Aerial Experimentation and Research Platform for Advanced Wireless

UAS Community Testbed Architecture for Advanced Wireless Research with Open-Source SDRs

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Unmanned Aerial Systems (UAS)

Urban Air Mobility

Creating a Secure Airspace

Moving Goods and Cargo

Giving People More Time
UAS Providing Advanced Wireless Service

- Hot-spot wireless access
- Post-disaster communications
- Search and rescue
- Situational awareness
- Jammer detection
- Detection and tracking of unauthorized UAS
NSF Names Third PAWR Wireless Research Platform in North Carolina’s Research Triangle

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https://advancedwireless.org/
Outline

- AERPAW Team and Objective
- AERPAW Radios
- Experimental Flow
- Research Examples
Mission

Serve as a unique technological enabler for research in advanced wireless with UAS
AERPAW: Aerial Experimentation and Research Platform for Advanced Wireless

Incubation site: develop unique testbed capabilities subsequently deployed at main sites to support corresponding experiments
Ismail Guvenc  
PI, NC State (SDRs, 4G/5G standards, PHY/MAC)

Rudra Dutta  
NC State (SDN, architecture, CentMesh)

Mihail Sichitiu  
NC State (drones, architecture, CentMesh)

Brian Floyd  
NC State (mmW circuits, arrays)

Tom Zajkowski  
NC State (drone operations, FAA permitting)

Vuk Marojevic  
MSU (security, SDRs, waveforms, CORNET)

Robert Moorhead  
MSU (drones, FAA ASSURE, visualization)

Gerard Hayes  
NC State, WRC (wireless and testing)
Partnerships and Users

PARTNERS

NC STATE UNIVERSITY
Mississippi State University
University of South Carolina
Purdue University
renCi
Town of Cary
Raleigh
Holly Springs
State of North Carolina
Department of Transportation

USERS

AT&T
Cisco
docomo
IBM
Keysight Technologies
National Instruments
Nokia
Mitsubishi Electric
Qualcomm
ASSURE
INL
NC DIT
AERPAW: At the Crossroad of Advanced Wireless and UAS Research

5G is unleashing new, transformative applications and services:

- Driverless cars
- Virtual/augmented reality (VR/AR)
- Internet of things (IoT)
- Unmanned aerial systems (UAS)

(Source: ETRI graphic, from ITU-R IMT 2020 requirements)
Advanced Wireless for Autonomous and BVLOS UAS Operations

Beyond visual line of sight (BVLOS)

Manual control ← Advanced Wireless Research → Autonomous

(1) Main operation mode today

(2) Operation mode that is growing in importance already today

(3) Main operation mode in the future

Image source: Ericsson
AERPAW: Applications and Use Cases

- **Cellular-Connected UAS for Delivery/Transportation, Trajectory Optimization**
  - Example Site: NC WakeMed Buildings, part of NCDOT IPP
  - Example Equipment: Fortem radars deployed in AERPAW sites

- **UAS/Balcony Ad hoc Networks and Swarm Autonomy**
  - Example Site: NCSU Agriculture Research Stations at Lake Wheeler

- **Agricultural IoT Monitoring and Data Collection**
  - Example Sites: NCSU PNC Arena, Koka Booth Amphitheater, Holly Springs Baseball Stadium

- **LTE/5G 3D UAS Connectivity and Beam Tracking**
  - Example Partners: NASA, ASSURE, Smart Sky Networks

- **Hot-Spot UAS BS**
  - Example Sites: City of Raleigh, Town of Cary, Town of Holly Springs

- **Urban Air Mobility, UMT/ATM**
  - Example Partners: NASA, ASSURE, Smart Sky Networks

- **City/Town Partners:**
  - City of Raleigh, Town of Cary, Town of Holly Springs

- **Rural Area UAV Relays and Post-Disaster Cellular Connectivity**
  - Towers for LTE, 5G, and other Wireless Base Stations: Available at WRCNC, at NCSU CentMesh, and to work with US-Ignite Members

- **Unauthorized UAS Detection/Tracking**
  - Example Partner: Carolina Unmanned Vehicles

- **Public Safety communications, indoor connectivity/localization**
  - Example Technologies: LTE, IoT, mmWave

- **Experiments with flying and ground LTE/5G UEs**

- **Example Site:**
  - NCSU Agriculture Research Stations at Lake Wheeler

- **Public Safety communications, indoor connectivity/localization**
  - Example Technologies: LTE, IoT, mmWave
Radios and Platforms
## Platform Equipment Options for Users

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Fixed Nodes (E.g., at Towers)</th>
<th>Mobile Nodes (E.g., at UAVs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDRs</td>
<td>NI USRP X310/N310/mmW</td>
<td>NI USRP B210/mmW</td>
</tr>
<tr>
<td>5G NR</td>
<td>5G gNBs from Ericsson</td>
<td>5G UEs from Ericsson</td>
</tr>
<tr>
<td>RF Sensors</td>
<td>Keysight N6841A RF Sensor</td>
<td>Keysight Nemo RF Sensors</td>
</tr>
<tr>
<td>IoT Devices</td>
<td>SigFox/LoRa Access Point</td>
<td>SigFox/Lora Sensor</td>
</tr>
<tr>
<td>UAS Radar</td>
<td>Fortem SkyDome</td>
<td>N/A</td>
</tr>
<tr>
<td>UWB</td>
<td>TimeDomain P410/P440 radios</td>
<td>TimeDomain P410/440 radios</td>
</tr>
<tr>
<td>WiFi Sniffers</td>
<td>WiFi Pineapple</td>
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</tr>
</tbody>
</table>

Bring your own device (BYOD) experiments will also be supported if they satisfy criteria.
AERPAW SDRs from National Instruments

**USRP X310 (fixed nodes)**
- Up to 160 MHz of bandwidth
- Frequency range: DC to 6 GHz (with daughterboards)
- 2 Channels
- Kintex-7 FPGA

**USRP N310 (fixed nodes)**
- Supports 4 channels for MIMO operation
- Up to 100 MHz of bandwidth/channel
- Frequency range: 10 MHz to 6 GHz
- Stand alone (embedded) or host-based (network streaming) operation
- Remote management capability

**USRP 5G mmW (expected, fixed & mobile nodes)**
- Up to 400 MHz bandwidth
- Expected center frequency: 28 GHz
- We anticipate payload will be similar to USRP X310 series
- Considered for both at towers and drones

**USRP B205mini / B210 (mobile nodes)**
- Up to 56 MHz of bandwidth
- Frequency range: 70 MHz to 6 GHz
- B210 supports 2 Channels for MIMO
- Spartan-6 FPGA
Custom Millimeter-Wave Extenders for USRPs

→ mmW beamforming for UAS is critical; however, low-cost beamforming solutions which easily interface with USRP are still being brought to market.

→ We plan to develop custom beamforming modules suitable for UAS using a mixture of commercial off-the-shelf (COTS) parts.
Communications Experiment Software

Software we will integrate and provision to experimenters

➔ srsLTE, 4G now, 5G in the future
➔ Open air interface (OAI), 4G and 5G software suites

Experiment support software we will develop

➔ Waveforms
➔ Adapted protocols for supporting research and standardization

Software developed by users
Keysight RF Sensors at Ground/Aerial Nodes

(a) Drone tracking RF N6820E sensor from Keysight, (b) Example use for UAS localization/tracking. Can be used to sense any other fixed/mobile RF source, e.g. for interference localization.

Keysight Technologies
Nemo Handy
Fast, Efficient, On-the-Go Network Measurement and Troubleshooting

Keysight 4G/5G network measurement solutions for commercial BS coverage experiments at aerial platforms
SigFox IoT and Fortem Radar

SigFox: Major applications in agriculture (Purdue, NCSU), Signals in the Soil, and broadly in UAS based monitoring

Fortem: A NCDOT IPP partner, detection of unauthorized or non-cooperating UAS

- Powerful Sensor
  - Effective 3D radar sensor that detects and monitors with precision, day or night and in all weather conditions
  - Simple intuitive interface and UI
  - Built for air and ground application

- Integrated and Compact
  - Integrated high-resolution electronically-steered patch antenna array
  - Integrated inertial navigation system (INS) enables clutter rejection in airborne applications

- Simple Connectivity
  - Ethernet output (JSON) for streaming detection & track data to other systems
  - Graphical User Interface (GUI) for radar operation and configuration
  - APIs for programmatic radar control
  - Ethernet provides up to 1 Gbps data transfer rates

Skydome
**UWB Transceivers and WiFi Sniffers**

**Time Domain P440 radios**
- Frequency: 3.1 GHz - 4.9 GHz
- 2 GHz of instantaneous bandwidth
- 2 cm ranging precision over 100

**WiFi Pineapple**
- Frequency: 2.4 GHz and 5 GHz WiFi
- Can capture probe requests from all WiFi-equipped mobile devices
- Applications in search and rescue, occupancy monitoring

**Localizing mobile phones with WiFi sniffers**

Image Source: Guvenc et al., 2017

Image Source: Guvenc et al., 2018
Fixed Nodes

→ Provides the users a programmable fixed node

→ Consists of:
  • Physical Host (workstation)
  • Radios
  • Antennas
  • Tower

→ Optionally, steerable directional antennas

→ The operator loads VM Image to the fixed node physical host through Testbed Backplane
Mobile Nodes Payload

→ Provides the **users** a programmable mobile node

→ Consists of:
  • Companion Computer + VMs
  • Radios
  • Antennas
  • Autopilot

→ Optionally, steerable directional antennas

→ The **operator** loads VM Image to the mobile node physical host through Testbed Backplane
Mobile Nodes Payload

→ Cellular Link 1 under **user** control
→ Cellular Link 2 under **operator** control
  • Start the experiment
  • Normal termination of experiment
  • Abort the experiment
→ RC Receiver under **operator** control
  • Abort experiment
Mobile Nodes Vehicle

- Multicopters
- Fixed wing
- Helikite
- Rover
- Bus
Experiment Preparation

- **Develop**
  - Development VMs (Ground and Aerial node images) – cloud
- **Sandbox**
  - Sandbox VMs (real radio, real drones minus props) – indoor facility
- **Emulate**
  - Emulation VMs (emulated radio, emulated drones, real code) – cloud
- **Submit**
  - Specify nodes, desired mapping, equip with AERPAW software tools and drivers, program
- **Observe**
- **Retrieve Results**
  - Test with real drivers, actual hardware (tutorial and sanity)
  - Test with real drivers, realistic hardware emulation (AERPAW safety check)
  - Testbed (real everything)
AERPAW Short & Long Term Research Examples

LTE eNB reference signal received power (RSRP) measurements at UAS [Sichitiu/Guvenc, 2019]

UAS autonomy and trajectory optimization [Bulut/Guvenc 2018]
Wireless Security Incubation Site @ MSU

• Aerial communications security
  – PHY layer and protocol security
  – Link and system reliability in harsh signaling environment
  – Counter UAS systems
  – Standardization

• Air interface & protocol design
  – Parameter exposure, incl. perform. measurement counters and KPIs
  – Adaptive waveforms and protocols
  – Smart interferers
We want to work with you!

- Developer
- User
- Collaborator
- Supporter
- ...

Students, postdocs, research faculty, …

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