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Precise Time Using Broadcast Positioning System (BPS)

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What is BPS?

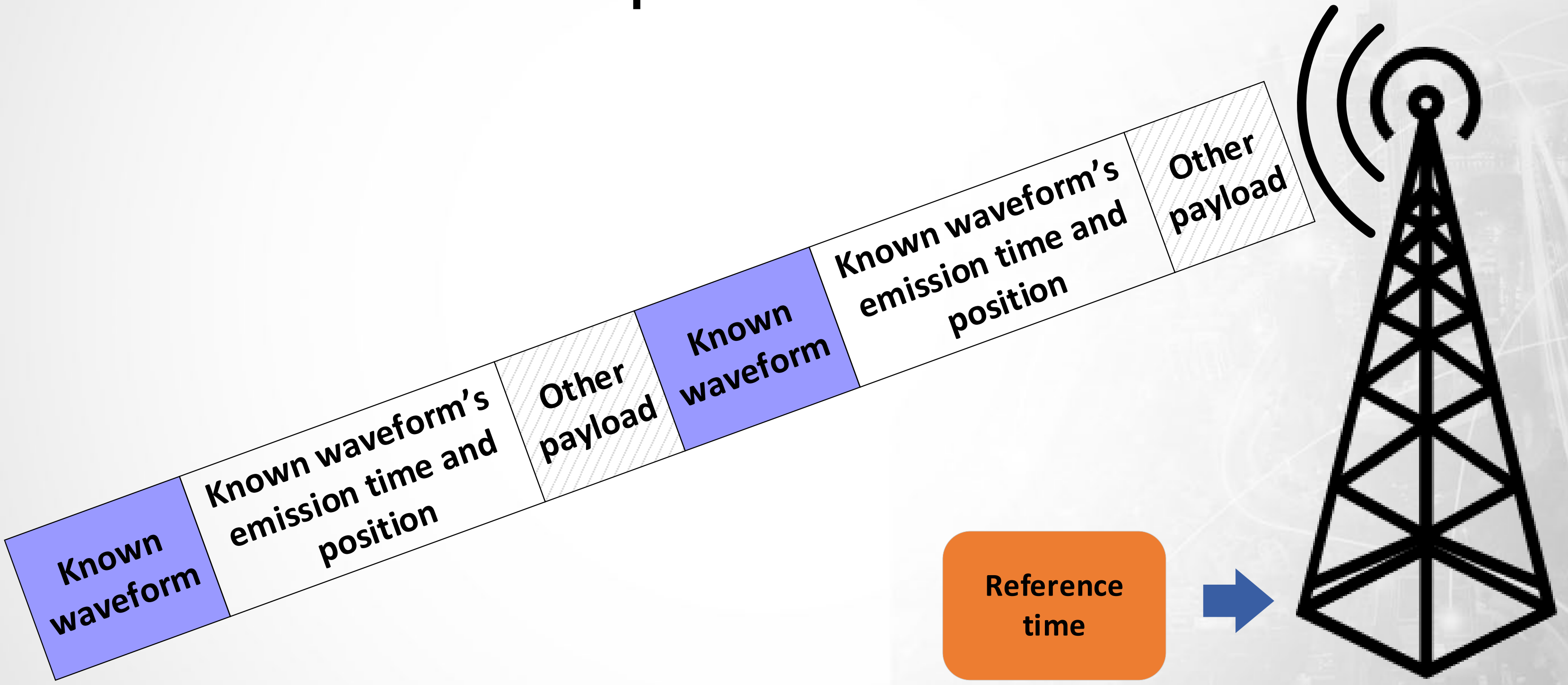
A system and method of estimating time and position at a receiver using Next Gen TV broadcast signals

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

439 VHF stations, up to 185 KW

1171 stations, up to 1000 KW

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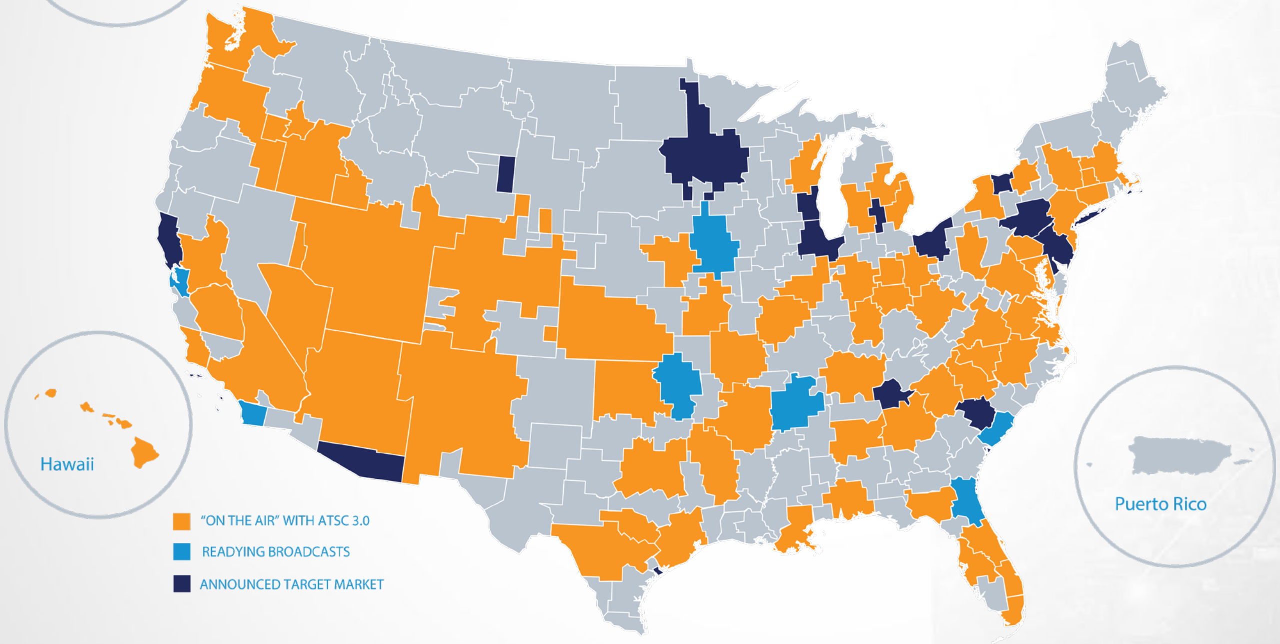
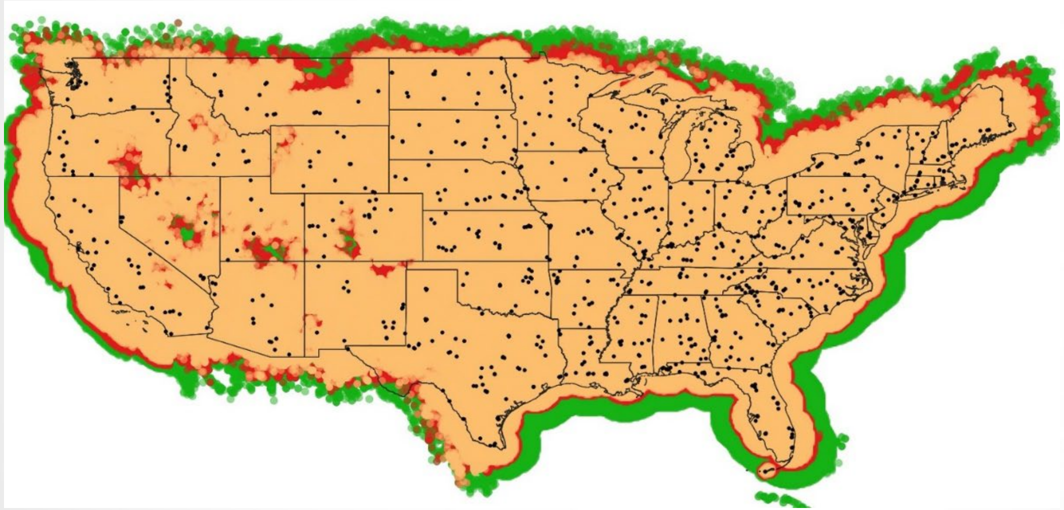
Current ATSC 3.0 Market Coverage



Source: atsc.org

BPS Coverage at Full Deployment



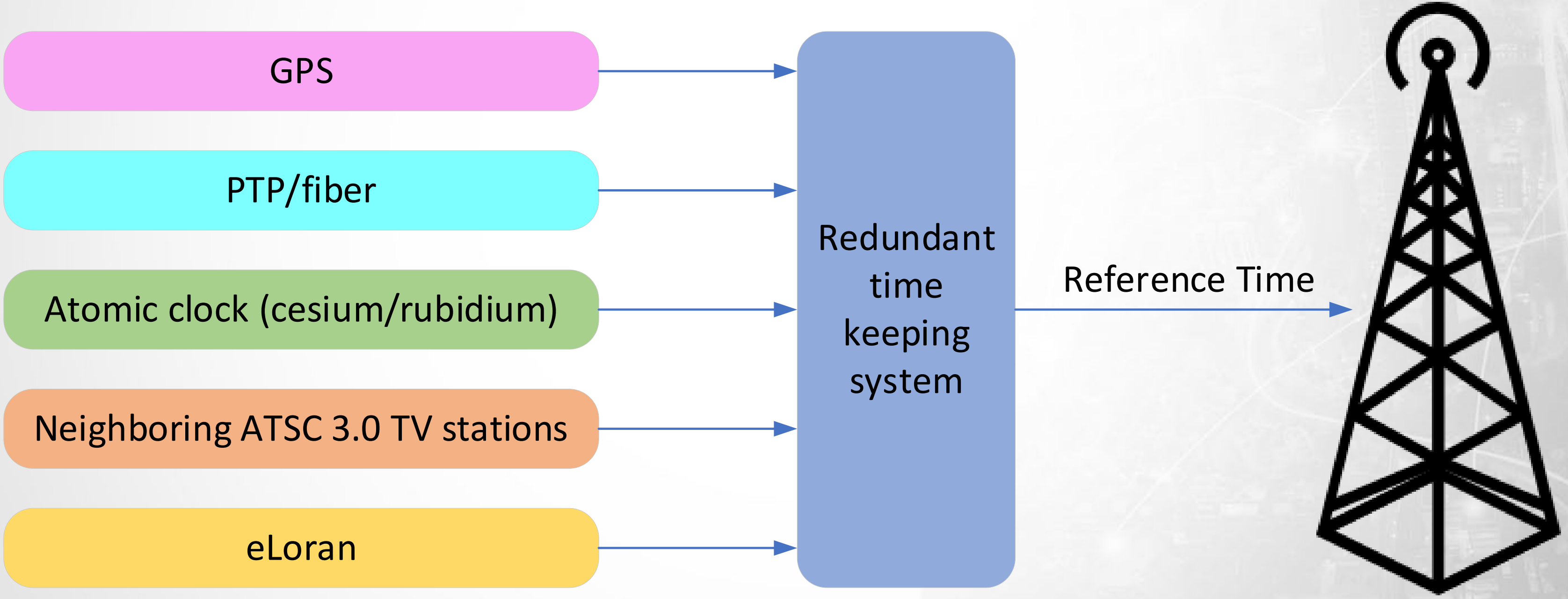
Average signal reception:

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

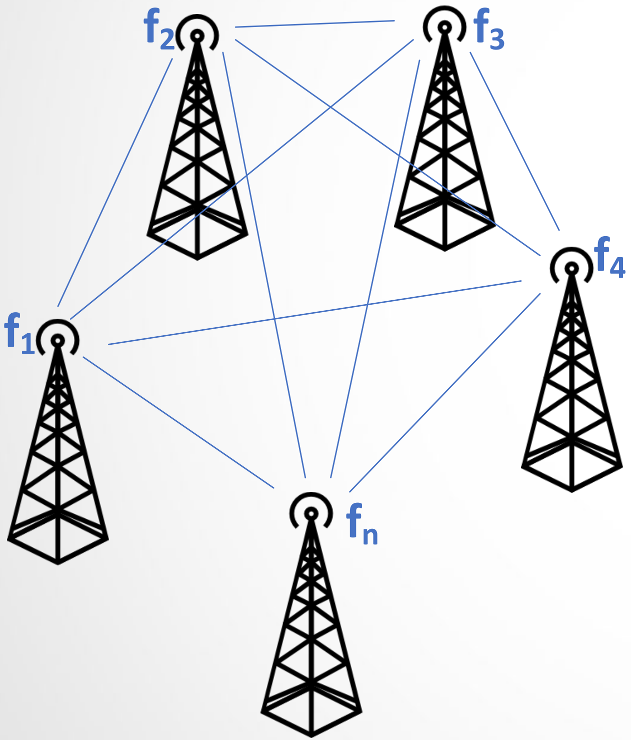
- At demodulation threshold (-5 dB SINR)
- Threshold + 10 dB
- Threshold + 20 dB

Coverage at 1.5 m antenna height

Redundant Timing Sources



Increasing Resiliency and Accuracy



Report emission time and location of neighboring stations

Report timestamping errors of previous frames

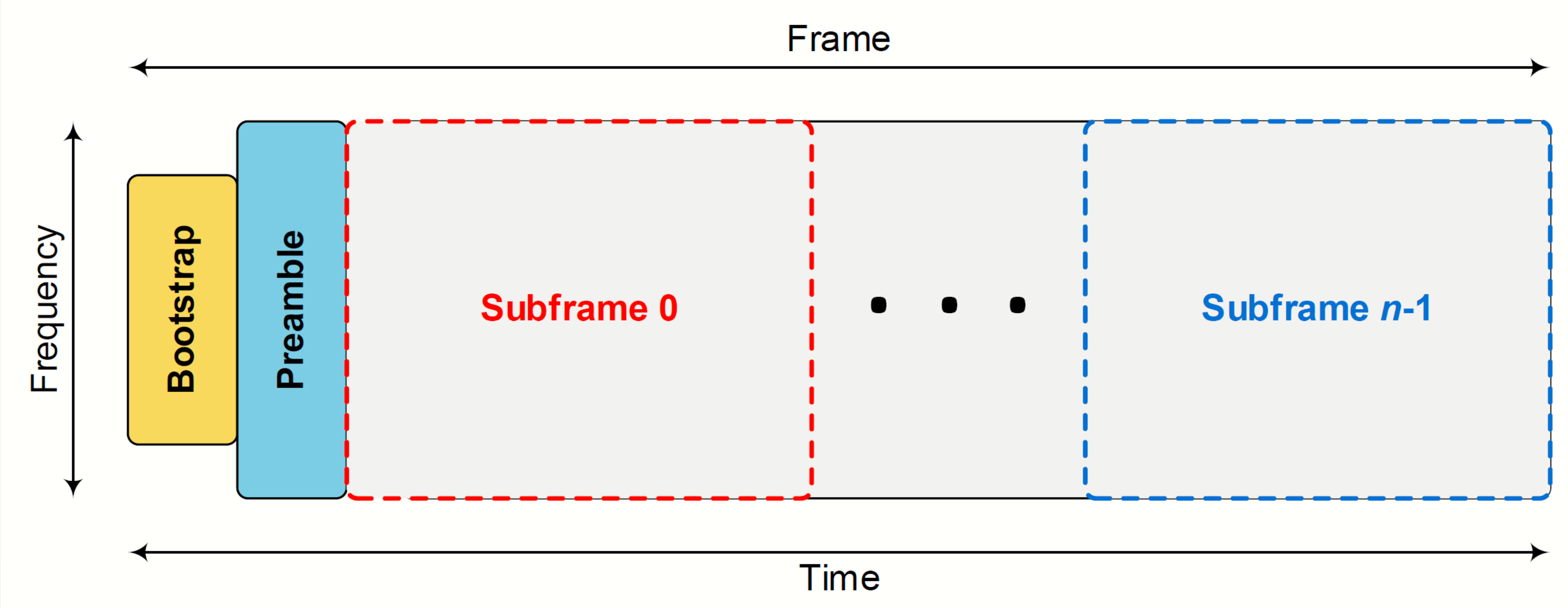
Advantages of BPS

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

Use Cases

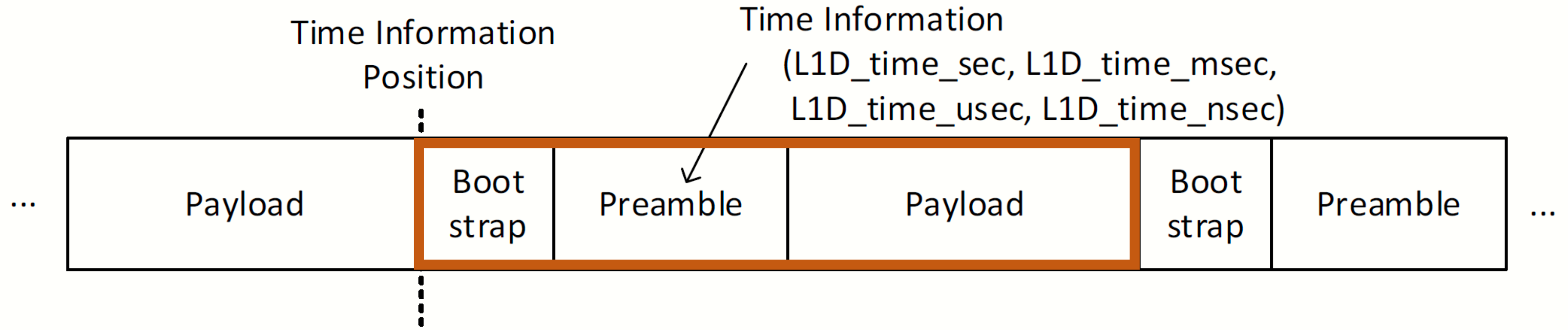
- Deliver GPS-independent time
- Deliver GPS-independent position and time
- Detect GPS spoofing
- GPS-BPS hybrid location, DGPS/RTK, A-GPS Assistance data

ATSC 3.0 Frame



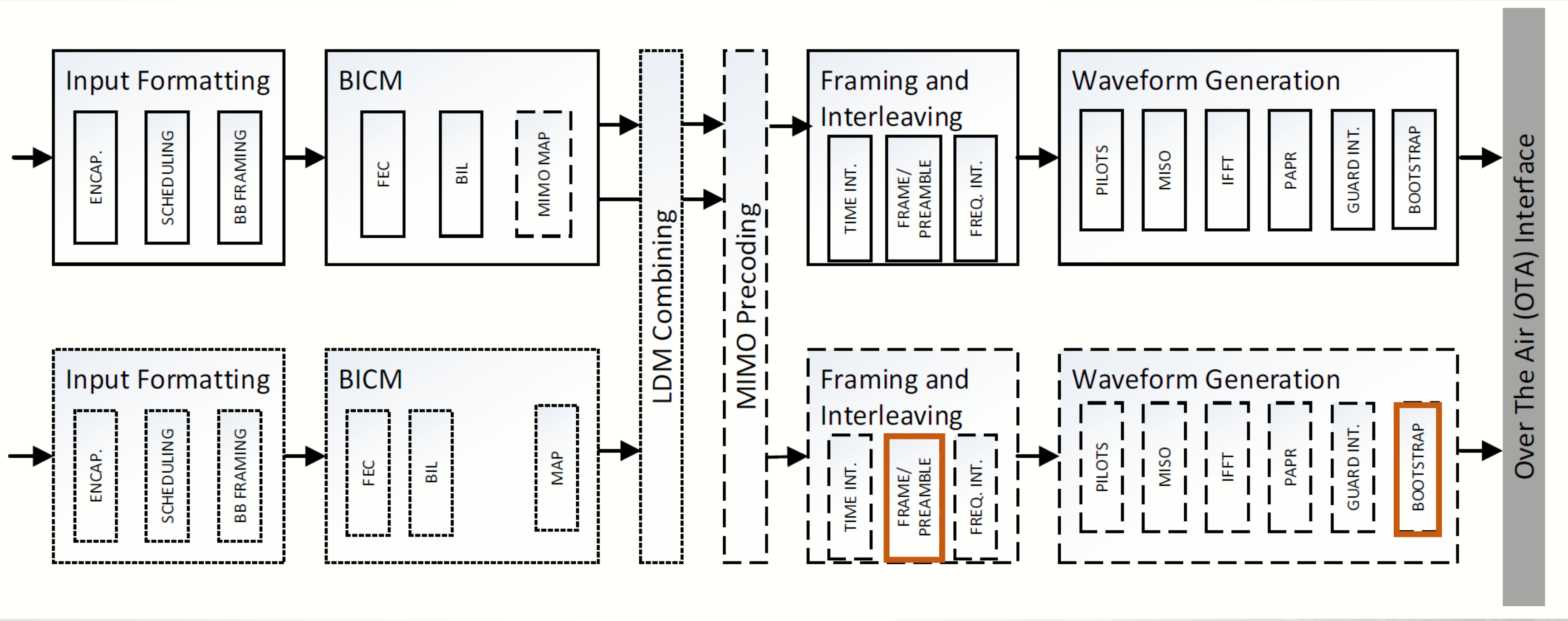
Source: atsc.org

Time Delivery in ATSC 3.0 Standard



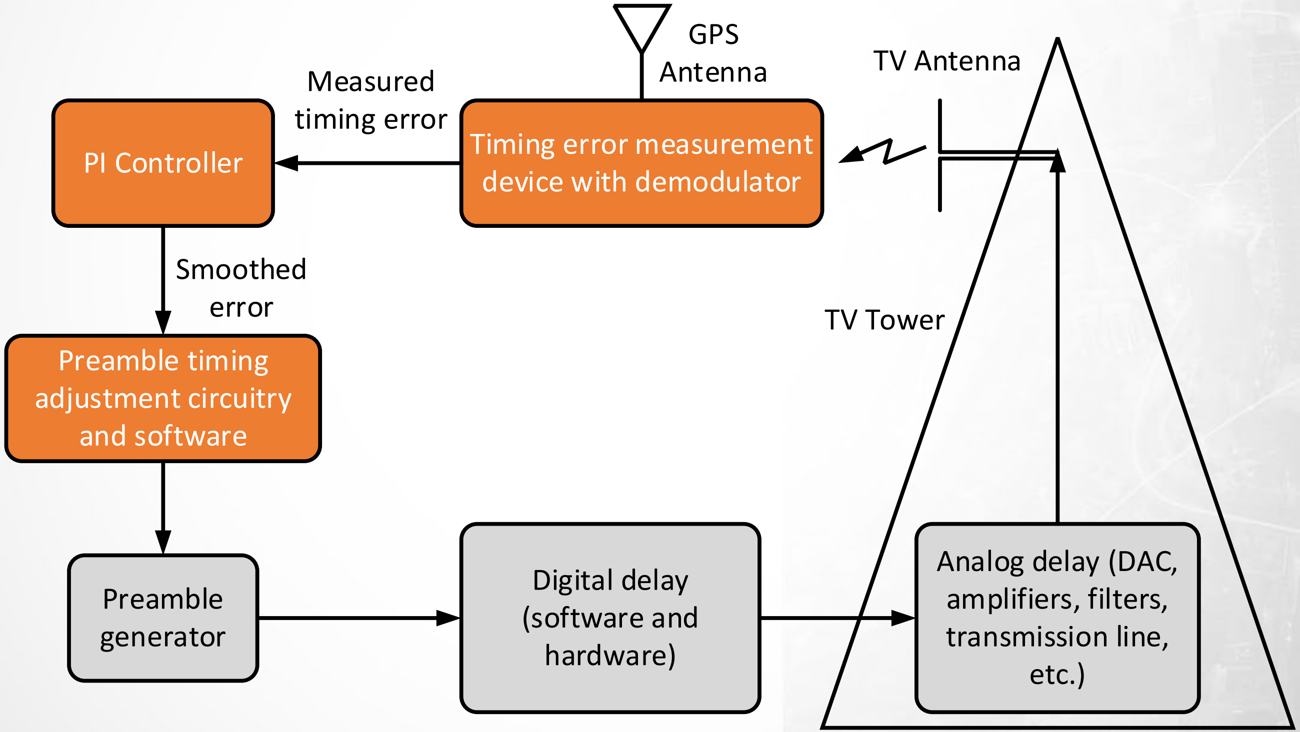
Source: atsc.org

ATSC 3.0 Transmission Chain

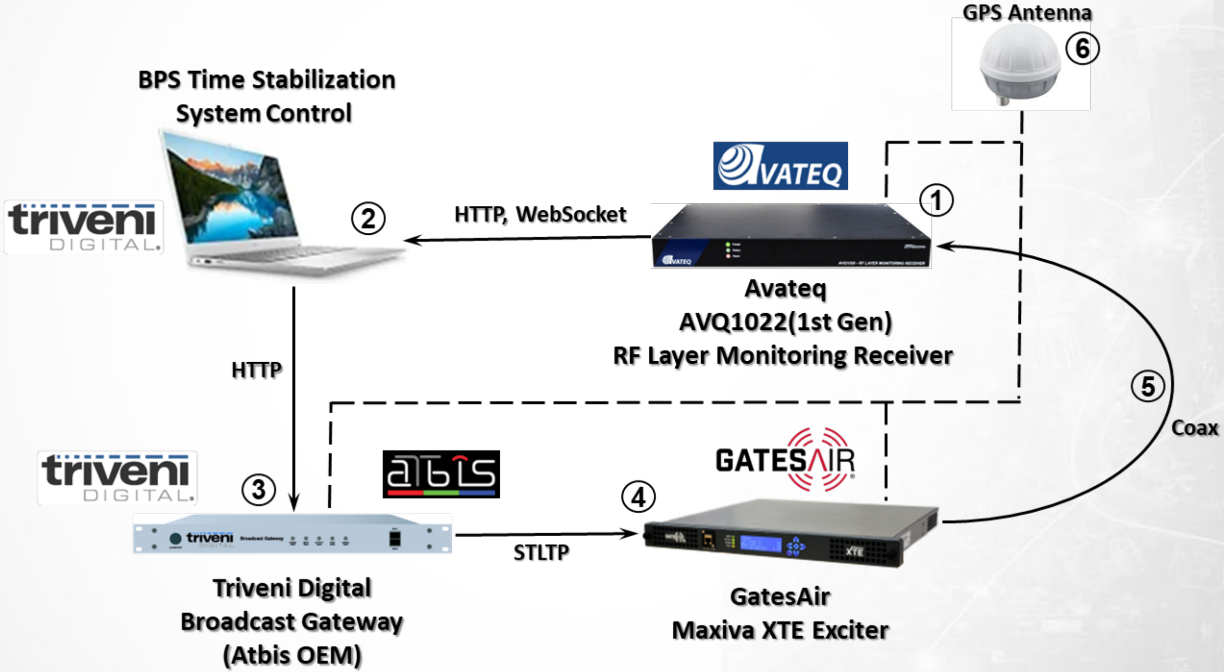


Source: atsc.org

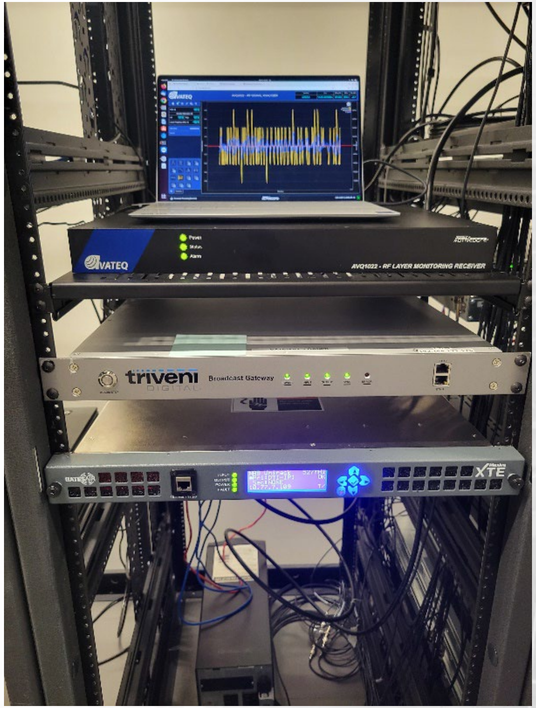
Time Synchronization at the Transmitter



Proof of Concept – Funded by NAB



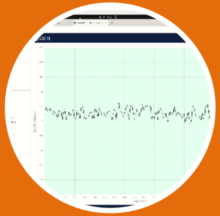
ATSC 3.0 Testbed at NAB 1M Lab



BPS Prototype at NAB 1M Lab

Timing Performance

Lessons Learned



Transmission time can be synchronized within 25-50 ns of reference time

Most of the existing infrastructure can be reused

Some ATSC 3.0 modules will need hardware and software modification

Next Step

- Upgrade HW and SW for better accuracy
- Deploy BPS at a transmission facility in a live market
- Demonstrate timing use case at a known location

Thank You

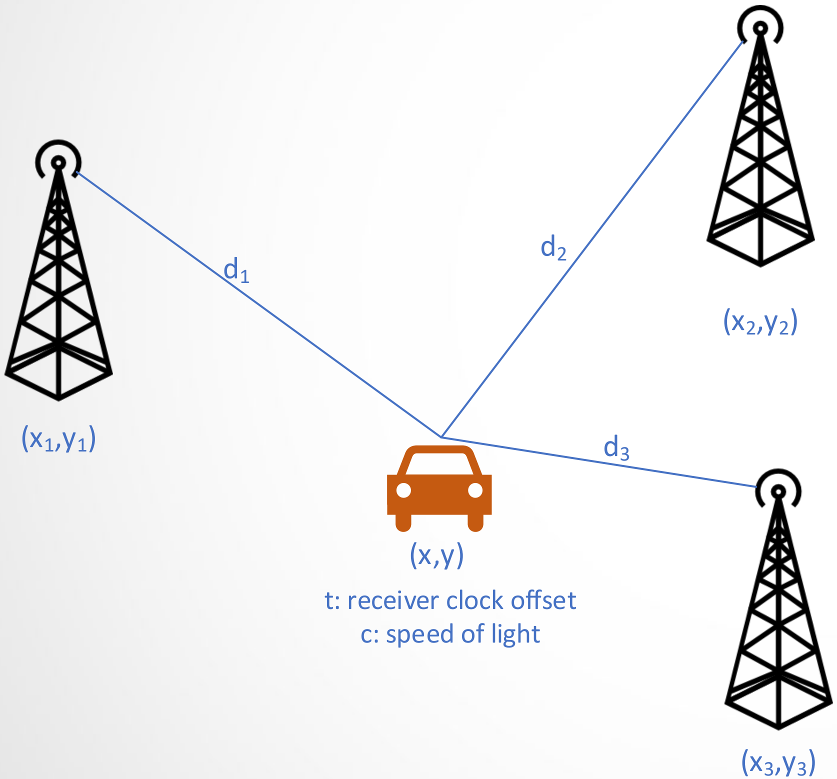
BACKUP SLIDES

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%	–

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 Iterative Solution

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

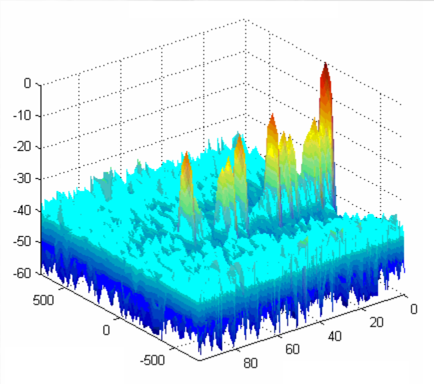
Least-square solution: $\boldsymbol{\Delta x} = (\boldsymbol{H}^T\boldsymbol{H})^{-1}\boldsymbol{H}^T\boldsymbol{\Delta r}$

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

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

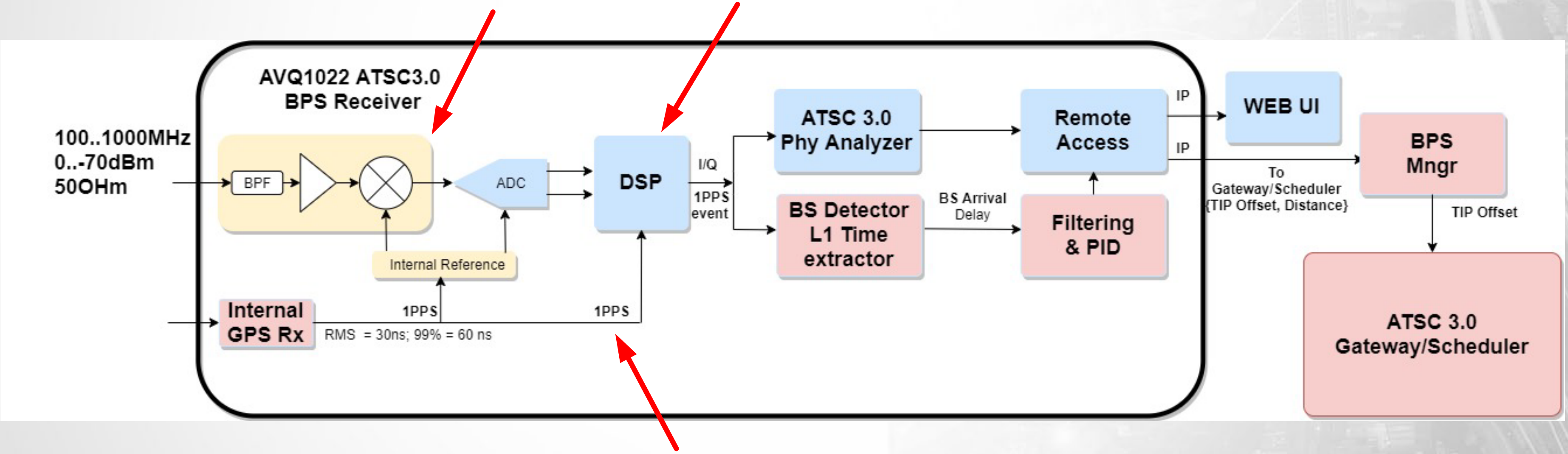


- Transmit antenna ID (a unique ID to distinguish the antenna)
- Transmit antenna position (latitude, longitude, and elevation)
- Transmit antenna radiated power
- Transmit antenna radiation pattern (and/or average coverage radius)
- Neighbor station antenna IDs
- Neighbor station channels (frequencies)
- 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)

Avateq's 1st Gen Analyzer

Front-end delay has not been calibrated yet

Uses symbol level TOA with 144 ns resolution on every 4th frame; needs to estimate earliest TOA with ambiguity function with 15 ns accuracy for every frame



Uses 1 PPS signal only; cannot use TAI/UTC timestamp yet

Syntax	*No. of bits*	*Format*
bps_info(){		
message_length	16	unsigned integer
version	8	unsigned integer
timing_source_info(){		
sync_hierarchy	7	unsigned integer
num_independent_sources	6	unsigned integer
for (i=0;i< num_independent_sources;i++){		
source_type_list	4	unsigned integer
}		
expected_accuracy	16	unsigned integer
source_used	4	unsigned integer
}		
self_measurement_info(){		
call_sign	42	array of 7 6-bit unsigned integers
tx_id	13	unsigned integer
tx_freq	32	32-bit floating point
geodetic_lat	64	64-bit double precision
geodetic_lon	64	64-bit double precision
geodetic_height	64	64-bit double precision
radiated_power	32	32-bit floating point
for (i=0;i<36;i++){		
antenna_pattern_relative_field	252	array of 36 7-bit unsigned integers
}		
max_gain_direction	10	unsigned integer
prev_bootstrap_time_sec	32	unsigned integer
prev_bootstrap_time_msec	10	unsigned integer
prev_bootstrap_time_usec	10	unsigned integer
prev_bootstrap_time_nsec	10	unsigned integer
prev_bootstrap_time_error_nsec	16	signed integer
}		
leap_seconds	8	unsigned integer
num_neighbors	6	unsigned integer
for (i=0;i<num_neighbors; i++){		
neighbor_measurement_info(){		
call_sign	42	array of 7 6-bit unsigned integers
tx_id	13	unsigned integer
tx_freq	32	32-bit floating point
geodetic_lat	64	64-bit double precision
geodetic_lon	64	64-bit double precision
geodetic_height	64	64-bit double precision
radiated_power	32	32-bit floating point
for (i=0;i<36;i++){		
antenna_pattern_relative_field	252	array of 36 7-bit unsigned integers
}		
max_gain_direction	10	unsigned integer
reported_bootstrap_time_sec	32	unsigned integer
reported_bootstrap_time_msec	10	unsigned integer
reported_bootstrap_time_usec	10	unsigned integer
reported_bootstrap_time_nsec	10	unsigned integer
bootstrap_toa_offset	32	signed integer
prev_bootstrap_time_sec	32	unsigned integer
prev_bootstrap_time_msec	10	unsigned integer
prev_bootstrap_time_usec	10	unsigned integer
prev_bootstrap_time_nsec	10	unsigned integer
prev_bootstrap_time_error_nsec	16	signed integer
}		
}		
reserved_bits	as needed	
bps_crc	32	unsigned integer
}		

Next Step (2023-2024)

- Develop a loop receiver that measures time with 15 ns accuracy
- Implement API for additional self-measurement fields
- Develop a test receiver that demonstrates GPS and BPS time differences at known locations
- Develop timestamp calibration method and equipment for real transmission facilities
- Deploy BPS at a transmission facility in a live market
- Demonstrate timing use case at a known location

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

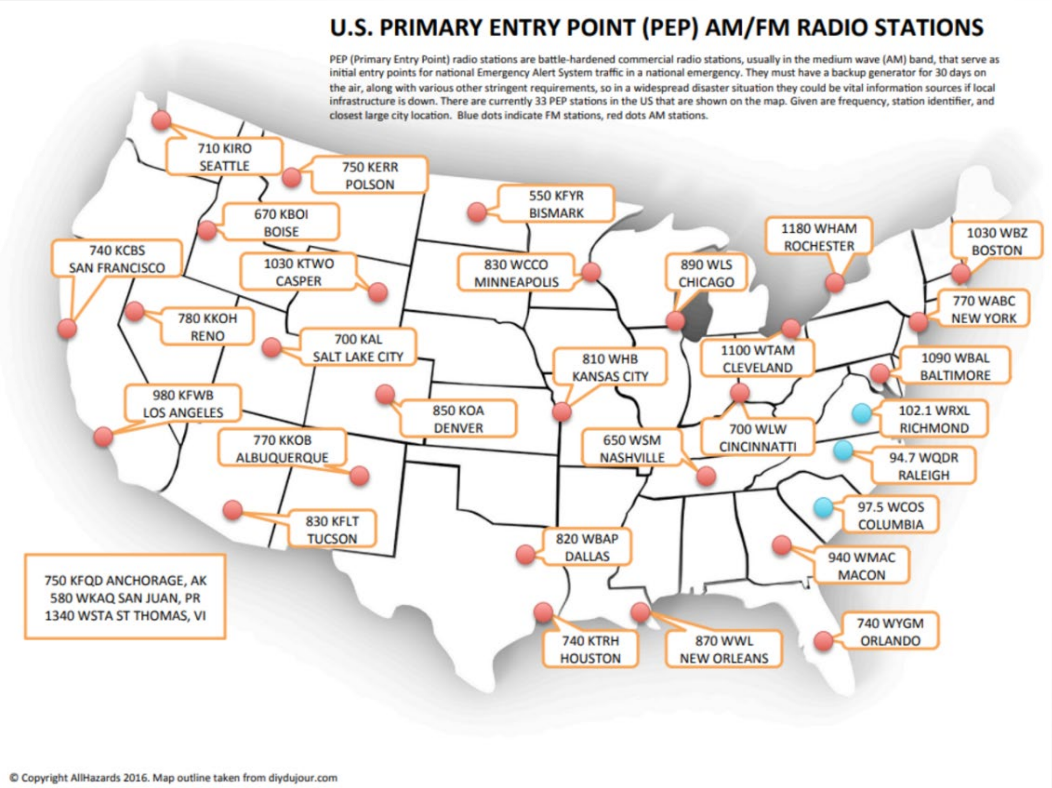
Phase 3 — 2024-2025
- Add backup timing sources at Tx site
- Demonstrate time delivery in a live market

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

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