国家无线电监测中心
The State Radio Monitoring Center

Advanced Satellite Interference Geolocation Techniques

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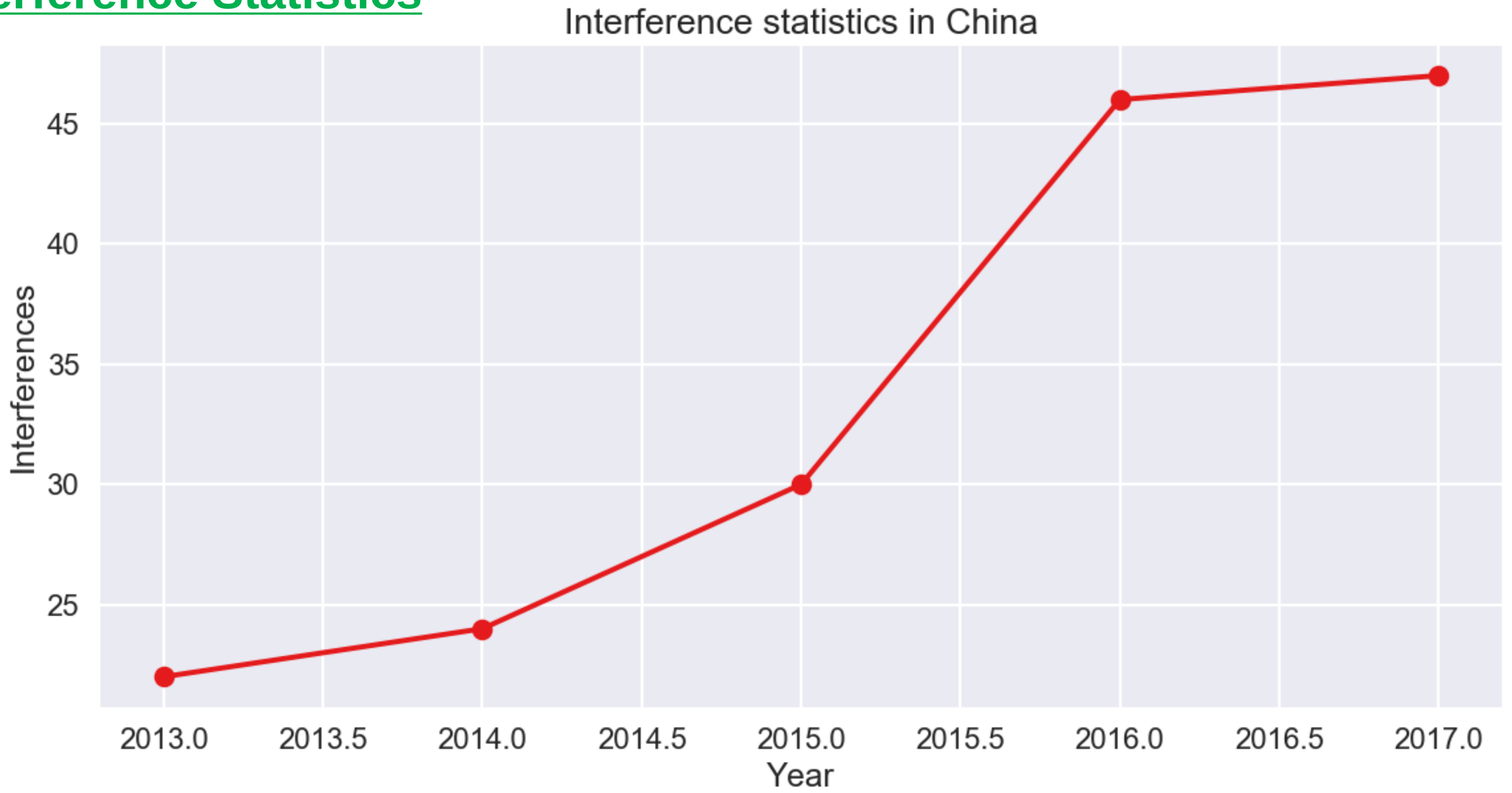
01 Principles

Principles

Interference Statistics



Principles

Type of Interference

- Adjacent satellite interference
  - poor satellite network coordination
  - become more prevalent because of increasing congestion
- Equipment failure
  - frequency drift, cross-polarization Interference
  - lack of type approvals and testing, low quality, poor installations
- Operator error
  - higher transmit levels, wrong frequency, improper polarization
  - lack of training

Principles

Type of Interference

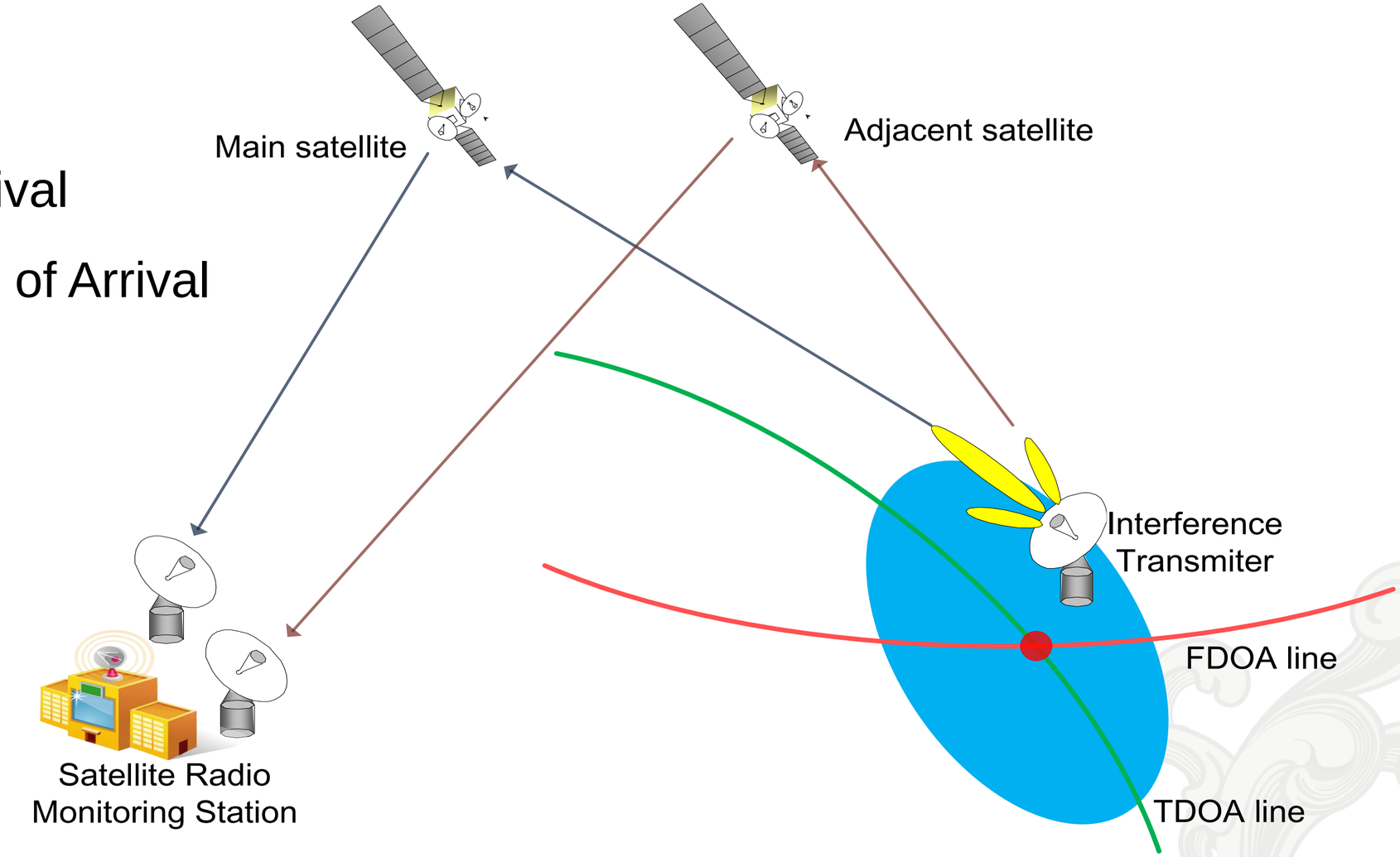
- Unauthorized Carrier (very common)
  - using satellite transponder without pay (piracy)
  - doing experiments
  - a major proportion of interference
- Deliberate jamming (rare)
  - hostile transmission to interrupt communication
  - intentional interference
  - political intention

Principles

Geolocation based on TDOA/FDOA

- TDOA: Time Difference of Arrival
- FDOA: Frequency Difference of Arrival

- Geolocation Accuracy: 20km



Principles

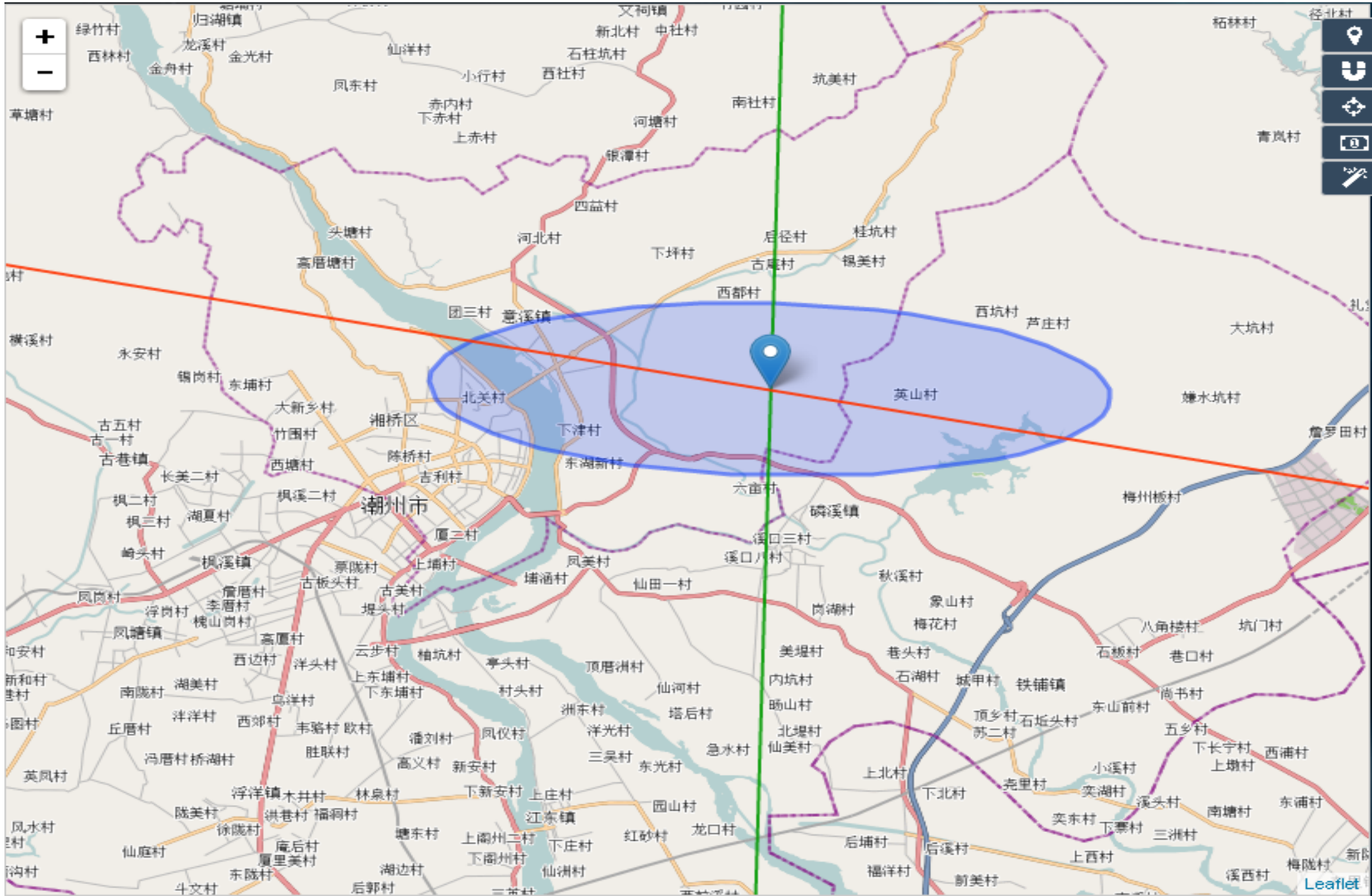
Geolocation Conditions

- Adjacent satellite (separation range, spectrum occupation)
- Satellite ephemeris (accuracy)
- Reference signals (calibrate satellite ephemeris. position, accuracy, at least 4)
- Coverage overlap (uplink and downlink)
- Frequency overlap (similar frequency band between the two satellite)
- Frequency occupations (blank spectrum on adjacent satellite)
- Signal features (antenna aperture size, modulation type, transmitter is moving or not)

Principles

Geolocation Performance 1

1. Geolocation Accuracy



Principles

Geolocation Performance 1

1. Geolocation Accuracy

- Satellite ephemeris accuracy (satellite velocity and position)
- Reference station (position especially the first reference, accuracy)
- Signal characteristics(e.g. modulation type, bandwidth)
- Correlation signal to noise ratio (higher SNR means higher accuracy)

The largest source of geolocation error is from the satellite ephemeris

Geolocation Performance 2

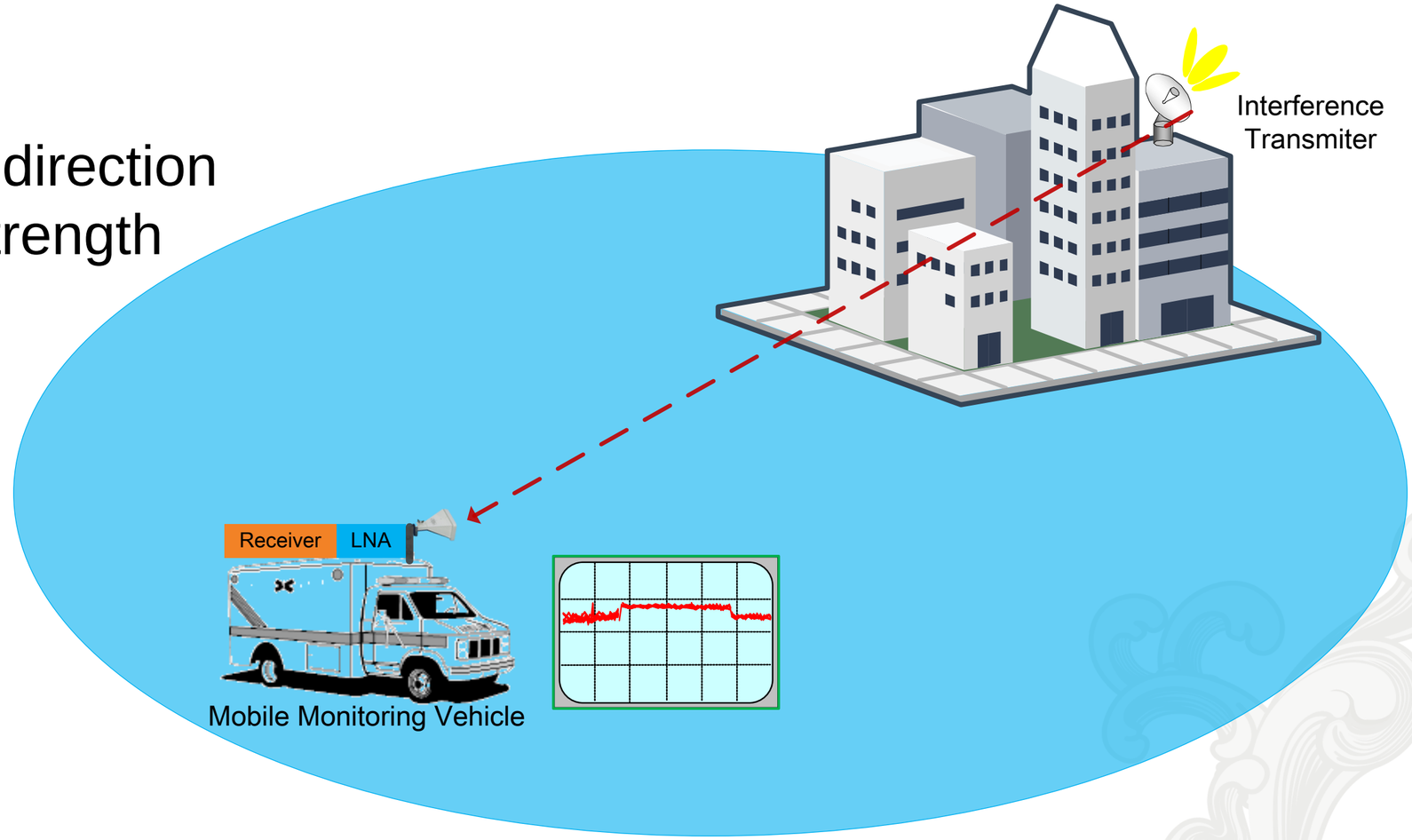
2. Geolocation success rate
    - adjacent satellite available
    - reference source available
    - system processing gain
3. Geolocation duration
    - adjacent satellite available
    - reference source available
    - Critical to instantaneous signal

Principles

Interferer finding based on ground search

- Interferer search by closing the vicinity of the localized point, with vehicles or handheld devices.

- Determine the transmitter by direction finding and received signal strength



02 Challenges

Challenges in Satellite interference geolocation

- accuracy:
  - satellite ephemeris accuracy
  - reference accuracy
- success rate:
  - weak signal detection
  - adjacent satellite availability (ka band, spot beam)
  - TDOA/FDOA available (onboard processing)
  - special signal (CDMA signal, instant signal)

Challenges in Satellite interference finding

- Geolocation accuracy is insufficient to limit the interferer to a small enough area (around 20km now)
- Most interferers lie in urban area, the uplink side-lobe signal is usually blocked by buildings.
- Side-lobe of signal is very weak and hard to detected by ground searching
- Time consuming and difficult to find interference

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03 Advanced-Techs

1. Geolocation based on TDOA

Why TDOA?

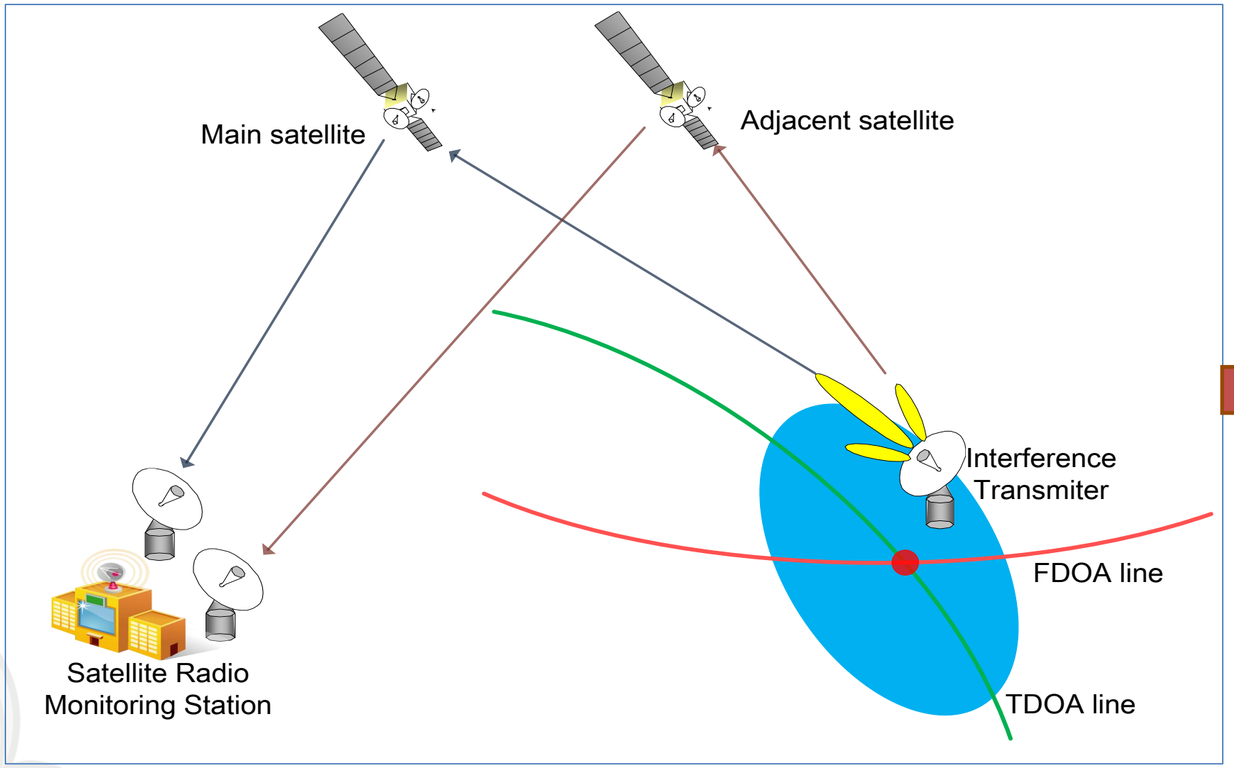
- The goal is to improve the geolocation accuracy
- TDOA is quite stable and accurate (satellite position error is negligible)
- The limiting factor of accuracy is the prediction of satellite velocity, which determines FDOA.

Could apply geolocation just via TDOA?

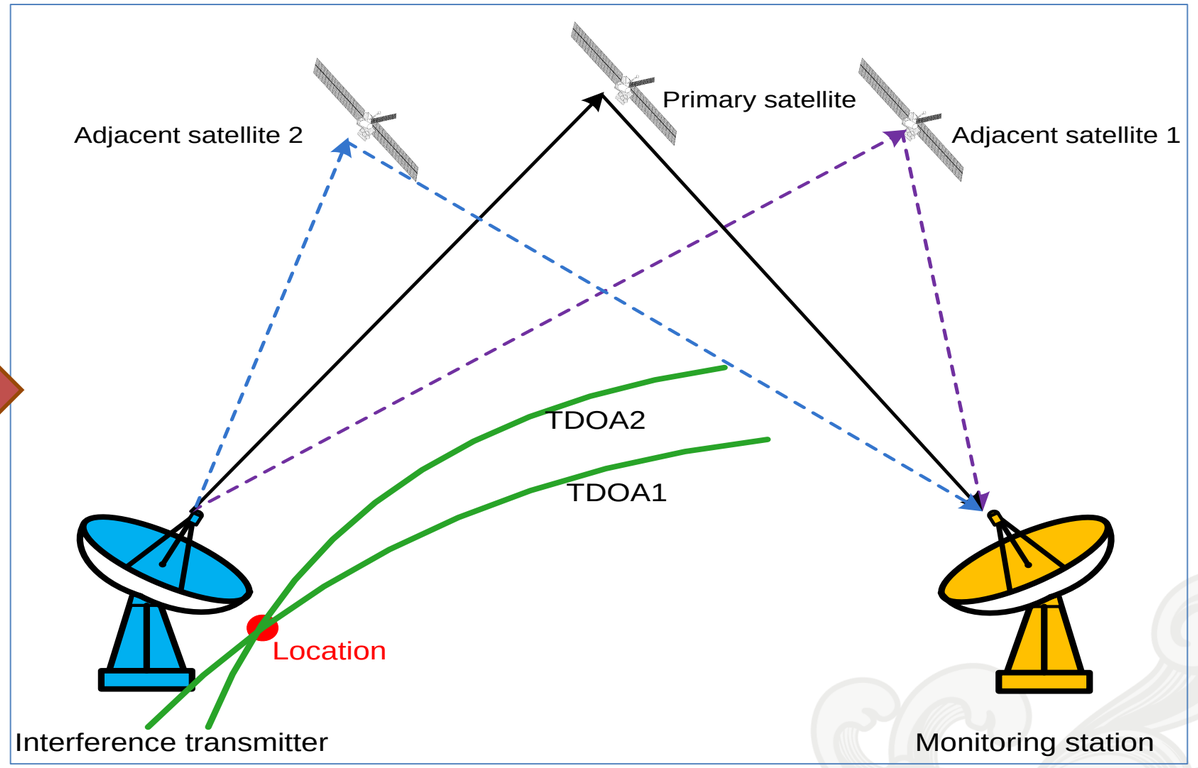
Advanced-Techs

1. Geolocation based on TDOA

How it works?



TDOA/FDOA



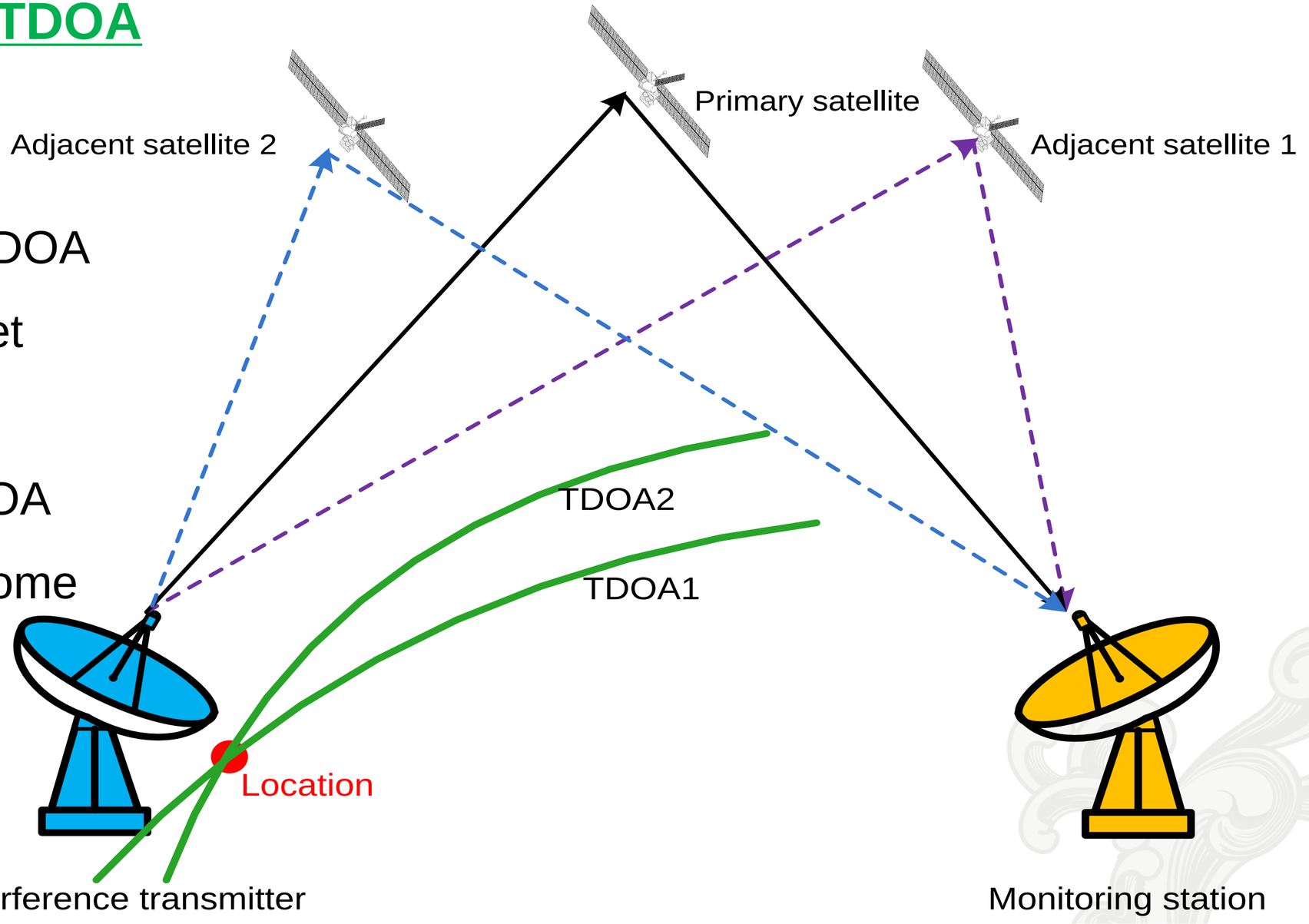
TDOA/TDOA

Advanced-Techs

1. Geolocation based on TDOA

How it works?

- Remove the FDOA, hold TDOA
- Need another satellite to get additional TDOA line
- The intersection of two TDOA lines give the locating outcome



Advanced-Techs

1. Geolocation based on TDOA

Advantages

- high locating accuracy (accuracy is usually less than 10km)
- reference source can be just one (compared 4 in TDOA/FDOA method)
- locating the moving target (without Doppler frequency ambiguity)

Disadvantages

- require another adjacent satellite
- The separation range should be large

2. High gain processing technology

Why high processing?

- The goal is to improve the geolocation success rate
- The power of the interfering signal leaking to the adjacent satellite is very low

  (typically 40 to 60 dB below the transponder noise floor)
- Weak signal is hard to detect and limits to successful rate
- Adjacent satellites are limited to a smaller range

  (C band:10 degree; Ku band:7 degree)

2. High gain processing technology

How it works?

$$\text{Post-processing SNR} = \frac{2BTsnr^2}{k[1+snr(1+1/k)]} \approx 2BT + snr_{adjacent}$$

$$PG = 2BT$$

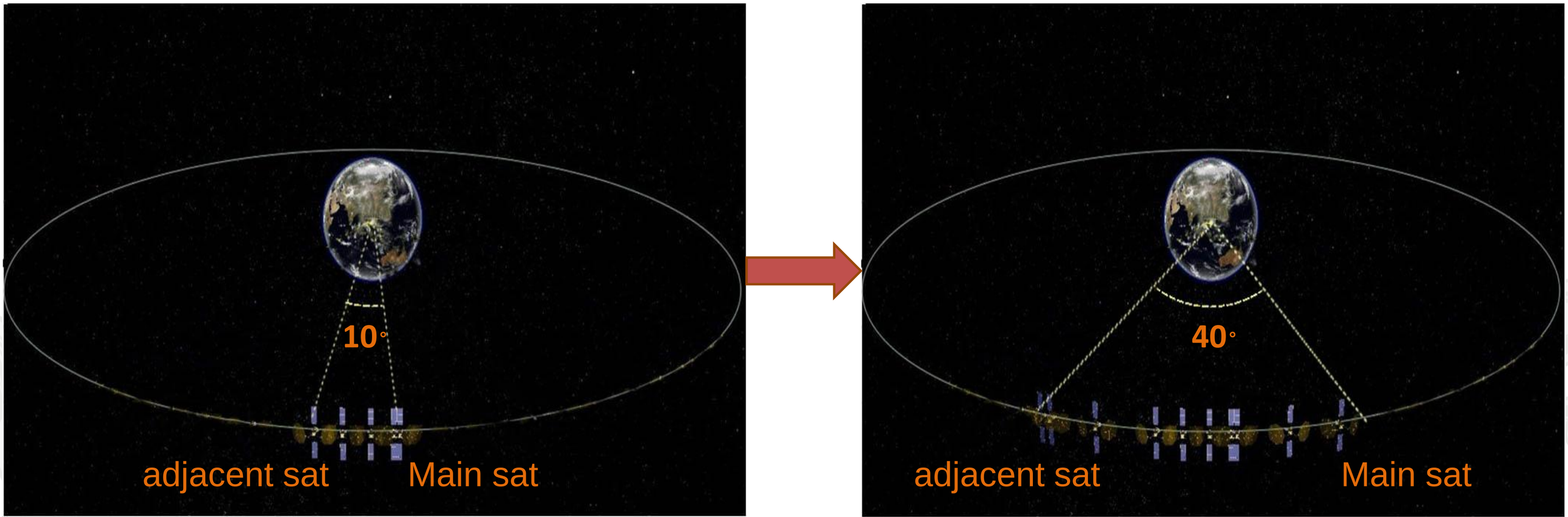
$$k = \frac{snr(main)}{snr(adjacent)}$$

Raise the processing gain by sampling data

in wider bandwidth and longer time duration.

2. High gain processing technology

High gain processing technology expands the range of adjacent satellites greatly

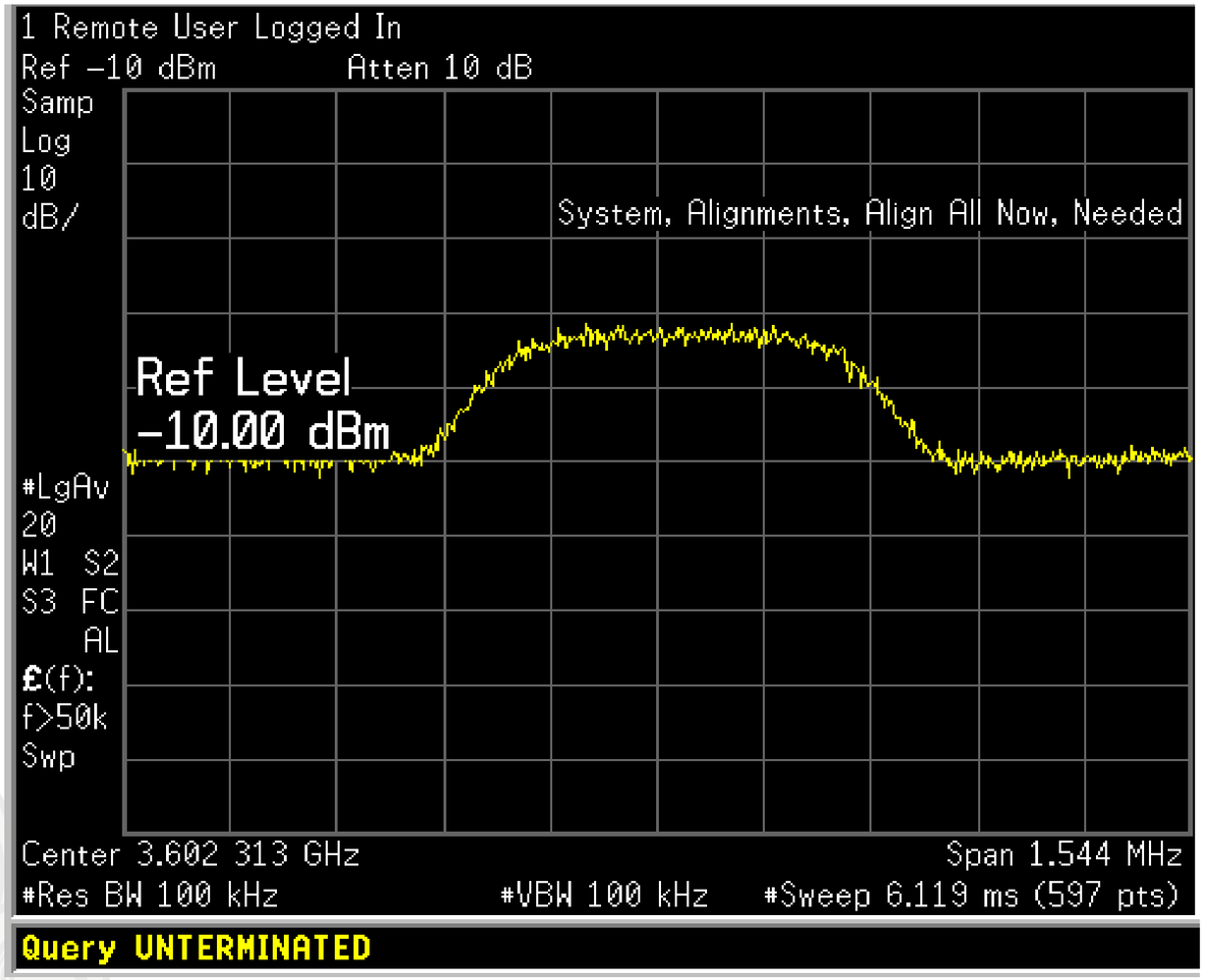


3. Signal cancellation technology

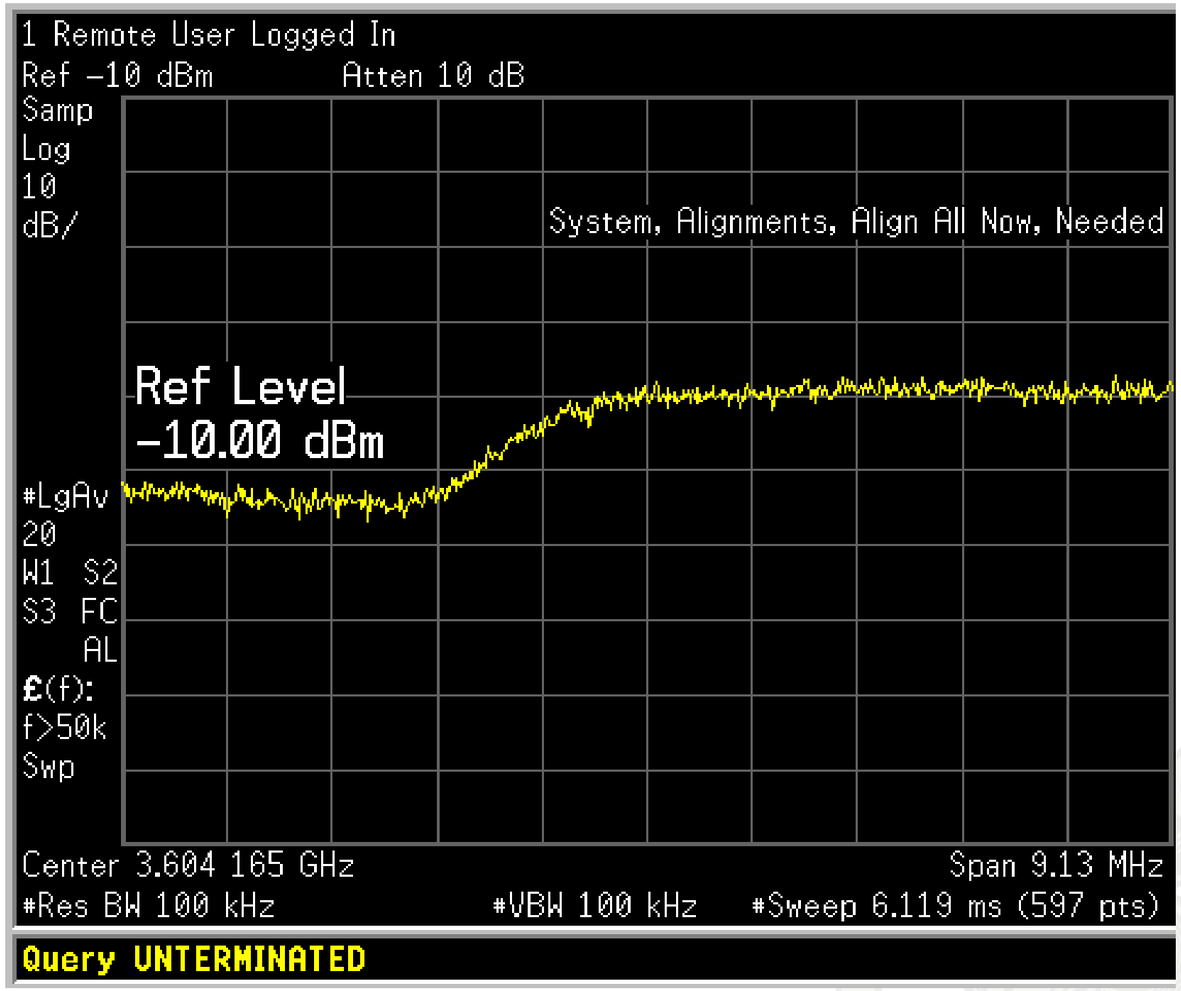
Why signal cancellation?

- The goal is to improve the geolocation success rate
- In some cases, there is a strong signal in the adjacent satellite, cover the leaking signal from the main satellite.
- Geolocation failure, because the strong signal in the adjacent satellite would have a very bad impact on extracting the weak side-lobe signal.

3. Signal cancellation technology



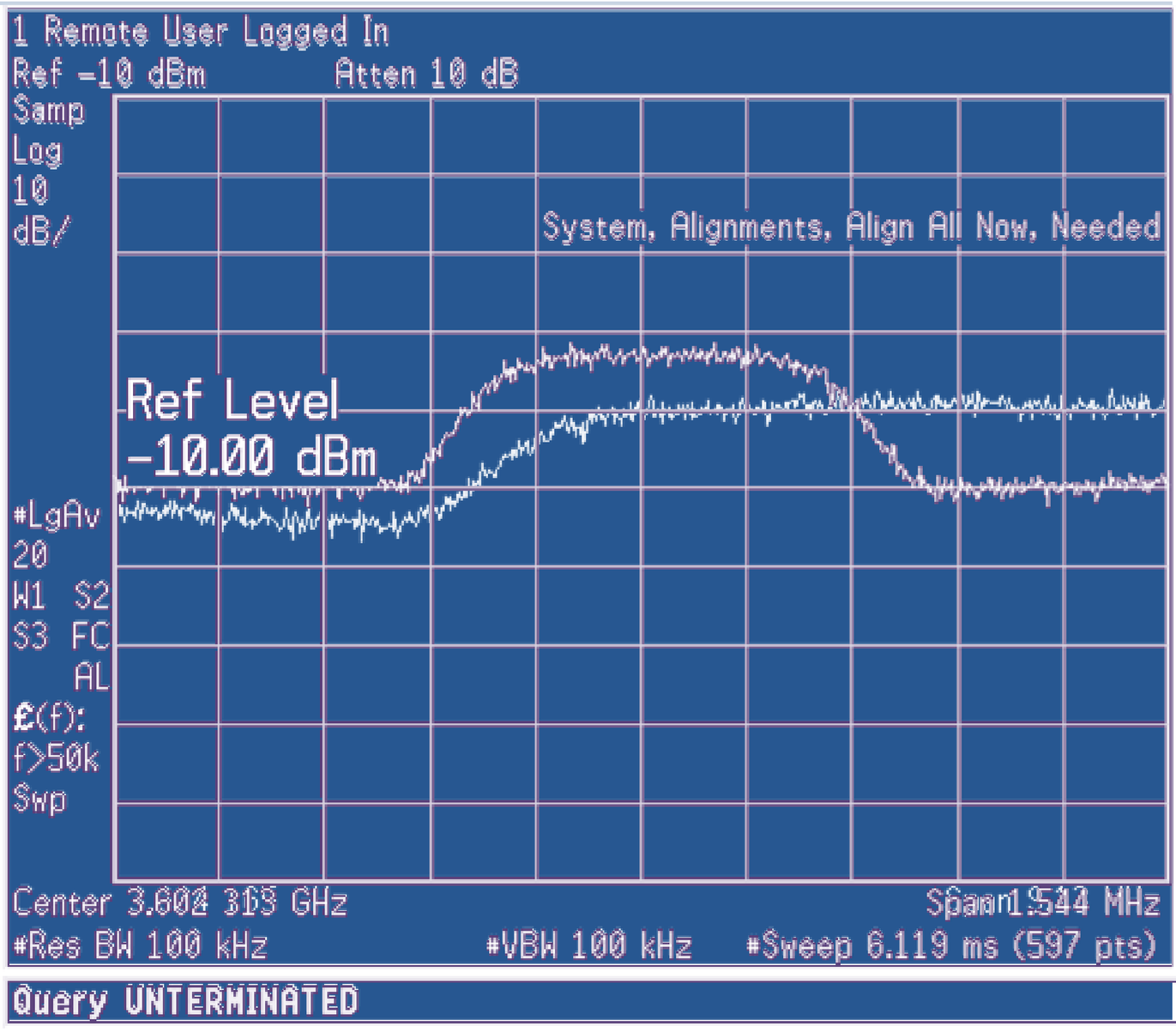
Main sat spectrum



Adjacent sat spectrum

3. Signal cancellation technology

- leaking signal(from main satellite) in adjacent satellite is covered by a big signal.
- hard to perform cross-correlation



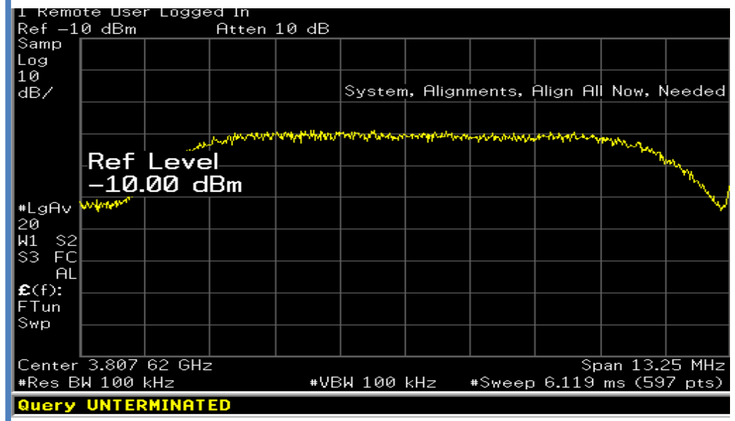
3. Signal cancellation technology

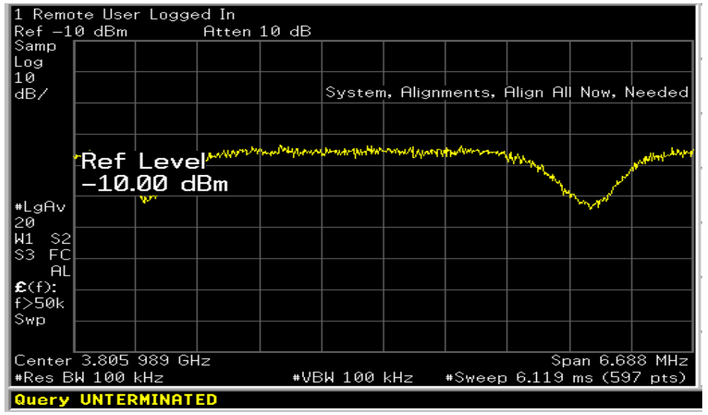
How it works?

1. The signal cancellation system analyzes and computes the signal's parameters, such as type of modulation, bandwidth, bit rate, and so on.
2. According to these parameters, the system will reconstruct the analyzed signal.
3. It uses the former signal to subtract the new one, the strong signal effects will be removed from the sampling data.

3. Signal cancellation technology

Before cancellation

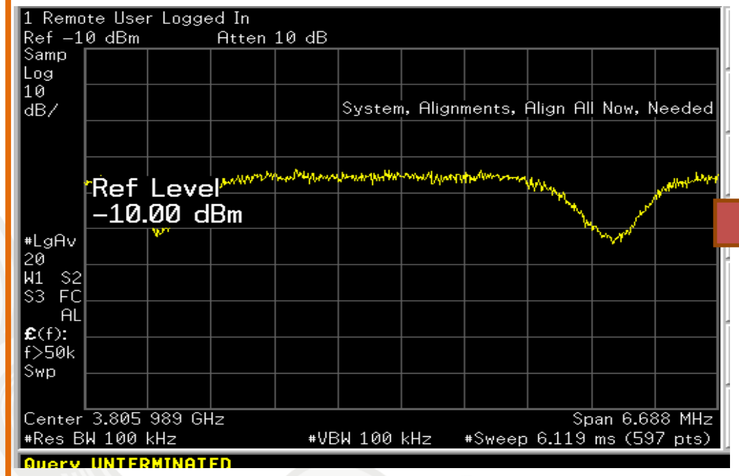


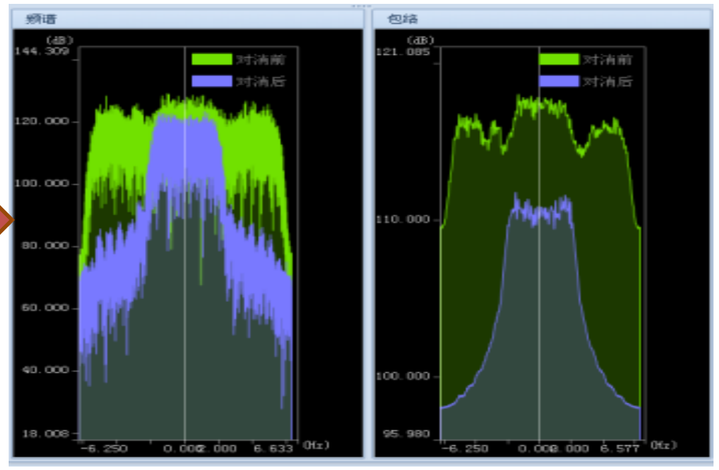


	DTO(us)	DFO(Hz)	SNR(dB)
目标	-15795.782	2286.984	14.8
参考-1	123.260	2278.343	17.1
参考-1	27000.000	10000.000	0.0
参考-1	123.469	2278.359	18.6

	DTO(us)	DFO(Hz)	SNR(dB)
参考-1	123.297	2278.171	18.7
参考-2	491.818	2278.921	26.4
参考-3	271.820	-4306.289	11.9
参考-4	876.165	2279.343	19.1

After cancellation





	DTO(us)	DFO(Hz)	SNR(dB)
目标	122.380	2278.224	19.8
参考-1	123.330	2278.322	21.5
参考-1	123.370	2278.183	19.6
参考-1	123.270	2278.373	21.8

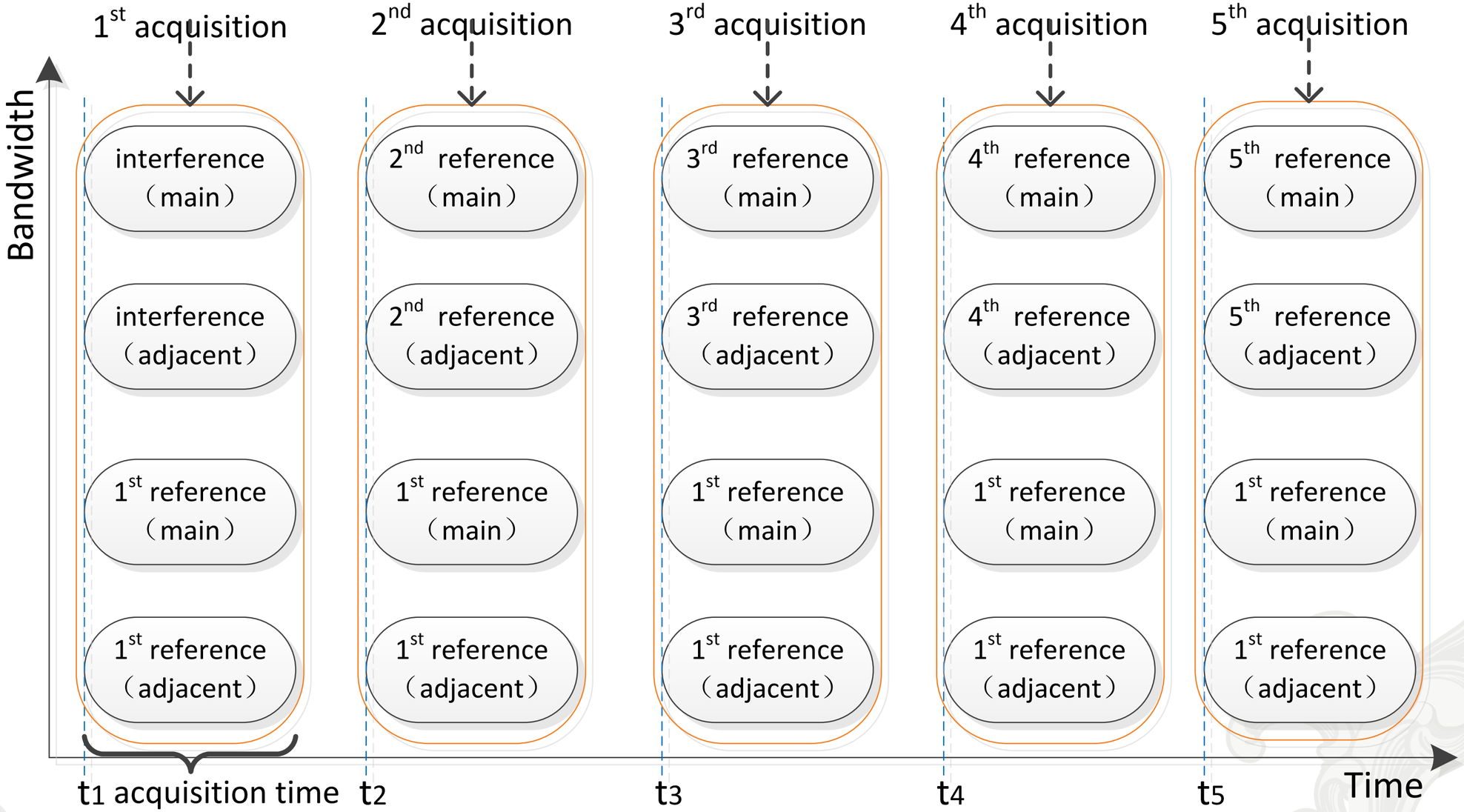
	DTO(us)	DFO(Hz)	SNR(dB)
参考-1	123.320	2278.223	26.6
参考-2	491.710	2278.910	37.8
参考-3	217.920	2278.238	22.9
参考-4	876.400	2279.367	25.8

4. Parallel data acquisition

Why parallel?

serial time process

required time is 5T

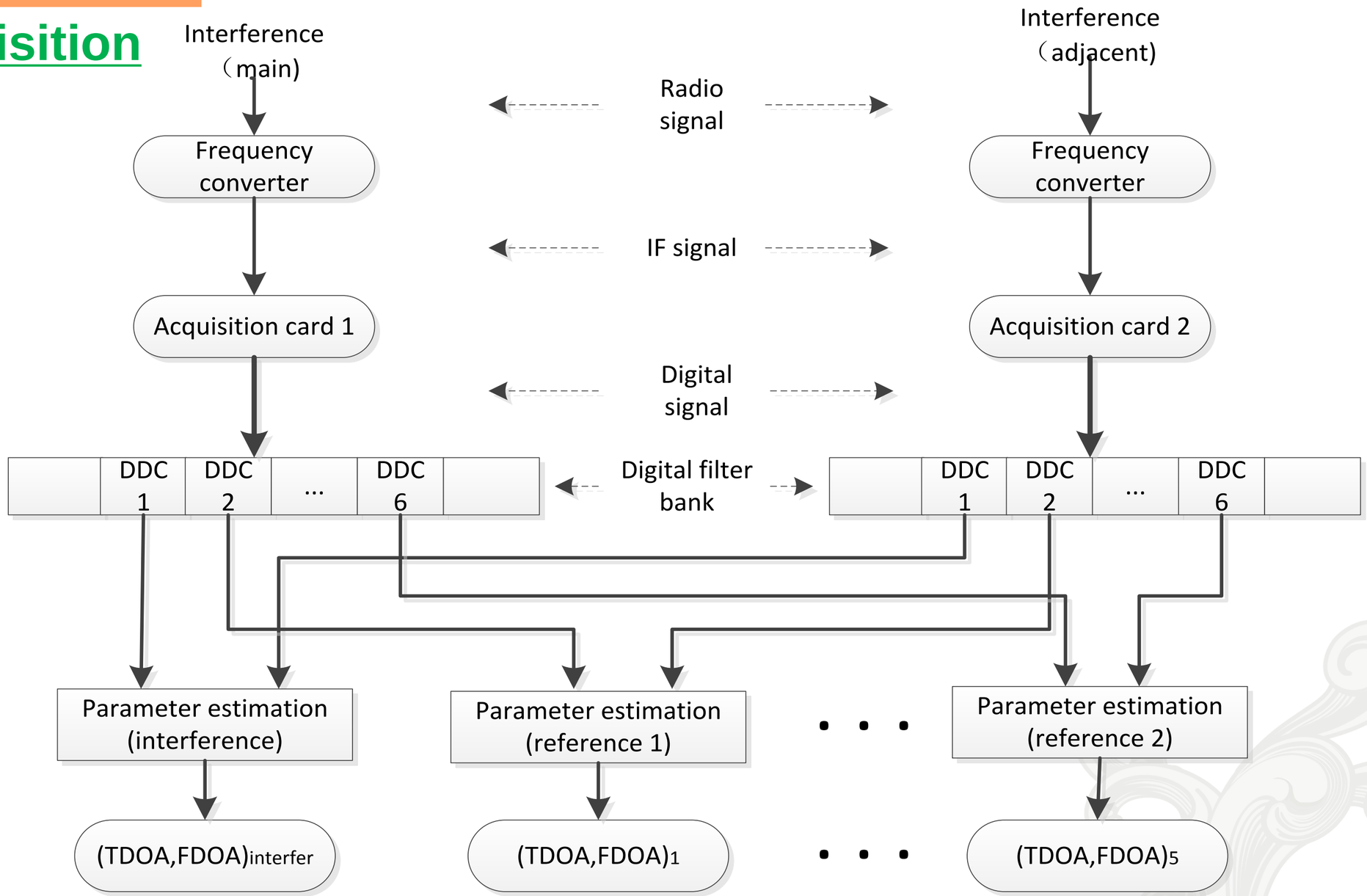


4. Parallel data acquisition

How it works?

parallel time process

required time is T



4. Parallel data acquisition

Advantages

- Improve geolocation accuracy (avoids the measurement error caused by acquisition the two separated signal in a time division way)
- Reduce signal acquisition time(from 5T to T)

5. Single Satellite Geolocation

Why single satellite?

- Use of higher frequency bands(Ka, Q/V band…) makes adjacent satellite unavailable
- Use of spot-beams reducing the availability of appropriate adjacent satellites
- On-board processing makes FDOA/TDOA measurement impossible
- Smaller satellite station keeping windows reduce FDOA values, degradation geolocation accuracy

5. Single Satellite Geolocation

How it works?

- Signal attenuation varies by the influence of atmospheric changes

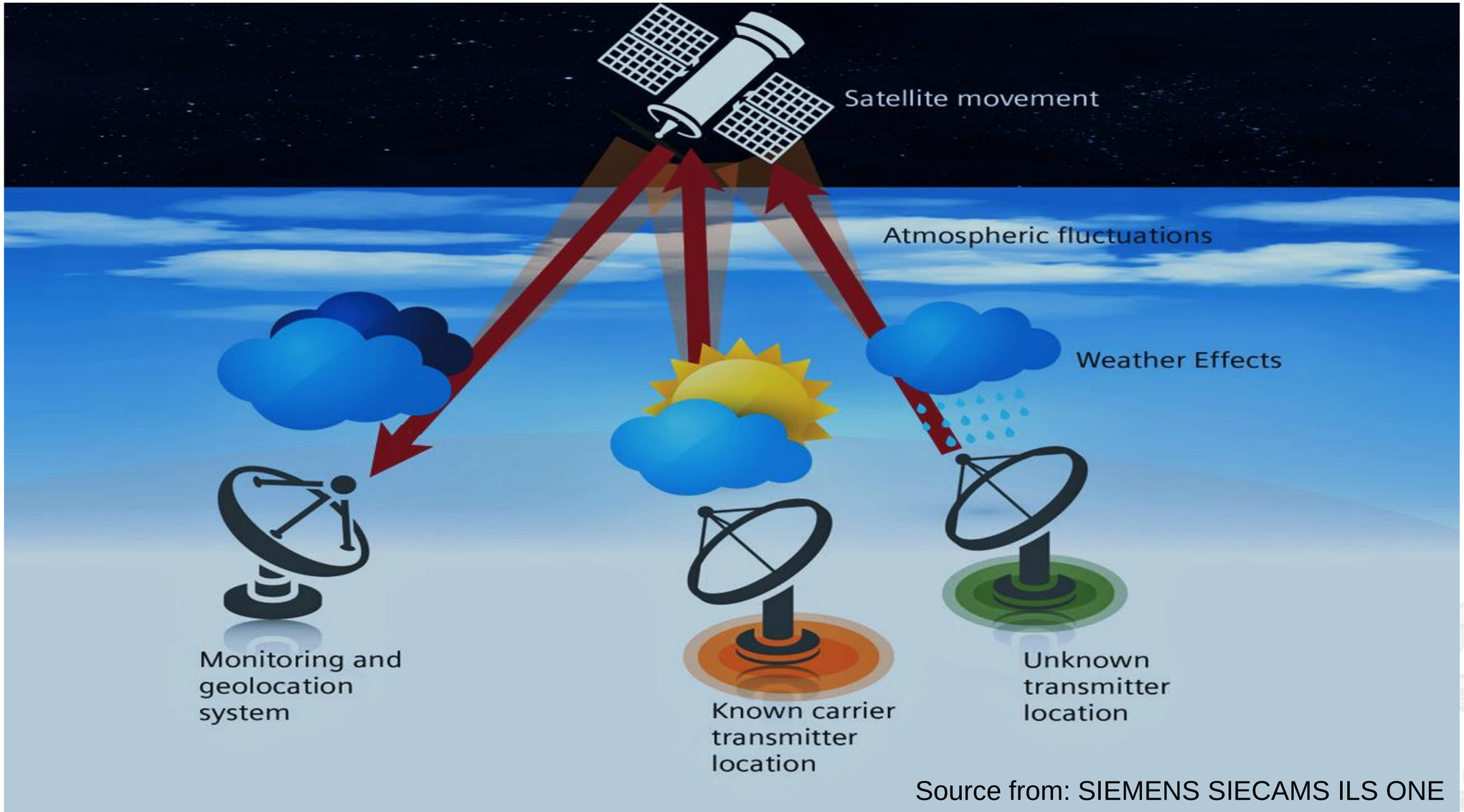
  (e.g. rain attenuation, atmosphere fluctuation)

- Measuring the power of multiple carrier signals simultaneously over a certain time

- The trends of power variation among these signals are compared

- The similarity between trends is interpreted as distance between stations (if the two signal transmitted from the same station, the matching is 100%)

5. Single Satellite Geolocation

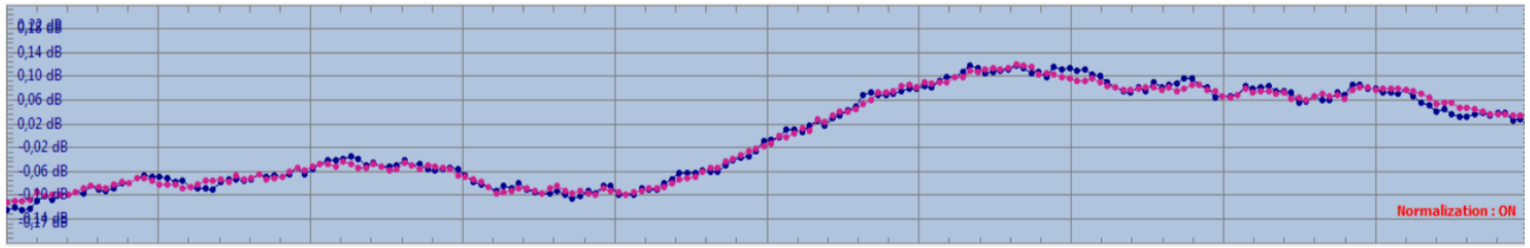


Source from: SIEMENS SIECAMS ILS ONE

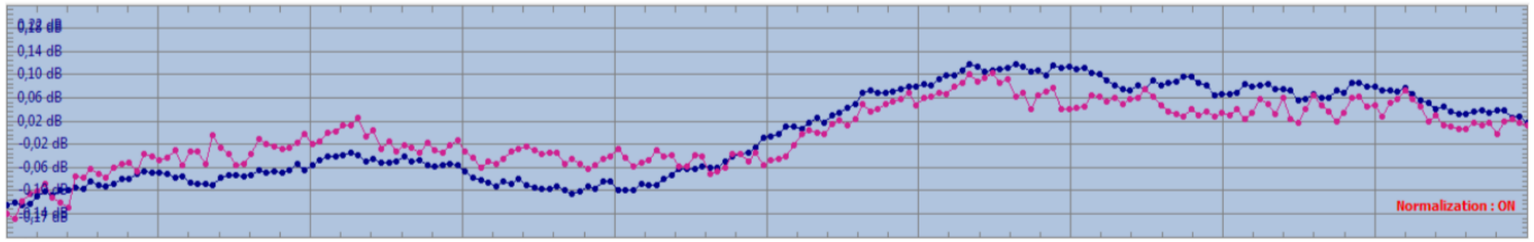
5. Single Satellite Geolocation

The matching value maps to the distance between reference and the interfering station

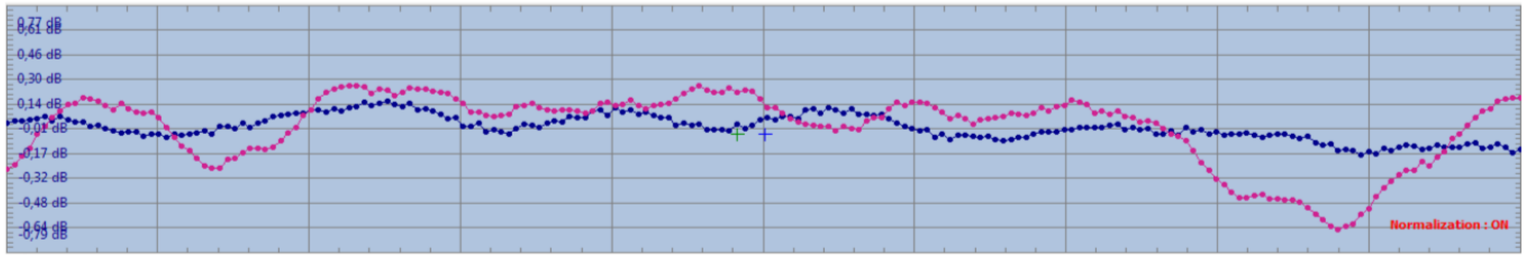
99% match same antenna



91% match same site



41% match different site



5. Single Satellite Geolocation

Advantages

- No adjacent satellite
- Do not need precise ephemeris

Disadvantages

- Need a number of reference source (near the interference station)

6. Interferer ground search using UAV

Why using UAV?

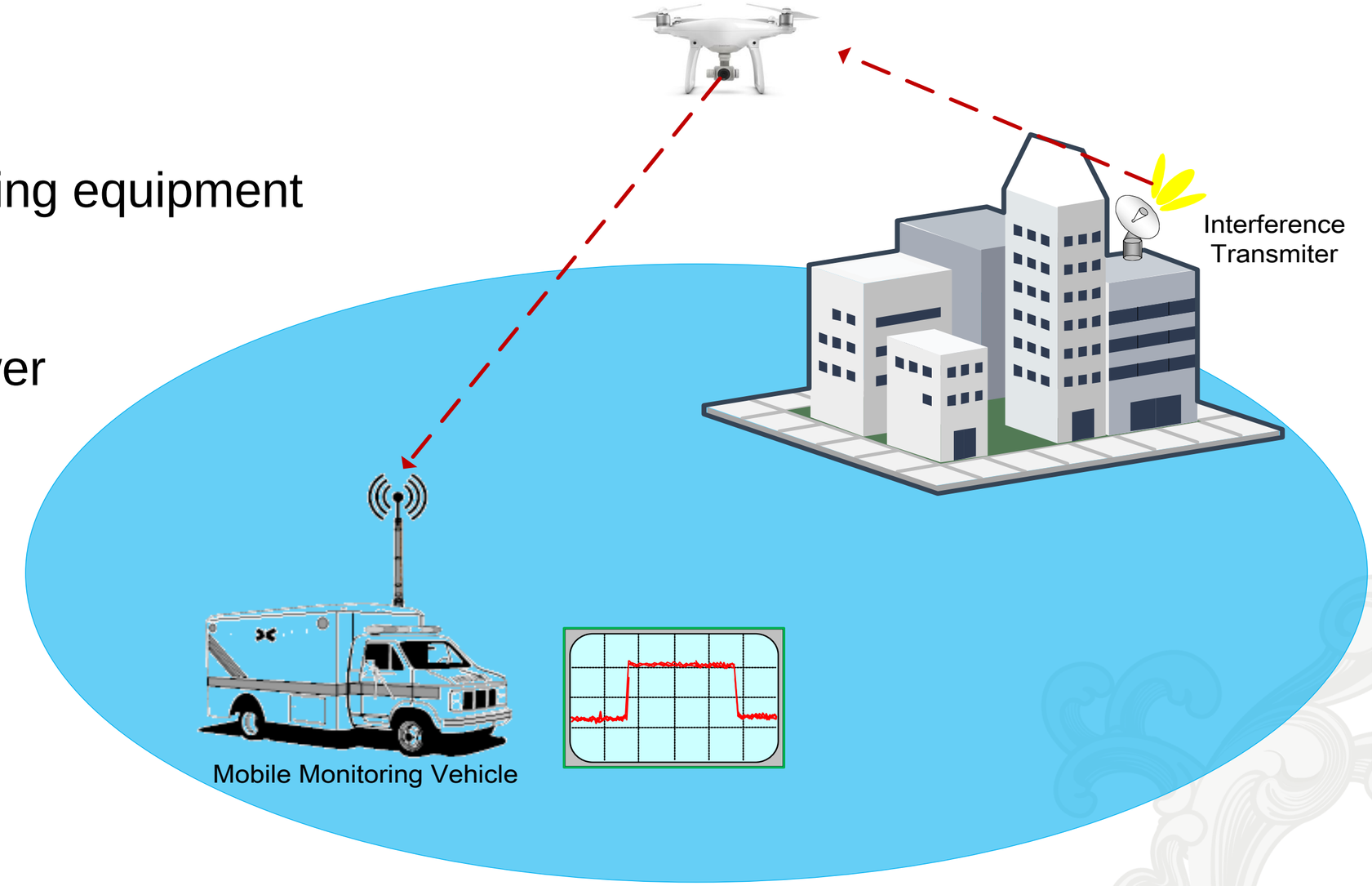
Search the interfering emitter on the ground is difficult and time consuming.

- signal is usually blocked by buildings.
- side-lobe of signal is very weak (antenna dish points to the sky).
- usually needs several days, weeks, or even months.

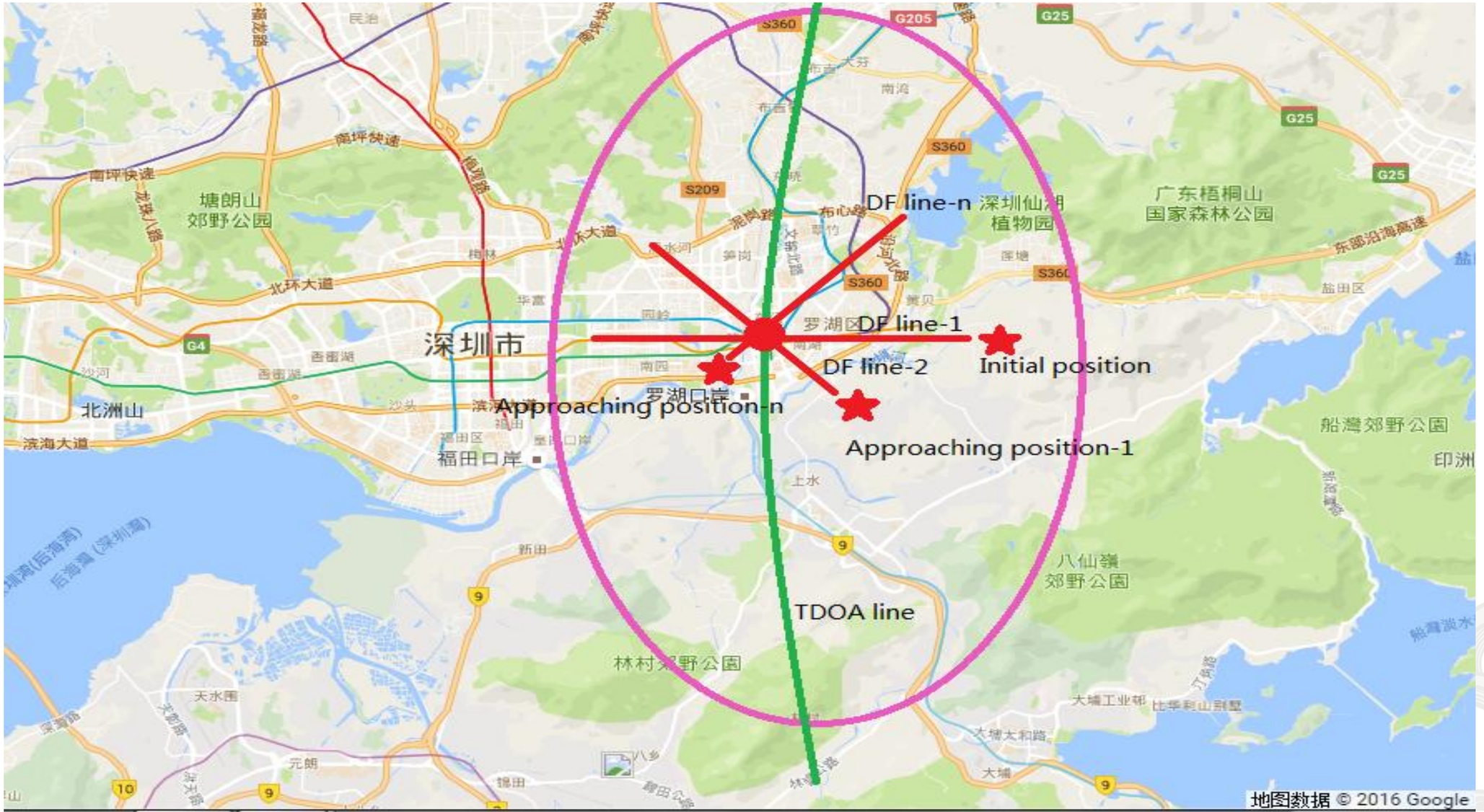
6. Interferer ground search using UAV

How it works?

- UAV Integrated with monitoring equipment
- increase visible horizon
- improve received signal power



6. Interferer ground search using UAV



7. Carrier Identification(Carrier ID)

Why Carrier ID?

- Traditionally, eliminate interference need two steps: localizing the interference and searching on the ground.
- Each steps have many constrains, which limit the accuracy, success rate and speed.
- The ultimate goal is resolving interference as quickly as possible

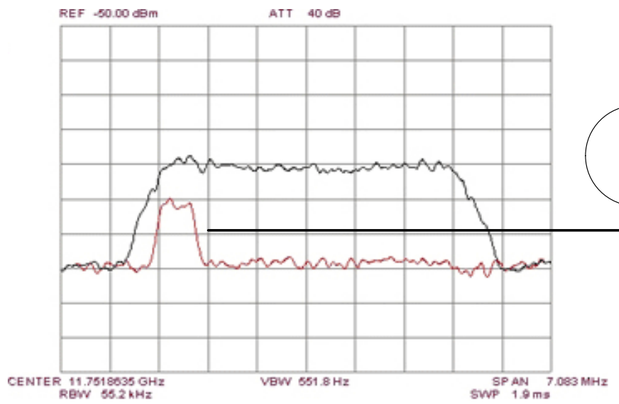
7. Carrier Identification(Carrier ID)

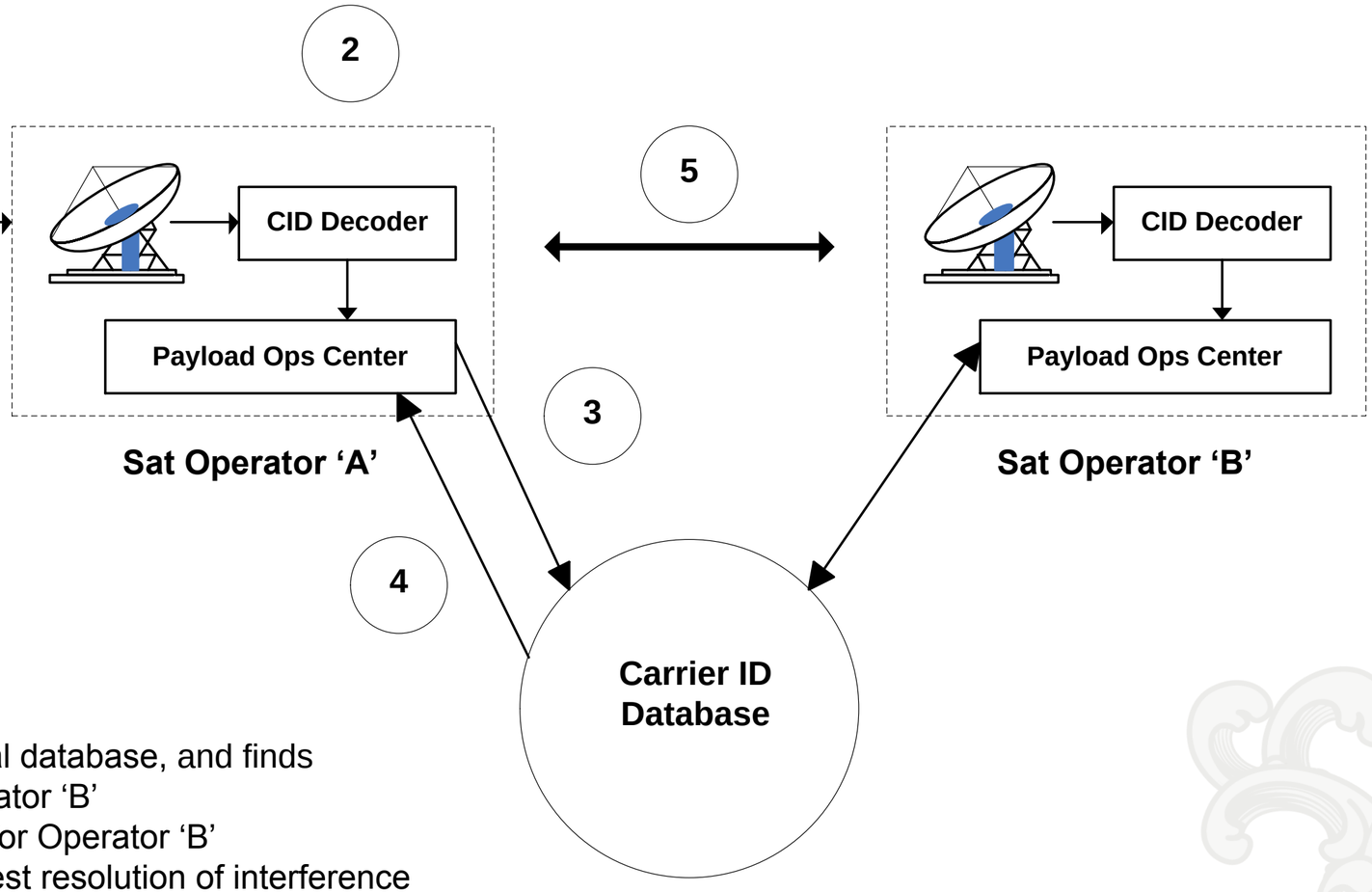
What is Carrier ID?

- Carrier ID is a unique identification code embedded on a transmitted carrier (using spread spectrum signals under the noise floor)
- Carrier ID contains: latitude and longitude, user's telephone numbers…
- Carrier ID can be decoded by satellite operators or regulatory agency, to identify the uplink of an interfering carrier

7. Carrier Identification(Carrier ID)

How it works?





1. Detect RF Interference
2. Decode Carrier ID from interference
3. Operator 'A' checks Carrier ID in global database, and finds association of the CID with Operator 'B'
4. Database returns name and contacts for Operator 'B'
5. Operator 'A' calls Operator 'B' to request resolution of interference

04 Summary

Summary

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The elimination of satellite interference is a systematic problem

- Geolocation technologies
- Awareness
- Training & Certification
- Earth station approvals
- Regulatory and political actions
- Data sharing
- International monitoring
- Smart receivers
- ……

Summary

"Spectrum management is the combination of administrative, scientific and technical procedures necessary to ensure the efficient operation of radio-communication equipment and services without causing interference."

ITU Handbook of Spectrum Monitoring

- Technology is a powerful method to solve the interference problem, but it is not the only one.
- Geolocation is used to resolve those difficulties where other methods fail.

Q&A

Thank you for your attention

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