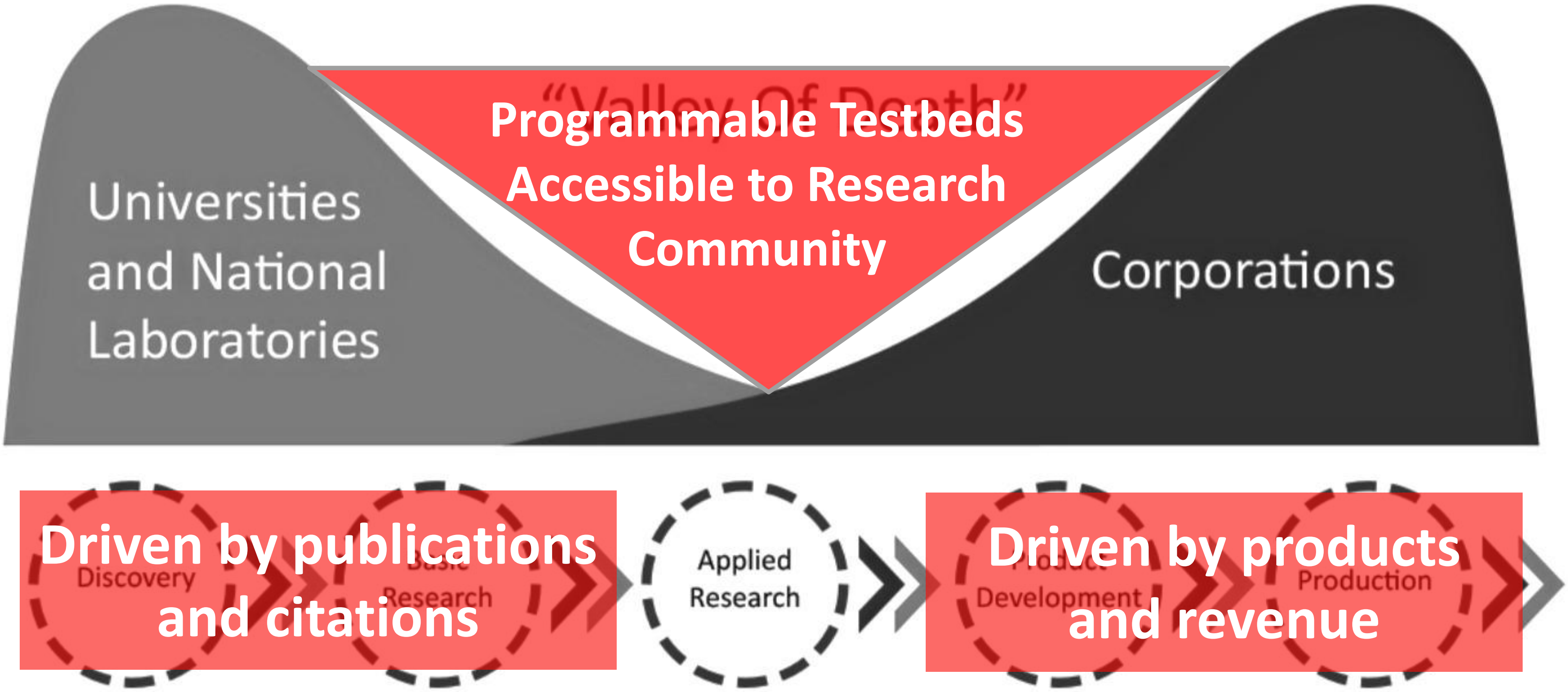
PAWR Project Office

https://aerpaw.org/

AERPAW: Aerial Experimentation and Research Platform for Advanced Wireless

Raleigh Amateur Radio Society (RARS) Monthly Meeting
January 9, 2024

Ismail Guvenc, Professor (ECE)



Programmable Testbeds
Accessible to Research
Community
Universities
and National
Laboratories
Corporations
Driven by publications
and citations
Discovery
Research
Applied
Research
Driven by products
and revenue
Development
Production

NSF Platforms for Advanced Wireless Research (PAWR)

Funded Apr. 2018

POWDER

Salt Lake City, UT

Software defined networks and massive MIMO

AVAILABLE TODAY !!

Funded Apr. 2018

COSMOS

West Harlem, NY

Millimeter wave and backhaul research

AVAILABLE TODAY !!

Funded Sept. 2019

AERPAW

Raleigh, NC

Unmanned aerial vehicles and mobility

AVAILABLE TODAY !!

Funded June 2021

ARA

Ames,IA

Rural broadband wireless

AVAILABLE TODAY !!

COLOSSEUM

Northeastern University, MA
Large-scale wireless emulation

AVAILABLE TODAY !!

NC STATE UNIVERSITY · wireless research center · MISSISSIPPI STATE UNIVERSITY · renci · PURDUE UNIVERSITY · UNIVERSITY OF SOUTH CAROLINA · ERICSSON · KEYSIGHT TECHNOLOGIES · ni · at&t · GUS · UNMANNED EXPERTS · COMMSCOPE · Meta · anymile · cisco

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 (UAS operations, FAA permitting)

Lavanya Sridharan, NC State, Project Coordinator

Ed Rogers, NC State
Construction Permits

Ozgur Ozdemir, NC State
SDRs, Keysight, Operations

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 (aerial propagation, waveforms)

David Love
Purdue (MIMO, SDRs, agriculture)

Magreth Mushi, NC State, Network Arch. & Platform Operations

Mike Barts, WRC-NC
RF, Towers, Antennas, Front Ends

Asokan Ram, WRC-NC
4G/5G Ericsson Deployment

Alphan Sahin, USC
mmWave Experiment Development

Andrew Balmos, Purdue, LoRa Experiment Development

Mark Funderburk, NC State
UAV/UGV Development

Anil Gurses, NC State
AERPAW Digital Twin

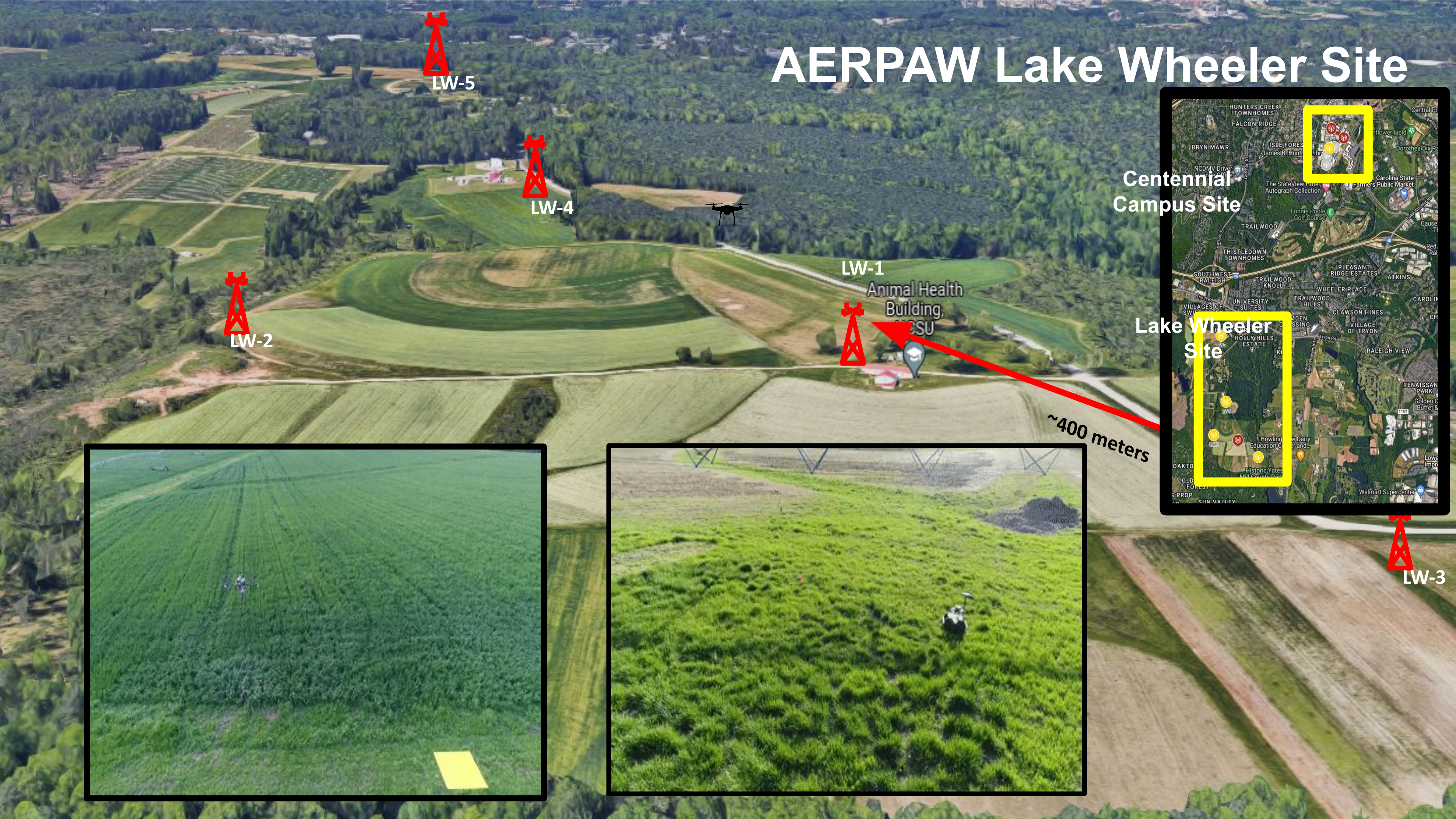
Ricardo Parchment, NC State, Network Architecture

Sunc Joon Maeng, NC State, Dynamic Radio Zones

Talha Faizur Rahman, MSU, SDRs and 4G/5G

Moahmed Rabeek Sarbudeen, NC State, RF Front Ends and O-RAN

NC STATE UNIVERSITY Electrical and Computer Engineering · NC STATE UNIVERSITY Computer Science · ITRE Institute for Transportation Research and Education NC STATE UNIVERSITY · NC STATE UNIVERSITY College of Agriculture and Life Sciences · NC STATE UNIVERSITY OFFICE OF INFORMATION TECHNOLOGY



AERPAW Lake Wheeler Site
LW-5
LW-4
LW-2
LW-1
Animal Health Building, NCSU
LW-3
~400 meters
Centennial Campus Site
Lake Wheeler Site

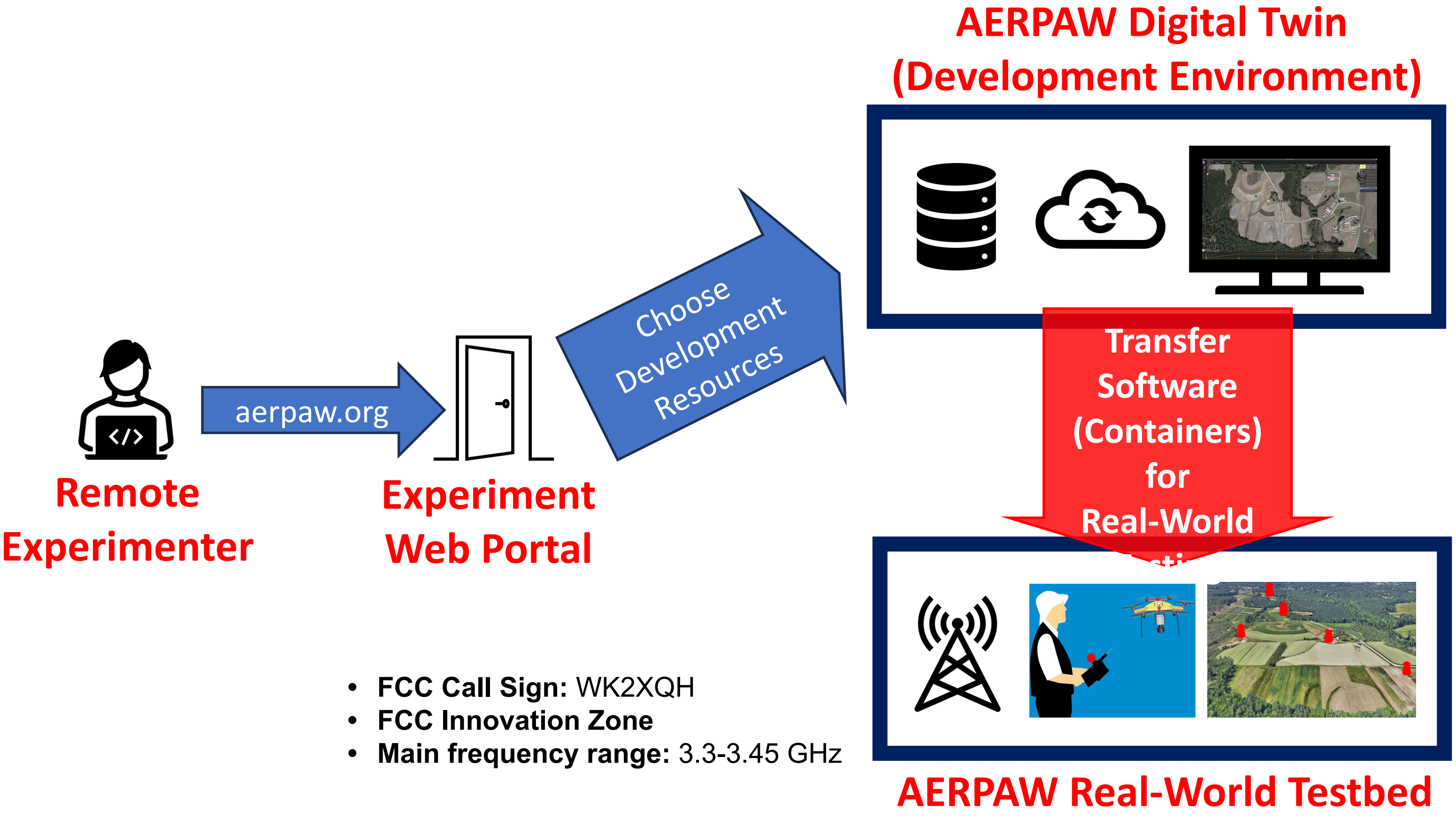
Supported Research and Application Examples

4G/5G/6G Wireless Networks	UAV Trajectory Optimization	Counter UAV Systems
UAV Corridor Design and Optimization	Smart Agriculture	Flying Base Stations
Advanced Aerial Mobility	Wireless Localization	Multi-Hop and Ad-Hoc Networks
Dynamic Spectrum Sharing	Open Radio Access Networks	Software Defined Radios and Networks
Disaster Response and Recovery	Vehicular Networks	AI/ML Enabled Wireless Networks

AERPAW by the Numbers

$10M+: Funding at NC State to date	1 of 4: FCC Innovation Zones in the US	$6M+: Industry In-Kind Contributions
11: # AERPAW Towers in NC State	347: # Experiments in Experiment Portal	51: Projects in Experiment Portal
20+: # REU Students Trained	20+: # Papers in 2023 by AERPAW	168: # Papers in GS Mentioning AERPAW
58: # Field Experiments (684: AERPAW Ops Person Hours)	5: # Finalists in AFAR Student Competition	37: # Universities with Students Trained on Campus at ACW 2023
11: # Datasets Released	50+: Number of Invited Talks Delivered	549: # Followers in LinkedIn

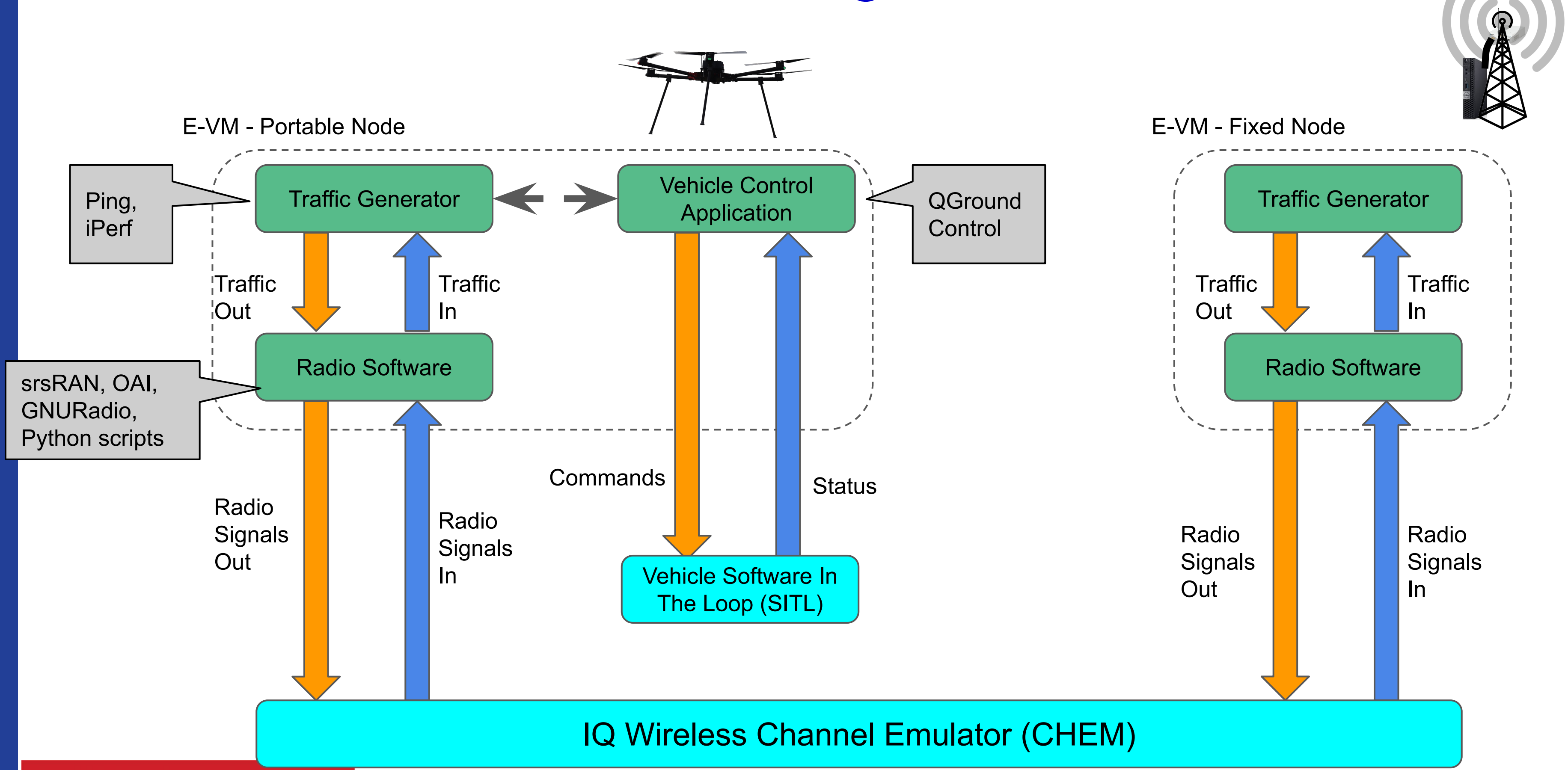
AERPAW Digital Twin and Real-World Testbed

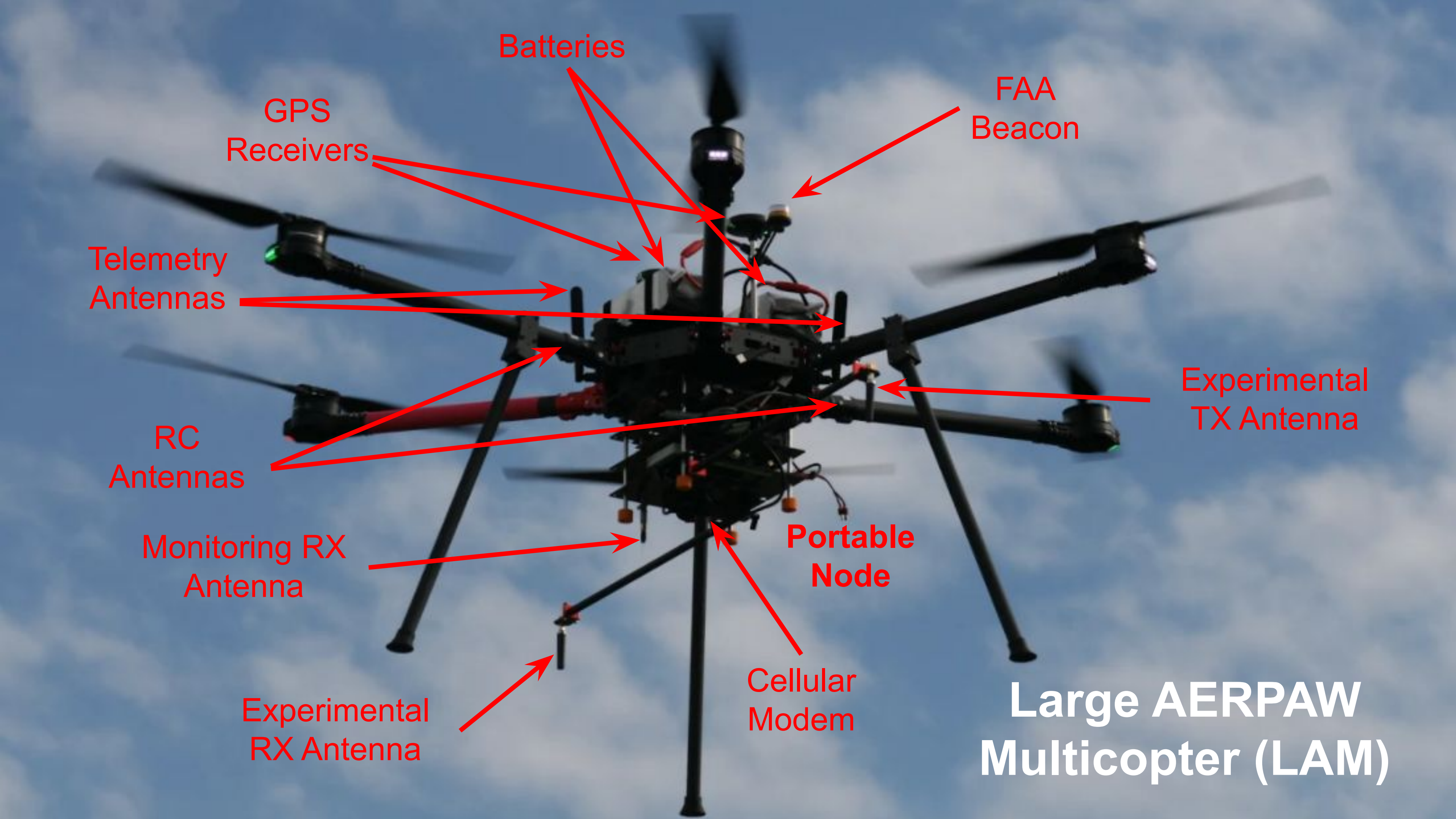


- **FCC Call Sign:** WK2XQH
- **FCC Innovation Zone**
- **Main frequency range:** 3.3-3.45 GHz

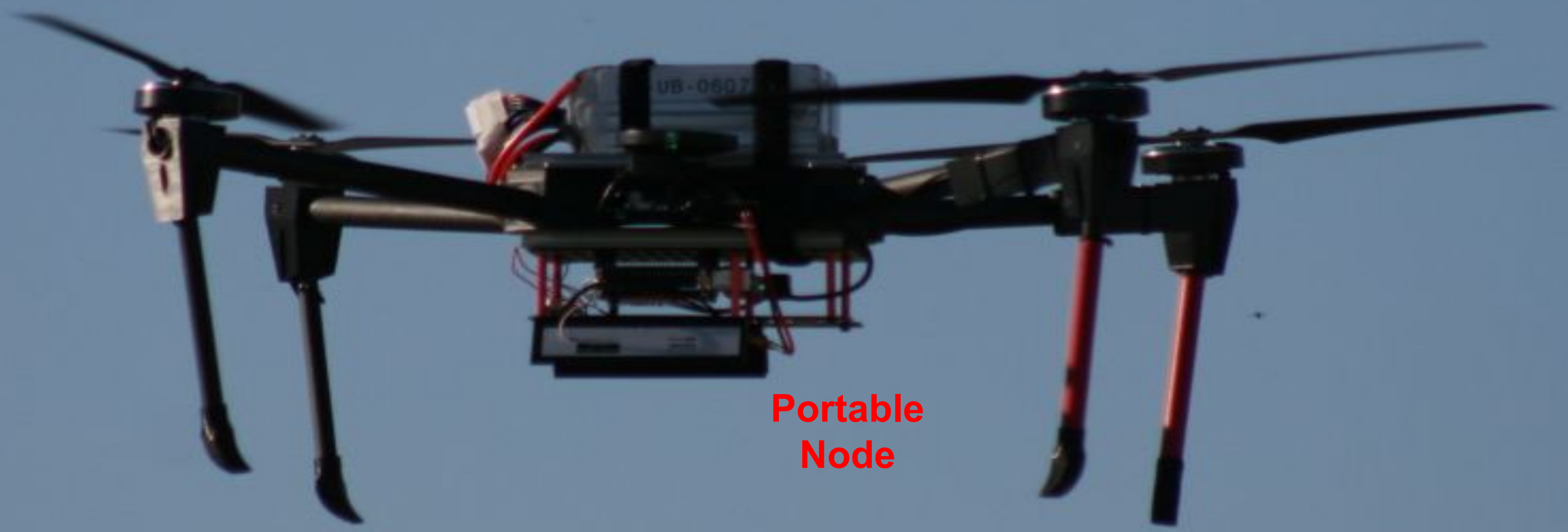

QGroundControl
Selected Waypoint
Alt diff: 0.0 m
Azimuth: 0
Distance: 0.0 m
Gradient: -.-
Heading: nan
Total Mission
Distance: 852 m
Time: 00:05:35
Max telem dist: 264 m
Plan
Fly
File
Takeoff
Waypoint
Pattern
Return
Center
Mission
Fence
Rally
Mission Start
Takeoff
Waypoint
Waypoint
Waypoint
Waypoint
Return To Launch
Send the vehicle back to the launch position.
Launch
Mid Pines Rd
Mid Pines Rd
Mid Pines Rd
Poultry Rd
Lake Wheeler R
100 m

AERPAW Digital Twin



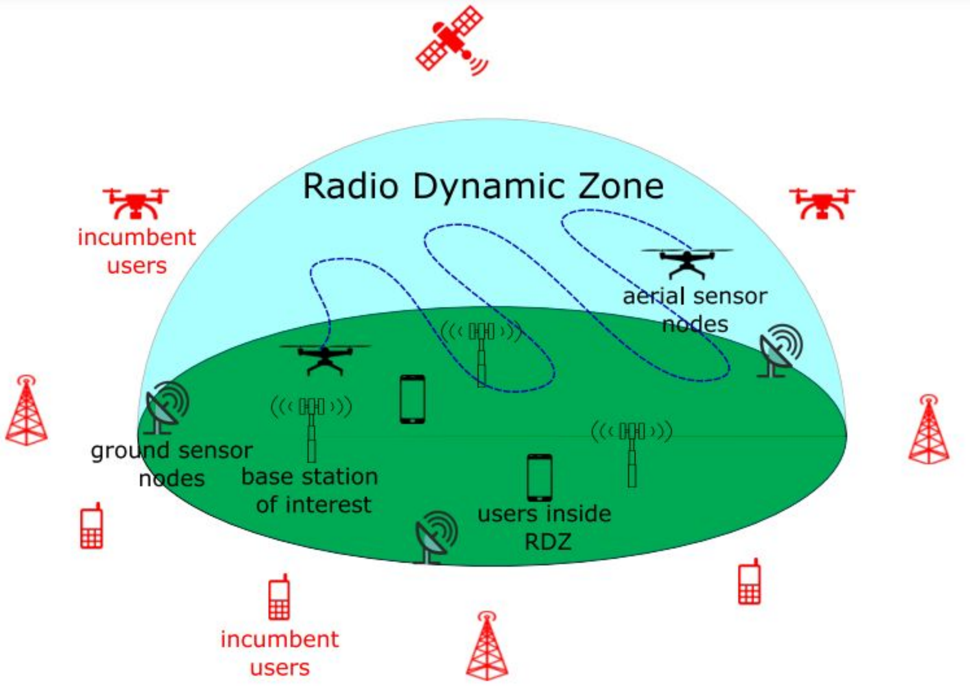

Batteries
GPS
Receivers
FAA
Beacon
Telemetry
Antennas
RC
Antennas
Experimental
TX Antenna
Monitoring RX
Antenna
Portable
Node
Experimental
RX Antenna
Cellular
Modem
Large AERPAW
Multicopter (LAM)

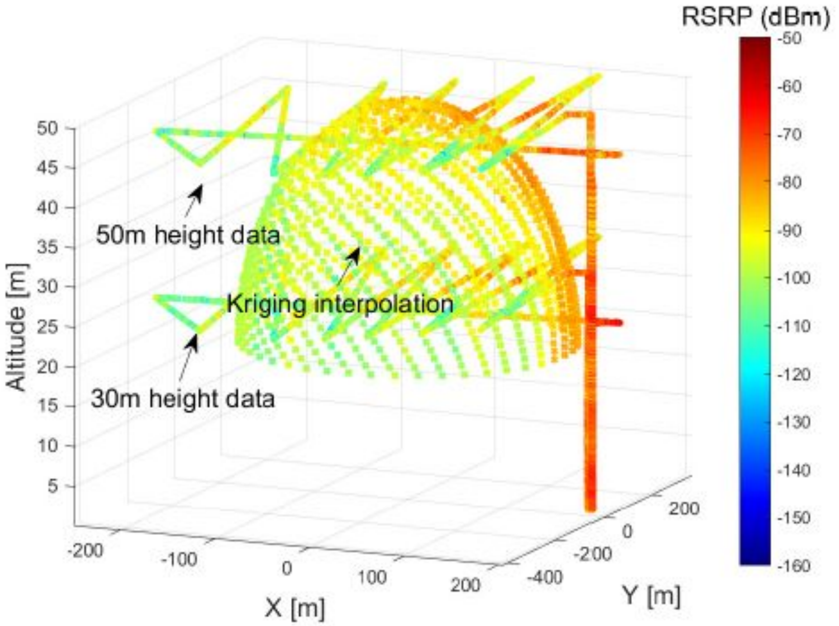
Small AERPAW Multicopter (SAM)



Portable
Node

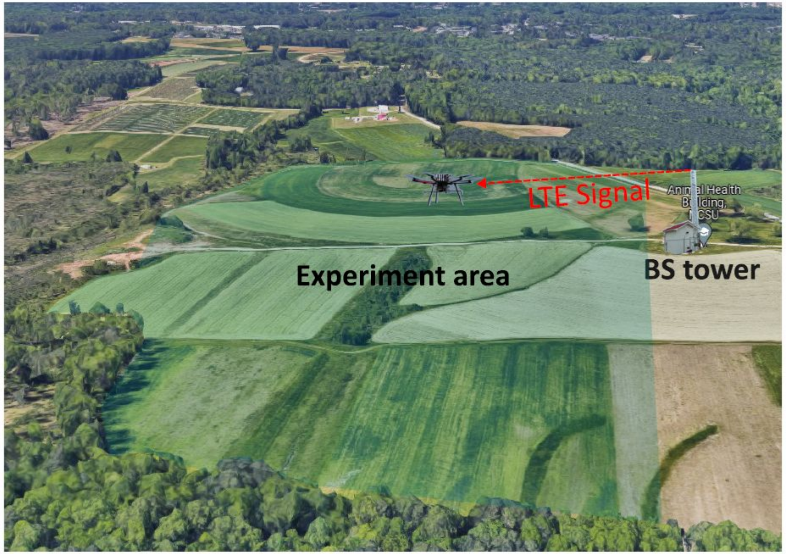
AERPAW and National Radio Dynamic Zones (NRDZs)

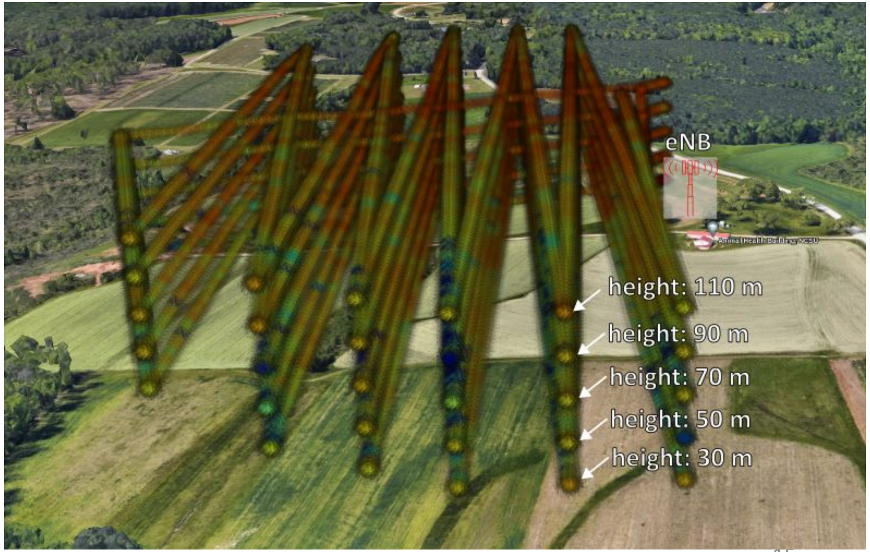




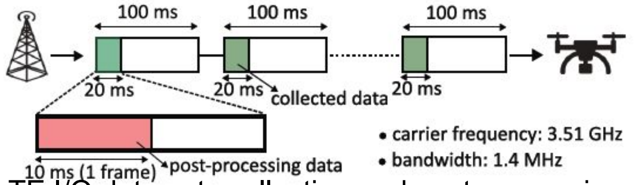
I/Q Data Collection Process (1/2)

- Measurement scenario (Spring 2022)
  - ✔ AERPAW's Lake Wheeler Field Labs in Raleigh NC
  - ✔ A USRP B205mini at the tower transmits LTE signal using srsRAN (@3.51 GHz, 1.4 MHz BW)
  - ✔ A USRP B205mini carried at a UAV collects LTE IQ samples at different altitudes
  - ✔ *Can simultaneously monitor large number of signal sources using the same approach*

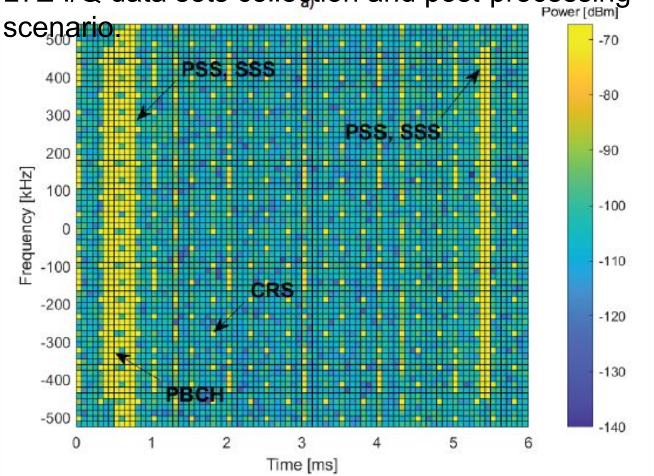




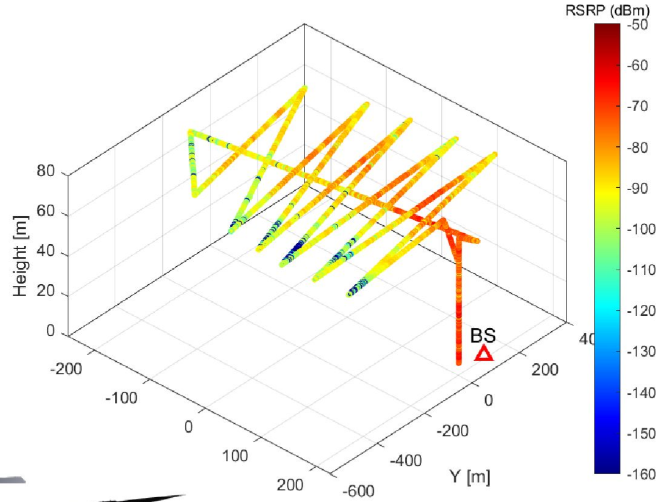
I/Q Data Collection Process (2/2)

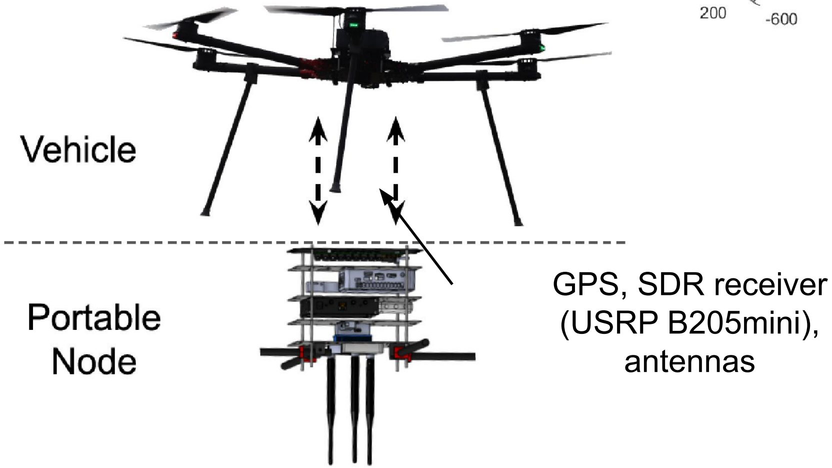


LTE I/Q data sets collection and post-processing scenario.



Received signal power in LTE resource grid of 6 ms duration.





3D Ordinary Kriging (1/4)

- Kriging interpolation (**ordinary** Kriging)
  - ✔ Problem statement: the error of the spatial prediction of an unknown location is minimized

$$\min_{\mu_1,\ldots,\mu_M} \quad \mathbb{E}\left[\left(\hat{r}(l_0^{\text{uav}}) - r(l_0^{\text{uav}})\right)^2\right],$$
$$\text{s.t.} \quad \hat{r}(l_0^{\text{uav}}) = \sum_{i=1}^{M} \mu_i r(l_i^{\text{uav}}),$$
$$\sum_{i=1}^{M} \mu_i = 1,$$

r : received signal strength, l_0^{uav}: unknown location
l_i^{uav}: known location

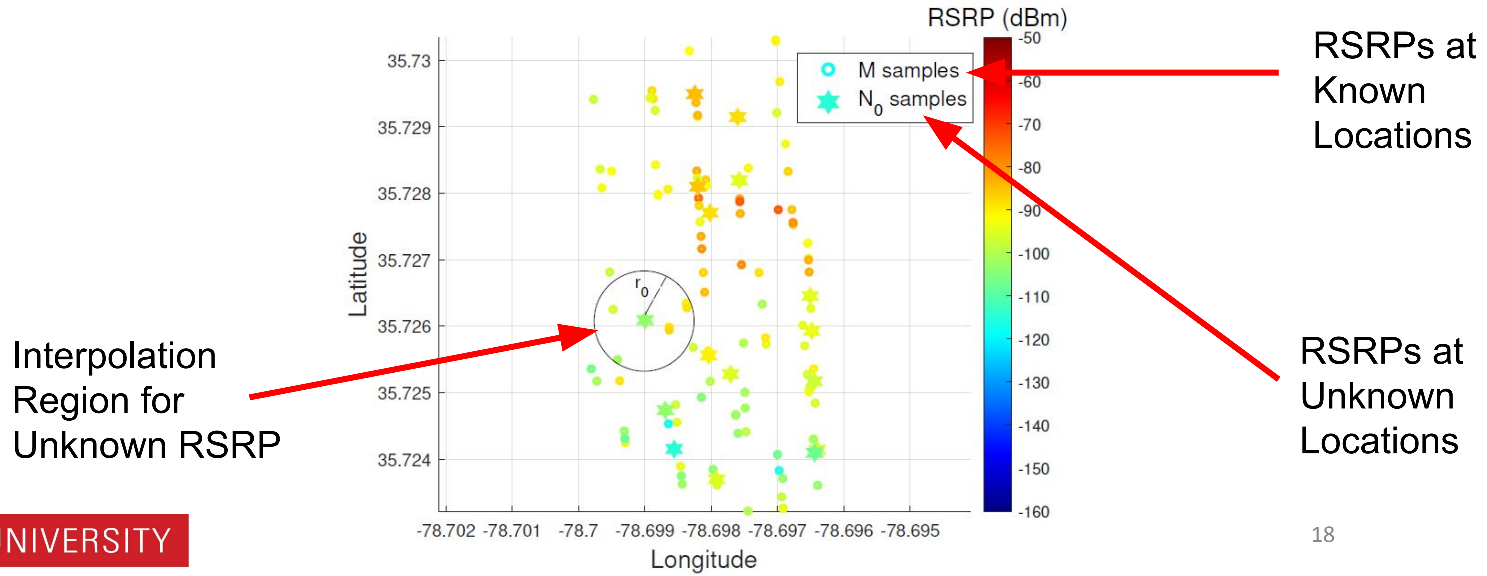
  - ✔ Interpolate the received signal powers of unknown locations by linear combination of the measured locations:

$$\hat{r}(l_0^{\text{uav}}) = \sum_{i=1}^{M} \mu_i^{\star} r(l_i^{\text{uav}})$$

$$\begin{bmatrix} \gamma(l_1^{\text{uav}}, l_1^{\text{uav}}) & \cdots & \gamma(l_1^{\text{uav}}, l_M^{\text{uav}}) & 1 \\ \gamma(l_2^{\text{uav}}, l_1^{\text{uav}}) & \cdots & \gamma(l_2^{\text{uav}}, l_M^{\text{uav}}) & 1 \\ \vdots & \vdots & \vdots & \vdots \\ \gamma(l_M^{\text{uav}}, l_1^{\text{uav}}) & \cdots & \gamma(l_M^{\text{uav}}, l_M^{\text{uav}}) & 1 \\ 1 & \cdots & 1 & 0 \end{bmatrix} \begin{bmatrix} \mu_1 \\ \mu_2 \\ \vdots \\ \mu_M \\ \kappa' \end{bmatrix} = \begin{bmatrix} \gamma(l_0^{\text{uav}}, l_1^{\text{uav}}) \\ \gamma(l_0^{\text{uav}}, l_2^{\text{uav}}) \\ \vdots \\ \gamma(l_0^{\text{uav}}, l_M^{\text{uav}}) \\ 1 \end{bmatrix}$$

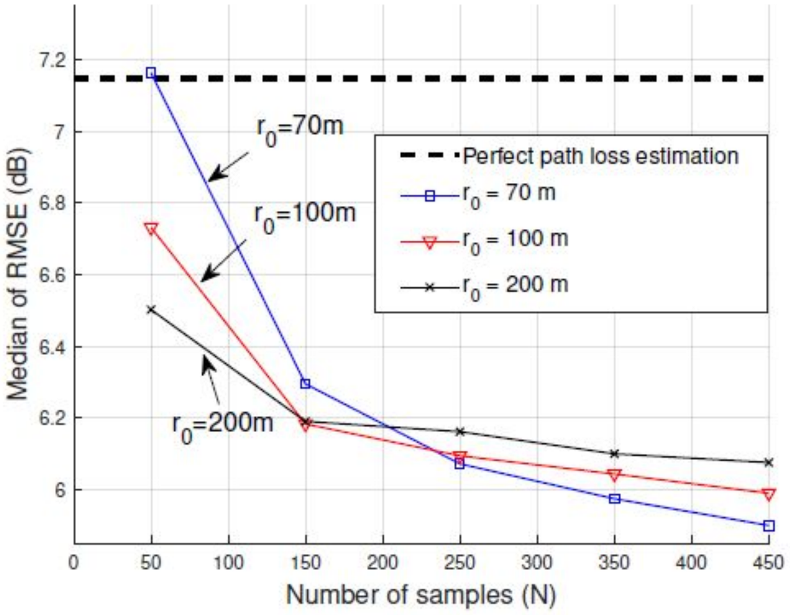
3D Kriging (2/4)

- Simulation setup for 3D Kriging by using real datasets
  - ✔ Cross-validation-based RMSE evaluation
    - ✔ Compares the predicted RSRP with the measured RSRP to observe the error
  - ✔ Predict RSRP of N_0 samples from M samples using samples within r_0 radius circle

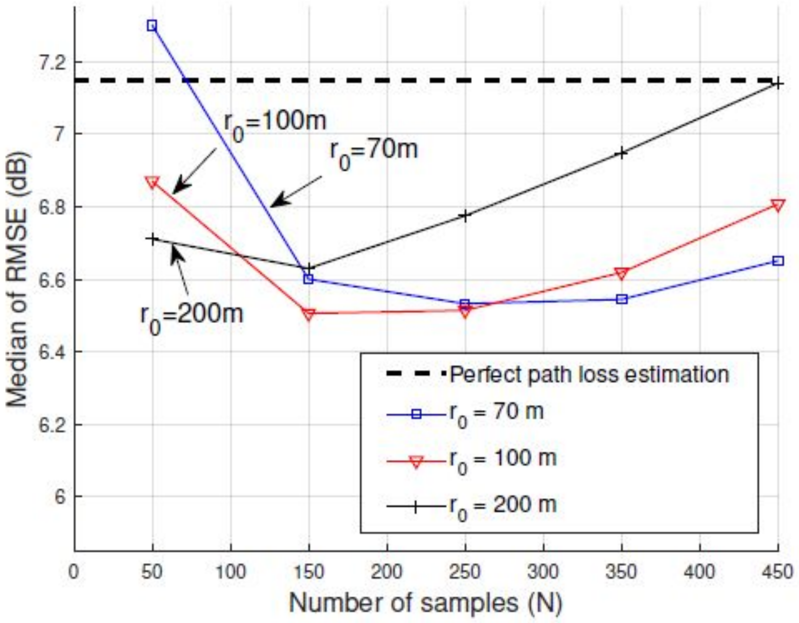


3D Kriging (3/4)

- 3D Kriging performance evaluation
  - ✔ Predict 30 m height from 30 m (a), 50 m (b)
  - ✔ Baseline: perfect path loss estimation (without spatial correlation information)

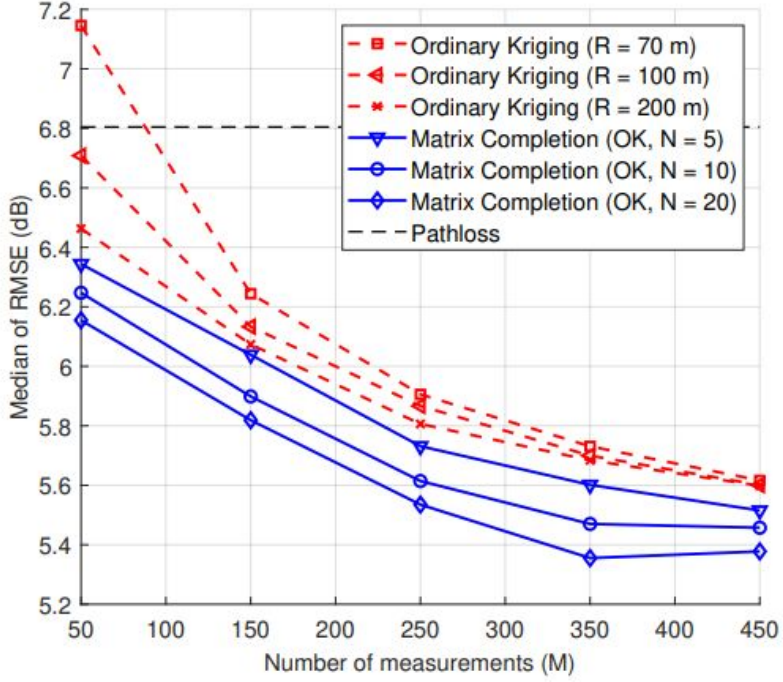


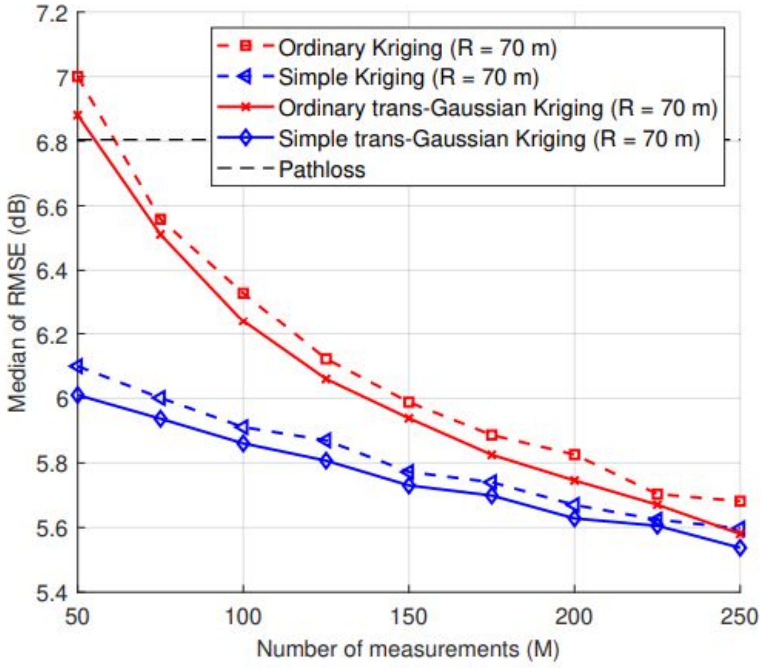
(a) Prediction by 30 m height measurement.



(b) Prediction by 50 m height measurement.

3D Kriging (4/4)



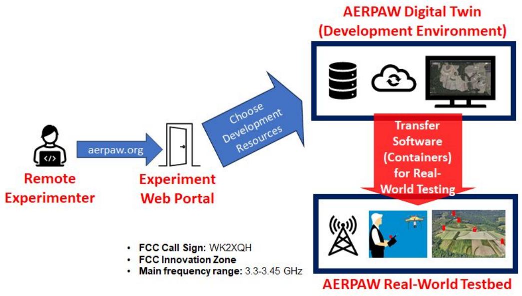


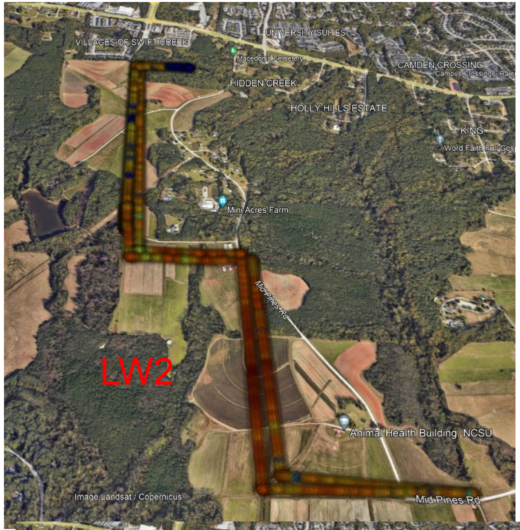
Recent Results (submitted to IEEE DySpan 2024)

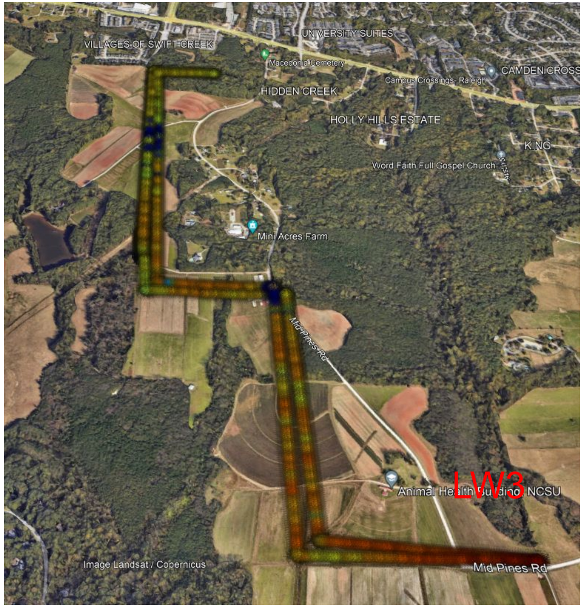
Open Research Problems

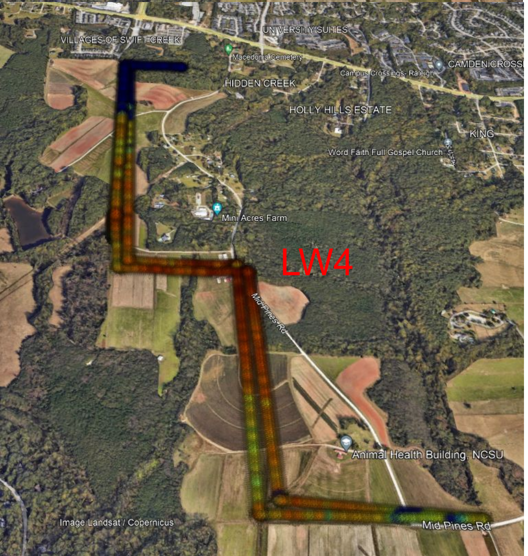
- Spectrum mapping for fixed (towers) and mobile (UEs) signal sources
- Freshness of spectrum information
- Drone orientation, speed, tilt vs. sensing outcome
- Separating different transmission signal sources (e.g. eNBs/gNBs based on PCIs), using Kriging with them
- Use of multiple drones and autonomous trajectory optimization for real-time sensing with mobile transmissions
- “Refining” measurements with periodic flights and limited measurements
- Interference/jammer signal source localization
- Deployment/testing at NSF RDZs

- All can be developed starting at AERPAW digital twin and then moving to testbed



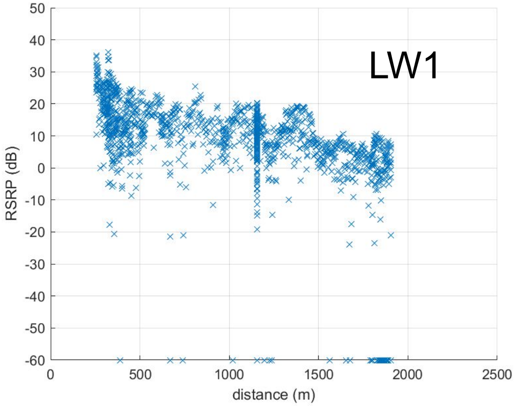


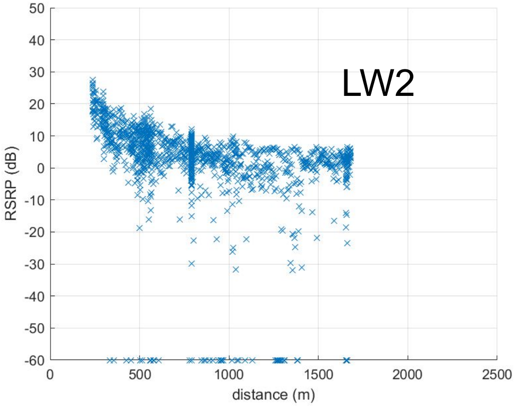


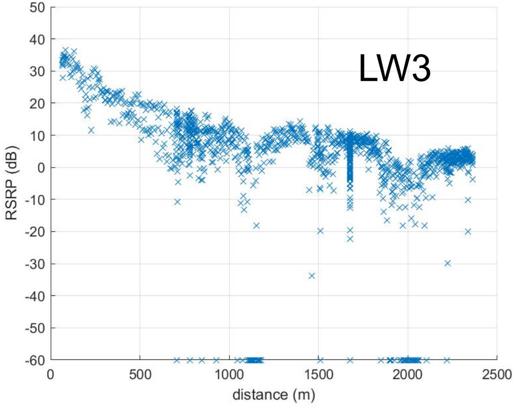


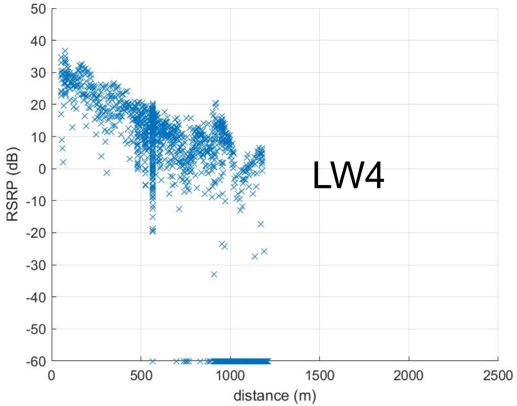
- 5 Fixed Nodes transmitting as LTE eNB (30 ft tower height)
- UAV (USRB B210) flies at 110 m, logs IQ simultaneously from each eNB

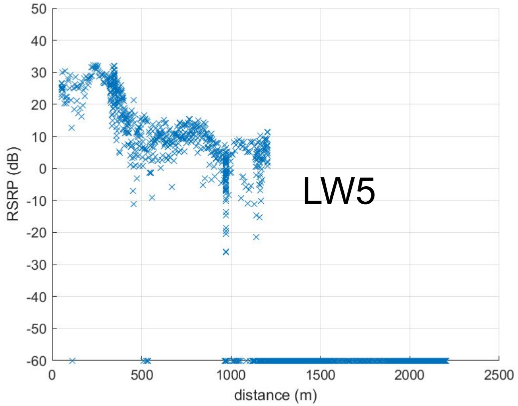
IQ recording and RSRPs at UAV from 5 Fixed Node eNBs*





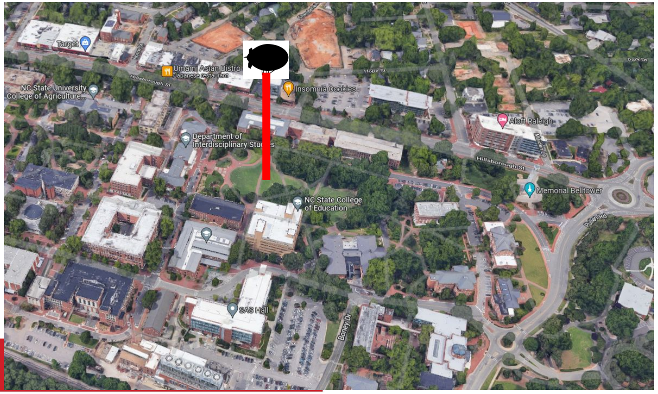




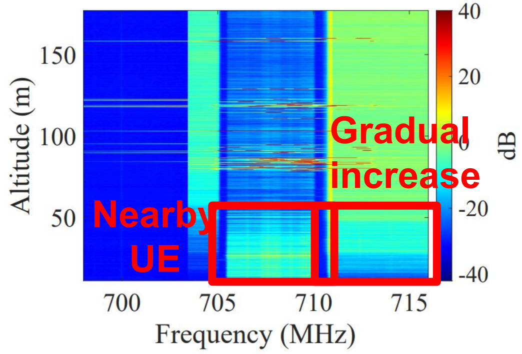


* RSRPs not calibrated

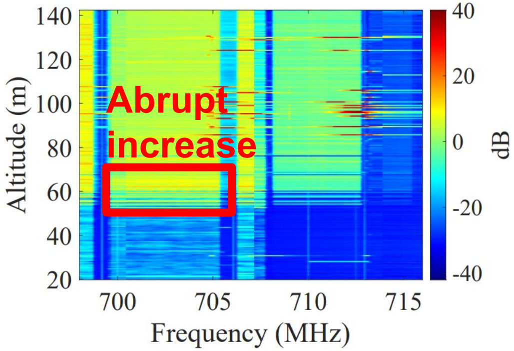
Helikite Measurements During NC State Packapalooza (Aug. 2022, Aug. 2023)



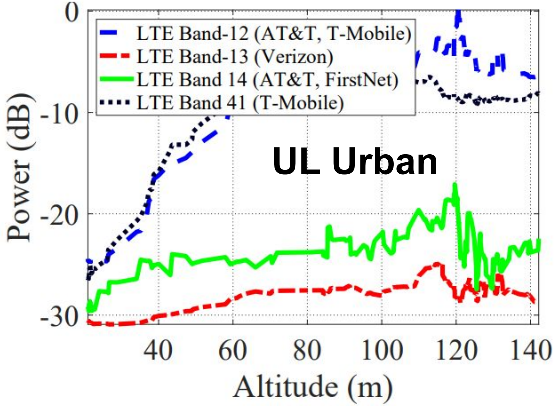
Spectrum Occupancy Measurements and Modeling in Rural & Urban Areas (2)

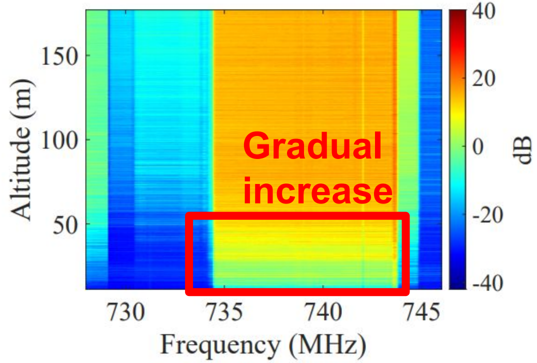


LTE band 12 (UL, Rural)

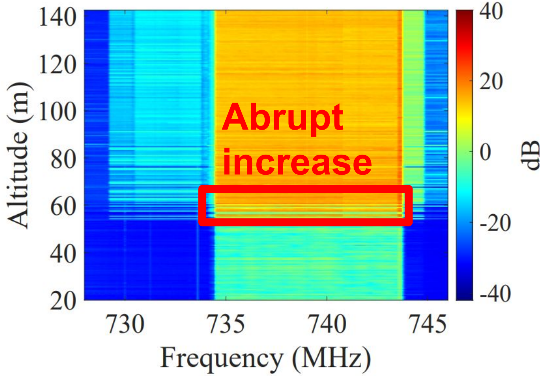


LTE band 12 (UL, Urban)

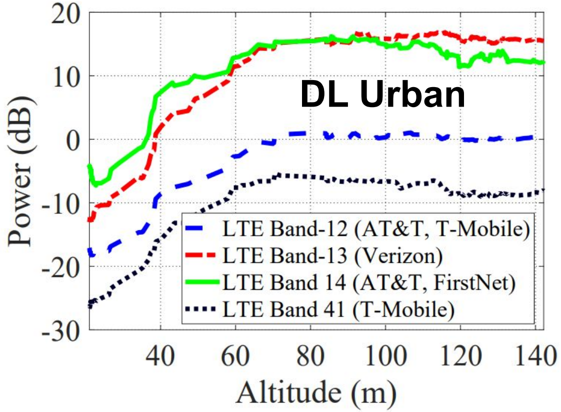




LTE band 12 (DL, Rural)

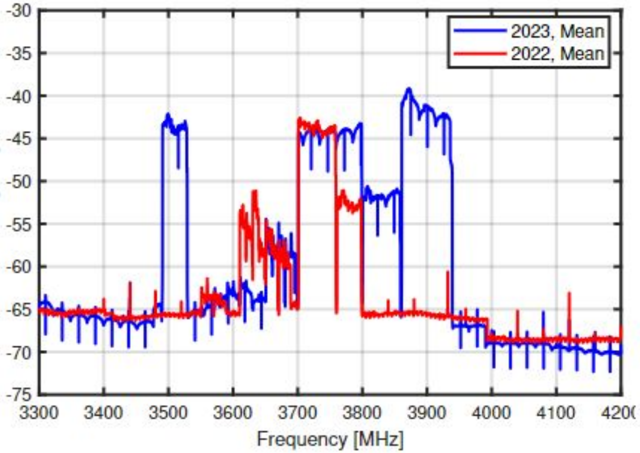


LTE band 12 (DL, Urban)

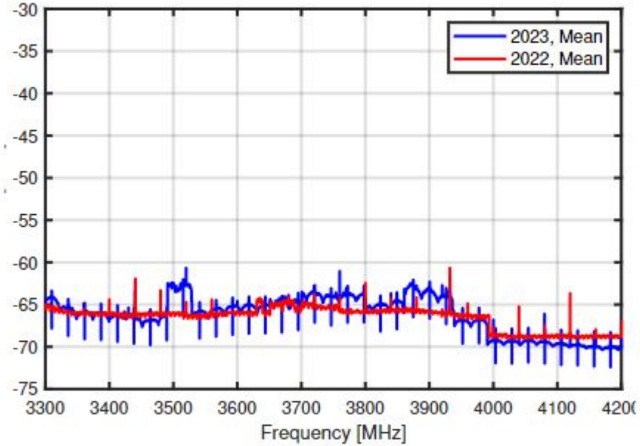


NC STATE UNIVERSITY

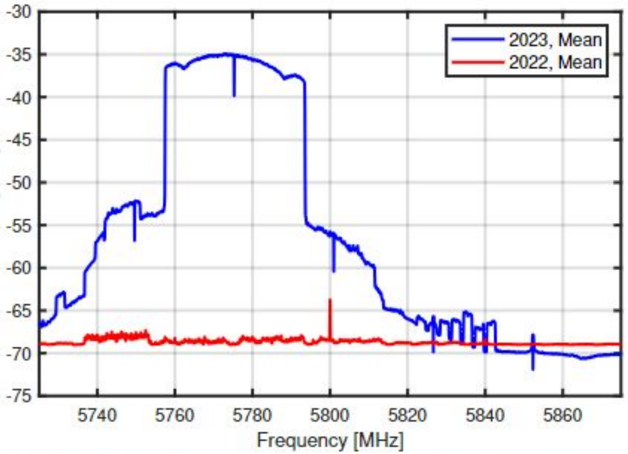
Spectrum Occupancy Comparison in 2022 and 2023 (>50 m and <50m) (submitted to IEEE DySPAN 2024)



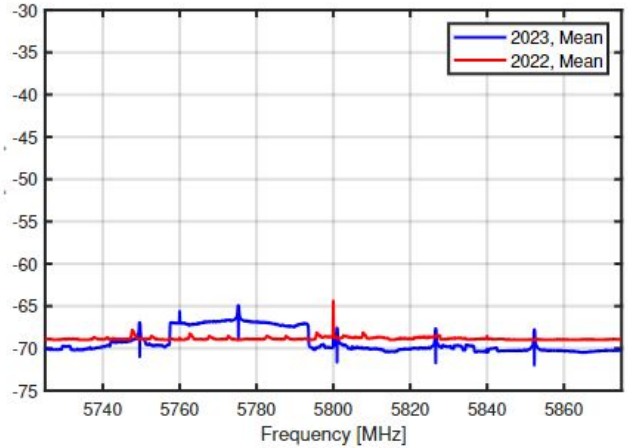
(a) n77 band (3300-4200 MHz), altitude≥ 50 m.



(c) n77 band (3300-4200 MHz), altitude< 50 m.

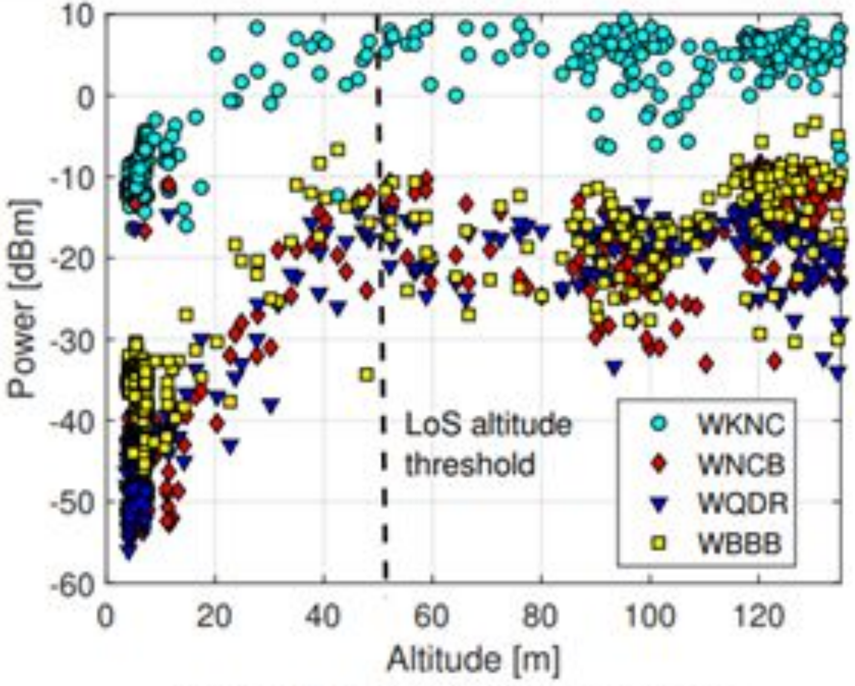


(b) ISM band (5725-5875 MHz), altitude≥ 50 m.

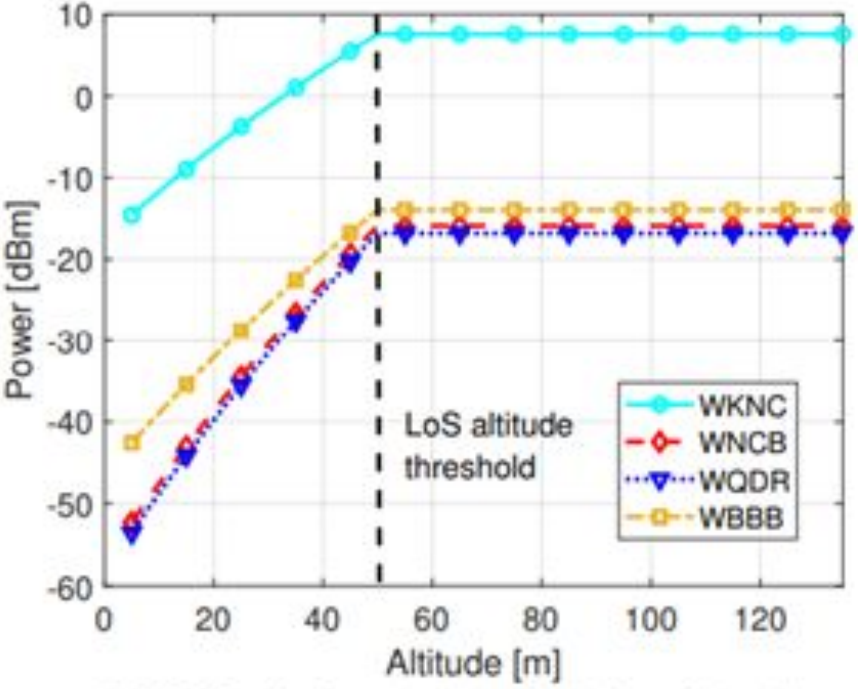


(d) ISM band (5725-5875 MHz), altitude< 50 m.

Received Power Modeling of FM Radio Station Signal vs. Altitude (submitted to IEEE DySPAN 2024)



(a) 2023 Packapalooza (urban) measurement.

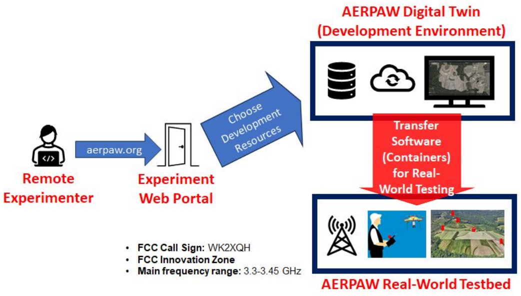


(b) 2023 Packapalooza (urban) analytical results by (1).

Open Research Problems

- Kriging interpolation based on PSD data (with UAV measurements)
- Spectrum occupancy vs. altitude models for various bands
- Uplink vs. downlink modeling using stochastic geometry techniques
- Use of known cellular tower locations, TX powers, etc. (cellmapper.net)
- Modeling probability of LoS in different bands and how it affects spectrum occupancy (using real-world data)
- Developing a realistic digital twin for rural and urban conditions with tactical spectrum sharing
- AI/ML based dynamic spectrum sharing, exploiting time/frequency plane and transmitter/receiver altitude/location

- All can be developed starting at AERPAW digital twin and then moving to testbed



aerpaw.org

Datasets

Dataset Types | Category | Search...

Experimental Study of Outdoor UAV Localization and Tracking Using Passive RF Sensing
Other Experiments by the Team
Udita Bhattacherjee, NC State University

3D Antenna Radiation Pattern Measurement
AERPAW NRDZ Experiments
Sungjoon Maeng, North Carolina State University

August 2022 Helikite Spectrum Measurements (Packapalooza)
AERPAW NRDZ Experiments
Ozgur Ozdemir, North Carolina State University

February 2022: CC1, CC2, LW1 Spectrum Measurements
AERPAW NRDZ Experiments
Ozgur Ozdemir, North Carolina State University

May 2022: Helikite Spectrum Measurements
AERPAW NRDZ Experiments
Ozgur Ozdemir, North Carolina State University

April 2022: LTE I/Q Measurements at Multiple UAV Heights
AERPAW NRDZ Experiments
Ozgur Ozdemir, North Carolina State University

FlyNet Experiments for the AERPAW Testbed
External AERPAW Users
Eric Lyons and Michael Zink, University of Massachusetts - Amherst

60 GHz Radar Measurements using VTT Finland Vehicular Radar
External AERPAW Users
Vasilii Semkin, VTT Finland

CARDINAL RF (CARDRF): An Outdoor UAV/UAS/DRONE RF Signals with Bluetooth and

Drone Remote Controller RF Signal Dataset
Other Experiments by the Team

Publications

2023:

- M. Drago, A. Gurses, R. W. Heath Jr., M. L. Sichitiu, and M. Zorzi, "End-to-end Full-Stack Drone Measurements: A Case Study Using AERPAW," in Proc. IEEE ICC Workshops, May 2023.
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AERPAW

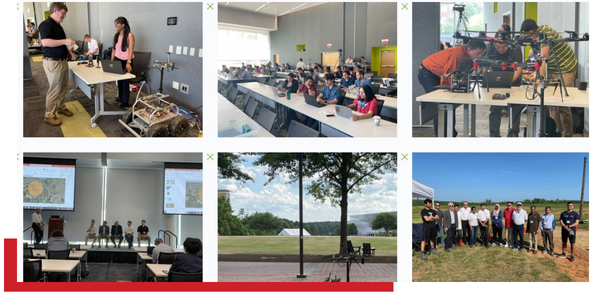
Please log in to gain full access of AERPAW testbed.

AERPAW

AERPAW (Aerial Experimentation and Research Platform for Advanced Wireless) is a $24 million grant, awarded by the PAWR Project Office on behalf of the National Science Foundation, to develop an advanced wireless research platform, led by **North Carolina State University**, in partnership with Wireless Research Center of North Carolina, Mississippi State

AERPAW Community Workshop 2023

The event was successfully completed with over 100 participants attending the 3-day event filled with a panel discussion from industry and government leadership, hand on tutorials for experiments, and a drone demonstration at Lake Wheeler. The entire picture album can be accessed and downloaded from here.



AERPAW User Manual

- AERPAW User Manual
  - 1) AERPAW Overview
  - 2) Experiment Lifecycle Workflows
  - 3) Experiment Structure Overview
  - 4) Sample Experiments Repository
  - 5) Future Platform Features

AERPAW User Manual

Welcome to the AERPAW User Manual website! AERPAW is the first wireless research platform envisioned and built to allow studying the convergence of advanced wireless technologies (such as 5G) and autonomous drones. This User Manual is your one-stop reference as an AERPAW User (an Experimenter, including those with PI roles).

You can access all the individual pages from the navigation bar at the left of the site. Alternatively, you can use the "Search" feature at the top right of the page to search for specific content that is available in the user manual.

AERPAW AFAR Challenge

Call for Participation: AERPAW Autonomous UAV Student Challenge

Challenge #1: AERPAW Find A Rover (AFAR) Challenge

Summary: The AERPAW platform is planning to host a series of autonomous unmanned aerial vehicle (UAV) student competitions. These competitions will require the use of autonomous navigation, wireless communication, and wireless sensing capabilities in the AERPAW platform. The experimenters will be expected to initially develop and test their UAV and radio frequency (RF) software in AERPAW's virtual development (digital twin) environment during the first round of each competition. Selected software from the competitors that satisfy minimum success criteria in the digital twin environment will then be deployed in the real testbed environment, without any modifications, for the second (and final) round of the competition. AERPAW is also planning to organize a number of data challenges which will be based on data posted at https://aerpaw.org/experiments/datasets/.

AERPAW Aerial Experimentation and Research Platform for Advanced Wireless

Office Hours

Starting June 5, 2023, the AERPAW team has been holding online office hours every Monday to provide "one-on-one" help to AERPAW users in using the AERPAW platform. If you wish to join the AERPAW office hours, here are the logistics to schedule a slot.

AERPAW Community Workshop (ACW) 2023: https://aerpaw.org/acw2023/

Contact: aerpaw-contact@ncsu.edu

LinkedIn: https://www.linkedin.com/company/aerpaw/