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NS/EP Implications of GPS Timing

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The Global Positioning System (GPS) is a satellite-based positioning and navigation system that is funded and operated by the United States Department of Defense. Although originally developed for use by the U.S. military, GPS now supports thousands of civilian users worldwide and is employed in a wide range of applications.

This technical note focuses on the use of GPS for telecommunications network timing and synchronization. The following sections describe the GPS system, how GPS calculates and transmits its timing signals, and how GPS timing is used in networks. Lastly, potential National Security/Emergency Preparedness (NS/EP) implications are discussed.

Overview of GPS

GPS provides two levels of operation: standard positioning service (SPS) and precise positioning service (PPS). SPS is available to all users, free of charge, on a continuous, worldwide basis. It is able to provide a predictable 95 percent positioning and time transfer accuracy, which translates to approximately 100 meters in the horizontal direction, 156 meters vertically, and timing to within 340 nanoseconds. PPS maintains an even greater level of accuracy, with a predictable horizontal accuracy to within 22 meters, 27.7 meters in the vertical direction, and timing to within 100 nanoseconds. However, this higher level of service is secured through encryption and is only available for use by U.S. military and other approved users.

GPS is composed of a space segment, a control segment, and a user segment. The space segment consists of a constellation of 24 satellites along with several spares (figure 1). Each satellite orbits the Earth once every 12 hours on one of six orbital planes. The GPS constellation is positioned such that at any given time, 5 to 8 satellites are visible from any point on Earth.

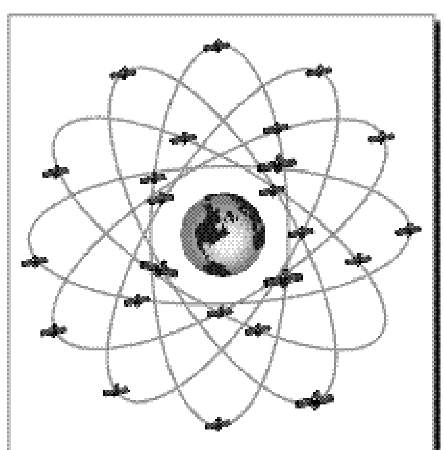

Figure 1. GPS Constellation

The control segment is a system of monitor stations, ground antennas, and a master control station. The monitor stations measure signals from all visible satellites. The accumulated data is then processed by the master control station to calculate satellite orbits and to update satellite navigation messages, including clock corrections. The revised information is transmitted back to the satellites via the ground antennas, and finally data is transferred over radio signals to GPS receivers. The receivers comprise the user segment, which is the portion of the GPS system that converts signals into timing and positioning information for users.

To perform positioning and timing calculations, GPS employs a triangulation technique. With this method, GPS receivers measure and compare the travel time of radio signals sent from four visible satellites with known positions. Three of the measurements are used to calculate the receiver's position in 3-dimensions, and the fourth is used to determine time. These signals, known as pseudo-random code (PRC), are unique to each satellite. This uniqueness allows all the signals to broadcast over the same frequency.

One caveat to this method of computation is that GPS users often reduce their costs by employing receivers with less accurate clocks. Although this has the potential of introducing error into positioning and timing calculations, GPS avoids this problem by taking an extra satellite range measurement during the triangulation phase. This allows the system to correct any timing offset and thus maintain GPS' overall high level of accuracy. Nevertheless, the triangulation technique requires that each of the satellites transmit its PRC in a highly synchronous manner. A timing error of just 1/1000 of a second would produce a measurement error of nearly 200 miles. Therefore, precise timing is a critical element for the proper implementation of GPS.

GPS Timing

The standard international reference for accurate time and frequency is known as Coordinated Universal Time, denoted UTC. Developed in 1970 by the International Telecommunication Union, official UTC time is generated at the Bureau International des Poids et Mesures, located near Paris, France. However, UTC is not directly available as a real-time clock. Therefore, many timing centers worldwide generate a localized estimate, which is accurate to within 100 nanoseconds of UTC. The time scale generated at the United States Naval Observatory (USNO) is one example. Known as UTC (USNO), the USNO Master Clock's approximation of official UTC is used as the timing reference for GPS.

GPS keeps its own system time that is derived from a composite clock consisting of all operational satellite clocks and the USNO timing standard. Each GPS satellite contains four atomic clocks (2 cesium and 2 rubidium), offering a very high level of precision. The satellites transmit clock information as part of the signals that are sent to the monitor stations. The master control station then gathers the data to calculate timing errors and to make appropriate clock corrections. When the revised timing signal is uploaded to the satellites, GPS system time can be broadcast to the receivers during the satellite navigation message.

As part of its error analysis of the satellite timing signals, the master control station compares the satellite clock times with the timing standard generated at the USNO. GPS system time is steered to remain within one microsecond of UTC (USNO). However, GPS does not allow for leap seconds, as does UTC, because any discontinuity would offset the receivers. As a result, GPS time is ahead of UTC by several seconds. The receivers compensate for this difference automatically during their signal conversions, and so the timing information that is passed to the user is in fact a very close approximation of UTC (USNO). Figure 2 illustrates the GPS timing sequence.

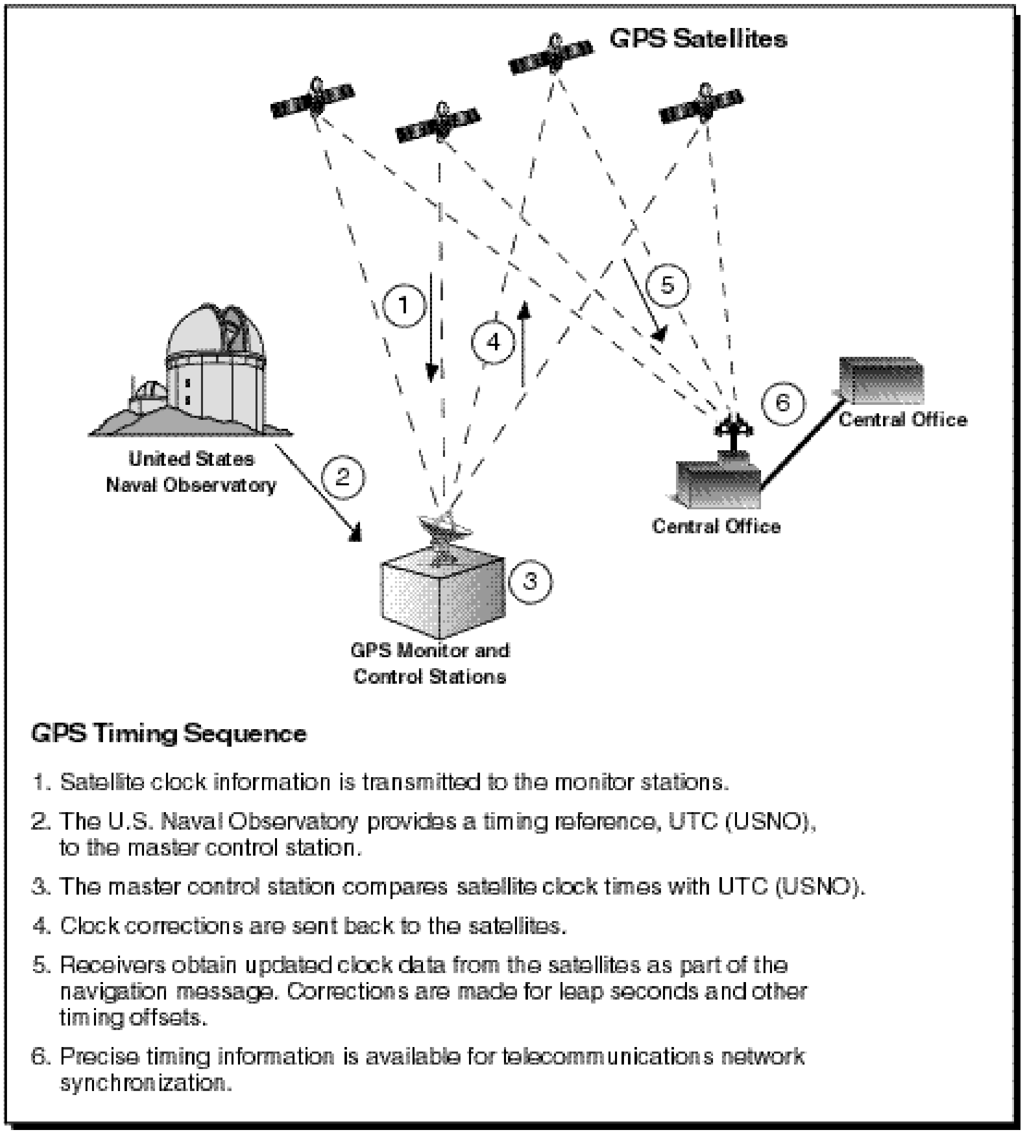

Figure 2. GPS Timing

Network Timing and Synchronization

Precise time dissemination is critical for the synchronization of telecommunications networks. Within both wireline and wireless systems, consistent pulses and time intervals are used to manage information flow through the network nodes. In particular, the Public Switched Network (PSN) relies on accurate timing information for the proper digital transmission of voice and data. Because of the high degree of accuracy of the GPS system, special-purpose GPS receivers are often employed as a timing source.

The GPS system records both the number of seconds that have passed in a given week and the number of weeks that have elapsed since the GPS time zero point (established at midnight (UTC) on January 6, 1980). The GPS week number cycles every 1024 weeks. After week 1023, the week number count is reset to 0, during what is called the week number rollover (WNRO) or end of week (EOW) rollover, approximately every 19.6 years. The first GPS rollover will occur just before midnight on August 21, 1999.

In addition to its use in telecommunications, GPS is used in other applications as a timing reference for wide-area synchronization. These include electric power systems, distributed computer networks, banking (for money transfers and bank time locks), manufacturing, and metrology.

NS/EP Vulnerabilities

Because GPS is commonly used as a timing source for telecommunications, any system vulnerabilities concern the NS/EP community.

One limitation of GPS is its susceptibility to interference. GPS signals are extremely weak, with satellites transmitting at power levels which measure only -160 dBW at the receiving antenna. This compares to the amount of light that can be seen from a 25-watt bulb at a distance of 10,000 miles [Ref. 1]. As a result, the GPS signals can be affected by both intentional and unintentional sources.

The deliberate interference with GPS signaling is known as "jamming." It has been shown that, using readily available materials, a one-watt jammer can be constructed to tamper with GPS reception from a distance of more than 60 kilometers. Even the best of receivers are susceptible to jamming. Additionally, signals whose fundamental frequencies are within the bandwidth of a GPS receiver could unintentionally cause problems. Possible sources of interference include emissions from both ground-based and aeronautical satellite communications equipment, wideband noise from electrical devices, and ultra high frequency (UHF)/very high frequency (VHF) communications. Regardless of the intention, interference with GPS signaling has the potential to decrease timing precision or even cause receivers to lose signal lock.

Another NS/EP concern is that the use of GPS as a timing reference could be jeopardized by selective availability. This is the military's current practice of introducing intentional random error into the SPS signal to limit hostile use of the service. However, telecommunications applications rely on real-time outputs. By adding random errors to the signal, peak-to-peak variations on the order of hundreds of nanoseconds can result, thereby affecting synchronization. This problem will be alleviated with the scheduled elimination of selective availability in 2006.

The pending date and time changes due to WNRO and the year 2000 (Y2K) have also caused some concern in the NS/EP community. The GPS Joint Program Office has certified that the space and control segments are WNRO/Y2K compliant. However, the compliance of the user segment, in particular, the receivers, will vary according to manufacturer and model. It is unclear what problems will occur as a result of receiver noncompliance. One scenario is that user equipment may experience delays while locating GPS satellites or while making position and date calculations. It is also possible that satellites might not be located at all. Even if receivers do properly access the satellite signals, they might display inaccurate timing and position information. Although it is uncertain how widespread such problems might be, it is expected that only older equipment could be affected. Newer models have been programmed to properly account for the date and time transitions.

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