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Enhancing Satellite Systems with Space Domain Awareness Capabilities

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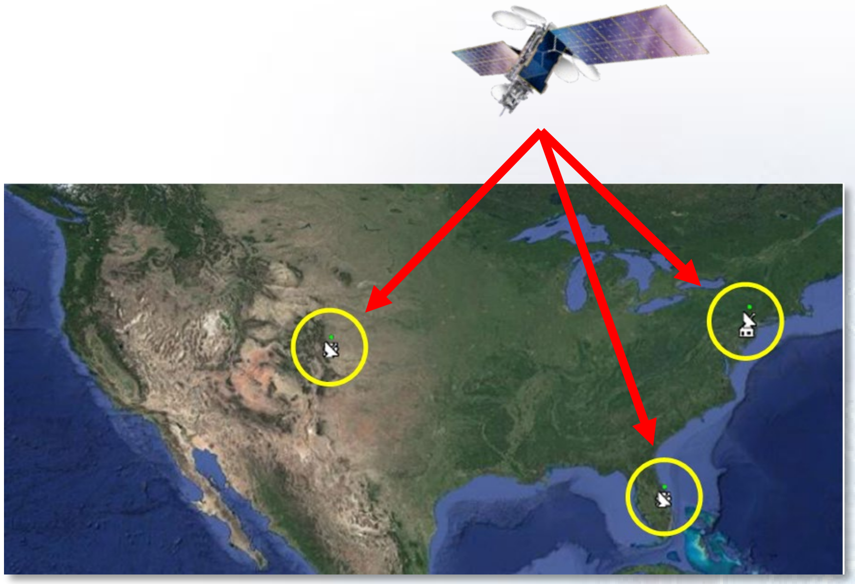
Introduction

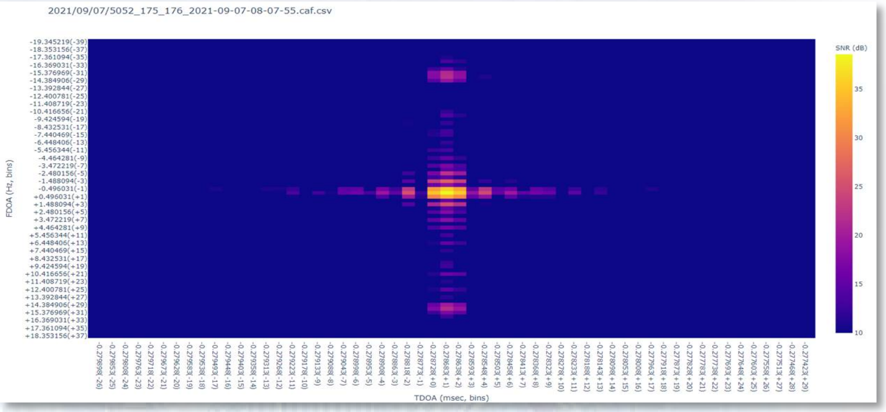
- Space Domain Awareness (SDA) functions are critical infrastructure items for all satellite systems
  - Satellite Position and Maneuver Detection via Passive RF Ranging
    - Detection and Confirmation
    - For the Ground Station's (GS) satellite(s) and their neighbors in space
  - Specific Emitter Identification
    - Identification of Radio Frequency (RF) transmitters
  - Signal Survey and Characterization
    - Accidental and Purposeful Electromagnetic Interference (EMI)
    - Transmission plan adherence
  - Signal Geolocation
    - Locate sources of EMI to assist in resolution
- These are all affordable capabilities that can be included in GS without architectural changes, since alerts, data and services are commercially available.

Passive RF Ranging as an SDA Augmentation

Attribute	EO	GBR	PRFR
Night-time operations	🟢	🟢	🟢
Daylight operations	🟡	🟢	🟢
Cloudy operations	🔴	🟢	🟢
Satellite with sunshades / dark paint	🟡	🟢	🟢
Discriminate satellites of same size and shape	🟡	🟡	🟢
Discriminate satellites very close together	🟡	🟡	🟢
Supports Specific Emitter Identification (SEI)	🔴	🔴	🟢
GEO Satellites	🟢	🟡	🟢
LEO Satellites	🟢	🟢	🟢
Satellite never emits RF signals	See Above	See Above	🔴

Passive RF Ranging Overview





❶ Receive & digitize normal signals

- SATCOM, Telemetry, C2, Beacons
- At least 3 sites, significantly separate, and in “triangular” form
- Send digital I/Q data to a central processing location

❷ Repeatedly compute TDOAs & FDOAs

- For all PRFR site pairs
- Using Cross-Ambiguity Function (CAF)

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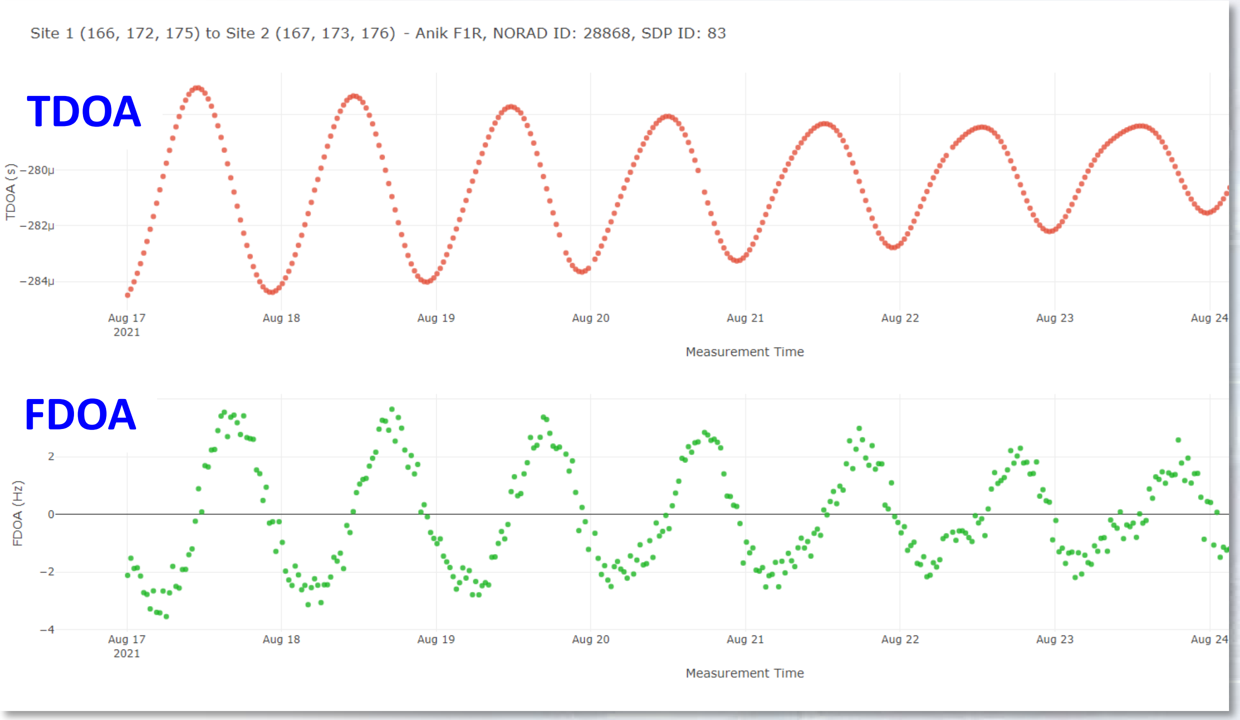
Passive Ranging Overview

From CAF processing:



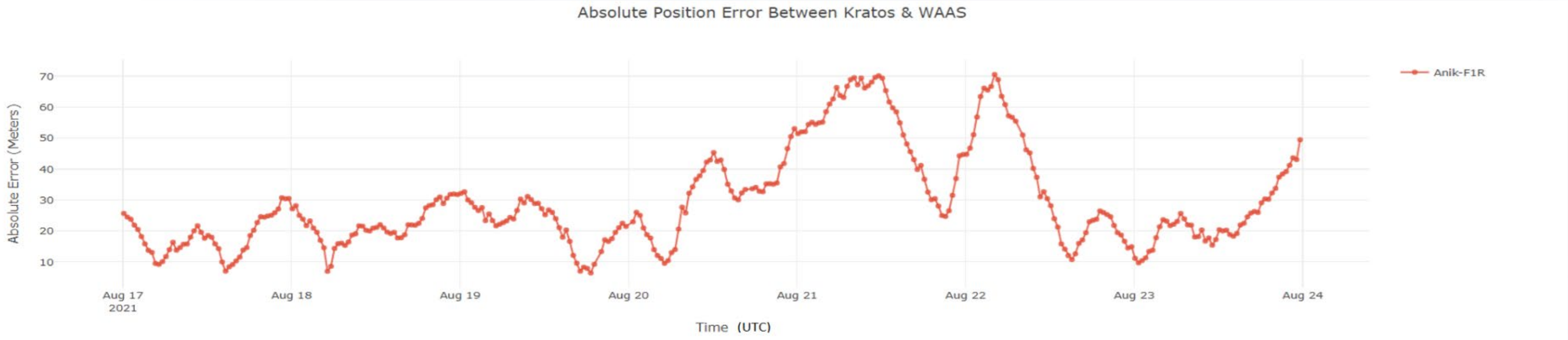
❸ Orbit Determination (OD)

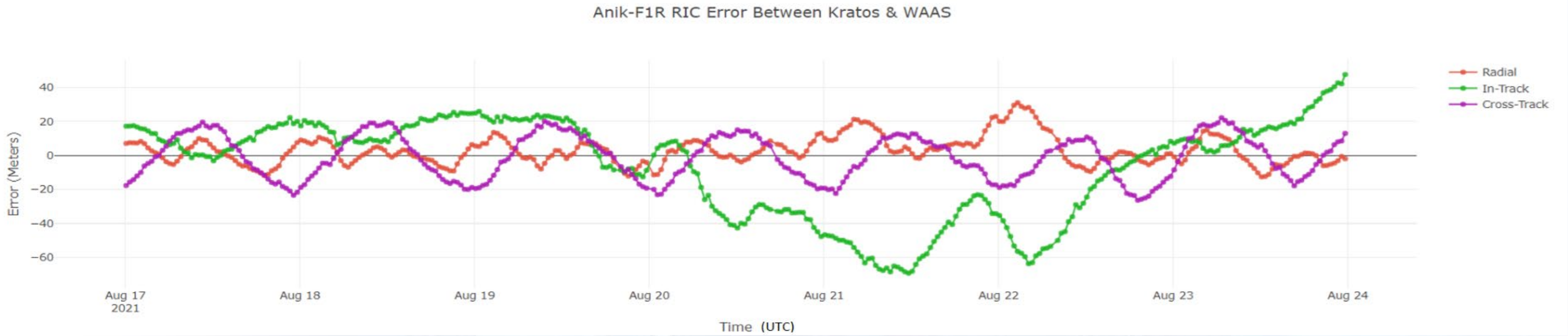
- Adjust for Maneuvers
- Batch Least-Squares (BLS)
- Unscented Kalman Filter (UKF)

❹ State Vectors (position)

For more detail, see *Geosynchronous Satellite Maneuver Identification and Characterization using Passive RF Ranging.* A. Beer, K. Simon, Kratos Defense.

PRFR High-Accuracy Position Determination





Truth Position = GPS-based Wide Area Augmentation System (WAAS). Measured Position = Kratos Global Sensor Network (KGSN) PRFR.

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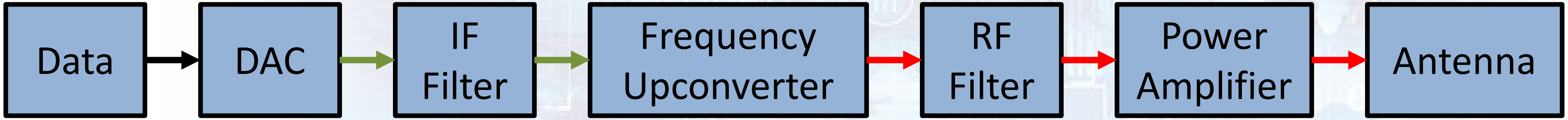
Specific Emitter Identification Overview

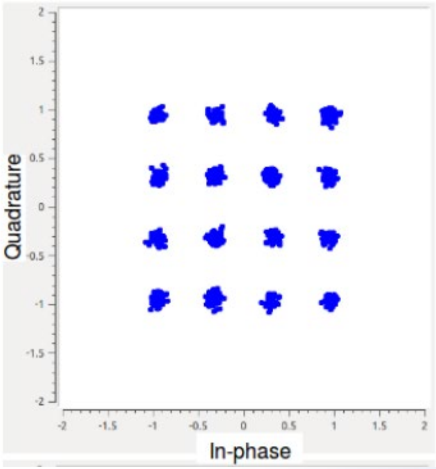
Basic high-level transmit chain:



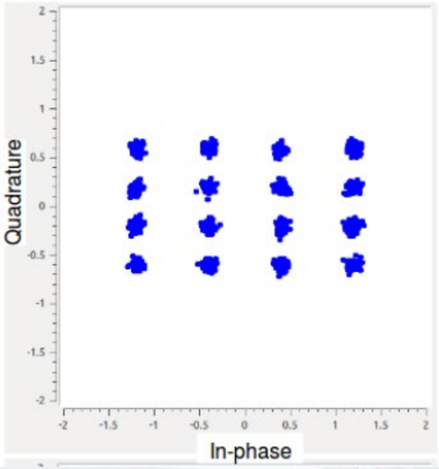
- Each of these components impacts the transmitted signal, even very slightly
- Phase imbalance and gain imbalance are typical RF fingerprints observed in the digitized I/Q data

Two RF Fingerprints: Phase and Gain Imbalance

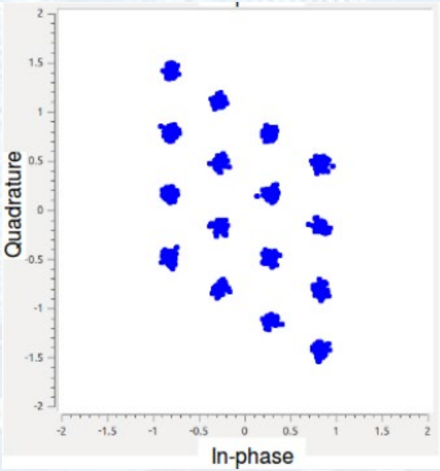
Transmitter Type 1
0^{o} Phase Imbalance
0 Gain Imbalance



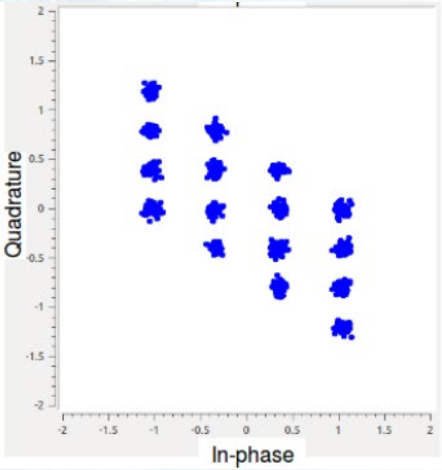
Transmitter Type 2
30^{o} Phase Imbalance
0 Gain Imbalance



Transmitter Type 3
0^{o} Phase Imbalance
0.9 Gain Imbalance



Transmitter Type 4
30^{o} Phase Imbalance
0.9 Gain Imbalance



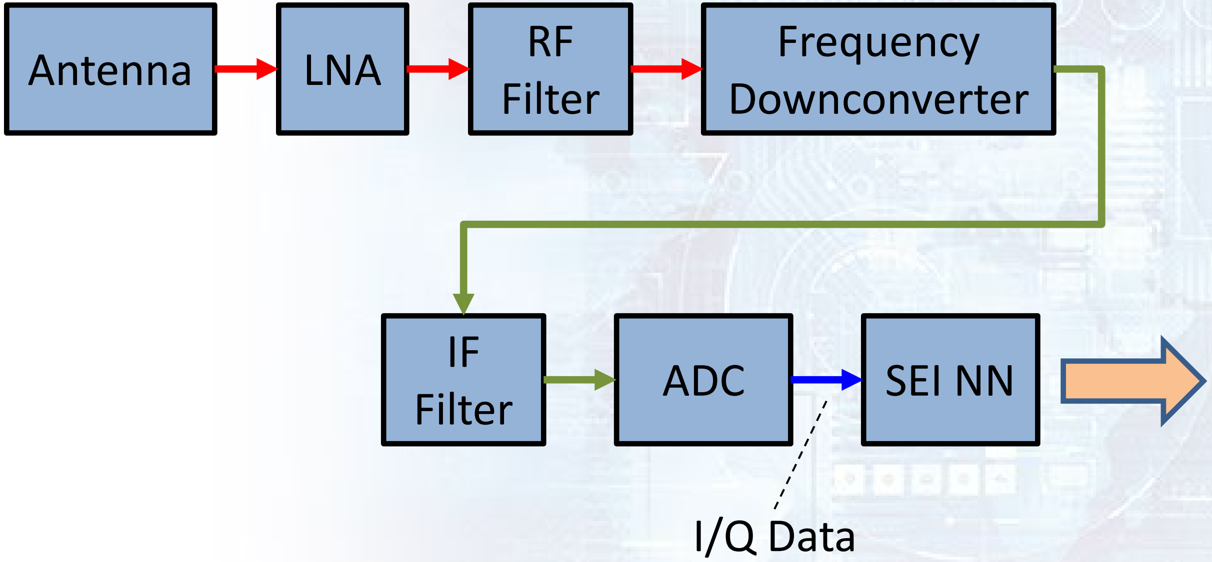
[1] *Specific Emitter Identification Using Convolutional Neural Network-Based IQ Imbalance Estimators.* L.J. Wong, W.C. Headley, A.J. Michaels, IEEE Access.

Current and Emerging SEI Systems

- **Current SEI systems**
  - SME involvement, often manually, to evaluate signal features under narrow circumstances and requiring a very high degree of measurement accuracy and estimation.
    - Specific MODCODS, demodulated signals, specific SNR, etc.
  - SME involvement, often manually, to compare results against a database of known emitters, applying fuzzy matching
- **Emerging SEI systems**
  - Applying RF Machine Learning (RFML) and Neural Network (NN) learning and processing
  - Processing can be done with the raw signal
  - Processing doesn't require SME involvement

Significant Research with Encouraging Results

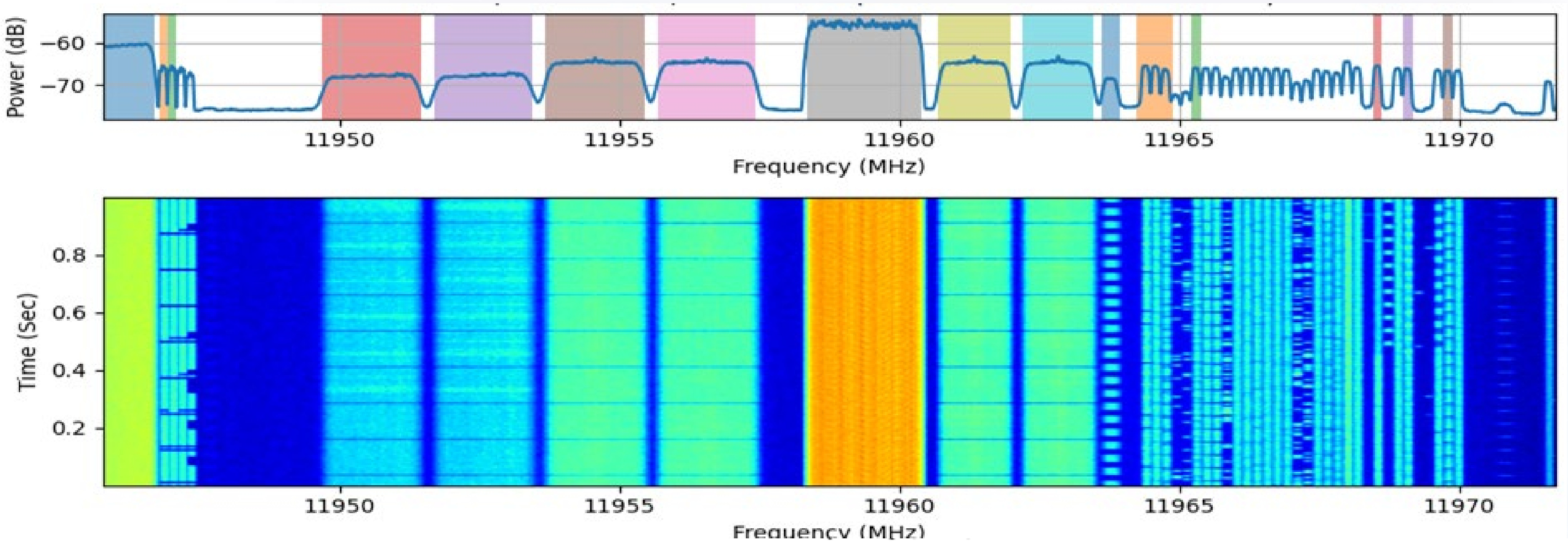
Basic high-level PRFR/SEI receive chain:



Actual Transmitter Type	1	2	3	4	5	6	7	8	9	10
1	40									
2		40								
3			39				1			
4				40						
5					38		2			
6						40				
7							39			1
8			2				2	36		
9							1		39	
10										40

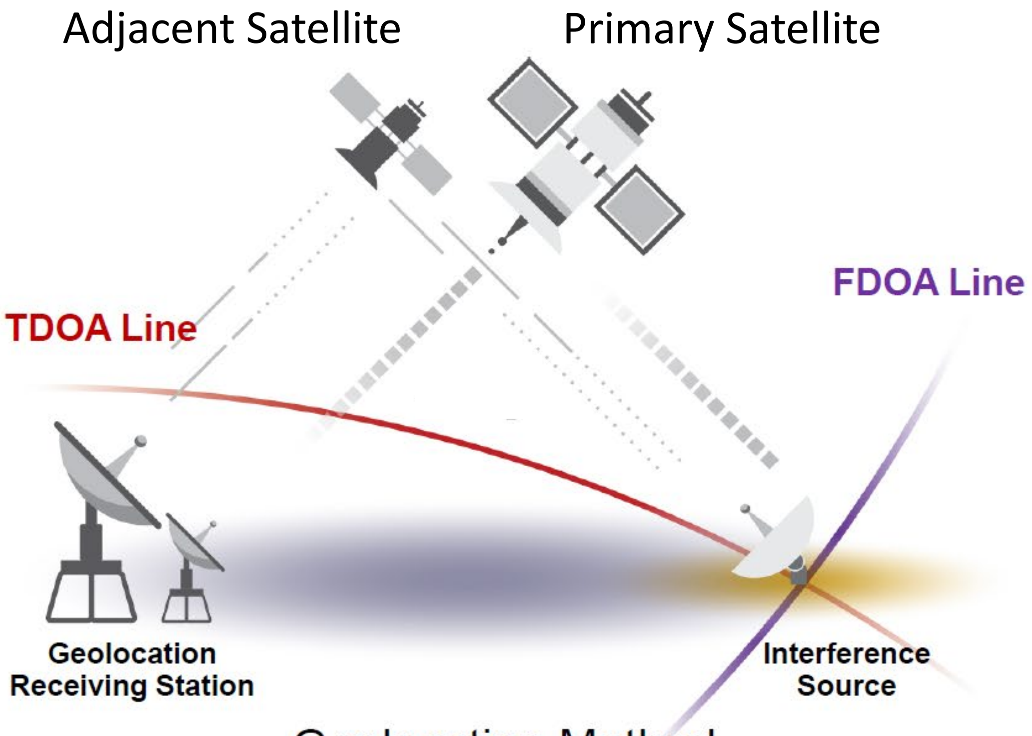
NN Determination of Transmitter Type

Signal Survey and Characterization Overview



Carrier	Center Freq (MHz)	Bandwidth (MHz)	EIRP (dBW)	C/N (dB)	Modulation Type	Symbol Rate (MSPS)	Es/N0 (dB)
0	11945.377	1.055	108.234	5.550	OQPSK	0.549	15.993
1	11946.166	1.062	104.618	11.312	32APSK	1.000	15.009
2	11946.993	0.520	108.491	7.509	OQPSK	0.262	15.505
3	11947.329	0.144	90.747	6.036	UNKNOWN	0.090	none
4	11947.494	0.145	90.939	6.227	8QAM	0.090	8.715
5	11947.739	0.265	92.476	6.160	8QAM	0.163	8.711
6	11950.563	1.724	100.171	5.202	QPSK	1.667	6.963

Geolocation Overview



Geolocation Method

Interference Located

Conclusion

- Important SDA Capabilities for Every Ground Station
  - Satellite Position and Maneuver Detection via Passive RF Ranging
    - High accuracy, all WX positioning, with Alerts on maneuvers and POL excursions
    - Combination with EO and Radar allows more tracking capability
  - Specific Emitter Identification
    - High accuracy emitter identification, with Alerts on unknown emitters, emitters where they shouldn't be, and POL excursions
  - Signal Survey and Characterization
    - Transponder utilization, signal characterization, EMI detection
  - Signal Geolocation
    - Locate sources of EMI to assist in resolution
- Affordable and without architectural impacts