MBS Indoor Timing Receiver

Concept, Implementation, and Test Results

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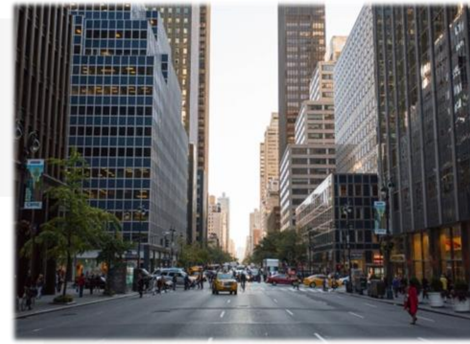
NEXTNAV

Motivation for Indoor Timing: Small Cells/5G



- Small-cell synchronization and timing is critical for network capacity and management reasons
- Current sync performance requirements approximately +/-1.1 µs and 16 ppb
- Current installations require GPS drop for time synchronization, distribution of time within building using IEEE 1588v2 (PTP)
  - Capex of $15k - $60k
  - 5G expected to be more stringent requirements and a bigger challenge for the Indoor and Urban canyons

Industry is headed towards the need for GPS grade phase and frequency, Indoors!
A seamless GNSS Augmentation solution would be highly desirable!

Terrestrial GPS Augmentation - Desired System Characteristics & Applicability to Time & Frequency

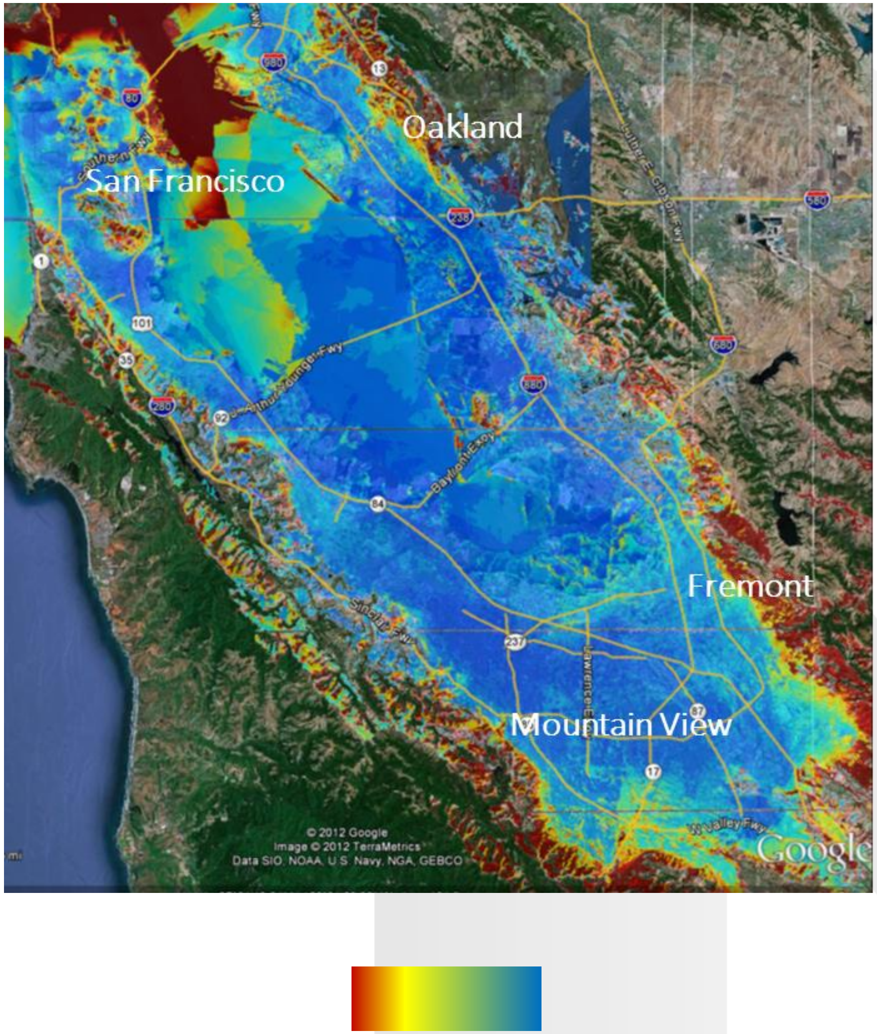
<table>
<tr><th></th><th>Positioning</th><th>Time & Frequency</th></tr>
<tr><td>Applications</td><td>• E-911
  • Accuracy by FCC-15-9A1 ruling: outdoor and indoor
    • Horizontal: 50 m (40% by 2017, 50% by 2018, 70% by 2020, 80% by 2021), vertical: 3 m
• First responder
• Asset tracking
• Location Based Services</td><td>• Telecommunications, for example small-cell sync
• Financial network synchronization
• Datacenter synchronization
• Power grid</td></tr>
<tr><td rowspan="6">Desired characteristics</td><td colspan="2">High reliability, encryption/authentication</td></tr>
<tr><td colspan="2">Coverage: sub-urban, urban, indoor</td></tr>
<tr><td colspan="2">Minimal device impact (cell phone/tablet): acceptance
GPS-like signal structure, but not on, or near L1, L2, L5</td></tr>
<tr><td>Low power, first fix in seconds</td><td></td></tr>
<tr><td colspan="2">Passive: no network saturation, privacy</td></tr>
<tr><td colspan="2">Scalable: metropolitan areas / building structures</td></tr>
</table>

NextNav Metropolitan Beacon System: Terrestrially-Based 'GPS'

- **Dedicated 3D positioning system, not a communications system**
  - Uses NextNav owned, licensed spectrum
  - 8MHz BW
  - Spectrum covers 93% of US pops
- Long-range broadcast transmitters; deployable solutions possible
- Based on GPS principles – synchronized transmitters and time-of-flight measurements
- Encrypted signal available to authorized users throughout footprint, no capacity limitations
- Significantly exceeds FCC E-911 indoor location mandate of 50m, 80% of the time in 3rd party trials

Core of NextNav solution is essentially a network of terrestrial "satellites", with fixed sites broadcasting from shared roof-top and tower infrastructure

Wide-Area System Creates Extensive Coverage Zones



- Consistent performance across Bay Area pilot market - ~2,500 sq. km over SJC and SFO CMAs
- Broadcast system with no capacity limits
- Sites are managed via low-bandwidth radio links, and 30W Tx utilizes standard "wall" power
- Bay Area network is designed for robust in-building penetration – 30dB of loss embedded in planning model
- Planning model takes into account DOP; i.e., a site that does not have adequate angular separation is discounted
- In-campus solutions available for international markets
- Timing coverage extends well beyond positioning
  - Only one beacon required for timing

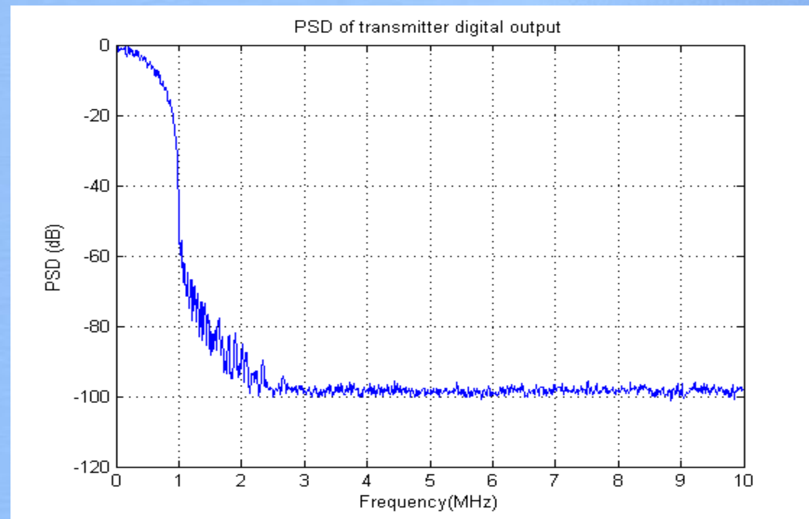
GNSS/MBS for Absolute Time & Frequency Synchronization

	GNSS	MBS
Frequency	1575 MHz	925 MHz
Power	50 Watts	30 Watts
Constellation	MEO satellites	Terrestrial transmitters
Coverage	Global	Local / regional
Outdoor Indoor Deep Indoor	++ - (high-sensitivity GNSS) ---	++ ++ ++ (by design)
Rx cost / integration cost	++	++ (negligible added cost for MBS-GNSS hybrid)
Other Notes	Low power signal, vulnerable to jamming and spoofing	"Sky-free" High-power Authentication / Encryption

3GPP Support for TBS/MBS

- TBS is the generic class of Beacons defined in 3GPP; MBS is the NextNav version
- MBS standardization implies the following
  - Air interface between MBS beacons and UE → Defined by ICD
  - Messaging between Carrier Network and UE → Defined by 3GPP
- Interface Control Document (ICD) published in two open fora
  - National Public Safety Telecommunications Council (NPSTC)
  - ATIS, the US Signatory to 3GPP (www.ATIS.org)
- 3GPP Release 13 supports for TBS/MBS
- MBS also supported by OMA in SUPL 2.1

MBS Transmitter



- Redundant configuration (Master/Slave) per transmitter
- Battery backup (per transmitter)
- Multiple transmit sites (system level redundancy)
- Typically co-located in cell-tower or roof-top installation

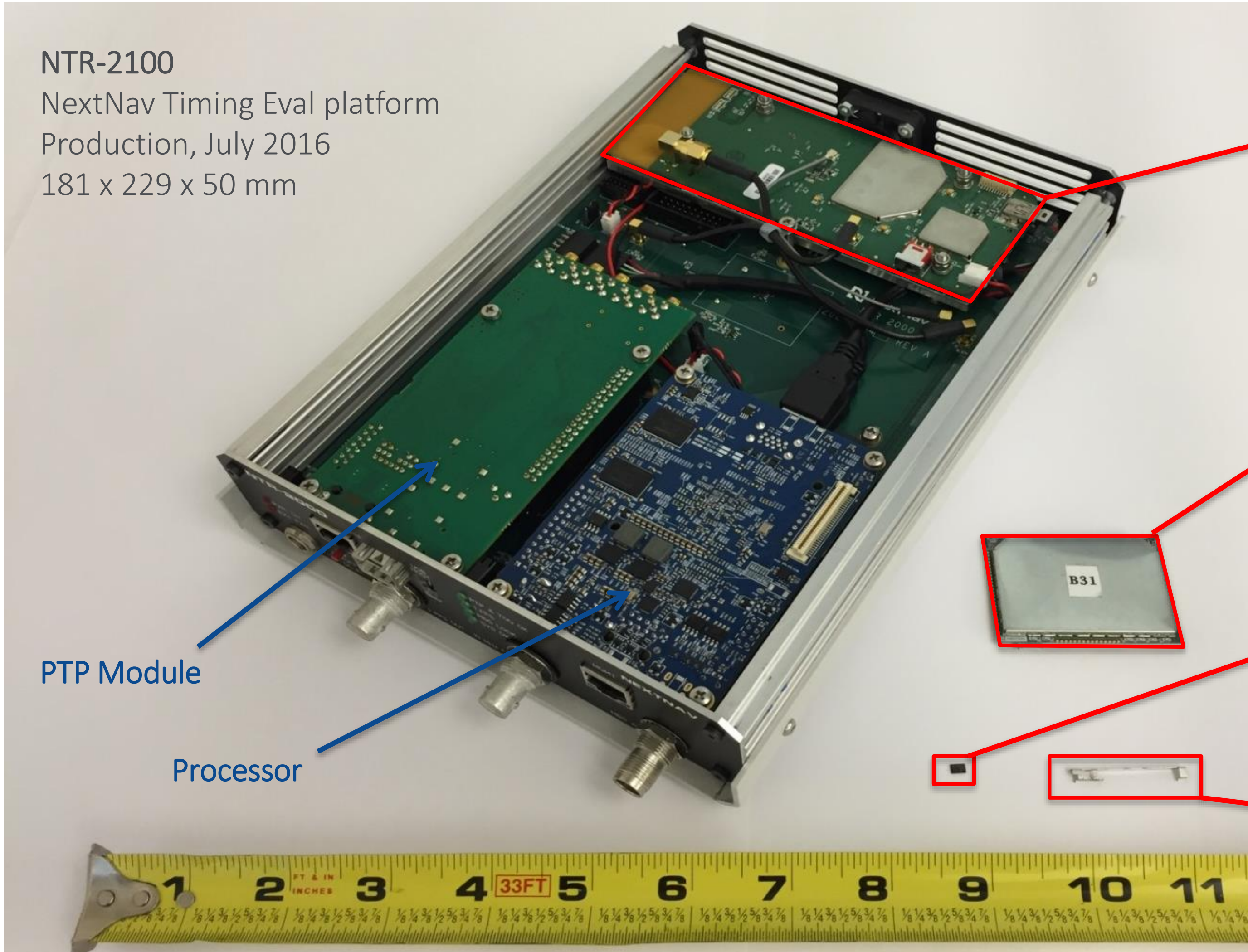
MBS Transmitter Synchronization

- MBS beacon primarily use GNSS in conjunction with a Rb oscillator for synchronization
- Relative beacon sync: MBS beacons have capability of listening to each other and therefore performing relative sync through means such as MBS Two-Way Time Transfer (MBS-TWTT)
- In the case of GNSS outages, different options are possible:
  - Rb coasting within the beacon <1µs/48 hrs
  - MBS-TWTT to maintain relative sync (for positioning) or transfer of GNSS time from beacons with healthy GNSS
  - Cesium oscillator, TWSTT or other absolute time sources: can be used to provide synchronization periodically to a subset of MBS beacons that can be transferred to the other beacons using MBS-TWTT

MBS Receiver Characteristics

- Signal looks like a GPS signal in a different frequency band
  - Engineering samples available now
  - Chip/module sizes similar to GPS
  - Hybrid GPS + MBS IC
  - Mass market GPS IC provider
  - Low power consumption
- Signals are strong
  - High SNR, even deep indoors
  - Multipath can be extreme
- High SNR allows for advanced signal processing
  - Passive/Integrated antenna would suffice to pick up the signals
- Stationary timing receiver at known location:
  - Can deploy additional techniques not necessarily available to positioning user:
    - Only single beacon required for timing fix, multiple beacons provide redundancy and RAIM capability
    - Validation of signal consistency over time increases robustness

NextNav MBS Positioning Rx generations & NTR Timing Evaluation Platform



MBS Rx Rev2
MBS measurement engine
Production, 2014
145 x 55 mm

MBS Rx Rev3
GNSS-MBS measurement engine
Production, July 2016
54 x 40 mm

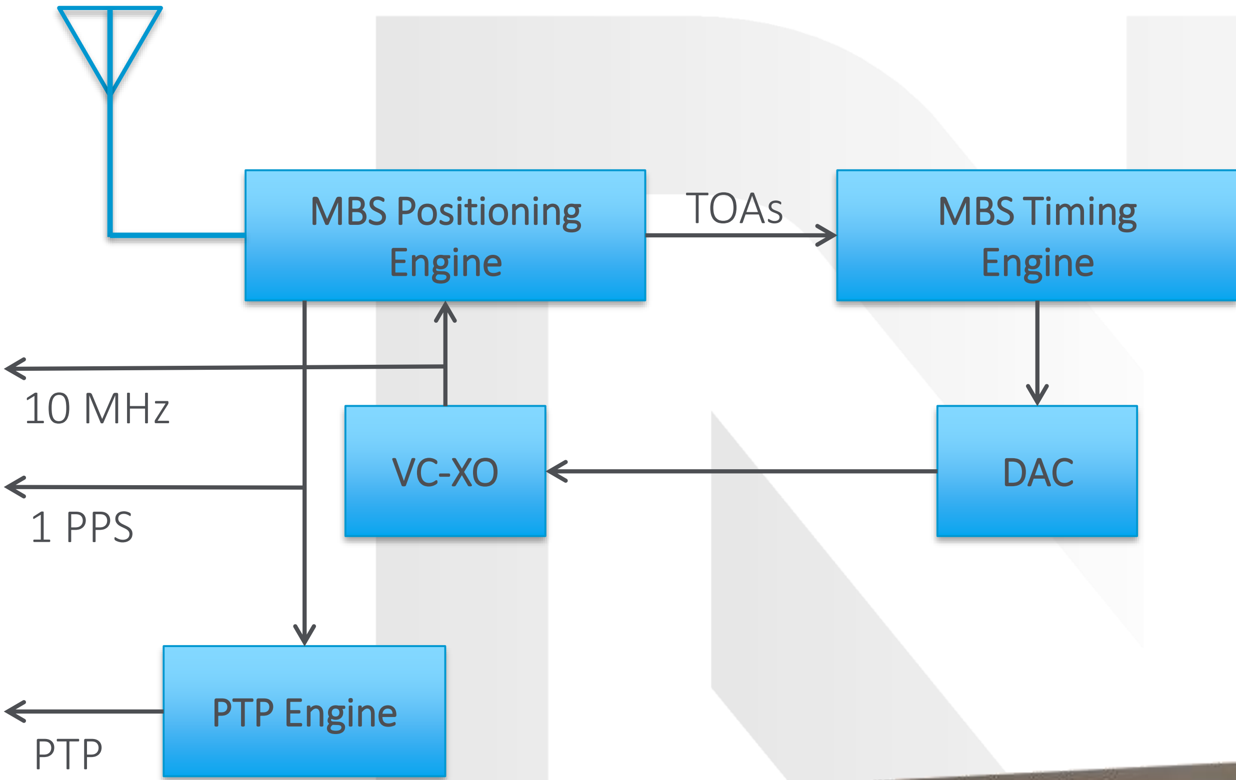
MBS Rx Rev4
GNSS-MBS measurement engine
Integrated chip

GPS + MBS antenna
32 x 3 x 3 mm

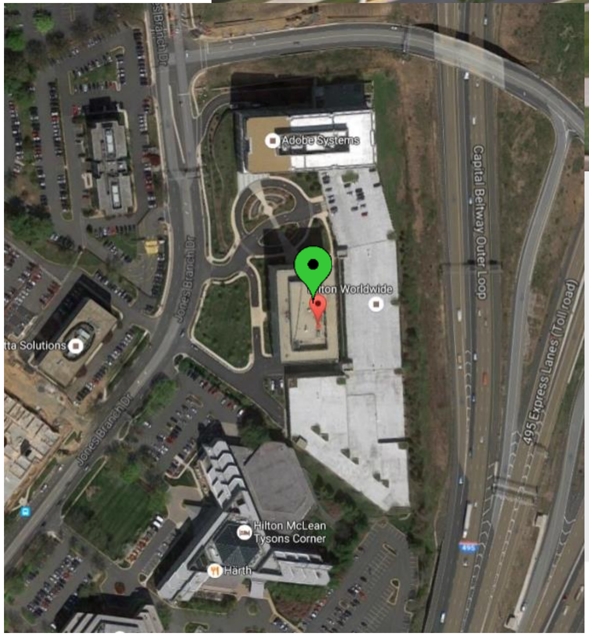
Telecom Phase and Frequency Requirements in LTE Networks

Application	Frequency: Network/Air	Phase	Note
LTE-TDD	16 ppb/50 ppb	± 1.5µs	< 3km cell radius
		± 5 µs	> 3km cell radius
LTE MBMS (LTE-FDD and LTE-TDD)	16 ppb/50 ppb	± 10 µs	Inter-cell time difference
LTE-Advanced	16 ppb/50 ppb	± 0.5µs to ± 1.5µs (CoMP) ± 1.5µs to ± 5µs (eICIC)	

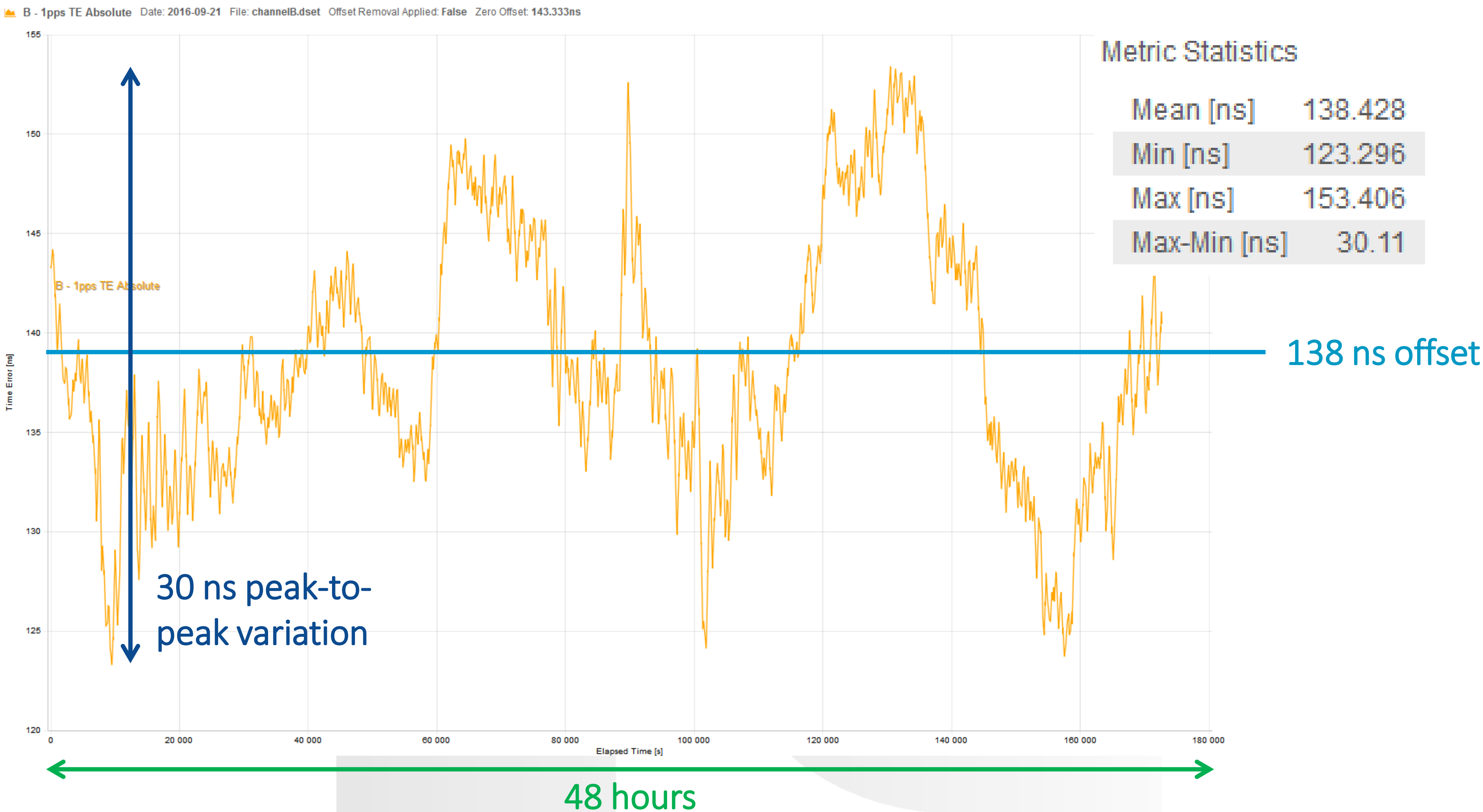
NextNav Timing Receiver - NTR



Test 1: Deep Indoors - Office building



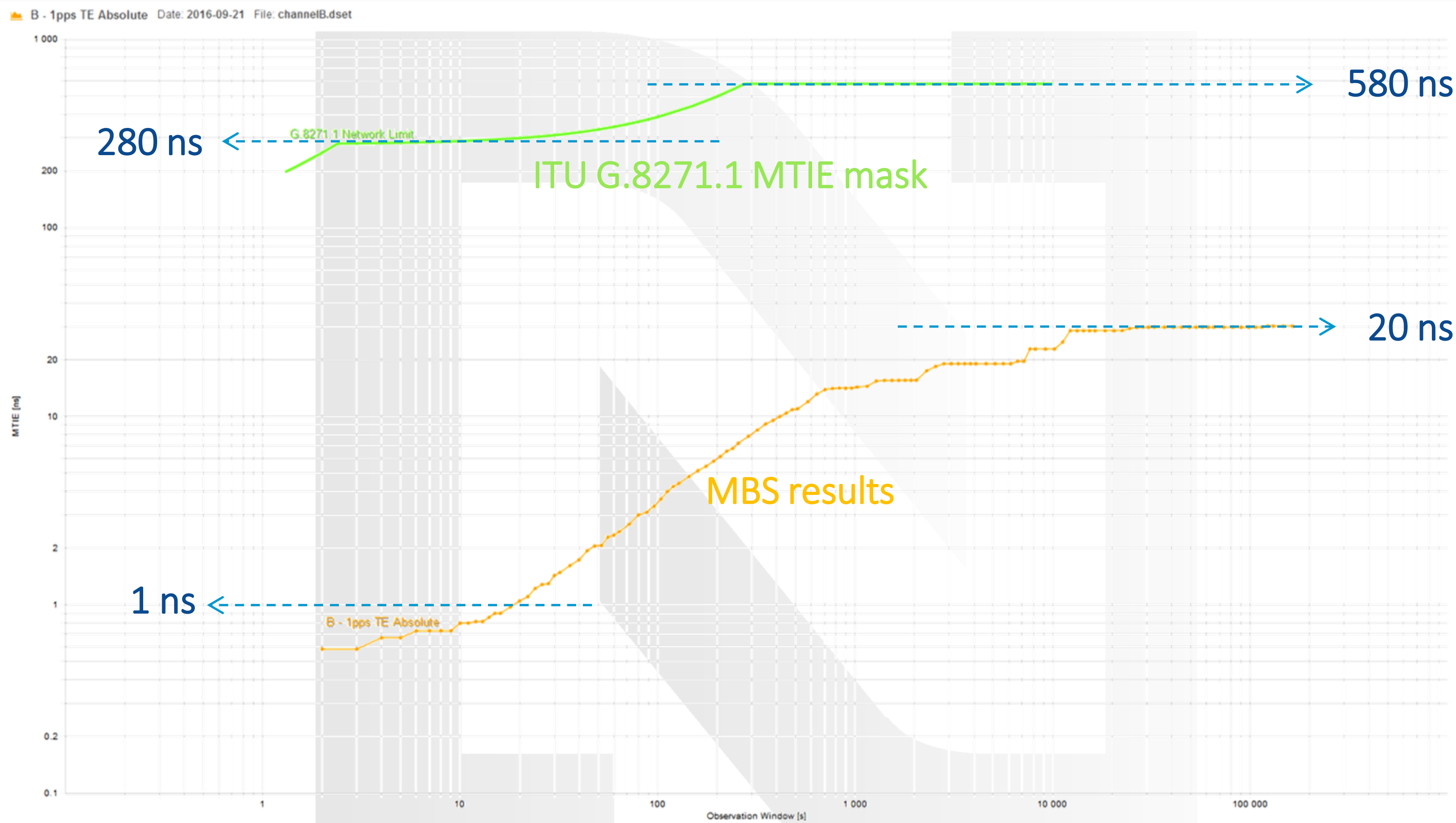
Test 1: Time Error over 48 hours



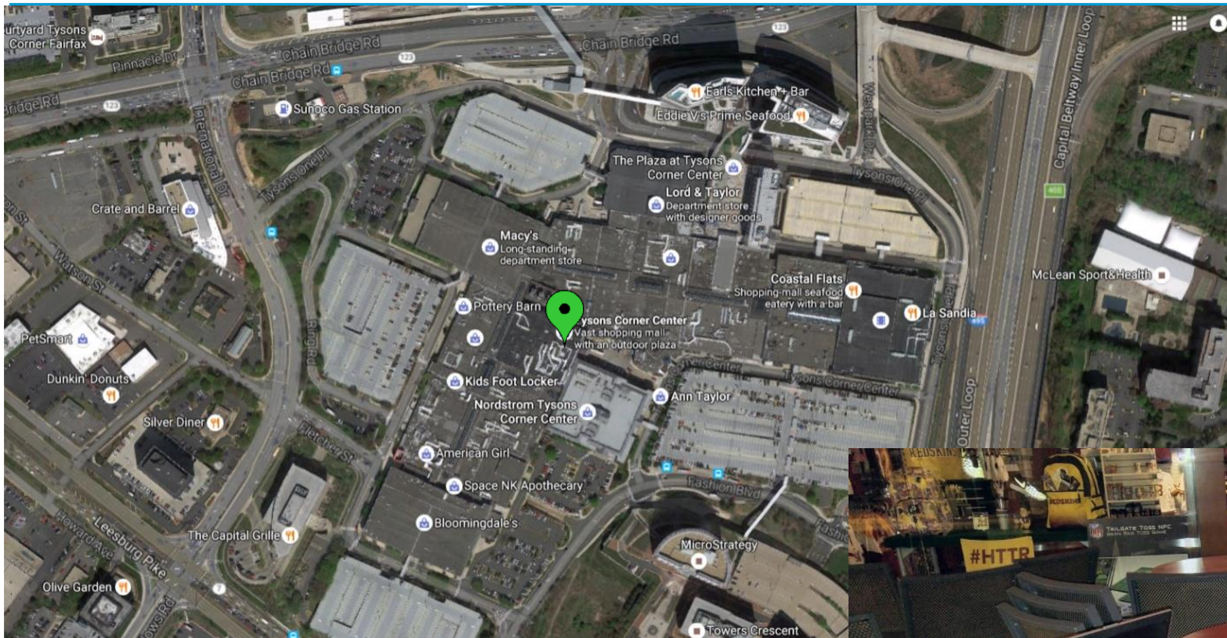
Metric Statistics

Mean [ns]	138.428
Min [ns]	123.296
Max [ns]	153.406
Max-Min [ns]	30.11

Test 1: Max Time Interval Error (MTIE)



Test 2: Time recovery in Indoor Mall



Location: Tysons Corner Center – Indoor mall, ground floor, food court

DUT: NextNav NTR

Test instrument: Calnex Sentinel

NTR-2000

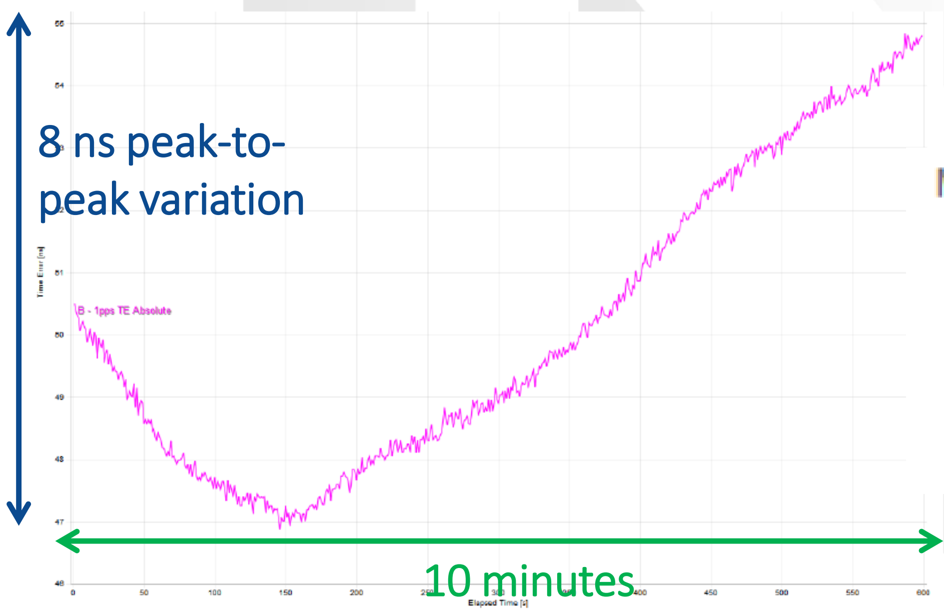
Calnex Sentinel
in Rb holdover mode

Test 2: Tysons Corner Center – Indoor Mall

Report Date	26/09/2016 17:47:25
Beginning of Test	21/09/2016 04:24:32
End of Test	21/09/2016 04:34:31
Instrument Type	Sentinel
Instrument Serial Number	
Test Duration	00:00:09:59

All Mask Results	Pass

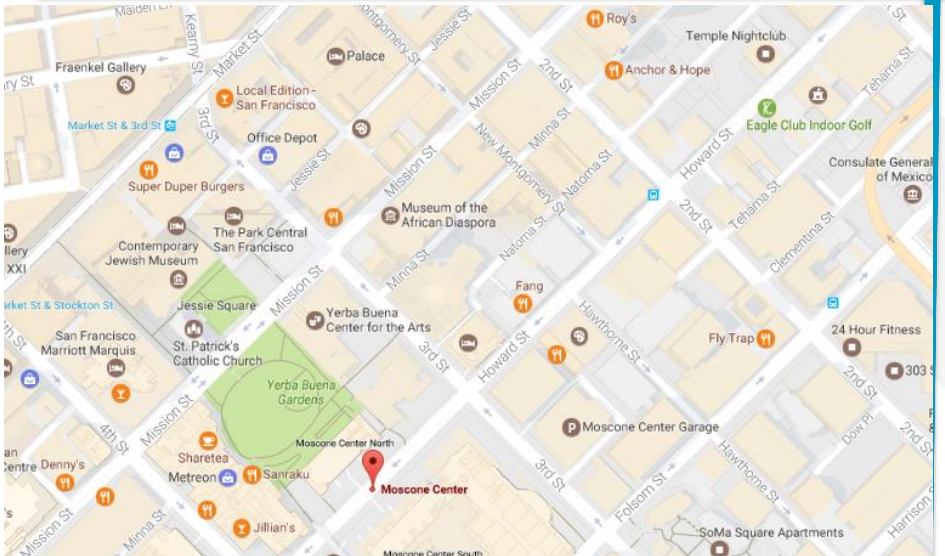
Mask B Time Error Result	Pass
Mask B MTIE Result	Pass

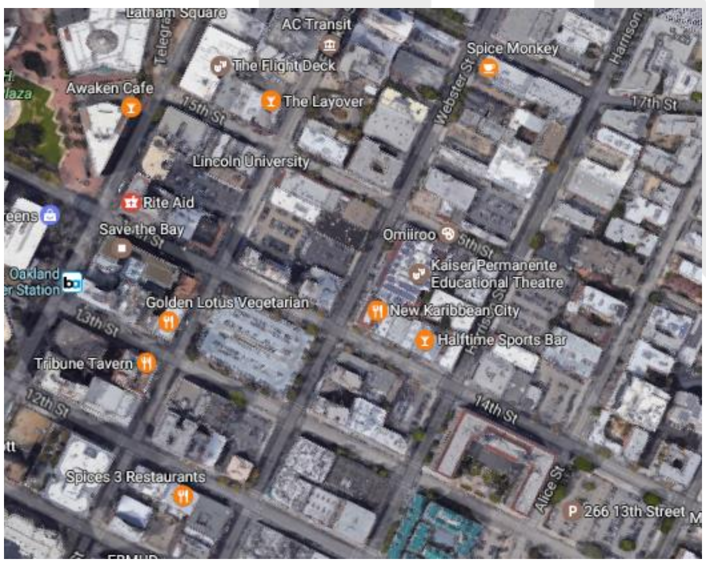


Metric Statistics

Mean [ns]	50.096
Min [ns]	46.88
Max [ns]	54.836
Max-Min [ns]	7.956

Test 3: MBS timing fix in various buildings





Downtown San Francisco
Modern building-steel and glass
Window film attenuates GPS

Floor	GPS Satellites	MBS Beacons	MBS Timing Fix?
B	N	.12	Y
2nd	N	>11	Y
6th	N	>11	Y
13th	Y, with external antenna	>15	Y

Downtown Oakland
Older building with masonry exterior

Floor	GPS Satellites	MBS Beacons	MBS Timing Fix?
B	N	3	Y
1st	N	>6	Y
3rd	N	>7	Y
7th	Y, with external antenna	.12	Y

Summary

- MBS is a proven technology delivering high precision location & timing in GPS challenged environments
- Availability of a low cost consumer grade UE drives mass market adoption
- Technology designed for mass market applications
  - Mass market Chipsets with MBS capability coming into market from Tier 1 GPS chipset providers
  - Technology standardized in 3GPP (Rel 13) and OMA (2.0.3)
- Successfully demonstrated timing capabilities with major Telecom Operators, Financial Markets and other industries