Whitepaper: Assisted GPS

1 Abstract

To provide a Position, Velocity, and Time (PVT) navigation solution, an autonomous GPS receiver must work within the limitations of the GPS system (the observable being the L1 signal as received by its antenna) as well as those of the receiver itself. There is a set of tasks that must be accomplished by any GPS receiver to achieve a fix from a cold start. In early receivers, the cold start Time to First Fix (TTFF) was relatively long due to hardware and software limitations. However, today's receiver designs have evolved to the point where the TTFF is essentially due to the (slow) speed of data transmission by the GPS satellites (assuming good signal conditions). Motivated in part by the E-911 mandate, developers have come up with several schemes for assisting a receiver with data that would otherwise have to come from the GPS signal.

This paper discusses some of the Assisted GPS (AGPS) schemes.

2 Problem Statement

For early GPS receivers (for this discussion, let's say those manufactured before 12 correlator channels became the norm for commercial receivers), the cold start Time To First Fix (TTFF) was dominated by several factors, including:

- Constructing the list of visible satellites, especially if the almanac was not current. If the almanac was missing, invalid, or aged out (some months old), a "sky search" (sometimes called a "frozen start") would be necessary. Since it takes 12.5 minutes for a GPS satellite to transmit a complete almanac, TTFFs of 15 minutes or more were not uncommon. Of course, construction of the list of visible satellite depends on the receiver having an initial estimate of the user's position as well as the approximate date and time, so a sky search may be necessary even with current almanac.
- Searching the Frequency and Code-phase bins (a 2-dimensional search) for a correlation peak for each of the visible satellites' Gold code. This could take several minutes (possibly many minutes for an old 1 or 2-channel receiver).
- Identifying the beginning of a data bit (bit synchronization) and frame (frame sync) to permit decoding of the Navigation Message.

However, with current 12-channel (or more) receivers, these tasks take only a few seconds and are no longer the principal delay in achieving a valid navigation solution (assuming good signal conditions).

Today, the most time-consuming part of the process is actually the acquisition of the navigation data from each of the satellites used in the nav solution. This data is contained in the Navigation Message and is transmitted at the leisurely pace of 50 bits per second (remember that the GPS signal is not intended to be an efficient data transmission protocol). The Nav message is organized in a frame of 1500 bits consisting of 5 subframes of 300 bits each, and each subframe takes 6 seconds to transmit (300 bits / 50 bps). The subframe is the smallest usable independent transmission unit. It must be checked to insure that subframes 1, 2, and 3 have matching values for Issue of Data (and thus are part of a matched set).

Since a frame consists of 5 subframes, the best-case cold start TTFF is 30 seconds (again, we assume that signal conditions are good and no bits are corrupted – therefore no parity errors are detected). Also, this best-case TTFF assumes that the receiver began decoding data just at the beginning of a subframe. One must therefore add an average delay of 3 seconds (it could be anywhere from 0 to 6 seconds – the time spent waiting for the beginning of a subframe). If we include a few more seconds for the receiver to initialize itself and perform all the other tasks required to begin decoding the nav message, we see the typical 35 second cold start TTFFs exhibited by the current crop of commercial grade autonomous GPS receivers.

The satellite clock parameters (in subframe 1 of the nav message) and ephemerides (in subframes 2 and 3) are absolutely essential to computing the nav solution. The GPS receiver uses the satellite clock corrections to determine the precise time that the signal was sent, and the orbital parameters are used to calculate the satellite's position in space at that time. It should be noted that some receivers may "cheat" by flagging a fix as valid even before subframes 4 and 5 (which contain health and almanac data, among other things) have been received, thus shaving 0 to 12 seconds from their TTFFs. Also, most receivers will flag a fix as valid (which includes the UTC) even if the current value for the UTC offset (leap second correction) is not known. So, even though the receiver knows the GPS time, the UTC display may be off (by 14 seconds as of this writing). The reason for this is that the number of leap seconds (which is the integer part of the difference between GPS time and UTC) is transmitted in page 18 of subframe 4 – once every 12.5 minutes. That is much too long to wait for a valid fix.

In the early days of GPS, a cold start TTFF of less than one minute would have seemed like a fantasy. However, today's expectations are much higher, to the point where 30 second TTFFs may be unacceptable to the user. The E-911 mandate also places requirements on a cellular phone system to be able to determine the location of a Mobile Station. Indeed, if the signal level is below about -143 dBm, an autonomous (unaided) GPS receiver may not be able to achieve a valid fix at all because the signal is too weak for the receiver to decode the data message. This situation is exacerbated by the small antennas typically available in wristwatches, PDAs, and cellular phones.

It is to reduce this cold start TTFF that a number of schemes for aiding the receiver were conceived. Another benefit is that an assisted GPS receiver may be able to calculate a position fix even when all visible satellite signals are below the data decode threshold. This effectively increases the cold start acquisition sensitivity of the receiver. Some of these schemes are discussed in the following sections.

3 What Is AGPS

Assisted (or Aided) GPS is a system which provides information to a GPS receiver more quickly that it could be gathered autonomously from satellite signals (or perhaps it could not be collected at all – due to low signal levels). The primary benefits to the user are:

- Faster TTFFs
- Better effective acquisition sensitivity, possibly allowing indoor acquisition

Indirect benefits include less workload for the GPS receiver, and lower power consumption.

A link from the receiver to a server is required so the assistance data can be sent to the AGPS receiver. The link could be implemented in any technology that is convenient for the user, e. g. SMS, GPRS, TCP/IP, or even SPI. The server will have access to broadcast ephemeris data and has much more processing power than a GPS receiver.

The server may send various data elements to the AGPS receiver, such as:

- Ephemerides and Satellite Clock parameters
- Position estimate
- Time estimate - may be either approximate (GSM) or precise (CDMA)
- Frequency estimate

The receiver can then quickly construct its list of visible satellites, estimate doppler and (with precise time) code phase, and then measure pseudoranges. With the assistance ephemerides, it can then calculate its PVT solution.

Note that some autonomous receivers do allow the user to input an initial time and position. However, this is not true AGPS because the data is only used to construct an initial list of visible satellites. The receiver must still wait to collect ephemeris data from the nav message before it can calculate a fix.

3.1 One flavor of AGPS – Ephemeris Assistance

It is of significant benefit if the server provides a set of current ephemerides to the receiver. This can shorten TTFF by the 18 to 30 s it takes to receive subframes 1 to 3 (or 1 to 5) and can enable pseudorange calculation when the signal is below the data decode threshold. This scheme places a minimal workload on the server – it must maintain a current set of broadcast ephemerides and provide them to the receiver when requested. It also entails very little design change to an autonomous receiver. The user can expect to see cold start? TTFFs approximating those of a hot start, perhaps 6 to 8 s.

3.2 Another flavor of AGPS – AGPS only

If the receiver designer can assume that the device will always have a link to a network server which provides estimates of code phase and Doppler (for a selected set of satellites), the frequency/code-phase search can be reduced to narrow limits. This can significantly reduce search time (if the receiver is not moving), and result in TTFFs similar to those of a quick/snap start, about 2 to 3 s. In this design, the receiver does not have the capability to decode the Nav Message, and is completely dependent on the network for position estimate and ephemeris. Obviously, the burden on the network server is significantly greater than in the first example.

3.3 Yet another flavor of AGPS – Measurement Engine only

If the system designer wishes to minimize the workload on the individual mobile station, he can have the network (in addition to the assistance offered to an AGPS-only receiver) further take on the calculation of the nav solution. The GPS receiver provides only the pseudoranges to a host processor and thus becomes a “measurement engine”. Obviously this places a higher workload on the server, but if only used for emergency location, it should not be significant. The advantage is a small cost reduction for each receiver (which can be multiplied by the very large number of receivers needed).

3.4 Extended Ephemeris

In this scheme, the receiver operates just as if it were autonomous, except that it is provided with ephemeris data that was generated by a server perhaps 3 to 7 days in advance. Some manufacturers claim an even longer validity period. This data consists of multiple sets of ephemerides, each of which is valid for 4 hours. This “extended ephemeris” can be provided to the receiver in one of two ways:

- Server (e.g. SiRF InstantFix) = Every day or so, the receiver can “phone home” (via wired or wireless internet connection) to download a new extended ephemeris. SiRF provides the following table:

Age (days)	Horizontal Position Accuracy (m)
1 - 2	< 10
3 - 4	< 20
5 - 7	< 40

- Host (e.g. SiRF InstantFixII) = While the GPS receiver is operating, the host processor monitors the output data stream. It projects ephemerides with a validity of perhaps 3 days. In this case, the “server” is part of the same product as the GPS receiver and requires no communication link with a “higher authority”. SiRF provides the following table:

Age (days)	Horizontal Position Accuracy (m)
1	< 7
2	< 18
3	< 28

You may think of extended ephemeris as “long term” assistance in that the assistance data file does not need to be downloaded fresh for each start. However, horizontal position error is greater than it would be in normal (unassisted) operation.

Also, be aware that at least one satellite must have a reasonable signal strength (e.g. -140 dBm) to provide precise timing to the receiver. Typical TTFFs will be under 5 seconds.

4 What is Not AGPS

There are currently several augmentation systems designed to improve the performance of GPS receivers, which do not fall under the classification of AGPS. These systems are based on the fact that the largest position errors in today’s receivers are “spatially correlated”. That is, they affect nearby receivers about equally. Now that Selective Availability has been discontinued, the largest item in the error budget is due to the inability to completely model the signal propagation properties of the Earth’s ionosphere using a single-frequency signal. Other items, such as satellite ephemeris and clock errors along with tropospheric model errors, make smaller contributions to position errors. These systems are collectively known as Differential GPS. They do not materially assist in achieving quicker TTFFs or higher effective sensitivity; their primary benefit is enhanced position accuracy. Some examples are:

- Satellite Based Augmentation Systems (SBAS) such as the U. S. Wide Area Augmentation System (WAAS) and the European Geostationary Navigation Overlay System (EGNOS) augment the information available to a GPS receiver, primarily with satellite health and ionospheric correction data. This data is transmitted in a format similar to (but not identical with) the “standard” GPS satellites, therefore a separate antenna and RF front end in the receiver is not required.
- Ground-based Differential GPS (DGPS) systems are another method of improving receiver performance, by transmitting corrections for the receiver’s range measurements over a non-GPS radio facility. In the U. S., the Coast Guard maintains a set of beacon stations that broadcast this data. Since the signal is very different from the GPS format, a separate antenna and receiver are required to process it and demodulate the data.
- Local area augmentation systems (e.g. LAAS in the U. S.) improve the position accuracy and provide very rapid status information to the receiver in a localized area, typically the approach to a runway. With LAAS, a successful approach can be executed even in very poor meteorological conditions. Again, a separate antenna and receiver are required.

The above systems address very important aspects of a complete navigation system and are highly valuable in their own right, but are not properly termed AGPS.

Another approach used by cell phone carriers is to determine the location of a device (Mobile Station) by analyzing the signal received by one or more cell towers. This is termed a Network-based solution and again, is not AGPS (or even GPS, for that matter).

5 Definitions

AGPS: A scheme whereby a GPS receiver receives assistance data (e.g. ephemeris) from a server (typically through a network) that would otherwise have to come from the GPS signal. It enables faster cold and warm starts, and permits starts below the data decoding threshold of the receiver.

Almanac: A data set of approximate orbit information, clock corrections, and health status for all GPS satellites. It is transmitted by each GPS satellite over a 12.5 minute period to facilitate acquisition of satellites by GPS receivers. The data is valid for several months and is normally refreshed once per week.

C/A Code: The spread spectrum PRN code modulated on L1 that is used by GPS receivers to measure the pseudorange from the transmitting GPS satellite. Each GPS satellite has a unique PRN Code (Gold Code) assigned. This code is 1023 chips long and is transmitted at 1.023 mcps, therefore repeating each millisecond.

Clock Corrections: The time difference between a GPS receiver's clock and the GPS clock.

Correlator: A functional subsystem of a GPS receiver (typically implemented using a delay lock loop) which identifies a match between the received PRN code and an internally-generated PRN code.

E-911: The regulation mandated by the US FCC requiring a cell phone system to be able to locate the position of a mobile station (cell phone) for emergency purposes.

Ephemeris: A data set of precise orbit information for a GPS satellite. It is transmitted by each GPS satellite every 30 seconds to allow calculation of the satellite's position in space. The data may be valid for several hours and is normally refreshed every two hours.

Frame: A set of 5 subframes. Subframes 1, 2, and 3 contain GPS time plus Satellite health, clock corrections, and orbital parameters. Subframes 4 and 5 contain Almanac and Health status for all satellites, along with other information.

L1: One of the carriers transmitted by the GPS satellites, on an apparent frequency of 1575.42 MHz. This carrier is modulated by the Coarse Acquisition Code (C/A code), Precise Code (P(Y) code) – which is usually encrypted, and the navigation message,

Navigation Message: The data message transmitted by each GPS satellite at 50 bps as a set of 25 frames. It includes system time, clock correction parameters, ionospheric propagation model parameters, the satellite's ephemeris data and health plus almanac data for all satellites. The message is defined in the Navstar GPS Interface Specification IS-GPS-200.

Navigation Solution: The position, velocity, and time (PVT) of the receiver antenna's phase center when a set of measurements is made.

Start: The operation of a GPS receiver from the time it is initialized to the time it achieves a valid fix. The start may be initiated by a power on, Reset, or software command. Starts are classified by the data that is retained by the receiver from previous operation (see below descriptions).

Start, Frozen: The start mode in which a GPS receiver has no previous information available except (perhaps) a factory-supplied almanac.

Start, Cold: The start mode in which a GPS receiver has no previous information available except (perhaps) almanac and clock offset data. Specifically, its position, the time, and ephemeris data is unknown.

Start, Warm: The start mode in which a GPS receiver has its position and approximate time available but not ephemeris data.

Start, Hot: The start mode in which a GPS receiver has its position, time, and ephemeris data available.

Start, Quick/Fast/Snap (depending on manufacturer): The start mode in which a GPS receiver has accurate time as well as position and ephemeris data available.

Subframe: The smallest independent transmission unit of the Navigation Message. Each subframe consists of 10 words of 30 bits each (24 data bits plus 6 parity bits) for a total of 300 bits. The first word contains a fixed preamble (identifying the start of a subframe), and the second word contains GPS time plus some status flags. The remaining 8 words are different for the various subframes.

Time, GPS: A time scale based on the USNO atomic clock. It has no leap seconds.

Time, UTC: A time scale based on the atomic second, which is periodically corrected to match solar time by adding (or subtracting) a leap second.

Time To First Fix (TTFF): The time interval beginning when the receiver is started (or restarted) and ending when it achieves a valid fix. The TTFF is classified by the type of Start.

References

GPS Interface Specification IS-GPS-200 Revision D.

6 Notices

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