Myths and Realities of Anywhere GPS

High Sensitivity versus Assisted Techniques

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Six GPS receiver chipsets from well-known manufacturers recently underwent evaluation at Engenex Technologies to test their high-sensitivity (HS) GPS and AGPS performance under various environmental conditions. This process revealed that some of the excitement about the capabilities of these GPS chipsets is indeed warranted, but definite limits still exist. Continued emphasis on improving sensitivity through any means may finally have yielded performance good enough for the majority of non-cell phone applications.

We stand at a point in the HS GPS and AGPS markets where application and system requirements will have more impact on overall performance. This means that in many cases, the accuracy and sensitivity of today's chipsets more than suffice, placing the priority on other aspects of a system's functions such as cost and complexity.

This article summarizes Engenex's experiences and highlights some key findings of our recent research. Our goal is to separate the myths of "Anywhere GPS" (including in this term *both* AGPS and HS GPS) from the practical reality and provide a basis for testing and analysis. We hope this information will help others in their evaluations of the new breed of GPS receivers and in determining whether HS GPS or AGPS is the right approach for their applications.

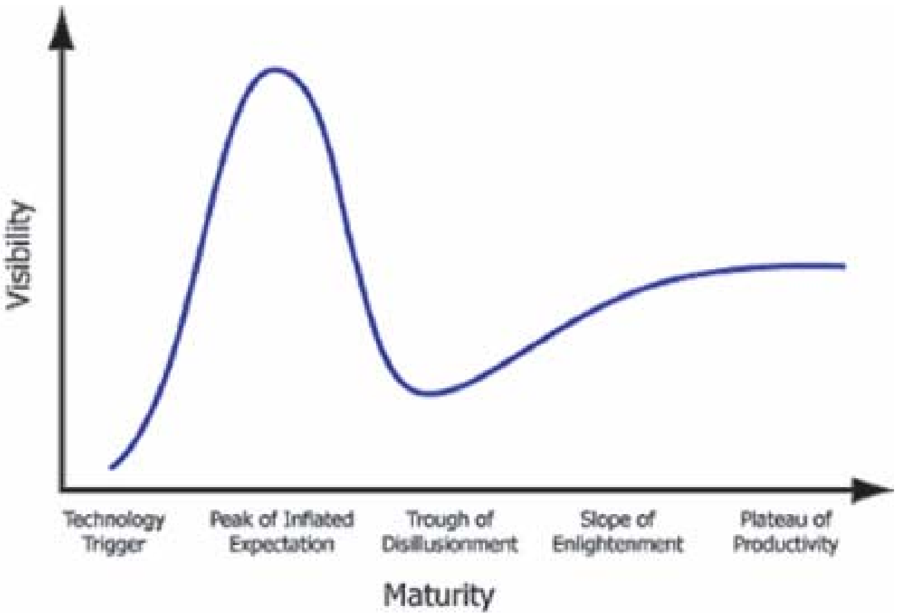

Figure 1: Gartner classic hype curve

We endeavor to separate promise from performance. As a preliminary step, let's view AGPS evolution in the context of the Gartner Hype Model (**Figure 1**). The generalized Gartner model seems to apply quite well to AGPS and tells us a few things about the general growth of AGPS. The case for AGPS reached the peak of the curve (the peak of inflated expectations) when Qualcomm paid a reported $1 billion for SnapTrack in March 2000.

A period of disillusionment followed as AGPS was implemented and rolled out into the mass market but failed to generate a wave of location-based services that so many analysts had predicted. During that time, alternatives to SnapTrack's AGPS emerged, causing some confusion as to who had the best solution, as well as many overstated claims and perceptions that AGPS receivers could work indoors through a pure User Plane implementation (see "Assisted GPS" in the May 2005 issue of *GPS World,* viewable on the magazine's website under the Innovation headbar), or as quickly as a normal GPS receiver (see explanation in the July 2005 issue, "Accurate Time Assistance," also on the website under Innovation). From a consumer perspective, the hype of AGPS far exceeded its actual capabilities and overshadowed some of the inherent complexities in delivering such a location service.

Today, the value of the Q-Point service — an "enlightened" version of SnapTrack with AFLT (Advanced Forward Link Trilateration) — is more realistic and climbing toward a plateau of productivity, with real services now showing up at the carriers, along with several credible alternatives. That is to say, the technology has just now passed the early hype and is reaching commercial success in the marketplace.

High Sensitivity or Assistance?

The recent articles in *GPS World* explaining AGPS technology did an exceptional job of examining the differences in the technology, but they didn't provide much in the way of actual results. As more engineers start to look at AGPS for their applications, a means of assessing performance needs to be discussed without forcing each engineering team to acquire a complete proprietary AGPS system. Further, some discussion is required to understand when to apply AGPS in a particular application versus a HS GPS implementation, which can have many of the same benefits at a potentially lower cost.

Although the basics of AGPS and HS GPS appear to be understood, we see our customers coming to entirely different conclusions about appropriate use of the same GPS chipset. Stated another way, the same chipset is being used strictly as a HS GPS receiver in applications where others have elected to use it in an AGPS mode.

For clarity let us define our terms:

- **AGPS.** Either assisted or aided GPS to determine a 3-D fix with improved sensitivity. Aided GPS techniques are generally understood to be either ephemeris or almanac aiding. Assisted GPS techniques include time, frequency, location and Doppler aiding and typically involve a wireless network infrastructure to communicate with the GPS device in the field.
- **HS GPS.** A high-sensitivity GPS receiver that operates in an autonomous mode but uses enhanced hardware signal processing and special algorithms to collect satellite code phase measurements very rapidly, and to propagate the error corrections forward in time. HS GPS receivers require a more-accurate time reference and might consume slightly more power during acquisition than equivalent non-HS GPS receivers.

- **AFLT.** Advan-ced Forward Link Trilateration does not use GPS satellites to determine location. Instead, the network-based service determines the phone's location using precise measurements from the tower range measurements to trilaterate, often to less than 100 meters, an approximate location of the user equipment. In general, this requires at least three surrounding base stations for an optimal position.
- **Autonomous GPS** refers to the mode of operation where the user equipment receives no *a priori* information from the location server and does not have any special algorithms or signal processing hardware to facilitate weak signal tracking.

TABLE 1 Expected performance for each positioning method

	AGPS	HS	AFLT
Time Required for Position Estimation	<20 seconds	20-35 seconds	<3 seconds
Accuracy	Good (<100m)	Excellent (<12m)	Poor (>1km)
Sensitivity	Excellent	Very Good	Network dependent
Coverage	Where network available	Everywhere	Where network available
Infrastructure	Web Based	None	Network
Yield	>90%	100%	85%
Implementation	Requires reference network and local receiver	Requires receiver to be ON within the previous 4 hours	Only one tower
Consistency	Excellent	Good	Poor
Infrastructure Cost	Low	None	Medium to High
User Equipment Cost	Moderate	Low	None
Interoperability	Yes	Yes	No
Overall Cost	Good	Excellent	Very Good

Table 1: Expected performance for each positioning method

Key Assessment Measures

We investigated the performance of several commonly available HS/AGPS receiver chipsets. We found immediately that making an "apples-to-apples" comparison of these receivers' high-sensitivity and assisted performance was going to be extremely difficult due to the major architectural differences and technical implementations. Undeterred, we set about defining a methodology to evaluate the performance in various environments and operating modes that would yield useful information about several key measures:

- **Position Fix Time**. This is the time for a user to achieve a complete navigation position, not a code phase or pseudorange measurement. With this definition we have not included network latency, that must be backed out to achieve a true comparison of AGPS technologies on different networks.
- **Accuracy**. In common practice the accuracy relative to a known point is expressed as the 2-D RMS, meaning the position is found to be within the defined accuracy circle 96 percent of the time.
- **Sensitivity.** This is a measure of the receiver's ability to track GPS signals in low signal environments. We measure two aspects: the ability of the receiver to acquire pseudo range/frequency/code-phase data and the ability of the receiver to process the navigation data (required to perform an autonomous solution).
- **Consistency.** Each chipset should produce consistent positioning results in different environments to be useful in a general solution. This means that in both AGPS and HS GPS operating modes the solution (receiver and supporting infrastructure in the case of AGPS) is capable of producing a positioning solution.

Table 1 shows these measures, and others, with respect to the three primary positioning methods (AGPS, HS GPS, and AFLT). The table seeks to indicate the expected results when these methods are employed. AFLT, shown for comparison, did not form part of our analysis.

Choice Summary

AGPS is the choice when consistent results are required in all environments, where wireless networks are available and service infrastructure costs are not an issue. HS GPS is the choice for broadest coverage, highly dynamic users, and when wireless networks are not available or service support costs are too expensive. AFLT is useful as a back-up and to augment AGPS, however its inherent low-accuracy makes it unsuitable as a standalone positioning solution for commercial users.

As part of our testing and analysis, we wanted to know how well the GPS receivers would perform in both the HS GPS and AGPS modes. Primarily, this was to determine which chipset was better suited for particular types of applications. Performance of the chipsets would be determined through a quantitative testing of each measure under various real-world scenarios.

In total, we tested six different GPS chipsets under various conditions and operating configurations designed to approximate common scenarios for both HS GPS and AGPS applications. In two of these cases, we were able to test the GPS chipsets AGPS modes directly since the requisite infrastructure was available to make the "assist." For the rest of the receivers, we approximated AGPS operation through configuration changes and injection of aiding data via a serial port from a PC. In all cases, HS GPS and AGPS testing was conducted independent of any wireless network, to focus on actual chipset performance rather than total solution performance that would also depend on the wireless network performance.

Overall Performance Results

The testing revealed that, in general, AGPS continues to improve performance (indoor usage and reduced battery power) by aiding initial acquisition time. The initial acquisition time was found to vary in these receivers from three seconds to two minutes depending on the type of aiding or assistance provided. However, claims that AGPS systems can deliver fixes "anywhere, anytime" are overstated. Assistance data enhances acquisition and initial sensitivity but not overall tracking capability after the receiver is locked on.

Figure 2 shows the expected performance of the positioning methods with respect to various assistance and aiding methods. Simple aiding measures with almanac and ephemeris definitely improve the sensitivity, but will have lesser effect on position fix time and have a negligible effect as signal strength weakens. Assistance with time, position, and Doppler information has the greatest effect on sensitivity and position fix time.

To test the sensitivity and consistency of the chipset receivers, these assist and aiding methods were simulated by injecting the various data types into the chip through the serial port and then measuring the receiver's time to acquire correlation lock on at least four satellites and the time to acquire useable ephemeris data (this is required for HS GPS autonomous mode). We applied these assist methods in each of the test environments with different signal levels.

As part of this testing, we also found that any analysis using finished receivers or modules could be misleading due to interference from the wireless transceivers and differences in the oscillators. Specifically, the same chipset in two different vendors' devices performed considerably differently. Quite a few receiver manufacturers that claim to have achieved weak signal acquisition have put demonstration or evaluation kits on the market, but comparing them can be a challenge.

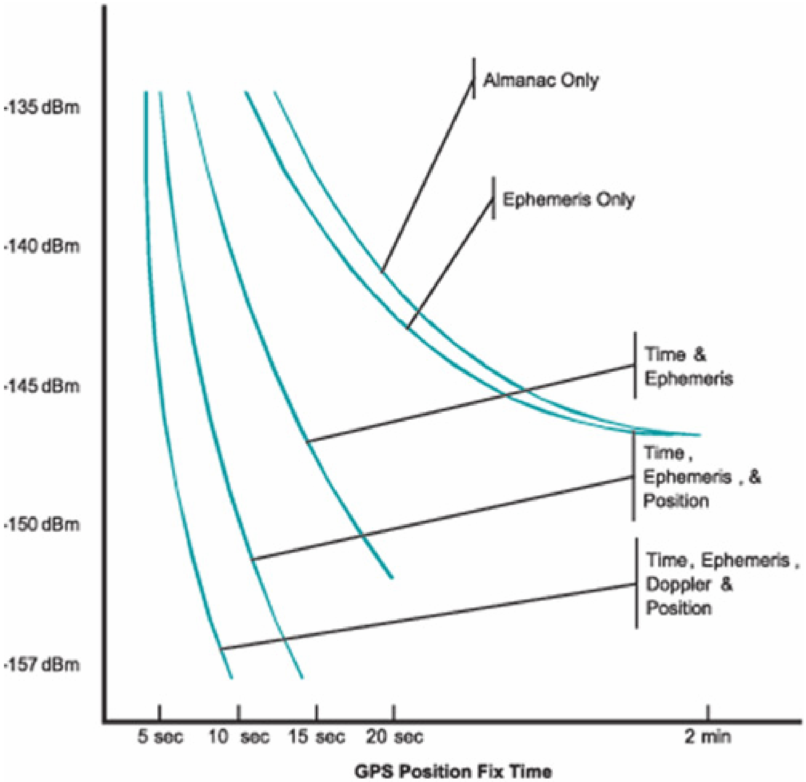

Figure 2: Benefits of assistance data.

Each evaluation kit was used to collect data in several different environments representative of the demand for high sensitivity. In general, all receivers tested were capable of tracking four or more satellites in residential indoor environments, even in the basement of a two-story house in a utility/furnace room with no windows, and a closed door. Several receivers tracked in more extreme environments, such as the closed glove compartment of a truck parked in a closed garage, or covered with a metal coffee can in the basement of a house. While these receivers tracked multiple satellites, they could not always produce navigation solutions.

Other Considerations

As discussed in the May issue of *GPS World*, several factors impact the benefit of assistance and facilitate the extraction of the navigation data. As long as the receiver has sufficient signal to make code-phase measurements, location determination is still possible with assistance from a wireless network. The data supplied by the network can include ephemeris elements, almanac elements, satellite health data, satellite clock and frequency corrections, atmospheric error coefficients, and so on.

Additionally, excerpts from the data sequence can be supplied to facilitate coherent integration over periods much longer than a navigation data bit interval.

Prior to analyzing a system as a candidate for AGPS versus HS, it is advantageous to first determine what the cost, implementation, power consumption, and performance requirements are for the system. Simply answering "the best of each" is not an engineering approach. The following are the parameters that should be considered in most system designs.

User Equipment Interference. While we did not evaluate this parameter specifically, we did see in the evaluation of some end-user equipment that degradation in the front-end performance of the GPS is quite common when the wireless subsystem is "on." The common approach is to simply disable the wireless subsystem entirely, but the ideal solution is to prevent interference in the GPS RF path to allow simultaneous operation for optimal battery life. This comes at a cost — if not real in parts count, then usually in sensitivity.

Cellular versus Packet-Based. In most cellular solutions (deployed CDMA and some next-generation GSM), the time and assistance data transfer is done in the control plane, meaning that the data is in the signaling channel. In other wireless systems (some GSM, and all WiFi and ReFLEX solutions), the data is transferred in an IP session that is commonly referred to as a User Equipment Plane (or User Plane for short) implementation.

Within the cellular community, different standards have emerged (see TIA-801 discussion in the next section and the May 2005 *GPS World* article). The fundamental differences start with the time transfer. A CDMA and a ReFLEX system have precise time available due to the protocol in use. GSM and TDMA networks do not and, therefore, resolve time using techniques also found on WiFi, WiMax, and other IP-based wireless networks. GSM by definition also uses smaller cell sizes (less than 25 miles in radius), which is nominally the limit for broadband wireless networks such as WiMax. This is advantageous for the later technologies because the errors or uncertainties in initial position are smaller.

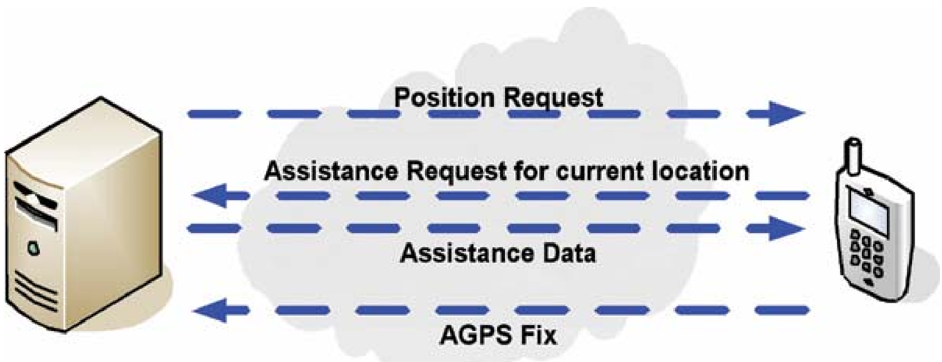

Figure 3: Typical communications sequence for AGPS position fix

AGPS Standards. Both cellular communities have developed standards for control plane AGPS messaging (CDMA uses TIA/IS-801-1 and GSM has implemented 3GPP TS 25.331). The performance metrics for User Equipment are defined for the primary cellular standards, for CDMA (TIA 916) and GSM (3GPP TS 25.171). There is considerable similarity between the assistance fields included in the two protocols. The minimum performance standards are measured in both cases using five separate statistical tests. The five tests are sensitivity, nominal accuracy (under typical signal conditions), dynamic range, multipath scenario, and moving scenario with periodic update. There is no standard yet for IP-based wireless networks but good usability dictates that a response time of less than 25 seconds should always be considered important.

Because these are the established parameters, these are the basis of the testing that we used to evaluate the performance of a group of well-known chipsets. Since these parameters change dramatically from receiver to receiver in a weak signal condition or in the presence of multipath, we expanded testing to include a means to capture the differences. **Figure 3** shows a typical communications sequence for an AGPS position fix.

Methodology and Results

Each GPS receiver under test was evaluated in several scenarios representative of expected weak signal environments, as well as in cases representing extreme signal degradation. The high-sensitivity receivers were also initialized in such a way as to simulate an assisted network approach. Each receiver had its memory cleared, was turned off for at least six hours, then had memory cleared again on power up to ensure no usable residual information was stored in the receiver.

Receiver maintains tracking and produces a navigation solution while placed in a closed glove box of a truck parked in a closed garage.

A Metal Can-Covered receiVer in the basement of a ranch-level house still tracks and produce a navigation solution.

The computer to which the GPS receivers were connected set time with TARDIS 2000, a PC application that can set PC system time to within five milliseconds of UTC time using atomic standards connected to the Internet. Computer time was then used to initialize receiver time. The GPS unit must also run long enough to allow the TCXO (temperature compensated crystal oscillator) to reach stability and this was also accomplished during the 15-minute interval.

This approach is a simulation of acquisition and tracking ability if assist data were provided. It is only an approximation since this allows for full download of ephemeris for all visible satellites, AGPS systems usually only provide ephemeris data for the optimum eight satellites.

In each test, at least two receivers were connected simultaneously to the laptop computer to allow direct comparison of results. No degradation in performance was noted as compared to tests in which receivers were run individually. The receivers were commanded to output data in NMEA-0183 format, and the log files were parsed with a PERL script, and loaded into MATLAB for analysis. The NMEA sentences provide data streams with a checksum as the last two characters to verify that the data was correctly received, and bad sentences were ignored.

Four environments were selected as representative of typical HS GPS and AGPS scenarios. Each of the tests repeated in each environment to provide a means to assess each receiver's overall consistency. The four environments are defined as follows:

- **Open sky view, outdoors**. The receivers/antennas were placed on an umbrella-covered glass picnic table on the exterior deck of a ranch-level house. The table was about eight feet from the house, and there was no significant blockage above 15 degrees elevation. This case represents a best scenario in which the antenna does not have significant blockage or multi-path in the immediate environment.
- **Basement.** In this environment, the receivers were placed on a table in an open room in the finished basement of a ranch-level house (wood construction, vinyl siding, tar shingle roof). This would represent most residential living scenarios.
- **Interior office.** The receivers were placed in an interior room of a school building. The building is constructed of brick and steel, and the room had no windows. This scenario is representative of placement in an office or work setting, and offers the most-significant challenges to tracking in the cases tested. It is likely that all signals received are from multi-path reflection, or heavily attenuated by the building's structure.
- **Urban canyon.** This test case consisted of collected data in an urban canyon environment in downtown Colorado Springs, Colorado. The receivers were set up approximately 10 feet from a 10-story office building on a bus bench in a weather enclosure. Pedestrian traffic, both on the sidewalk near the enclosure, and within the enclosure itself was a factor, as well as vehicle traffic from the nearby street. Across the street was a 15-story office building, with other office buildings on either side. The signals in this environment are mostly multi-path reflections from the buildings, and from the metal/glass bus stop enclosure.

Tracking results for two of these environments are shown in the accompanying figures. Additionally, extreme degradation testing data was collected with each receiver placed in two metal cans in a basement, and with each receiver placed in a glove box of a truck parked in a garage.

The MATLAB analysis carried out on the parsed NMEA data results in the following plots. While each receiver provides an estimate of signal-to-noise ratio for each satellite tracked, these can not be used to compare between receivers. However, the signal-to-noise values are a valid comparison for a given receiver type between scenarios.

Therefore for inter-receiver comparisons, the items of interest are the ability to acquire and track four or more satellites, and the precision of the navigation solution produced. Additional tests were completed observing time-to-first-fix in each environment from both a hot start (full ephemeris) and from a cold start (no ephemeris or almanac).

Figure 6 and **Figure 7** show tracking results from one high-sensitivity receiver used in this study under two of the environments tested. Each graph consists of three subplots that show various items of interest.

- **Subplot A** shows the navigation solution scatter about the mean solution. This plot is obtained by logging the Lat/Lon solution points, creating a mean solution, then rotating the differences of each point from this mean into an East/North Up reference frame. The plot is then generated from the horizontal components, and Circular Error Probability is calculated as the median of the horizontal deviations from mean.

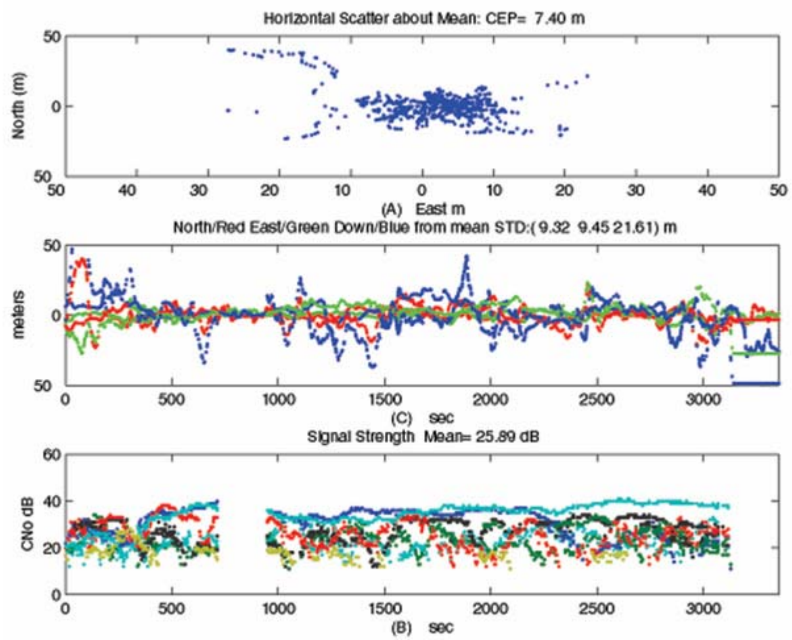

Figure 6: HS GPS receiver in urban canyon

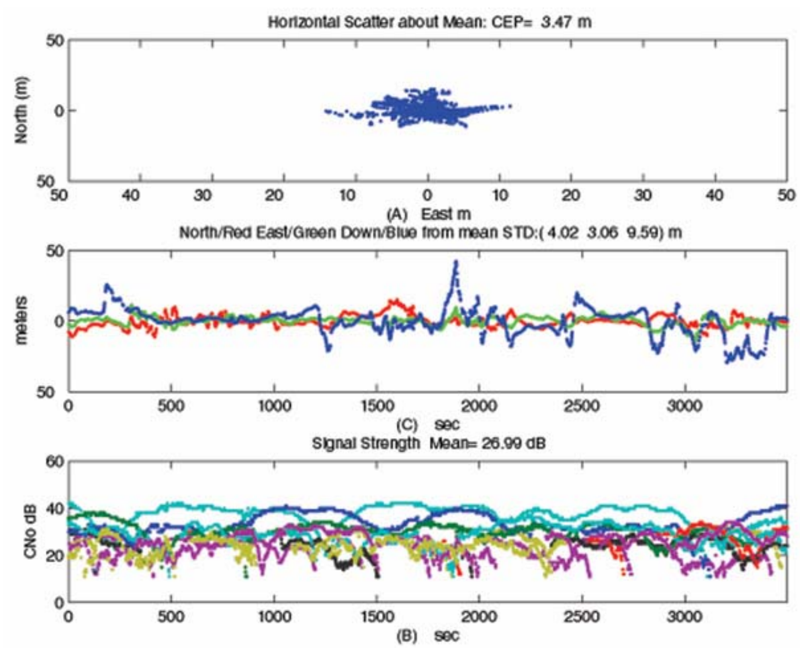

Figure 7: High-sensitivity receiver in interior office of brick/steel building

- **Subplot B** shows the deviation from the mean solution in each direction (North, East, Down) as a function of time.
- **Subplot C** shows the C/No from each satellite tracked. Again, these plots are useful for comparison of the same receiver in different scenarios, but are not necessarily calculated the same between receivers.

Of particular interest is the fact that the same receiver placed in an interior office setting (the most degraded of the indoor environments) seemed to perform better (lower CEP and higher precision, lower standard deviation, higher SNR, and so on) than when placed in an urban canyon environment.

This is likely due to the fact that the office setting was static and unchanging, while the urban environment, though the receiver was static, was a dynamic environment with pedestrian and automobile traffic. This changing environment likely results in a more-challenging multipath environment, which adversely affected the tracking results. In fact, in the urban setting, the receiver under test lost all ability to track for several minutes, as indicated in SNR plots and deviation versus time plots (Subplots C and B, Figure 6).

Of the six receivers under test, four were able to lock on and track satellites. Of the four, only three were able to actually produce a navigation solution. The net result was that only 50 percent of the receivers were able to provide code phase and pseudorange measurements in all four of the challenging environments described above, but these same receivers were also able to track in the extreme environments shown in the photos.

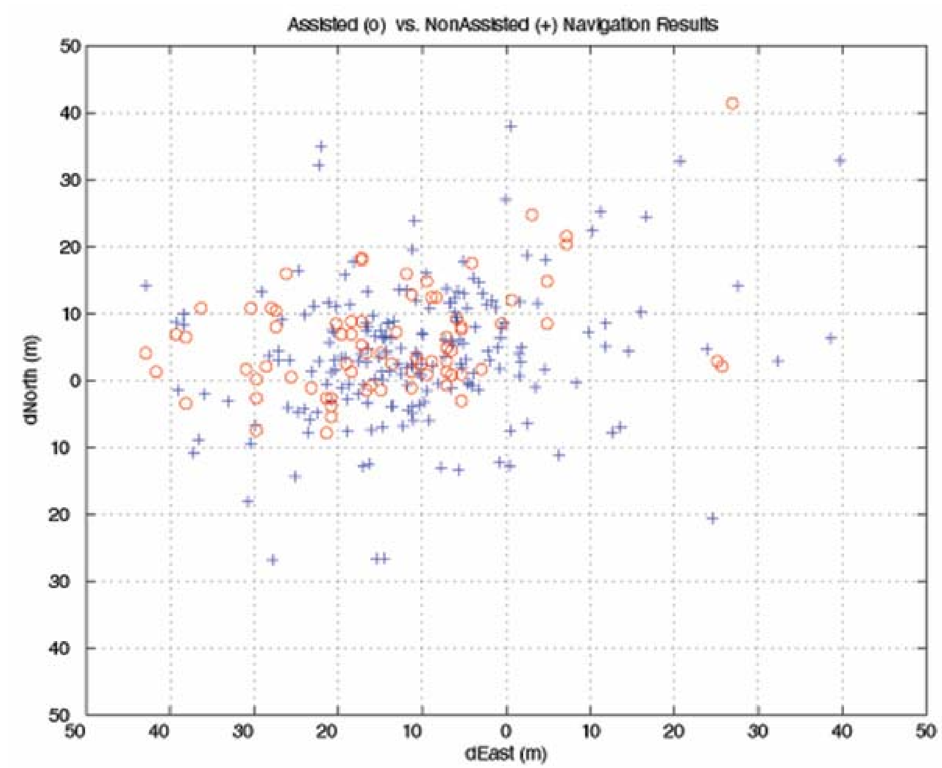

Figure 8 Plot of HS GPS and AGPS fixes

AGPS Accuracy and HS GPS

In an actual test of real-world use, the HS GPS provides a solution that is more capable of handling dynamics, and some of the receivers tested clearly did a better job when moving in an urban area. These same receivers were not the most accurate in a static environment when compared with the same device operating in an AGPS mode. As shown in **Figure 8**, it was relatively easy to demonstrate similar levels of accuracy between HS and AGPS in low-dynamic/low-signal environments.

In this experiment, the HS GPS and AGPS devices were placed in a low signal environment. The HS GPS device was allowed time to initialize and obtain useable navigation information such that it could produce position fixes on a consistent basis. The AGPS device was powered on allowing the oscillator to stabilize, but the GPS components were inactive. The devices were polled periodically — one in autonomous mode and one using full assist with server computed fixes. The results for the devices indicated as the dynamics increased, the initial accuracy of the AGPS solution was predictably worse but quickly converged when allowed to operate for periods longer than the short sampling interval found in a typical handset.

TABLE 2 AGPS an HS GPS Performance in a Low Dynamic and Low Signal Environment

Device Mode	East Std. Dev.	North Std. Dev.	Horiz. Std. Dev.	CEP
AGPS	8.8217 deg.	20.5404 deg.	22.3 m	16.0850 m
HS GPS (Autonomous)	14.7323 deg.	18.5832 deg.	23.71 m	19.2698 m

Table 2: AGPS an HS GPS Performance in a Low Dynamic and Low Signal Environment

Conclusions

AGPS testing can be done in a variety of ways. Without understanding the ultimate operational performance desired, the decision to provision a GPS system for the delivery of assistance data wirelessly can be misleading. This assistance can be supplied one of two ways, via user plane or control plane, but that does not impact chipset selection.

The use of assistance can result in much faster acquisition of weaker signals, and can facilitate navigation solutions that would not otherwise be possible. The benefit of the time assistance is dependent in a complicated way but is extremely important in the system design. In the User Equipment design, interference issues need to be carefully considered, as well as time transfer and maintaining time accuracy. The results of our study do not attempt to make statements about particular AGPS solutions but rather show the performance of AGPS devices and HS GPS devices can be very close in difficult environments.

Our evaluation shows that AGPS performance has a place when integrated with wireless networks to clearly benefit the overall fix yield and consistency. The AGPS receivers considered all make use of some conditioning of frequency and time. Our results show that many applications achieve acceptable results with high-sensitivity GPS receivers. The new generation of HS GPS receivers, especially those with an ability to implement User Plane assistance, should be analyzed for augmented performance only if the application requires improvement in the consistency and yield of the fixes for a very short sampling interval.

All the receivers tracked well in the residential and urban environments. Only three receivers were effective in the extreme environments, where degraded receiver performance was the norm. For these three, it was difficult to find environments where the receiver could not at least correlate.

These results showed that an analysis of AGPS receiver level performance can be done by using a system level test. It was also determined that using the actual wireless delivery mechanism does not test AGPS or HS GPS, rather it tests latency. Accuracy and power consumption are the parameters most often being measured and advertised as necessary to evaluate AGPS or HS receivers; these parameters didn't directly correlate with the best sensitivity results. Because of the large variation in startup times and current draw during that time on all the receivers, one can not simply use current statistics to select an ideal receiver. The HS GPS receiver could not outperform the AGPS receiver on power even though the HS GPS receiver had a current draw in the navigation mode that was 50 percent less than the AGPS receiver.

One more fact to consider when setting up your own HS GPS or AGPS "Reality Test": The sensitivity required by cell phone standards is not sufficient to meet the needs of indoor GPS. Hence, evolution of alternative (such as existing ReFLEX and newer IP-based) wireless AGPS systems will continue to drive the state of the art in this much hyped and now better understood technology.

Manufacturers

The GPS chipsets tested were made by **SiRF Technology, u-blox, QintetiQ, Global Locate, Sony**, and **Texas Instruments.**

Engenex Technologies

Based in Bellevue, Washington, Enegenex Technologies has compiled a full report providing actual receiver data, high sensitivity and assisted approximations, available for a fee. This article was adapted from the report prepared by Kenn Gold with assistance from Michael Mathews and Pete MacDoran. Data sets were collected by Robert Gold.