clock. Although accuracy is improved, the number of users is limited because the terminals must transmit. This method was proposed in Geostar's RDSS system. In any case, users must know their height (the geocentric height and not simply height above sea-level).

Three satellites can give two ranges and hold a clock synchronized However, users still need to input their height to get a two dimensional fix. With four satellites, three distance measurements and one time measurement are obtained. Thus, a three-dimensional position fix is obtained without any external references.

In summary, a system based on two or three satellites can only provide low accuracies, in the order of few miles, depending on the kind of height information provided by the user. However, these low accuracies may be acceptable for some land-based applications (e.g., when locating a truck in a remote area, as opposed to locating a rail car at a classification yard).

A civil navigation system using dedicated satellites has yet to be launched although specific frequencies have been allocated to RDSS systems. This is understandable if one considers the staggering costs of designing, manufacturing, insuring, launching and operating the necessary satellites. To achieve 90% world coverage from geosynchronous orbits (one of several orbits used by satellites) at least 10 satellites would be required **[5].** With an average satellite life of 7 to 10 years, capital costs would be great and to cover costs, large number of users would have to be served. Geostar proposed such a system and was in the process of implementing it. However, its financial difficulties and eventual bankruptcy confirm the hardships facing anyone wanting to undertake the development of a satellite positioning system.

Two alternatives exist for a civilian system with dedicated satellites:

1. The use of navigation systems designed for and operated by the military;
2. The sharing of payloads with communications satellites.

These alternatives are not without problems. Military and civilian needs are not similar. Military designers have to take costly precautions against jamming. Satellites must continue operating even if ground contact is lost, and a broadcast system is necessary so that users need not disclose their positions. These considerations add to the complexity of a system such as the GPS. From an international perspective, an open question remains as to whether the user community is prepared to accept a system which is under the control of the military of a single country.

In the second alternative, the use of transponders on board existing communications satellites and the different engineering requirements for location and communications need to be reconciled. Communications satellite systems do not need to keep track of the precise location of the space platforms. When using satellites to derive locations using satellites, however, the exact position of the satellites must be known. The **geometrics** of a geosynchronous orbit (popular with communications satellites) are such that the calculated location has a considerable uncertainty in latitude. Also, equatorial regions (about 5 from the equator) are at a disadvantage. In addition, satellite operators adjust the orbit so the satellite can better "see" an earth station **[5].** These station-keeping manoeuvres must be known, otherwise accurate positions cannot be calculated.

Three satellite radiodetermination systems will be outlined in the following sections: the Global Positioning System (GPS), Qualcomm's QASPR, and Geostar's RDSS proposal.

### 4.2.2.1 The Global Positioning System (GPS)

The Global Positioning System (GPS), also known as Navstar, is the most prominent of the satellite positioning systems. It is a military system that will eventually replace other federally operated radionavigation systems (e.g., OMEGA, TRANSIT, LORAN-C). GPS has many advantages compared to other satellite systems [6]:

1. GPS allocates frequencies more **efficiently** and uses only 2 MHz of bandwidth;
2. As a broadcast system, GPS can serve an infinite number of users. Other RDSS proposals (e.g., Geostar's) were frequency-limited because they both received and transmitted data via satellites and, therefore, could only serve a certain number of users;
3. With GPS, the user would pay once to purchase the receiver and would not pay for the use of positioning information;
4. If it becomes the predominant technology, the cost of GPS receivers should drop substantially.

The system will ultimately comprise a constellation of 21 satellites (plus three operating spares) on circular orbits at about 20,000 km of altitude. The satellites are arranged so that four will always be visible from all points on the earth. The U.S. Department of Defense is expected to declare the system fully operational in 1993. By then it will be possible to get a three-dimensional position 24 hours a day. Position fixes are obtained now at the user's risk. Currently 15 satellites are operational, 10 of which are Block II satellites (eventually all 24 satellites will be Block II or later). These provide a minimum of 21.5 cumulative hours of two-dimensional positioning per 24-hour period, and 15.5 cumulative hours of three-dimensional positioning per 24-hour period **[18].** The next satellite will be launched before the end of the summer of 1991.

GPS receivers are passive. Built-in microprocessors in the receivers not only determine the optimal set of satellites for use, but also perform calculations. The equipment is easily built, and is getting smaller and less expensive. A GPS receiver in the form of a board complete with its antenna, mounting bracket, cable driver software, and user manual has been priced at about $3,000 in recent years. Currently, some receivers are available for about $1,000, and industry experts expect that the price will eventually come down to about $500. The most significant recent development has been the announcement of small, low-cost, multichannel receivers that can be integrated into other electronics equipment.

For national security reasons, civilian accuracy has been restricted to about 100 meters, making use of the Standard Positioning Service (SPS). Military users on the other hand, have access to the Precise Positioning Service **(PPS).** Some ways to boost accuracy include the use of processed satellite orbiting data (post-processed satellite ephemerides) and differential techniques (where positions are derived relative to precisely surveyed points). The limited availability of the PPS to selected civilian users is much discussed. However, accuracy is not the only controversy surrounding GPS. The question of user fees (none, for the time being) is an issue that may affect the operational success of the system. Lastly, as with all military systems, responsiveness to civilian users and the question of control are major concerns.

There has been recent interest in integrating the GPS with the GLONASS system, to improve the accuracy of both **[19].** GLONASS is a Navstar-like Soviet radionavigation system, consisting of 12 satellites. Experts on both systems are conducting joint tests to determine how the U.S.- and Soviet-manufactured products perform in real-life environments. Preliminary data from tests on board an airliner showed that the differences between the two systems were mainly due to the different earth models used by each [20]. Additional investigations of GPS/GLONASS interoperability will undoubtedly follow.

#### 4.2.2.2 QUALCOMM's OASPR

In February of 1990, Qualcomm, a vendor of satellite communications services, announced the introduction of the Qualcomm Automatic Satellite Position Reporting (QASPR) system to the U.S. market. This system is claimed to have an accuracy of better than 1000 feet under any circumstances, significantly improving the accuracy of position reporting when compared to LORAN-C systems. Using existing civilian communications satellites, it processes the signal from one satellite and monitors a beacon signal from a second. A vehicle can be tracked 24 hours a day anywhere within the continental United States. QASPR is part of Qualcomm's OmniTRACS mobile communications system.

#### 4.2.2.3 Geostar's RDSS Proposal

The FCC granted a license to Geostar for a private RDSS system in 1984. Geostar's technical design was also adopted as a baseline for RDSS systems. At the time the FCC held the view that providing spectrum for an alternative system to GPS was beneficial in that services could be tailored to the needs of the market. Presently, however, the company has ceased operations, and the future of Geostar is uncertain.

The Geostar system in its full implementation would consist of three geostationary satellites carrying the necessary transponders. User terminals would both receive and transmit but would not perform calculations or accurate timing functions. Precise timing signals would be transmitted from an operations center in Washington D.C., and then retransmitted by one of the three satellites. User terminals would receive the signals, synchronize themselves, and transmit their own signals. These signals would be picked up by all satellites and relayed back to the operations center along with other information such as user identity. When the signals reached the operations center their travel time and other pertinent data would be extracted. That information would be routed to fleet headquarters after being processed at the central facility. Users, however, would have to input their geocentric height, information that may not be readily available. Geostar, then patented a satellite compass system which according to company officials will indicate position within 2 to 7 meters, using a portable 20-ounce radio costing several hundred dollars (assuming mass production). Accuracy would be achieved using a nationwide digital terrain map stored in a ground-based computer. Heights would be calculated from the terrain map starting with an initial position estimate and iterating a number of times. Position information would be given in plain English, e.g., "You are 70 feet north of the intersection of East Road and West Street." The time for a fix would depend on the accuracy of the initial estimate. The system's accuracy may never be demonstrated, and the quoted 2 to 7 meters may be optimistic.

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