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Abstract

In the next 5 to 10 years, the world will experience the emergence of a true Global Navigation Satellite System (GNSS) - a compatible and, in many respects, interoperable system of systems. The U.S. Global Positioning System, Europe's Galileo, perhaps Russia's Glonass system, and regional augmentations including the Wide Area Augmentation System (WAAS), the European Geostationary Navigation Overlay Service (EGNOS), radiobeacon-based systems such as the U.S. Nationwide Differential GPS, and compatible commercial differential correction services will comprise this multifaceted GNSS. Common signal structures and frequency plans will enable combined user equipment that reduces the technical complexity and cost, while vastly expanding related applications. Additional satellites and signals, both more powerful and with improved designs, will increase the availability of robust signal reception outdoors and strengthen the potential of indoor positioning using only GNSS user equipment. But the path to the future is not without its risks: political, technical, economic, and cultural.

After nearly a decade of distrust and bickering, Europe and the United States are showing signs of real harmony in the matter of global navigation satellite systems. Last June, the two powers signed an agreement that lays the foundation for substantive cooperation on GPS and Galileo - not merely in system compatibility and interoperability, but also in matters of trade and security.

In certain respects, one can imagine no more unlike enterprises than the U.S. Global Positioning System and Europe's Galileo system. GPS is operated by the U.S. military establishment as a public entity; Galileo will be managed by a private consortium as a public-private enterprise fully under civil control. GPS uses one time standard; Galileo, another. The geodetic coordinate frameworks are different. Not all the frequencies match up and signal designs will vary. GPS is operated as a national system; Galileo is multinational - encompassing not merely the 25 nations joined in the European Union, but also the People's Republic of China, Israel, India, and a half dozen or more other nations with whom the EU has been talking. GPS delivers signals in space for free; Galileo proposes to deliver certifiable, guaranteed fee-based services in addition to a free open-access signal.

And then, of course, there's the most obvious difference: GPS is a real, existing system with 29 satellites in orbit and tens of millions of users around the world. Galileo is a work in progress. Galileo is a developmental program with a couple of billion euros in its pocket, some leased channels on telecommunication satellites to support the European Geostationary Navigation Overlay Service

(EGNOS), a bunch of components not yet assembled into the first Galileo spacecraft (out of 30 planned for a full constellation), and a patchwork of ground infrastructure. GPS has been fully operational for 10 years. Galileo's original completion date, originally planned for 2008, may actually arrive even later.

Despite these substantial design differences, the two GNSS systems are basically variations on a common technological theme. Over the long run, the political, institutional, and commercial realm is where interoperability may meet its greatest challenge. Technical experts will continually fine-tune frequency plans and signal structures. Equipment manufacturers will come up with ever-better products based on those designs. Service providers and end users will apply them in unpredictable and imaginative ways. But everywhere, these efforts will be facilitated - or constrained - by the business models, the rules adopted on intellectual property rights, tax policies, security arrangements, carriage requirements and regulatory policy, control and management of the space and ground infrastructures, international participation in the GNSS programs, and so forth.

Ironically, GPS and Galileo have inhabited a looking-glass world in which the two sides were sometimes as divided by their similarities as they were united by their differences. The experience with dueling GNSSes has demonstrated a similar principle of contrary dynamics. Never were the two sides so far apart as when Europeans first wanted to put themselves into the same GPS control room as the Americans and, later, when they wanted to put certain Galileo signals on some of the same frequencies as certain GPS signals.

Back in the mid-1990s, a delegation of officials from Brussels came to Washington, D.C., to discuss the idea of European participation in the management and operation of GPS. The Europeans said they'd even be willing to help pay for the operation and modernization of the American system.

The first thing the Americans asked was Who are you and whom do you represent? The European Union? France? Germany? Italy? Brussels? Our NATO allies? The European Commission? The European Space Agency? Who are we talking to? And the next thing the Americans said was, we don't need your money and we don't want it if it means we have to give up an iota of control over a key national infrastructure. And besides, you haven't actually allocated any money for GNSS, no serious money, anyway; just some study funds.

Well, the Europeans went off and set about answering those questions and, in the meantime, came up with a GNSS of their own - Galileo. Along the way, they also created another practical example of how to go about building a political union. Nothing sorts out the rhetoric from the real stuff as having to build a tangible system and service. After the Airbus project and implementation of the euro currency, Galileo already stands as a notable example of successful common effort by the European Union. At least, so far.

Anyway, after a few years, the European Commission came back to the United States once again and said, okay, let's talk about GNSS now. And, because the EU appeared to have its diplomatic act together, the United States set up an interagency working group, led by the State Department, to meet with the Europeans. Nonetheless, for the next couple of years, the two sides seemed to be talking past each other, not to each other: the Europeans wanted to talk about specific details of the technical designs of the systems. The United States insisted on first discussing more general matters such as trade policy and regulatory issues first. This went on until two things happened: first, the EU made a firm commitment of funding to build Galileo. And, second, the Europeans went ahead and came up with a provisional Galileo signal design on their own. Now, what got the United States' attention was a part of the proposed Galileo design that would have overlaid the publicly regulated service (PRS), an encrypted security-oriented signal, on top of part of the new GPS military signal (M-code) planned for the L1 band.

Once again, a seeming common ground - use of the same radio frequency - became a point of contention. U.S. defense officials argued strongly that the PRS overlay would undermine GPS operators' ability to jam non-military signals in a theater of operations without interfering with the M-code. At that point, the two sides began talking about all of the issues at once. They set up technical working groups - which sometimes met under secret classified conditions -- to come up with mutually workable solutions. The United States even went so far as to propose that GPS would use a similar signal structure as Galileo - the binary offset carrier (BOC) - if the EU would agree to a narrower frequency plan that moved the PRS away from the M-code.

In effect, a change in political reality - the fact that Galileo would be built whether or not the U.S. government wanted that to occur - precipitated a change in U.S. technology policy. So, in Washington, D.C., the question was no longer how to keep GPS as the only fully operational GNSS. The question for the United States became how to ensure that the systems were secure, compatible, and interoperable. By compatible, I mean that the systems do not interfere with each other. Interoperable refers to the synergistic effect of being able to use both systems together to accomplish things that could not be achieved by either system alone - for instance, greater continuity in tracking vehicles or persons in urban areas.

Now, the technical compatibility and interoperability of these two GNSSes for which the initial U.S.-EU agreement has laid the foundation will definitely bring GPS and Galileo closer together. On the other hand, the differences between the two complementary systems will tend to bring the GNSS world closer together. By complementary, I mean the two systems are similar enough to be compatible, but different enough to be useful. Separate GPS and Galileo signals, separate ground and space infrastructures, separate operating entities, and separate budgets. These things will build the global GNSS marketplace and user

community faster than one system alone. That will occur as a result of the increased redundancy, signal availability, robustness, and ultimately, user confidence that result from having compatible but independent systems.

Not only will they be complementary systems, but they will also be two primary systems - that is, each on its own will be capable of providing a complete positioning and timing service. This simple and seemingly self-evident concept has not fully taken root yet. A few years ago, about the time the European system was designated Galileo, I was moderating a GNSS panel at a conference in Toulouse, France - a center of the European space industry. An official from EADS, one of the leading European defense and aerospace companies, made the observation, "It will be desirable to have a back-up GNSS." And I said, "Yes, GPS as a back-up to Galileo, right?" And the EADS official looked at me quite blankly, because he had meant the opposite. At the time, part of the argument for building Galileo was that it would provide a back-up for GPS in case the U.S. system experienced a failure. That rationale and the fact that GPS came first and had been an operational system for many years has created the sense of its primacy - even among public and private advocates for Galileo. That unspoken attitude still persists in some quarters, and probably will persist until an operational Galileo system has achieved true parity - or even a superior position - with GPS. At which point, either system will serve as a back-up - as well as a complement - for the other.

In addition to these benefits, Galileo will help keep the United States honest in its management of GPS. Not that I think the U.S. government has been noticeably dishonest or narrowly manipulative in this matter. Quite the contrary, the United States has been remarkably open-handed in ensuring access to GPS by users around the world. In fact, the rapid adoption and spread of GPS technology and applications could not possibly have taken place the way it did without that policy. And it is a precedent that I believe Galileo's leaders would benefit from considering further.

Over the years, the United States has been criticized for many things regarding its GPS policies and management. But one thing that it did get right - perhaps in large part accidentally and almost unwittingly - was to make the civil signal open and free to users around the world.

Nonetheless, unilateral control, like unilateral policy-making, of such a potent global utility is an invitation to complacence and unresponsiveness by the system operator. Monopolies also tend to pose threats to technological innovation and economic progress.

To this end, the mere discussion of a European system has already benefited GNSS users, and Galileo's implementation will extend those benefits. I believe the prospect of Galileo contributed to the urgency to craft the first comprehensive U.S. presidential policy on GPS in 1996, to eliminate selective availability in May

2000, and to modernize the Block IIR generation of satellites. I believe that approval of Galileo's implementation by the European heads of state and authorization of public funding will help keep GPS modernization, including the GPS III program, on track. Completion of Galileo within the near term will definitely accelerate growth in GNSS product and service markets, as well as drive new applications. It could also encourage the United States to change its launch policy from launch-on-need, that is, replacing satellites only as they fail. This launch-on-need policy means that many critical innovations in GPS signal and system design have to wait until after launch of all the unused satellites with an earlier technology that has been outstripped by technical advances. Successful completion of a Galileo constellation with new signals and higher power could encourage GPS' managers to launch on a planned schedule to more quickly install a new operational capability with the modernized GPS signals and satellites.

So, all this comes as good news for GNSS equipment manufacturers and users around the world. But many objectives must still be achieved and many obstacles, avoided, before compatible, interoperable GNSS becomes a reality. An example of the kinds of things that can derail this process can be seen in a recent article in a British newspaper. The article described an exchange between U.S. and European officials attending a conference on military space relations that led to one U.S. delegate suggesting that the United States would attack Galileo satellites if they continued transmitting signals that might be used by adversaries in a theater of conflict.

Now, I would not invest this anecdote with too much weight or power - even if it is completely true, even if these comments were actually made. I believe that they represent more an expression of anxiety than of intention. Indeed, I think that we should all share the anxiety of misuse of GNSS, whether GPS or Galileo. But, as I understand the NAVWAR (navigation warfare) scenarios, capabilities, and solutions developed by the U.S. Defense Department, the primary means to prevent hostile use of GNSS will be much more benign, limited in scope and targeted against the perpetrators and not GNSS system operators. And between any GNSS-related crisis and an assault on Galileo satellites or infrastructure stands the agreement signed in June, which established the official channel for relations between the European Union and the United States in GNSS matters.

Let's turn briefly to the new U.S. presidential policy on GPS issued December 8, 2005. What the policy actually addresses is the broader term of space-based positioning, navigation, and time or PNT, but for all practical purposes, it refers to GPS and its augmentations.

Let me mention five specific themes in this new space-based PNT policy that have a bearing on the issue of an interoperable GNSS.

First, the policy elevates the level of coordination of GPS policy and management. It replaces the Interagency GPS Executive Board established under

President Clinton's GPS policy directive in 1996 with a National Space-Based Positioning, Navigation, and Timing Executive Committee. The new group will be cochaired by deputy sectaries of defense and transportation. The former body had been headed by lower ranking officials.

Second, the policy reaffirmed the free, open use of current and future civil GPS signals as well as the free availability of technical specifications for the system. These specifications enable manufacturers to design and build GPS receiver equipment. They can be found in the GPS Interface Control Document or ICD.

Third, the policy directs the new PNT Executive Committee to oversee creation of a five-year plan that provides for cost-sharing among federal agencies that represent civil user communities. The plan must also address the need for further augmentation systems for space-based PNT and for any unique or accelerated PNT capabilities.

Fourth, the new policy spends a great deal of time addressing security-related needs and issues. That should not be surprising, because we are living in a very different world than the one in which the 1996 policy was created. The PNT policy process was overseen by the National Security Council rather than the White House Office on Science and Technology Policy, which directed the first effort on GPS. The Bush policy identifies GPS - or PNT - as a component in critical U.S. infrastructures, such as transportation and telecommunications.

The new directive issues a long series of mandates to the secretaries of defense and homeland security to increase the nation's capability to anticipate, protect against, and detect interference, attacks, or hostile exploitation of GPS. It even discusses the potential need to deny hostile use of space-based PNT within the United States, and calls for provision of back-up systems to take over PNT functions in the extremely unlikely case that space-based systems become temporarily unavailable.

Finally, the policy directive - both implicitly and explicitly - has the goal of maintaining U.S. primacy in GNSS affairs. It speaks of GPS remaining "the pre-eminent military space-based PNT service." It calls for ensuring civil PNT services "that exceed or are competitive" with foreign systems." And it seeks to promote U.S. technological leadership in applications involving space-based positioning, navigation, and timing.

Unfortunately, one of the things that the document does not address very substantially is the relationship between GPS and other GNSS systems. Despite last June's agreement with the European Union on GPS/Galileo cooperation, it does not mention Galileo by name. The directive does mention the goal of seeking to ensure that foreign space-based positioning, navigation, and timing systems are interoperable with the civil services of the Global Positioning System and to address mutual security concerns with foreign PNT providers to prevent hostile

use of space-based positioning, navigation, and timing service. It gives the PNT Executive Committee the responsibility for relationships with foreign positioning, navigation, and timing services. But nowhere does the policy document provide an enabling directive to implement the goal of compatible, interoperable global navigation satellite systems.

So, what are some of the things that need to be done to continue the auspicious beginning on GPS and Galileo cooperation? Well, here a few suggestions:

- Establishing a permanent mechanism for regular political consultations on the GNSS agenda, which must inevitably evolve as the systems mature and modernize.
- Cooperation in system operations and open formal lines of communications, 24/7, between GPS and Galileo controllers - whether that's a black box or a red telephone, or even an exchange of liaison officers in master control stations.
- A further agreement on security-related matters that sketches out the appropriate actions for possible threat scenarios. That could even include creation of a joint security board for assessing threats against either system, evaluating situations that might require jamming or degradation of civil signals, and recommending appropriate courses of action. Of course, actual events rarely take the exact form or follow the exact course anticipated by contingency plans. But forward-looking conventions would increase the state of readiness, the familiarity of GNSS operators and officials with their counterparts, and the capacity for responding to threat situations in whatever form they may arise.
- Clear statements on the reciprocal role that industrial partners from the United States and Europe can have in building and operating the other's GNSS. The Boeing Company has included Alenia Spazio and Alcatel Space on its GPS III team, EADS-Astrium is working with Boeing in GPS/Galileo matters, and the iNavsat consortium has done the same with Lockheed Martin, SiRF Technology, and NavTeq in its efforts to secure the Galileo concession.

  But more needs to be done. The Galileo Joint Undertaking, the Galileo Supervisory Authority, or, if necessary, the European Council of Transport Ministers should provide a clear statement on status, ownership, and access to the Galileo equivalent of the GPS Interface Control Document (ICD). The GPS ICD provides complete technical specifications that enable manufacturers to build GPS equipment.

  The two sides should also clarify the rules for U.S. companies' participation in building, maintaining, and operating Galileo. At the same time, the United States should clarify its guidelines on the export of GNSS-related technologies and the allowable scope for European industrial participation in the GPS III program.

- Agreements on carriage requirements for airplanes and commercial vessels that minimize the financial burdens on the transport companies and maximizes the use of combined GPS/Galileo equipment.

In closing, I'd like to end with a small warning. You often hear people say that the uses of GPS are limited only by the human imagination. I've used the expression myself. It has a wonderful gee-whiz quality to it: Limited only by the human imagination. And with a second, interoperable GNSS, I guess that, what, the human imagination will get twice as big, or GNSS innovations will take place twice as fast, or something like that?

But I had an experience a few months ago as led me to think about that idea a little more closely: While attending a conference in Sydney, Australia, l visited the Royal Botanical Gardens. One of the many amazing facts that I learned there is that the world contains 80,000 species of edible plants. However, only 20 species comprise 90 percent of the food actually eaten by the world's population - things like corn, wheat, and rice. So, before we start feeling too smug about the prospects of GNSS, and assuming that a second system is going to make things twice as good, I think we need to recall our track record with the human diet. Only implementing 20 out 80,000 options isn't so hot, and we need to do better with GNSS. And that will take not merely imagination, but hard work, good intentions, and sustained effort.

GPS and Galileo represent very different ways of achieving the same ends. It's a little like the differences among faith traditions that are so troubling the world today. The religious supremacists argue, sometimes violently, that their tradition is the only way. But a modern sensibility suggests that faith - while each can be primary and unique for its followers - should not be considered exclusive. We should let every person find his or her own way to the heavens - whether in matters of faith or of GNSS.