SPACE-BASED POSITIONING
NAVIGATION & TIMING

NATIONAL ADVISORY BOARD

Protect, Toughen, and Augment Global Positioning System for Users

National Space-Based Positioning, Navigation, and Timing (PNT) Advisory Board Topic Papers

September 2018

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SPACE-BASED POSITIONING NAVIGATION & TIMING

NATIONAL ADVISORY BOARD

September 28, 2018

Honorable Patrick M. Shanahan, Deputy Secretary of Defense
Honorable Jeffrey A. Rosen, Deputy Secretary of Transportation
Co-Chairs, National Executive Committee for Space-based Positioning, Navigation and Timing
Herbert C. Hoover Building, Room 2518
1401 Constitution Ave., NW
Washington, D.C. 20230

Subject: PNT Advisory Board Topic Area Engagement

Dear Sirs,

The Positioning, Navigation, and Timing (PNT) Advisory Board (PNTAB) consists of members nominated by your PNT Executive Committee (PNT EXCOM) and appointed by the NASA Administrator. As such, they serve as Special Government Employees (SGEs) and Representatives active in national and international technical and policy forums. PNTAB members are internationally recognized experts in PNT, the Global Positioning System (GPS), and other Global Navigation Satellite Systems (GNSS).

They as a group are tasked via Presidential PNT Policy (NSPD-39) to provide independent technical and policy counsel in the form of formal Recommendations to the PNT EXCOM. The attached topic papers examine PNT applications and uses in several critical areas, and include recommendations for further engagement by PNT EXCOM member agencies, departments, and stakeholders. The ultimate goal is to protect and enhance the worldwide utility and reach of GPS even as new GNSS constellations are being deployed by other nations.

The reasons for this are simple, yet authoritative. GPS services, such as precision timing, have become thoroughly integrated into every facet of the U.S. economy. Estimates of the economic value of GPS to the U.S. are as high as US$ 2.9 Trillion/year,[1] but because of the ubiquity and impact of GPS on the economy and national security the true value is beyond calculation.[2] The board's Recommendations are intended to help preserve such critical national capabilities.

Of all the Recommendations, those summarized below are of the utmost importance to maintain U.S. leadership in core sectors. The continued and successful execution of the GPS Enterprise will require PNT EXCOM vigilance and committed governance:

1. **Continue the support of on-going GPS modernization, including space, control and user segments.** The U.S. must maintain its leading edge among world satellite-based navigation and timing systems.
2. **Ensure that complementary and back-up capabilities for GPS-derived PNT are available and used to protect the nation's critical infrastructure and public-safety applications.** Implement Enhanced Loran (eLoran) as a back-up for GPS

[1] Extrapolated from a 2017 study of GPS value to the economy of the United Kingdom. https://www.gov.uk/government/publications/the-economic-impact-on-the-uk-of-a-disruption-to-gnss

[2] "Placing an economic value on GPS has become nearly as impossible as pegging the value of other utilities. How much money do electricity and telephones generate? How much is oxygen worth to the human respiratory system?" *Pinpoint: How GPS Is Changing Technology, Culture, and Our Minds*, Greg Milner, 2016, W.W. Norton & Company, New York

timing in the continental U.S., subject to verification of cost and performance. Further, U.S. agencies should continue the development of additional capabilities that reinforce PNT resiliency.

3. **Protect GPS signals from interference.** The potential for more powerful radio signals in adjacent bands and on-going deliberate disruption by malicious actors remain real and present dangers that will continue to grow.
4. **Encourage the use of toughened GPS receivers which can resist interference such as jamming and spoofing, especially in critical applications.** The technology is available, but it is not being used.
5. **Permit users in the U.S. to access other nations' properly vetted GNSS signals.** This will increase resilience, receiver performance, and legitimize many receivers already in service.
6. **Demonstrate the utility of backup/augmentation of allied GNSS signals in military receivers:** This could allow improved resilience, assurance, and GPS back-up capabilities to military operations in increasingly contested environments.

Sincerely,

Hon. J. Stenbit, Chair

Dr. B. Parkinson, 1st Vice-Chair

Gov. J. Geringer, 2nd Vice-Chair

Enclosure: PNT Advisory Board Topic Area Engagement

cc:
Hon. Jim Bridenstine, NASA Administrator
PNT EXCOM Departments and Agencies
Mr. Harold "Stormy" Martin, Director, PNT National Coordination Office (NCO)

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PNT Advisory Board Membership & Subcommittees

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Ann Ciganer, GPS Innovation Alliance (U.S.)	Refaat M. Rashad, Arab Institute of Navigation (Egypt)
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PNT Advisory Board Subcommittees

Agriculture: Ms. Ciganer, Mr. Hatch	***Policy & Governance***: ADM Allen, Mr. Faga, Mr. Goward, Mr. P. Marquez, Mr. McGurn
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Critical Infrastructure & Timing: ADM Allen, Dr. Betz, Mr. Faga, Mr. Goward, Mr. Shields	***Spectrum***: Mr. Brenner, Mr. Burgett, Dr. Camacho-Lara, Ms. Ciganer
Military: Dr. Betz, Gen James, Mr. McGurn	***Transportation (Non-Aviation)***: Mr. Dimmen, Dr. Rashad, Mr. Shields

Summary of Recommendations

To support U.S. Positioning, Navigation, and Timing (PNT) policy goals, and the economic benefits of the Global Positioning System (GPS), the U.S. National Space-Based PNT Advisory Board (PNTAB) has developed topic papers for the following sectors: (1) Agriculture; (2) Aviation & Aerospace; (3) Critical Infrastructure & Timing; (4) Military; (5) Policy & Governance; (6) Science; (7) Spectrum; and (8) Transportation (Non-Aviation). These papers include specific recommendations to implement the high-level actions to protect, toughen, and augment GPS, which are summarized below:

Agriculture:

- GPS has revolutionized agriculture by allowing precision control of almost all aspects of farming which depend on reliable GPS use. The GPS spectrum environment must be protected from changes that would affect the reliable reception of GPS signals in order to ensure continued great economic benefit to agriculture.

Aviation & Aerospace:

- GPS Space Segment:
  - Continue to support the deployment and enhancement of four signals for civil users (L1 C/A, L2C, L5, and L1C)
  - Implement explicit Space Service Volume (SSV) signal coverage requirements to support high altitude satellite users
  - Ensure stability of satellite clocks to support carrier phase tracking for aircraft navigation integrity and scientific use of GPS
  - Manage satellite power to sustain or improve robustness in challenging environments and against threats
  - Continue to maintain an active GPS constellation of approximately 30 satellite vehicles (SV) whenever possible to ensure maximum availability and continuity of service
- GPS Ground Segment:
  - Upgrade the ground segment to securely control GPS III satellites and enable monitoring of GPS Civil Signals — required to bridge between current control segment and the Modernized Operational Control Segment (OCX)
  - Reflect improvements in accuracy of the reported user range accuracy (URA) data broadcast by the satellites
  - Maintain utilization of National Geospatial-Intelligence Agency (NGA) monitor stations to enhance signal status information and investigate use of other worldwide monitoring capabilities to enhance robustness of signal information
  - Add monitoring of other Global Navigation Satellite Systems, or GNSS, (e.g. Europe's Galileo) signals at GPS monitoring sites to enhance solution integrity for aviation and space users
  - Support advancement of civil ground system to support Ground Based Augmentation Systems (GBAS) and Space Based Augmentation Systems (SBASs) such as the Federal Aviation Administration's (FAA's) Wide Area Augmentation System (WAAS). For example, continue to prioritize the inclusion of the L5 signal (GPS safety-of-life signal used in aviation) in GBAS and SBAS.
  - Continue/increase U.S. technical and scientific leadership in international GNSS monitoring, data analysis, product generation and dissemination
- Aviation and Space GPS and GNSS Receivers:
  - Improve requirements/capabilities of aviation receivers to enhance, among other things, Receiver Autonomous Integrity Monitoring (RAIM) and robustness to interference and spoofing
  - Resolve both technical and institutional/political issues related to use of non-U.S. GNSS for aviation
  - Enhance U.S. competitiveness by reducing export control barriers for space borne GPS receiver manufacturers and technologies that enhance receiver resistance to jamming and spoofing

Critical Infrastructure & Timing:

- The U.S. must adopt and maintain spectrum regulations and allocations that protect critical infrastructure timing receivers from interference due to legal transmitters in Radio Navigation Satellite Services (RNSS) bands and excessive power from transmitters in adjacent frequency bands. The PNTAB has made a recommendation on this separately.
- Significant sources of jamming and spoofing need to be promptly located and removed, not merely defended against. Nationwide capabilities for GPS Interference detection and mitigation should be implemented. The PNTAB has not yet made specific recommendations for how this should or could be accomplished.
- Encourage manufacturers to develop more variety and less expensive options for receivers and antennae with improved resilience. Critical infrastructure owner/operators need to evaluate and, as appropriate, acquire, properly install, and maintain such equipment. Recommended practices to achieve improved receiver competency have been published by

the Department of Homeland Security (DHS) National Cybersecurity & Communications Integration Center National Coordinating Center for Communications (NCC).

- To improve receiver performance and resilience, the Federal Communications Commission (FCC) should waive its requirement for licensing non-Federal use of signals from the Galileo GNSS as requested and recommended by stakeholders within the Administration
- Promptly implement back-up capabilities for GPS per NSPD-39. Implement Enhanced Loran (eLoran) as a back-up for GPS timing in the continental United States, subject to verification of cost and performance. Further, agencies should be strongly encouraged to continue development of other capabilities that heighten resiliency.

Military:

- GPS Space Segment:
  - Provide higher power (regional military protection) M-Code (GPS military signal) to improve robustness in challenging environments and against threats
  - Operationalize the GPS military signal (M-Code) to provide more secure and robust performance
  - Support procurement of GPS Block III and IIIF satellite vehicles, providing satellites that deliver signals three times more accurate than current GPS spacecraft and provide more power for military users, improve signal acquisition and tracking capability, and faster data downloads
  - Given existing and future threats, military users must continue to exercise in challenging PNT environments and develop best practices to ensure mission success while under jamming and spoofing conditions
- GPS Ground Segment:
  - Upgrade the current ground segment to securely control GPS III satellites and enable monitoring of modernized GPS signals—required to bridge between current ground segment and OCX
  - Maintain utilization of NGA monitor stations to enhance signal status information and investigate use of other worldwide monitoring capabilities to enhance robustness of signal information
  - Add monitoring of international GNSS signals at GPS monitoring sites to enhance solution integrity
  - Support advancement of civil ground systems to support GBAS and SBAS systems
  - Continue/increase U.S. technical and scientific leadership in international GNSS monitoring, data analysis, product generation and dissemination
- U.S. Military GPS Receivers:
  - Affirm continued support for the Joint Program developing Military GPS User Equipment (MGUE)
  - Rapidly develop MGUE Increment 2, providing enhanced anti-jam and anti-spoof processing, to improve synchronization between spacecraft capability and MGUE procurement and fielding
  - Demonstrate utility of using allied GNSS signals, including open signals, to augment military receiver capability, distinct from the MGUE Increment 2 program
  - Accelerate the implementation and deployment of the latest generation of anti-jam technology to further enhance GPS-aided military operations in a hostile electronic warfare environment

Policy & Governance:

- Civil users in the U.S. should be allowed to legally access and use non-U.S. GNSS signals
- The Administration should consider revisions to current policy guidance and an integrated governance framework that addresses current fragmentation of resources and accountability
- To address the current fragmentation of resources, execution, and accountability it is recommended that the Administration study, recommend, and institute revisions, if necessary, to current policy guidance and governance structures

Science:

- Minimize bureaucratic obstacles hindering the use of other GNSS open services and endorse measures to mitigate or avoid radio frequency interference
- All future GPS satellites should be equipped with laser retro-reflector arrays to enable independent orbit validation
- There needs to be easy access to GPS satellite characteristics required for precise orbit determination, and encouragement for other GNSS providers to provide the same to the science community
- Support all monitoring and coordinating activities for scientific GNSS applications of the International GNSS Service (IGS) and United Nations International Committee on GNSS (ICG), in particular in the area of multi-GNSS use

Spectrum:

- When setting national regulations, apply the International Telecommunication Union (ITU) Radio Regulations and Recommendations to avoid introducing interference in the RNSS spectrum
- Interference detection and mitigation infrastructure is needed to monitor the RNSS spectrum and ensure regulations are followed
- Adopt and enforce policies to prohibit the manufacture, import, sale, and use of illegal jammers
- Support the proposal at the ICG regarding the international general exchange of information related to GNSS spectrum protection and interference detection and mitigation
- Coordinate with the National Space Council (NSpC) on GPS/GNSS spectrum issues as it will participate in ITU's next World Radiocommunications Conference (WRC) in November 2019

Transportation (Non-Aviation):

- Keep spectrum for ground communication adequately distant from GPS spectrum
- Adopt approaches to harden GPS devices to recognize jamming and spoofing and counteract them
- Encourage GNSS manufacturers to offer more competent and robust receivers and antennas, and encourage product manufacturers to incorporate enhanced GNSS receivers in their products
- Encourage diversification of PNT sources. The FCC should remove the requirement for licensing non-Federal use of foreign GNSS.
- Select and implement backup capabilities for GPS per NSPD-39

1. Agriculture

Overview

GPS has revolutionized agriculture by allowing precision control of almost all aspects of farming. It provides direct operational benefits such as automated steering, and allows operation at night, in dust and in fog. This results in additional economic and environmental benefits including, for example, precision application of water, seeds, nutrients and pesticides, which saves money by applying only where needed and by avoiding overlapping and unneeded application. The direct economic benefits are estimated at more than US$ 30 Billion annually.

Utilization and Benefits

GPS is used extensively in agriculture from initial tillage to final harvesting. Precision at the inch and sub-inch levels can be achieved using corrections from nearby reference sites or from global reference networks delivered by satellite or the internet. Precision farming applications make use of the entire specified bandwidth of the GPS signal to achieve the high precision needed. For example, the injection of a small amount of fertilizer directly over a seed not only lowers the cost of the material used but also minimizes the environmental impact of the runoff of excess fertilizer into downstream watersheds. Estimates of the annual economic benefit in California alone exceed US$ 2 Billion. Both the huge economic and environmental benefits which can accrue in some special situations is exhibited in an Australian study of “Controlled Traffic Farming” (CTF), in which precisely the same path is followed by the wheels of all farm implements such that no soil compaction occurs where the plants are grown. The benefits documented were: (1) 68% increase in farm gross margin; (2) 67% reduction in farm labor costs; (3) 90% reduction in soil erosion; (4) 93% reduction in nitrogen loss through soil runoff; (5) 52% reduction in CO_2 emissions; (6) 52% reduction in diesel use; and (7) 45% reduction in repair and maintenance costs. In like manner, water usage and pesticides can be minimized by precise control of the application.

Threats

Although GPS is commonly used in open farm fields, very high precision in many applications is needed even when there is partial blockage of signals such as foliage along tree lined field boundaries. The high precision applications require wide bandwidths and very sensitive receivers to achieve the few inch accuracy needed for many applications. The injection of fertilizer directly over seeds, as mentioned above, is an example. Changes to the GPS radio spectrum environment that affect the reliable reception of GPS signals for uses, such as agriculture, are a threat.

Recommended Actions

The huge economic benefit to agriculture and other high precision applications use reliable GPS. High precision GPS receivers are designed to take advantage of the full spectrum allocated to GPS, which optimizes the performance and benefits provided to farmers. The GPS radio spectrum environment needs to be protected from interference to ensure these continued benefits to agriculture.

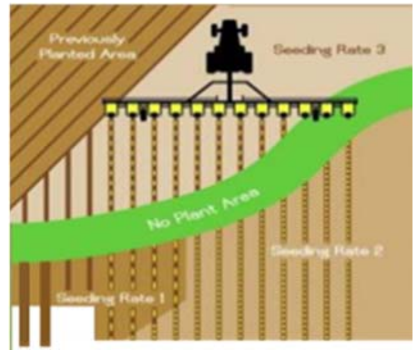
Summary

The use of GPS in agriculture has become ubiquitous and of great economic benefit. A number of pictures with brief descriptions are provided in the next two pages to illustrate the broad array of GPS usage in farming. These pictures have been provided courtesy of John Deere, Trimble, and Valmont Industries.

Uses of GPS in Farming

Tilling: Overlap minimization prevents waste of inputs and machine time and allows easy turn-around by skipping swaths for a second pass.

Planting: Prescription seeding allows adjusting the seed rate to match the capability of the soil and drainage conditions.



Application Control: Precise application of water, nutrients, pesticides, and herbicides saves on costs, increases yield and minimizes the impact to the environment.

Harvesting: Precise control of machine during harvest minimizes the number of required machine trips through the field, thus saving time and reducing expense.

Yield Monitoring: Provides information for seed and nutrient adjustment for use during the following planting season.

Relative Control: Precise control of combined use of vehicles ensures even loads and no need to stop harvesting to unload.

Other Associated Uses of GPS in Farming

Crop Scouting: Dedicated GPS handheld receivers and GPS-enabled smartphone and tablets are ideal for agronomists and farmers to use for agriculture applications. These devices, operating with agriculture field software, can be used for soil sampling, basic mapping and crop scouting tasks. Users can map field acreage, locate soil sample points by grid or zone and scout for pests and other problem areas.

Soil Mapping Technology: Using GPS with advanced sensors, intelligent targeting and geo-processing algorithms can produce high-resolution, accurate soil and topographic information. By providing a greater understanding of the physical and chemical characteristics of the soil, including the response of the soil to treatment, the technology enables farmers and agronomists to implement effective solutions adapted to each area within their fields. The mapping information enables critical management decisions regarding irrigation, drainage, nutrients, etc.

Land Contouring: GPS-based land forming solutions are used by contractors and farmers to minimize water costs and efficiently distribute water by maintaining grade in the field—enabling farmers to see improvements in yields, water usage and farm productivity. The solutions allow users to design variable-shaped fields and topography based on the best use of existing contours, the water needs of individual crops, and even individual farming practices.

Correction Services: GPS corrections provide greater accuracy for use in tilling, planting, application of water, nutrients and pesticides and harvesting. A variety of corrections services are available—from dedicated base stations and local reference station networks to subscription-based services that are delivered via satellite or the internet. These corrections improve the accuracy from a few feet down to a few inches.

All Weather Operation: Extended hours of operation at night or even in fog or dust provides additional economic benefits.

The direct economic benefit of GPS to agriculture is on the order of US$ 30 Billion annually

2. Aviation & Aerospace

Overview

GPS provides the essential/fundamental infrastructure for real-time navigation of all types of aircraft from drones to commercial and military aircraft. Augmented by space and ground based systems, GPS supports all phases of flight including taxi, takeoff, climb, cruise, descent, approach and landing in all weather conditions. Responding to a wide variety of operational benefits, aircraft fleets have embraced satellite-based navigation. Specifically, every aircraft built from Boeing and Airbus since the late 1990s carries GPS. As an example, the Boeing 777 shown in Fig. 2.1 carries GPS receivers and the position information obtained by those receivers is used by many systems on the aircraft for safety-related functions. These systems include: the flight management system (FMS) for basic navigation, the Enhanced Ground Proximity Warning System (EGPWS) to prevent controlled flight into terrain accidents, and the ATC Transponder to support Automatic Dependent Surveillance-Broadcast (ADS-B) surveillance of the aircraft by Air Traffic Control (ATC), as well as other systems. Virtually all commercial transport aircraft, including business jets, carry GPS.

Fig. 2.1: Flight Deck of the Boeing 777[3]

General Aviation (GA) also makes good use of GPS. GA is the term for all civil aviation operations other than scheduled air services. It also excludes any non-scheduled air transport operations for hire. GA flights range from gliders to corporate business jet flights. The FAA estimates that there are 200,000 aircraft in the U.S., and Garmin Inc. asserts that almost all of them carry GPS of some sort.

Space missions, including human spaceflight and operational satellites, make widespread use of GPS for onboard positioning and timing. The new Low Earth Orbit (LEO) constellations, designed for worldwide internet and weather, will increase this reliance on GPS. Launch vehicles rely on GPS integrated with inertial and other sensors to support all mission phases. GPS measurements from orbiting satellites provide critical data for weather prediction, scientific analysis of global water distribution, and space weather. In addition, space borne GPS enables surveillance of the ground based on so-called synthetic aperture radar. Fig. 2.2 depicts this application, where GPS registers images take along the spacecraft arc. With GPS relative positioning of these images, a very sharp ground image can be formed.

Aviation and aerospace applications require aggressive protection of the GPS spectrum to ensure future use and will benefit substantially from multi-GNSS implementations and modernization/advancements in signals and coverage. Specifically, strong terrestrial radio transmissions in or adjacent to the GPS spectrum constitute a direct threat to the continuity of aviation operations.

[3] Picture courtesy of The Boeing Company

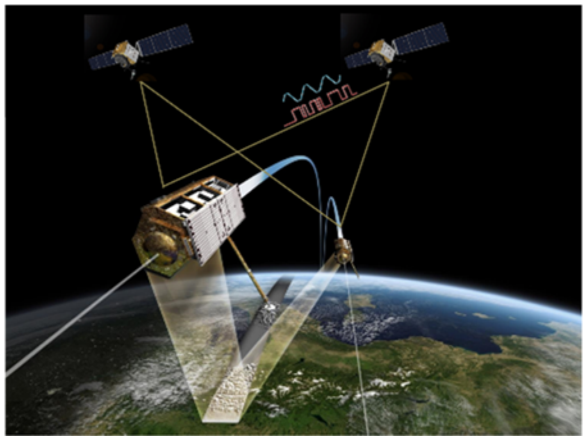


Fig. 2.2: GPS enables space borne imaging of the Earth's surface using synthetic aperture radar[4]

Utilization and Benefits

Current and future aviation and aerospace operations are dependent on reliable, accurate PNT information. GPS with ground and space-based augmentations provides this securely and accurately. Examples include:

- The use of GPS makes the airspace more efficient, provides fuel cost savings and enables adaptation to bad weather
- Aircraft navigation and guidance in all phases of flight including precision approach and landing
- Aircraft surveillance by air traffic controllers increasingly depends on GPS, and improves safety
- GPS is used in terrain awareness and warning systems (TAWS), which has had the single greatest impact to improving U.S. commercial aviation safety in the last 20 years
- Aircraft tracking based on GPS would enhance search and rescue operations globally (e.g. Malaysia Airlines MH370).
- Integration of drones into the national airspace
- Satellite operations including the International Space Station (ISS) and commercial human spaceflight
- Navigation and time for the upcoming large constellations of LEO satellites for communications
- GPS Radio Occultation (GPS-RO) for remote sensing and prediction of atmospheric and space weather
- Integrated GPS with inertial sensors for all phases of reusable launch vehicle flight

Threats

The threats to GPS continue to evolve, increase and proliferate. The availability of systems to interfere with or deny GPS has dramatically increased over the last decade, and the competition for spectrum across a broad range of users places additional pressure on the clear use of the GPS frequencies.

Cyber-attack threats are real and growing. Specifically, technologies are available for intentional Jamming (blocking the GPS signal) and spoofing (providing false signals to GPS receivers). Protecting GPS users is essential. In addition, the ground based reference receivers used by GBAS and SBAS ground stations must also be protected from physical and cyber threats.

In addition, inadvertent radio frequency interference can impact users on the ground, in flight and in space. Other radio services seek to utilize frequencies very close to GPS operating frequencies, placing clear reception of the GPS signal at risk.

The FAA formed a GNSS Intentional Interference and Spoofing Study Team to develop requirements and a set of acceptable techniques to mitigate cyber threats to aviation. They have begun to work with RTCA (Radio Technical Commission for Aeronautics) on the implementation of these techniques.

Recommended Actions

<u>GPS Space Segment</u>:

The Space Segment currently consists of approximately 30 operational satellites with differing configurations, up through GPS Block IIF. These satellites transmit both military and civil signals, supporting military operations in threat environments, and supporting commercial/civil/aviation utilization. GPS Block III is the next generation of satellites, currently in production. The following actions are recommended:

[4] Picture courtesy of Professor Simone D'Amico, Stanford University

- Continue to support the deployment and improvement of four signals for civil users. These four signals are designated L1 C/A, L2C, L5 and L1C
- Implement space service volume signal coverage requirements to support high altitude satellite users
- Ensure stability of satellite clocks to support carrier phase tracking for aircraft navigation integrity and scientific applications
- Manage satellite power to sustain or improve robustness in challenging environments and against threats
- Continue to maintain a constellation of approximately 30 operational satellites whenever possible to ensure maximum availability and continuity of service

<u>GPS Ground Segment</u>:

The ground segment consists of a global network of ground facilities that track the GPS satellites, monitor their transmissions, perform analyses, and send commands and data to the constellation. The current operational control segment includes a master control station, an alternate master control station, 11 command and control antennas, and 15 monitoring sites. OCX is essential to fully utilizing GPS system capabilities. It provides the following key enhancements:

- The new Kalman filter that is at the heart of the GPS OCX navigation solution will double the accuracy of the signal in space
- GPS OCX will allow control of more satellites, providing better geometry in hard-to-reach areas such as urban canyons and mountainous terrain
- All critical OCX external interfaces will employ digital signatures, protecting information from cyber threats so users can trust it

The following actions are recommended:

- Upgrade Interim Ground Segment to control GPS III satellites and enable monitoring of GPS Civil Signals—required to bridge between current Control Segment and OCX
- Reflect improvements in accuracy of the reported URA data broadcast by the satellites
- Maintain utilization of NGA monitor stations to enhance signal status information and investigate use of other worldwide monitoring capabilities to enhance robustness of signal information
- With multiple satnav systems operating, relying solely on GPS is an anachronism; use of reliably operating foreign satnav systems should be permitted along with GPS, without requirements for licensing
- Add monitoring of other GNSS (e.g. Galileo) signals at GPS monitoring sites to enhance solution integrity for aviation and space users
- Support advancement of civil ground system to support GBAS and SBAS systems such as the FAA's WAAS. For example, continue to prioritize the inclusion of L5 (GPS safety-of-life signal for aviation) in SBAS and GBAS
- Continue/increase U.S. technical and scientific leadership in international GNSS monitoring, data analysis, product generation and dissemination

<u>Aviation and Space Receivers:</u>

The following actions are recommended:

- Improve requirements/capabilities of aviation receivers to enhance, among other things, RAIM, as well as robustness to interference and spoofing
- Resolve both technical and institutional/political issues related to use of non-U.S. GNSS for aviation
- Enhance U.S. competitiveness by reducing export control barriers for space borne GPS receiver manufacturers and technologies that enhance receiver resistance to jamming and spoofing

Summary

- Continued use of a solid GPS is critical for current and future aviation and space operations
- No other system provides comparable coverage, ease of access, reliability and performance
- It is essential to support on-going modernization of Space, Ground and User Segments to ensure leading edge capabilities for U.S. national security and commercial interests
- The Department of Defense (DoD) and Air Force have been excellent stewards of GPS capability and continue to provide additional civil/commercial signals and capability to enhance this global utility

3. Critical Infrastructure & Timing

Overview

"There are 16 critical infrastructure sectors whose assets, systems, and networks, whether physical or virtual, are considered so vital to the U.S. that their incapacitation or destruction would have a debilitating effect on security, national economic security, national public health or safety, or any combination thereof." Presidential Decision Directive 21 (PDD 21) identifies those sectors and the policies and federal responsibilities associated with their protection. Further, Presidential Executive Order on Strengthening the Cybersecurity of Federal Networks and Critical Infrastructure, states that "It is the policy of the executive branch to use its authorities and capabilities to support the cybersecurity risk management efforts of the owners and operators of the Nation's critical infrastructure [as defined in section 5195c(e) of title 42, United States Code] (critical infrastructure entities), as appropriate."

GPS and the PNT services it provides is not a critical infrastructure, but it is ubiquitous in daily life and in all critical infrastructure that rely on highly precise geolocation and timing services. GPS signals are exceptionally weak, line of sight signals. They are easily jammed, spoofed, or disrupted. Similar to cyber vulnerabilities they represent a single point of failure for the U.S.' critical infrastructure.

Utilization and Benefits

GPS and the PNT are ubiquitous in daily life and underpin all networks and virtually all critical infrastructure. Disruptions to GPS signals can deny service to end use devices, disable information pathways, and provide users and databases hazardously misleading information.

Disruptions

- Natural – Some terrain features and urban canyons can degrade GPS reception for some users. Solar flares in 2007 and 2014 disrupted GPS services for users in some parts of the world for about 15 minutes. Major solar flares could cause longer term disruptions.
- Purposeful -
    - International – Multiple open source reports have identified Russia, China, North Korea, Iran, and terrorist forces in the Middle East as repeat sources of GPS jamming and spoofing
    - Domestic – "Personal privacy devices" are illegal to use, but easily obtained via the internet. Anecdotal reports indicate that use is widespread and that the devices are popular with criminal organizations. The U.S. has no systematic way of monitoring or even surveying to estimate the rate of use. Sampling in Europe has detected over 240,000 unique electronic signatures and an increase over time in use and sophistication. Devices designed to deny service to areas up to 20 miles in diameter are also easily available on the internet.
    - Licensed – The FCC is considering licensing a service in a frequency adjacent to the GPS band. The PNTAB believes this will degrade and disrupt GPS service for many users. See separate paper.
- Accidental – Improper installation and use of electrical and electronic devices of many kinds has been found to interfere with reception of GPS signals. This includes installing GPS antennae in close proximity.
- Systematic – Equipment failure and operational errors have caused problems. Two examples:
    - A GPS system error caused navigation errors of about 16 km (10 miles) for three hours on 1 January 2004
    - On 25 January 2016 a 13.7 microsecond timing error migrated to 15 GPS satellites. This caused scattered faults and failures for 12 hours across infrastructures and around the world. Systems included the U.S. aviation safety ADS-B network and most all the first responder radio systems in North America.[5]

[5] http://rntfnd.org/wp-content/uploads/3.-Fault-Reports.pdf

Challenges to Reducing Risk

Users are typically unaware of GPS vulnerabilities. Even when they are, they are not willing to invest in more expensive equipment to reduce their threat of disruption. This lack of consumer demand has kept the cost of better equipment relatively high.

Recommended Actions

- Protect:

  The Nation must adopt and maintain spectrum regulations and allocations that protect critical infrastructure timing receivers from interference due to legal transmitters in the RNSS frequency bands and excessive power from transmitters in adjacent frequency bands. The PNTAB has made a recommendation on this separately.

  Significant sources of jamming and spoofing need to be promptly located and removed, not merely defended against. Nationwide capabilities for GPS Interference detection and mitigation should be implemented. The PNTAB has not made specific recommendations for how this should or could be accomplished.

- Toughen:

  Encourage manufacturers to develop more variety and less expensive receivers and antennae with improved resilience. Critical infrastructure owner/operators need to evaluate and, as appropriate, acquire, properly install and maintain such equipment. Recommended practices to achieve improved competency have been published by the NCC[6].

- Augment:

  Use of Multiple Satellite Constellations - Using selected signals from foreign satnav systems as well as GPS can improve receiver performance and resilience. The PNTAB has recommended separately that the FCC waive its requirement for licensing of non-Federal use of signals from Galileo as requested and recommended by key stakeholder agencies of the Administration.

  Backup System – Ensure backup capabilities for GPS-derived PNT are available and used to protect the nation's critical infrastructure and public-safety applications. Dependence on GPS signals and increasing instances of jamming and spoofing have created a single point of failure for U.S. Critical Infrastructure. In 2015, the PNTAB recommended an initial deployment of four eLoran transmitter sites, assuming cost of US$ 10 Million per site through refurbishment of existing Loran sites. Annual maintenance cost per site was assumed at US$ 1 Million. The PNTAB stated it is essential to verify these cost and performance assumptions. The PNTAB recommends prompt implementation of back-up capabilities for GPS per NSPD-39. Implement eLoran as a back-up for GPS timing in the continental United States, subject to verification of cost and performance. Further, agencies should be strongly encouraged to continue development of other capabilities that heighten resiliency.

  The PNTAB recommends prompt completion of civil agency deliberations on back-up capabilities, and prompt actions to implement the resulting decisions.

Summary

GPS timing is an asset to many aspects of critical infrastructure, but the fragility of many current implementations has created significant national vulnerabilities. Additional work needs to be done to make the use of GPS and other satnav systems' signals more resilient against existing and evolving threats, both intentional and unintentional. Modern GPS-derived timing, properly supported by cost-effective backup and complementary technologies, can help ensure the health of the nation's critical infrastructures. The first step is recognition of the extent to which GPS is present in all aspects of American life.

[6] https://ics-cert.us-cert.gov/sites/default/files/documents/Improving_the_Operation_and_Development_of_Global_Positioning_System_%28GPS%29_Equipment_Used_by_Critical_Infrastructure_S508C.pdf)

4. Military

Overview

GPS is a dual use system serving military and civil users. Its PNT capabilities are essential for U.S. military operations, yielding significant operational efficiencies, enabling a streamlined force structure, while reducing casualties and collateral damage. GPS is essential for military use, and we must maintain our leadership in this area.

Utilization and Benefits

Current and future military operations are dependent on reliable, accurate PNT information. Only GPS provides this securely, accurately and worldwide. Examples include:

- Ship, ground force and aircraft precise navigation and positioning
- Precise munitions delivery to minimize collateral damage
- Unmanned Aerial Vehicle (UAV) operations
- Special forces operations
- Communication network synchronization
- Satellite operations
- Rocket launch safety operations

Threats

The threat to GPS continues to evolve, increase and proliferate. The availability of systems to interfere with or deny GPS has dramatically increased over the last decade, and the competition for spectrum across a broad range of users places additional pressure on the clear use of the GPS frequencies.

- Adversaries recognize our utilization of GPS as a force multiplier and operations enhancer
- Jamming (blocking the GPS signal) and spoofing (providing false signals to GPS receivers) are available technologies that have been demonstrated by adversaries
- Jamming can also be accomplished by civilians or terrorists with available technology, impacting both military and non-military operations
- Inadvertent terrestrial and space spectrum radiofrequency interference can also impact users
- Cyber-attack threats are real and growing, especially against the ground segment
- Protecting GPS ground stations from physical and cyber threats is also essential, as well as accounting for threats to on-orbit spacecraft
- Other commercial and civil users seek to utilize frequencies very close to GPS operating frequencies, placing at risk clear reception of the GPS signal

Recommended Actions

<u>GPS Space Segment</u>:

It currently consists of approximately 30 operational satellites of differing configuration, up through GPS Block IIF. These satellites transmit both military and civil signals, supporting military operations in threat environments, and commercial/civil/aviation utilization. GPS III is the next generation of satellites, currently in production. The following actions are recommended:

- Provide higher power (regional military protection) M-Code (GPS military signal) to improve robustness in challenging environments and against threats
- Operationalize the GPS military signal (M-Code) to provide more secure and robust performance
- Support procurement of GPS Block III and IIIF satellite vehicles, providing satellites that deliver signals three times more accurate than current GPS spacecraft and provide more power for military users, improve signal acquisition and tracking capability, and faster data downloads
- Given existing and future threats, military users must continue to exercise in challenging PNT environments and develop best practices to ensure mission success while under jamming and spoofing conditions

GPS Ground Segment:

It consists of a global network of ground facilities that track the GPS satellites, monitor their transmissions, perform analyses, and send commands and data to the constellation. The current operational control segment includes a master control station, an alternate master control station, 11 command and control antennas, and 15 monitoring sites. OCX is essential to fully utilizing GPS system capabilities. It provides the following key enhancements:

- New Kalman filter that is at the heart of the GPS OCX navigation solution will double the accuracy of the signal in space
- GPS OCX will allow control of more satellites, providing better geometry in hard-to-reach areas such as urban canyons and mountainous terrain
- All critical OCX external interfaces will employ digital signatures, protecting information from tampering so users can trust it

The following actions are recommended:

- Upgrade the current ground segment to securely control GPS III satellites and enable monitoring of modernized GPS signals—required to bridge between current ground segment and OCX
- Maintain utilization of NGA monitor stations to enhance signal status information and investigate use of other worldwide monitoring capabilities to enhance robustness of signal information
- Add monitoring of international GNSS signals at GPS monitoring sites to enhance solution integrity
- Support advancement of civil ground systems to support GBAS and SBAS systems
- Continue/increase U.S. technical and scientific leadership in international GNSS monitoring, data analysis, product generation and dissemination

U.S. Military GPS Receivers:

Military GPS User Equipment (MGUE) is a joint service program to develop a modernized set of M-code capable military GPS receivers delivering improved capabilities to allow for accurate, reliable and available positioning, navigation, and timing service where current non-M-Code receiver performance might be compromised or unavailable. The following actions are recommended:

- Affirm continued support for the Joint Program developing MGUE
- Rapidly develop MGUE Increment 2, providing enhanced anti-jam and anti-spoof processing, to improve synchronization between spacecraft capability and MGUE procurement and fielding
- Demonstrate utility of using international GNSS signals including open signals, to augment military receiver capability, distinct from the MGUE Increment 2 program
- Accelerate the implementation and deployment of the latest generation of anti-jam technology to further enhance GPS-aided military operations in a hostile electronic warfare environment

Summary

- Military use of GPS is critical for current and future military operations
- No other system provides the coverage, ease of access, reliability and performance
- Essential to support on-going modernization of Space, Ground and User Segments to ensure leading edge capabilities
- Military users must be protected from inadvertent jamming through careful spectrum management and the 1 dB interference criteria
- The DoD and Air Force have been excellent stewards of GPS capability and continue to provide additional civil/commercial signals and capability to enhance this global utility

5. Policy & Governance

Overview

A number of challenges persist regarding the use of signals from multiple GNSS. Uses of space-based PNT services have grown far beyond the scope of what existed when the current policy and governance (NSPD-39[7]) were established in 2004. In the last 14 years unanswered policy questions and a rapidly evolving technology environment have resulted in many NSPD-39 mandates being unexecuted. It has also become clear that a more coherent governance structure must be implemented to ensure current and future mandates are met.

Examples of continuing challenges are provided below. The use of non-U.S. GNSS constellations within the United States is provided as a use case.

Examples – Critical unresolved GPS/PNT issues:

- Monitoring Performance of GPS Civil Signal – GPS is "America's gift to the world" and we have made international commitments as to its performance. NSPD-39 requires that the signal be monitored. Efforts to establish a monitoring regime to ensure we meet our commitments have, to date, been poorly supported and funded, especially as it relates to the civil user segment where capabilities exist but are not resourced or integrated in national monitoring framework.
- Interference Detection and Mitigation – NSPD-39 assigns specific responsibilities to five departments and agencies, and encourages others to contribute. The PNTAB knows of no systematic government efforts to either detect interference with GPS signals or to mitigate their effects.[8] By contrast, the European Union has conducted several studies and found over 240,000 unique electronic signatures of GPS/GNSS jamming devices on the continent. There is no clear, coherent policy and enforcement framework that links departments and agencies involved in PNT governance with independent regulatory agencies.
- International Data Sharing – In the last decade five other sovereign satellite navigation systems have been developed. NSPD-39 encourages interoperability with these systems. Since GPS is both a civil and a military system, how information sharing requests should be adjudicated has remained an open question. The PNT governance structure is dispersed functionally and the various roles of agencies and departments lack integration (see comments below).
- Complementary and Back-up System – Senior Government officials have twice announced plans to meet this NSPD-39 mandate, once in 2008 and again in 2015. No action has been taken.
- Spectrum Protection – NSPD-39 is an Administration document, while the responsibility for protecting the spectrum used by GPS lies with the FCC, an independent agency. The FCC's expertise with radio-communications, and its lack of expertise in radio-navigation, continues to be a challenge for GPS stakeholders. Additionally, extant relevant spectrum protection legislation was enacted well before the advent of GPS. Comprehensive and coherent governance may require legislation to update foundational laws and regulations.

Use of Multiple GNSS Constellations Within the United States – Cell phone and satellite navigation receiver manufacturers have incorporated non-U.S. GNSS within their equipment. In 2016 an estimated 90 Million of these devices were being used in the United States. Yet FCC rules require any non-federal receiver in the U.S. using non-U.S. signals to be licensed.[9] None of the millions of receivers in the U.S. have yet been licensed.

Use of multiple GNSS can increase users' location accuracy and resilience to disruption.

- Accessing a larger number of satellites increases the chance for ideal geometry for location calculations and reduces position uncertainty. This is particularly important for altitude/elevation calculations such as those needed to determine the floor of a building for Enhanced 911 (E911) responses.
- User resilience is increased as equipment or system malfunctions within one sovereign constellation could be compensated for by other, unaffected constellations

[7] The White House, "U.S. Space-Based Positioning, Navigation, and Timing (PNT) Policy," Washington, D.C., December 8, 2004
[8] The FCC has responded to some chronic interference incidents, but has extremely limited capability and capacity.
[9] 47 CFR § 25,131(j)(1), 25.137

Factors that have caused manufacturers to incorporate multiple GNSS systems within their equipment include:

- Ignorance of the FCC regulation and the complete lack of enforcement
- Global market pressures – Most manufacturers supply a global market that is not subject to U.S. FCC restrictions
- Improved performance and resilience, as described above

The inability of manufacturers to apply for and obtain a license from the FCC. Under FCC rules, non-U.S. satellite system providers (Russia, China, and the European Union) must apply to the FCC for a license to have their system's signals legally received and used in the U.S. Note that the European Union made such an application in 2012, but the FCC has yet to act upon it.

Recommendations

- Multi-GNSS:

  In the near term we recommended to waive the requirement for licensing non-Federal use of foreign GNSS signals so that civil users in the U.S. can access those signals, beginning with services not critical to the U.S. infrastructure. As we obtain greater transparency into the operation of non-US and receivers are demonstrated to competently use these signals, this access may be expanded into critical-infrastructure applications.

- Policy:

  The current governance and policy structures have created a situation where the Executive Office of the President is the only level of interagency coordination, decision making, and implementation for the wide variety of GPS/PNT challenges within the U.S. Government. Given the number of unexecuted mandates after 14 years, this has not been an effective approach. For example, effective and executed measures for protecting GPS services should be reflected in an integrated, cohesive, and "whole-of-government" governance framework. To address current fragmentation of resources, execution, and accountability the PNTAB recommends the Administration study, recommend, and institute revisions, if necessary, to current policy guidance and governance structures.

6. Science

Overview

Ultra-precise GNSS orbits and satellite clock corrections are the basis for all PNT applications in science and for society. Generation of these primary products require detailed knowledge of GNSS spacecraft properties (mass, surface properties, attitude) and absolute observations via Satellite Laser Ranging (SLR), requiring in turn laser retro-reflector arrays on-board GNSS satellites.

GPS is indispensable for Earth and atmosphere science. Global products include the International Terrestrial Reference Frame (ITRF) with cm-accuracy in position and mm/year-accuracy in velocity of its globally distributed sites, the monitoring of Earth rotation, in particular polar motion and length of day, global change monitoring, including the detailed sea level changes over decades.

GPS is one of currently four GNSS deployed or in deployment. Regional augmentations complement the GNSS. Research in multi-GNSS therefore has the potential to make all openly accessible GNSS services interoperable, in the sense that all systems can be used as one. SLR plays a key role to make multi-GNSS successful.

All global GNSS applications rely on a global network of permanent high-quality GNSS tracking receivers. The IGS, as shown in Fig. 6.1, consisting today of more than 400 sites, is the only global system for scientific use openly available (http://www.igs.org/). Scientific applications of GNSS are primarily based on IGS data and products such as, for example, maps showing total electron content in the ionosphere (Fig. 6.2). The IGS is based on a voluntary collaboration of more than 400 governmental and other organizations distributed all over the globe.

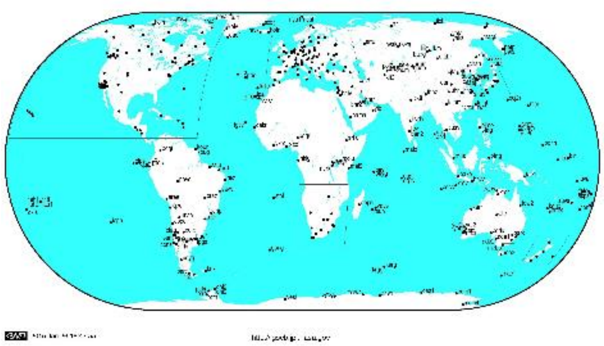


Fig. 6.1: IGS permanent tracking network

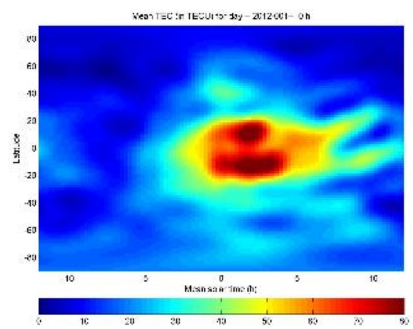


Fig. 6.2: Electron content on Jan. 1, 2012, 00^h-01^h

Utilization and Benefits

GNSS applications are not only important for science; they are relevant for the much larger international community of high-accuracy GNSS users. Virtually every first-order national survey is now based on GNSS.

GNSS applications include earthquake monitoring, tsunami warning, but also the determination of centimeter-level precise orbit of LEO satellites. Dedicated LEO missions like the German-led CHAMP (Challenging Mini-satellite Payload) mission, the U.S.-led GRACE (Gravity Recovery and Climate Experiment) mission, and the European Space Agency (ESA) -led GOCE (Gravity Field and Steady-State Ocean Circulation Explorer) mission have determined the Earth's gravity field and its temporal variations with unprecedented accuracy in the first decade of the 21st century. Such missions provide one of the metrological foundations of global change monitoring. The GRACE-FO (GRACE Follow-On) mission is scheduled for launch early in 2018 to continue these crucial tasks in the next decade.

GNSS is of central importance for atmospheric research: the GNSS signals travel through the atmosphere, in particular the ionosphere with its free electrons and the lower atmosphere with its water vapor content. From ionospheric signal delays the number of free electrons between the satellite and the receiver can be extracted. Figure 6.2 (above) depicts the global distribution of the mean density of free electrons in the ionosphere as a function of the mean solar time and the geographical latitude during the first hour of the year 2012. The data was derived from all available GNSS signals travelling to all available receivers of the IGS network. GNSS is thus a unique tool for space weather monitoring.

The signal delays in the lowest parts of the atmosphere are used routinely to determine the water vapor content. Dedicated arrays of GNSS receivers are routinely used for weather prediction.

GNSS is routinely used for global time and frequency synchronization. The establishment of Universal Coordinated Time (UTC) cannot be imagined without GNSS.

Threats

High-accuracy GNSS products are of paramount importance for science and society. Such products are among other based on the open availability of GNSS-specific information from all GNSS providers, and on important assets like laser retro-reflectors on the satellites to enable SLR. The open availability of all GNSS-specific satellite information is currently not ensured and laser retro-reflectors are not available on all GNSS satellites.

Scientific GNSS receivers are so-to-speak the “Formula-I” GNSS user equipment, extracting “the last bit of information” out of the GNSS signals. Scientific GNSS receivers are, however, extremely vulnerable to interference, be it intentional or unintended.

Recommended Actions

In order to ensure high-accuracy multi-GNSS applications, the following action items are proposed from the point of view of science:

- Minimize bureaucratic obstacles hindering the use of other GNSS open services and endorse all measures to mitigate or to avoid interference
- All future GPS satellites should be equipped with laser retro-reflector arrays to enable independent orbit validation
- There needs to be easy access to GPS satellite characteristics required for precise orbit determination, and encouragement for other GNSS providers to provide the same to the science community
- Support all monitoring and coordinating activities for scientific GNSS applications of the IGS and ICG, in particular in the area of multi-GNSS use

Summary

GPS is one of two fully deployed GNSS and provides, with its 30+ active satellites, the backbone for all GNSS applications striving for highest accuracy, which include science applications. The IGS organizes the global tracking of all fully and partially deployed GNSS and coordinates the generation of highest accuracy products based on these data, including precise orbits for all active GNSS satellites, the coordinates and the motion of the globally distributed tracking sites (ITRF), precise length of day and polar motion, and atmosphere information related to space weather (ionosphere) and normal weather (troposphere). The maintenance of ITRF, the monitoring of the Earth’s rotational characteristics, and the monitoring of the Earth’s atmosphere are not possible without high-accuracy GNSS, in particular GPS.

7. Spectrum

Overview

GPS and other GNSS operate in spectrum allocated by the ITU to RNSS. Ensuring the continuity of the GPS/GNSS services requires protection of RNSS spectrum use from interference.

Utilization and Benefits

Protecting the availability and reliable reception of PNT information, delivered by GPS/GNSS satellite signals, benefits users in a broad range of applications. GPS technology innovation is an engine of the national and global economies. GPS/GNSS technology enables safer and more efficient transportation by land, sea, and air. GPS/GNSS applications improve productivity, efficiency, and sustainability in: agriculture and food security; disaster risk reduction; emergency response; surveying and mapping; construction; air, maritime, and land transportation; scientific research; mobile broadband communications; financial operations; power grids; and other critical infrastructure.

Threats

Access to radio frequencies free of harmful interference is crucial for reliable GPS/GNSS receiver performance. GPS/GNSS receivers operate below the ambient noise level in the RNSS spectrum when receiving PNT information delivered by signals from GPS/GNSS satellites operating over 12,550 miles from the Earth's surface. Emissions which raise the noise level in the GPS spectrum can harm the functioning of GPS receivers and constrain the development of new innovative applications.

Interference affecting the availability and reliable reception of GPS/GNSS can come from a variety of sources, including radio emissions in nearby bands, intentional or unintentional jamming, naturally occurring space weather phenomena, and potential incompatibility of new radio technologies.

Recommended Actions

Protecting the capabilities of GPS/GNSS receivers that operate below the ambient noise floor requires prudent spectrum management, including: sensible spectrum regulations (domestic and international) that minimize human-generated sources of interference affecting the availability and reliable reception of GPS/GNSS; interference detection and mitigation efforts; and law enforcement.

- Spectrum Regulations: The ITU publishes the International Radio Regulations, which is treaty-level text that contains the international rules on spectrum use. To minimize interference among different radio systems, the fundamental approach is to divide radio frequency spectrum into blocks known as allocations that group together similar radio services determined to be compatible. The Radio Regulations are the result of more than a century of detailed technical compatibility studies by engineers and other subject matter experts worldwide, and are constantly reviewed to consider new radio technologies. The RNSS frequency allocations were made following such technical compatibility studies. New radio technologies or expansions of existing technologies need to take the RNSS allocations, where all GNSS operate, into account. When setting national regulations, applying the ITU Radio Regulations and Recommendations to avoid introducing interference in the RNSS spectrum, gives the continuous reception of GPS/GNSS PNT information the best opportunity to work effectively and efficiently.

- Interference Detection and Mitigation: Ensuring that the Radio Regulations and related national regulations are followed requires monitoring the RNSS spectrum where GPS operates. To detect signals that can disrupt GPS signals requires special techniques such as geolocation and dense detector networks.

- Spectrum Enforcement: GPS/GNSS jammers are illegal and nearly all countries have national regulations that prohibit their manufacturer, import, sale and use. National market surveillance authorities need to ensure that illegal jammers are not available on the market and need to enforce strict measures as appropriate. When interfering emissions occur in RNSS allocations where GPS/GNSS operates, they should be found quickly, stopped, and prevented from reoccurring.

- International Spectrum Reporting: At the 2017 session of the Scientific and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS), the ICG proposed that under the Subcommittee's regular agenda item, "Recent Developments in Global Navigation Satellite Systems," a general exchange of information related to GNSS spectrum protection and interference detection and mitigation should be included. Beginning in 2018, Member States of the United Nations have begun to report on a voluntary basis on: (a) National RNSS Spectrum Allocations and Consistency with ITU Allocations; (b) Regulations Regarding Non-licensed Emissions Limits From Radiofrequency (RF) Emitters and Non-emitters; (c) Planned or Existing Laws and Regulations Related To The Manufacture, Sale, Export, Import, Purchase, Ownership, and Use of GNSS Jammers; and (d) Domestic Efforts To Detect and Mitigate GNSS Interference, with the overall goal of promoting effective use of GNSS open services by the global community. We recommend that:

- Support the proposal at the ICG regarding the international general exchange of information related to GNSS spectrum protection and interference detection and mitigation
- Coordinate with the NSpC on GPS/GNSS spectrum issues as it will participate in ITU's next WRC in November 2019

Summary

The ITU Radio Regulations are a sound basis for national regulations governing frequency use, especially for GPS/GNSS. For over two decades, the U.S. GPS PNT service has been globally pre-eminent, in large part due to committed spectrum leadership and effective national regulations that protect GPS utility while enabling new communications services where feasible. Prudent spectrum management enables continued realization of the benefits of GPS PNT innovation for the nation and society at large.

8. Transportation (Non-Aviation)

Overview

The use of GPS in surface transportation is estimated to exceed US$ 25 Billion annually. Every sector of surface transportation has become dependent on GPS.

Utilization and Benefits

Mapping and Guidance: Mapping such as Google and directions on internet, smart phones, and in-vehicle are used by businesses and individuals ubiquitously.

Portable navigation devices are affordable and widely available (image courtesy of Garmin Corporation).

Traffic Information: Traffic information is also widely available on the Internet, on smart phones, and on in-vehicle navigation units.

A free website provides real-time traffic information for Midwestern cities including Pittsburgh, Pennsylvania (image courtesy of localconditions.com).

Public Transit: Arrival times of buses and trains are widely available on internet, smart phones, and displays at stops. Public transit operators are using the GPS in their vehicles to improve vehicle dispatching, plan bus routes and vehicle maintenance, and send arrival times and traffic jam alerts to riders.

Bus shelters in Chicago provide arrival information based on GPS tracking of buses (photo courtesy of Ygomi LLC).

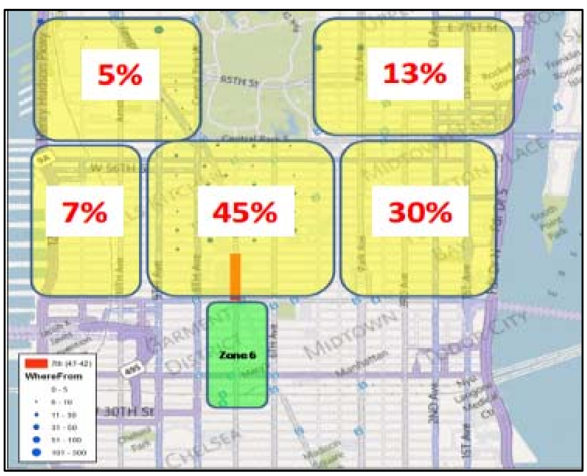
Vehicle Communications: In-vehicle telematics including automated emergency call are becoming widespread in new vehicles sold in the U.S. vehicle-to-vehicle (V2V) communications are planned to reduce vehicle accidents.

General Motors is one U.S. auto maker that is demonstrating V2V technology (photo courtesy of General Motors Corporation).

Automated Driving: Levels of automated driving in vehicles are being developed to reduce accidents and support people who have difficulty driving. These systems often include mapping and GPS.

A Chevrolet Bolt is equipped with sensors for development of automated driving (photo courtesy of General Motors Corporation).

Traffic Management: Traffic management authorities use GPS information to identify traffic patterns. Such data is used to plan road construction and maintenance, and set variable toll rates and speed limits.



For the Times Square Reconstruction Project in New York City, GPS-determined origin and destination zones (yellow) of taxi trips through the construction area (green) were used to identify likely detours while planning construction closures (image courtesy of New York City Department of Transportation).

Logistics: Freight handling companies are equipping vehicles and containers with GPS to improve efficiency and security. Uses include fleet management, load and delivery route optimization, real-time delivery assignments, and shipment tracking and monitoring.

Intermodal shipping containers on railway flat cars are tracked with GPS devices (photo by Tyler Silvest, licensed under the Creative Commons Attribution 2.0 Generic license).

Inland Waterway Transportation: The inland waterways of the United States include more than 25,000 miles of commercially navigable waters. River transportation is an important part of the integrated international multimodal transportation system. These waterways carry recreational craft as well as domestic and international cargo. GPS is the backbone of positioning, timing, navigation, tracking, and identification for the safety and security of river craft and infrastructure.

A single 15-barge tow, such as is common on the Upper Mississippi, is equivalent to about 225 railroad cars or 870 tractor-trailer trucks (photo by Ed Schipul, licensed under the Creative Commons Attribution-Share Alike 2.0 Generic license).

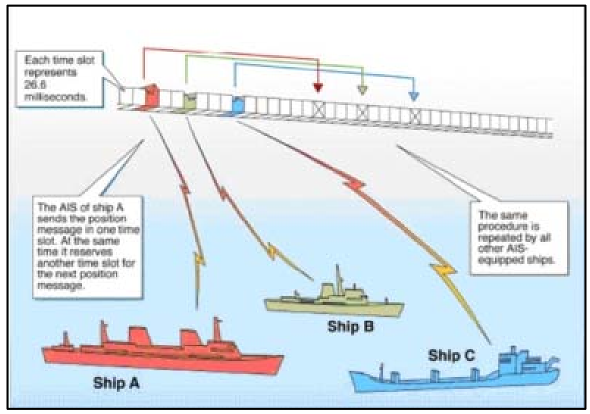
<u>Maritime Transportation</u>:

International maritime shipping is essential for global trade and for the global economy. Indeed, more than 80 percent of global trade relies on ship transportation. Maritime shipping provides a dependable and low-cost means of transporting goods globally, facilitating commerce, and helping to create prosperity for the nation.

Maritime shipping is the most energy-efficient, cost-efficient, and environmentally friendly means for the long-distance and high-volume transportation of goods, and is a key element for a sustainable global transportation system for U.S. business.

Safe and efficient navigation of ships depends on GPS during all phases of any voyage including oceanic passages, coastal approach, and entry into port. It is essential for route optimization, collision avoidance, emergency alert signals, search and rescue operations, and operating broadband ship communication systems. Ship management relies on GPS for purposes such as vessel monitoring, traffic management, fleet tracking, and management and national security purposes. GPS will play an enabling role in the development of future autonomous operations.

The TransAtlantic Lines ship MV TransAtlantic (photo courtesy of the United States Navy).



Position and timing information for an automatic identification system (AIS) is normally derived from an integral or external GPS receiver (graphic courtesy of the United States Coast Guard).

The U.S. is a signatory to the International Convention for the Safety of Life at Sea (SOLAS), which mandates a range of safety systems for ships, including those that depend on GPS for functionality such as AIS, voyage data recorders (VDRs), emergency positioning indicating radio beacons (EPIRBs), and the Global Maritime Distress Safety System (GMDSS).

GPS, increasingly accompanied by other GNSS systems, is in practice the sole source of PNT on board ships. GPS signal interference, whether intentional or unintentional, will thus greatly hinder maritime navigation and safety. GPS is essential infrastructure needed to maintain and further develop maritime shipping. GPS needs to be globally and continuously available, reliable, and accurate.

Threats

GPS and other GNSS are in practice the only source of PNT data for many land vehicles and ships. This presents a single point of failure.

Signal interference, intentional or unintentional, threatens all GNSS users. A conversion from satellite use to ground use of communications frequencies close to GPS would significantly degrade GPS in land vehicles. Spoofing and jamming are becoming true infrastructure threats, especially as connected and automated vehicles are rolled out.

Opportunities

Opportunities include emerging alternative backup capabilities for PNT and, also, more competent and robust receivers.

Recommended Actions

To protect the huge economic benefit of GPS/GNSS to surface transportation and other high precision applications, the PNTAB recommends the following:

- Keep spectrum for ground communication adequately distant from GPS spectrum
- Adopt approaches to harden GPS devices to recognize jamming and spoofing and counteract them
- Encourage GNSS manufacturers to offer more competent and robust receivers and antennas, and encourage product manufacturers to incorporate enhanced GNSS receivers in their products
- Encourage diversification of PNT sources. Have the FCC remove the requirement for licensing of non-Federal use of foreign GNSS
- Select and implement backup capabilities for GPS per NSPD-39

Summary

The use of GPS in surface transportation has become ubiquitous and of great economic benefit. It needs to be protected from the encroachment of more powerful signals in adjacent bands.

Acronyms & Definitions

AIS	Automatic Identification System (for ships)
ADS-B	Automatic dependent surveillance –is a surveillance technology in which an aircraft determines its position via satellite navigation and periodically broadcasts it, enabling it to be tracked.
ATC	Air Traffic Control
BeiDou	China's GNSS
CHAMP	Challenging Mini-satellite Payload space mission
COPUOS	United Nations Committee on the Peaceful Uses of Outer Space
DHS	Department of Homeland Security
DoD	Department of Defense
E911	In the U.S. E911 (Enhanced 911) is support for wireless phone users who dial 911, the standard number for requesting help in an emergency. Since wireless users are often mobile, an enhancement was needed to 911 service that allows the location of the user to be known to the call receiver.
EGPWS	Enhanced Ground Proximity Warning System
eLoran	Enhanced Loran
EPIRB	Emergency Positioning Indicating Radio Beacons (for ships)
ESA	European Space Agency
EU	European Union
FAA	Federal Aviation Authority
FCC	Federal Communications Commission
FMS	Flight Management System
GA	General Aviation
Galileo	European Union's GNSS
GBAS	Ground-Based Augmentation Systems
GLONASS	Russia's GNSS
GMDSS	Global Maritime Distress Safety System
GNSS	Global Navigation Satellite System (i.e. GPS, GLONASS, Galileo, BeiDou, etc.)
GOCE	ESA's Gravity Field and Steady-State Ocean Circulation Explorer space mission
GRACE	Gravity Recovery and Climate Experiment space mission
GRACE-FO	GRACE Follow-On space mission
GPS	U.S. Global Positioning System
GPS IIF	GPS Block IIF (all 12 satellite vehicles have been launched)
GPS III	GPS Block III (1st launch currently expected in Dec.2018)
GPS-RO	GPS Radio Occultation
Kalman Filter	Algorithm that uses a series of measurements observed over time, containing statistical noise and other inaccuracies, and produces estimates of unknown variables
ICG	UN International Committee on GNSS (www.unoosa.org/oosa/en/ourwork/icg/icg.html)
IGMA	International GNSS Monitoring and Assessment
IGS	International GNSS Service (www.igs.org)
ISS	International Space Station
ITRF	International Terrestrial Reference Frame
ITU	International Telecommunication Union
km	kilometer

L1 C/A	GPS L1 Coarse/Acquisition Signal, also known as the GPS 1st civil signal
L1C	GPS 4th civil signal – new signal on GPS Block III vehicles intended to be interoperable with the Galileo Open Service (OS)
L2C	GPS 2nd civil signal – intended to primarily support surveyors and science applications
L5	GPS 3rd civil signal – intended for safety-of-life aviation applications
LEO	Low Earth Orbit
LORAN	Long-Range Navigation. Loran-C was a ground-based navigation system operated by the U.S. Coast Guard. In accordance with the 2010 DHS Appropriations Act, the U.S. Coast Guard terminated the transmission of all U.S. Loran-C signals on 8 Feb 2010. (https://www.gps.gov/policy/legislation/loran-c/)
M-Code	GPS Military Signal
MGUE	Military GPS User Equipment
microsecond	.000001 seconds
mm	millimeter
NCC	DHS National Cybersecurity & Communications Integration Center National Coordinating Center for Communications
NCO	National Coordination Office (see www.gps.gov)
NGA	National Geospatial-Intelligence Agency
NSpC	National Space Council
NSPD-39	National Security Presidential Directive 39, "U.S. Space-based PNT Policy," Washington, D.C., December 8, 2004
OCX	GPS Modernized Ground Segment
PDD-21	Presidential Decision Directive 21
PNT	Positioning, Navigation, and Timing
PNTAB	National Space-based PNT Advisory Board
PTA	Protect, Toughen, Augment
RAIM	Receiver Autonomous Integrity Monitoring
RF	Radio Frequency
RNSS	Radio Navigation Satellite Services
RTCA	Radio Technical Commission for Aeronautics
SBAS	Space-Based Augmentation Systems
SLR	Satellite Laser Ranging
SOLAS	International Convention for the Safety of Life at Sea
SV	GPS Satellite Vehicle/s
TAWS	Terrain Awareness and Warning Systems
UAV	Unmanned Aerial Vehicle
UN	United Nations
UTC	Universal Coordinated Time
V2V	Vehicle to Vehicle
VDR	Voyage Data Recorder (for ships)
WAAS	Wide Area Augmentation System
WRC	World Radiocommunications Conference