TerraPoiNT

The Resilient Terrestrial Timing Network

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Agenda

- Need for Resilient Timing
- TerraPoiNT System
- TerraPoiNT Network and Beacon Timing
- Trials and Results
- Conclusion

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Resilient Timing – Need of the hour

- Timing has become a critical system, backbone of major critical infrastructure and hence, there is a strong need for **Resilient Timing system**
  - Most of the timing systems utilize GNSS receivers to derive and provide timing information

- GNSS-based Timing systems are susceptible to following problems
  - Need to get good signal strength of the GNSS signals

    ➔ *Implies stricter requirements for Antenna placement and cable calibration*
  - *Easily prone to Interference*

    ➔ Signals are weak in power and can be easily jammed
  - *Spoofing*

    ➔ Various incidents have indicated that GPS system is vulnerable to spoofing which can cause more damage than undesired interference

- **'NextNav's TerraPoiNT System'** provides a better timing solution that overcomes the challenges of existing systems

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TerraPoiNT System– ‘Terrestrial GPS’

FCC Certified Transmitter

- ✓Provides full Position, Navigation and Timing Capabilities in urban, indoor locations in the presence and absence of GPS
- ✓Scalable – Terrestrial transmitters (beacons) deployed around campus or city and provides PNT services under it’s entire coverage footprint
  - ✓Timing only services offered with 1-2 beacon overlap
  - ✓Full PNT services with 4 beacon overlap
- ✓“Mission critical” reliability
  - ✓Encrypted Signal
  - ✓Resistant to spoofing and jamming
- ✓Onboard atomic clock on each beacon with ability to self synchronize; allows transmitter to operate independent of GPS
- ✓PNT IC based capability available in 1H, 2021
- ✓Nationwide spectrum owner (920 – 928 MHz) – 95% urbanized POPs
- ✓Standardized in Global Cellular Standards - 3GPP (Rel. 13+) and OMA (SUPL 2.0.3) as “MBS”, a type of terrestrial beacon system (TBS)

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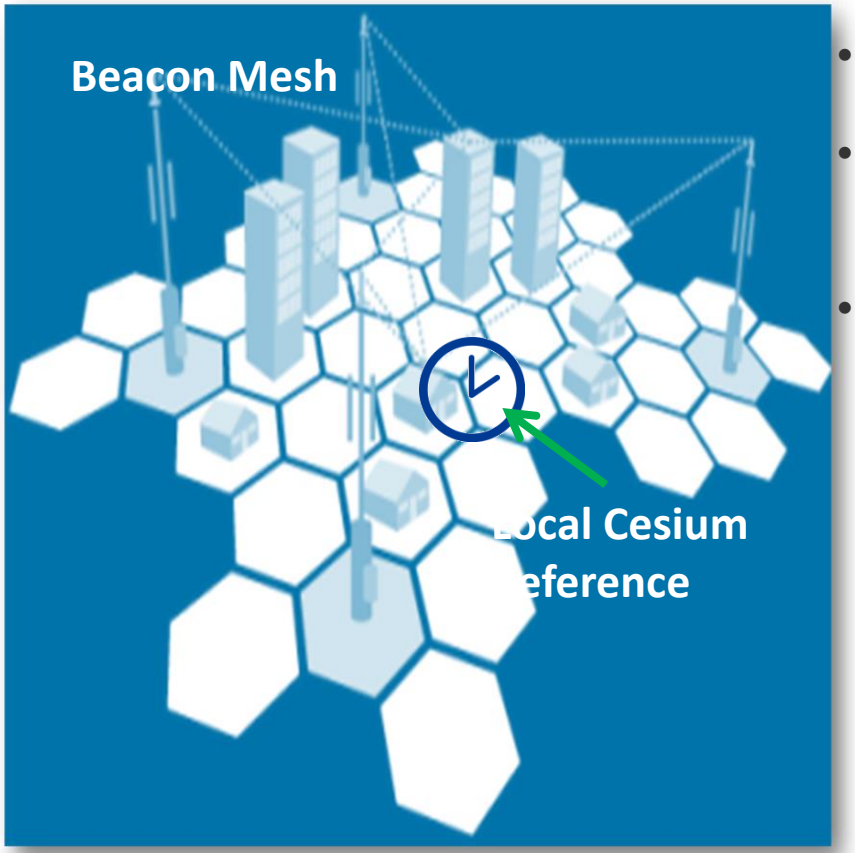
TerraPoiNT System Architecture



- Beacons deployed around service area
- Each beacon has an onboard timing source
- Beacons share time with each other to maintain local synchronization
- UTC sync to a small subset of beacons can be provided using
  - Any absolute alternate timing source (eg. ToF, LEO satellite, TWSTT) and can also be maintained across outages using a local Cesium.
  - Or, holdover from GNSS maintained using local Cesium during GNSS outages
- Signal is encrypted to enable user authentication and to provide a level of spoofing protection

Resilient mesh architecture: if any beacon compromised, service will continue

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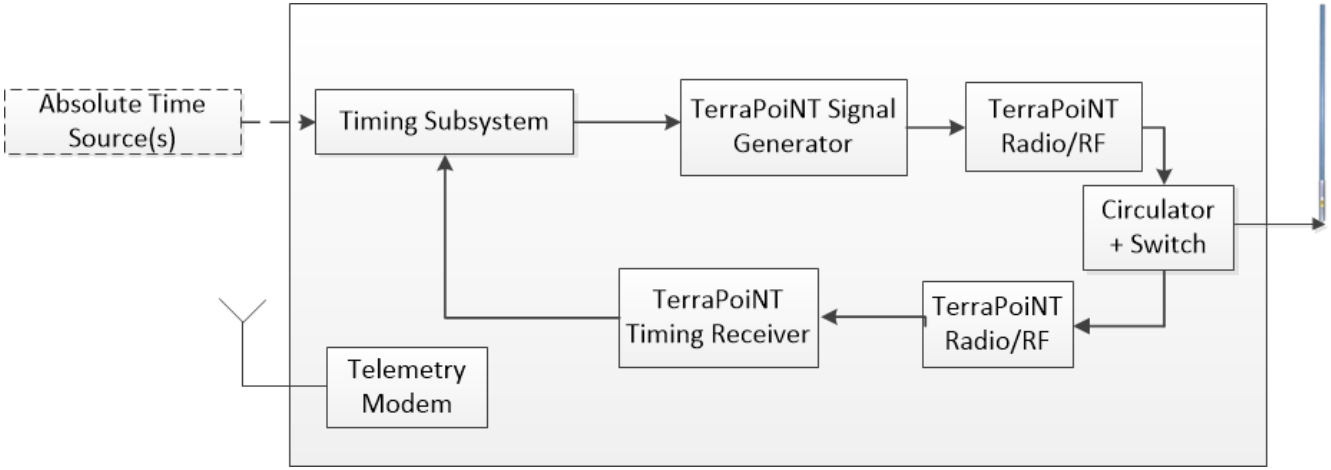
TerraPoiNT Beacon Timing

- TerraPoiNT beacons in the network can be categorized as “Leader” and “Follower”
- All beacons listen to transmissions from all other “hearable” beacons in the network
  - Perform measurements to facilitate relative beacon sync
- “Leader” Beacons have a timing sub-system which has access to one or more absolute time sources like GNSS, LEO or ToF, along with a precise atomic clock (such as Cesium/Rb) allowing long holdover time to be maintained during outage of absolute time sources
- “Follower” beacons listen to “Leader” and perform measurements required to enable time transfer relative to the “Leader”
- This method allows time synchronization to be maintained within few nanoseconds



Beacon Block Diagram showing Timing subsystem

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TerraPoiNT network for DOT Trials

- The image below depicts NextNav's GPS-free TerraPoinNT network at NASA's Langley Research Center used during the DOT GPS free APNT demonstration
- All beacons listen to the other beacons to enable synchronization through time transfer
- Both single hop and multi-hop time transfer were demonstrated
- Magenta lines depict time transfer arrangement among the beacons
  - Multiple hop time transfer – demonstrates time transfer scalability to a larger network
  - Multiple beacon paths for time transfer between any two beacons - provides improved redundancy and robustness

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Timing Accuracy Tests

- Timing accuracy of TerraPoiNT system was tested by the DOT as part of GPS-Back up demonstration in the NASA Langley campus
- Different timing scenarios were developed to assess TerraPoiNT system:
  - 72-Hour Bench Static Timing, Static Outdoor Timing, Static Indoor Timing, and Static Basement Timing
- TerraPoiNT network was operated in GPS-free mode for the entire duration of the tests.
- TerraPoiNT receiver was used to test the timing performance for the above scenarios
- TerraPoiNT receiver's timing is compared with an absolute time truth reference system to determine the accuracy

Test Location for 72-hour test and basement test

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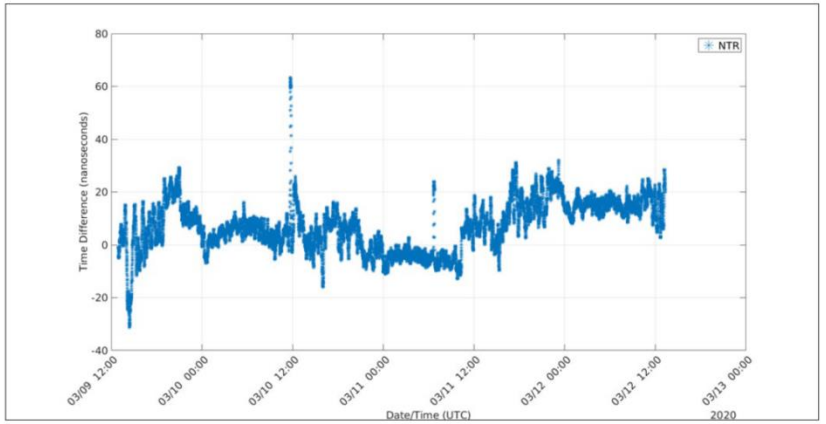
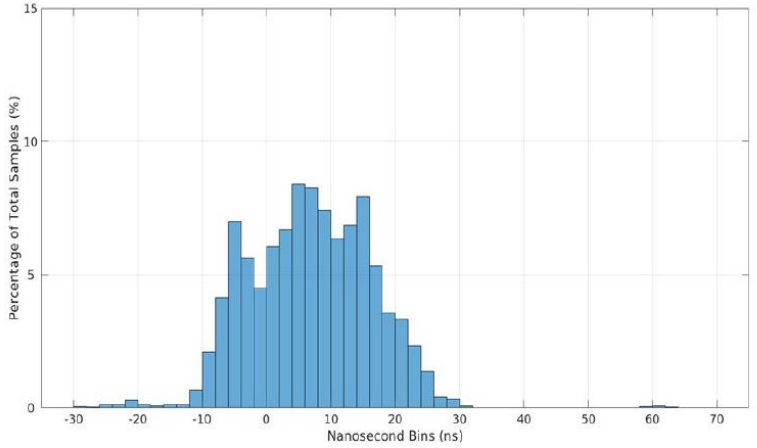
Timing Performance: 72-hour GPS Outage Test

- A 72-hour test was performed to assess timing service availability and long-term time transfer error and stability
- In this test, TerraPoiNT receiver performance was within +/- 25ns (95%)
- The results indicated that TerraPoiNT receiver can provide accurate absolute time during the test.
  - Note that, it is enough to maintain relative time synchronization during outages for position and navigation applications



72 – Hour Bench Test Result



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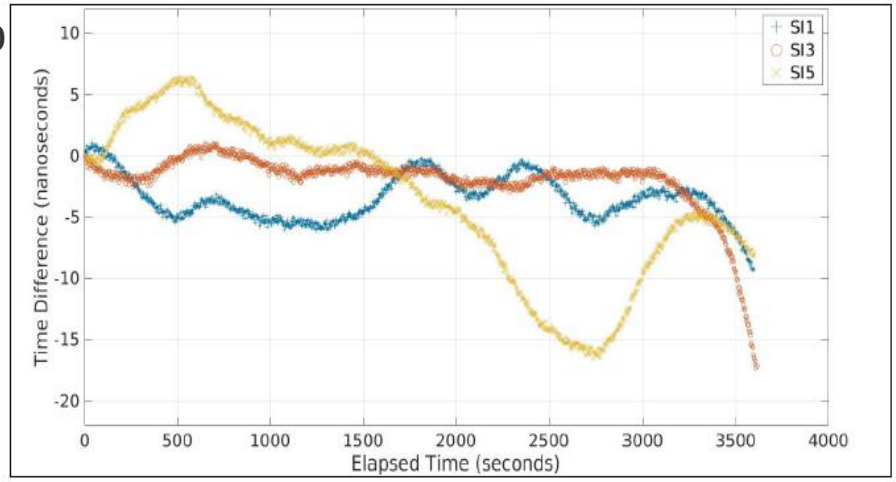
Source: Complementary PNT and GPS Backup Technologies Demonstration Report

Timing Performance: Static Outdoor

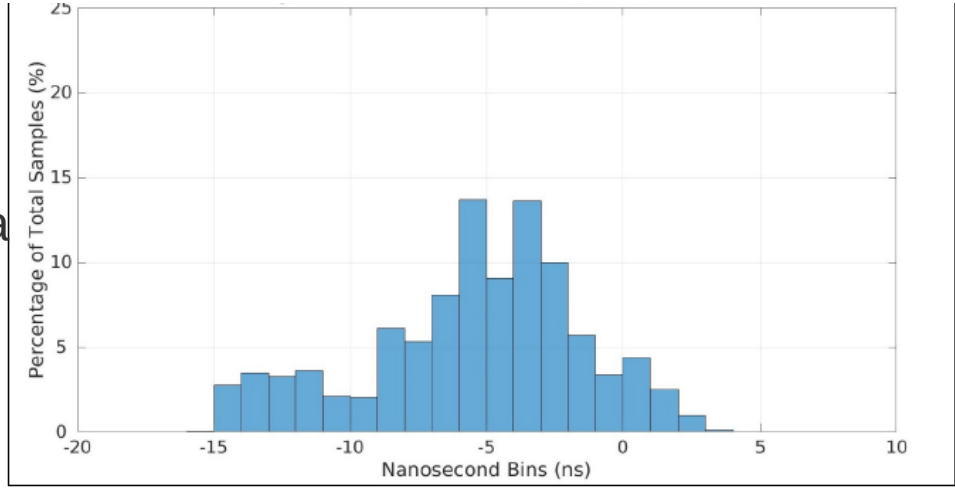
- Multiple outdoor test locations were used to check the uniformity of coverage within the demonstration region.

- Data was collected for 60-minutes in each test location

- Results indicate TerraPoiNT receiver's accuracy is within +/- 15ns (95%) which indicate that performance is similar across different locations within the coverage area



Outdoor Timing Result for 3 locations



[1] Source: Complementary PNT and GPS Backup Technologies Demonstration Report

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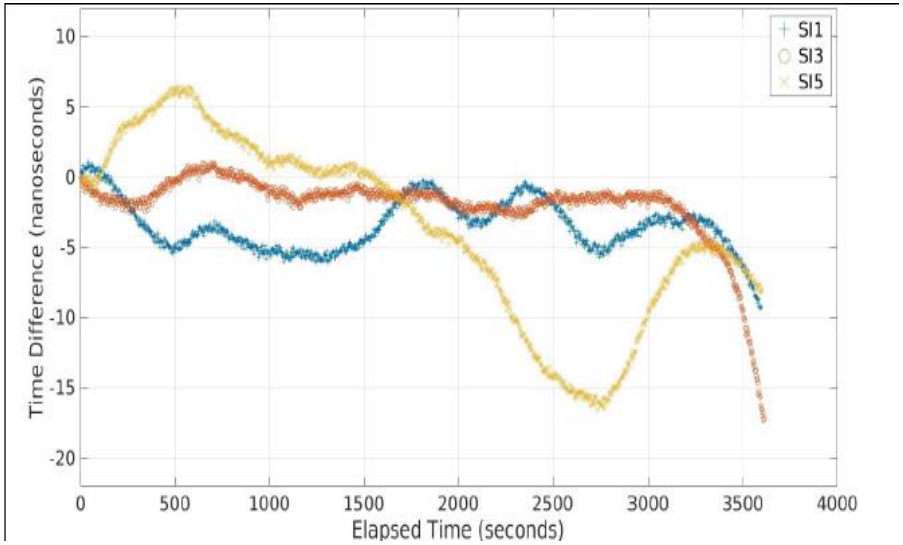
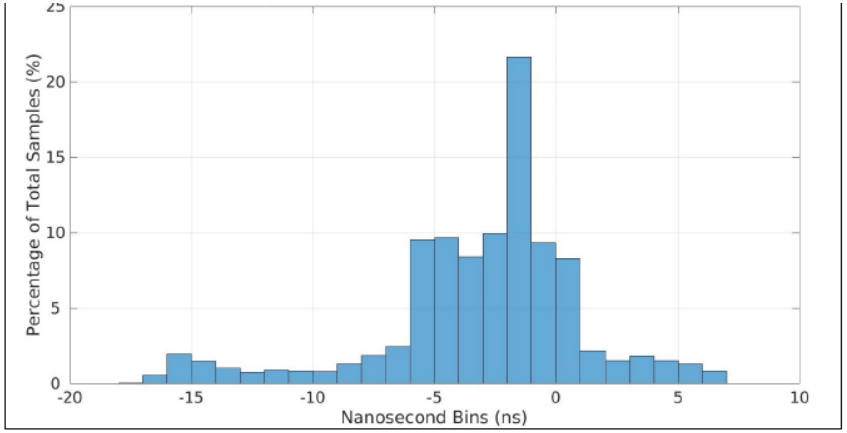
Timing Performance: Static Indoor

- Multiple indoor test locations were used to check the uniformity of coverage within the demonstration region.
- Test was done over 60-minutes per test location
- Results indicate TerraPoiNT receiver's accuracy is within +/- 15ns (95%) which indicate that performance is similar across different locations within the coverage area



Indoor Timing Result for 3 locations



[1] Source: Complementary PNT and GPS Backup Technologies Demonstration Report

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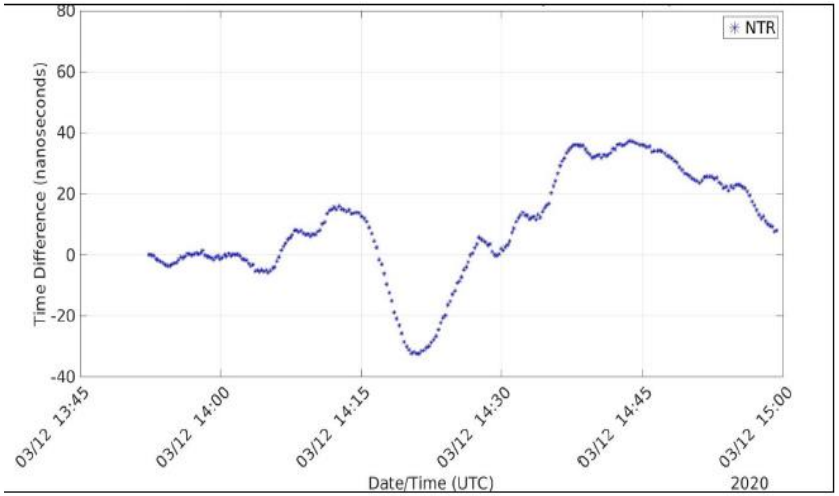
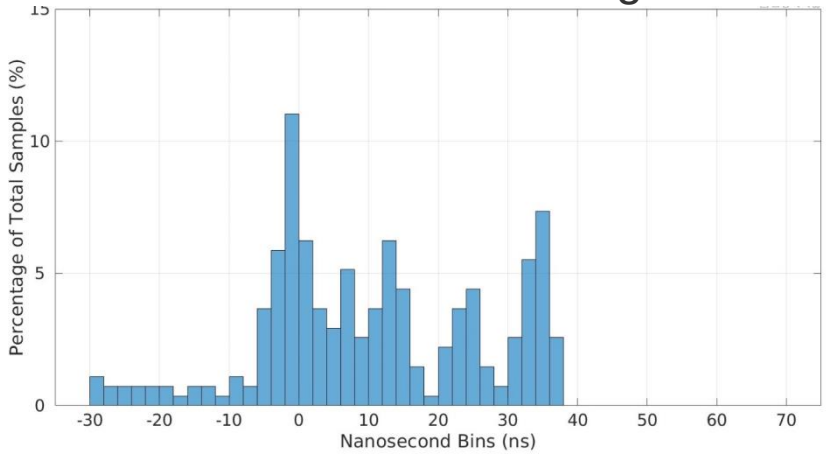
Timing Performance: Basement

- This basement test was used to check coverage in a high signal attenuation environment such as deep inside multi-story buildings and below grade
- Test was done over 60-minutes per test location
- Results indicate accuracy is within +/- 30ns (95%) even with deep indoor locations indicating the reach of TerraPoiNT signals and their usability below grade



Basement Test for Timing



[1] Source: Complementary PNT and GPS Backup Technologies Demonstration Report

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Result Summary

- TerraPoiNT System successfully demonstrated accurate timing within +/- 30ns for various outdoor and indoor locations across the demonstration area in absence of GPS

- Demonstration showed that TerraPoiNT architecture provides good scalability for large area deployment and shows high resiliency due to redundancy

- TerraPoiNT was the only technology that offered a solution for all the desired use cases

- DOT analysis on the various technologies participating rated the TerraPoiNT system as #1 for timing as well as position/navigation applications
  - Combination of factors including performance accuracy, system/UE maturity, spectrum protection, signal robustness, service resilience, system interoperability and service longevity were considered to arrive at this rating

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Complementary PNT and GPS Backup Technologies Demonstration Report: Summary of PNT Vendors supporting different scenarios

Table ES.2. PNT Technology Vendor Participation in Scenarios

			Timing Scenarios					Positioning Scenarios			
Vendor	PNT Technology	Demo Site	72-Hr Bench Static Timing	Static Outdoor Timing	Static Indoor Timing	Static Basement Timing	Reference Station Offset (eLORAN Timing)	Dynamic Outdoor Positioning with Holds	Static Outdoor Positioning	Static Indoor Positioning	Airborne 3D Positioning
Echo Ridge	LEO commercial S-band (2483.5 - 2500 MHz)	LaRC					N/A		X		
Hellen Sys	eLORAN terrestrial RF (90-110 kHz)	JBCC	X			X	X				
NextNav	UHF terrestrial RF (920 - 928 MHz)	LaRC	X	X	X	X	N/A	X	X	X	X
OPNT	fiber optic time service (white rabbit PTP)	LaRC	X				N/A				
PhasorLab	802.11 terrestrial RF (2.4 GHz)	JBCC	X	X	X		N/A	X	X		X
Satelles	LEO commercial L-band (1616 - 1626.5 MHz)	JBCC	X	X	X	X	N/A		X		
Serco	R-mode terrestrial RF (283.5 - 325 KHz)	JBCC					N/A	X	X		
Seven Solns	fiber optic time transfer (white rabbit PTP)	LaRC	X				N/A				
Skyhook	802.11 terrestrial RF (900 MHz, 2.4 & 5 GHz)	LaRC					N/A	X	X	X	X
TRX	UWB & IMU map matching (3.1 - 5 GHz)	LaRC					N/A	X*	X	X	
UrsaNav	eLORAN terrestrial RF (90 - 110 kHz)	JBCC	X		X	X	X				
GPS (SPS PS)	MEO government L-band (1575, 1227, 1176 MHz)	All	X	X			X	X	X		X

*static holds only

Key: N/A Technology incompatible with scenario definition

TerraPoiNT was the only technology that offered a solution for all the desired use cases

[1] Source: Complementary PNT and GPS Backup Technologies Demonstration Report

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Complementary PNT and GPS Backup Technologies Demonstration Report: Result Summary

	PNT Technology	Timing Performance RANK	Timing Performance SCORE	Positioning Performance RANK	Positioning Performance SCORE	Timing Ground Broadcast RANK	Timing Ground Broadcast SCORE	PNT Ground Broadcast RANK	PNT Ground Broadcast SCORE	Timing Broadcast RANK	Timing Broadcast SCORE	PNT Broadcast RANK	PNT Broadcast SCORE
ECHO RIDGE	LEO commercial S-band (2483.5 - 2500 MHz)	-	-	5	38	-	-	-	-	-	-	-	-
HELLEN systems	eLORAN terrestrial RF (90-110 kHz)	6	62	-	-	3	66	-	-	4	66	-	-
NEXTNAV	UHF terrestrial RF (920 - 928 MHz)	1	91	1	91	1	82	1	82	1	82	1	82
opnt.	Fiber optic time service (white rabbit PTP)	2	87	-		-		-		-		-	
PHASORLAB	802.11 terrestrial RF (2.4 HGz)	6	62	3		4		2		5		3	
Satelles	LEO commercial L-band (1616 - 1626.5 MHz)	4	78	2	78	-	-	-	-	2	80	1	82
serco	R-mode terrestrial RF (283.5 - 325 KHz)	-	-	-	-	-	-	-	-	-	-	-	-
SEVEN Solutions	Fiber optic time trasnfer (white rabbit PTP)	3	84	-	-	-	-	-	-	-	-	-	-
SKYHOOK°	802.11 terrestrial RF (900 MHz, 2.4 & 5 GHz)	-	-	4		-		-		-		-	
TRX systems	UWB & IMU map matching (3.1 - 5 GHz)	-	-	5	38	-	-	-	-	-	-	-	-
UrsaNav	eLORAN terrestrial RF (90 - 110KHz)	5	69	-	-	2	70	-	-	3	70	-	-
GPS (SPS PS)	MEO government L-band (1575, 1227, 1176 MHz)	-	67	-		-		-		-		-	

Timing Performance: Weighted score based upon accuracy, availability, product readiness, resilience and security
Positioning Performance: Weighted score upon accuracy, availability, product readiness, resilience and security
Timing Ground Broadcast: Market readiness of Timing Performance using terrestrial RF broadcast

PNT Ground Broadcast: Mass market readiness for Position AND Timing using terrestrial RF broadcast
Timing Broadcast: Mass market readiness of timing using RF broadcast
PNT Broadcast : Mass market readiness for Timing AND Positioning using RF broadcast

Weighted score assessment based on accuracy, availability, product readiness, resilience and security
NextNav's TerraPoiNT system ranked #1

Reproduced from Fig 127

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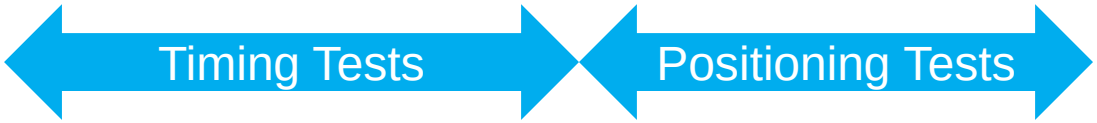
[1] Source: Complementary PNT and GPS Backup Technologies Demonstration Report

Complementary PNT and GPS Backup Technologies Demonstration Report: Timing and Positioning Accuracy of various systems



PNT Technology Vendor	Demo Site	72-Hr Bench Static Timing	Static Outdoor Timing	Static Indoor Timing	Static Basement Timing	Reference Station Offset (eLoran Timing)	Dynamic Outdoor Positioning with Holds	Static Outdoor Positioning	Static Indoor Positioning	Airborne Positioning
Echo Ridge LLC	LaRC					N/A		333.2		
Hellen Systems, LLC	JBCC	114.9			failed to close	3.4				
NextNav LLC	LaRC	23.1	7.1	5.8	17.5	N/A	15.6	6.7	8.9	3.8
OPNT B.V.^	LaRC	0.2				N/A				
PhasorLab Inc.	JBCC	9.4	17.4	18.7		N/A	11.7	7.4		8.6
Satelles, Inc.	JBCC	75.5	75.0	9.0	117.0	N/A		9.0		
Serco Inc.	JBCC					N/A	DNQ	39.4		
Seven Solutions S.L.^	LaRC	0.1				N/A				
Skyhook Wireless, Inc.	LaRC					N/A	7.6	1.8	23.5	14.6
TRX Systems, Inc.	LaRC					N/A	9.7	6.2	9.8	
UrsaNav Inc.	JBCC	80.1		57.4	failed to close	9.7				
GPS (SPS PS)	All	30	30			30	5	5		7

Rubric:

positioning: max 95%{runs} (m)

1.8 to 333

timing: max 95%{runs} (ns)

0.1 to 117

^ 1PPS from USG at measurement node

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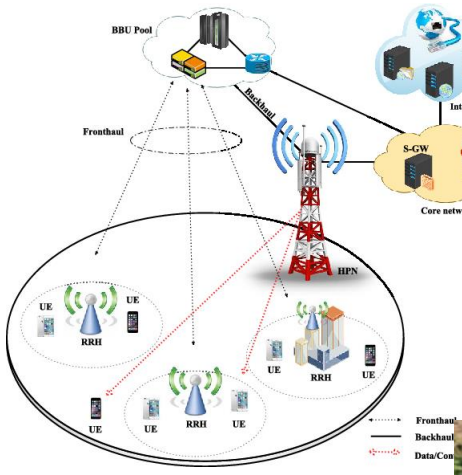
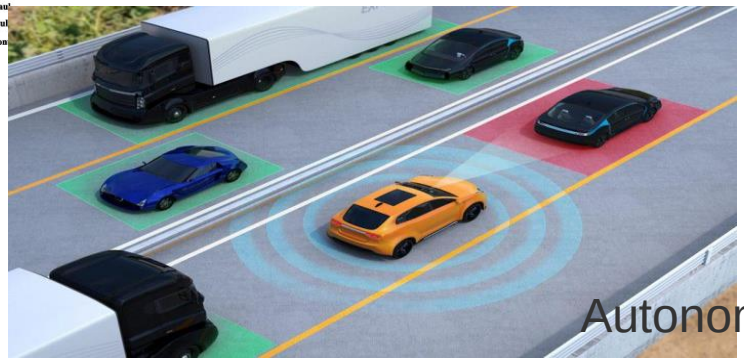
Applications



Cellular Network

Data Centers

Power Grid



Autonomous vehicles

Different Applications - One important Requirement

Accurate and Precise Timing

Enabled by TerraPoiNT

Image source: Internet