Three Critical Issues

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By: Brad Parkinson
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I'm going to discuss the three critical issues for GPtS. That's not a typo. It stands for the Global Positioning and *timing Service*. GPtS is a four dimensional service, with time as important as the other three dimensions. I credit Kirk Lewis for the emphasis; he strongly pushes the service aspect.

To set the scene, GPtS has a myriad of applications, both military and civil. The latter includes transportation (aviation, automobiles, maritime, rail control), public services, timing and frequency, surveying, surveillance, agriculture, and many others.

Charlie Trimble says there are more than 150 million users. I honestly think nobody knows; it has gotten beyond us. We are victims of our enormous success. We have this capability that has led to its being indispensable. It is a worldwide dependency.

The general issue is: What must we do to ensure that the trust in GPtS is not misplaced? To structure an answer, I go back to the "Big Five" civil goals for GPS, as recommended by the Independent Review Team (IRT) in 1999, and generally accepted by all.

The Big Five are:

1. Assured Availability of GPS signals including in impaired situations

2. Resistance to Interference (RFI), whether intentional or unintentional

3. Accuracy, only third because unless we do the first two, accuracy doesn't really count

4. Bounded Inaccuracy. We measure accuracy as a circular error probable (CEP), as a 50th or 95th percentile, but another real issue is: What's the tail of that distribution at the 1 percent of extreme outliers, wild data points, and how does that affect our operation?

5. Integrity, eliminating hazardous and misleading information, meeting a time-to-alert to tell the user that a particular satellite is not functioning reliably at the moment.

What are the essential enablers to attain these five goals?

Assured availability is driven by the number of satellites and their geometry. Very elegant mathematics are used to derive the formula for GPS availability. This tells us availability is steeply dependent on the number of satellites, particularly in impaired areas such as mountains or urban canyons. More satellites are usually a lot better for the impaired user. The second way to ensure availability is with interoperability and standardization. I am strongly in favor of Galileo. When deployed, it will more than double the opportunity to receive enough signals (this is because the missing one or two satellites are probably available in the other constellation).

For *resistance to interference,* we need additional satellite power, and more jam-resistant receivers.

For *accuracy,* we need the ability to predict in four dimensions where clocks and satellites are going. Those stable satellite clocks are critical — hopefully GPS III will be a further improvement in this regard. Improved satellite geometry (achieved with larger constellations) is also essential. And augmentations like the Wide Area Augmentation System (WAAS) and National Differential GPS (NDGPS) help a lot.

For *bounded inaccuracy,* we can have lots of satellites, but if the satellite geometry is poor, we will not have acceptable bounds on inaccuracy. Geometry is usually more important than ranging errors.

Regarding *integrity,* the Federal Aviation Administration (FAA) of course has deployed WAAS, which alarms out-of-tolerance situations in 6 seconds and is readily available to all users in the U.S. and Canada. Europe has the European Geostationary Navigation Overlay Service (EGNOS) and similar systems are being deployed elsewhere. Also, as a technique to insure integrity, there is receiver autonomous integrity monitoring (RAIM), pioneered by Penny Axelrad. This is enabled with six or more satellite signals being received. A robust — that is, large — satellite constellation greatly enhances RAIM.

Note that four of the top five goals are driven by the number of satellites. In fact, both the IRT and the Defense Science Board task force have recommended that we specify the current constellation size (30 plus spares) as the standard for GPS. Currently the official requirement is for 21 plus 3 spares to achieve a 24-satellite configuration.

So, what are the issues?

The number-one issue we should worry about is **constellation sustainment.** The on-orbit satellite lifetime is a very old 8.83 years right now. Under the current plan, the first IIF satellite won't be available until May 2008, and right now the plan is that the first GPS III won't be available for operation until April 2014. Frankly, that leaves me nervous. The history, with due respect to the Joint Program Office (JPO) and Air Force, has not been stellar in getting these new satellites launched.

Constellation holes can lead to brownouts where GPS might not be totally broken, but all users will suffer in attaining the Big Five Goals. It is imperative that we avoid GPS brownouts that would be caused by some combination of failures of the old and late deliveries of the new. *We need **sustained high-level support** for earlier GPS III delivery and availability.* A major part of the problem lies not with the blue suits, but with the people who put the budget together.

Issue number two is GPS robustness, which also provides deterrence. This is related to issue one. I am concerned about some terrorist deliberately trying to interfere with our GPtS. The more robust we make the system, the more we can deter the fanatic from hostile activities. A satellite constellation of 30-plus ("30 + *x*" where *x* are spares), would be a deterrent, particularly when we have all the authorized frequencies online. As I mentioned, prestigious advisory groups want 30`x to be the standard. *We need commitment by senior Department of Defense leadership to make that happen.*

To attain robustness, we also need affordable GPtS receiver interference rejection technology (A/J). This technology will become less and less expensive, with digital beam steering, and inertial integration, but that *needs full development by our manufacturers.*

For GPtS, one robustness technique is to provide backups: an example might be to retain LORAN indefinitely. Another technique, advocated by the FAA, is to keep selected VHF Omnidirectional Radio-range (VORs) and Tactical Air Navigation (TACANs) in place. We need to decide what set of backups are required. With true robustness, terrorists would be convinced that interference would not affect safety of life, and hence not be worth the effort. (bold by Jac Spaans)

And critical issue number three: Attaining **true, total interoperability** between GPS and Galileo. The payoff is obvious: improved availability, accuracy, and robustness. In fact, all of the Big Five measures are improved.I measure interoperability a little differently than politicians do. The devil truly is in the details. The real measure is whether we can mix and match satellites from different constellations and still retain the same ranging accuracy. Specifically, can we use any four satellites, regardless of who launched them, and still retain the same performance?

To achieve this interoperability goal, we need a complete, detailed definition of L1C, then we need to build the payloads, launch them, and demonstrate that the two systems are truly interoperable.

At the same time, we need mutually interoperable WAAS, EGNOS, and MSAS, in that each augmentation system can, in turn, correct and make adjustment for clocks, etcetera, in all available satellites. We need this infrastructure completely in place and understood by manufacturers.

Finally, for interoperability we need true clock synchronization between GPS and Galileo: once it is a truly integrated clock, we don't need an extra satellite to solve for an extra offset that the user doesn't really need.

What it all boils down to: As providers of GPtS, we must ensure the service is *always available* at the specified accuracy and integrity. Thereby, we will have met the safety, economic, and convenience needs of the world.

Brad Parkinson received his Ph.D. in aeronautics and astronautics at Stanford, and served in the U.S. Air Force from 1957 to 1978, retiring as a colonel. In 1973, he directed the effort to define a new satellite-based navigation system that became GPS, led the fight to gain Department of Defense approval, and ran the NavStar GPS Joint Program Office from 1973 to 1978. He is a charter member of the Editorial Advisory Board of GPS World, principal investigator for GPS research programs at Stanford, member of the board of Navigation Technology Ventures and Trimble Navigation, and chair of the Jet Propulsion Laboratory Advisory Council. He delivered this addressed at the Opening Plenary Session of ION GNSS 2006, September 26, Fort Worth, Texas.