CELLULAR BASED SMALL UNMANNED AIRCRAFT SYSTEMS (sUAS) MIMO COMMUNICATIONS

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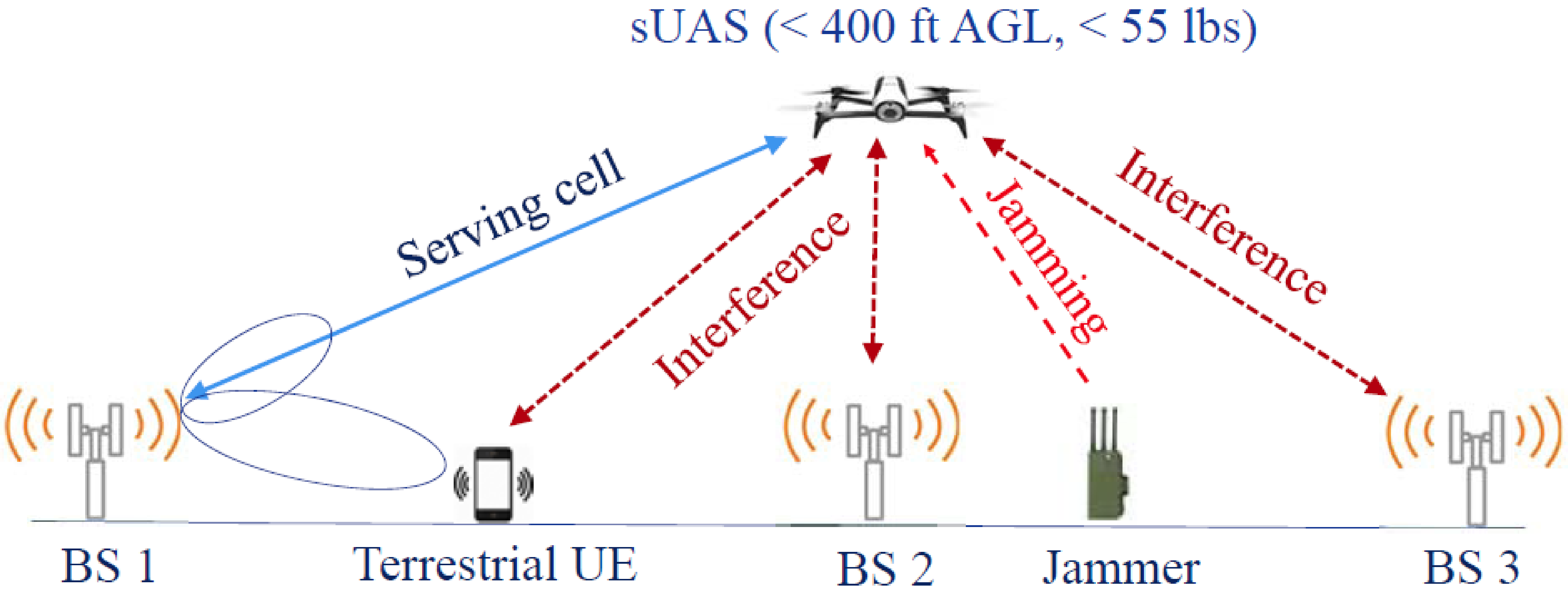
Introduction

- Remotely piloted unmanned aircraft systems/vehicles (UAS/UAV)
  - Widely used by hobbyists, scientists, military, civilian government agencies, and commercial enterprises
  - More than double from 1.1 million units in 2017 to more than 2.4 million by 2022
- Integrate UAS into the National Airspace System (NAS)
  - controlled airspace
  - uncontrolled airspace
- UAS Traffic Management (UTM)
  - Civilian low-altitude (below 400 feet) sUAS (less than 55 pounds) operations
  - From VLOS to BVLOS
  - Command and control (C2) communications

Cellular based sUAS communications

- Advantages
  - In place infrastructure with ubiquitous coverage
  - BVLOS connection
  - Reliable command and control link and broadband data communications
- Disadvantages
  - Have to share resource (power, spectrum) with terrestrial user equipment (TUE)
  - Increased uplink/downlink interference due to elevation
  - Vulnerable to jamming

Interference and Jamming in sUAS cellular communications



Interference/jamming in sUAS communications with terrestrial cellular networks

State of the art

- **Terminal-based interference mitigation techniques (Downlink)**
  - Antenna Beam selection
  - Interference cancellation
- **Network-based interference mitigation techniques (Uplink)**
  - Power control
  - Inter-cell interference coordination
- **Existing anti-jamming approaches**
  - Frequency-domain solution (e.g. FHSS and DSSS)
  - Time-domain solution
  - Spatial-domain solution

State of the art cont’

Limitations:

- need prior knowledge of the interference;
- added complexity and communication overhead;
- cannot handle smart jamming attacks;
- cannot handle multiple interference/jamming signals

MIMO in sUAS Communications

- **Directionality**
  - Sectorization or phased array for directional antenna gain
  - Single RF chain
- **Multiplexing**
  - MIMO channel decomposed into parallel subchannels
  - Independent data streams
  - Degree of freedom = $min(m, n)$
- **Diversity**
  - Single data stream
  - Maximum diversity gain = mn
- **Interference/jamming cancellation**
  - Blind interference and jamming cancellation
  - Channel state information may not required

MIMO configurations

DJI S1000 used in NASA’s UTM project

Sector Antennas

A Verizon Base Station with Sector Antennas

- Directional antenna with a sector-shaped radiation pattern
- Widely used in cellular base stations (BS)
- Relatively cheap and easy to implement

We propose to use sector antennas in sUAS

MIMO configurations for sUAS (1)

- **Configuration A: 3 sectors with 4 sector antennas per sector**
  - 120 degree per sector
  - A total of 12 directional antennas
  - 4 independent RF chains
- **Antenna Separation**
  - LTE frequencies in US: 700MHZ to 2.5GHz
  - For 1.9GHz, half wavelength is about 3 inches
  - For 700MHz, half wavelength is about 8 inches
  - Correlated MIMO channel -> performance degradation

MIMO configurations for sUAS (2)

- **Configuration B: 4 sectors with 3 sector antennas per sector**
  - 90 degree per sector
  - A total of 12 directional antennas
  - 3 independent RF chains
- **Pros and Cons**
  - # of RF chain is reduced
  - antenna separation distance is increased
  - More frequent switching among sector antennas

MIMO design tradeoff

- **Multiplexing, diversity and BIJC tradeoff**
  - Multiplexing works the best in high SNR regime when the system is DoF limited
  - Diversity works the best in low SNR regime when the system is noise limited
  - BIJC works the best when the system is interference/jamming limited
- **Other considerations**
  - Sector antenna should first be used to void interference/jamming
  - sUAS operation environment is highly dynamic
  - Dynamic MIMO mode switching among Multiplexing, Diversity and BIJC

More about BIJC

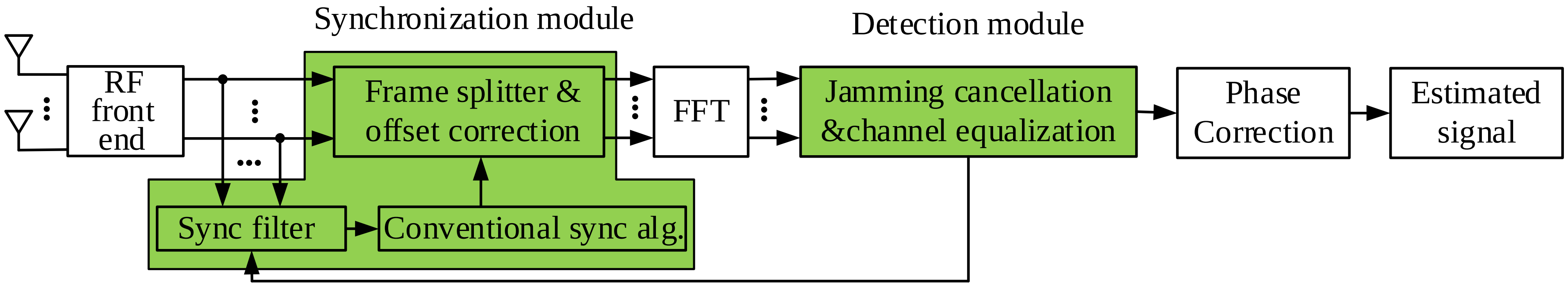
Challenge: unknown interference/jamming signals

- The number of undesired signals
- The location of undesired transmitters
- The number of antennas at each undesired transmitter
- The structure of each undesired signal (e.g. waveform and bandwidth)
- The power of jamming signals
- The type of jammers (constant jamming, reactive jamming, etc.)

Objective: design, analyze and implement a Blind Interference and jamming Cancellation (BIJC) solution with limited knowledge of undesired signals.

Our Approach & Main Finding

- Our approach
  - Design blind interference/jamming-resistant receiver for unknown signals
  - Design the baseband signal processing at the PHY layer for the receiver

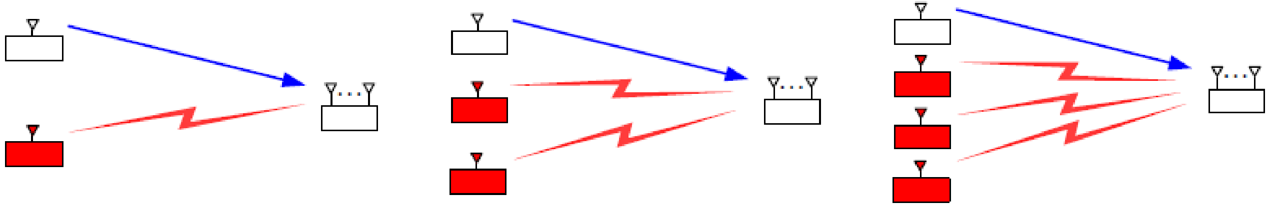


- Main finding: If the receiver has more antennas than the number of independent interference/jamming signals, the communication can be secured against these undesired signals.

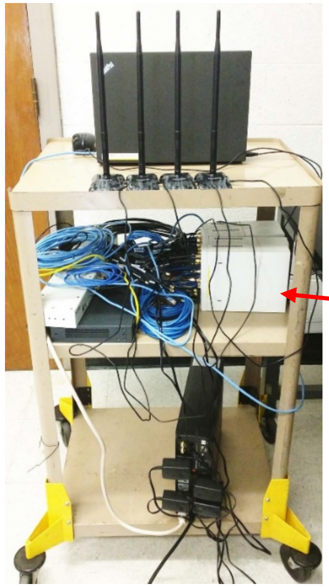
H. Zeng, C. Cao, H. Li and Q. Yan, “Enabling Jamming-Resilient Communications in Wireless MIMO Networks”, *IEEE Conference on Communications and Network Security (CNS)*, pp. 1-9, Las Vegas, NV, Oct. 2017

Performance Evaluation in WiFi Network

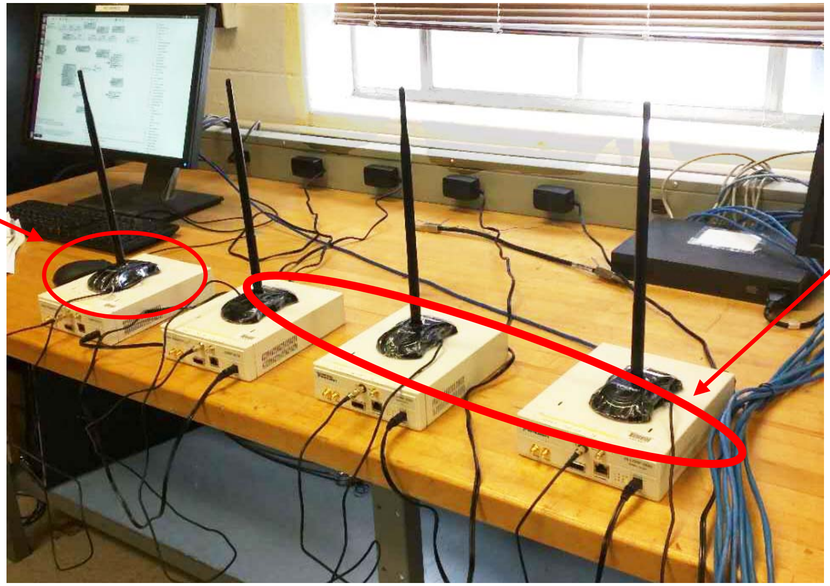
- Evaluate the performance of proposed solution in three scenarios
  - Tx: transmit Wi-Fi signals with bandwidth 10 MHz
  - Jammer: Full-spectrum pseudorandom-noise jamming signals, constant jamming attack



- Implementation



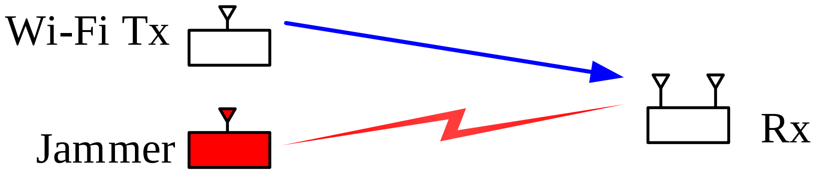
Our receiver

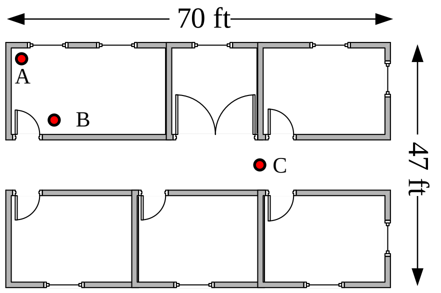


Wi-Fi Transmitter

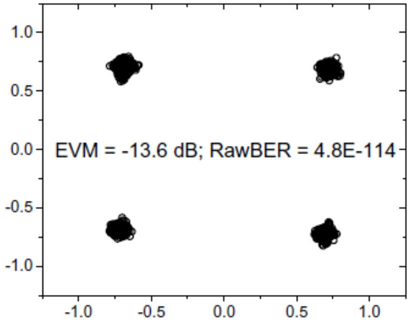
3 jammers

Constellation Diagram at Rx

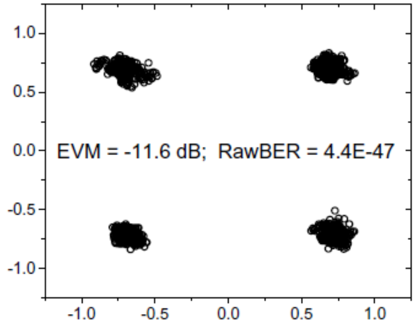




Case 1: Tx and jammer at A; Rx at B

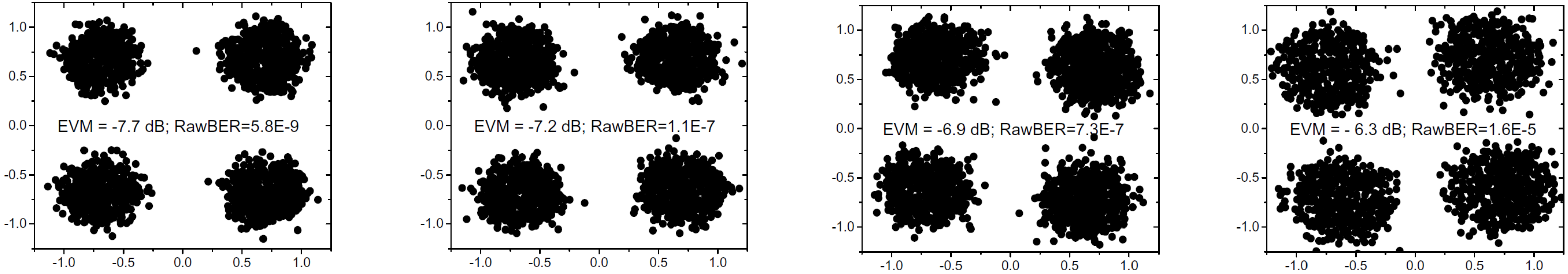


No jamming



Jamming with the same power

Case 2: Tx and jammer at A; Rx at C (Tx's power is 0 dBm)



(a) No jamming attack (b) Jammer's power: 0dBm (c) Jammer's power: 10dBm (d) Jammer's power: 20dBm

Future Work: LTE based BIJC receiver

WiFi vs. LTE

	WiFi	LTE
MAC protocol	CSMA	OFDMA
Traffic pattern	bursty	persistent
signal	intermittent	continuous
channel coherence time	Long	short

Challenges

- WiFi and LTE have different signal structures (frame length, sampling rate, FFT size, etc.)
- In sUAS applications, the aerial channel coherent time could be much shorter than that of the terrestrial channel.

Question?

Thank you!