Radio Frequency Interference Monitoring System for Weather Satellite Ground Stations: Challenges and Opportunities

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History

- The Middle Class Tax Relief and Job Creation Act of 2012 directed the Department of Commerce (DOC) to identify 15 megahertz (MHz) of Federal use spectrum between 1675 - 1710 MHz suitable for sharing with commercial wireless carriers
- 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.
- According to the FCC ruling the commercial wireless entities will share their uplink transmission from their user equipment (UE) in this band.
- In the DOC Transition Plan, NOAA identified 17 meteorological satellite Federal earth stations, within 15 *Protection Zones* that operate in the 1675 – 1710 MHz band.

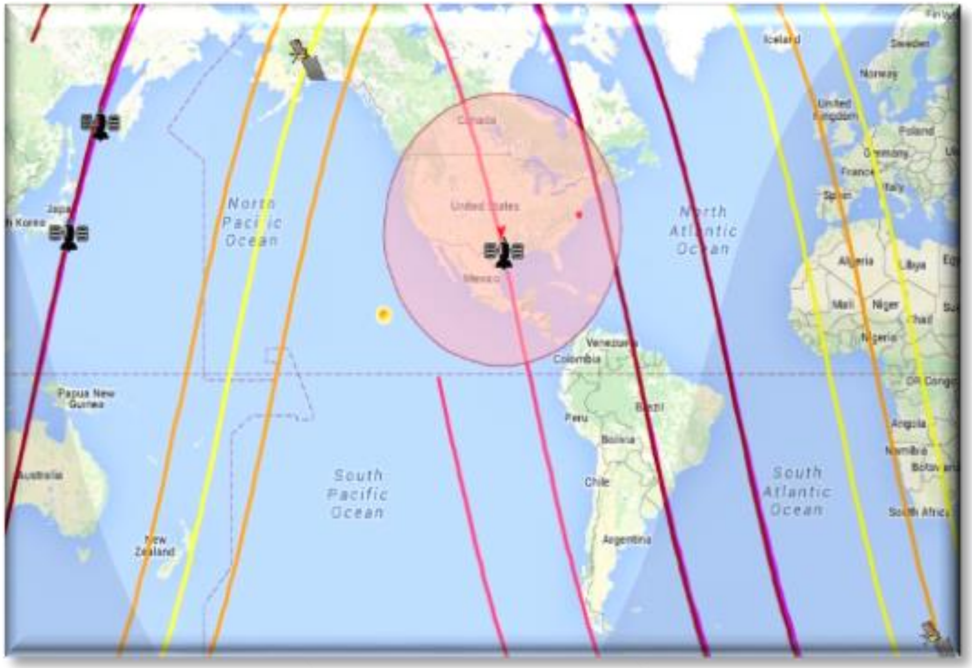
RFIMS Background

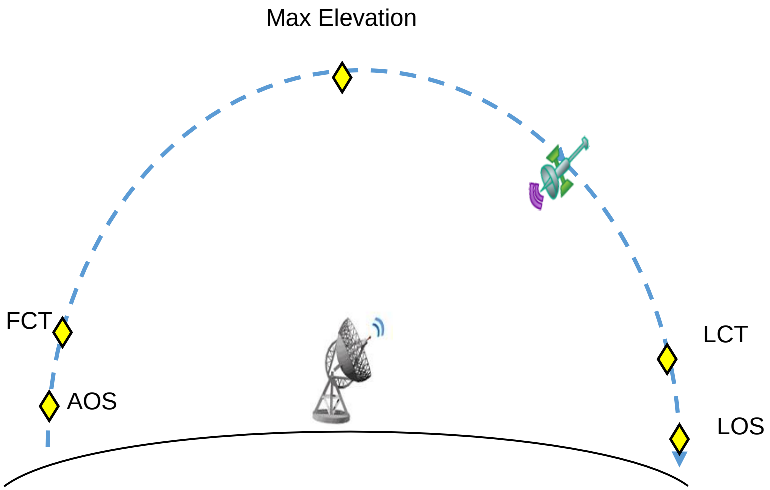
- The need for an interference monitoring system was identified in the National Telecommunications and Information Administration (NTIA), Commerce Spectrum Management Advisory Committee (CSMAC) Working Group 1 (WG-1)'s final report recommendations.
- In order to protect earth station communications, the Office of Satellite Ground Services (OSGS) within NOAA is executing a project and undertaking contractual action to implement a Radio Frequency Monitoring System (RFIMS) across NOAA's Federal earth stations.
- The RFIMS will enable government operators to:
  - Detect RF interference
  - Classify the nature of RF interference
  - Identify the source(s) of interference
  - Notify NOAA government operators and wireless carriers of interference RFIMS) across NOAA's Federal earth stations.

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.

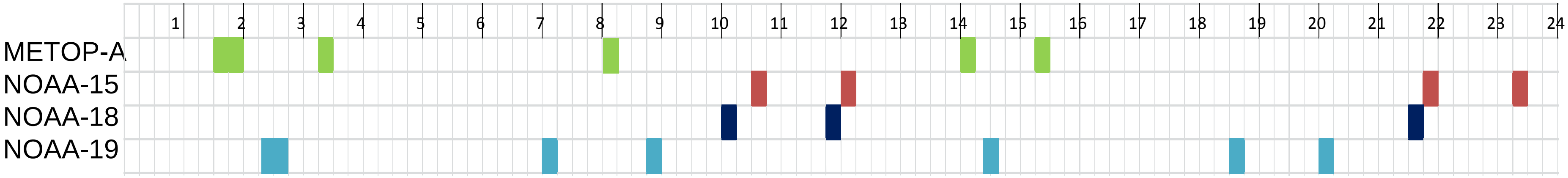
POES field of view and contact





Predicting polar satellite position

- Satellite orbits are defined using **two-line element sets** (**TLE**)
- TLE's list a satellite's orbital elements that define it's orbit, provides it's location in space at a given time (epoch), which can be used to predict it's position in the future.
- TLE's are routinely updated to account for planned orbit adjustments and changes in the orbit due to atmospheric drag
- 10-day pass plans are generated once per week, unless there are changes

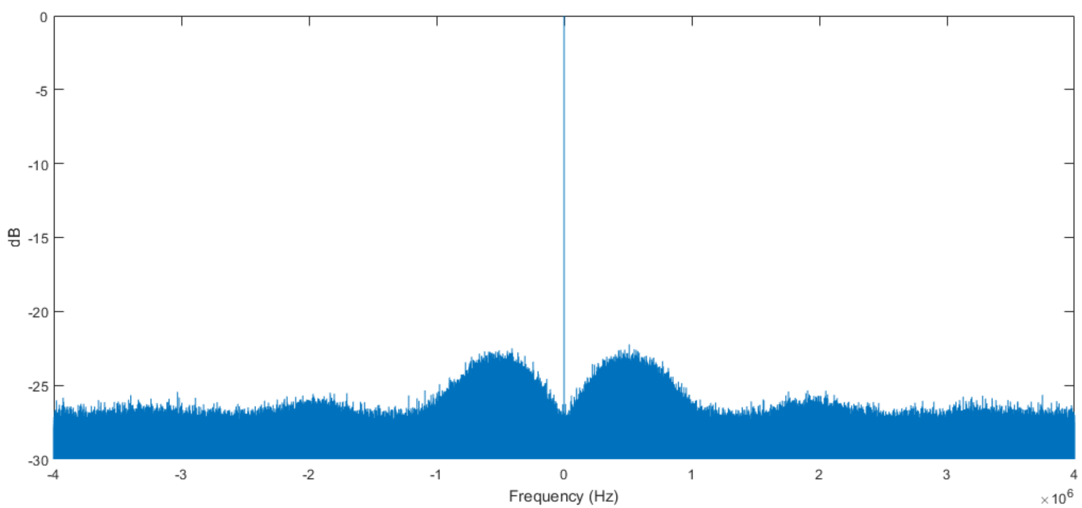


POES downlink signals

- POES satellites transmit three type of signals in the AWS-3 band: High Resolution Picture Transmission (HRPT), Global Area Coverage (GAC) and Local Area Coverage (LAC).
- HRPT is dedicated to real-time transmissions and is available to all local users on the ground.
- The LAC data are essentially the stored version of HRPT, played back at either two or four times the real-time rate, and are made available <u>ONLY</u> for centralized processing, which are usually command and data acquisition stations (CDAS).
- GAC data contains reduced resolution HRPT data. The overall data rate is one-tenth of the LAC data rate, allowing over 100 minutes of data to be stored on one tape transport. The GAC stream is for stored data only and is used to develop global data sets for centralized processing and analysis. It is not intended <u>ONLY</u> for CDAS. The reduced resolution of this format allows 100% recovery of the data even under worst-case blind-orbit conditions.

POES downlink signals characteristics

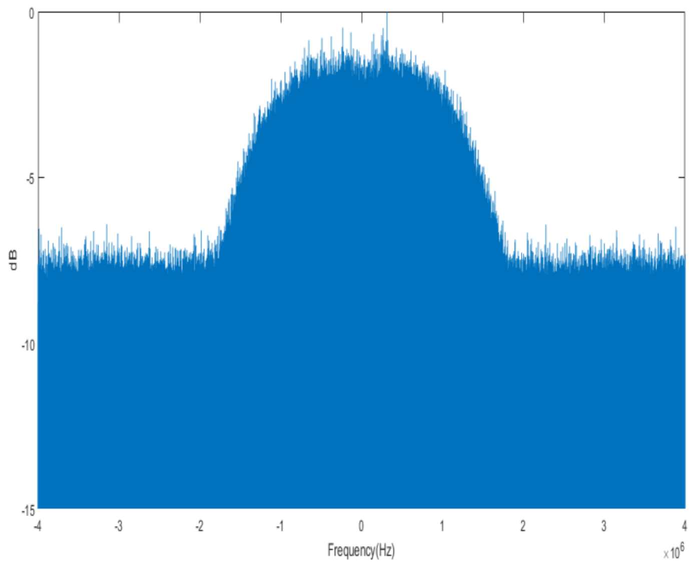
Signal Name	Center Frequency	Data rate	BW	Modulation	Coding
LAC	1698 MHz 1702.5 MHz 1707 MHz	1.33 Mbps or 2.66Mbps	5.32 MHz	Split Phase Modulated +/-67'	None
GAC	1698 MHz 1702.5 MHz 1707 MHz	1.33 Mbps or 2.66Mbps	5.32 MHz	Split Phase Modulated +/-67'	None
HRPT	1698 MHz 1702.5 MHz 1707 MHz	665.4 Kbps	2.66 MHz	Split Phase Modulated +/-67'	None



Baseband received HRPT signal at 10 dB SNR.

MetOp downlink signals characteristics

- Metop satellites transmit one signal in the AWS-3 band: Advanced High Resolution Picture Transmission (AHRPT).
- The Metop Direct Readout Service provides to local user stations the real-time transmission of data limited to the instantaneous sub-satellite observation. The data source is the satellite as it passes over the user's field of view
- The AHRPT frequency of Metop-A and Metop-B is:
  - 1) Prime 1701.3 MHz
  - 2) Backup 1707.0 MHz
- The AHRPT signal is QPSK-modulated with 4.5 MHz bandwidth. Unlike POES signals, the data transmitted through Metop satellites are convolutional coded.

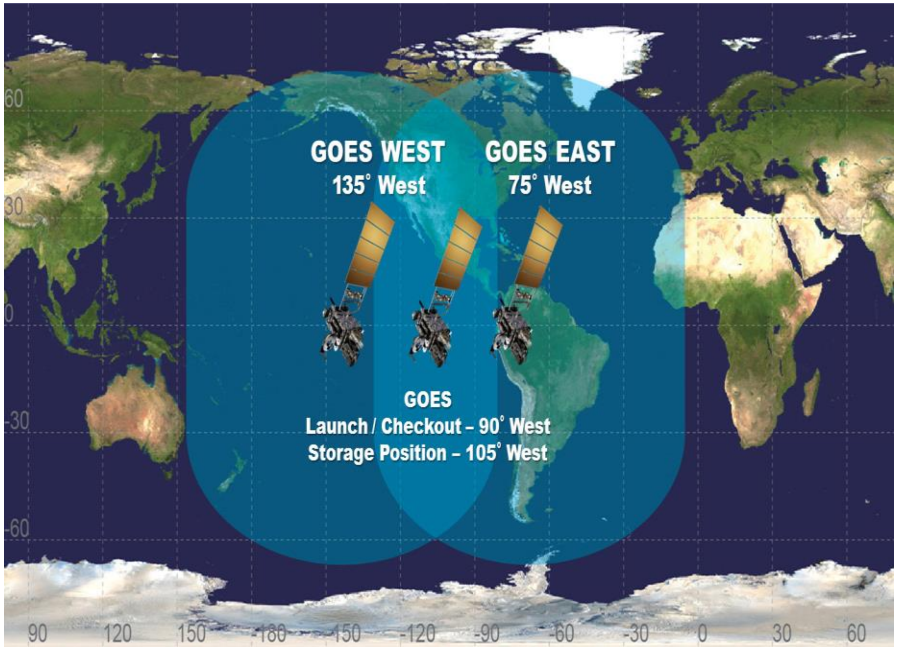


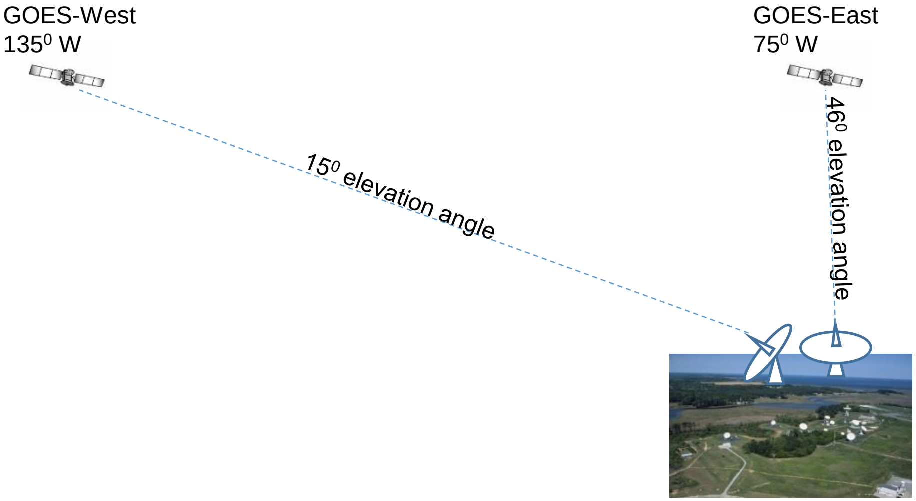
Baseband received AHRPT signal at 10 dB SNR

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 legacy satellites:
  - GOES-East
  - GOES-West
  - (GOES-Spare)
- GOES-R- The newest GOES series launched

GOES field of view and contact





GOES downlink signals characteristics

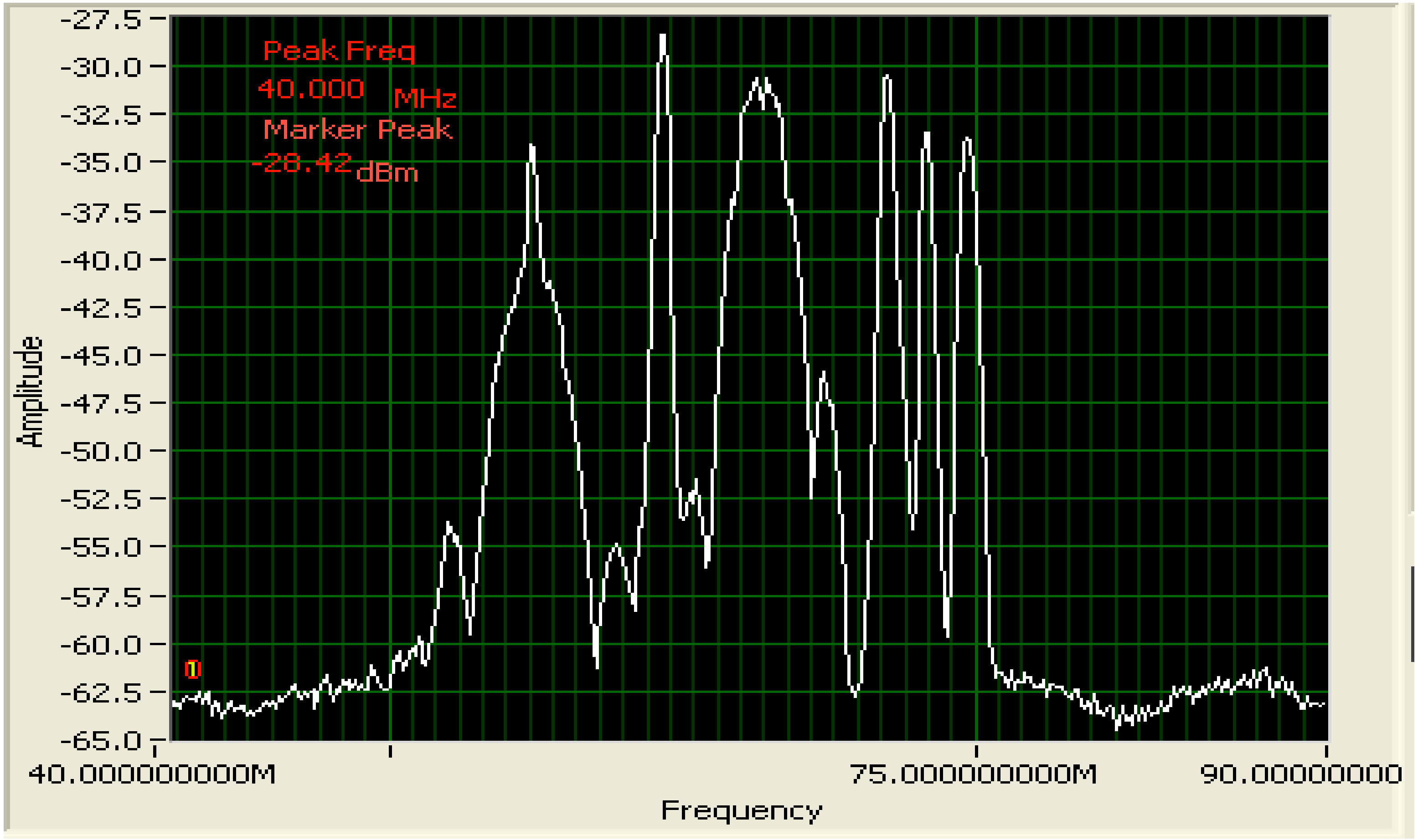
Signal Name	Center Frequency (MHz)	Data rate	BW	Modulation	Coding
SDL	1676	2.62 Mbps (Imager) 40 Kbps (Sounder)	5.2 MHz	UQPSK (QPSK 4:1)	None
MDL	1681.5	400Kbps	400KHz	QPSK	None
GVAR	1685.7	2.11 Mbps	4.22 MHz	BPSK	None
LRIT	1691	293Kbps	586KHz	BPSK	Rate 1/2 Convolutional code with Reed-Solomon (255,223) Outer code
EMWIN-N	1692.7	35.94Kbps	27KHz	OQPSK	Rate 1/2 Convolutional code with Reed-Solomon (255,223) Outer code
CDA Telemetry	1694	1 and 4 Kbps	16KHz	BPSK	None
DCPR	1694.5 or 1694.8	300 &1200 bps	475KHz	8PSK	Trellis Coded

Legacy GOES downlink signals at AWS-3 adjacent bands

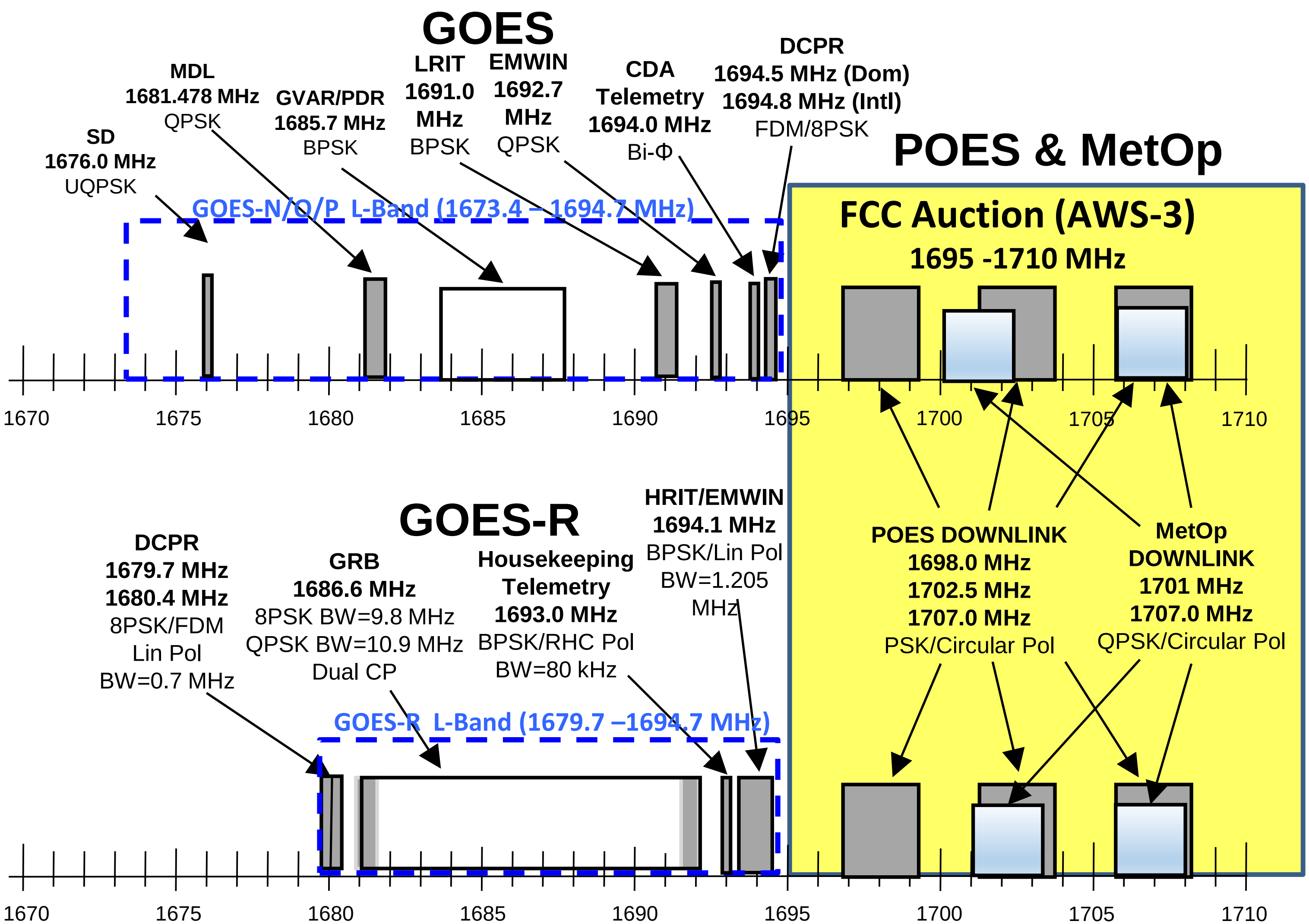
Signal Name	Center Frequency (MHz)	Data rate	BW	Modulation	Coding
DCPR	1680	300 &1200 bps	475KHz	8PSK	Trellis Coded
GRB	1686.6	15.5 Mbps	9.8 or 10.9 MHz	8 PSK or QPSK	LDPC
CDA Telemetry	1693	4 or 40 Kbps	80KHz	BPSK, NRZ-M	Reed-Solomon (252,220)
HRIT	1694.1	400.131 Kbps	1.205 MHz	BPSK, NRZ-M	Convolutional R=1/2, with Reed-Solomon (255,223)

GOES-R downlink signals at AWS-3 adjacent bands

Received Legacy GOES Signals



NOAA L-Band Frequency Use



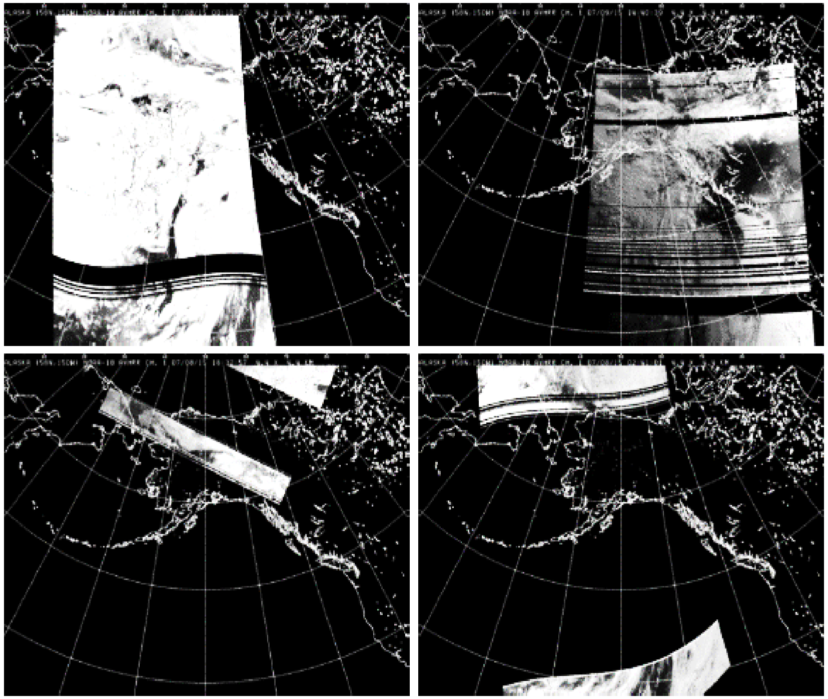
NOAA weather satellite ground stations

- 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

Effect of RF interference on NOAA signal reception

- RF interference can cause degradation in the reception of satellite downlink in two scenarios:
  - Loss of link margin
  - Front-end amplifier saturation.
- In the first scenario interference manifests itself as a noise source (either background noise or impulsive noise) and that will cause the signal to noise ratio (SNR) of the receiver to drop under a certain limit to cause data loss.
- In the second scenario interference signals emit enough power at front-end amplifier's frequency band that will cause the power amplifier at the receive antenna to saturate.



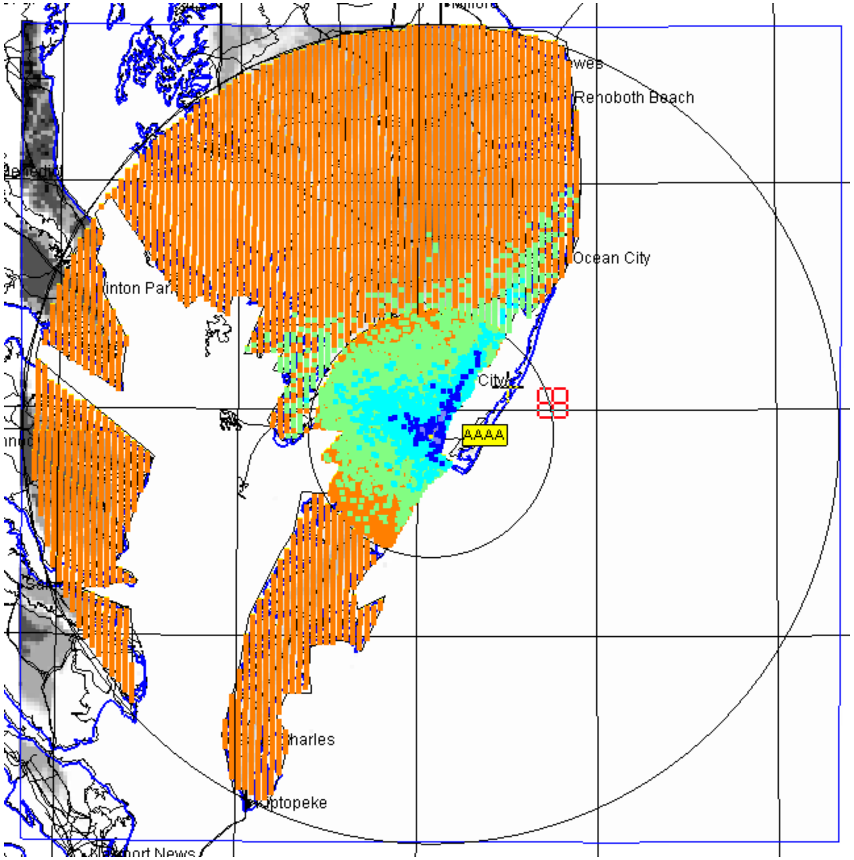
Protection Zones

- 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

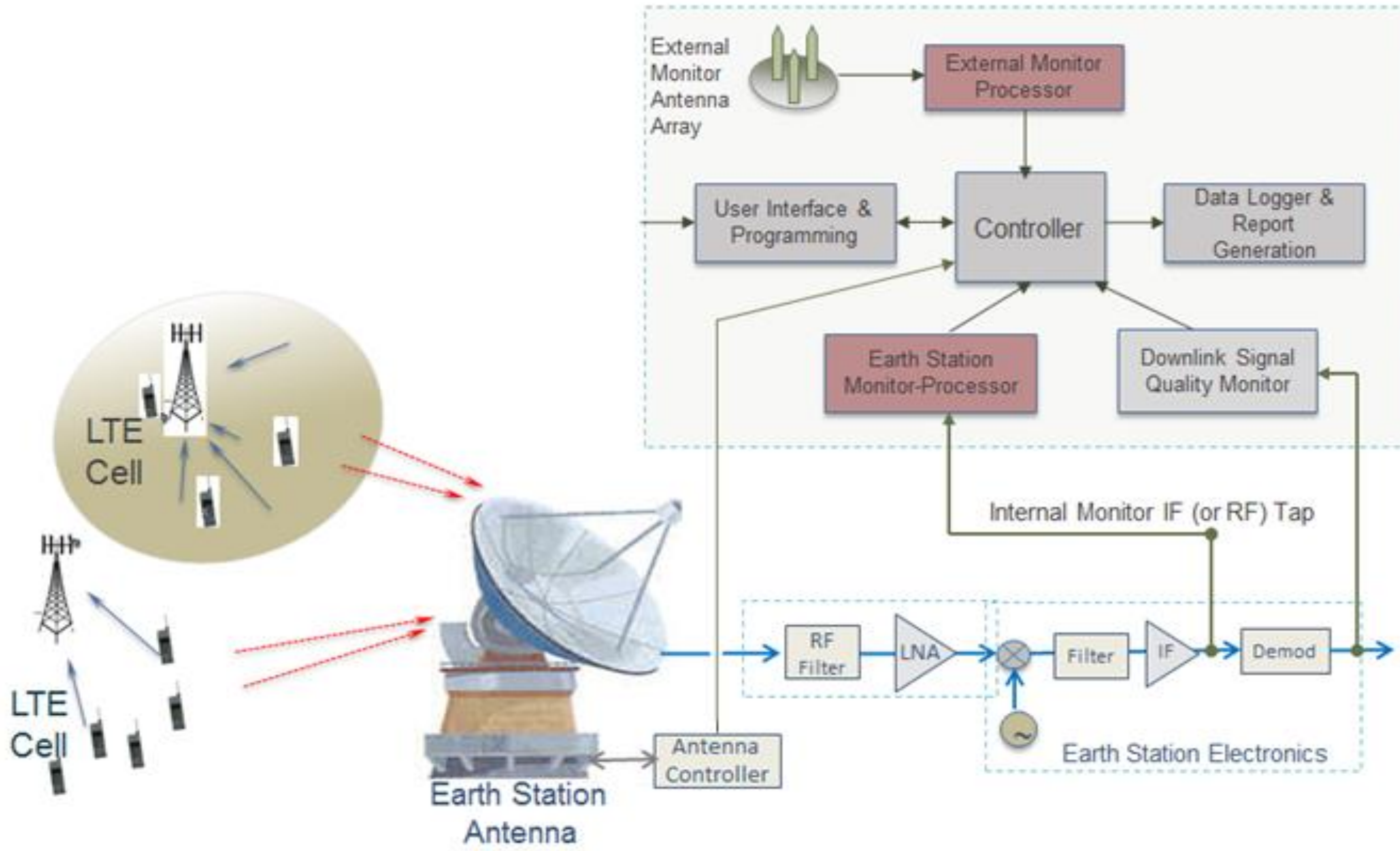
- Example of a Protection Zone
  - Wallops Island, VA
  - 30 Km Zone
- Once LTE-carriers have been issued licenses from the FCC
  - Must have build-out plans inside the Protection Zone approved through the Coordination Portal (website)
  - Outside the Protection Zone do not require coordination via the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



RFIMS Functional Capabilities

- The RFIMS must monitor the integrity of the signal of interest at the receiver, as well as the overall spectrum environment at the receive location, to detect the presence of interfering signals as well as informing the stakeholders. To do this, the system must perform the four basic monitoring functions:
  - **Detect -** The system should detect, in real-time, “events” in which the interference level lies at or above -10 dB Interference to Noise Ratio (INR) during NOAA’s earth station downlink reception.
  - **Classify** - The system should 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 should identify the source(s) of interference in real-time or as near to real-time as possible.
  - **Notify -** The system should notify NOAA operators, and potentially the wireless carriers, that wireless carriers are creating interference to NOAA.

RFIMS Notional Block Diagram

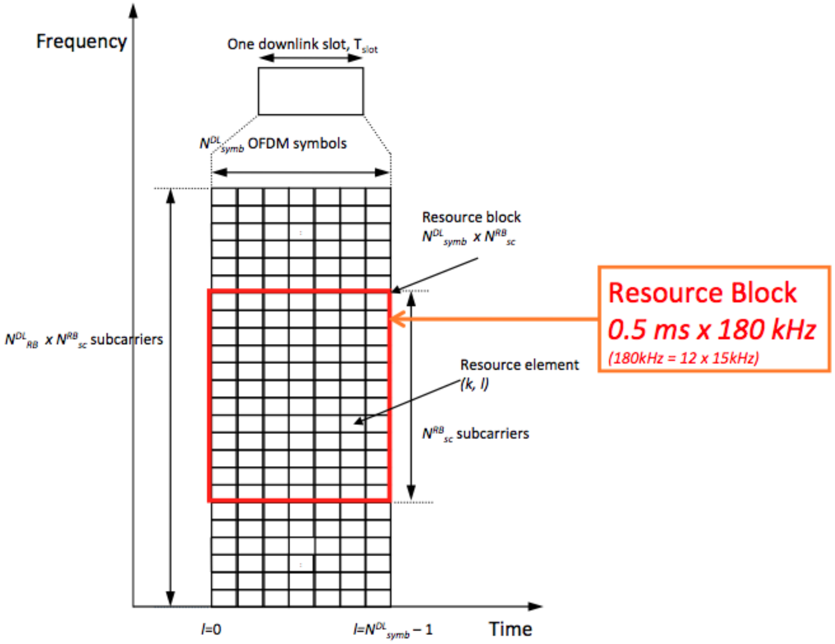


RFIMS Challenges: Detection (1)

- For a RFIMS detector to detect an interference event at -10dB INR, it needs to be more sensitive than NOAA receive system.
- Some NOAA antennas have ~45 dB of gain and that makes the design of RFIMS very complicated.
- While the polar satellites are transmitting signals in AWS-3 band, their signal power will be much stronger than the aggregate LTE uplink transmission.
- CSMAC WG-1 in assumed that LTE UE uplink is always transmitting signal at 100% power using all resource blocks!!

RFIMS Challenges: Detection (2), LTE characteristics

- 3GPP standard (Release 8): LTE
  - Tx bandwidth: 1.4 – 20 MHz
  - Peak data rate: 100 Mbps DL / 50 Mbps UL
  - Multiple access scheme: OFDMA DL / SC-FDMA UL
    - Flexible resource (time and frequency) allocation
    - Dynamic resource allocation (DRA) to avoid interference
  - Power control and link adaptation
  - Support for both FDD and TDD
  - Advanced MIMO spatial multiplexing techniques
- What is resource?
  - The basic time-frequency unit is the resource block (RB)
- The scheduler determines dynamically, each 1 ms, which mobiles are supposed to receive/transmit data on the uplink channels

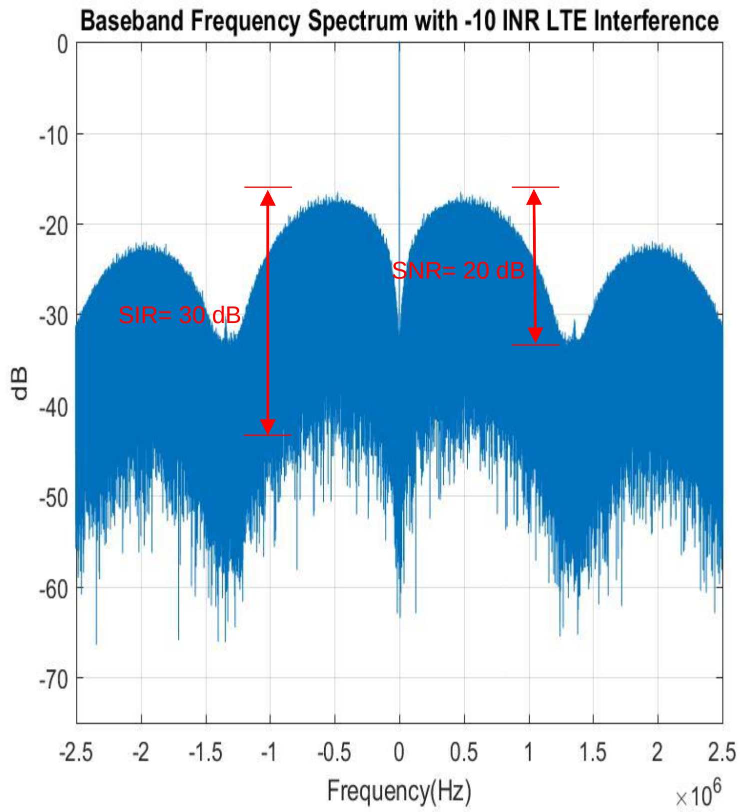


RFIMS Challenges: Detection (3), LTE Configuration

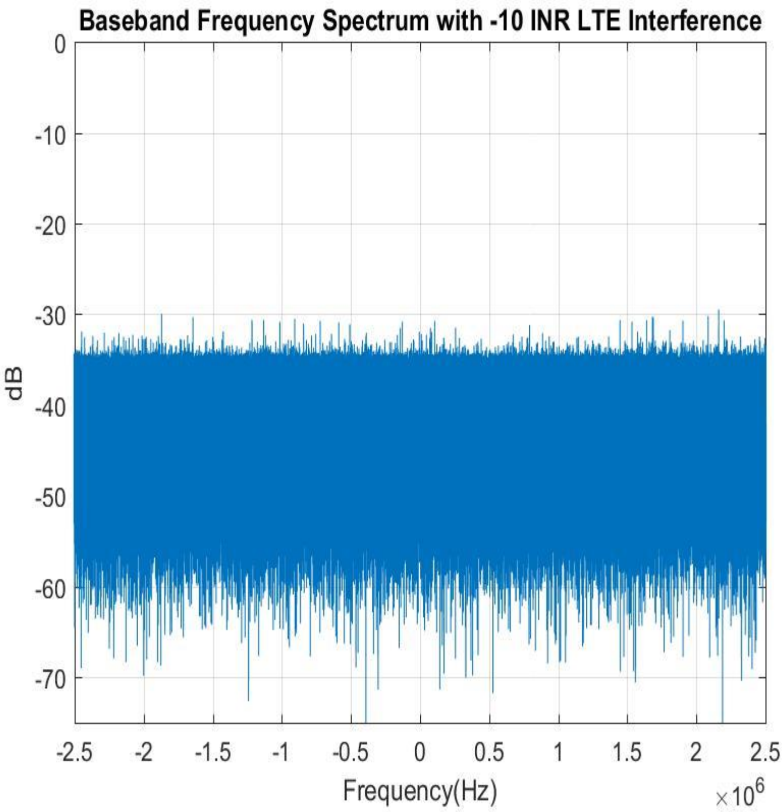
- LTE supports scalable bandwidth from 1.4 MHz to 20 MHz in steps of 180 kHz (resource block channel spacing)

Channel Bandwidth	Number of Usable Subcarriers	Occupied Bandwidth	Number of Physical Resource Block (PRB)	**Number of UE / sector**
1.4 MHz	72	1.08 MHz	6	
3 MHz	180	2.7 MHz	15	
5 MHz	300	4.5 MHz	25	**3**
10 MHz	600	9 MHz	50	**6**
15 MHz	900	13.5 MHz	75	9
20 MHz	1200	18 MHz	100	12

RFIMS Challenges: Detection (4), Presence of downlink signal



With NOAA downlink signal



Without NOAA downlink signal

RFIMS Challenges: Classification and Identification

- The sporadic and fast changing nature of LTE uplink signals makes classification and identification extremely difficult.
  - On top of a very sensitive receiver, due to -10 dB INR requirement, RFIMS will need complex signal processing algorithms with large integration time to classify the signals.
- The received interference at NOAA earth station will most likely be due to aggregate interference caused by several UEs from different directions.
- Classifying & Identifying the aggregate uplink transmission is complicated for several reasons:
  - It is difficult to measure aggregate power when multiple UEs may be present or disappear in a highly random, sporadic, transient, or overlapping manner.
  - The UE signals received at the NOAA terminal will be time misaligned and this will make these signals look more like noise than actual LTE signals.
  - Geolocating/direction finding of aggregate signals is non-trivial

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.

RFIMS Challenges: Establishing Incumbent Receivers’ Sensitivity

- Before developing any policies and rules for the monitoring systems, a thorough and detailed analysis of the sensitivity of the incumbent users is required.
- Setting too restrictive monitoring and enforcing policies will make the systems in the spectrum sharing scheme impractical
- Setting too liberal policies will leave the incumbent legacy users vulnerable.
- Knowing the interference threshold above which the quality of the incumbent users’ services degrades will be an invaluable asset to set the spectrum sharing policies that will both protect the incumbent users and are achievable.
- This threshold most likely will be different for each site.

Conclusion

- The RF environment for the weather satellite stations is a very unique and sensitive environment.
- Uplink LTE signal characteristics are sporadic and hard detect, classify and identify.
- The incumbent systems need to be characterized before making a policy for spectrum sharing and monitoring.
- Thorough analysis needs to take place **before** policy making and planning spectrum monitoring systems in order to enable a safe spectrum sharing scheme between these system and commercial wireless systems.