BENEFITS AND ISSUES ON THE INTEGRATION OF GPS WITH A WIRELESS COMMUNICATIONS LINK

Raymond DiEsposti, Steve Saks, Lubo Jocic
The Aerospace Corporation
Los Angeles CA 90009

Capt.Jordan Kayloe
Space and Missile Center
Los Angeles Air Force Base, CA 90009

Abstract

The NAVSTAR Global Positioning System (GPS) provides worldwide positioning service to 2-Dimensional, 95 percentile accuracies of 100 meters for the Standard Positioning Service (SPS) for civilians and about 15 meters for the Precise Positioning Service (PPS) available to authorized users only. In the past, GPS has been combined with other instruments, such as Inertial Navigation Systems (INS) and Doppler radars for navigation, and precise frequency standards for timing, to produce more robust and accurate integrated systems. Within the past few years, significant advances have been made in GPS receiver and wireless communication (comm) technologies. Handheld devices for GPS and Personal Communication Service (PCS) have decreased in size and cost, yet increased in capability and battery life. This paper analyzes the benefits and discusses conceptual design issues associated with a tight integration of GPS with a wireless communication link for both military and civilian users. In addition to providing a means for data and voice communication, the comm link can provide GPS initialization data that could significantly improve GPS acquisition and navigation (nav) performance, especially in stressed (interference prone) environments.

INTRODUCTION

Two technologies that have recently become prevalent in the private sector are wireless PCS (including cellular telephony and data messaging) and GPS. Many commercial applications require that the two technologies be merged. For example, fleet resource monitoring and emergency notification devices integrate both technologies. Since GPS and wireless PCS technologies are continuously shrinking in size and power consumption, it is reasonable to expect that the two can be effectively integrated into a single, practical handheld device in the near future. Also, the recent availability of low-cost GPS chip sets now allows a cost-effective way for vendors of PCS devices to integrate GPS into their products.

In a manner similar to GPS/INS integration, the two technologies of GPS and wireless communication can complement each other very well. In the GPS/INS union, the INS has good short-term stability, but poor long-term stability due to IMU drift. On the other hand, GPS accuracy is independent of elapsed time, but short-term errors on the order of several meters (PPS user) exist due to satellite switching (in the navigation solution), multipath, ionosphere, etc. Therefore, when combined, the GPS can be used to calibrate the long-term INS drift error, while the INS can be used to aid (steer) the GPS tracking loops and provide smoothing for GPS error fluctuations. A tight GPS/INS integration also enhances performance in stressed environments.

Now, consider the integration of GPS with wireless communication. Data supplied via a wireless comm link can greatly assist GPS initial signal acquisition. Without prior initialization data, a GPS "Cold Start" fix (acquisition without prior almanac, user location, or time data) may require several minutes or more. However, if initialization data can be supplied by a wireless comm link, GPS acquisition could be very fast, on the order of a few seconds. For GPS handsets operated in the quick fix mode, fast acquisition may have a large, positive impact on battery life. Accurate initialization data will allow a more effective GPS acquisition in the presence of interference and spoofing. Some of the other navigation benefits of a comm link are: (1) the ability to receive differential and ionospheric corrections for improved accuracy, (2) the ability to receive real-time GPS integrity information, (3) the ability of the user to report his location or intelligence data back to an emergency, central control, or monitoring center, and (4) the ability to assess positions of other users reporting their positions on a satcom-based mobile internet.

The addition of a comm link to a GPS user set provides the GPS user with obvious benefits,as discussed above. However, the benefits of adding GPS to assist the user whose primary function is communication, are also great -- In this case, the addition of GPS satisfies the needs of many commercial users to maintain accurate time and to report position to the resource control center for billing purposes. GPS further enables the following comm system features: (1) pre-synchronization interference with other comm links would be minimized in situations where GPS time is available to comm users prior to the uplink synchronization time-search, (2) control channel orderwire can be simplified if the user could report his position and time to the control center in the initial contact, and (3) a database of the mobile users' positions in the control center would improve resource allocation.

Most of the remainder of this paper further describes the ways in which a tightly coupled, wireless comm link could aid the primary function of navigation for a GPS user.

WIRELESS COMMUNICATION LINK AIDING GPS

Data received from an existing wireless comm link can benefit both GPS performance and security. Both speed of acquisition and anti-jam capability (increased Jammer/Signal (J/S) capability) for acquisition and track are possible. Navigation accuracy can be improved through the transmission of differential and ionospheric corrections. Security can be improved by using the comm link for transmission of electronic "black" keys for GPS encryption. Assuming that the comm link is tolerant to interference (stressed environment), it allows an efficient solution to the Direct-Y code acquisition problem. The direct acquisition of GPS Y code, which has been advocated as a more reliable method of protecting the availability of GPS, requires prior knowledge of accurate time, rough user location, recent almanac, and cryptokey. The maintenance of thesedata when the GPS receiver is turned off for extended periods of time represents a logistics challenge, wnich can, however, be greatly simplified through the use of a wireless comm link.

Acquisition Time Enhancement

GPS acquisition speed is enhanced by the comm link's ability to provide the equivalent of the satellite's broadcast 50 Hz navigation message at a faster rate or at a much higher power level. The time and data maintenance requirement (necessity to maintain accurate time and recent nav message data) associated with the Direct-Y mode can be eliminated, since the comm link can provide the data at any time independent of the satellite signals. Faster acquisitions will result for both Normal Start (acquisition with satellite almanac, rough user location, and time) and Cold Start conditions (acquisition without prior almanac, user location, or time data). For both Cold Start and Normal Start initial conditions, the time required to read the entire 50 Hz nav message for almanac, ephemeris, and other data could be reduced from 12.5 minutes to a few seconds. Normal Start mode would then use the almanac or ephemeris nav message data along with resident user location and time. For Cold Start conditions, user location and time could be provided by the comm controller at the basestation. Time accurate to a millisecond and position to 300 km are reasonable in theater. Repeated time pulses also allows syntonization of the receiver oscillator frequency. This further enhances acquisition by reducing the frequency offset search space.

Acquisition Anti-Jam (J/S) Enhancement

Whereas the GPS satellites are at an altitude of about 20,200 km, a terrestrial line-of-sight comm transmitter may be only a few 10's of kilometers away. Even at 100 km, the ratio of the 1/R squared path loss of a locally broadcast signal compared to a satellite signal amounts to over 40 dB. The GPS signal, as received at the Earth's surface, varies between -166 dBW (L2 P(Y)-code) and -160 dBW (L1 C/A-code), about 20-25 dB below ambient noise level. Through correlation despreading, the signal is amplified above the noise level to enable acquisition and tracking. Future satellites may employ spot beams which are capable of increasing power in a region by 20-25 dB. However, a local terrestrial comm link does not have the severe power constraints associated with the current GPS satellites,which derive their energy from solar power. Local comm signals, broadcast from a base station, can be several orders of magnitude stronger than the GPS signal.

The GPS C/A code acquisition threshold is 24 dB J/S. However, once the signal is acquired and the tracking loops have achieved lock on Y code, the J/S threshold to maintain Y code tracking/data demodulation exceeds 40 dB. Also, the J/S threshold to maintain code loop track can extend beyond 50 dB. Since the comm link can provide the GPS satellite message data, there is the possibility that GPS navigation can operate in the code only track mode. (GPS carrier track and data demodulation are no longer required, and code tracking can be extended by either data stripping the nav message data or squaring.) Accurate time and velocity aiding data may allow a direct handover from acquisition to code track without achieving carrier lock. -- Thus, with the addition of a higher power comm link, there is the potential of increasing the J/S capability of GPS operation by more than 20 dB.

Similarly, for a comm link provided via satellites, the satcom to omni receiver link has to be 20 to 30 dB higher than the GPS signal in order to enable more than 20 dB higher data rate (e.g., 4.8 kHz comm vs. 50 Hz GPS data rate). If the satellite is built for comm signal levels, it can also provide similar nav signal strength for acquisition.

Tracking Anti-Jam (J/S) Enhancement

High-power navigation signals compatible with satcom signal strength would increase the J/S capability for tracking by 20 dB to 30 dB. In addition, it may be possible to extend the J/S tracking threshold through the procedure of "data stripping", in which the coherent integration time is extended beyond the 20 msec data bit interval by removing the known data bit from the signal stream. In this case, the GPS data bits can be provided through the comm link.

Security Enhancement

A wireless comm link capability in GPS receivers would greatly facilitate the planned implementation of electronic keying. The comm link provides a very efficient means for the distribution of "black" keys. In addition, more sophisticated encryption schemes can be developed when two-way comm is available. The integration of comm and nav terminals reduces the number of crypto systems for platforms that require both user terminals.

Logistics Enhancement

Direct-Y requires the maintenance of recent almanac or ephemeris data, rough user location, accurate time, and keying data [2]. When a receiver is turned on, these data can be kept current. However, when the receiver is turned off, time starts to drift based on the receiver oscillator instability. In general, increased oscillator stability requires increased power, which adversely impacts battery life, especially in handheld devices. A properly designed comm link can provide time to better than a millisecond accuracy. Also, as already discussed, the above data could be provided relatively quickly with a comm link having data rates of several kHz. Hence, the comm link can provide a enormous reduction in logistics burden associated with implementing Direct-Y code acquisition.

Accuracy Enhancement

The comm link can provide differential corrections, which can be applied to achieve accuracy on the order of a few meters, or even a few centimeters for cases when the carrier cycle ambiguities can be resolved.

Integrity Enhancement

The comm link can provide very timely integrity information related to satellite health and status, and the existence, characteristics, and location of any interference sources. If comm link data received by the user to initialize the GPS function can be provided securely and reliably, then the risk of spoofing GPS during acquisition can be significantly reduced. -- Independent, precise timing data from the comm link may be used to detect erroneous signals. If carrier cycle ambiguity tracking can be applied, extremely reliable Receiver Autonomous Integrity Monitoring (RAIM) may be achievable, since a signal phase error of only a few centimeters is detectable.

INTEGRATION AND IMPLEMENTATION ISSUES

Some of the arguments discussed above relating the benefits of the merger of GPS and wireless comm link also apply to military users. However, many additional issues need to be considered by the military user that may be irrelevant to most civilian users.

Some conceptual design alternatives and other issues common to both are listed below:

- Two way vs. one way comm link. Significant benefit related to enhanced GPS performance requires only a one-way comm link, from the base station to the user. A one-way user set only requires a comm link receiver and not a transmitter. Thus, considerable cost and improved power consumption can be realized compared to a comm link needing a two-way capability. However, some electronic keying schemes require a two-way capability. Some military users need to remain "undetected". Thus, in some cases, a return path comm link may not be acceptable, unless a Low Probability of Detection (LPD) signal is employed.
- Partial GPS receiver integrated with a two-way comm link. An example of such a device is a translator, which takes in GPS signals, then rebroadcasts them to some central processing facility at a base station. The central processing station performs the tracking and navigation functions, adds in corrections, such as ionospheric, tropospheric, or differential, etc., then broadcasts the solution back to the user. However, in such a system, data latency or decorrelation of spatial corrections may be issues for the user that is located at a large distance from the base station. For a user moving at sufficiently high speeds, data latency may also effect navigation accuracy. Also, a partial receiver will not be able to operate as an independent, autonomous device -- that is, it will be useless when the comm link and central processing station is unavailable. Another advantage of this approach is that the user location is known by the central processing facility, which can then also be used as a resource management facility and command center. The ground and space-based cellular comm link infrastructure to support this type of capability is being rapidly developed in many parts of the world.
- Complete, autonomous GPS receiver is one that is able to operate with or without the comm link. This receiver has the capability to acquire and track the GPS satellites and compute the navigation solution when comm data are not available (in the same way that GPS user sets currently operate). However, when the comm link is present, the GPS performance, accuracy, and integrity can be greatly enhanced, as discussed above. The comm link can be used to provide accurate initialization data from the base station (such as almanac, ephemeris, accurate time and syntonization data, approximate user position,

and in the case of the military user, keying data). The availability of this data will allow very fast acquisition (even Direct-Y) and track of the GPS satellite signals, typically within a few seconds.

- Reporting information back to a central control facility. Both civilian and military users may benefit from this capability. Again, this requires that the user set include a comm link transmitter. Some commercial users may only need the transmit capability, in which case the user location (or measurements) is automatically sent back to the monitoring station. At the monitoring station, differential corrections can be applied for improved accuracy. In the case of military users, the ability to relay user location (and other intelligence information) to a central control facility is consistent with DoD plan to "digitize" the battlefield. Friendly and unfriendly forces could be digitized on a computer database and map. Information, such as location and description of friendly and unfriendly forces, provided through the receive comm link, would also be very useful to the user.
- Interference of comm link with GPS signal. Since a local comm link signal may be several orders of magnitude stronger than the global GPS signal, integrated systems need to be properly designed so that the stronger comm link signal does not jam nor cause degradation of the local GPS signal.

MILITARY UNIQUE ISSUES

- Implementation schedule. The cycle time associated with the acquisition, design, and launch of military satellites usually consists of 5 to 10 years (or more). On the other hand, cycle times for the acquisition of GPS user equipment are much shorter, 2 to 3 years. Since wireless comm technology is available today, there is the possibility of adding this enhancing technology within a much shorter time frame.
- Integration with a data bus. If the GPS and comm transceiver are integrated via a platform data bus, there is the issue of data latency. While latencies on the order of tens of milliseconds may be adequate for nav message data transfer, they may not be for time transfer to enable Direct-Y acquisition. Rewriting the data bus software to decrease latency may be very costly. We define a tight integration as one in which the GPS receiver and comm link transceiver are connected directly to each other, and to each respective antenna, bypassing the platform bus. -- In this case, latency errors are negligibly small.
- Comm link security. For military applications, there are several issues related to the security of the comm link. First of all is resistance of the comm link to jamming. The ability of the comm link to be spoofed, or provide misleading information to either the user, the GPS receiver, or the base station/control facility is also an important concern. For user sets that transmit and receive, there is also the concern of giving away the user's location and message. These concerns may require that a bursty comm link be designed using direct sequence spread-spectrum techniques with encrypted signals. With encrypted comm signals, there is the additional problem of key distribution.
- Comm link signal acquisition. Other issues related to military comm link usage are the speed of acquisition of the comm link signal and power levels. The comm signal can be designed so that acquiring the comm link signal is faster than typical GPS acquisition, while maintaining security. For a fixed data rate, the frequency hopping techniques can enable faster acquisition than direct sequence spread spectrum. Even if the signal is encrypted, this should be the case since the comm transmitter is not as severely power-limited as the GPS signal broadcast from current satellites. Higher comm link power levels (relative to GPS signal) can allow the increase of C/A code acquisition performance from the current J/S of 24 dB to the GPS data demodulation threshold of about 40 dB. In fact, with a comm

link providing the GPS nav message data, potential anti-jam performance may extend out to the Y code tracking threshold of about 50 dB for some cases.

- Comm link data rates. Also of issue is the comm link data rates. While the GPS data rate is 50 Hz, data rates approaching 5 kHz, typical of voice communication, are desirable for high speed transmission of GPS initialization data. The complete GPS data message is 37,500 bits long (12.5 minutes @ 50 Hz). The satellite constellation almanac dataarespread out over 25 pages of length 30 sec each, whereas, the precise ephemeris data repeats every 30 sec. The almanac data assist acquisition by providing satellite position data to determine which satellites are in view. Almanac dataarealso used to reduce the time/frequency search space when combined with a priori user location/velocity and time. The ephemeris dataaretypically used for the navigation solution. Whereas almanac data several weeks old or more may provide sufficient accuracy for acquisition, in most cases, the ephemeris data must be read prior to computation of the navigation solution. Together with the overhead time associated with satellite C/A code acquisition, bit synch, frame synch, settling of tracking loops, etc., this limits the acquisition time to be no smaller than about 40 seconds, even for a warm receiver. However, assuming a comm link data rate of 5 kHz, all of the GPS nav message can be relayed in about 8 seconds, along with rough user location, and fairly accurate time. The GPS acquisition and navigation solution should then require no more than about 10 to 15 additional seconds, even for the case of a prior "Cold" receiver.
- GPS enhanced capability using comm link vs. advanced technology, such as precise clocks and advanced Digital Signal Processing (DSP) chips. Improved GPS performance (improved security and J/S) can also be realized without a comm link through the implementation of a near-autonomous form of Direct-Y employing advanced technologies. However, at this time, a robust form of Direct-Y is technically very difficult. Direct-Y is further complicated by the necessity of periodic operations needed to maintain current time and keying information. Direct-Y acquisition time can be greatly improved through the introduction of advanced, high accuracy, low-power time sources and DSP technologies. Then, if the keying methodology can be simplified, fast, reliable operation may be achieved without the use of a receive comm link to provide GPS initialization data. However, even with technology to provide "fast" acquisition, given the GPS signal structure, the fastest possible fix time for the general case, as discussed above (and without a comm link or direct data input via wireline), is about 40 sec. This constraint is not present with a high data rate comm link -- the ephemeris data could be quickly sent to the user in under a second.
- Global vs. local comm link. A global comm link using communications satellites would be widely available without the need to set up the infrastructure associated with terrestrial base stations. Also, dedicated military satellites could be more easily controlled and protected. Even though satellite signal power can be concentrated in spot beams, local base stations could have much larger power advantages than satellites, especially important in stressed environments. However, terrestrial stations often have significant range limitations associated with the line-of-sight constraint. In addition, they are very vulnerable to enemy or terrorist actions, when they transmit high-power signals above the ambient noise level. Improvement on these limitations is possible by placing the comm transmitter or relay station on a stand-off, high altitude platform.

- Integrated GPS/INS/comm link. Faster PPS fixes (when GPS is aided by the comm link), possibly even centimeter-level accuracies associated with carrier cycle ambiguity resolution, may greatly improve the speed and accuracy of INS calibration in integrated GPS/INS systems.

CONCLUSIONS

This paper provides a discussion of the benefits to GPS users of an integrated wireless communication data link. Recent technological advances in the field of wireless PCS make such a capability practical (size, battery life and cost considerations) even for GPS handheld user sets. The primary benefits of a receive comm link are: (1) very fast acquisition, even for the case of a "Cold" user set, without the need for advanced clock and digital signal processing technologies, (2) improved J/S capability during acquisition and possibly track, (3) if comm link is secure, reduced risk of spoofing GPS, (4) improved accuracy through the use of broadcast differential corrections, (5) improved integrity, (6) greatly reduced logistics burden associated with the Direct-Y acquisition mode of operation, and separate nav and comm crypto systems and user equipment, (7) reception of other sensitive data, such as location and description of friendly and unfriendly forces and commands, and (8) for handheld user sets, potential for greatly improved battery life. The main benefit of a transmit comm link would be to relay user location (and other intelligence data) and to communicate with a central control facility.

In some cases, it may be possible to implement a receive comm link through the use of a pseudolite type of local transmitter that broadcasts using a GPS-like signal, received through the GPS antenna and receiver, and that does not interfere with the satellite signals. In this case, the comm link receiver becomes an integral part of the GPS receiver.

REFERENCES

[1] GPS Interface Control Document ICD-GPS-200, Revision C, 10 October 1993.

[2] Direct-Y: Fast Acquisition of the GPS PPS Signal, O. M. Namoos, R. S. DiEsposti, Proceedings of the 27th Annual precise Time and Time Interval (PTTI) Applications and Planning Meeting, Nov 29 - Dec 1, 1995.