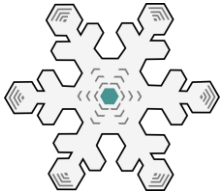


Towards frictionless reproducibility in the POWDER platform

Kobus Van der Merwe
kobus@cs.utah.edu

https://powderwireless.net

NSF award: # 1827940

Platforms for Advanced Wireless Research

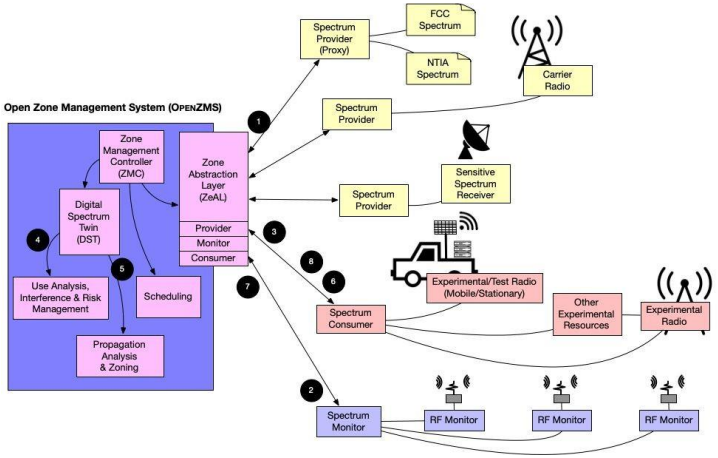
THE UNIVERSITY OF UTAH

RICE

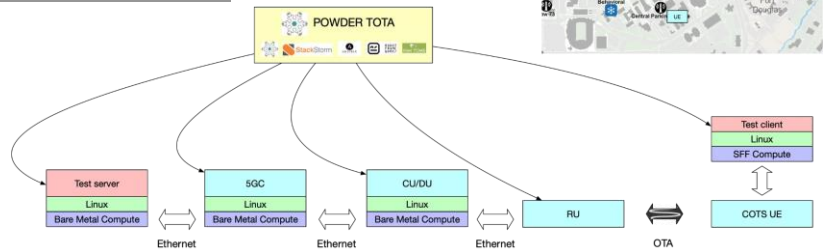
Washington University in St. Louis

POWDER Ecosystem Overview

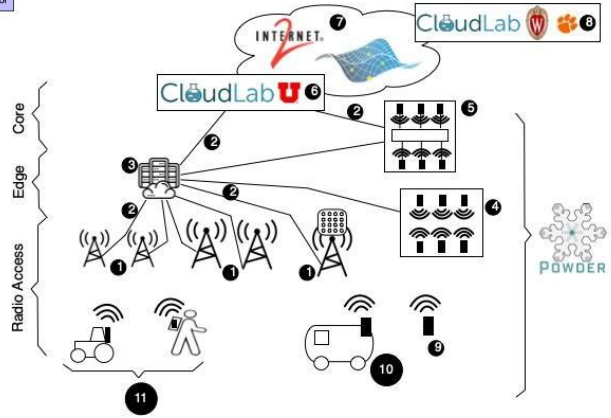
POWDER "Ecosystem"



POWDER Radio Dynamic Zone (RDZ)



POWDER Open RAN Open Test and Integration Center (OTIC)



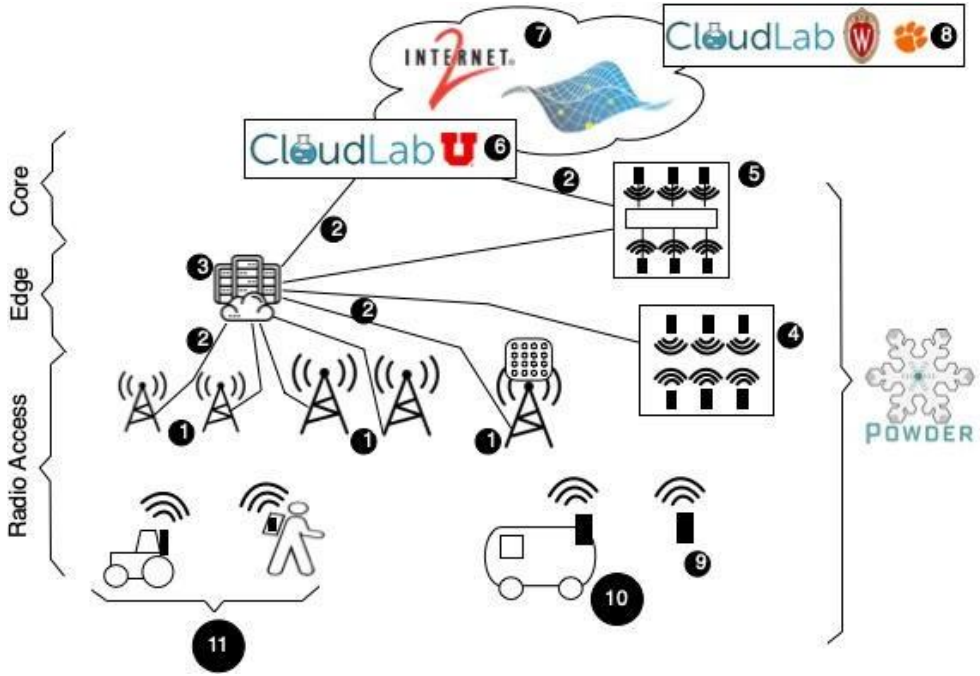
POWDER Platform

(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

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 ffexible real-world lab-as-a-service



(1) Basestation (rooftop, mMIMO, dense), (2) Fiber front/backhaul,
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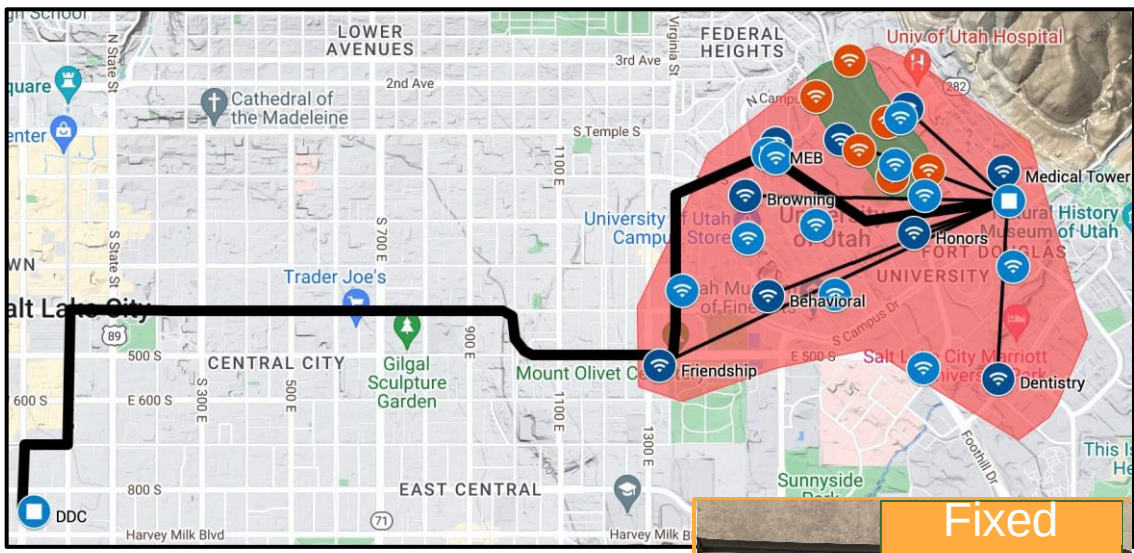
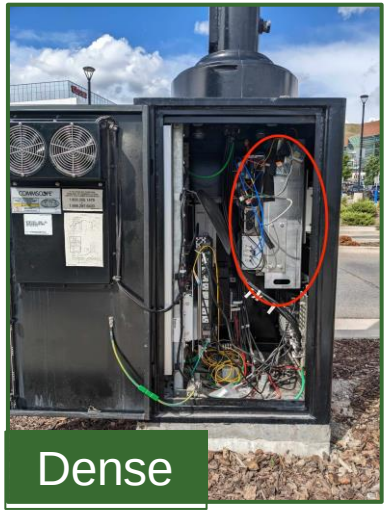
(10) Predictable courier w/ endpoint, (11) Other courier w/endpoint


Rooftop

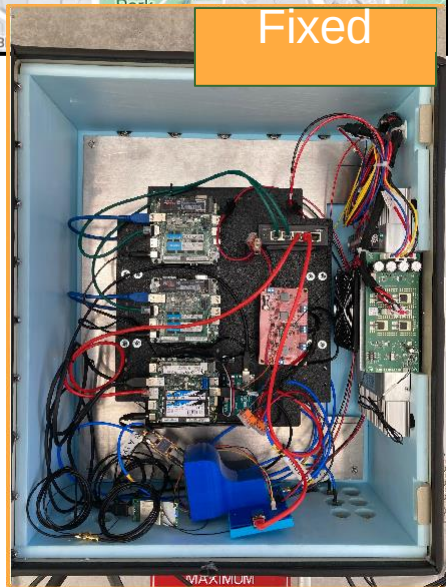

Dense

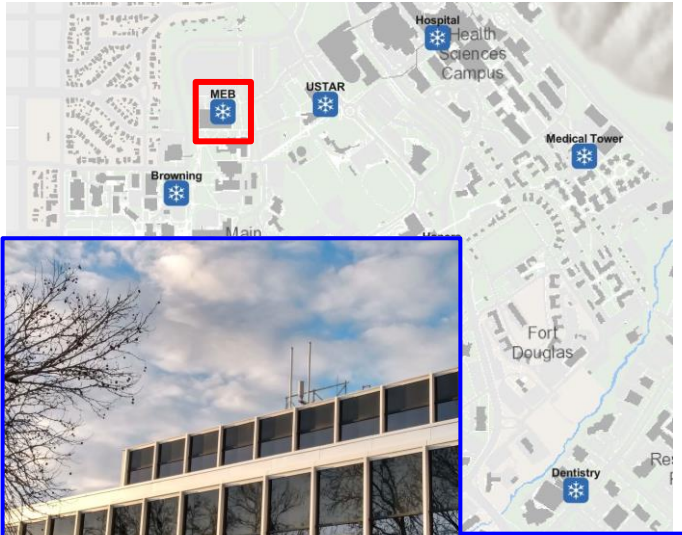

LOWER AVENUES
FEDERAL HEIGHTS
Univ of Utah Hospital
3rd Ave
2nd Ave
Virginia St
N State St
Cathedral of the Madeleine
S Temple S
1100 E
MEB
Medical Tower
Browning
Honors
University Campu
Trader Joe's
S State St
S 700 E
UNIVERSITY
Behavioral
Friendship
Dentistry
500 S
CENTRAL CITY
Gilgal Sculpture Garden
900 E
600 S
E 600 S
S 300 E
500 E
1100 E
1300 E
800 S
EAST CENTRAL
DDC
Harvey Milk Blvd
Sunnyside


Rooftop


Dense

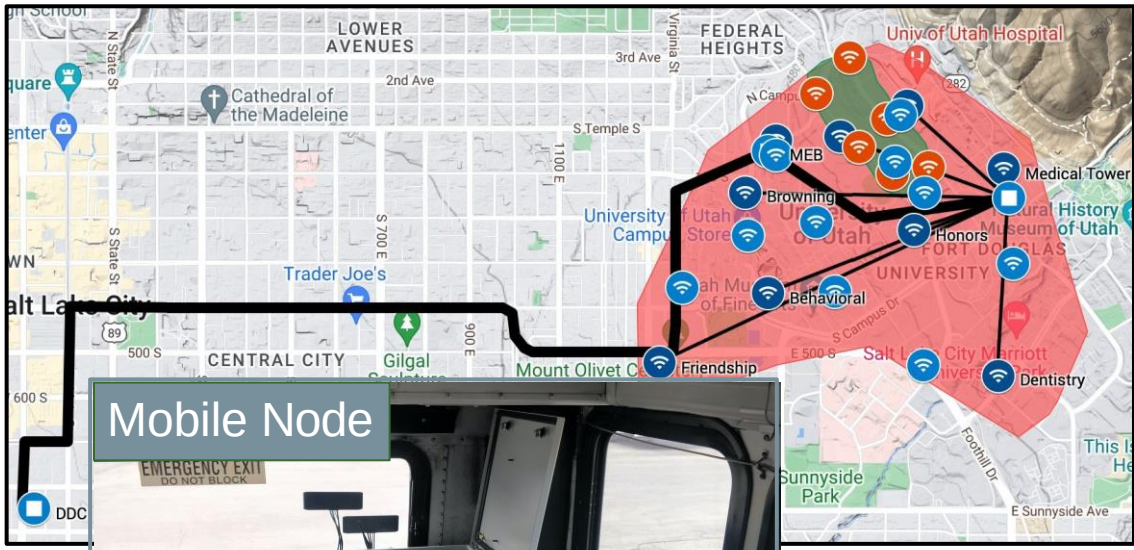

Fixed


Fixed


Hospital
Health Sciences Campus
MEB
USTAR
Medical Tower
Browning
Main
Fort Douglas
Dentistry

O-RU


O-RU


LOWER AVENUES
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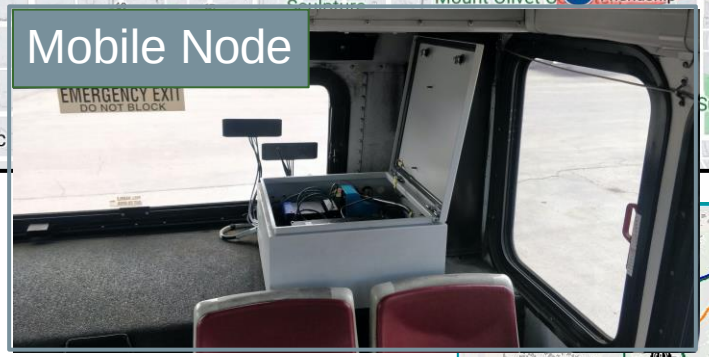
600 S
DDC
Sunnyside Park
E Sunnyside Ave
Foothill Dr
UNIVERSITY
FORT DOUGLAS


Mobile Node
EMERGENCY EXIT
DO NOT BLOCK

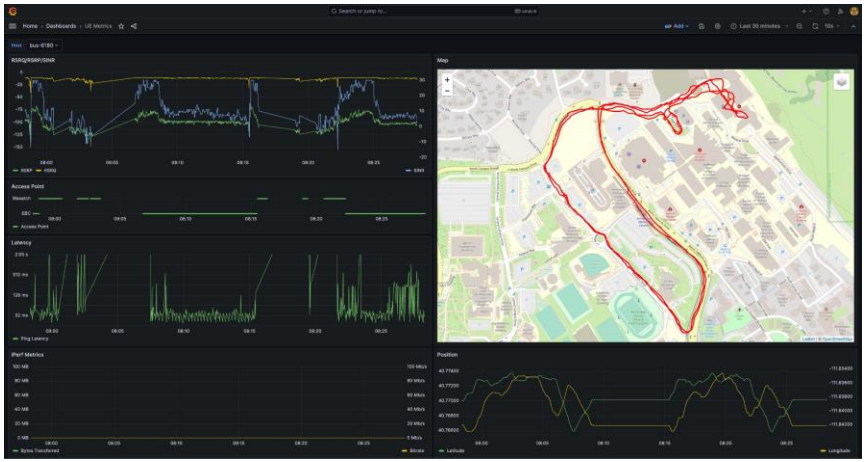

Mobile Node
Campus Shuttle

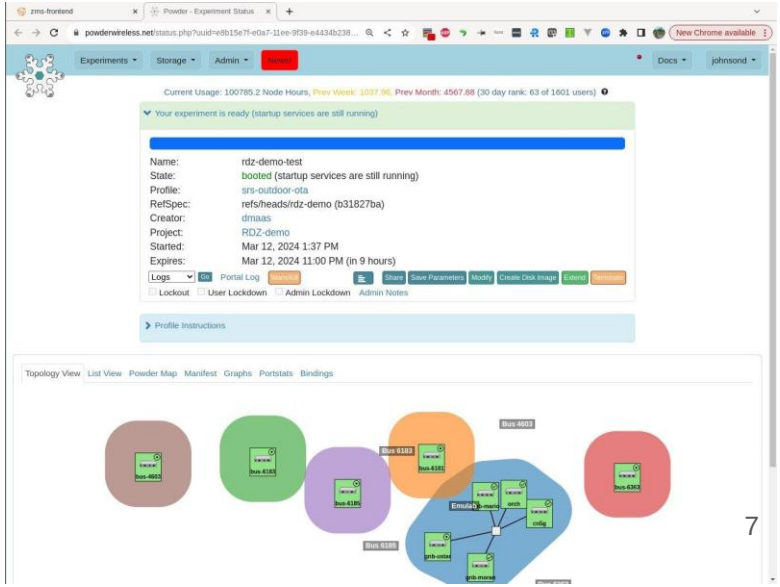

Hospital
Health Sciences Campus
USTAR
Medical Tower
Browning
Honors
Bookstore
Behavioral
Central Parking Garage
Fort Douglas
Dentistry
VA Hospital

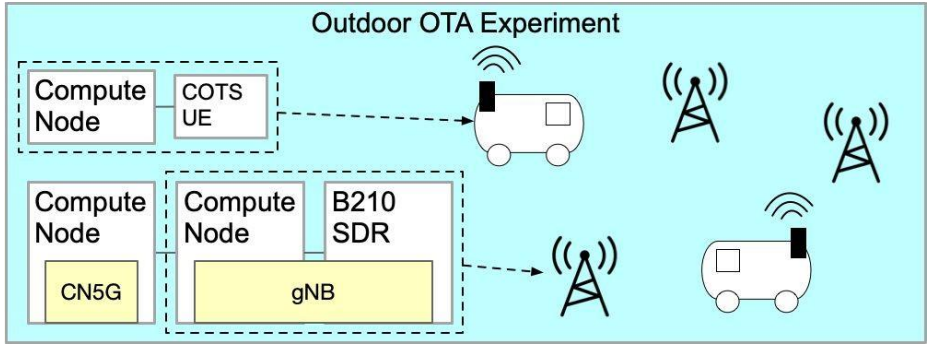
Illustrative example

From “nothing” to operational 5G network in less than 10 minutes

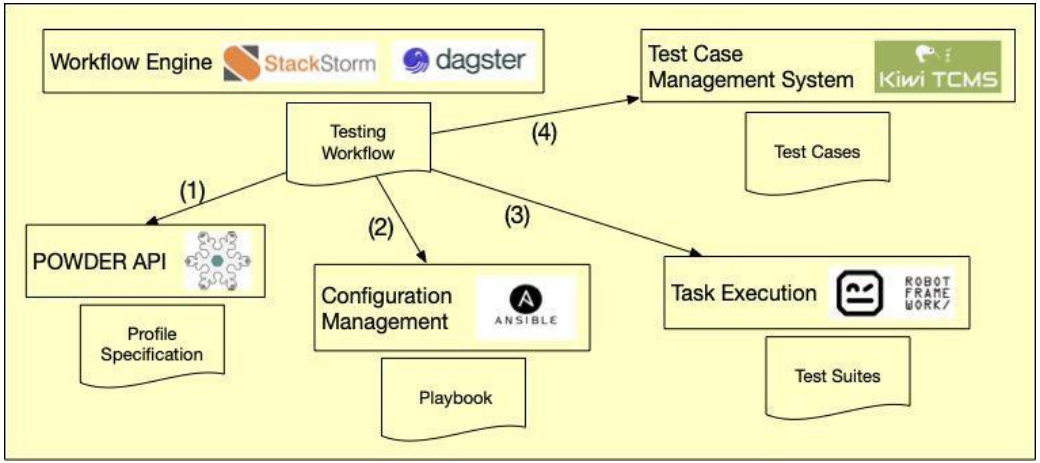
- Operating over-the-air
- With open source building blocks
- Remote access to user equipment on campus shuttle
- Data being collected for analysis

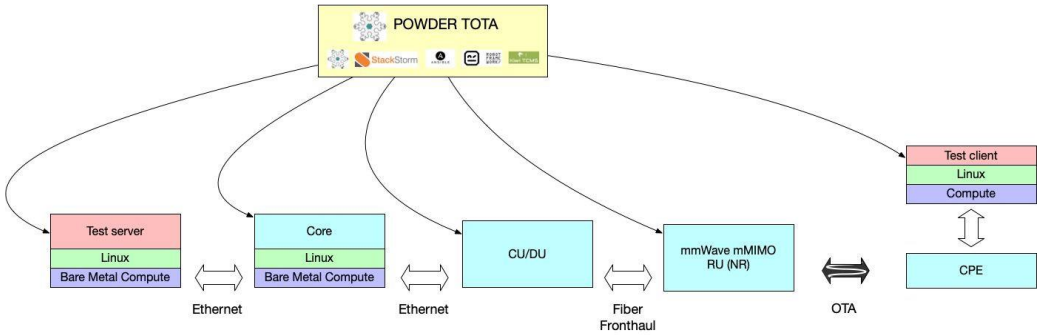






POWDER OTIC





- 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

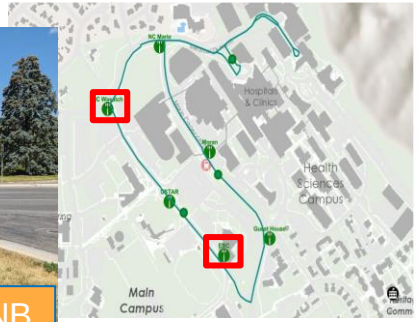
Sophisticated 5G/NextG/Open RAN testing environment

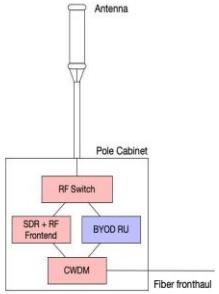
Illustrative examples

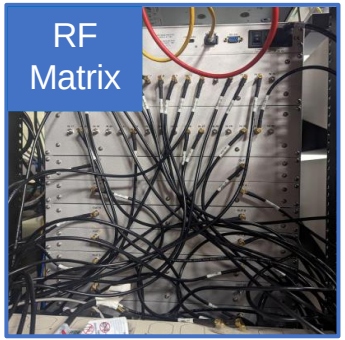
- Private-5G vendor (Celona) using POWDER for handover testing in real world environment
- O-RAN vendor (Mavenir) using POWDER for 5G mMIMO mmWave testing
- Handover testing with COTS RU and open source CU/DU (srsRAN + Benetel)

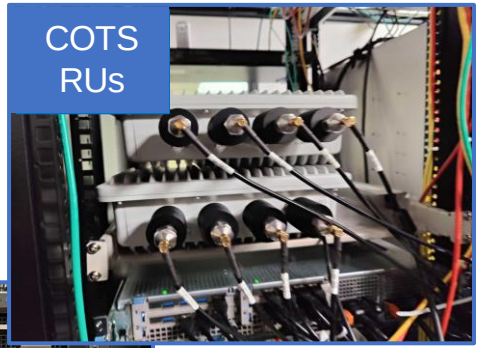
Mix of BYOD + POWDER equipment

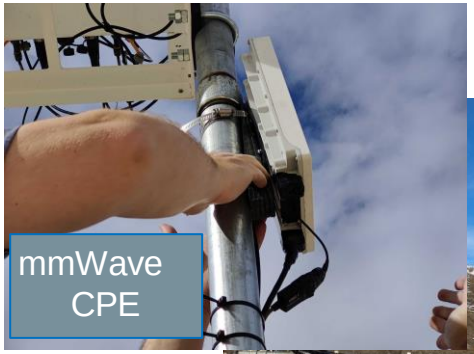
Using POWDER TOTA workflow











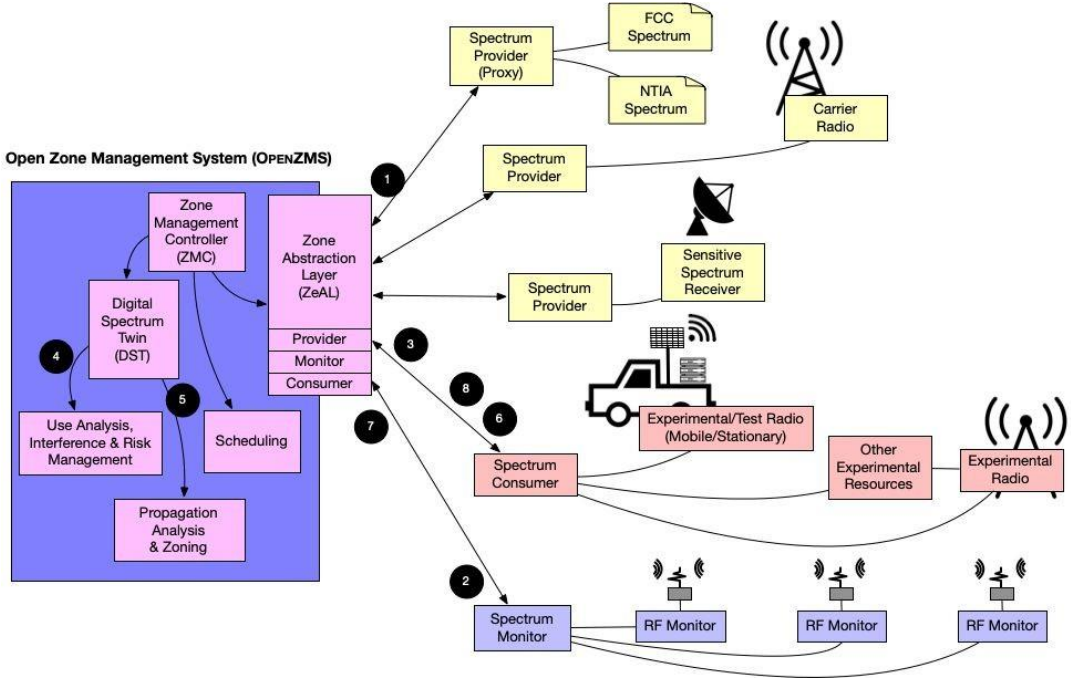
POWDER-RDZ

OpenZMS

NRDZ National Radio Dynamic Zone

- Use POWDER to prototype a radio dynamic zone (RDZ)
- Explore use cases and workflows to define software architecture: roles, interfaces, APIs
- Build an open source Zone Management System (***OpenZMS***)
  - Separate from POWDER: well-defined interface to integrate at any facility
- POWDER-RDZ: use OpenZMS to manage spectrum for POWDER

Operational (prototype) RDZ



THE UNIVERSITY OF UTAH — Kobus Van der Merwe, Sneha Kasera, # 2232463

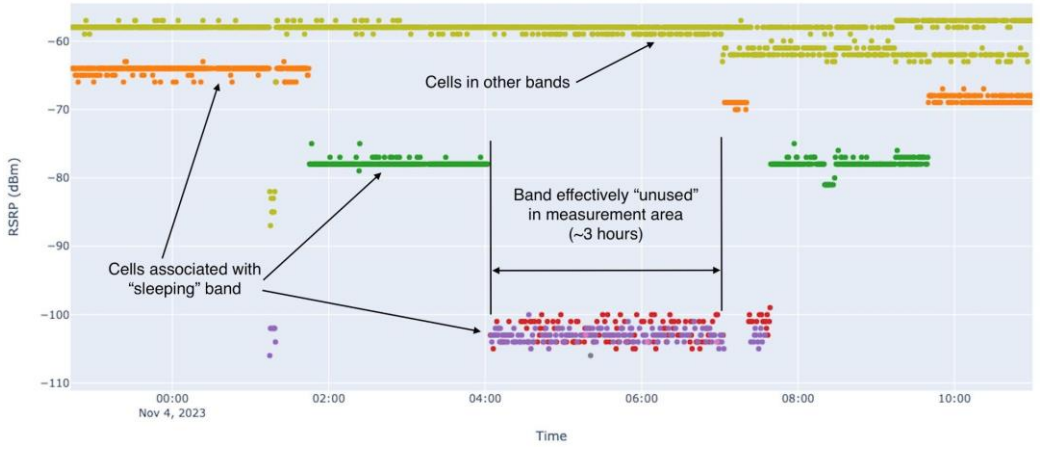
Washington University in St. Louis — Neal Patwari, # 2232464

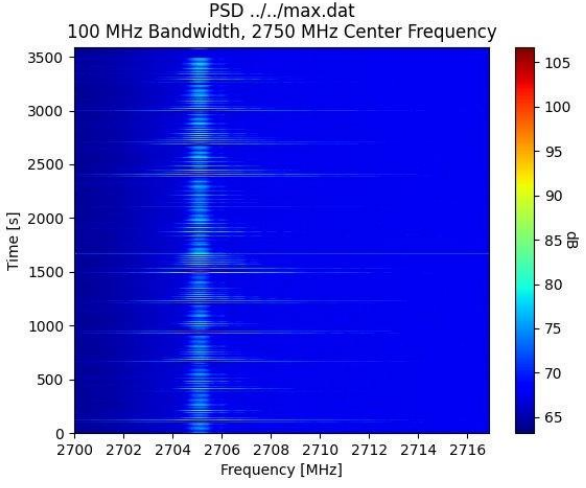
Georgia Tech — Greg Durgin, #2232465

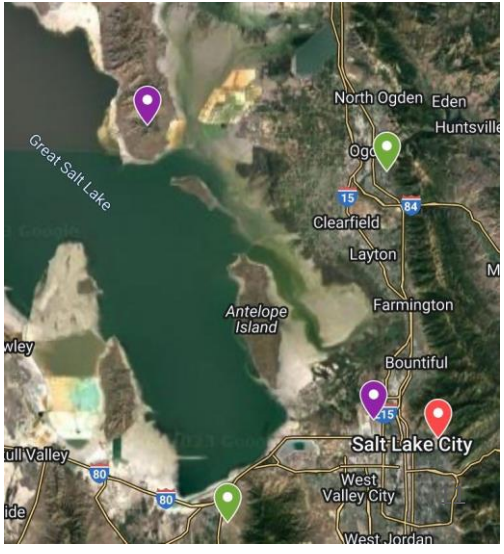
AT&T — Vijay Gopalakrishnan

Illustrative examples

- POWDER spectrum access:
  - Program experimental license (PEL)
  - FCC Innovation Zone
  - Allowed to use, but not interfere
- OpenZMS:
  - Operational spectral intelligence and management
  - More on PEL coming up
- Other use cases ->
  - Sharing with commercial provider
  - Sharing with federal radar systems



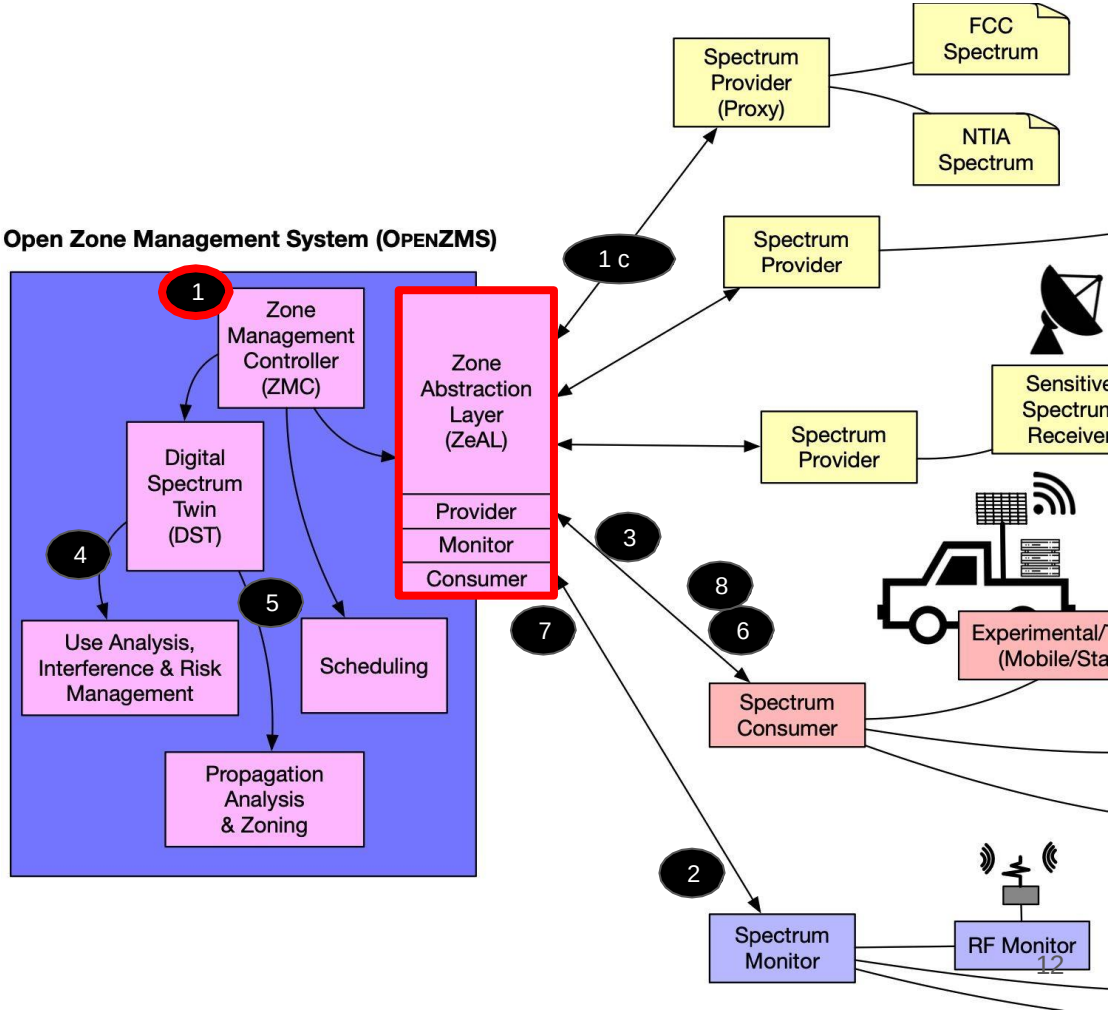




Use case: PEL Workflow

Program Experimental License (PEL)

1. ***Initialization***
   a. Role/element player registration
   b. Initial RDZ geography, models
   c. Spectrum available through PEL



Use case: PEL Workflow

Program Experimental License (PEL)

1. Initialization
   a. Role/element player registration
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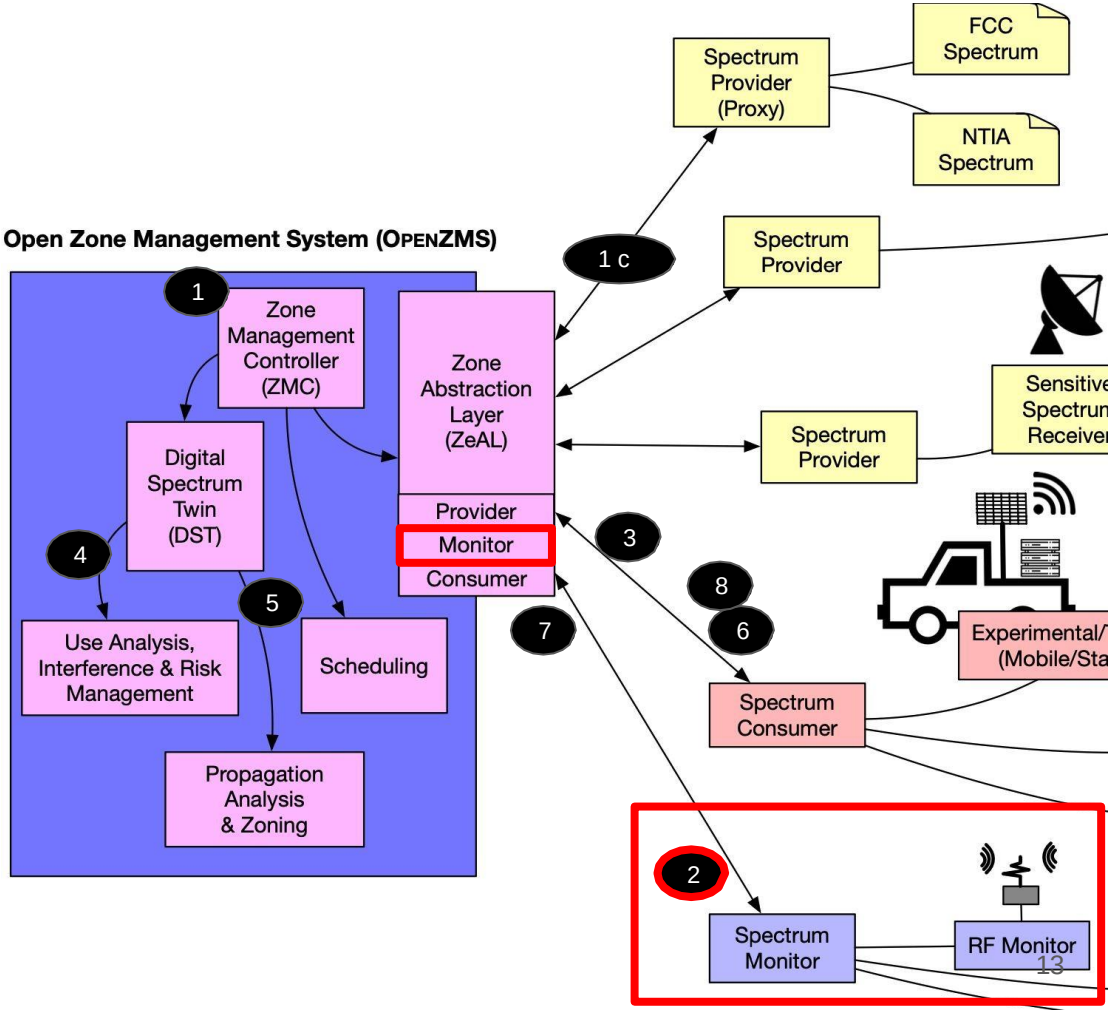
2. ***ZMS observes PEL spectrum range*** *(monitor)*, data into DST *(in ZMS)*



Use case: PEL Workflow

Program Experimental License (PEL)

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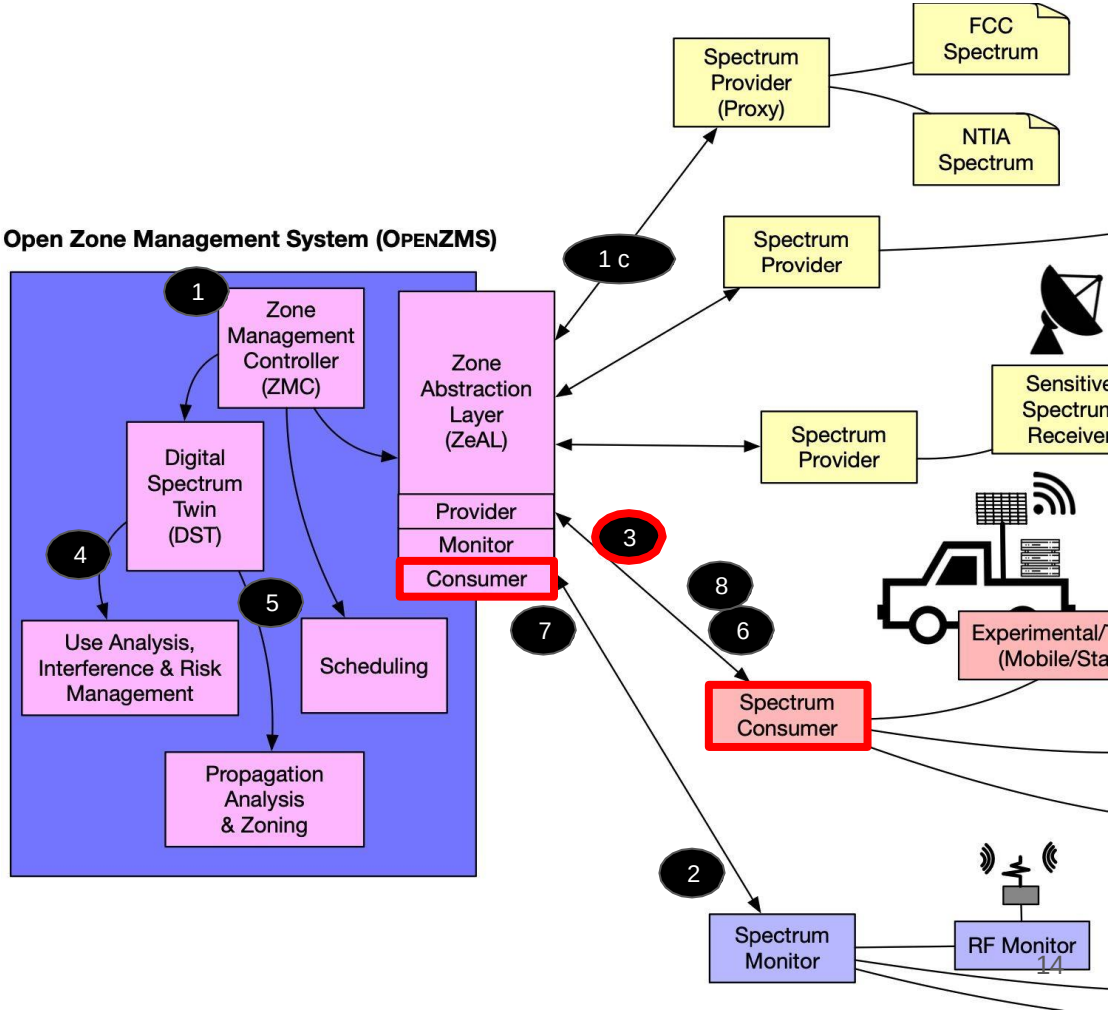
2. ZMS observes PEL spectrum range *(monitor)*, data into DST *(in ZMS)*
3. ***Request to use spectrum from platform*** *(consumer)* (X MHz in range Y-Z MHz)



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Program Experimental License (PEL)

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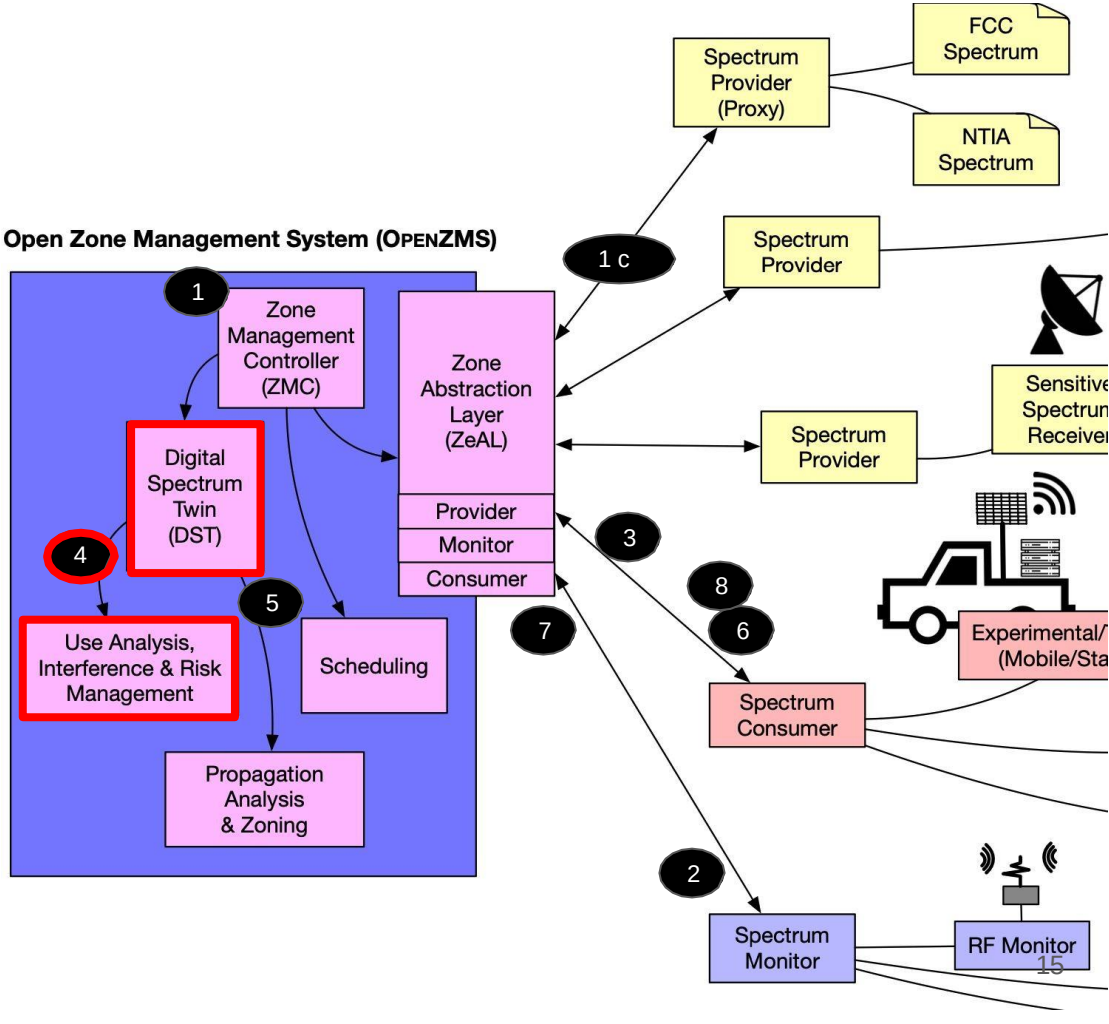
2. ZMS observes PEL spectrum range *(monitor)*, data into DST *(in ZMS)*
3. Request to use spectrum from platform *(consumer)* (X MHz in range Y-Z MHz)
4. ***Use monitor data to determine if/where request fits*** *(in ZMS)*



Use case: PEL Workflow

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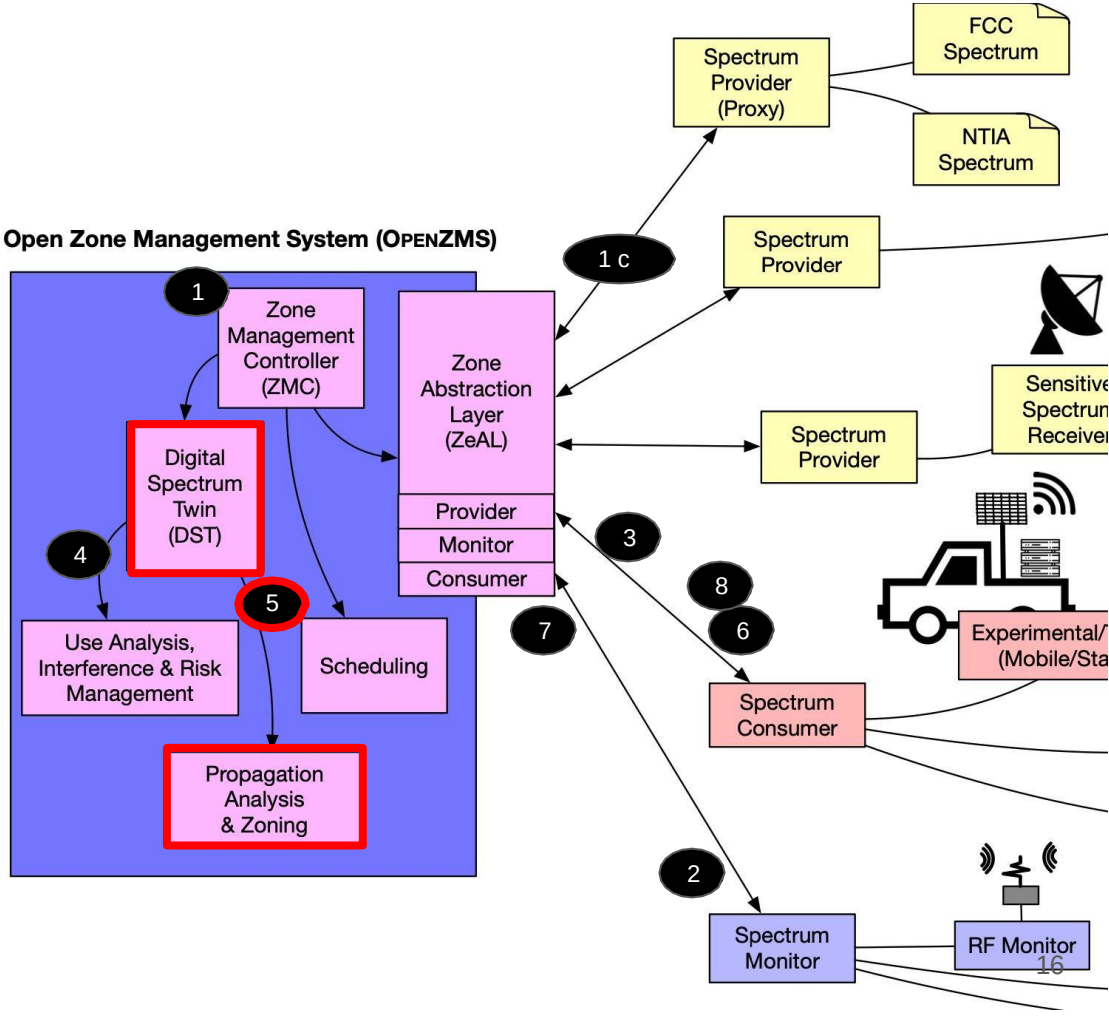
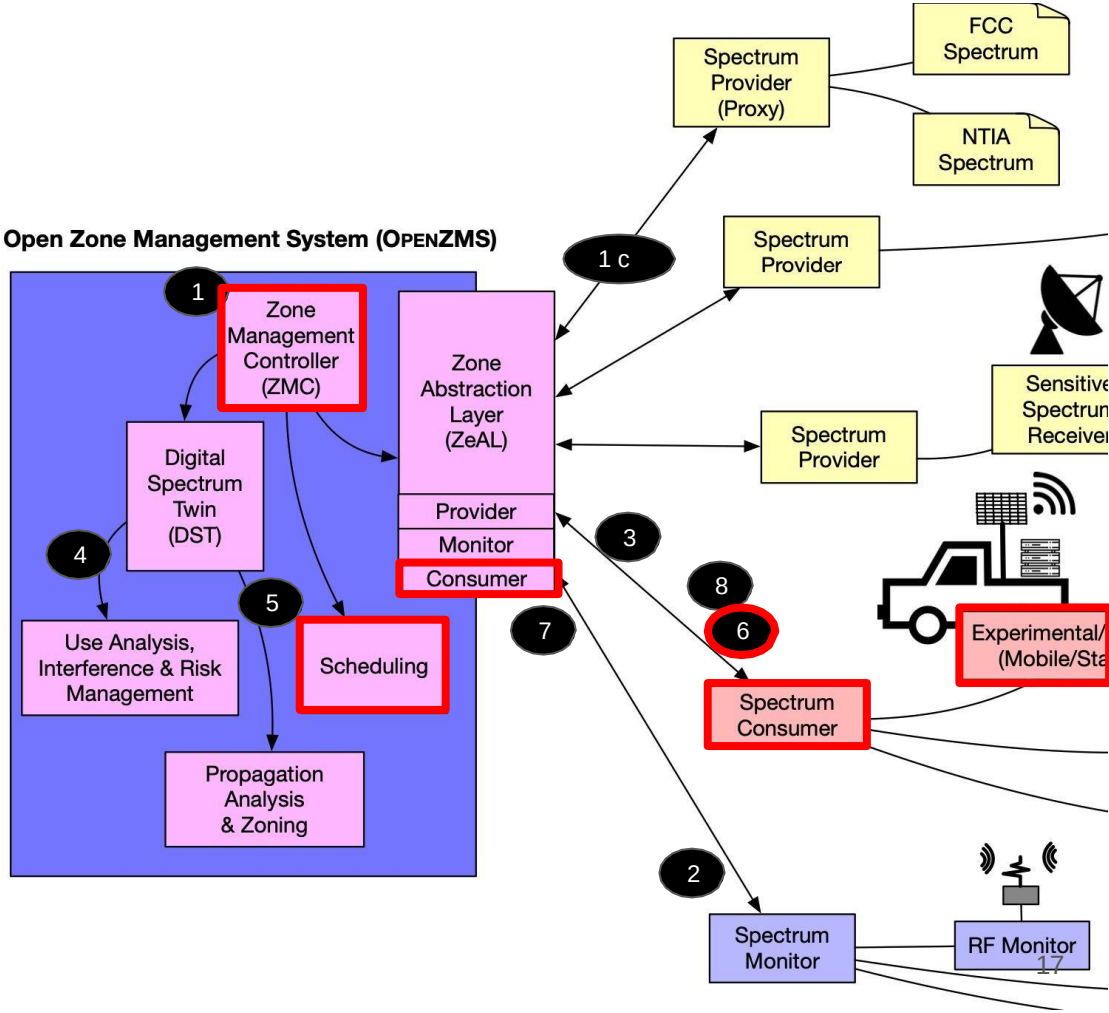
   c. Spectrum available through PEL
2. ZMS observes PEL spectrum range *(monitor)*, data into DST *(in ZMS)*
3. Request to use spectrum from platform *(consumer)* (X MHz in range Y-Z MHz)
4. Use monitor data to determine if/where request fits *(in ZMS)*
5. ***Use propagation analysis to ensure test will not interfere*** outside RDZ *(in ZMS)*



Use case: PEL Workflow

Program Experimental License (PEL)

1. Initialization
   a. Role/element player registration
   b. Initial RDZ geography, models
   c. Spectrum available through PEL
2. ZMS observes PEL spectrum range *(monitor)*, data into DST *(in ZMS)*
3. Request to use spectrum from platform *(consumer)* (X MHz in range Y-Z MHz)
4. Use monitor data to determine if/where request fits *(in ZMS)*
5. Use propagation analysis to ensure test will not interfere outside RDZ *(in ZMS)*
6. ***Notify platform (consumer) to proceed***



Use case: PEL Workflow

Program Experimental License (PEL)

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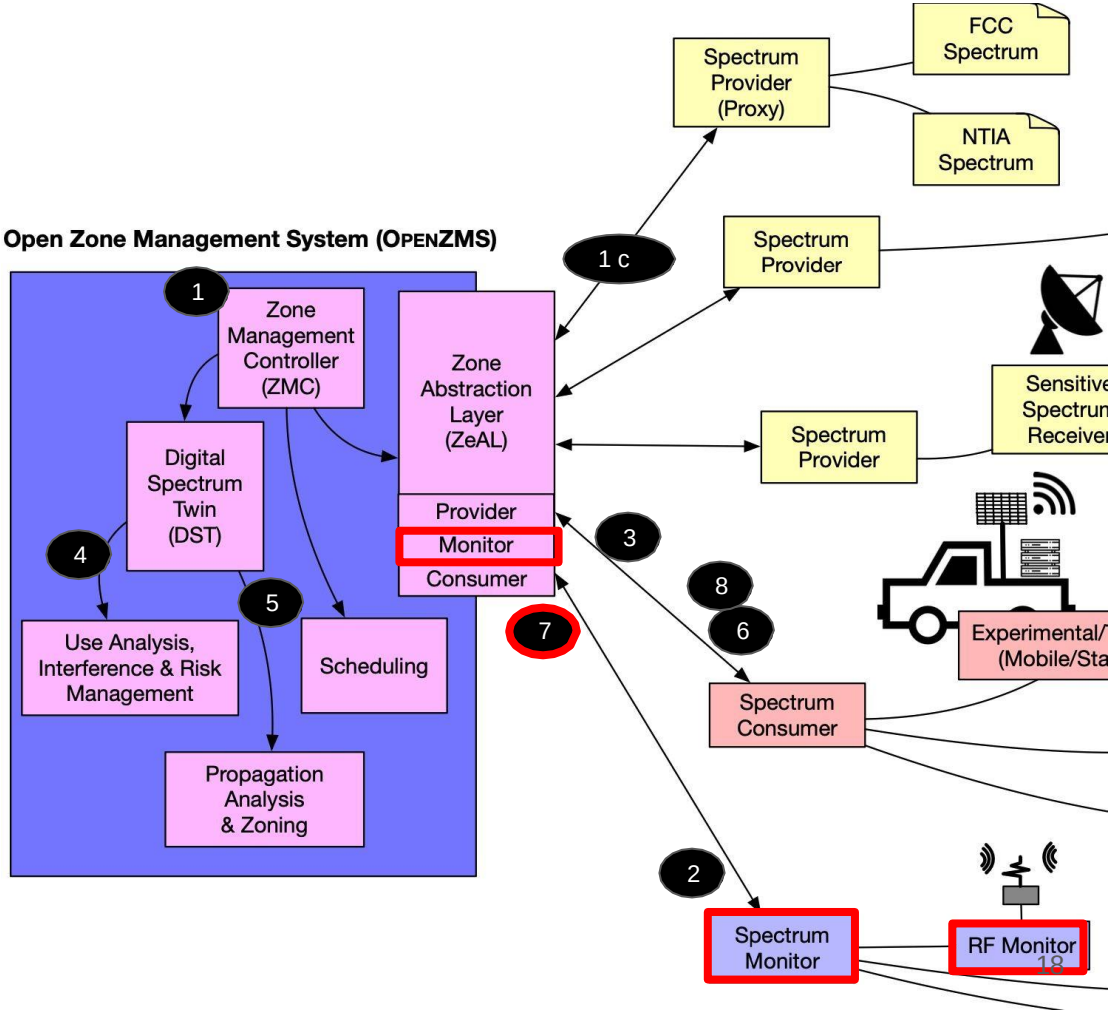
   b. Initial RDZ geography, models
   c. Spectrum available through PEL
2. ZMS observes PEL spectrum range *(monitor)*, data into DST *(in ZMS)*
3. Request to use spectrum from platform *(consumer)* (X MHz in range Y-Z MHz)
4. Use monitor data to determine if/where request fits *(in ZMS)*
5. Use propagation analysis to ensure test will not interfere outside RDZ *(in ZMS)*
6. Notify platform *(consumer)* to proceed
7. ***If spectrum monitor (monitor) indicates interference…***



Use case: PEL Workflow

Program Experimental License (PEL)

1. Initialization
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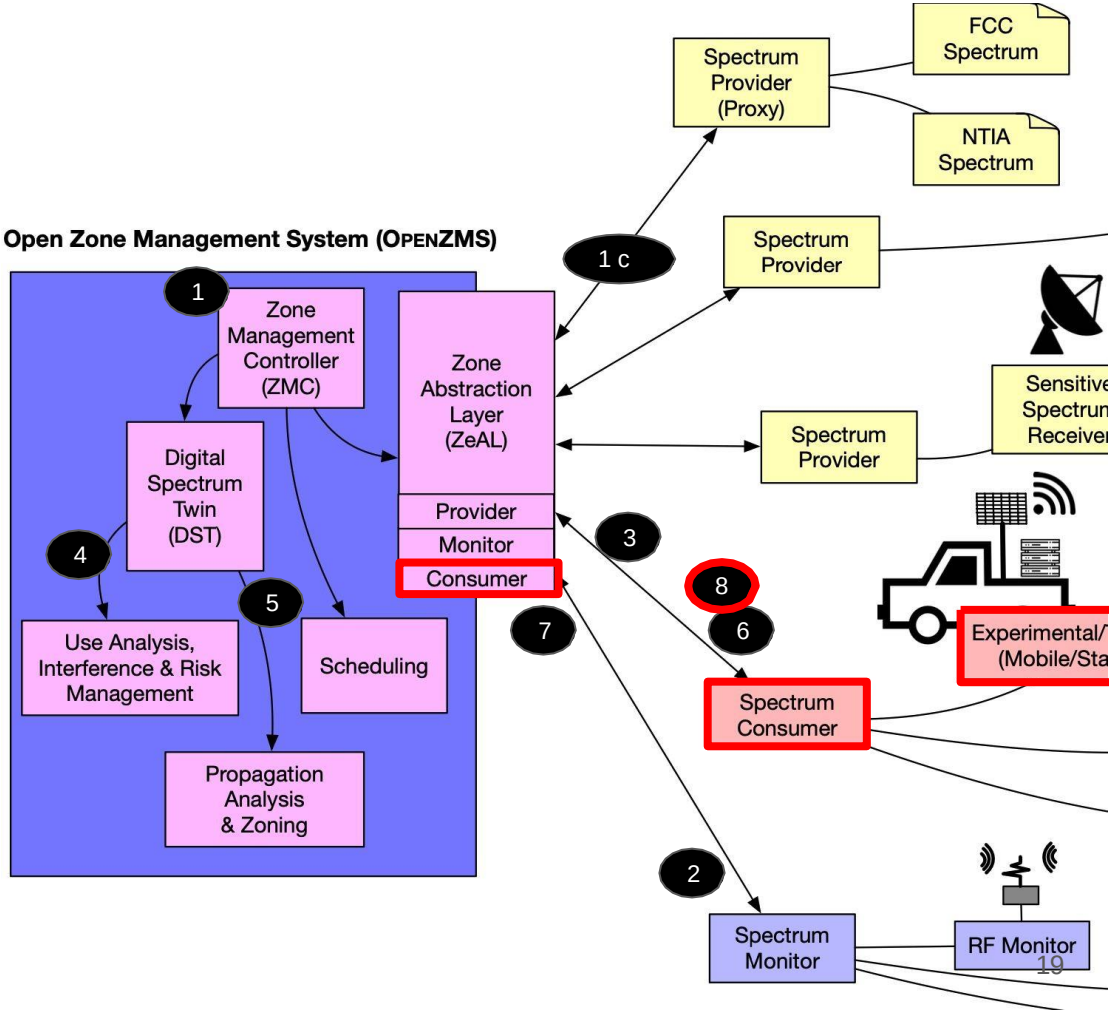
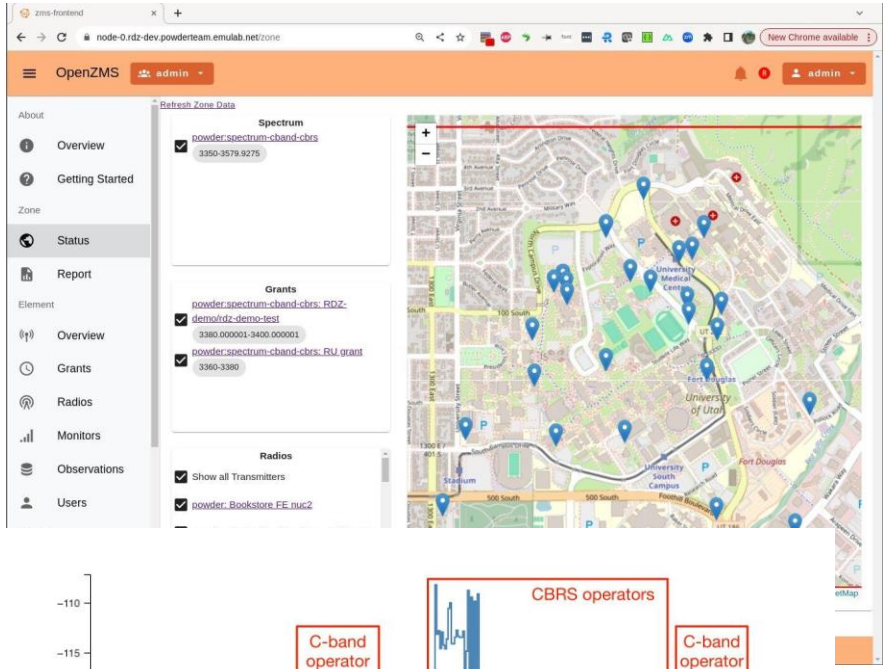
   c. Spectrum available through PEL
2. ZMS observes PEL spectrum range *(monitor)*, data into DST *(in ZMS)*
3. Request to use spectrum from platform *(consumer)* (X MHz in range Y-Z MHz)
4. Use monitor data to determine if/where request fits *(in ZMS)*
5. Use propagation analysis to ensure test will not interfere outside RDZ *(in ZMS)*
6. Notify platform *(consumer)* to proceed
7. If spectrum monitor *(monitor)* indicates interference…
8. ***…Instruct platform (consumer) to terminate transmission***

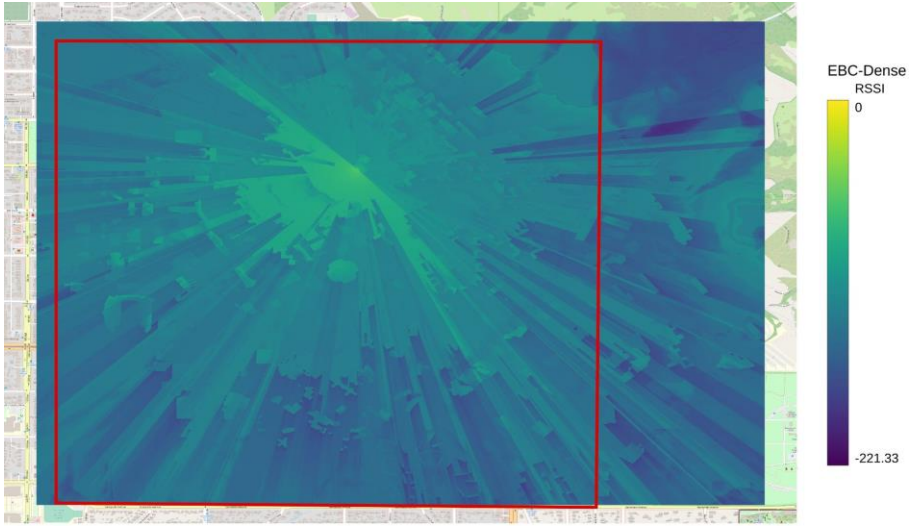


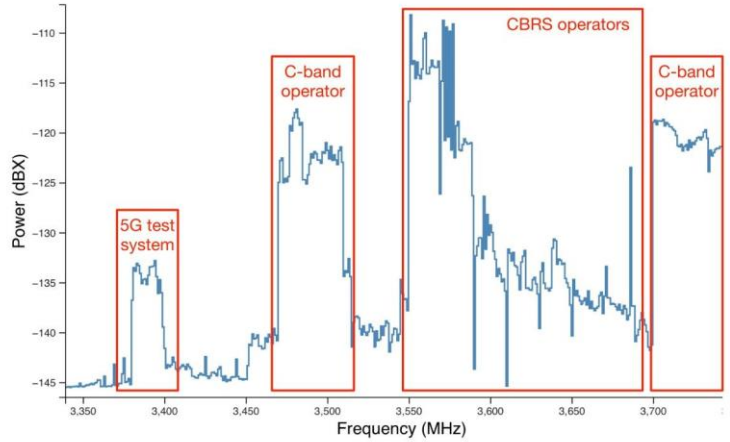
PEL use case

OpenZMS:

- Ensures test transmitter does not interfere outside RDZ
- Uses monitor data to schedule test transmitter grant in unoccupied spectrum





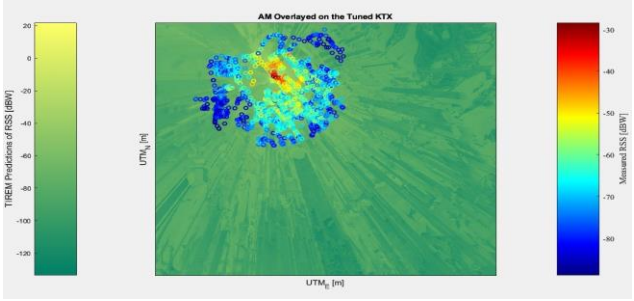


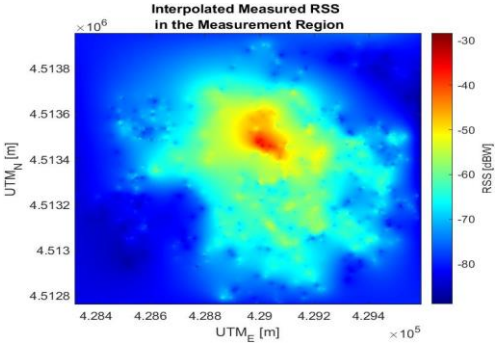
POWDER-RDZ: Digital Spectrum Twin

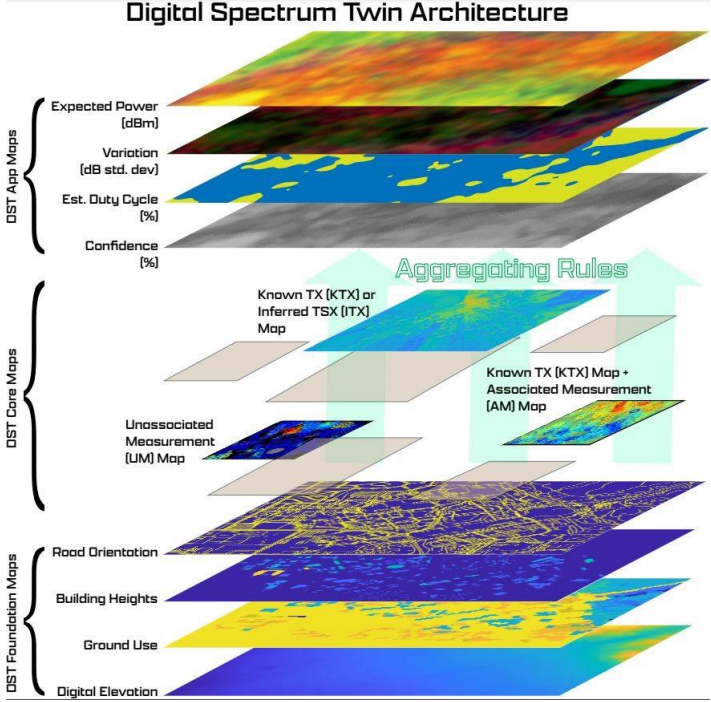
Digital spectrum twin (DST):

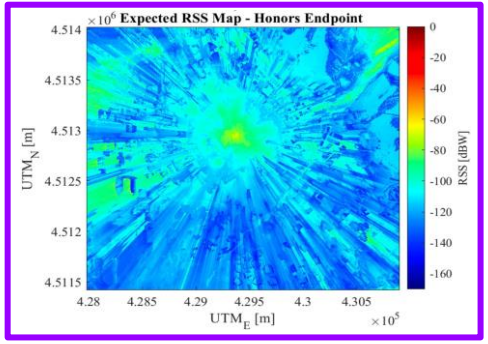
- Based on TIREM plus enhancements:
  - *Full DST life cycle*
- Detailed topology maps of POWDER environment (“foundation maps”)
- Improving prediction accuracy using measurement data (“core maps”)
- Developing “application maps”
  - E.g., expected power for different RDZ scenarios

(Also using Altair Feko)





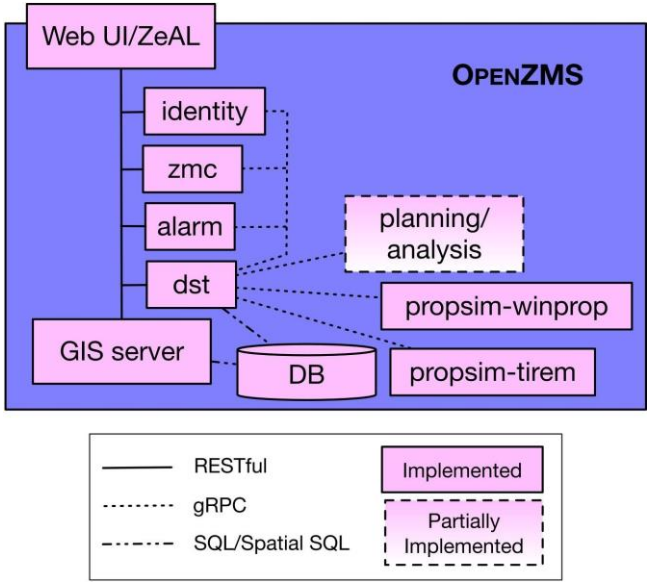


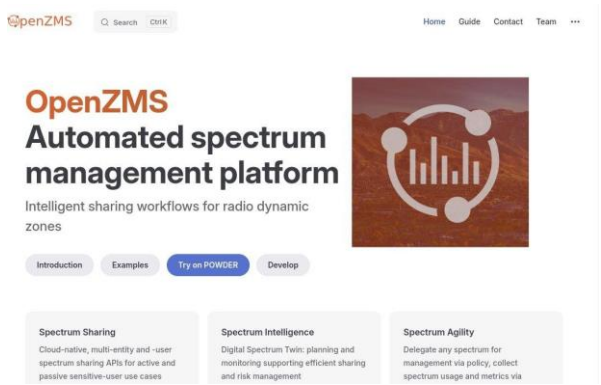


Source: Serhat Tadik and Greg Durgin (Georgia Tech)

Conclusion: Community, Resources

- POWDER-RDZ is available, pre-release: https://powderwireless.net
  - Use via POWDER experiments
- OpenZMS: https://openzms.net
  - Test-drive on POWDER; or manually deploy (pre-release, early adoption)
  - Heavy development: sharing (efficiency, parallelism), monitoring/detection, RFI mitigations
  - ***Deployed at Hat Creek Radio Observatory*** (collaboration with CU Boulder) in March 2024

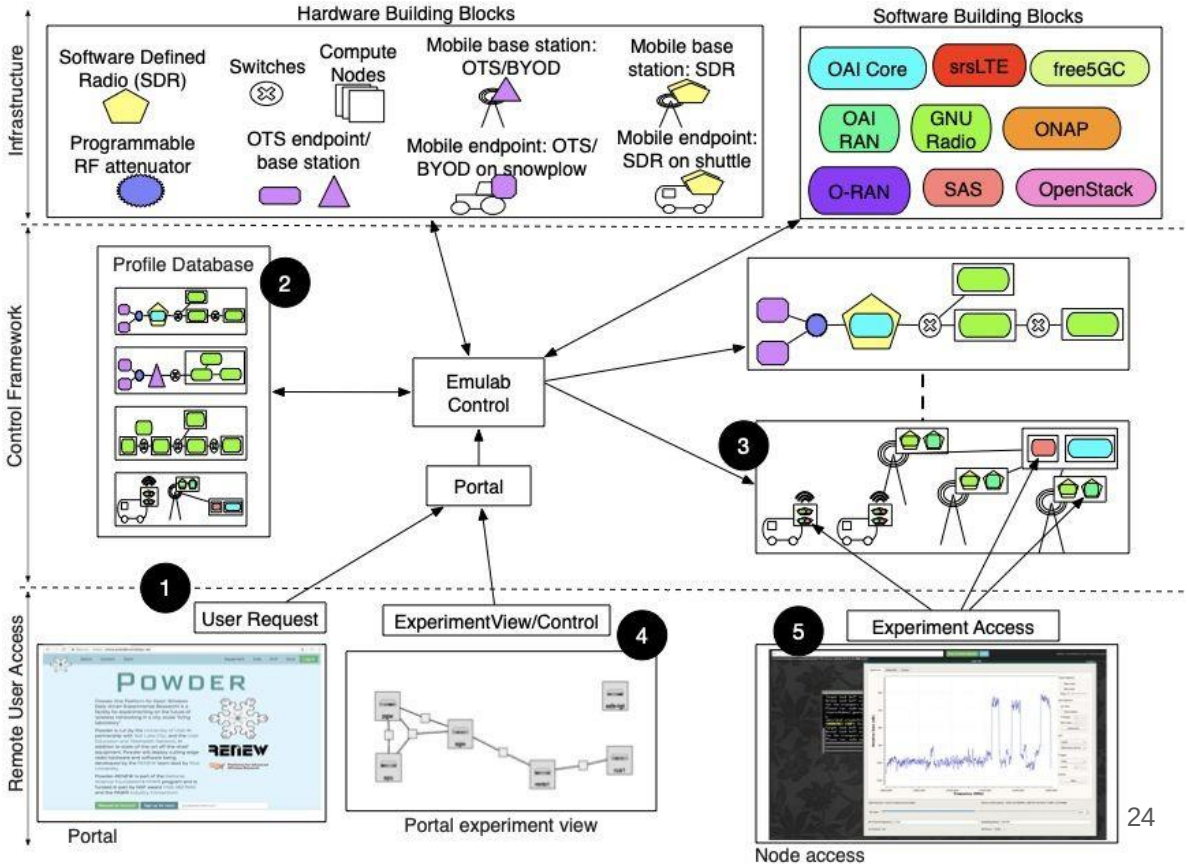




Towards frictionless reproducibility

POWDER concepts and workflow

- Hardware and software “building blocks”
- *Profile* mechanism:
  - “Recipe” to combine building blocks into an E2E experiment
- Basic workflow:
  - Access portal & select profile
  - Select profile parameters
  - POWDER control framework “instantiates” profile into running experiment
    - On-demand, or scheduled when resources become available
    - Configures experiment as specified in profile
  - User access experiment resources (remotely)



POWDER concepts and workflow

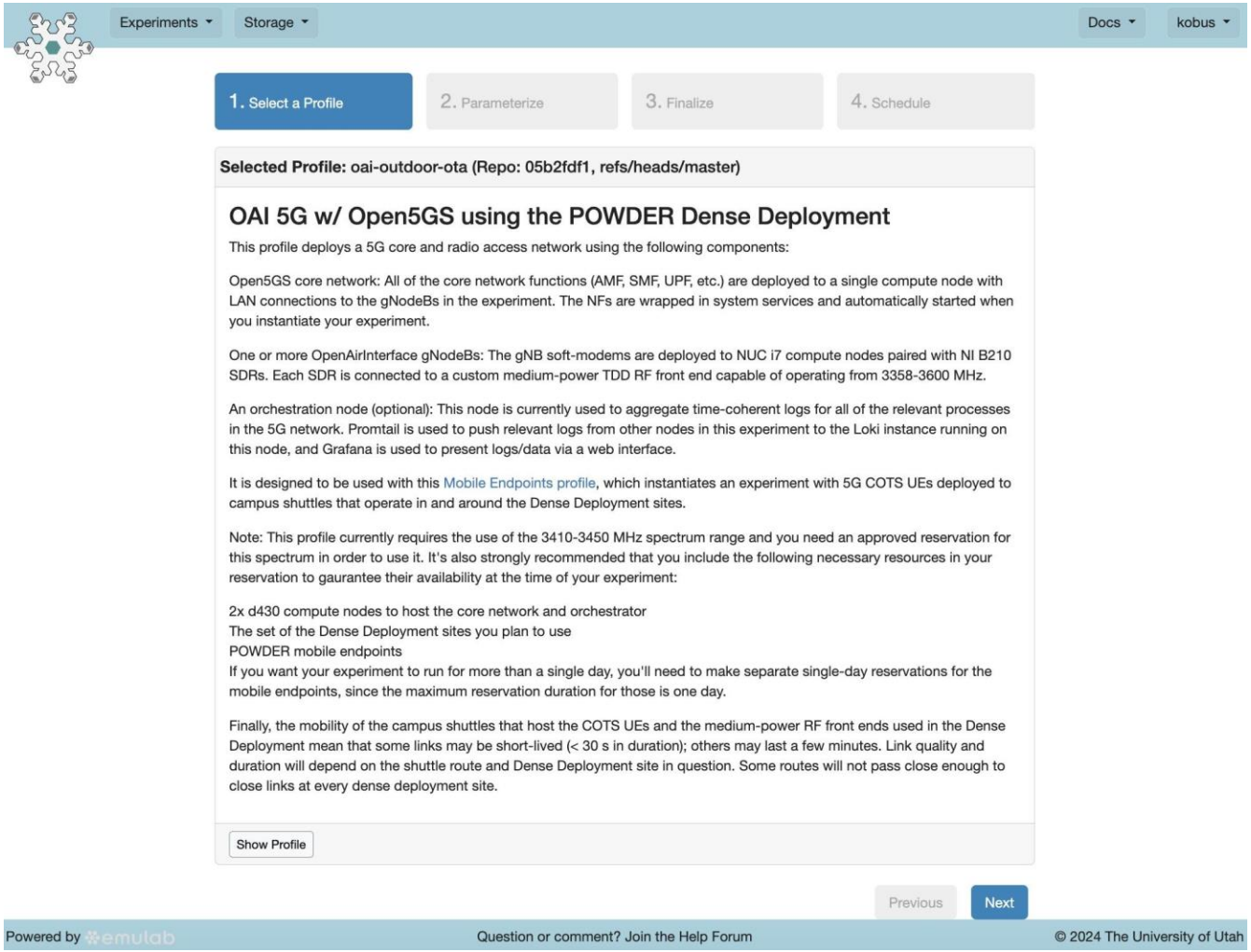
More on profiles:

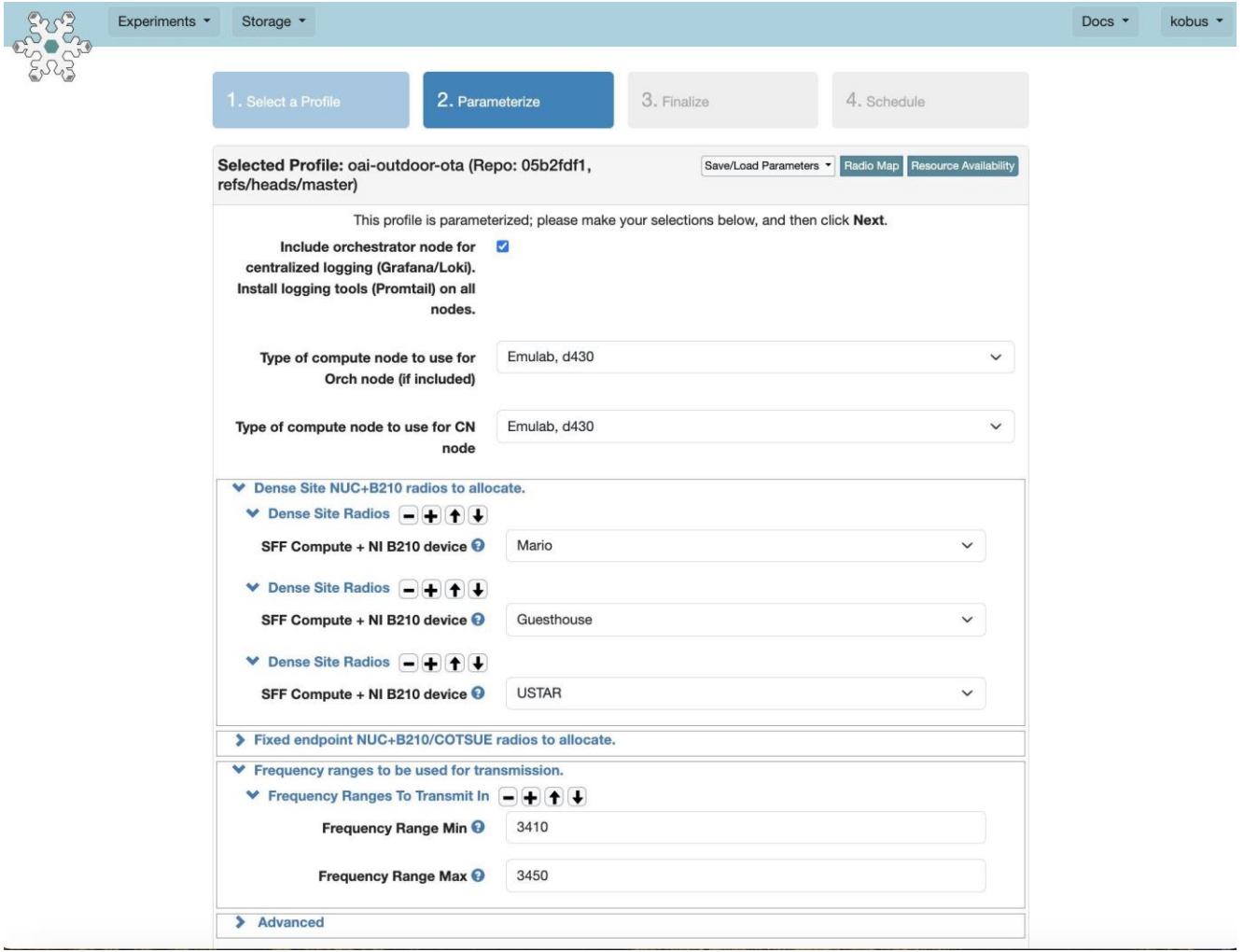
- Request required resources (radios, servers, spectrum…)
- Describe experiment configuration (network, software, config scripts…)
- Parameterizable, version controlled; git repo backed;
- Means to create sophisticated E2E experiments
- Instantiate via graphical user interface or through programmatic API
- *POWDER provided:*
  - "library" of parameterized ready-to-run profiles (srsRAN, OpenAirInterface, Open RAN, RF measurement)
- *User created:*
  - from scratch, fork POWDER provided..

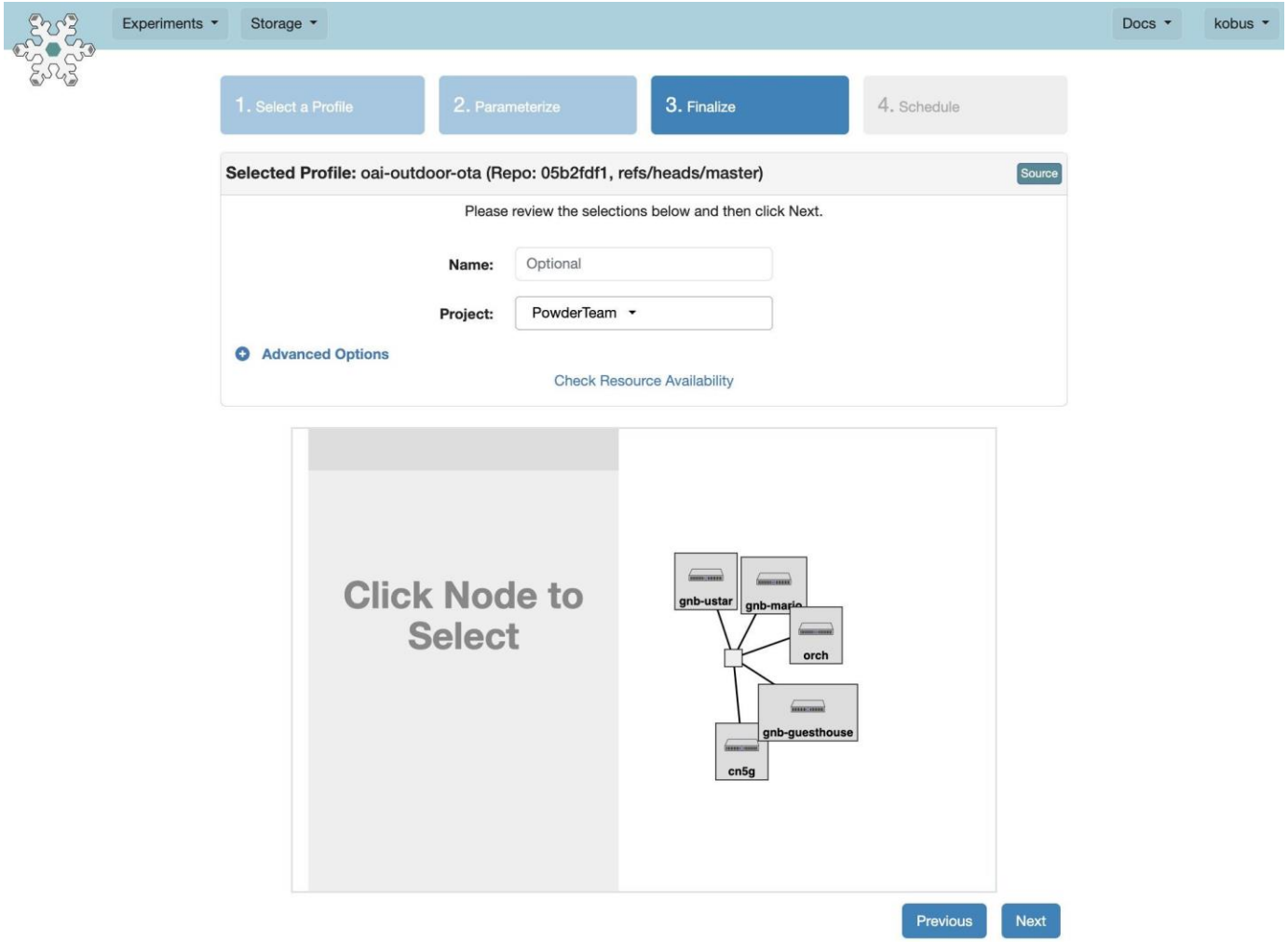
- *All* the examples and use cases described earlier are realized through profiles

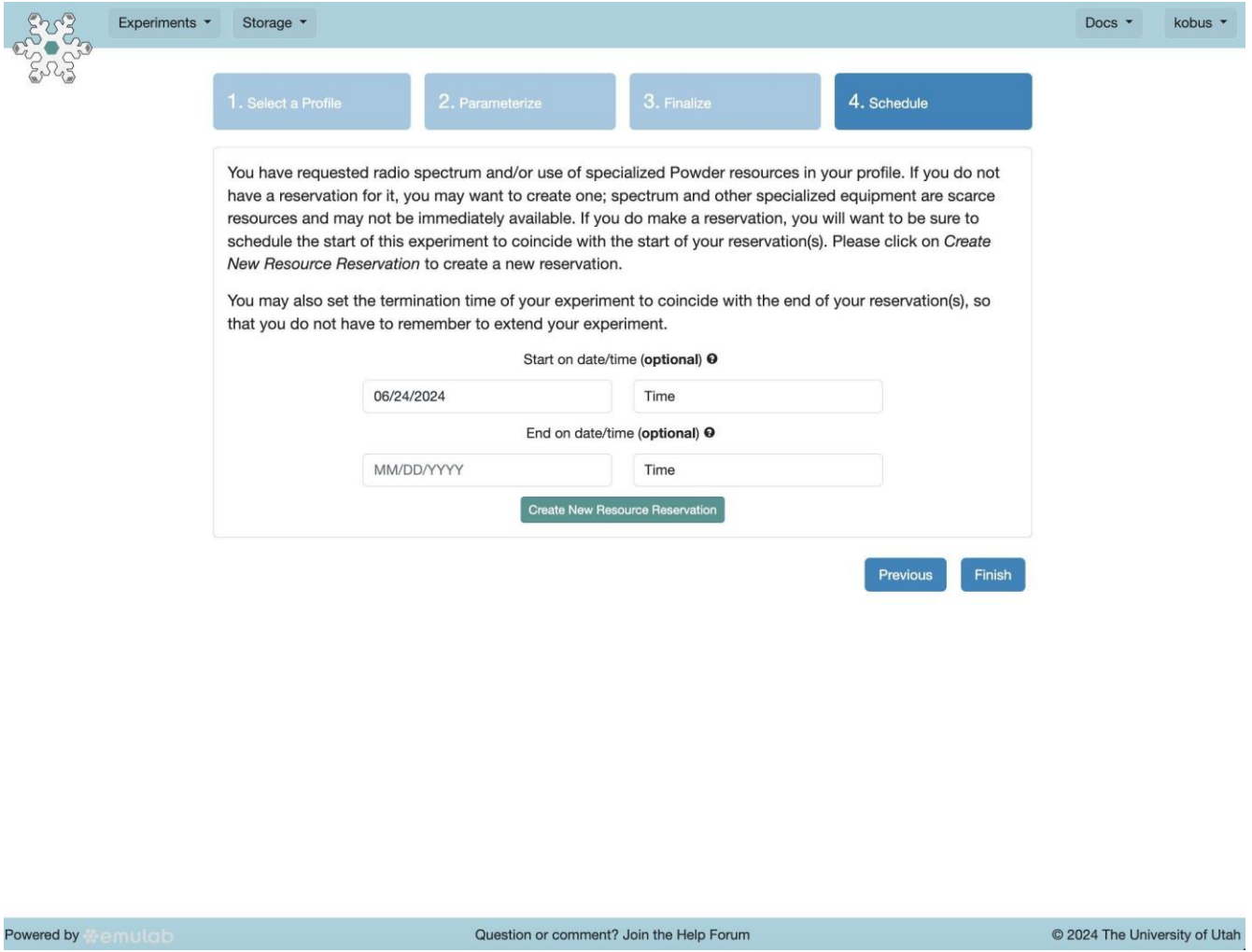
Primary reproducibility mechanism in POWDER

POWDER experimental workflow




Experiments
Storage
Docs
kobus
1. Select a Profile
2. Parameterize
3. Finalize
4. Schedule
Selected Profile: oai-outdoor-ota (Repo: 05b2fdf1, refs/heads/master)
Save/Load Parameters
Radio Map
Resource Availability
This profile is parameterized; please make your selections below, and then click Next.
Include orchestrator node for centralized logging (Grafana/Loki). Install logging tools (Promtail) on all nodes.
Type of compute node to use for Orch node (if included)
Emulab, d430
Type of compute node to use for CN node
Emulab, d430
Dense Site NUC+B210 radios to allocate.
Dense Site Radios
SFF Compute + NI B210 device
Mario
Dense Site Radios
SFF Compute + NI B210 device
Guesthouse
Dense Site Radios
SFF Compute + NI B210 device
USTAR
Fixed endpoint NUC+B210/COTSUE radios to allocate.
Frequency ranges to be used for transmission.
Frequency Ranges To Transmit In
Frequency Range Min
3410
Frequency Range Max
3450
Advanced


Experiments
Storage
Docs
kobus
1. Select a Profile
2. Parameterize
3. Finalize
4. Schedule
Selected Profile: oai-outdoor-ota (Repo: 05b2fdf1, refs/heads/master)
Source
Please review the selections below and then click Next.
Name:
Optional
Project:
PowderTeam
Advanced Options
Check Resource Availability
Click Node to Select
gnb-ustar
gnb-mario
orch
gnb-guesthouse
cn5g
Previous
Next


Experiments
Storage
Docs
kobus
1. Select a Profile
2. Parameterize
3. Finalize
4. Schedule
You have requested radio spectrum and/or use of specialized Powder resources in your profile. If you do not have a reservation for it, you may want to create one; spectrum and other specialized equipment are scarce resources and may not be immediately available. If you do make a reservation, you will want to be sure to schedule the start of this experiment to coincide with the start of your reservation(s). Please click on Create New Resource Reservation to create a new reservation.
You may also set the termination time of your experiment to coincide with the end of your reservation(s), so that you do not have to remember to extend your experiment.
Start on date/time (optional)
06/24/2024
Time
End on date/time (optional)
MM/DD/YYYY
Time
Create New Resource Reservation
Previous
Finish
Powered by emulab
Question or comment? Join the Help Forum
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Topology Visualize View Source View XML

Repository https://gitlab.flux.utah.edu/dmaas/srs-outdoor-ota.git

Description

srsRAN 5G w/ Open5GS CN5G using the POWDER Dense Deployment

This profile deploys a 5G core and radio access network using the following components:

- Open5GS core network: All of the core network functions (AMF, SMF, UPF, etc.) are deployed to a single compute node with LAN connections to the gNodeBs in the experiment. The NFs are wrapped in system services and automatically started when you instantiate your experiment.
- One or more srsRAN gNodeBs: The gNB soft-modems are deployed to NUC i7 compute nodes paired with NI B210 SDRs. Each SDR is connected to a custom medium-power TDD RF front end capable of operating from 3358-3600 MHz.
- An orchestration node (optional): This node is currently used to aggregate time-coherent logs for all of the relevant processes in the 5G network. Promtail is used to push relevant

Topology Visualize View Source View XML

Repository https://gitlab.flux.utah.edu/dmaas/mobile-endpoints.git

Description

Mobile Endpoints for LTE/5G Experiments

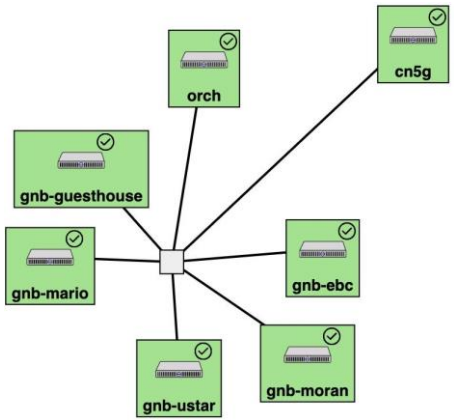
POWDER provides a number of mobile endpoints deployed to university campus shuttles. In addition to other tools and SDRs, these mobile endpoints are equipped with LTE/5G modems that are capable of attaching to networks that include gNodeBs running at POWDER Dense Deployment sites.

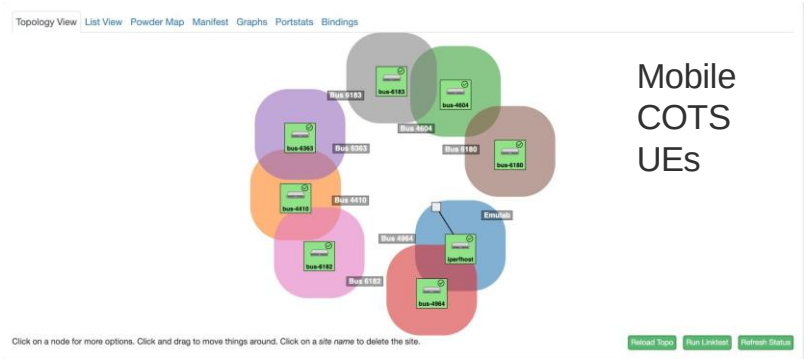
This profile instantiates an exeriment that includes all of the currently available mobile endpoints traversing routes that come near one or more Dense Deployment sites. It is primarily intended to be run in conjunction with one of our outdoor 5G profiles:

- OAI Outdoor 5G
- srsRAN Project Outdoor 5G

You'll need to instantiate one of these, or something similar, before you instantiate this profile if you want the UEs to attach to a 5G network. In fact, in its default configuration, this

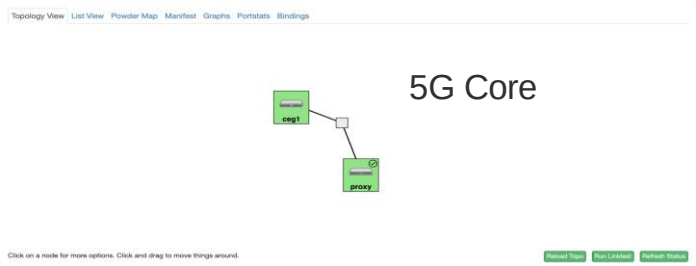
5G RAN
+ Core



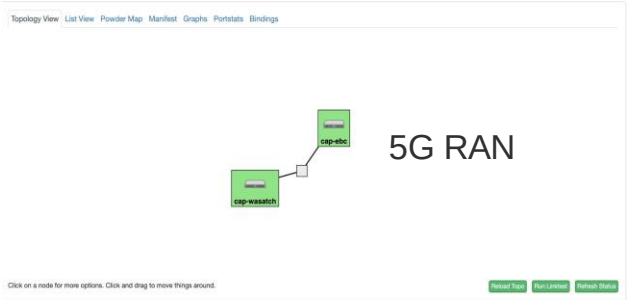


Mobile
COTS
UEs

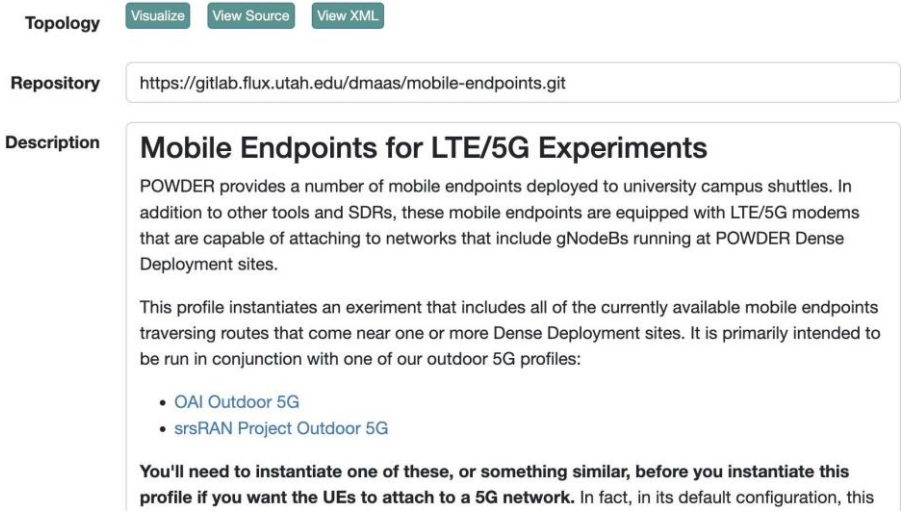
Different core + RAN profiles for private 5G vendor + same mobile endpoint profile

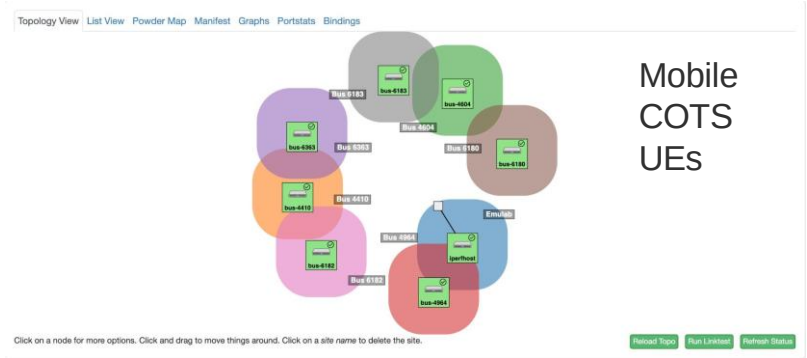


5G Core



5G RAN



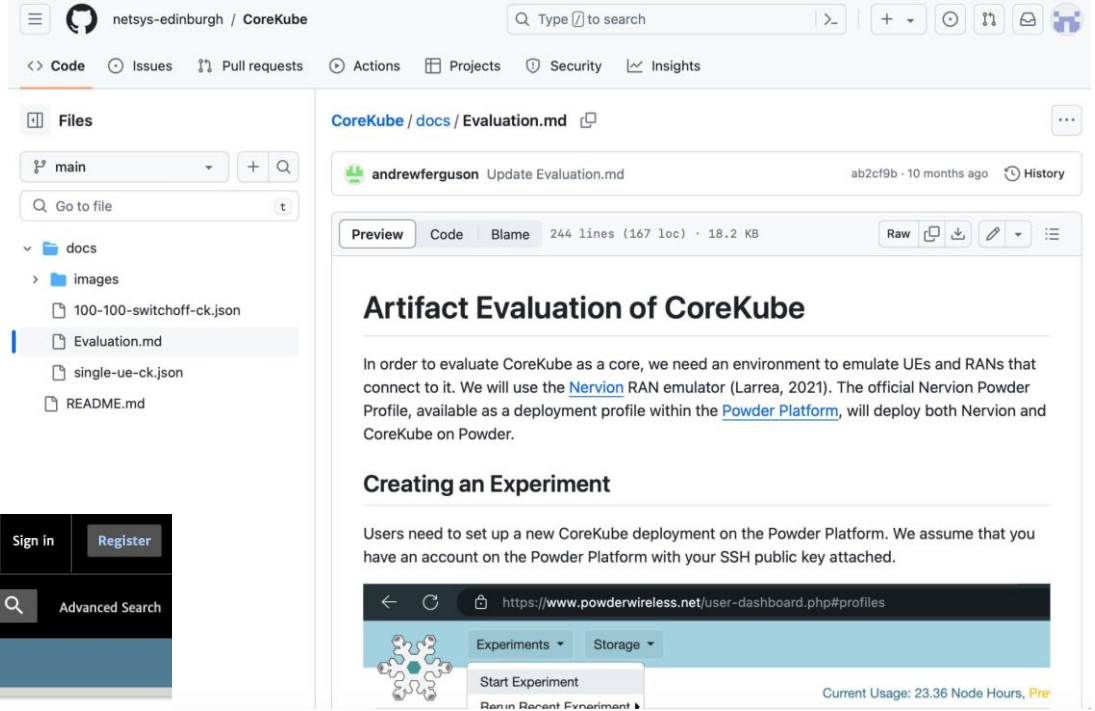


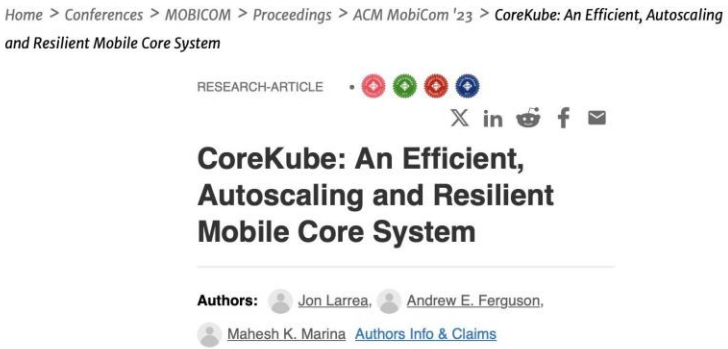
Mobile COTS UEs

User examples

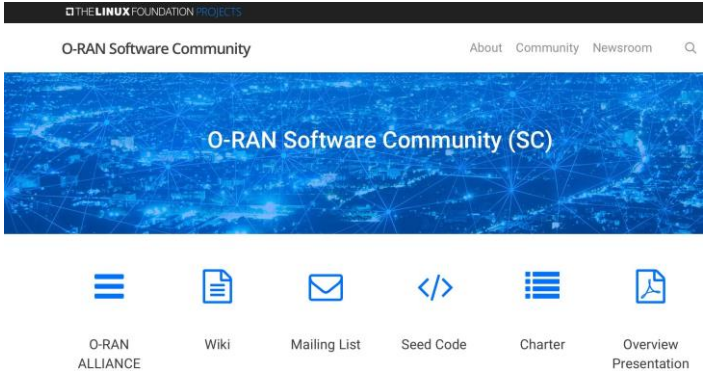
ACM MobiCom paper: Mahesh Marina and students (University of Edinburgh)

- Made available as POWDER profile to community



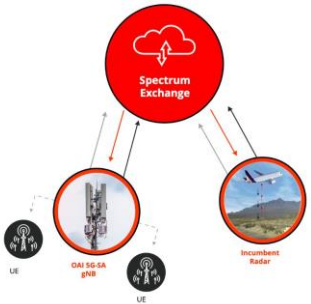


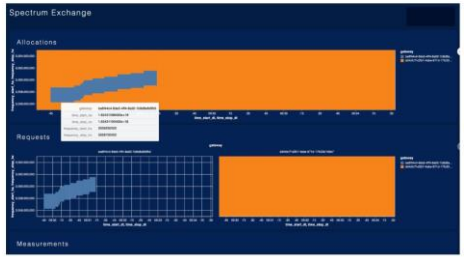
User examples

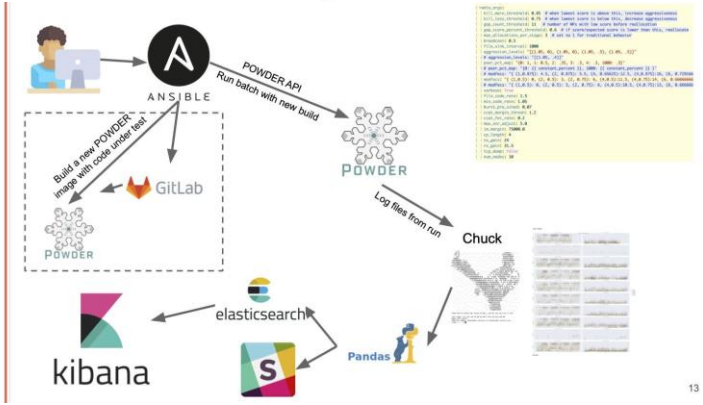


O-RAN Software Community (OSC)
(Community lab offline)
Using POWDER for testing
Use POWDER APIs:

- Quick setup of OSC SW components
- Run complex test scenarios







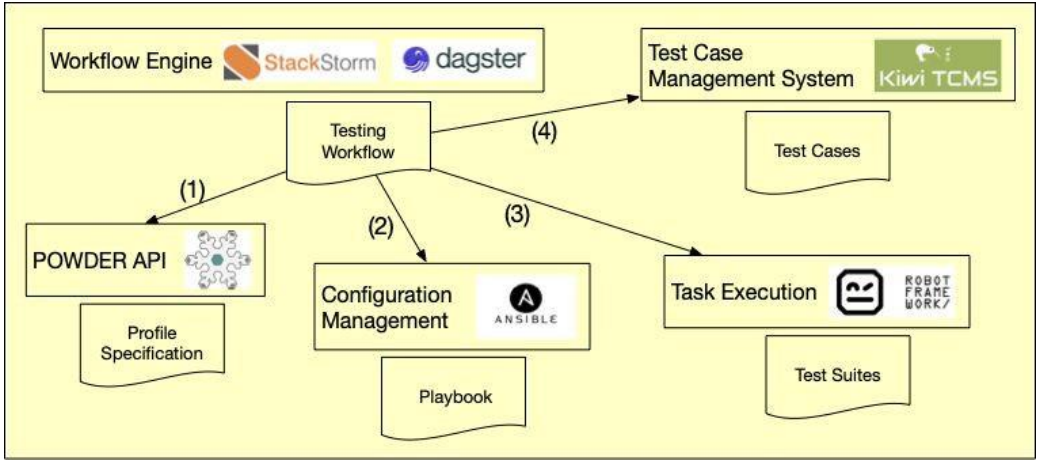
Zylinium Research
DoD funded Spectrum Sharing research
Used POWDER for over-the-air (OTA) testing
Use POWDER APIs:

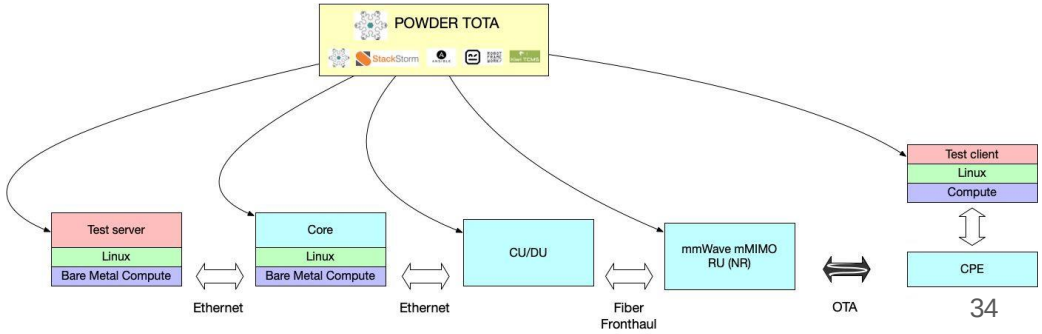
- Spinning up OTA resources as part of development/testing workflow

Testing example

Testing Orchestration and Testing Automation (TOTA)

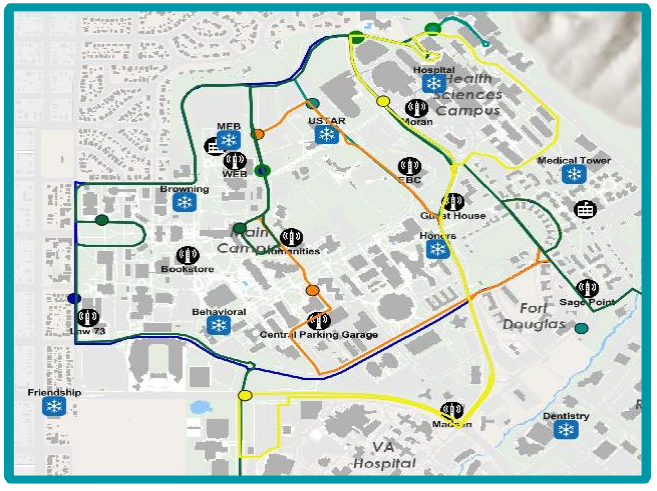
- Testing Orchestration: using profile mechanism
- Testing Automation: framework of open source tools
- Workflow engine:
  - (1) Interacts with POWDER platform to orchestrate test setup (profile mechanism)
  - (2) Uses Ansible to configure components in the test setup
  - (3) Uses Robot to execute the required test suite
  - (4) Stores results in Kiwi Test Case Management System

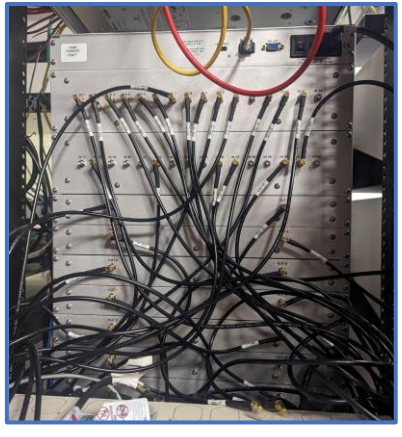


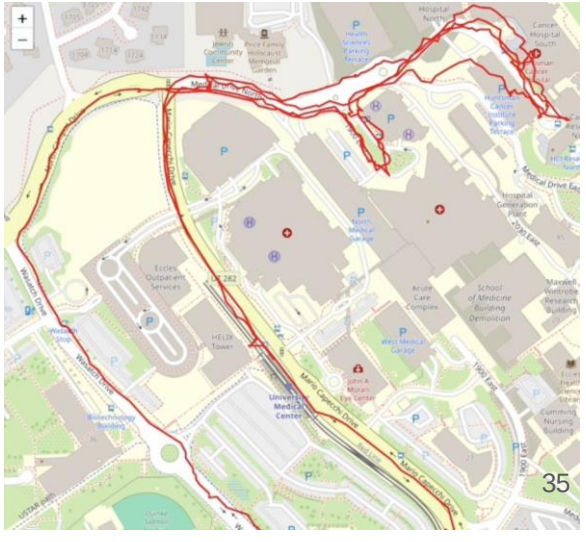


Repeatable mobility?

- Programmable conducted RF attenuator matrix
  - Repeatable, but lacks realism
- Mobile endpoints on campus shuttles
  - (Sort of) repeatable, real world
- Often: start conducted, then outdoor

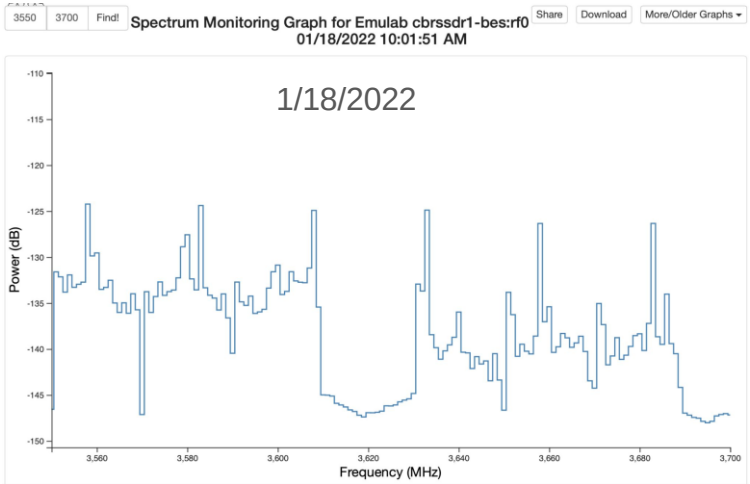


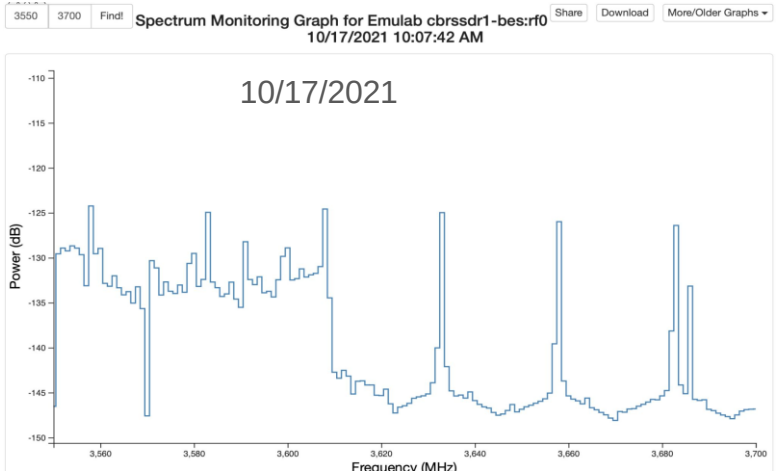


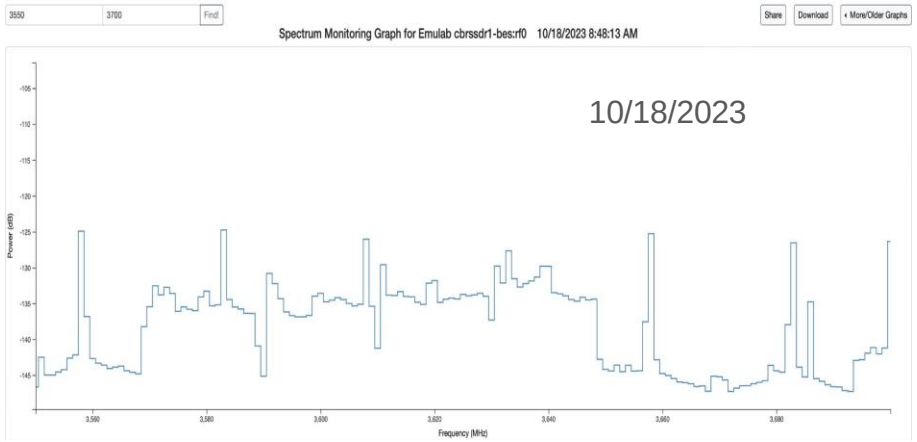


What about spectrum/RF conditions?

- Maybe:
  - Point of outdoor wireless testbed is repeatable experiments in the context of changing spectrum/RF conditions?
- Still:
  - We need better “spectral intelligence”..
    - Can we capture the “spectral conditions” at play during an experiment?
    - Can we programmatically “capture changes” in the spectral environment?
  - Maybe… OpenZMS DST is a starting point





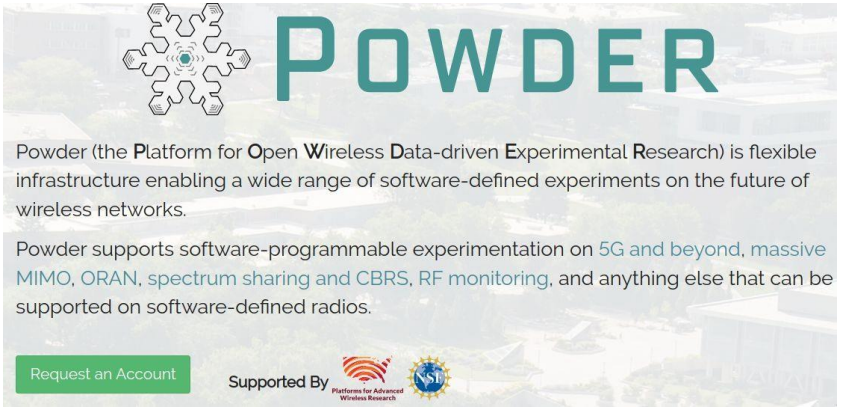


Lessons?

What makes wireless frictionless repeatability hard?

- Changing wireless environment
- “Real world labs” are difficult to operate!
- Complex “ecosystem”
  - And testbeds are difficult to use
- “Domain science” is rapidly evolving
- Open source is great, but not necessarily mature
- Inherently cross-disciplinary
- “Stakeholders” have different interests, needs and skill levels

Thank you!



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