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Critical Issues in Global Navigation Satellite Systems

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THE EVOLUTION OF GLOBAL NAVIGATION SATELLITE SYSTEMS

Global Navigation Satellite Systems (GNSS) is a concept that relays accurate information of a position or location anywhere on the globe using a minimum of four satellites, a control station, and a user receiver. GNSS owes its origins to Rabi's work in the early 1940s with the concept of an atomic clock (Nobel Museum, http://www.nobel.se/physics/laureates/1944/rabi-bio.html). In October 1940, the National Defense Research Council in the U.S. recommended implementing a new navigation system that combined radio signals with this new technology of time interval measurements. From this, MIT developed Long Range Radio Aid to Navigation (LORAN), which was refined by scientists at John Hopkins University and utilized during World War II through the late 1950s.

Following World War II, the cold war between the U.S. and the USSR embraced GNSS. The world first witnessed the emergence of the space segment of a GNSS system with the Russian Global Navigation Satellite System (GLONASS), which launched the first ICBM missile that traveled for 8,000 kilometers and the first Sputnik satellite in 1957. During this time, Dr. Ivan Getting, a man commonly noted as the father of Global Positioning System (GPS) (Anonymous, 2002), left the U.S. Department of Defense to work with Raytheon Corporation and incorporated Einstein's conceptualization of time and space into a guidance system for intercontinental missiles. Using many of these concepts, Getting worked on the first three-dimensional, time-difference-of-arrival position-finding system, creating a solid foundation for GNSS (http://www.peterson.af.mil). In 1960, Getting became the founding president of Aerospace Corp., a nonprofit corporation that works with the U.S. Department of Defense to conduct research. Getting's ongoing research resulted in a navigation system called TRANSIT, developed in the 1950s and deployed in 1960, using Doppler radar (Anonymous, 1998) and proving its effectiveness with the discovery of a Soviet missile shipment resulting in the Cuban Missile Crisis of October 1962. With the success of this system, the U.S. Secretary of Defense formed a Joint Program Office called NAVSTAR in 1973 with the intent of unifying navigation assistance within one universal system. In December 1973, the Department of Defense and the Department of Transportation published a communiqué announcing joint management of the program due to increased civilian use. Today, this is known as the Interagency GPS Executive Board (IGEB). In December 1973, the Defense System Acquisition and Review Council approved the Defense Navigation Satellite System proposal for a GNSS system, resulting in the first satellite (Navigation Technology Satellite 1—NTS1), launching on July 14, 1974 and carrying two atomic clocks (rubidium oscillators) into space. The first NAVSTAR satellites were launched in 1978 (Anonymous, 1998).

The launching of satellites in the U.S. continued until 1986, when the first *Challenger* space shuttle disaster cancelled the schedule but revived in 1989 with changes in the design of the satellite constellation, allowing enhanced access to the GNSS system by non-military users. The U.S. Coast Guard was appointed as the responsible party representing the Department of Transportation for civilian inquiries into the NAVSTAR system, resulting in the first handheld GNSS receiver, marketed by Magellan Corporation in 1989.

In January 1991, the armed conflict in Operation Desert Storm saw the GNSS system in a critical field operations role (Anonymous, 1998). Partially due to Raytheon's declaration of success in this conflict, the U.S. Secretary of Defense's Initial Operational Capability (IOC) recognized some of the flaws, including the inadequate satellite coverage, in the Middle East and called for improvement of the system and the resumption of research. On June 26, 1993, the U.S. Air Force launched into orbit the 24th Navstar Satellite, completing the requisites for the American GNSS system.

On July 9, 1993, the U.S. Federal Aviation Administration (FAA) approved in principle the use of the American GNSS for civil aviation. This cleared the way for the use of the system for a three-dimensional location of an object. The first official notification of this was in the February 17, 1994, FAA announcement of the increasing reliance on GNSS for civil air traffic. In 1996, a Presidential Decision Directive authorized the satellite signals to be available to civil users, and on May 2, 2000, Selective Availability was turned off, improving performance from approximately 100 meters accuracy to 10-15 meters. With the anticipated modernization of the constellation to add a third frequency to the satellites, the accuracy of the system will be enhanced to a few meters in real time. As of 2004, GPS has cost the American taxpayers $12 billion (Bellis, 2004).

THE GLOBAL GROWTH OF GNSS

Since the dissolution of the USSR, the GLONASS system has become the responsibility of the Russian Federation, and on September 24, 1993, GLONASS was placed under the auspices of the Russian Military Space Forces. The Russian government authorized civilian utilization of GLONASS in March 1995. This system declined (Langley, 1997) and did not evolve, making the system questionable for civilian or commercial use (Misra & Enge, 2001). Recognizing this, the European Union announced its intent to develop a separate civilian system known as Galileo. In 2004, the Russian government made a commitment to bring back GLONASS to a world-class system and has increased the number of functional satellites to 10 with more anticipated to a level concurrent with the American GPS.

Today, other countries of the world have recognized the importance and commercial value of GNSS and are taking steps to both broaden the technology and utilize it for their populations. The European Space Agency (ESA) has entered the second development phase to make Galileo interoperable with the U.S. GPS by developing appropriate hardware and software. Its first satellite launch is scheduled for 2008. China, India, Israel, and South Africa all have expressed an interest in joining Europe in developing the 30-satellite Galileo GNSS under the auspices of the Galileo Joint Undertaking (GJU), a management committee of the European Space Agency and the European Commission. The Japanese government is exploring the possibility of a Quazi-Zenith system that will bring the number of GNSS globally to four in the next 10 years. Thus, the globalization of navigation and positioning standards is progressing, albeit under the watchful eye of the United States, who may fear a weakening of its military prowess, and of Europe, who wants sovereign control of essential navigation services.

THE MECHANICS OF GNSS

GNSS requires access to three segments: specialized satellites in space (space segment); the operational, tracking, or control stations on the ground (control segment); and the appropriate use of localized receiver equipment (user segment). The following diagrammed system (NovAtel, Inc. Diagrams) uses a plane as the user, but it could be any user, as the same mechanics apply throughout all systems:

The following is a description of GPS; however, the same principles apply to all GNSSs.

Space Segment

GPS relies on 24 operational satellites (a minimum of four satellites in six orbital planes, although there are often more, depending upon maintenance schedules and projected life spans) that travel at a 54.8-degree inclination to the equator in 12-hour circular orbits, 20,200 kilometers above earth (http://www.space-technology.com/projects/gps/). They are positioned so there are usually six to eight observable at any moment and at any position on the face of the earth. Each carries atomic clocks that are accurate to within one 10-billionth of a second and broadcast signals on two frequencies (L1 and L2) (Anonymous, 1998).

The satellite emits a Pseudo Random Code (PRC)

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