Emitter Location for Use Against Modern Non-Cooperative Signals

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RF/uW Sensors & Geolocation Technologies

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KEYSIGHT TECHNOLOGIES

Agenda

- Definitions, Trends in the Wireless Market, Impact on Monitoring
- Introduction to Time-Difference-of-Arrival (TDOA)
- Sources of Error in TDOA
- Comparison of TDOA and AOA Technologies
- Common Myths Around TDOA
- What Keysight Has to Offer
- Conclusion, Additional Resources

Trends In the Wireless Market

THE IMPACT ON MONITORING

Definitions

TERMS IN THIS PRESENTATION

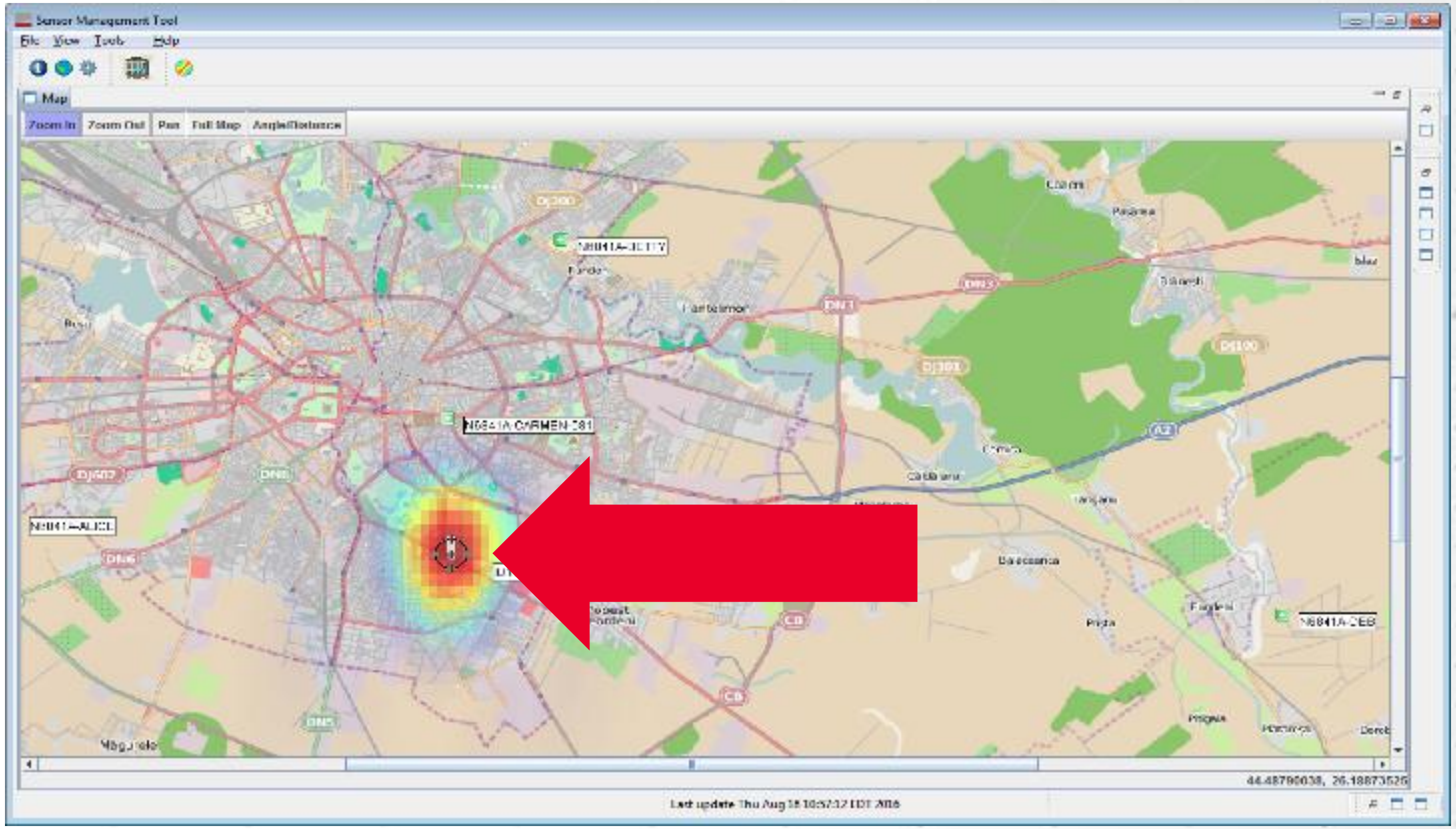
- Non-cooperative emitters – emitter of unknown location, time of transmission, duration, modulation format, symbol rate (if digital)
- TDOA – time difference of arrival; a method for estimating emitter location by measuring the time difference of arrival of a radio wave at three or more receivers.
- DF – direction finding
- AOA – Angle of Arrival; one method used by DF systems to estimate the line of bearing (LOB) to an emitter.

Definitions (continued)

GEOLOCATION DEFINED

Wikipedia definition: *Geolocation* is the identification of the real-world geographic location of an object, such as a radar, mobile phone or an Internet-connected computer terminal.

Geolocation may refer to the practice of *assessing* the location, or to the *actual location*.



KEYSIGHT TECHNOLOGIES

Today's Wireless Environment …

INCREASING COMPLEXITY IN THE SPECTRUM LANDSCAPE

- Increased demand for spectrum to support new commercial wireless services. Global.
- Spectrum is changing. Frequencies being re-allocated and re-purposed.
- More services are being packed into less spectrum with tighter guard bands.
- More RF station equipment being collocated.
- Spectrum sharing puts multiple services into single, shared frequency channel.

More difficult to isolate, detect and locate signals of interest

Need to get closer proximity

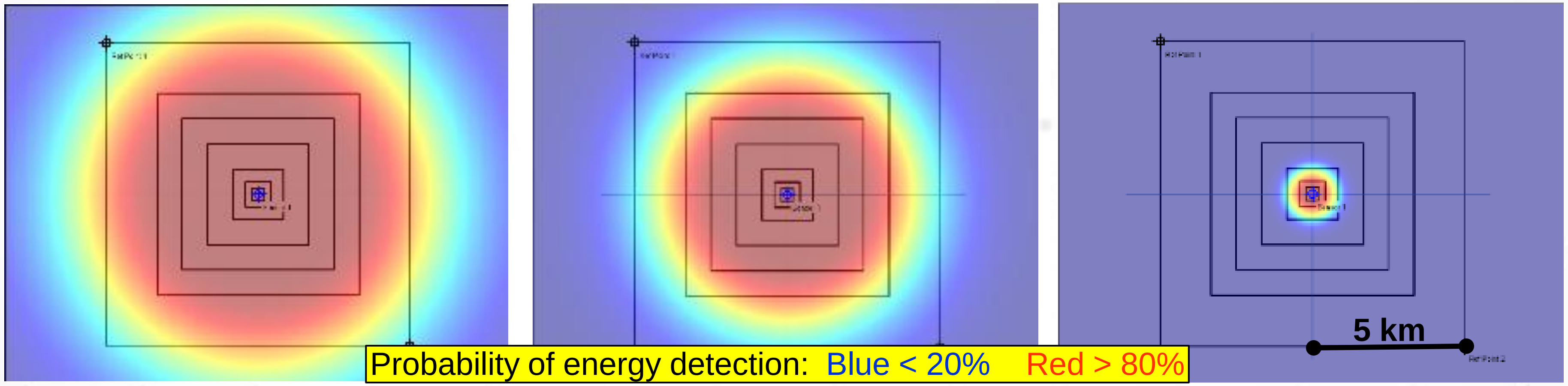
Higher risk of (localized) interference

RF Signal Trends Impact Monitoring Strategies

RF DETECTION RANGE OF A SINGLE MONITORING STATION

Path Loss Increases with Frequency

Noise Power Increases, PSD Decreases with Bandwidth



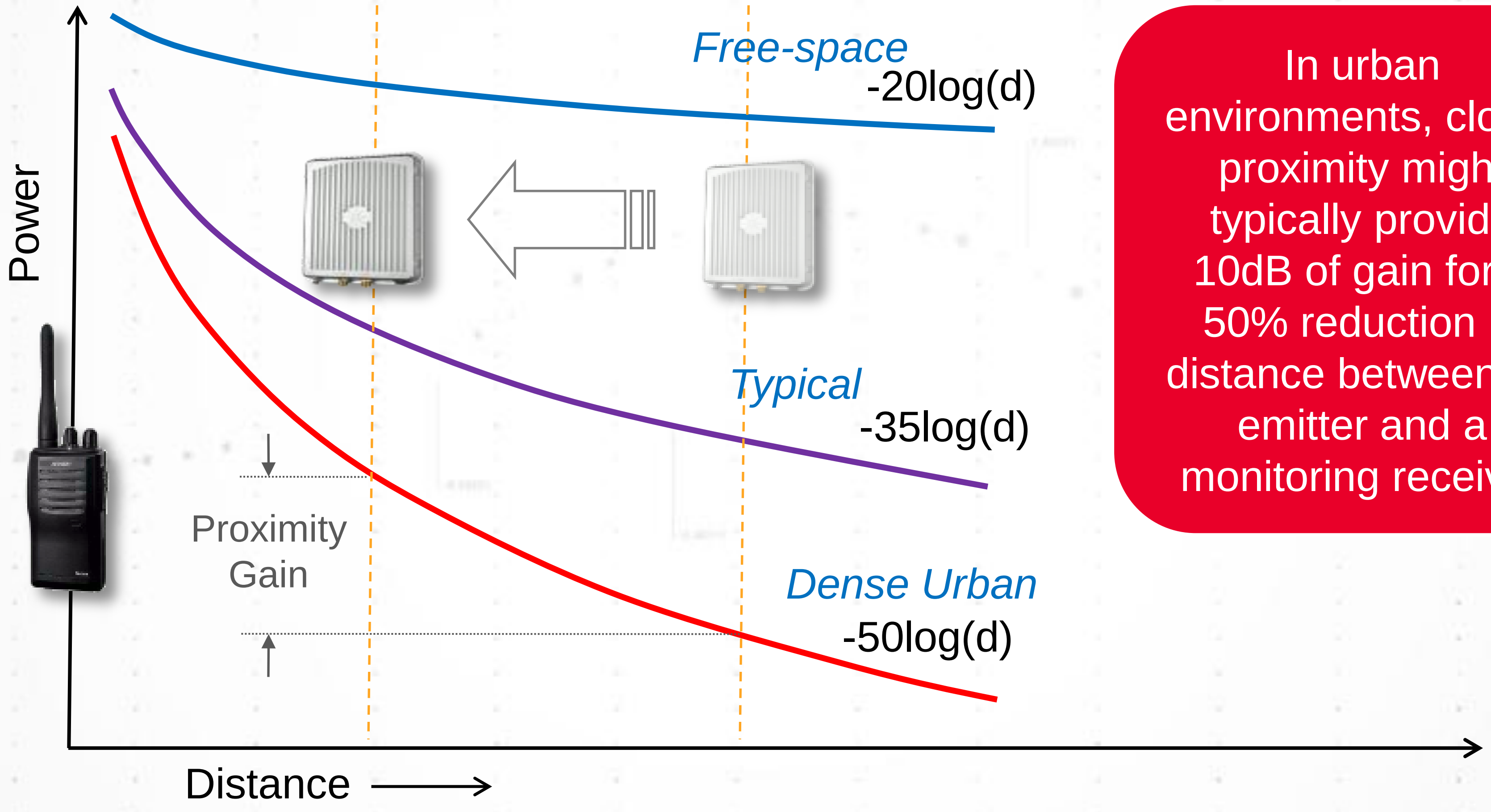
Frequency: 400 MHz → 3 GHz 3 GHz

Bandwidth: 20 kHz 20 kHz → 20 MHz

Trends in Wireless Communication Technology

RF Signal Trends Impact Monitoring Strategies

PATH LOSS VARIES WITH DIFFERENT ENVIRONMENTS

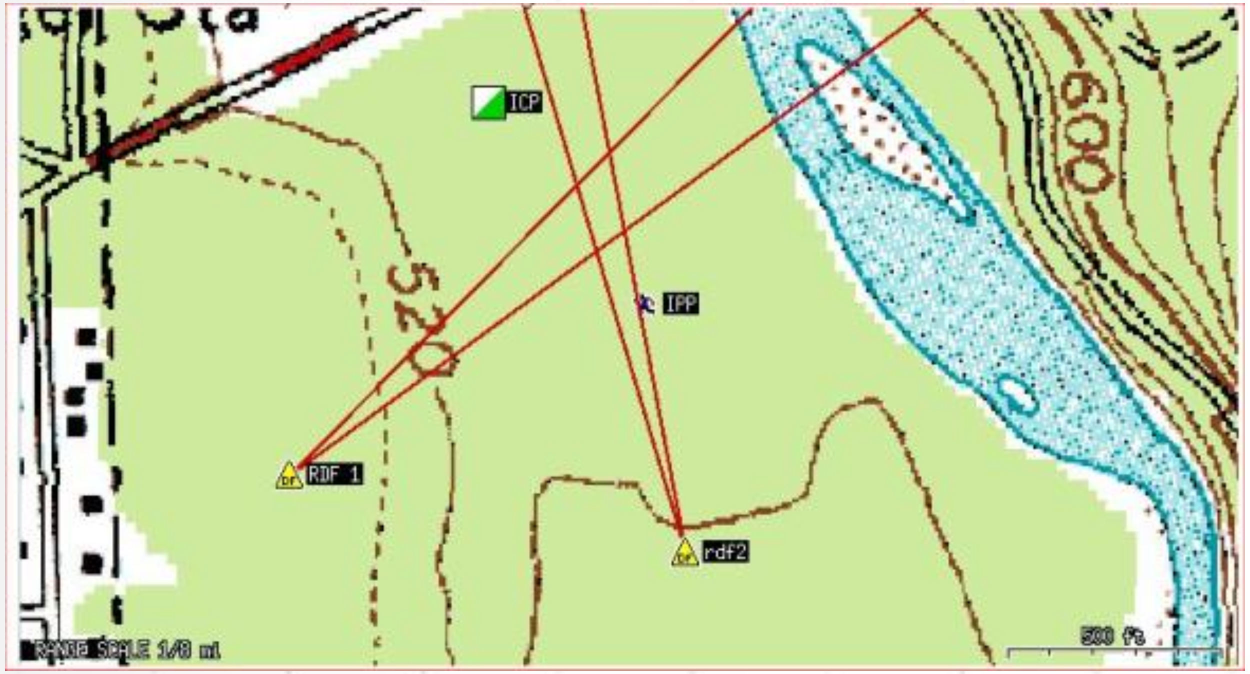


In urban environments, closer proximity might typically provide 10dB of gain for a 50% reduction in distance between an emitter and a monitoring receiver

Requirement for monitoring equipment

IT HAS TO IN ORDER TO KEEP UP…

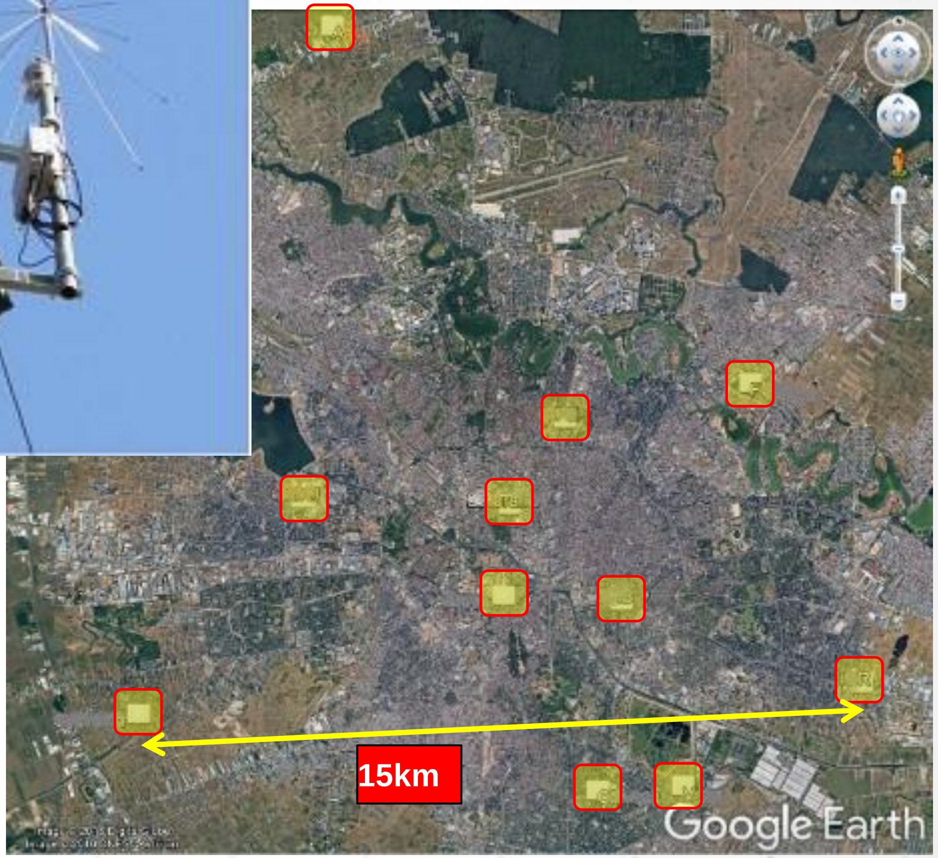
Traditional spectrum monitoring and DF systems are too big, expensive, and hard to site for today's high-density urban settings *and* modern wideband signals.



Time-Synchronous RF Sensor Networks

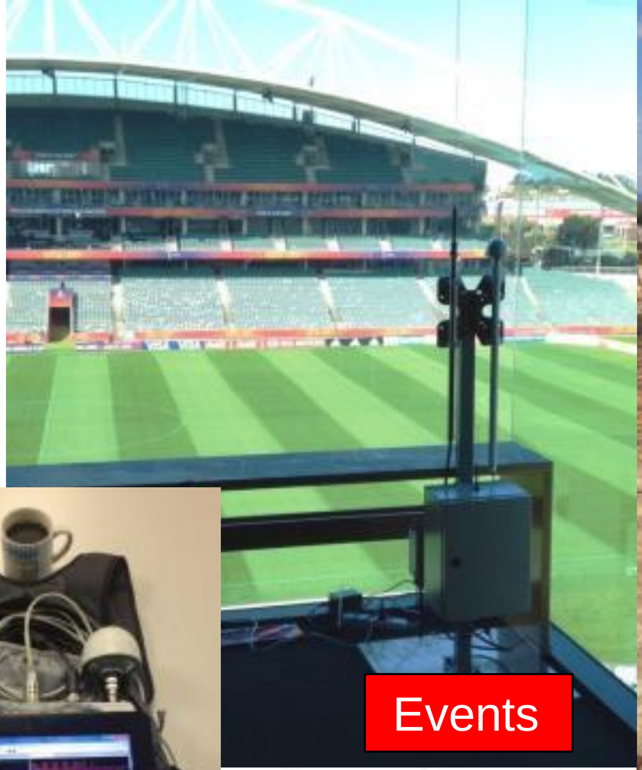
MONITORING AND LOCATING MODERN COMMUNICATION SIGNALS

- RF sensors can be deployed in higher number and density where needed to provide RF coverage and emitter location capabilities.
- Each sensor is synchronized precisely to the GPS constellation and derives location, time and frequency reference.
- This forms a network of synchronous RF sensors capable of time-cooperative measurements.



Time-Synchronous RF Sensors

INSTALLATIONS FROM AROUND THE WORLD



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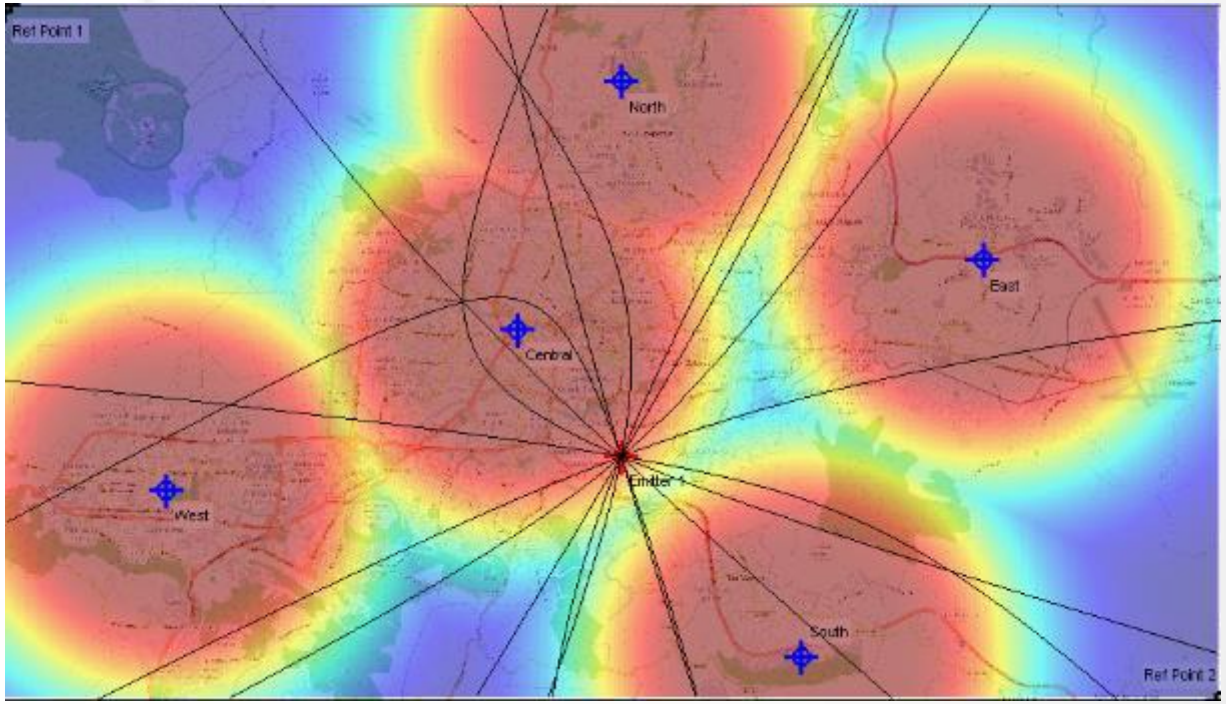
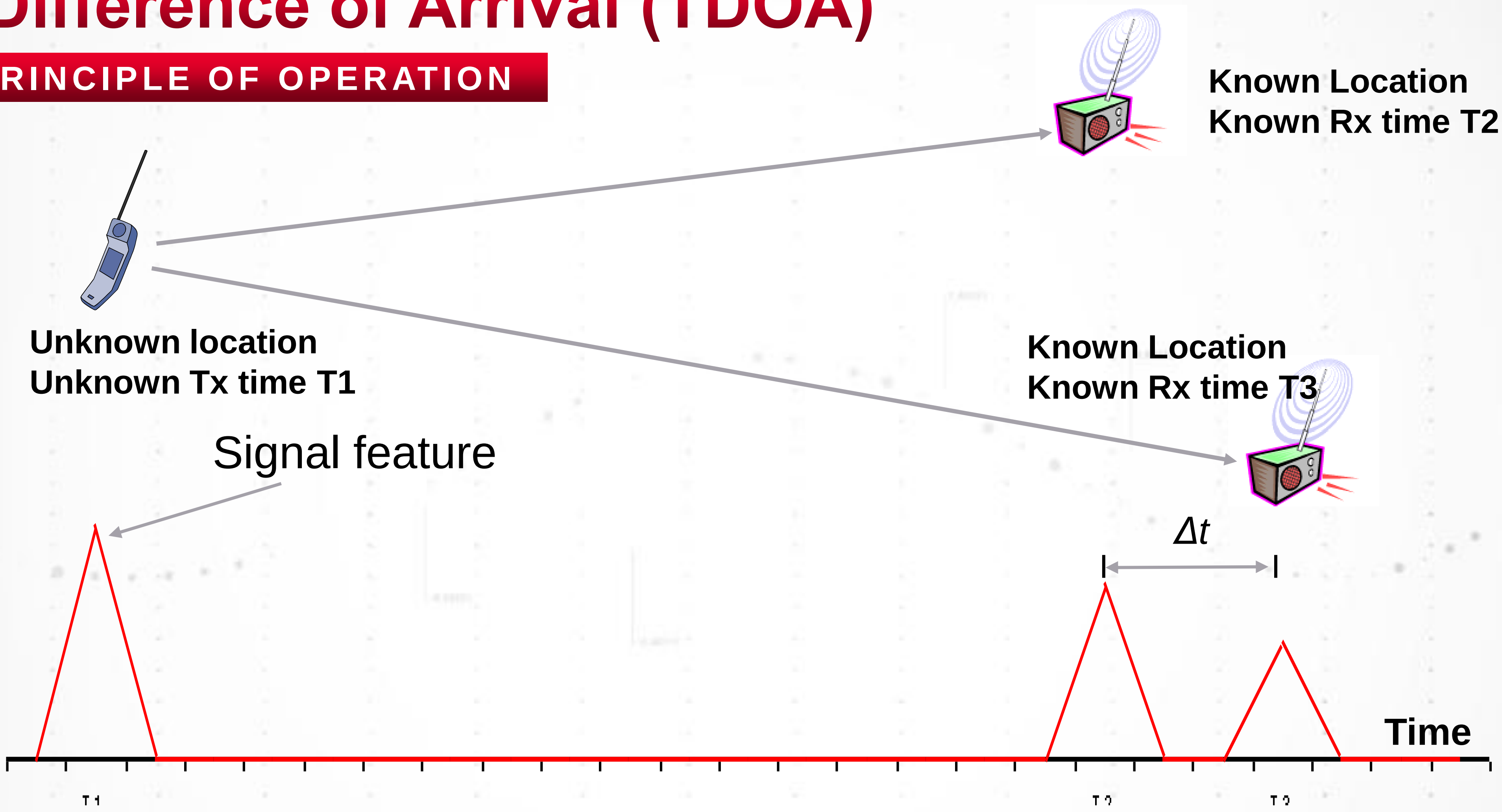


Time Difference of Arrival (TDOA)

BASIC PRINCIPLE OF OPERATION



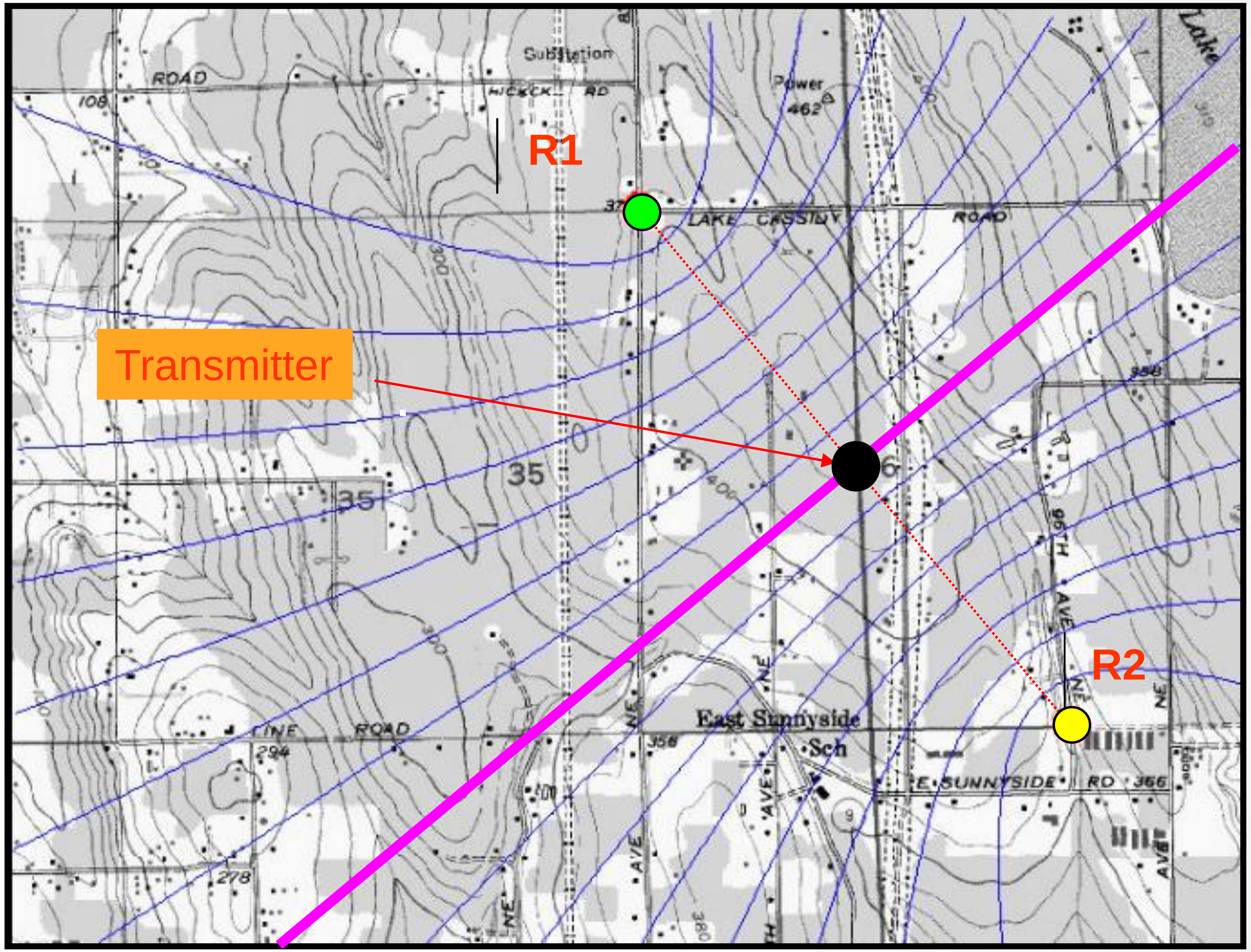
Measure time difference (Δt) between the arrival of the signal at each receiver

Time Difference of Arrival (TDOA)

TWO-DIMENSIONAL VIEW OF HYPERBOLA

- Lines of constant time difference of arrival for a signal measured at two receivers form hyperbola, also known as isochrones.

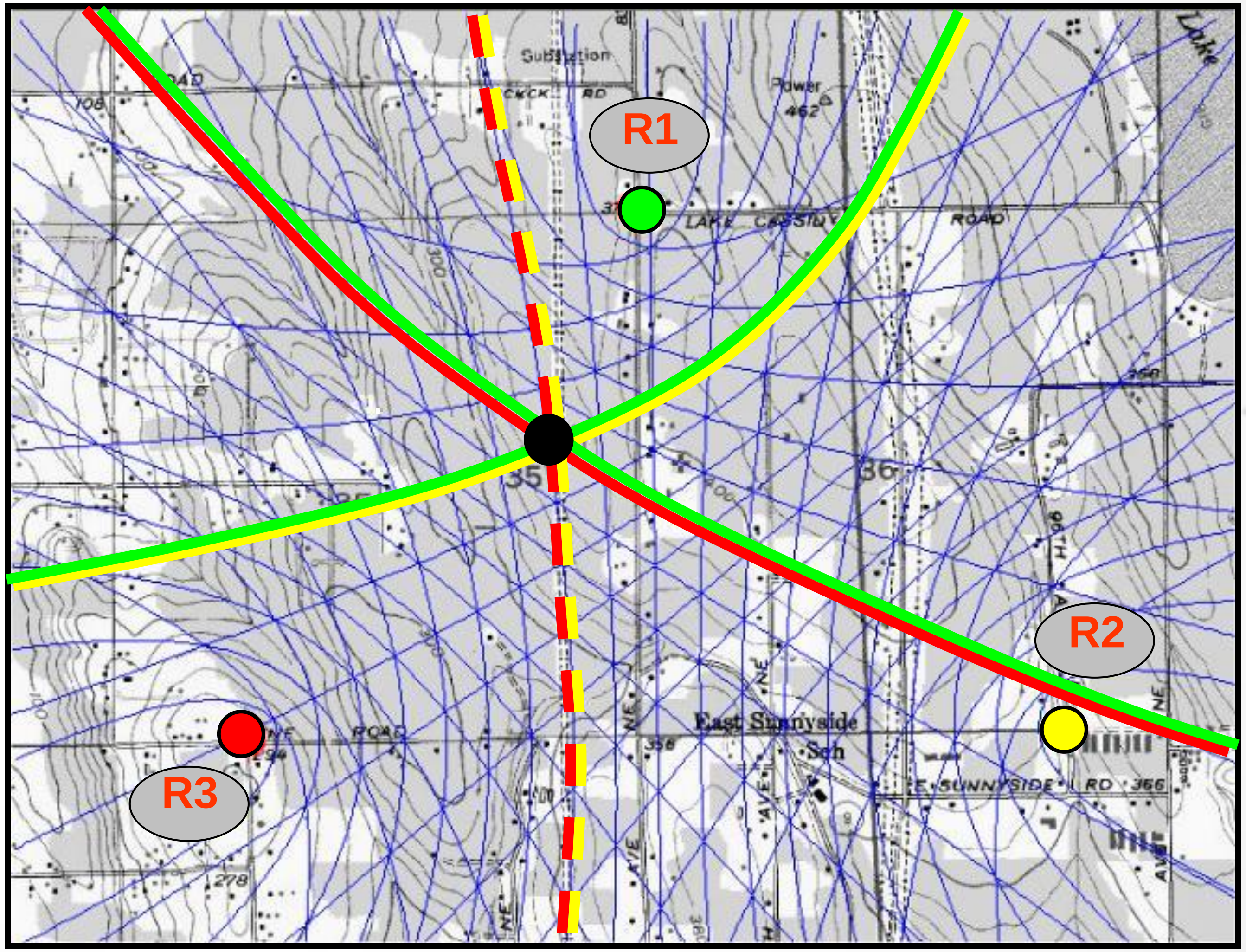
- The two receiver locations are referred to as the foci of the hyperbola



Time Difference of Arrival (TDOA)

ADDING A THIRD RECEIVER

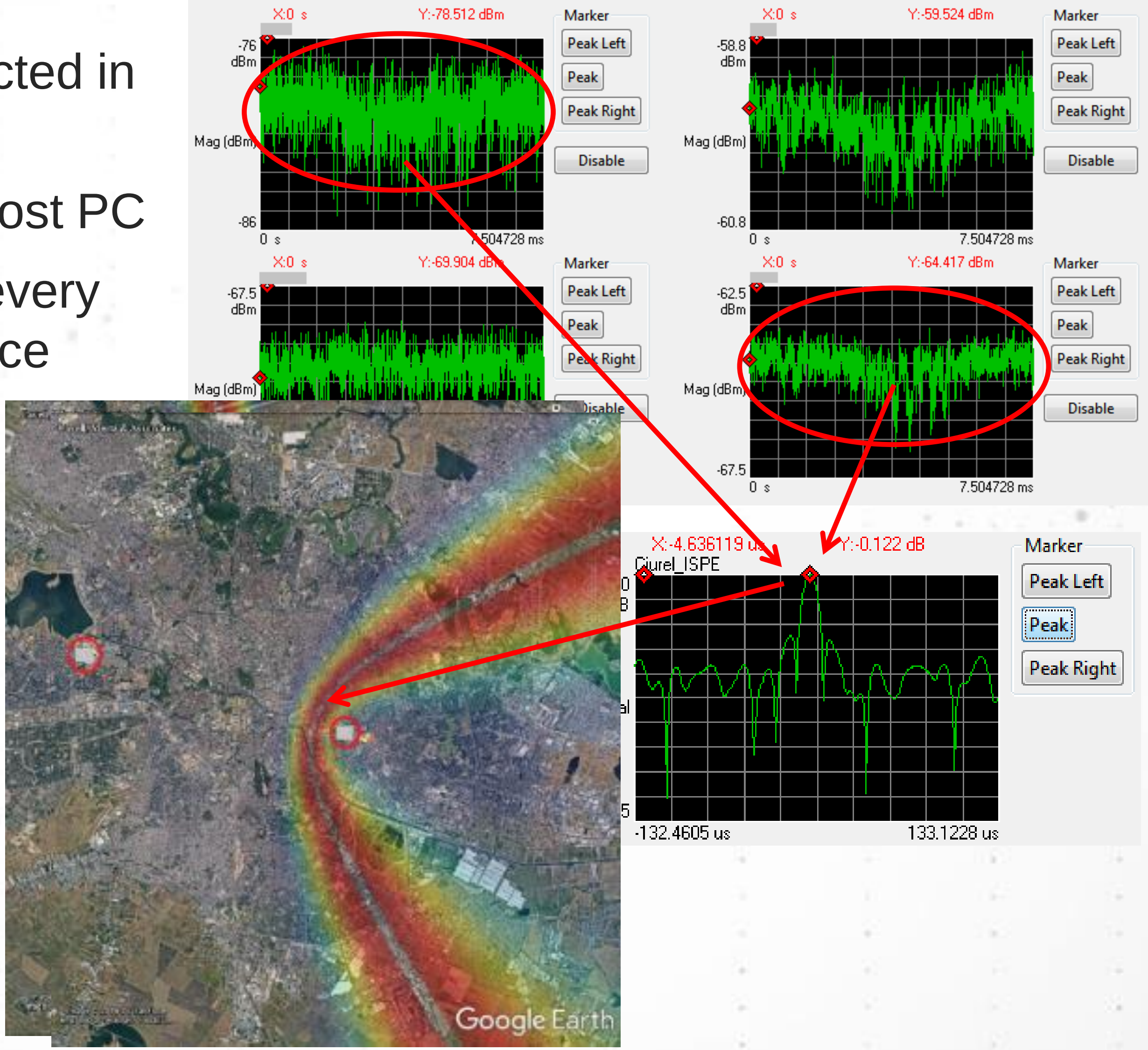
- 3rd receiver enables an estimated position (EP) or “fix” of the transmitter to be calculated
- Three sensors produce three correlations from three sensor pairs.



TDOA Computational Considerations

HOW ARE THE HYPERBOLAS MATHEMATICALLY DEVELOPED?

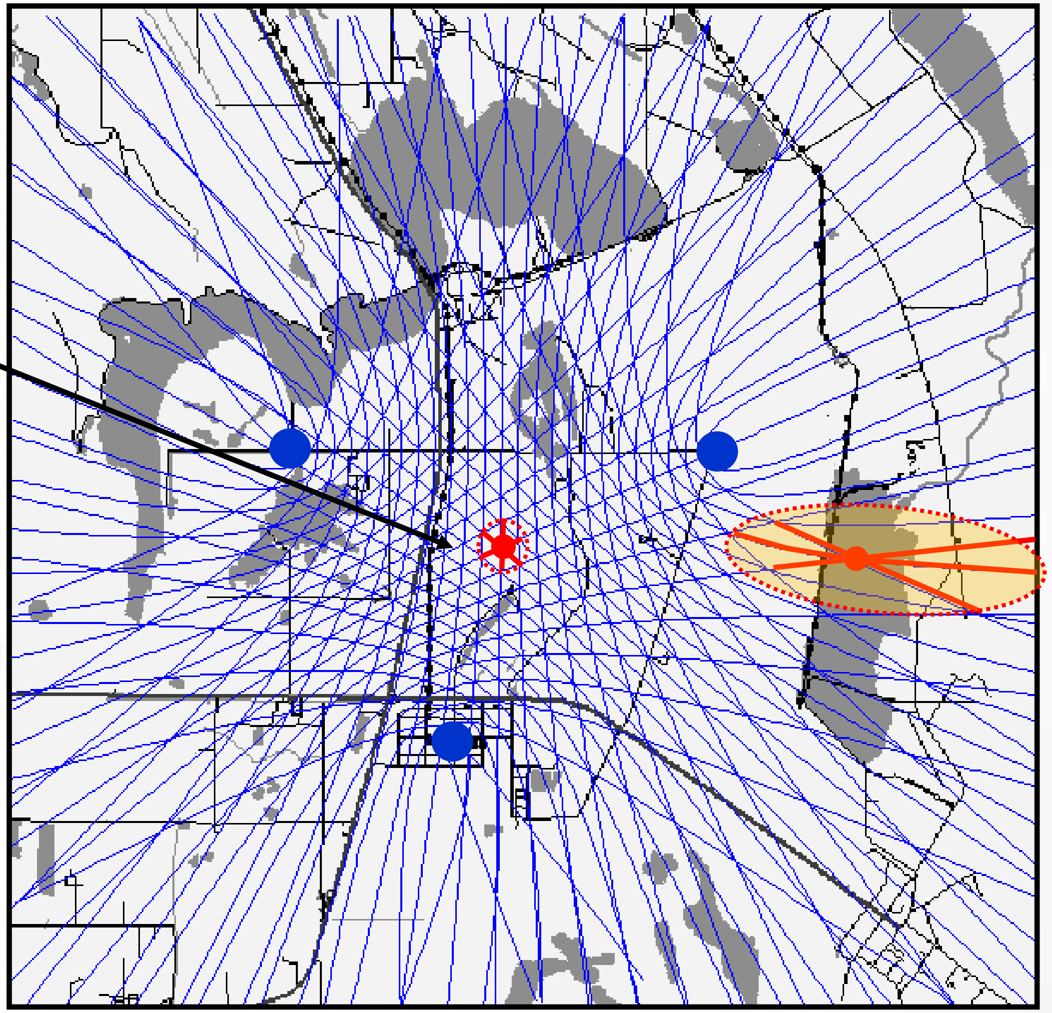
- Synchronous IQ samples are collected in the sensor network.
- Data from all sensors is sent to a host PC
- Cross-correlation is computed for every sensor pair in the network to produce the hyperbolas.



TDOA Accuracy Considerations

IMPACT OF GEOMETRY

- Geolocation accuracy is highest inside the sensor perimeter where hyperbolic lines cross perpendicularly.
- Uncertainty increases outside sensor network.

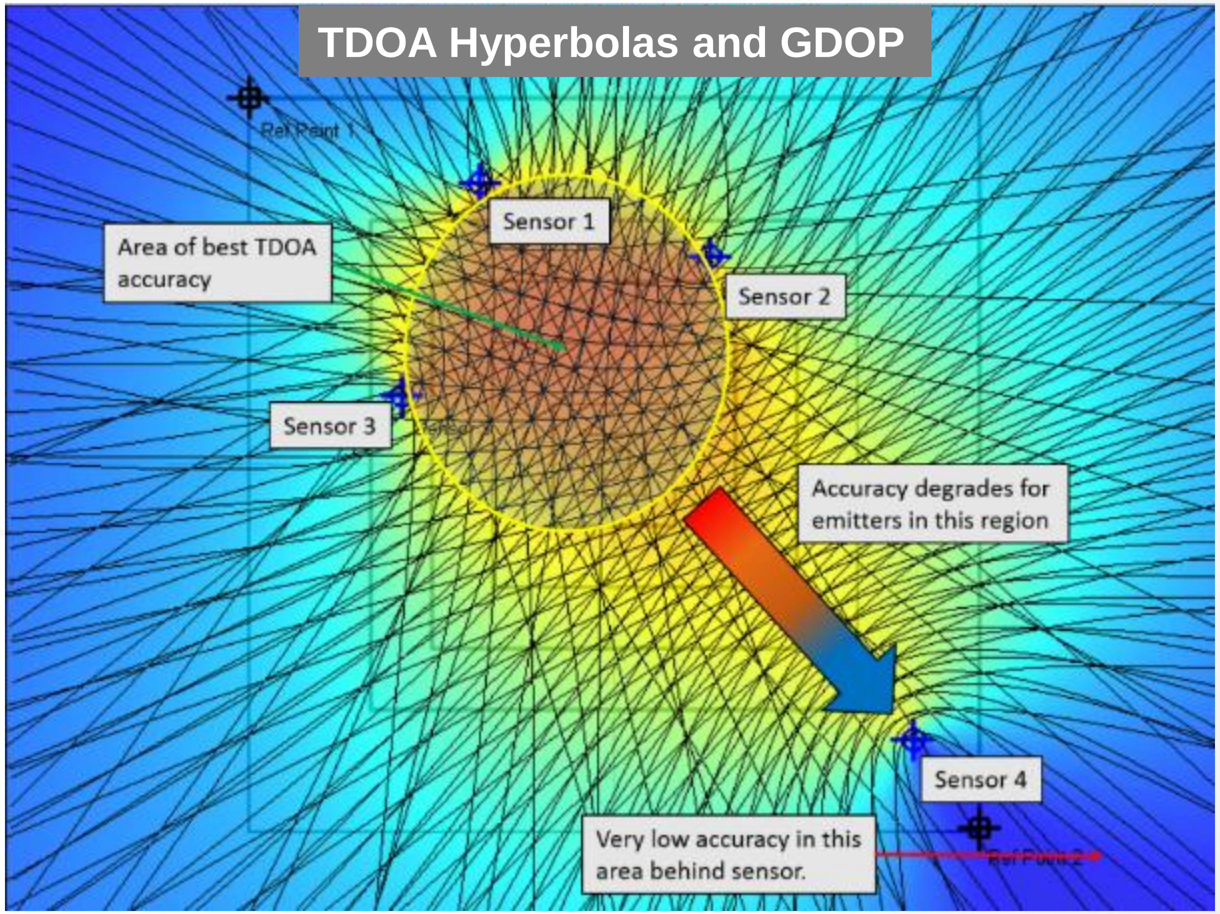


TDOA Accuracy Considerations

GEOGRAPHIC DILUTION OF PRECISION (GDOP)

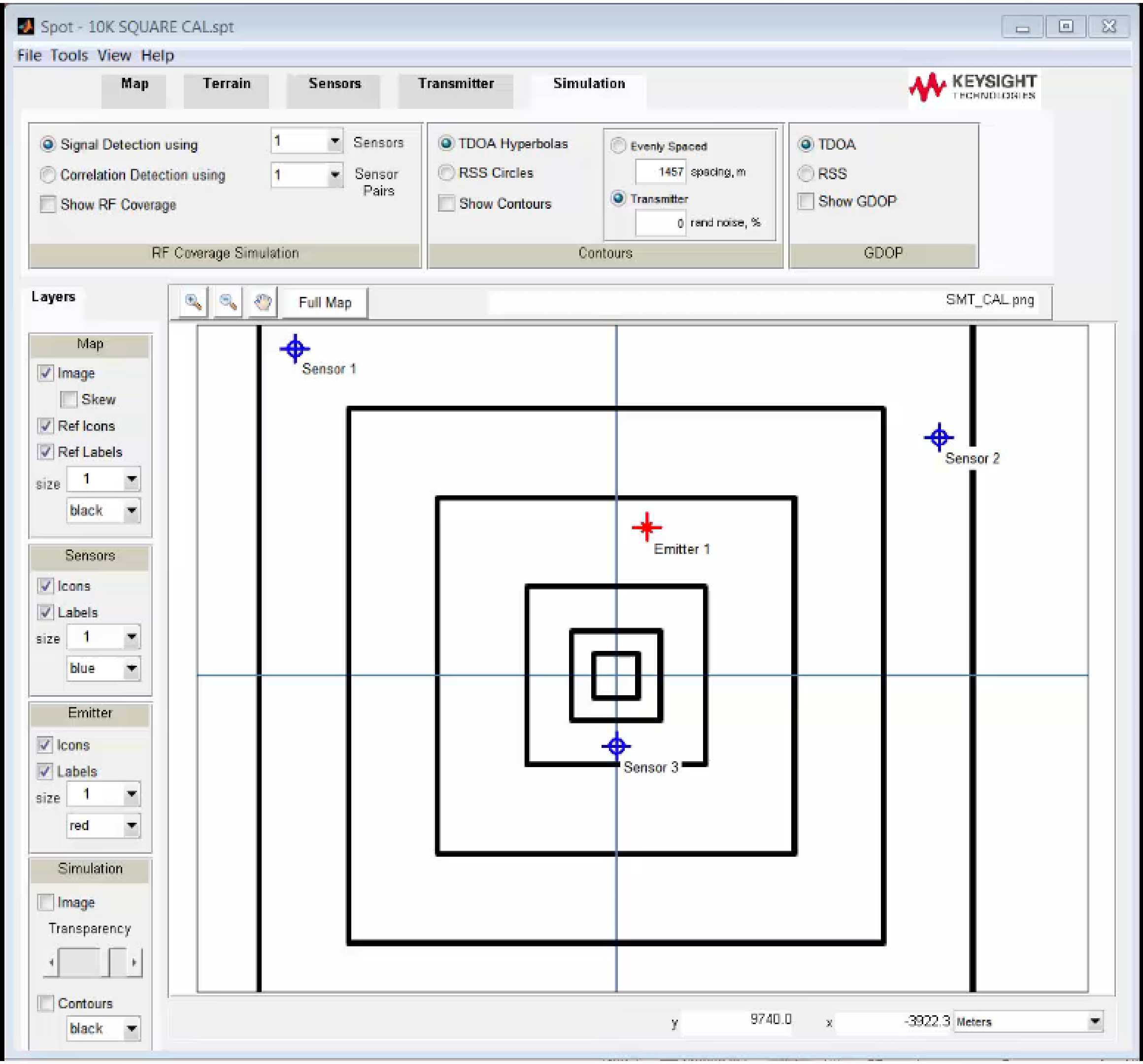
How far (spatially) the hyperbolas move for a given increase in time difference of arrival?

- Many factors affect the accuracy and sensitivity of the sensor array such as noise, multipath, etc.
- The impact of these errors on accuracy depends on the geometry of the sensor network and the location of the emitter.



Effects of GDOP on TDOA Accuracy

THREE SENSOR DEPLOYMENT

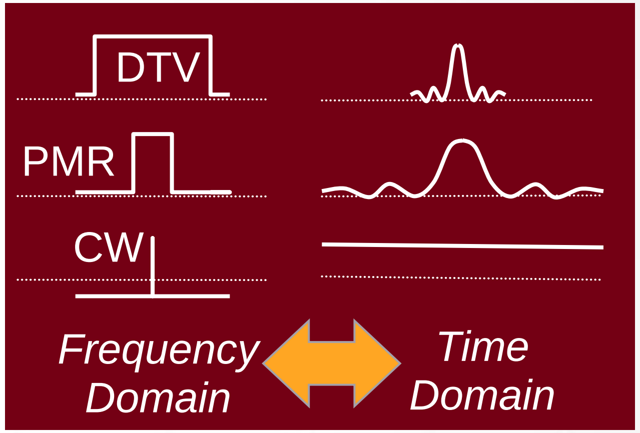


TDOA Signal Considerations

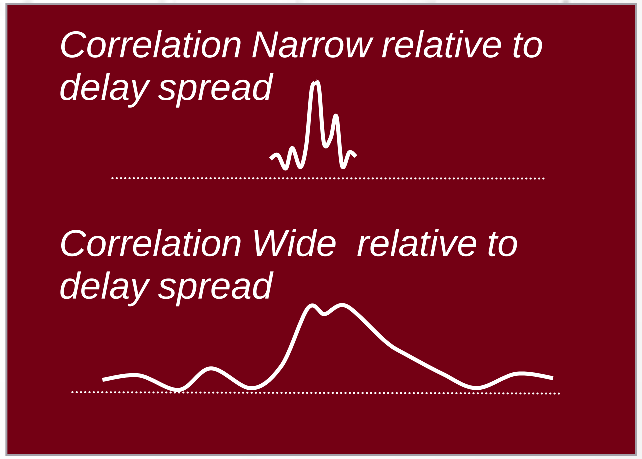
IMPORTANT CONCEPTS TO GRASP

- Time – Bandwidth relationship
  - Wide signals produce narrow correlation peaks
  - Accuracy improves with increasing bandwidth (if SNR held constant)
- Multipath
  - For wideband signals, this results in multiple correlation peaks
  - For narrowband signals, this distorts the correlation pulse shape
  - Geo Result improves with increased sensor density
- Signal to Noise
  - This will be addressed on a later slide.

Time-BW

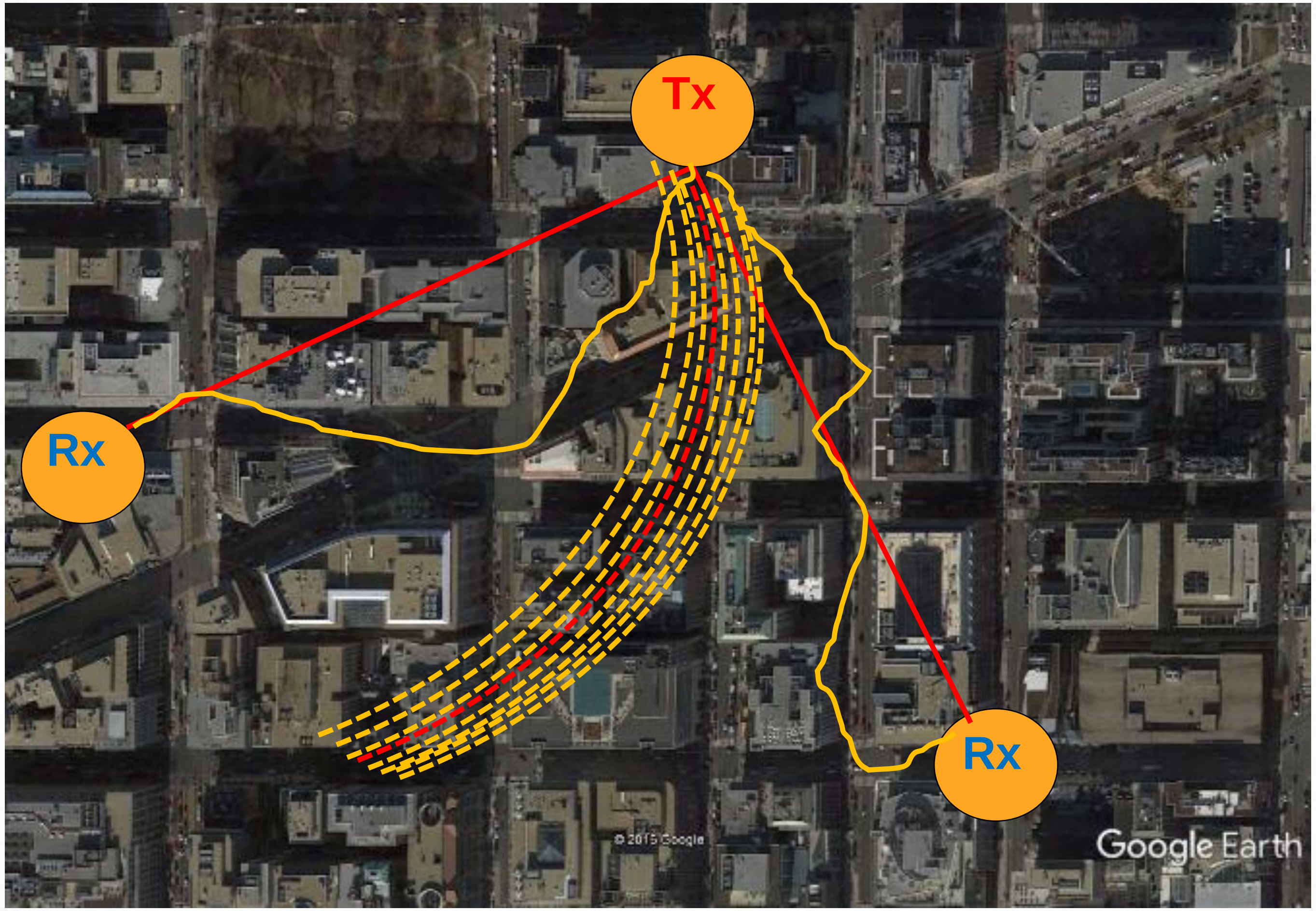


Multi-Path

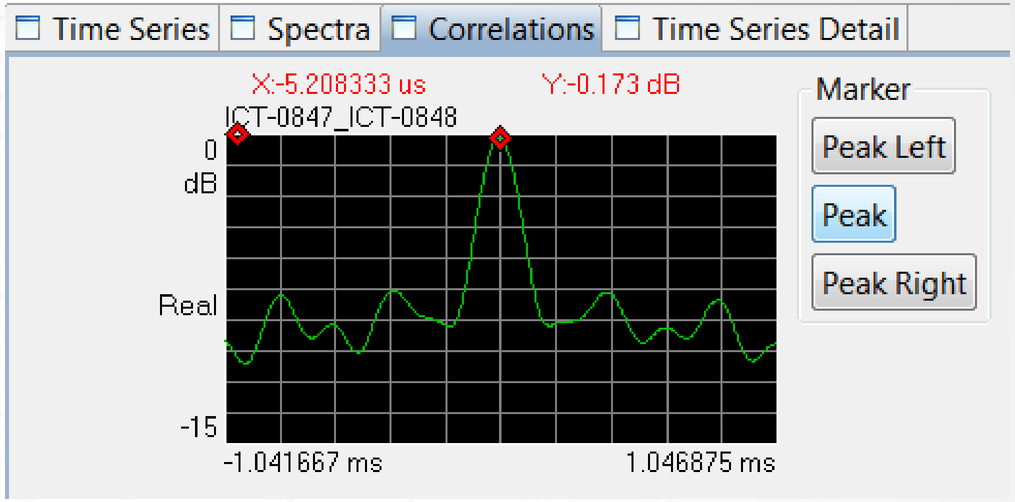


TDOA Signal Considerations - Multipath

POSITIONAL ERROR FROM MULTIPATH COMPOUNDED BY GDOP

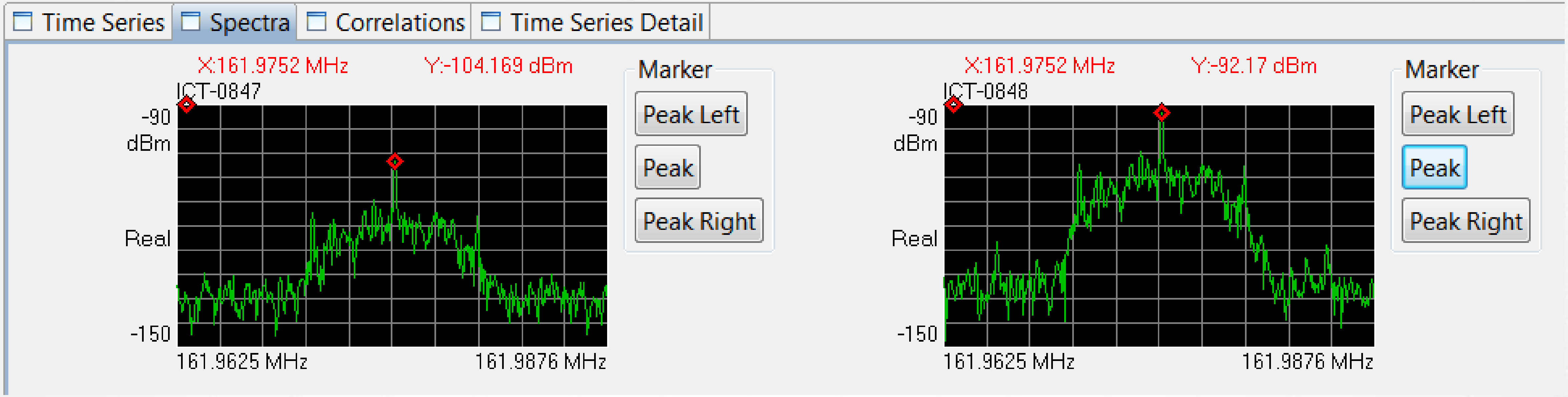


TDOA Signal Considerations



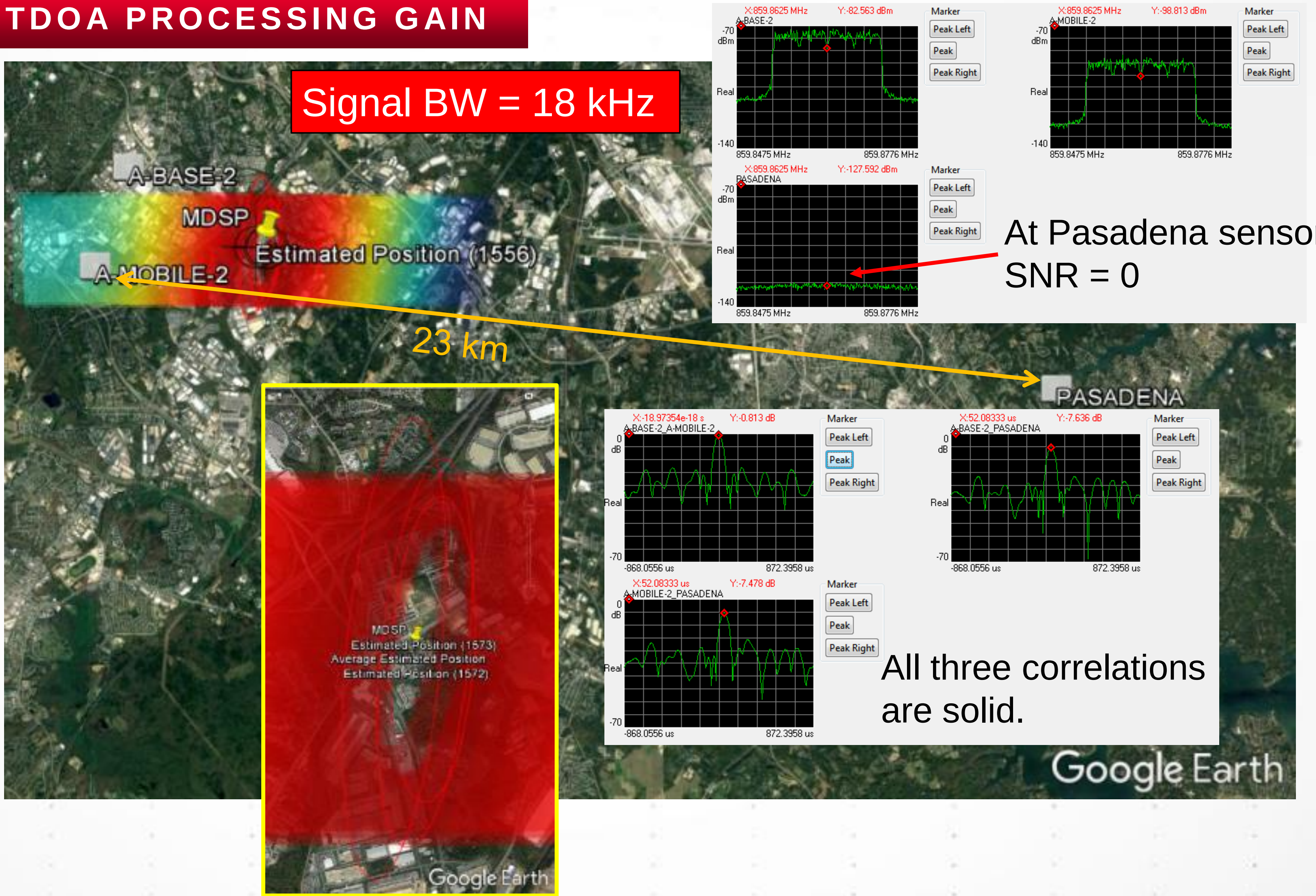
Signal to Noise

- Cross-correlation function can pull signals out of the noise (TDOA processing gain)
- Locate signals that are too weak to observe with a spectrum analyzer
- Geo Result improves the longer you acquire the signal (up to a point of de-correlation)



TDOA Signal Considerations - SNR

EXAMPLE OF TDOA PROCESSING GAIN



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TDOA Sources of Error

MOST SIGNIFICANT SHOWN FIRST

- Signal Bandwidth and SNR
  - The Cramer Rao Lower Bound, a statistically based estimate of the lower bound, predicts TDOA error to be inversely proportional to signal bandwidth and to the square root of the SNR
- GDOP (impact of geometry)
- Environmental effects (multipath and co-channel interference)
- Timing accuracy of the sensor
- Accuracy of the physical location of the sensor

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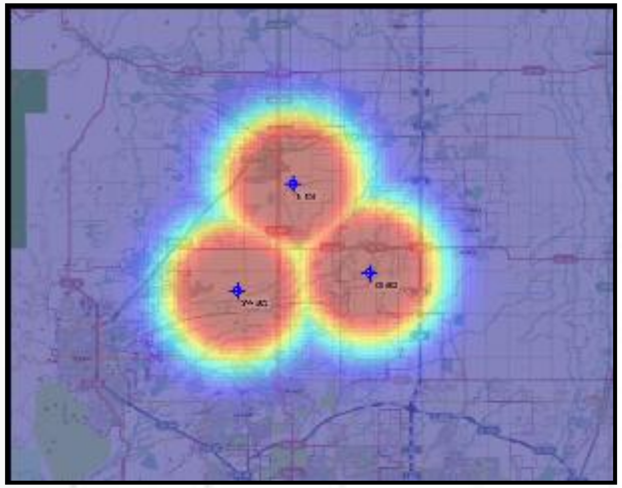
KEYSIGHT TECHNOLOGIES

Advantage of Time-Synchronous Sensor Networks

MORE EFFICIENT COVERAGE AREA FOR GEO

Target: Low Power Spread Spectrum emitter

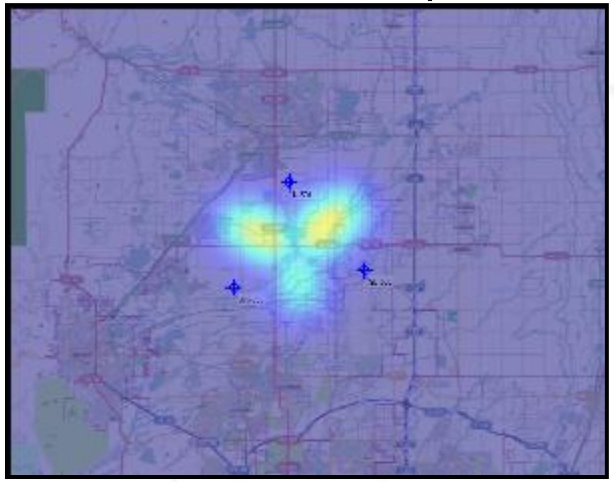
RF Detection Range



Probability of > 0dB SNR at <u>one</u> sensor

i.e. Detecting signal with conventional monitoring receiver

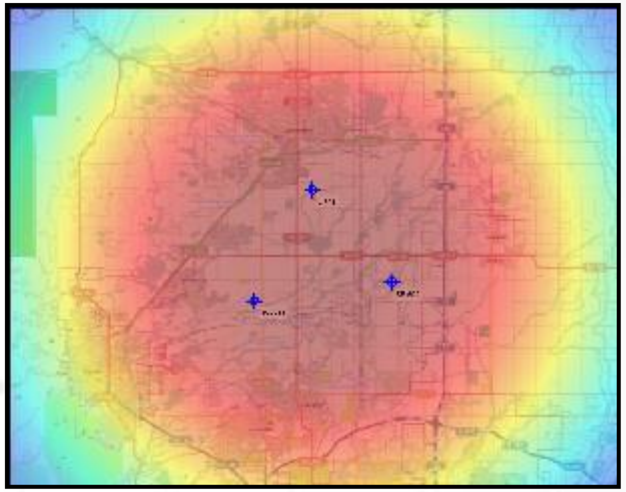
AOA Technique



Probability of > 0dB SNR at <u>two</u> sensors

i.e. DF Location Coverage Template

TDOA Correlation Technique



Probability of three usable correlation pairs (fix)

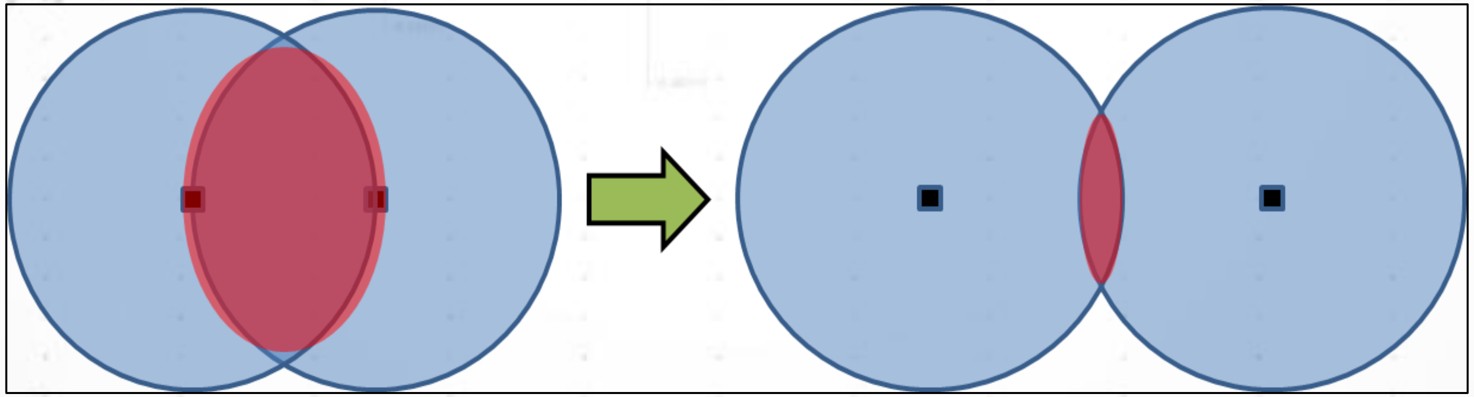
i.e. TDOA Geolocation Coverage Area with time-synchronous RF sensors

Blue < 20% **Red > 80%**

Comparison of TDOA and AOA Deployment

SEPARATION DISTANCE IS DETERMINED DIFFERENTLY

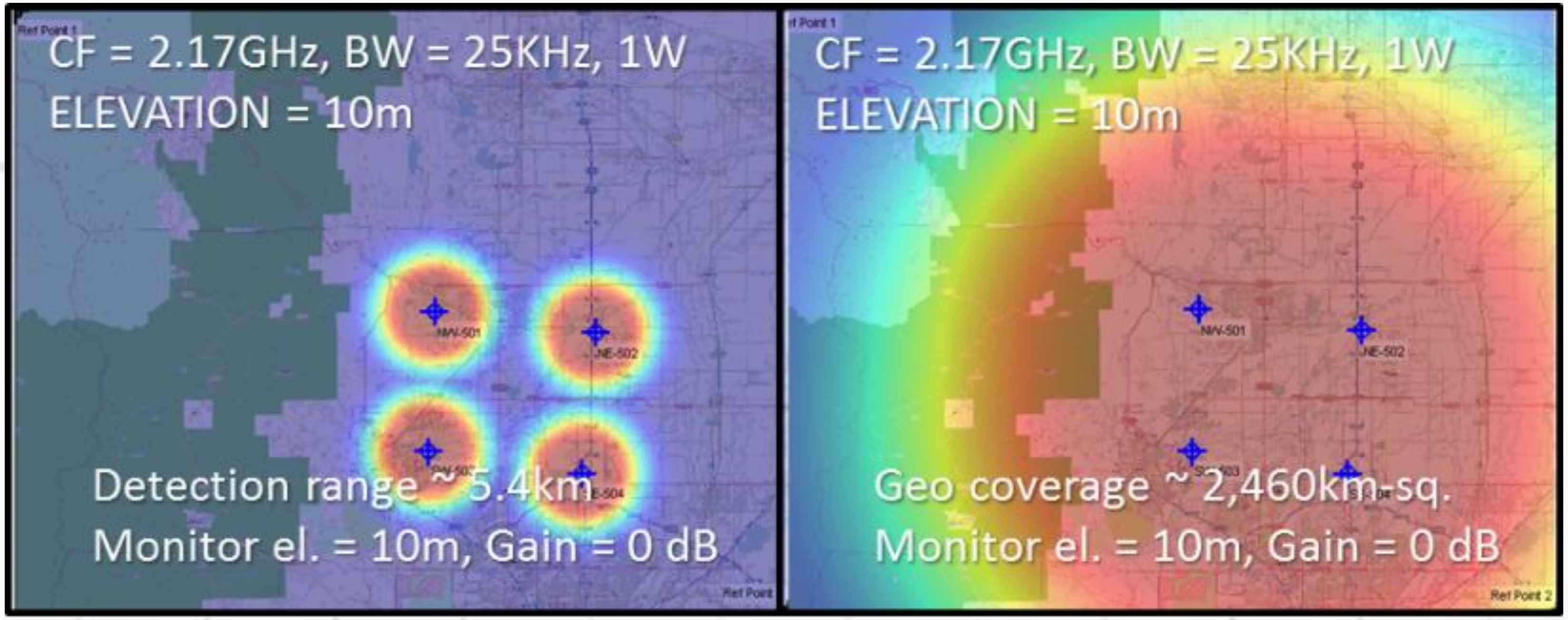
- Report ITU-R SM.2356 "*Procedures for planning and optimization of spectrum-monitoring networks in the VHF/UHF frequency range*", Section 3.1 states, "As the distance between (DF) stations increases, the size of the overlapping direction-finding zones rapidly diminishes to nothing."
- The area where emitters can be located using DF is shown in red – between the locations of the monitoring stations. RF Detection Range is shown in blue.



Comparison of TDOA and AOA Deployment

SEPARATION DISTANCE IS DETERMINED DIFFERENTLY

- Report ITU-R SM.2211, “*Comparison of TDOA and AOA methods of signal geolocation*”, Section 4 states, “Processing gains achieved by advanced TDOA algorithms can provide emitter location capabilities over an area greater than the detection range of the individual stations.”
- Detection range is shown on the left while geolocation coverage area is shown on the right – in red.



Comparison of TDOA and AOA Deployment

SITING AND CALIBRATION REQUIREMENTS

TDOA

- Small antennas and size allow for flexibility in siting
- Better suited for high multipath environments (indoors, stadiums, dense urban)
- Faster to deploy, no recalibration after siting
- More efficient spacing of sensors is possible due to TDOA processing gain.

DF (AoA)

- More restrictive requirements: Typically on tall masts or towers
- Avoid local wavefront distortion due to nearby obstacles, ground reflections, and ground conductivity changes (i.e. rural)
- May require recalibration after installation to reduce frequency and direction dependent errors
- Overlap of RF detection range is required for successful geolocation.

Comparison of Methods

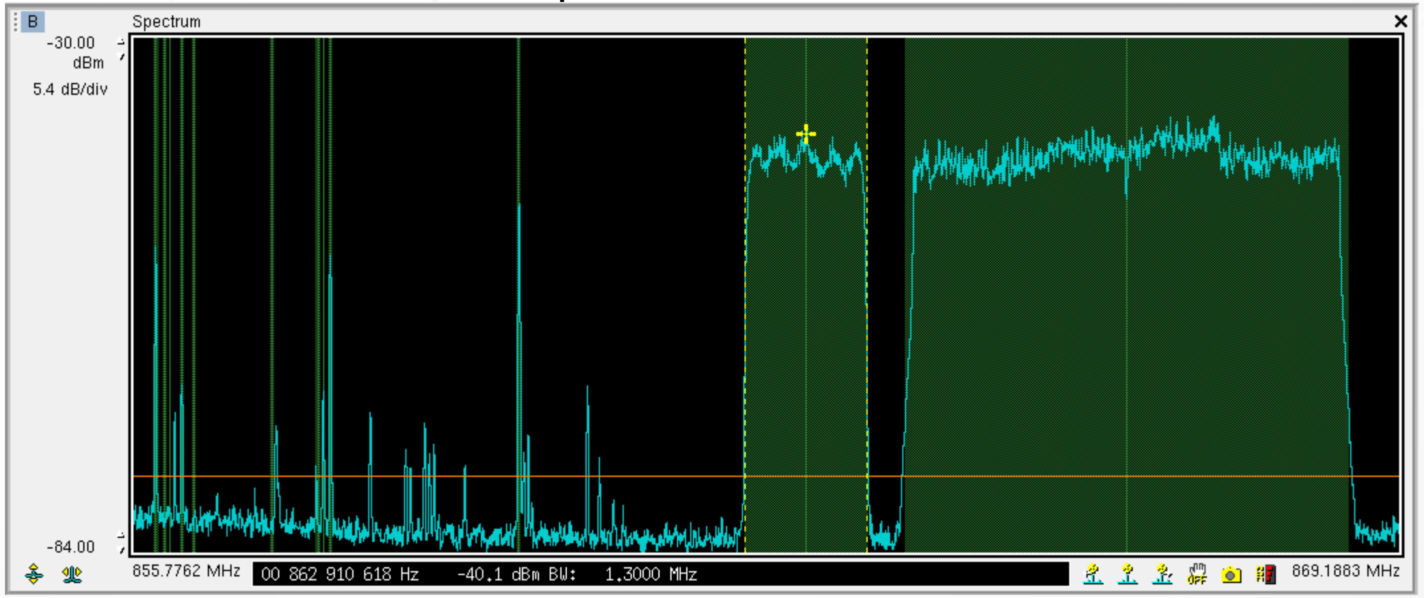
SIGNAL BANDWIDTH CONSIDERATIONS

TDOA

- Accuracy is affected by signal bandwidth (best for BW > 10 kHz)
- However, even signals with only a few kHz of modulation bandwidth have been reliably geolocated in urban environments
- RF sensor networks can also use power-based geolocation (RSS) for very narrowband and CW signals

DF (AoA)

- Better suited for narrowband and CW signals
- Depending on the technology of the system and the antenna design, DF systems may be very accurate on emitters with wide bandwidth and complex modulation.

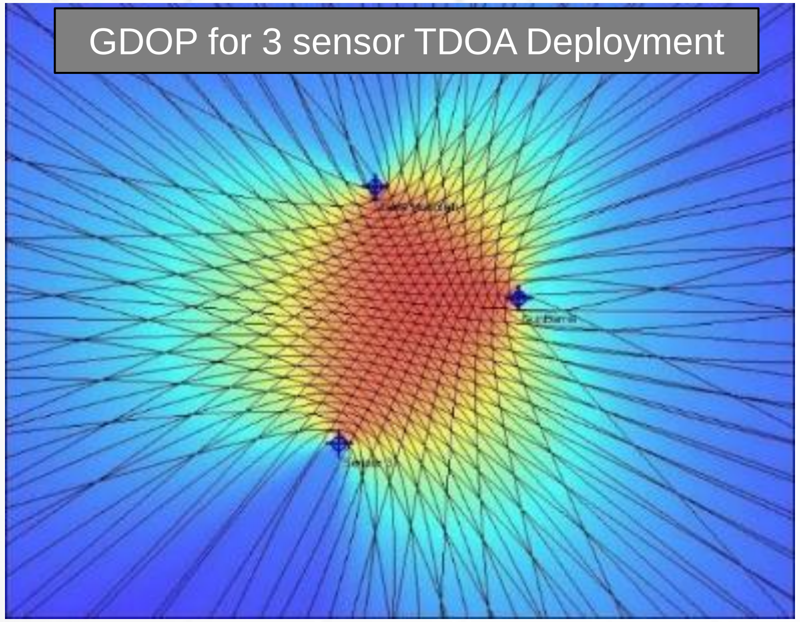


Comparison of Methods

GEOMETRY CONSIDERATIONS

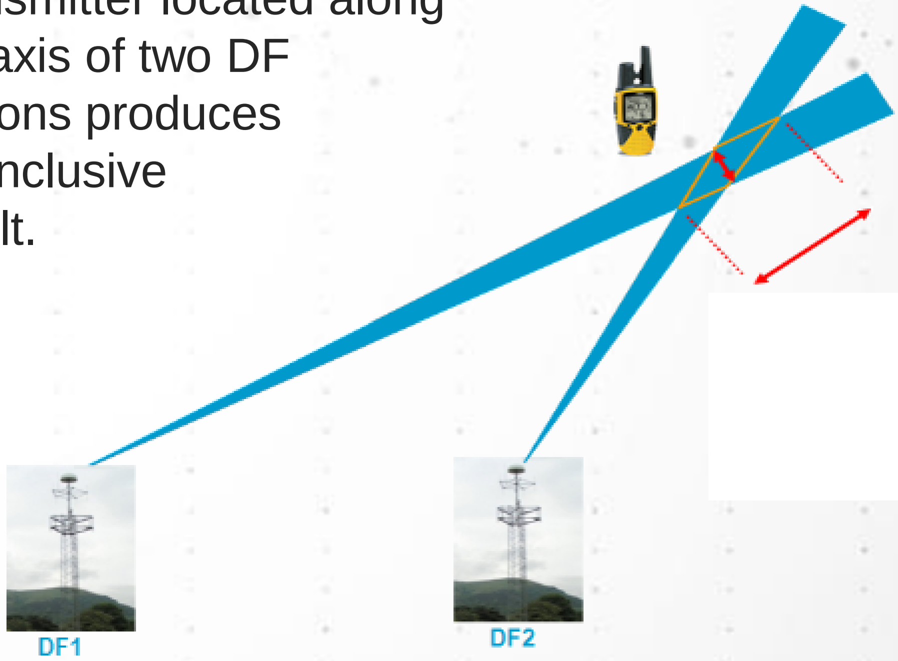
TDOA

- Requires two stations for signal homing
- Well suited for monitoring and geolocation over large area due to easier siting of receiver locations
- LOB outside sensor perimeter



DF (AoA)

- Well suited for signal homing with one mobile system
- Can provide azimuth AND elevation
- Uncertainty in azimuth increases with the range to the emitter.
- Transmitter located along the axis of two DF stations produces inconclusive result.



Comparison of Methods

SYSTEM COST CONSIDERATIONS

Description	TDOA	DF (AOA)
Equipment cost	Low	Mid to High
Antenna	Simple, low-cost	Complex, high-cost
Calibration/Maintenance	Low or none	Regular
# Receivers/site	Single	Multiple
Data Backhaul	Higher	Lower
Time Synchronization	High performance	Not essential
Siting constraints	Simple	Complex

3 Station DF system - $2 - $5M initial cost
10 Station TDOA system - $350 - $500K initial cost

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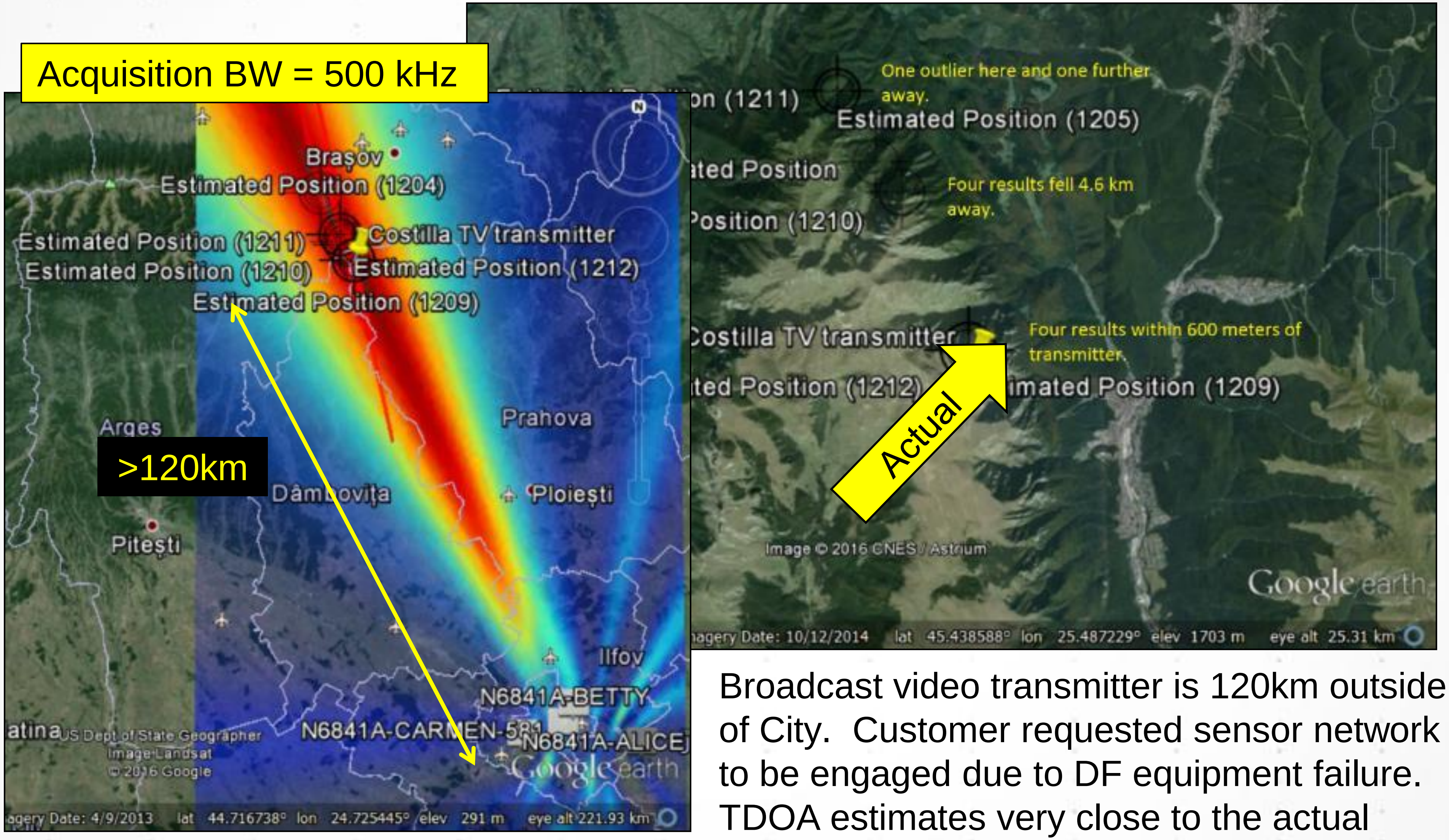
Common myths about TDOA

THINGS HEARD OUT IN THE WILD ABOUT THIS TECHNOLOGY (FAKE NEWS)

- Requires positive SNR at minimum of three sensors
  FACT: Positive SNR is needed at one sensor – to detect the signal.
- Requires a special synchronized network technology
  FACT: True only for indoor installations where GPS is not available to all sensors.
- Does NOT work on narrowband signals
  FACT: TDOA produces less accurate results on narrowband signals.
- Is not yet a proven technology. FACT: Really?
- Is just as expensive to site as other types of monitoring stations
  FACT: Leasing real estate can be a significant factor. TDOA sensors are very compact.
- Is not ITU compliant. FACT: Has been adopted over last 7 years.
- Does NOT work on signals outside the Sensor network.
  FACT: Accuracy is less for emitters outside the sensor network

TDOA Myths: Operations Outside of the Sensor Network



Broadcast video transmitter is 120km outside of City. Customer requested sensor network to be engaged due to DF equipment failure. TDOA estimates very close to the actual antenna site. The DF accuracy was < 1 degree.

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Brief Overview of the N6841A RF Sensor

BASIC SPECIFICATIONS

- 20 MHz to 6 GHz tuning range
- 20 MHz processing bandwidth (completely digital IF)
- 4.8 seconds of IQ capture (LookBack) memory
- Integrated GPS receiver for location and time synchronization
- Compact, low-power design (15-24VDC, 30W max)
- Standard 100 baseT network interface for data output, command and control
- Integrated 2-port RF input switch
- 7 pre-selector bands, pre-amplifiers and attenuators (62 dB range)
- Onboard computer (LINUX kernel) and FPGA

N6841A Value Points:
****Low-Cost
***Weatherproof: IP 67
**Synchronization < 20 nsec
*Proven Reliability (~2% CCAFR)

Deployment: Keysight Broadband Omni Antenna

MODEL NUMBER N6850A

- Consistent pattern in both azimuth & elevation.
  Improves potential for effective power-based geolocation
- Compact, simple to mount (~42 cm high)
- Operating range 20 MHz to 6 GHz
- Best performance 300 MHz to 6 GHz
- Creative mounting bracket suitable for:
  - Tripod
  - Pole/Rail
  - Mobile (magnetic)

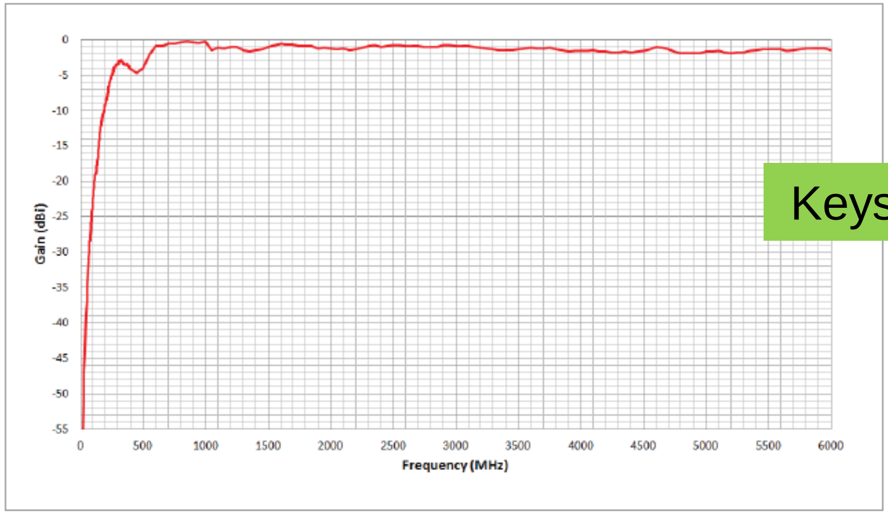


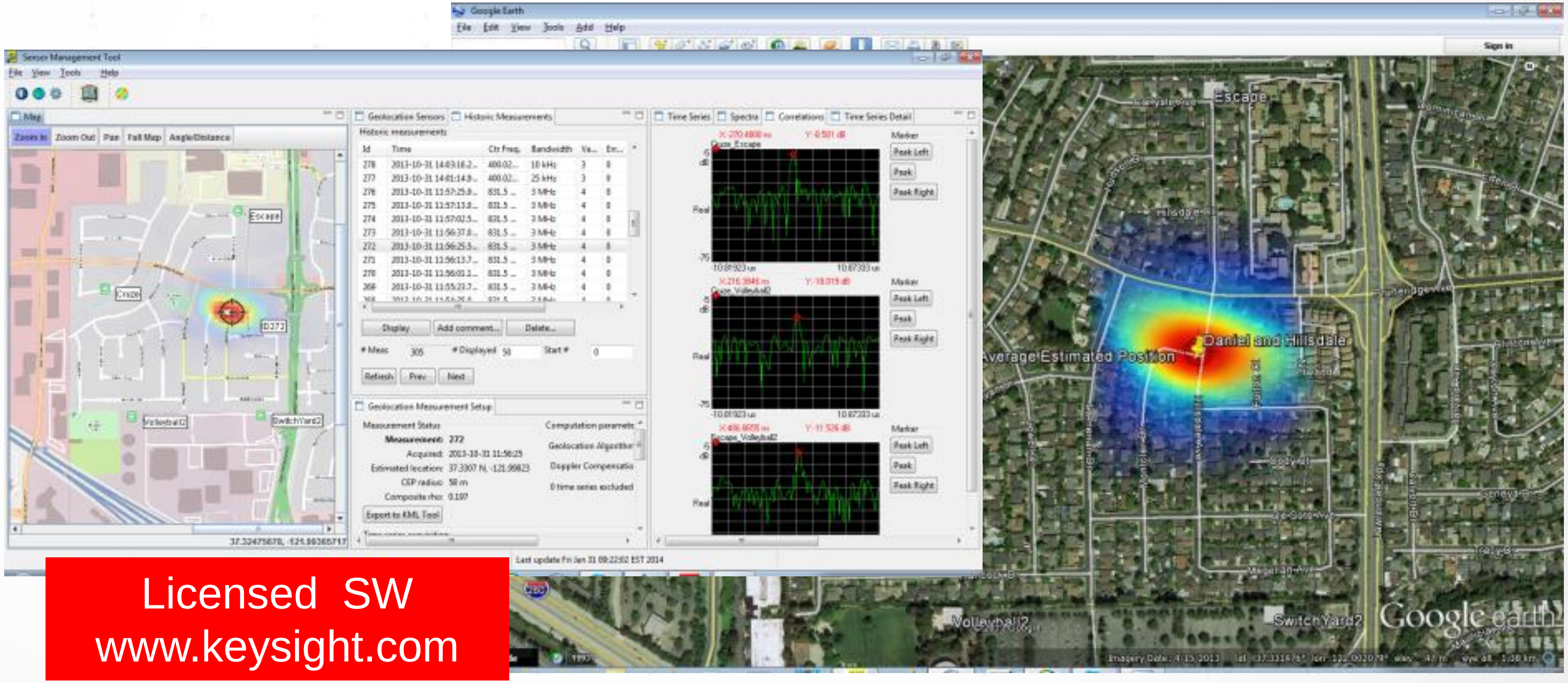
Figure 5. Average gain over all space at ambient temperature

Keysight patent pending

Locating Non-Cooperative Emitters

N6854A GEOLOCATION SERVER SOFTWARE

Synchronizes a group of RF sensors to locate RF emitters using time difference of arrival (TDOA), received signal strength (RSS) or hybrid algorithms.



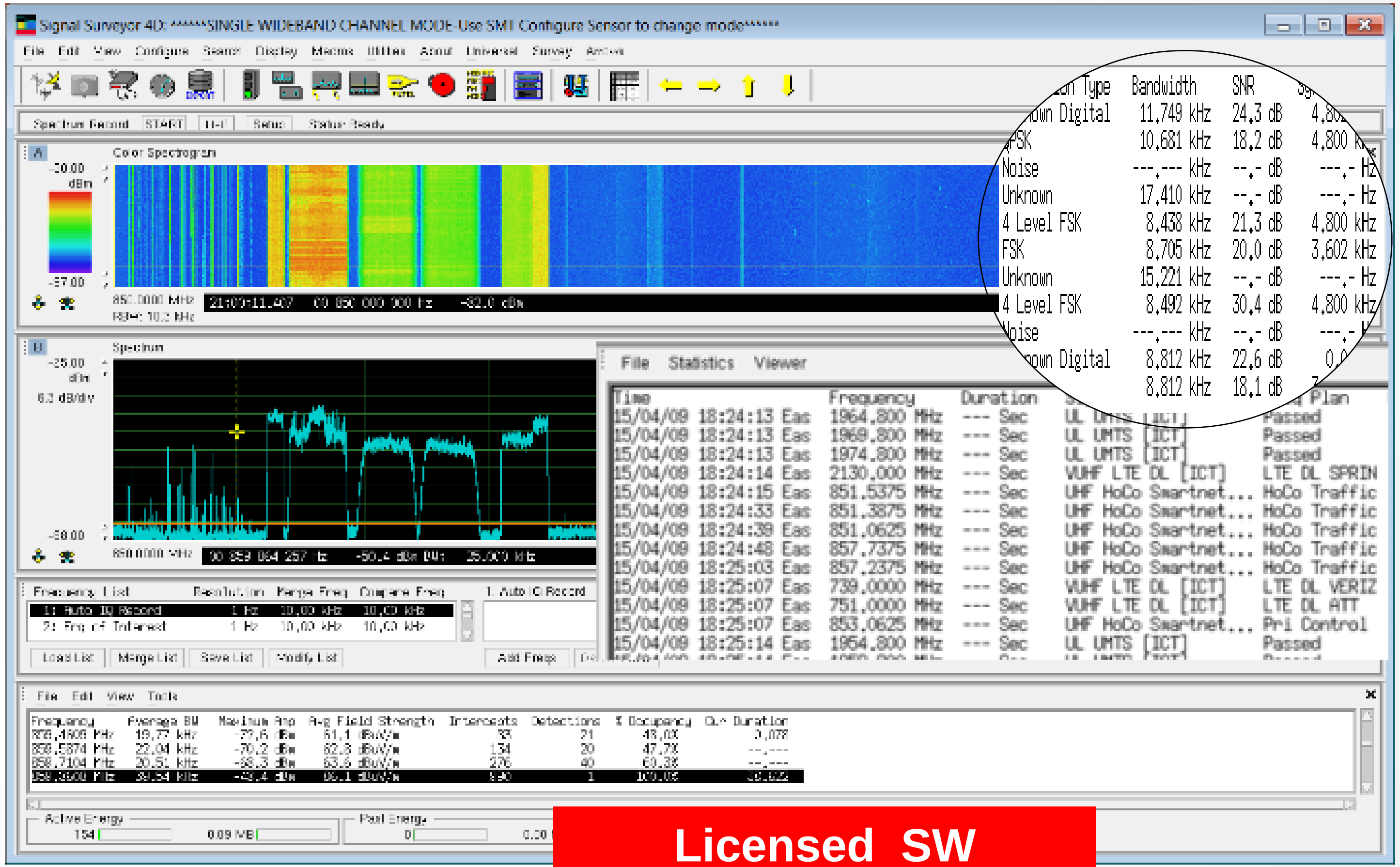
Licensed SW
www.keysight.com

KEYSIGHT TECHNOLOGIES

Automating RF Survey, Signal Classification

N6820ES SIGNAL SURVEYOR 4D

- Awareness of spectrum use, advanced energy detection, trigger and automatic alarm tasking
- Creates SQL database of spectral statistics including:
  - Signal externals/internals
  - Takes advantage of a priori knowledge
- Modulation and symbol rate classification (opt.)
- Flexible search modes (single or multi-band)
- Execute automatic or manual IQ or demodulated audio collection
- Supports multiple hardware platforms



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New Portable Tools are Now Available…

FIELD FOX PORTABLE RF TOOLKIT

- Highly effective for "walking down" the signal source to identify the antenna causing the problem.
- Useful for the last 100 meters of hunting.
- This step must be taken before you can "knock on the right door"…
- Incorporates multiple RF tools in one portable package.
- Can be used as RF front end for Surveyor 4D software

Many RF measurements in one portable, rugged package.

Summary

TDOA IS VITAL TO THE FUTURE OF SPECTRUM MONITORING

Spectrum monitoring networks based on TDOA are affordable, and based on proven technology for monitoring and locating non-cooperative, modern communication signals in urban and rural environments from fixed, mobile or temporary sites.

Thank you!

KEYSIGHT
TECHNOLOGIES