GNSS Interoperability
Not So Easy, After All

GLEN GIBBONS

The idea sounds great — working out ways to use multiple GNSS systems interchangeably while minimizing the harmful effects on one another. But can it really be done? Who is trying to do it? And what are the consequences of failure?

In the beginning, there was only the NAVSTAR Global Positioning System (GPS): an astounding start to the world of global navigation satellite systems (GNSS).

Since the United States declared full operational capability (FOC) for GPS in 1995, two major things have occurred:

- a phenomenal uptake of GPS technology — with a global installed based now estimated to be around a billion receivers — and
- the emergence of three other GNSS systems, two regional systems, and several space-based augmentations.

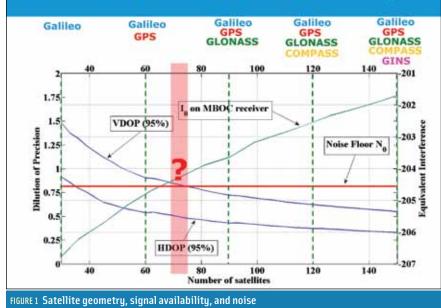Today, we have more than 60 operational GNSS satellites in orbit from several systems, transmitting a variety of signals on multiple frequencies. Within five years, given the plans of GNSS system operators, the number of satellites will reach 90 or more — with even more types of signals broadcast on even more frequencies.

All of which represents good news and maybe some not-such-good news for GNSS product designers, service providers, and end users. Because even as this trend increases access to the fundamental GNSS resource — signals in space — it introduces several challenges for the global GNSS community.

For example, recent studies indicate that more than three GNSS systems operating in the same band can cause problems: too many satellite signals may do more harm increasing the RF noise floor with which receivers have to deal than they help by increasing the accuracy and availability of positioning services.
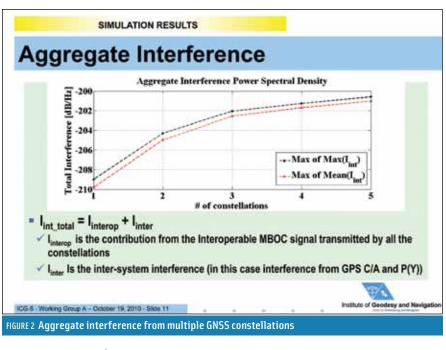
First, Do No Harm

Figure 1 comes from a presentation given at the Stanford PNT Symposium last November by Günter Hein, head of the Galileo Operations and Evolution Department of the European Space Agency (ESA). It summarizes the results of an initial analysis of the tradeoffs between improved satellite geometry — thus, signal availability — measured by dilution of precision (DOP) and the increase in the noise floor caused by increasing numbers of signals being transmitted in the L1 band.

Hein's initial conclusion: the optimal intersection or "sweet spot" of these factors may lie in the range of about 70 satellites (represented in the figure by the pink band). The number of GNSS space vehicles (SVs) in orbit is rapidly approaching this range.

FIGURE 1 Satellite geometry, signal availability, and noise

Figure 2 is a slide from a presentation by Matteo Paonni at the fifth meeting of the International Committee on GNSS (ICG-5) in Turin, Italy, last September. Paonni is a research associate at the Institute of Geodesy and Navigation at the University of the Federal Armed Forces Munich, Germany. Based on simulations of the multiplexed binary offset signals (MBOC) that most GNSS systems will use in the future, his presentation shows the cumulative effects of interference caused by additional GNSS constellations.

Such studies raise fundamental questions about achieving GNSS compatibility, which refers to the use of multiple civil satellite navigation systems without causing harmful interference with use of individual services or signals.

Here such issues arise as link budgets, maximum/minimum received power, minimum receiver C/N_0, and signal protection thresholds.

This is not a theoretical exercise but rather a near-term concern, especially for the L1 band centered at 1575.42 MHz where GPS, Galileo, GLONASS, Compass, QZSS, and satellite-based augmentation systems all operate or plan to operate, and for L5 (1176.45 MHZ) where these systems will

FIGURE 2 **Aggregate interference from multiple GNSS constellations**

be joined by the Indian Regional Navigation Satellite Systems (IRNSS).

So, are we facing merely an embarrassment of riches or could we find ourselves with too much of a good thing? If borne out by experience as new systems and satellites come on-line, a new race for space and spectrum could occur in the absence of comprehensive and binding agreements among providers.

Interoperability in Practice

Beyond the challenges of compatibility lies the goal of GNSS interoperability. The ICG has agreed that the use of two or more space-based positioning, navigation, and timing systems should provide better service than can be achieved by relying solely on any one system.

Here we encounter such factors as GNSS signal modulation, codes, data rates, navigation message structure, geodetic and timing reference frames, and even orbital configuration of constellations — all of which have a practical bearing on receiver design and the robustness of user applications.

At the system level, interoperability is primarily a responsibility of the GNSS service providers: the United States, Russia, China, and the European Union as well as operators of regional systems, including Japan, India, and others.

Bilateral efforts have produced substantive progress that represents more than "feel-good" moments for providers and users. In the recently released Galileo mid-term review (see article on page 14 of this issue), the European Commission said that, as the result of a 2004 agreement with the United States on interoperability with GPS, it expects at least 80 percent of GNSS receivers in operation worldwide to use Galileo from 2014 onwards.

Similarly, an ongoing series of cooperation talks since 1998 between Japan and the United States has ensured that the Quasi-Zenith Satellite Systems (QZSS) will transmit several signals that are identical with GPS. Indeed, the first QZSS spacecraft launched last September is the first to broadcast the GPS version of the modernized civil L1 signal (L1C) that is the subject of the agreement with Galileo.

Ultimately, of course, frequency allocation and signal plans are formally coordinated between nations on a bilateral basis through the International Telecommunication Union.

At the multilateral level, the UN-backed ICG has made an important contribution by bringing all the players together in a roundtable setting that encourages open exchange of information about the systems. The ICG also provides a forum in which to address potential conflicts in technical designs, particularly within ICG Working Group A on compatibility and interoperability.

Much work remains in both bilateral and multilateral settings in order to advance the cause of optimal interoperability and even what some are calling "interchangeability" — the transparent use of any set of open signals from any combination of systems and satellites.

The search for interoperability also arises in the per-

formance standards in specific application environments. Groups such as the International Civil Aviation Organization, International Maritime Organization, RTCA, EURO-CAE, and RTCM have established baseline performance standards for air and sea operations using GNSS.

However, converting the noble concepts of compatibility and interoperability into binding agreements that support reliable operations will require providers to take their efforts to another level.

In this effort, GNSS providers could learn from the experience of the International COSPAS-SARSAT Program Agreement (ICSPA) signed by the United States, Russia, France, and Canada in 1988 to coordinate satellite-based search and rescue operations. ICSPA members contribute funds to a permanent secretariat charged with coordinating the efforts of the independent systems operated by four nations.

Thinking Inside the Box

Finally, there is the matter of achieving interoperability in the design of GNSS user equipment.

Receiver manufacturers are addressing hardware issues involving the antenna, RF front-end, and correlator channels. Software-based approaches to building interoperability into receivers address such factors as upgradable software, configurable correlator channels, flexible digital signal processing (DSP), and field programmability.

In another presentation at the ICG-5 Working Group A, Shaowei Han, CEO of China's Unicore Communications, Inc., described his company's development of a unified and configurable baseband architecture that can process signals from all for GNSS systems, QZSS and IRNSS. It includes a code-generation unit to support all types of pseudorandom noise (PRN) codes, as well as the ability to process various types of signal modulations used by GNSS systems, such as BPSK, QPSK, BOC, MBOC, AltBOC, and so forth.

Han, a former vice-president of engineering at SiRF Technology, said that Unicore has incorporated other such elements such as correlators, fast Fourier transform (FFT) algorithms, and match filters that can support all systems.

Other companies are following similar paths. Last September, NovAtel announced its next-generation OEM6 technology — in addition to embracing the functionality of GPS, GLONASS, Galileo, and augmentation systems— was designed to accommodate software upgrades to include signal designs for Phase 3 of China's Compass/BeiDou-2 system.

In 2009, Trimble and the China Aerospace Science & Industry Academy of Information Technology formed a 50/50 joint venture in China to develop, manufacture, and distribute Compass GNSS receivers, an initiative that undoubtedly will produce interoperable GNSS equipment as well.

So, it appears the GNSS community has got a good start on identifying the challenge, but still has a long way to go before meeting it. **IG**