

Introduction to the Wide Area Augmentation System

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Received: 28 October 2002 / Accepted: 4 November 2002

Biography

Dr. Todd Walter received his B. S. in physics from Rensselaer Polytechnic Institute and his Ph.D. in 1993 from Stanford University. He is currently a Senior Research Engineer at Stanford University. He is a member of the WAAS Integrity Performance Panel (WIPP) focused on the implementation of WAAS and the development of its later stages. Key contributions include: early prototype development proving the feasibility of WAAS, significant contribution to MOPS design and validation, co-editing of the Institute of Navigation's book of papers about WAAS and its European and Japanese counterparts, and design of ionospheric algorithms for WAAS. He was the co-recipient of the 2001 ION early achievement award.

The United States Federal Aviation Administration (FAA) is on the verge of implementing an entirely new navigation system. The Wide Area Augmentation System (WAAS) will monitor and correct the ranging signals from the GPS constellation of satellites. Most importantly, WAAS will provide a certified level of integrity. The corrections will improve the vertical accuracy of the system from ten or more meters to just one or two. It is the integrity, however, that will open the doors for widespread aviation use. Integrity is the ability to bound the remaining errors on the signal. Thus, the user will have a rigid limit on the magnitude of their position error. Although GPS does have a strong track record, it has not yet been generally approved for the most demanding of aviation applications: precision approach. GPS was not designed for this application and lacks the necessary real-time monitoring. Currently, aviation uses a technique exploiting redundant satellites,

to provide sufficient integrity. This technique requires good geometry and offers confidence bounds, termed protection levels, measured in hundreds of meters. As such it is suitable for en route flying and non-precision approach. However, precision approach, which brings airplanes within a few hundred feet of the ground, has more stringent needs. Here the protection level must be measured in tens of meters. WAAS will enable aircraft to conduct several forms of precision approach.

WAAS grew out of several concepts that originated in the 1980s. The first, the GPS Integrity Channel (GIC), proposed using ground monitoring to determine GPS satellite integrity. The integrity information was to be broadcast to users via a communication satellite. Separately, researchers examined the concept of Wide Area Differential GPS (WADGPS). This was a real-time extension to earlier work for surveying that uses a network of widely distributed reference stations to improve the accuracy of GPS position fixes. These ideas were combined, in the early 1990s, with the recognition that the communication downlink could be accomplished with a GPS like signal at the same frequency. This final design would provide differential corrections (WADGPS), integrity (GIC), and an additional ranging source to supplement GPS. In 1994, the FAA awarded a contract to create this system.

WAAS measures observed ranges to the satellites from its reference stations. These raw observables are transmitted to master stations via a terrestrial communication network. Each master station processes the measurements to create corrections for satellite clock error, satellite ephemeris error, and ionospheric path delay. More importantly, it determines bounds for the uncertainty in the remaining errors. These corrections and bounds are sent to a ground uplink station that transmits them to geostationary satellites. The geostationary satellites act as "bent-pipes" and reradiate the signal down toward Earth. These signals are received along with the GPS signals and used to formulate position estimates.

The geostationary signal is very similar to the GPS signal. It provides an additional ranging source as well as carrying differential corrections and confidence bounds. In order to achieve these two goals, the signal must have a very low data rate. Otherwise, the required signal power would interfere with the GPS satellites. The chosen data rate is only 250 bits per second. This low bandwidth must carry all of the differential corrections and confidences applicable over a broad geographic range.

Although WAAS is not yet certified, there is an operational test signal that has been available since August of 2000. Already there are several commercial WAAS-capable receivers. Because it now incorporates all of the integrity monitoring algorithms that will exist at commissioning, this experimental signal has a much higher level of integrity than the typical differential system. It is finding widespread use in agricultural and many other applications, as more and more non-aviation users are discovering the benefits of this free signal. It offers the great advantage that the differential corrections come in the same antenna that the GPS signals do. There are no additional antennas to install, no local reference stations to set up, and no additional communication channels to maintain. Just turn it on and use it anywhere in the United States. Similar systems are also being developed in Europe, Japan, India, and China.

The main challenge for WAAS is the certification of the system's integrity. It is not enough that the system has performed flawlessly in the past. We must be confident that it will continue to operate fault-free in the future. This is accomplished by investigating the possible fault modes of the system for different operating conditions. System performance in the face of worst-case faults is analyzed. Confidence bounds are generated based on this very conservative analysis. The result is large confidence bounds that we are certain contain the worst undetected error modes. While this makes the system safe, the resulting confidence bounds in the position domain, termed Vertical Protection Level (VPL) and Horizontal Protection Level (HPL), range from 20 meters upward, while the accuracy remains better than a few meters. This conservatism is necessary at the early stages of the system. As we gain more understanding of the different fault-modes and their likelihood of occurrence we will be able to lower these protection levels, while having little impact on the underlying accuracy. Smaller protection levels will translate into higher availability and lower approach minima.

The WAAS test signal-in-space has attracted numerous users for its improved accuracy. However, these users have encountered some shortcomings in its performance. Chief among these is the limited geostationary satellites' coverage. Currently, there are only two geostationary satellites and both are relatively low to the horizon for most of the U.S. While these are sufficient for aviation

users with unobstructed views to the sky, they are problematic for terrestrial users. Very few parts of the country can see both satellites. If the only geostationary satellite above your horizon is obstructed, you will no longer receive differential corrections. The long-term plan is to have redundant coverage everywhere within the U.S. and have satellites at higher elevation angles. Although users may encounter limited accessibility today, the FAA intends to utilize additional geostationary satellites beginning in 2005. The final configuration will likely be four geostationary satellites. While they offer the advantage of always being in view, geostationary satellites have the drawback that they can only be in a certain part of the sky. For the United States, these satellites will always be to the south and below 50 degrees elevation angle for all but the southernmost parts of the country. However, the additional geostationary satellites at more optimal locations should provide dramatic improvements for nearly all users.

Two other limitations of the system are uncertainty in ionospheric delay and susceptibility to interference. Bounding the possible errors in the ionosphere, for single frequency users, is currently the dominant source of uncertainty for WAAS. Furthermore, the ionosphere above the U. S. is better-studied and less variable than most of the rest of the world. Thus, it will pose an even greater threat to availability in other regions. Vulnerability to interference has been the topic of several reports and results from our use of an extremely low power signal on a single frequency. Fortunately, GPS modernization addresses both problems. Two civil frequencies in protected spectrum bands allow users to directly measure their own ionosphere. This allows smaller uncertainties and greater availability. Furthermore, the aircraft has a reversionary mode if either frequency is lost since it can use the existing WAAS grid of ionospheric corrections. Additionally the modernized signals will have more power making them more resistant to interference. Current research focuses on further mitigation of these issues.

WAAS will provide numerous aviation benefits when it is declared operational in mid to late 2003. There will be enhanced runway capability as all usable runway ends can have some level of service. How low one can fly depends on local terrain and obstacles as well as airport infrastructure (paint and lighting). The increased accuracy throughout the service region will eventually allow closer separations with the same or greater level of safety as today's equipment. Additionally, the instrumentation required to provide and use WAAS is substantially less expensive than today's suite of equipment. In 2003, the first level of service, LPV, will be offered. This will allow aircraft to come as low as 250 feet above the ground before transitioning to visual guidance. Over time the level of service is expected to improve. In later phases better availability and lower decision heights will become

possible. To learn more about this exciting system please go to <http://gps.faa.gov/Programs/WAAS/waas.htm> or <http://waas.stanford.edu>.

Further Reading

Red Book Volume VI, Selected Papers on Satellite Based Augmentation Systems, published by the Institute of Navigation.

