Broadcast Positioning System (BPS) Using ATSC 3.0

Tariq Mondal, Robert D. Weller, Sam Matheny

What is BPS?

A system and method of estimating time and position at a receiver using Next Gen TV broadcast signals

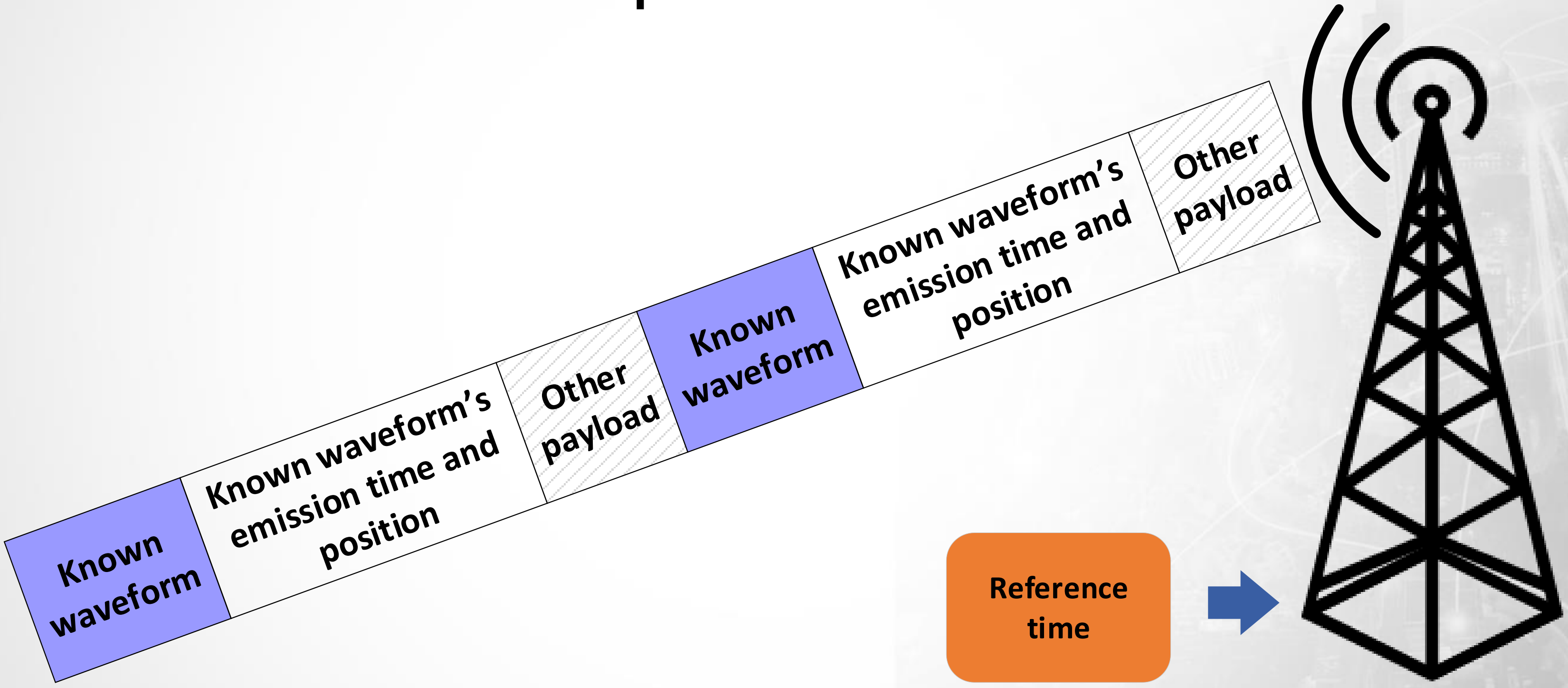
ATSC ADVANCED TELEVISION SYSTEMS COMMITTEE

Compliant with Next Gen TV (ATSC 3.0) standard currently being deployed in the US

Independent and stand-alone

- GPS, Internet or cellular connectivity not required

Concept


Known waveform
Known waveform's emission time and position
Other payload
Known waveform
Known waveform's emission time and position
Other payload
Reference time

PNT Capability

One TV tower can provide accurate time at a known position

- 100 ns, 95% of the time

Four TV towers can provide both time and position estimation

- 100 m average accuracy expected

ATSC 3.0 Standard – Next Gen TV

ATSC

- Standardization completed in 2018
- U.S. deployment started in 2019
- Can deliver data with television
- Works inside buildings

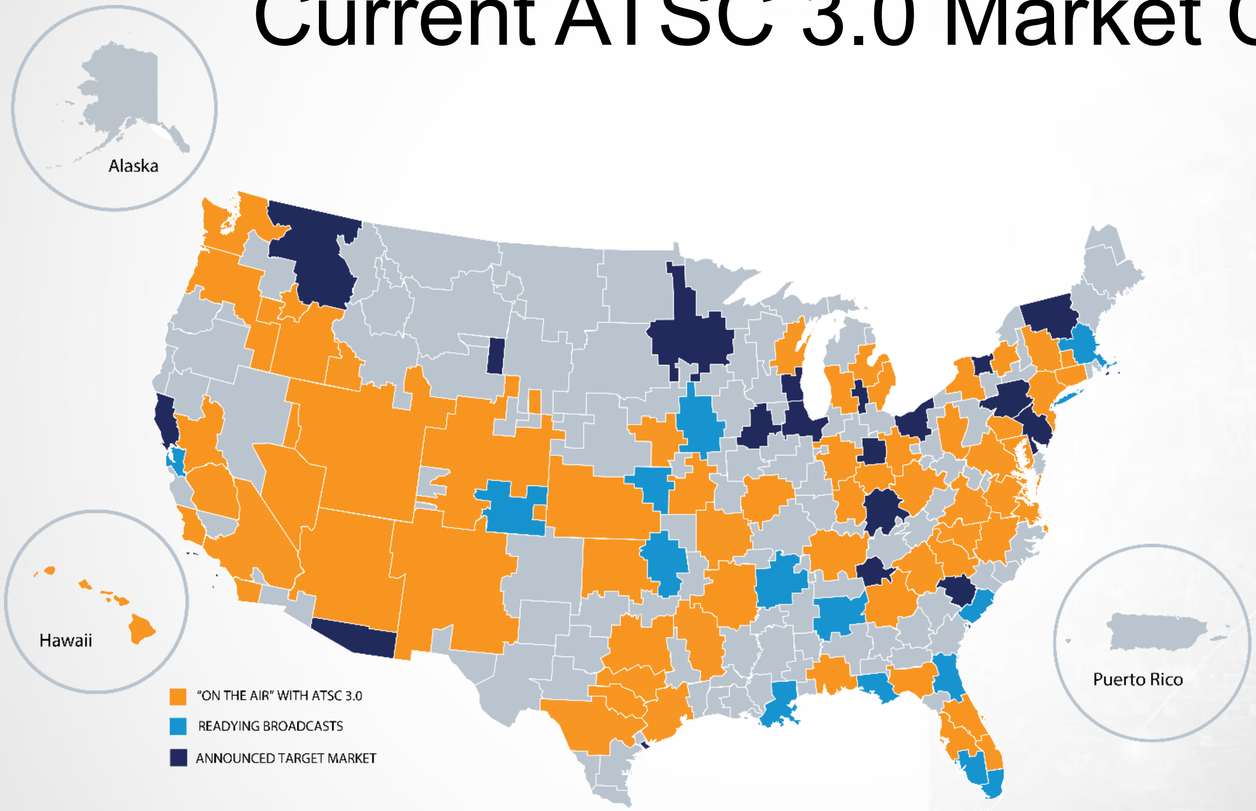
High Power with Frequency Diversity

Low VHF	High VHF	UHF
2-6 Channels	7-13 Channels	14-36 Channels
54-88 MHz Frequency	174-216 MHz Frequency	470-608 MHz Frequency

516 VHF stations, up to 10 KW

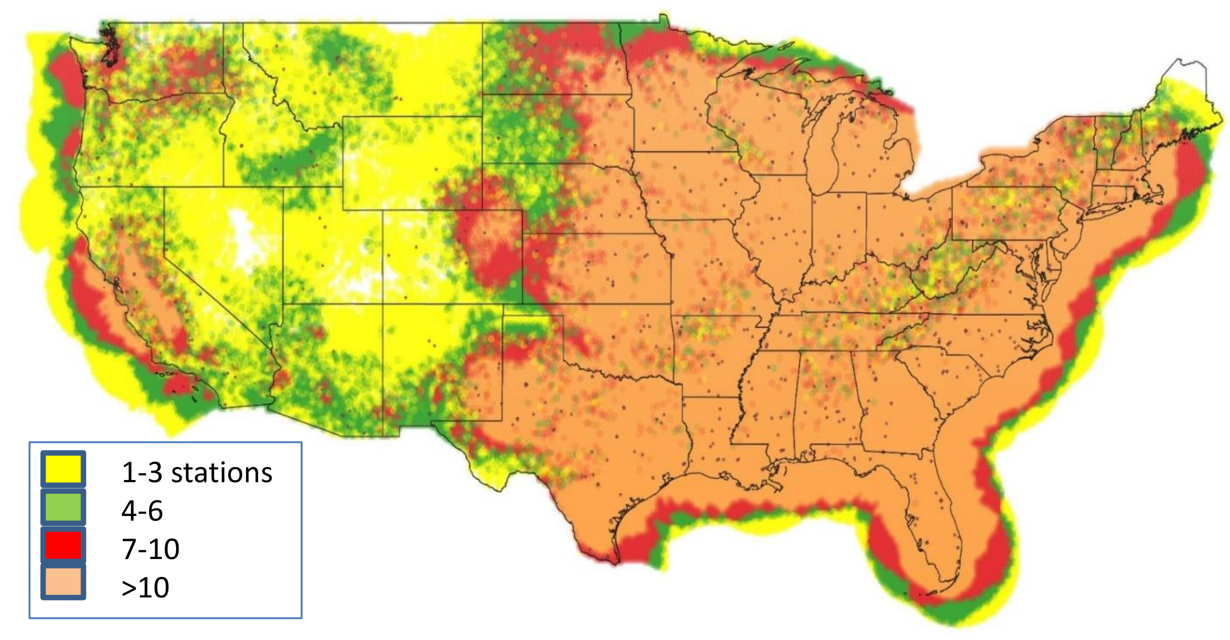
1,526 stations, 100 – 1000 KW

Current ATSC 3.0 Market Coverage



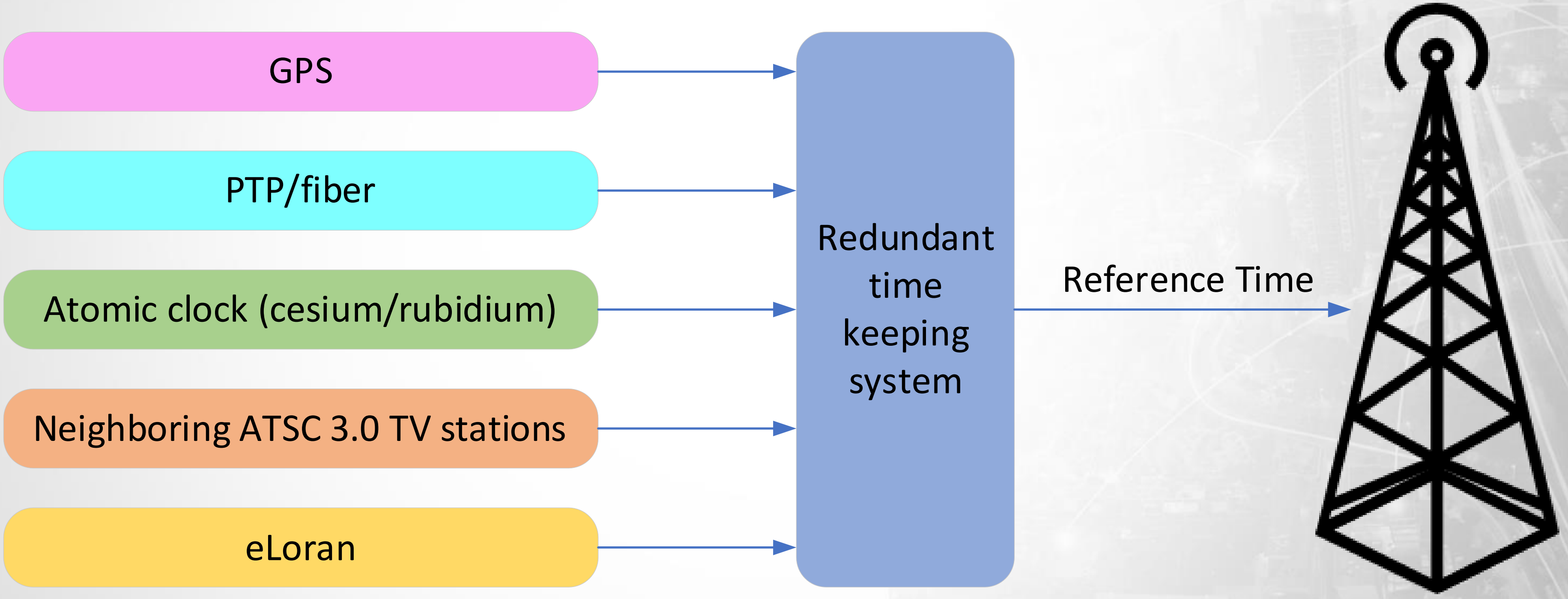
Source: atsc.org

ATSC 3.0 Coverage at Full UHF Deployment

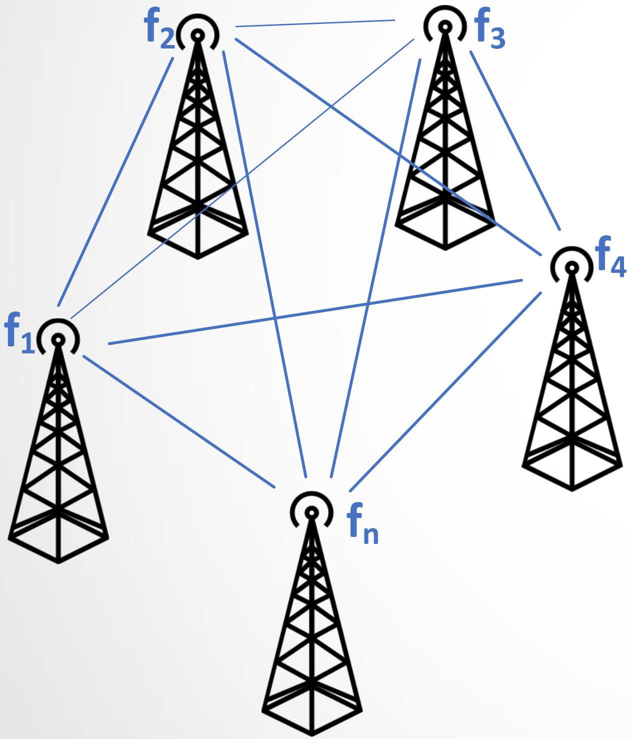


- Only 696 UHF towers separated by at least 1km are considered
- 830 UHF and 516 VHF towers are excluded for analysis
- Thousands of low power stations are also excluded

Redundant Timing Sources



Increasing Resiliency and Accuracy



Report emission time and location of neighboring stations

Report timestamping errors of previous frames

Advantages of BPS

- Infrastructure is already built; can be deployed with low incremental cost
- Reliable Tx facility designed to continue to operate during emergencies
- Frequency diversity (wide range of frequencies)
- In-building coverage (high-power, high-tower)
- Works when GPS is spoofed or unavailable
- Free to use
- Receiver chip-sets are mass produced
- Handles unlimited number of users

Use Cases

- Deliver GPS-independent time
- Deliver GPS-independent position and time
- Detect GPS spoofing
- GPS-BPS hybrid location, DGPS/RTK, A-GPS Assistance data

Development Phases

Phase 1 — *2022-2023*

- Build Tx-side prototype
- Demonstrate ATSC 3.0 compliance
- Identify technology gaps
- Measure timing accuracy

Phase 2 — *2023-2024*

- Modify equipment/software as needed
- Deploy in a live market
- Build a prototype receiver
- Demonstrate timing at a known location

Phase 3 — *2024-2025*

- Add backup timing sources at Tx site
- Demonstrate time delivery in a live market

Phase 4 — *2025-2027*

- Deploy ATSC 3.0 based timing for use by the public
- Fund system operations

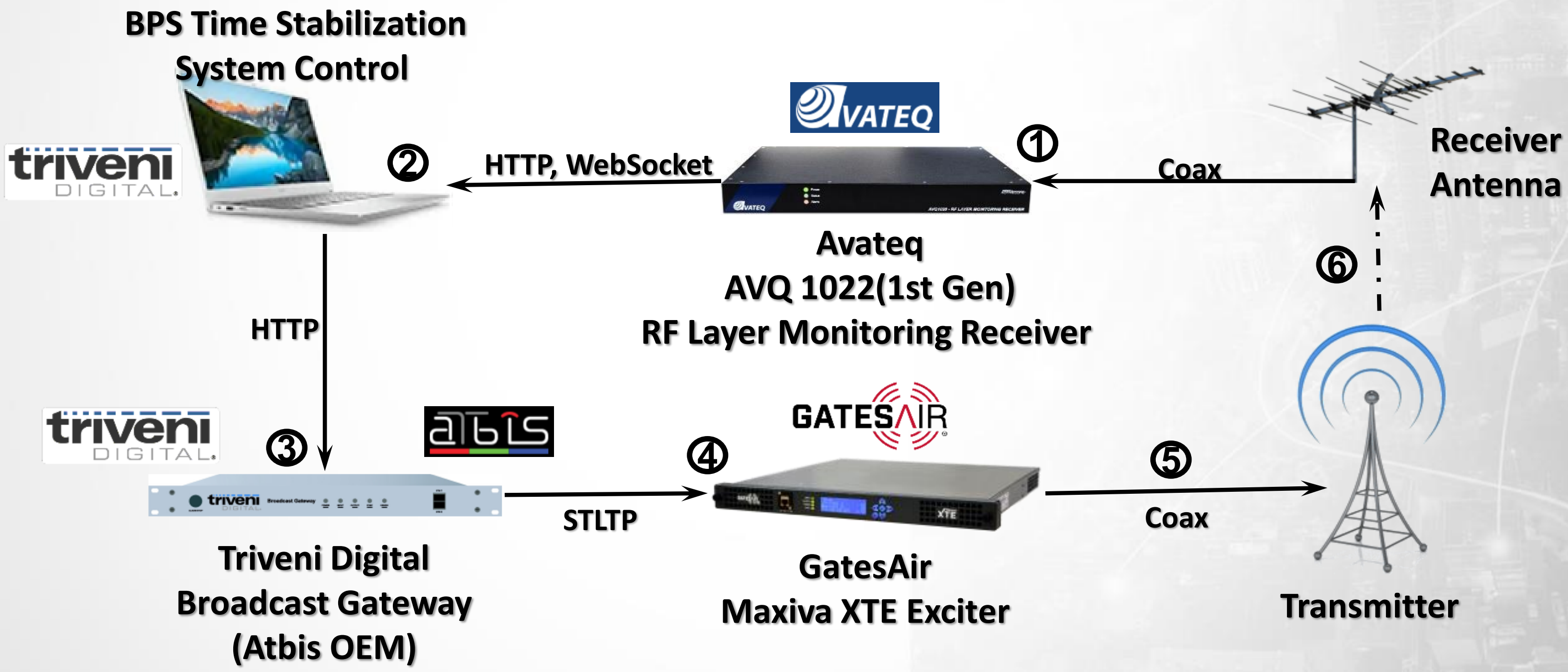
Phase 5 — *2026-2027*

- Build multilateration receiver prototype
- Set up a test area with four TV towers
- Demonstrate joint positioning and timing use case

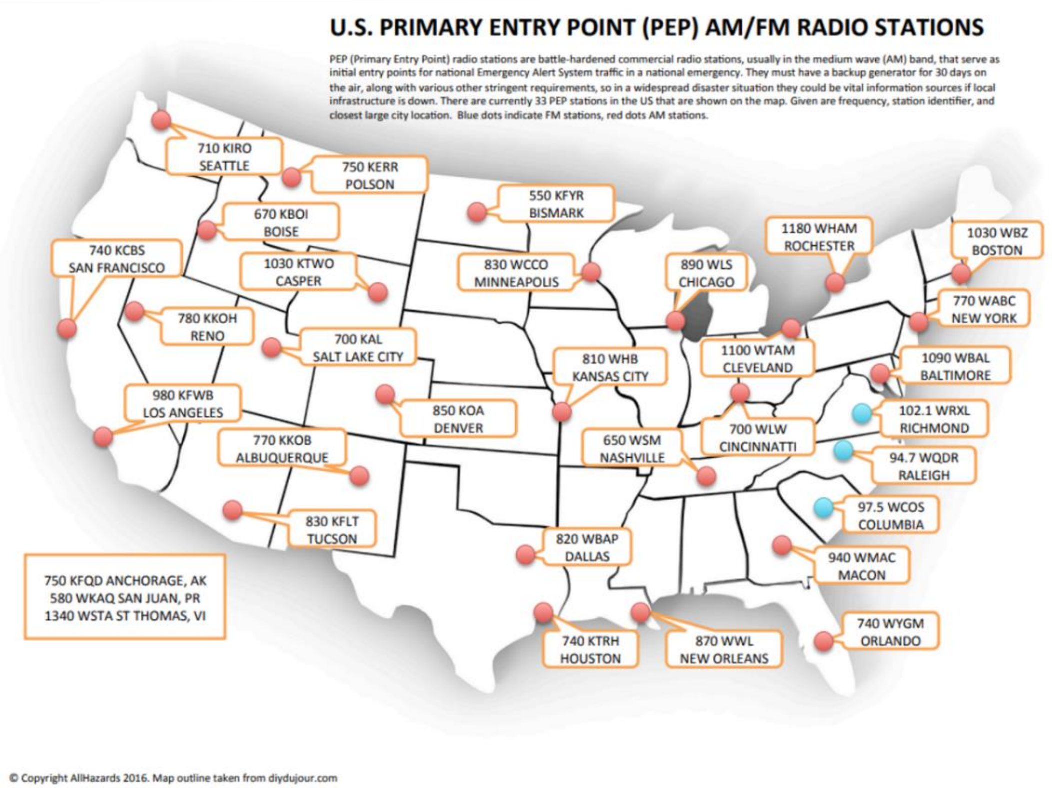
Phase 6 — *2027-2029*

- Add neighbor measurement features
- Deploy BPS (time and position) for use by the public
- Fund system operations
- Plan for future improvement

Phase 1 – Funded by NAB



PEP: Example of Broadcaster-Gov't Partnership



- Executive Order 13407 - Public Alert and Warning System
- FEMA Primary Entry Point (PEP) Stations
- ATSC 3.0 supports Emergency Alert System (EAS)

Government Support for Free-to-use Service

Develop public-private partnership

Fund R&D for Phases 2 and 3

Demonstrate in a live market

→

Phase 4

Deploy time use case nationwide

→

Phase 5

Test in live markets

→

Phase 6

Deploy time and position use case nationwide

Questions?

Thank You

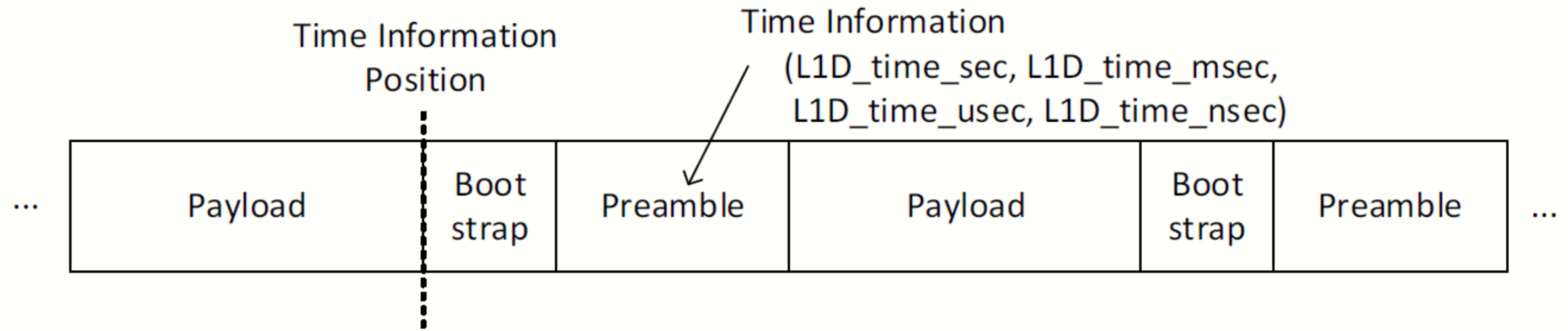
BACKUP SLIDES

ATSC 3.0 Signal

Bootstrap – time of arrival (TOA) estimation

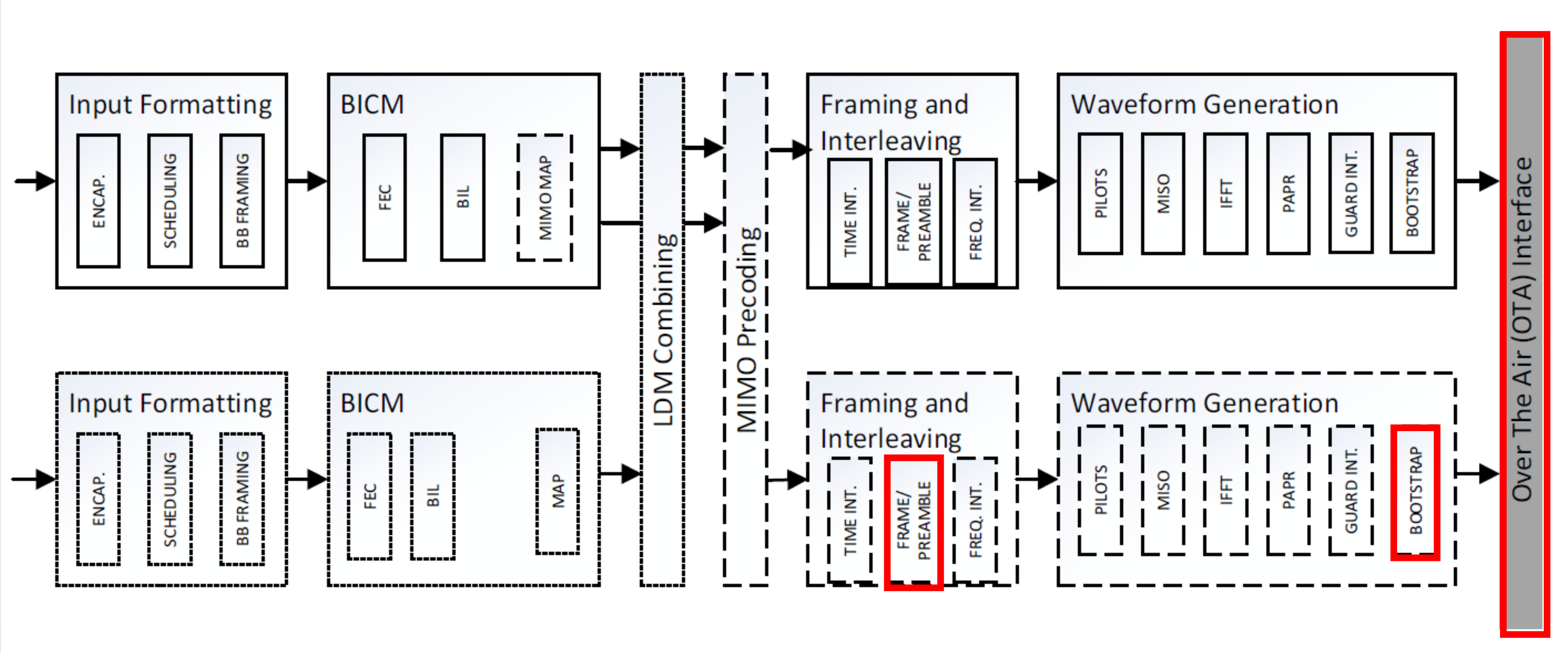
Preamble – time information

Payload- tower location, neighbor measurements, and past measurement errors



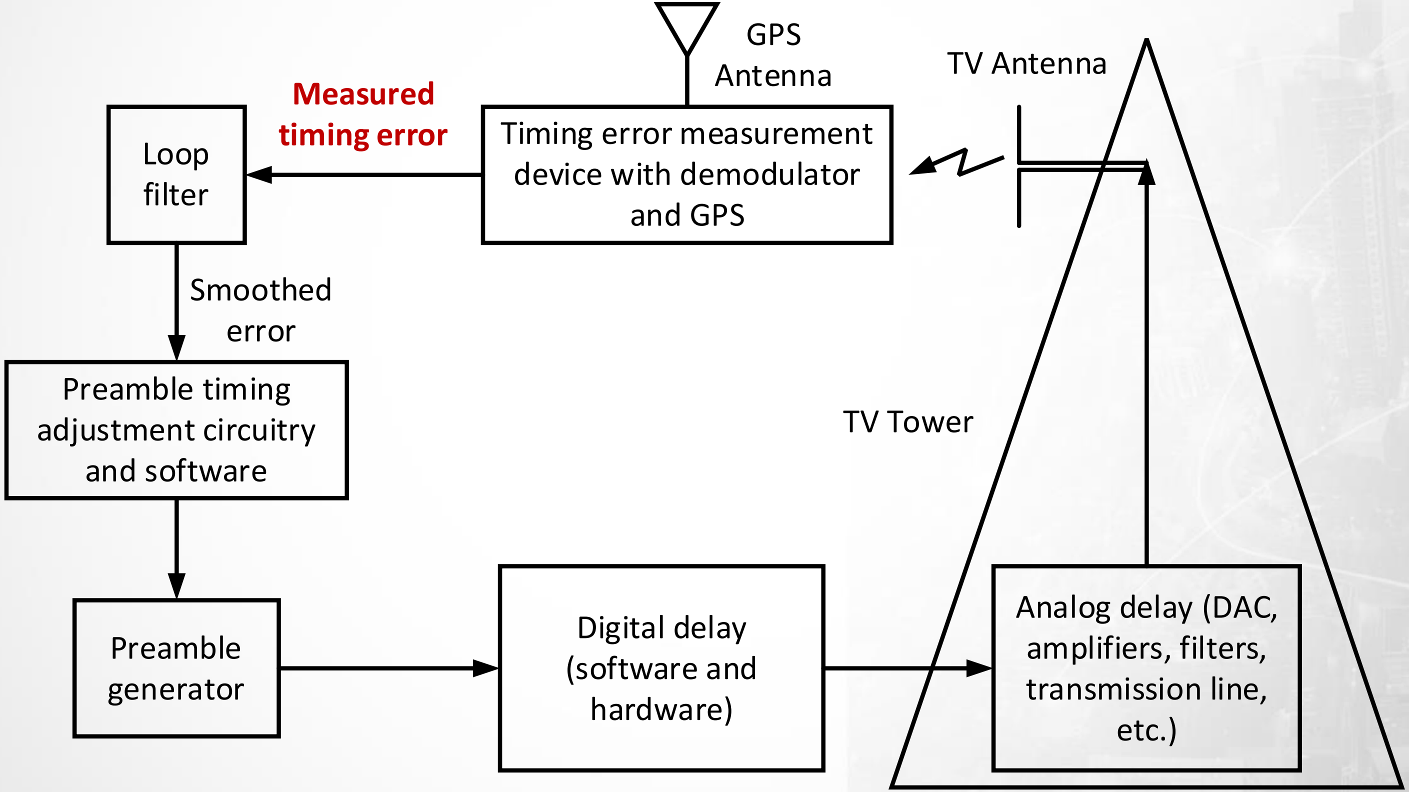
Source: ATSC Standard, Physical Layer Protocol, Doc. A/322:2020

Preamble Timestamp



Source: ATSC Standard, Physical Layer Protocol, Doc. A/322:2020

Time Synchronization at the Transmitter



Coverage Assumptions

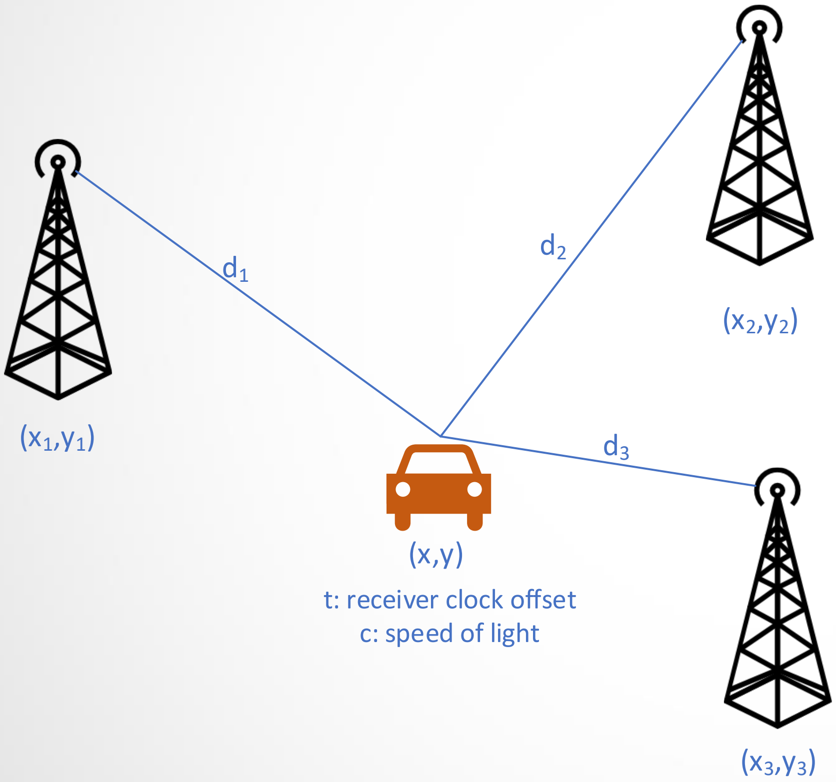
- System threshold -5 dB SNR (Data PLP is the weakest link)
- Longley–Rice propagation model is used

Parameter	Value	Unit
System Bandwidth	6	MHz
Thermal Noise (kTB)	-106.2	dBm
Frequency of Operation	539	MHz
Antenna Gain	0	dBi
Antenna Factor	-129.6	dBm-dBμV/m
Noise Figure	6	dB
Required Field Strength	24.4	dBμV/m
RX Antenna height, AGL	1.5	m
Location, Time Variability	50%, 50%	–

Approximate BPS Coverage Area (CONUS)

# Stations	Cell Count	Cumulative Fraction of CONUS
≥10	40969	53%
≥9	43235	56%
≥8	45854	60%
≥7	48801	63%
≥6	52038	68%
≥5	55794	72%
≥4	60232	78%
≥3	65606	85%
≥2	71264	93%
≥1	76076	99%
Total CONUS Land Area	77000	(100% = 7.7 million km^2)

Pseudorange Multilateration Concept



Pseudorange equations:

$$r_1 = \sqrt{(x_1 - x)^2 + (y_1 - y)^2} + ct$$

$$r_2 = \sqrt{(x_2 - x)^2 + (y_2 - y)^2} + ct$$

$$r_3 = \sqrt{(x_3 - x)^2 + (y_3 - y)^2} + ct$$

Multilateration Technique

- $(\hat{x},\hat{y})$ is the estimated location of the receiver
- $\hat{t}$ is the estimated clock offset
- $\hat{r}1$, $\hat{r}2$, and $\hat{r}3$ are the estimated pseudoranges

$$x = \hat{x} + \Delta x$$

$$y = \hat{y} + \Delta y$$

$$t = \hat{t} + \Delta t$$

$$\Delta r_1 = \hat{r}_1 - r_1$$

$$\Delta r_2 = \hat{r}_2 - r_2$$

$$\Delta r_3 = \hat{r}_3 - r_3$$

Multilateration Iterative Solution

$$\boldsymbol{\Delta x} = \begin{bmatrix} \Delta x \\ \Delta y \\ -c\Delta t \end{bmatrix} \qquad \boldsymbol{H} = \begin{bmatrix} \frac{(x_1-\hat{x})}{\sqrt{(x_1-\hat{x})^2+(y_1-\hat{y})^2}} & \frac{(y_1-\hat{y})}{\sqrt{(x_1-\hat{x})^2+(y_1-\hat{y})^2}} & 1 \\ \frac{(x_2-\hat{x})}{\sqrt{(x_2-\hat{x})^2+(y_2-\hat{y})^2}} & \frac{(y_2-\hat{y})}{\sqrt{(x_2-\hat{x})^2+(y_2-\hat{y})^2}} & 1 \\ \frac{(x-\hat{x})}{\sqrt{(x_3-\hat{x})^2+(y_3-\hat{y})^2}} & \frac{(y-\hat{y})}{\sqrt{(x_3-\hat{x})^2+(y_3-\hat{y})^2}} & 1 \end{bmatrix} \qquad \boldsymbol{\Delta r} = \begin{bmatrix} \Delta r_1 \\ \Delta r_2 \\ \Delta r_3 \end{bmatrix}$$

Least-square solution: $\boldsymbol{\Delta x} = (\boldsymbol{H}^T\boldsymbol{H})^{-1}\boldsymbol{H}^T\boldsymbol{\Delta r}$

Weighted least-square solution: $\boldsymbol{\Delta x} = (\boldsymbol{H}^T\boldsymbol{W}\boldsymbol{H})^{-1}\boldsymbol{H}^T\boldsymbol{W}\boldsymbol{\Delta r}$ where $\boldsymbol{W} = \begin{bmatrix} w_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & w_n \end{bmatrix}$

Simulation Set-up

4 towers at (50000, 0), (0, 50000), (-50000, 0), and (0, -50000) meters on X-Y plane

200 m antenna height

Random TOA estimation error between -5 m to +5 m (uniform dist.)

Standard deviation well above Cramer-Rao bound

Bootstrap sample duration is 48.8 m

Unresolved multipath error at the receiver 0-100 m (uniform dist.)

Assumed that TOA detector will detect the earliest path

Assumed that ambiguity function based joint time-frequency estimation

Receiver clock offset is set to the distance of the nearest tower

Assumed that receiver clock will synchronize with the strongest signal

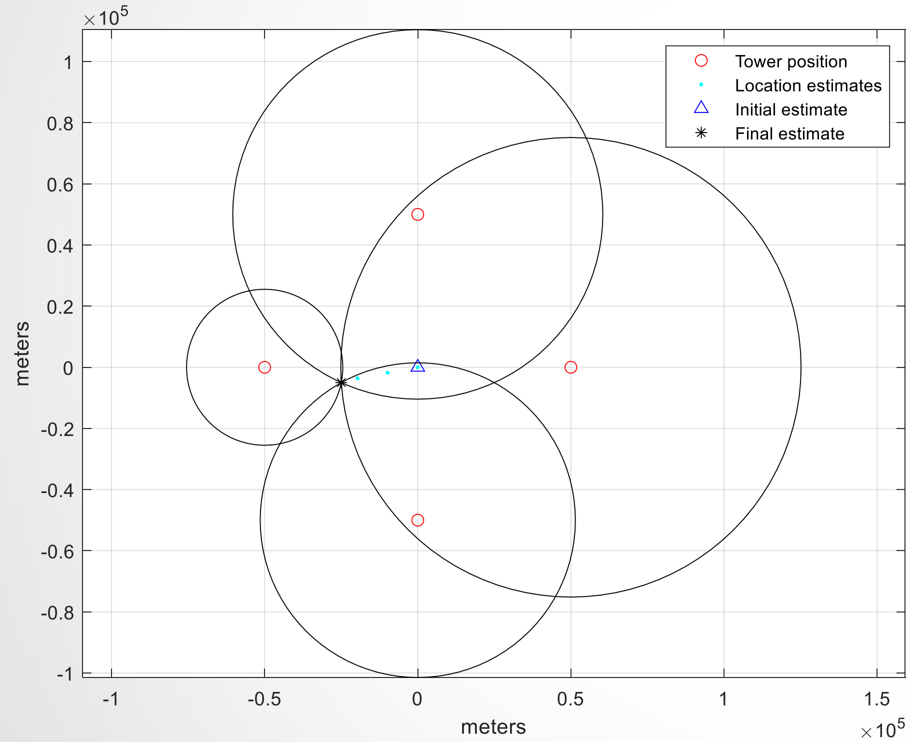
A Typical Simulation Run

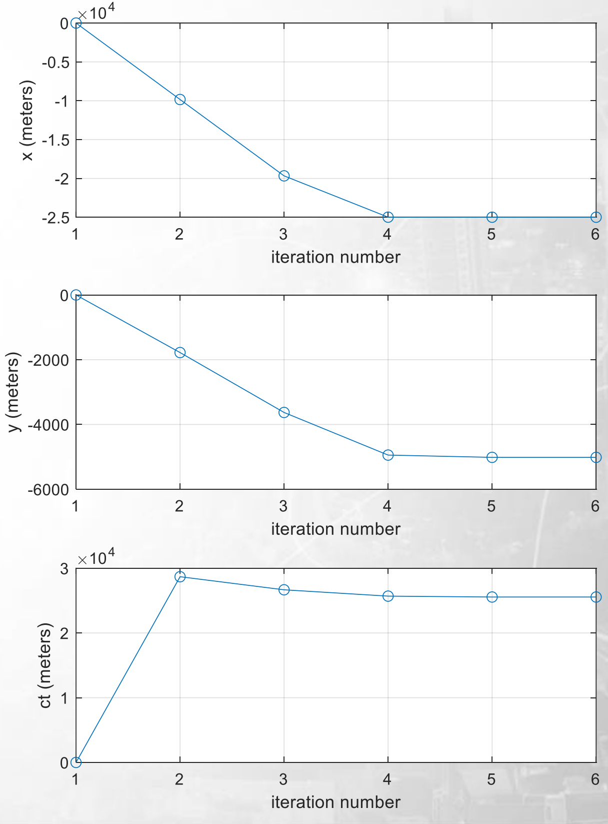
```
TOA estimation error:  4.1 m, -3.2 m, -2.4 m, -3.5 m,
multipath error:      13.6 m, 86.9 m, 58.0 m, 55.0 m,
clock offset:  25495.9 m

true (x,y,t):       x = -25000.0 m, y =  -5000.0 m, t =  25495.9 m
estimated (x,y,t):  x = -24989.9 m, y =  -5015.7 m, t =  25549.6 m

estimation error:   x =    -10.1 m, y =     15.7 m, t =    -53.7 m
estimation error (distance):      18.7 m
```

A Typical Simulation Run





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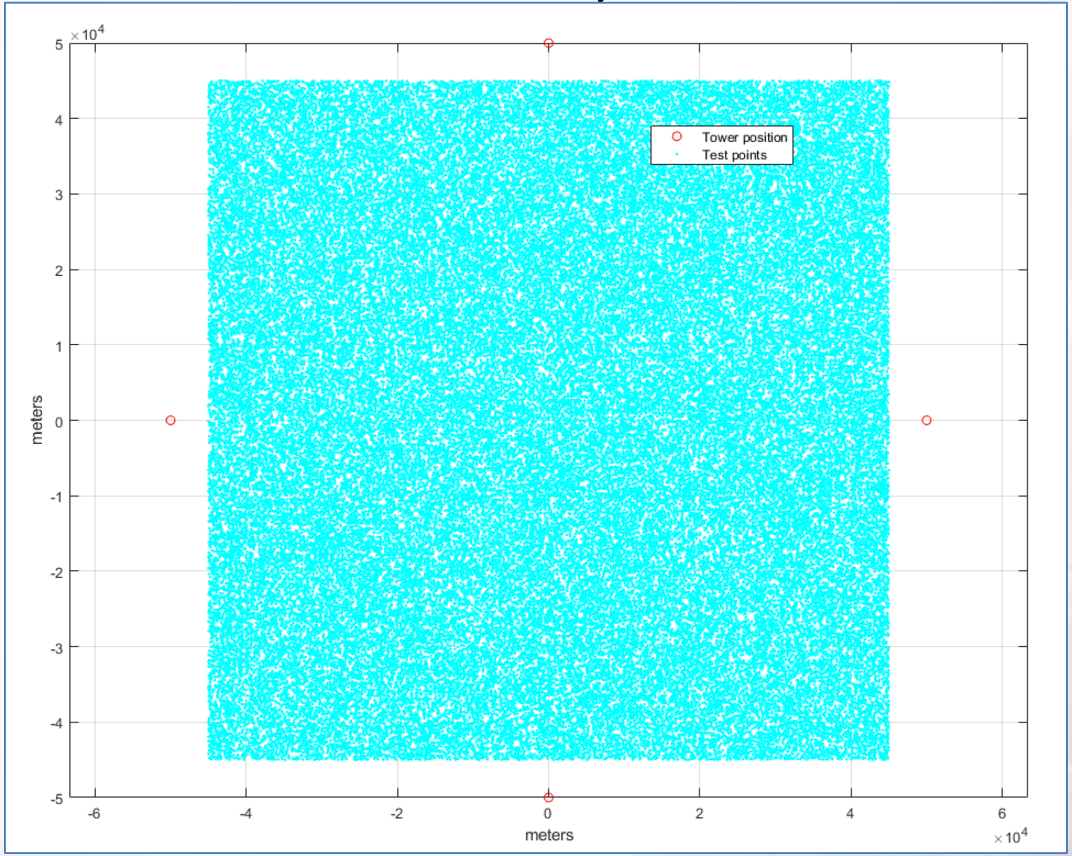
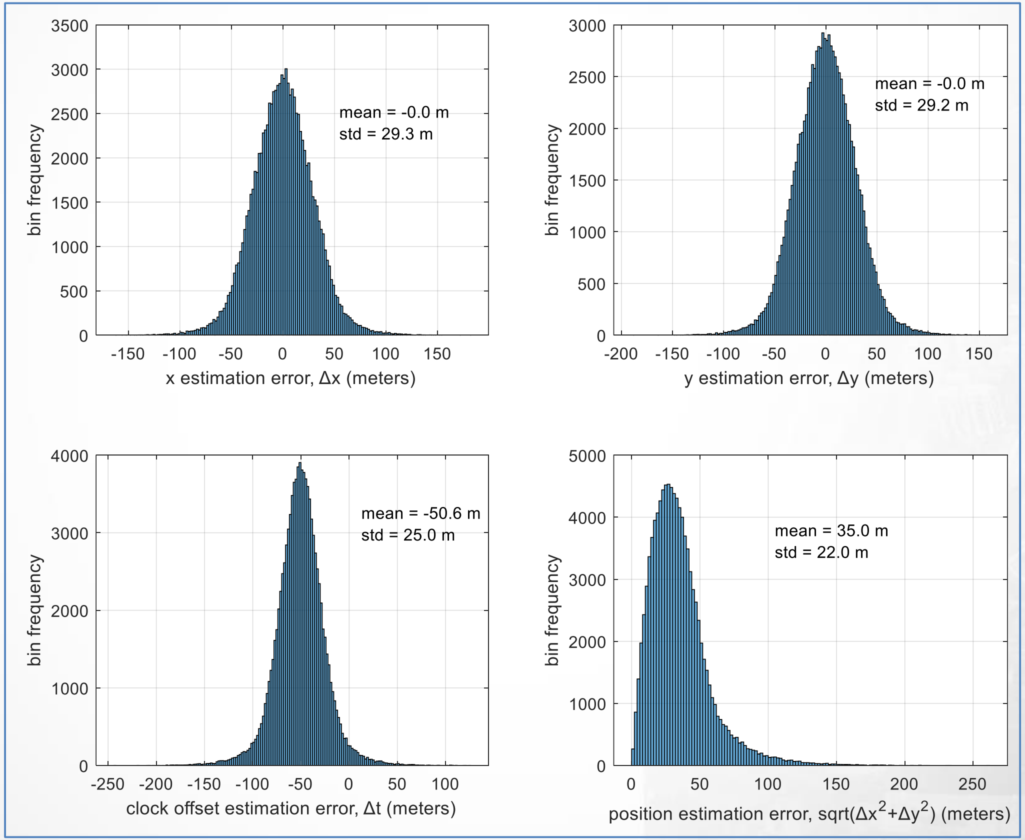
Simulation of 10,000 Points



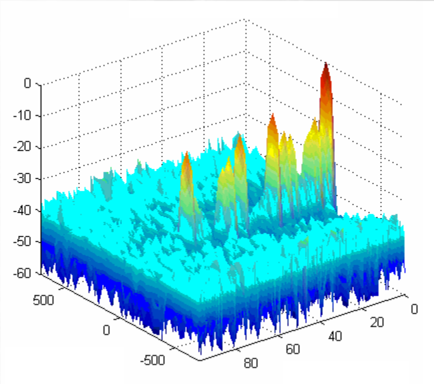
Simulation Results of 10,000 Points



Increasing Yield, Resiliency, and Accuracy

- System threshold can be reduced to -9 dB SNR (preamble) if neighbor stations report all nearby neighbor antenna locations
- System threshold can be reduced to -12 dB SNR (bootstrap) if neighbor stations report all neighbor antenna locations, timing, and frequency
- Accuracies of previous fixes can be improved if timestamping error of the previous frame is sent on the next data frame

Recommended Neighbor Measurements



- Transmit antenna ID (a unique ID to distinguish the antenna)
- Transmit antenna position (latitude, longitude, and elevation)
- Transmit antenna radiated power
- Transmit antenna radiation pattern (and/or average coverage radius)
- Neighbor station antenna IDs
- Neighbor station channels (frequencies)
- Neighbor antenna positions (latitudes, longitudes, and elevations)
- Neighbor antenna radiated power levels
- Neighbor antenna radiation patterns
- Timing offset of the neighbor bootstrap signals relative to the self bootstrap signal
  – Could either be the value observed at the self (transmitter) site or can be compensated for the distance travelled
- Current number of leap seconds expressed as TAI – UTC
  – To avoid decoding of A/331 video service messages for location computation
- Reported bootstrap transmission time of the previous frames (for both self and neighbors)
- Measured time-stamp reporting error of the previous frames (for both self and neighbors)