



POWDER: Platform for Open Wireless Data-driven Experimental Research

RENEW: Reconfigurable Ecosystem for Next-gen End-to-end Wireless

powderwireless.net

renew.rice.edu

Status — May 2019



**Platforms for Advanced
Wireless Research**





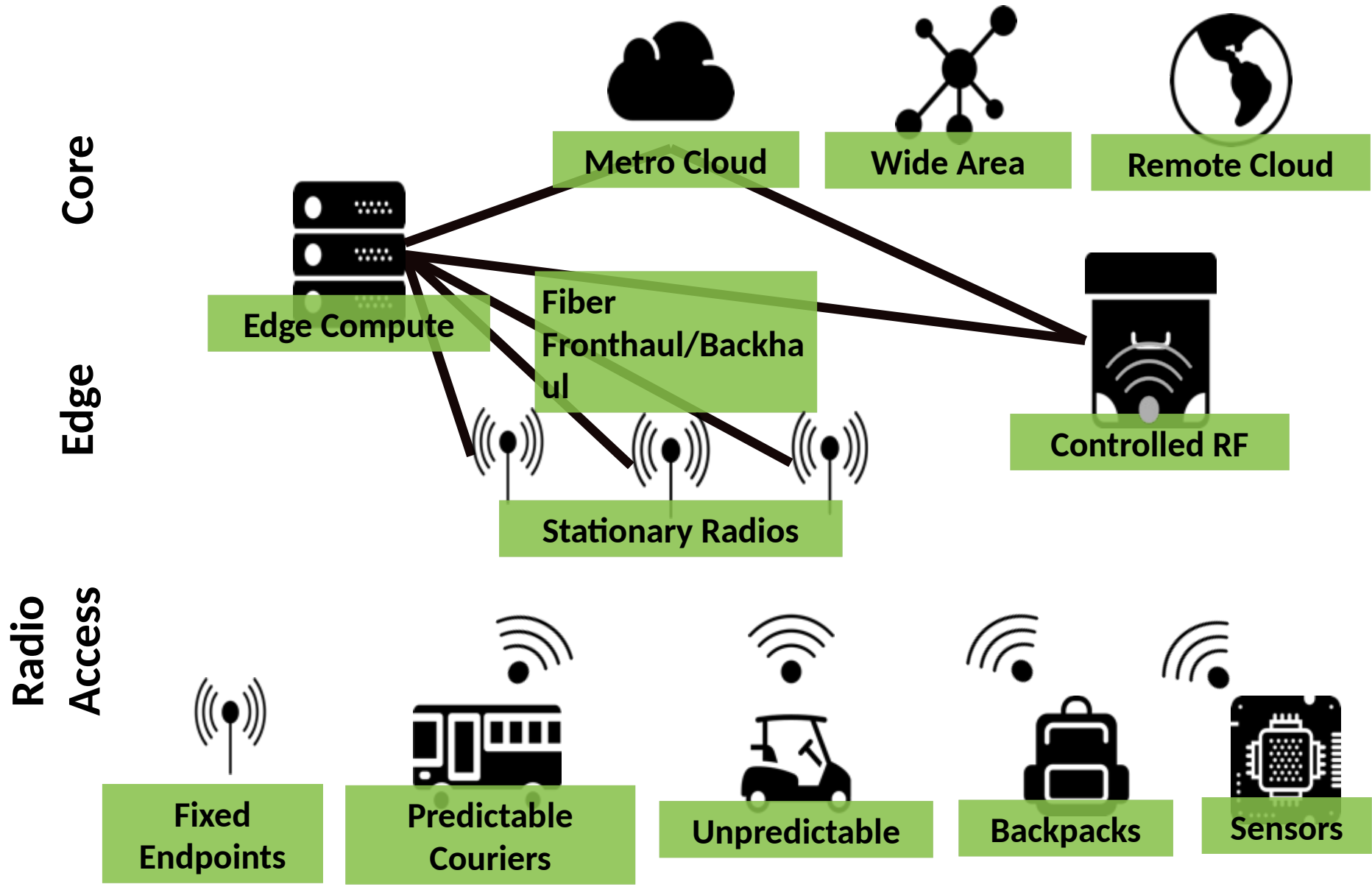
Broader Context

- **POWDER-RENEW** is a project under the National Science Foundation (NSF) PAWR program
 - **POWDER** (U of U) is a living lab research platform we are building in Salt Lake City
 - **RENEW** (Rice) is providing additional equipment for POWDER
- **PAWR:**
 - Platforms for Advanced Wireless Research
 - NSF public/private program (\$100M)
 - Build four “city scale” platforms in US
 - Enable core wireless and mobile research
 - Enable research related to services/applications that rely on wireless and mobile
- First round completed in early 2018:
 - POWDER-RENEW (U of U with Rice) selected as one of the platforms
 - COSMOS (Rutgers, Columbia, NYU) other first round platform





POWDER Overview





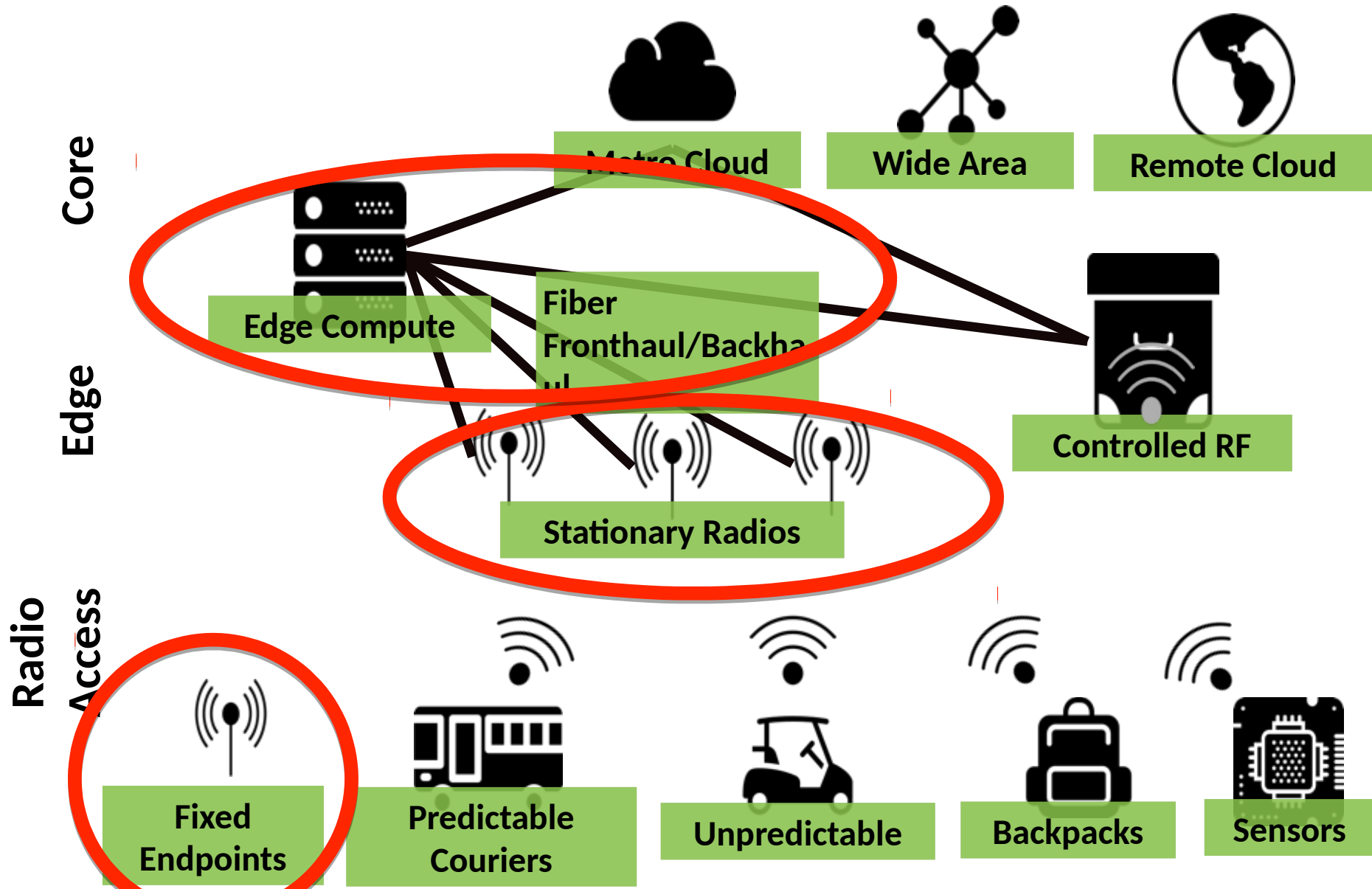
Supported Research Domains

- Industrial and academic research
- **Wireless communication**
 - 100X wireless data rates, ultra reliability, dynamic spectrum access, spectral efficiencies
- **Wireless and mobile networking**
 - Network densification, network virtualization, network management and operation, mobile edge cloud
- **Security and privacy**
 - Jamming detection/prevention, data/location privacy
- **Applications and services**
 - IoT, public safety, augmented/virtual reality, vehicular/drone communication

YEAR 1: PROCESS & STATUS

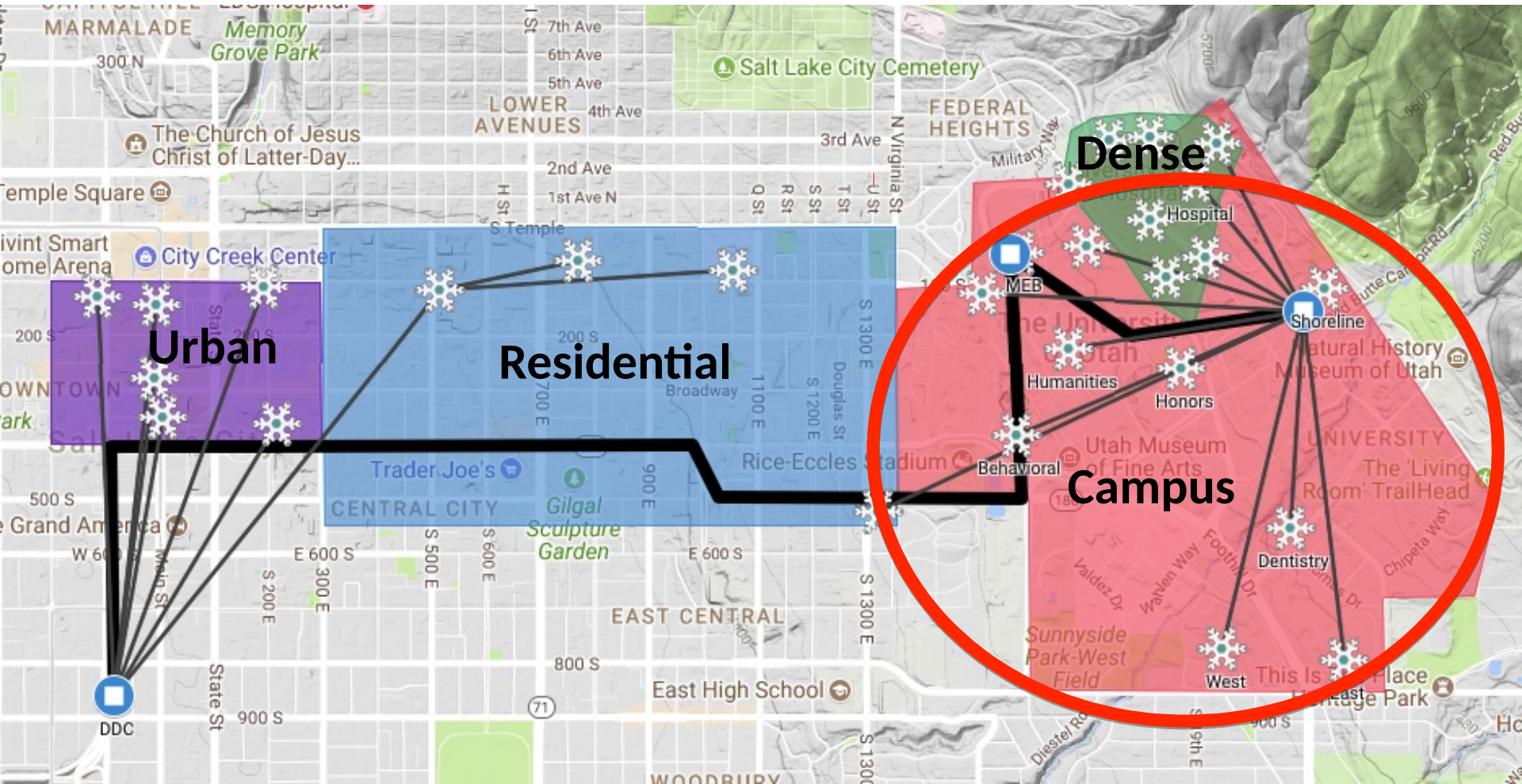


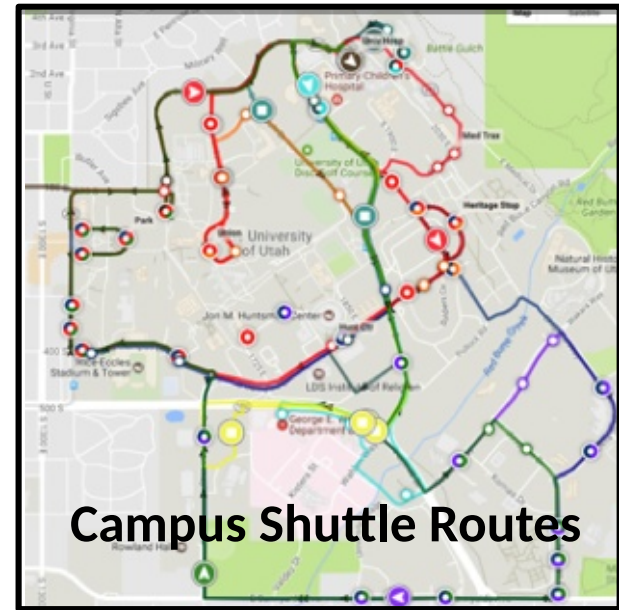
Campus fixed deployment





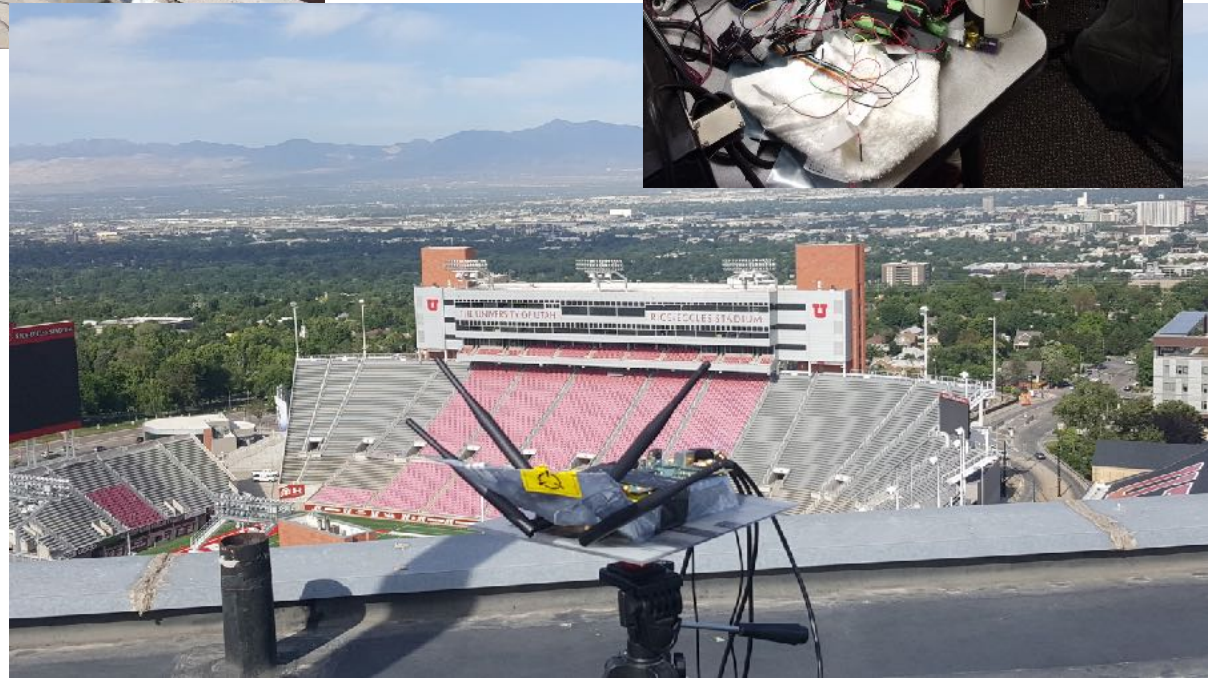
Campus fixed deployment





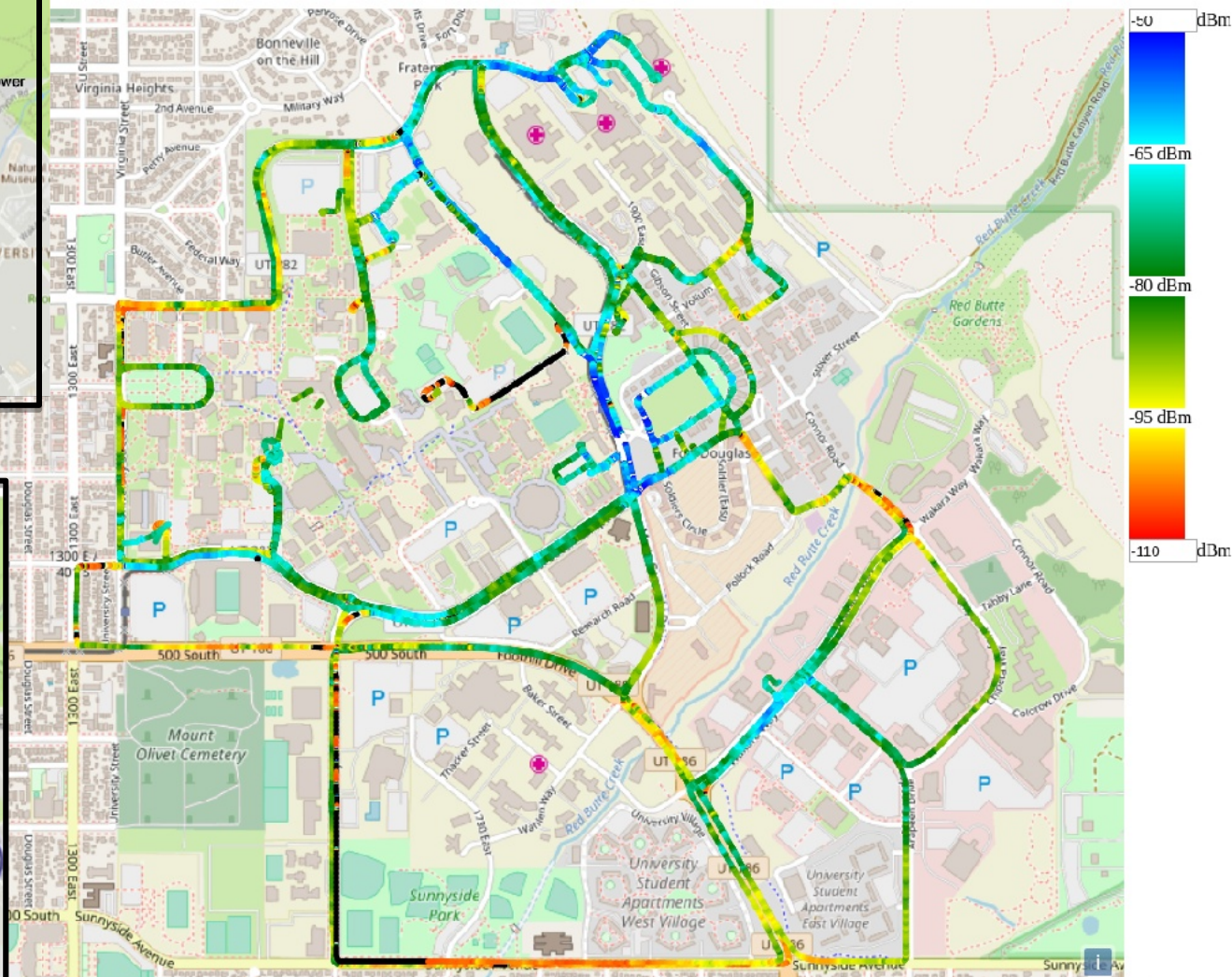
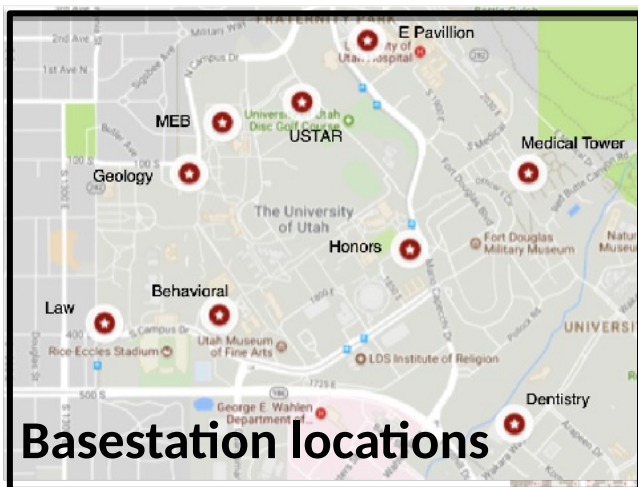


RF measurements from target locations





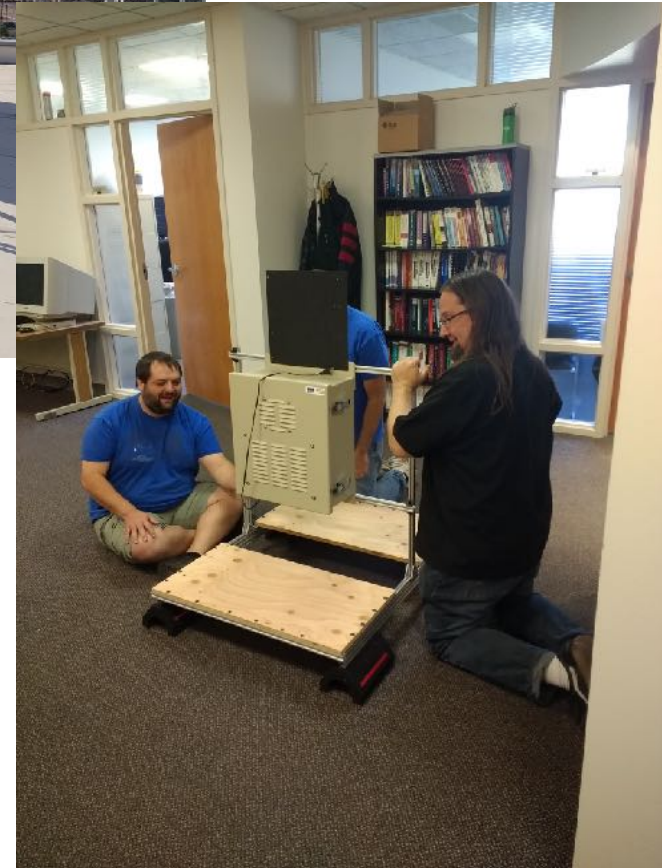
RF measurements from target locations





Site surveys...





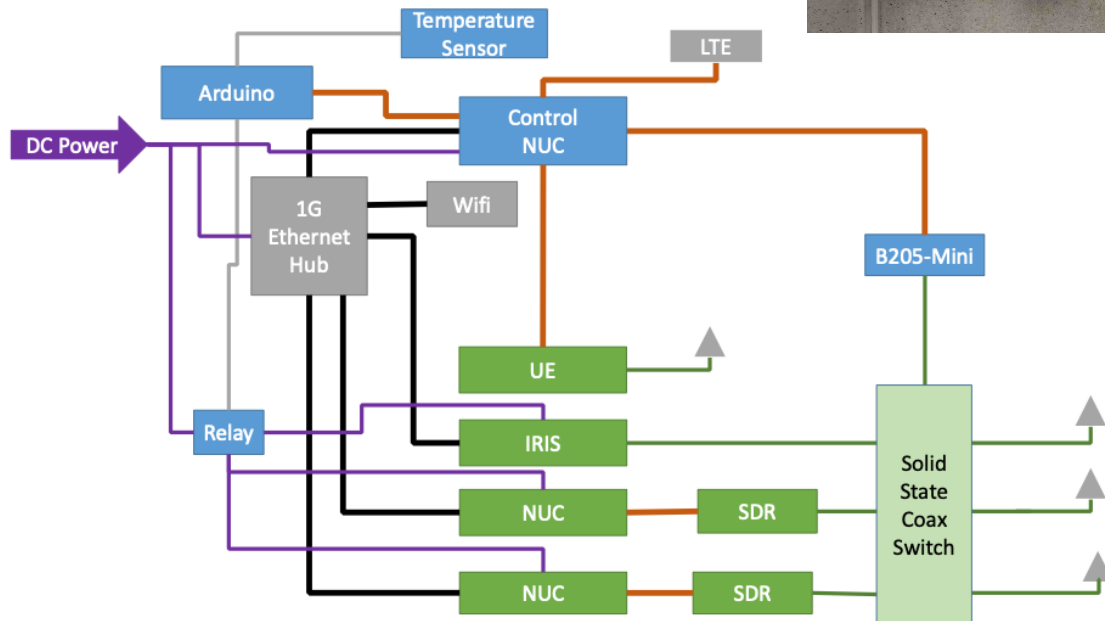


Equipment arriving...



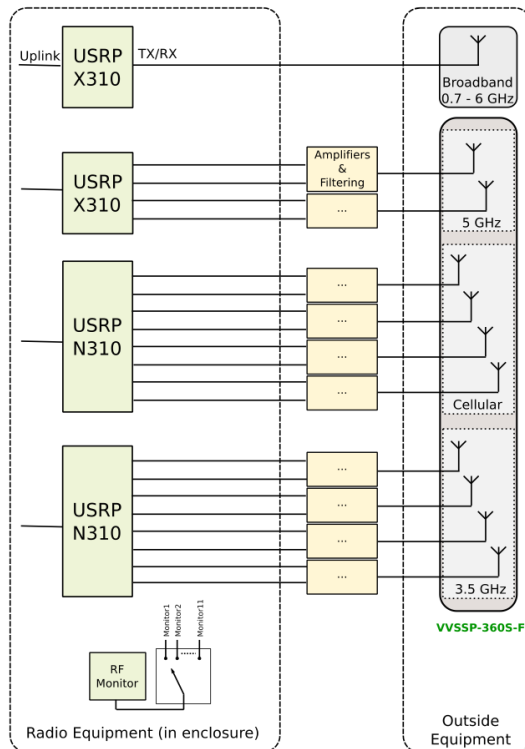
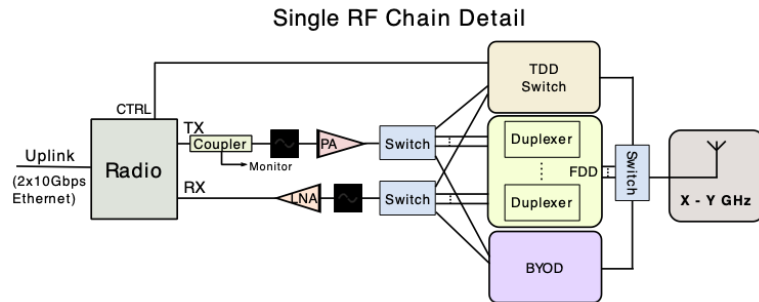


Fixed-endpoint





Stationary Radio (Rooftop Basestation)



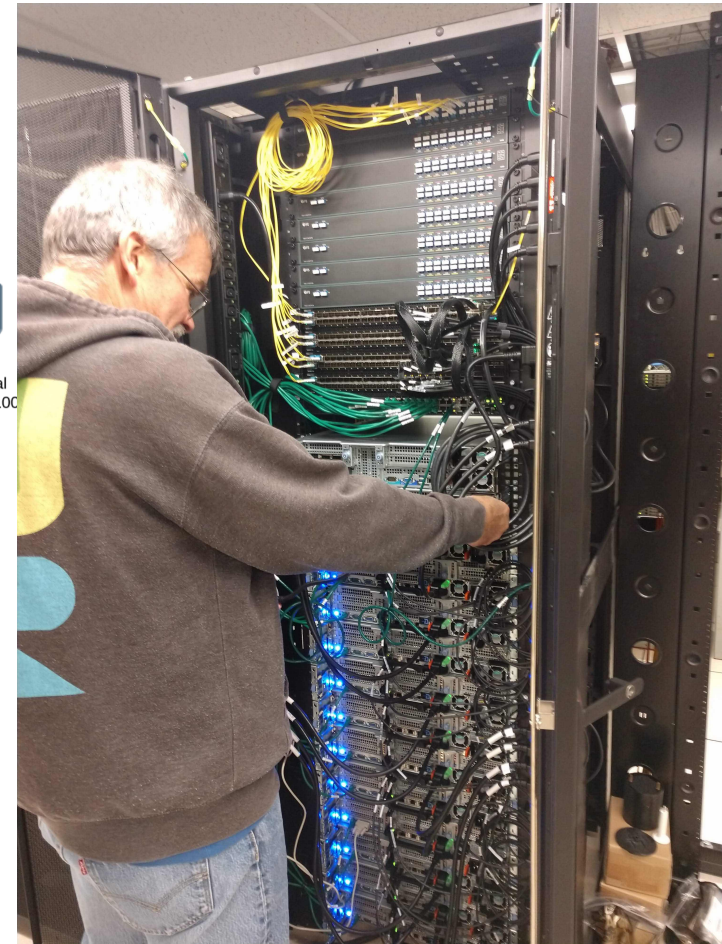
Powder Base Station RF Front-end





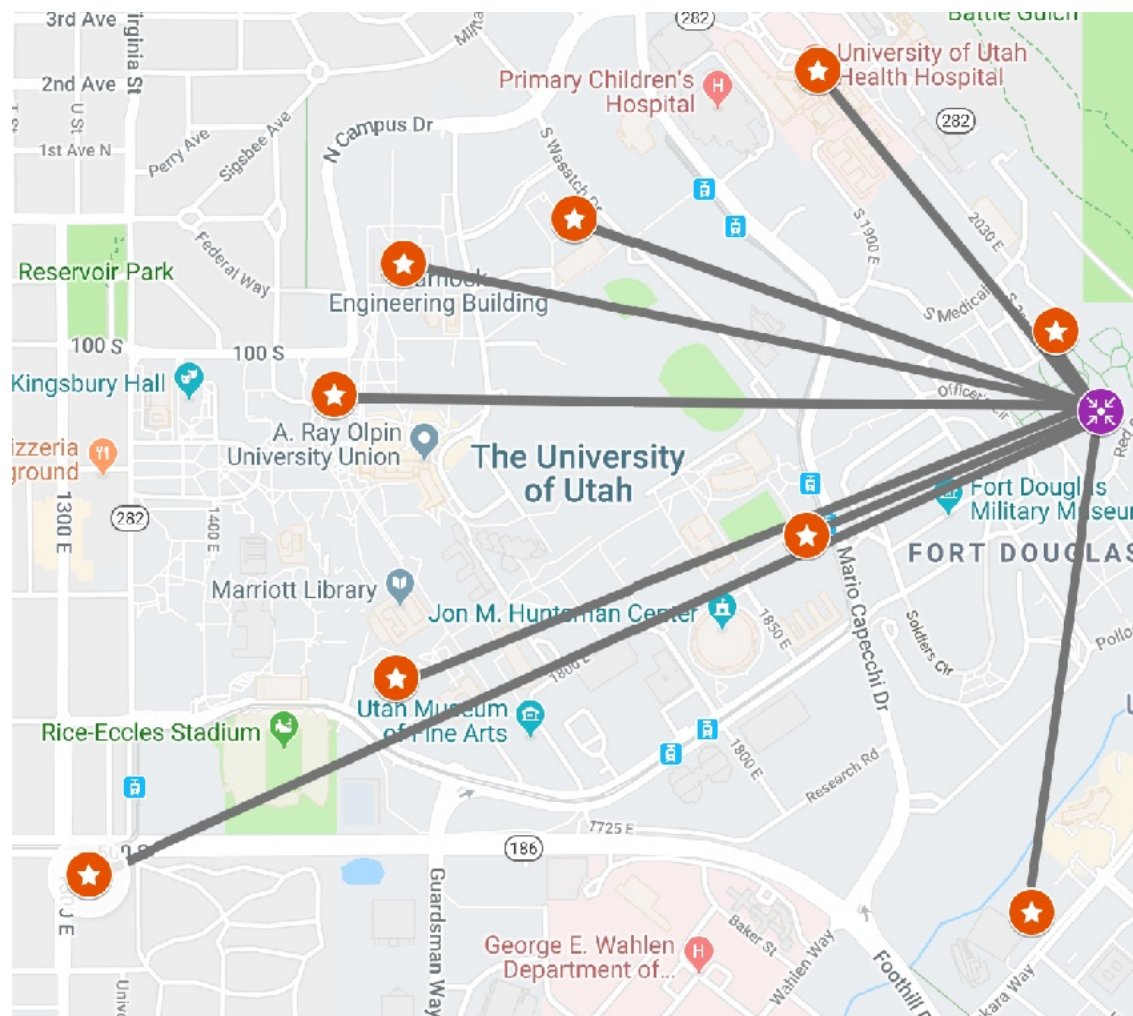
Stationary Radio (Rooftop Basestation)





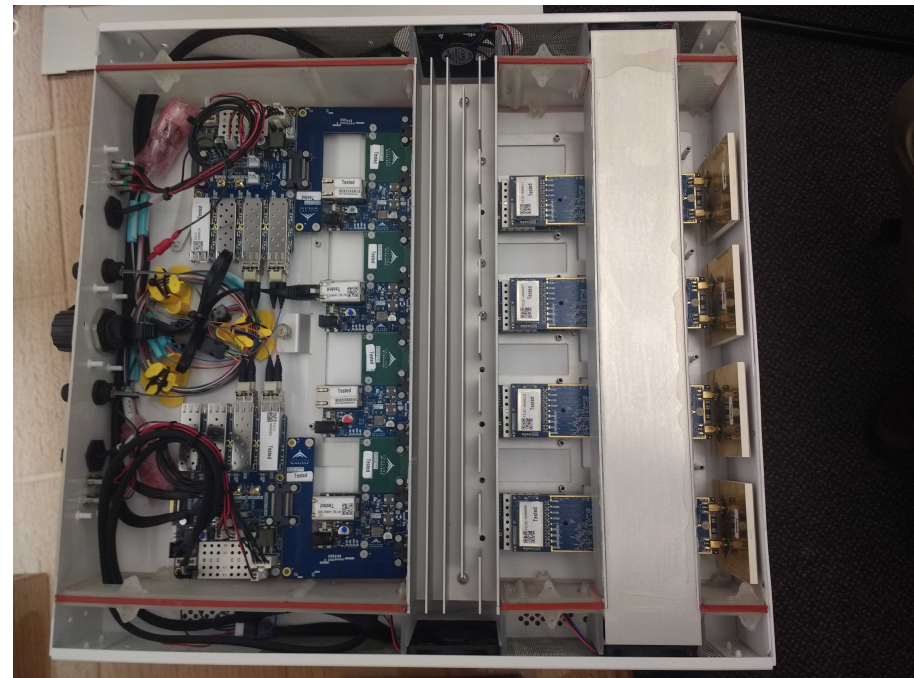


Edge compute, fiber fronthaul/backhaul





Massive MIMO



Software

- Profiles available on POWDER
 - Openstack
 - ONAP
 - srsLTE
 - Open Air Interface
 - 4G and 5G
 - GNU Radio

ACKNOWLEDGEMENT...

UofU partners

- UETN
- UIT (PM, fiber, security, communications)
- Campus Facilities(Electrical shop, Building Management, Rooftop group, Keyshop)
- GIS
- Student Housing
- Medical Student Housing
- Moran Eye Center Facilities
- Hospital Facilities
- Commuter Service
- Legal

Backup slides



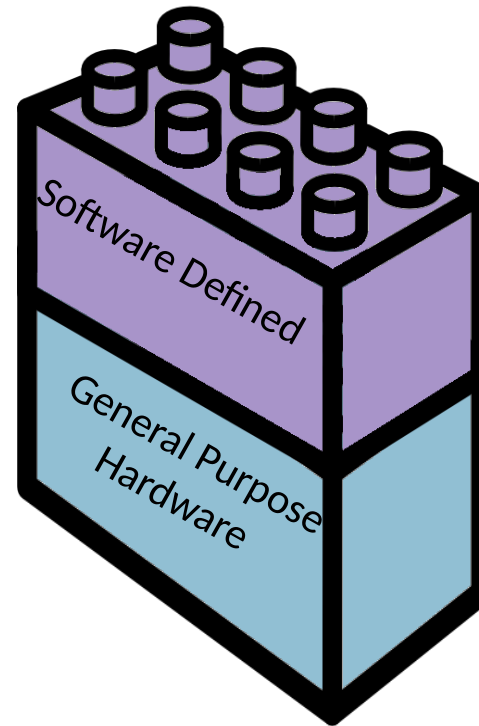
City scale...





Software defined...

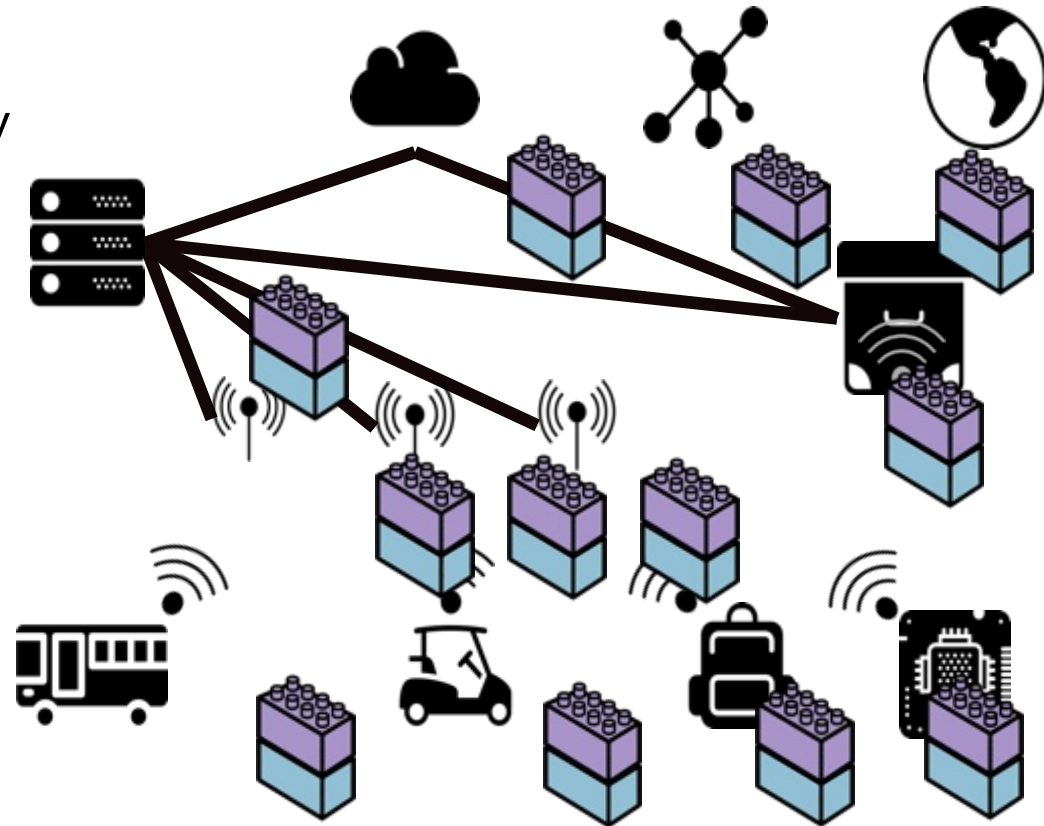
- **Basic Functionality:**
 - General purpose hardware
 - Functionality determined by software you add





Software defined...

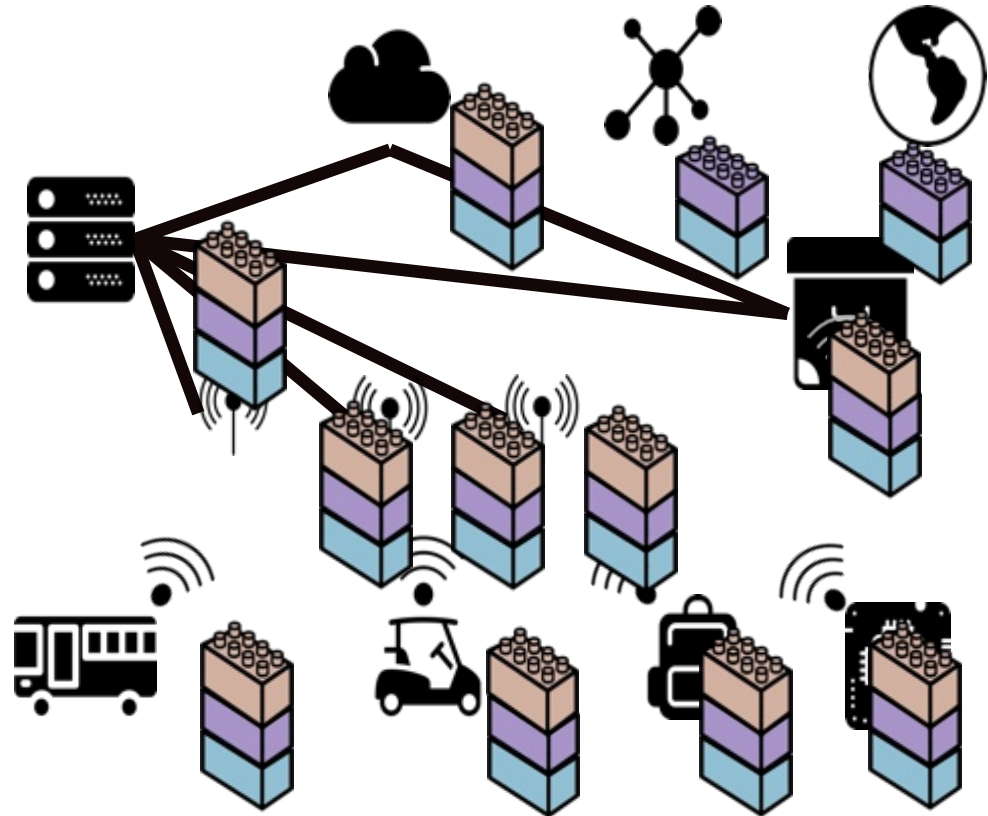
- **Basic Functionality:**
 - General purpose hardware
 - Functionality determined by software you add
- Do this end-to-end
 - Offers great flexibility in enabled research





Novice through expert...

- **Basic Functionality:**
 - General purpose hardware
 - Functionality determined by software you add
 - Do this end-to-end
 - Offers great flexibility in enabled research
- **Extended functionality:**
 - Bring-your-own-device research
 - All layers of the architecture

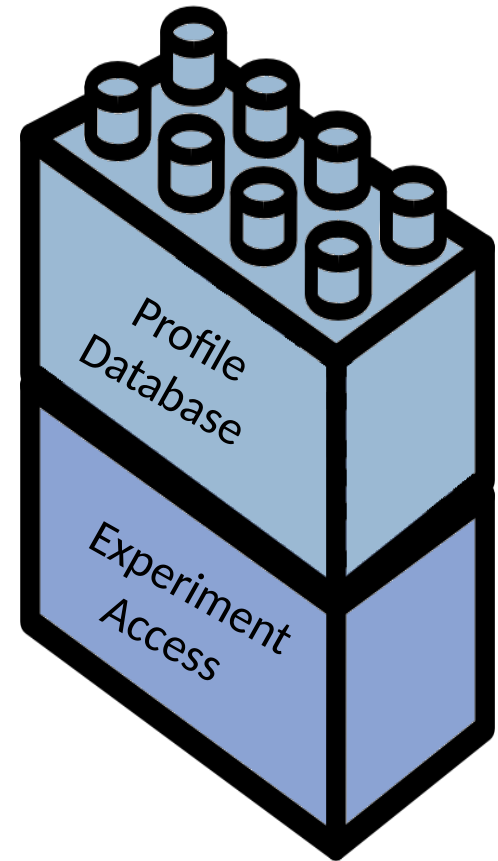
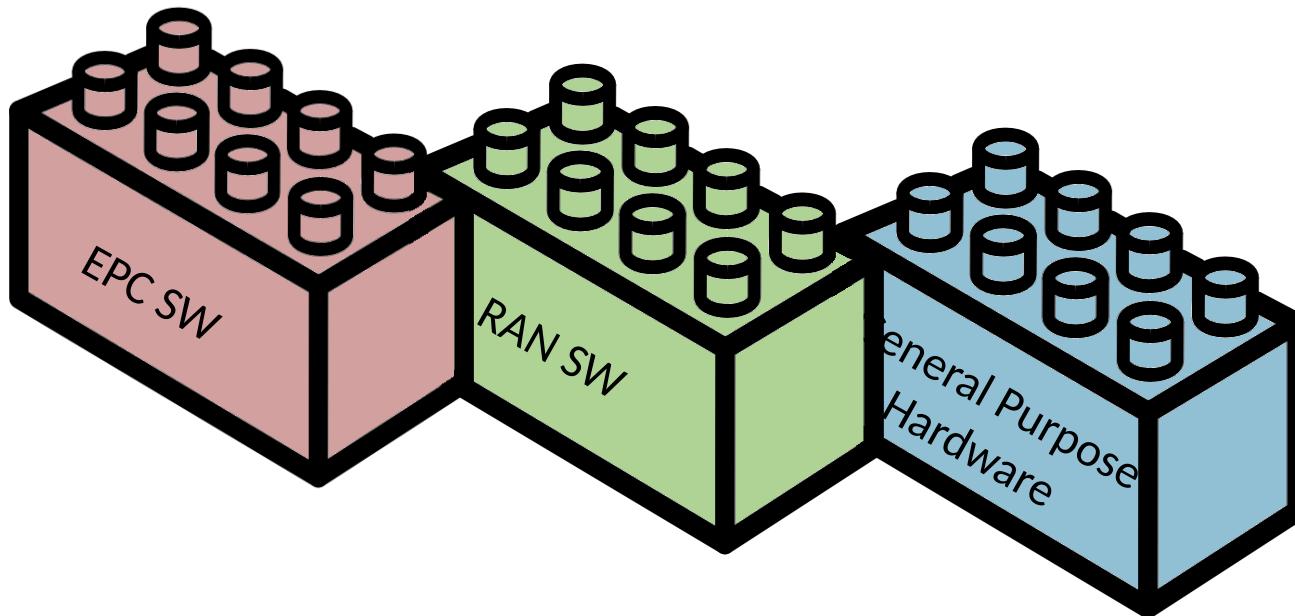




Novice through expert...

- **Research/experiment Composition**

- Building block approach
- Many existing blocks (novice)
- Build your own blocks (expert)
- End-to-end recipes called **profiles** (novice and expert)

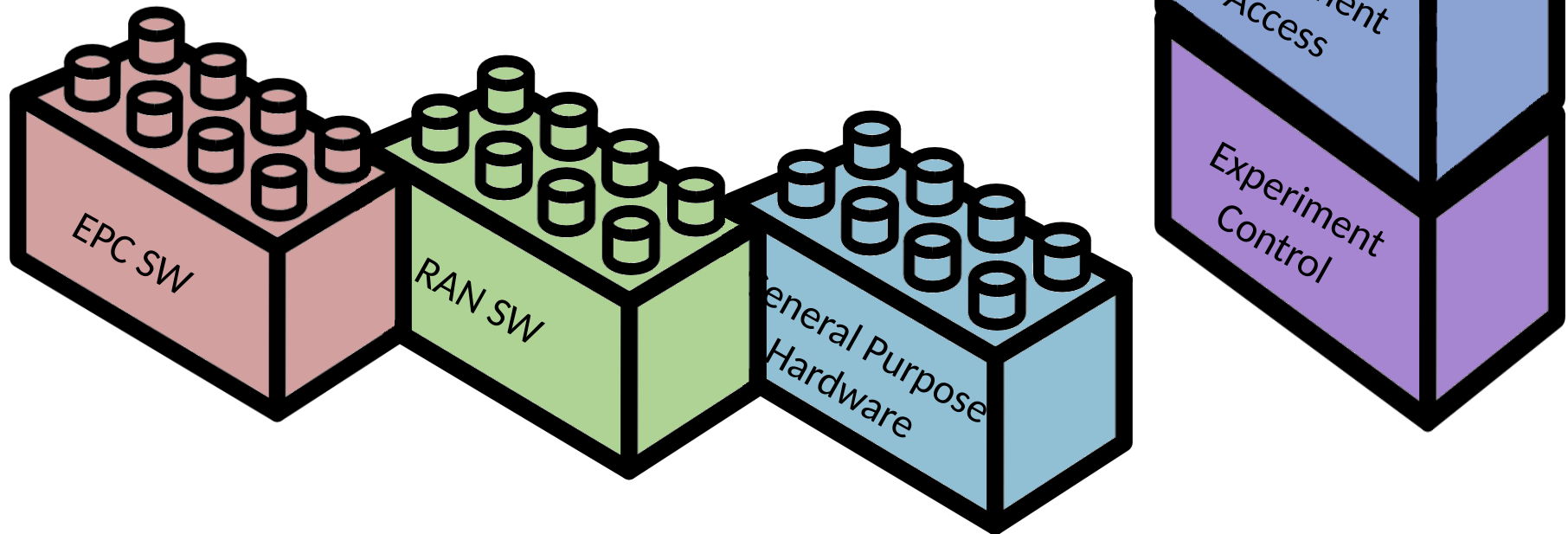




Repeatable...

- **Execution**

- Sophisticated control framework
- Profile mechanism (again)

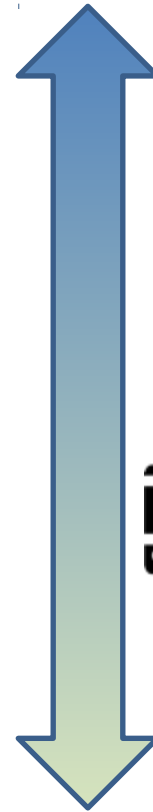




Repeatable...

- **Execution**
 - Sophisticated control framework
 - Profile mechanism (again)
- **Mobility:**
 - range of options

More



Controlled RF



Stationary radios



Predictable couriers



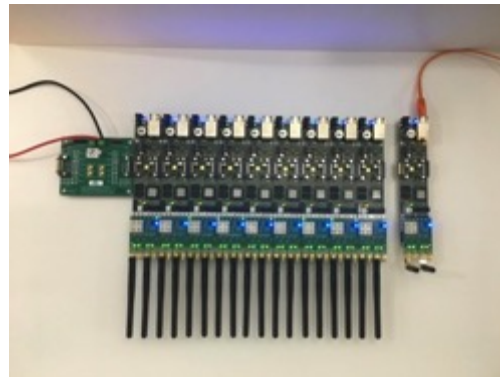
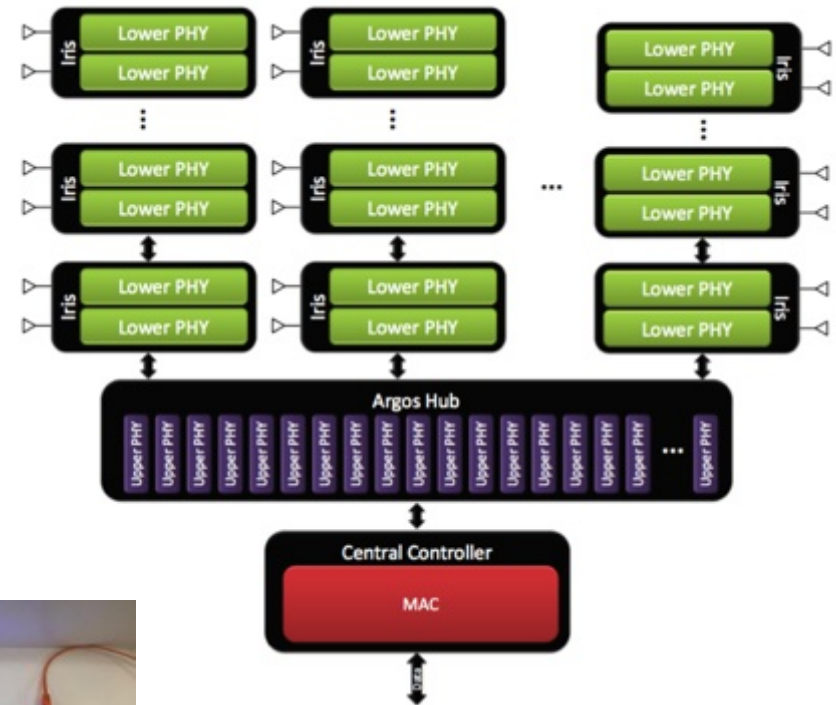
Unpredictable couriers

Less



Fully programmable & observable massive MIMO platform

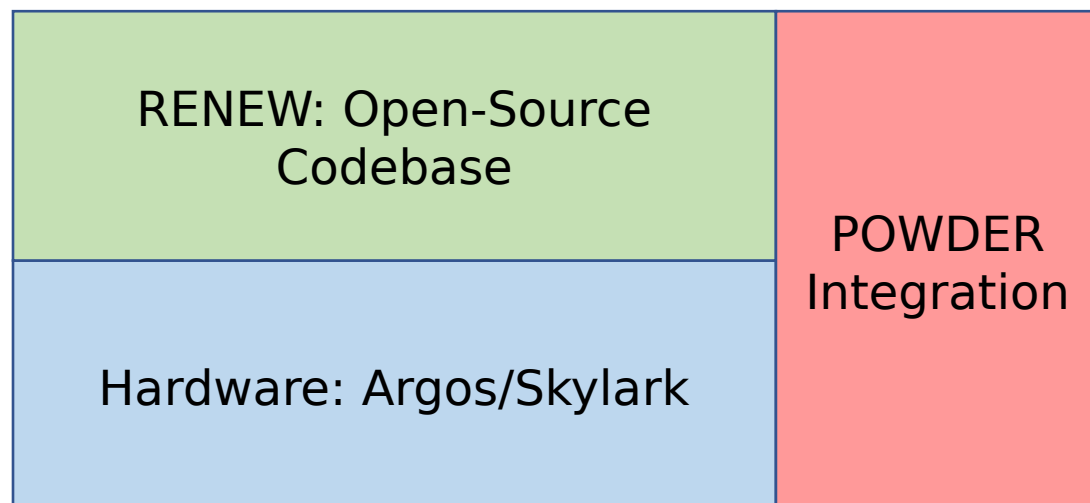
- Hardware from Rice's Argos platform
 - Now Skylark Wireless





Open-access complete Massive MIMO stack

- Argos/Skylark hardware
- Soapy Ecosystem
- Software
 - mMIMO PHY
 - 5G waveforms
 - 802.11 ac/ax
 - End-to-end 3GPP-like stack
- Integration POWDER platform



OTHER DETAIL



Datacenter/cloud

- University of Utah Datacenter
- Cloudlab facility
 - **Utah**/Clemson/Wisconsin
 - 5,000 cores; 500 TB storage
 - UT: 300 servers; 2,500 cores
 - Existing profiles for popular cloud stacks: OpenStack, CORD etc.





Spectrum

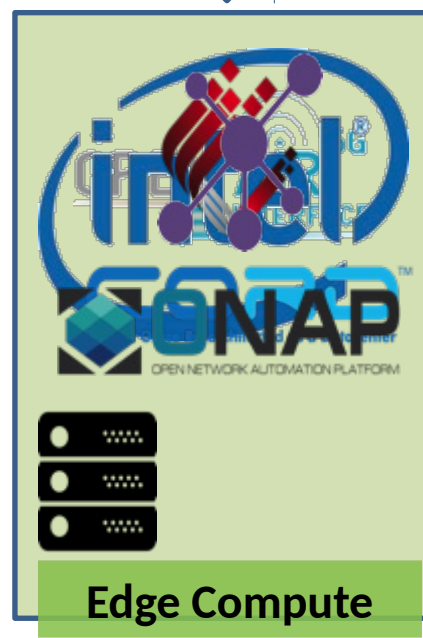
| Range (MHz) | |
|-------------|--|
| 698-806 | Commercial/Public Safety |
| 902-928 | Industrial, scientific and medical (ISM) |
| 1710-1755 | Extended Advanced Wireless Services (EAWS) uplink |
| 2110-2155 | Extended Advanced Wireless Services (EAWS) downlink |
| 3550-3650 | Citizens Broadband Service |
| 5150-5925 | Unlicensed National Information Infrastructure (U-NII) |

- Broad range of frequencies
- **Program license/Innovation zone**
- Dynamic spectrum access system: **federated** wireless™

POWDER EXPERIMENTAL PROCESS



POWDER experimental process



POWDER Experimental Process

- Build profile from scratch (using existing building blocks), or, start with existing profile (close to target profile, or use “raw” resource profile)
- Install software needed, make new images
- Add to profile and save as new profile
- Repeat...
- Publish “final” profile as supporting artifact



Experimental workflow – ONAP



Experiments ▾

Storage ▾

Docs

kobus ▾

1. Select a Profile

2. Parameterize

3. Finalize

4. Schedule

Selected Profile: OAI-Real-Hardware (Repohash: 05c8dce8)

Use this profile to instantiate an experiment using Open Air Interface to realize an end-to-end SDR-based mobile network. This profile includes the following resources:

- Off-the-shelf Nexus 5 UE running Android 4.4.4 KitKat ('rue1')
- SDR eNodeB (Intel NUC + USRP B210) running OAI on Ubuntu 16 ('enb1')
- All-in-one EPC node (HSS, MME, SPGW) running OAI on Ubuntu 16 ('epc')
- A node providing out-of-band ADB access to the UE ('adb-tgt')
- PhantomNet startup scripts automatically configure OAI for the specific allocated resources.

For more detailed information:

[Getting Started](#)

Show Profile

Change Profile

Previous

Next

Select a Profile

ONAP-OpenStack

utahstud -

knownet -

cs6480-2017-cl -

PowderProfiles -

SafeEdge -

cs6480-2017-pnet -

PowderTeam -

CS4480-2018 -

Policy -

PhantomSandbox -

geni -

cs6480-2016-pnet -

KExplore -

GLOBECOMTutorial -

cs6480-2016 -

SIGCOMMTutorial -

cs6480-2015 -

Default Profiles -

ONAP-OpenStack

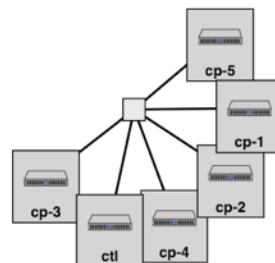
Other Profiles -

ONAP-OpenStack

★ Add to Favorites

Created By: jonnsong
Project: emulab-ops
Latest Version: 0
Repo Based?: Yes
Repo Hash: 05d9153b
Last Updated: 2018-10-19 15:20:23
Description:

This profile provides an ONAP instance that runs in containers deployed in a custom-built, configurable OpenStack instance. We have tested ONAP with the OpenStack Queens release, but you can try to instantiate with other OpenStack releases if you like by changing the release parameter. This profile is an extension of the standard OpenStack profile, so first OpenStack is configured, then ONAP is installed. When you click the Instantiate button, you'll be presented with a list of parameters that you can change to control what ONAP and your OpenStack instance will look like; **carefully** read the parameter documentation on that page (or in the Instructions) to understand the various features available to you. The Instructions shown on your



Select Profile

Cancel

[Experiments ▾](#)[Storage ▾](#)[Docs](#)[kobus ▾](#)[1. Select a Profile](#)[2. Parameterize](#)[3. Finalize](#)[4. Schedule](#)

Selected Profile: ONAP-OpenStack (Repohash: 05d9153b)

This profile provides an ONAP instance that runs in containers deployed in a custom-built, configurable OpenStack instance. We have tested ONAP with the OpenStack Queens release, but you can try to instantiate with other OpenStack releases if you like by changing the release parameter. This profile is an extension of the standard OpenStack profile, so first OpenStack is configured, then ONAP is installed. When you click the Instantiate button, you'll be presented with a list of parameters that you can change to control what ONAP and your OpenStack instance will look like; **carefully** read the parameter documentation on that page (or in the Instructions) to understand the various features available to you. The Instructions shown on your experiment's status page will provide URLs and a random password for you to login to both OpenStack and ONAP's Rancher instance. You

[Show Profile](#)[Change Profile](#)[Previous](#)[Next](#)



Experiments ▾

Storage ▾

Docs

kobus ▾

1. Select a Profile

2. Parameterize

3. Finalize

4. Schedule

This profile is parameterized; please make your selections below, and then click to continue.

[+ Show All Parameter Help](#)

ONAP External Network ?

flat-lan-1-net

OpenStack Release ?

Queens

Keystone API Version ?

v3

Number of compute nodes

5

Number of public IP
addresses ?

6

Hardware Type ?

d430



Experiment Link Speed ?

Any

ML2 Plugin ?

OpenVSwitch

Extra VM Image URLs ?

Experiment Firewall ?

☐



Experiments ▾

Storage ▾

Docs

kobus ▾

1. Select a Profile

2. Parameterize

3. Finalize

4. Schedule

Profile: ONAP-OpenStack

Version: 0

Source

Please review the selections below and then click Next.

Name:

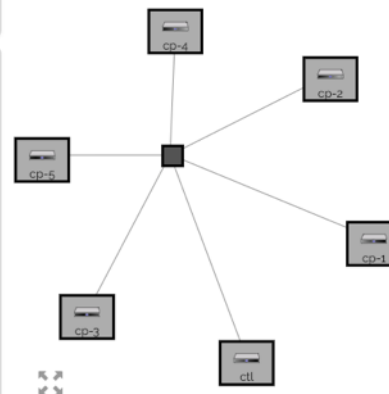
onap

Project:

PowderSandbox

+ Advanced Options

[Check Resource Availability](#)



Previous

Next



Experiments ▾

Storage ▾

Docs

kobus ▾

1. Select a Profile

2. Parameterize

3. Finalize

4. Schedule

Please select when you would like to start this experiment and then click Finish.

Start immediately



or

Start on date/time

MM/DD/YYYY

Time



Experiment Duration

16

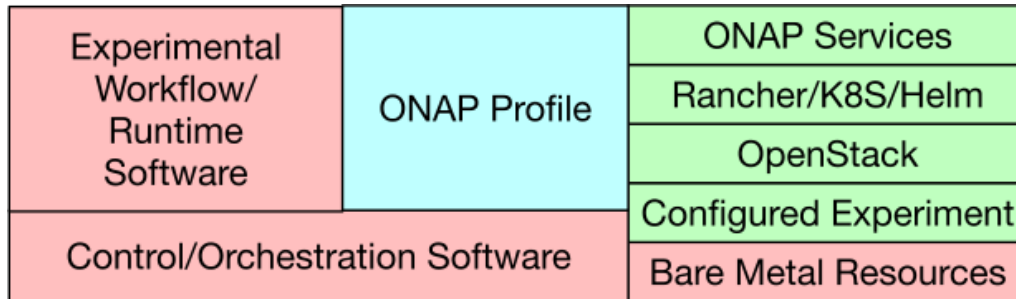
hours






Previous

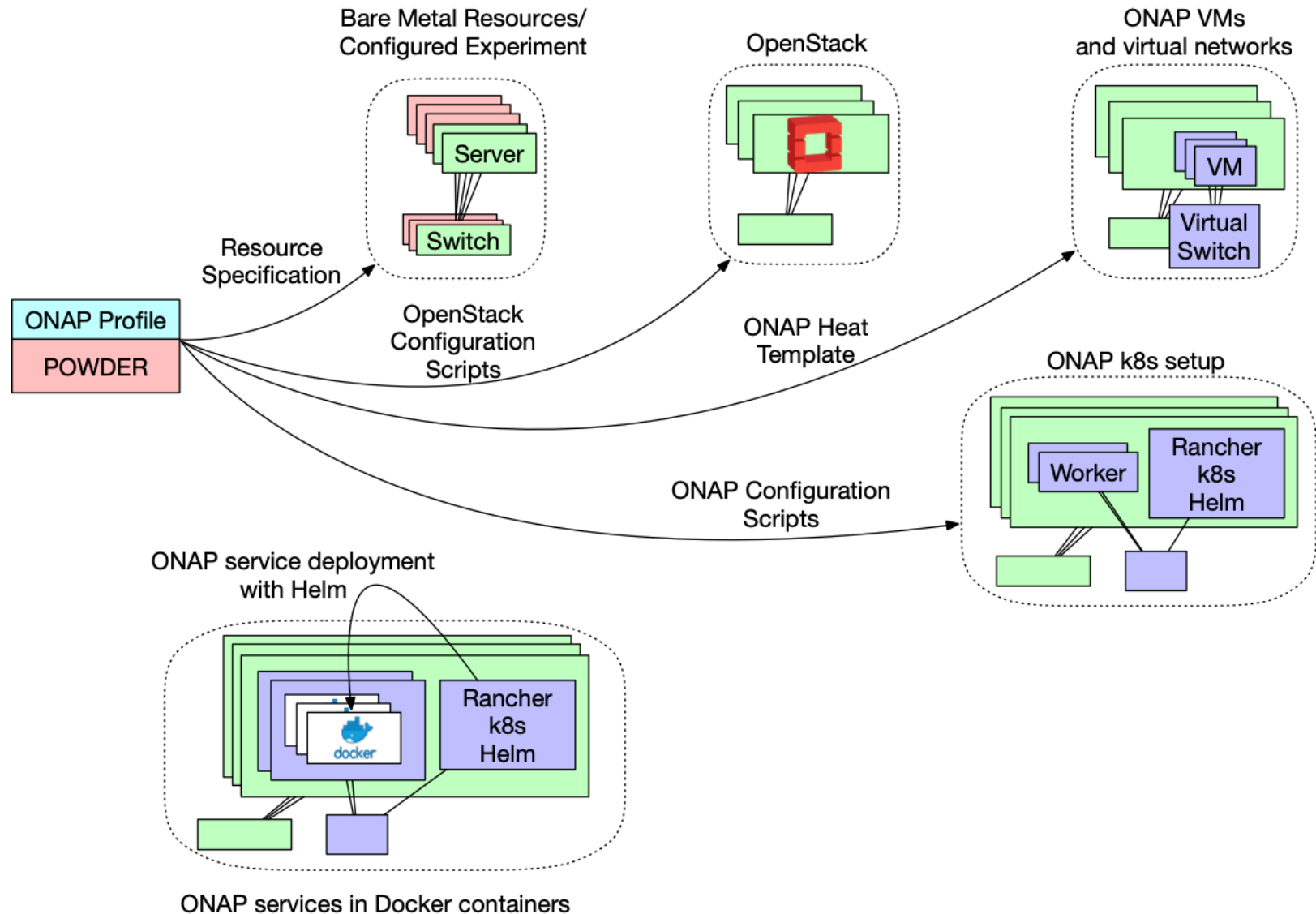
Finish

ONAP on POWDER



-  Instantiated User Experiment
-  Profile
-  POWDER platform

ONAP on POWDER






Other existing profiles



GNU Radio Profile

← → ↻ <https://www.powderwireless.net/status.php?uuid=d5101297-d497-11e8-b339-90e2ba22fee4> 🔍 ☆ ⓘ | 👤 ⋮


 Experiments ▾ Storage ▾ Docs kobus ▾

Current Usage: 20.52 Node Hours, **Prev Week: 187**, **Prev Month: 189** (30 day rank: 227 of 412 users) ⓘ

Experiment expires: Oct 21, 2018 4:42 AM (in 9 hours) >

Profile Instructions >


Topology View List View Manifest Graphs



```
graph LR; node0[GNU Radio] --- square[ ]; square --- node1[GNU Radio];
```

Click on a node for more options. Click and drag to move things around.

Reload Topo Run Linktest Refresh Status

Powered by  emulab Question or comment? Join the Help Forum © 2018 The University of Utah



GNU Radio Profile

```
#!/usr/bin/python
```

```
"""
```

Two SDR nodes running GNU Radio with an RF link.

Instructions:

Once the experiment is ready, choose one node in the experiment and open a shell. Within the shell, execute:

```
/share/phantomnet/bin/runvnc.sh
```

Open the link given in the shell. Within a terminal in the resulting VNC desktop, you can open GNU Radio Companion flow graphs, e.g.:

```
gnuradio-companion /share/phantomnet/grcon/rx.grc
```

Repeat the process of opening a shell and VNC desktop on the other node, but this time bring up a complementary flow graph, e.g.:

```
gnuradio-companion /share/phantomnet/grcon/tx.grc
```

```
"""
```

```
import geni.portal as portal
import geni.rspec.pg as rspec
import geni.rspec.emulab.pnext as pn
```

```
request = portal.context.makeRequestRSpec()
```

```
node0 = request.RawPC( "node0" )
node0.hardware_type = "nuc5300"
node0.disk_image =
"urn:publicid:IDN+emulab.net+image+grcon2018:grcon2018"
node0if = node0.addInterface( "rf0" )
```

```
node1 = request.RawPC( "node1" )
node1.hardware_type = "nuc5300"
node1.disk_image =
"urn:publicid:IDN+emulab.net+image+grcon2018:grcon2018"
node1if = node1.addInterface( "rf0" )
```

```
rflink = request.RFLink( "rflink" )
rflink.addInterface( node0if )
rflink.addInterface( node1if )
```

```
portal.context.printRequestRSpec()
```

- Allocates two SDRs and associated compute
- With associated software
- Very simple profile



5G NR Profile

UE and gNB

Three node types:

- SDR (USRP)
- Compute (Rackmount server)
- Data store (OAI software stack)

Option to bind to specific hardware

The screenshot displays the Powder Wireless web interface. The browser address bar shows the URL: <https://www.powderwireless.net/status.php?uuid=02a20e4b-d4d7-11e8-b339-90e2ba22fee4>. The interface includes navigation tabs for 'Experiments' and 'Storage', and a user profile 'kobus'. A green banner at the top states 'Your experiment is ready!'. Below this, a table provides experiment details:

| | |
|----------|-------------------------------------|
| Name: | kobus-QV42262 |
| State: | ready |
| Profile: | OAI-NR |
| Started: | Oct 20, 2018 8:14 PM |
| Expires: | Oct 21, 2018 12:14 PM (in 16 hours) |

Buttons for 'Logs', 'Create Disk Image', 'Copy', 'Extend', and 'Terminate' are visible. A 'Profile Instructions' link is also present. At the bottom, a 'Topology View' shows a network diagram with nodes labeled 'enb1', 'usrp_enb', 'usrp_ue', 'rue1', 'ds-enb1', and 'ds-rue1'.



LTE/EPC Profile

Four node types:

- OTS UE
- SDR and compute: eNodeB
- Compute (Rackmount server): EPC
- Data store (OAI software stack: RAN and core)

Options:

- Over-air
- Controlled RF
- Number of UEs/eNodeBs

https://www.powderwireless.net/status.php?uuid=c7622169-d4d6-11e8-b339-90e2ba22fee4

Experiments ▾ Storage ▾ Docs kobus ▾

Current Usage: 21.63 Node Hours, Prev Week: 188, Prev Month: 190 (30 day rank: 227 of 412 users) ⓘ

Your experiment is ready! ➤

Name: kobus-QV42261
State: ready
Profile: OAI-Real-Hardware
RefSpec: refs/heads/master (05c8dce8459f028cc7ba6389f6736e2ceae9a748)
Started: Oct 20, 2018 8:12 PM
Expires: Oct 21, 2018 12:12 PM (in 16 hours)
Logs Extend Terminate

Profile Instructions ➤

Log View List View Manifest Graphs

```
graph LR
    rue1[rue1] --- enb1[enb1]
    enb1 --- epc[epc]
    enb1 --- ds-enb1[ds-enb1]
    epc --- ds-epc[ds-epc]
    ds-ue1[ds-ue1] --- rue1
```



OpenStack Profile

OpenStack instance in
15-20 minutes

Highly parameterized
(58...):

- Version of Openstack
- Services to enable
- Number of compute nodes
- Hardware type
- Number public Ips
- Multi-site options
- Network options
- Use remote dataset
- etc.

The screenshot shows a web browser window with the URL <https://www.powderwireless.net/status.php?uuid=e290bc36-d5fc-11e8-b339-90e2ba22fee4>. The page displays the status of an OpenStack instance named 'kobus-QV42286'. The instance is in a 'ready' state and is using the 'OpenStack' profile. The dashboard also shows usage statistics: Current Usage: 0 Node Hours, Prev Week: 281, Prev Month: 284 (30 day rank: 212 of 407 users). Below the status information, there are buttons for 'Logs', 'Extend', and 'Terminate'. At the bottom, there is a section for 'Profile Instructions' and a diagram showing the network topology with nodes 'cp-1' and 'ctl' connected to a central switch.

← → ↻ <https://www.powderwireless.net/status.php?uuid=e290bc36-d5fc-11e8-b339-90e2ba22fee4> 🔍 ☆ ⓘ | 👤 ⋮

Experiments ▾ Storage ▾ Docs kobus ▾

Current Usage: 0 Node Hours, Prev Week: 281, Prev Month: 284 (30 day rank: 212 of 407 users) ⓘ

Your experiment is ready! ➤

Name: kobus-QV42286
State: ready
Profile: OpenStack
RefSpec: refs/heads/master (e48f0660d1fb91cc8c94e5493bce0g6f186aoc78)
Started: Oct 22, 2018 7:17 AM
Expires: Oct 22, 2018 11:17 PM (in 16 hours)
Logs Extend Terminate

Profile Instructions ➤

st View Manifest Graphs

cp-1 ctl



ONAP OpenStack Profile

- Took existing OpenStack profile
- Added a post-deployment option: ONAP deployment script

The screenshot shows a web browser window with the URL <https://www.powderwireless.net/instantiate.php>. The page displays a "Select a Profile" modal window. On the left, a list of profiles is shown, with "ONAP-OpenStack" selected. On the right, the details for the "ONAP-OpenStack" profile are displayed, including its creation date, project, version, and a detailed description. Below the text, a diagram shows the architecture of the profile, consisting of a controller node (cp-1) and a compute node (cti) connected by a line. At the bottom right, there are "Select Profile" and "Cancel" buttons.

onap

utahstud -
knownet -
SafeEdge -
PowderProfiles -
cs6480-2017-cl -
cs6480-2017-pnet -
PowderTeam -
CS4480-2018 -
Policy -
PhantomSandbox -
geni -
cs6480-2016-pnet -
KExplore -
GLOBECOMTutorial -
cs6480-2016 -
SIGCOMMTutorial -
cs6480-2015 -
Default Profiles -
ONAP-OpenStack
Other Profiles -

ONAP-OpenStack ★ Add to Favorites

Created By: johnsond
Project: emulab-ops
Latest Version: 0
Repo Based?: Yes
Repo Hash: e48f0660
Last Updated: 2018-10-19 15:20:23
Description: This profile provides a highly-configurable OpenStack instance with a controller and one or more compute nodes (potentially at multiple Cloudlab sites) (and optionally a network manager node, in a split configuration). This profile runs x86 or arm64 nodes. It sets up OpenStack Queens (Ubuntu 18.04), Pike, Ocata, Newton, or Mitaka (Ubuntu 16.04) (Liberty on 15.10, Kilo on 15.04, and Juno on 14.10 are *deprecated*) according to your choice, and configures all OpenStack services, pulls in some VM disk images, and creates basic networks accessible via floating IPs. You'll be able to create instances and access them over the Internet in just a few minutes. When you click the instantiate button, you'll be presented with a list of parameters that you

cp-1
cti

Select Profile Cancel

PARTNERS

Key partners



Salt Lake City: “Crossroads of the West”

- Economic, Transportation, Networking, Cultural Hub
- *Use of City buildings and City vehicles as couriers*



UETN: Statewide Education and Health Network

- > 1,400 schools/libraries; > 75 healthcare facilities
- *Use of extensive fiber network and operations*



Utah Department of Transportation

- Fiber infrastructure; connected vehicle pioneer
- *Access to fiber and use of traffic signal poles*



Infrastructure partners



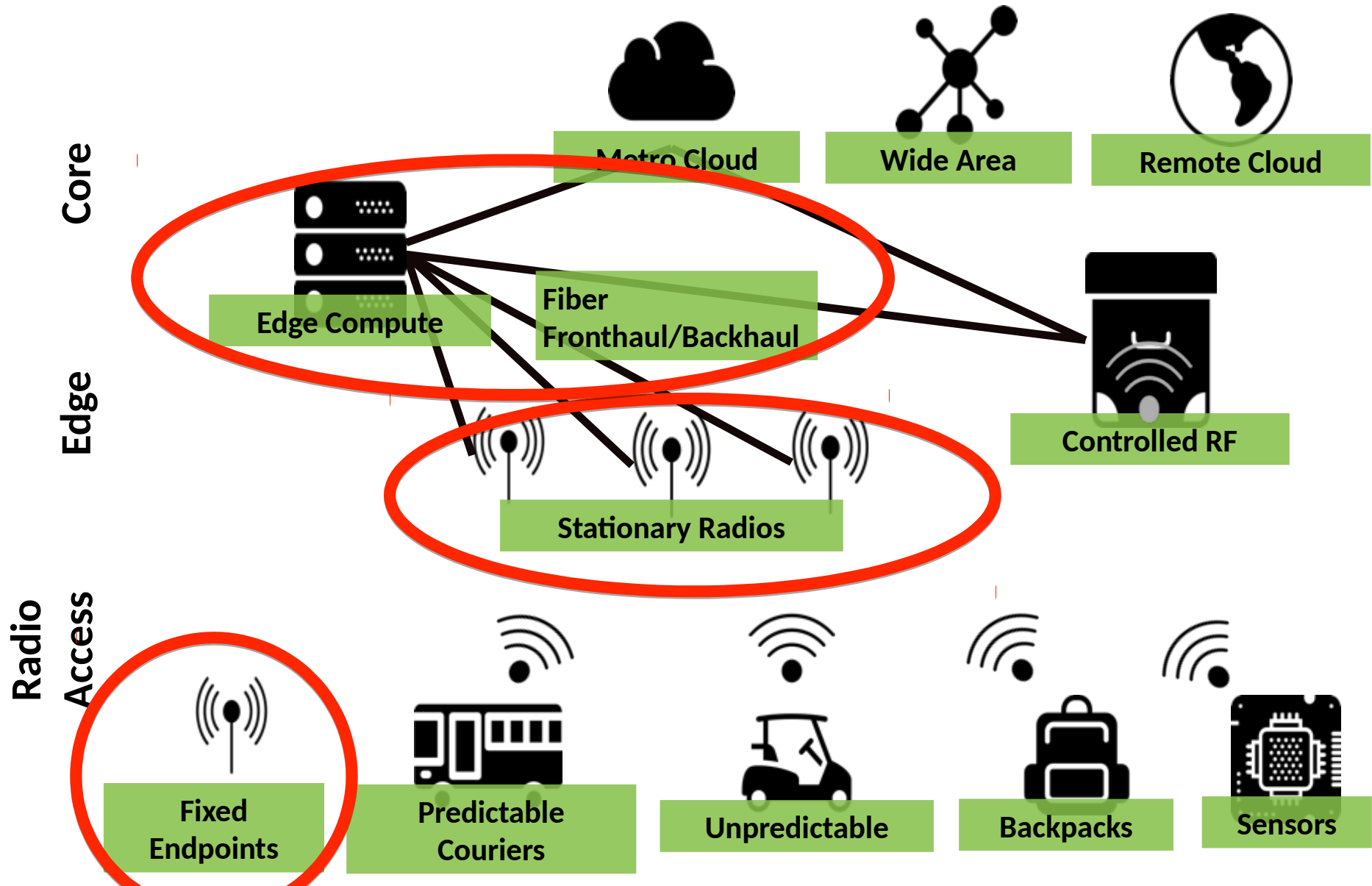
Hines



PROCESS/STATUS

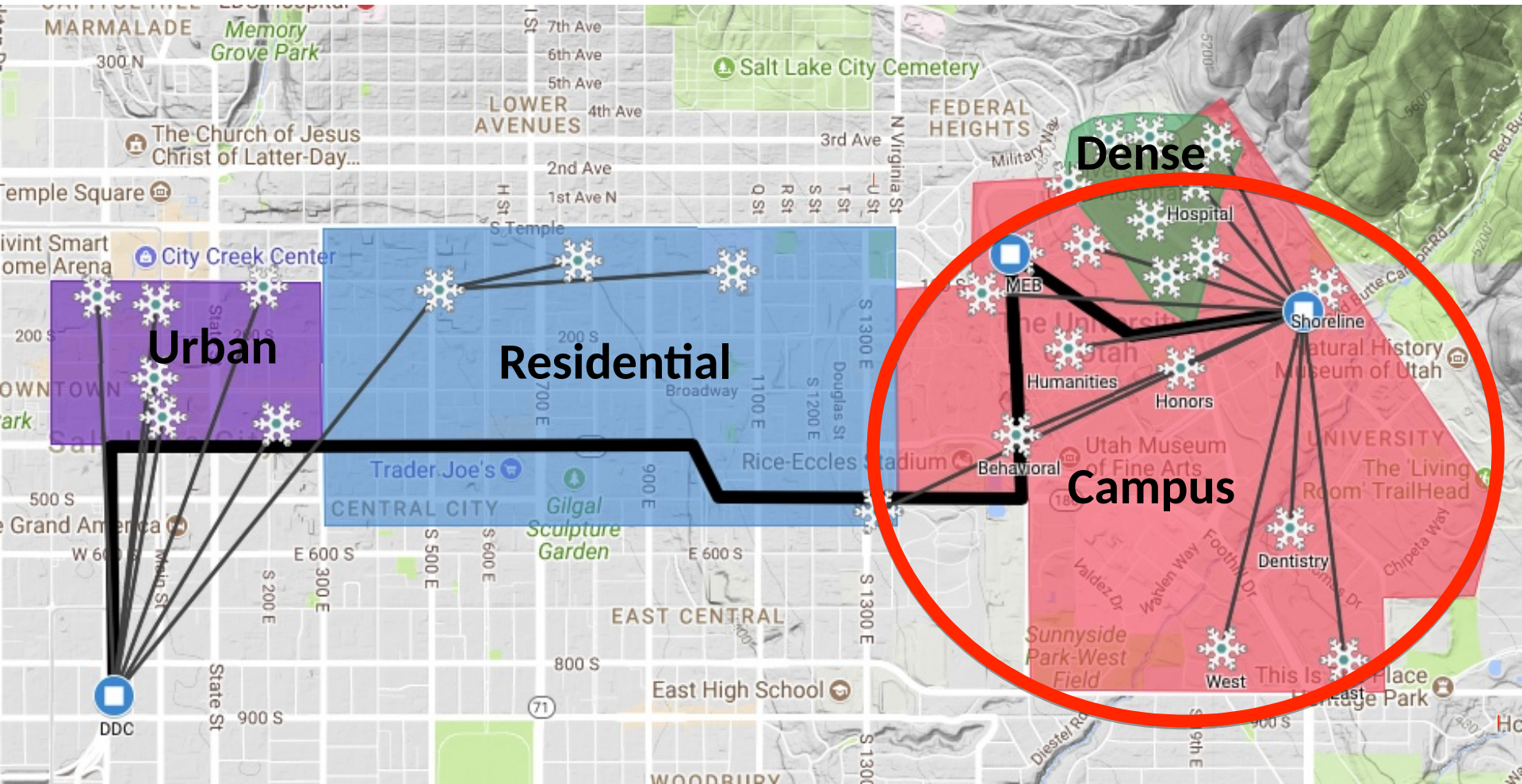


Campus fixed deployment



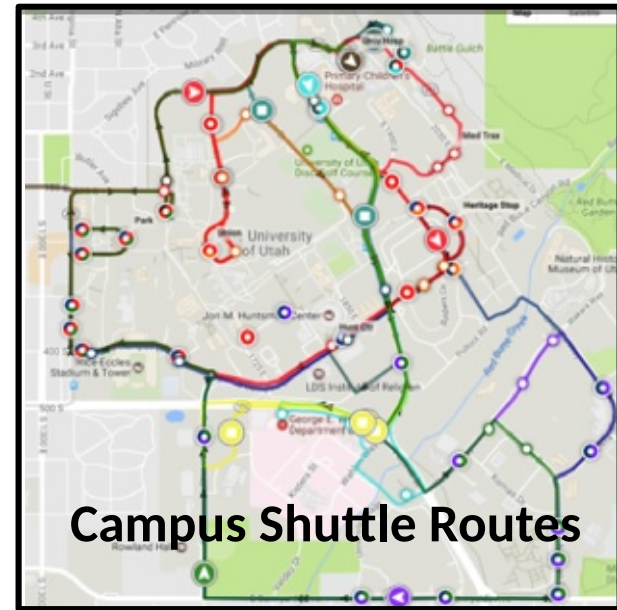
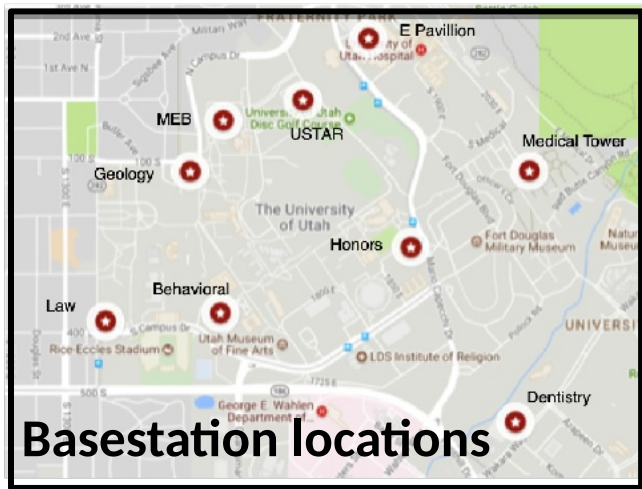


Campus fixed deployment



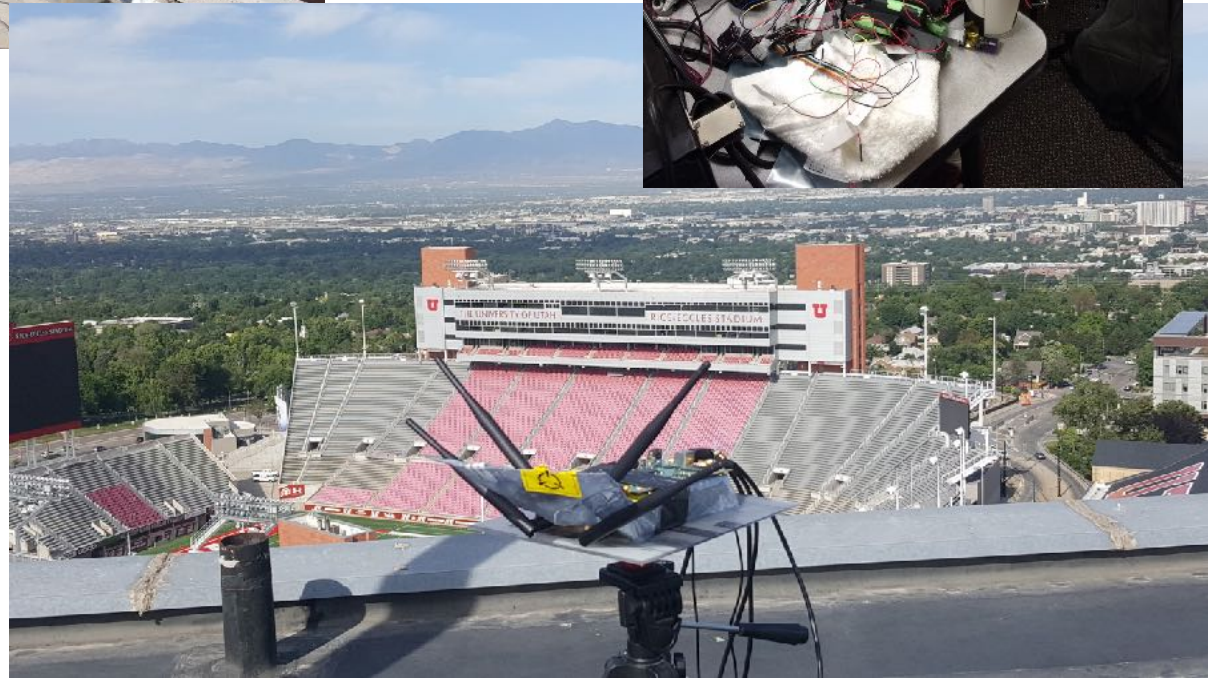


Finding target locations





RF measurements from target locations

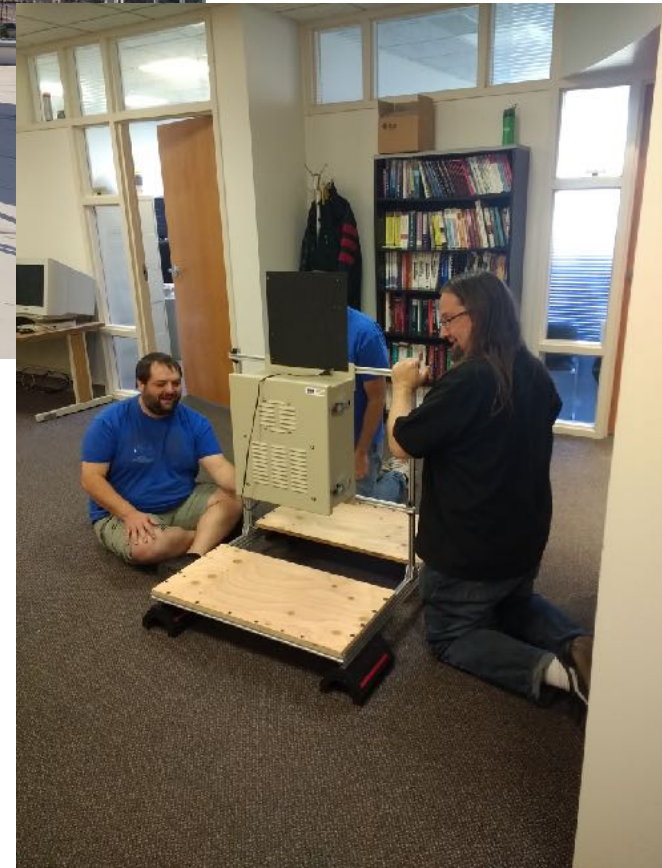






Site surveys...





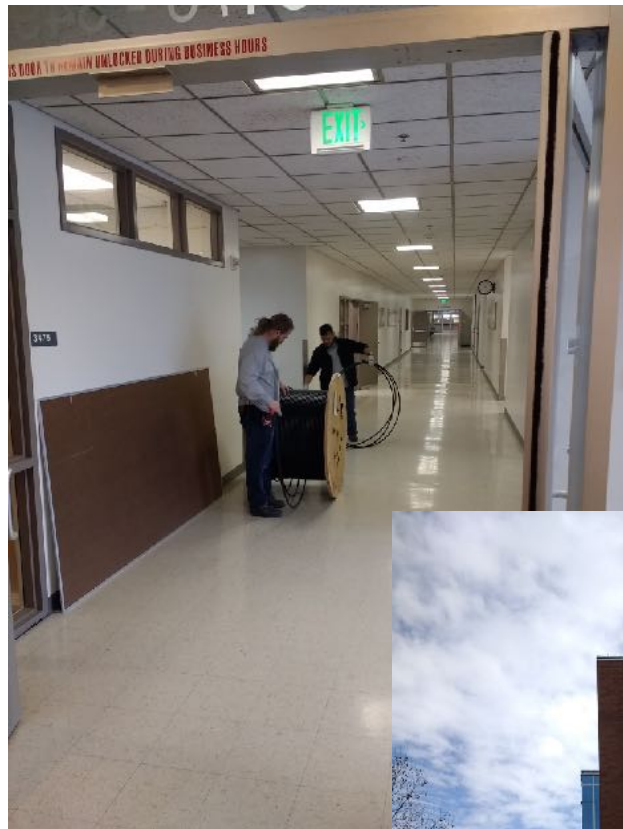


Equipment arriving...





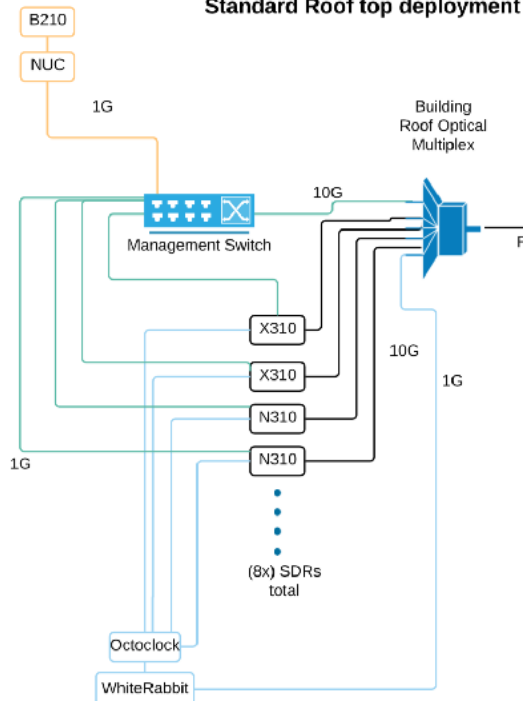
Deployment...



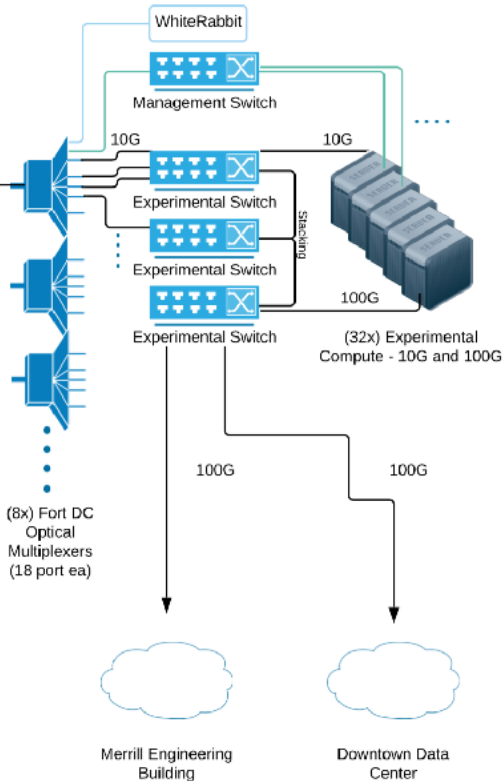


Edge compute, fiber fronthaul/backhaul

Standard Roof top deployment



Fort Data Center deployment

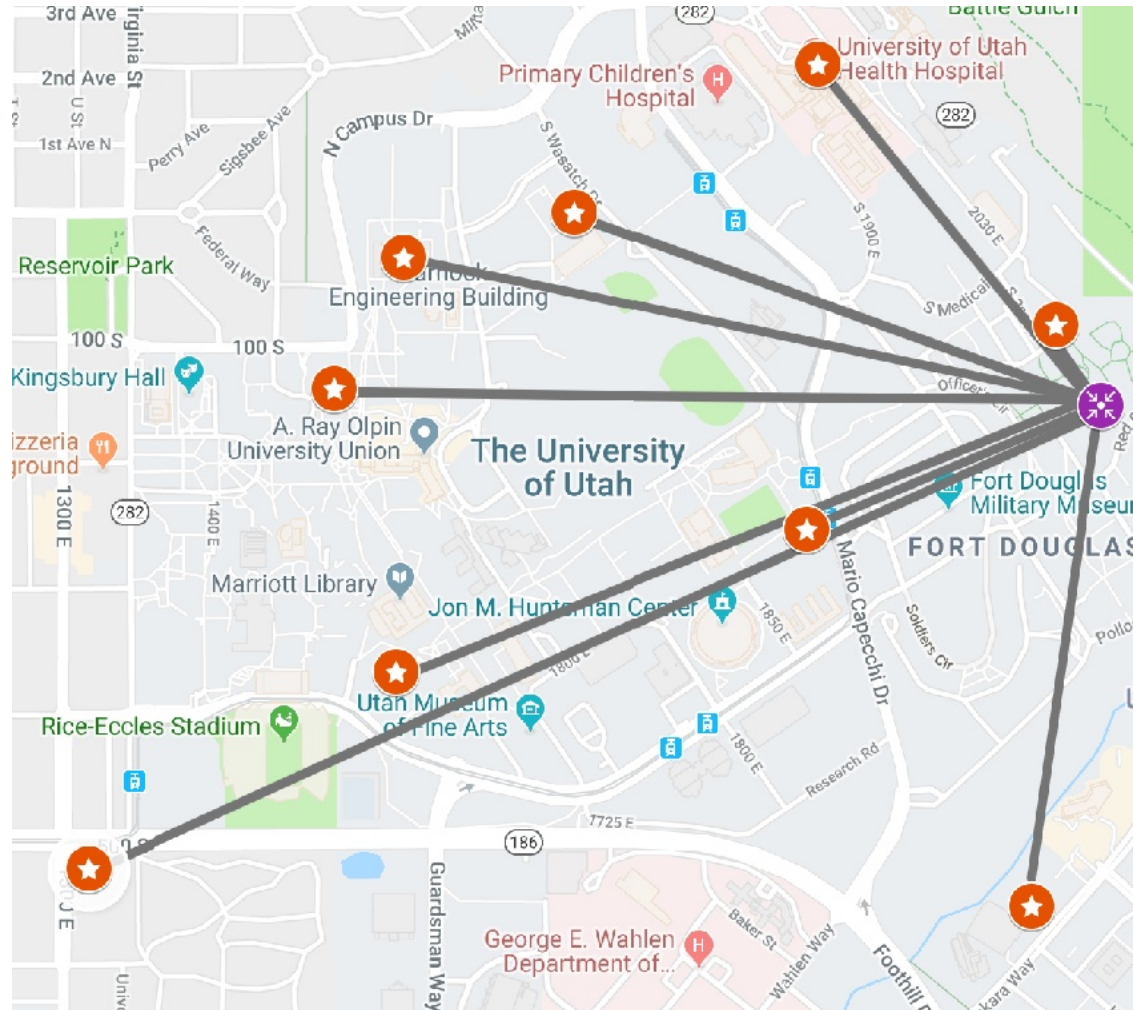


Legend

- Monitoring
- Management
- Experimental/Data
- Clock synchronization



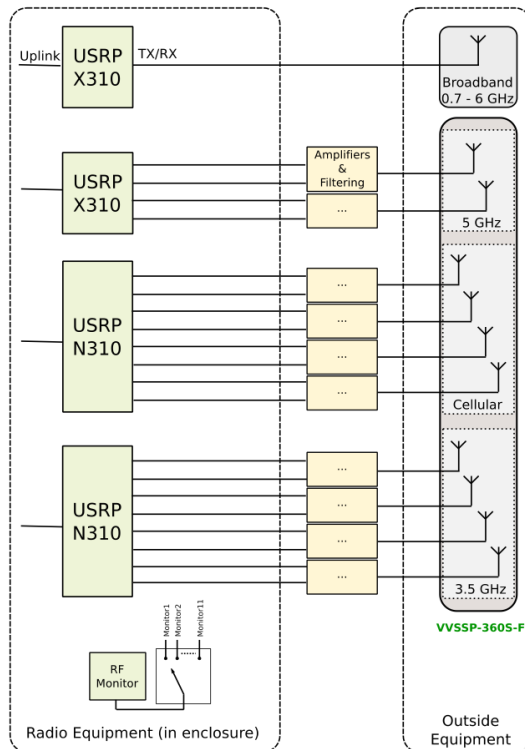
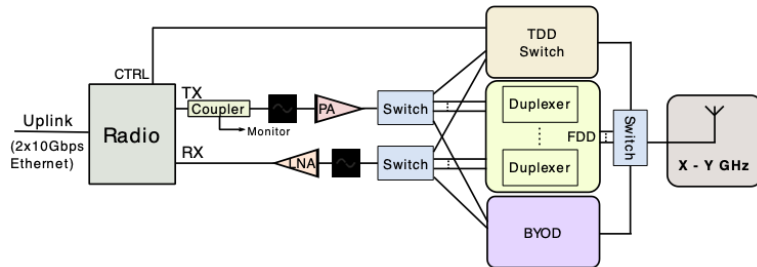
Edge compute, fiber fronthaul/backhaul





Stationary Radio (Rooftop Basestation)

Single RF Chain Detail

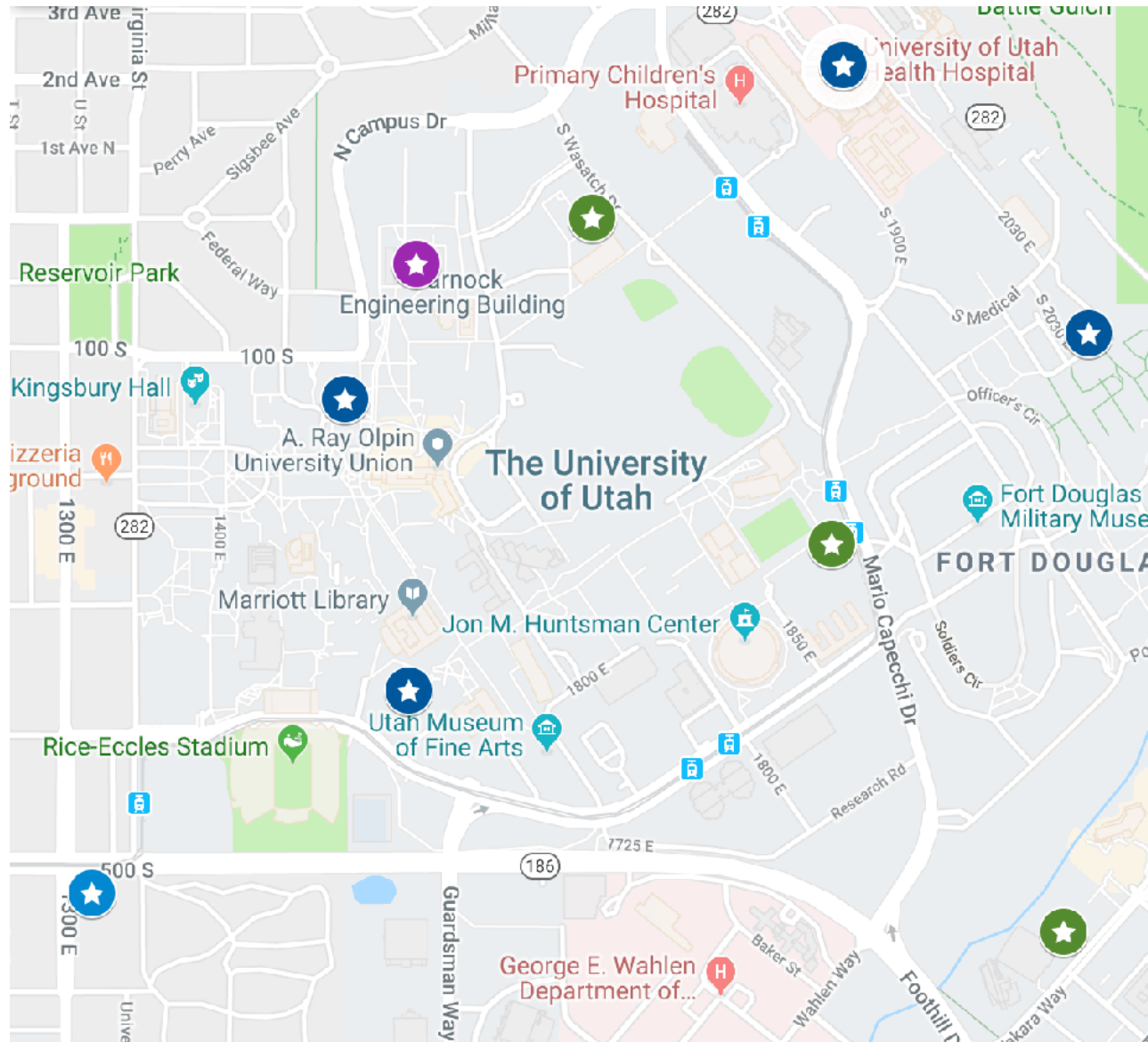


Powder Base Station RF Front-end



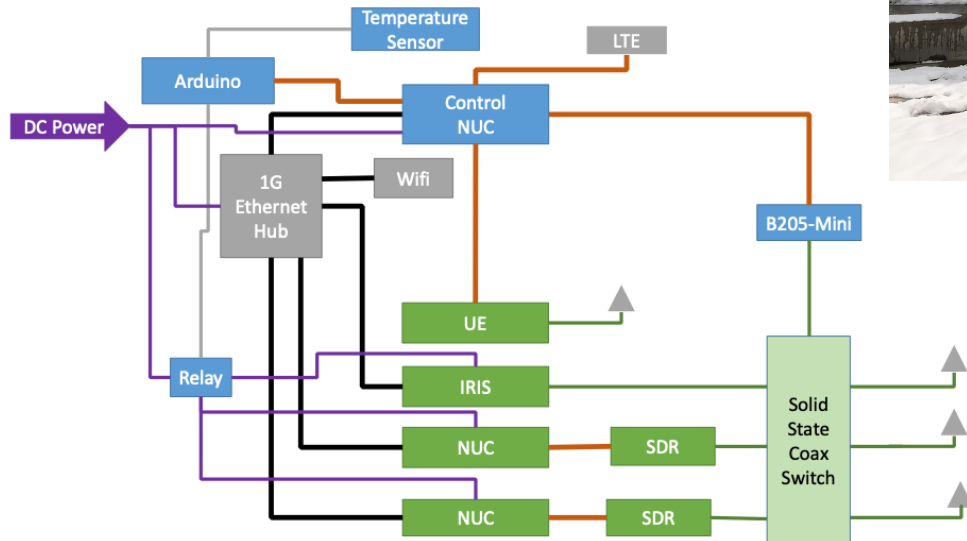


Stationary Radio (Rooftop Basestation)





Fixed-endpoint





Fixed-endpoint

