Changing the Game Changer

The Way Ahead for Military PNT

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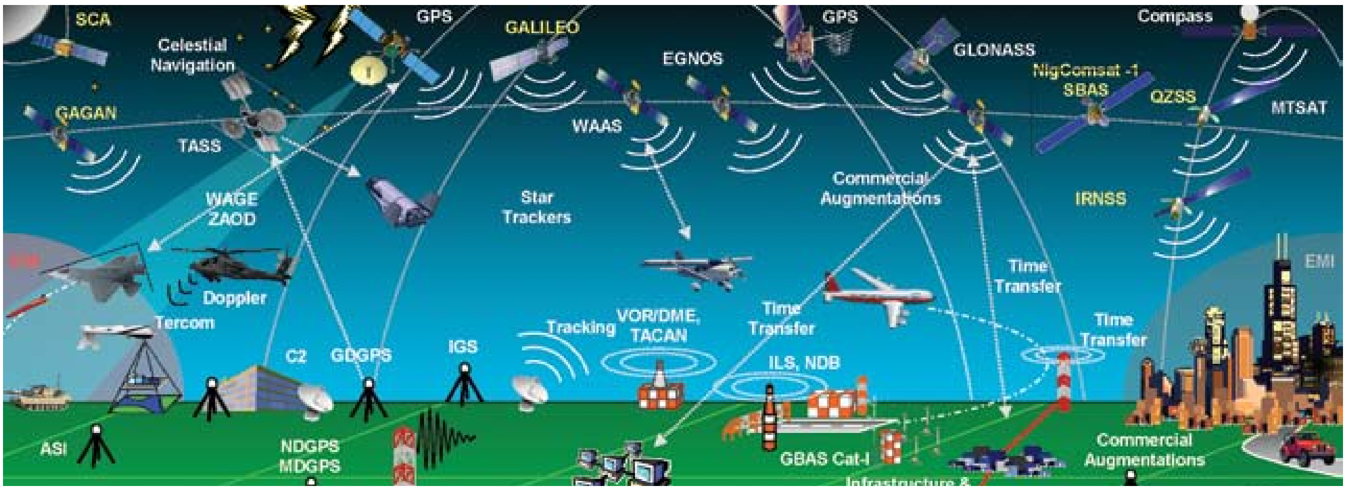


GPS-based positioning, navigation, and timing (PNT) have profoundly changed how the U.S. Defense Department carries out command and control in the electronic battlespace – from a reactive to a real-time mode of continuous situational awareness. Now military leaders are looking for the technologies that can fill the gaps in PNT that occur in GPS signal–challenged conditions.

With thanks to Yogi Berra, it's "déjà vu all over again" for the Global Positioning System, but this time with a twist.

Twenty-five years ago, the question asked by U.S. military commanders and combat personnel in the field was, "Why should I go to the trouble to use this space-based system called GPS?" Today, the question being asked is, "GPS is vital to the success of my mission; so, why are you asking me to consider using something else?"

The original question has been answered in countless ways for military users beginning with Operation Desert Shield/Storm and continuing through Operation Enduring Freedom/New Dawn. Today's question arises from recent concerns about U.S. military dependence on GPS and the vulnerabilities that may affect mission success if GPS is not available — even if only for the briefest of periods.

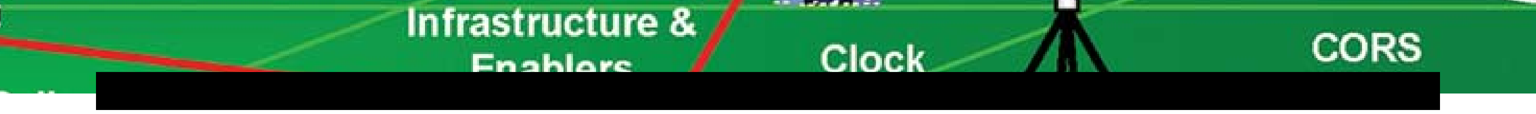
Those concerns also underpin a growing Defense Department interest over the last few years in alternate sources of positioning, navigation, and timing (PNT) to augment or complement GPS. Studies by U.S. Strategic Command (STRATCOM) and by an interagency group that recently produced a proposal for implementing an enterprise-level National PNT Architecture have highlighted the fact that even a modernized GPS cannot satisfy all the military's PNT needs all the time.

As a result, efforts are now underway to characterize the full spectrum of possible PNT sources and assess their capability, in combination with GPS, to meet those needs. Those efforts will be discussed in some detail later in this article. First, some additional background. . . .

Air Force Chief of Staff, General Norton Schwartz directly addressed the concern about GPS dependency in a February 2010 speech to the Air Force Association's Air Warfare Symposium and Technology Exposition meeting in Orlando, Florida.

In that speech, Gen. Schwartz noted, "[O]ur dependency on the Global Positioning System has also created certain vulnerabilities that our adversaries can exploit through jamming and other tactical denial techniques. While we remain unequivocally committed to proper stewardship and use of the world's unparalleled standard in precision navigation and timing, as well as advancing enhanced capabilities with new GPS Block IIF satellites and next-generation GPS III concepts, we also recognize the need to be able to continue to operate effectively, through improvement to GPS and other methods, in a denied or degraded localized environment."

Gen. Schwartz's comments reflect the full spectrum of issues regarding use of GPS by the military as well as throughout the civilian infrastructure. It's almost a "can't live with it, can't live without it" dichotomy.



However, we shouldn't assume from the general's comments that the Department of Defense (DoD) is engaged in a full-court press to replace the Global Positioning System. GPS is unique and will remain so for the foreseeable future as the only discrete system providing global availability of precise three-dimensional position and time.

This uniqueness was captured in the following passage from a report by a joint DoD/Department of Transportation (DoT) Task Force in 1993, and it remains true today as a description of the essence of GPS military utility.

> GPS aids in all aspects of military combat operations, from designation of precise target coordinates to delivery of conventional munitions, with extreme accuracy under any conditions of target visibility (e.g., night, clouds, smoke, dust). . . .The essence of GPS use, inherent in the precise signals that are its fundamental feature, is that GPS provides a direct, unambiguous correlation between a target point and the weapon intended to hit the target point. This translates directly into increased probability of kill for any particular weapon, increased force employment efficiency for military mission planners, and overall lower risk for the individual military members and units that must execute the missions. . . .To the extent that a target point is defined and a weapon is guided by precise GPS signals, the probability that the target will be hit despite any other circumstances that exist is significantly higher with GPS than with any other combination of targeting and positioning technologies. It is this precise positioning capability, common to both target [location] and weapon [guidance], that is both the military strength and fundamental military threat of GPS.

In the relatively short time since becoming operational, GPS has built a dual-use following of incredible proportions among civil and military user communities.

The utility described here captured the military's attention and its use has now expanded to improve the effectiveness, efficiency, and safety of most military combat and support activities. These unique characteristics are of strategic value for many reasons, not the least of which is the ability to exercise the military option while limiting fratricide and collateral damage.

We can safely say that the military depends on an available and reliable GPS signal but also that the level of this dependence raises concerns regarding mission success should that availability be disrupted. It is also safe to say — without any sense of surprise — that GPS availability cannot be assured under all conditions, as it is susceptible to both RF interference and the laws of physics regarding L-band radio waves.

The remainder of this article will examine how GPS has fundamentally changed the nature of military PNT, which in turn transformed the military command and control paradigm, and how — in light of GPS's potential limitations and our dependence on it — the time has come to look at changing the game-changer.

GPS Lays the Foundation

In the relatively short time since becoming operational, GPS has built a dual-use following of incredible proportions among civil and military user communities. With that popularity has come an implicit awareness of the added value of and increased reliance upon continuous access to ubiquitous precise position and time in virtually every human activity. In fact, though it is not the only factor, I contend that the ubiquitous, precise position and time provided by GPS has had a game-changing effect on command and control (C2) not seen since the advent of the radio.

C2 has leaped from a historically reactive state to a state of near coincidence. With the extent of precise position and time information now available, real-time situational awareness (SA) and the corresponding capability to execute time-sensitive target engagements now provide commanders a level of control virtually coincident with events as they occur. (Additionally, the implications for intelligence collection and analysis processes are enormous and worthy of mention at this point, although they lie beyond the scope of this article.).

As notionally depicted in Figure 1, continually improving communications capabilities have supported the functions of military C2 for decades, particularly since the advent of radios early in the 20th century, first with terrestrial radios, and later, SATCOM radios. However, even as communications capabilities improved, the latencies inherent in the communications links and the limitations forced by channel and circuit protocol constraints have allowed only *reactive* C2 execution.

Even with the advent of computers and the evolution from channelized communications to more efficient and responsive packet technologies, a "C2 Divide" remained. The advent of GPS in the 1990s was the catalyst for an awakening to the essential role that PNT plays in operations of all kinds.

GPS is unique in providing continuous, worldwide, three-dimensional precise positioning and time (Positime – a term that captures the unique duality of the actual service GPS provides). Initially, positioning and navigation applications attracted the most attention from new GPS users. However, the space-based technology's extremely precise time and frequency capabilities soon resulted in applications across the global communications landscape — improving efficiencies in network synchronization and use of spectrum and increasing information throughput, particularly for mobile and handheld devices.

For the first time, GPS enabled continuous and real-time situational awareness for commanders and provided the impetus to cross the C2 Divide from the reactive state to

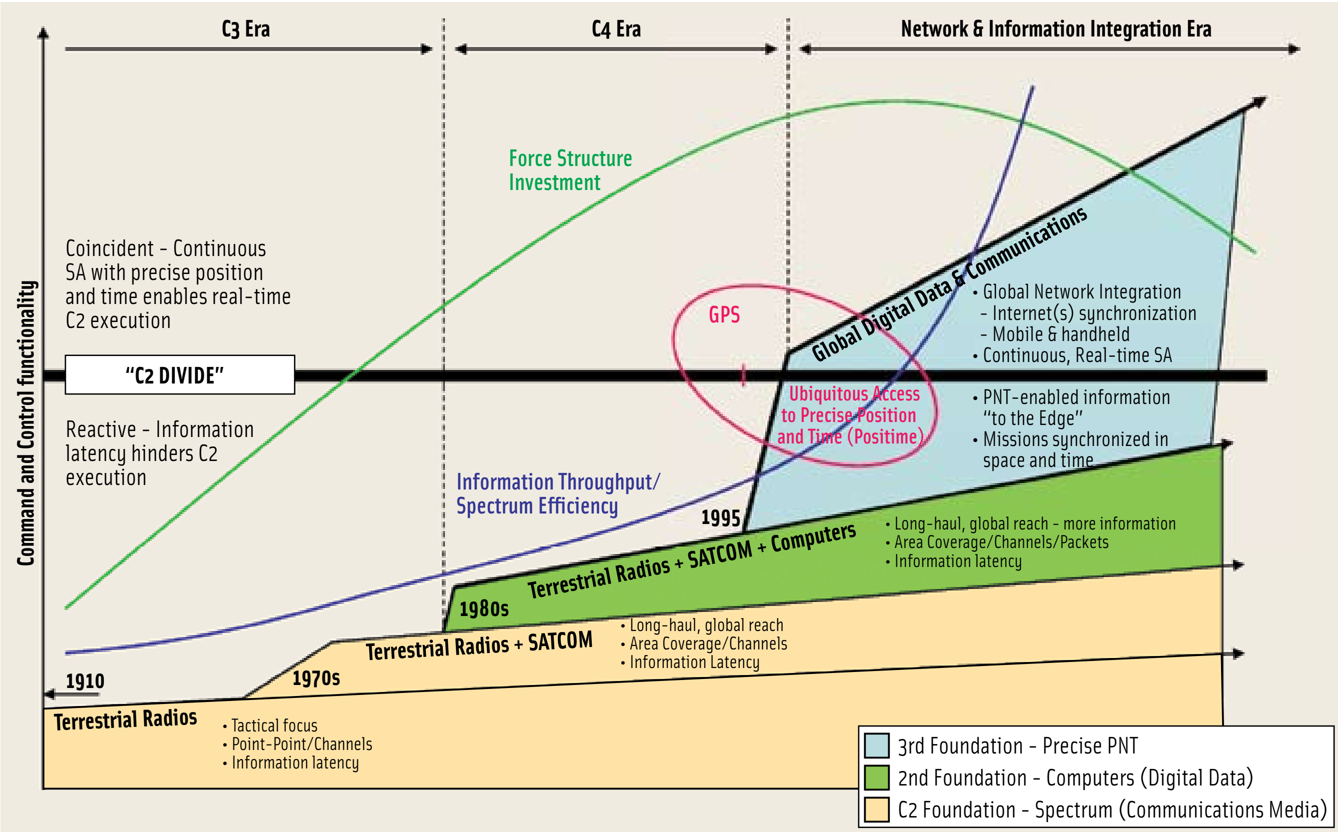


FIGURE 1 The three foundations of C2 and how they are "changing the game" in an electronic battlespace: spectrum (communications media), yellow; computers (digital data), green; PNT (precise position and timing), blue.

coincident operations. Coincident C2 takes advantage of the real-time SA inherent in PNT-enabled forces. This, coupled with the availability of responsive, integrated information networks (data and communications), provides a C2 capability able to execute high-tempo, time-sensitive operations.

Those capabilities are only now beginning to be fully realized in military operations, and we can expect their contributions will be refined and expanded as long as access to accurate, reliable, and globally available PNT is assured.

Figure 1 also highlights the notion that, in addition to enabling efficiencies in execution of all types of operations, GPS and precise PNT also enable more efficient use of force structure. In turn, this reduces pressure on the size of investments in associated systems, demonstrating that assured precision truly enables more to be done with less.

PNT: More than GPS

Widespread incorporation of precise PNT applications has truly changed the game for military, civil, commercial, and scientific endeavors of all kinds. To the extent that GPS has represented the popular face of the PNT revolution, we now need to consider changes to the PNT universe by adding resources to assure its continuity under all conditions.

GPS modernization is now well underway with the addition of new signals on Block IIF satellites and the development of future capabilities in the next-generation GPS III program. However, as our discussion to this point has shown, GPS alone — even modernized GPS — will not be enough to ensure a continuing U.S. "competitive advantage" in PNT. The physical realities inherent in providing signals from space limit their accessibility to users under conditions of intense interference or physical obscuration due to buildings, terrain, and sometimes vegetation.

Despite its well-documented limitations, GPS is envisioned as the cornerstone of military PNT well into the future and as such will require continued investment for modernization. Meanwhile, the previously mentioned proposal for implementing a National PNT Architecture by 2025 represents one effort to envision and develop a more robust PNT for the future.

With an appreciation for how vital GPS-provided PNT has become, the time has come to invest in "other methods" (per Gen. Schwartz) to augment and complement GPS for the occasions when its signals may be blocked or otherwise rendered unavailable or unreliable. Developing ways to provide military PNT information via other means is vital if we are to maintain our C2 advantages on the battlefield.

The task is made more urgent by the rapid pace of commercial technology innovation, which is already incorporating such advances in consumer electronics around the world. As we have seen routinely in the pages of this magazine, consumers and scientists around the world are becoming enamored of applications incorporating PNT, and manufacturers are finding diverse ways to augment GPS services.

One manufacturer noted in a private conversation with me that a "hodgepodge" of GNSS and PNT combinations would soon exist across the commercial marketplace. While providing a diversity of choices undoubtedly helps most commercial and consumer applications, many government users — and particularly the military — must know of and be able to rely on the availability and characteristics of PNT sources that they use.

A hodgepodge of PNT services on the battlefield introduces vulnerabilities and confusion that can undermine both situational awareness and command and control. Therefore, a thorough understanding of PNT options and what each brings to the game is absolutely essential in order to be able to winnow down the alternatives to a select few that will be integrated with GPS and made available to warfighters.

GPSS: Building on Success

Before considering these options, we need to look at where GPS resides within the growing panoply of PNT sources and services around the world.

Figure 2 provides a notional taxonomy of the global PNT system-of-systems of which GPS is but a part (however, a very essential and foundational part). Each of these elements has been addressed individually in articles, papers, and presentations in this and other forums. However, our presentation here seeks to provide a holistic perspective representing a view of their aggregation into a global PNT architecture framework.

The *Global PNT System-of-Systems* (GPSS) comprises all the elements (systems, services, components, applications) used by people around the world for absolute and relative positioning and orientation, navigation, and timing (synchronization and syntonization) purposes.

This "System-of-Systems" construct acknowledges that many — in fact, most — of the disparate parts of the GPSS are individual systems or elements that are independently designed, implemented and operated by nations or regional coalitions. However, with some thought to compatibility and interoperability among the parties, a coherent "System" can result in which combined use of all the parts by users and applications produces a robust and high-fidelity, global PNT service.

Global Navigation Satellite Systems (GNSS). Currently, four individual space-based systems have been or are being developed to provide continuous worldwide PNT services. Others may follow. GNSS signals are transmitted in portions of the radio frequency spectrum allocated for radio navigation satellite service — (space-to-Earth) [RNSS(s-e)], as defined and coordinated through the International Telecommunication Union (ITU).

Regional systems that transmit GNSS-like signals are also being developed to provide space-based PNT services over discrete areas of the world. These regional systems can either be a space-based augmentation system (SBAS) for one or more GNSSes (e.g., WAAS, EGNOS) or separate, independently operated space-based PNT systems (e.g., QZSS, IRNSS).

Ground-Based Augmentation Systems (GBAS). These terrestrial PNT systems augment GNSS by providing localized service enhancements that can be geographically limited or proliferated over broad areas (e.g., Australia's ground-based augmentation system or GRAS).

Significantly, GBASes can also provide separate ranging signals that are interoperable with GNSS signals for trilateration and timing purposes but that are transmitted via separately allocated RF spectrum bands. Ground-based (or airborne) pseudolites represent one example of elements of such a system. *[Note: including the U.S. Nationwide Differential GPS system (NDGPS) in this definition would require the addition of ranging signals to the differential GPS corrections currently broadcast by this system.]*

Ground-Based PNT Systems (GBPS). These are independent ground-based PNT systems that provide PNT services either regionally or locally, *which are separate and distinct from GNSS-based services but are both geo-referenced and time-referenced to GNSS.* To qualify as a GBPS in this construct, such systems must provide separate timing and/or ranging signals that are compatible or interoperable with GNSS signals or provide useable PNT signals of opportunity and not simply serve as lower fidelity backups to GNSS. *[Note: including enhanced LORAN (eLORAN) in this definition presupposes the addition of higher fidelity timing and ranging signals — and probably some form of differential GNSS corrections — to signals transmitted by the remaining LORAN systems in Europe, Saudi Arabia, and Korea/Japan, and Russia's LORAN-like system (Chayka).]*

Hybrid & Autonomous PNT Systems (HAPS). These systems include technologies and individual components that provide PNT services via separate mechanisms, either as stand-alone capabilities or in combination with the previously described systems. HAPS services are expected to provide fidelity such that GPSS services in general are not compromised.

Hybrid systems are synergistic combinations of PNT systems with other electronic information systems such as communications or digital data networks such that the services provided by both systems are enhanced. *Autonomous systems and components* can be employed either as closely coupled complements to improve robustness and fidelity of PNT system performance or, discretely, to provide PNT service for limited periods of time on a stand-alone basis.

Within this array of PNT technology alternatives are the systems and components that will provide PNT continuity well into this century. Not all will survive, and those found most effective will likely be deeply integrated into end-user devices where they will perform vital and continuous functions in near anonymity. Such is the role and reality for PNT in the global electronic infrastructure.

Figure 2 and the foregoing discussion of resource categories provides a more detailed breakdown of the enterprise-level architecture developed and presented by an interagency team in 2008 as the National PNT Architecture. Representing the efforts of more than 30 federal government agencies, the exercise reflected a "greater common denominator" strategy that recognized that *most* PNT users' needs are common and can be satisfied with a commonly available resource such as GPS.

However, the architecture study also recognized that not *all* PNT needs could be met by common services; so, in addition to the cornerstone GPS, the strategy that emerged from the interagency study included vectors encouraging multiple additional PNT sources at other frequencies and employing other technologies not originally designed for PNT purposes. It also highlighted the mutual benefits to be drawn from a natural synergy between PNT and communications systems.

Considerable frustration was expressed when the 2008 report did not "pick winners" and define an end-state system-of-systems that could be implemented in the near term. However, much work remains to be done in order to thoroughly evaluate and down-select among many available and soon-to-be-available technologies that will comprise a future, long-term system architecture.

Those efforts are now beginning with the release in July 2010 of a National PNT Architecture Implementation Plan based on the enterprise-level document. The following sections will summarize the alternatives and define a way ahead toward a future GPSS for U.S. military users. An important note: separate implementation actions are underway among civil agencies, most notably the Federal Aviation Administration (FAA), which is also beginning to evaluate alternative sources of PNT for aviation.

Alternatives for Assured PNT (GPS+)

We have not reached the end of the line with respect to opportunities for both refining and enhancing GPS performance to improve the probability of its availability under adverse conditions. Within GPS itself, spectral diversity can strengthen GPS robustness and resistance to hostile interference.

Alternate L-band signals can further improve GPS service fidelity by increasing frequency diversity and affording use of special processing techniques such as tri-laning to remove atmospheric effects on signal propagation. Adding a new GPS signal at C-band would take advantage of an existing ITU RNSS allocation and offer RF characteristics with very appealing antenna and receiver performance advantages. GPS performance can also be augmented by integration with other technologies, such as communications and cyber networks, to the mutual benefit of both.

Ultimately, however, even a sky blanketed with GPS satellites will not guarantee service in all possible locations at all times; consequently, complementary technologies will be needed to maintain high fidelity PNT service when GPS is unavailable.

The PNT package or application that ensures this level of operation must be able to transition seamlessly and without user intervention (or even awareness) among GPS and various other sources. It will need to operate as a form of "cloud PNT," analogous to "cloud computing," which is being considered as a means to improve information assurance within the cyber environment.

Let's take a closer look at the range of further GPS improvements, augmentations, and complements now under consideration as elements of a future PNT system-of-systems architecture.

GNSS Alternatives

Because of the success of GPS and a growing recognition of space as the ultimate high ground, various GNSS options are receiving particular attention.

Further improvements to GPS. The current GPS program of record envisions enhancements to radiated signal power as a potential means to improve performance. These include

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adoption of the M-code signal structure, already being implemented, and possible employment of spot beams to significantly increase M-code signal power on future configurations of GPS satellites.

Other alternatives for improving GPS services include the addition of signals at frequencies other than the legacy L1 and L2 locations. Transmitting another L-band signal at the E6 location (1278.75 MHz) could support extremely high-precision operations in conjunction with other GPS signals, and, as mentioned earlier, the C-band RNSS allocation at 5010-5030 MHz offers opportunities for spectral diversification that would significantly complicate the jamming efforts of adversaries.

Over time, if changes to the GPS signal menu are proposed and adopted, timely notice of implementation plans must be given to all affected users. This will ensure that actions to add new signals or discontinue existing ones have minimal adverse effects on operations and equipment/application purchase decisions.

In addition to possible changes to GPS signals, improvements to GPS antennas and signal processing in receiver hardware and software can improve GPS performance in the presence of jamming and in signal-challenged environments.

Foreign GNSS: Along with the continued evolution of GPS, the addition of foreign counterparts to GPS will increase the number of PNT sources available to global users. The Russian GLONASS has been in operation since shortly after GPS and over the last 10 years has been upgraded in terms of reliability and availability. GLONASS is also projected to begin transmitting (CDMA) signals similar to GPS and other GNSSes, which will improve mutual interoperability.

Other GNSSes are being developed by the European Union (Galileo) and China (Compass/BeiDou-2). Moreover, these foreign space-based PNT providers, joined by Japan and India, either currently provide or plan to provide various combinations of regional PNT services and augmentations to GPS over the coming decade or more.

Use of these foreign GNSS services by the U.S. military to improve PNT availability may be considered as the systems evolve; however, the United States would never rely solely on foreign signals for national security purposes. Of course, the open services of these systems will certainly be of use to civil users of all kinds, and the new National Space Policy released by the White House in June 2010 further encouraged their use.

Many issues — including signal compatibility, performance standards, reference frames, and service fidelity and certification — still must be addressed before either military or civil navigators could confidently use such systems for regular operations. Also, as all of these systems operate primarily in the same general RF spectrum as GPS, they are subject to the same vulnerabilities and limitations of physics that can hinder GPS reception.

GPS Augmentations: Differential GPS (DGPS) augmentations have been in use by the military for more than 10 years. Beginning with Wide Area GPS Enhancement (WAGE) and continuing with Talon NAMATH and Zero Age of Data updates, Air Force operators have improved GPS performance for military users in the field. These augmentations have primarily focused on improving accuracy of GPS solutions by correcting errors in the direct signals or providing more rapid updates of broadcast GPS satellite ephemeris and clock state estimates.

Other augmentations are being considered to improve GPS availability by transmitting separate ranging signals that can be accessed in addition to those being transmitted from the GPS satellites or in instances when the satellite signals may be blocked by interference. Such pseudolite signals may be transmitted from ground-based or airborne sources; however, their use and effectiveness are complicated by logistics and signal generation considerations.

We also should not overlook civil GPS augmentations represented by the FAA Wide Area Augmentation System (WAAS) and Local Area Augmentation System (LAAS) and the Nationwide DGPS (NDGPS) operated by the U.S. Coast Guard and U.S. Army Corps of Engineers. DoD use of their signals may be necessary for military-civil compatibility in some domestic precision transportation applications or emergency response and recovery situations.

GBPS: Alternate RF PNT Sources & Signals of Opportunity

Additional sources of PNT information are afforded by navigation systems that operate at different frequencies than

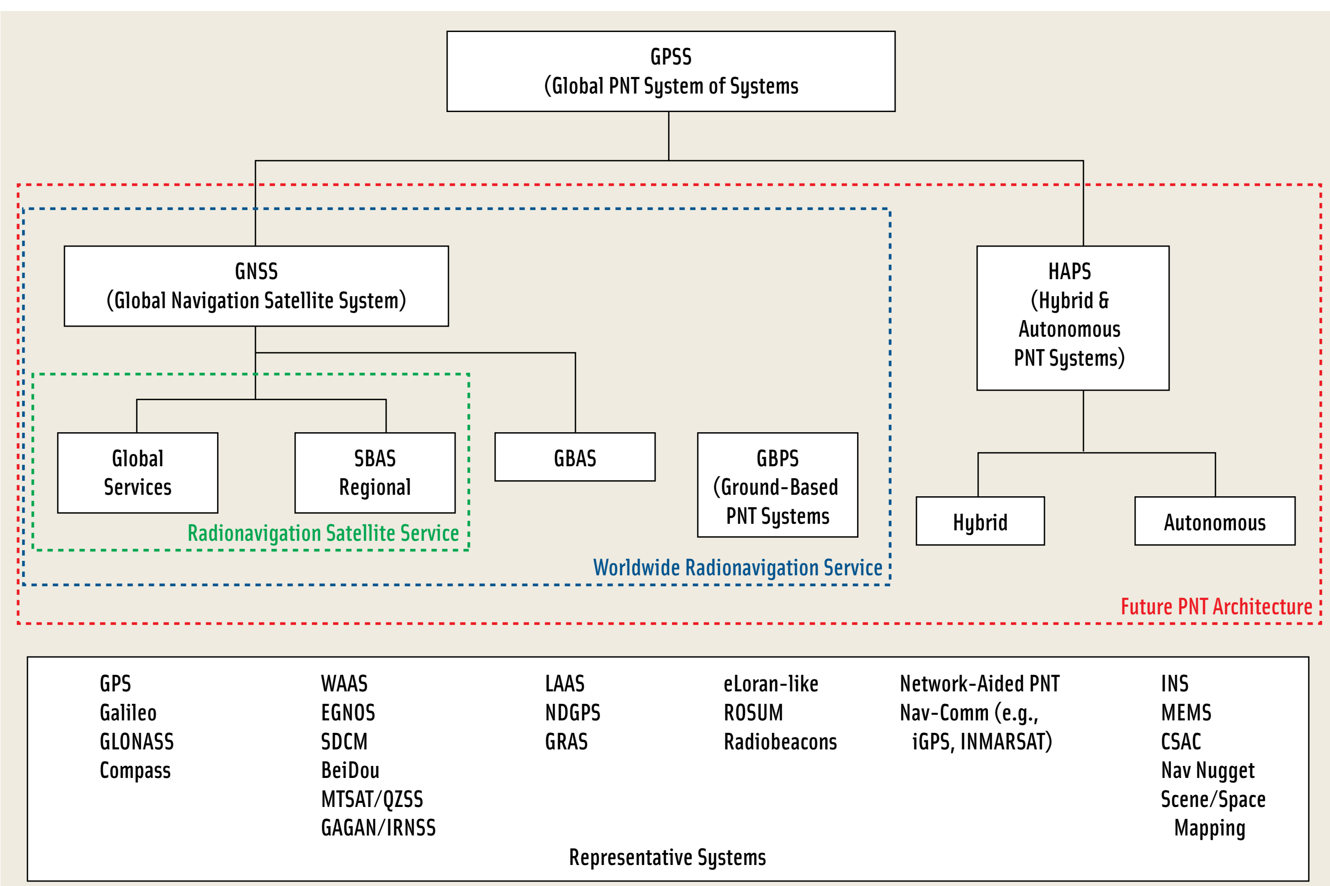

FIGURE 2 The Global PNT System-of-Systems

the space-based GNSS services. Such sources may include navigation signals at low and medium frequencies (LF/MF) provided by systems such as eLORAN (if LORAN-C is resurrected) or by the addition of time-tagged navigation signals to NDGPS transmissions.

These high-power, low-frequency signals are very difficult to jam and have the added benefit of penetrating buildings, foliage, and shallow water. In local and regional areas, and in urban environments, they can be useful sources of two-dimensional position and precise time.

Other potential GBPS resources are signals of opportunity that may be employed for PNT purposes even though the systems are primarily used for applications other than navigation or timing.

Absent a technological revolution in autonomous devices, GPS will clearly remain as the DoD's principal global source of three-dimensional position and time far into the future.

An excellent example of such a system is a proprietary, commercial venture that takes advantage of precisely timed digital television signals intended for mobile video applications to derive precise position and time. TV signals are high power and widespread, allowing two-dimensional position determination. Furthermore, the timing portion of these TV signals can be accessed at far greater ranges and in more obstructed environments (indoors and underground) than the digital video content itself.

Similarly, as digital networks proliferate, the addition of time-stamps to Wi-Fi hot-spot or femtocell transmissions can enable their use as beacons or PNT signals of opportunity in localized situations.

HAPS: Hybrid and Autonomous Alternatives

The essential idea behind autonomous sources of PNT is that, once initialized, PNT applications and operations may be executed without the need for position or timing updates from external systems. In this realm, the ideal PNT device — the Holy Grail of PNT research and development efforts — is a driftless, chip-scale, power-efficient, GPS-quality inertial navigator and clock combination.

Did I mention that it must also be affordable? Of course, while elements of such a device are under development and coming along nicely, the reality is that attaining all those qualities, particularly the elimination of drift, is nowhere on or even over the horizon.

Until the Holy Grail arrives, then, the most generally anticipated sources of autonomous PNT are the chip-scale atomic clock (CSAC) and micro-electro-mechanical systems (MEMS) versions of an inertial measurement unit (IMU) integrated into a GPS receiver. Inertial integration with GPS is important, as the technologies are complementary and mutually beneficial in operation.

Size, weight, cost, and power issues remain limiting factors for near-term incorporation of such devices in applications in which space and power are limited. Furthermore, MEMS IMU drift rates are still too high for use without GPS or another source of position updates.

Celestial navigation employing state-of-the-art optics, and feature mapping and visualization technologies could provide another option.. Visualization and feature mapping concepts require a comprehensive database of terrain and structural features stored in a user's PNT application that can be compared to real-time information detected by the user equipment. These techniques can be used for terrestrial, urban, indoor, underground, and underwater operations.

Hybrid PNT Systems (Comm/PNT Integration and Network Aided). The integration of PNT with advanced digital communications and data networks provides substantial mutual benefits. Benefits to networks include improved synchronization and throughput. Benefits to PNT systems include transmission of aiding information to assist in signal acquisition and retention in jammed or obstructed environments. With network time-tagging, wireless network signals can also serve as an alternate-frequency PNT source and means of direct position calculation (i.e., signals of opportunity as discussed in the previous section).

Benefits of hybrid systems include more consistent service for both PNT and networks, location-based situational awareness (Blue Force, Red Force, fixed and moving targets, interference, downed aircrews, fratricide avoidance, etc.), updates to geographic information system data important to ongoing missions, and multi-sensor integration and correlation, to name just a few. The DoD's Enhanced Position Location Reporting System (EPLRS) and the Joint Tactical Information Distribution System (JTIDS - Link 16) are examples of land-based and airborne tactical networks, respectively, which combine communications with a two-dimensional relative navigation capability linked to GPS.

Another hybrid alternative known as iGPS (also as HiGPS) can relay GPS information through the Iridium low-earth orbit (LEO) communications satellite constellation. Iridium offers higher power, a measure of frequency diversity, and constantly changing geometry to augment GPS coverage in urban or jamming environments. This LEO system also offers the flexibility of crosslink communications to relay information from outside a theater of operations, beyond the range of likely countermeasures.

Questions that bear on the iGPS alternative — and which would need to be answered before any decision to proceed — include issues of constellation sustainment, added component requirements for GPS receivers to take advantage of the Iridium signal and data, and issues related to use and protection of spectrum allocated for communications vis-à-vis navigation.

In addition to these few examples, many more satellite-based, airborne, and land-based networks are candidates for similar integration.

Next Steps – Achieving a Future Vision for PNT

A well-known saying tells us that, "If you don't know where you're going, any path will take you there." Conversely, any path taken at random will lead to an uncertain destination. That is the dilemma currently facing the U.S. Department of Defense with respect to the myriad choices for future sources of PNT information.

Absent a technological revolution in autonomous devices, GPS will clearly remain as the DoD's principal global source of three-dimensional position and time far into the future. And I believe it remains vital that the DoD continue to thoroughly consider improvements to GPS that will ensure its continued preeminence in the face of growing international participation in that arena.

Such consideration needs to happen within the next year or two, because changes to GPS signals — whether to add to or delete from the menu —take decades to implement due to satellite procurement lead times, control segment modification and validation timelines, and timely user notification to accommodate planning for equipment development/modification and legacy equipment life-cycle expiration.

Decisions about developing other means for providing PNT information also must be made systematically and soon. The need to strengthen vital PNT terrestrial coverage and extend PNT service in urban, indoor, underground, and underwater environments will continue to grow.

Pressures to expedite improvements in military equipage as the result of consumer-driven commercial advances in location-based technologies can lead to chaos in the future military PNT system-of-systems if the military's choices are made on an ad hoc basis. Fortunately, even though the process is maligned by many as cumbersome and bureaucratic, the Defense Acquisition System (DAS) offers a very systematic method for making such choices once a need is acknowledged.

The DAS process includes steps to validate operational need, conduct analyses of alternatives to sort among options, and establish technology development strategies to ensure selected options are viable. The process will also need to define specific system-of-systems architectures to ensure that any future "cloud PNT" capability can be procured, fielded, and operated to seamlessly fill the known gaps that have been identified to date while remaining effective well into the future.

The DoD is at the front end of that process today. Nearly coincident with completion of the Architecture Implementation Plan, an Initial Capabilities Document for PNT Assurance was approved through the department's joint requirements process. Those documents provide the fodder for a formal "Analysis of Alternatives" (AOA) effort now starting up within the DoD.

This PNT AOA focuses on specific future improvements to GPS while also sorting among the myriad complementary techniques and technologies, including those addressed in this article. The job will be complex and will engage all the military services as well as STRATCOM, the Joint Staff, and Office of the Secretary of Defense over several months of activity.

The goal of this AoA effort is to arrive at recommendations to be implemented in DoD programs over the next few years and out to beyond 2020 to provide affordable, reliable, robust PNT services to military users for decades to come.

As awareness of the value of PNT to the future evolution of military operations continues to grow, the PNT landscape is ripe with opportunity and choices. For military operations, the challenge will be to systematically select among what is both effective and affordable in such a way that PNT continues to provide advantages — not a source of chaos — in the future battlespace.

Now that we can see the choices ahead, we must not wait any longer to begin addressing the alternatives.

Acknowledgments

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Additional Resources

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