Utility Evaluation of Improved Event Triangulation Using Synchrophasor Technology

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Southern Company Overview

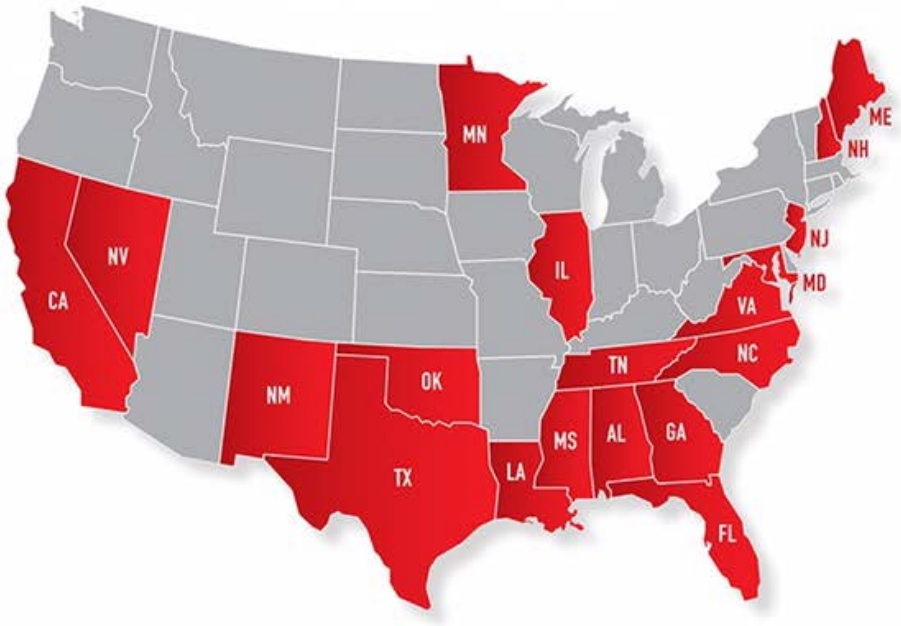
Approximately
44,000 MW
of Generating Capacity

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

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On-line Event Location

US Patent:
7519454,7765034

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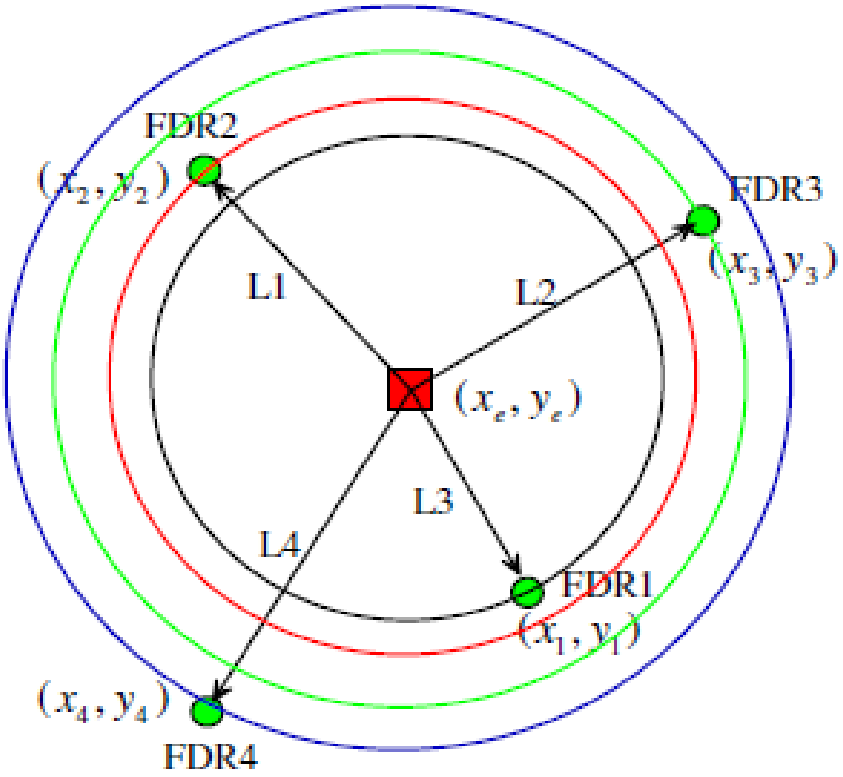
Event Location Triangulation



$$(x_1 - x_e)^2 + (y_1 - y_e)^2 = V^2 (t_1 - t_e)^2$$

$$(x_2 - x_e)^2 + (y_2 - y_e)^2 = V^2 (t_2 - t_e)^2$$

$$\vdots$$

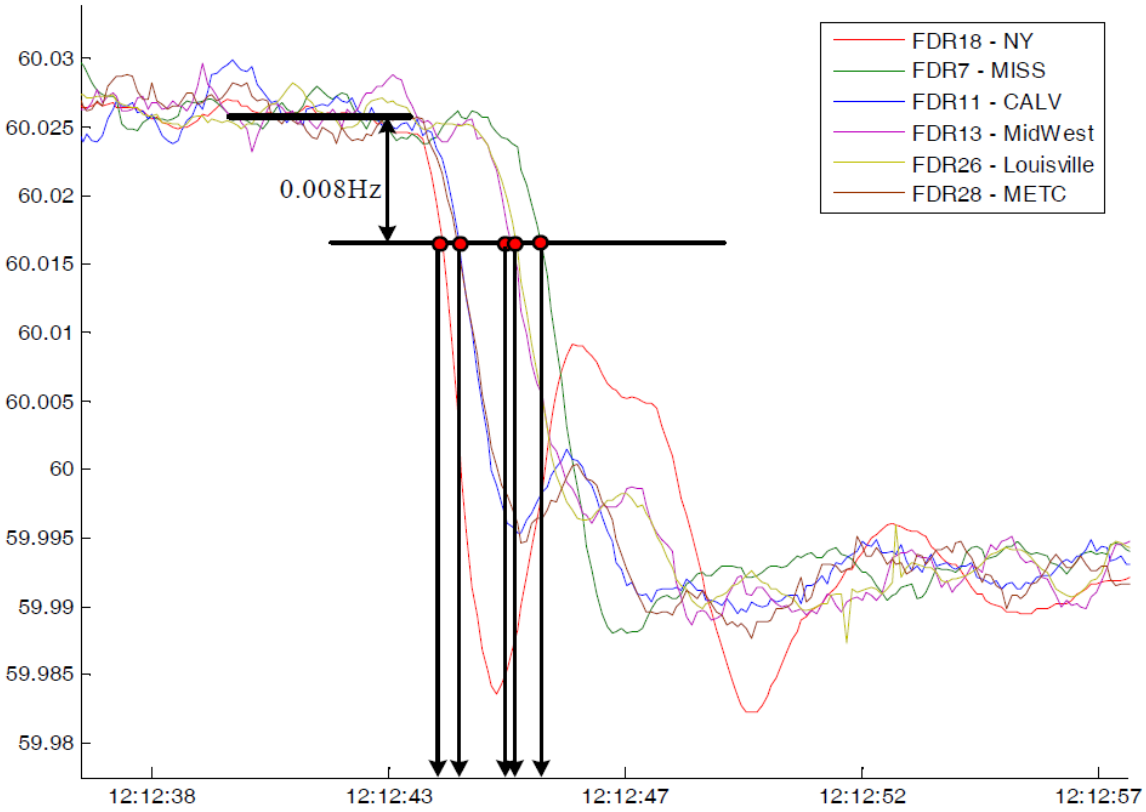
$$(x_n - x_e)^2 + (y_n - y_e)^2 = V^2 (t_n - t_e)^2$$

Time Delay of Arrival (TDOA)

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

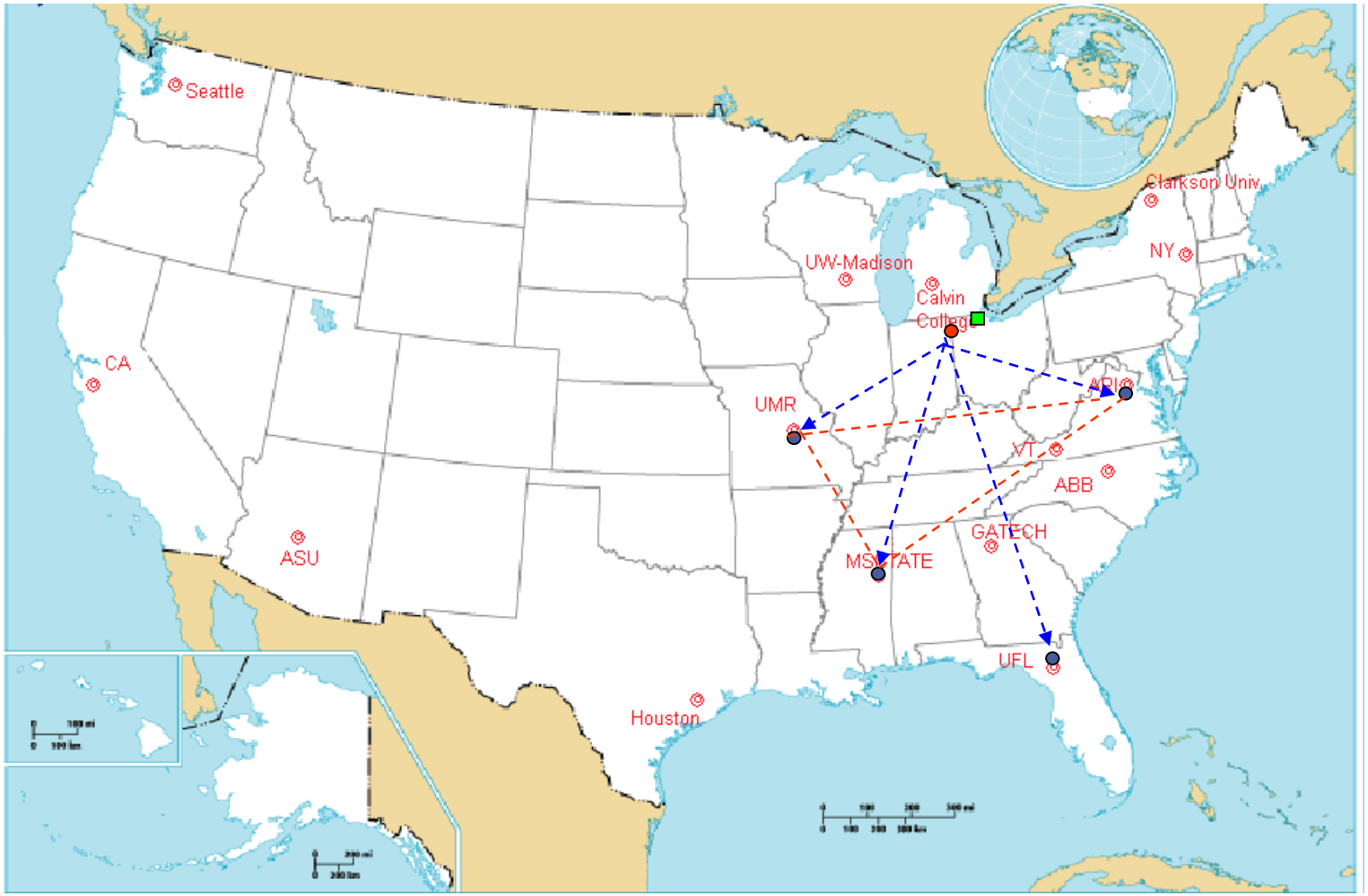
TDOAs can be derived from both frequency and phase angle measurements.

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

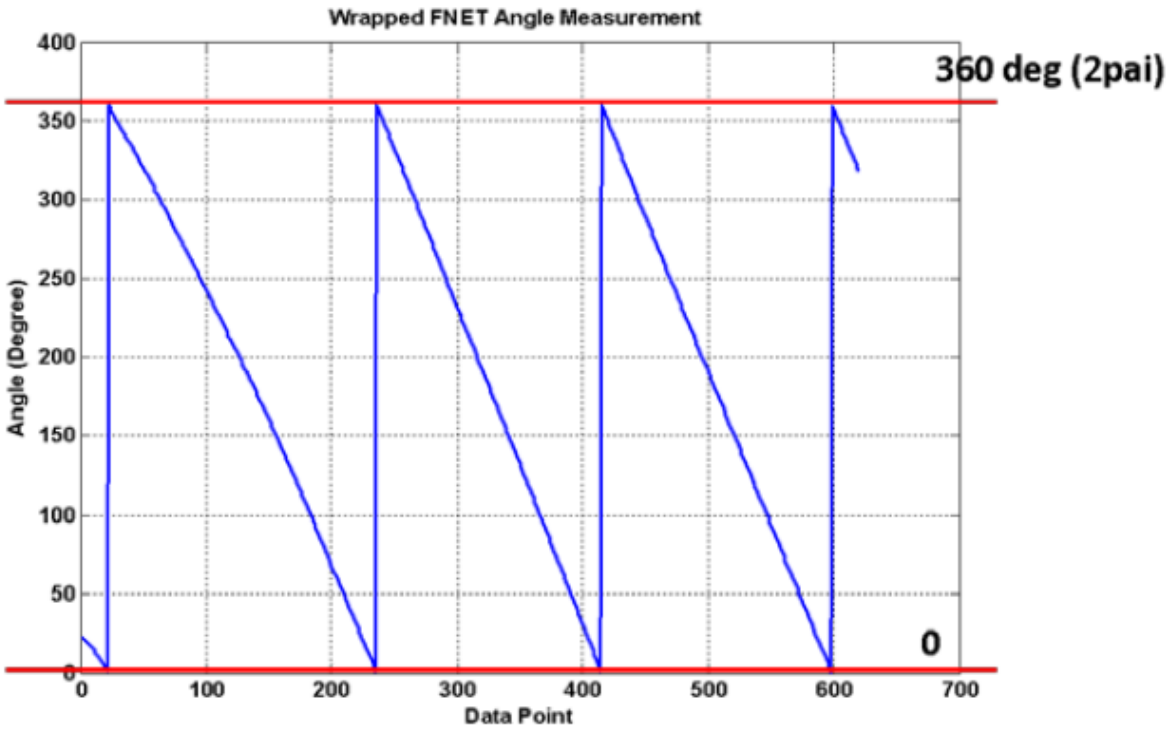
$$\theta(t_i) = \int_{t=t_0}^{t_1} 2\pi(f - f_0)tdt + \theta_0$$

Angle measurement

Angle unwrapping

Angle self normalization

Angle detrending



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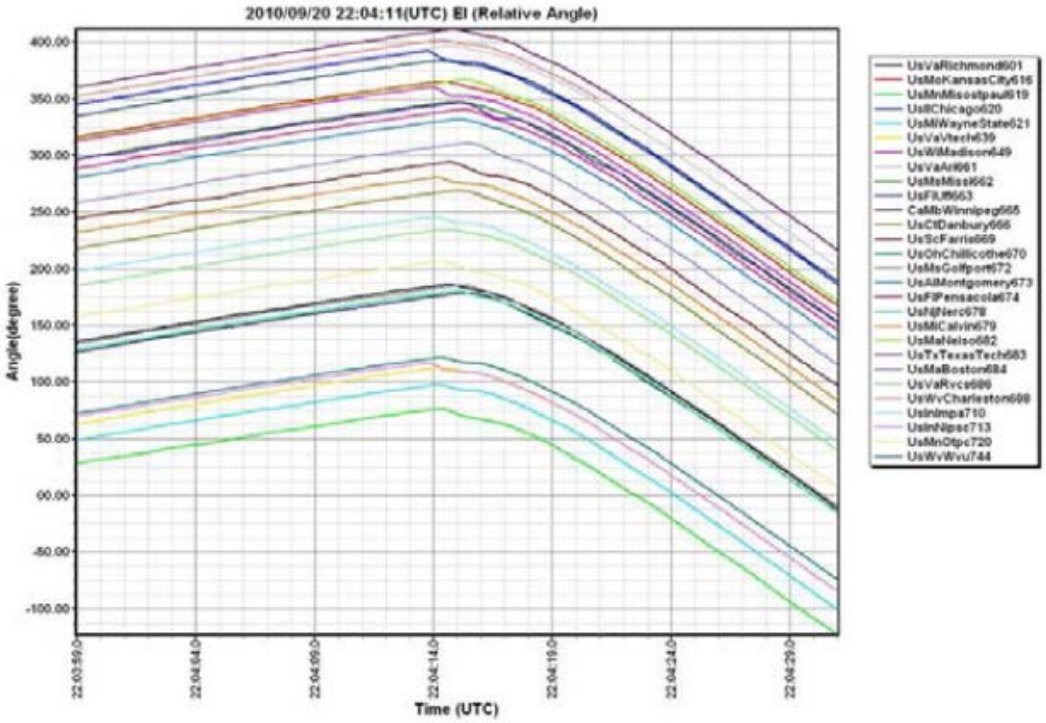

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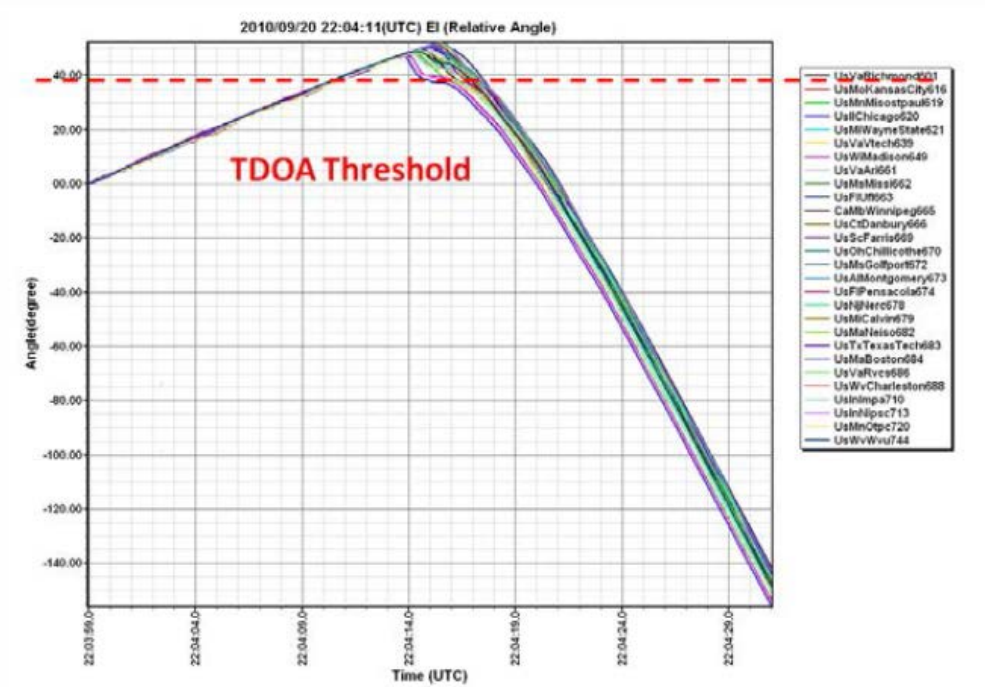

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Angle-based Triangulation

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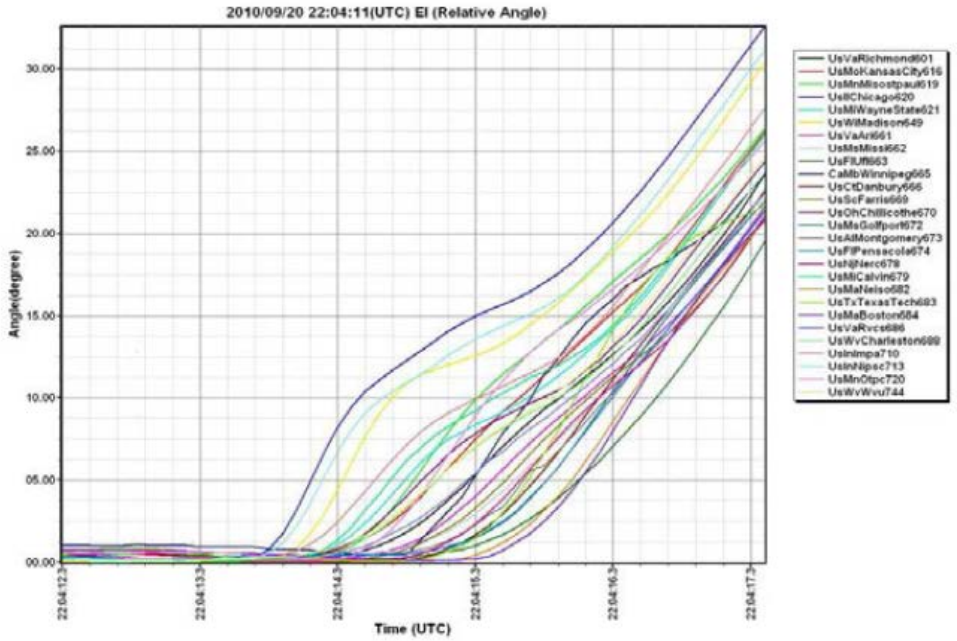
- Angle measurement
- Angle unwrapping
- Angle self normalization
- **Angle detrending**



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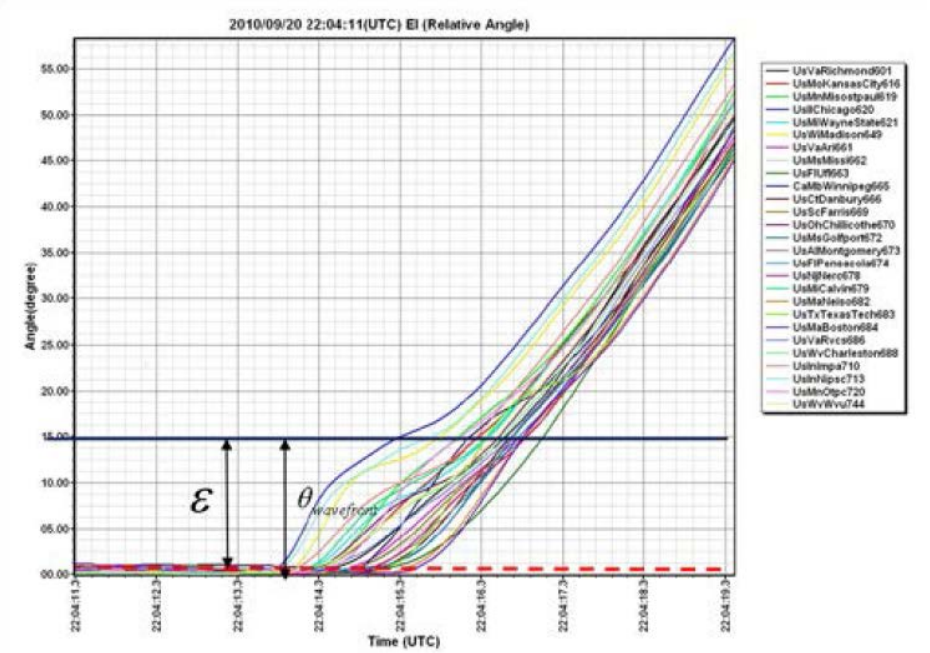

The sequence of TDOAs are determined by the final processed angle data.

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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

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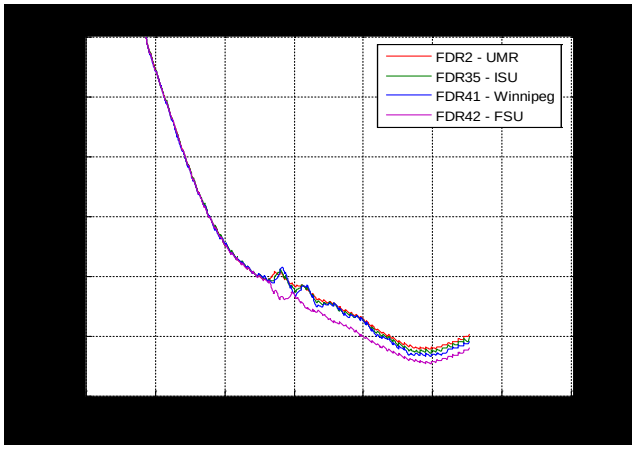
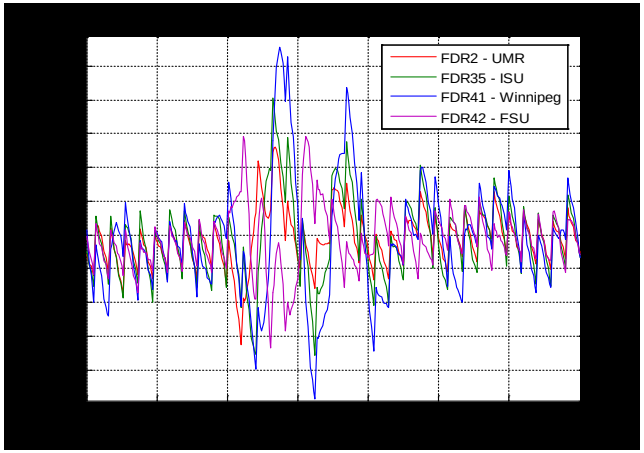
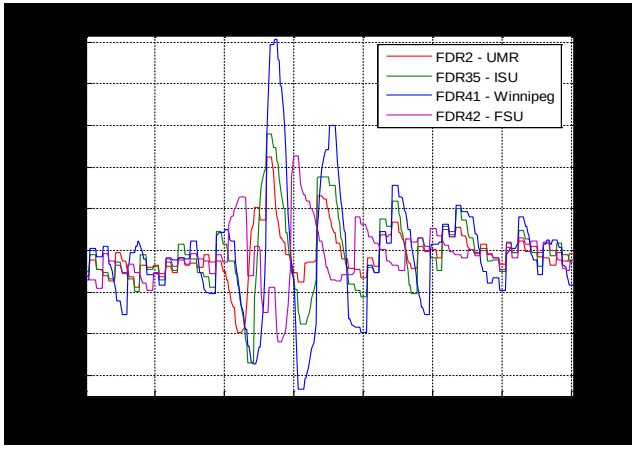
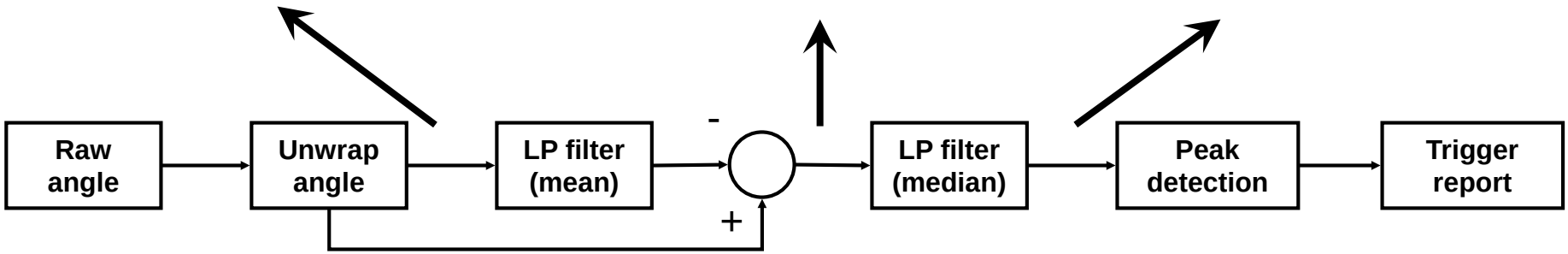
Next Step: Line Trip Detection & Location Based on Phase Angle









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