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Quantime Lab

Broadcast Positioning System (BPS) as a Terrestrial Alternative to GNSS for Precision Timing and Positioning

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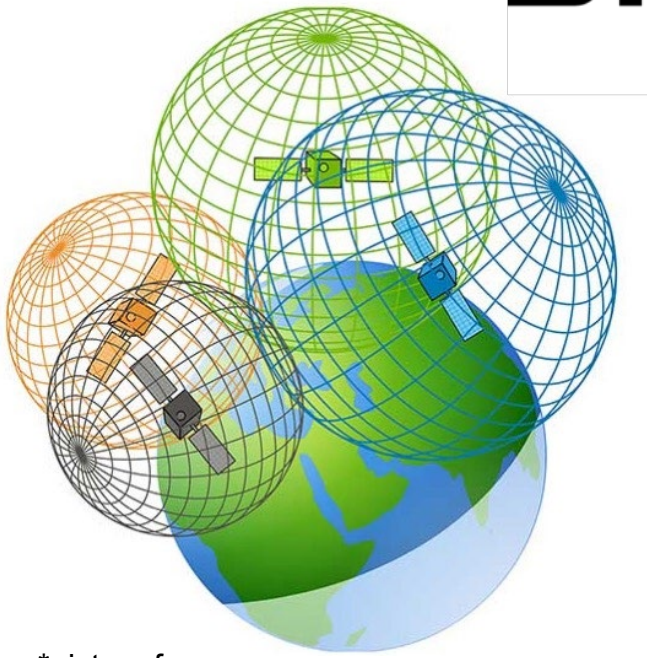
ACCEPT
Alabama Collaborative for Contemporary Education in Precision Timing

History of precision navigation

- *1973 – GPS Development Begins*
- *1978 – First GPS Satellite Launched*
- *1983 – Civilian Access to GPS*
- *2000s – Multi-Constellation Era*
- *2010s – Precision GNSS Techniques*
- *Present & Future*

Integration with AI, quantum sensors, resilient PNT systems, and multi-sensor fusion for ultra-precise navigation in GPS-denied environments and LEO PNT.

GNSS working principle: Trilateration

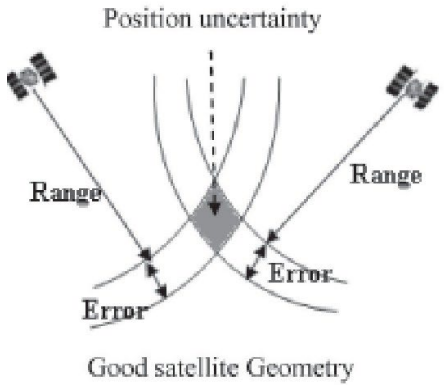


*picture from https://gisgeography.com/trilateration-triangulation-gps/

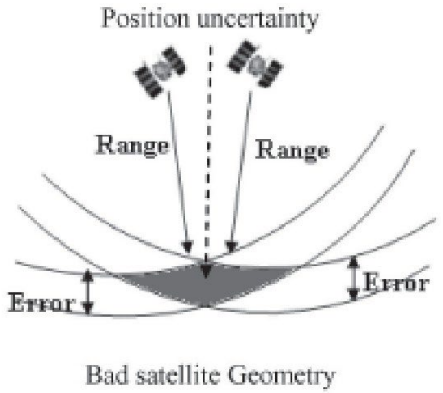
- *Trilateration Principle:* GNSS determines receiver position by calculating distances from at least four visible satellites, ρ (pseudorange).
- *Distance Calculation:*

$$\rho_j = c(TOA_j - TOT_j)$$

- GNSS calculates receiver position (three variables) and the time difference between receiver and satellite clocks.
- *Geometric Dilution of Precision:* Navigation requires GDOP < 5.



Good satellite Geometry



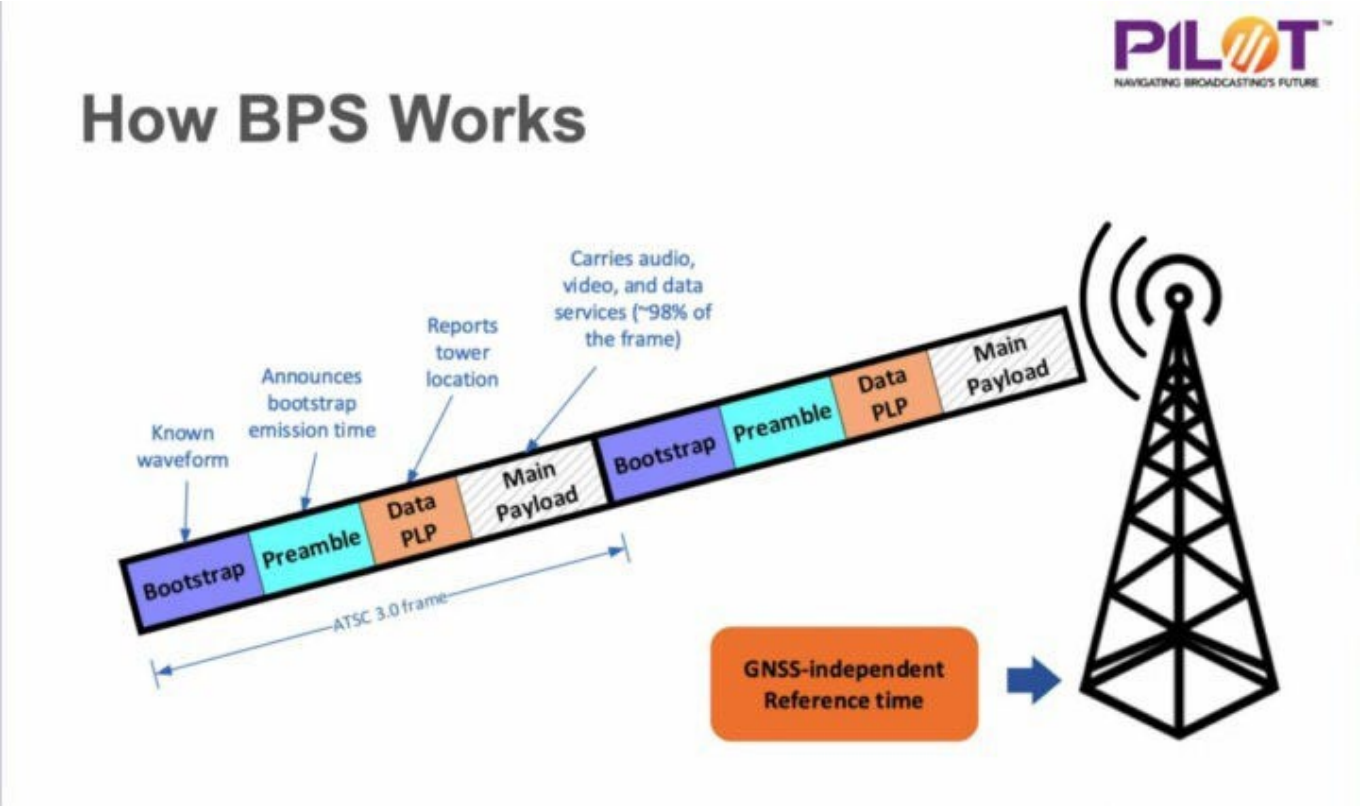
Bad satellite Geometry

Error Sources in GNSS: Ionospheric and tropospheric delays, satellite clock inaccuracies

GNSS threats

Alternative and robust solution(s) are needed…..

Broadcast positioning system as GNSS alternative



Broadcast positioning system:

- GNSS-independent timing and positioning using ATSC 3.0 broadcast signals.
- Decreased signal loss due to ground-based transmission.
- GNSS signal strength is around –128 dBm while BPS signal strength is at least –65 dBm.
- Transmits timing signals and antenna location.
- Operates across multiple frequency bands (54–88 MHz, 174–216 MHz, and 470–608 MHz).

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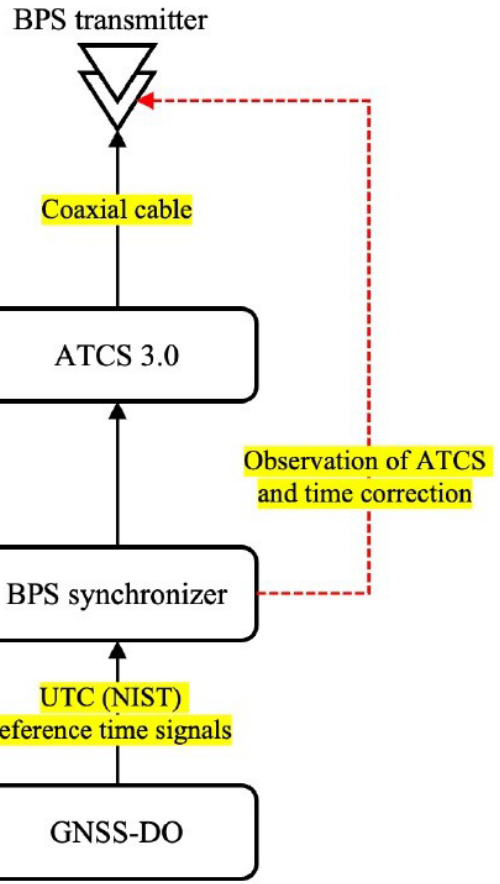
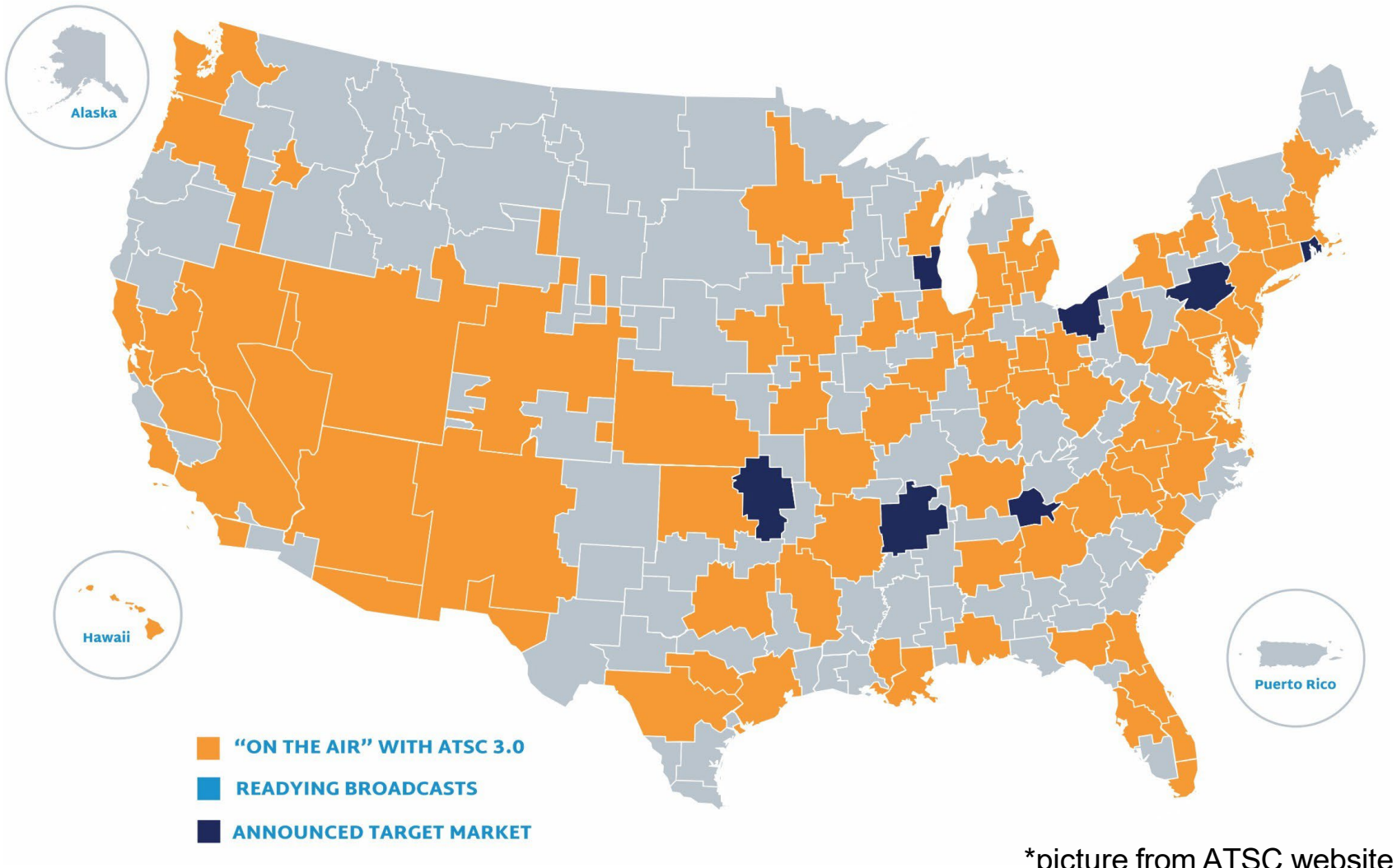
BPS through ATSC 3.0



Generation of BPS signals at the tower site

ATSC 3.0 at 83 locations in the US



*picture from ATSC website

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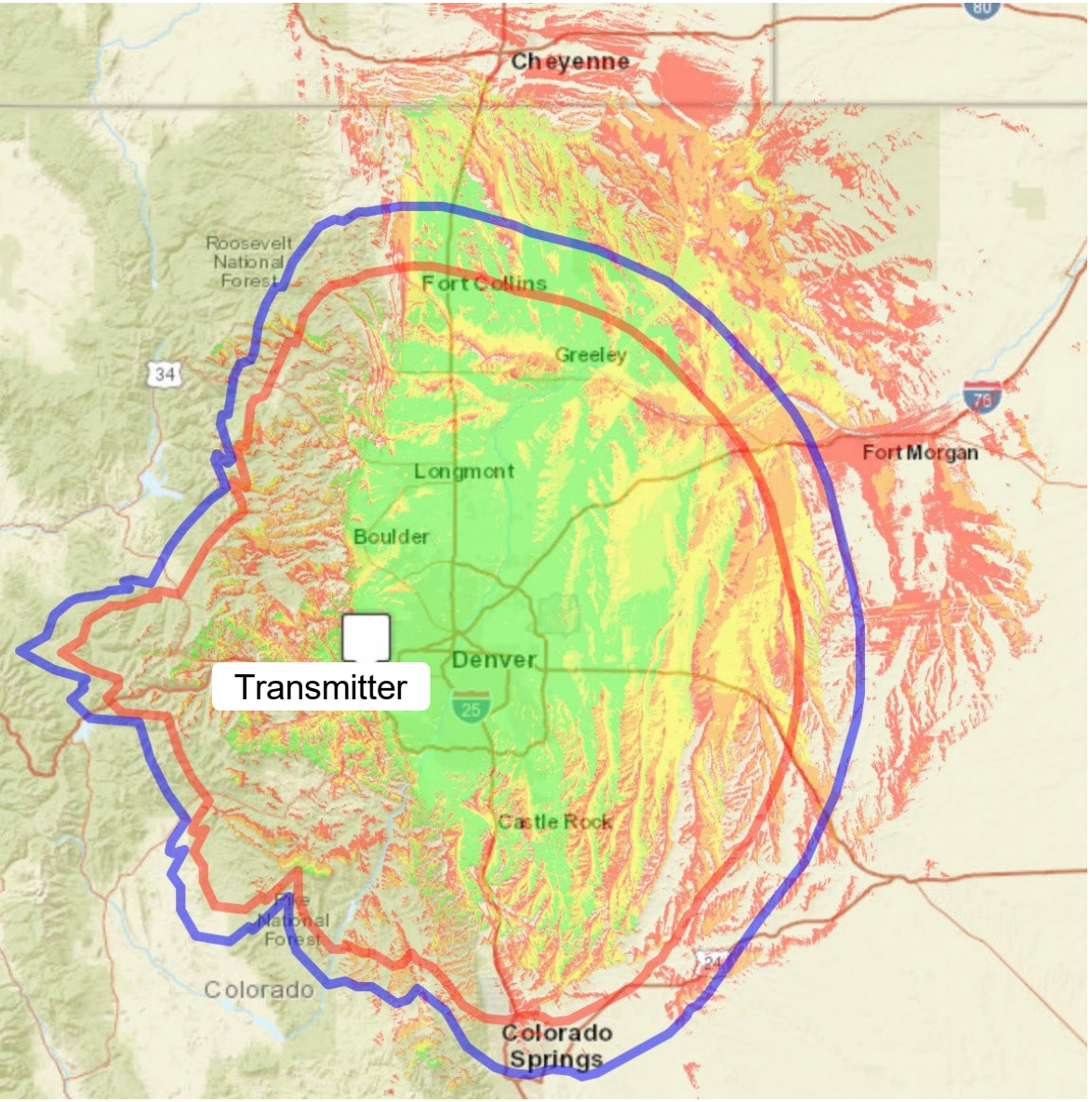
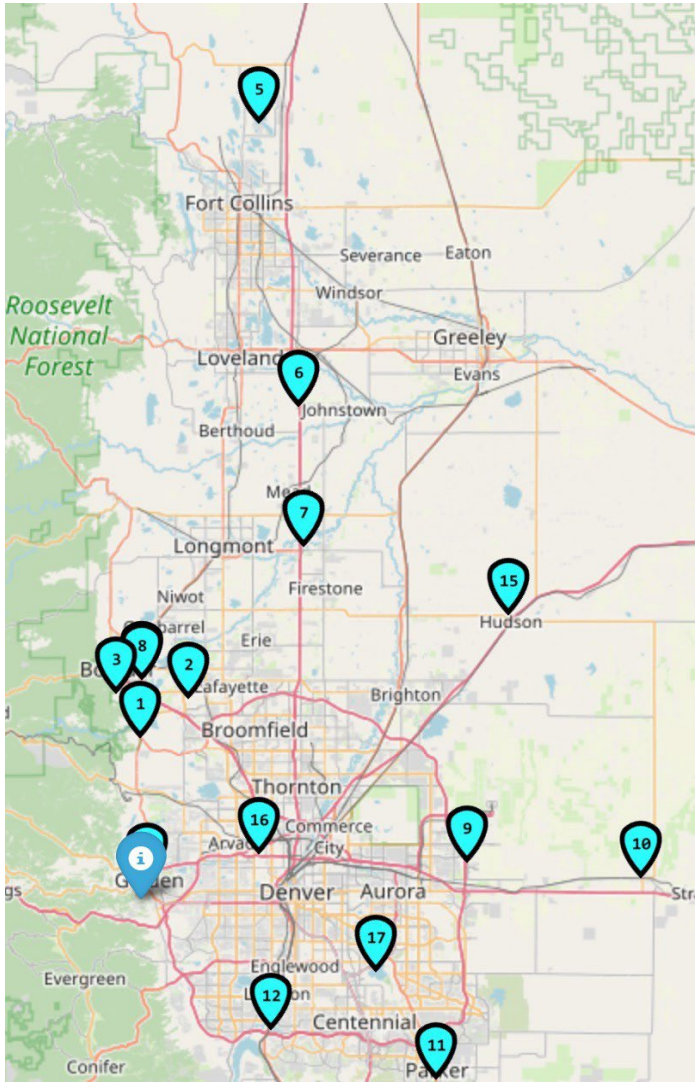
Testing Locations

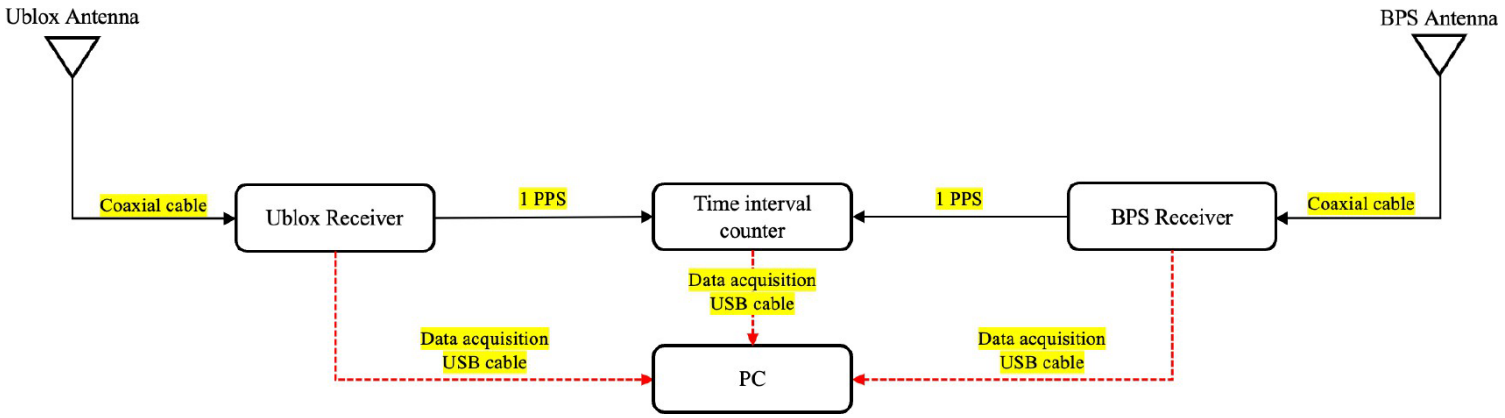


- *Transmission Site Location:* Lookout Mountain, at an elevation of 2,249 meters.
- *Reason for Location Selection:* To minimize obstructions and maximize line-of-sight connectivity.
- *Expected Coverage Area:* Over 50 kilometers north and east of the transmission site.

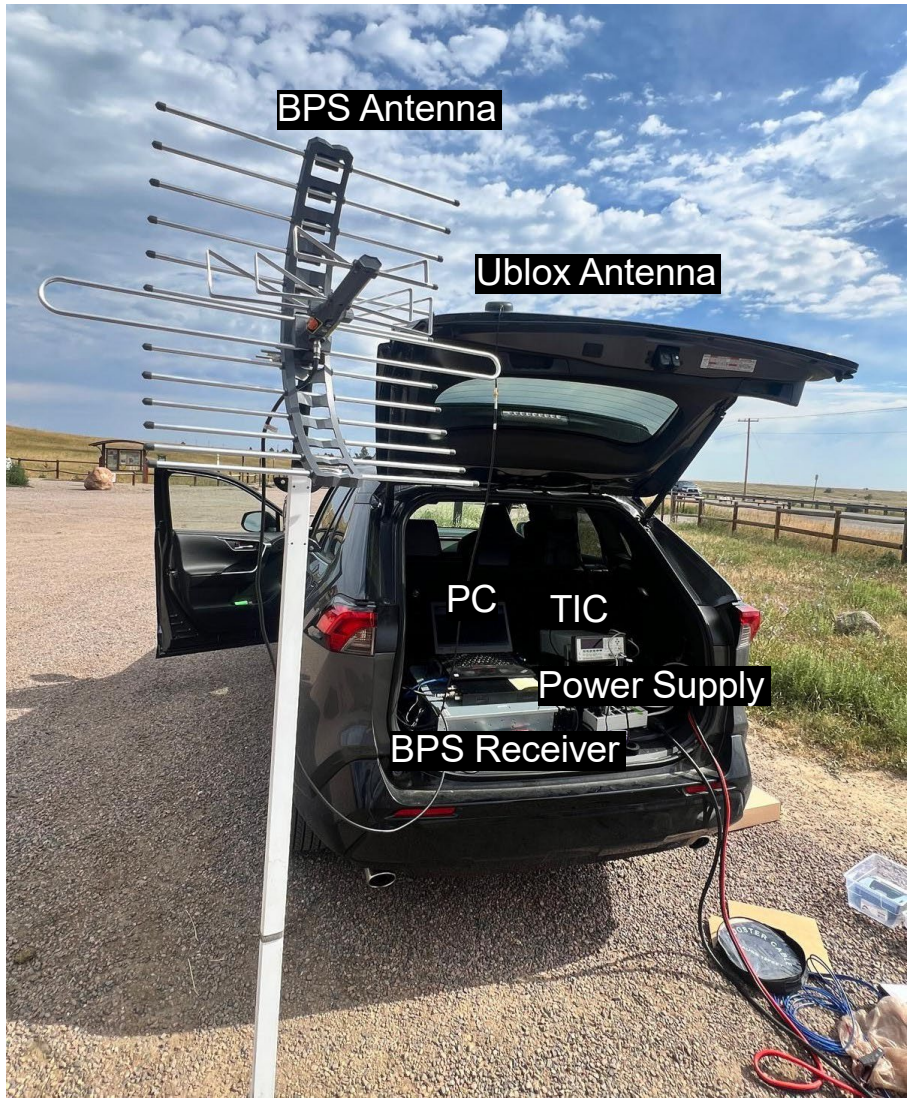


The blue boundary shows noise-limited bounding contour at 41 dBu.
The red boundary represents minimum field strength contour at 48 dBu.

Experimental Scheme

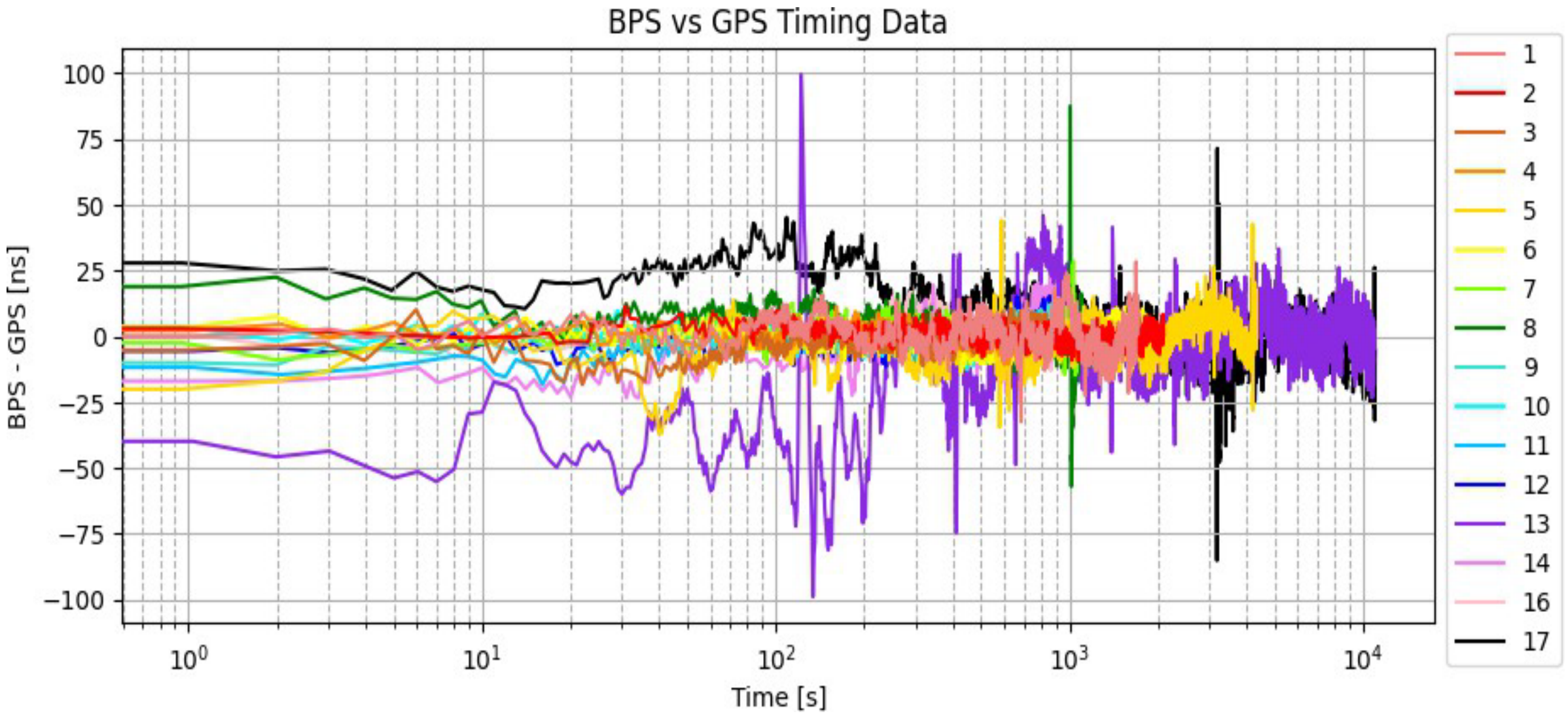


BPS signal testing setup



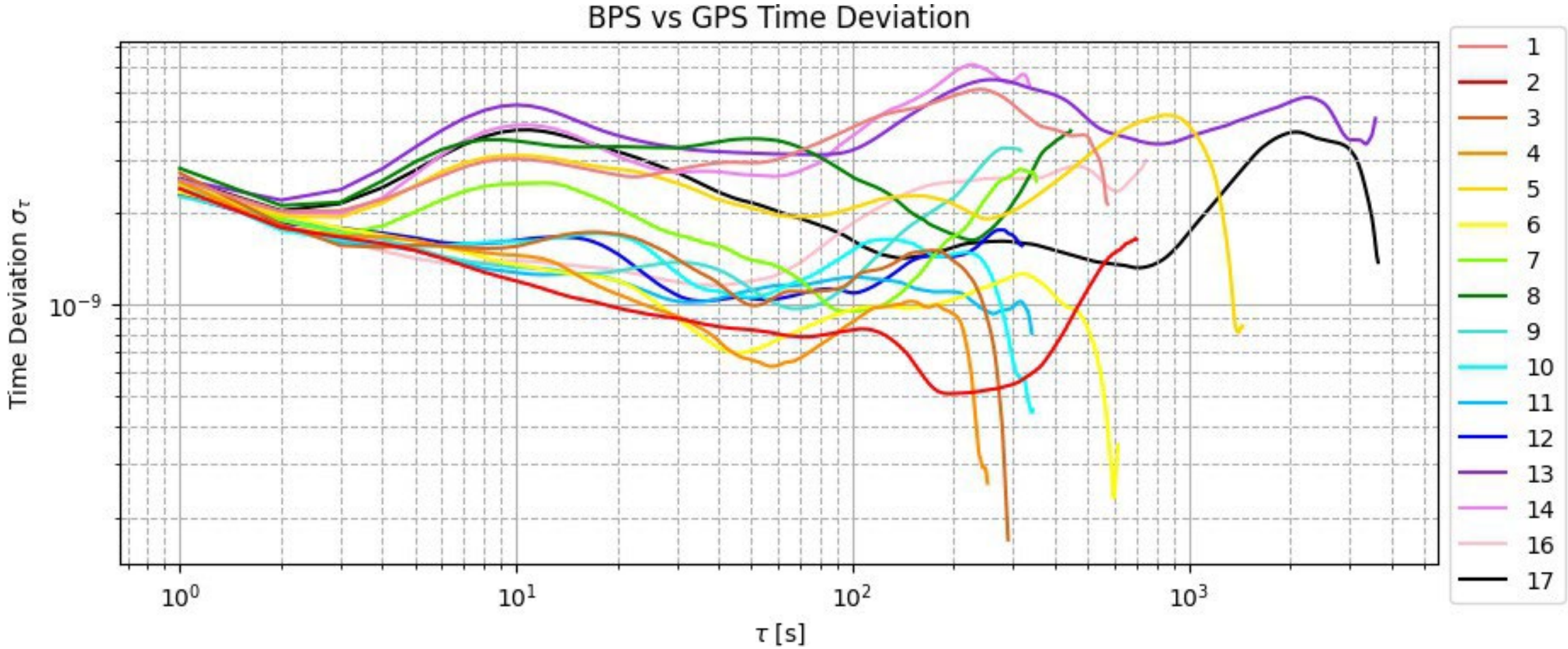
- *Signal Measurement:* BPS signals are recorded for at least 20 minutes at 17 locations to assess signal reliability.
- *BPS for PNT:* BPS signals from at least four transmission sites are used for trilateration, demonstrating their potential as a PNT alternative to GPS.
- *Time interval measurement:* Comparing the timing performance of GPS signals and BPS signals simultaneously at remote locations.

BPS Timing Stability



BPS Timing Stability

Time deviation of 1PPS from BPS receiver vs GNSS receiver for different locations



All time deviations are under 7ns!

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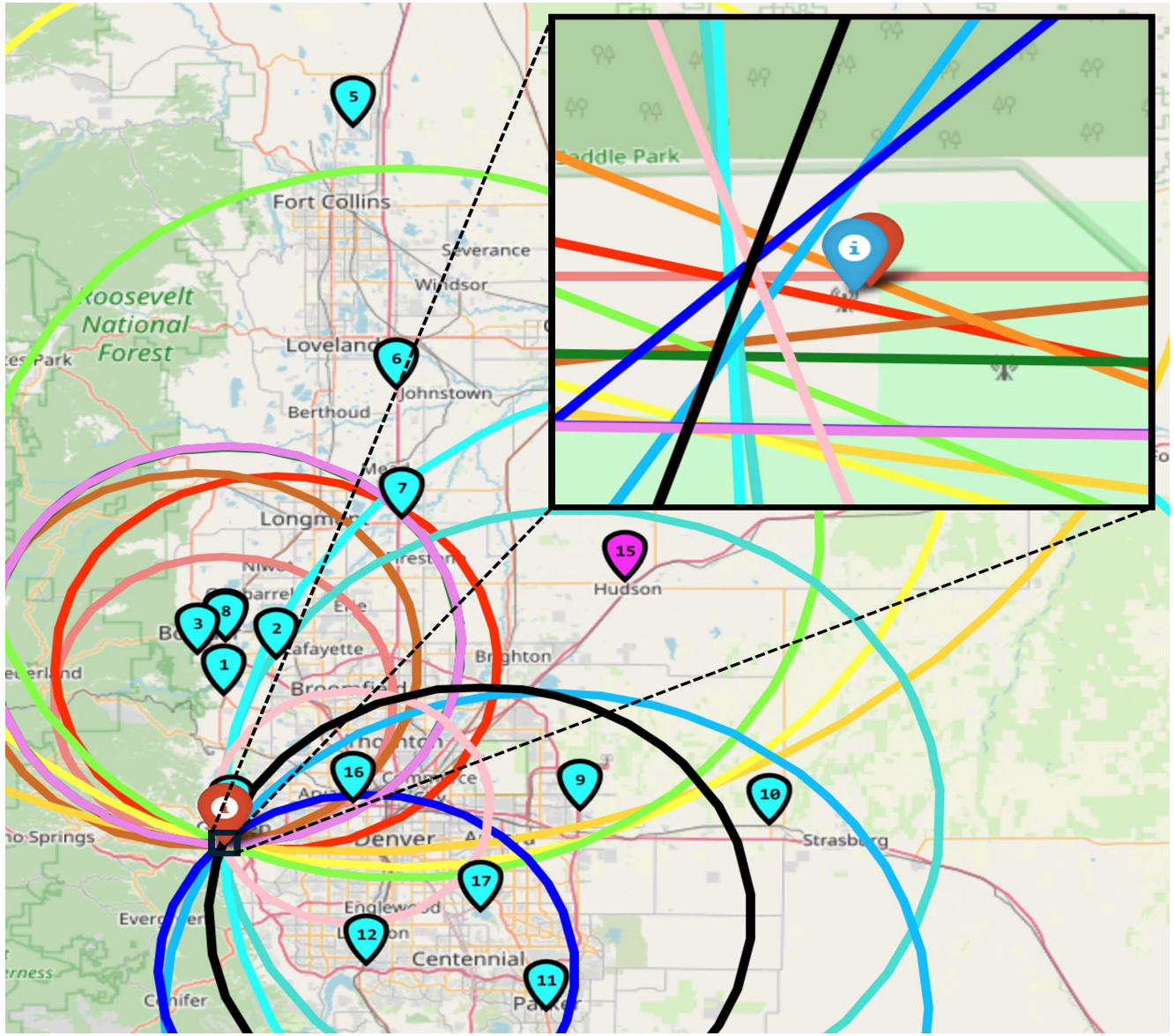
Position Determination



$$r_i = \sqrt{(x_i - x)^2 + (y_i - y)^2 + (z_i - z)^2} = \frac{c}{n} t_i$$

$$t_i = TOA_i - TOT_i = t_i^{BPS} + t_i^{TIC} + \Delta t$$

$$\Delta t = t_{offset}^{BPS} - (t_{internal}^{BPS} + t_{internal}^{TIC} + t_{internal}^{GNSS} + t_{cables})$$

$$x = \hat{x} + \Delta x, \quad y = \hat{y} + \Delta y, \quad z = \hat{z} + \Delta z$$

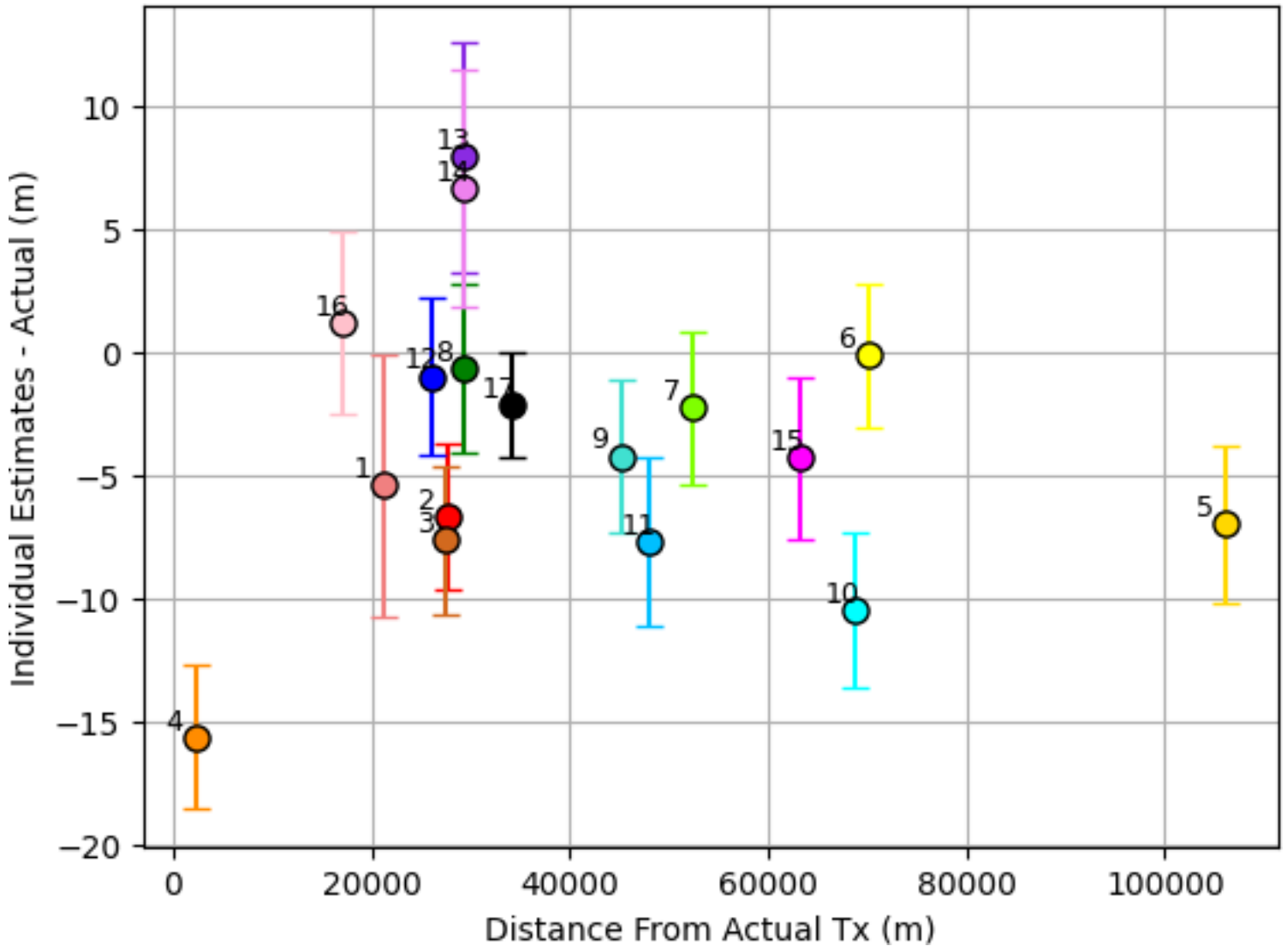
Geometric Dilution of Precision (GDOP): 5.243

Ground distance error: 3.38m

Total distance error (including altitude error): ***49.68m***

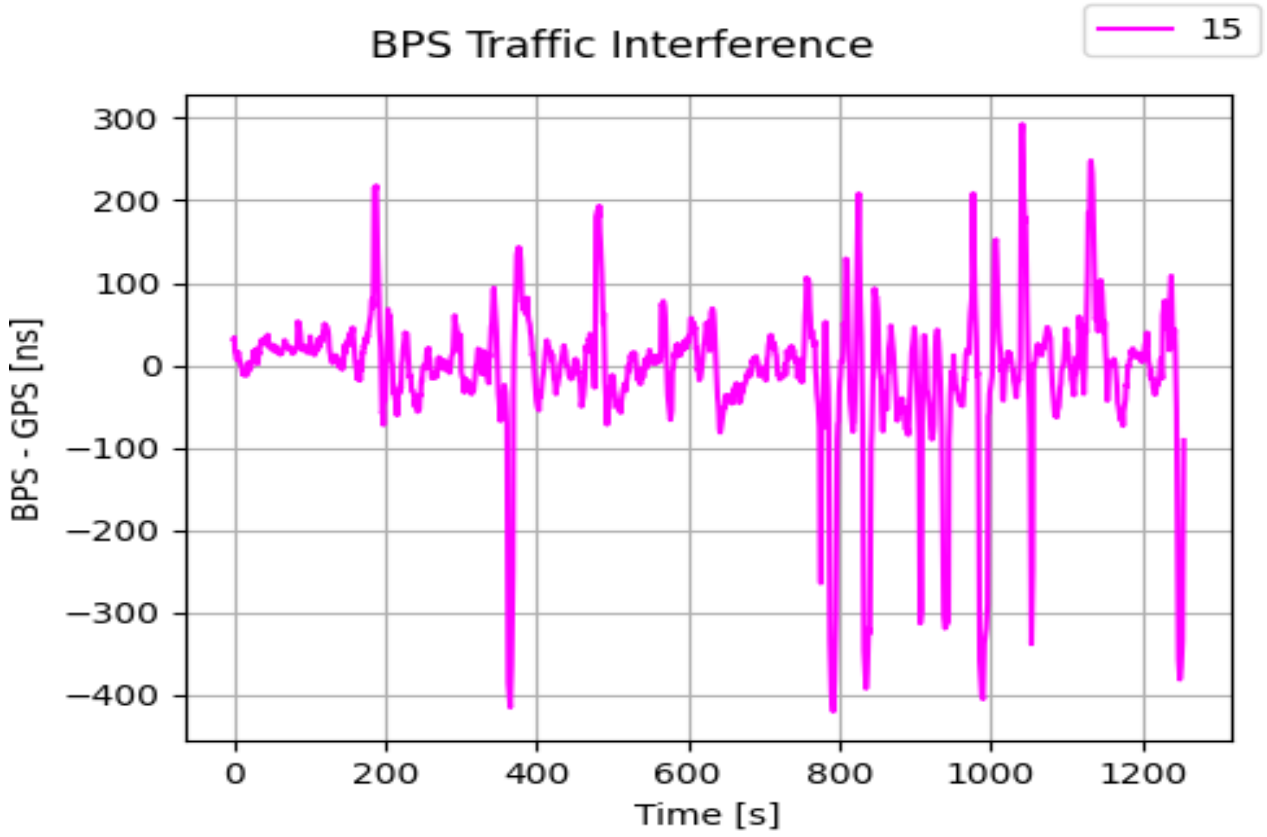
Position Error

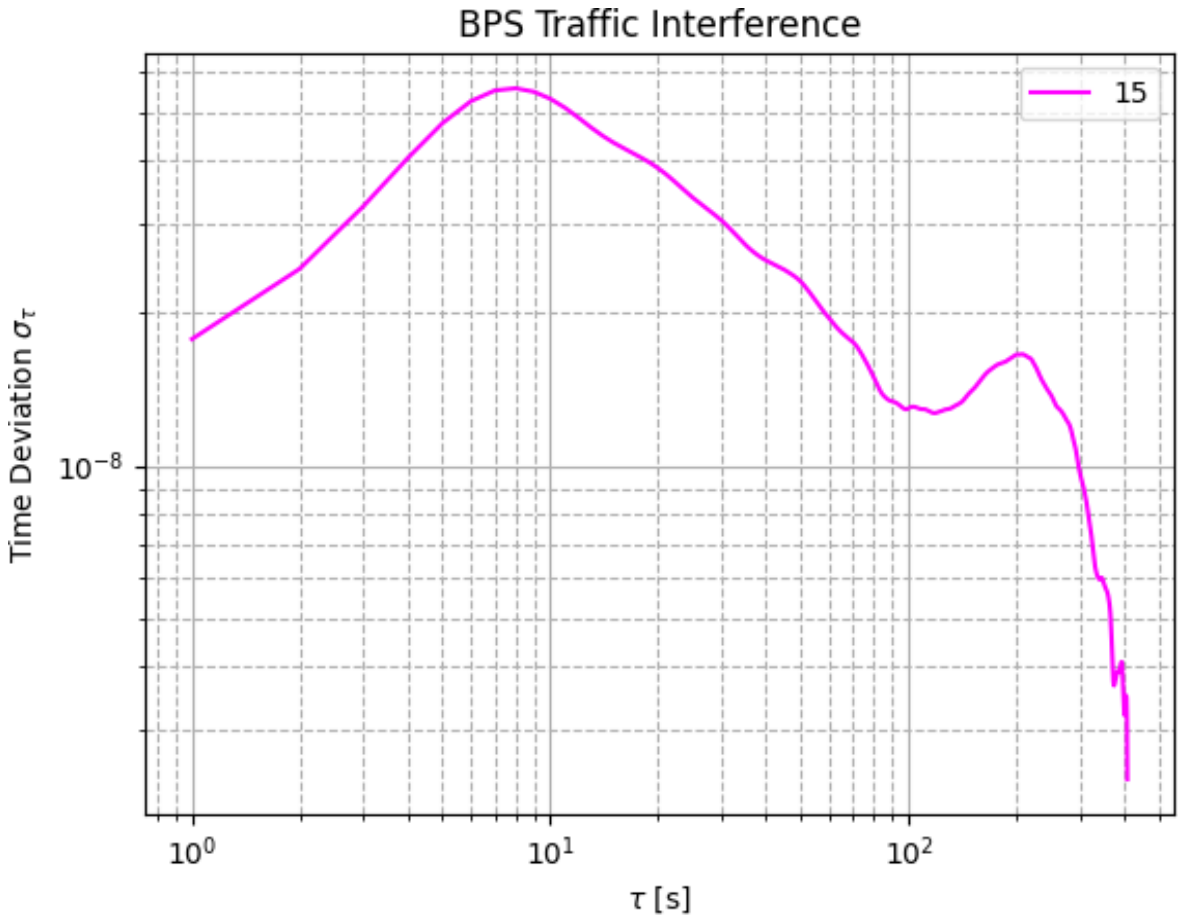
Variation in individual estimates is less than 23 m



Potential Error Sources

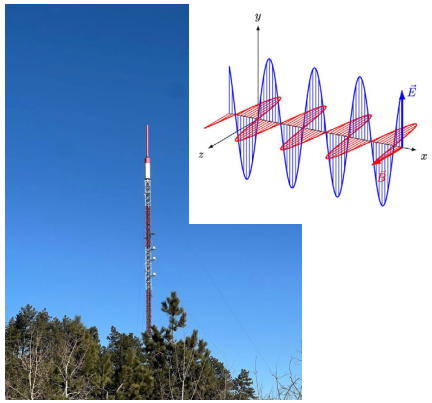
- Roadside (trucks) Interference



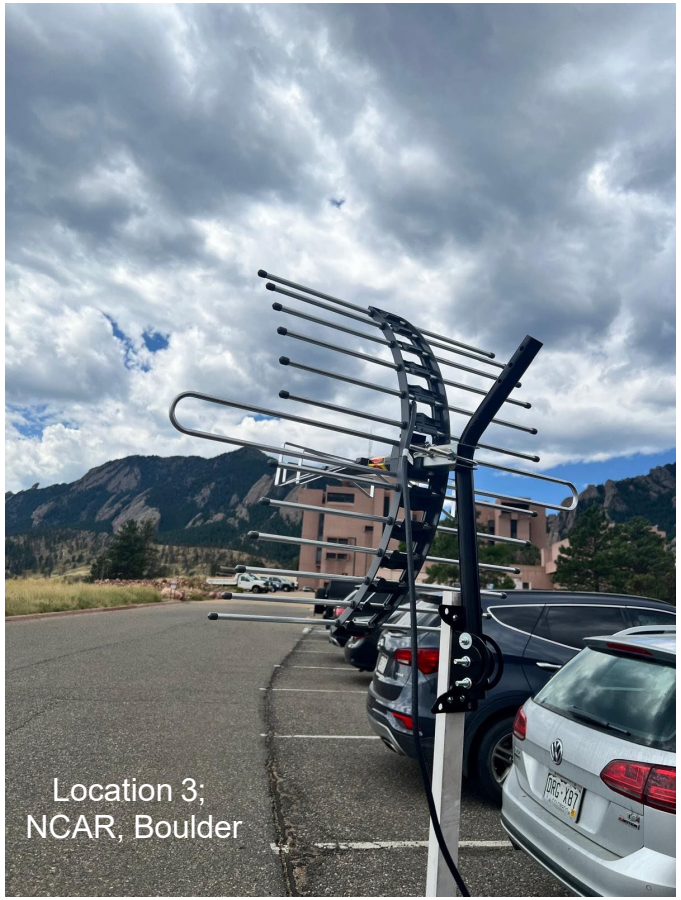


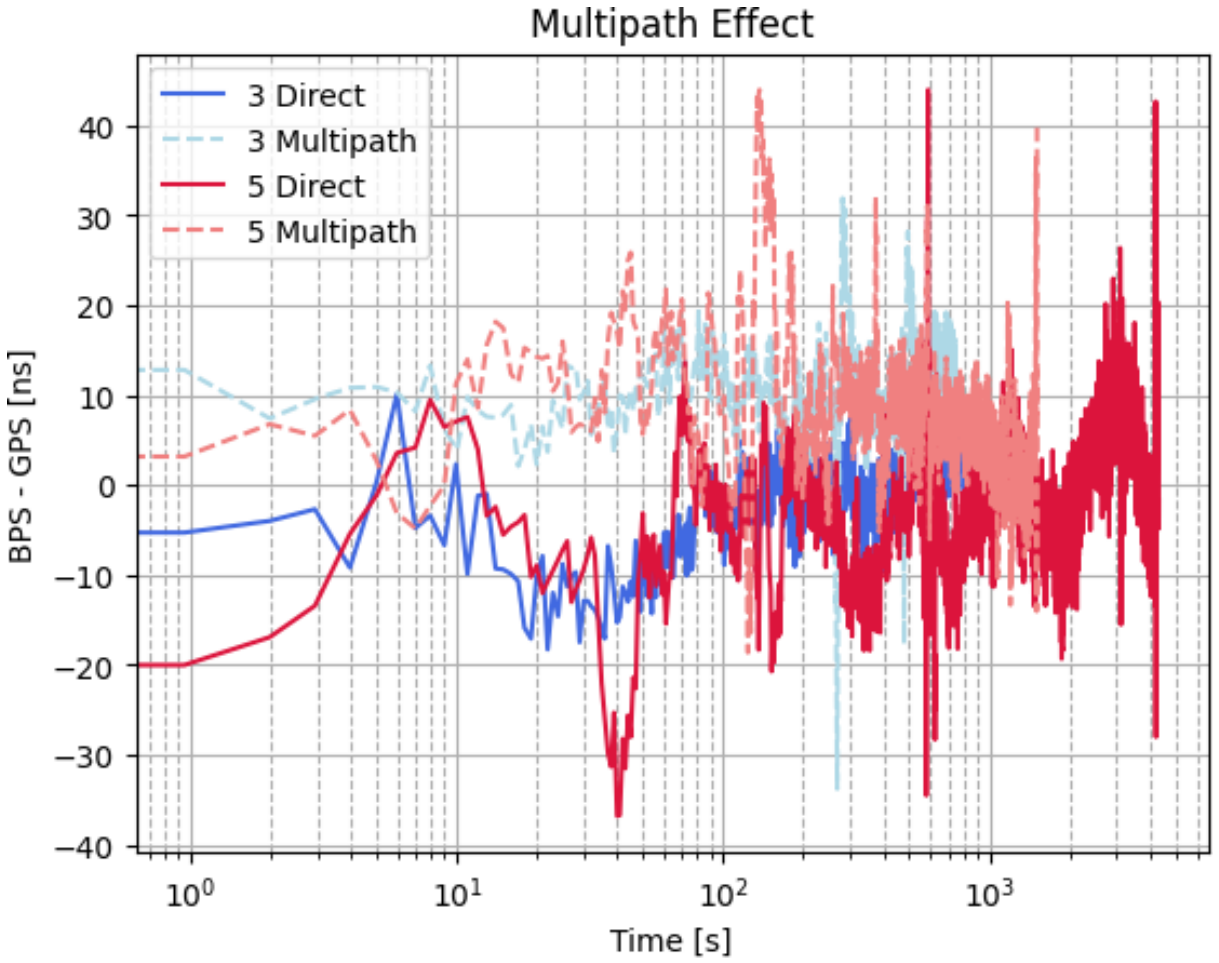
Potential Error Sources

- Multipath Errors



Antenna atop
Lookout Mt., Golden





Summary

- ***Position Determination (Multilateration Method):*** Simultaneous trilateration with 17 locations: Ground distance error of 3.38m
- ***Time Deviation:*** Less than seven nanoseconds for all tau, for all measurements

Future work:

- Trophospheric corrections (effects of pressure, temperature, and humidity)
- Hyperbolic method for trilateration
- Weighting algorithms for trilateration

https://Quantime.ua.edu

Thank you

Questions?