Introduction

NextNav applauds NIST's efforts to catalog use cases for PNT services in pursuit of greater resiliency for the critical services on which the nation relies.

GPS has become the fifth utility in the world. In addition to being the primary source for the distribution of accurate time, GPS is the now-vulnerable foundation for hundreds of millions of location-aware devices providing Positioning and Navigation services. While a bright light has been directed towards timing for critical infrastructure, like cellular service and the electrical grid, it is equally important to consider the important role these critical infrastructure elements function to downstream services such as those for First Responders and Enhanced 911 (E911) services for citizens.

A good example is telecommunication services. In addition to providing critical voice and data communication for the public at large, telecommunication services are responsible for providing 911 services for consumers, public response systems for public safety and providing communication links for transportation systems. Therefore, in assessing the impact of PNT services on critical infrastructure and the development of profiles, it is important to not only consider the direct impact on critical infrastructure but also key adjacent services that are fundamental to functioning of the economy -- especially safety of life applications. Location-aware cellular devices in particular are the critical lifeline for prompt access to emergency services in the U.S. – especially for our most vulnerable citizens. According to the CDC's *Wireless Substitution Survey*, as of the end of 2018, 67% of lower income households relied exclusively on wireless service for telephony and broadband[1].

This emphasizes the criticality of alternate PNT solutions that can be accessed by mobile devices when GPS isn't available. While a landline is easily traceable to its actual location, especially in single-family dwellings, wireless devices require accurate location technology for effective emergency response. Alternate PNT is necessary to ensure mass-market users can depend on GPS for lifesaving services, every day. The economic impacts for higher-volume applications, including GPS location services on mobile devices, in automobiles, and in lower-cost drones are also significant. A disruption to GPS service would have an immediate impact on anyone that depends on these services for their job, their ability to participate in commerce, and the abundant lifestyle improvements associated with mass-market availability of GPS services.

Our RFI response below addresses the eight questions submitted in the RFI, which generally correspond to the five elements of the CyberSecurity Framework (CSF) "Core" elements – Identify, Protect, Detect, Respond, and Recover.

1. Describe any public or private sector need for and/or dependency on the use of positioning, navigation, and timing, or any combination of these, services.

Over the last 5 years, many Federal agencies have reported on the nation's increasing reliance of PNT capabilities to support the daily services nearly every American now takes for granted. As stated in Executive Order 13095, PNT services are essential components of many technology and infrastructure services (including utilities, telecommunications, transportation, and emergency

[1] See https://www.cdc.gov/nchs/data/nhis/earlyrelease/wireless201906.pdf.

response) whose efficient and continuous operation is critical to the national and economic security of the United States. Primary among these are:

Timing for Telecommunication Services. Telecommunication services are one of the critical services that provide voice and data services. The overall economic impact of telecommunication services is $60 billion annually to the economy.

Mobile telecom timing has evolved in recent years from precision frequency delivery to precision time delivery. There are a number of telecommunication systems and end-to-end applications that rely on some level of time and phase synchronization -- among them LTE FDD, in which base stations are synchronized to GPS Time. Other examples are LTE TDD and 5G networks, in which base stations on the same frequency are synchronized to facilitate spectrum sharing through time division with minimal inter-cell interference. Additional examples are location-based services using Observed Time Difference of Arrivals (OTDOA) and Coordinated Multipoint (CoMP), which enable the coordination of transmission and/or reception at multiple geographically separated sites to enhance system performance and end-user service quality. This has driven the industry toward the increased use of GPS and GPS dependent technologies.

Service providers have already launched commercial 5G services. By end of 2025, it is estimated that there will be around 325 million 5G subscriptions in North America. The mobile telecom industry adds many new GPS receivers in infrastructure elements each year as the network grows, especially in wireless. These GPS receivers, which have a lifetime of more than 15 years, are used for precision timing from fixed locations. Based on industry estimates, fewer than 5% of these units are used to support fiber optic networks and more than 95% are used to support the fixed infrastructure for wireless (i.e., wireless base stations, 4G, 5G, and E911 systems). Over 30K central offices need microsecond level timing to provide wireline services and, for 5G wireless, it is estimated that more than two million 5G pico cells require the precise nanosecond level time accuracy. The UTC time standard, can only be widely distributed by GPS receivers.

In order to provide voice and data communications, mobile telecommunication services rely on precise timing to ensure proper handoff between cell sites. Precise timing also ensures better utilization of spectrum by allowing finer time resolution, thus increasing the bits/Hz (a key efficiency factor). In addition to providing voice and data communication, the telecom GPS timing systems are the enabling systems for other systems such as E911 positioning and Assisted GPS (AGPS), which are used to find the location of wireless handsets. This in turn connects citizens to E911 services and also provides First Responders direct usage to PNT services through services such as FirstNet.

This GPS dependency has left the telecommunications industry vulnerable to disruptions and manipulations of the GPS signal. Such disruptions may have economic, financial, and service impacts to carrier network operators, suppliers, cellular services, and adjacent industries and government agencies that depend upon a functioning wireless communication infrastructure.

E911 Emergency Assistance Requests. Since 2000, there has been a federal mandate as enacted by the Federal Communication Commission to locate wireless callers when they dial E911. GPS has become the de-facto technology in meeting the FCC’s requirements. GPS has also been an integral part of current emergency response systems in guiding emergency vehicles. Fallback techniques such as using cell site service areas, and even cell sector service areas, can cover tens or hundreds of square kilometers – rendering them useless and requiring the emergency caller to verbally describe their precise location to the Public Safety Access Point (PSAP) operator to ensure emergency personnel can be dispatched to the correct location - often when the caller is most in distress, disoriented or unfamiliar with their surroundings, or unable to speak.

Today all techniques rely on GPS for communicating the user's location to the PSAP. For users outdoors, GPS is used directly as most U.S. wireless devices have embedded GPS receivers. For users indoors, GPS is used indirectly by parties such as Google and Apple as part of sophisticated systems that learn the approximate location of Wi-Fi access points based on periodic GPS, inertial, Wi-Fi signal strength and other measurements. The cellular industry refers to these systems as Device-Based Hybrid (DBH) location. Other techniques that are built natively into the cellular system such as OTDOA rely on synchronization between base stations using GPS. In the absence of GPS all these systems would be unable to provide the location of the caller to the PSAP and essentially will cripple the 911 system.

First Responders. GPS is critical to police, fire and EMS services (1M Fire fighters, 700K Policemen and 600K paramedics). GPS and GPS tracking increases public safety in the following applications:

1) GPS reduces emergency response time for first responders to responding to an emergency E911 call by getting them to the Caller's location as quickly as possible in the golden hour when the potential to save a life is greatest.

2) It improves the situational awareness of First Responders by providing the ability to identify the location of individual first responders and determining their location relative to other first responders and an entire network of transportation systems in a geographic area. For instance, First Responders at an emergency need to know their location relative to the emergency and to the right entry way. This requires GPS to determine the First Responder's location.

3) GPS optimizes patrol coverage by tracking where vehicular assets are in the field at any given time and showing how long it's been since a particular route was patrolled. When an emergency call is received, dispatch can identify which vehicle is closest, to reduce emergency response times for over half a million emergency vehicles.

4) GPS allows public safety agencies to deter thefts and minimize the possibility of losing a vehicle by using GPS tracking tags that monitor location.

FirstNet, the federal government program to build a nationwide broadband network for public safety, recognized the huge benefit of enhancing the personal protection of first responders. FirstNet included enhanced location services as an essential need.

Mass Market Location Based Services (LBS). GPS chips in smartphones and other consumer devices receive satellite signals and generate precision location information that software applications use to deliver services and experiences to users. There are navigation and non-navigation applications:

1. Navigation services refer to navigation devices and smartphone applications that provide users with turn-by-turn driving directions and real-time alerts on road conditions.

2. Non-navigation smartphone applications refer to applications that use location information to track location in real time, enhance social networking and gaming, and tailor local search to geographic position and advertising.

An RTI study qualified the benefits GPS-enabled LBS generate for users (e.g., driving times reduced by turn-by-turn directions) and society (e.g., air pollution reduced by shorter driving times). It estimated that GPS-enabled location services for smartphones and consumer devices generated about $218 billion in private and public benefits between 2007 (the first year for which benefits could be reliably calculated) and 2017.

Power Grid. Data about dynamic stability events on the grid must possess an absolute time precision of 1 usec (NASPI). Electricity suppliers use the precision timing provided by GPS to monitor the daily operations of the power grid down to the nanosecond. This monitoring is conducted by PMUs, which evaluate electrical waves to detect potential problems and faults in the power distribution infrastructure. To realize this real-time monitoring and analysis, a large number of synchronized PMUs, (synchrophasors), are linked to a common time source that enables them to time stamp the dynamics of the electrical system. The time source is the Coordinated Universal Time (UTC), which is provided relatively inexpensively using the GPS system.

In particular, the electrical sector uses synchrophasors to synchronize electrical waves in the power grid and detect potential problems and faults in the transmission infrastructure. Synchrophasors are precise grid measurements available from monitors called phasor measurement units (PMUs). PMU measurements are taken at high speed (typically 30 observations per second, over 100 times faster than conventional SCADA technology). Each measurement is time-stamped according to a common time reference such as GPS. Time-stamping allows measurements from different locations and utilities to be time-aligned (synchronized) and combined together providing a precise and comprehensive view of the entire interconnection. Synchrophasor measurements can be used to indicate grid stress and can be used to trigger corrective actions to maintain reliability. As a result of these developments, over 60k substations incur a high level of reliance on GPS in their power grid deployments.

Automotive Navigation Systems. On October 23, 2018, the Auto Alliance sent a letter to the FCC stating: “GPS is a critical technology for many current and future vehicle safety systems, including both Advanced Driver Assist Systems (ADAS) and Automated Driving Systems (ADS). Navigation and driver behavior monitoring would not be possible without GPS because a high level of precision (less than 5 m) is required. Features like GPS and other sensors collect data on speed, acceleration, fast lane changing, harshness of braking, frequency of reversing, engine idling, and other behaviors that increase the risk of accidents. The availability and accuracy of GPS offers increased safety for vehicles and other road users traveling on our nation’s roadways. At least half a million of today’s vehicles are equipped with ADAS safety features or other onboard telematic navigation systems that rely on precise GPS signals for position, navigation, emergency services and other applications.

GPS tracking devices, combined with fleet management software, can document how many miles a vehicle has traveled and engine performance statistics which can reduce breakdowns on the road, and make certain that emergency vehicles are able to respond when they are needed.

According to the National Highway Traffic Safety Administration (NHTSA), it is difficult to estimate with accuracy the precise total number of on-highway vehicles equipped with GPS enabled devices. However, it is reasonable to assume that there may be between 50 and 100 million light duty vehicles equipped with some type of GPS receiver in the US.

Uses of GPS receiver chipsets includes onboard navigation units, telematics/ concierge systems (i.e., OnStar, Sync, Enform, Mbrace, BMWAssist, etc). Since 2010, all GM cars have been equipped with OnStar, for a total production of 27.3 million cars and light trucks. Other manufacturers have followed the trend of equipping all cars with a telematics system to varying degrees and at different times. As of 2020, 12 million cars were reported to have a fleet management system with GPS-enabled location capability.

Commercial Trucking and Public Transit Systems. The Federal Motor Carrier Safety Administration (FMCSA) estimates there are over 580,000 interstate motor carriers and 12 million registered large trucks.

The GPS Innovation Alliance estimates that between 50 percent and 86 percent of all fleet owning firms adopted GPS for fleet management. In addition, they estimate a total adoption rate of 67.9 percent of trucks (https://www.gpsalliance.org). They do not separate adoption rate by truck class. Using these estimates provides a range of 7 million to 10.5 million medium and heavy trucks with GPS.

FMCSA regulation (49 CFR 395.20, Appendix A to Subpart B), requires that an Electronic Logging Device (ELD) measure a commercial motor vehicle's position every five miles, and record the position each hour to the log. In addition, ELDs must record events, such as a driver's changing of duty status from "driving" to "sleeper berth" or "on-duty not driving" with the precision of +/- 1 mile. FMCSA estimates 2.8 million to 3 million drivers are required to use ELDs in interstate CMV operations.

The American Public Transportation Association (APTA) has an extensive database of Transit/Commuter Bus with Automated Vehicle Location (AVL) units installed which are based on GPS technology. In 2019, there are over 57,000 buses with AVL units installed among 330+ transit agencies.

Commercial Drones. Unmanned aircraft systems (UAS) would also be significantly affected, particularly on almost half a million commercial drones and over a million hobbyist drones. High precision drones can operate at very low altitudes and use very sensitive, high-accuracy GPS receivers complemented by inertial navigation.

2. Identify and describe any impacts to public or private sector operations if PNT services are disrupted or manipulated. [Identify]

The DHS Cybersecurity and Infrastructure Security Agency (CISA) reported that "the President's Commission on Critical Infrastructure Protection (PCCIP) identified overdependence on the Global Positioning System (GPS) as a growing vulnerability within the United States Critical Infrastructure. In 2017, 5.8 billion Global Navigation Satellite Systems (GNSS) devices, such as those using GPS, were in use. By 2020, this number is forecasted to increase to almost 8 billion—an estimate of more than one device per person on the planet."

According to a June 2019 NIST-sponsored study conducted by RTI, the overall economic impact of GPS on the economy since 1984-2017 is estimated to be $1.4 trillion dollars across 9 critical industries. U.S. citizens have become dependent on GPS to provide these critical services in a transparent, secure, and reliable manner. Disruption in GPS availability, reliability, resiliency, and integrity would weaken the critical infrastructures that sustain our national security, the strength of US business operations, and public health and safety. It is estimated that a 30-day outage of GPS could cost about a $1 billion/day in economic activity.

Telecommunications. The impact of interference to GPS receivers deployed to the telecom industry would be significant. While the total number of receivers today may be lower than in other industry sectors, a problem with a telecom receiver has a larger impact because the receiver supports many customers. For instance, a problem with a precision timing GPS receiver located at a wireless base station could impact all wireless handset users that use that base station to connect the handsets to the fixed part of the wireless carrier's network. Considering the requirements related to network reliability and the provision of E911 positioning services, the correct operation of these GPS receivers is important both to the operation of carriers' networks and to users of voice, data, and location services.

ATIS Sync has estimated[2] that in LTE TDD networks, a GPS outage would likely result in service disruption and degradation. After 24 hours, the 3rd Generation Partnership Project (3GPP) time requirement may be reached and the wireless air interface of cell sites without a backup time reference would need to be shut down. While they can generally continue to operate, LTE FDD networks may experience some degradation in intra-band carrier aggregation and location-based services using Observed Time Difference of Arrival (OTDOA) technology, and need to be shut down in case of a prolonged outage (e.g. 30 days or longer). Similar issues are expected in 5G networks, where early deployments are similar to LTE, although 5G is a set of evolving standards. Some variation among cellular operators and equipment vendor implementations is expected.

911 Emergency Assistance Requests. The value of high accuracy 911 location capability is immense.

NENA, the 911 Association, estimates that 240 million 911 calls are placed each year, of which approximately 80% are placed from wireless devices; the National 911 Program in their annual Progress Report estimates similar statistics. This means an estimated 192 million wireless 911 calls (E911) annually, and over 500,000 per day, require accurate location to ensure dispatch of emergency personnel in all conditions. Today, the direct or indirect source of that accurate location is GPS.

The FCC, in its recent *5th Report and Order* in proceeding 07-114 on wireless E911 location accuracy, estimated that over 10,000 lives annually and nearly $100B dollars will be saved by the location accuracy standards encompassed in the previous *4th Report and Order*, which led to the adoption of GPS-dependent indoor location standards in the *5th Report and Order*. These effects are cumulative with the substantial embedded benefits to direct GPS-based E911 call location for outdoor location:

[2] ATIS-0900005 Technical Report: GPS Vulnerability, 7 September 2017

> *As we affirmed in the Fourth Further Notice, this addition of new vertical information—together with the refinement of existing horizontal information— has the potential of saving "approximately 10,120 lives annually at a value of $9.1 million per statistical life, for an annual benefit of approximately $92 billion or $291 per wireless subscriber."220 Due to U.S. Department of Transportation updates for value of a statistical life, we presently estimate this annual benefit floor at $97 billion.* – 5th Report and Order and Fifth Further Notice of Proposed Rule Making, FCC 07-114 at para. 57, November 2019.

First Responders. GPS has become an integral part of all modern emergency response systems, from assisting stranded motorists to guiding emergency vehicles (police, fire, ambulance). Since GPS is the only accurate and reliable location service available to first responders for general use, GPS disruption would prevent any location-oriented automation in emergency response for the duration of the disruption. If an address were unfamiliar, manual navigation using maps without location would be required. Automated situational awareness and tracking individual responders would not be possible.

Location is so important to first responders that enhanced location service offering capabilities beyond GPS were embedded in the requirements for FirstNet, the nationwide first responder broadband network. The basic GPS capability, however, remains a single point of failure for emergency response processes and procedures.

Location Based Services (LBS). The location information needed for LBS to operate is obtained from a combination of GPS, Wi-Fi hotspot, and cell towers. However, GPS is often the most critical of these. Navigation services almost entirely rely on GPS today and would cease to provide services without GPS. LBS would be far less precise without GPS, which could undermine some applications' utility. For example, without GPS, navigation systems could not accurately track a driver's position and deliver live turn-by-turn directions.

Power Industry. According to an RTI study, a GPS outage of 30 days can result in a loss of an estimated $275 million to the electricity industry and immeasurable loss of life support services to customers that support their ability to transact business, hospitals and their ability to carry out their services would be impacted, communication services.

Automotive Navigation Systems. Similarly, RTI identified that GPS-enabled LBS helped U.S. consumers save 2.3 billion driving hours in 2012. This is the product of 65 billion driving hours, a 11% reduction in travel time, 44% of American adults owning smartphones, and 74% of smartphone owners using LBS. The report identified that LBS helped U.S. consumers save 95.4 billion vehicle-miles and 4.4 billion gallons of fuel in 2012.

RTI repeated similar calculations for each year from 2007 through 2017 and adding together the results suggest LBS helped consumers save 52 billion gallons of fuel and drive 1.1 trillion fewer vehicle-miles during this 11-year period. (see table below)

Year	Total Fuel Savings (Millions of Gallons)	Total Vehicle Miles Traveled (VMT) Savings (Millions of Miles)
2007	412.75	8,792
2008	846.74	18,459
2009	1,452.02	31,509
2010	2,205.98	47,429
2011	2,618.81	56,043
2012	4,418.04	95,430
2013	5,449.26	117,704
2014	6,512.17	139,361
2015	8,505.86	187,129
2016	9,361.32	205,949
2017	9,874.27	217,234
Total	**51,657.24**	**1,125,036**

Commercial Trucking and Public Transit Systems. Many commercial and public fleets are turning to satellite-based tracking technologies for tracking and coordination of vehicles, untethered trailers and other assets. Loss of GPS service will significantly increase operating costs, reduce cargo security, weaken "just in time" manufacturing and delivery, and re-establish the need to maintain large inventories. The loss of satellite-based Automatic Vehicle Location (AVL) technologies would disable precise position and load status reporting, electronic logging, calculating ETAs, route guidance and fuel tax mileage reporting.

Commercial Drones. Disruption of GPS would impact the use of just under a half million Unmanned Aircraft Systems (UAS) used in professional applications for critical, high accuracy missions such as mapping/survey, delivery, precision agriculture (delivery services, planting, fertilizing, and pest control), as well as approximately one million recreational UAS.

3. Identify any standards, guidance, industry practices and sector specific requirements referenced in association with managing public or private sector cybersecurity risk to PNT services. [Protect]

Some of the groups working on developing resiliency to manage public or private sector cybersecurity risk to PNT services include:

- Resilient PNT Conformance Framework Working Group (CFWF) led by DHS and HSSEDI
- 3GPP SA1 WG that has a newly approved study item on 5G Timing Resilience (Feasibility Study on 5G Timing Resiliency System)
- NIST-led AAA group exploring Assured Access to Accurate time, although this group is not currently active
- EPRI IG exploring Resilient Time Synchronization for the Energy Sector
- ATIS Sync, that has explored GPS Vulnerabilities and alternate PNT solutions

Encryption and authentication mechanisms can be leveraged effectively to minimize cyber security attacks such as from data spoofing. Furthermore, interference and jamming mitigation, ICD whitelisting, software assurance and good cyber hygiene practices are also actively pursued and leveraged to ensure a high level of resilience for the PNT receivers and system as a whole.

NIST's 4 June 2020 PNT Development Profile webinar noted that GPS has become the oldest and most widely used PNT, but that alternative systems are in development in the private sector. NextNav, one such company, was founded in 2008 to develop PNT technology to provide services when GPS cannot be reliably received. The 3GPP compliant Metropolitan Beacon System (MBS) eliminates the major vulnerabilities of GPS and minimizes the cybersecurity risks that can threaten the reliable operation of the nation's critical infrastructure systems dependent on PNT services. (Please see Attachment A for a summary overview of MBS.)

NextNav's conditional access system provides a higher degree of reliability and security to its service. Prior to transmission, the MBS' signal is encrypted to ensure its security, limit the ability of those with malicious intent from "spoofing" the signal (an occurrence that has become increasingly common with GPS), and to prevent unauthorized access to its positioning information.

NextNav's conditional access system also offers multi-level access to the positioning information generated by its technology. For example, in a cell phone environment, this system allows one level of access for critical safety services, such as provided for E911, and another level of access, potentially to different customers, for consumer applications.

NextNav's Interface Control Document is currently an open standard, available through NPSTC and through ATIS, the North American Partner to 3GPP, as part of ATIS Document 0500027 (by reference).

Support for MBS was included in 3GPP Release 13 and was adopted by OMA for its SUPL 2.0.3 specification.

4. Identify and describe any processes or procedures employed by the public or private sector to manage cybersecurity risks to PNT services. [Protect]

The MBS system allows for multiple PNT sources and fusion engines to be exploited at various nodes in the network, including at transmitters and receivers, in order to increase the system PNT resilience. The fusion engines include functionality to prevent, respond and recover from threats, by exploiting cross-checks on the data across the various PNT sources, isolating compromised components and leveraging the alternate sources to produce positioning, velocity and timing solutions.

Every element in NextNav's MBS network is actively monitored and managed through the Company's cloud-based network monitoring system. At a dedicated NextNav 24x7 Network Operations Center (NOC) in in Sunnyvale, California, NextNav's cloud-based architecture ensures that backup NOC access is available from NextNav's offices in McLean, Virginia or from any location where a secure VPN connection can be established with NextNav's systems. The Company can thus ensure rapid response to network anomalies and is constantly aware of the operational capability of each beacon on the network. Network updates are remotely loaded onto its transmitters from the NOC.

5. Identify and describe any approaches or technologies employed by the public or private sector to detect disruption or manipulation of PNT services. [Detect]

Disruption and/or manipulation can be detected by looking at a drift in phase of the timing. Similarly, a system can be developed to detect a sudden change or loss in position. A terrestrial network could be built to identify deviations between the surveyed position and the reported position. This approach can also be extended to compare location computed from terrestrial positioning systems and GPS.

The MBS beacon network is a geographically distributed terrestrial network of beacons, with each beacon containing a GPS receiver and an atomic clock. The beacons are designed to detect anomalies in position and timing. This enables MBS network to detect local anomalies in GPS through measurement data consistency check using historical data as well as stability comparisons with respect to the atomic clock.

6. Identify any processes or procedures employed in the public or private sector to manage the risk that disruption or manipulation to PNT services pose. [Respond]

Using alternate technologies that are complementary in nature is a good way of being able to respond to targeted disruption and manipulation. This redundancy also helps in preventing local outages.

A vast number of consumer devices, including mobile phones, rely on GPS. Mobile phones already supporting alternate Satellite Positioning Systems (SPS) like Galileo (collectively referred to as GNSS). An ideal solution would be for next generation phones to support GNSS (satellite) and a terrestrial positioning system like MBS to respond to outages.

7. Identify and describe any approaches, practices, and/or technologies used by the public or private sector to recover or respond to PNT disruptions. [Recover]

The MBS system allows for multiple PNT sources and fusion engines to be exploited at various nodes in the network, including at transmitters and receivers, in order to increase the system PNT resilience. The fusion engines include functionality to prevent, respond and recover from threats, by exploiting cross-checks on the data across the various PNT sources, isolating compromised components and leveraging the alternate sources to produce positioning, velocity and timing solutions.

8. Any other comments or suggestions related to the responsible use of PNT services.

Included above.

Attachment A: Overview of NextNav's Metropolitan Beacon System (MBS)

As shown in ***Figure 1,*** the MBS system consists of a network of long-range, low-cost broadcast beacons that transmit Global Navigation Satellite System (GNSS) compatible waveforms on NextNav's 920-928MHz near-nationwide licensed spectrum. The beacons are typically placed on cell towers and rooftops and are deployed and managed to deliver PNT services with multi-layer reliability. This is achieved through the use of:

- Multiple transmitters in a given geographical area for system level redundancy
- A power supply backup to ensure continuity during power outages
- A timing fusion architecture at beacons that uses a diverse set of time and frequency sources to enable a seamless transition between clock sources
- The use of encrypted signal transmission

Figure 1: NextNav's Metropolitan Beacon System (MBS) Network

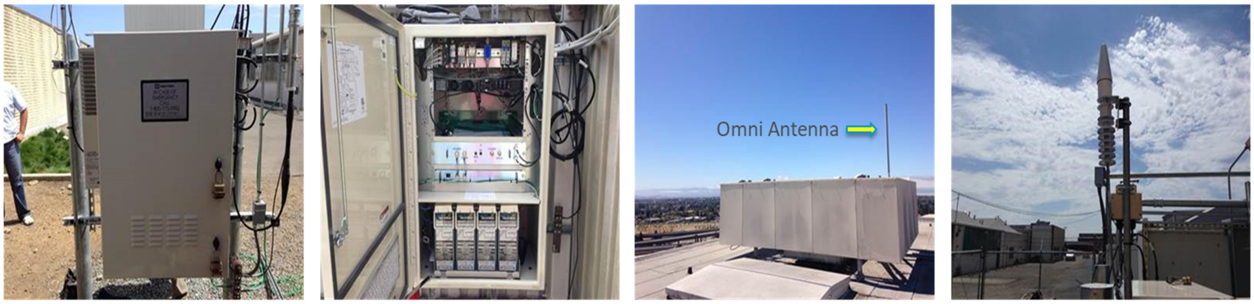
The data broadcast by MBS transmitters includes all of the necessary information for standalone timing, ranging and positioning of the receiver, including UTC time, precise latitude, longitude and altitude of the transmitter.

Unlike GPS, which relies exclusively on range measurements to estimate position, NextNav also broadcasts environmental data collected at each transmitter site, such as barometric pressure and temperature at the transmitters' locations and the altitude at which the pressure measurement was taken. This allows devices equipped with optional, low-cost micro-electromechanical system ("MEMS") barometric pressure sensors to combine this information with the MEMS pressure readings to accurately compute their altitude with floor-level accuracy.

The typical MBS deployment density is 10-15% of a cellular build in a market. Similar to GPS, the MBS system has unlimited capacity and can provide full PNT services to all devices within its footprint. Precision Timing and Frequency applications require only one transmitter to be in view, while Positioning and Navigation applications require signals from three or more transmitter locations.

In non-cluttered environments, the terrestrial range limitation is related to Transmit ("Tx") and Receive ("Rx") antenna heights. While NextNav's MBS implementation operates in the Multi-lateration Location and Monitoring Service (M-LMS) band, the technology is frequency agnostic and can be made to operate at other frequencies and power levels as required, either within the U.S. or internationally. ***Figure 2*** illustrates the components of a typical MBS transmitter.

NextNav Beacon | Beacon Interior | Omni Antenna | Altitude Station



NextNav Beacon

- Designed for deployment in unconditioned space
- Small form factor 38”H x 31”W x 20”D
- No special power requirements or backhaul
- Management link via LTE or POTS

Beacon Interior

- Transmit Trays and Battery backup
- Battery backup ensures continued operation without power

Omni Antenna

- Low-impact 5’ omni antenna
- Eases zoning, and creates placement flexibility
- Omni antennas are ideal for location

Altitude Station

- Altitude stations deployed across NextNav network
- Data encoded in NextNav transmission
- Enables high-accuracy absolute altitude

Figure 2: Picture of a typical MBS Transmitter

MBS Receivers: Receivers for the MBS system are designed to leverage a standard standalone GPS/GNSS chipset or an integrated Long Term Evolution (LTE) based GPS/GNSS chipset. The MBS technology has been licensed to multiple IC manufacturers such as Broadcom, GCT Semiconductor and Intel and it has been integrated as an additional “constellation” into some of their commercial ICs for both location and timing applications.

MBS Cybersecurity: The MBS system provides multiple levels of cybersecurity. The data payload which allows the receiver to determine timing and position is encrypted, and only authorized receivers can decrypt the data. Encryption enhances resistance to spoofing or other attempts to corrupt MBS-generated location and timing information since the encryption scheme allows the receivers to authenticate MBS transmitters. In addition, there is a “service level” encryption that ensures only authorized applications can get access to the service. MBS beacons themselves are deployed in secure access-controlled locations and telemetry to the beacons is protected by a secure virtual private network (VPN) tunnel to the NextNav network operations center (NOC).

MBS Coverage: In the U.S., NextNav operates an MBS network in 47 markets, with three markets built densely enough to deliver both outdoor and indoor PNT services for mobile phones, transportation vehicles such as automobiles and drones, financial systems and other critical infrastructure applications similar to GPS.

MBS Testing. MBS has undergone extensive independent testing both by the Government and multiple tier 1 U.S. operators, demonstrating “best in class” system capabilities that exceed FCC’s metrics on E911 and Public Safety’s objective on ‘Z’. These tests included:

- DOT GPS Backup demonstration project, which took place at NASA Langley in March 2020
- DHS testing of GPS backup technologies, which took place at NASA Langley in December 2018
- FCC/Communications Security, Reliability Interoperability Council (CSRIC) tests in 2012/2013 which formed the basis for the E911 rule making (FCC 4th Report and Order (R&O)
- CTIA/ATIS tests in the Fall of 2016 validating horizontal performance

- CTIA/ATIS tests in the Spring of 2018 validating vertical performance

As summarized above, the MBS technology has been tested by third parties in relevant environments and outside of the laboratory. The implementation solutions satisfy all operational requirements when confronted with realistic problems posed in such environments. In addition, NASA has purchased an MBS based system for urban drone operations at NASA Langley. The MBS system will also be providing enhanced location capabilities to Public Safety.

MBS is a standards-based technology, supported in specifications generated and maintained by the 3rd Generation Partnership Projection organization (3GPP) starting with Release 13. 3GPP is an international standards organization that develops protocols for the mobile industry, such as those used in 4G and 5G. In addition, MBS is supported in specifications of the Open Mobile Alliance (OMA), including the Secure User-Plane Location protocol (SUPL) and the Mobile Location Protocol (MLP). The MBS ICD can be requested through ATIS by sending an email to info@atis.org.

MBS is supported in Core wireless infrastructure servers (Enhanced-Serving Mobile Location Center (E-SMLC) and SUPL server) developed by Tier 1 network equipment providers implementing the 3GPP and OMA specifications, including Ericsson and Comtech. The Cellular Telecommunications Industry Association (CTIA) is a trade association representing the wireless industry in the U.S. that also develops test standards for the wireless industry (as required),and operates certification programs for wireless carriers in the United States. CTIA's Over-The-Air Test Plan version 3.8, released in 2018, includes test procedures for MBS, which are supported by some of the commercial test equipment providers such as Rohde & Schwarz.

In summary, the key features of NextNav's technology include:

- A fully managed, terrestrial positioning network with GPS-like accuracy from highly synchronized transmitters ("fixed deployment");
- Deployable-type transmitters that can be mounted on vehicles that can provide enhanced accuracy in an area that the "fixed" positioning network operates or coverage in an area where no "fixed" coverage exists;
- Demonstrated ability to operate with no GPS assistance or reference;
- 24/7 NOC facilities;
- Consistent, wide-area indoor and outdoor 3D location capabilities (across buildings, campuses and cities)
- High horizontal accuracy and precise vertical accuracy (~1 – 3m) available today;
- Complementary to GPS, while taking advantage of basic GPS chipsets for the lowest cost device solution;
- Operation as an "overlay" location network similar to GPS, independent of any communication network such as P25, TETRA, Wi-Fi, CDMA, GSM/EDGE, UMTS, LTE, tactical radios and future communications air interface technologies including LoRA, SigFox, LTE-M etc.

Together, these features provide a unique range of capabilities for a wide range of location-based and timing applications, from specialized military and industrial services to mass-market consumer and commercial applications.