AERPAW Platform
A Testbed for versatile mobile NextG Research

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Rudra Dutta, NC State University

https://aerpaw.org/
AERPAW Project Vision and Scope

- **Funding:** 3rd NSF PAWR project awarded in Sep. 2019
- **Project Team:** NC State University, WRC, Mississippi State University, RENCI, Purdue University, University of South Carolina
- **AERPAW Vision:** Serve as a unique technological infrastructure, to be used by advanced wireless and UAS researchers
- **Project Heart:** Programmable radios, programmable UAS, on a programmable network
Team and Partners

Project Investigators

- Ismail Guvenc: 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 (mmWave circuits, arrays)
- Tom Zajkowski: NC State (USAS operations, FAA permitting)
- Vuk Marojevic: MSU (security, SDRs, waveforms, CORNET)
- Gerard Hayes: NC State, WRC (wireless and testing)
- Yufeng Xin: RENCI, UNC-CH (data models, software architecture control framework)
- David W. Matolak: USC (linear propagation, waveforms)
- David Love: Purdue (毫米波, SDRs, agriculture)

Senior Personnel

- Lavanya Sridharan: NC State (Project Coordinator)
- Ed Rogers: NC State (installations and permits)
- Ozgur Ozdemir: NC State (SDRs, Keysight, Facebook TG)
- Magreth Mushi: NC State (Network Architecture, Platform Operations)
- Mike Barts: WRC (RF, Towers, Antennas, Front Ends)
- Turker Yilmaz: NC State (SDRs and mmWave Development)

Municipality and Government Partners

Town of Cary

Other Personnel:

- Postdoctoral Scholars: Talha F. Rahman, Ender Ozturk
- PhD Students: Keith Powell, Anil Gurses, Aly Abdalla, Andrew Yingst, Daniel Brennan, Simran Singh
- MS Students: Ashwin Panicker, Vedashree Chaphekar, Udita Bhattacharjee, Jonah Gandy, Ananya Nunna
- Other WRC and RENCI Personnel: Thomas Hoover, Michael Stealey, Erica Fu, Erik Scott, Hannah Hiles
- ITRE Aviation Personnel/Pilots: Evan Arnold, Shawn Deardorff, Michael Picinich
- Undergrad Students: Mark Funderburk, John Kessler, Keshav Sridhar, Byron Qi, Joshua Moore
Phase 0 + Phase 1 Goals (Sep. 2019 – Nov. 2021)

**General Availability:**
- 3 Fixed SDR Nodes
- 3 Portable SDR Nodes
- 2 UAVs, 1 UGV
- Experiment Portal
- Initial SDR and Vehicle Control Profiles

**Initial Deployment & Testing:**
- Keysight RF Sensors
- 6 Terragraph Radios
- LoRa Dongles/Gateways
- Fortem Radar
- 1 Ericsson 4G/5G BS & UEs
- Keysight Propsim Emulator

Phase 2 Goals (Nov. 2021 – Nov. 2022)

**General Availability:**
- 8 Fixed SDR Nodes
- 13 Portable SDR Nodes
- 6 UAVs, 4 UGVs
- Experiment Portal
- 5 Keysight RF Sensors
- Keysight Propsim Emulator
- 6 Terragraph Radios
- LoRa Dongles/Gateways
- Fortem Radar
- Ericsson 4G/5G BSs/UEs

**Initial Deployment & Testing:**
- Interdigital mmWave SDRs
- IsoBLUE Radios

Phase 3 Goals (Nov. 2022 – Nov. 2023)

**General Availability:**
- 16 Fixed SDR Nodes
- 23 Portable SDR Nodes
- 10 UAVs, 6 UGVs, 1 Helikite
- Experiment Portal
- 5 Keysight RF Sensors
- Keysight Propsim Emulator
- 6 Terragraph Radios
- LoRa Dongles/Gateways
- Fortem Radar
- 5 Ericsson 4G/5G BSs/UEs

**Initial Deployment & Testing:**
- Interdigital mmWave SDRs
- IsoBLUE Radios

Phase 4 Goals (Nov. 2023 – Nov. 2024)

**General Availability:**
- 16 Fixed SDR Nodes
- 23 Portable SDR Nodes
- 10 UAVs, 6 UGVs, 1 Helikite
- Experiment Portal
- 5 Keysight RF Sensors
- Keysight Propsim Emulator
- 6 Terragraph Radios
- LoRa Dongles/Gateways
- Fortem Radar
- 5 Ericsson 4G/5G BSs/UEs

**Initial Deployment & Testing:**
- Interdigital mmWave SDRs
- IsoBLUE Radios

Phase 5 Goals (Nov. 2024 – Nov. 2025)

**General Availability:**
- 16 Fixed SDR Nodes
- 23 Portable SDR Nodes
- 10 UAVs, 6 UGVs, 1 Helikite
- Experiment Portal
- 5 Keysight RF Sensors
- Keysight Propsim Emulator
- 6 Terragraph Radios
- LoRa Dongles/Gateways
- Fortem Radar
- 5 Ericsson 4G/5G BSs/UEs

**Initial Deployment & Testing:**
- Interdigital mmWave SDRs
- IsoBLUE Radios

**AERPAW Project Timeline and General Availability**

Will support bring-your-own-device (BYOD) experiments on a case-by-case basis
AERPAW Deployment Areas

- **Late 2021 (Phase-1, 3 new fixed nodes)**
- **Late 2022 (Phase-2, 5 new fixed nodes)**
- **Late 2023 (Phase-3, 8 new fixed nodes)**
The "5G" Triangle

AERPAW’s Vision for a New Paradigm

New Mobility Modes

The AERPAW Pyramid

- Advanced wireless to enable new UAS capabilities
- Advanced UAS to enable new wireless services
- Will also support other fixed and mobile experiments

Enhanced Broadband

Low Latency

Massive IoT
Fixed Node Equipment
- NI Software Defined Radios (Every Fixed Node)
- Keysight RF Sensors
- Facebook Terragraph Radios (Centennial Campus)
- Fortem Drone Detection Radars
- LoRa IoT Equipment

Portable Node Equipment
- CC1
- CC2
- LW1
- Compute: Dell 5820 with Intel Xeon Processor
- AERPAW Phase-1 Fixed Nodes (3)
- AERPAW Phase-1 Vehicles
- AERPAW UAV (2) AERPAW UGV (1)
- LoRa Sensors
- Mobile Phones
- Compute: Intel NUC10
- AERPAW Phase-1 Portable Nodes (3)

Sandbox
- Keysight Propsim Channel Emulator (32 Ports)
- Wireless and drone emulation
- Cabled testing

Experimentation Software
- USRPs: OpenAirInterface, srsLTE, GNU Radio, Matlab
- Other software by Keysight, Facebook, Ericsson, Facebook, LoRa
- Experiments run on containers at fixed/portable nodes, both in development and testbed experiment modes

Indicates Phase-1 General Availability
Portable Node
Experimental TX Antenna
Experimental RX Antenna
Monitoring RX Antenna
Cellular Modem
FAA Beacon
GPS Receivers
Telemetry Antennas
RC Antennas
Batteries
Telemetry Antennas
Portable Node
UAV Trajectories
Controlled by the Portable Node
Portable Node
AERPAW Ericsson Equipment
AERPAW Ericsson Equipment

4G LTE Network
- 2sectors, each sector with 2x2 MIMO in Band 43 (3.6-3.8 GHz) and B66A (1.7/2.1 GHz)
- 3GPP Release 13 compliant
- Different bandwidths – 5, 10, 15, 20 MHz
- Different MIMO modes (TM2 Transmit Diversity, TM3 Open-loop 2x2 MIMO, TM4 Closed-loop 2x2 MIMO)
- Carrier aggregation
- Channel quality (CSI/PMI/RI) performance
- Link adaptation
- Various RRC procedures
- Cell-selection/Re-selection, Re-establishment, Handover

5G NR Non-Standalone (NSA) Network
- 2sectors, each sector with 4G & 5G overlaid cells
- 4G in Band 66A & 5G in n77/78 (3.3-4.2 GHz), with 2x2 MIMO
- 3GPP Release 15
- LTE node for Control plane (+ Data plane)
- NR node for Data plane only
- All functionalities offered by LTE standalone node + Additional channel BW – 20, 40, 60, 100 MHz on NR
- Dual-connectivity operation
- 4x4 MIMO (with single sector setup)

Status:
- Deployed and tested 4G/5G NSA network in Phase-1 (see poster presentation)
- Phase-2 plans:
  - work towards making the network generally available to AERPAW users
  - scale up the number of base stations
### Phase-1 General Availability

- **AERPAW** focuses on 3.3-3.55 GHz band for Phase-1 USRP experiments
  - Have experimental licenses, will merge to innovation zone in the future
- We are also doing testing with commercial Ericsson (1.7/2.1 GHz and 3.7 GHz), LoRa (900 MHz), and Facebook (60 GHz) equipment at other bands, to be general available after Phase-2
- Additional SDR frequencies are being explored for Phase-2 airborne operations

### FCC Innovation Zone and Experimental Licenses

<table>
<thead>
<tr>
<th>Frequency Band</th>
<th>Type of operation</th>
<th>Allocation</th>
<th>Fixed Station Maximum EIRP (dBm)</th>
<th>Mobile Station Maximum EIRP (dBm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>617-634.5 MHz (DL)</td>
<td>Fixed</td>
<td>Non-federal</td>
<td>65</td>
<td>-</td>
</tr>
<tr>
<td>663-698 MHz (UL)</td>
<td>Mobile</td>
<td>Non-federal</td>
<td>-</td>
<td>20</td>
</tr>
<tr>
<td>907.5-912.5 MHz</td>
<td>Fixed &amp; Mobile</td>
<td>Shared</td>
<td>65</td>
<td>20</td>
</tr>
<tr>
<td>1755-1760 MHz (UL)</td>
<td>Mobile</td>
<td>Shared</td>
<td>-</td>
<td>20</td>
</tr>
<tr>
<td>2155-2160 MHz (DL)</td>
<td>Fixed</td>
<td>Non-federal</td>
<td>65</td>
<td>-</td>
</tr>
<tr>
<td>2390-2483.5 MHz</td>
<td>Fixed &amp; Mobile</td>
<td>Shared</td>
<td>65</td>
<td>20</td>
</tr>
<tr>
<td>2500-2690 MHz&lt;sup&gt;1,2&lt;/sup&gt;</td>
<td>Fixed &amp; Mobile</td>
<td>Non-federal</td>
<td>65</td>
<td>20</td>
</tr>
<tr>
<td>3550-3700 MHz&lt;sup&gt;1,2,3&lt;/sup&gt;</td>
<td>Fixed &amp; Mobile</td>
<td>Shared</td>
<td>65</td>
<td>20</td>
</tr>
<tr>
<td>3700-3980 MHz&lt;sup&gt;1,2&lt;/sup&gt;</td>
<td>Mobile</td>
<td>Non-federal</td>
<td>-</td>
<td>20</td>
</tr>
<tr>
<td>5850-5925 MHz</td>
<td>Fixed &amp; Mobile</td>
<td>Shared</td>
<td>65</td>
<td>20</td>
</tr>
<tr>
<td>5925-7125 MHz&lt;sup&gt;2&lt;/sup&gt;</td>
<td>Fixed &amp; Mobile</td>
<td>Non-Federal</td>
<td>65</td>
<td>20</td>
</tr>
<tr>
<td>27.5-28.35 GHz</td>
<td>Fixed</td>
<td>Non-Federal</td>
<td>65</td>
<td>20</td>
</tr>
<tr>
<td>38.6-40.0 GHz</td>
<td>Fixed</td>
<td>Non-federal</td>
<td>65</td>
<td>20</td>
</tr>
</tbody>
</table>

<sup>1</sup> Commission rules do not permit airborne use on all or portions of these bands.
<sup>2</sup> Any experimental use must be coordinated with authorized users and registered receive-only fixed satellite earth stations.
<sup>3</sup> Operations must be coordinated with a spectrum access system administrator.
**FAA Constraints and Exemptions**

- Baseline operation under Part 107
  - Line of sight, under 55 pounds, under 100 Mph, below 400 feet

- Currently collecting data for waivers under:
  - § 107.35 – Operation of Multiple Small UAS

- AERPAW Air Operations under ITRE-Aviation (Co-PI Tom Zajkowski)
  - Currently these as well as other exemptions in place, but for specific prior contexts
  - Need to be re-done for new aircraft type
Other Modes not Impossible, but not Norm

- **Approach 1: Program-it-Yourself (PiY)**
  - Main modalities – as on previous slide

- **Experiment-as-a-Service (EaaS)**
  - You explain your experimental intent to us, we develop and execute it
  - You get results

- **Experiment-Development-as-a-Service (EDaaS)**
  - You explain your experimental intent to us, we develop it
  - You get developed experiment, modify, follow PiY from there on

- **Live Limited Access**
  - For parts of the testbed facilities, for some clients with documented and verified expertise (and possible indemnification and liability assumption)

- **Bring your own Device**
  - Case-by-case basis; Initial plan submission → Review → Detailed plan submission → approval → agreement execution

- **Mixed and Custom Approaches**
  - Nothing is impossible, let’s discuss
Main Entities and Interactions

1. Register, supply credentials
2. Create experiment, request develop
3. Pass virtual request info
4. Instantiate virtual experiment
5. Pass virtual manifest, change status
6. Pass virtual manifest info
7. Login to virtual nodes, code, test
8. Submit experiment for testbed
9. Retrieve experimenter code
10. Install experimenter code
11. Handover to pilots/operators
12. Retrieve experimenter data
13. Inform completion
14. Inform experimenter
15. Request develop returned expmt.
16. Pass request info
17. Re-instantiate virtual experiment
18. Change status
19. Notify changed status
20. Login to virtual nodes, view
AERPAW E-VM and C-VM Architecture

Programmable SDR-based nodes

E-VM software is what the experimenter develops.
End Goal – Representative Experiments

- **Counter UAS:** radar, passive RF sensing
- **Coverage optimization of commercial 4G/5G for UAS**
- **UAS trajectory optimization**
- **mmWave beamforming and tracking**
- **Smart agriculture / cities / buildings**
- **Multi-hop networks and UAS swarms**
- **4G/5G/Next-G PHY/MAC/NET experiments**
- **V2X networks**

AERPAW wireless node
Questions?