHz
Primary Tx-Rx Distance	200 meters
Interferer-Rx Distance	5, 50, 200 meters

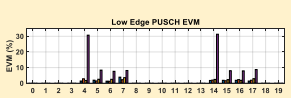


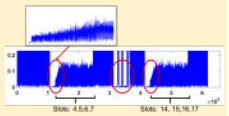
Frequency Domain Superposition

Co-channel Interference:

- Near-far Problem (Same TDD-SSF configuration):
- Primary Signal- Uplink; Interference Signal- Downlink
- UL signal power in slots 4 & 14 are reduced by automatic gain control due to proceeding high-power DL signal ➔ **High EVM**



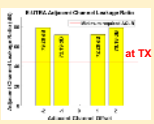




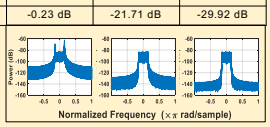
Adjacent Channel Interference:

- Different TDD formats

Primary Signal (Uplink), Interference Signal (Downlink)			
Interferer-Rx Distance	5m	50m	200m
EVM	-0.23 dB	-21.71 dB	-29.92 dB



Different TDD config.



- **Tx** adjacent power leakage ratio is compliant with the 3GPP requirement (> 47 dB)
- **Rx** at adjacent channel still suffers from high EVM in Slots # 6, 7, 16, and 17