BROADCAST POSITIONING SYSTEM (BPS)
TIME AND POSITION USING ATSC 3.0 SIGNALS

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Timing Needs for U.S. Critical Infrastructure

- Energy & Power Grid
- Communications
- Financial Transactions
- Transportation (Aviation, Maritime, Rail, Surface, Pipeline)
- First Responders
- Chemical
- Dams
- Information Technology
- Critical Defense Manufacturing
- Healthcare and Public Health
- Food and Agriculture

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Technical Requirements to Satisfy Critical Infrastructure Usability Needs

Name of Industry	Timing Requirements
Mobile Wireless Networks	**1.1 µsec** traceable to UTC
Equity Trading Systems	**1 µsec** within UTC NIST (SEC Section 613 rules, MifID II EU)
Power Grid	**1 µsec** to UTC, IEEE 37-238, (Synchro-phasors)
Other CI Industries	**200 ns** satisfies all requirements

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

Broadcast Positioning System (BPS)

A system and method of estimating time and position at a receiver using ATSC 3.0 broadcast signals

Compliant with ATSC 3.0 standard; uses datacasting feature

Independent and stand-alone

- GPS, Internet or cellular connectivity not required

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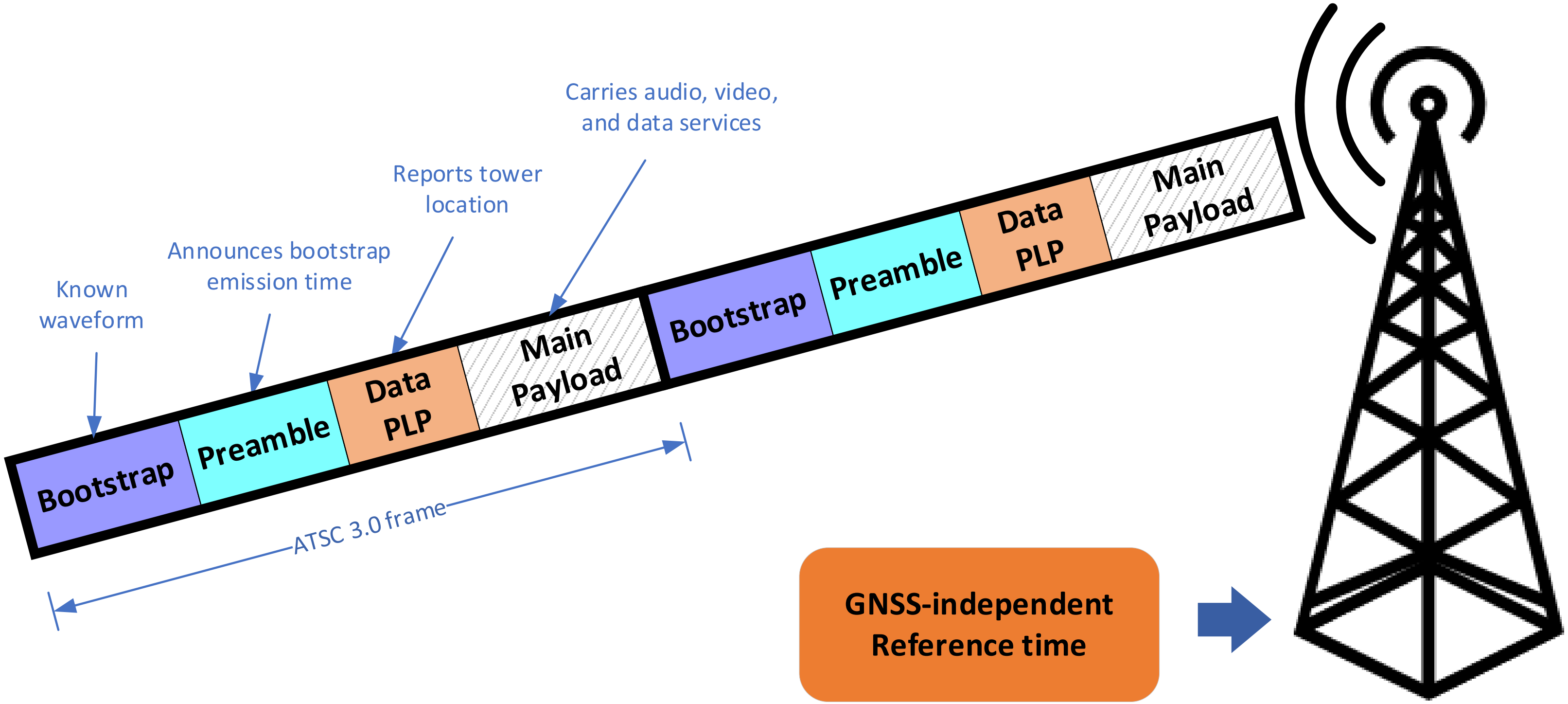
Time Delivery



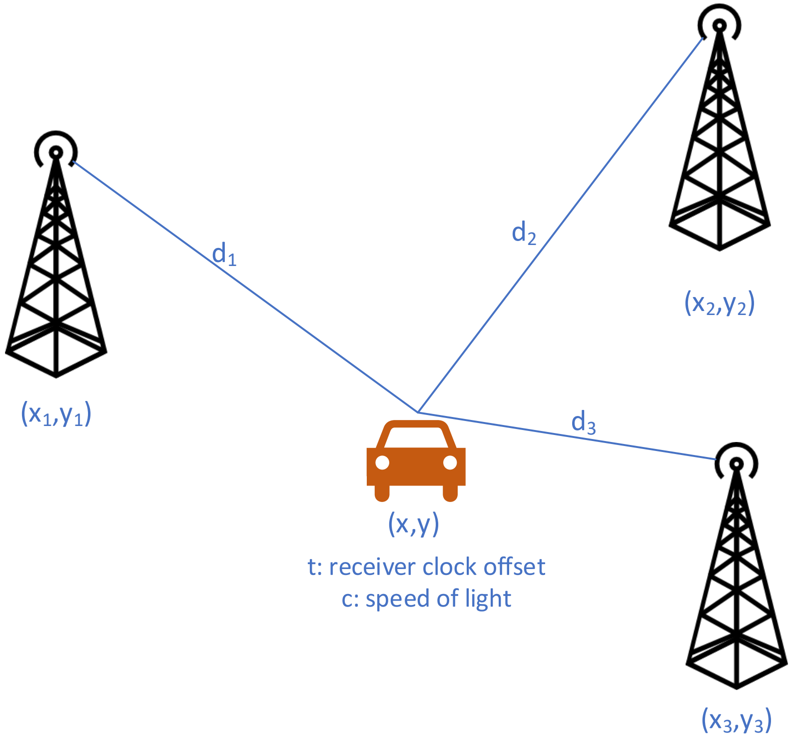
Pseudorange Multilateration Concept

Pseudorange equations:

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

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

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



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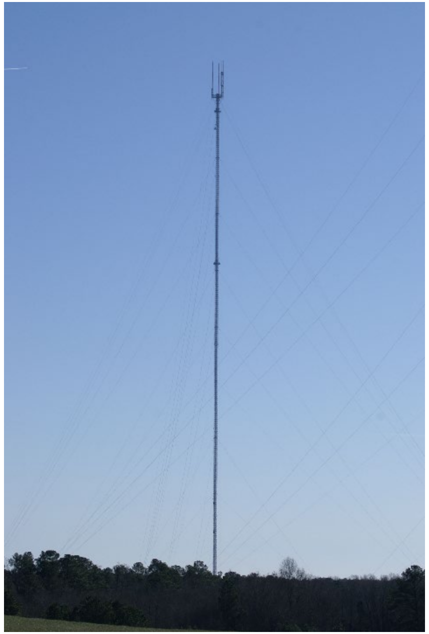
PNT Capabilities of BPS



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

- 70 m positioning accuracy 50% of the time

Can detect GPS spoofing

Can enable GPS-BPS hybrid location

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

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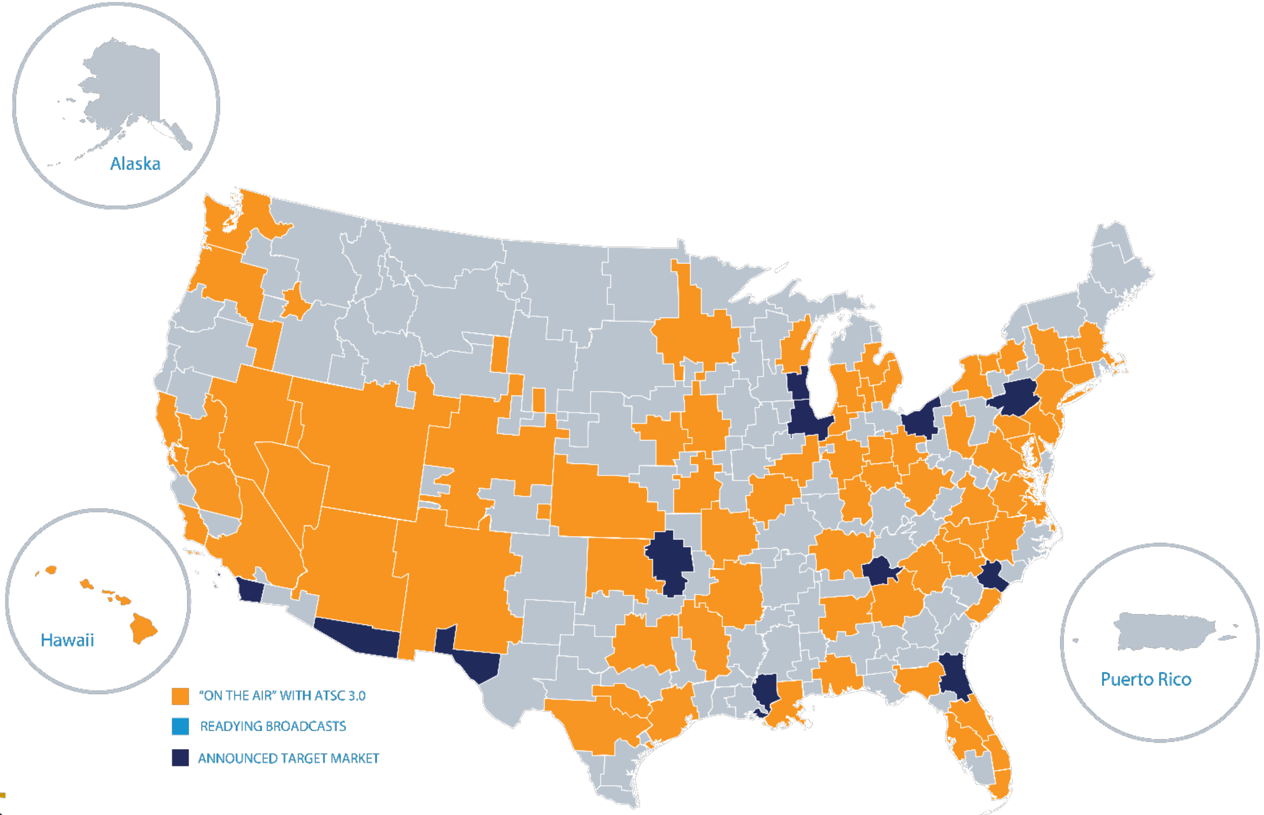
Current ATSC 3.0 Market Coverage in US



Source: atsc.org

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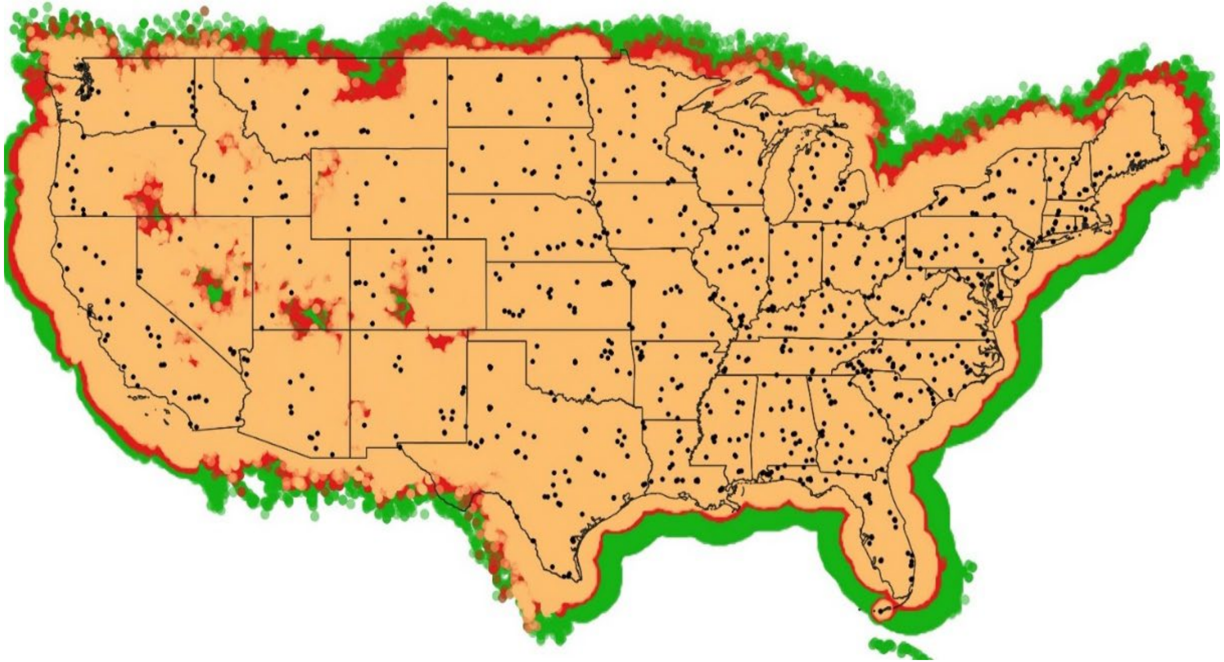
BPS (UHF & VHF) Coverage at Full Deployment

Coverage at 1.5 m antenna height:

- At demodulation threshold (-5 dB SINR)
- Threshold + 10 dB
- Threshold + 20 dB

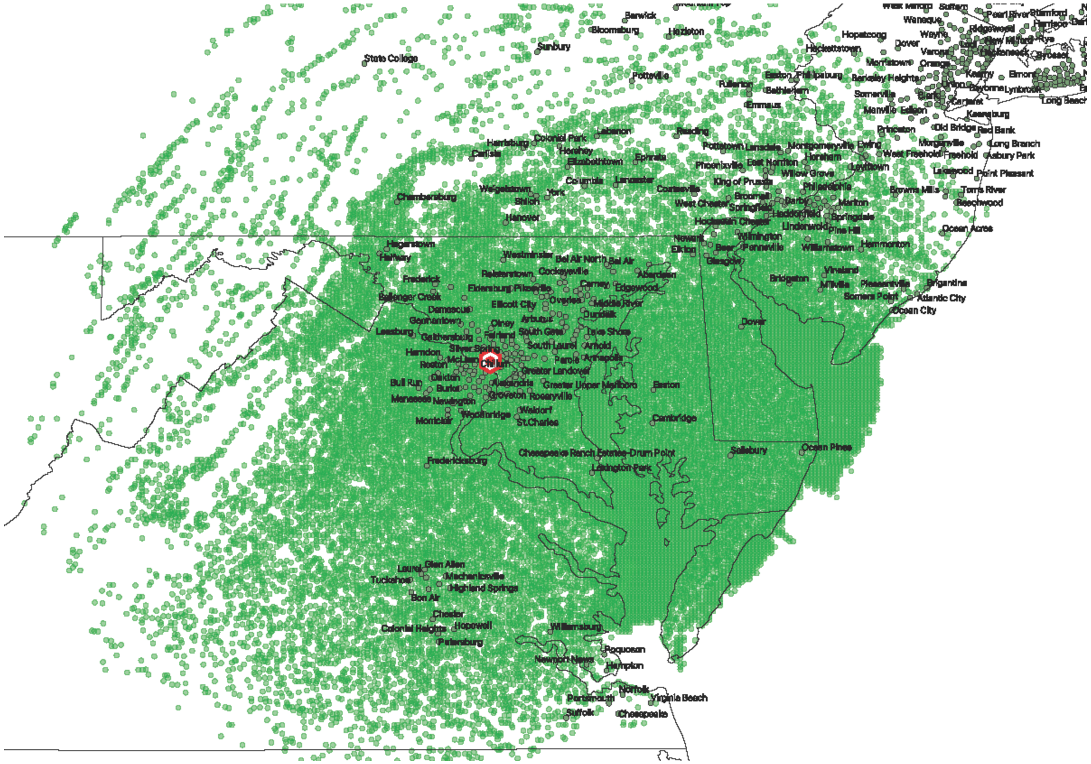


Average signal reception:

- 17 towers at 1.5 m antenna height
- 70 towers at 50m antenna height

Typical Predicted BPS Coverage (50/50) of a TV Station

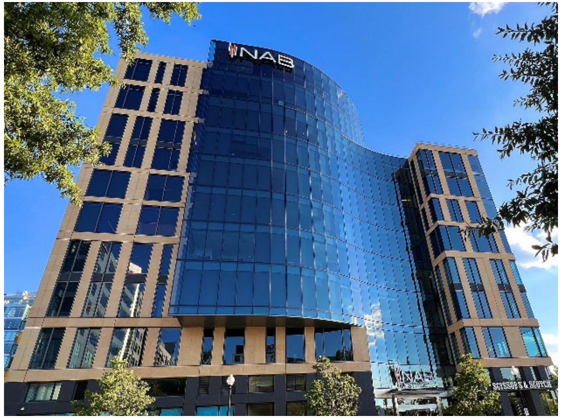
- WHUT-TV, Howard University
- 833 ft antenna height (HAAT)
- 416 kW ERP
- Channel 32, 587 MHz (center)

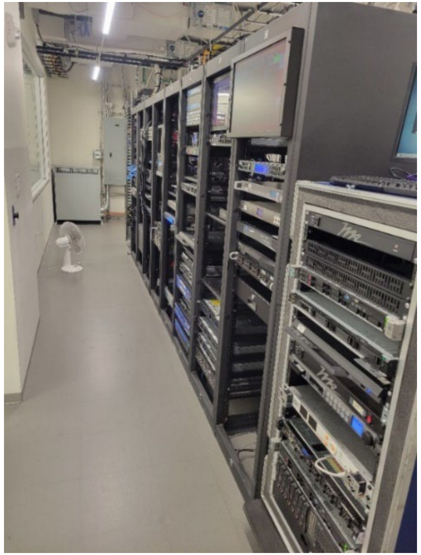


Advantages of BPS

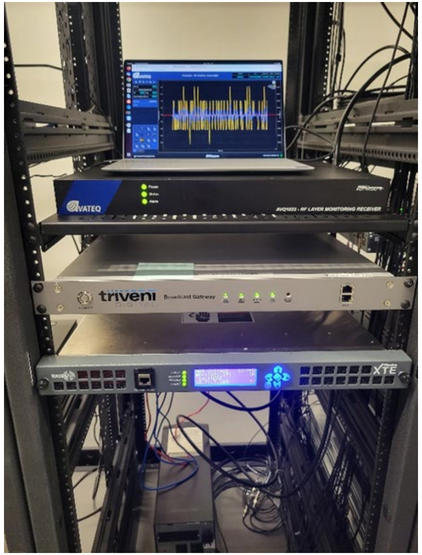
- Infrastructure is already built
- Global standard
- Passive consumer service
- Independent
- Frequency diversity
- Nationwide coverage

1st Gen Prototype Running at NAB 1M Lab





ATSC 3.0 Testbed at NAB 1M Lab



Operational BPS Prototype at NAB 1M Lab

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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 — 2024-2026
- Deploy ATSC 3.0 based timing for use by the public
- Fund system operations

Phase 5 — 2025-2027
- Build multilateration receiver prototype
- Set up a test area with four TV towers
- Demonstrate joint positioning and timing use case

Phase 6 — 2025-2029
- Add neighbor measurement features
- Deploy BPS (time and position) for use by the public
- Fund system operations
- Plan for future improvement

References

Mondal, T., Weller, R., and Matheny, S., "Broadcast Positioning System (BPS) Using ATSC 3.0," *Proceedings of the 2021 NAB Broadcast Engineering and Information Technology (BEIT) Conference*

- https://nabpilot.org/product/broadcast-positioning-system-bps-using-atsc-3-0-2/

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- https://nabpilot.org/product/delivering-traceable-reference-time-for-atsc-3-0-based-broadcast-positioning-system-bps/

Corl, M., Anishchenko, V., and Mondal, T., "BPS ATSC 3.0 Broadcast Emission Time Stabilization System Proof-of-concept," *Proceedings of the 2023 NAB Broadcast Engineering and Information Technology (BEIT) Conference*

- https://nabpilot.org/product/bps-atsc-3-0-broadcast-emission-time-stabilization-system-proof-of-concept/

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IN-DEPTH BPS TECHNICAL PRESENTATION AND DEMO

Tariq Mondal, NAB

Mark Corl, Triveni Digital

Vlad Anishchenko, Avateq Corp

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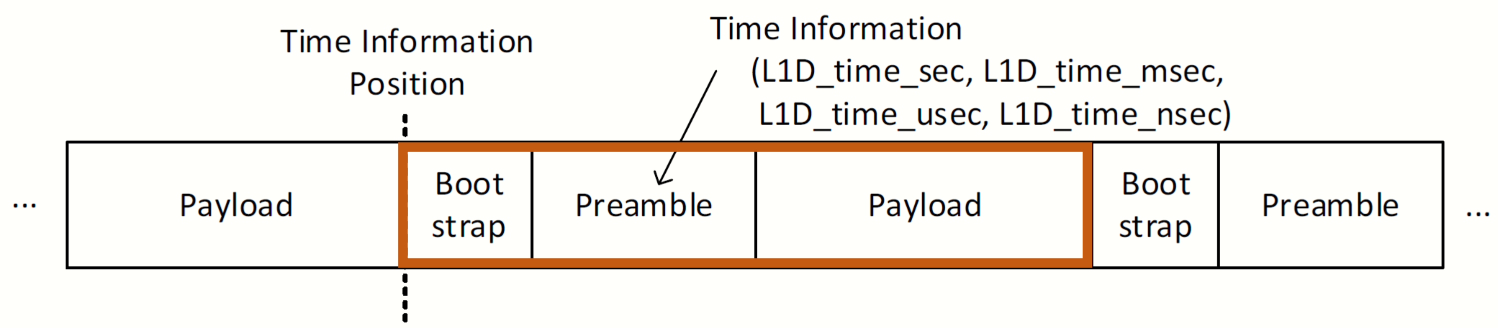
ATSC 3.0 Physical Layer Frame

Bootstrap – time of arrival (TOA) estimation

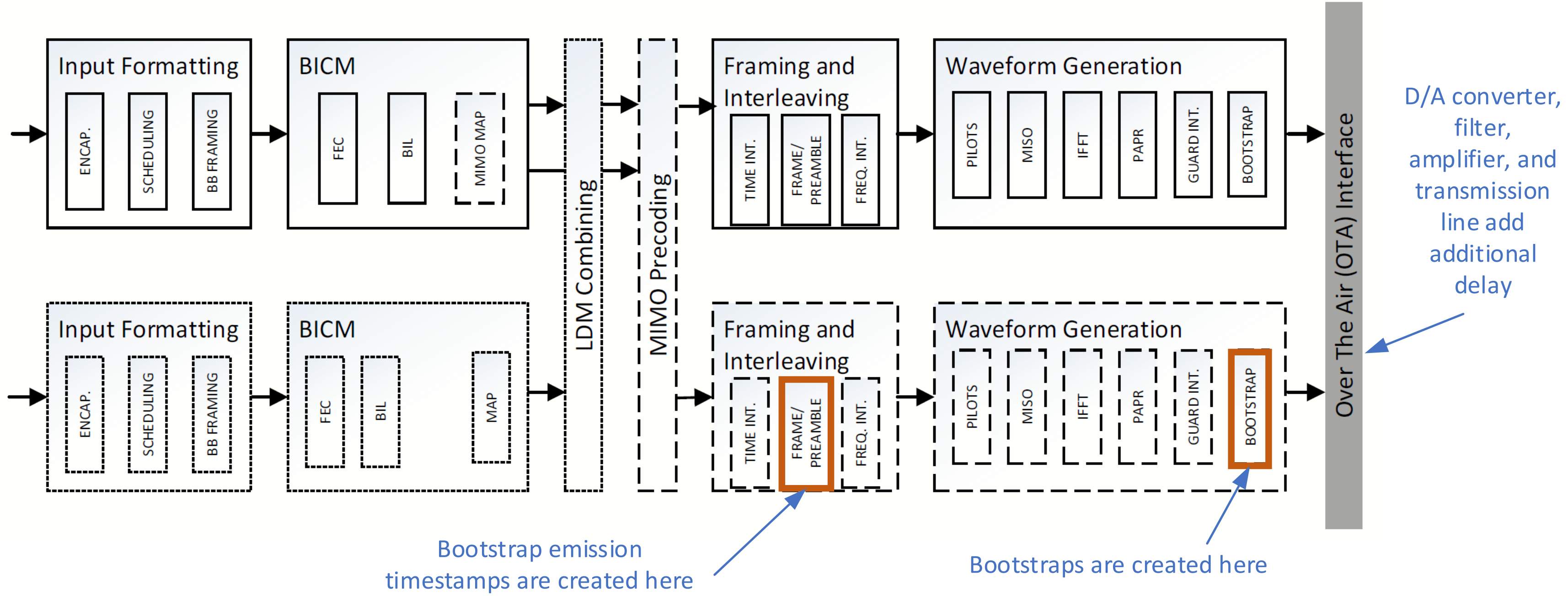
Preamble (L1-Basic and L1-Detail) – timing info

Data PLP - tower location and neighbor measurement info



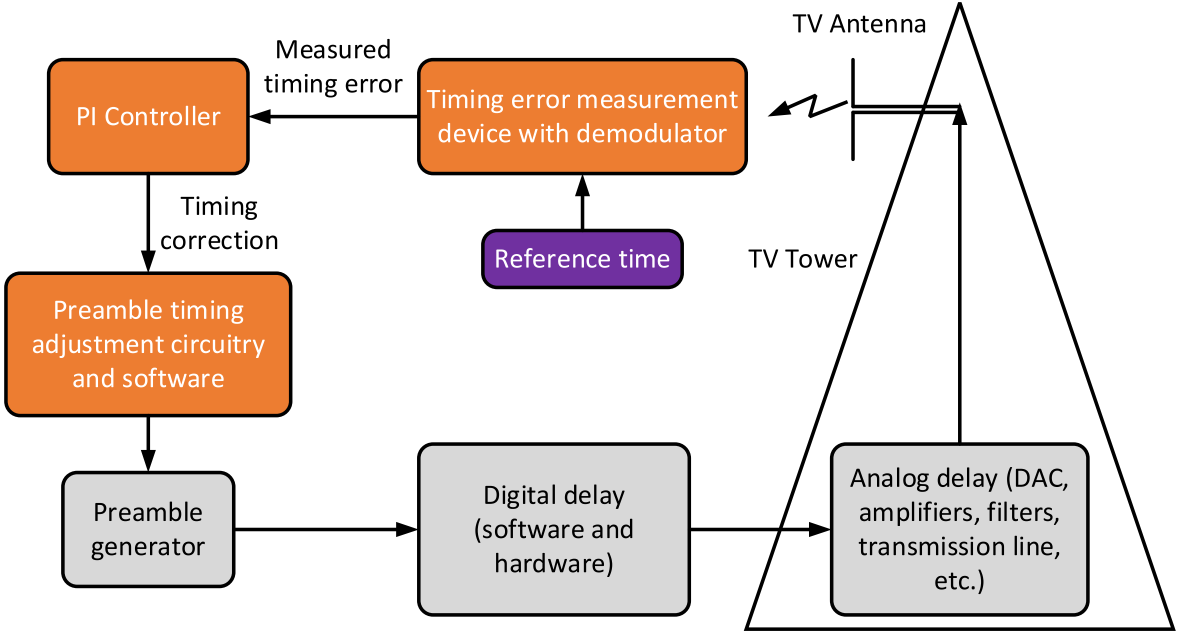
Source: ATSC Standard, Physical Layer Protocol, Doc. A/322:2020

Preamble Timestamping Challenge

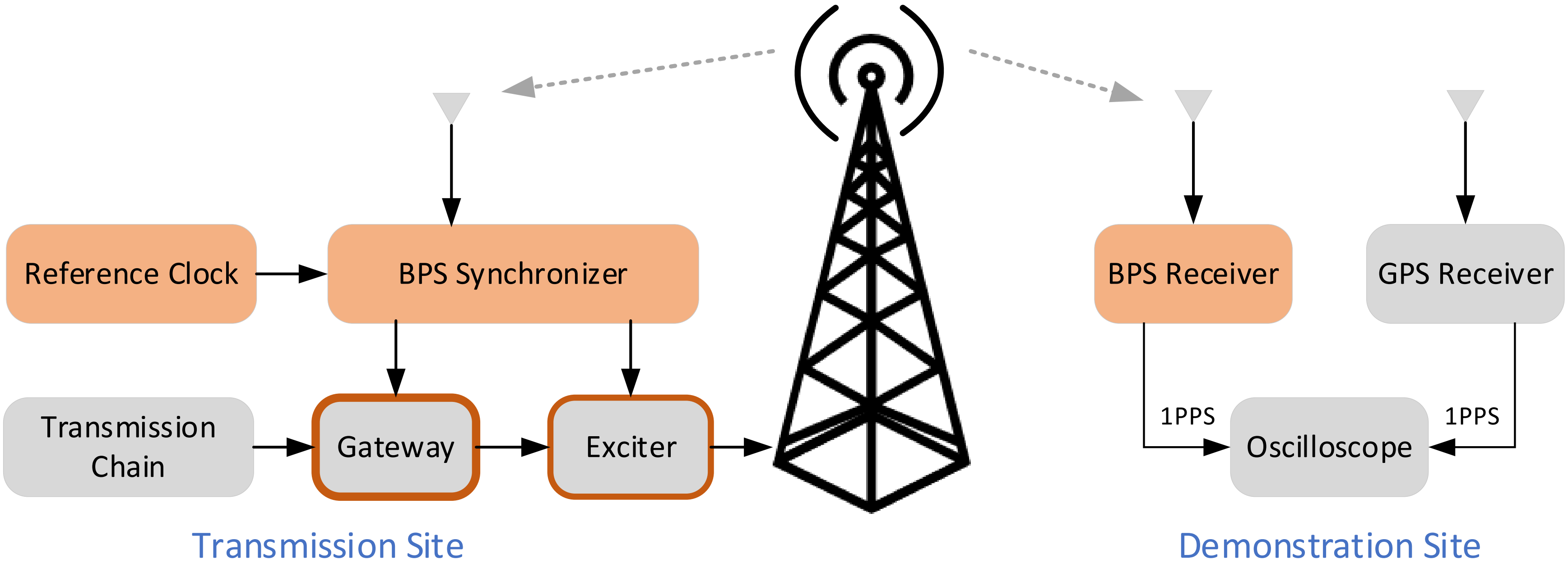


Source: ATSC Standard, Physical Layer Protocol, Doc. A/322:2020

Time Synchronization at the Transmitter



Humber College Demo Setup



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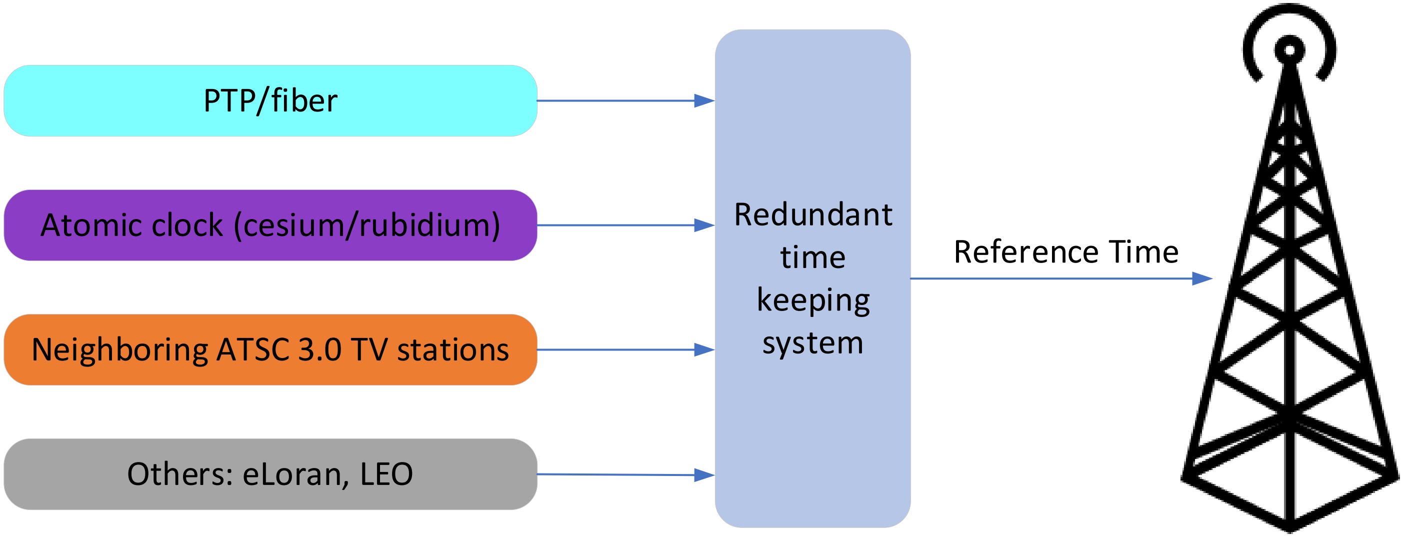
Reliable and Traceable Timing Source



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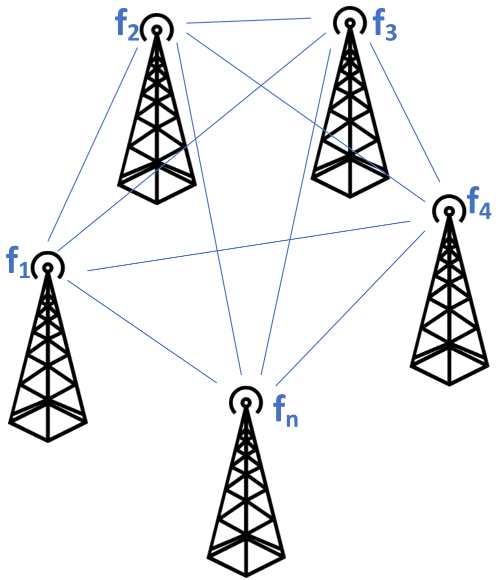
Increasing Resiliency and Accuracy



Report timestamping errors of previous frames

Report emission time and location of neighboring stations

Nationwide self-synchronizing network 23

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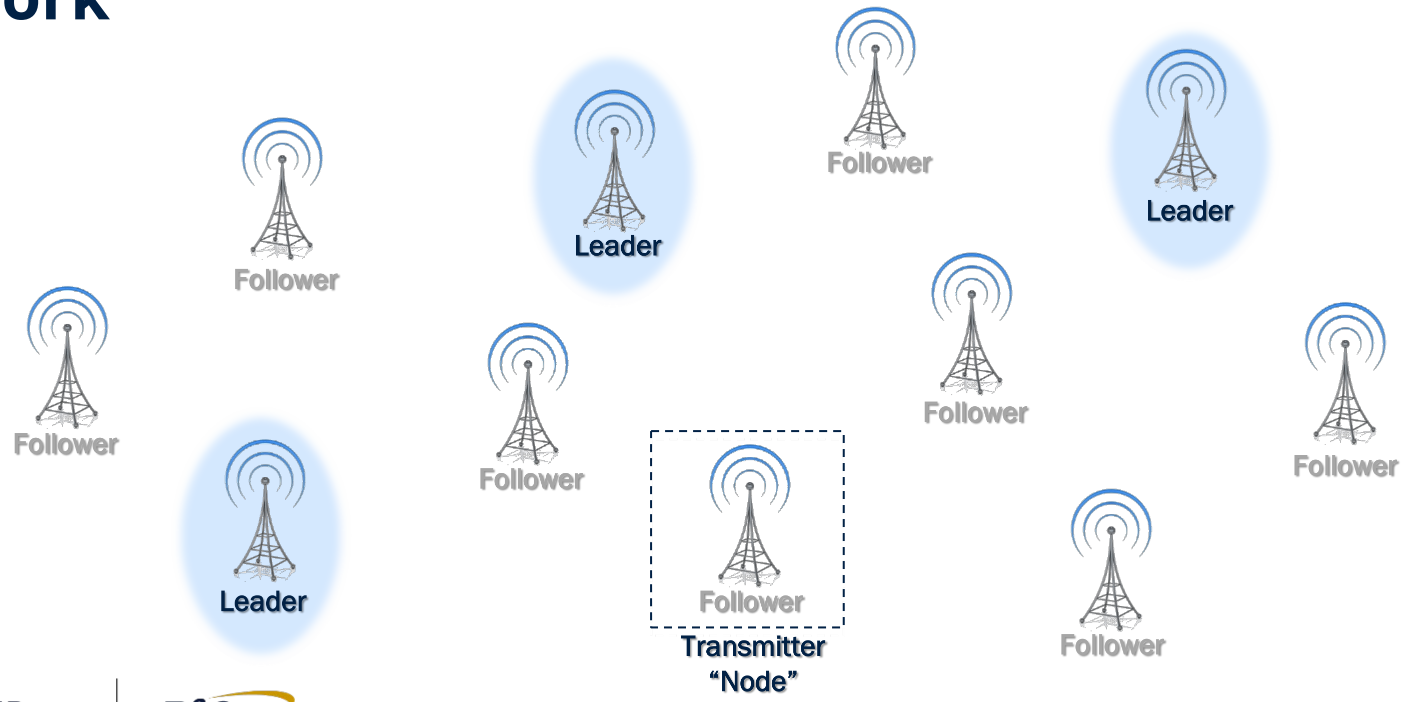
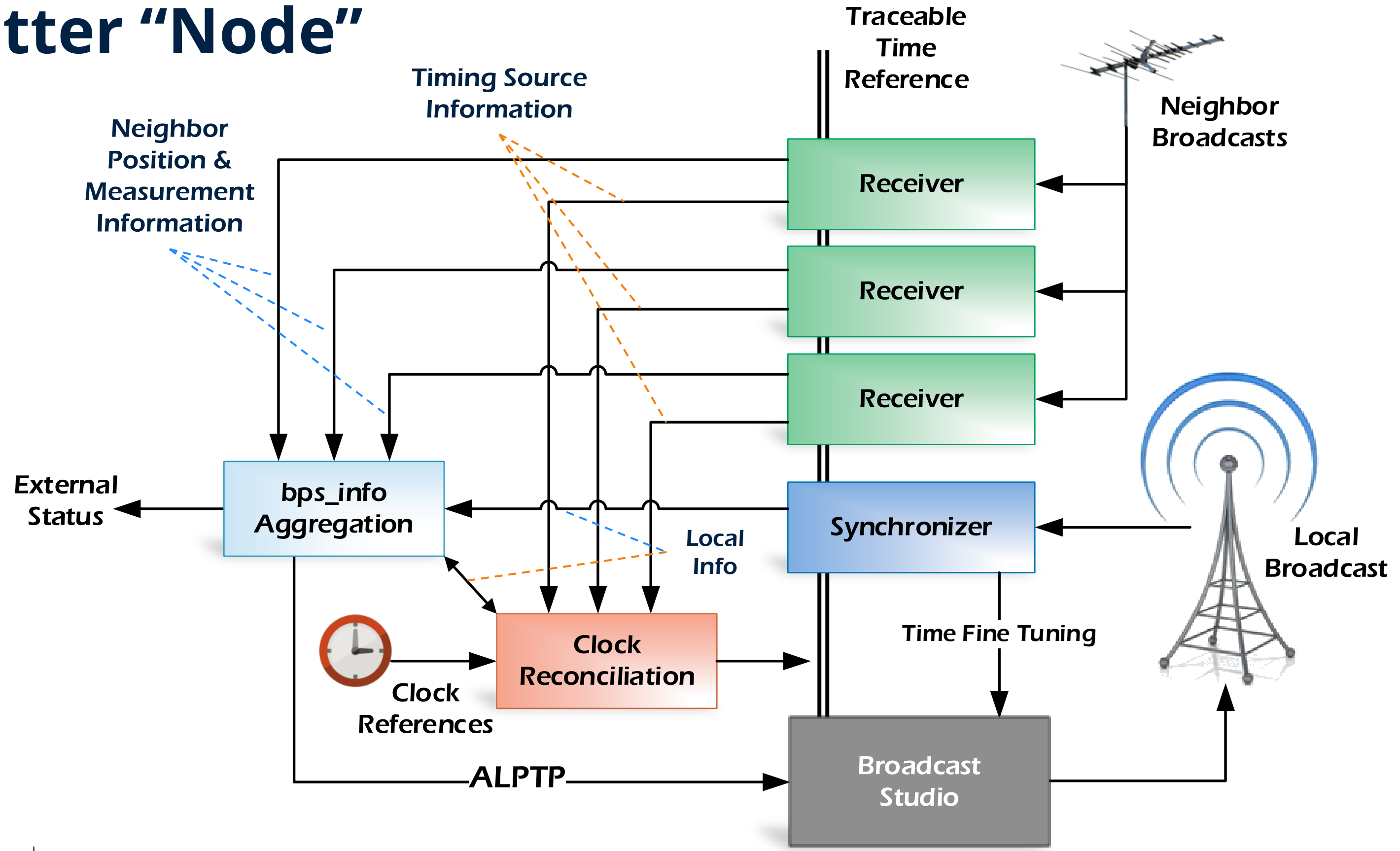
Self-Synchronizing, Traceable Time Mesh Network



Transmitter "Node"



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BPS Information Data Structure

Single data structure containing one or more fragments

- **Each fragment contains a unique transmitter ID**
- **Fragments can be grouped and routed as appropriate**

Provides “GPS Almanac/Ephemeris” Functionality

Measurement Fragment

- Neighbor Bootstrap Time Accuracy and Offset
- Previous Time and Error

Timing Source Fragment

- Position in Network
  - Offset from Leader
- Expected Timing Source Accuracy
- Timing Source Used
- List of available Timing Sources

Description Fragment

- Transmitter Description
  - Maximum Gain Direction
  - Position (Lat, Lon, Height)
  - Radiated Power
  - Antenna Field Pattern

Thank You

Backup Slides

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: $\boldsymbol{\Delta x} = \left(\boldsymbol{H}^T\boldsymbol{W}\boldsymbol{H}\right)^{-1}\boldsymbol{H}^T\boldsymbol{W}\boldsymbol{\Delta r}$

where $\boldsymbol{W} = \begin{bmatrix} w_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & w_n \end{bmatrix}$

Coverage Planning Factors

Parameter	BPS Value	TV Value	Unit
System Bandwidth	6	6	MHz
Required C/(I+N)	-5	15	dB
Thermal Noise (kTB)	-106.2	-106.2	dBm
Frequency of Operation	539	615	MHz
Antenna Gain	0	12.15	dBi
Antenna Factor	-129.6	-132.95	dBm-dBμV/m
Noise Figure	6	7	dB
Line Loss	0	4	dB
Required Field Strength	**24.4**	**40.8**	**dBμV/m**
Required Power at RX	**-109.05**	**-84.85**	**dBm**
RX Antenna height, AGL	1.5	10	m
Location, Time Variability	50%, 50%	50%, 90%	–

Coverage Definition (Planning Factors)

Nominal Coverage Threshold, dBμV/m

Band	TV	BPS
VHF-L (54-88 MHz)	28	6.6
VHF-H (174-213 MHz)	36	15.6
UHF (470-608 MHz)	41	24.4