Chapter 25
Time Synchronization and the Origins of GPS

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Abstract The Global Positioning System has been called the first global utility. Yet its origins are relatively obscure; the timing aspect of this PNT system (positioning, navigation, and timing) is less obvious to the general public than are the positioning and navigation aspects. The slogan of the first head of the GPS Joint Program Office, Col. Brad Parkinson, was, "Drop 5 bombs in the same hole. . .and don't you forget it!" (Parkinson and Powers, Part 2: The Origins of GPS, Fighting to Survive. *GPS World*, June 2010). This article will demonstrate that, contrary to a common assertion in the literature, time synchronization was anticipated by some of the GPS pioneers.

Keywords GPS • Time synchronization

Description

GPS is run by the US Air Force. It has three segments. The **space segment** currently uses 31 satellites; limitations in the ground segment software restrict it to actively using at most 32 satellites, in six evenly spaced constellations (60° apart). The satellites are in close to 12 h circular orbits inclined at 55°. The last of the GPS 2 satellites have been launched, and the new GPS 3 satellites are scheduled to start launching in 2018. GPS 3 currently requires the new ground control system, OCX, to be up and running. However, OCX is behind schedule and over budget. One possibility, which the Air Force is studying, is modifying the current ground system to allow it to control these new satellites. The **ground segment** updates the clocks and orbits of the satellites. The **user segment** is the GPS receiver. The receiver's three-dimensional position and time are obtained when signals from four GPS satellites are received. GPS is a passive system; the receiver does not need to make a transmission. The signal sent from the satellite includes the time of transmission; if the receiver has a synchronized clock, the time difference reveals

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the distance between the satellite and the receiver. With four satellites in sight, the receiver's three-dimensional position and clock synchronization can be computed.

GNSS

GPS was the first global navigation satellite system to be developed. The first GPS Block 1 test satellite was launched in 1978. Three other systems either are or intend to be global in nature. The Soviet Union launched its first GLONASS satellite in 1982. It fell on hard times after the breakup of the Soviet Union but has been built back to 25 satellites. The European Galileo system and the Chinese BeiDou system are being rapidly developed. Regional systems are being built by India (NAVIC (Navigation with Indian Constellation) or IRNSS (Indian Regional Navigation Satellite System)) and Japan (QZSS (Quasi-Zenith Satellite System)). These use satellites in geosynchronous orbits at the longitudes of these countries. Used in combination with GPS or other systems, they improve navigation in these countries. They are particularly helpful in large cities such as Tokyo where the tall buildings can block the signals from GPS satellites.

Was Time Synchronization Anticipated in the Creation of GPS?

There are numerous sources which assert that time synchronization was not anticipated in GPS. Thus, Don Jewell, a longtime Air Force officer who worked on GPS, wrote:

> You need to know that in those days [the late 1970s], GPS was seen as a military system only, and there were no thoughts of granting public, much less worldwide, free access to the GPS signals. It was basically a military en route navigation system, and not much was thought about it beyond that. Certainly there was no serious consideration given to GPS becoming the de facto world standard for time. (Jewell 2008)

Similarly, a 2009 Ph.D. thesis on Galileo stated, "Somewhat unexpectedly, the precise timing information transmitted by GPS satellites was quickly incorporated into many inventive applications that were not related to navigation" (Gleason 2009). Nunzio Gambale [CEO and co-founder of Locata Corporation] stated, "There was never an intention for it [GPS] to be used for infrastructure, for timing" (Milner 2016).

Exhibit 1 shows eight US pre-GPS space-based navigation proposals. They are discussed in detail in my book (Easton and Frazier 2013). Three of these proposals were done by individuals or groups who previously tracked Sputnik. They were George Weiffenbach and William Guier from the Applied Physics Lab, Roy Anderson from General Electric, and Roger Easton from the Naval Research

Laboratory. They then inverted the problem. Instead of using one or more ground stations to track a satellite, they used one or more satellites to provide the position of a receiver. The 1973 synthesis of the last two systems, Timation and 621B, gave us GPS.

Weiffenbach and Guier tracked Sputnik 1 in October 1957 by measuring the Doppler shift in its signal. The following March, they began work on what became Transit, the first space-based navigation system. Roy Anderson, at the Schenectady, NY, office of General Electric, also tracked Sputnik. Later, he tracked Pioneer 4 and had an amusing story about how the media distorts stories:

> Three tracking stations demonstrated the ability to track Pioneer 4 to the great distance: Jodrell Bank in England with its 150-foot diameter antenna, the Jet Propulsion Laboratory (JPL) at Goldstone Lake, California with its 85-foot antenna, and a temporary setup at the GE Research Laboratory, Schenectady, with an 18-foot diameter parabolic antenna. … There was immense media interest in our effort. Pioneer 4 was the first object to escape Earth's gravity. We were besieged with phone calls at all hours of the day and night. With our small antenna we were seen as David against Goliath. On the morning of 6 March, the signal was weak and intermittent. Finally, search as we could, we could no longer get a lock on it. In mid-morning, a reporter called and said, "JPL announced that they lost a signal. Do you still have it?" "No." "When did you lose it?" "I don't know exactly?" "Can we say that at 10:25 you said that you lost the signal?" It was 10:25. "Yeah." By 10:27 the whole world was informed that GE had tracked the space probe farther than JPL. I went to a newspaper office and asked them to publish a disclaimer. They were not interested. JPL was not pleased (Anderson 2008).

Roger Easton, of the Naval Research Laboratory, was a coauthor of the 1955 proposal which was selected to launch the first American satellite (the project was named Vanguard). It mentioned the use of satellites for navigation, "It would also be possible to determine the absolute longitudes and latitudes by observation of the satellite. Such observations would also yield the height of the observer above the center of the earth" (A Scientific Satellite Program 1955). He helped design the Minitrack system which was intended to track the Vanguard satellite. When Sputnik was launched, modifications were needed to Minitrack since Sputnik transmitted at 20 MHz and 40 MHz, whereas the International Geophysical Year standards specified 108 MHz (McLaughlin and Lomask 2009). In January 1958, before the first American satellite was launched, Explorer 1, he conceived what became the Naval Space Surveillance System, later the Air Force Space Surveillance System, to track Soviet spy satellites which would not emit a signal most of the time. He started the Timation (time navigation) program in 1964. This partially arose out of the need to synchronize the clocks in the two transmitter stations in Texas. We see a symbiotic relationship where space tracking improves the accuracy of satellite navigation systems such as GPS which in turn improves the accuracy of the space tracking systems. The last two Timation satellites, renamed NTS-1 and NTS-2 (Navigation Technology Satellite), carried the first rubidium and cesium atomic clocks into orbit.

Time Synchronization Was Foreseen

Roy Anderson wrote in 1964 that his system would provide worldwide synchronization to approximately 1 microsecond (Anderson 2008). Easton wrote in 1967 that "Possible fallouts from such a system are worldwide time synchronized to better than 0.1 microsecond" (Easton 1967). Thus, the time was more accurate by a factor of ten. In the Timation Development Plan (1971), the estimated time transfer accuracy was improved again by a factor of ten to better than 0.01 microsecond. Easton stated in 1974 that "precise orbiting clocks will prove to be a valuable tool in a variety of applications, by providing the entire planet earth with a single, accurate time system, enveloping the globe in a web of synchronized satellite signals" (Eberhart 1974). This was about 15 years before the term World Wide Web was coined. GPS and GNSS systems provide three-dimensional position and time. Even though time was less prominent than positioning at the time when GPS was formulated, it was extremely important for these pioneers of satellite navigation.

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