Protecting the Satellite Data Fidelity by Monitoring the RF Spectrum at the Ground Station

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Overview

- History
- RFIMS Background
- RFIMS Challenges
- RFIMS solution
- RFIMS results and observation
- Next steps
- Conclusion

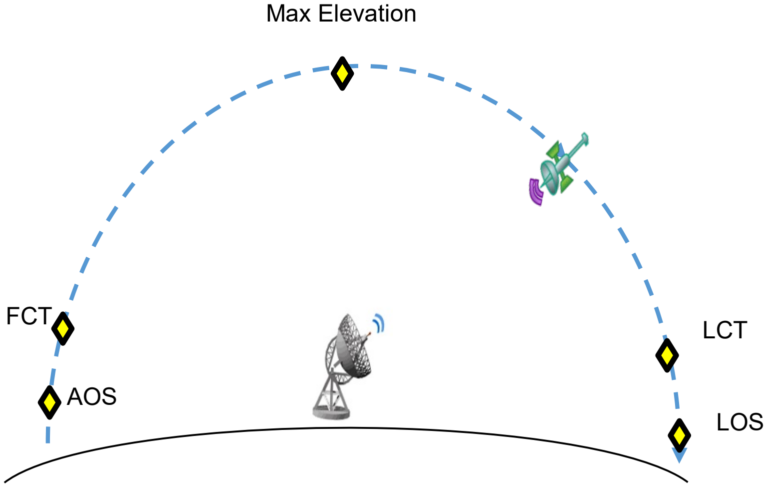
History

- FCC AWS-3 auction in Jan 2015 auctioned licenses to commercial LTE wireless carriers to operate in the 1695-1710 MHz band.
- In this band and its adjacent bands National Oceanic and Atmospheric Administration (NOAA) operates its downlink of weather satellites.
- The polar orbiting satellites, which include Polar-orbiting Operational Environmental Satellites (POES) and Meteorological Operational (Metop) satellites, are in highly inclined low earth orbits (LEO), or “polar” orbits.
- The Geostationary Operational Environmental Satellite (GOES) is in a geostationary earth orbit (GEO). At 35,000 Km above earth’s surface.

NOAA weather satellite missions: LEO

- The polar orbiting satellites, which include Polar-orbiting Operational Environmental Satellites (POES) and Meteorological Operational (MetOp) satellites, are in highly inclined low earth orbits (LEO), or "polar" orbits.
- The polar systems offers daily global coverage by making nearly polar, low earth orbits 14.1 times per day (an orbital period of about 100 minutes) at approximately 800 km above the Earth's surface.
- A typical contact between a Federal earth station and a polar satellite is only 8-14 minutes in duration.
- Depending on the latitude of each earth station, number of visible passes per day at each earth stations changes:
  - Wallops Island might have as much as 30 visible passes
  - Fairbanks might have as high 50 visible passes.
- The downlink frequencies used by POES and MetOp are in the shared 1695-1710 MHz band.

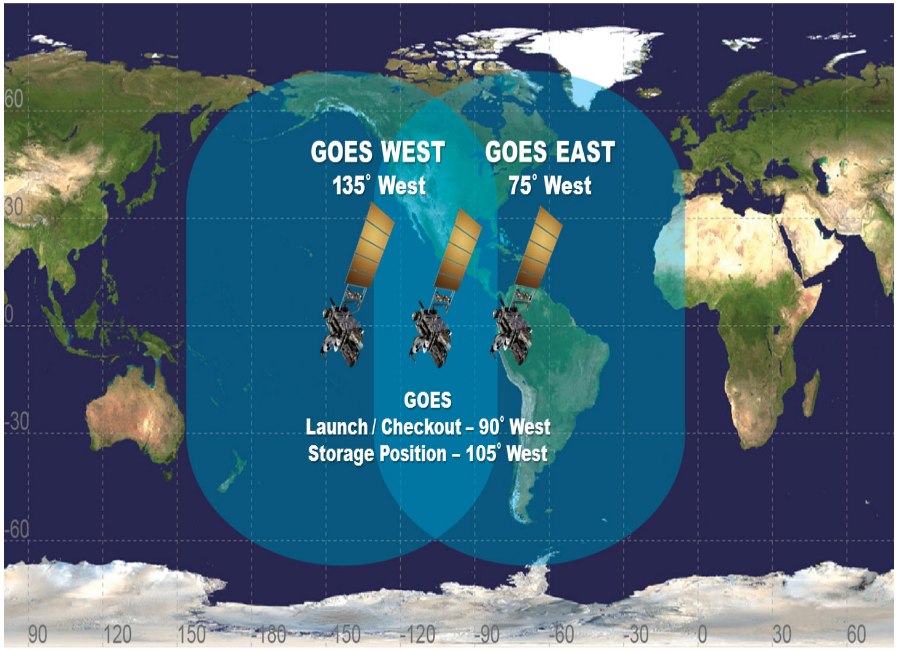
POES field of view and contact

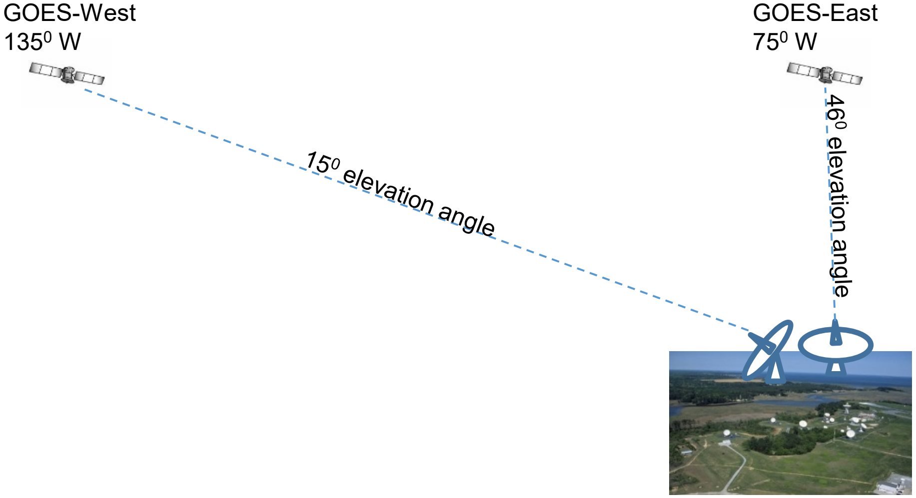


NOAA weather satellite missions: GEO

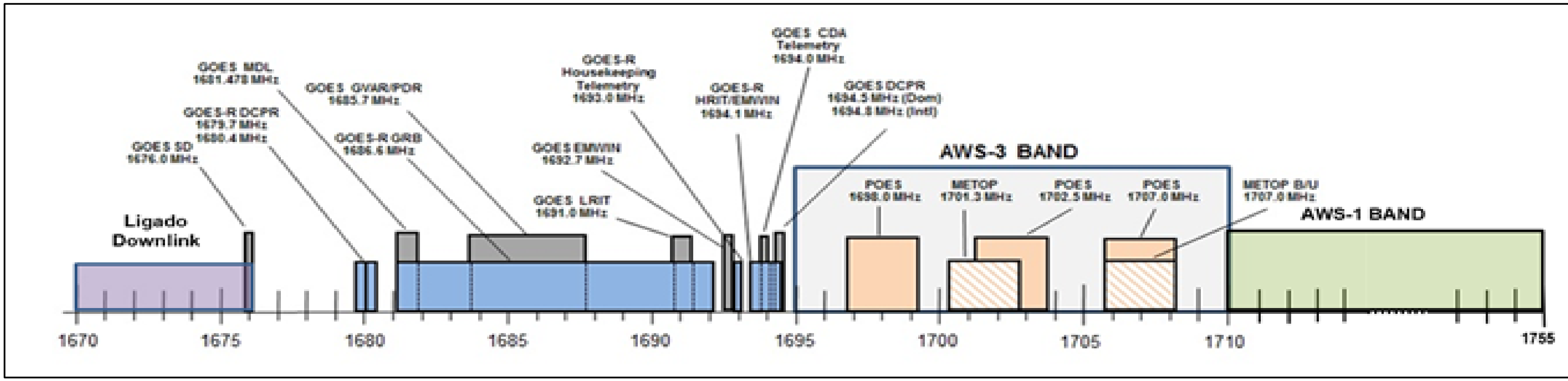
- The Geostationary Operational Environmental Satellite (GOES) is in a geostationary earth orbit (GEO). At 35,000 Km above earth’s surface.
- Due to its orbit, a GOES satellite has continuous visibility of each Federal earth station in its footprint. Therefore, GOES-equipped Federal earth stations can receive data from any GOES satellite in view 24 hours per day, 7 days per week.
- The GOES downlink frequencies are adjacent to the shared band in the 1675-1695 MHz band, but are still protected from interference from AWS-3 commercial wireless carriers.

GOES field of view and contact





NOAA's L-band RF Environment

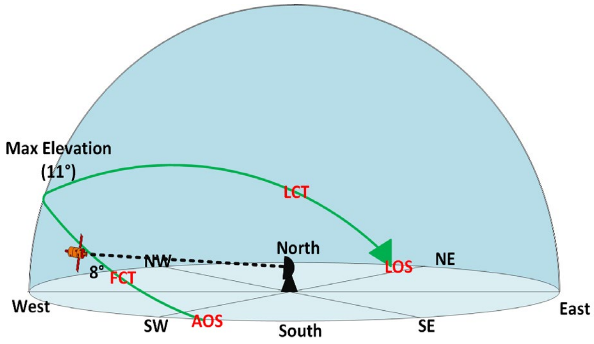


- The operational L-band RF environment at NOAA's ground stations are very crowded and it is going to be more utilized in near future.

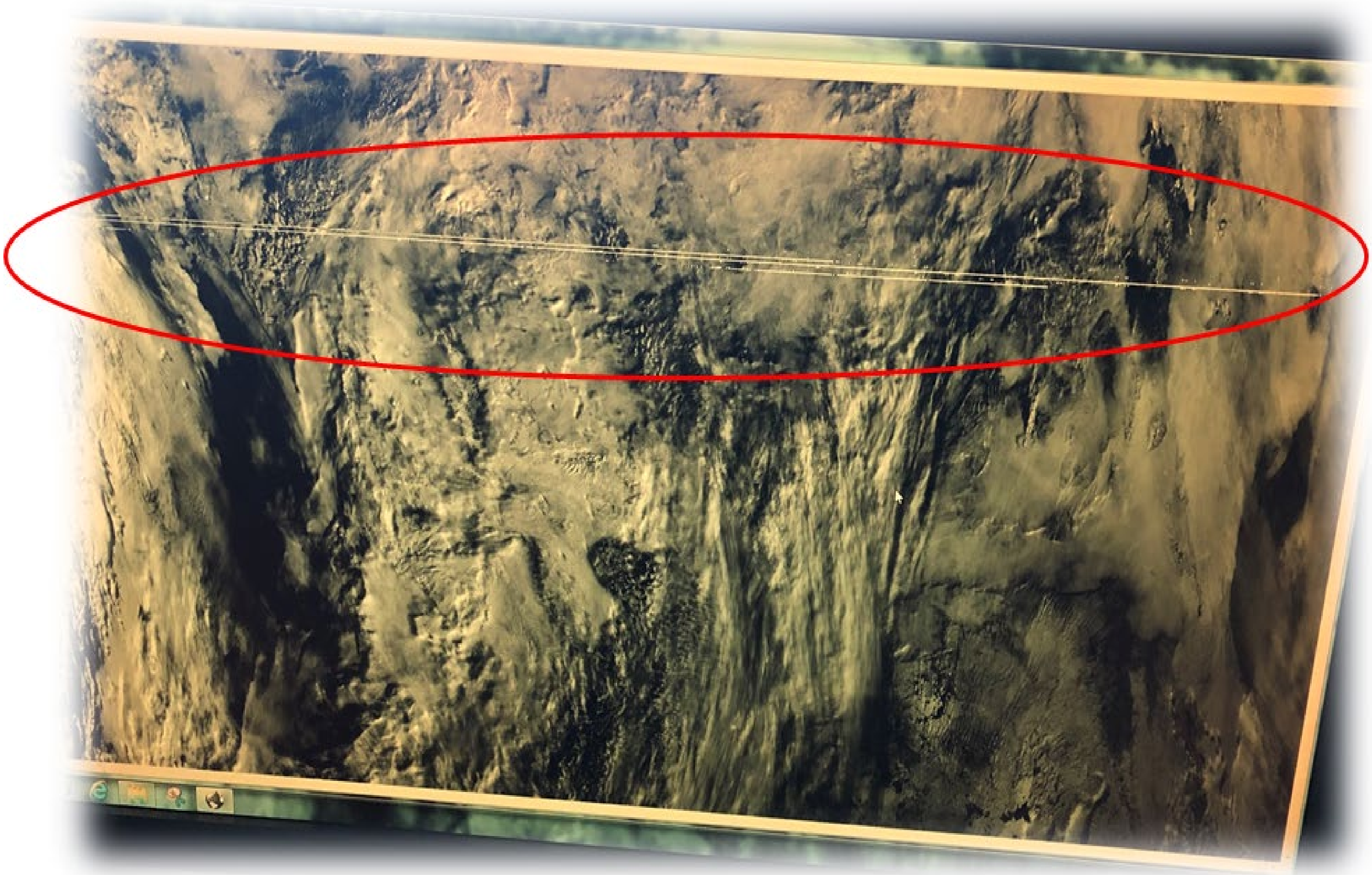
In-band and Out-of-band Interference

- If the interfering signal is generated inside the band of protection, it is called in-band interference.
- If the interfering signal is generated outside the band of protection, it is called out-of-band interference.
- The RFIMS in order to protect the AWS-3 band needs to monitor all of 1670-1755 MHz.

RFI Seen at NOAA's Ground Station



Effect of RFI on NOAA's mission



NOAA weather satellite ground stations

- NOAA operates several satellite ground stations and each ground station is operated by different agencies under NOAA”
  - Oceanic and Atmospheric Research (OAR)
  - National Weather Services (NWS)
  - National Environmental Satellite, Data, and Information Service (NESDIS).
- Different stations support different missions and the type equipment used in different stations are diverse. Some stations such as Wallops Island and Fairbanks are operated by staff continuously for 365 days in a year. Some stations are in very remote areas and are not fully staffed.
- The antennas in these stations have different sizes and characteristics.

Ground Station	Mission
Fairbanks, AK	POES/GOES
Anchorage, AK	POES
Barrow, AK	POES
Monterey, CA	POES
Boulder, CO	GOES
Miami, FL(OAR)	POES
Miami, FL(NHC)	GOES
Barrigada, GU	POES
Ford Island, HI	POES
Suitland, MD	GOES/POES
Greenbelt, MD	GOES
Bay St. Louis, MS	POES
Kansas City, MO	GOES
Norman, OK	GOES
Guaynabo, PR	GOES
Wallops Island, VA	POES/GOES
Fairmont, WV	GOES

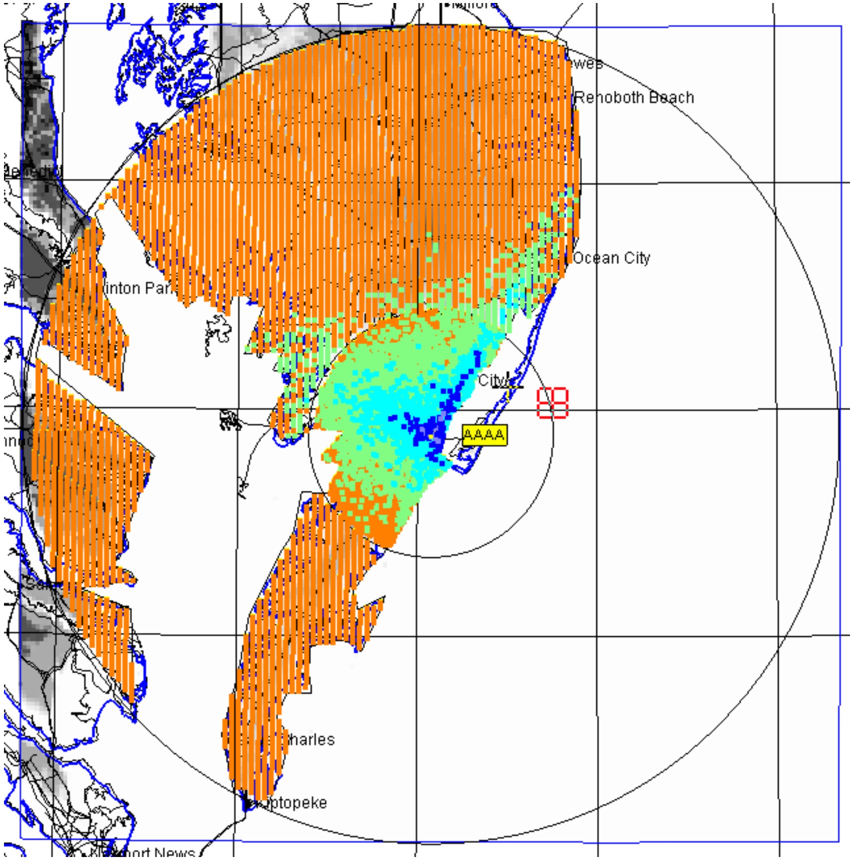
Protection Zones

- CSMAC WG-1 report recommended implementing protection zones around federal agency facilities.
- To produce these protection zones CSMAC made the assumption that LTE uplink signal is at full load 100% of the time and used Irregular Terrain Model (ITM) to simulate the propagation of LTE upload transmission.
- The criteria for the protection zone size was that the interference caused by the LTE uplink signals outside the protection zone will not increase the noise floor of the federal satellite receiver more than 0.4 dBm. This equals to the interference to noise ratio (INR) of -10 dB at the satellite receiver.

Ground Station	Mission	Protection Zone	Radius (km)
Fairbanks, AK	POES/GOES	Fairbanks	20
Anchorage, AK	POES	Elmendorf AFB	98
Barrow, AK	POES	Barrow	35
Monterey, CA	POES	Monterey	76
Boulder, CO	GOES	Boulder	2
Miami, FL(OAR)	POES	Miami	51
Miami, FL(NHC)	GOES		
Barrigada, GU	POES	Andersen AFB	42
Ford Island, HI	POES	Hickam AFB	28
Suitland, MD	GOES/POES	Suitland, Washington, DC	98
Greenbelt, MD	GOES		
Bay St. Louis, MS	POES	Stennis Space Center	57
Kansas City, MO	GOES	Kansas City	40
Norman, OK	GOES	Norman	3
Guaynabo, PR	GOES	Guaynabo	48
Wallops Island, VA	POES/GOES	Wallops Island	30
Fairmont, WV	GOES	Fairmont	4

Sample Protection Zone

- Example of a Protection Zone
  - Wallops Island, VA
  - 30 Km Zone
- Once LTE-carriers have been issued licenses from the FCC
  - Must have build-out plans inside the Protection Zone approved through the Coordination Portal (website)
  - Outside the Protection Zone do not require coordination via the Portal
- Assumptions for monitoring system
  - Interference could come from anywhere, inside or outside the Protection Zone
  - Spurious interferers (non-LTE)

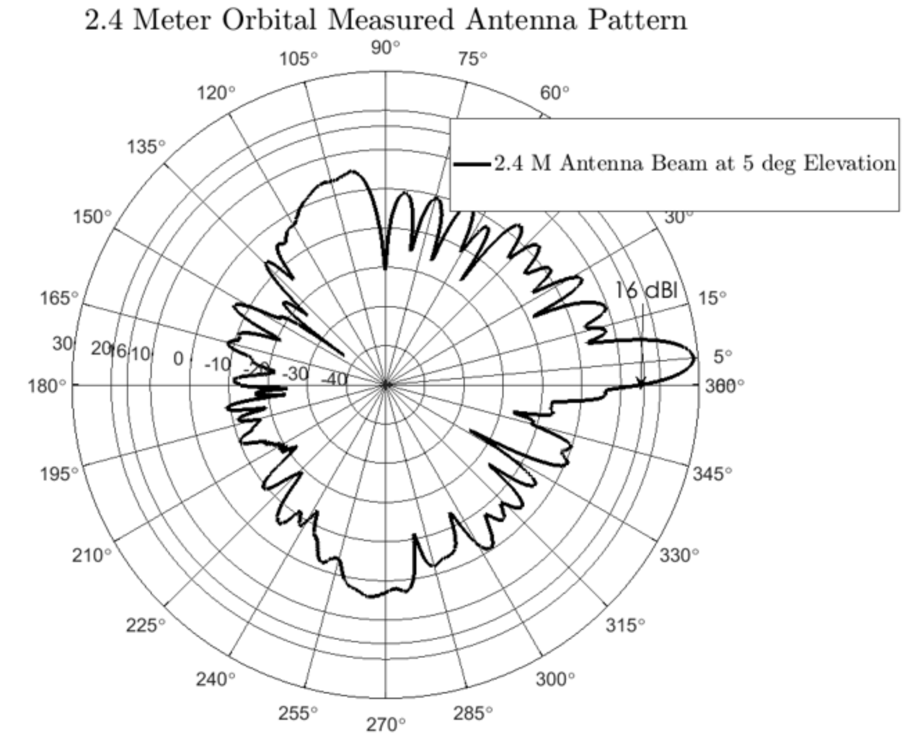


RFIMS Functional Requirements

- To protect earth station communications from LTE interference, NOAA is executing a project to implement a Radio Frequency Interference Monitoring System (RFIMS) across NOAA's Federal earth stations. The monitoring system functions are:
  - **Detect -** The system will detect, in real-time, interference "events" at levels at or above -10 dB Interference-to-Noise Ratio (INR) during NOAA's earth station downlink reception.
  - **Classify** - The system will classify, in real-time, the nature of RF interference. Where "classify" is the *discrimination* between 1695 – 1710 MHz LTE UE uplink signals and all other radio frequency interference (RFI) such as background impulsive noise and out-of-band emissions from other RF sources.
  - **Identify -** If the system determines the RFI is related to 1695 – 1710 MHz LTE UE uplink signal interference, then the system will identify the source(s) of interference in real-time
  - **Notify -** The system will notify NOAA operators, and the wireless carriers responsible for the interference

RFIMS Challenges: Detection Sensitivity

- For an RFIMS to detect an interferer at -10 dB INR, RFIMS must be more sensitive relative to the NOAA receive system.
- NOAA's wide beamwidth antennas are most susceptible to interference at horizon.
  - High Gain antennas have narrower beamwidths and lower sidelobes

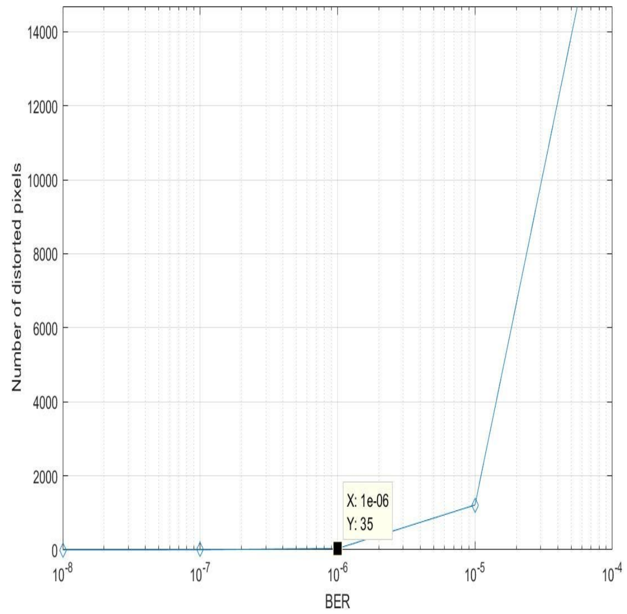


NOAA Earth Station 2.4 Meter Antenna

2.4 - Meter antenna at 5°elevation delivers 16 dBi of gain. The RFIMS sensitivity for requirement is -200 dBm/Hz at the surface of the 2.4-M antenna to satisfy -10 dB INR for the same antenna receiver.

RFIMS Challenges: Definition of Harmful Interference

- To define harmful interference, we analyzed the BER of POES (HRPT) meteorological product, because it is the most vulnerable meteorological product.
  - Analysis suggested our link budgets should based on BER of 10^{-6} and identified the link margins.
  - Using the recommendations from ITU-R SA.1022-1 and ITU-R SA.1026-3, we defined the interference protection criteria (IPC) for each of our ground stations
  - This method suggested our IPC should be -5dB INR.



POES HRPT weather product distorted pixels vs. BER

RFIMS Challenges: Monitoring Environment or the Receivers or Both?

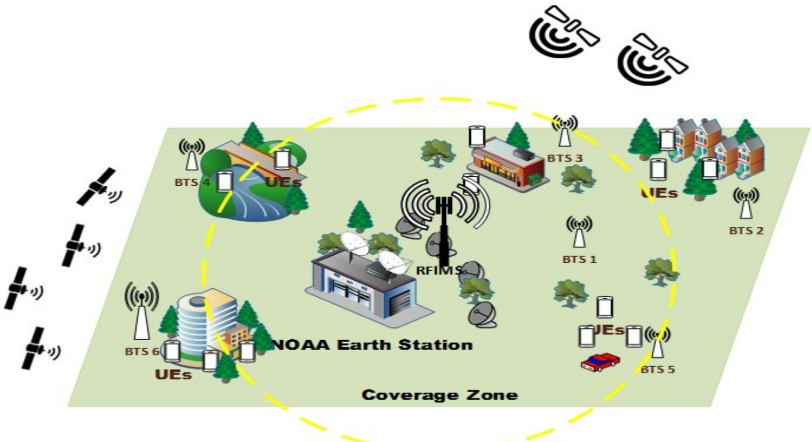
- Monitoring systems should identify events that cause interference to the incumbent user.
- An independent sensor might not detect exactly the event that caused the interference for the incumbent user or might detect several events that are registered as interference at the sensor but have no effect on the incumbent receiver.
- This suggests two things:
  - The monitoring systems need to be at least as sensitive as the system they are monitoring and also
  - The monitoring systems should have means to correlate the measured events at their sensors to the signals received at the incumbent users' receivers.
- Due to security concerns it might not be possible to have a direct RF signal path from NOAA's receivers to RFIMS at certain sites.

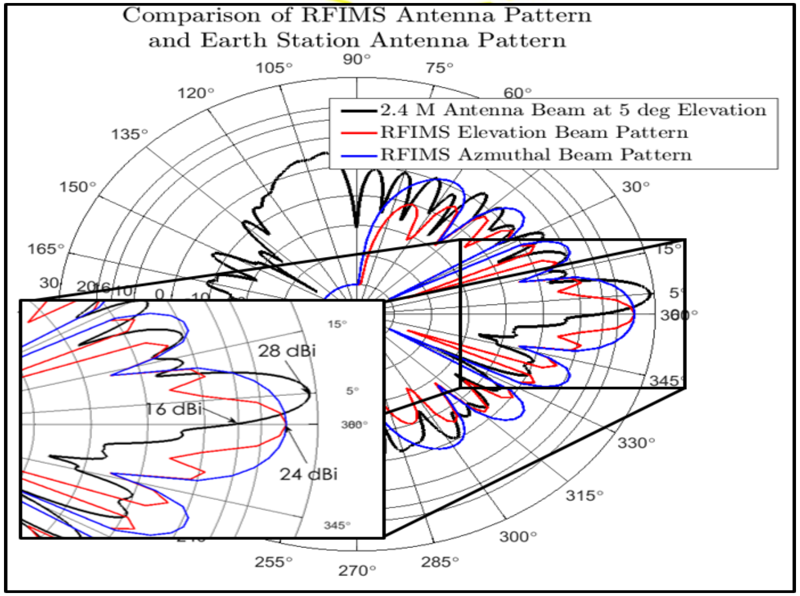
RFIMS Challenges: 5G, IoT, Future Systems?

- Studies and analyses conducted so far assume that the wireless carriers will deploy an LTE system in the AWS-3 bands.
- FCC did not restrict the technology that can be deployed within the AWS-3 band.
- Deployment of any new technology such as NB-IoT or 5G could drastically change effectiveness RFIMS.
- Moreover, the use of spectrum by NOAA for future operations could change, which in turn will affect the way spectrum sharing and monitoring is implemented.

RFIMS Design: Detecting Interference

- The RFIMS is deployed at the earth station and scans a coverage area using a cylindrical phased array antenna.
- This system is heavily dependent on the capability of the antenna.
- To sensitivity requirement, a cylindrical antenna was developed with 24.4 dBi of gain and a 1-dB beamwidth of 3.
- To detect a signal, the system requires 1 dB of SNR.
- This system only monitors 1675-1755 MHz.





RFIMS Design: Classifying and Identifying Interference

- After the detection, it will attempt to do classification and identification. It will need a 10 dB SNR to perform these functions.
- The system will use digital beamforming using individual columns on the detected signal to increase the SNR.
- Identification happens at two levels: one level is the direction of received signal and the other by extracting LTE protocol characteristics of the received uplink signal.
- This prototype could be built either on a fixed or transportable platform.

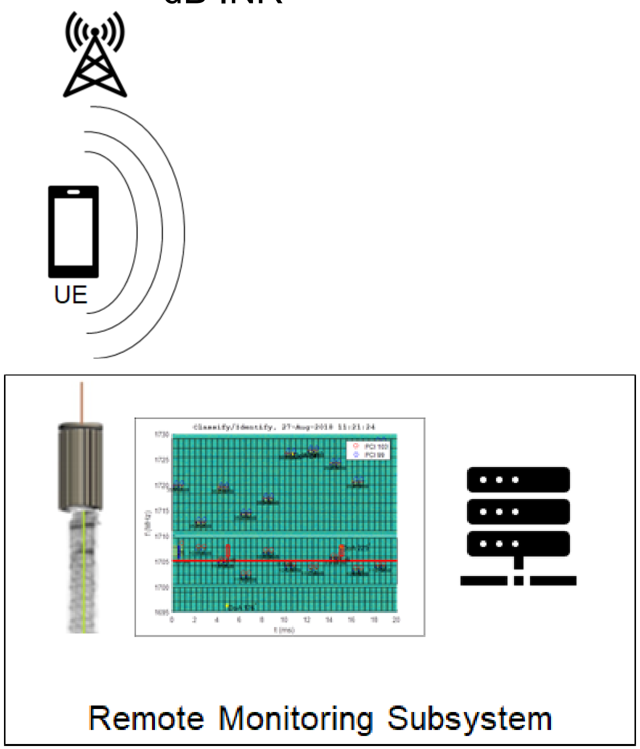
RFIMS Transportable Platform

RFIMS Operational Conecpt-RFI Event

Signal at the receiver ≥ -10 dB INR

RFIMS Operational Conecept- RFI Event

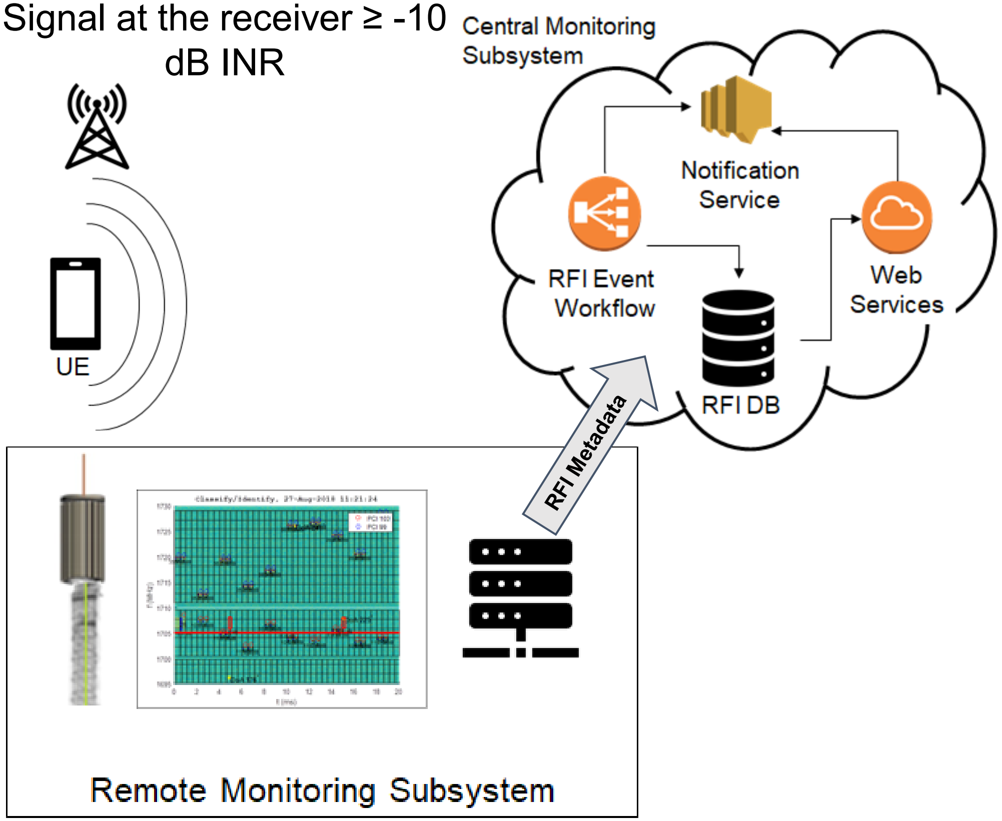
Signal at the receiver ≥ -10 dB INR



Detect ≥ -10 dB INR

RFIMS Operational Conecpt- RFI Event

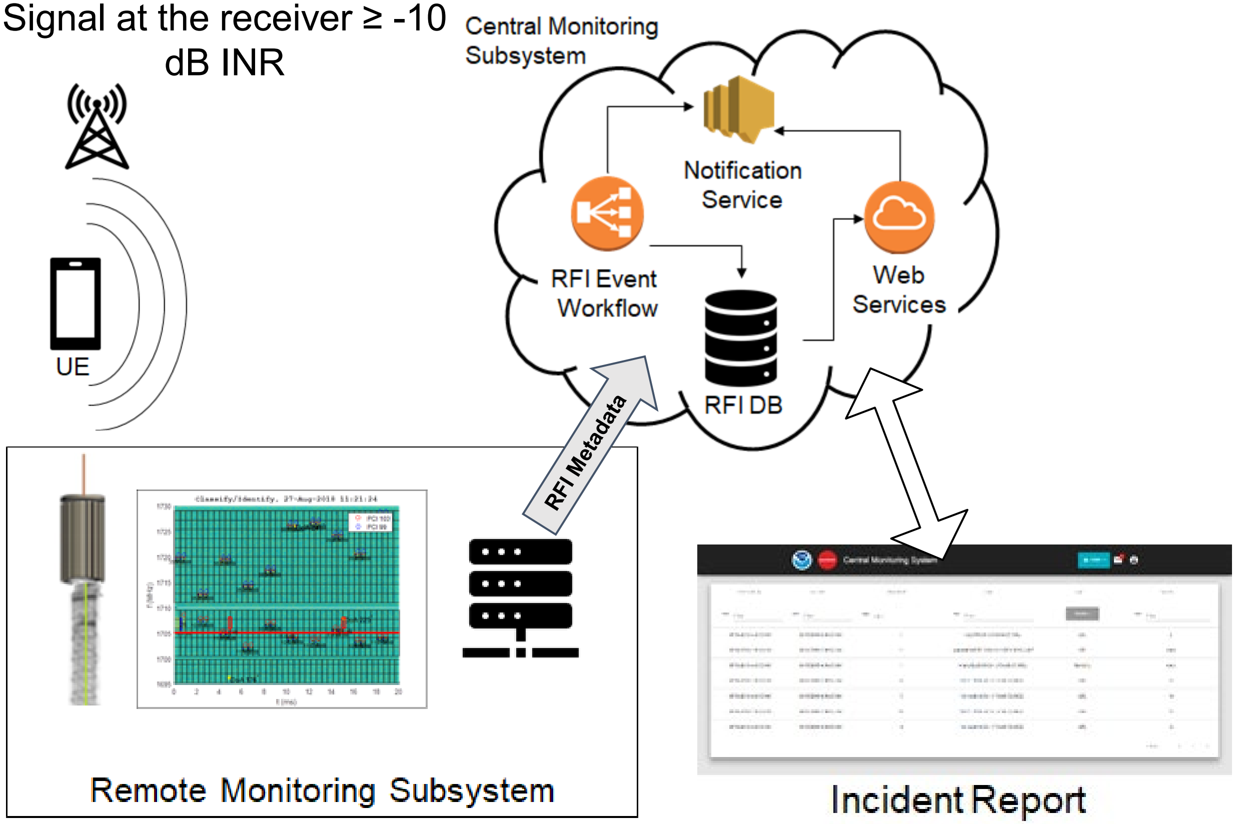
Signal at the receiver ≥ -10 dB INR



Classify LTE or Non-LTE

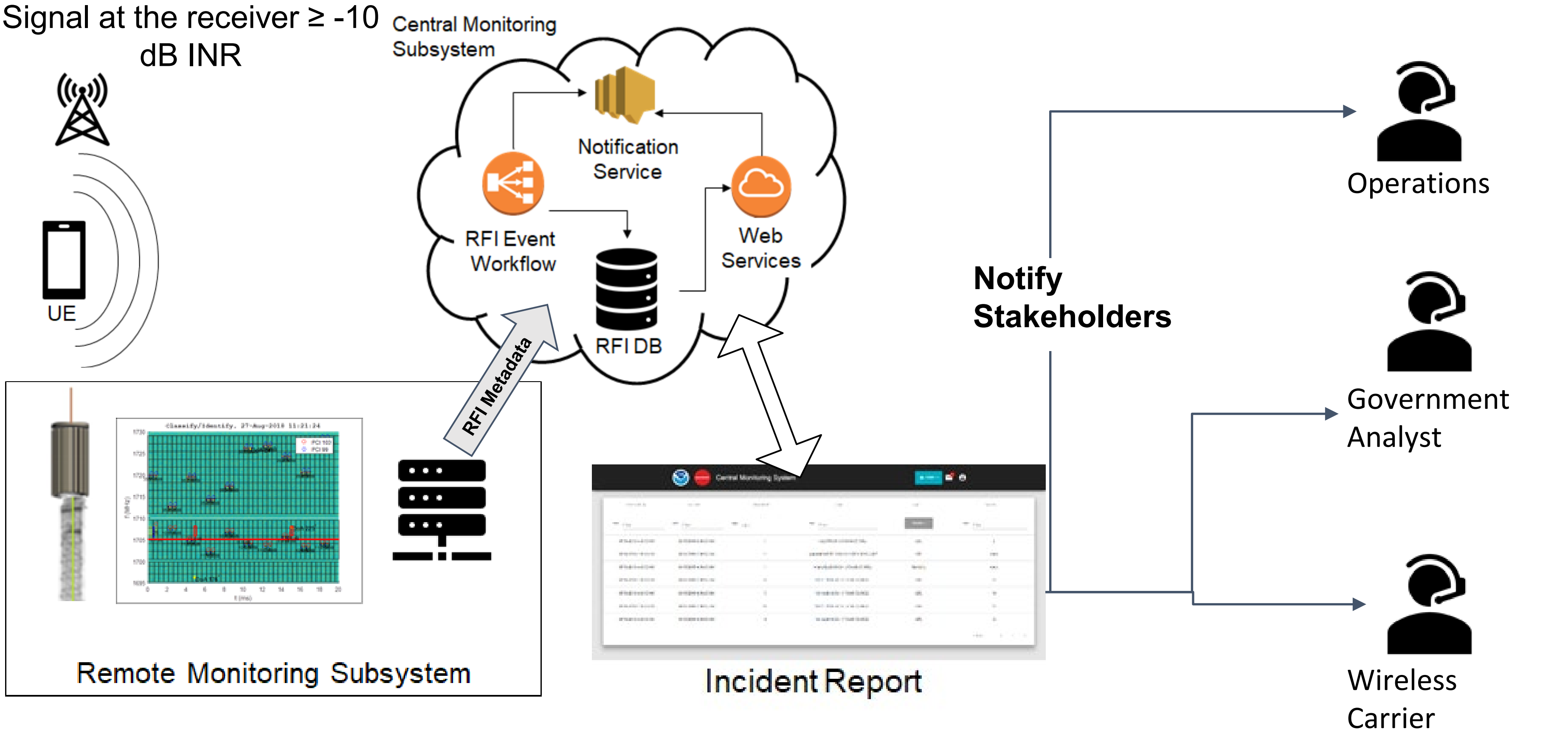
RFIMS Operational Conecpt- RFI Event

Signal at the receiver ≥ -10 dB INR

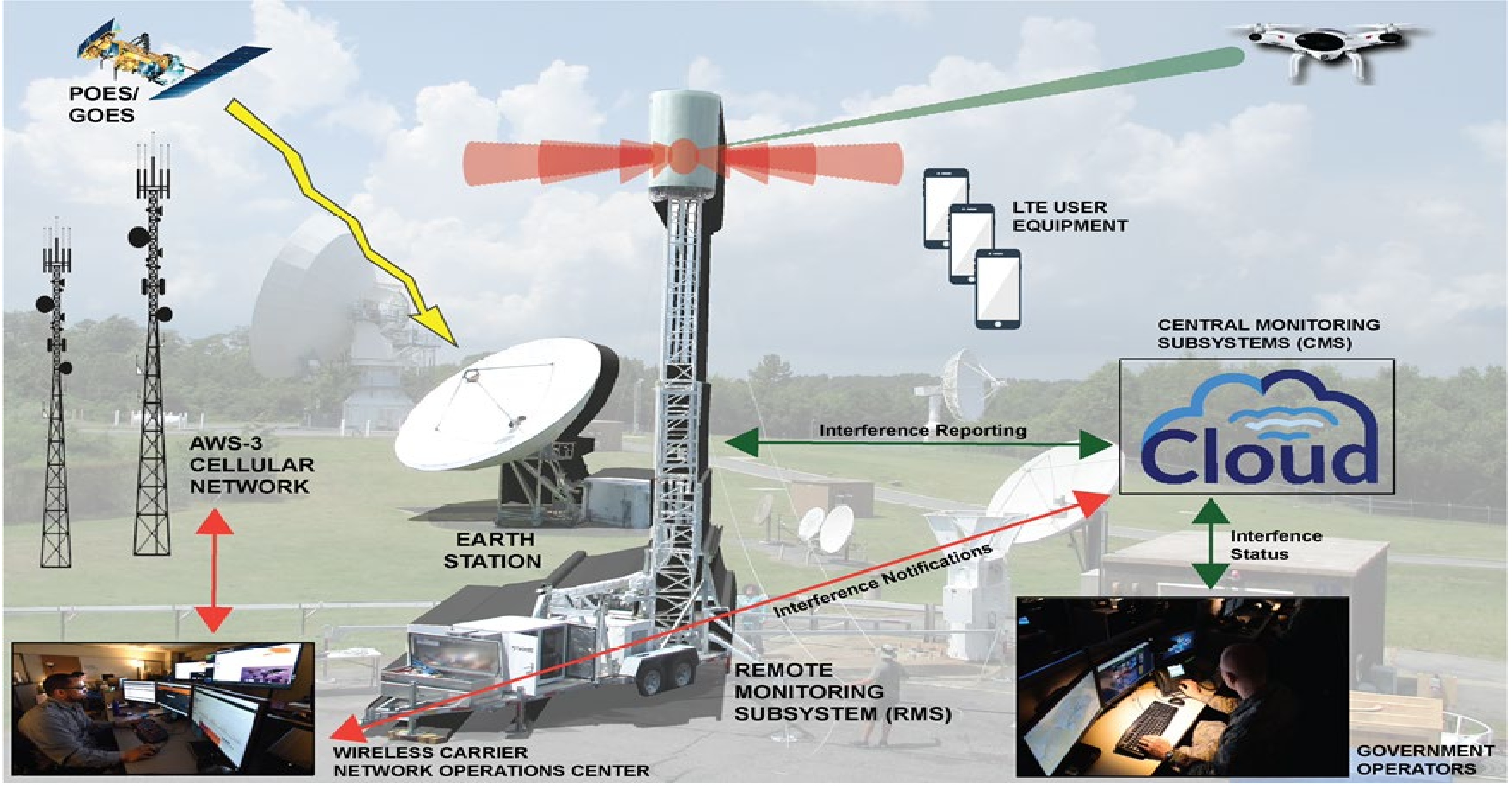


Identify LTE Tower and Sector

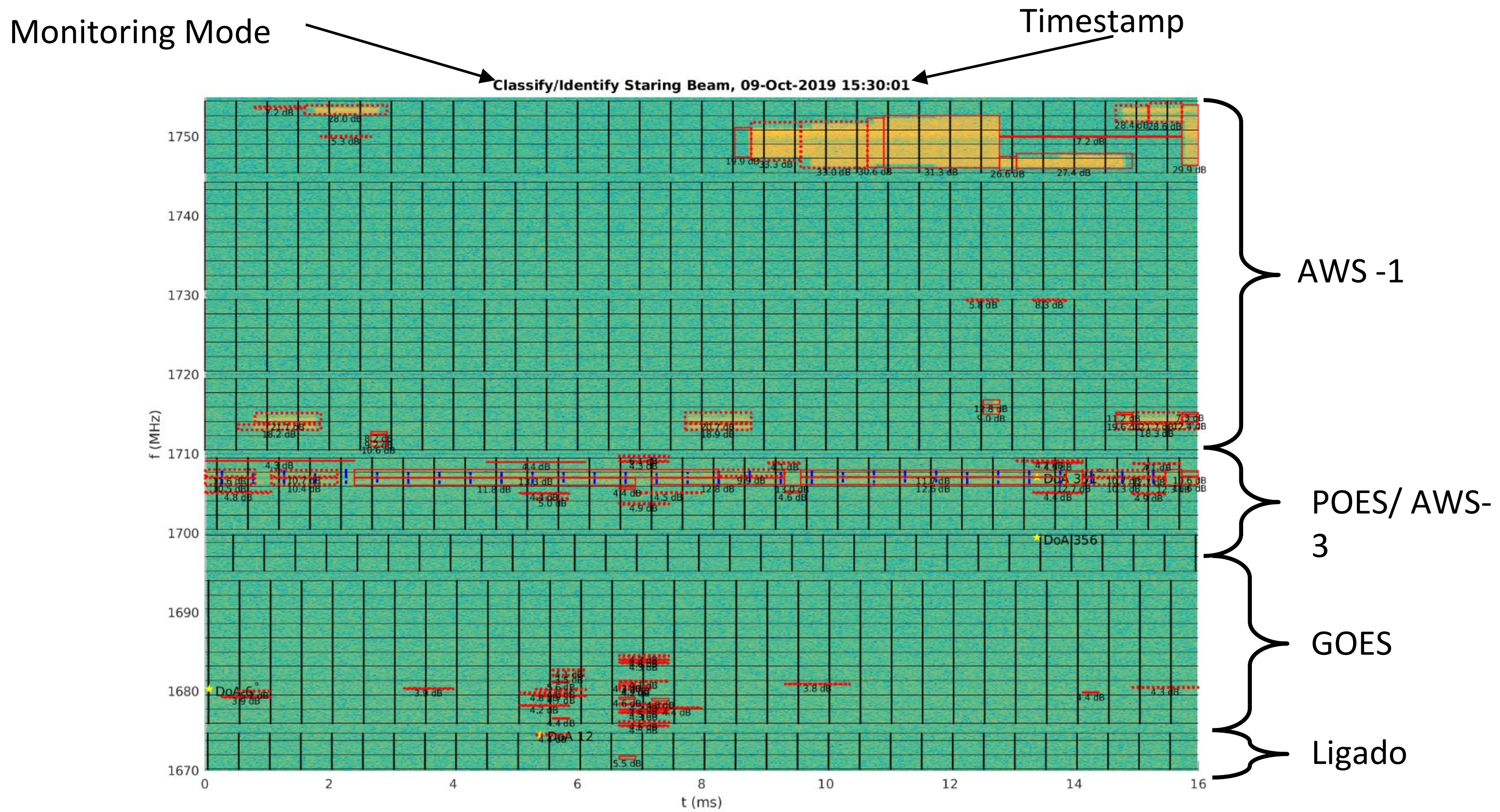
RFIMS Operational Conecept- RFI Event



RFIMS Operational View



Spectrogram - RFIMS Analysis Tool



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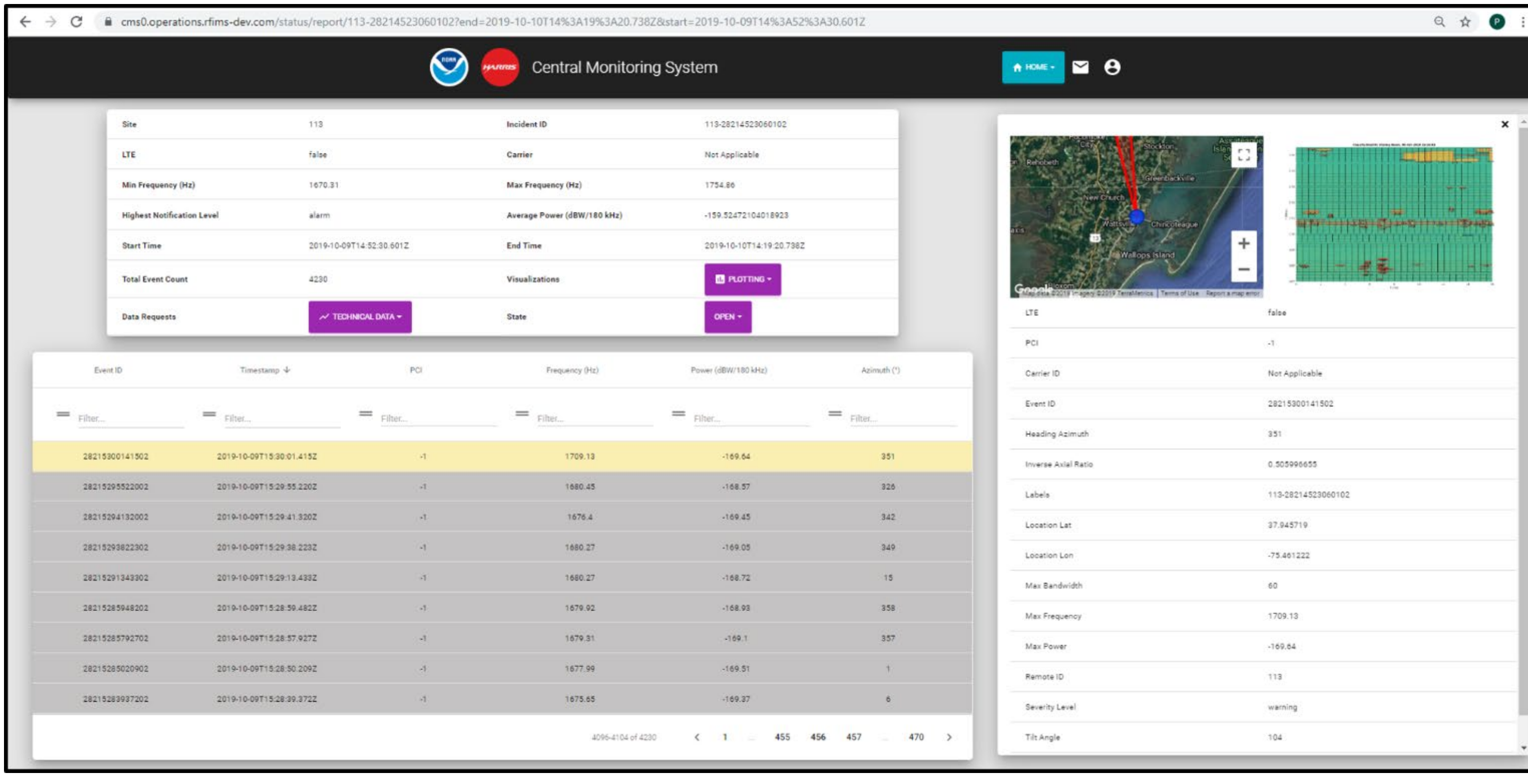
Central Monitoring System Interface



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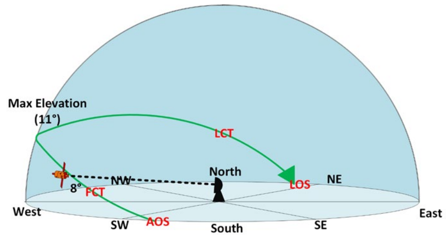
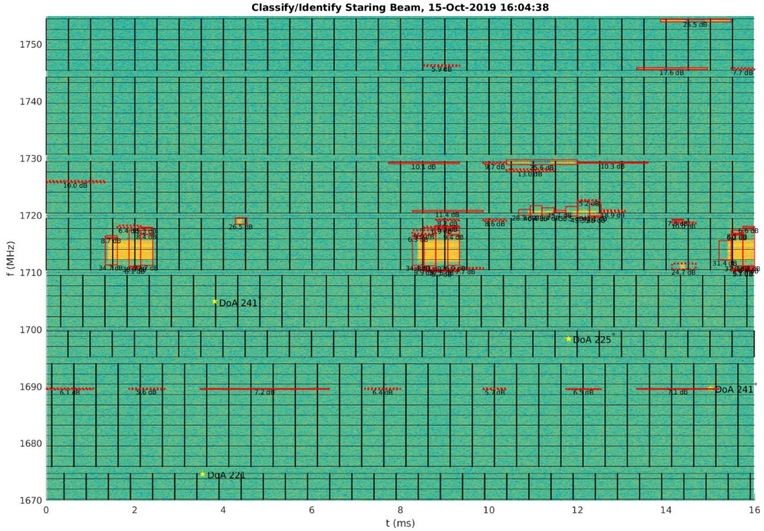
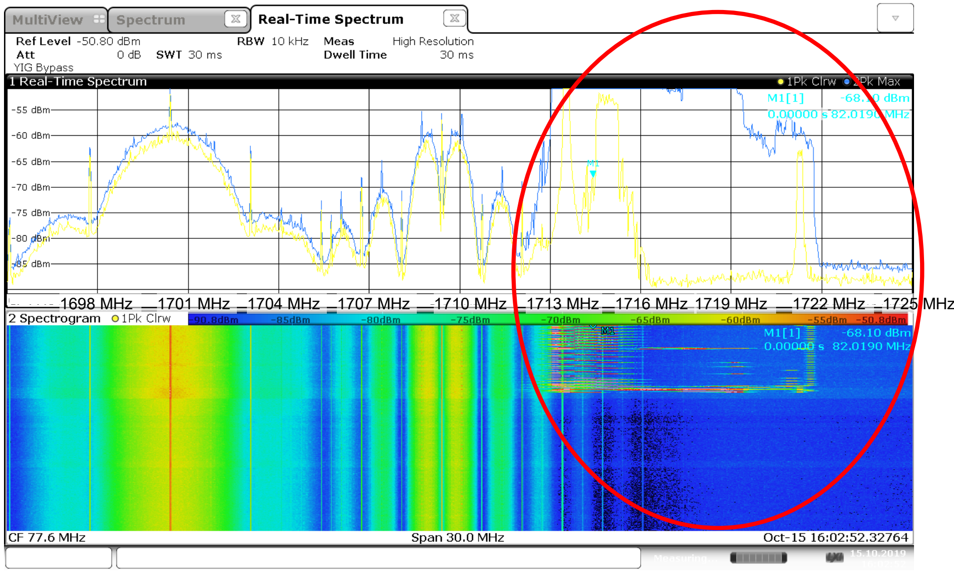
NOAA 18 RFI - 15 October 2019







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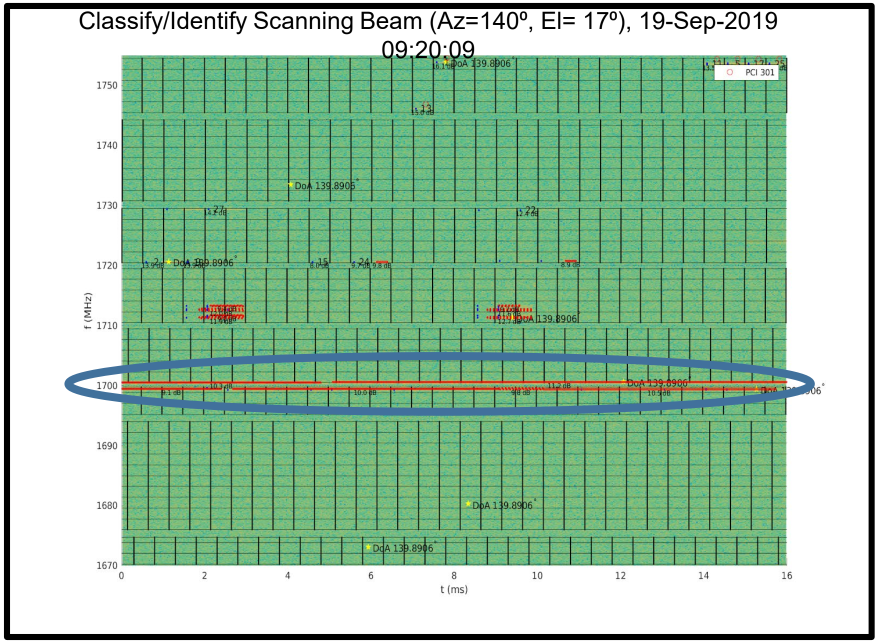
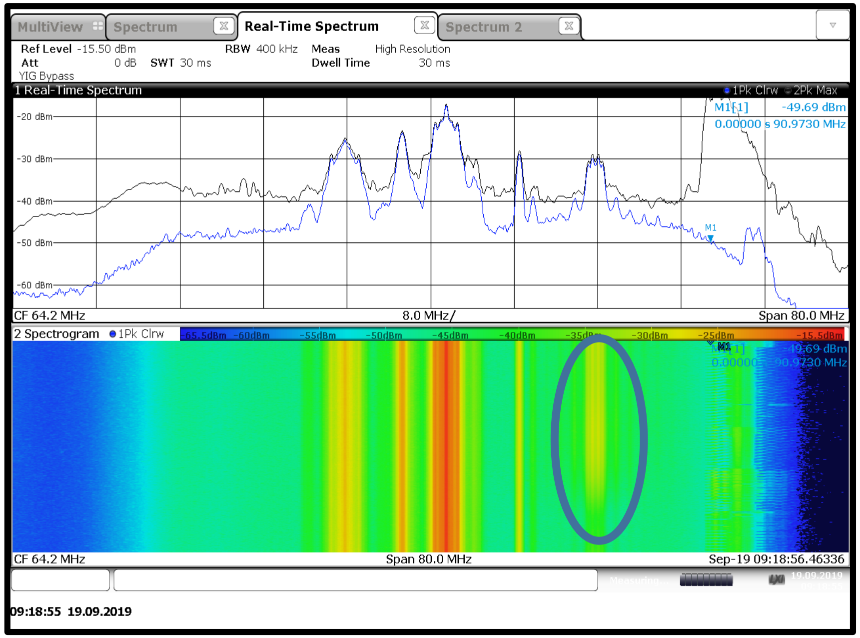
GOES-R Interference

- 140 degrees azimuth, 17 degrees elevation





What is next with RFIMS

- In June 2020 the first article of RFIMS will be delivered to NOAA's testbed at NTIA's Table Mountain facility for further testing and capabilities assessment.
  - Table Mountain facility is a radio quiet zone.
  - The facility is equipped with antennas and receivers that are normally found at NOAA's ground stations.
  - The facility will also house an emulated LTE network that operates its uplink at AWS-3.

Conclusion

- The RF environment for the weather satellite stations is a very unique and sensitive environment.
- Designing an RFIMS for this environment is very challenging.
- RFIMS solution is heavily dependent on its antenna capabilities but provide very robust solutions.
- The data provided by RFIMS can help operators and spectrum managers of the ground stations to better protect invaluable satellite data from being corrupted by RF interference.