Site-Specific Millimeter-Wave Propagation Modeling
for Wide Area Wireless Networks

NSF PAWR POWDER-RENEW Testbed Measurement Plan

DRAFT v2.0

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Contents

1 Objective

The objective of this measurement campaign is to obtain a reasonably large dataset of site-specific signal propagation characteristics for experimenting Artificial Intelligence (A.I.) algorithms in mmWave radio ecosystems. Measurements will be performed on the NSF PAWR POWDER-RENEW testbed at the University of Utah in Salt Lake City, UT, to emulate typical 5G (and beyond) deployments in urban and suburban environments. The Tx will be temporarily installed at designated points on the roof of several buildings at the University of Utah (e.g., University of Utah Hospital Building, Behavioral Sciences Building, etc). The Rx, on the other hand, would be mounted on top of a van, and driven around campus along pre-determined routes (e.g., Blue Detour, Suburban, etc) to collect these geographically correlated measurements – intended to be used for transmission loss evaluations in direct-link large-scale propagation modeling and for beam-steering/multipath evaluations under different angle-of-departure (AoD)/angle-of-arrival (AoA) values.

2 Background

Electromagnetic signals in the mmWave bands are expected to experience more attenuation over distance and be extremely sensitive to obstacles in the environment. To take full advantage of the vast mmWave bandwidth to be available in next-generation radio access technologies, service providers will need channel information based on Tx and Rx locations in both planning and operating these networks: a comprehensive channel measurement dataset with detailed geographic information is the key to fostering these site-specific mmWave channel models. In this measurement campaign, we would like to create such a dataset for urban and suburban environments at 28GHz. Two types of measurement results are planned to be extracted:

- Transmission loss assessments of the direct link between a fixed Tx and a mobile Rx covering a reasonably large geographic area (≈1 sq. km) for large-scale site-specific propagation modeling, and
- Transmission loss assessments at pre-determined Rx locations with a pre-assigned combination of different AoD/AoA values for multipath evaluation.

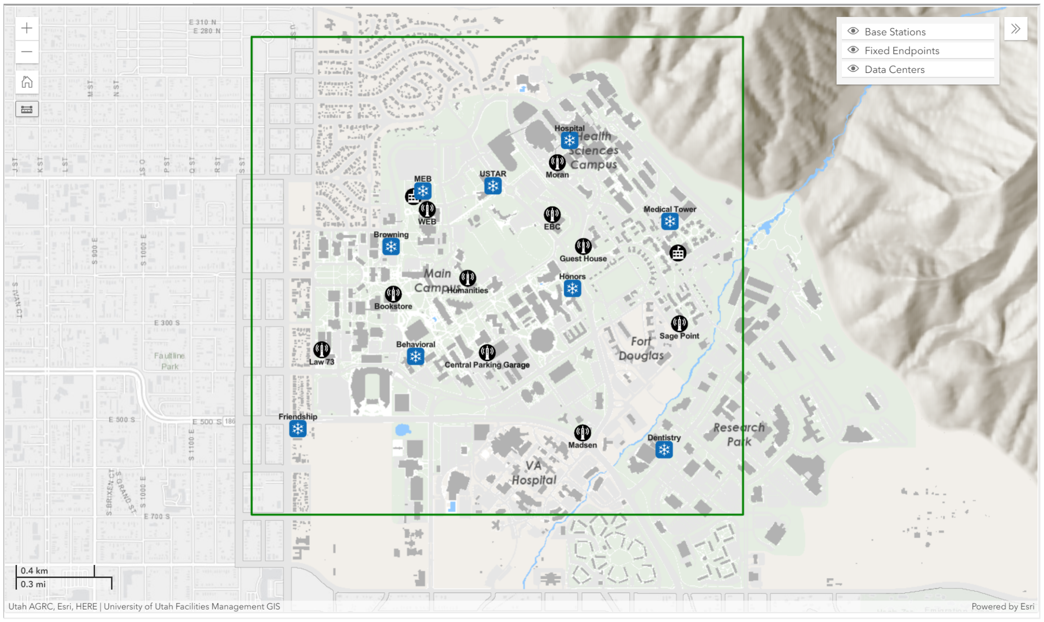


Figure 1: The NSF PAWR POWDER-RENEW testbed at the University of Utah: our measurement arena

3 Methodology

3.1 Introduction

The measurement campaign will be conducted using a pair of autonomous antenna tracking platforms – one at the Tx and another at the Rx – developed under Project Odin at Purdue University, in collaboration with Dr. Chris Anderson of the United States Naval Academy (USNA). Details about our sounder design at 28GHz are provided in Sec. 4, and details about our autonomous antenna tracking platforms are outlined in Sec. 5. Finally, introducing our playground, Fig. 1 depicts our arena for this measurement campaign – constituting both urban and suburban environments in and around the University of Utah.

3.2 Potential Tx Mount-Point Candidates

- Fig. 2 illustrates a set of potential Tx mount-points at the University of Utah – designated as “fixed end-points” on the POWDER testbed – with their corresponding USRP B210 radios and Intel NUC small form-factor compute nodes; and
- Fig. 3 illustrates another set of potential Tx mount-points – designated as “roof-top base-stations” on the POWDER testbed – with their corresponding USRP X310 radios and more powerful Dell PowerEdge R740/R840 compute nodes.

3.3 Potential Mobile Rx Routes

Although some of the following routes match the routes of the “mobile nodes” (shuttles) available on the POWDER testbed, we do not intend to use these shuttles for our measurement campaign; instead, we would provision a van on our own and mount our Rx setup on top of it.

- Blue Detour: Rx along the route depicted in Fig. 4 – with the Tx affixed at the mount-point depicted in Fig. 5 and Fig. 6 – for site-specific mmWave propagation modeling in urban environments;
- Orange: Rx along the route depicted in Fig. 9 – with the Tx affixed at the mount-point depicted in Fig. 10 and Fig. 11 – for site-specific mmWave propagation modeling in urban environments;
- Circulator: Rx along the route depicted in Fig. 12 – with the Tx affixed at the mount-point depicted in Fig. 13 and Fig. 14 – for site-specific mmWave propagation modeling in urban environments;
- Guardsmen Direct: Rx along the route depicted in Fig. 15 – with the Tx affixed at the mount-point depicted in Fig. 16 and Fig. 17 – for site-specific mmWave propagation modeling in urban environments;
- Wasatch Express: Rx along the route depicted in Fig. 18 – with the Tx affixed at the mount-point depicted in Fig. 19 and Fig. 20 – for site-specific mmWave propagation modeling in urban environments; and
- Suburban: Rx along the route depicted in Fig. 21 – with the Tx affixed at the mount-point depicted in Fig. 22 and Fig. 23 – for site-specific mmWave propagation modeling in suburban environments.

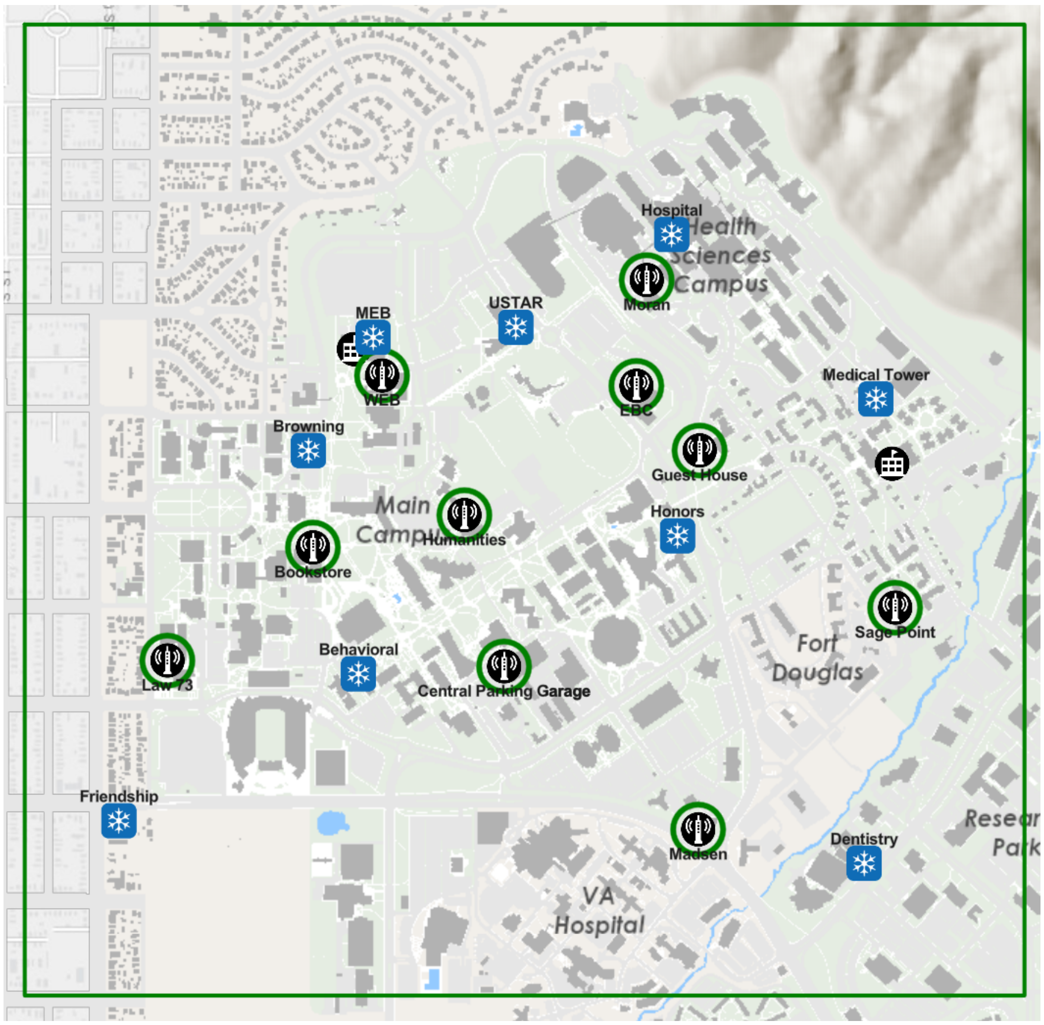


Figure 2: Potential Tx mount-point candidates: The fixed end-points (with their associated Intel NUC small form-factor compute nodes) available for provisioning on the University of Utah's POWDER testbed

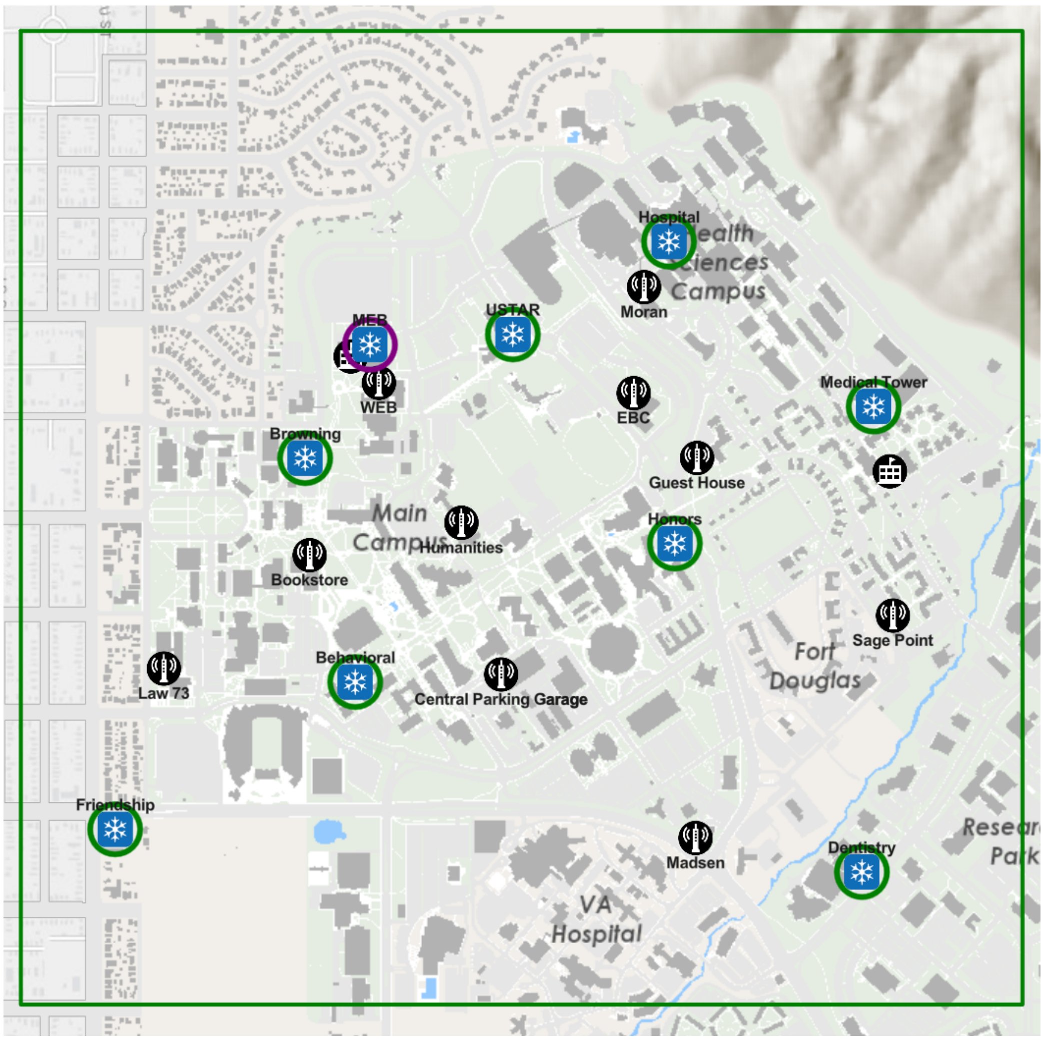


Figure 3: Potential Tx mount-point candidates: The roof-top base-stations (with their associated Dell PowerEdge compute nodes) available for provisioning on the University of Utah's POWDER testbed

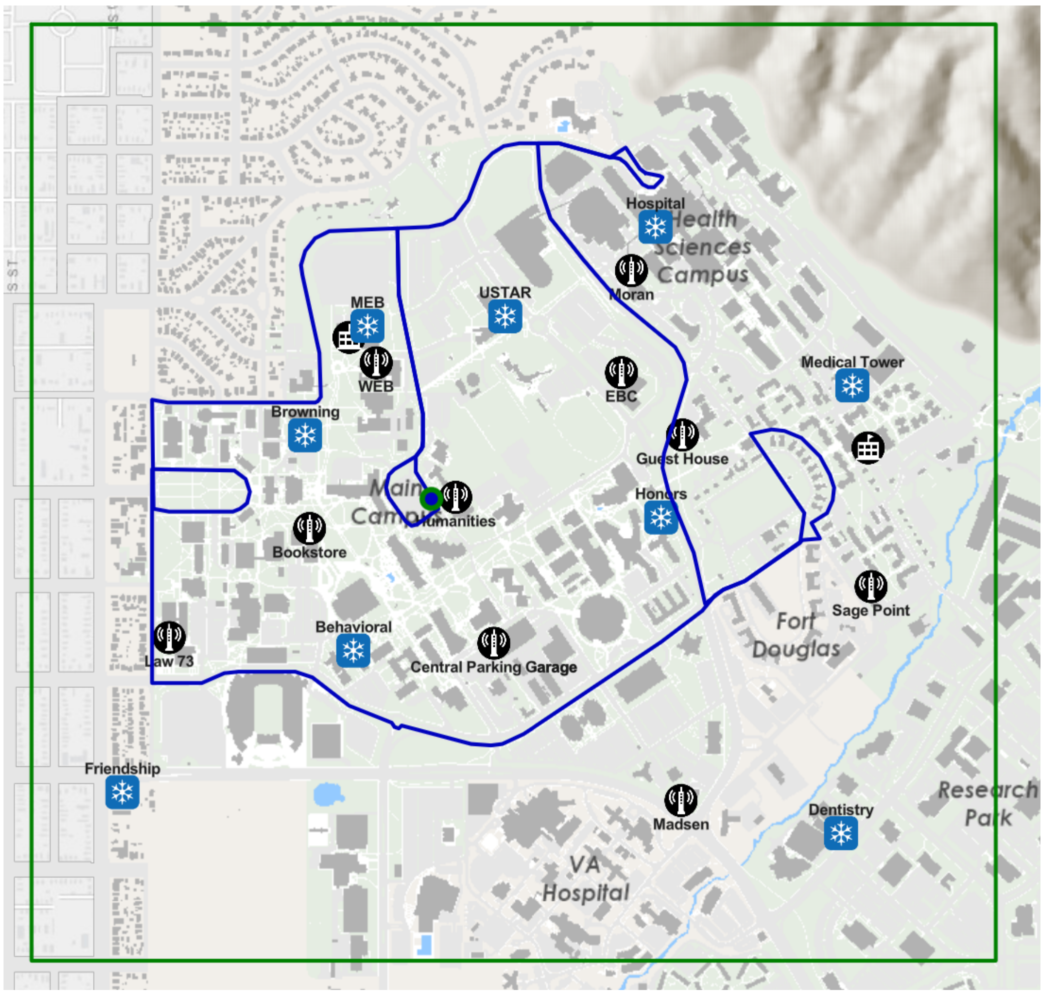


Figure 4: The "Blue Detour" route around the University of Utah campus – to be traversed by the Rx

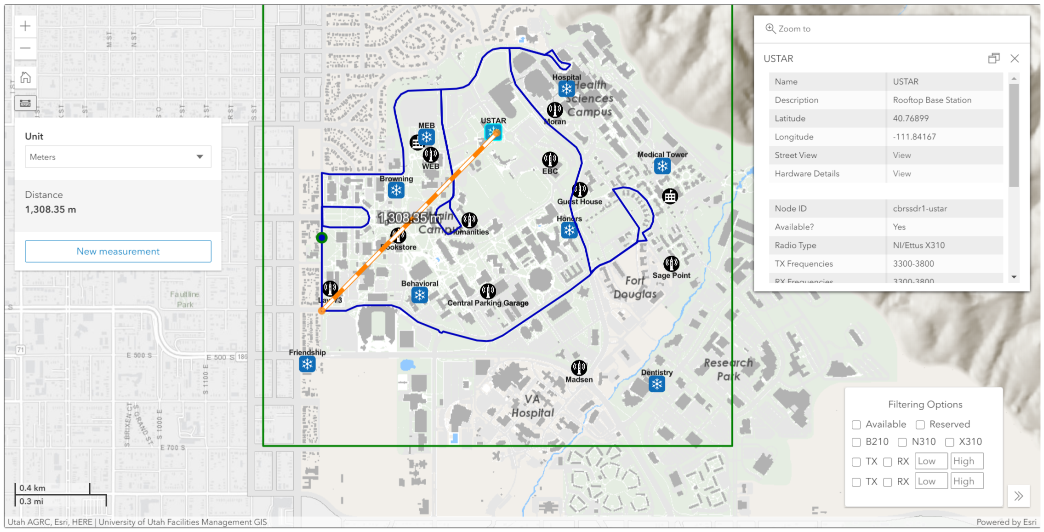


Figure 5: The location of the Tx (fixed) while the Rx moves along the “Blue Detour” route

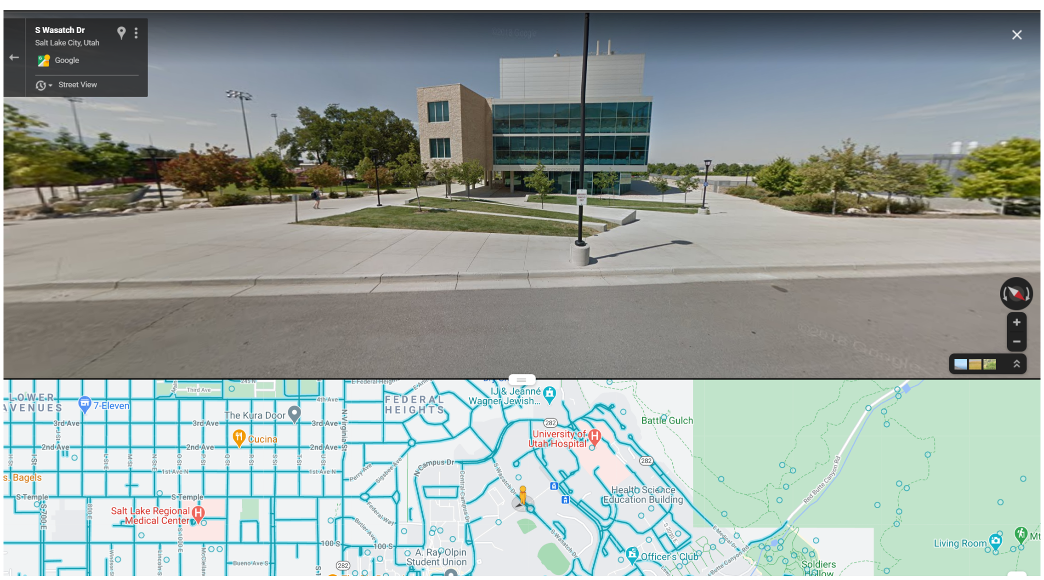


Figure 6: A street view of the USTAR Building Tx mount point for the “Blue Detour” Rx route

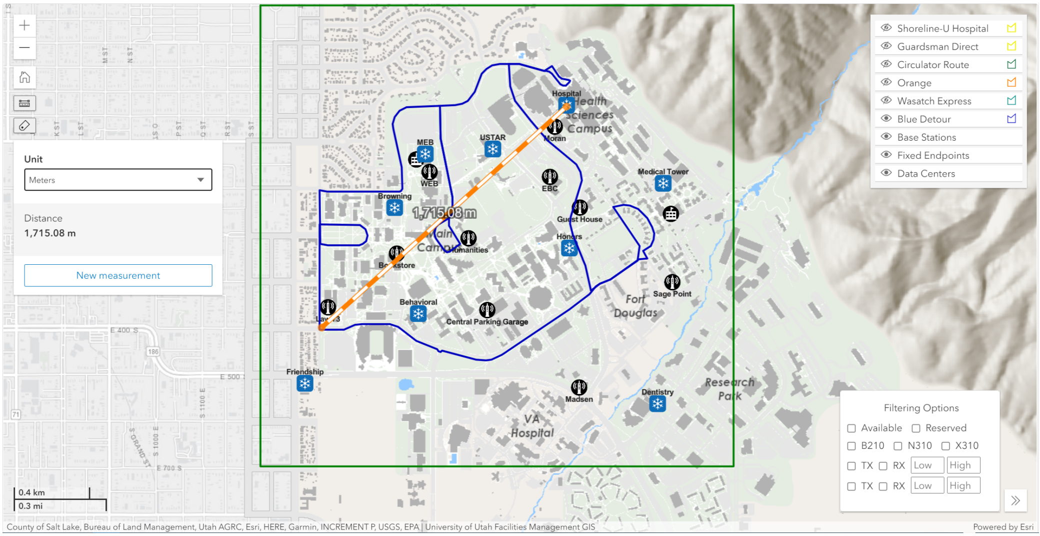


Figure 7: The location of the Tx (fixed) while the Rx moves along the "Blue Detour" route

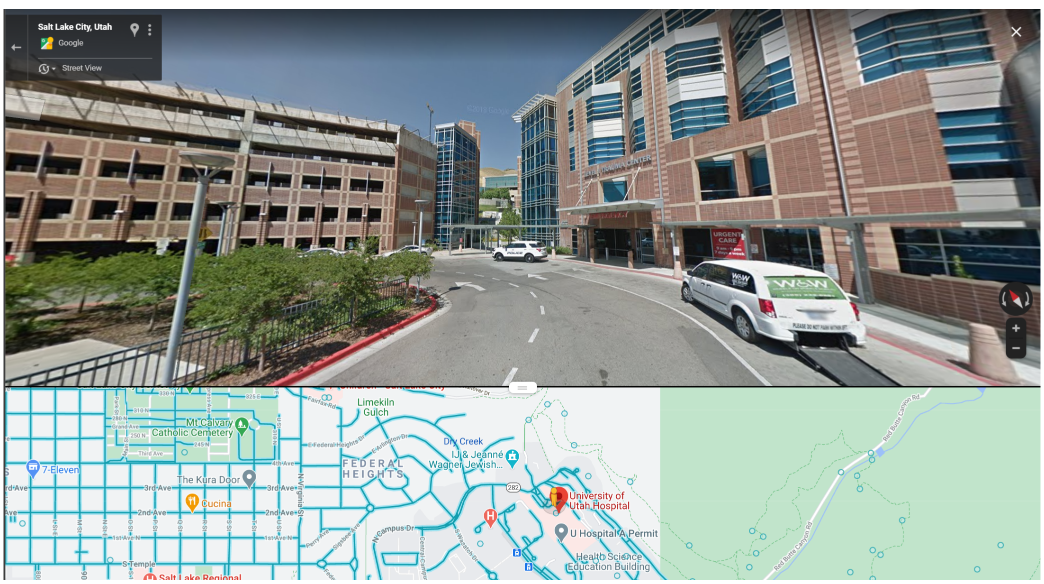


Figure 8: A street view of the University of Utah Hospital Building Tx mount point for the "Blue Detour" Rx route

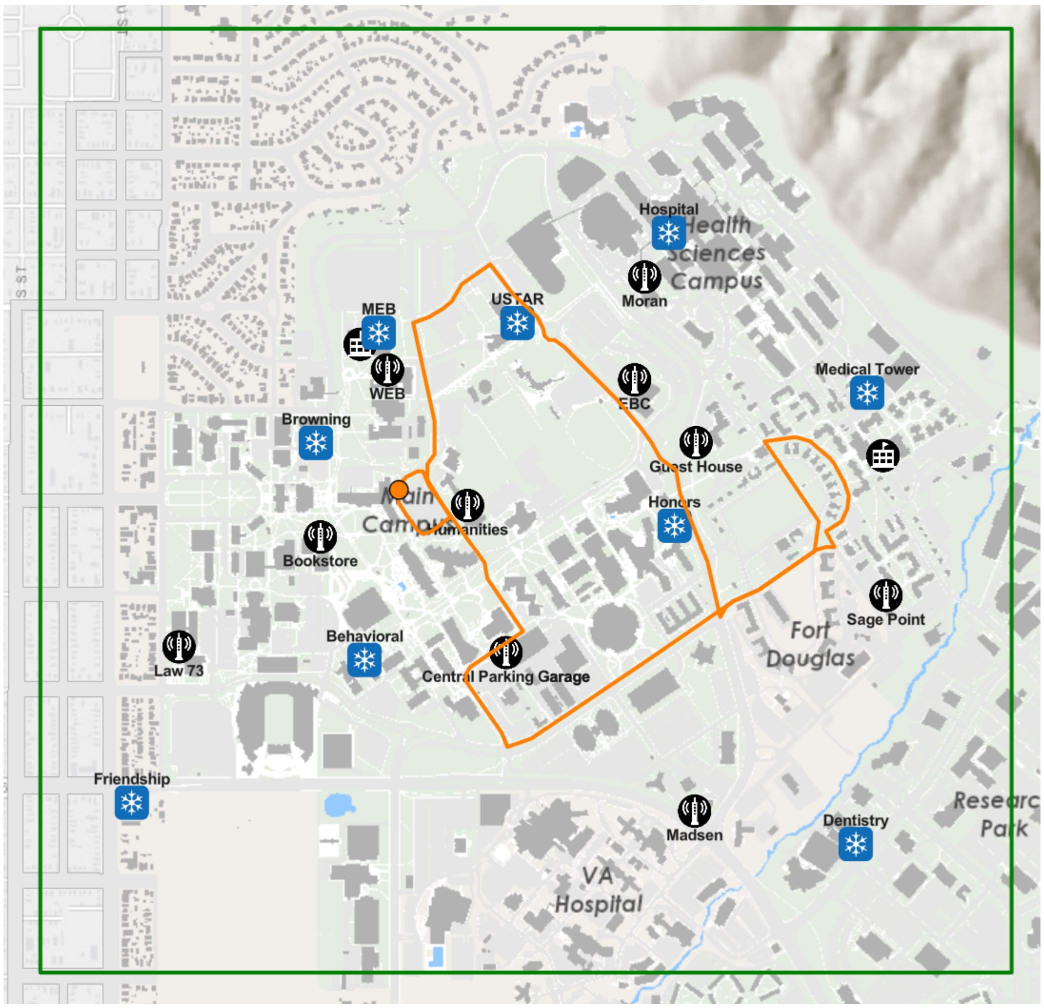


Figure 9: The "Orange" route around the University of Utah campus – to be traversed by the Rx

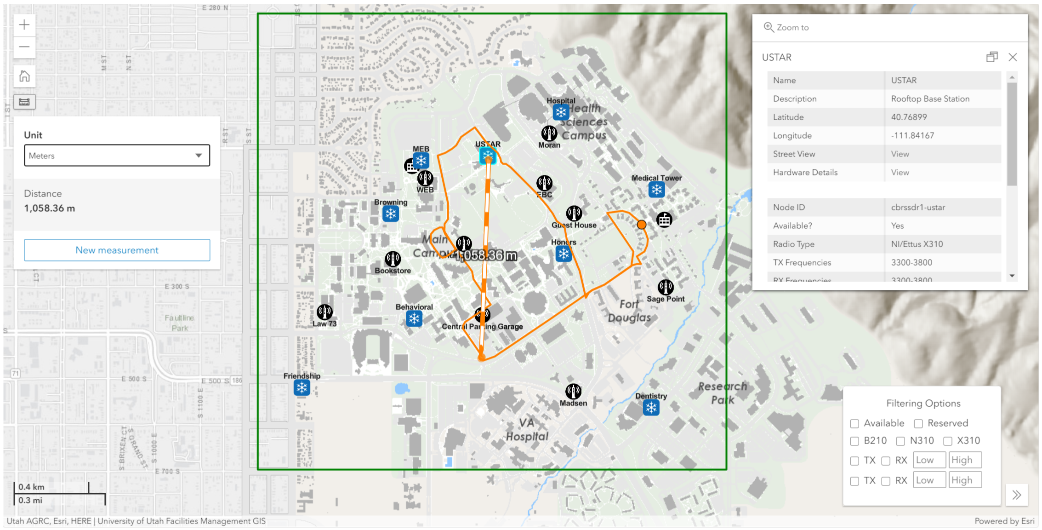


Figure 10: The location of the Tx (fixed) while the Rx moves along the "Orange" route

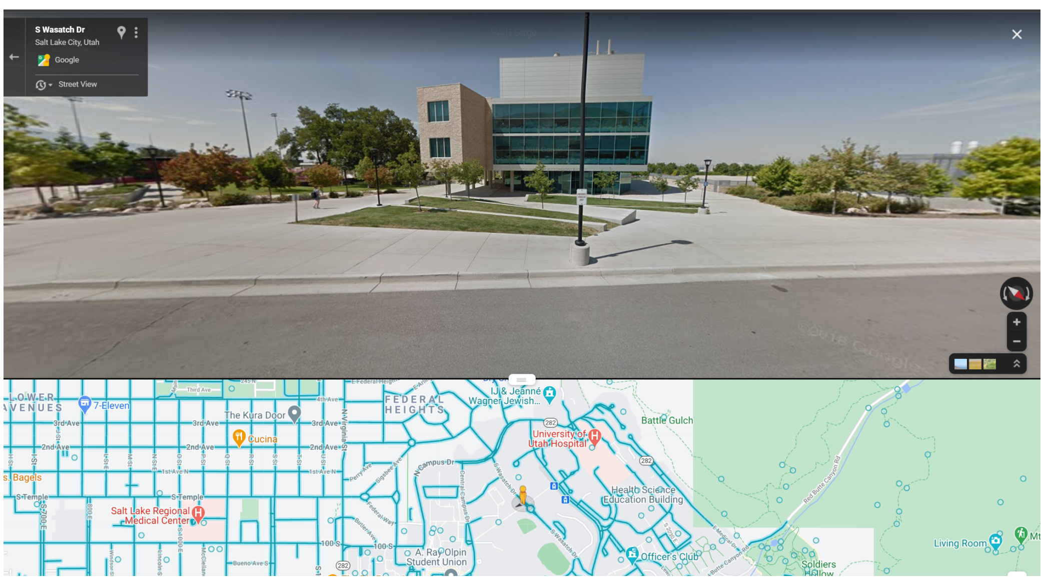


Figure 11: A street view of the USTAR Building Tx mount point for the "Orange" Rx route

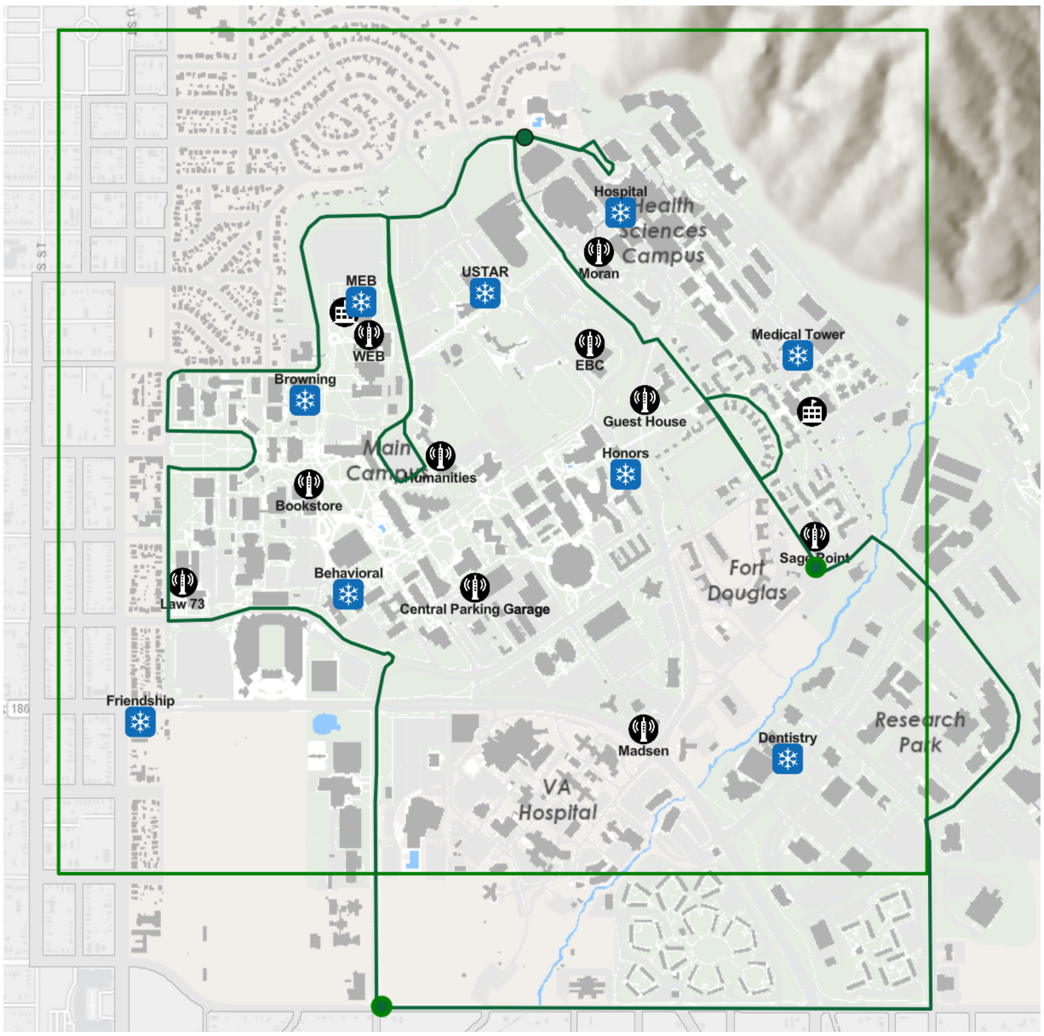


Figure 12: The "Circulator" route around the University of Utah campus – to be traversed by the Rx

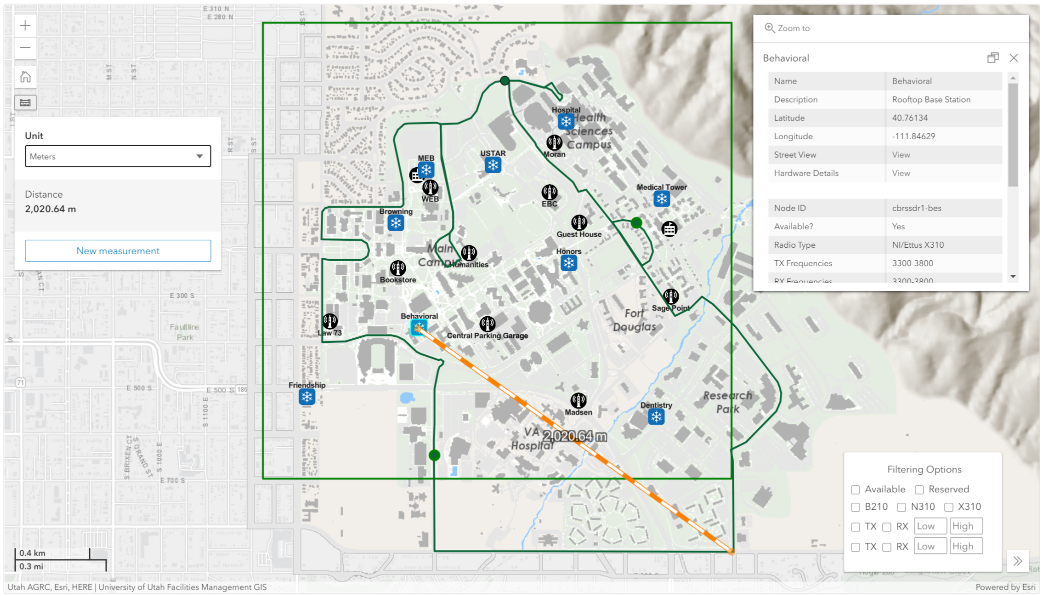


Figure 13: The location of the Tx (fixed) while the Rx moves along the "Circulator" route

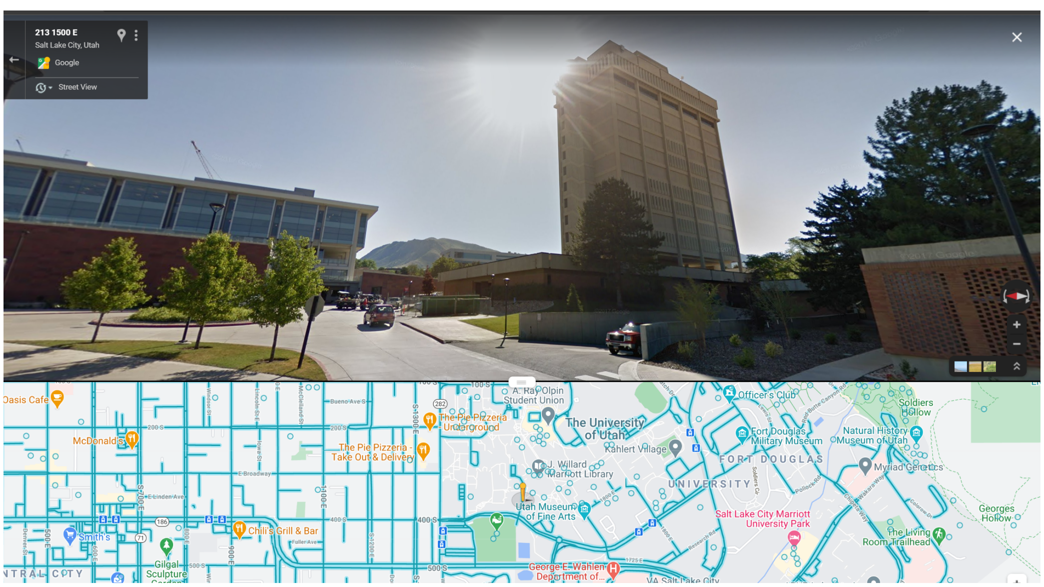


Figure 14: A street view of the Behavioral Sciences Building Tx mount point for the "Circulator" Rx route

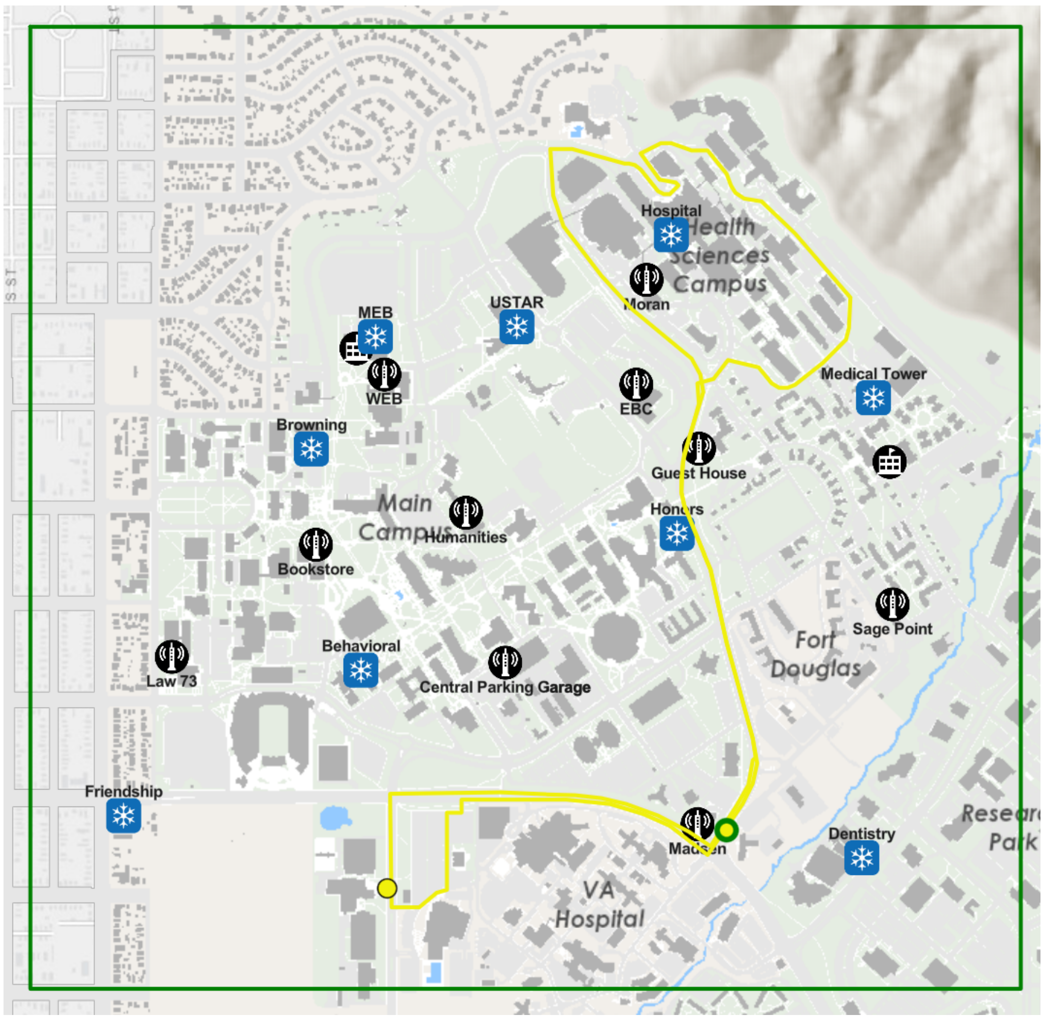


Figure 15: The "Guardsmen Direct" route around the University of Utah campus – to be traversed by the Rx

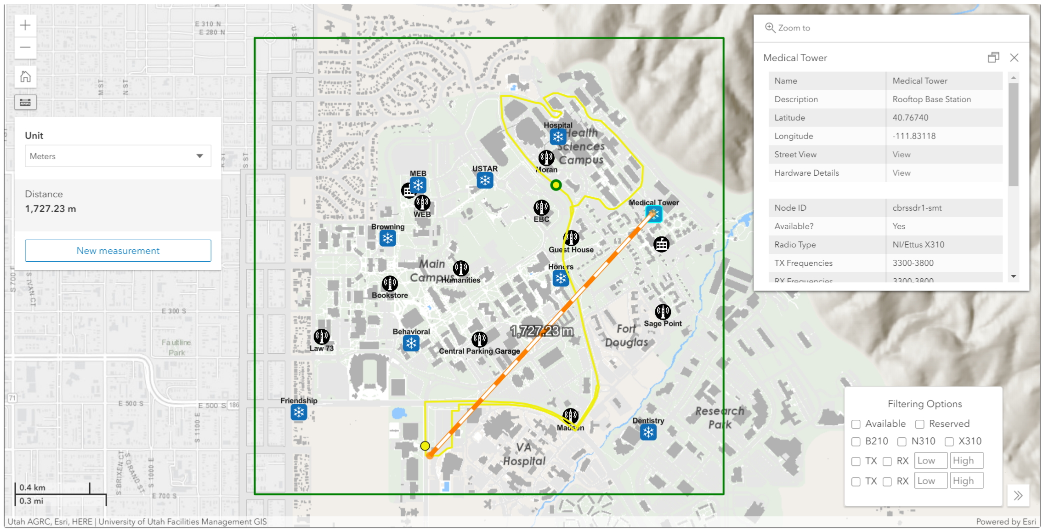


Figure 16: The location of the Tx (fixed) while the Rx moves along the "Guardsmen Direct" route

Figure 17: A street view of the Medical Tower Tx mount point for the "Guardsmen Direct" Rx route

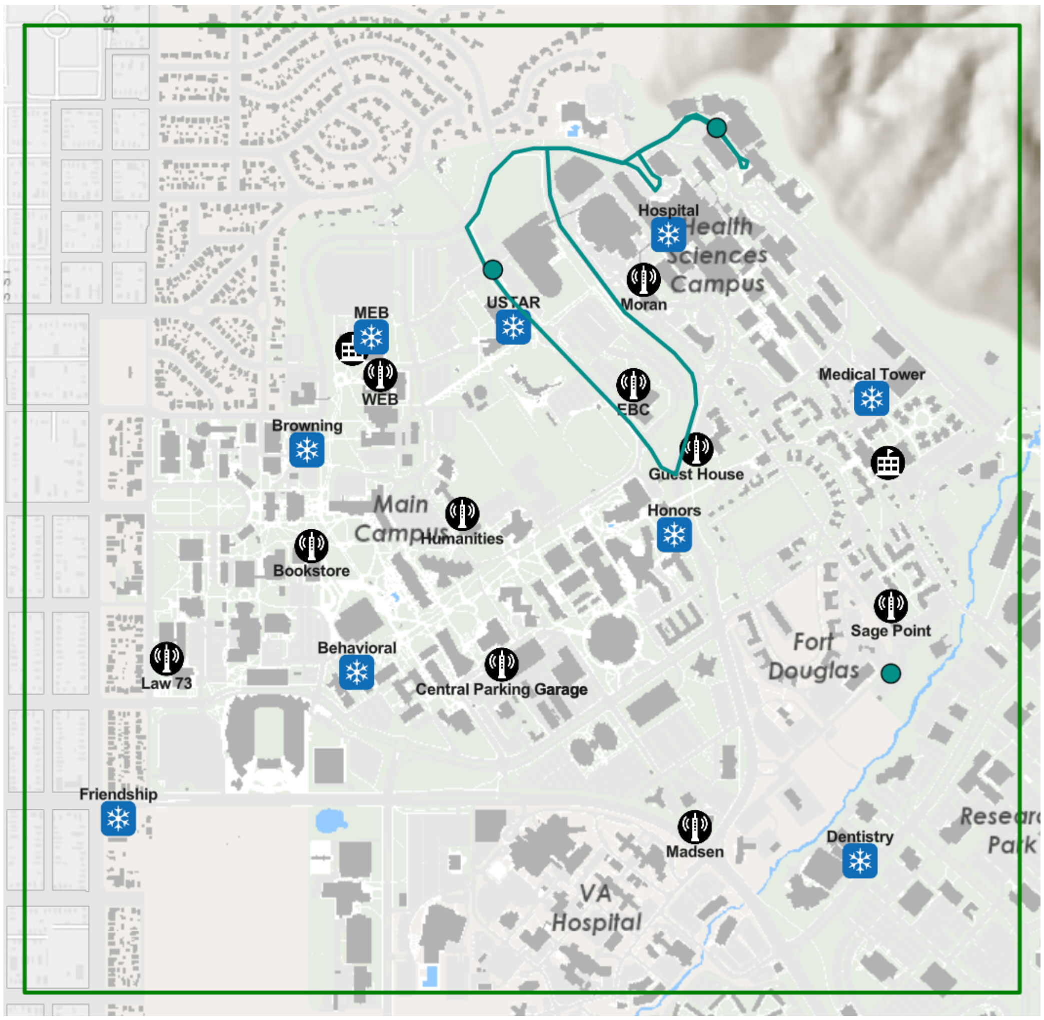


Figure 18: The “Wasatch Express” route around the University of Utah campus – to be traversed by the Rx

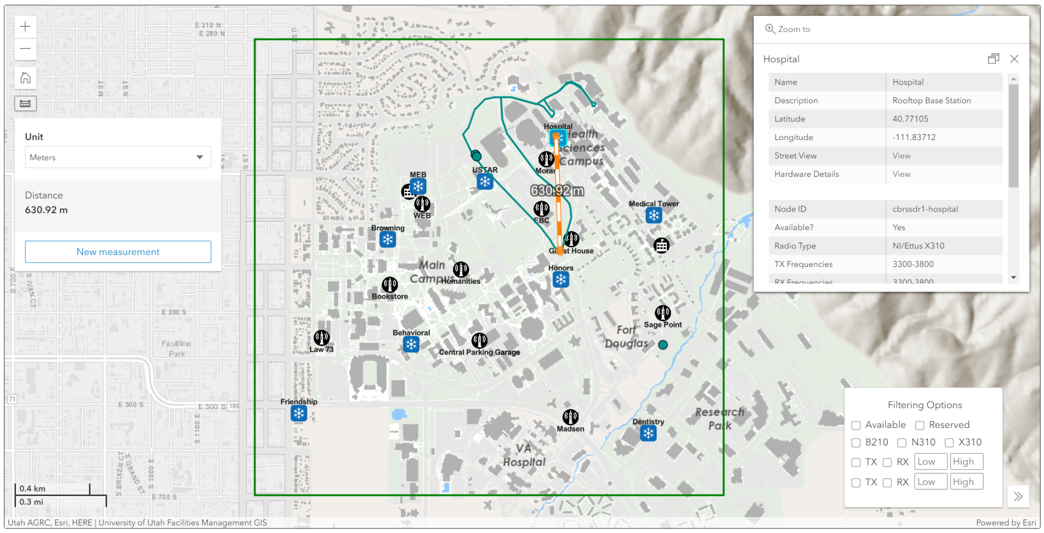


Figure 19: The location of the Tx (fixed) while the Rx moves along the "Wasatch Express" route

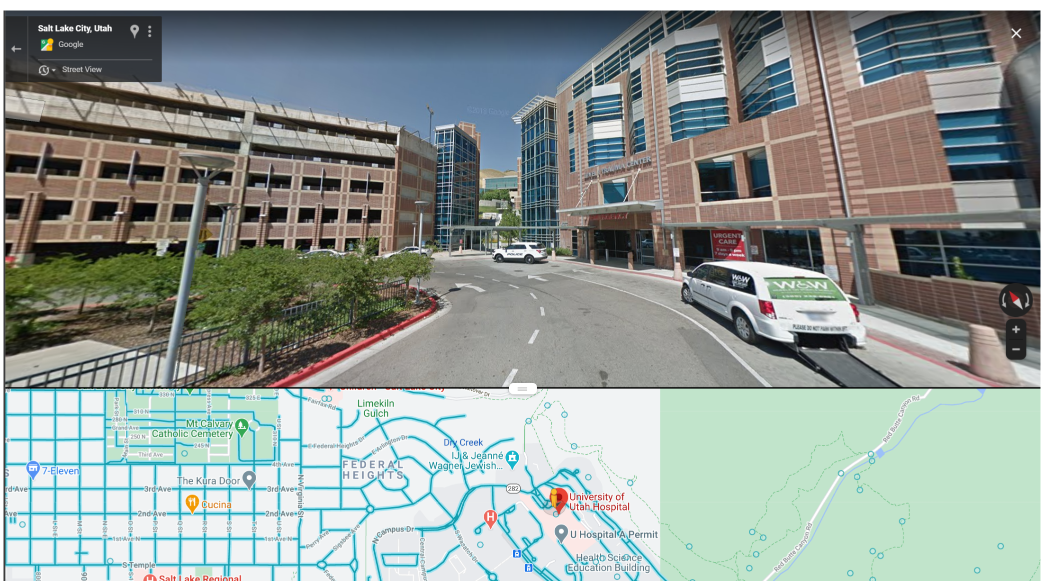


Figure 20: A street view of the University of Utah Hospital Building Tx mount point for the "Wasatch Express" Rx route

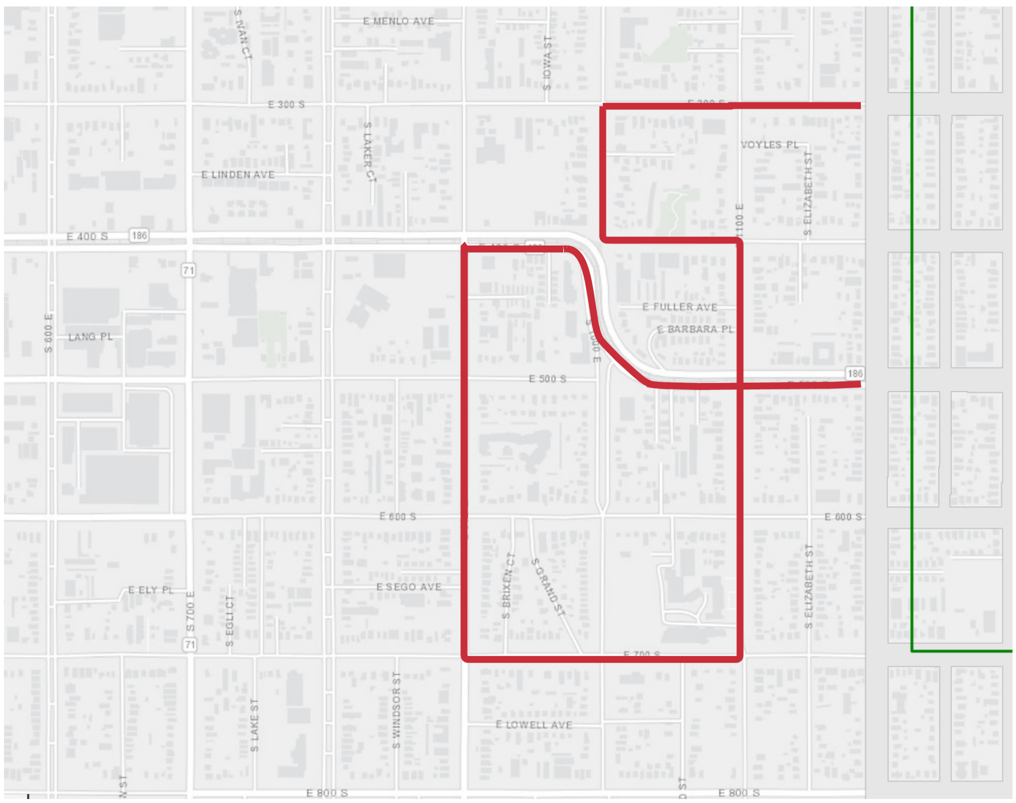


Figure 21: The “Suburban” route around the University of Utah campus – to be traversed by the Rx

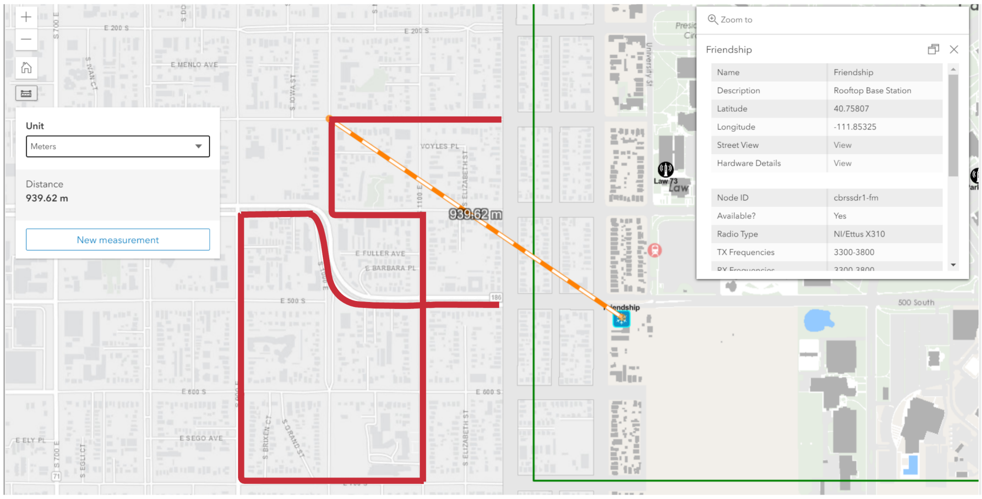


Figure 22: The location of the Tx (fixed) while the Rx moves along the "Suburban" route

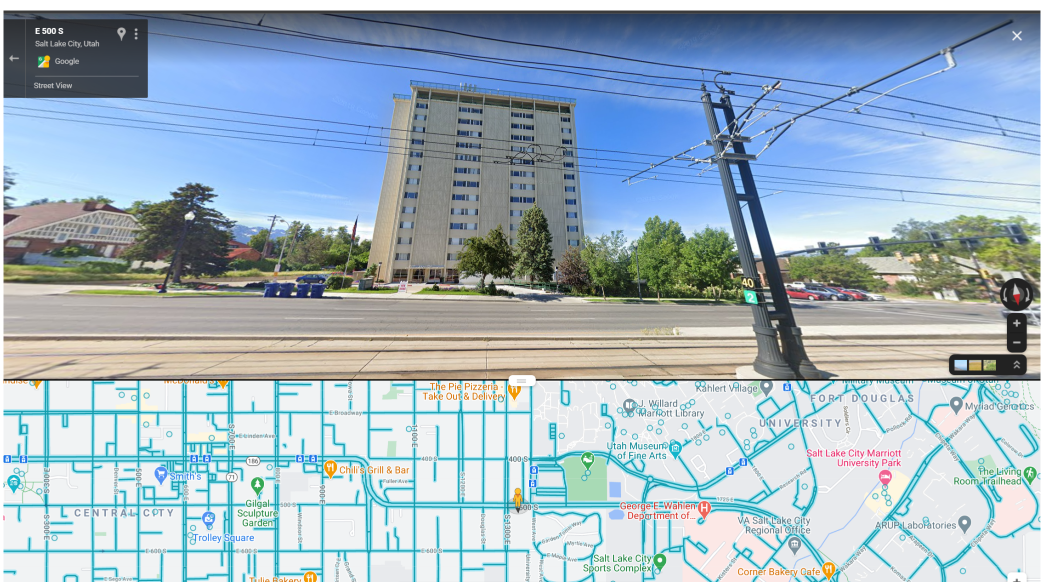


Figure 23: A street view of the Friendship Manor Tx mount point for the "Suburban" Rx route

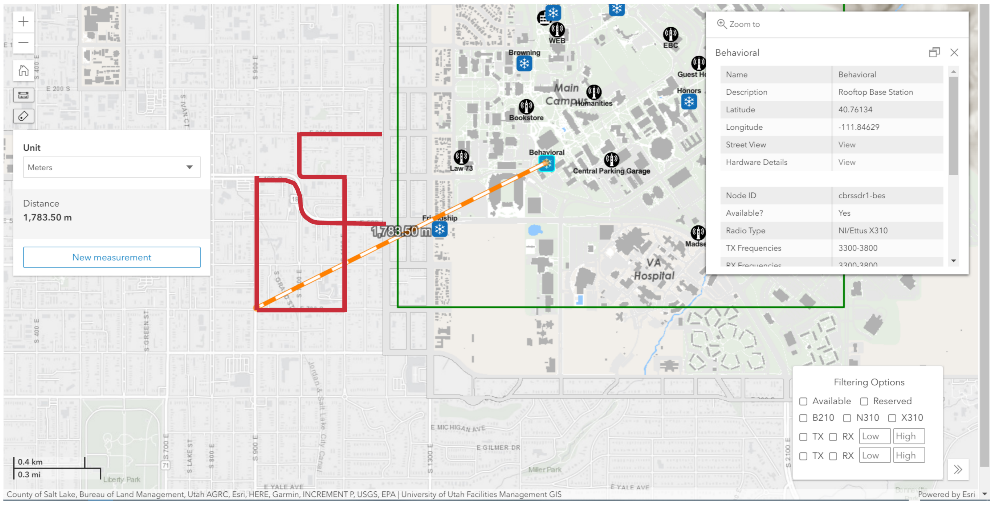


Figure 24: The location of the Tx (fixed) while the Rx moves along the "Suburban" route

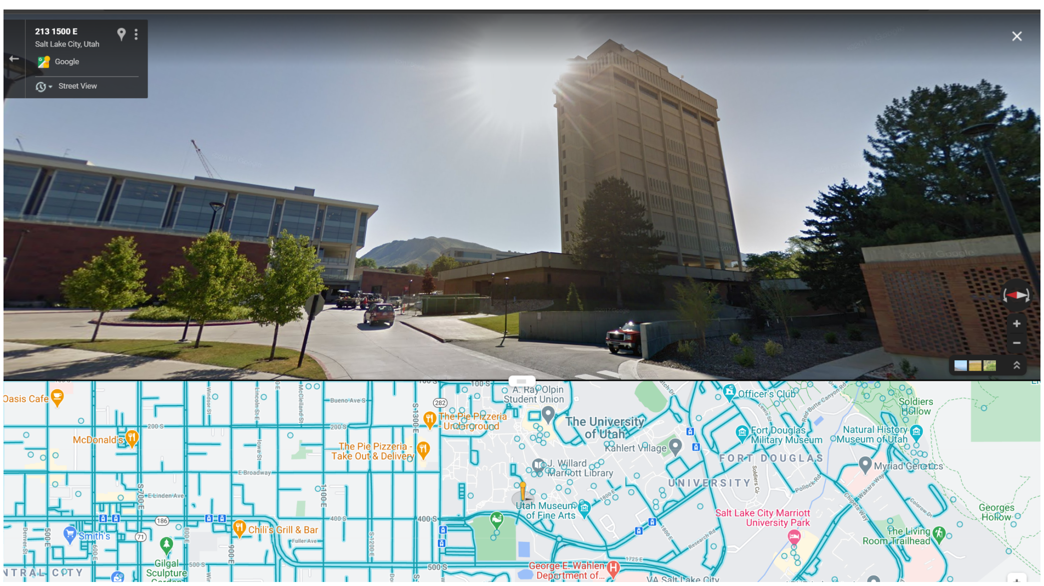


Figure 25: A street view of the Behavioral Sciences Building Tx mount point for the "Suburban" Rx route

3.4 Rx Chosen Routes

Of the potential Rx route candidates listed in Sec. 3.3, based on our internal discussions, we have decided to use the “Blue Detour” route for urban measurements and the “Suburban” route for suburban measurements. As a result, the corresponding Tx mount points are chosen to be the roof-top of the University of Utah Hospital building (for the “Blue Detour” route) and the roof-top of the Behavioral Sciences building (for the “Suburban” route).

The other routes listed in Sec. 3.3 will serve as backups in case we encounter unforeseen circumstances during our measurement runs along the chosen routes.

3.5 Resource Availability and Provisioning

A detailed list of roof-top base-stations, near-edge computing resources (at the Fort Douglas datacenter), and Emulab compute nodes – along with their availabilities during our measurement campaign (8-June-2021 to 18-June-2021) is provided in Fig. 26.

As of writing this measurement plan, we do not intend to use the USRP radios available at the various Tx mount-point candidates (Sec. 3.2), i.e., the fixed end-points and roof-top base-stations; instead, we would be leveraging the flexible BYOD capabilities of the POWDER testbed by integrating an internally developed 28GHz communication system (detailed in Sec. 4) with our autonomous antenna tracking system (Sec. 5). However, we plan to provision compute nodes – either near-edge computing resources or compute nodes from the Emulab/Cloudlab clusters – for fault-tolerant data storage, global system installations, centralized coordination of our Tx and Rx autonomous antenna rotating platforms (via Docker, Apache Zookeeper, Apache Kafka, and RPyC distributed control), and to handle offloaded processing tasks from our Tx and Rx end-points. As a result, resource provisioning scripts have been written to orchestrate the following capabilities: node (and Linux image) provisioning, package installations, startup shell script executions, and SCM clones (main repository and sub-modules). A sample Python script involving a geni-lib resource request for a Dell PowerEdge R740 server (d740 near-edge compute resource) is shown in Fig. 27.

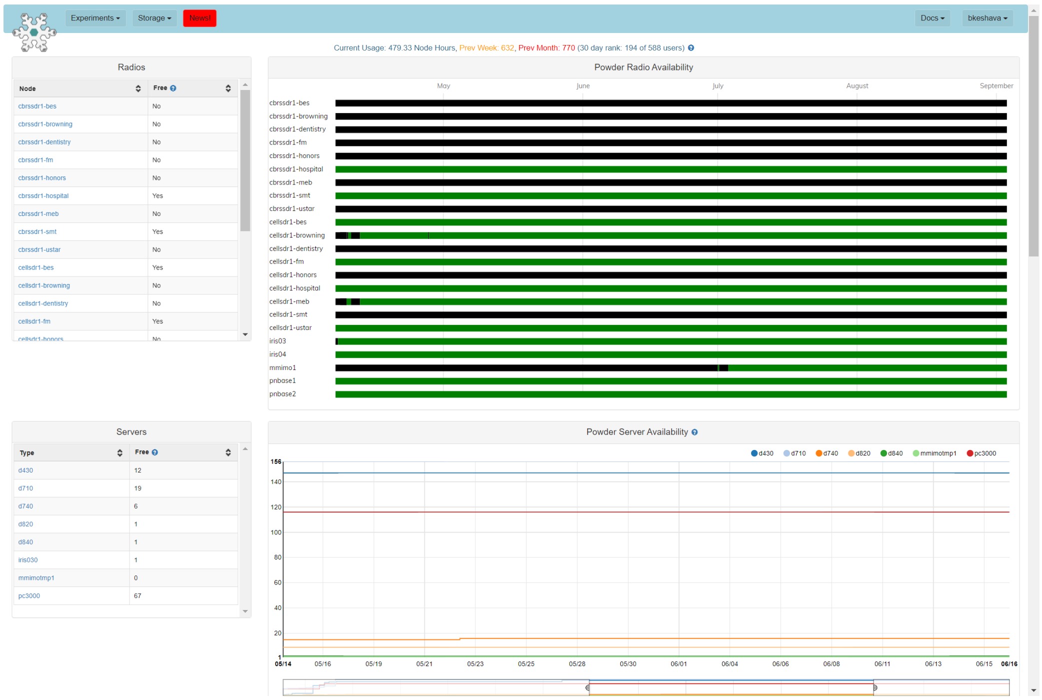


Figure 26: A list of radio and compute resources available on the University of Utah's POWDER testbed

As mentioned earlier, our Rx autonomous antenna tracking platform along with its 28GHz communication setup, would be mounted on a van and driven around the University of Utah along pre-determined routes (Sec. 3.4); while our Tx autonomous antenna tracking platform along with its 28GHz communication setup, would be affixed atop suitable route-specific mount-points (Sec. 3.4).

During a particular run of this measurement campaign, both the Tx and Rx antenna tracking platforms log their IMU (pan & tilt) and GPS (NMEA-JSON) measurements locally – along with distributed, redundant storage at the provisioned compute nodes, facilitated by Apache Kafka; additionally, time-stamped power delay profile samples (swept at 2.5GHz at the Rx) would be logged onto the file-system of an Rx-mounted Raspberry Pi via a USRP B200mini GNURadio implementation – which would be published to the aforementioned fault-tolerant Apache Kafka message-oriented middleware framework.

```python

import geni.portal as portal
import geni.rspec.pg as rspec

request = portal.context.makeRequestRSpec()

node = request.RawPC( "node" )
node.hardware_type = "d740"
node.disk_image = "urn:publicid:IDN+emulab.net+image+PowderProfiles:gnuradio-srslte"

portal.context.printRequestRSpec()
```

Figure 27: A resource-provisioning script (Python/geni-lib/RSpec) incorporated within a newly-instantiated POWDER profile

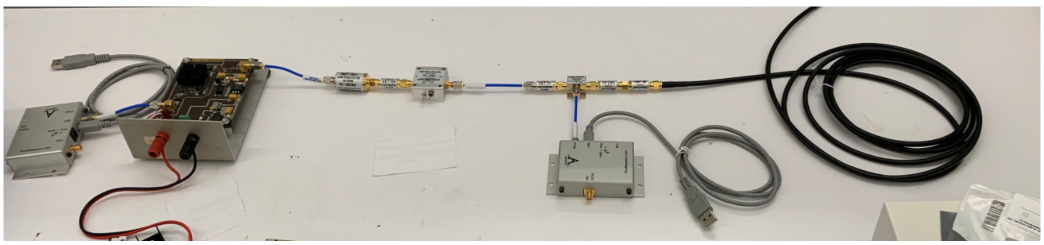


Figure 28: The Tx communication circuit components that would be encased in an ABS enclosure for weather-proofing

3.6 Planned Measurement Campaign Schedule

We plan to conduct 8 hour stints (1000-1800 hrs MT) along the chosen routes (Sec. 3.4) – with the Tx mounted at chosen site-specific locations (Sec. 3.4) – every day for 6 days during the week of June 8, 2021, i.e., 20 hours of measurements along the "Blue Detour" route and 20 hours of measurements along the "Suburban" route, with 4 additional hours dedicated to the [tear-down⟶transport⟶setup] of the Tx when we switch routes. This schedule accounts for 2 hours of initial campaign setup and 2 hours of terminal campaign tear-down.

A subsequent week has been set aside to serve as a reserve week to handle travel delays, setup errors, and any other unforeseen circumstances that may arise during this measurement campaign.

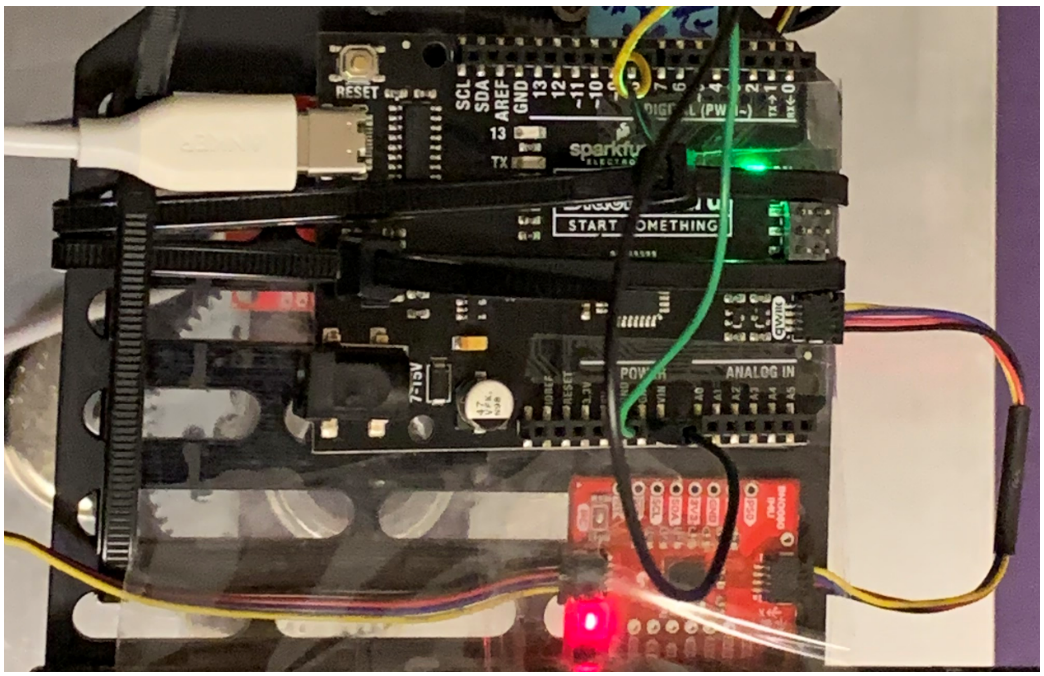


Figure 29: The ICs (uC + IMU) corresponding to our Tx-side antenna rotating platform that would be encased in an ABS enclosure for weather-proofing

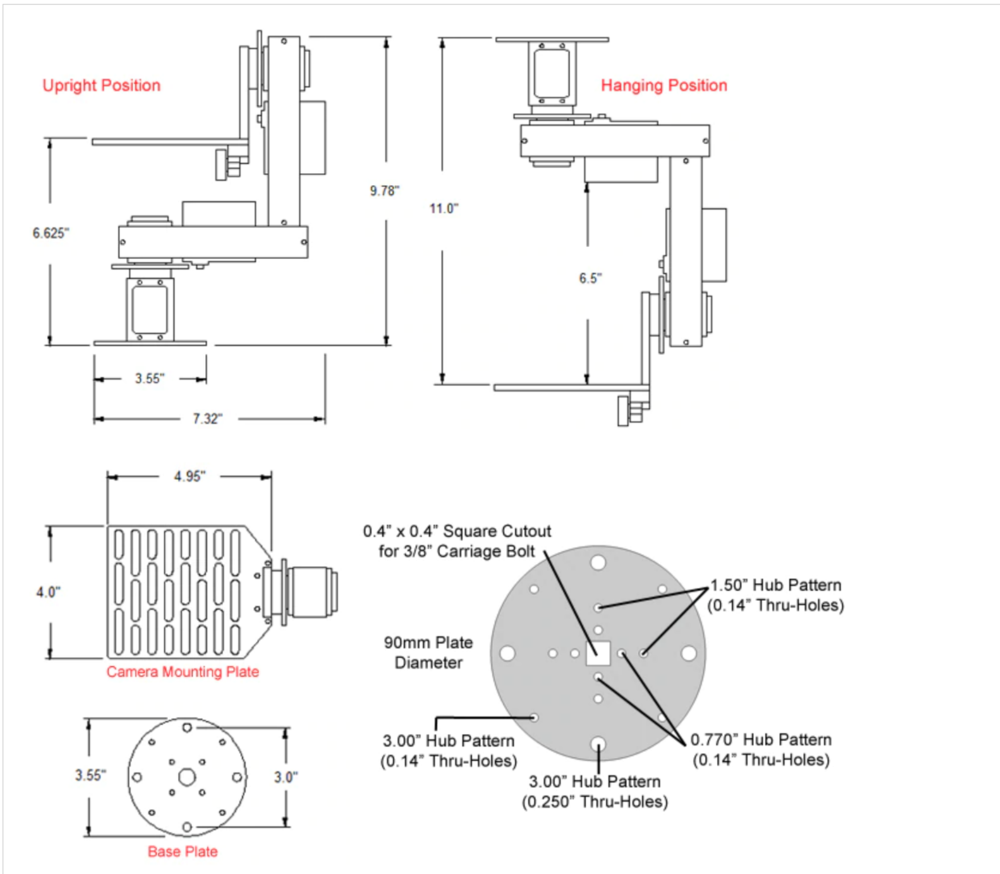


Figure 30: The schematics of our Tx-side antenna rotating platform that would hold the 28GHz WR-28 horn antenna and up-converter setup – with servo control achieved via ICs encased in an off-platform weather-proof ABS enclosure; the Tx communication circuit components would also be housed in an off-platform weather-proof ABS enclosure

3.7 Requirements to be fulfilled by POWDER Support

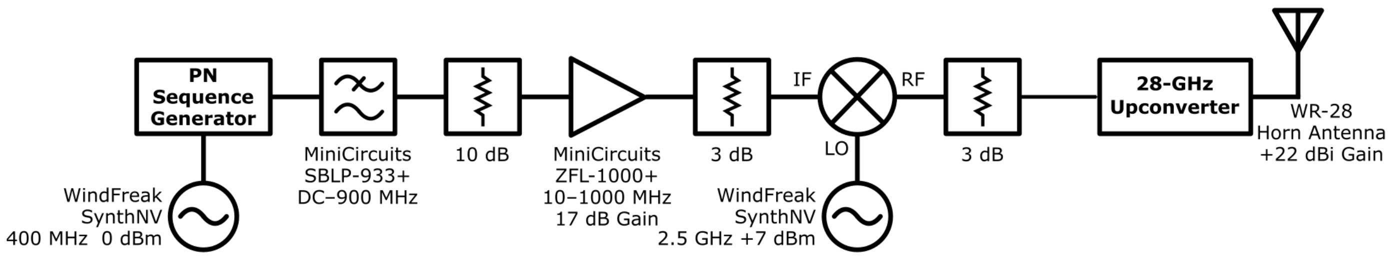
- Near-edge computing resource(s) and/or Cloudlab/Emulab compute node(s) provisioning;
- Authorizations (FCC experimental license) to utilize the $27 - 29$GHz spectrum; and
- BYOD flexibility, i.e., authorizations and support to install the Tx at designated mount-points around the University of Utah campus:
  - The base mount schematics for our Tx-side antenna rotating platform are shown in Fig. 30: the plan is to mount this platform via a 3/8" carriage bolt, and $1/4-20$ UNC & $\#6-32$ UNC fasteners in 3" hub-patterns. If this hole-pattern is not available at an installation point, we plan to augment/modify the rotator's base mount to achieve compatibility (e.g., via side-tapped pattern mounts, U-brackets, etc).
  - No network back-haul links are needed at the Tx mount-points; instead, a laptop would be used to log the Tx-side IMU measurements. We would like to have these measurements periodically written-through to a fault-tolerant storage mechanism on a provisioned compute node: so, a good WiFi connection is preferred (not absolutely necessary).
  - Since the Tx employs an antenna rotating platform, our system does not mandate directionality constraints during installation – although, the Tx-side antenna rotating platform would need to be appropriately mounted to facilitate 360^{o} of rotation.
  - Facilitate access to power for our programmable DC power-supplies (x2): one of these is employed to output 12V/0.64A for the 28GHz antenna and up-converter system, while the other 12V/0.4A for the PN-sequence generator and the ZFL-1000 amplifier.
  - Facilitate weather protection at the chosen Tx sites (Sec. 3.4):
    1. Our Tx communication circuit components (Fig. 28) and the ICs corresponding to our Tx-side antenna rotating platform (Fig. 29) would be encased in separate weather-proof ABS enclosures – along with the required weather-proof protections for any cables/wires coming-out/going-into these enclosures.

2. Our 28GHz antenna and up-converter setup does not currently have a weather-proof dome encasing it. If this setup is to be mounted at a location where appropriate weather protections cannot be provided, we plan to design the required enclosure to weather-proof this setup.
3. The PT2645-S Pan & Tilt kit, i.e., the base antenna rotator platform, does not need weather-proofing – however, the servo wires on this platform are weather-proofed as a part of Item 1.
4. The regulated power-supplies for our 28GHz antenna and up-converter setup, ZFL-1000 amplifier, and PN-sequence generator would need to be placed in suitable locations at the installation point such that they are protected from adverse weather conditions.

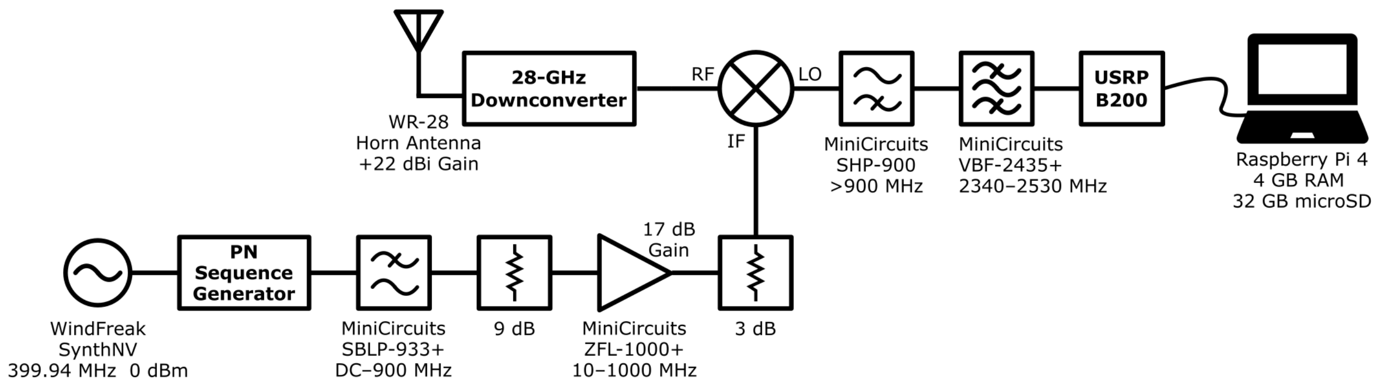
4 Sliding Correlator Channel Sounder Design

Our 28GHz sliding correlator channel sounder is the same one used by us in the past for our USNA suburban measurement campaign [1], now integrated with our autonomous antenna tracking system (Sec. 5). Fig. 31 illustrates the overall system structure for the sounder at both the Tx and the Rx. The corresponding specifications are listed in Table 1. More details about our 28GHz circuit components can be furnished upon request.

For all measurements, the pseudo-random noise (PN) rate will be set to $\approx$400MHz and the PN code will be an 11-bit (length=2047) sequence. The transmitter and receiver both utilize a vertically polarized horn antenna with 10^{o} half power beam-width.



(a) Transmitter



(b) Receiver

Figure 31: Block diagrams for the 28GHz broadband sliding correlator channel sounder (the model numbers are provided for some commercially available parts).

Carrier Frequency	28GHz
Chip Sequence Length	2047
RF Bandwidth	800MHz
Tx Chip Rate	400Mcps
Temporal Resolution	2.5ns
Rx Chip Rate	399.95Mcps
Tx Power	23dBm
Tx/Rx Antenna Gain	22dBi
Measured Tx/Rx Azimuth HPBW	10.1^{o}
Measured Tx/Rx Elevation HPBW	11.5^{o}
Maximum Measurable Path Loss	182dB

Table 1: Broadband Sliding Correlator Channel Sounder Specifications

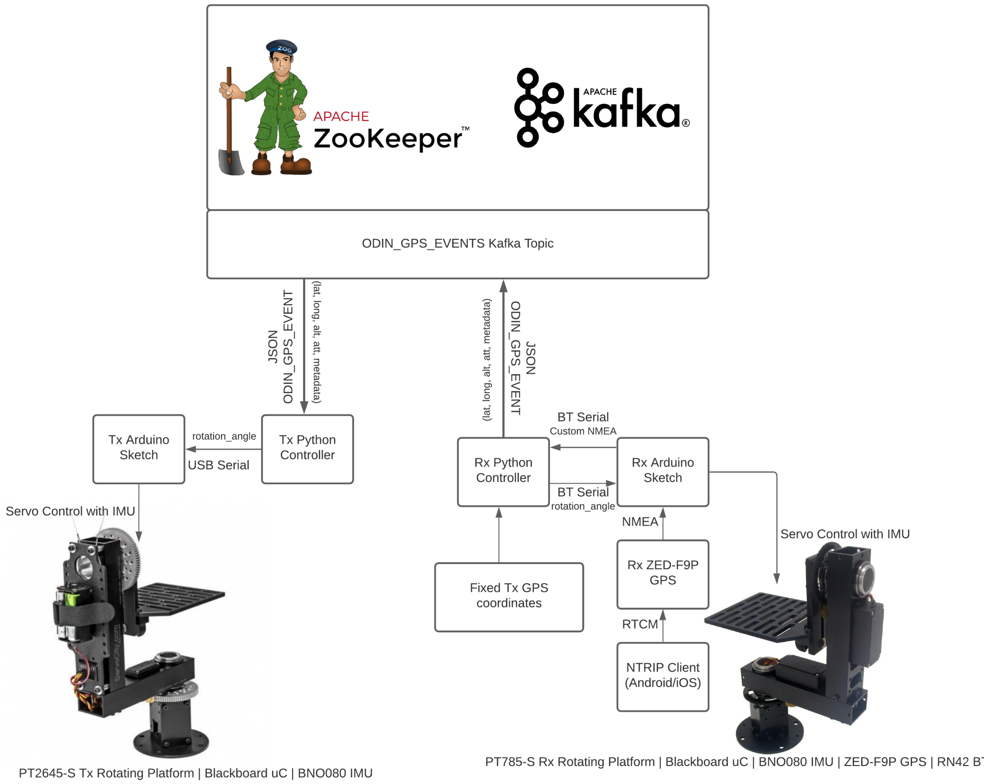


Figure 32: The E2E system architecture for the autonomous antenna rotating platforms for a mobile Rx and a fixed roof-top mounted Tx

5 Autonomous Antenna Tracker Design

To ensure the antenna alignment between a fixed Tx and a mobile Rx (along both the "pitch" and "yaw" axes), we have implemented an autonomous antenna rotator system[1] involving micro-controllers, IMUs, RTK-GPS modules, pan & tilt kits, USRP B200mini SDRs, and Raspberry Pi micro-computers – the system architecture for which is illustrated in Fig. 32, and the associated software is encapsulated in a GitHub repository, Odin [2]. More details about our autonomous antenna tracking system under Project Odin can be furnished upon request.

[1]Some demonstration screenshots and videos for the system can be found on iCloud.

References

[1] Y. Zhang, S. Jyoti, C. R. Anderson, D. J. Love, N. Michelusi, A. Sprintson, and J. V. Krogmeier, "28-GHz channel measurements and modeling for suburban environments," in *2018 IEEE Intl. Conf. Commun.*, May 2018, pp. 1–6.

[2] B. Keshavamurthy and Y. Zhang, "Odin," 2020-21. [Online]. Available: https://github.com/bharathkeshavamurthy/Odin.git