Building a Network and Data Management for Low Cost GNSS Monitors

SCPNT 2022

Benon Gattis[1], Pierre-Antoine Kosmala[1], Maxime Olivier[1], Dennis Akos[1,2],

Yu-Hsuan Chen[2], Sherman Lo[2], Todd Walter[2]

1- University of Colorado Boulder

2- Stanford University

Outline

1. Background and Motivation
2. Monitor System
   A. System Breakdown
   B. u-blox F9 Receiver
   C. u-blox F9 Metrics and Plots
3. Data Management
4. Data Collection Results
   A. Receiver Locations
   B. Long-term Statistics
   C. RFI Example
5. Summary and Future Work

Outline

1. Background and Motivation
2. Monitor System
   A. System Breakdown
   B. u-blox F9 Receiver
   C. u-blox F9 Metrics and Plots
3. Data Management
4. Data Collection Results
   A. Receiver Locations
   B. Long-term Statistics
   C. RFI Example
5. Summary and Future Work

Low Cost GNSS Monitor Background

Critical GNSS relying systems can be

easily disrupted by **Radio Frequency Interference (RFI)** such as:

Jamming - denying signals

Spoofing - producing fake signals

- Current RFI detection methods are hard to procure or expensive, making them unavailable to many users
- There is a need for an inexpensive and widely deployable GNSS RFI detector

News

N.J. man fined $32K for illegal GPS device that disrupted Newark airport system

Published: Aug. 08, 2013, 8:28 p.m. By Steve Strunsky | NJ Advance Media for NJ.com

Outline

1. Background and Motivation
2. Monitor System
   A. System Breakdown
   B. u-blox F9 Receiver
   C. u-blox F9 Metrics and Plots
3. Data Management
4. Data Collection Results
   A. Receiver Locations
   B. Long-term Statistics
   C. RFI Example
5. Summary and Future Work

u-blox Monitor System Overview

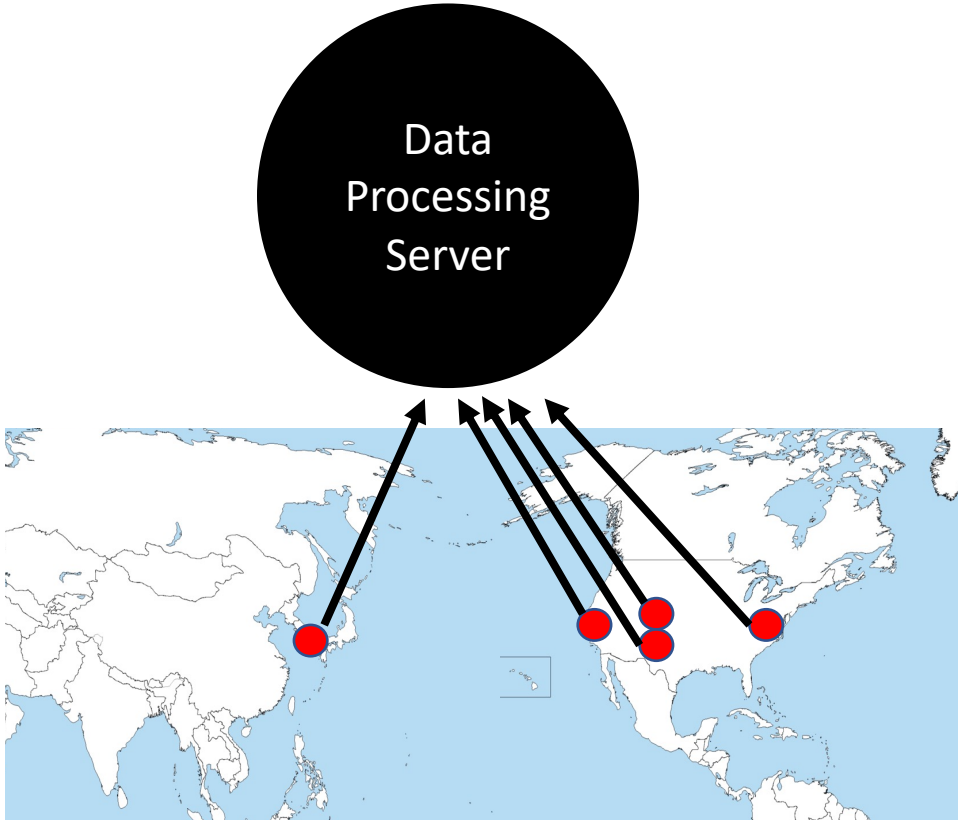
Low-cost nodes are deployed to sensitive locations to monitor for RFI

↓

Each node records data continuously, sending 24-hour files to the server

↓

The server parses, processes, and plots the data, and alerts users of any suspected RFI



u-blox Monitor Node

Antenna

u-blox F9 Receiver

Computational Node
(PC or Raspberry Pi)

Server

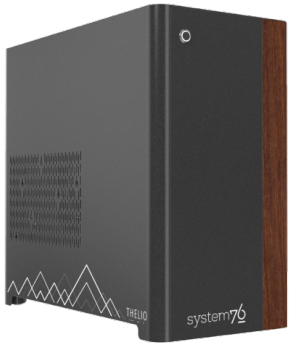
- Based around the **u-blox F9** GNSS receiver – **many useful RFI detection metrics**
- Paired with a PC or Raspberry Pi to record and upload data to server every 24 hours
- An entire node can be built for **less than 300 USD**

u-blox Monitor Server

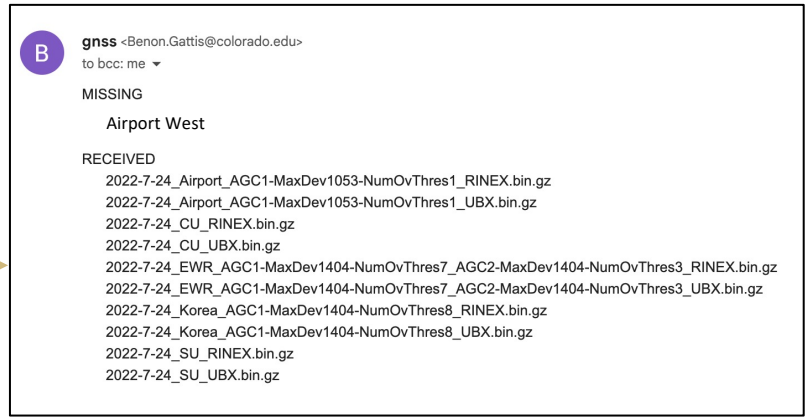
Node

SFTP

Network-Attached-Storage



Data Processing Computer



B

gnss <Benon.Gattis@colorado.edu>
to bcc: me

MISSING

Airport West

RECEIVED

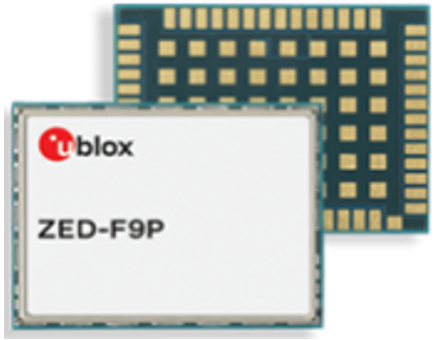
2022-7-24_Airport_AGC1-MaxDev1053-NumOvThres1_RINEX.bin.gz
2022-7-24_Airport_AGC1-MaxDev1053-NumOvThres1_UBX.bin.gz
2022-7-24_CU_RINEX.bin.gz
2022-7-24_CU_UBX.bin.gz
2022-7-24_EWR_AGC1-MaxDev1404-NumOvThres7_AGC2-MaxDev1404-NumOvThres3_RINEX.bin.gz
2022-7-24_EWR_AGC1-MaxDev1404-NumOvThres7_AGC2-MaxDev1404-NumOvThres3_UBX.bin.gz
2022-7-24_Korea_AGC1-MaxDev1404-NumOvThres8_RINEX.bin.gz
2022-7-24_Korea_AGC1-MaxDev1404-NumOvThres8_UBX.bin.gz
2022-7-24_SU_RINEX.bin.gz
2022-7-24_SU_UBX.bin.gz

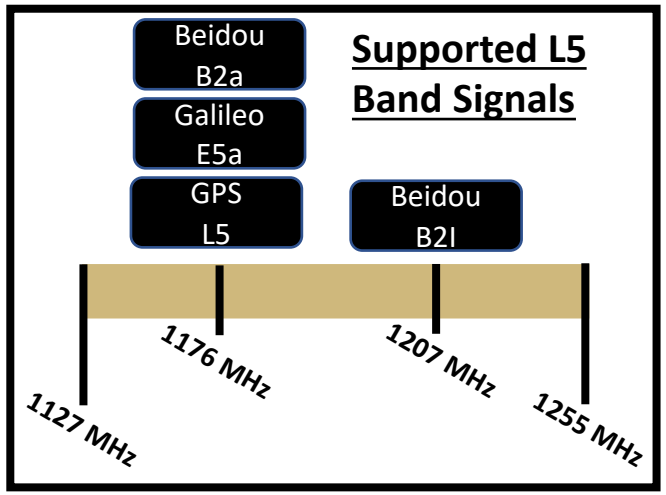
Alert Users of RFI

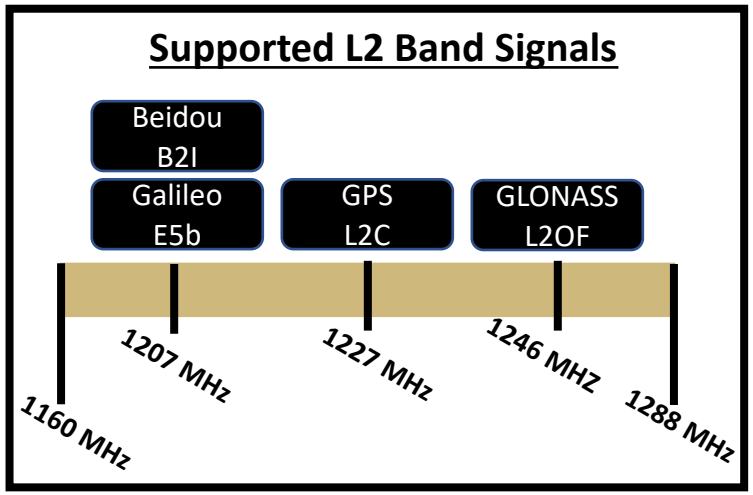
- Data transfer through SFTP (Secure File Transfer Protocol)
- Synology NAS (Network-Attach-Storage) receives and is primary storage location for all data
- Computer parses and plots the data every 24 hours in MATLAB, alerts users of RFI

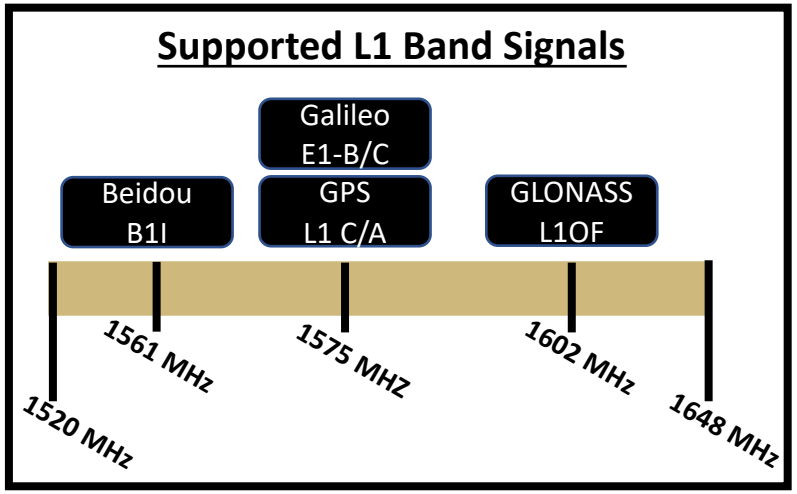
u-blox F9 Receiver

- Three receiver variants:
  - F9P, F9T-00B: Covers L1 and L2 GNSS bands
  - F9T-10B: Covers L1 and L5 GNSS bands
- Inexpensive and COTS, $150-200 USD
- Multi-constellation
- Dual frequency
- Many RFI detection metrics available, like Automatic Gain Control (AGC)









u-blox F9 Metrics and Plots

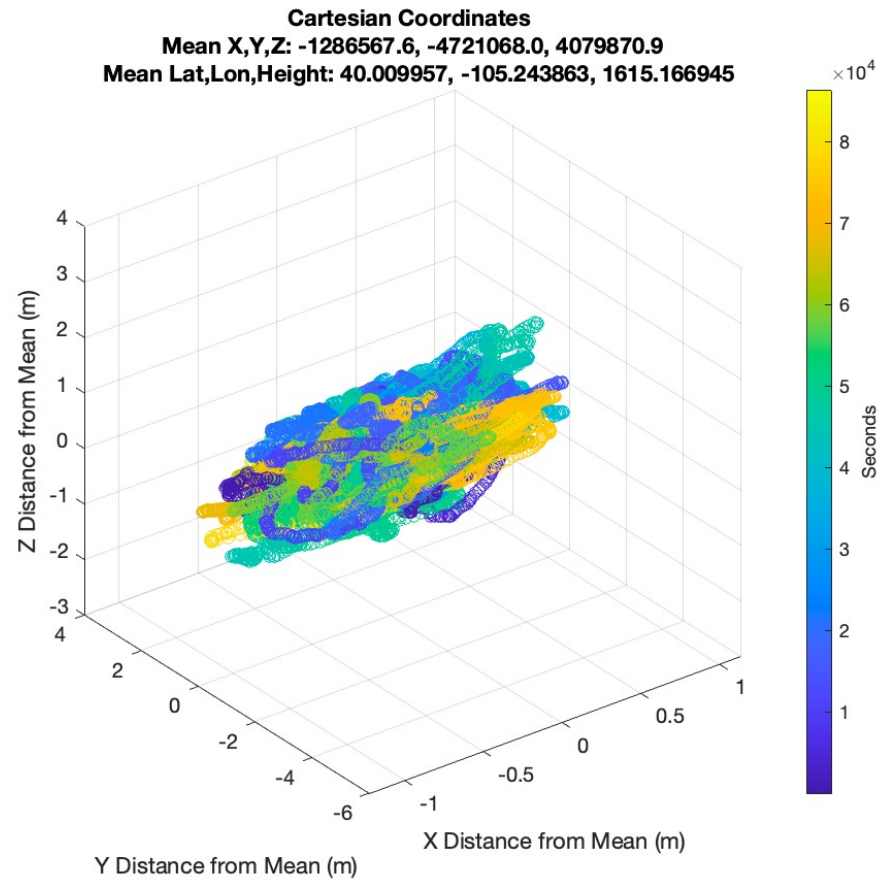
The F9 receiver outputs many powerful RFI detection metrics including

- Position
- Number of satellites and signals
- Time info- clock bias and drift
- Carrier to noise ratio (C/N_0)
- Automatic Gain Control (AGC)
- Spectrum data

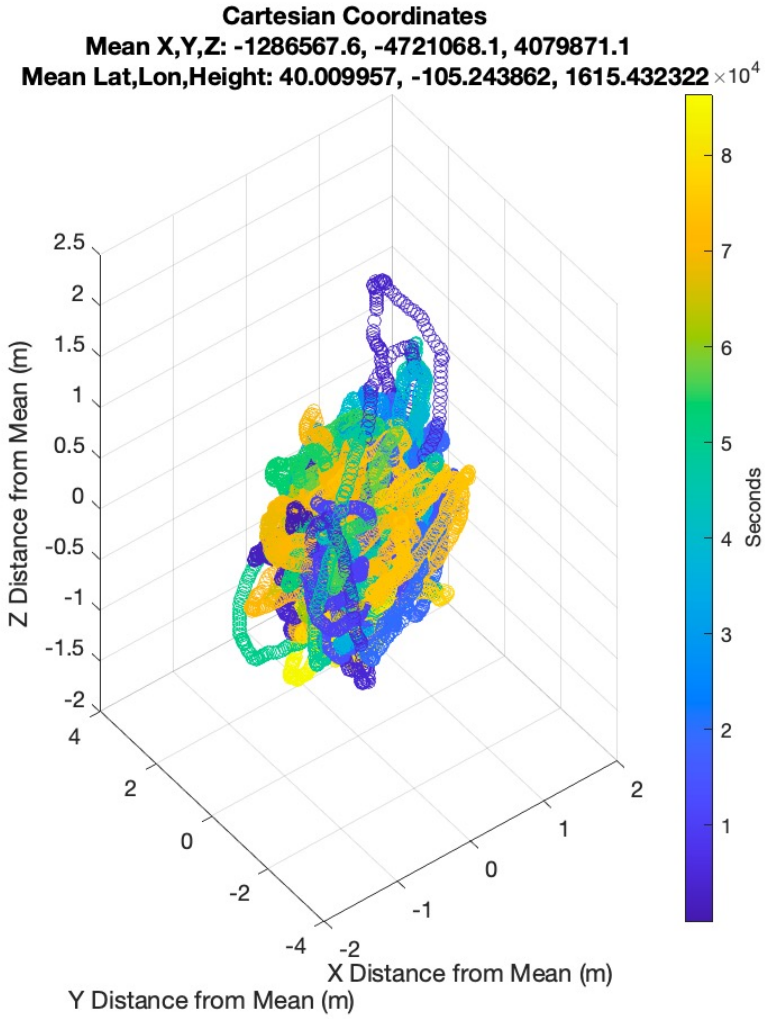
Fields we explore further

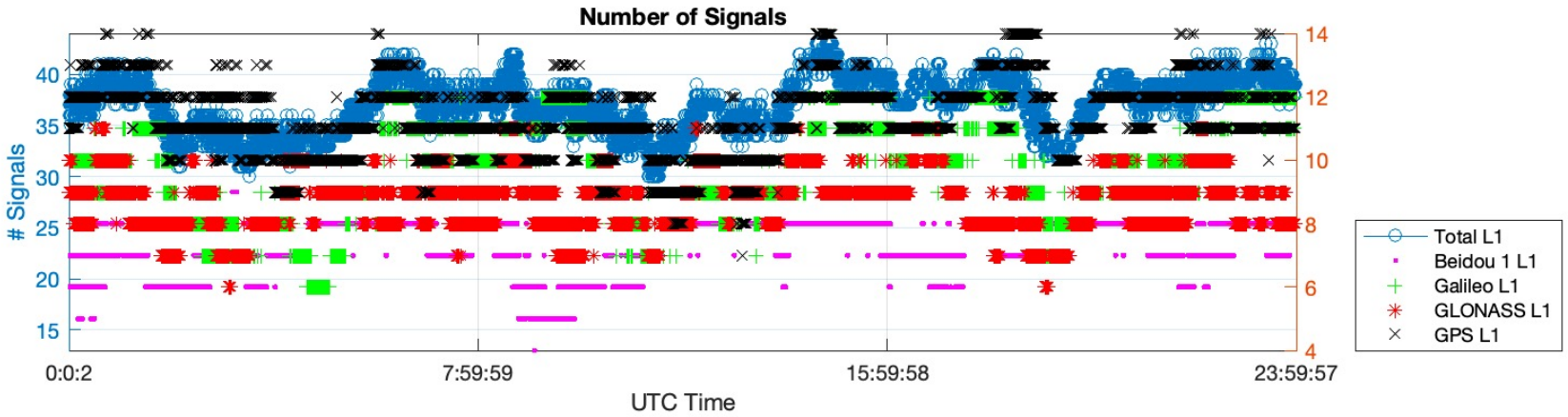
Each day the server plots many of these metrics for closer analysis

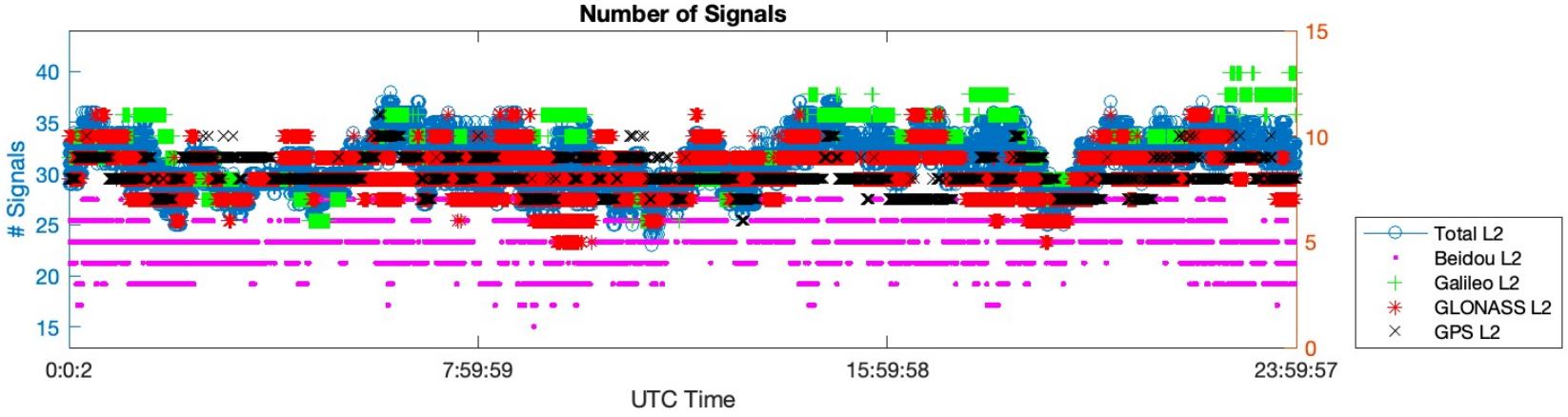
Position plot generated daily by the server



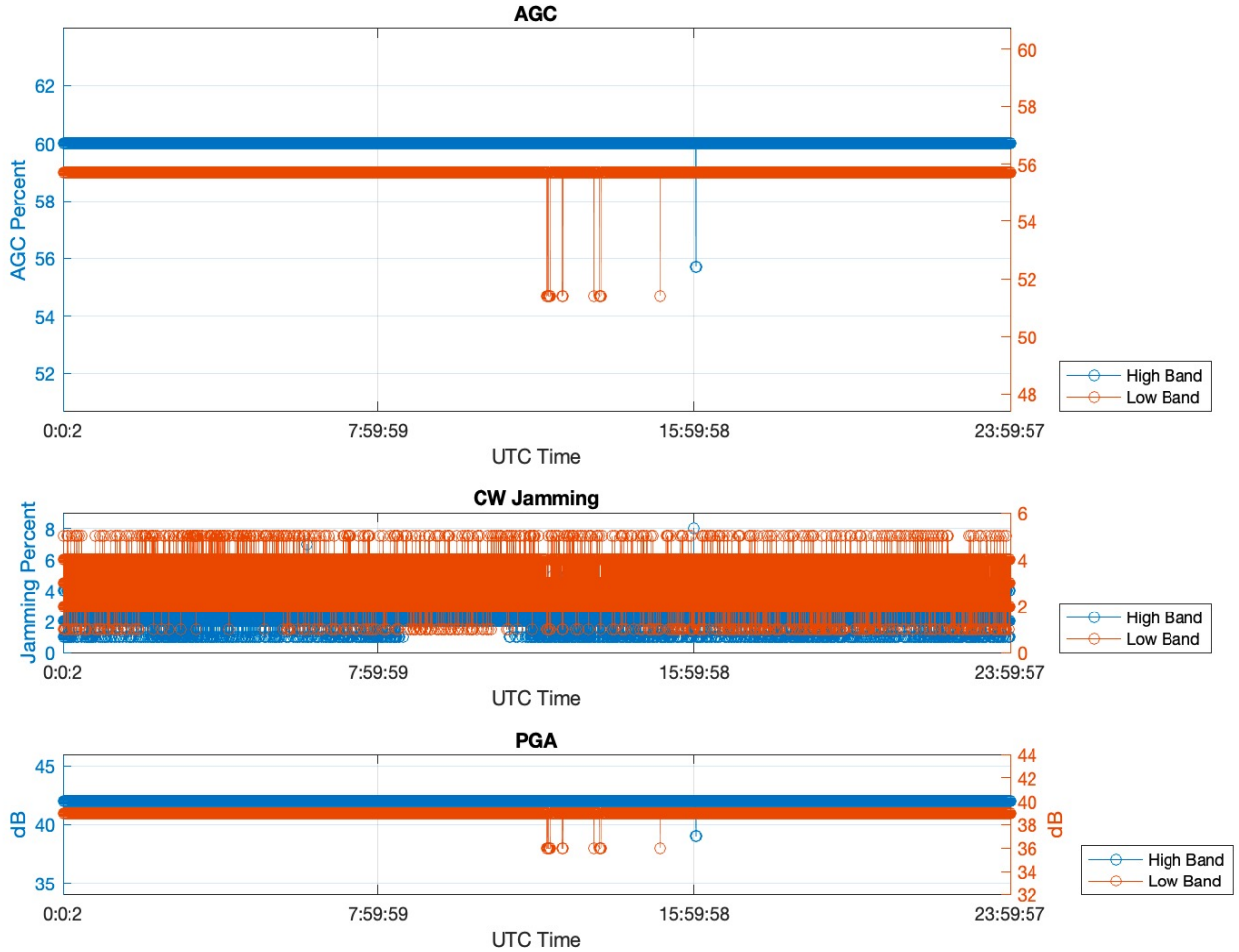
24 Hour Position and Satellite Plot

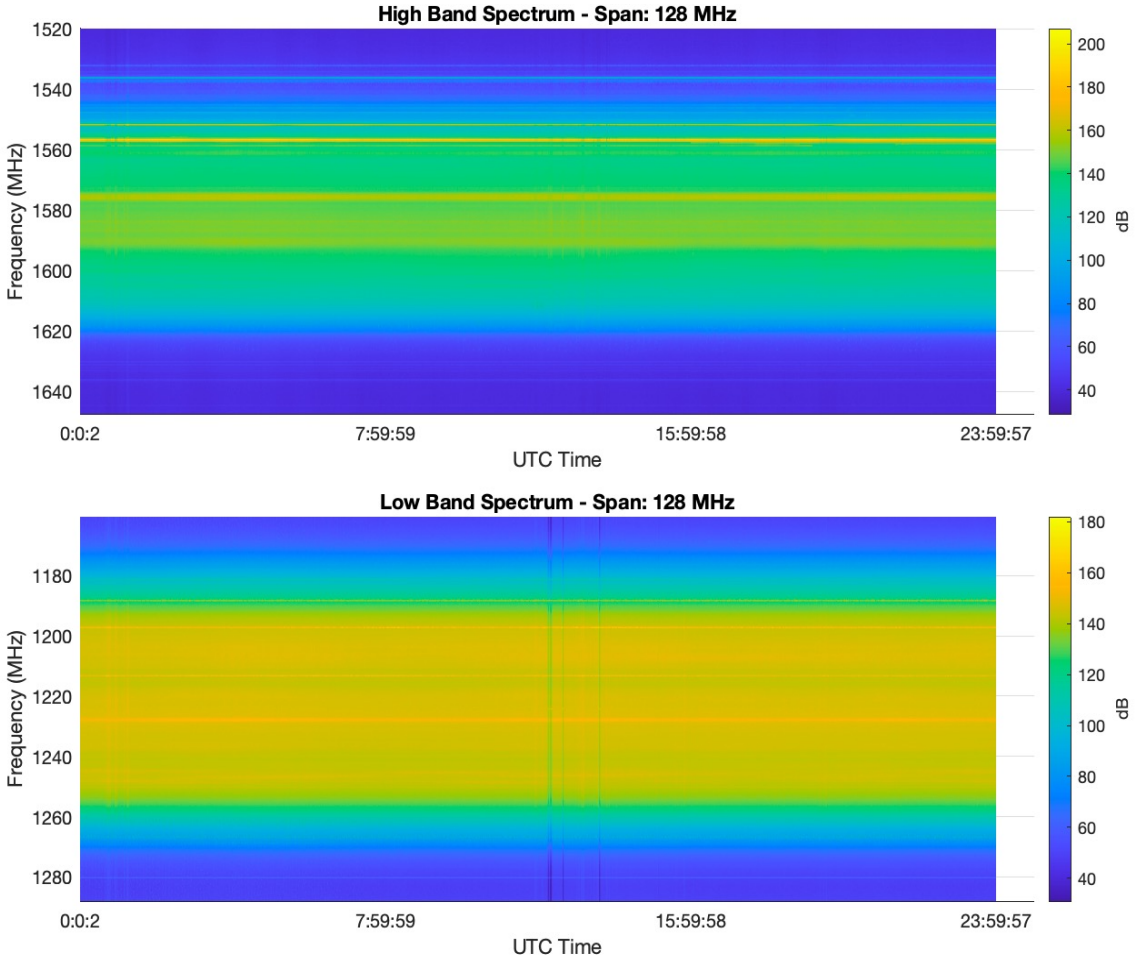




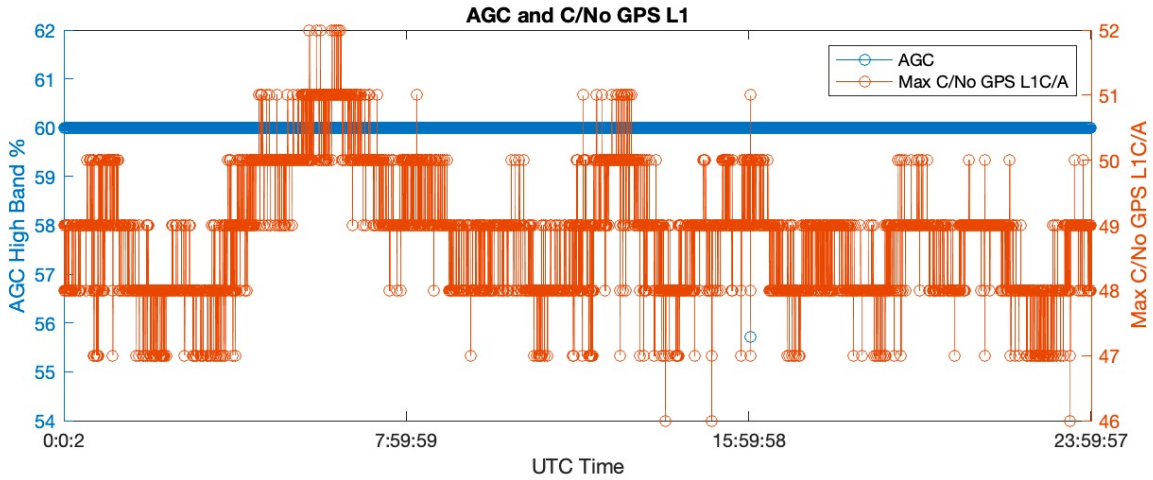


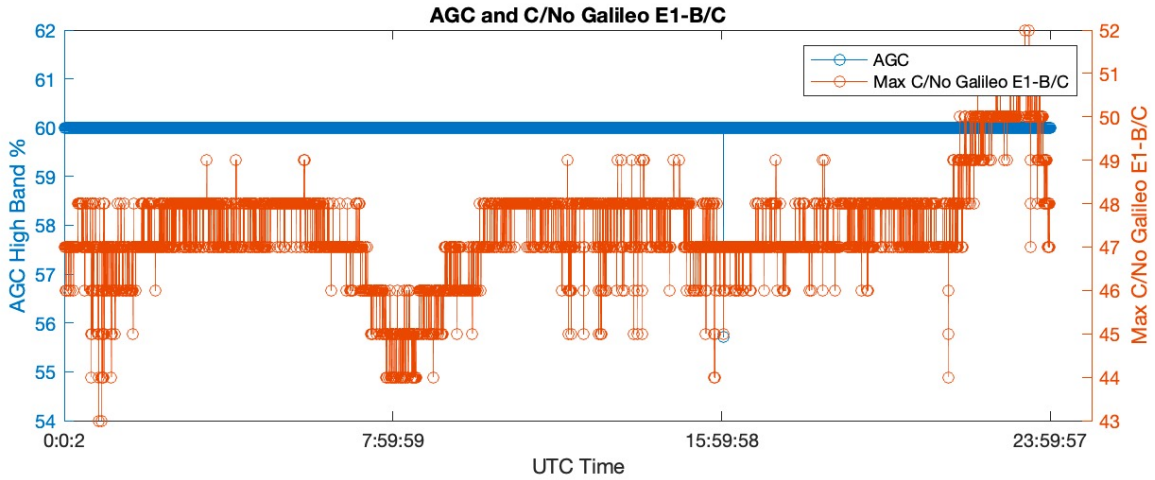
24 Hour RF and Power Plot

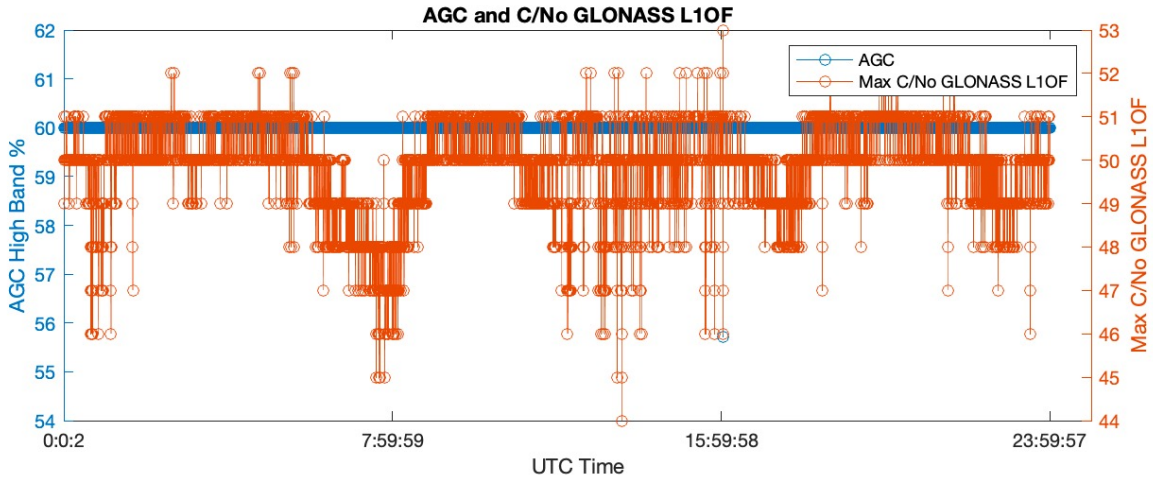


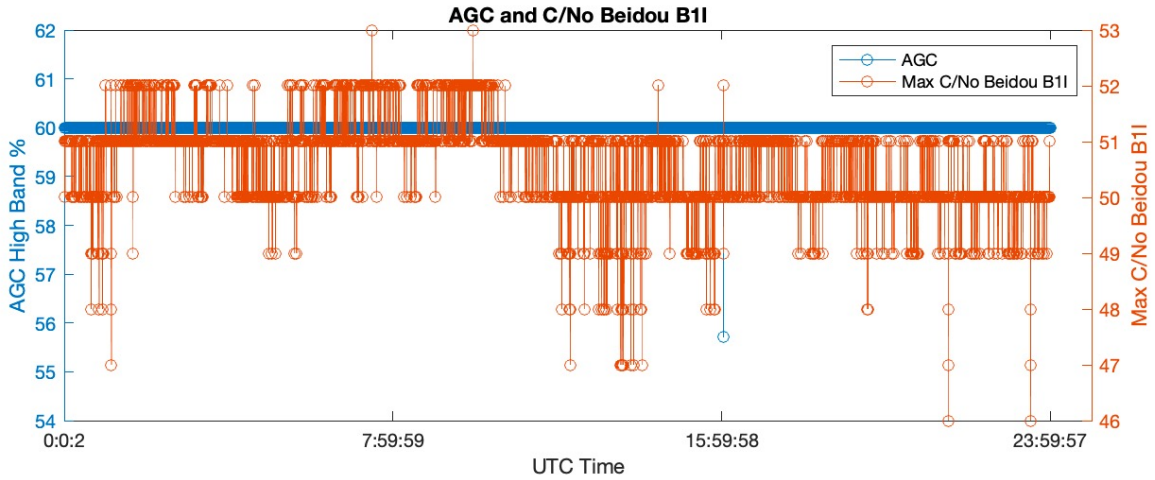


24 Hour AGC and Max C/No









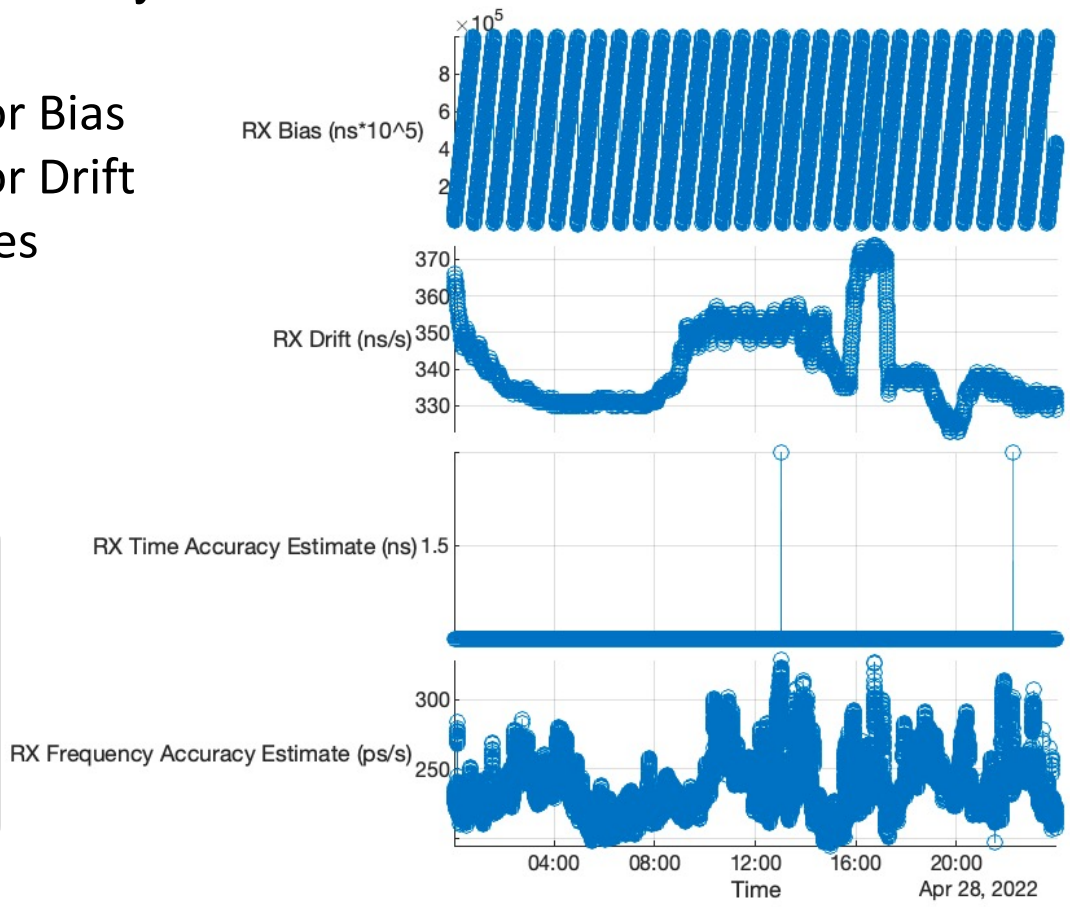
Time

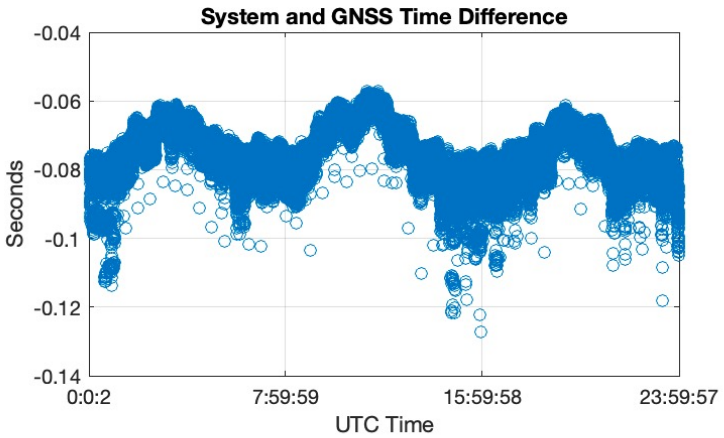
Daily time plot generated by the server

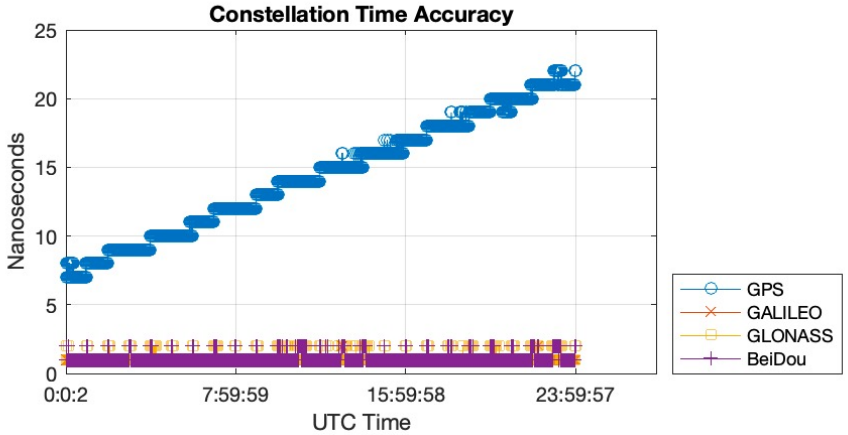
Includes:

- Receiver Oscillator Bias
- Receiver Oscillator Drift
- Accuracy Estimates
- System and GNSS time comparison

Each receiver's oscillator will be different out of the box and affected by the local setup. Insight into the oscillator bias and drift is necessary for time critical applications.







Outline

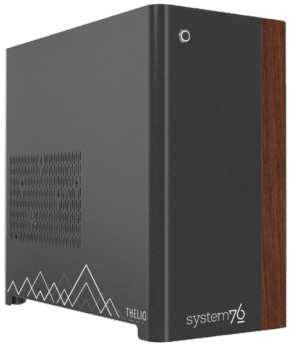
1. Background and Motivation
2. Monitor System
   A. System Breakdown
   B. u-blox F9 Receiver
   C. u-blox F9 Metrics and Plots
3. Data Management
4. Data Collection Results
   A. Receiver Locations
   B. Long-term Statistics
   C. RFI Example
5. Summary and Future Work

Data Management

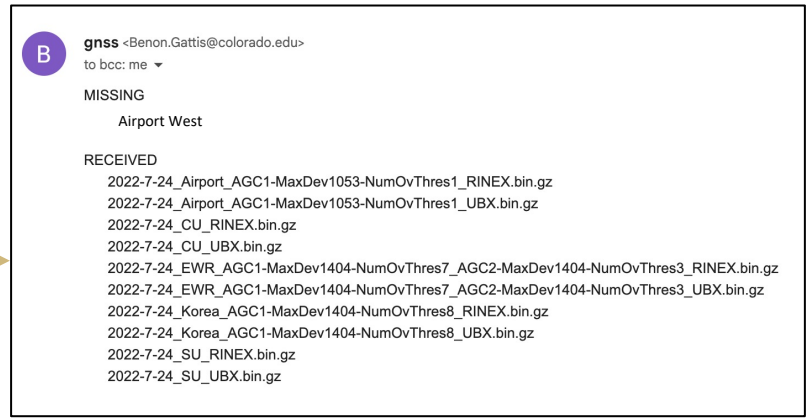
Node

SFTP

Network-Attached-Storage



Data Processing Computer



B

gnss <Benon.Gattis@colorado.edu>
to bcc: me

MISSING

Airport West

RECEIVED

2022-7-24_Airport_AGC1-MaxDev1053-NumOvThres1_RINEX.bin.gz
2022-7-24_Airport_AGC1-MaxDev1053-NumOvThres1_UBX.bin.gz
2022-7-24_CU_RINEX.bin.gz
2022-7-24_CU_UBX.bin.gz
2022-7-24_EWR_AGC1-MaxDev1404-NumOvThres7_AGC2-MaxDev1404-NumOvThres3_RINEX.bin.gz
2022-7-24_EWR_AGC1-MaxDev1404-NumOvThres7_AGC2-MaxDev1404-NumOvThres3_UBX.bin.gz
2022-7-24_Korea_AGC1-MaxDev1404-NumOvThres8_RINEX.bin.gz
2022-7-24_Korea_AGC1-MaxDev1404-NumOvThres8_UBX.bin.gz
2022-7-24_SU_RINEX.bin.gz
2022-7-24_SU_UBX.bin.gz

Alert Users of RFI

SFTP (Secure File Transfer Protocol) is used to send data from node to server

Internet connectivity is required:

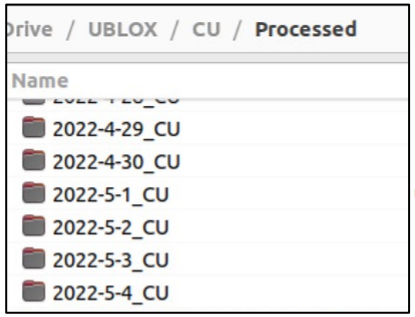
- Utilizing available Wi-Fi is free and simple
- Cellular modems covers other areas
  - Monthly fee is expensive and not suitable for mass deployment

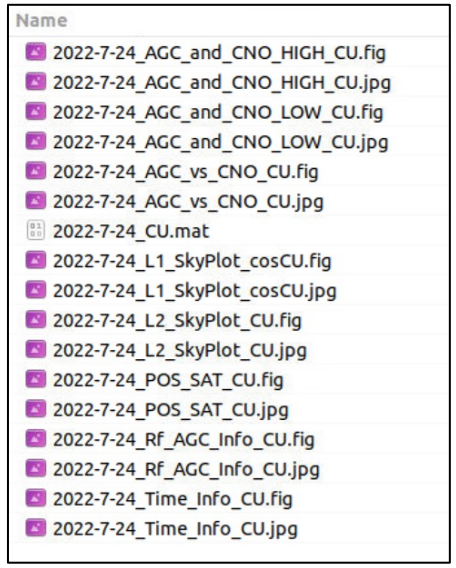
Data Management – File Structure

2022-7-24_CU_RINEX.bin.gz
2022-7-24_CU_UBX.bin.gz

Network-Attached-Storage

Data Processing Computer





Folder Contents

- Node records two binary files: RINEX and UBX messages
- Both binary files are compressed and saved on node and NAS
  - UBX file ~50 MB, RINEX ~150 MB = 200 MB of raw data a day per location
- Computer parses the UBX file into a .mat file, creates plots
- Folder containing .mat and plots is saved with other days from that location
  - Folder is ~ 500 MB

Data Management - Initial Alert

The node pulls the AGC (Automatic Gain Control) out in real time:

- AGC is a measure of the overall power entering a receiver, making it effective in RFI detection[1]
- If the AGC crosses a certain threshold, the filename is changed to acknowledge the AGC

2022-6-27_CU_AGC1-MaxDev3136-NumOvThres123_AGC2-MaxDev2784-NumOvThres122_UBX.bin.gz

- Each day, an email is sent out with the received and missing files
- This notifies users if any nodes disconnect, as well if any files are worth analyzing further

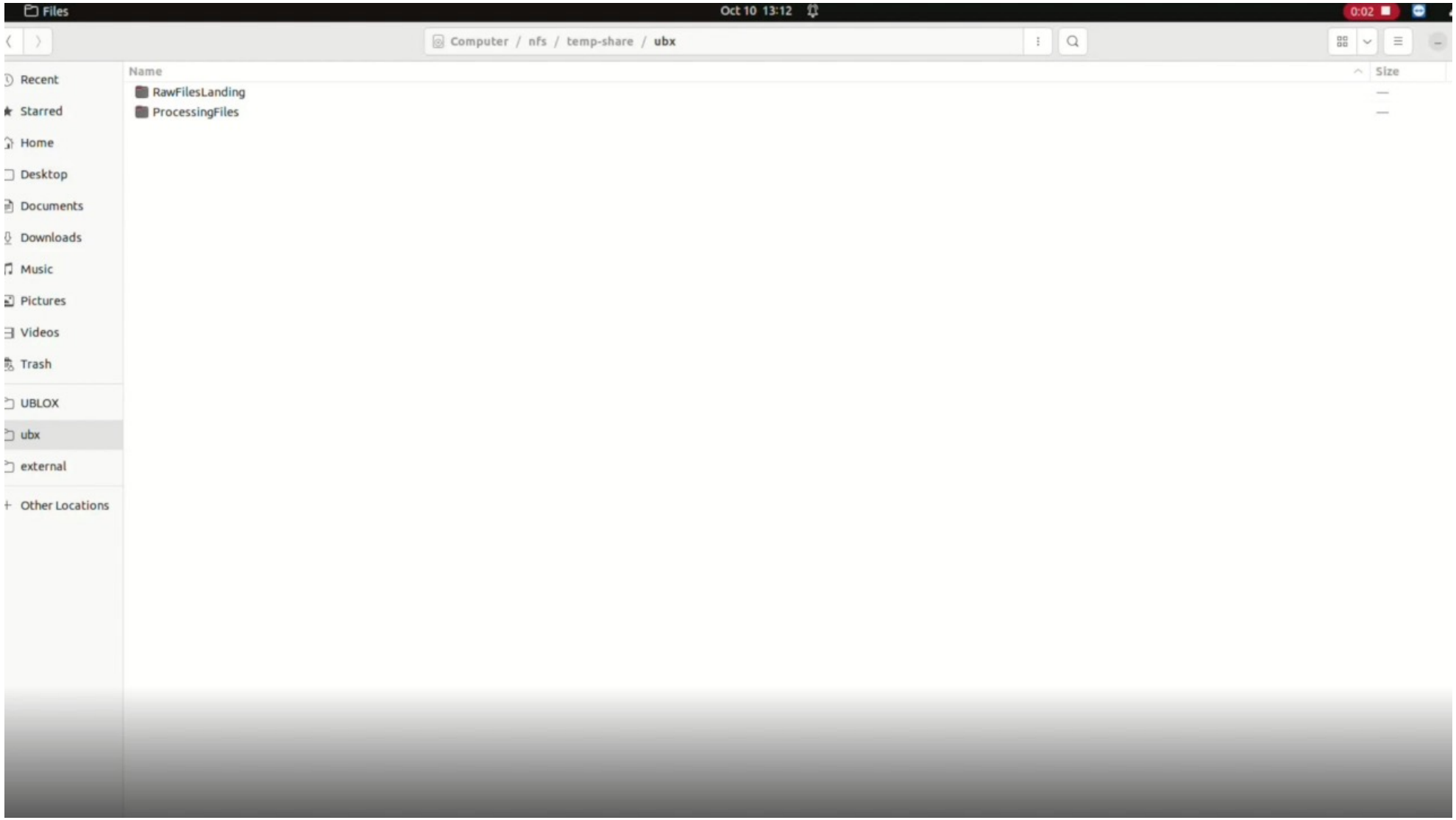
B

gnss <Benon.Gattis@colorado.edu>
to bcc: me

MISSING
Airport West

RECEIVED
2022-7-24_Airport_AGC1-MaxDev1053-NumOvThres1_RINEX.bin.gz
2022-7-24_Airport_AGC1-MaxDev1053-NumOvThres1_UBX.bin.gz
2022-7-24_CU_RINEX.bin.gz
2022-7-24_CU_UBX.bin.gz
2022-7-24_EWR_AGC1-MaxDev1404-NumOvThres7_AGC2-MaxDev1404-NumOvThres3_RINEX.bin.gz
2022-7-24_EWR_AGC1-MaxDev1404-NumOvThres7_AGC2-MaxDev1404-NumOvThres3_UBX.bin.gz
2022-7-24_Korea_AGC1-MaxDev1404-NumOvThres8_RINEX.bin.gz
2022-7-24_Korea_AGC1-MaxDev1404-NumOvThres8_UBX.bin.gz
2022-7-24_SU_RINEX.bin.gz
2022-7-24_SU_UBX.bin.gz

Server Demo


Files
Oct 10 13:12
0:02
Computer / nfs / temp-share / ubx
Recent
Starred
Home
Desktop
Documents
Downloads
Music
Pictures
Videos
Trash
UBLOX
ubx
external
Other Locations
Name
Size
RawFilesLanding
ProcessingFiles

Outline

1. Background and Motivation
2. Monitor System
   A. System Breakdown
   B. u-blox F9 Receiver
   C. u-blox F9 Metrics and Plots
3. Data Management
4. Data Collection Results
   A. Receiver Locations
   B. Long-term Statistics
   C. RFI Example
5. Summary and Future Work

Receiver Locations

- Six receivers have been deployed across the globe for extended periods (3-15 months) collecting data
- Data has been collected to set baseline values for expected noise and variation under nominal conditions

Location	Receiver Type
University of Colorado Boulder	F9P (L1 + L2)
Stanford University	F9P (L1 + L2)
Colorado Springs Airport West	F9P (L1 + L2)
Colorado Springs Airport East	F9T-10B (L1 +L5)
Newark Airport	F9T-10B (L1 +L5)
South Korea	F9T-10B (L1 +L5)

Rooftop antenna in Seoul, South Korea

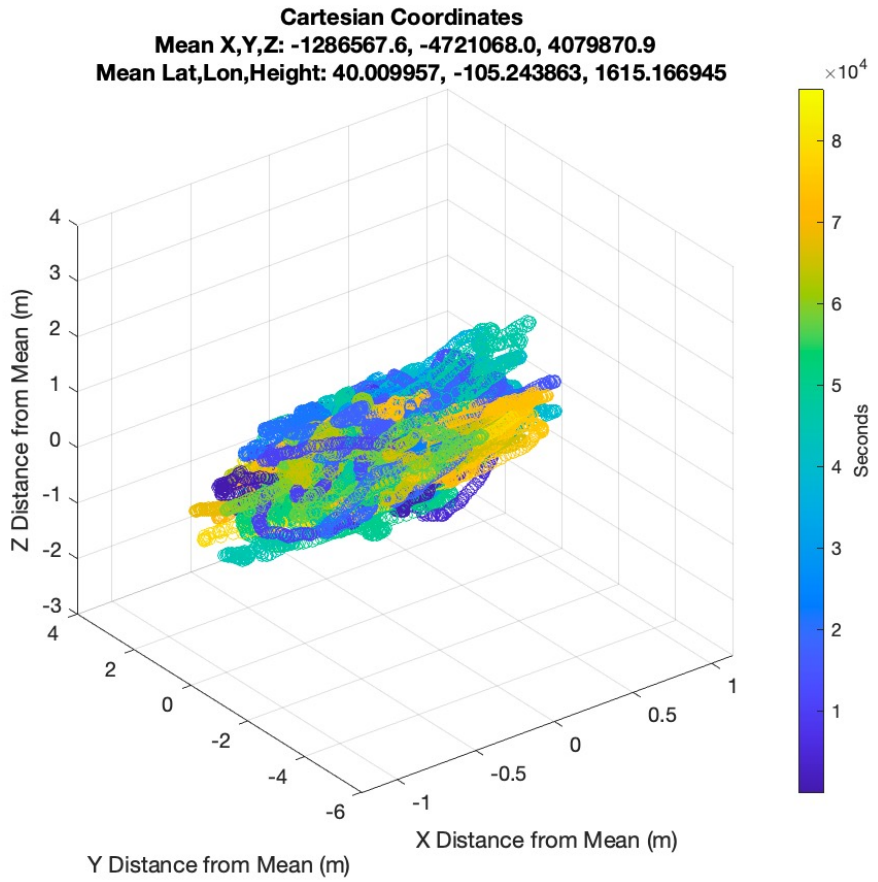
Position

Position accuracy for each location

- Boulder, Stanford, and South Korea use survey-grade antennas, while the others use the u-blox antenna
- The South Korea node experiences occasional large “drifts” in location

Location	X Error (m)		Y Error (m)		Z Error (m)	
	1 σ,	Max	1 σ,	Max	1 σ,	Max
University of Colorado Boulder	0.367,	1.92	0.693,	4.11	0.560,	3.45
Stanford University	0.368,	1.77	0.487,	2.76	0.421,	1.86
Colorado Springs Airport West	0.386,	2.59	0.703,	5.76	0.623,	5.46
Colorado Springs Airport East	0.408,	1.80	0.676,	4.02	0.564,	3.45
Newark Airport	0.510,	3.26	0.757,	4.88	0.784,	5.67
South Korea	1.129,	6.85	1.368,	15.32	0.865,	5.17

Position plot generated daily by the server



The position is usually accurate to 1m, with maximum nominal deviations of 4-6 meters.

Automatic Gain Control (AGC)

AGC can be powerful in detecting and characterizing RFI[1].

As a measure of the overall power entering the receiver, different hardware setups and locations will result in different baseline AGC values. Calibration is required to account for this.

u-blox AGC Properties

Two AGC's, each spanning 128MHz, one at L1, one at L2 or L5

AGC is reported as a percentage

The AGC is coarse, the step sizes are ~4% or ~3dB apart

The AGC is coarse resulting in minimal nominal variations. Deviations more than 2 steps are rare and should be analyzed further.

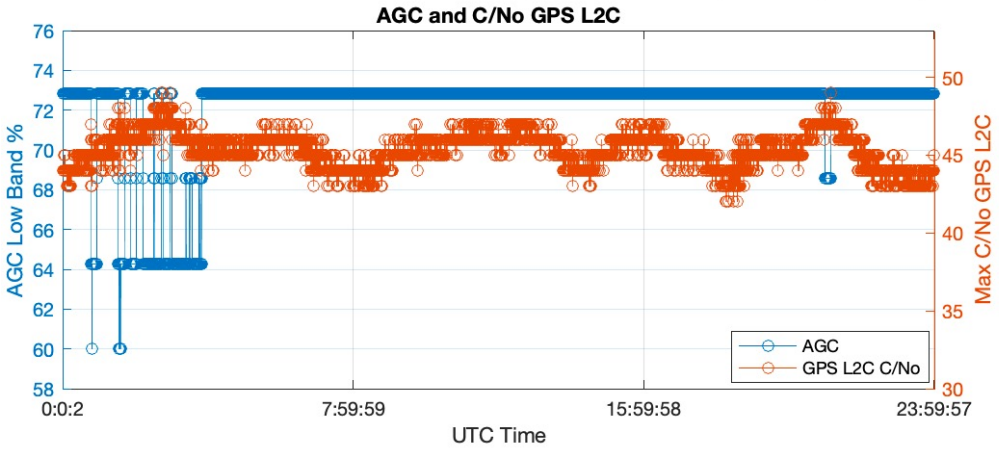
Location	Baseline AGC Value High / Low Band	Mean Epochs per Day 1 Step Away High / Low Band	Mean Epochs per Day 2 Steps Away High / Low Band
University of Colorado Boulder	59 / 55	1 / 449	0 / 26
Stanford University	72 / 72	0 / 2573	0 / 2122
Colorado Springs Airport West	64 / 59	3 / 10206	1 / 0
Colorado Springs Airport East	72 / 64	9692 / 0	0 / 0
Newark Airport	64 / 60	62 / 28	18 / 7
South Korea	51 / 47	1,521 / 895	4 / 4

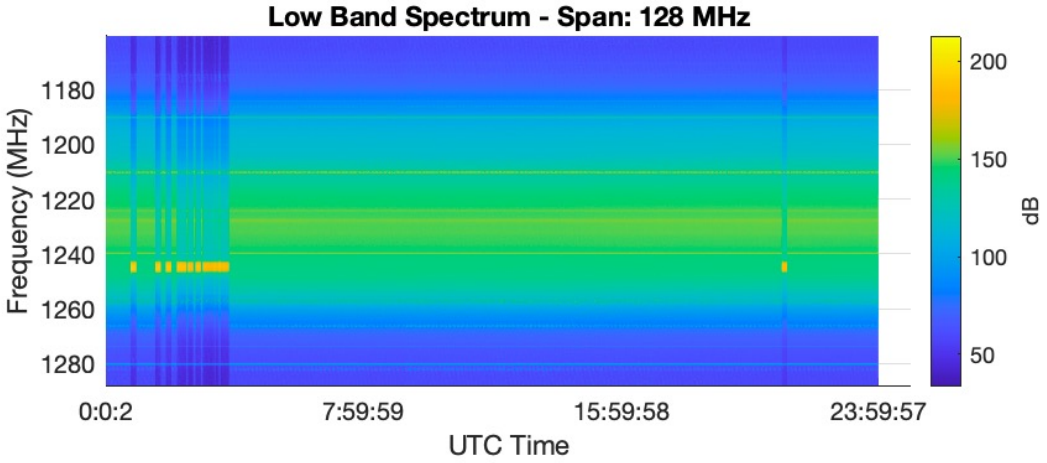
How RFI is Detected: Post Processing

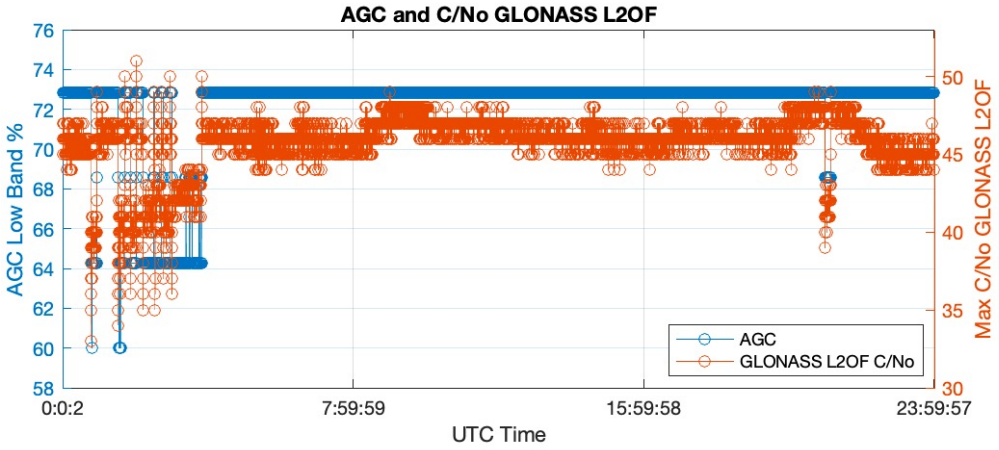
Automatic Gain Control: AGC is a measure of the overall power entering a receiver, making it effective in RFI detection[1]

Carrier to Noise Ratio: A measure of an individual signal's strength entering the receiver

Spectrum Data: Also useful for identifying power changes in the spectrum, with the benefit of seeing where the power is

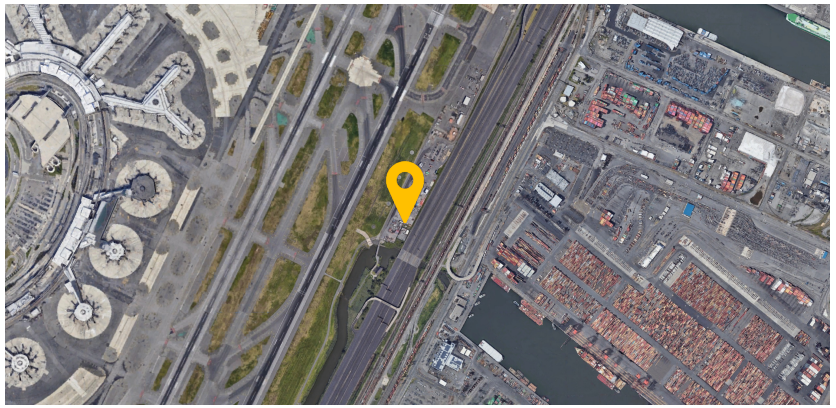






Newark Airport

The receiver at Newark Airport is also next to a major freeway, and experiences significantly more RFI than the other receivers.
Illegal personal jamming devices on trucks are thought to be the cause.

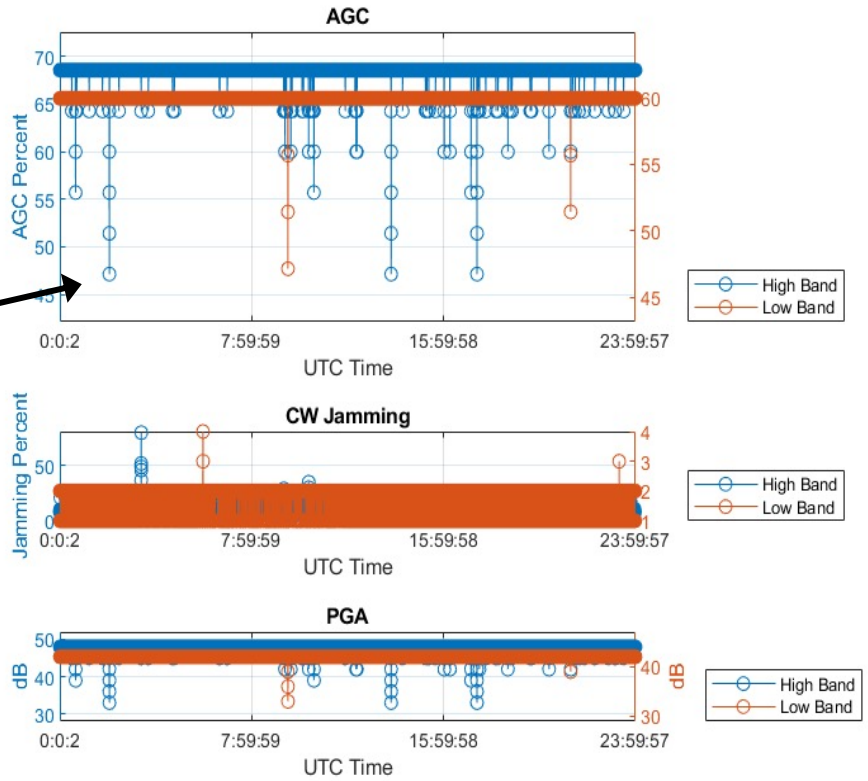


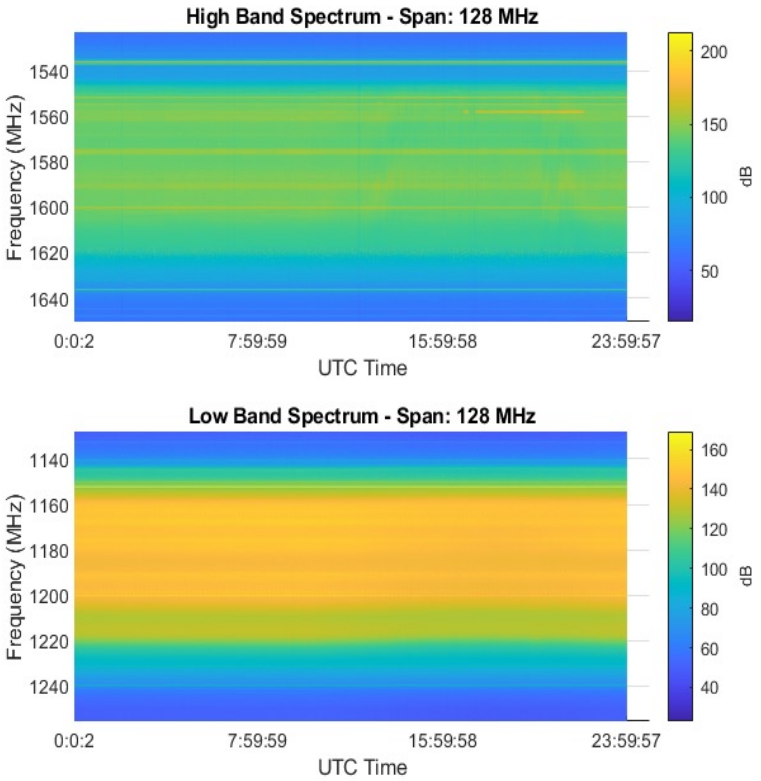
Newark experiences many brief and powerful influxes in power

The spikes are short, <10s, but often drop the AGC by 20%, or 5 steps

There are no relevant changes in position during these RFI events

While most locations see minimal change in nominal power, others will require more thorough screening for more dangerous RFI



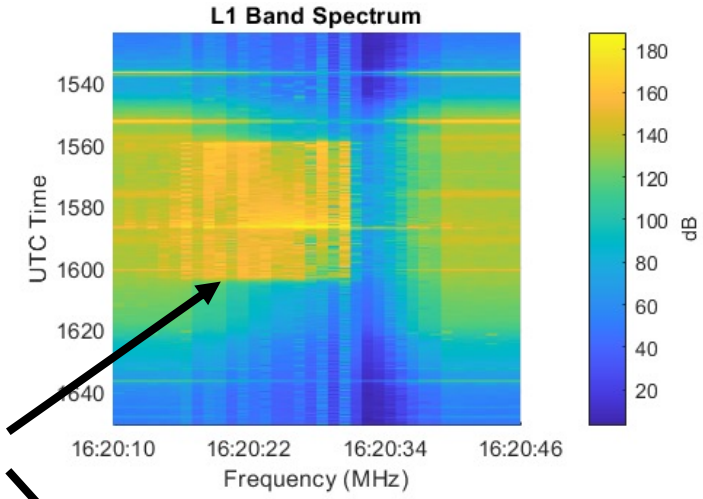


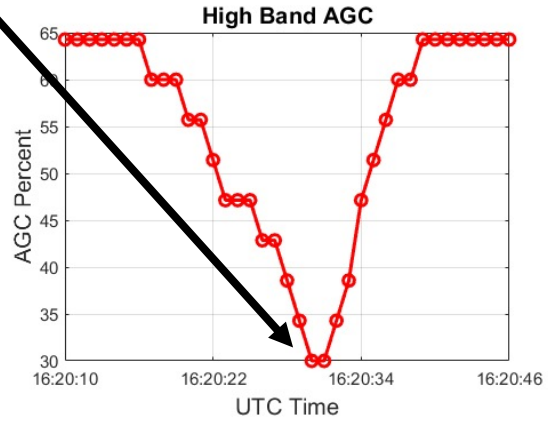
Newark Airport

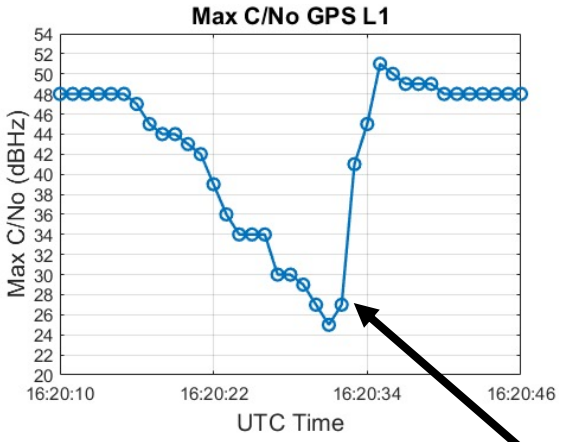
The monitor produces several plots allowing easy analysis of suspected RFI.

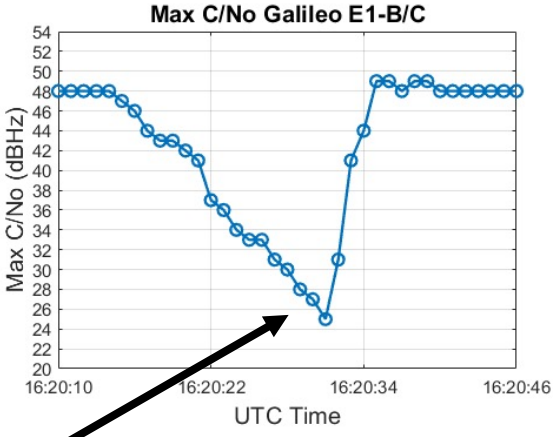
An influx of power between 1560 and 1600 MHz is seen in the spectrum, with the power also reflected in the AGC.

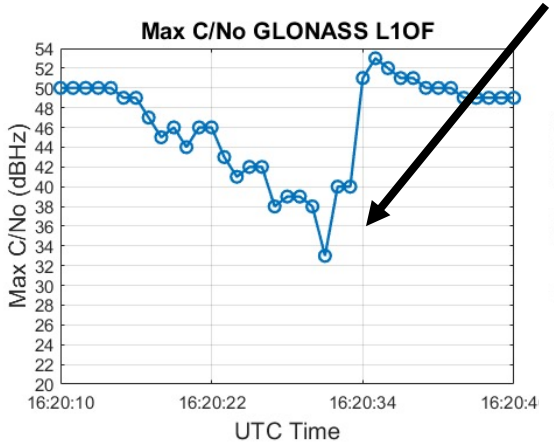
The max C/N_0 of all constellations in that band drop substantially.

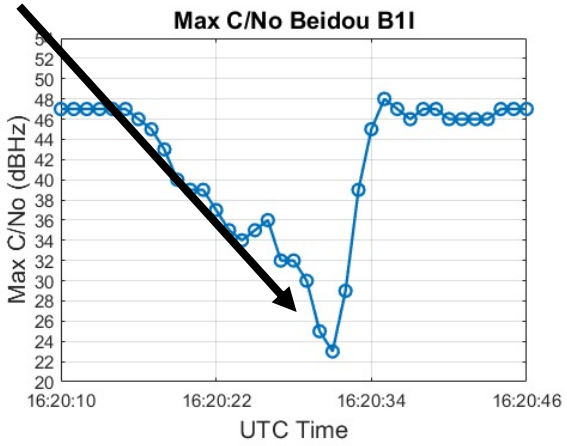












Outline

1. Background and Motivation
2. Monitor System
   A. System Breakdown
   B. u-blox F9 Receiver
   C. u-blox F9 Metrics and Plots
3. Data Management
4. Data Collection Results
   A. Receiver Locations
   B. Long-term Statistics
   C. RFI Example
5. Summary and Future Work

Summary and Next Steps

The current deployment of nodes and a server has proven the concept, and the extensive data collection provides reliable values for baselines and thresholds for RFI detection

Several Future Paths:

- Give the node more “brains” – allow the node to do more real time processing
  - Requires a more powerful computer with the node
- Stream data in real time to a server for real time processing
  - Requires reliable internet connection
- Streamline node and server design
  - Build a more compact all in one node unit
  - Refine server to be more resilient and easier to manage nodes

Acknowledgements

We'd like to thank Roger Ishimoto from Zeta Associates for helping to get the Newark receiver installed and running in such an interesting environment.

Citations

[1]D. M. Akos, "Who's Afraid of the Spoofer? GPS/GNSS Spoofing Detection via Automatic Gain Control (AGC)," NAVIGATION, Journal of the Institute of Navigation, vol. 59, no. 4, pp. 281–290, 2012.

L. Taleghani, F. Rothmaier, Y. Chen, S. Lo, T. Walter, D. Akos, B. Gattis, "Low Cost RFI Monitor for Continuous Observation and Characterization of Localized Interference Sources," Proceedings of the 2022 International Technical Meeting of The Institute of Navigation, Long Beach, California, January 2022, pp. 1216-1245

Newark Airport

Using the AGC as the main source of detection requires special care on with u-blox

Upon further inspection, the incoming power is not as destructive as the AGC would suggest.

A large drop in AGC triggers the initial alarm