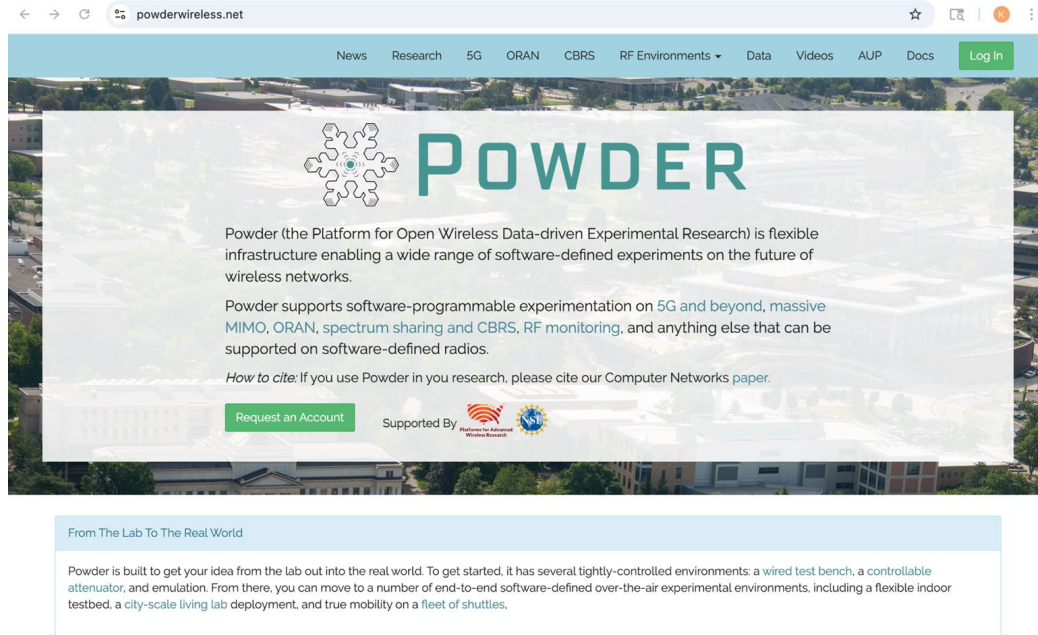


Final POWDER slides
will be dropped here:



<https://tinyurl.com/powder-ens>



The screenshot shows the homepage of the POWDER website. The header includes navigation links for News, Research, 5G, ORAN, CBRS, RF Environments, Data, Videos, AUP, Docs, and a Log In button. The main content area features the POWDER logo and a description: "Powder (the Platform for Open Wireless Data-driven Experimental Research) is flexible infrastructure enabling a wide range of software-defined experiments on the future of wireless networks." It also lists supported technologies: 5G and beyond, massive MIMO, ORAN, spectrum sharing, and CBRS. A "Request an Account" button is present. Below this, a section titled "From The Lab To The Real World" describes various experimental environments supported by POWDER.

PAWR PI Meeting

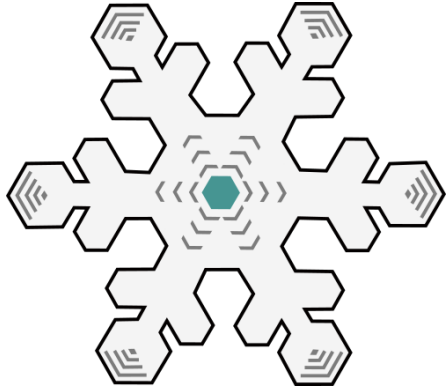
September 2026

Kobus Van der Merwe
kobus.van.der.merwe@utah.edu

NSF awards:

1827940
2232463
2346555
2417934

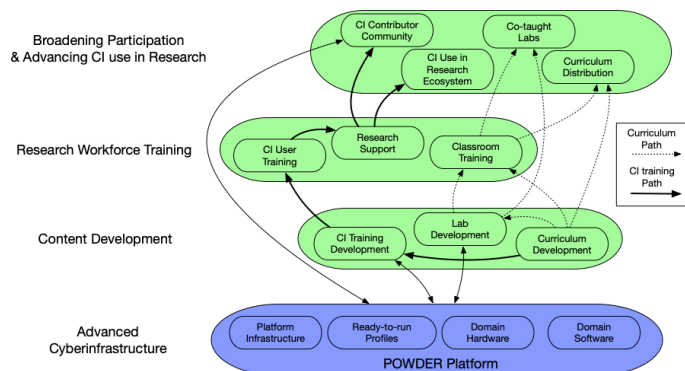
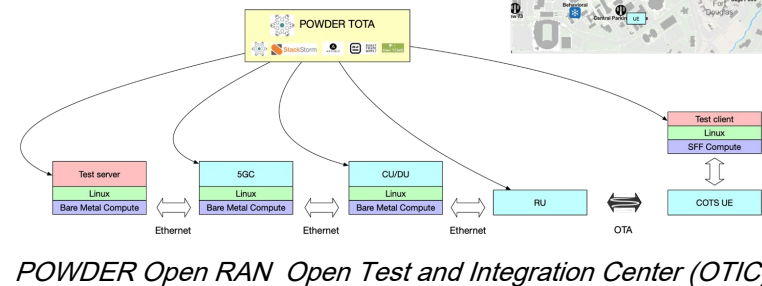
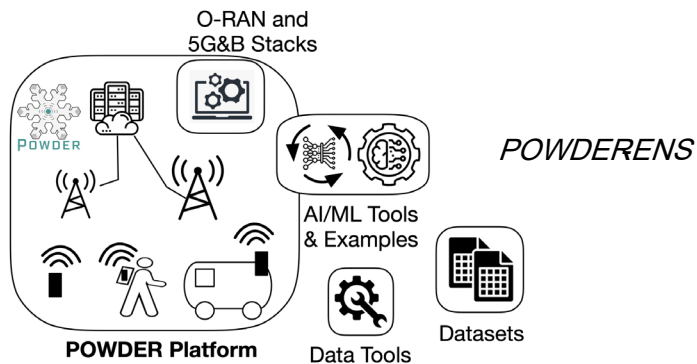




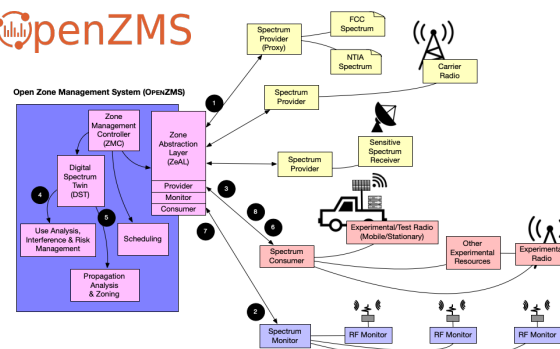
POWDER Ecosystem



The POWDER Ecosystem



CyberPowder - Wireless Networking Workforce Development



POWDER Radio Dynamic Zone (RDZ)



NSF awards:
1827940
2232463
2346555
2417934

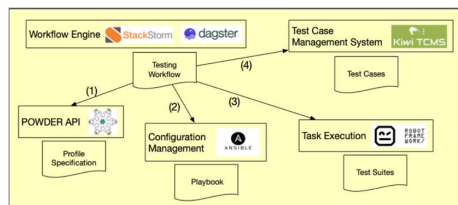




POWDER OTIC



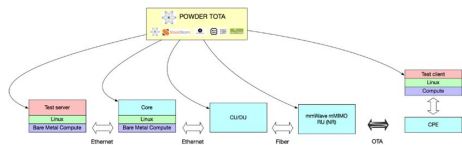
POWDER OTIC



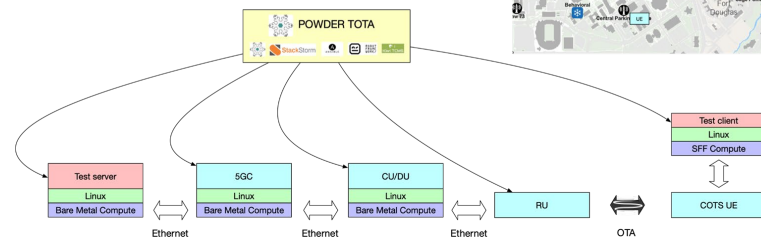
Sophisticated 5G/NextG/Open RAN testing environment

- O-RAN Alliance **Open Test and Integration Center (OTIC)**
- Open RAN & 5G/NextG related testing
 - E2E and functional testing
- Developed Testing Orchestration & Testing Automation (TOTA) framework
 - Integrates with POWDER to "orchestrate" test setup
 - Interact with commercial/open source tools to "automate" testing

Focus on over-the-air (OTA) and automation



Focus on over-the-air testing and automation



POWDER Open RAN Open Test and Integration Center (OTIC)

Over the Air Evaluation of Jamming Detection & Mitigation using OCUDU

Goal:

- Over the Air evaluation of jamming detection and mitigation methods for 5G/6G networks
- Unlock the potential of open source OCUDU RAN for network resiliency
- Generate realistic training and test datasets for AI/ML-driven detection & mitigation

Next steps:

- Real-time jamming detection & mitigation based on RAN metrics exposed by OCUDU
- Near real-time AI/ML-based jamming detection in the OTA scenario
- Dynamic AI/ML-based MCS adaptation in response to detected jamming
- Closed-loop detection and mitigation using OCUDU and POWDER network

POWDER testbed:

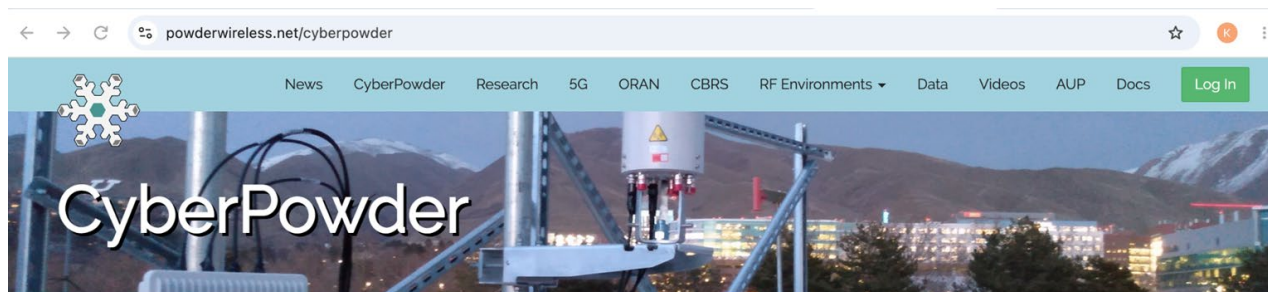
- Real 5G/O-RAN setup deployed on POWDER
 - OCUDU gNB + commercial UE for the 5G connection
 - SDR-based interference generator for controlled jamming
 - RAN and RF measurements collected during experiment
- What do we use it for?**
- Create controlled jamming scenarios
 - Measure the impact of CQI, MCS, NACKs, RSRP, etc. on OCUDU-based RAN
 - Build dataset covering different interference levels and network conditions
 - Deploy, train and evaluate the Jamming Detection & Mitigation using OCUDU





CyberPowder - Wireless Network Workforce Development

Accepting applications for
2027 CyberPowder Fellows Program



UPDATE: CyberPowder Fellows Program for Spring 2027

We are accepting applications for the CyberPowder Fellows Program for Spring 2027!!

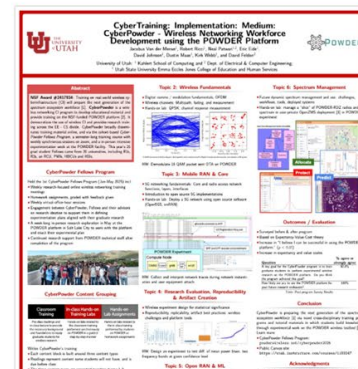
More details at <https://www.powderwireless.net/cyberpowder2027>

Applications are due by November 13th 2026.

CyberPowder Overview

CyberPowder is a project funded (grant #: 2417934) by the [NSF CyberTraining](#) program in the Office of Advanced Cyberinfrastructure (OAC) in the Directorate for Computer and Information Science and Engineering (CISE).

CyberPowder develops wireless networking content and training material for both classroom teaching and hands-on cyberinfrastructure training. Classroom teaching focuses on developing and teaching curricula that address the inherent multi-disciplinary nature of wireless networking by co-teaching



<https://www.powderwireless.net/cyberpowder>

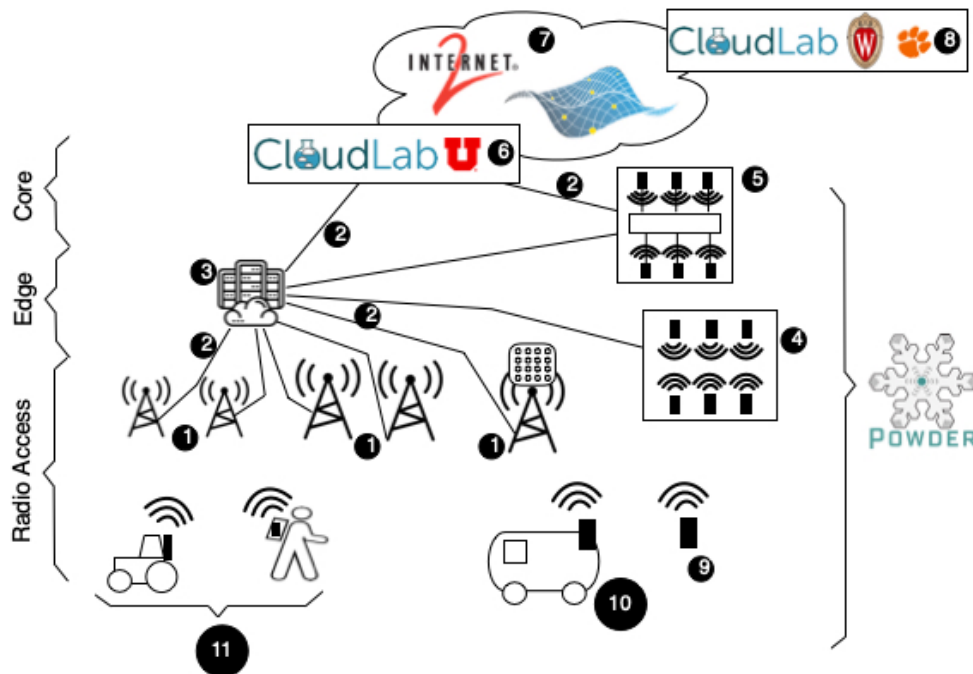




POWDER platform overview



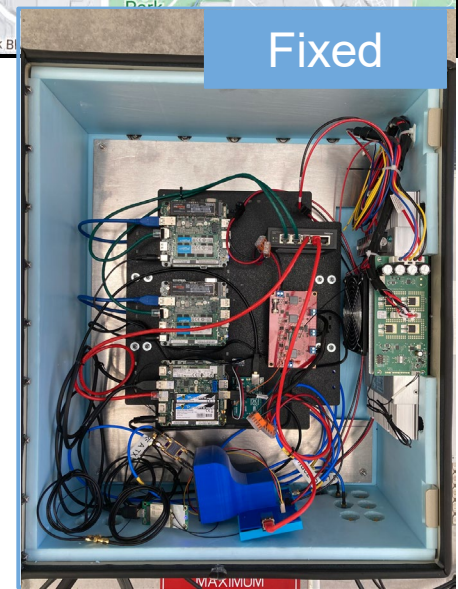
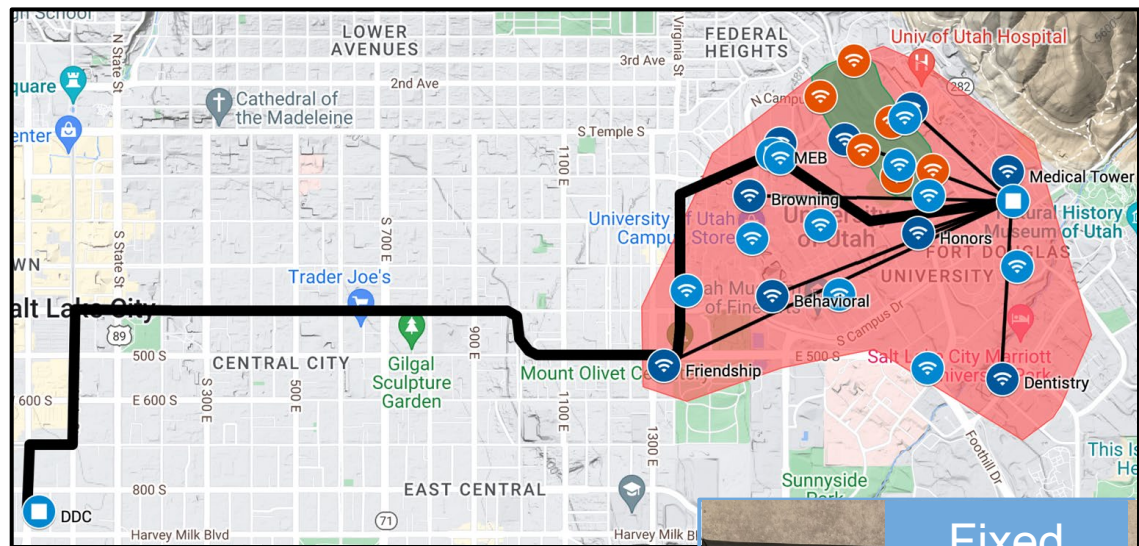
POWDER Platform

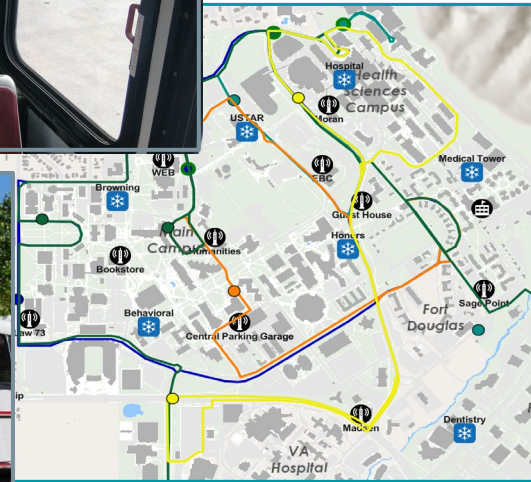
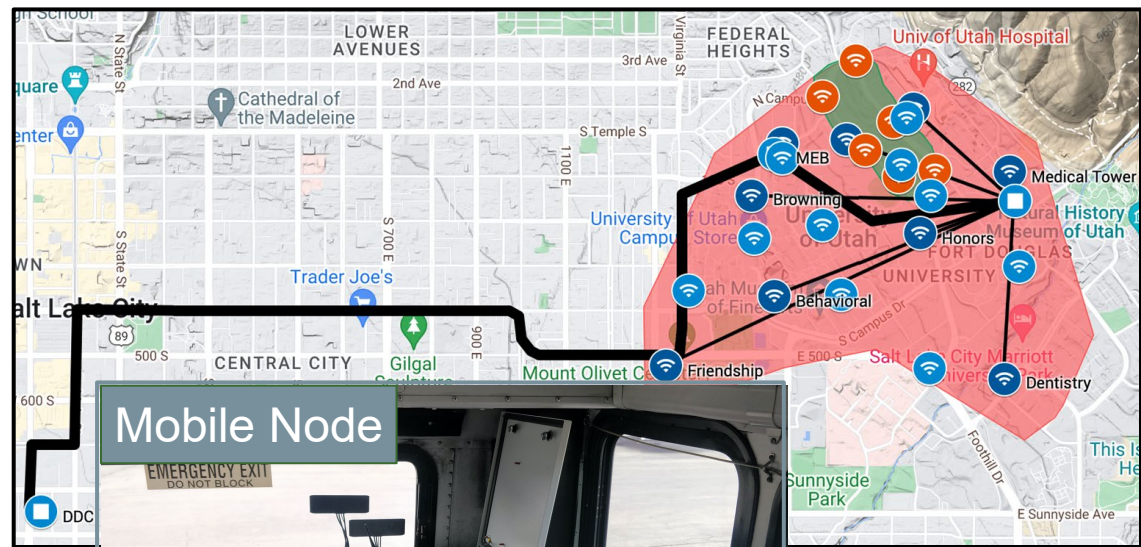


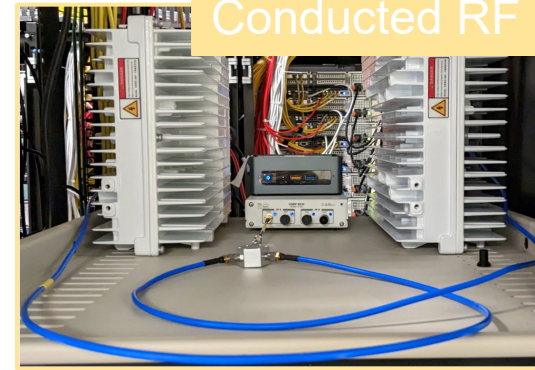
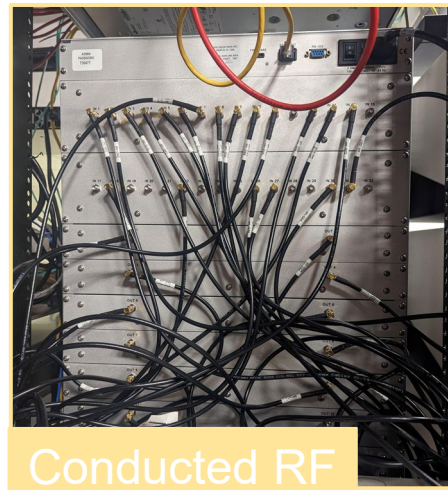
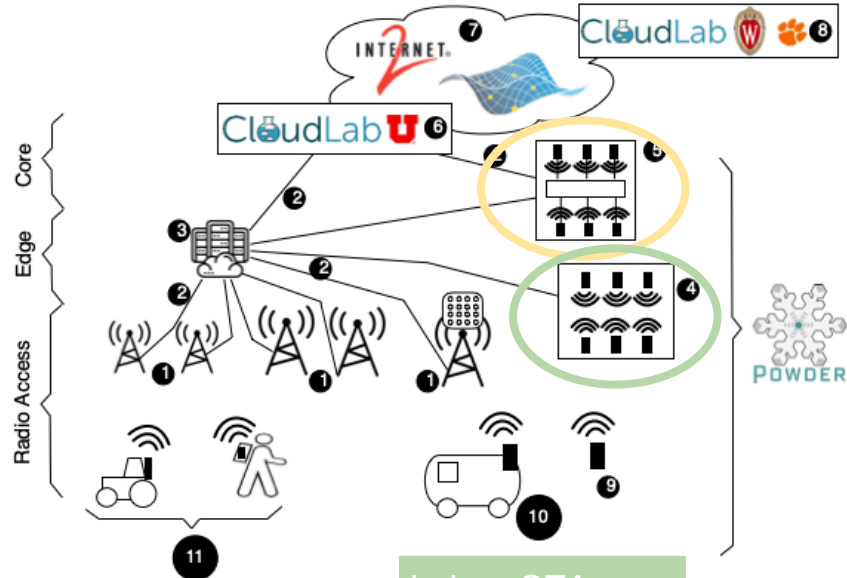
- Remotely accessible research infrastructure for mobile and wireless research
- Used for fundamental research (academic/non-academic) & testing/development & teaching
- Key features:
 - Variety of **hardware building blocks** - deployed in lab & outdoors
 - Variety of compatible **ready-to-run open source software stacks**
 - Sophisticated experimental control framework/experimental workflow
 - FCC Innovation Zone
 - BYOD/BYOS capabilities

Highly flexible real -world lab -as-a-service

(1) Basestation (rooftop, mMIMO, dense), (2) Fiber front/backhaul, (3) Near Edge Compute, (4) Indoor OTA Lab, (5) Controlled RF Lab, (6) Edge/Metro Compute, (7) WAN connectivity, (8) Remote cloud, (9) Fixed Endpoint, (10) Predictable courier w/ endpoint, (11) Other courier w/endpoint

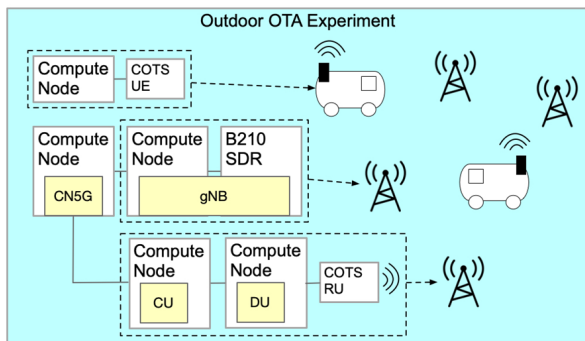
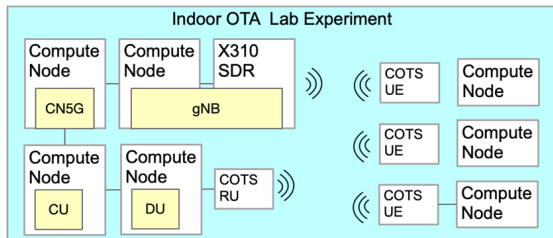
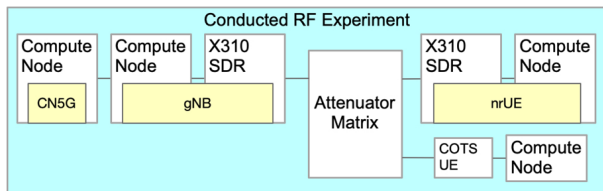
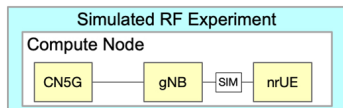








Remote out-of-band access to all resources



Transition smoothly from simulated RF to controlled RF to over-the-air transmission within the same platform.

Remotely accessible real world lab-as-a-service

- Combining software and hardware **building blocks** into sophisticated wireless experiments
 - Packaged as parameterized ready-to-run **profiles**
- 5G/NextG & O-RAN open source stacks with example use-cases and applications
 - POWDER-ENS focus:
 - Data + AI/ML



5G/NextG profile support, maintenance

- OAI and Open5GS core networks (latest versions)
- OAI and srsRAN/OCUDU 5G SA mode (recent and latest versions)
 - Simulated, conducted RF, indoor/outdoor OTA environments
 - COTS O-RUs/UEs and SDRs in all environments
 - Mobile SDR (no RF front end) and COTS UE endpoints outdoors
 - SDRs (srsRAN) + C-band RF front ends outdoors
 - Profiles covering HO, interference scenarios, O-RAN xApps, etc.
 - Conducted RF environment allows emulating HO conditions
- O-RAN 7.2 split RU integrations
 - Benetel indoor/outdoor/conducted O-RUs + OCUDU/OAI
 - VVDN/Amplitech indoor/outdoor/conducted O-RUs + OCUDU
- NVIDIA Aerial
 - NVIDIA Aerial CUDA-Accelerated RAN (ACAR) for L1 and integrates with Duranta/OpenAirInterface (OAI) Software Alliance L2
 - Benetel RAN650 O-RUs (tested in conducted RF (attenuator matrix))





POWDER Radios

VVDN MPRU - outdoor rooftop	2	2 more to be deployed by Oct. (dense sites) + 4 more by Spring 2027
Benetel RAN650 - outdoor rooftop	2	Overlapping coverage for handover
NI N310 - outdoor rooftop	2	Version 1.1 RF frontend; 8 more by Z
NI X310 - outdoor rooftop	8	N310s w/ v1.1 RFFE are displacing most of these
Quectel RM520N-GL - outdoor/dense	2	@ USTAR rooftop and dense sites
NI B210 - outdoor dense deployment	6	Version 1.0 RF frontend
NI B210 - fixed endpoint	20	Deployed at all FE sites w/ companion compute
Quectel RM520N-GL - fixed endpoint	10	Deployed at all FE sites w/ companion compute
NI B210 - mobile endpoint (shuttle)	20	Deployed to all ME shuttles w/ companion compute
Quectel RM520N-GL - mobile (shuttle)	20	Deployed to all ME shuttles w/ companion compute
NI B210 - indoor OTA lab	4	Hosted by companion Intel NUC SFF compute
NI X310 - indoor OTA lab	4	
Benetel RAN550 - indoor OTA lab	2	
Quectel RM520N-GL - indoor OTA lab	4	Hosted by companion Intel NUC SFF compute
Benetel RAN650 - RF matrix	2	
VVDN MPRU - RF matrix	2	
NI B210 - RF matrix	4	Hosted by companion Intel NUC SFF compute
NI X310 - RF matrix	1	
NI N300 - RF matrix	2	
Quectel RM520N-GL UE - RF matrix	5	Hosted by companion Intel NUC SFF compute
NI X310 - paired workbench	4	Connected in pairs via conducted RF w/ fixed atten.
NI X410 - paired workbench	2	Connected via conducted RF w/ fixed atten.

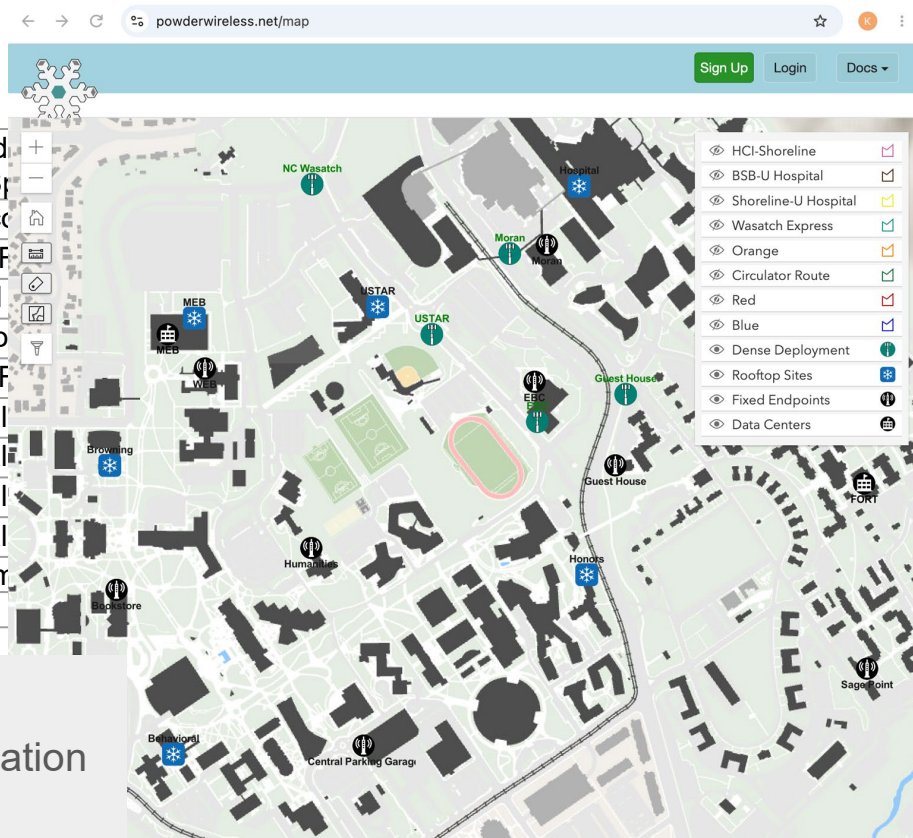


POWDER Radios

VVDN MPRU - outdoor rooftop	2	2 more to be d + 4 more by Sp
Benetel RAN650 - outdoor rooftop	2	Overlapping co
NI N310 - outdoor rooftop	2	Version 1.1 RF
NI X310 - outdoor rooftop	8	N310s w/ v1.1
Quectel RM520N-GL - outdoor/dense	2	@ USTAR roo
NI B210 - outdoor dense deployment	6	Version 1.0 RF
NI B210 - fixed endpoint	20	Deployed at al
Quectel RM520N-GL - fixed endpoint	10	Deployed at al
NI B210 - mobile endpoint (shuttle)	20	Deployed to al
Quectel RM520N-GL - mobile (shuttle)	20	Deployed to al
NI B210 - indoor OTA lab	4	Hosted by com
NI X310 - indoor OTA lab	4	
Benetel RAN550 - indoor OTA lab	2	

Various options... and capabilities/limitations

- Updated [Using radios on POWDER](#) documentation
- And/or ask for help...
 - [POWDER users mailing list](#)
 - Email to powder-support@powderwireless.net
 - Sign up for POWDER [virtual office hours](#)



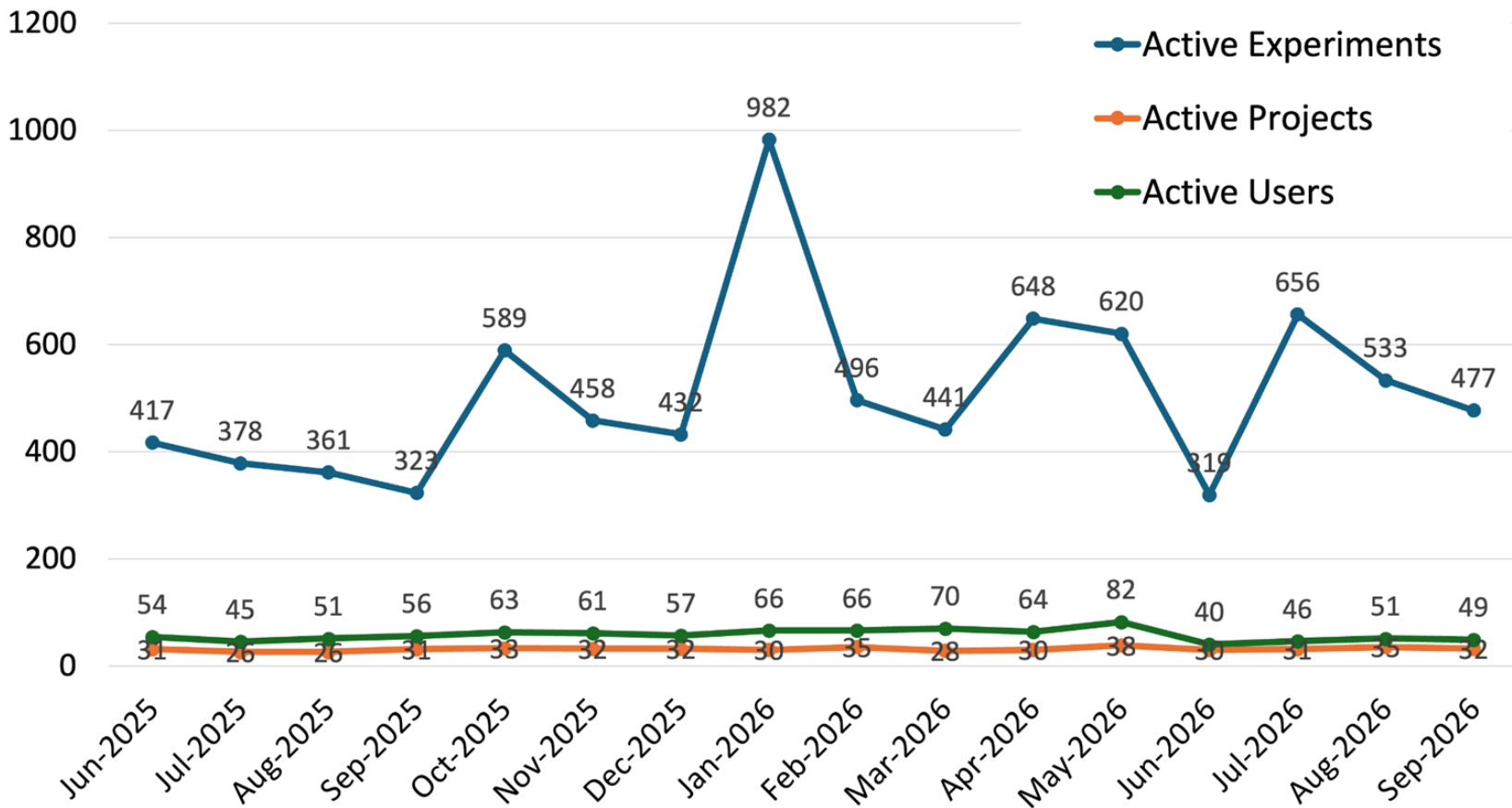
Intel NUC SFF compute
conducted RF w/ fixed atten.
ed RF w/ fixed atten.



POWDER user statistics



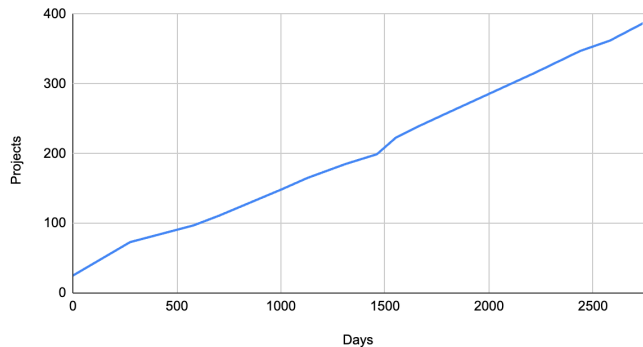
POWDER Use by Month



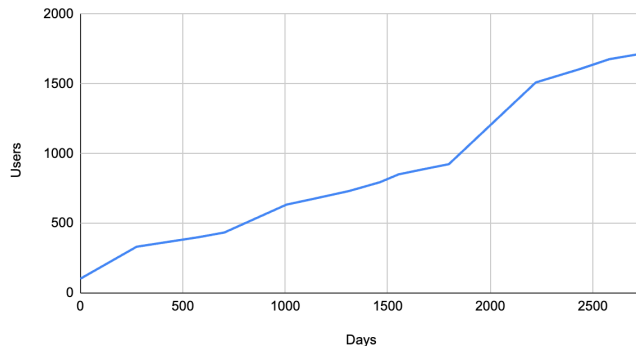


Totals (projects, users, experiments, papers) since March 2019

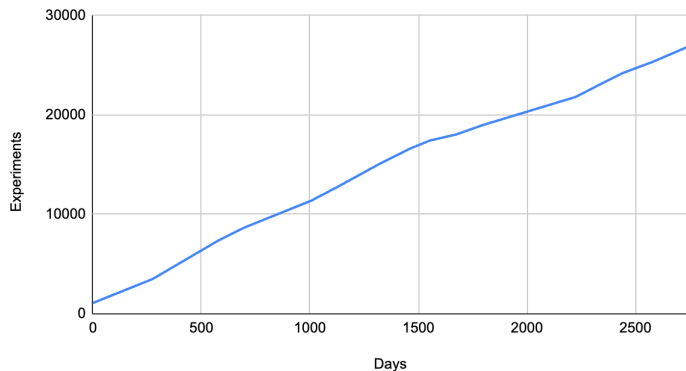
Number of Projects vs. Days (since March 2019)



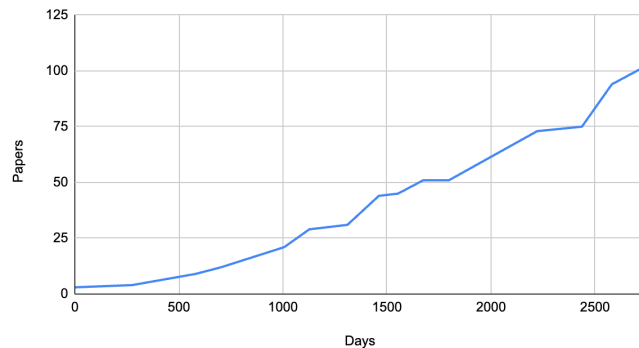
Number of Users vs. Days (since March 2019)



Number of Experiments vs. Days (since March 2019)



Number of Papers vs. Days (since March 2019)





New updates



POWDER Enhancements - Experiments using COTS O-RUs

- Users are now able to allocate and work with **POWDER COTS O-RU devices**
 - Full automated E2E setup, including 5G Core, O-CU/DU (OCUDU), COTS O-RU(s), and UE devices
 - Selectable from one profile: Conducted RF matrix, Indoor OTA Lab, or outdoor OTA
 - All existing POWDER O-RU devices supported (models from Benetel and VVDN)
 - ***User-customizable setup via profile parameters, and changes to O-CU/DU software and/or configuration***
 - KPI logging (events: attach, detach, handover; channel quality; etc.)
- Future enhancements
 - Extend to SDR-based O-RUs (augmented with POWDER's new v1.1 RFFE)s
 - Split 8, until O-RU split 7.2x effort comes to fruition in OCUDU
 - Inclusion of mobile UE devices in E2E outdoor COTS O-RU setup
 - Currently operates with fixed location UEs; mobile UEs possible with separate profile.
 - API/UI-driven dynamic modification of O-CU/DU/RU configuration in a running experiment
 - Manual O-CU/DU configuration changes (or user-automated) are already possible

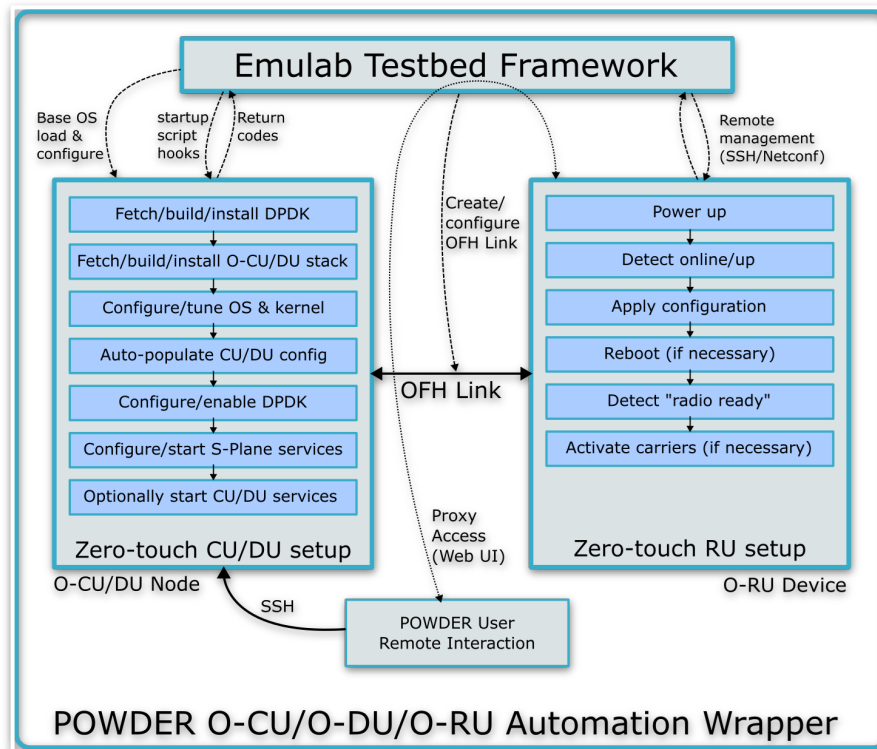




Platform Enhancements - O-CU/DU/RU setup automation

POWDER automatically provisions and configures key O-RAN O-CU/DU/RU components

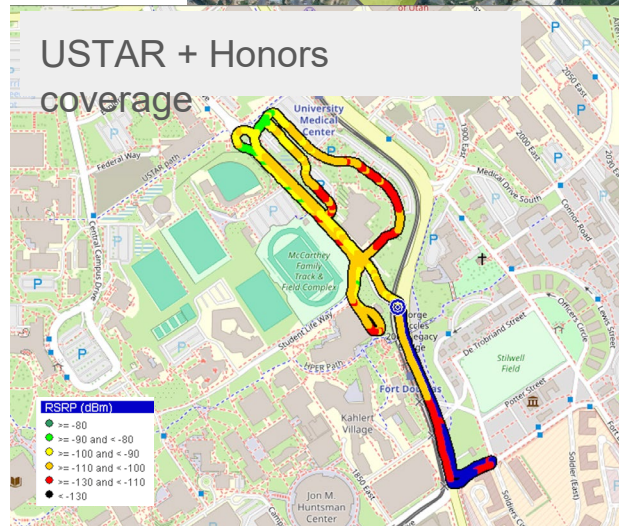
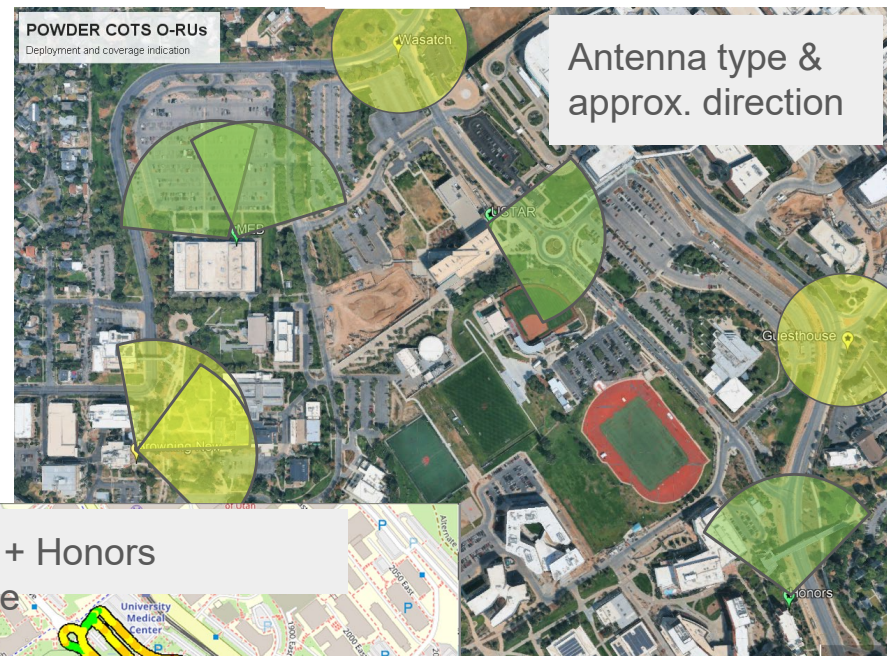
- Profile API updates to support O-RAN
 - Configuration flows from profile to POWDER database and expt manifest, to experiment devices/elements (O-CU/DU/RU)
- O-CU/DU configuration
 - Supports current/latest srsRAN and OCUDU versions
 - Profile inputs substituted into macro-ized config templates
 - Supports many-to-one association RU to DU
 - Sets key parameters: RU details, bandwidth, center freq...
 - Automated DPDK setup
 - Will be extended to support Open Air Interface / Duranta
- O-RU configuration
 - Integrated into POWDER's control framework
 - Supports Benetel and VVDN devices
 - Sets key parameters: bandwidth, center frequency (ARFCN), DU identifiers and assignments, network interface configuration, MIMO modes, and more





POWDER COTS O-RU outdoor deployment status

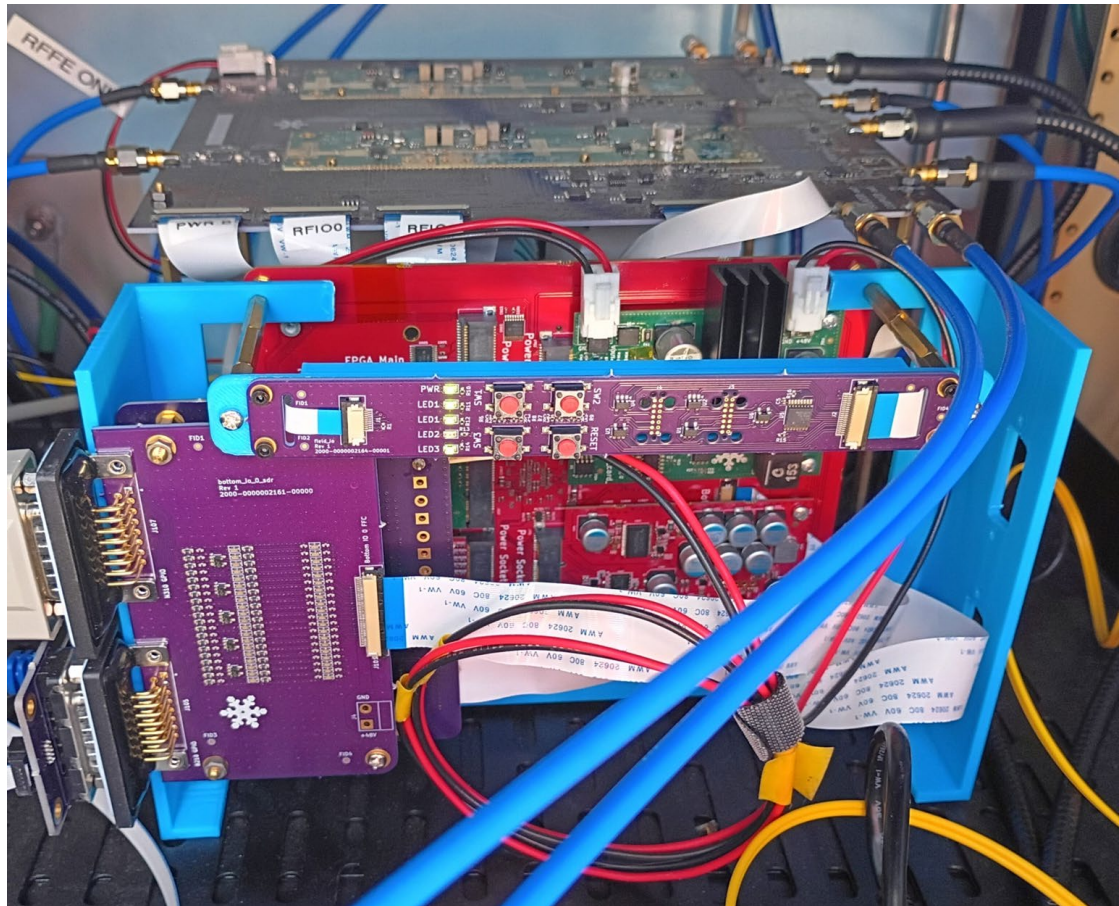
- Current
 - 2 x Benetel RAN650 on MEB
 - 2 x VVDN MPRU on USTAR and Honors
- Pending / planned
 - 1 VVDN @ Wasatch Dense Site (Oct.)
 - 1 VVDN @ GH Dense Site (Oct.)
 - 4 VVDN @ Browning Rooftop (Winter)
 - Directional antennas
 - Guesthouse & Mario Sites
 - Winter/Spring 2027





New RF FE: Overview

- 3.3-3.7 GHz RFFE v1.1
 - 2x2 MIMO
 - Improved output power
 - Filtering
 - Calibration
- System Modularity
 - Replace frontend and keep all the rest, e.g. for new frequency bands
 - Reduced cost to change
- Deployment
 - Deployed on MEB and Browning
 - Other rooftop nodes by Spring 2027

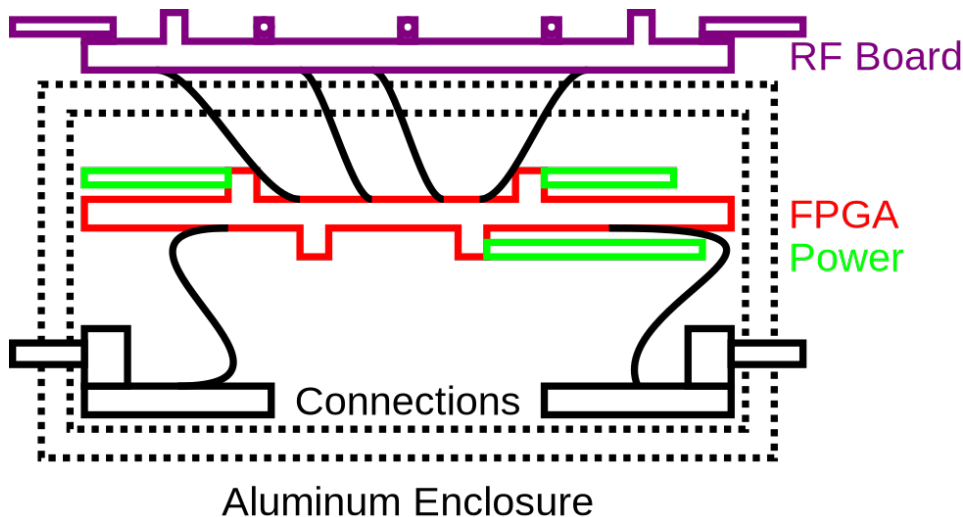




New RF FE: System Modularity

- System Modularity

- Easy to replace RF frontend and keep all the rest
 - Interface to SDRs
 - Power (variable voltage/current)
 - FPGA
 - Ethernet
- Power boards
 - Variable voltage/current for PA and LNA
 - Overcurrent protection built in
- FPGA running a RISC-V core with FreeRTOS
 - Ethernet communication
 - MQTT metrics for debugging and maintenance





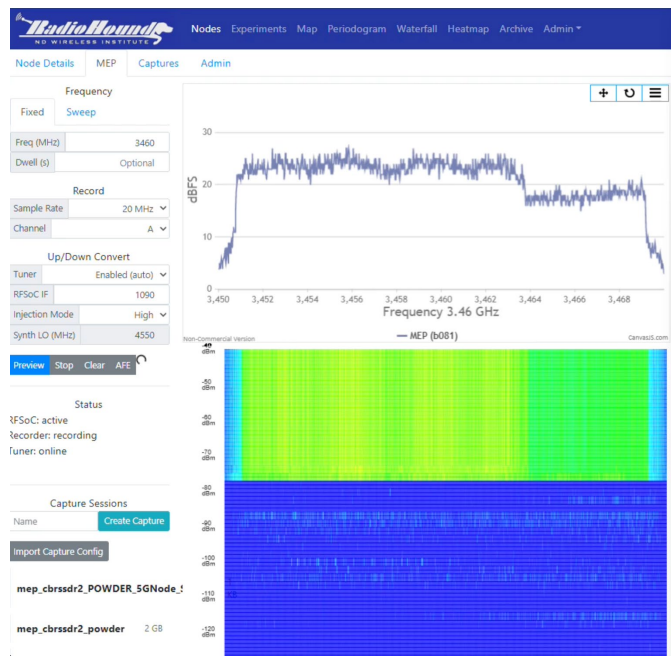
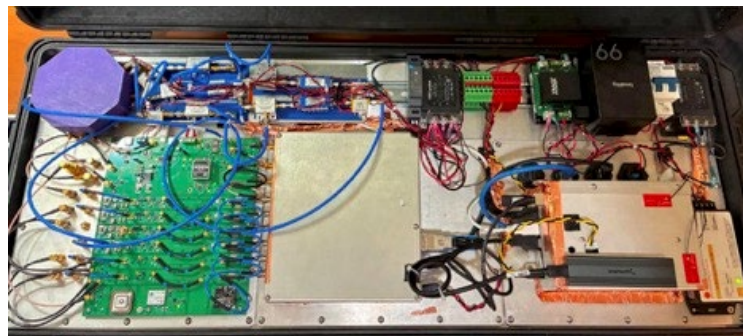
New RF FE: Profiles

- [SDR-outdoor-srsRAN](#)
 - srsRAN + *Frontend GPIO patches* + other SDR improvement patches
 - *Upgrade to OCUDU in progress*
 - Open5GS core
 - Docker containers for data-network (DN) experiment applications
- [quectel-UE](#)
 - Sets up a COTS UE
 - Provides control/UE network separation
 - Docker containers for User Equipment (UE) experiment applications
- [SDR-outdoor-GNURadio](#)
 - Basic profile for outdoor radios
 - Has GNURadio and UHD with patches for frontends
 - ***General waveform experimentation***



Used by SpectrumX

- Deployed SpectrumX Mobile Experimentation Platform (MEP):
 - BYOD device on POWDER
- Used SDR + new RF FE:
 - Played out MATLAB generated waveforms
 - Monitored/recorded using SpectrumX RadioHound





OCUDU PHY TAP experiments

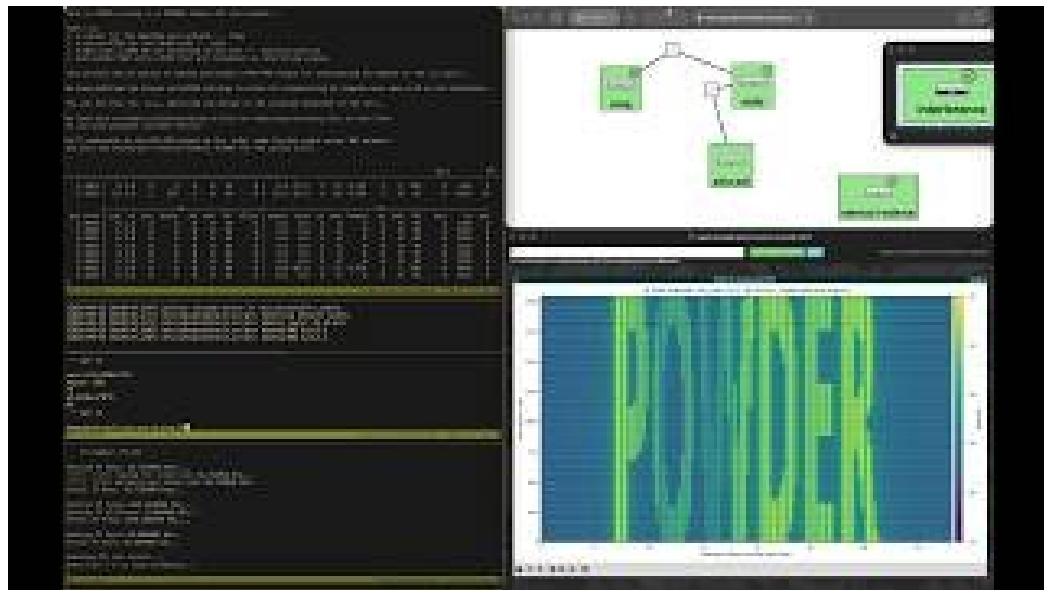


OCUDU PHY TAP experiment - indoor

- Try out [OCUDU PHY TAP](#) in real world setting ([profile link](#))
 - Indoor over-the-air
 - O-RAN 7.2a tap + **SDR RU**
 - PHY TAP to extract IQ samples
- Setup
 - X310 SDR RU + COTS Handset
 - OCUDU version 26/04 + Open5GS
 - B210 acting as interferer
- Experiment
 - Modified plugin and OCUDU settings:
 - Broadcast UL samples even when UE not scheduled
 - Subscribe to PHY TAP
 - Plot energy-per-resource-element (EPRE) for uplink

IQ samples at upper PHY:

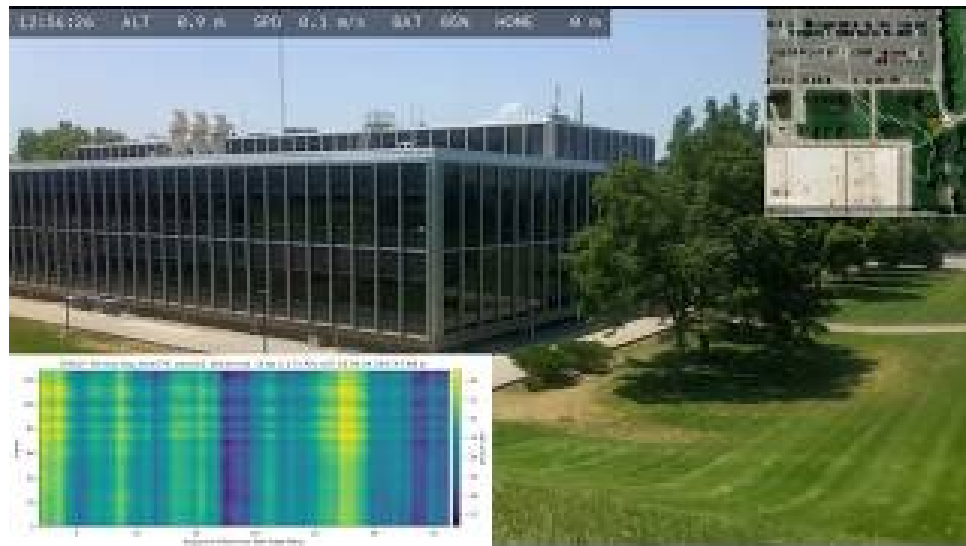
- After RF FE and FFT
- Before OCUDU channel estimation and decoding
- Access to resource grid on every slot





OCUDU PHY TAP experiment - outdoor

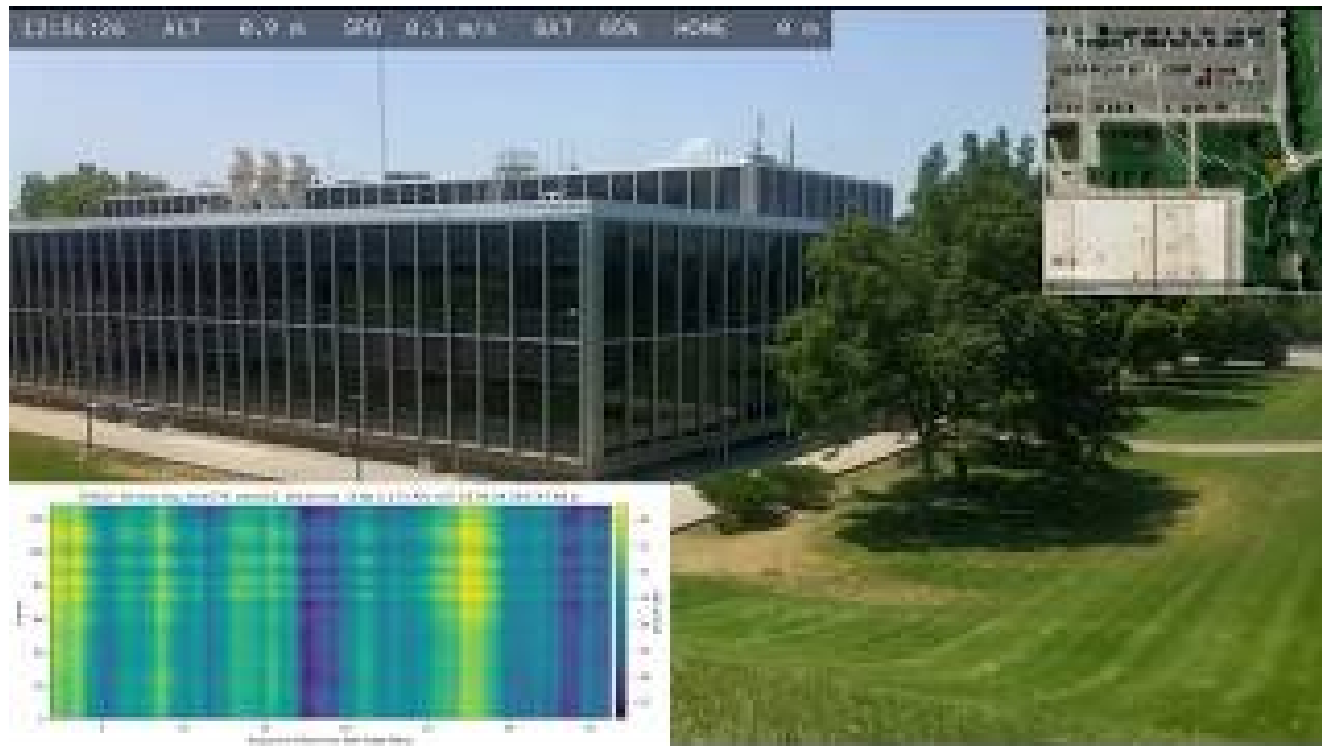
- Try out [OCUDU PHY TAP](#) in real world outdoor setting
 - O-RAN 7.2a tap + **COTS O-RU**
 - Intercepts UL IQ samples @ upper PHY
 - Modified plugin uses IQ data and CU/DU SRS context to **calculate/plot channel frequency response (CFR)**
- Setup
 - Benetel COTS O-RU + COTS Handset
 - OCUDU version 26/04 + Open5GS
- Experiment
 - Drone flying “in between”
 - Collect IQ samples + CFR estimates
 - Post processing - Coordinated video:
 - Drone view
 - Drone location
 - Waterfall plot
 - Interesting events...





OCUDU PHY TAP experiment - outdoor

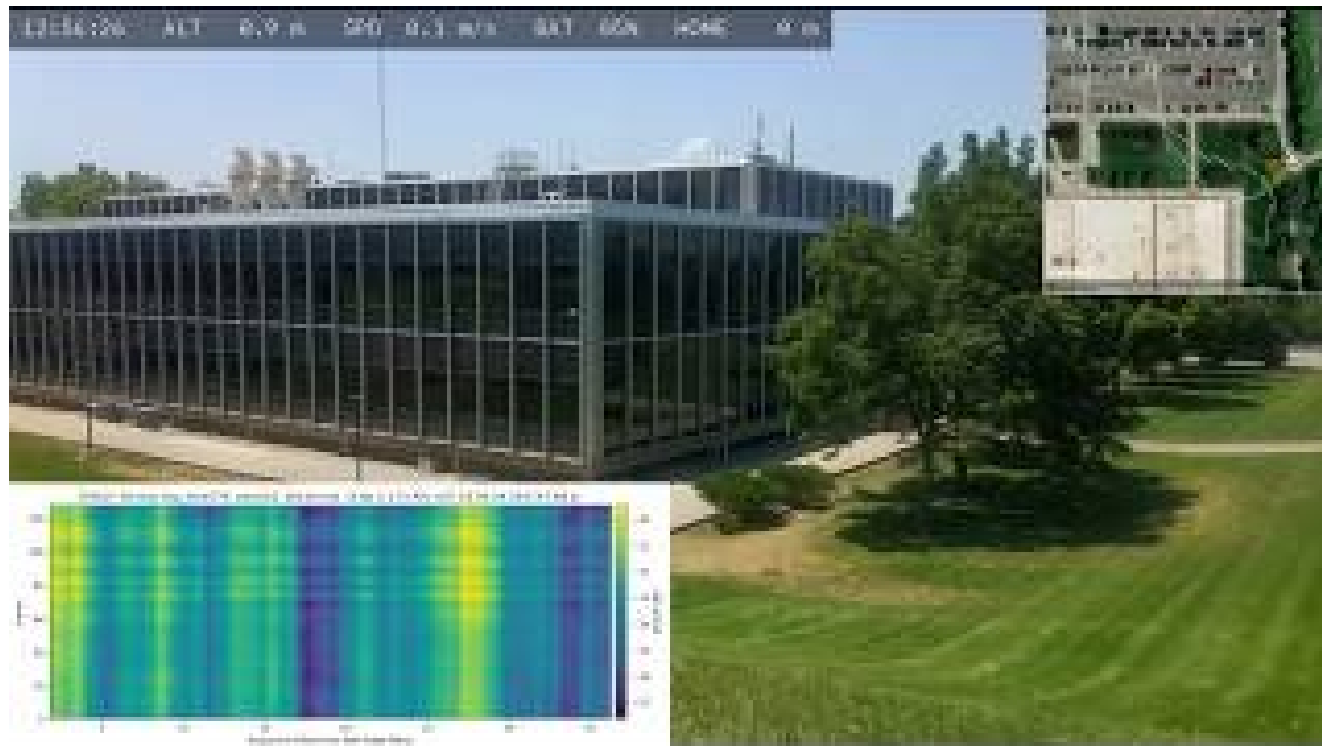
- Drone takeoff





OCUDU PHY TAP experiment - outdoor

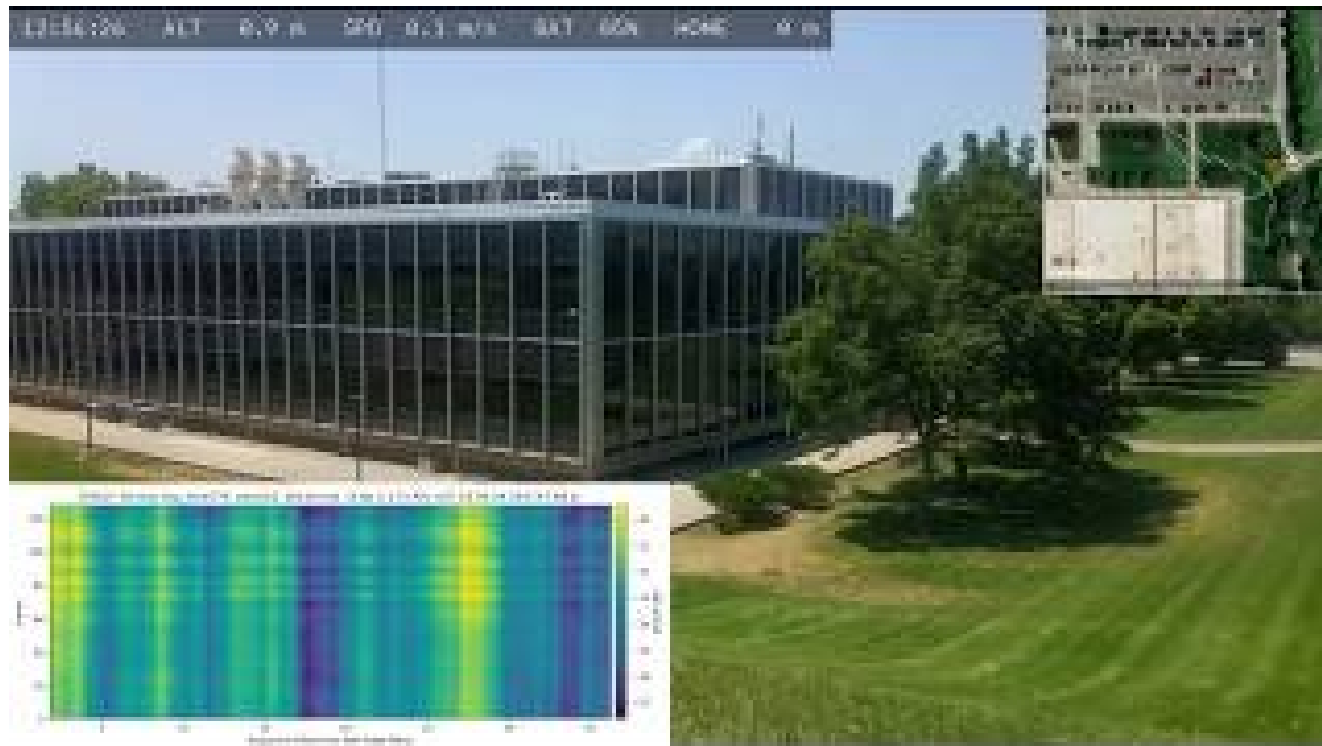
- Person in front of UE





OCUDU PHY TAP experiment - outdoor

- Drone pass through beam



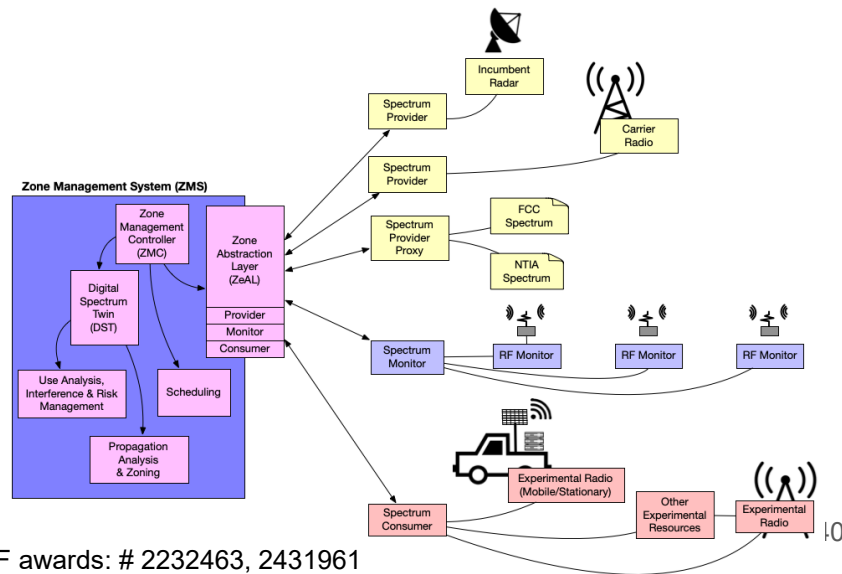
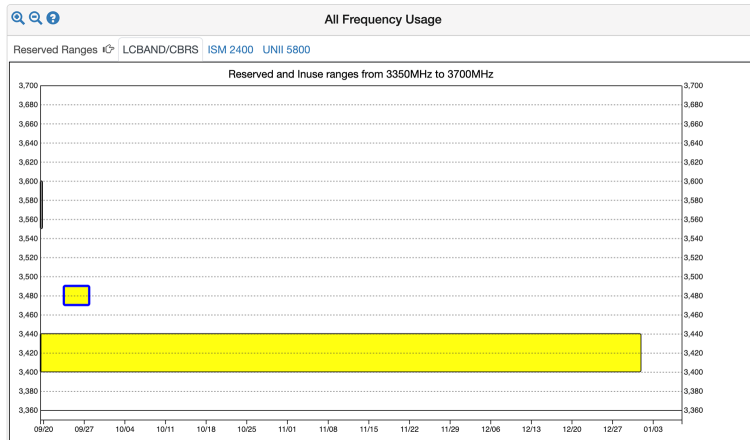


Spectrum in POWDER



Spectrum in POWDER

- Spectrum ranges available via Program Experimental Licence (PEL) and FCC Innovation Zone (IZ)
- Has always treated like any other resource
 - Make reservations
 - **Exclusive access**
 - Inline monitoring for SDRs
- Also been working on dealing with spectrum more intelligently/dynamically
 - **POWDER-RDZ** effort
 - Developed an open source zone management system: OpenZMS
 - POWDER + OpenZMS = POWDER-RDZ
- Focus for today:
 - **OpenZMS for POWDER users**



NSF awards: # 2232463, 2431961



OpenZMS for POWDER users

- OpenZMS is a spectrum management framework
 - POWDER users can get “their own slice” of delegated spectrum from OpenZMS
 - Allows more dynamic and fine grained user spectrum access
- OpenZMS is a spectrum sensing and intelligence framework
 - Spectrum visibility for POWDER users:
 - SSO access to OpenZMS from POWDER
 - Overall spectrum view + data about spectrum ranges they are using
 - Export OpenZMS spectrum sensing data for user research



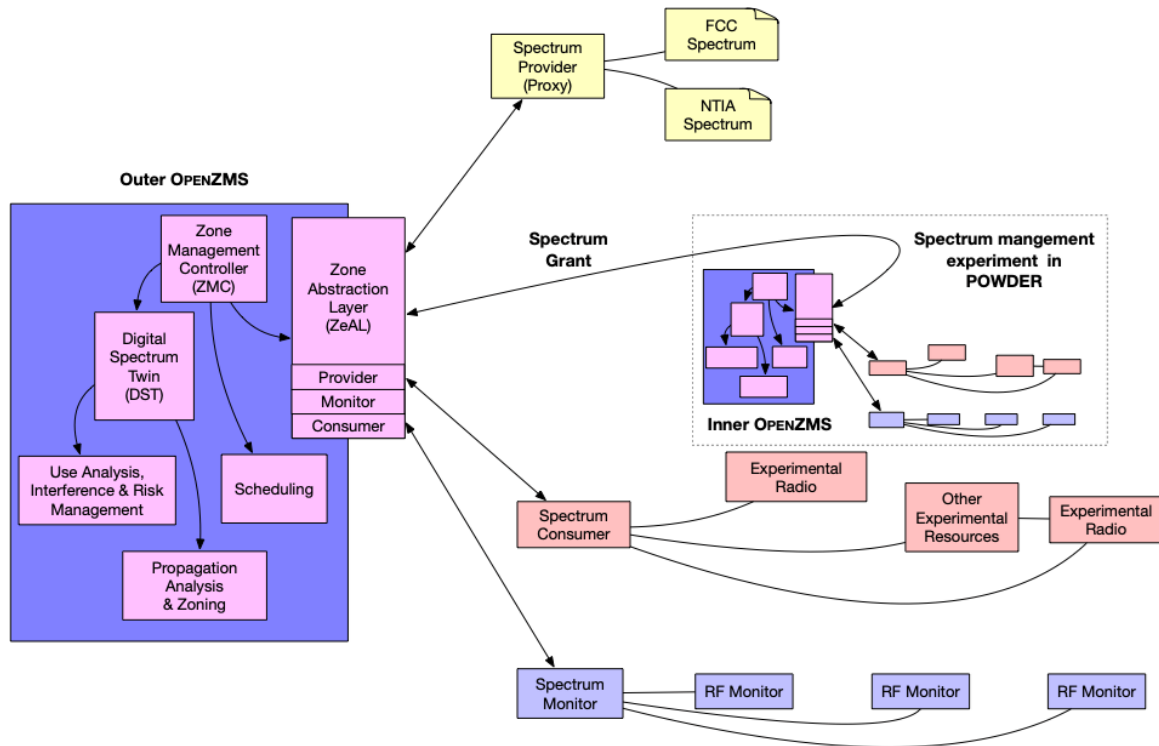
OpenZMS is a spectrum management framework

Manages spectrum in POWDER

- **Delegates spectrum to POWDER users spectrum management system**
 - “Own” spectrum slice
 - **Spectrum sharing/coexistence research**
 - With POWDER resources

Developed RDZ-in-RDZ

- (OpenZMS-in-OpenZMS)
- Outer OpenZMS grants a sliver of its spectrum to an Inner OpenZMS
 - Or other spectrum management system
- Outer OpenZMS monitoring data “relayed” into inner if desired



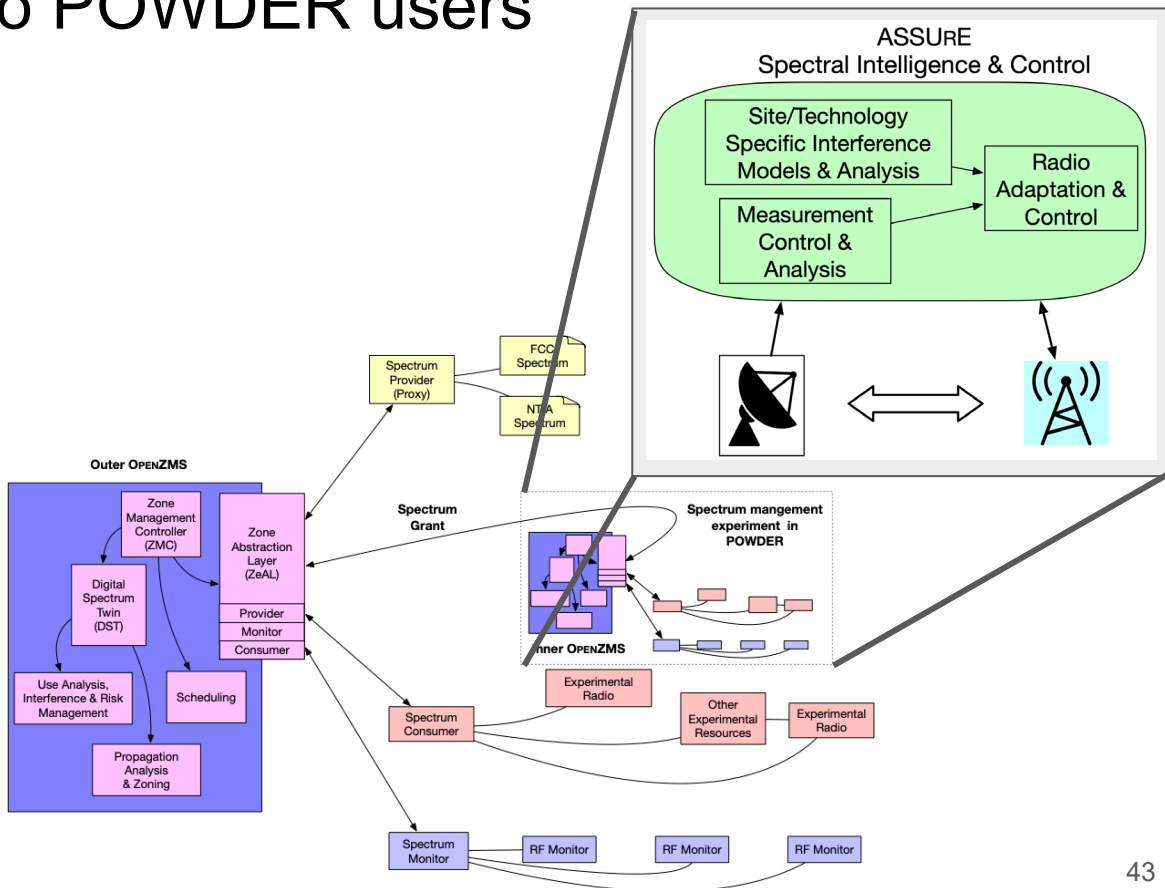


Delegates spectrum to POWDER users

RDZ-in-RDZ example...

ASSURE project

- Spectrum coexistence between federal radar systems and cellular
- ASSURE runs in inner-RDZ
 - Manage spectrum in inner RDZ





OpenZMS is a spectrum management framework

More dynamic spectrum access for POWDER

- POWDER-RDZ paths for spectrum allocation:
 - Classic POWDER experiments: exclusive, zone-wide spectrum allocations
- Dynamic spectrum request to OpenZMS
 - Steer user toward least-noisy spectrum based on continuous occupancy monitoring
 - Easier, hands-off option: POWDER handles all OpenZMS interactions on user behalf
- (In progress) More dynamic/flexible spectrum use
 - **Shared and/or opportunistic access to spectrum**
 - Users may share in same time, frequency, space
 - Get opportunistic access when “higher priority” user is not actually using spectrum
 - Requires programmatic experiment interaction with OpenZMS
 - User “smart tx” software talks directly to OpenZMS
 - More on smarttx:
 - Documentation to create a smarttx experiment with OpenZMS-in-OpenZMS:
 - <https://openzms.net/guide/deploy/powder/#smart-transmitter-demo>
 - Python smarttx wrapper:
 - <https://gitlab.flux.utah.edu/openzms/zms-client-py/-/blob/dev/zmsclient/tools/smarttx.py>
 - *Still thinking through POWDER operational implications*

User has a reservation, but not using spectrum all the time...



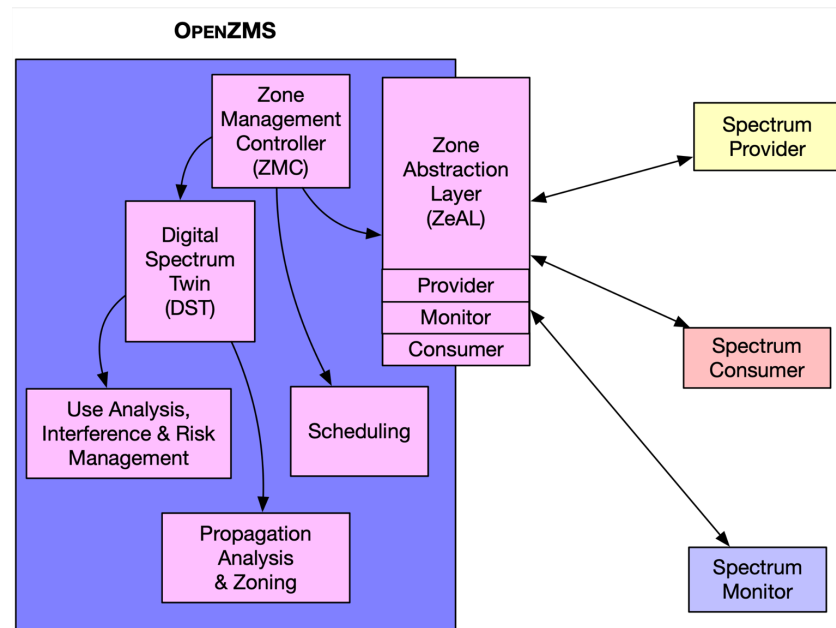
Dynamic spectrum access

Workflow & concepts

1. Initialization
 - a. Role player registration (ZeAL)
 - b. Initial RDZ geography, models
2. FCC PEL for CBRS band
 - a. OZMS: *Spectrum* object
3. Request RF monitoring of CBRS band
 - a. OZMS: *Monitor* object provide *Observations*
4. **Experimental radio requests spectrum**
 - a. OZMS: *Grant* request
5. ZMC allocates spectrum
 - a. Queries DST (propagation/risk/zone services)
 - b. Schedule spectrum use
6. OZMS: Issues spectrum *Grant*
7. **CBRS SAS starts using spectrum** in issued *Grant*
 - a. CBRS domain proxy issues a higher priority *Claim* for (newly used) CBRS spectrum
8. OZMS: Revokes previously issues *Grant*
 - a. **Experimental radio stops transmission**
 - i. **Optionally re-issues spectrum request**

PEL use case in wireless testbed:

- Permission to use CBRS band (lowest priority)





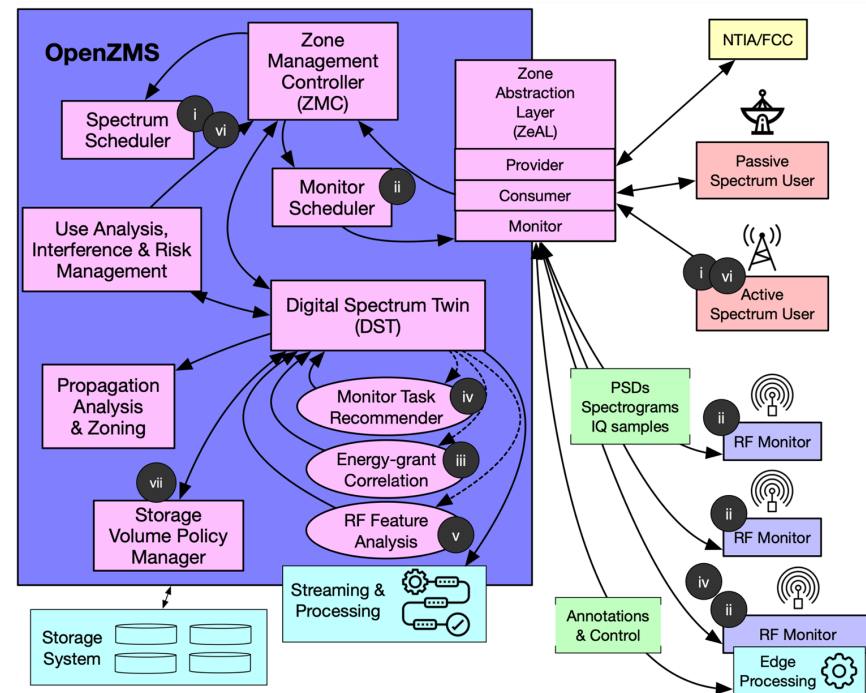
OpenZMS: Spectrum sensing & intelligence framework

- Spectrum monitoring: SDR, Signalhound rfmonitor software
 - Collects SigMF {PSD, IQ, spectrogram} and uploads into OpenZMS
 - Uses native SigMF spec fields, as well as NTIA extensions for processed data
- Focuses on *operational* use of spectrum data



OpenZMS: Spectrum sensing & intelligence framework

- OpenZMS focuses on *operational* use spectrum data
 - APIs to **retrieve RF data and link it to operational events** (allocation, RFI, etc) and **analyses** (waveform classification, energy detection, fingerprinting, etc)
 - Taskable RF monitor APIs allow the automatic OpenZMS monitor scheduler to **orchestrate different RF sensing tasks**
 - Intelligent services **annotate data with features and analysis**; label with criticality; discover new signals of interest
 - **Policy-driven data management** persists critical data and discards unimportant baseline/normative data

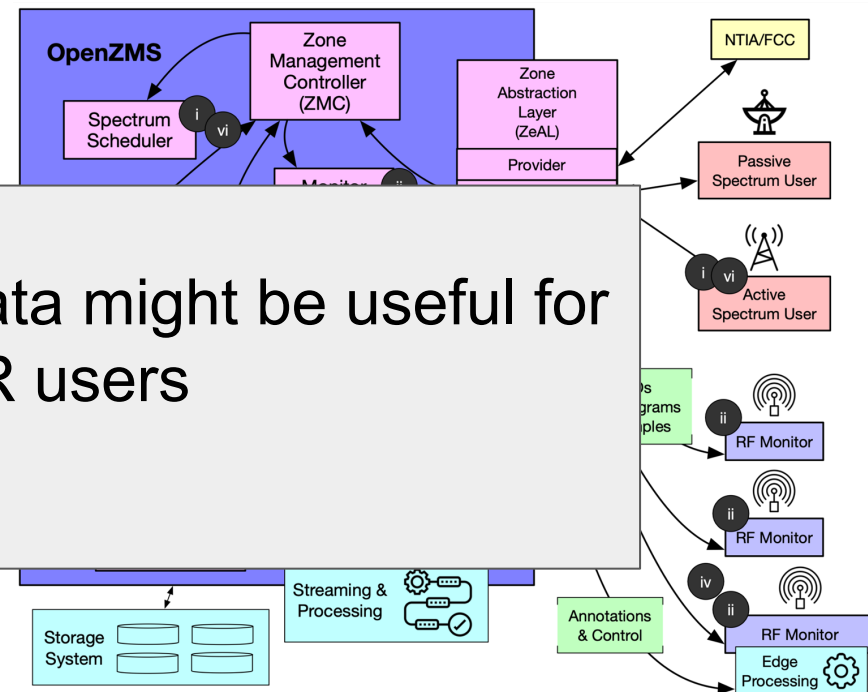




OpenZMS: Spectrum sensing & intelligence framework

- OpenZMS focuses on *operational* use spectrum data
 - APIs to retrieve RF data and link it to
 -
 -
 -
 -
 -
 -
 - Policy-driven data management persists critical data and discards unimportant baseline/normative data

Operational spectrum data might be useful for
POWDER users

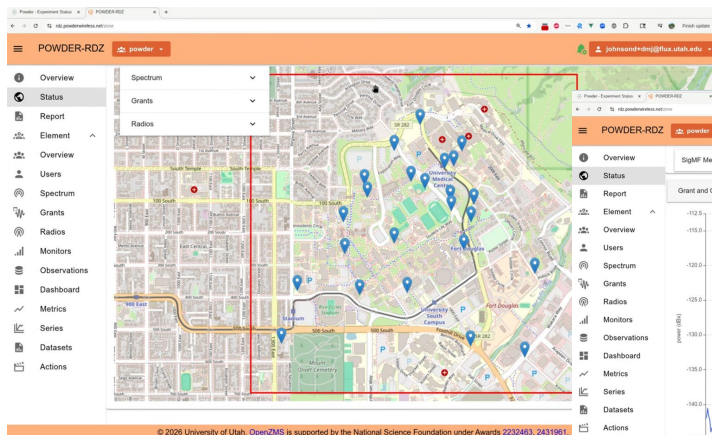
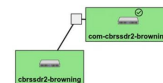
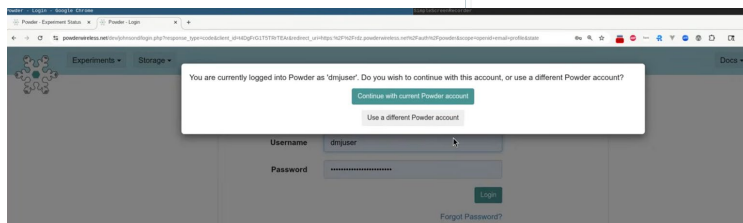
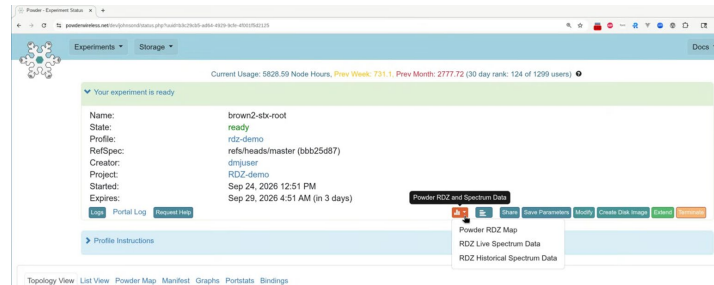




Spectrum visibility for POWDER users

POWDER & OpenZMS Federation

- Single Sign-On (SSO) implementation:
 - OpenZMS: Identity Provider (IdP)
 - POWDER: Service Provider (SP)
- POWDER users login to OpenZMS
 - Browse spectrum allocations and live/historical monitoring data and analysis
 - Your spectrum assignment
 - **Available NOW!**
- ToDo/Vision:
 - Full dynamic “privilege awareness”
 - POWDER roles/rights
 - More sophisticated spectral intelligence about **your experiment**
 - Enabler for more sophisticated federation between spectrum management systems





Spectrum visibility for POWDER users

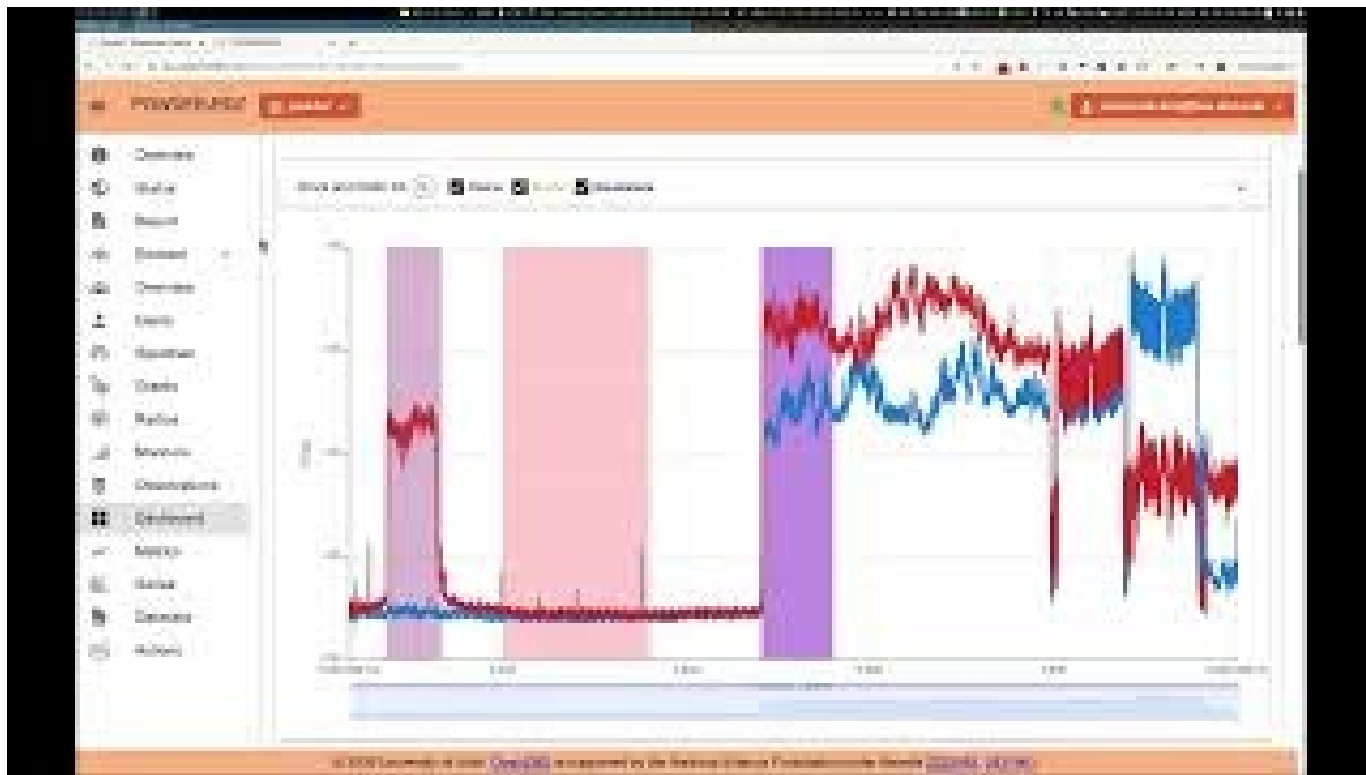
OpenZMS SSO
from POWDER





Spectrum visibility for POWDER users

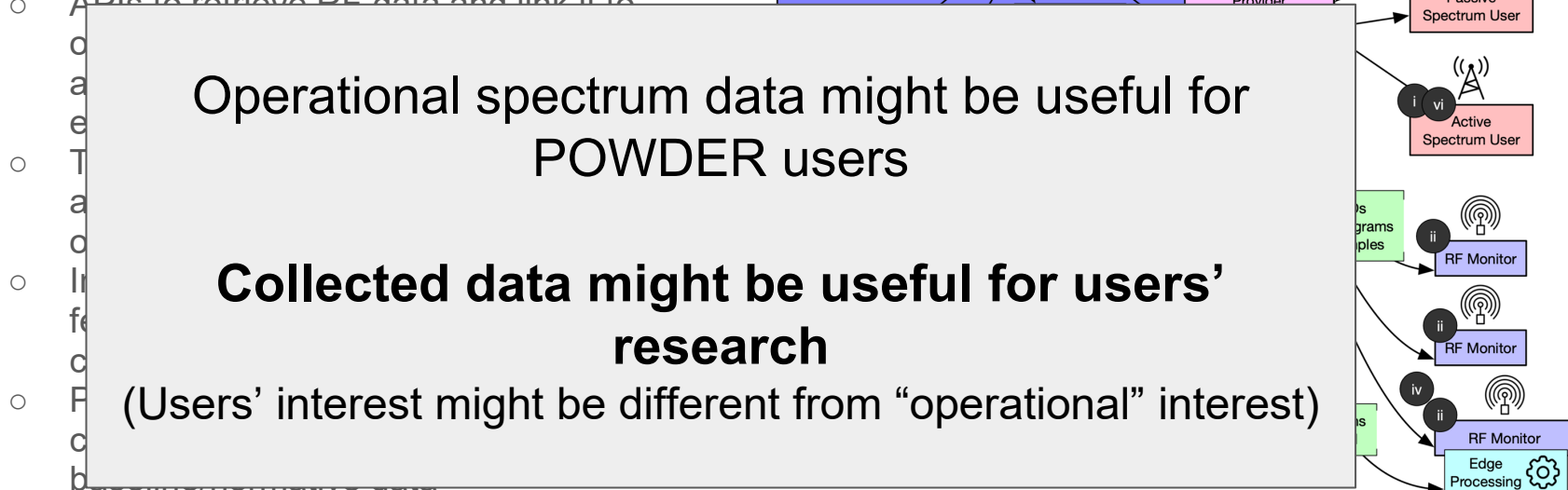
Live PSD and
OpenZMS
spectrum allocation
information





- OpenZMS focuses on *operational* use spectrum data

- ADLc to retrieve DC data and link it to





Export spectrum data for POWDER users

- How can we build a more permanent archive of spectrum data?
 - I.e., beyond “operationally interesting data”
 - *Data lake approach*: persist “everything” – original data, original format
 - Example scenario: OpenZMS might aggregate wideband occupancy into simple time-series data
 - But if a detailed view of a specific period in time was later required, the original PSDs could be retrieved from a data lake in bulk and re-analyzed
- OpenZMS exports data into POWDER data lake
 - Simple table metadata captures high-level properties (e.g. frequency range, time, radio) & raw SigMF data/metadata (PSDs, annotations from analyses – e.g. energy detection, ...)
 - ***More on this below as part of POWDER data/model-commons***

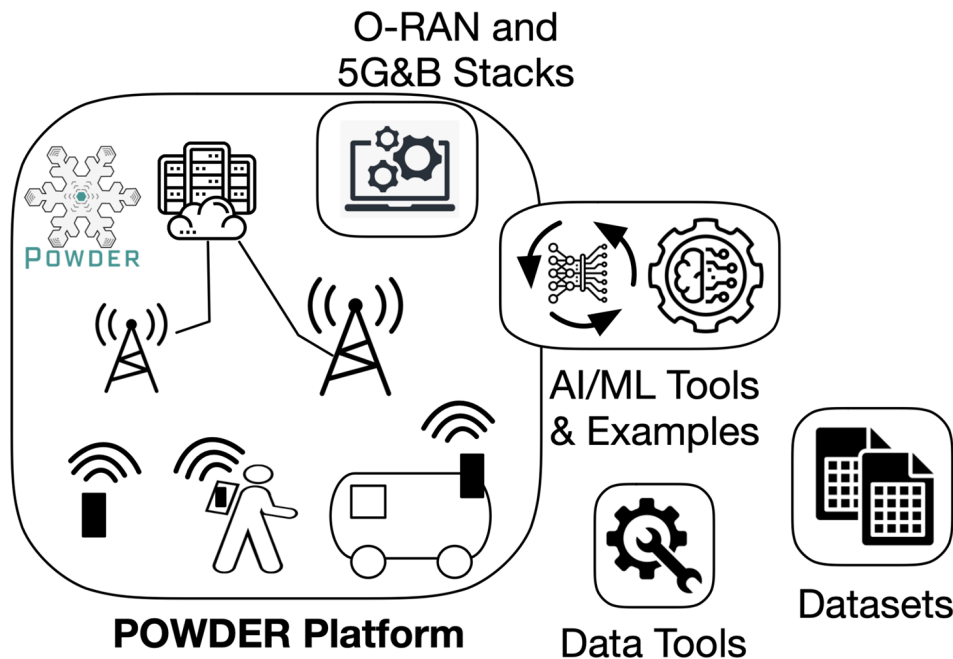


POWDER Data/Model Commons



POWDER-ENS focus

AI/ML tools & examples; Data tools;
Datasets

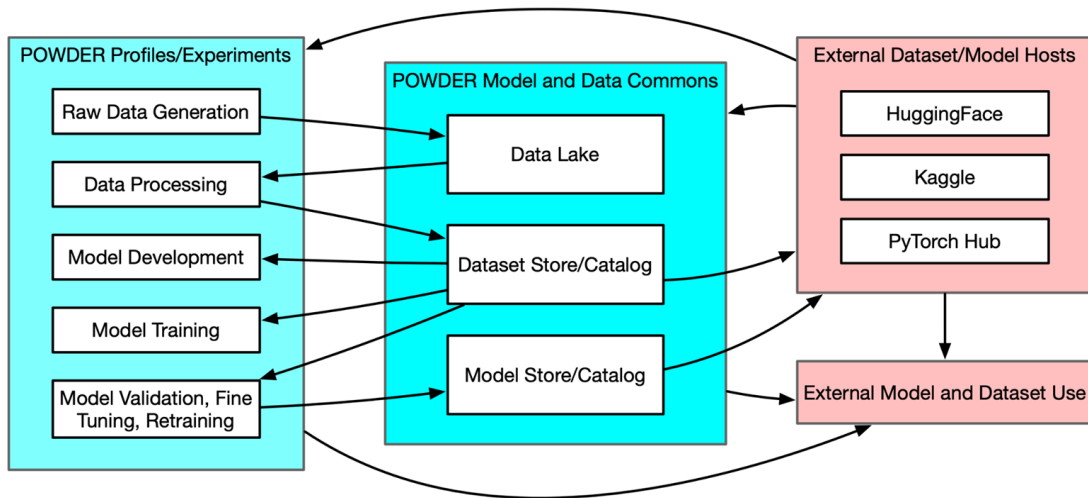




POWDER Model/Data Commons Architecture

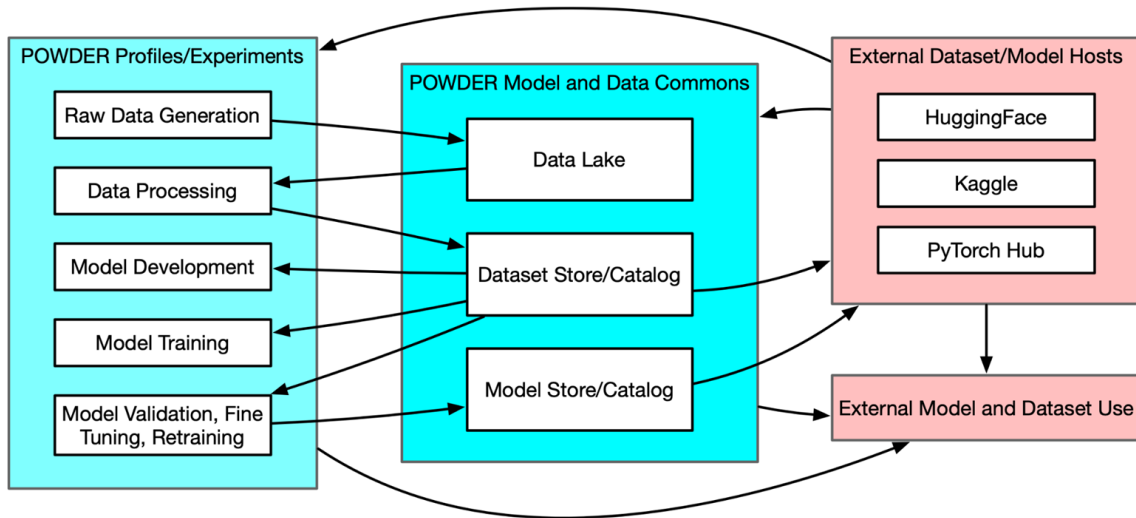
Objectives:

- POWDER for data generation & real world AI/ML
- Model/data commons: data exploration & interface between POWDER and other AI/ML environments





POWDER Model/Data Commons Architecture



POWDER experimental workflows for data and ML processes

Curated datasets, pre-trained models and supporting code, as well as metadata will be exported to popular external dataset and model platforms. Metadata will include backlinks to supporting POWDER profiles.

For many applications, it may be desirable to use POWDER Datasets and Models externally. Or combine external datasets with POWDER datasets.

Data Lake: Raw or minimally processed data generated via experiments

Dataset Store: Curated datasets featuring processed data/metadata; ready for use in model training/testing

Model Store: Pre-trained models with supporting code and metadata

Data and model metadata will include links to profiles where data were created/processed and models were trained/tested.



NIST et. al. paper: Wireless Dataset Principles

- Available and Accessible
 - Publicly available with open access licensing
- Realism and Environmental Fidelity
 - Physical, statistical & operational characteristics of real-world networks
- Intra-Dataset Diversity and Coverage of Rare Events
 - Capture typical and rare events
 - Including anomalies... interference bursts
 - Collected over extended periods of time
- Diversity of Collection Methods
 - Multiple layers of stack
 - Physical, networking, service
 - Same environment, different modalities

Why Aren't We Reusing Datasets More in Wireless Research?

Nithanth Ram
Carnegie Mellon University
Pittsburgh, PA, USA

Angad Bajwa
Carnegie Mellon University
Pittsburgh, PA, USA

Tarun Chawla
Remcom, Inc.
State College, PA, USA

Claudio Fiandrino
IMDEA Networks Institute
Madrid, Spain

Camillo Gentile
National Institute of Standards
and Technology
Gaithersburg, MD, USA

Miller Higgins
Corner Alliance, Inc.
Washington, DC, USA

Marc Leh
Corner Alliance, Inc.
Washington, DC, USA

David Love
Purdue University
West Lafayette, IN, USA

Abhinav Mahadevan
Keysight Technologies
Santa Rosa, CA, USA

Andreas Molisch
University of Southern California
Los Angeles, CA, USA

Swagato Mukherjee
Remcom, Inc.
State College, PA, USA

Jeanne Quimby
National Institute of Standards
and Technology
Boulder, CO, USA

Vyas Sekar
Carnegie Mellon University
Pittsburgh, PA, USA

Alexander Sprintson
George Mason University
Fairfax, VA, USA

Paige Walker
Corner Alliance, Inc.
Washington, DC, USA

Jörg Widmer
IMDEA Networks Institute
Madrid, Spain

Giulia Fanti
Carnegie Mellon University
Pittsburgh, PA, USA

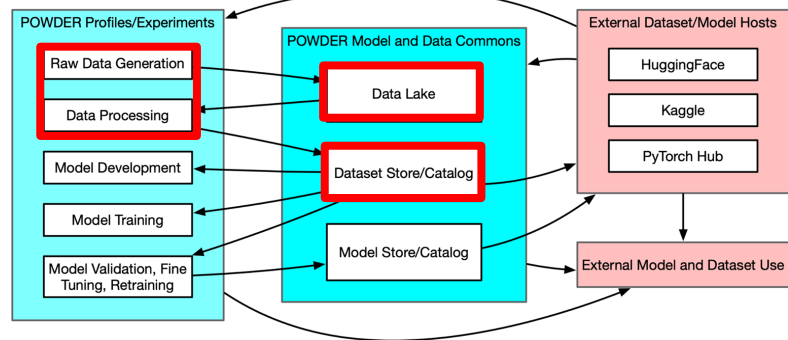
Nada Golmie*
National Institute of Standards
and Technology
Gaithersburg, MD, USA



POWDER Model/Data Commons Architecture

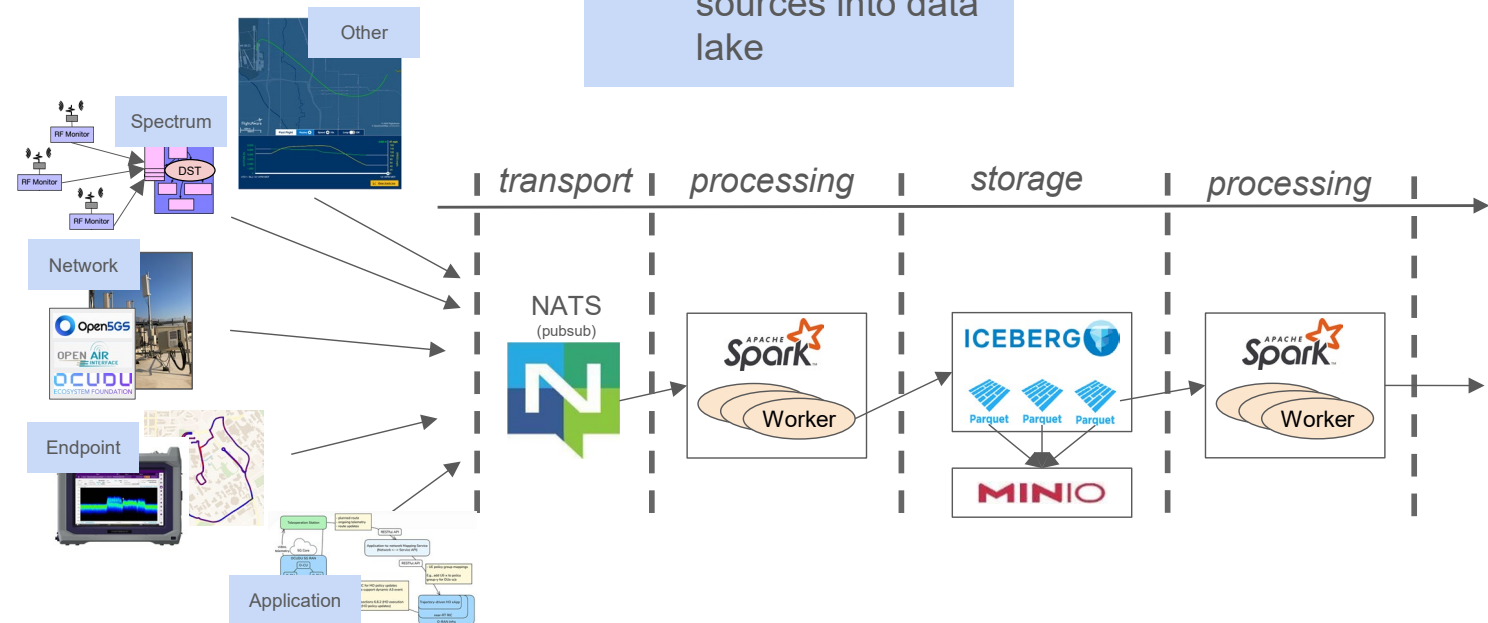
E2E Cross-layer
Data exploration

- Multiple data sources into data lake



producers

consumers



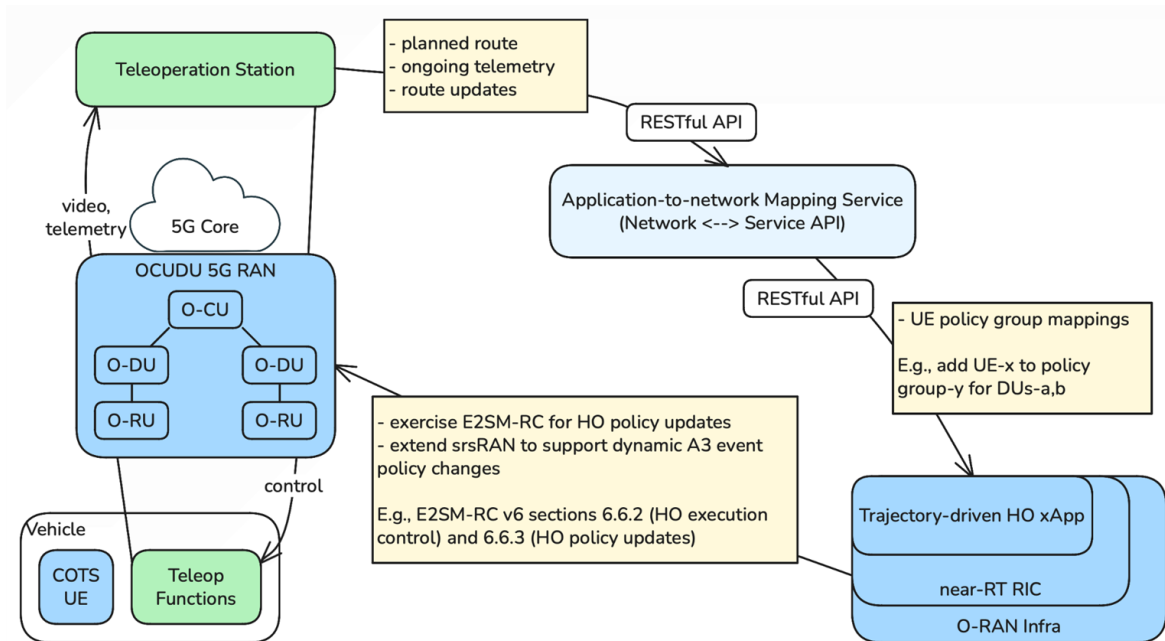
- Cross-layer optimization
- Network configuration & optimization
- RF propagation analysis
- Spectrum coexistence & Interference analysis
- ISAC algorithms



Driving example - Drive-Safe

Trajectory-driven tele-operated driving

- Details not that important here
 - (Zhi-Li will explain in next talk)
- Interesting “data” example
 - Network data
 - Application data
 - Endpoint data
 - O-RAN/policy data
 - Spectrum data





Driving example - Drive-Safe

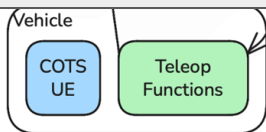
Trajectory
operated

- Detail
import
- Interest
exam

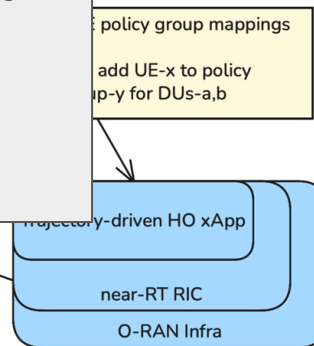
Lots of drive testing:

- Different network configurations
- Separate endpoint tools (Nemo)
- Full end-to-end with application level performance
- Different vehicle configurations
- Different spectrum ranges
- ...

- N
- Application data
- Endpoint data
- O-RAN/policy data
- Spectrum data



Signaling (HO policy updates and 6.6.3 (HO policy updates)

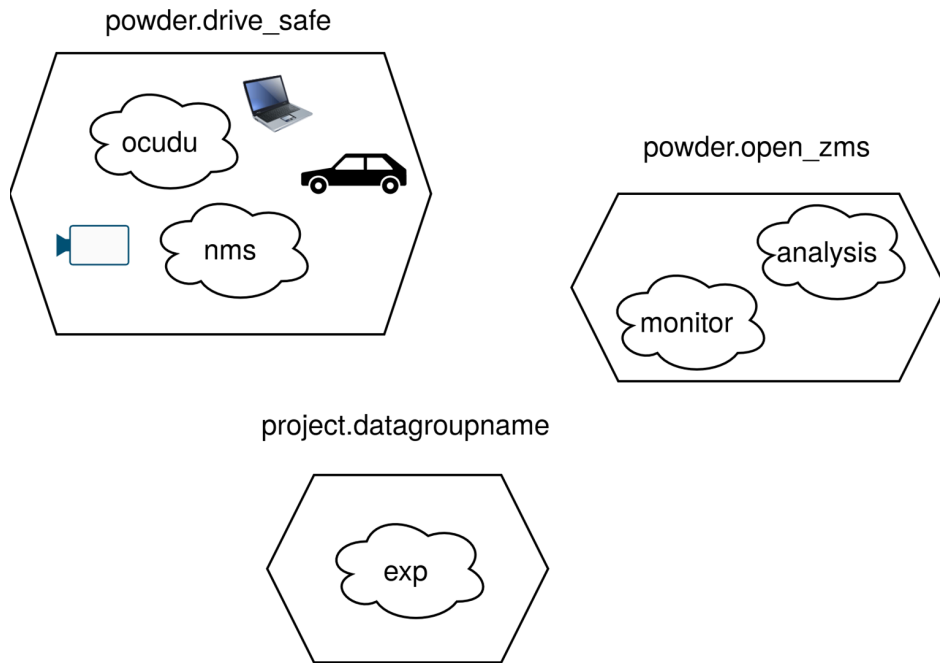




POWDER Data Lake Metadata

- ***Datagroups (core abstraction)***

- Grouping related data beyond single project/experiment/user
 - Series of experimental runs
- Persistent
 - Re-used across time for related data
- Contains (multiple) data producers
 - POWDER experiments:
 - Data from experiment
 - OpenZMS spectrum data
 - BYOD devices
 - User-managed compute
- Data provenance
 - POWDER metadata:
 - Experiment ->
 - Profile ->
 - Profile repository commit ->
 - Source Code
 - Other user provided metadata

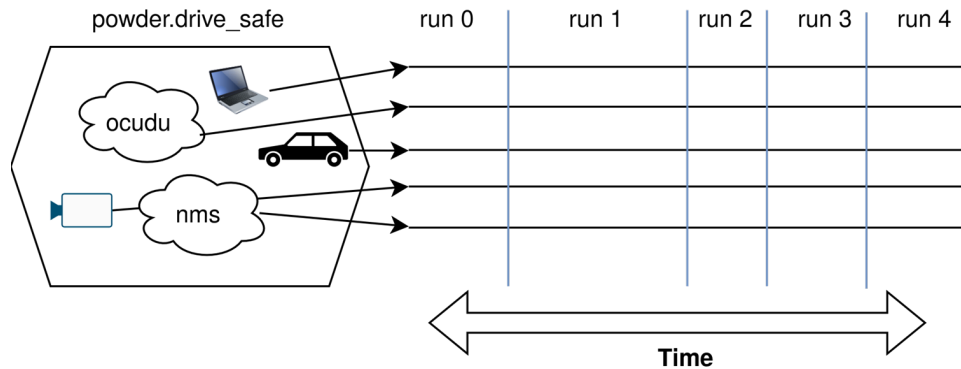




POWDER Data Lake Metadata

- ***Experimental Runs***

- ***Divide time within a datagroup***
- User “decided/declared”
- Per-run configuration
- Per-run notes
 - Human observations
 - Real world conditions
 - Antenna placement
- No need for orchestration across producers

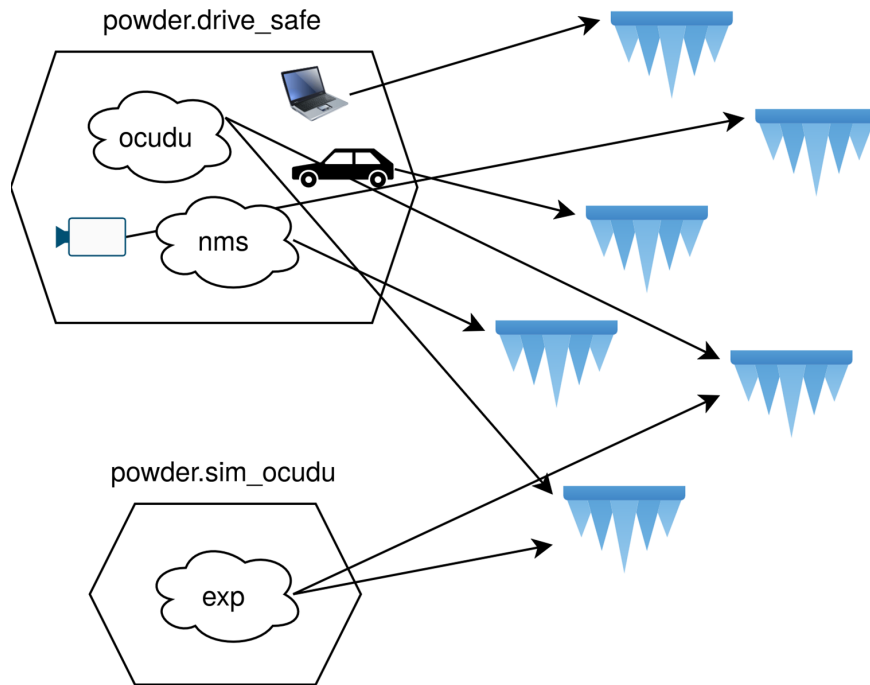




POWDER Data Lake Architecture

- **Iceberg Tables**

- For each **type** of producer
 - **Common schema / format**
- Comparable dataset
- Shared
 - Across datagroups
 - Across experiment runs
- *Main idea:*
 - **Related data end up in same table**
 - Might be from different experimenters, different conditions
- Filter for provenance, or process across all data in a table
 - Depending on use...





POWDER Data Lake Architecture

- Iceberg Table Example

- `ocudu\_ws` table
- Metrics from [OCUDU websocket](#)
 - JSON formatted data stream from CU/DU
- Results from multiple datagroups
 - Simulated / Drive Safe / etc
- Results across runs
- Analysis
 - Filter for single datagroup
 - Or compare sim to real
- *Common OCUDU WS format*

```
+-----+-----+-----+
| datagroup_id| run_id| payload|
+-----+-----+-----+
| powder.sim_ocudu|15ef4792-9f14-43c...|{"cu-cp": {"id": ...|
| powder.sim_ocudu|15ef4792-9f14-43c...|{"du": {"du_high"...|
| powder.sim_ocudu|15ef4792-9f14-43c...|{"cells": [{"cell...|
| powder.sim_ocudu|15ef4792-9f14-43c...|{"cu-cp": {"id": ...|
| powder.sim_ocudu|15ef4792-9f14-43c...|{"du": {"du_high"...|
| powder.sim_ocudu|15ef4792-9f14-43c...|{"cells": [{"cell...|
| powder.sim_ocudu|15ef4792-9f14-43c...|{"cells": [{"cell...|
| powder.sim_ocudu|15ef4792-9f14-43c...|{"du": {"du_high"...|
| powder.drive_safe|4bde2d8e-9b0b-4cc...|{"du": {"du_high"...|
| powder.drive_safe|4bde2d8e-9b0b-4cc...|{"du_low": {"dl":...|
| powder.drive_safe|4bde2d8e-9b0b-4cc...|{"ru": {"ofh": {""...|
| powder.drive_safe|bd4019a9-1b32-4d2...|{"ru": {"ofh": {""...|
| powder.drive_safe|4bde2d8e-9b0b-4cc...|{"cells": [{"cell...|
| powder.drive_safe|bd4019a9-1b32-4d2...|{"du": {"du_high"...|
| powder.drive_safe|bd4019a9-1b32-4d2...|{"cells": [{"cell...|
| powder.drive_safe|bd4019a9-1b32-4d2...|{"du_low": {"dl":...|
| powder.drive_safe|bd4019a9-1b32-4d2...|{"du": {"du_high"...|
| powder.drive_safe|bd4019a9-1b32-4d2...|{"du_low": {"dl":...|
| powder.drive_safe|4bde2d8e-9b0b-4cc...|{"ru": {"ofh": {""...|
| powder.drive_safe|bd4019a9-1b32-4d2...|{"ru": {"ofh": {""...|
+-----+-----+-----+
only showing top 20 rows
```



POWDER Data Lake Architecture

- Producers outside POWDER experiments can also stream data to the data lake
 - If the device can run the data lake client and has internet access, it can stream the live experiment data to the data lake
 - Otherwise, the device can transfer the logs to another device for post-hoc data lake ingestion
 - Configure appropriate Datagroup ID and Experiment ID
- Examples:
 - OpenZMS provided SigMF data
 - PSD, IQ, spectrogram
 - Devices running diagnostic tools like **KeySight Nemo** or application clients such as **iperf**.



POWDER Data Lake - status

- Prototype
 - Started using internally
 - With Drive-Safe project
 - With OpenZMS data
 - Current very modest scale:
 - 200k OpenZMS observations/annotations
 - Consistent flow of automated observations
 - 50M Drive Safe log entries and metrics
 - Bursty when doing physical drive tests
- Packaged as a “data pond”
 - Private user data
 - Path to drain into lake...



POWDER data-pond

- Data-commons tools for POWDER users
 - Maintaining data in their own data pond
 - Use POWDER data tools
 - Stepping stone towards using POWDER data lake
 - *Still thinking through operational process...*
- Example: Simulated RF profile with data lake components
 - OCUDU+Open5GS simulated RF experiment on POWDER
 - On startup, installs (along with OCUDU + Open5GS)
 - **data pond** (<https://gitlab.flux.utah.edu/anirudhkamath/powder-data-lake>)
 - Spark-iceberg and NATS docker containers
 - **data pond client** (<https://gitlab.flux.utah.edu/anirudhkamath/lake-data-tools>)
 - Pushes data to on device data pond storage
 - Profile comes with instructions on
 - Organizing data with runs
 - Using the data pond client to publish data to the pond
 - Extracting data using the PySpark environment
 - Profile link (use **data - pond** branch): <https://www.powderwireless.net/show-profile.php?uuid=55b0e2b0-2991-44bd-b78c-5e589884e586>



POWDER data/model commons: plans

- POWDER Data Lake Scale:

- Modest Prototype...
- Scaling Up/Future Work
 - Move to petabyte-scale backend on top of CephFS (existing)
 - Design and implement robust authentication/multi-tenant policies

- Produce datasets:

- ***Make producing data into data lake option on all POWDER provided profiles...***
 - ***Add data-lake client to profile***
- ***Infrastructure for creating large high quality wireless datasets***
- Figure out Data Ponds -> Data Lake workflow

- Model commons:

- Continue working on processing and model part of POWDER data and model commons
 - Data access/processing/model profiles
 - Curated datasets

- 5G/NextG: network, endpoint, mobility
- Custom/non-5G waveforms
- Application: connected vehicle, performance tools
- Spectrum: PSD, spectrogram, IQ samples
- PHY-TAP: EPRE, CFR
- External: ADS-B flight data, light rail & bus locations
- ...

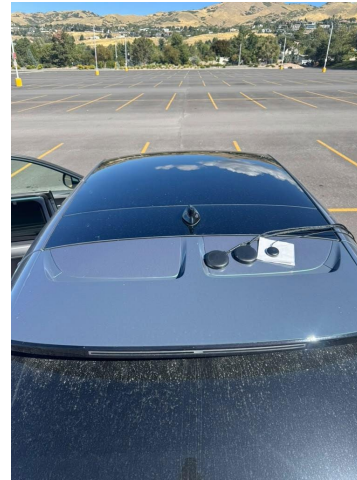


Data processing examples

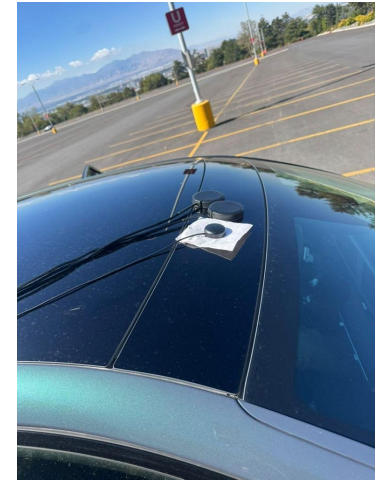


Antenna placement affects vehicle connectivity

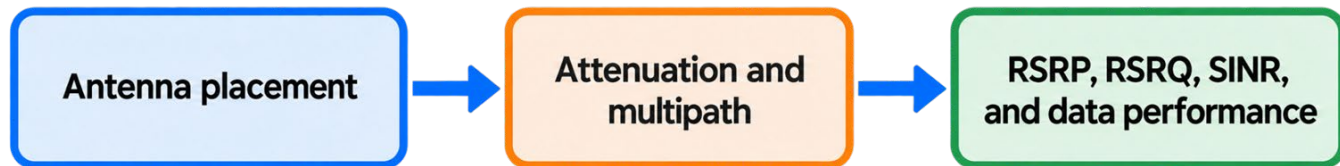
- Why antenna placement matters?
 - Vehicle body can attenuate wireless signals.
 - Antenna position changes the multipath environment.
 - Antenna geometry relative to base station changes especially during turns.
- Why collect radio and transport performance measurements?
 - Rapid changes in **RSRP**, **RSRQ**, and **SINR** during turns can affect **throughput**, **latency**, and **packet loss**.
 - Synchronized radio and transport performance measurements enable **cross-layer analysis** that links wireless fluctuations to end-to-end performance.



Rear-middle
placement



Front-middle
placement





POWDER data-commons example: data sources

- *Antenna placement*

- **Antenna placement** is logged by the researcher using the “run notes” functionality
- Relevant runs are identified via run ID notes (**blue**=back-left-middle, **red**=front-middle).

datagroup_id	run_id	key	value
powder.drive_safe 4bde2d8e-9b0b-4cc1-b00d-5365381bc8e5	note	Starting new run with t310 and n310 and with back-left-middle antenna placement	
powder.drive_safe 4bde2d8e-9b0b-4cc1-b00d-5365381bc8e5	started_at	2026-09-20T19:33:54.815057	
powder.drive_safe 42dd4654-710c-4ede-be09-456626900854	note	Starting new run with t310 and n310 and with front-middle antenna placement	
powder.drive_safe 42dd4654-710c-4ede-be09-456626900854	started_at	2026-09-20T19:22:26.317710	

- *RSRP, RSRQ, SINR*

- Collected by 2 sources, both measuring the SSB:
 - **KeySight Nemo**: Measures at a **coarse** granularity (1-2 times a second)
 - **gNB logs**: Measurement reports sent at a **fine** granularity (every 120ms)

- *Throughput, latency, packet loss:*

- Collected in **iperf3** logs measured at the UE end (receiver)

- *Latitude, Longitude*

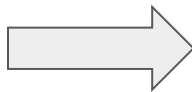
- Captured in **KeySight Nemo logs**



POWDER data-commons example: gNB log querying

- For both runs, get:
 - gNB logs: measurement reports
 - Filter log lines containing RRC measurement reports
 - Parse out RSRP, RSRQ, SINR, and the PCI it measured
 - Convert indexed values to dBm/dB units

```
+-----+-----+
|timestamp|payload|
+-----+-----+
|2026-09-20 19:16:34.338385|{"line": "          \"rsrq\": 42,\n"}|
|2026-09-20 19:16:35.057309|{"line": "          \"physCellId\": 2,\n"}|
|2026-09-20 19:16:38.536399|{"line": "          \"measurementReport\": {\n"}|
|2026-09-20 19:16:38.776937|{"line": "          \"sinr\": 72\n"}|
|2026-09-20 19:16:38.777565|{"line": "          \"sinr\": 25\n"}|
|2026-09-20 19:16:38.896421|{"line": "          \"physCellId\": 1,\n"}|
|2026-09-20 19:16:38.896627|{"line": "          \"sinr\": 72\n"}|
|2026-09-20 19:16:38.900593|{"line": "          \"rsrp\": 58,\n"}|
|2026-09-20 19:16:39.016596|{"line": "          \"rsrq\": 65,\n"}|
|2026-09-20 19:16:39.136995|{"line": "          \"sinr\": 72\n"}|
|2026-09-20 19:16:39.379201|{"line": "          \"rsrp\": 59,\n"}|
|2026-09-20 19:16:39.619152|{"line": "          \"rsrp\": 70,\n"}|
```

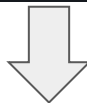


```
+-----+-----+-----+-----+
|timestamp|pci|rsrp|rsrq|sinr|
+-----+-----+-----+-----+
|2026-09-20 19:16:39|1|-87.0|-11.5|12.0|
|2026-09-20 19:16:39|2|-99.0|-23.5|-12.0|
|2026-09-20 19:16:40|1|-87.0|-11.5|12.38029247065792|
|2026-09-20 19:16:40|2|-98.72759957154628|-22.537588000175695|-11.413026214671106|
|2026-09-20 19:16:41|1|-87.0|-11.5|12.38029247065792|
|2026-09-20 19:16:41|2|-98.47128104620114|-22.57709868903463|-11.428367541821888|
|2026-09-20 19:16:42|1|-87.0|-11.5|12.339645319760017|
|2026-09-20 19:16:42|2|-98.0|-22.326857888639164|-11.160354680239982|
|2026-09-20 19:16:43|1|-87.0|-11.5|12.5|
|2026-09-20 19:16:44|1|-87.0|-11.5|12.565739849377955|
+-----+-----+-----+-----+
only showing top 10 rows
```



- For both runs, get:
 - iperf3 logs: bitrate
 - Parse iperf bitrate (RX)

2026-09-20 19:23:58	Sun Sep 20 19:23:58 2026	[ID][Role]	Interval	Transfer	Bitrate	Jitter	Lost/Total Datagrams	\n
2026-09-20 19:23:58	Sun Sep 20 19:23:58 2026	[5][TX-C]	0.00-1.00 sec	2.38 MBytes	19.9 Mb/s		1835	\n
2026-09-20 19:23:58	Sun Sep 20 19:23:58 2026	[7][RX-C]	0.00-1.00 sec	7.61 MBytes	63.8 Mb/s	0.348 ms	3267/9136 (36%)	\n
2026-09-20 19:23:59	Sun Sep 20 19:23:59 2026	[5][TX-C]	1.00-2.00 sec	1.34 MBytes	11.3 Mb/s		1036	\n
2026-09-20 19:23:59	Sun Sep 20 19:23:59 2026	[7][RX-C]	1.00-2.00 sec	8.42 MBytes	70.7 Mb/s	0.136 ms	2738/9228 (30%)	\n
2026-09-20 19:24:00	Sun Sep 20 19:24:00 2026	[5][TX-C]	2.00-3.00 sec	1.99 MBytes	16.7 Mb/s		1534	\n
2026-09-20 19:24:00	Sun Sep 20 19:24:00 2026	[7][RX-C]	2.00-3.00 sec	8.61 MBytes	72.2 Mb/s	0.370 ms	2518/9157 (27%)	\n



```
+-----+-----+
|timestamp|dl_rx_bitrate|
+-----+-----+
|2026-09-20 19:23:58|63.8|
|2026-09-20 19:23:59|70.7|
|2026-09-20 19:24:00|72.2|
```



POWDER data-commons example: Nemo querying

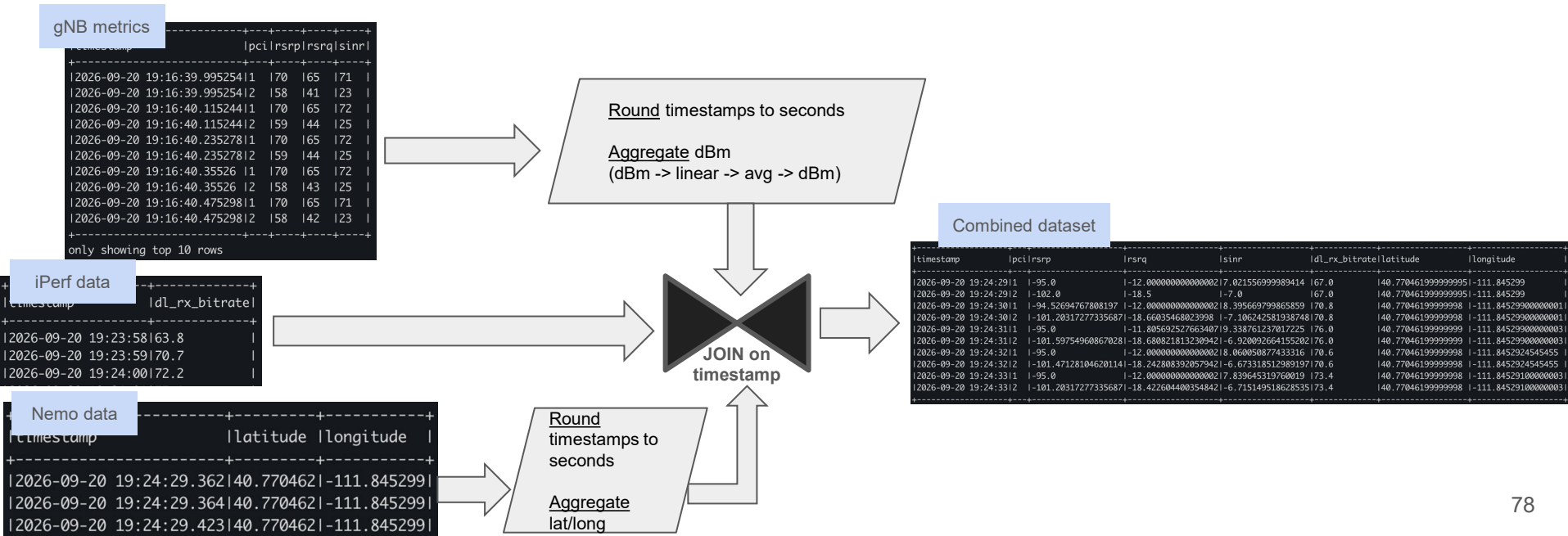
- For both runs, get:
 - Nemo logs: latitude and longitude (user position)
 - As it is in CSV, parsing not needed - simple field lookup

```
+-----+-----+-----+
|timestamp      |latitude      |longitude     |
+-----+-----+-----+
|2026-09-20 19:24:29|40.770461999999995|-111.845299   |
|2026-09-20 19:24:30|40.770461999999998 |-111.84529900000001|
|2026-09-20 19:24:31|40.770461999999999 |-111.84529900000003|
|2026-09-20 19:24:32|40.770461999999998 |-111.84529900000001|
```



POWDER data-commons example: Merging all sources

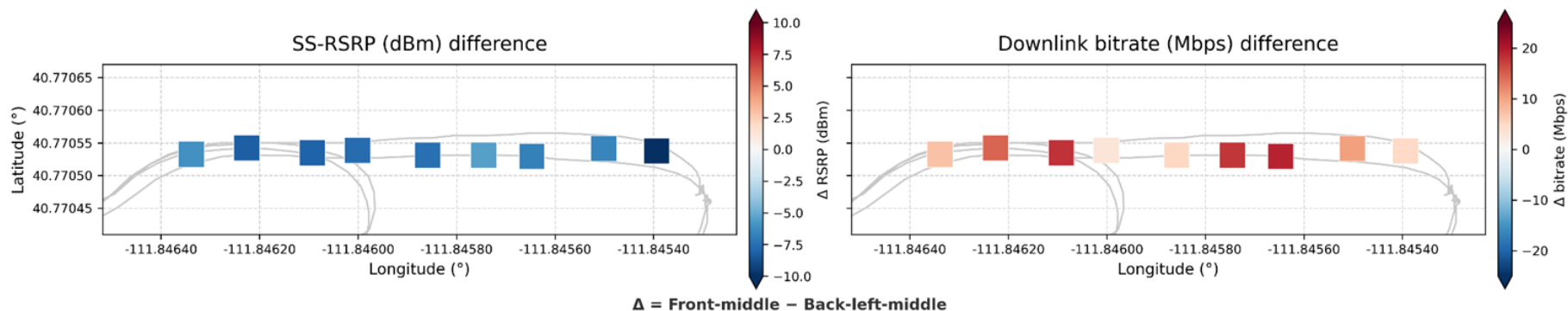
- For both runs:
 - The 3 data sources have timestamps in different granularities
 - Needs time-series wrangling:





Analysis results

SS-RSRP (dBm) relation with DL Bitrate (Mbps)
Red: front-middle higher • Blue: back-left-middle higher



- **Results:** Back-left-middle placement provides a **7.53 dBm** better median RSRP delta, while front-middle placement achieves **10.25 Mbps** higher throughput.
- **Insight:** SS-RSRP has only a weak correlation with downlink bitrate because it is measured on the **PBCH**, whereas downlink application data is transmitted over the **PDSCH**.



Observing Spectrum for DriveSafe Runs

- POWDER data-lake producer: OpenZMS and rfmonitors
 - Continuously stores timestamped, RDZ-wide spectrum data
 - Both **raw observations** (e.g., PSDs, spectrograms, samples) and **extracted annotations** (e.g., waveform classification, correlation with spectrum grants)
 - Observations are stored as SigMF using both native spec fields and extension fields
 - PSDs/spectrograms with NTIA SigMF extensions to encode processing info
 - OpenZMS SigMF extension fields attributing source radio, etc
- Writes directly to the lake
 - Iceberg protocol ensures safe coordination between multiple data producers
- Users can query to understand "spectrum environment" in which their experiments ran
 - Detect/identify sources of interference
 - Generate summaries of spectrum activity

```
>>> spark.sql("DESCRIBE default.openzms_observations")
+-----+-----+-----+
| col_name | data_type | comment |
+-----+-----+-----+
| observation_id | string | NULL |
| experiment_id | string | NULL |
| run_id | string | NULL |
| datagroup_id | string | NULL |
| monitor_id | string | NULL |
| min_freq | bigint | NULL |
| max_freq | bigint | NULL |
| kind | string | NULL |
| format | string | NULL |
| datatype | string | NULL |
| freq_step | bigint | NULL |
| timestamp | string | NULL |
| arrival_timestamp | string | NULL |
| starts_at | string | NULL |
| ends_at | string | NULL |
| metadata | string | NULL |
| data | binary | NULL |
+-----+-----+-----+
```

```
>>> spark.sql("DESCRIBE default.openzms_annotations")
+-----+-----+-----+
| col_name | data_type | comment |
+-----+-----+-----+
| annotation_id | string | NULL |
| observation_id | string | NULL |
| type | string | NULL |
| name | string | NULL |
| description | string | NULL |
| value | string | NULL |
| min_freq | bigint | NULL |
| max_freq | bigint | NULL |
| sample_start | bigint | NULL |
| sample_count | bigint | NULL |
| datagroup_id | string | NULL |
| run_id | string | NULL |
| experiment_id | string | NULL |
| timestamp | string | NULL |
| arrival_timestamp | string | NULL |
+-----+-----+-----+
```



Observing Spectrum for DriveSafe Runs

- POWDER data-lake producer: OpenZMS and rfmonitors
 - Continuously stores timestamped, RDZ-wide spectrum data
 - Both raw *observations* (e.g., PSDs, spectrograms, samples) and extracted *annotations* (e.g., waveform classification, correlation with

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Did the spectrum environment impact the experiment?

- Writes directly to the lake
 - Iceberg protocol ensures safe coordination between multiple data producers
- Users can query to understand "spectrum environment" in which their experiments ran
 - Detect/identify sources of interference
 - Generate summaries of spectrum activity

```
>>> spark.sql("DESCRIBE default.openzms_observations")
```

col_name	data_type	comment
observation_id	string	NULL
experiment_id	string	NULL
run_id	string	NULL
datagroup_id	string	NULL
monitor_id	string	NULL
min_freq	bigint	NULL
max_freq	bigint	NULL
kind	string	NULL

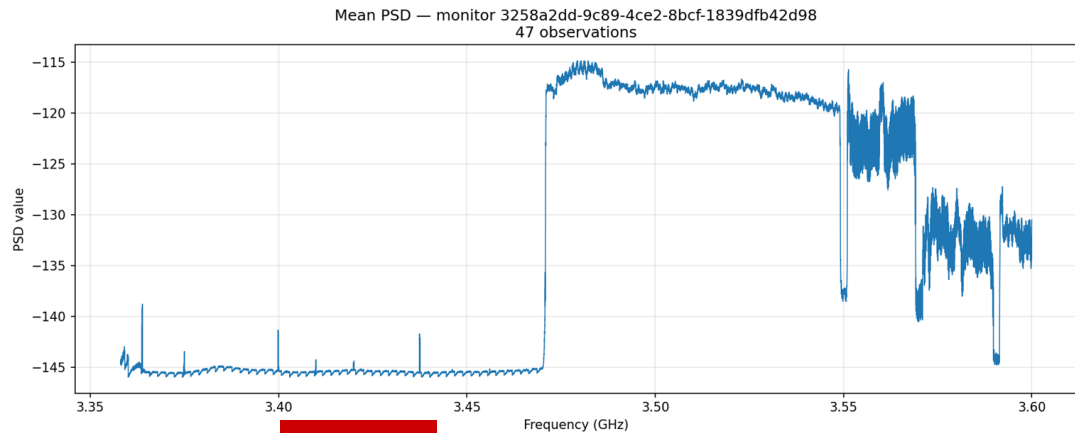
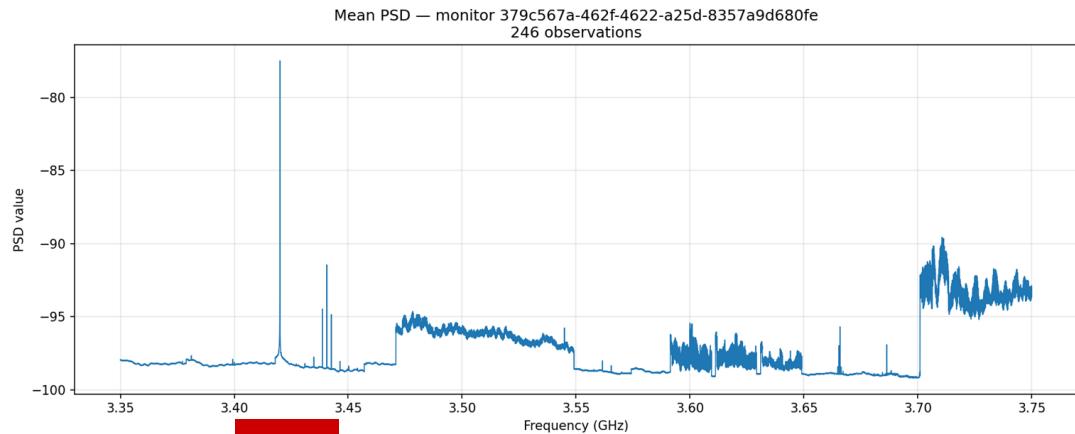
```
ult.openzms_annotations")
```

col_name	data_type	comment
annotation_id	string	NULL
observation_id	string	NULL
type	string	NULL
name	string	NULL
description	string	NULL
value	string	NULL
min_freq	bigint	NULL
max_freq	bigint	NULL
sample_start	bigint	NULL
sample_count	bigint	NULL
datagroup_id	string	NULL
run_id	string	NULL
experiment_id	string	NULL
timestamp	string	NULL
arrival_timestamp	string	NULL



Observing Spectrum: **Before** DriveSafe Runs

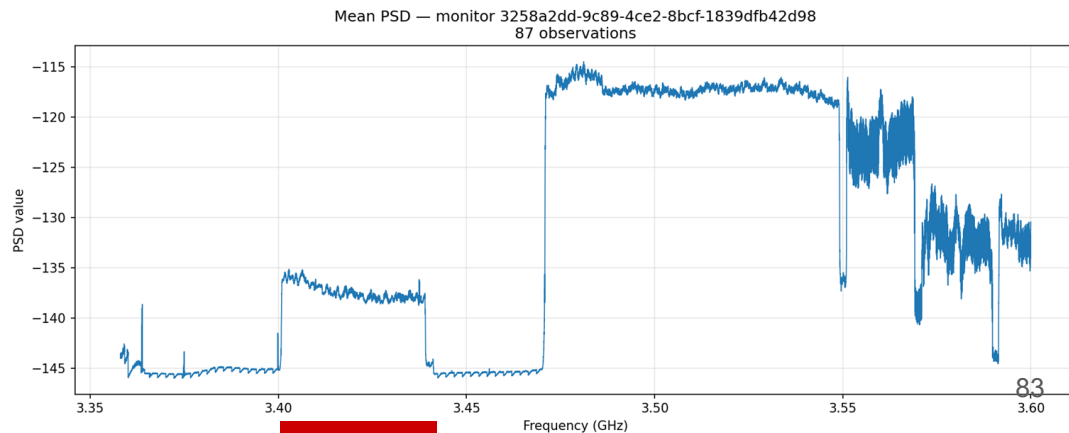
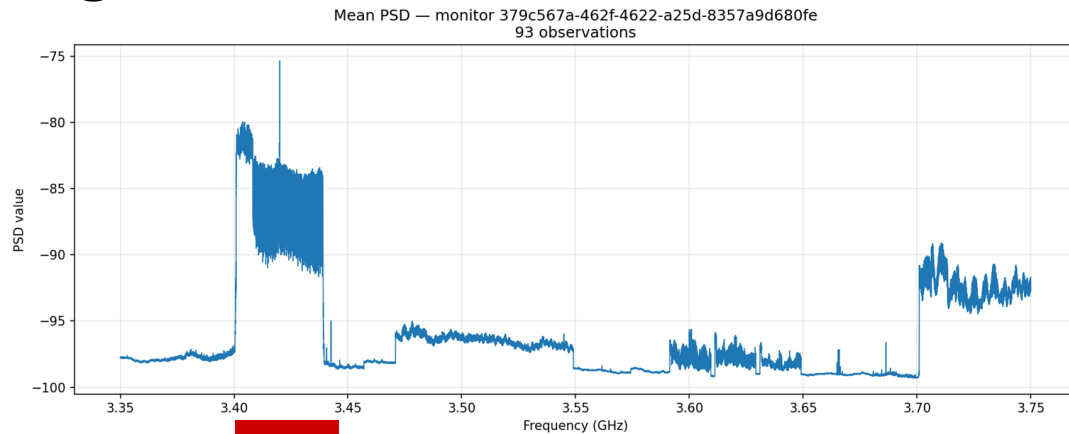
- Goal: use data lake to verify absence of incumbent use and RFI in experiment operational range (3.40-3.44G – approx [REDACTED])
 - Using spectrum data (SigMF PSD) archived into data lake from OpenZMS monitors in POWDER
 - Originally sourced from OpenZMS monitors in POWDER
 - 2026-09-20T16:30:00Z + 30min
- Upper plot: Signalhound SM200C sweep PSD, located on same rooftop as DriveSafe O-RUs (3.35-3.75 GHz)
- Lower plot: NI X310 with POWDER OTA rfmonitor sweep PSD, located on Ustar rooftop (3.358-3.60 GHz)





Observing Spectrum: **During** “front-middle” Run

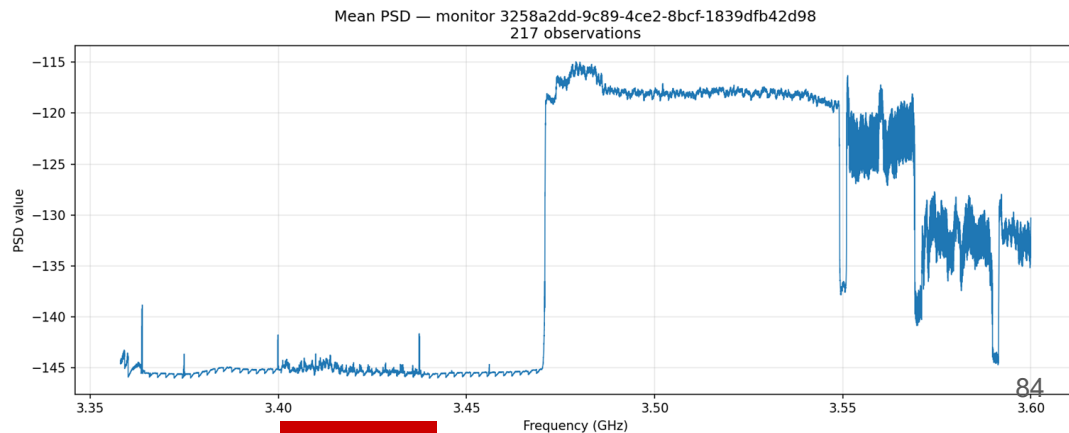
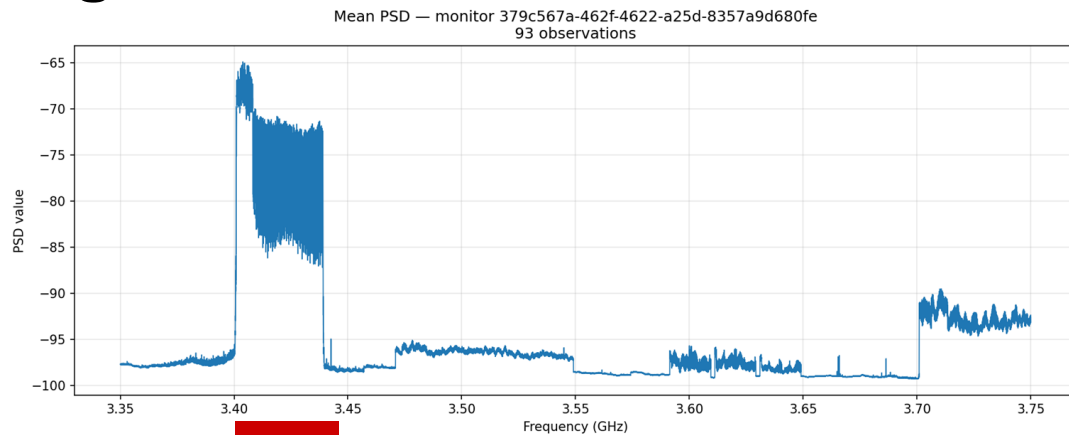
- Goal: use data lake to observe DriveSafe experiment transmissions (3.40-3.44G)
 - Focusing on “front-middle” run
 - 2026-09-20T19:12:26Z + 10min
- Upper plot: Signalhound SM200C sweep PSD, located on same rooftop as DriveSafe O-RUs (3.35-3.75 GHz)
- Lower plot: NI X310 with POWDER OTA rfmonitor sweep PSD, located on Ustar rooftop (3.358-3.60 GHz)





Observing Spectrum: **During** “back-left-middle” Run

- Goal: use data lake to observe DriveSafe experiment transmissions (3.40-3.44G)
 - Focusing on “back-left-middle” run
 - 2026-09-20T19:22:26Z + 10min
- Upper plot: Signalhound SM200C sweep PSD, located on same rooftop as DriveSafe O-RUs (3.35-3.75 GHz)
- Lower plot: NI X310 with POWDER OTA rfmonitor sweep PSD, located on Ustar rooftop (3.358-3.60 GHz)





Observing Spectrum: **During** “back-left-middle” Run

- Goal: use data lake to observe DriveSafe experiment transmissions (3.40-3.44G)

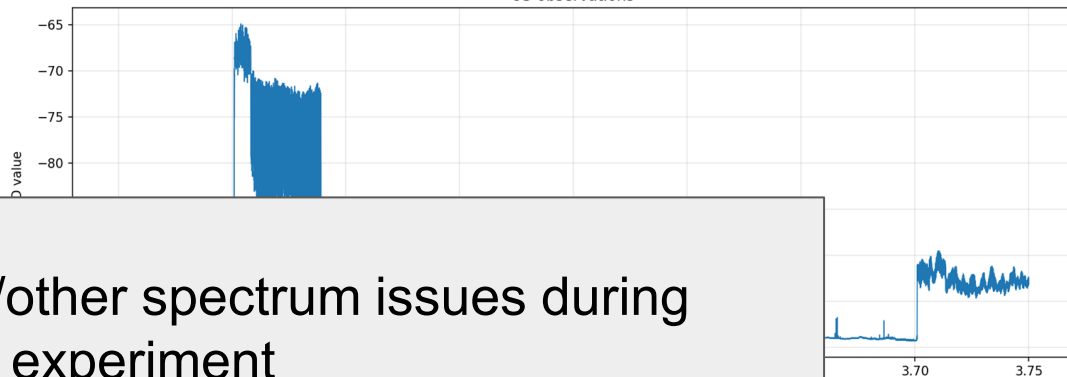
- For
- ru
- 20

- Upper SM200

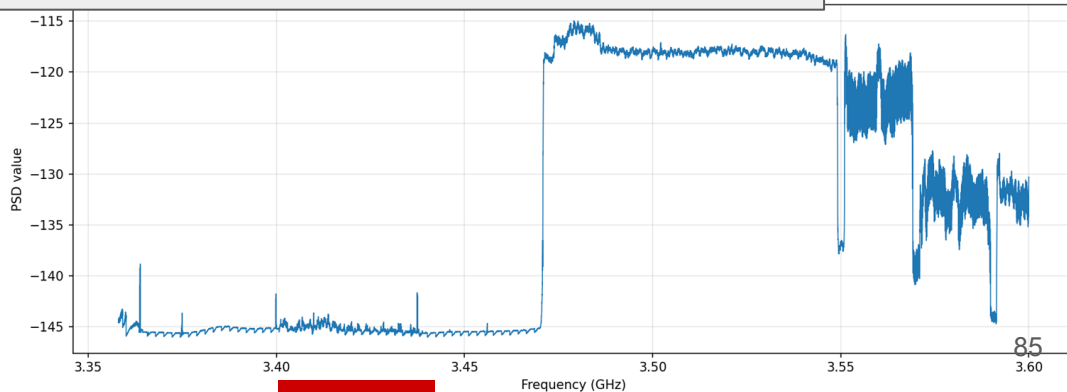
on same rooftop as DriveSafe O-RUs (3.35-3.75 GHz)

- Lower plot: NI X310 with POWDER OTA rfmonitor sweep PSD, located on Ustar rooftop (3.358-3.60 GHz)

Mean PSD — monitor 379c567a-462f-4622-a25d-8357a9d680fe
93 observations



No apparent RFI/other spectrum issues during experiment

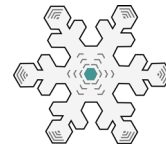




CyberPowder - Wireless Network Workforce Development



CyberPowder - Wireless Networking Workforce Development using the POWDER platform



Problem: *Experimental Wireless Research is Challenging:*

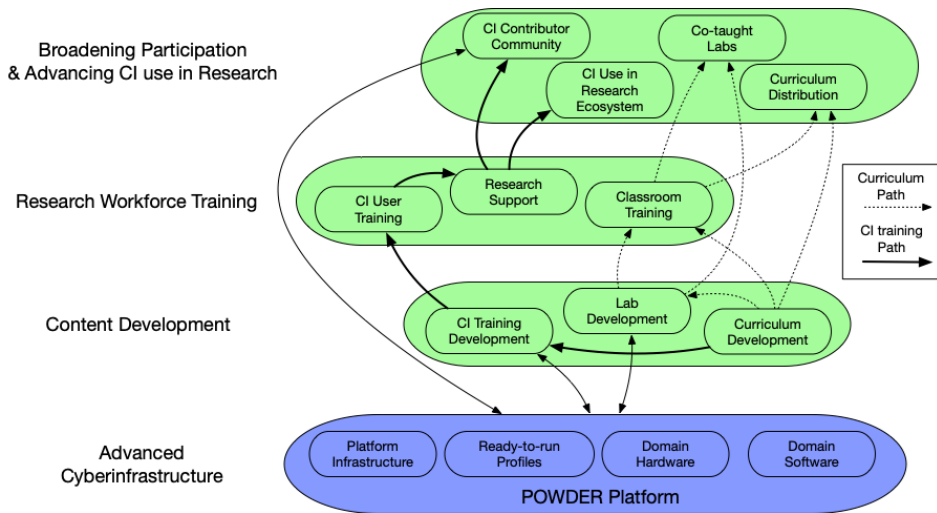
- Inherently multidisciplinary; Rapidly technology/regulatory change; Testbeds sophisticated/difficult to use

CyberPowder Intellectual Merit: Enable Transformative Experimental Wireless Research:

- Develop Wireless Networking training material: Use in classroom & train-the-trainer training; Basis for CI training
- **Cohort-based CI research workforce training**: Recruit across US; Virtual & in-person; Engage with local advisors; Follow-on CI use support
- Wireless community experimental research: Nudge community this direction; Artifact evaluation program

CyberPowder Broader Impact: Strengthen US Wireless Networking Research

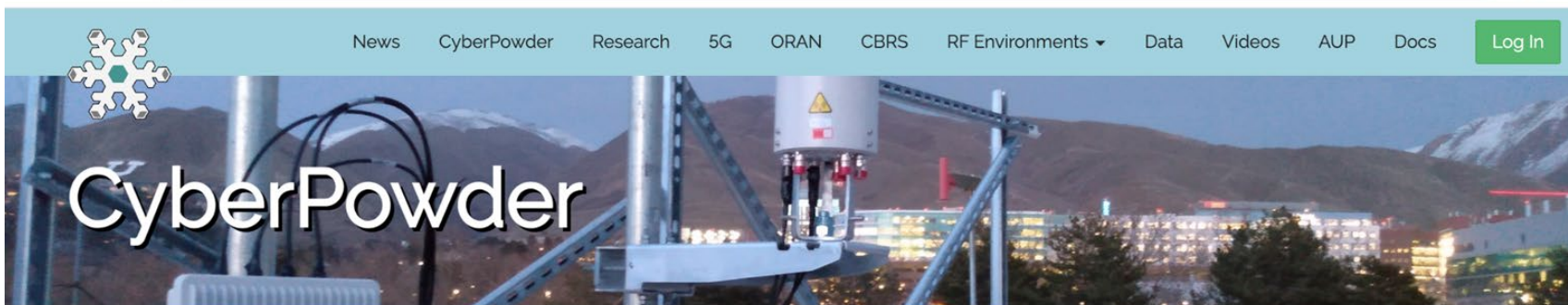
- Broaden & democratize use Wireless Networking CI; Research workforce development; US global leadership in wireless networking



NSF award: # 2417934

Kobus Van der Merwe (PI)
Neal Patwari (Co-PI)
Rob Ricci (Co-PI)

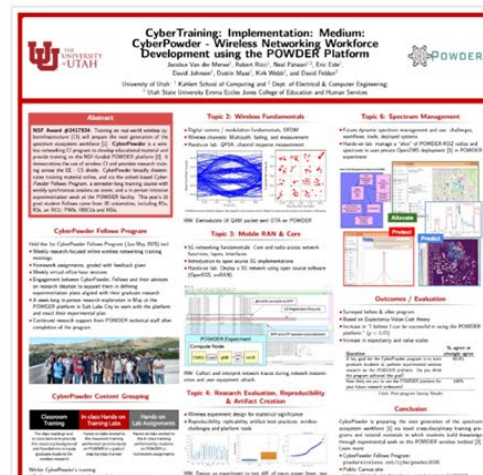




CyberPowder Overview

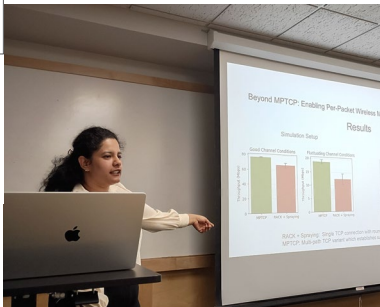
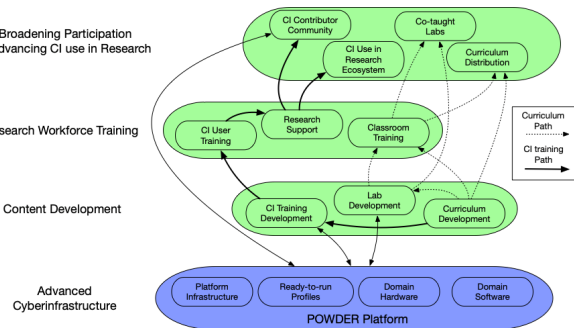
CyberPowder is a project funded (grant #: [2417934](#)) by the [NSF CyberTraining](#) program in the Office of Advanced Cyberinfrastructure (OAC) in the Directorate for Computer and Information Science and Engineering (CISE).

CyberPowder develops wireless networking content and training material for both classroom teaching and hands-on cyberinfrastructure training. Classroom teaching focuses on developing and teaching curricula that address the inherent multi-disciplinary nature of wireless networking by co-teaching material that is traditionally siloed in either the computer science or electrical engineering disciplines. CyberPowder's cyberinfrastructure training follows a novel cohort approach that combines online and in-person, research-focused training on the POWDER platform, followed by structured research support involving both the trainees and their faculty advisors. The cyberinfrastructure training program provides training on the use of wireless networking and experimental research fundamentals as well as specific advanced wireless technologies.



CyberPowder - Wireless Networking Workforce Development using the POWDER platform

PI: Kobus Van der Merwe, Co-PIs: Rob Ricci and Neal Patwari
(University of Utah - UofU)



Project Goals and Significance

- **Hands-on training of next generation spectrum ecosystem workforce**
- Develop wireless networking educational material & provide training using the NSF-funded POWDER testbed
- Cohort-based research-focused training of graduate students from across the US

Accomplishments and Highlights

- Conducted CyberPowder Fellows Program - 2026
 - Spring 2026: 14-week virtual training & 1-week in-person
 - Domain science; CI Hands-on; Research Ideation, Research Execution; Staff support;
 - Applications: 54 graduate students from 36 US universities
 - Fellows: 25 graduate students from 25 universities
- Conducted Classroom Training at UofU
 - Combined undergrad/grad + ECE/CS
- CyberPowder 2025 Cohort: 3 publications





CyberPowder Fellows: 4 Components, 3 Content Types

1. **Online training:** Weekly zoom class, readings, group lab work, homework assigned

Classroom Training	In-class Hands-on Training Labs	Hands-on Lab Assignments
Pre-class readings and in-class lecture to provide the necessary background and foundations to equip graduate students for wireless research	Hands-on labs related to the classroom training performed synchronously on POWDER in a guided step-by-step manner	Hands-on labs related to the in-class training performed by students on POWDER as homework assignments

Crossing the EE / CS boundary from the “air” to the “cloud”:

1. POWDER concepts/workflow
2. Wireless fundamentals
3. Mobile networking
4. Experimental evaluation, repeatability & artifact creation
5. Open RAN + ML
6. Spectrum sharing/management

2. **Research ideation:** Engaging with students (and advisors); map to POWDER resources

3. **In-person research exploration:** includes weeklong event at UofU

4. **Continued support** after program completes

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CyberPowder Fellows Program - 2027

Accepting applications for
**2027 CyberPowder Fellows
Program**

Call for Applications

CyberPowder 2027

We are pleased to announce that we are accepting applications for the 2027 *CyberPowder Fellows Program*. CyberPowder is an NSF-funded wireless networking hands-on training and research mentoring program for US-based graduate students. (NSF CyberTraining award number: [2417934](#))

<https://www.powderwireless.net/cyberpowder2027>

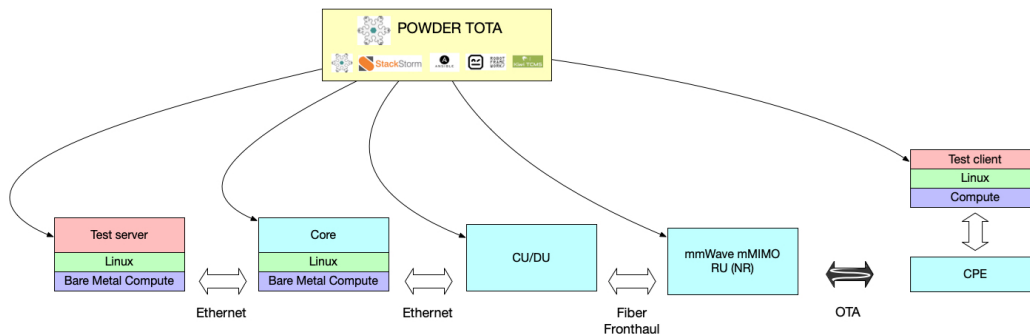
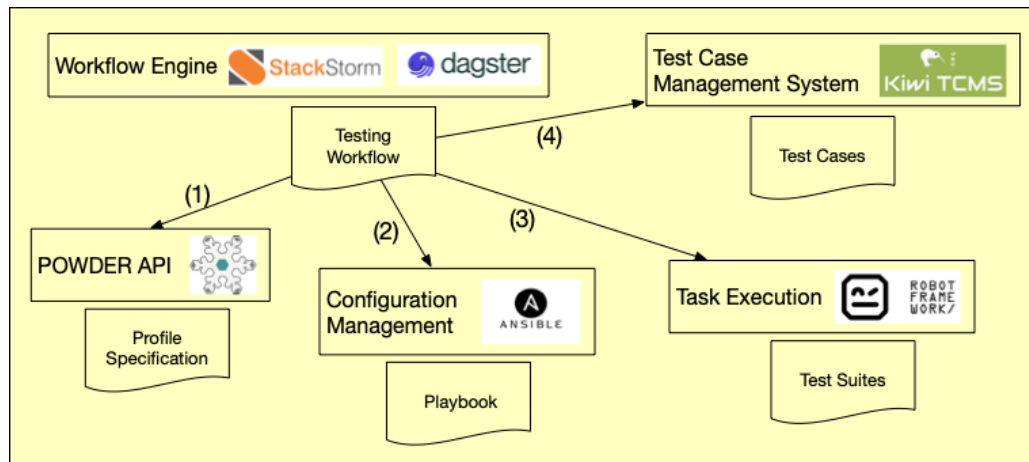




POWDER OTIC



POWDER OTIC



Sophisticated 5G/NextG/Open RAN testing environment

- O-RAN Alliance **Open Test and Integration Center (OTIC)**
- Open RAN & 5G/NextG related testing
 - E2E and functional testing
- Developed Testing Orchestration & Testing Automation (TOTA) framework
 - Integrates with POWDER to “orchestrate” test setup
 - Interact with commercial/open source tools to “automate” testing

Focus on over-the-air (OTA) and automation

Over the Air Evaluation of Jamming Detection & Mitigation using OCUDU



Goal:

- Over the Air evaluation of jamming detection and mitigation methods for 5G/6G networks
- Unlock the potential of open source OCUDU RAN for network resiliency
- Generate realistic training and test datasets for AI/ML - driven detection & mitigation

Next steps:

- Real-time jamming detection & mitigation based on RAN metrics exposed by OCUDU
- Near real-time AI/ML-based jamming detection in the OTA scenario
- Dynamic AI/ML-based MCS adaptation in response to detected jamming
- Closed-loop detection and mitigation using OCUDU and POWDER network

POWDER testbed:

- Real 5G/O - RAN setup deployed on POWDER
- OCUDU gNB + commercial UE for the 5G connection
- SDR-based interference generator for controlled jamming
- RAN and RF measurements collected during experiment

What do we use it for?

- Create controlled jamming scenarios
- Measure the impact of CQI, MCS, NACKs, RSRP, etc. on OCUDU - based RAN
- Build dataset covering different interference levels and network conditions
- Deploy, train and evaluate the Jamming Detection & Mitigation using OCUDU



rimedolabs.com