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

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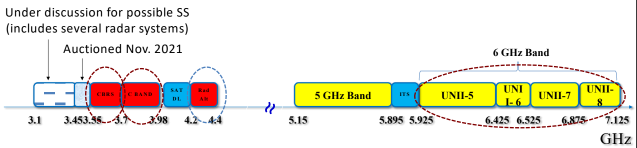
WiCON

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 5 & 6 GHz.

Protocol, Modulation, and PCI Classification for Harmonious Coexistence

Background

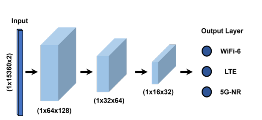
- ML-based **protocol, modulation, and Physical Cell Identity (PCI) classification** is vital for spectrum sharing and interference mitigation

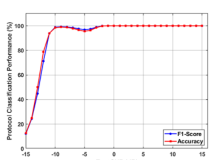
Challenges

- OFDM-based signals (Wi-Fi 6, LTE, and 5G-NR) combine multiple subcarriers in time-domain samples, making feature extraction less effective
- Conventional PCI estimation requires signal decoding at both LTE and 5G. It also needs RRC message in Non-Standalone (NSA) mode or full-band scans in a Standalone (SA) 5G system; detection becomes unreliable at low SNR

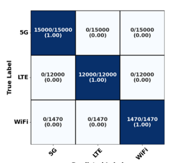
Protocol Identification

- Classifies Wi-Fi, LTE, and 5G-NR directly from raw I/Q signals using
- Trained on a subset of MCS formats and tested on unseen modulation
- Classifier achieves 100% accuracy for SNR > –2 dB





Test accuracy and F1-score for different SNRs

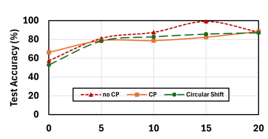


Protocol classifier at SNRs ≥ −2 dB

Modulation Classification

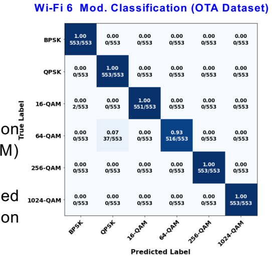
1) Wi-Fi 6

- 6 modulation and coding schemes (MCS's)
- Apply FFT to time-domain I/Q samples in windows of 1 OFDM symbol duration to expose hidden subcarrier patterns
- Compared training with/without CP and applied circular shifts to simulate practical impairments



- Coarse symbol synchronization is performed prior to FFT
- Achieved ~ 98.76% inference accuracy

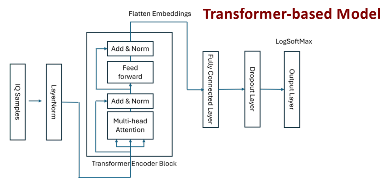
Wi-Fi 6 Mod. Classification (OTA Dataset)

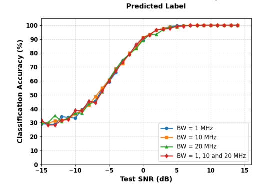


2) LTE

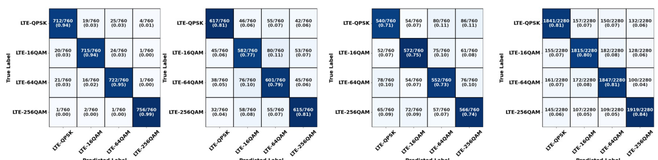
- Transformer-based classifier for LTE modulation schemes (QPSK, 16-QAM, 64-QAM, and 256-QAM)
- Three bandwidths (1.4, 10, and 20 MHz)
- For BW of 10 and 20 MHz, signal is down-sampled to 1.4 MHz (using a discrete LPF) to focus on center RBs

Transformer-based Model





Test accuracy for different SNRs and BWs



Trained with signals having BW = 1.4 MHz

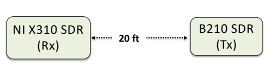
Trained with down-sampled signals having BW = 10 MHz

Trained with down-sampled signals having BW = 20 MHz

Trained across all BWs

Experimental Results

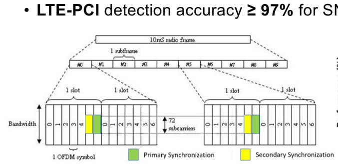
- OTA experiments on POWDER's indoor lab
- Selected lower C-band with a center frequency of 3.41GHz and bandwidth of 20 MHz
- Built a dataset of OTA Wi-Fi 6 signals of different modulation schemes



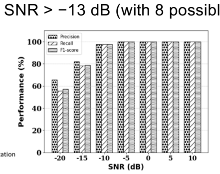
Indoor experiment setup. Source: POWDER, 2025 https://docs.powderwireless.net/hardware.html

PCI Estimation

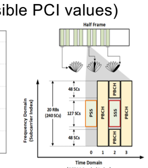
- Protocol classifier (LTE, 5G-NR/SCS 15 kHz, or 5G-NR/SCS 30 kHz) followed by PCI classifier in 2nd stage
- MLP design for LTE and CNN–BiLSTM design for both 5G with 15 and 30 kHz SCS
- **LTE-PCI** detection accuracy **≥ 97%** for SNR > −13 dB (with 8 possible PCI values)



LTE Frame Structure

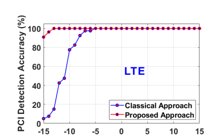


PCI Classification (LTE)



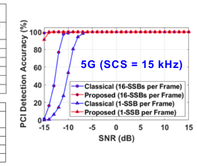
SSB Structure in 5G

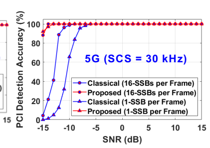
- **5G-PCI** detection accuracy **≥ 90%** for both SCS values (window-based prediction)
- **Multi-stage classifier accuracy:** Predict label for each window in 1-frame and then use **majority voting** to decide final protocol or PCI for the entire frame
  - For SNR > −12 dB, PCI detection ~ 100%
- Outperforms the classical approach at low SNRs



Inference SNR (dB)	Complete SSB Precision (%)	Complete SSB Recall (%)	Complete SSB F1-Score (%)	3rd OFDM symbol of SSB Precision (%)	3rd OFDM symbol of SSB Recall (%)	3rd OFDM symbol of SSB F1-Score (%)
0	99.65	99.65	99.65	100.00	100.00	100.00
−2	96.82	96.82	96.82	100.00	100.00	100.00
−4	88.19	88.20	88.17	100.00	100.00	100.00
−6	76.45	76.08	76.19	100.00	100.00	100.00
−8	63.47	62.61	62.81	99.56	99.56	99.56
−10	49.20	48.05	48.17	96.19	96.17	96.17

Inference SNR (dB)	Overall Accuracy (%)	Stage-1 Protocol Identification (%)	Stage-2 (PCI-Detection) LTE (%)	Stage-2 (PCI-Detection) 5G-CaseA (%)	Stage-2 (PCI-Detection) 5G-CaseB (%)
−15	69.72	73.61	90.91	98.75	88.30
−14	87.78	88.33	96.30	99.38	100.00
−13	97.50	97.50	100.00	100.00	100.00
≥ −12	100.00	100.00	100.00	100.00	100.00

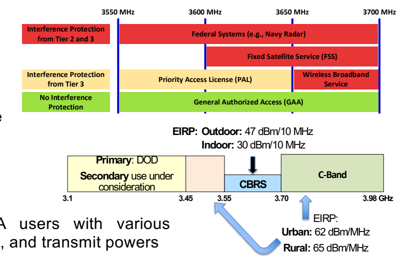




Coexistence and Interference in CBRS Band

Background

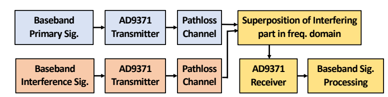
- CBRS band: 3-tier hierarchy
- GAA/GAA coexistence issue
- Adjacent (C-band) interference

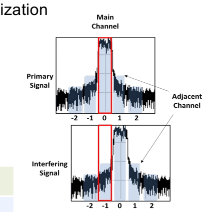


Objectives

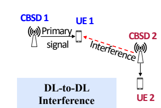
- Evaluate ACI between GAA users with various MCS's, TDD config., distances, and transmit powers
- Design protocol-based and ML-based methods for GAA coexistence to minimize interference while maximizing spectrum utilization

Simulation Setup (Matlab)





Superposition of Interfering part in freq. domain



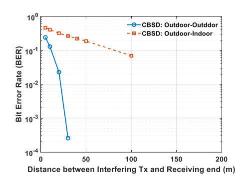
ACI between GAA users within CBRS band or between CBRS and C-band (DL-DL)

Center Frequency		
Primary Sig.	Interfering Sig.-1	Interfering Sig.-2
3.69 GHz (CBRS Band)	3.67 GHz (CBRS Band)	3.71 GHz (C-Band)

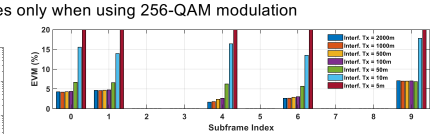
GAA/GAA Coexistence

- Consider an LTE system
- BER performance degrades only when using 256-QAM modulation

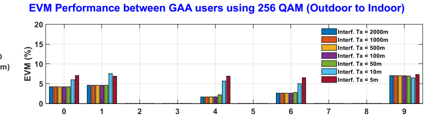
EVM of each E-UTRA carrier			
QPSK	16QAM	64QAM	256QAM
17.5%	12.5%	8%	3.5%



ACI between GAA users in the CBRS band using 256-QAM



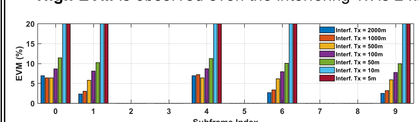
EVM Performance between GAA users using 256 QAM (Outdoor to Indoor)



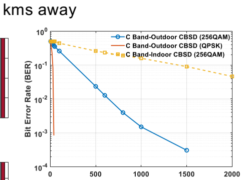
EVM Performance between GAA users using 256 QAM (Outdoor to Outdoor)

ACI from C-band onto CBRS GAA Users

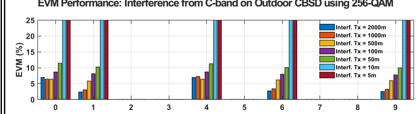
- **High EVM** is observed even the interfering Tx is 2 kms away



EVM Performance: Interference from C-band on Outdoor CBSD using 256-QAM



ACI from C-band on CBRS band users



EVM Performance: Interference from C-band on Indoor CBSD using QPSK

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