AERPAW

https://aerpaw.org/

PAWR Project Office

AERPAW: Aerial Experimentation and Research Platform for Advanced Wireless

Ismail Guvenc, NC State University

NITRD – FMG 5G Workshop

April 26, 2021

NC STATE UNIVERSITY

AERPAW Project Vision and Scope

- ➔ **Funding:** NSF project awarded in Sep. 2019 ($9M + $15M in kind resources from PAWR consortium)
- ➔ **AERPAW Vision:** Serve as a unique technological infrastructure for advanced wireless and UAS research, to be used by researchers nationwide
- ➔ **Project Heart:** Programmable radios, programmable UAS, on a programmable network

ERICSSON
KEYSIGHT TECHNOLOGIES
COMMSCOPE®
INTERDIGITAL
at&t
FACEBOOK

- Phase-0 Starts — Sept. 2019
- Phase-1 Starts — Mar. 2020
- Phase-2 Starts — June 2021
- General Availability
- Phase-3 Starts — June 2022
- Phase-4 Starts — June 2023
- Phase-5 Starts — June 2024

Project Investigators

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NC State (SDN, architecture, CentMesh)

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Brian Floyd
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NC State (UAS operations, FAA permitting)

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Purdue (MIMO, SDRs, agriculture)

Senior Personnel

Lavanya Sridharan
NC State (Project Coordinator)

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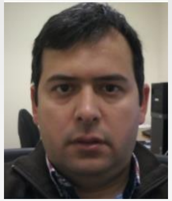
NC State (installations and permits)



Ozgur Ozdemir
NC State (SDRs, Keysight, Facebook TG)

Mike Barts
WRC (RF, Towers, Antennas, Front Ends)

Asokan Ram
WRC (Commercial 4G/5G Network)

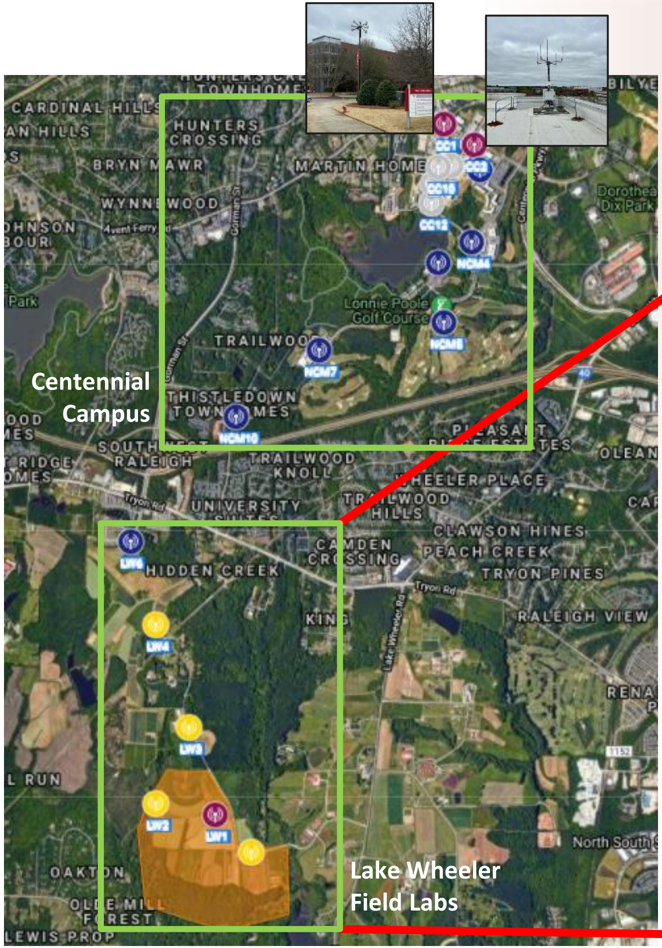
Municipality and Government Partners

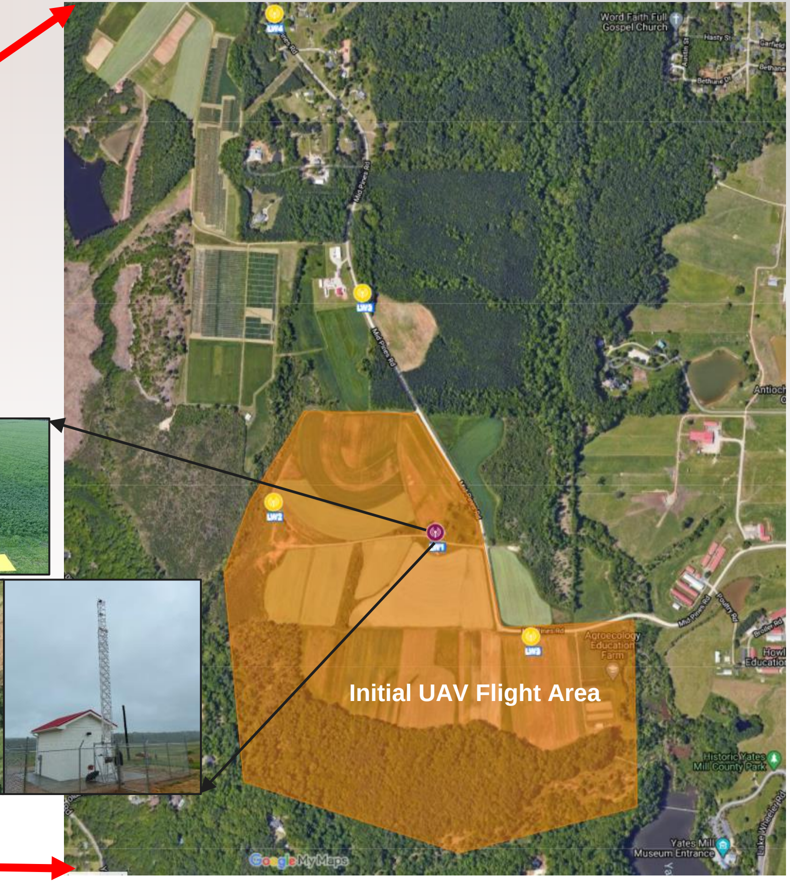
Town of Cary

Raleigh

State of North Carolina Department of Transportation

AERPAW Deployment Area





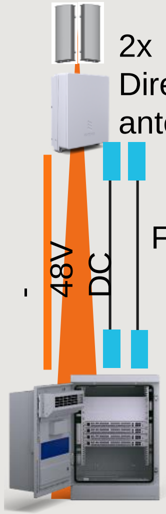
Lake Wheeler Field Labs

Fixed Node Locations and Availability

Mid-2021 (Phase-1, 3 new fixed nodes)	Mid-2022 (Phase-2, 5 new fixed nodes)	Mid-2023 (Phase-3, 8 new fixed nodes)

Fixed Node Equipment

NI Software Defined Radios
(Every Fixed Node)



2x Directional antenna
2x SFP
Fiber
48V DC

Keysight RF Sensors

Ericsson 4G/5G Base Stations
(Lake Wheeler)

Facebook Terragraph Radios
(Centennial Campus)

Fortem Drone Detection Radars

LoRa IoT Equipment

Compute: Dell 5820 with Intel Xeon Processor

Portable Node Equipment

NI Software Defined Radios

Mobile Phones

Sensors

Compute: Intel NUC10

Portable Node

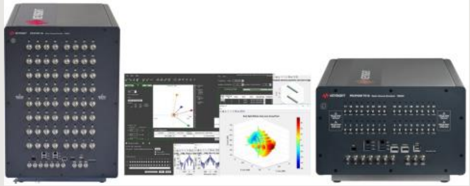
Carried By

Custom-Built Unmanned Aerial and Ground Vehicles (UAVs/UGVs) and Helikite

Vehicles

Sandbox

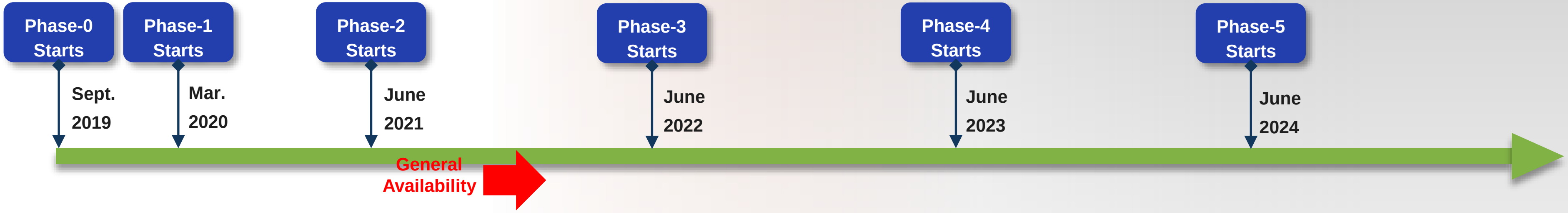
Keysight Propsim Channel Emulator



Experimentation Software

- USRPs: **OpenAirInterface, srsLTE**, GNU Radio, Matlab
- Other software by Keysight, Facebook, etc.
- Experiment software runs on docker containers at fixed/portable nodes

AERPAW Project Timeline and General Availability



Phase 0 + Phase 1 Goals (Sep. 2019 – June 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 (As Is Availability):

- Keysight RF Sensors
- Terragraph Radios
- LoRa Dongles/Gateways
- Fortem Radar
- 1 Ericsson 4G/5G BSUE
- Keysight Propsim Emulator

Phase 2 Goals (Apr. 2021 – June 2022)

General Availability:

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

Initial Deployment & Testing (As Is Availability):

- Interdigital mmWave SDRs
- IsoBLUE Radios

Phase 3 Goals (April 2022 – March 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
- Terragraph Radios
- LoRa Dongles/Gateways
- Fortem Radar
- 5 Ericsson 4G/5G BSs
- Interdigital mmWave SDRs
- IsoBLUE Radios

Phase 4 Goals April 2023 – March 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
- Terragraph Radios
- LoRa Dongles/Gateways
- Fortem Radar
- 5 Ericsson 4G/5G BSs
- Interdigital mmWave SDRs
- IsoBLUE Radios

Phase 5 Goals April 2024 – March 2025

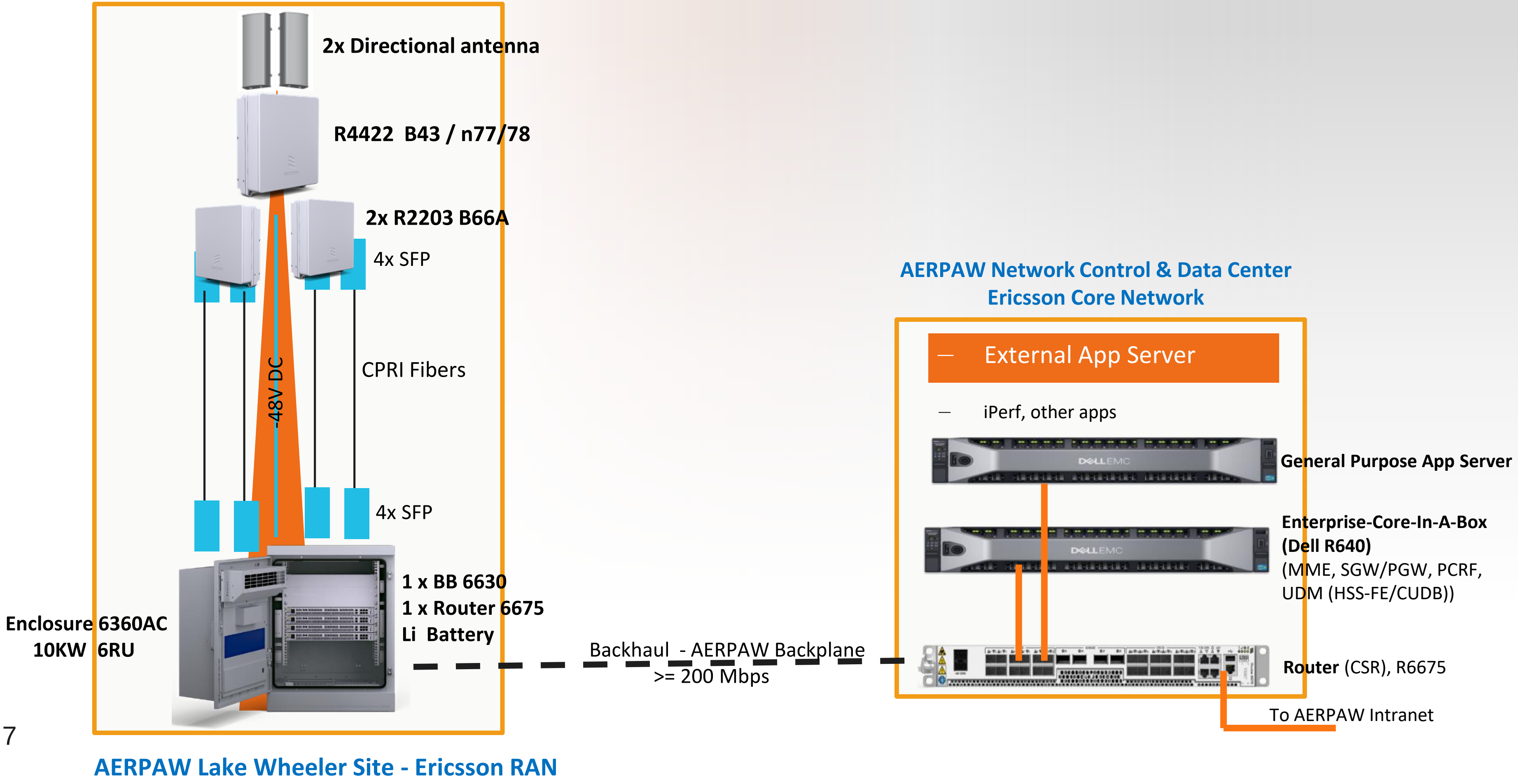
General Availability:

- 16 Fixed SDR Nodes
- 23 Portable SDR Nodes
- 10 UAVs, 6 UGVs, 1 Helikite
- Experiment Portal
- 5+ Keysight RF Sensors
- Keysight Propsim Emulator
- Terragraph Radios
- LoRa Dongles/Gateways
- Fortem Radar
- 5 Ericsson 4G/5G BSs
- Interdigital mmWave SDRs
- IsoBLUE Radios

Full-Scale Operations

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

AERPAW - Ericsson LTE / NR-NSA Network @ Lake Wheeler



Ericsson Network Capabilities

AERPAW Phase-1 Plan

4G LTE Network

- 2-sectors, 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

- 2-sectors, 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)

AERPAW Phase-2 Plan

Network enhancements (in planning stage)

- Deploy at **two more** LWRFL towers
- 5G NR Standalone (SA) network
- 5G mmWave sectors
- 5G-U NR in unlicensed spectrum
- 5G-U Standalone, 5 GHz & 6 GHz unlicensed bands
- NB-IoT

Experiments Planned with Ericsson Equipment (Phase-2)

- Integration of UAV Aerial 5G mobile devices with Ericsson network
- Coverage measurements and analysis: impact of antenna patterns/tilts, power control, interference management, handover…

FCC Innovation Zone Request and FAA Waivers

Frequency Band	Type of Operation	Allocation	Fixed Station Maximum EIRP (dBm)	Mobile Station Maximum EIRP (dBm)
617-634.5 MHz (DL)	Fixed	Shared	65	20
663-698 MHz (UL)	Mobile	Shared	65	20
907.5 – 912.5 MHz	Fixed & Mobile	Shared	65	20
1755-1760 MHz (UL)	Mobile	Shared	65	20
2155-2160 MHz (DL)	Fixed	Shared	65	20
2390-2483.5 MHz	Fixed & Mobile	Shared	65	20
2500-2690 MHz	Fixed & Mobile	Non-federal	65	20
3550-3700 MHz	Fixed & Mobile	Shared	65	20
3700-4200 MHz	Mobile	Non-federal	65	20
5850-5925 MHz	Fixed & Mobile	Shared	65	20
5925-7125 MHz	Fixed & Mobile	Non-Federal	65	20
27.5-28.35 GHz	Fixed & Mobile	Non-federal	65	20
38.6-40.0 GHz	Fixed & Mobile	Non-federal	65	20

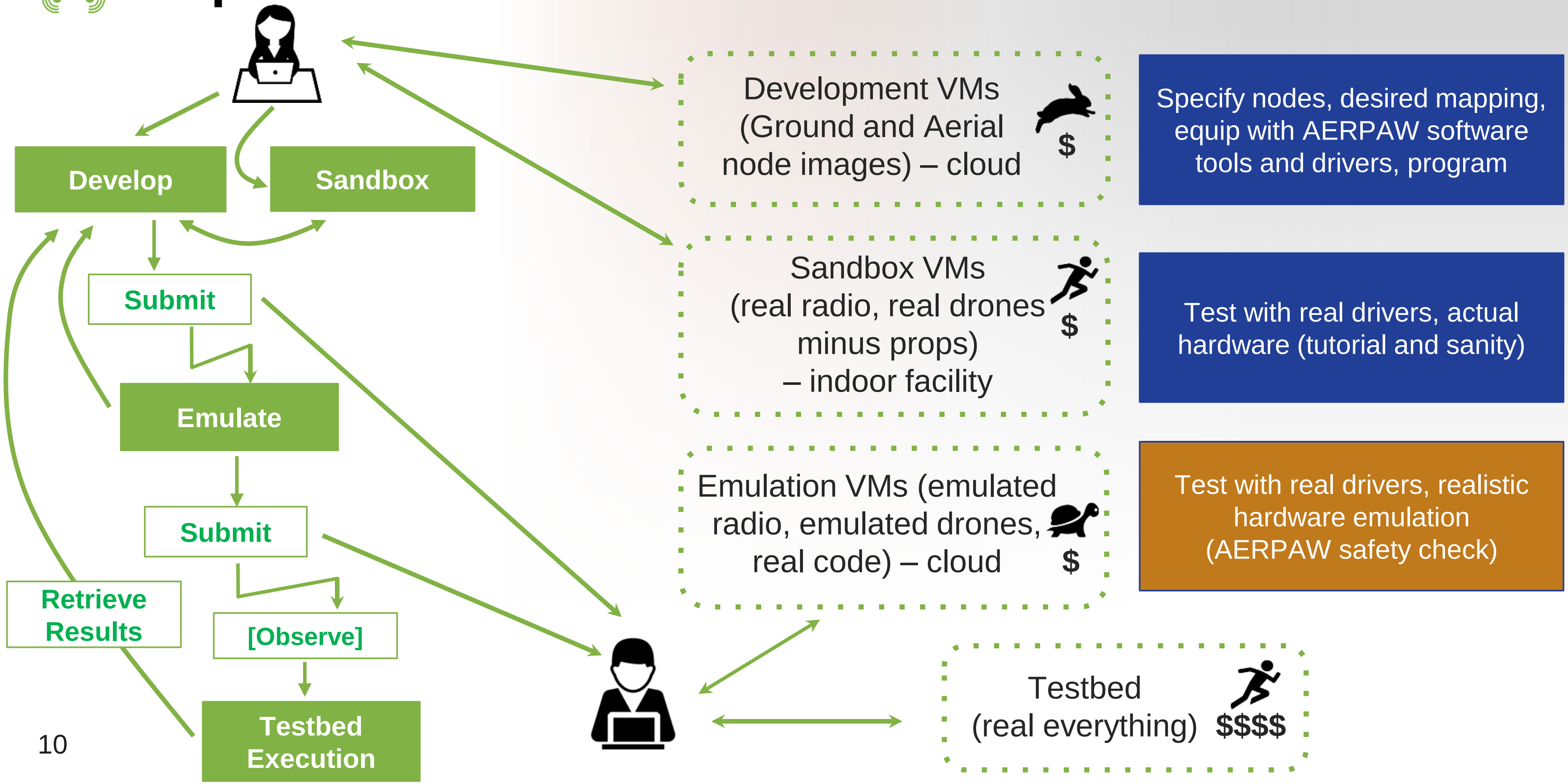
Initial Ericsson Operations (1755-1760 MHz (UL), 2155-2160 MHz (DL))

Initial SDR Front-Ends (2500-2690 MHz, 3550-3700 MHz, 3700-4200 MHz)

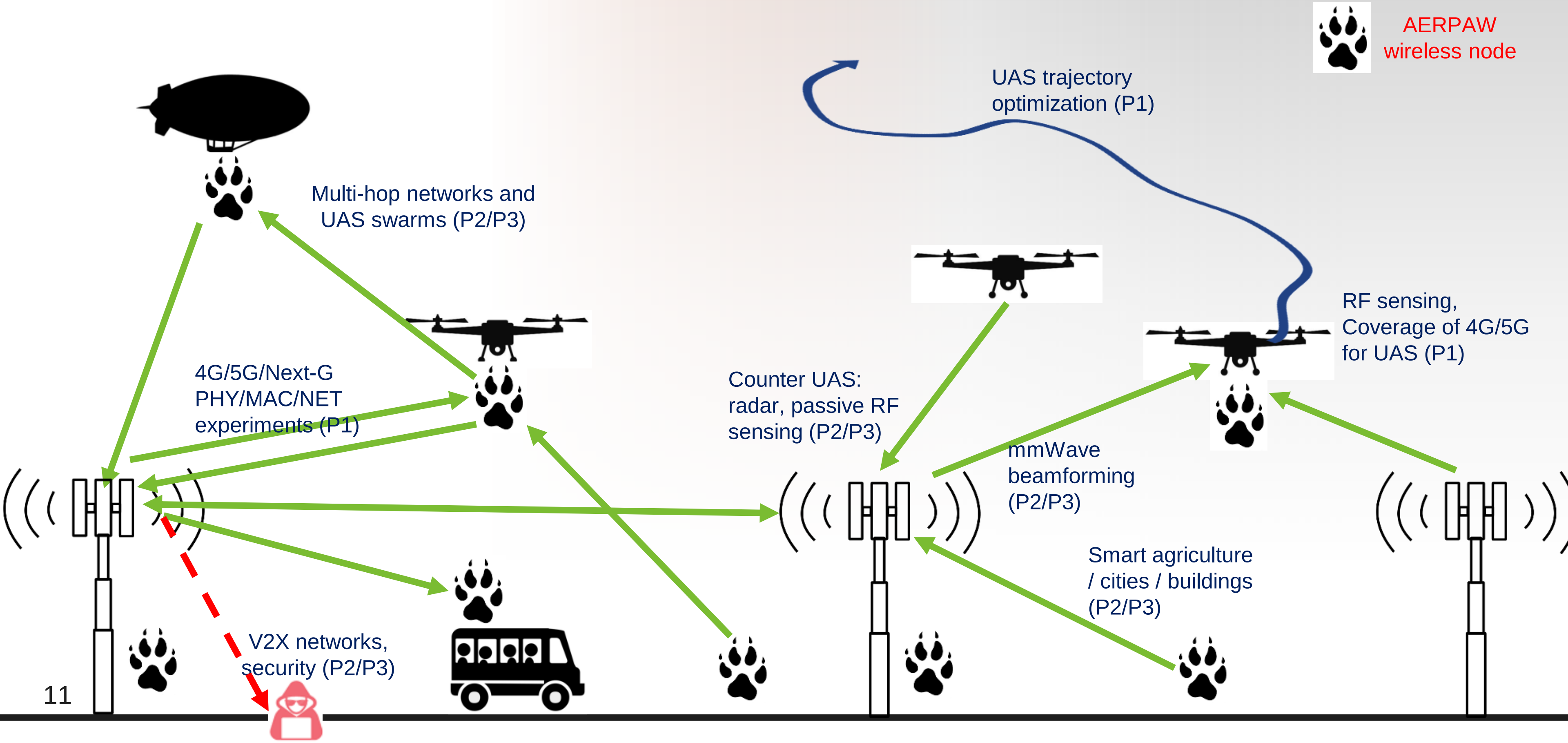
FAA Waivers to be Applied:

- Initially: Part 107 licensed pilots, visual line-of-sight, <400 feet, daytime operation
- Future: FAA waivers for flying over people, autonomous operation, multi-UAV operation, *etc*.

Experiment Flow



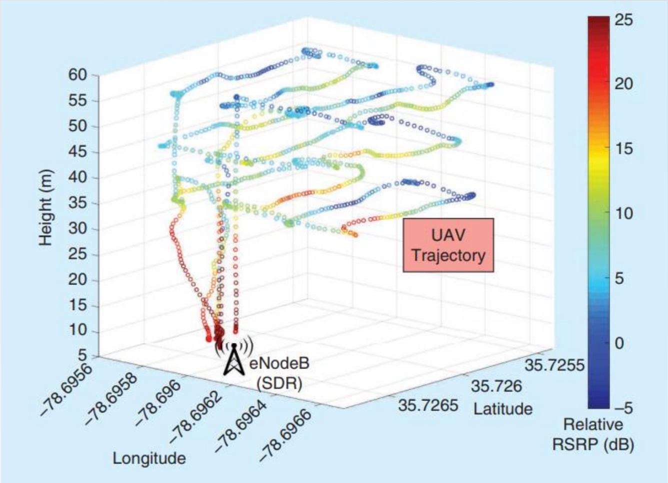
Planned Experiment Examples



Experiment Examples (1)

AERPAW UAV

LTE RSRP Measurements (2019)

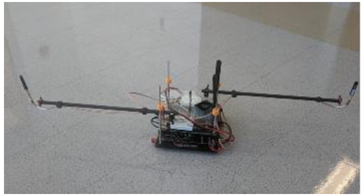


Repeatable Trajectory

Phase-1:
- Record measurements at pre-defined waypoints
- Each *wireless* measurement is tagged with a precise location and time stamp

Phase-2:
- Locations can trigger measurements
- Measurements can trigger trajectory updates

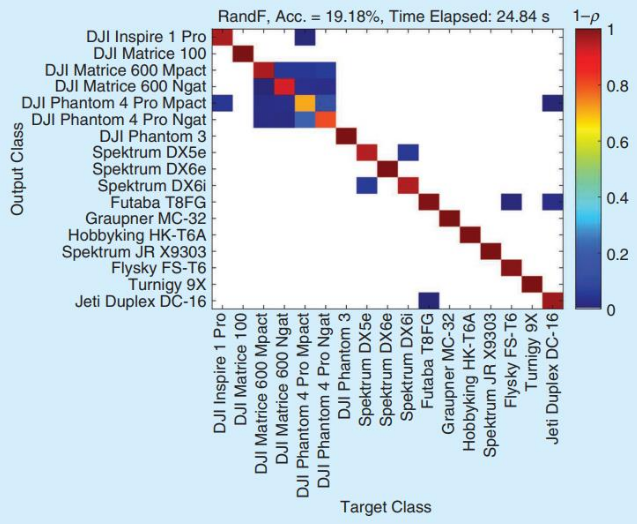
Portable Node

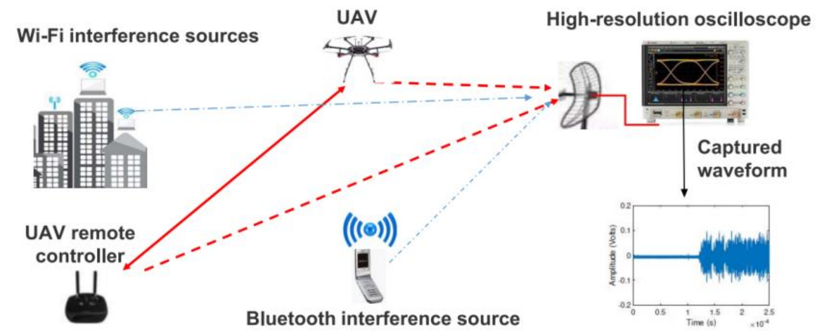


Experiment Examples (2)

AERPAW UGV Testing

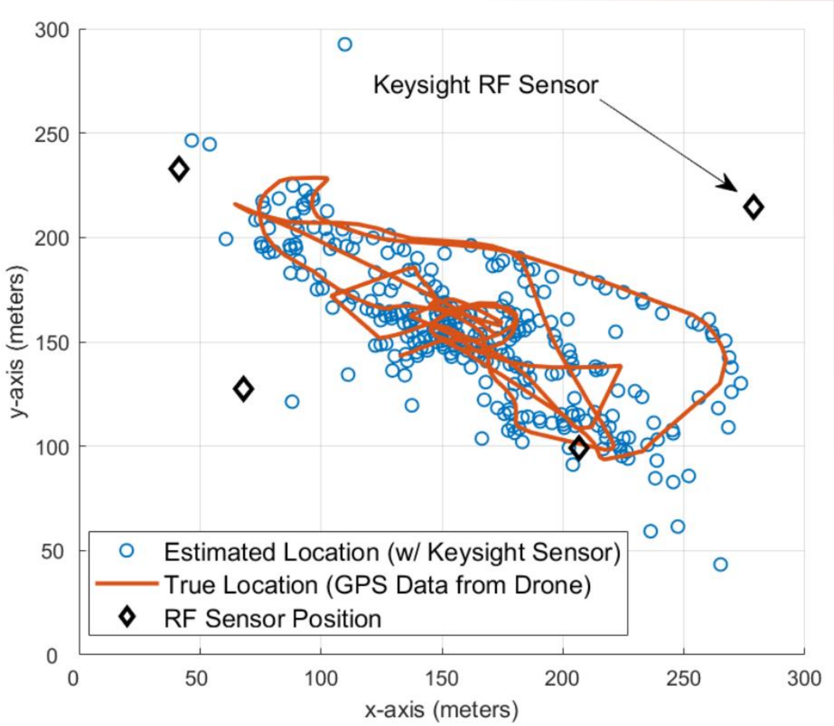
RF Based UAV Classification using ML
(BYOD with University of Louisville, 2020)

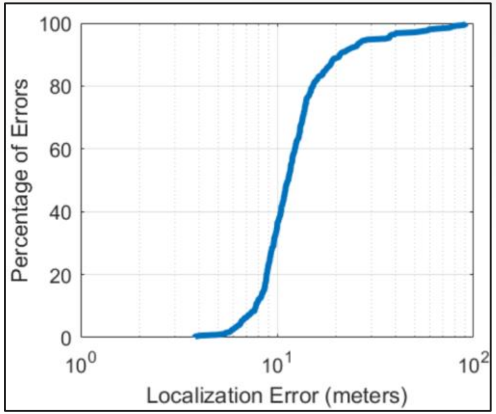




Experiment Examples (3)

RF-Based Passive UAV Tracking with Keysight RF Sensors





Experiment Examples (4)

Fortem Radar Field Testing in LWRFL

5G Testing Capabilities (1)

Use Case Requirements

Requirements	Desired Value
	Cellular Drone Delivery/UAS
Connection Density	10s-100s over >10 km
Environment	Any
Mobility	8-50 km/h
Security	Authentication, encryption, IoT security, vulnerability testing
Sensitivity	Unclassified to classified
Spectrum	All
Traffic Type	Video, data, IoT

AERPAW Features

A few (short-term), 10s (long-term), >10 km^2 experiment area in Centennial + Lake Wheeler (3 km^2 initial drone flight area)

Rural (short-term), Sub-urban (long-term)

Supported with drones

Partially supported

Both to be supported

Initially 1.7/2.1 GHz (Ericsson), and 2.6/3.5 GHz (SDRs and ERicsson), to expand in the future

Supported (LoRa short-term, NB-IoT long-term)

Source: FMG 5G Testing White Paper, pp. 13

5G Testing Capabilities (2)

Source: FMG 5G Testing White Paper, pp. 15

5G Features and Capabilities	AERPAW Features
eMBB, URLLC, and mMTC	As Supported by Ericsson, OAI, and srsLTE
Low-, mid-, and high-band spectrum	Mid-Band by Phase-2, high-band (28 GHz) and low-band by the end of Phase-3
Network slicing	Planned by the end of Phase-3
Fixed wireless to replace or supplement wired access	FB Terragraph, Interdigital mmWave (SDR and proprietary), Ericsson mmWave
Edge computing	Planned by the end of Phase-3
Ubiquitous connectivity to support multiple device types: smartphones/tablets, UAVs/robots, autonomous vehicles, cameras, AR/VR headsets, wearables, and IoT sensors and actuators	Focused on UAV/UGV experiments Experiment will have full control on UAV/UGV autonomous trajectory
Network performance improvements (latency, throughput, reliability)	As Supported by Ericsson, OAI, and srsLTE
Beamforming and mmWave to enhance coverage/capacity and minimize interference	FB Terragraph, Interdigital mmWave (SDR and proprietary), Ericsson mmWave (long-term)

5G Testing Capabilities (3)

Source: [FMG 5G Testing White Paper, pp. 15]

Security testing for federal use cases

➔ Federal cybersecurity requirements (e.g., encryption, authentication)
➔ Adoption of Zero Trust security architectures
➔ Security concerns associated with 5G and legacy 3GPP known attacks
➔ 5G guidelines with security protocols
➔ IoT security
➔ 5G cloud and edge security
➔ Secure network slicing
➔ Secure Software Defined Networking (SDN)
➔ Blue/Red teaming
➔ Vulnerability and security assessment

RAN Security Testing Resources at AERPAW

- **Hardware:** SDRs (fixed, portable, and mobile), Ericsson network, sandbox, emulator (Keysight Propsim)
- **Software:** Open-source software with SDRs for jamming, spoofing, eavesdropping, protocol aware, smart attacks
- **Additional Resources (Miss. State):** Amarisoft Call Box Pro, Wavejudge 5G analyzer

Methodology and Example Scenarios/Results

- Radio performance (KPI), messages, and parameter logging and analysis [1]
- **Red team/blue team example:** Red team (attacker) can try to, for instance, obtain the UE identifier or track a user. This will reveal how easy or difficult it is to launch easy 4G/legacy attacks.
- Test the 5G security framework by looking at which security features are in place (e.g., encryption) and how to exploit them [2]
- **Possible countermeasures:** Beamforming, aerial relays, PHY security [3] and authentication

5G Testing Capabilities (4)

Source: FMG 5G Testing White Paper, pp. 15

5G Testing: Drone Use Case

Step 1: Start with the use case

- Drone near the border

Step 2: Collect the requirements for testing scenarios.

- A drone requires high-data rates with low latency for end-to-end connectivity, so 5G SA mode support with URLLC feature is required. (Note: If there are many drones, massive IoT features are also required.)
- There is a constraint on spectrum because drones operate outdoors and require spectrum coordination.
- Only outdoor testing is feasible.
- Multiple base stations are required.
- Drone is needed.
- If 5G security enhancements are required, a 5G SA mode is needed.

Step 3: Map the requirements to the capabilities in the testing framework.

I. Capabilities

- Specify performance requirements in terms of:
  - Data rate
  - Latency
  - Reliability
  - Mobility
- Performance metrics to be collected
- Identify security requirements and security metrics to be collected

II. Architecture

- 5G standalone

III. Spectrum

- Sub-3GHz
- CBRS (note that CBRS currently does not support 5G)

IV. Testing resources required

- Environment of use/area: rural, uneven terrain, possibly contested
- Specify size of area of operation
- Specify network size
- Number of 5G base stations: Multiple
- Type/number of mobile devices: Smartphone/tablet and drones/IoT
- Traffic type: Video, data
- Project traffic volume (bandwidth and number of simultaneous connections)
- Communication interaction: Human to Machine and Machine to Machine
- 5G innovation capabilities:
  - Network slicing to support traffic priority differentiation
  - MEC to enable low-latency applications
  - Security classification: Unclassified, FOUO, Classified

Step 4: Develop a testing plan with test cases that include test objective, testing approach, and measurements to be collected.

Step 5: What existing capabilities/resources can be leveraged: national laboratory, university, DoD, spectrum from carriers? See AR/VR subsection. Some federal labs have air space for UAV testing.

AERPAW will be able to support:

- a subset of these requirements later this year once achieving general availability (Phase-1)
- most/all requirements by the end of Phase-3 (mid to late 2023)

"Any opinions, findings, conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the Networking and Information Technology Research and Development Program."

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