

Utility Evaluation of Improved Event Triangulation Using Synchrophasor Technology

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Southern Company Overview

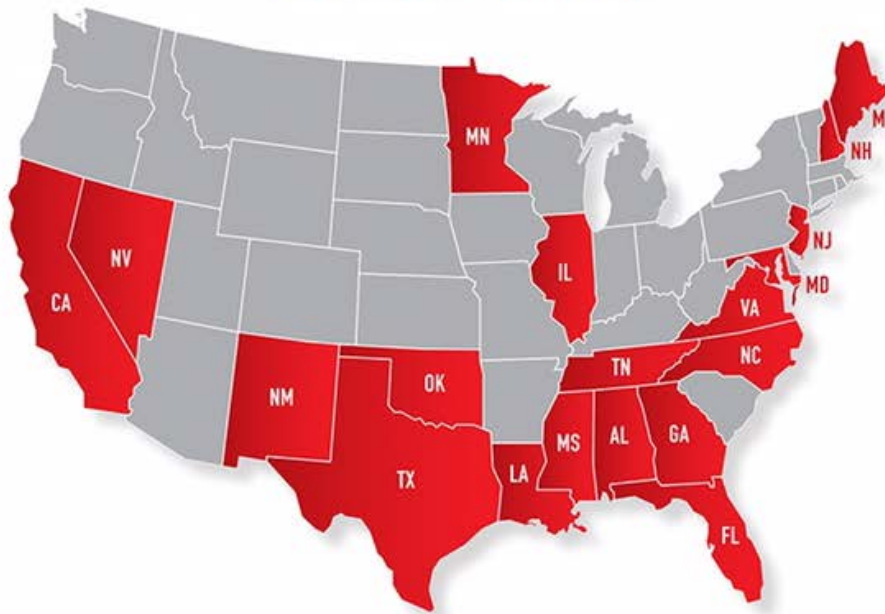
APPROXIMATELY
44,000 MW
OF GENERATING CAPACITY

NEARLY
200,000
MILES OF POWER LINES

MORE THAN
80,000
MILES OF NATURAL GAS PIPELINES

190 Bcf
OF NATURAL GAS
STORAGE CAPACITY

Service Territory



OPERATIONS IN
19 STATES

11
ELECTRIC & NATURAL GAS UTILITIES

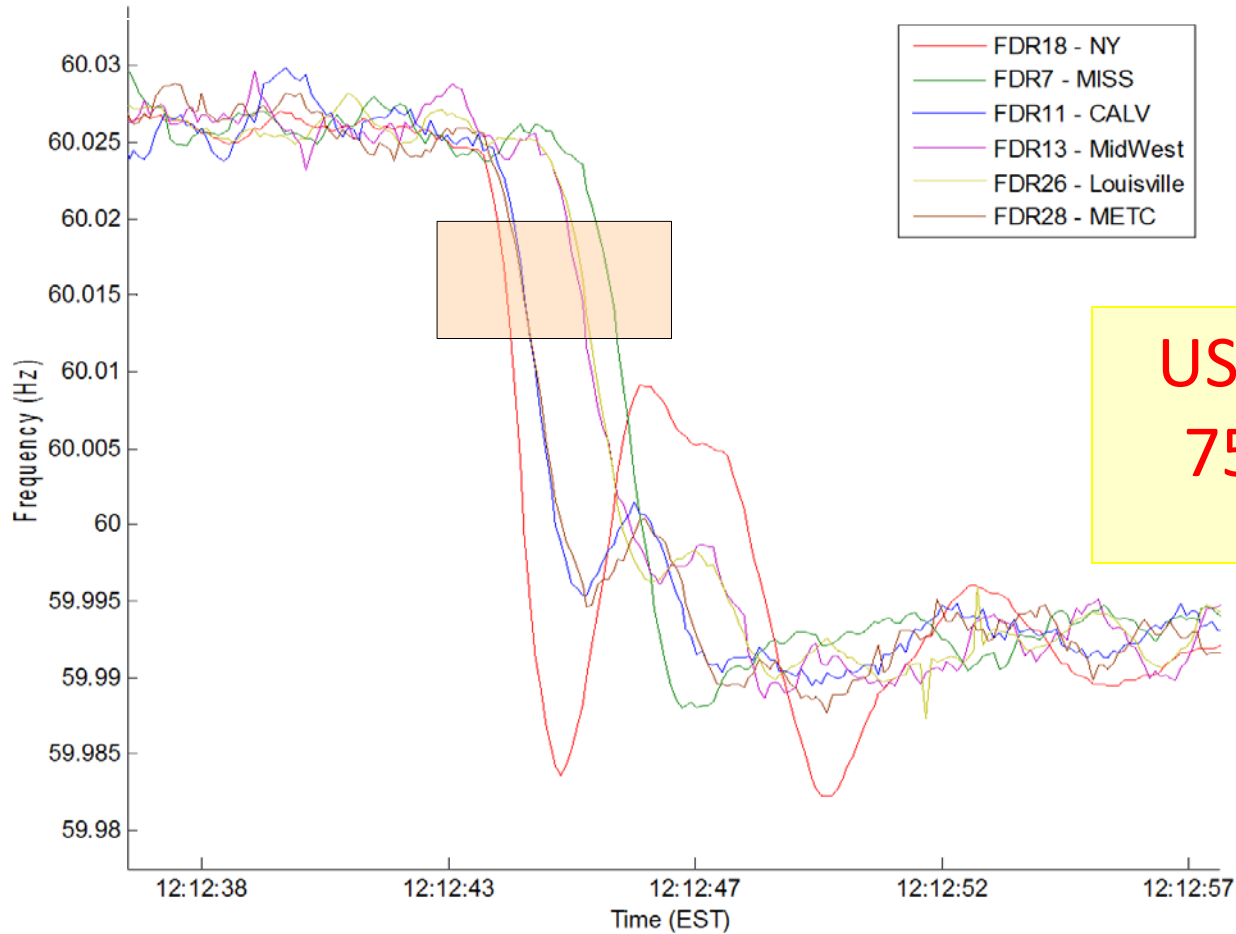
32,500
TOTAL EMPLOYEES

9 MILLION
UTILITY CUSTOMERS

MORE THAN
1 MILLION
RETAIL CUSTOMERS

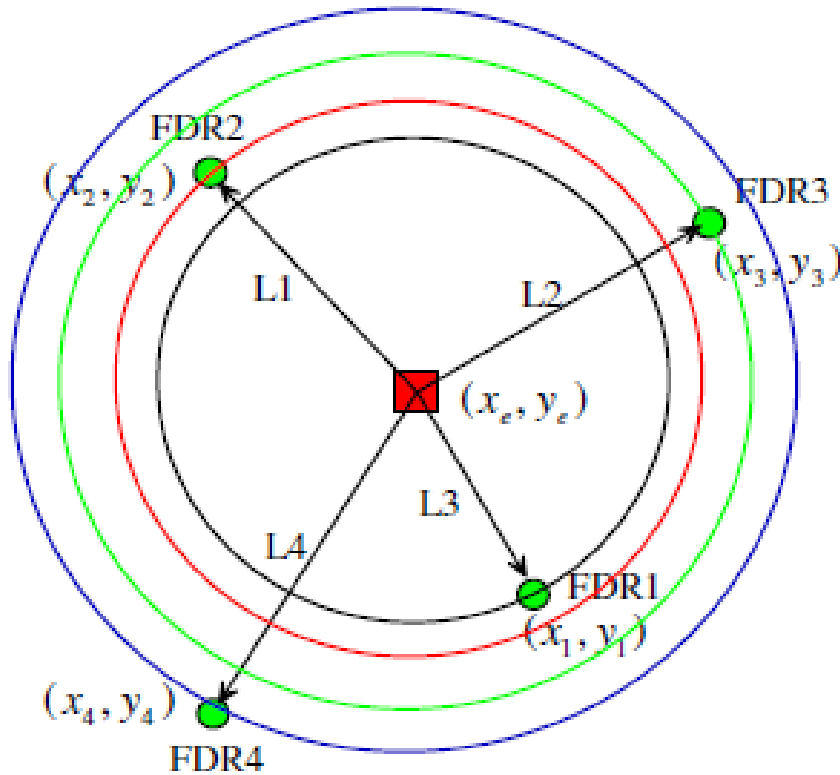
On-line Event Location

2005/9/29 10-point average



US Patent:
7519454,7765034

Event Location Triangulation



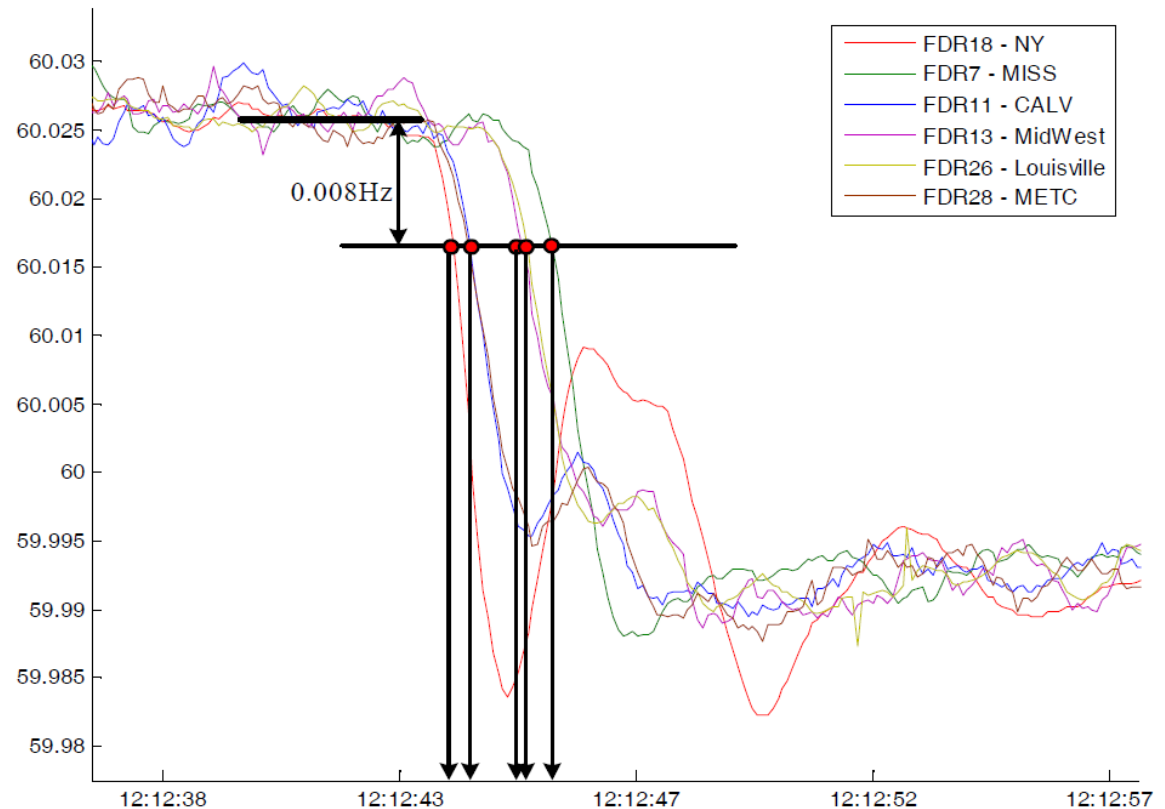
$$\begin{aligned}(x_1 - x_e)^2 + (y_1 - y_e)^2 &= V^2(t_1 - t_e)^2 \\(x_2 - x_e)^2 + (y_2 - y_e)^2 &= V^2(t_2 - t_e)^2 \\&\vdots \\(x_n - x_e)^2 + (y_n - y_e)^2 &= V^2(t_n - t_e)^2\end{aligned}$$

Time Delay of Arrival (TDOA)

Correct sequence of TDOAs is critical to solve the triangulation equations.

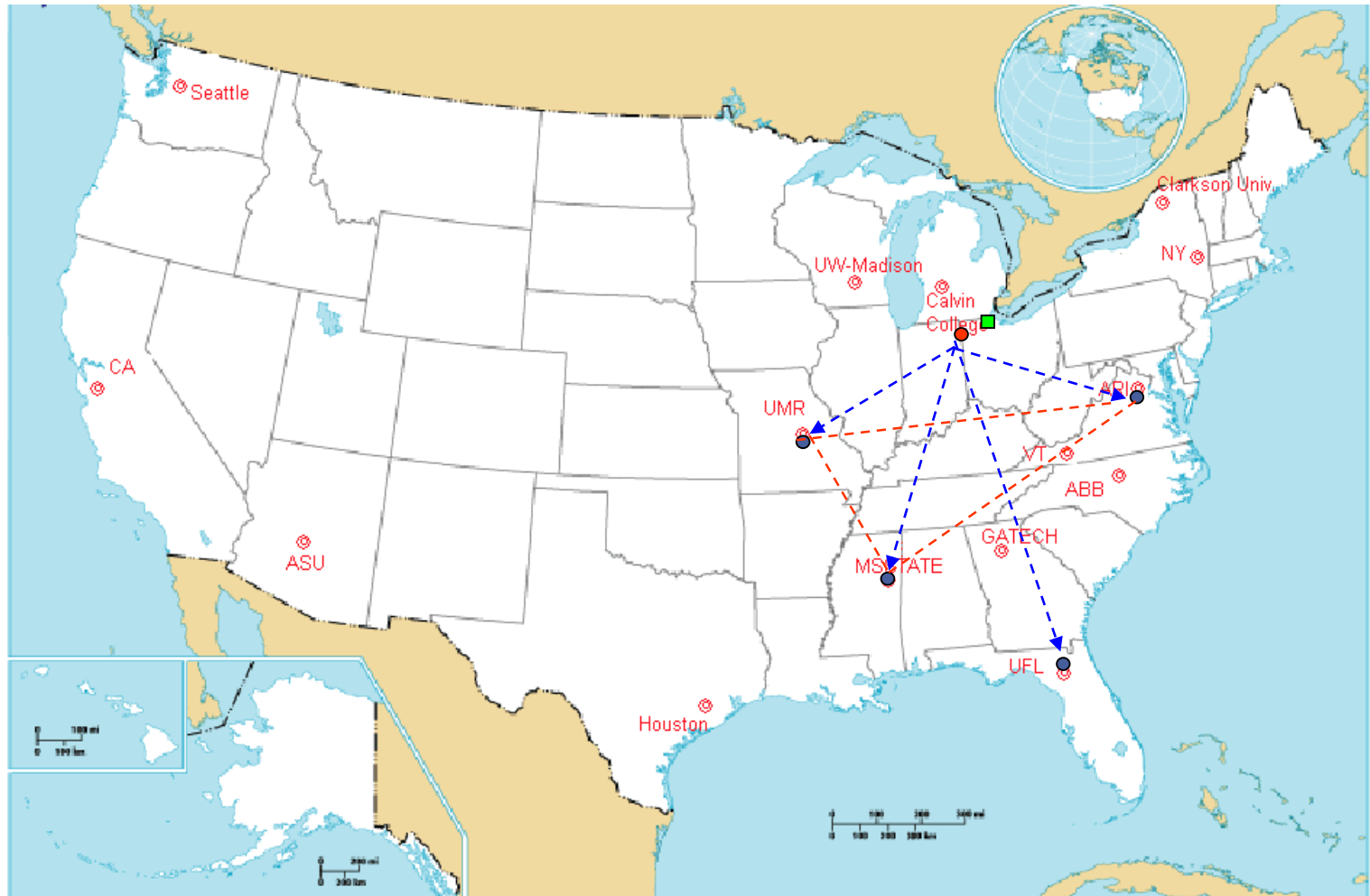
TDOAs can be derived from both frequency and phase angle measurements.

Frequency measurements directly give the TDOAs, but angle measurements need a series of process



Triangulation of Event Location

Red dot estimated location, Green square is actual location



Angle-based Triangulation

Angle measurement is the integration of frequency measurement

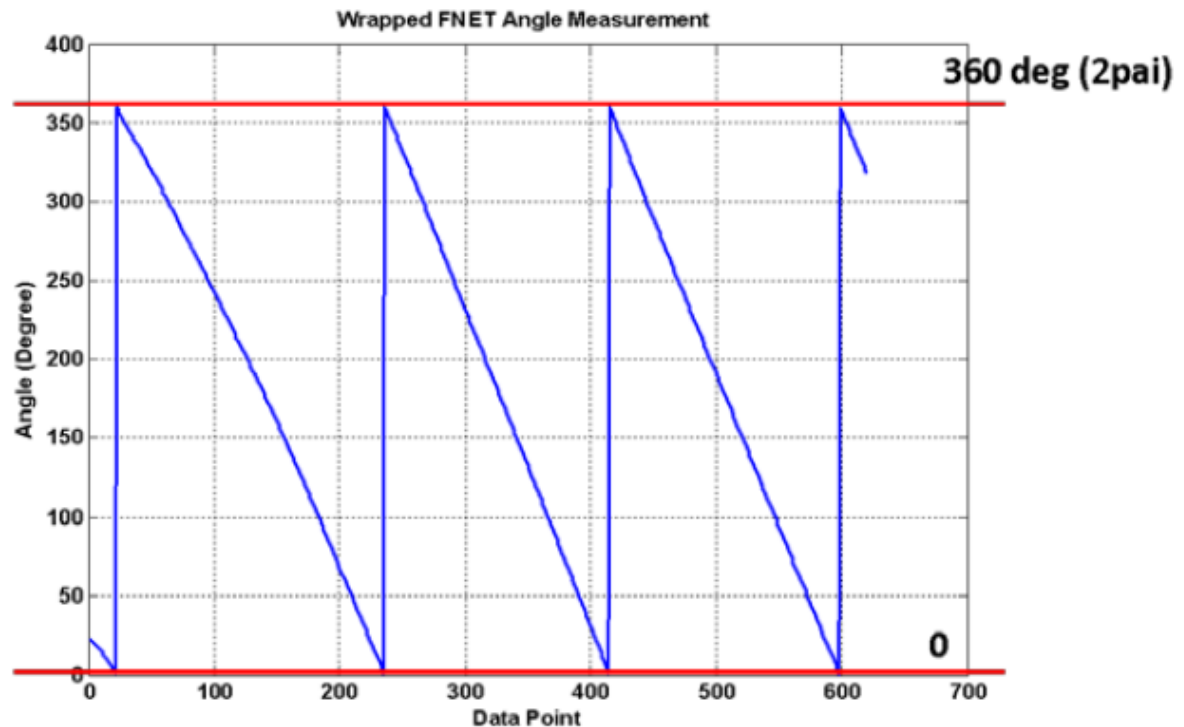
$$\theta(t_i) = \int_{t=t_0}^{t_1} 2\pi(f - f_0)tdt + \theta_0$$

Angle measurement

Angle unwrapping

Angle self normalization

Angle detrending



Angle-based Triangulation

Angle measurement is the integration of frequency measurement

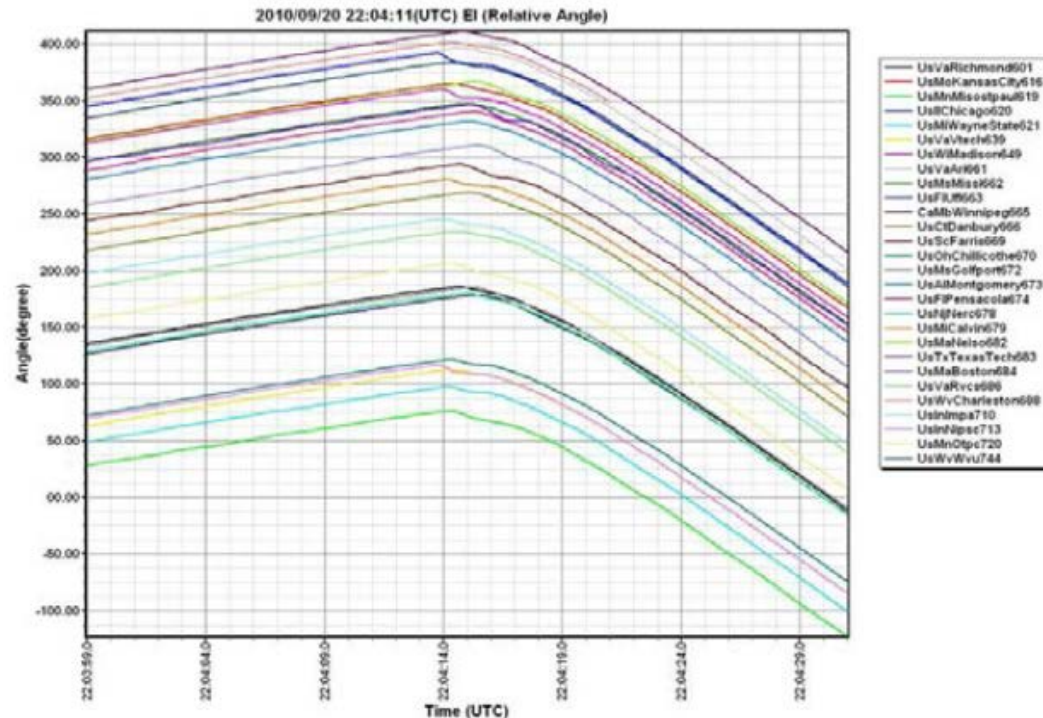
$$\theta(t_i) = \int_{t=t_0}^{t_1} 2\pi(f - f_0)tdt + \theta_0$$

Angle measurement

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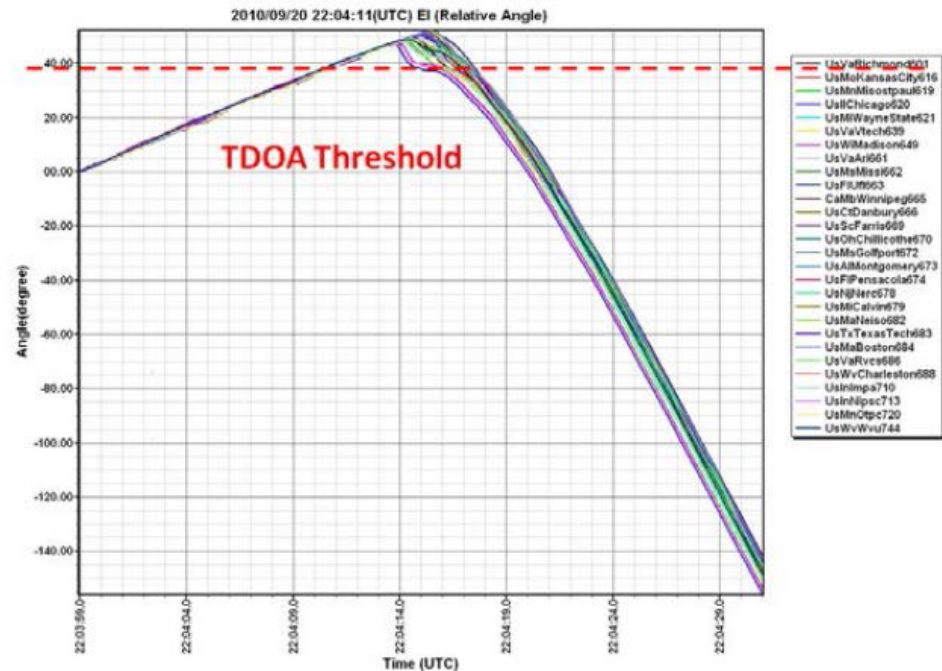
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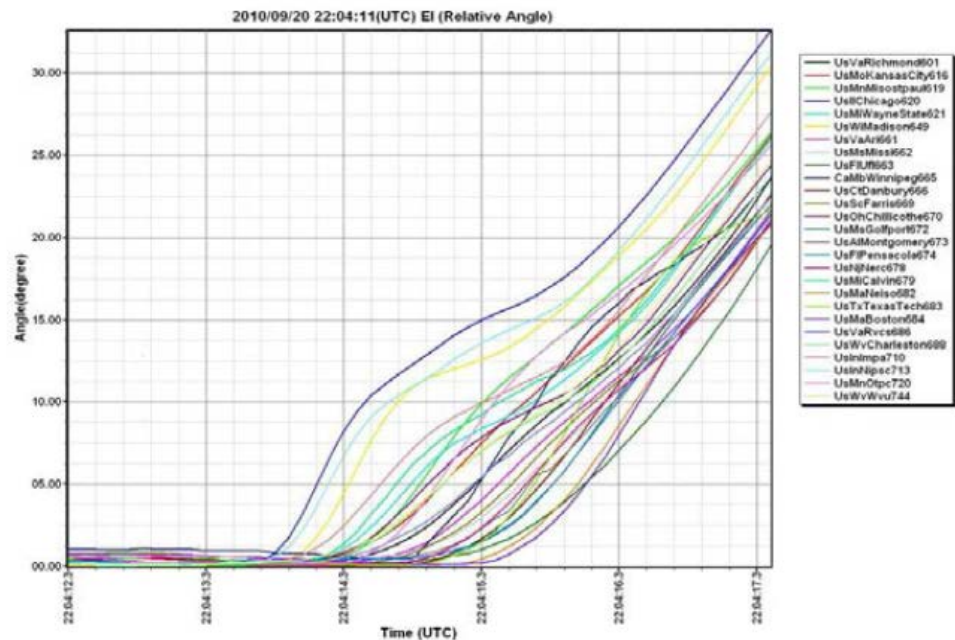
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Angle measurement

Angle unwrapping

Angle self normalization

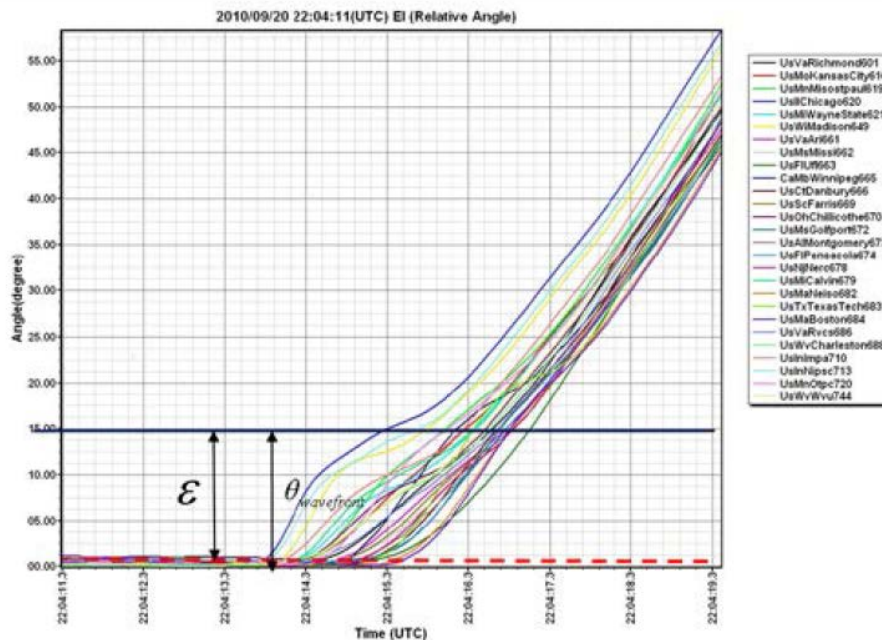
Angle detrending



Angle-based Triangulation

Angle measurement is the integration of frequency measurement

$$\theta(t_i) = \int_{t=t_0}^{t_1} 2\pi(f - f_0)tdt + \theta_0$$



The sequence of TDOAs are determined by the final processed angle data.

Angle vs. Frequency Triangulation Comparison

23 Events used for Comparison

Comparison between triangulations and correct latitude:

	Maximum Difference (Degrees)	Maximum Difference (Miles)	Average Difference (Degrees)	Average Difference (Miles)	Number of Events with No Difference
Angle-based Triangulation	3.3344	230.07	1.2112	83.57	1
Frequency-based Triangulation	4.4317	305.79	1.4957	103.20	1

Comparison between triangulations and correct longitude:

	Maximum Difference (Degrees)	Maximum Difference (Miles)	Average Difference (Degrees)	Average Difference (Miles)	Number of Events with No Difference
Angle-based Triangulation	4.7481	259.2463	1.4285	78.00	1
Frequency-based Triangulation	10.4006	567.8728	3.0195	164.86	1

Angle vs. Frequency Triangulation Comparison

Number of cases with better accuracy:

	Latitude	Longitude
Angle-based Triangulation	10	14
Frequency-based Triangulation	12	8

Angle vs. Frequency Triangulation Comparison

23 Events used for Comparison

Comparison between triangulations and correct location:

	Maximum Difference (Miles)	Average Difference (Miles)	Number of Events with No Difference
Angle-based Triangulation	343.27	122.65	1
Frequency-based Triangulation	623.08	201.38	1

Number of cases with better accuracy:

	Location
Angle-based Triangulation	13
Frequency-based Triangulation	9

Next Step: Line Trip Detection & Location Based on Phase Angle

