SOME THOUGHTS CONCERNING GEOSYNCHRONOUS MISSIONS FOR THE NEXT CENTURY

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ABSTRACT. Satellites in geosynchronous orbit are revolutionizing the telecommunications industry and enhancing growth of the internet, driven largely by commercial interest. In addition to communication relay, they provide weather data, assistance to navigation, earth observation, and search-and-rescue support. Physical properties of the geostationary orbit belt make it a unique global resource suitable also for scientific experimentation. Improved monitoring of it will become practical in the 21st Century. After the International Space Station is operational it may serve as a staging platform for a manned shuttle to the belt, and later for a geostationary space station. An American president has set a manned mission to Mars as a major goal of future space exploration. This will require creation of a lunar outpost as a base for the test range necessary for developing and evaluating the systems to perform that mission. Communications with the Moon may be accomplished by outward-looking relay satellites from geostationary orbit at electromagnetic frequencies of shorter wavelength.

1. INTRODUCTION

Operation of satellites in geosynchronous orbit is becoming one of the most diversified and commercially important applications of space technology as the twentieth century draws to a close. Geosynchronous satellites provide weather information around the world, as well as communication relay, science data, assistance to navigation, surveillance, and search-and-rescue services. The benefits of improved weather prediction are so pervasive, in agriculture, construction, transportation and other areas of society, that they can not be quantified in economic terms, but annual revenues associated with satellite communications relay are estimated to be in the hundreds of millions of dollars.

As early as 1963, NASA's Syncom II demonstrated that a satellite could operate in an inclined geosynchronous orbit, and the following year Syncom III demonstrated that one could operate in a zero inclination geosynchronous orbit, known as a geostationary orbit. Since then hundreds of spacecraft have been launched into the geostationary orbit belt to take advantage of its unique features. Many new missions for geostationary spacecraft are expected to unfold in the twenty-first century.

2. PROPERTIES OF GEOSYNCHRONOUS SATELLITES

The general property of a geosynchronous satellite is that it makes one orbital revolution of the Earth per day. It is in synchronism with the Earth, turning as the Earth turns. It may be in an inclined orbit, in which case its ground track describes a slim figure 8, with the node of the 8 at a point on the equator. The subset known as geostationary satellites, which are synchronous, but in circular equatorial orbits, i.e. whose orbits have zero inclination, remain fixed over points on the equator. Geostationary earth orbit is usually referred to as GSO to distinguish it from the more general type of geosynchronous earth orbit usually referred to as GEO. A truly geostationary satellite would have a negligible requirement for tracking. However in current practice a geostationary satellite will drift slowly in relation to its designated subsatellite point. Varying gravitational effects from the Sun and Moon, the traxiality of the Earth, and solar wind pressure are causes of this aberration. Adjustments for drift are therefore occasionally required. Geostationary satellites also have the following advantageous characteristics:

(1) They can view the diurnal cycle through night and day, as it occurs in the Earth below, continuously. This view covers nearly a full hemisphere.

(2) Their constant position is favorable for time-lapse imaging and for repetitive measurements, permitting capture of weather pictures and data.

(3) Their sensors can have a long dwell time, which assists both focusing and faint signal acquisition.

(4) Their timing of detected events can be accomplished with superior accuracy.

(5) They can communicate with a high gain, directional antenna on Earth which does not have to move much to keep the satellite within its beam.

(6) Their solar array pointing is simplified and improved by slower, less varying motion relative to the Sun than that of low-orbit satellites.

(7) The GSO belt is above the Earth's atmosphere where satellites can sense and utilize electromagnetic frequencies unsuitable for terrestrial communication.

(8) Because geostationary orbits are highly systematic, measurement of aberrations permits meaningful analysis of perturbing effects.

3. CONSTRAINTS ON GSO OPERATIONS

Allocation of positions in geostationary orbit has been accomplished through the International Telecommunications Union (ITU), which includes 160 countries as members. Limiting communications interference is a major consideration. A minimum distance of 225 kilometers between satellites has been deemed necessary to avoid signal interference. Even with meteorological and scientific satellites occupying some of the GSO belt, much of the resource is unused. Constraints on GSO utilization have led to the alternative of using swarms of lower-orbit satellites for communication relay. These may be less efficient, and more costly to operate. They must travel around the entire globe continuously. Their wider antenna beams and doppler effects may generate RF problems. Eventually congestion, interference, and debris concerns will lead to constraining regulation of them also. These multi-satellite low-orbit systems do not lend themselves to use of large, sophisticated satellites with great transponding capability like the GSO systems do.

The features of the GSO belt make it an identifiable, unique global resource. It has large physical proportions. It is 265,000 kilometers in circumference. If one considers the belt to include plus and minus two degrees above and below the exact equatorial plane, a spread to which geostationary satellites sometimes drift, then the belt comprises a four degree wide zone with an area of 782 million square kilometers. This is fifty percent larger than the surface area of the Earth. Such an area can accommodate a vast number of spacecraft without material interference. Present regulation however, complicated by inability to inspect and enforce proper international use, is inhibiting development of the GSO resource and its commercial potential.

4. TRENDS AFFECTING FUTURE GSO OPERATIONS

In addition to those demographic trends, such as worldwide population growth, improved standards of living, more education, lengthening lifespans, etc. which are in place as we approach the twenty-first century, continuing progress in technology is expected to have a major impact on space operations. Some of the more specific trends which will generate changes in future geosynchronous missions are as follows:

(1) Growing commercial demand for more communicaton relay facilities in space.

(2) Ever-improving quality and performance in systems, component hardware and

software.

(3) Movement to higher spectral bands for communication, increasing bandwidth and enhancing tranmission data rates.

(4) Greater satellite congestion in near-Earth space, and cluttering with debris.

(5) Relaxation of concerns over all-out nuclear war, which required extensive military monitoring by satellites on both sides.

(6) Expanding human presence in space on stations Mir and Freedom, on the Space Shuttles, and intentions to return to the Moon and visit Mars.

(7) Greater public awareness of the importance of space exploration and its challenges.

Comments on anticipated developments resulting from these trends are contained in the paragaphs which follow.

5. COMMUNICATION RELAY VIA GSO

Two major forces, one governmental and the other private, may be regarded as drivers of developments in space. They are based on widespread recognition that the confining limits of this planet are identified, that it is becoming crowded, and that space is the logical direction for future expansion. Governments, responding to the will of the people, apply a small portion of their resources to providing for this future by funding developments in space. They foster research and exploration to discover how space can be utilized. When enterprises which can be economically self-sustaining are identified, entreprenurial involvement is encouraged. Private industry thus also becomes a major driving force in developing certain space applications.

Communication relay satellites in GSO provide by far the most profitable utilization of space for commercial purposes. The electronics revolution of the twentieth century has spawned a panoply of information-handling systems, including radio, teletype, copiers, printers, faxes, main-frame and personal computers, television, videocameras, recorders, and scanners. Instantaneous transfer from place to place of the images and sounds produced by these devices is an accepted part of modern life. Television networks want to relay their news and other programming over an increasing number of channels. Businesses want to relay their messages across their entire market areas. Newspapers want to remotely print the latest issue of their journal in several cities simultaneously, etc.. Electronic information transfer is an activity which has been accelerating and will continue in the twenty-first century.

The trend toward more and bigger spacecraft for communication relay has existed for many years and is continuing. Entrepreneurs appreciate the substantial financial rewards which are possible if the hurdles of placing spacecraft in operation can be successfully passed. Recognizing the increasing demand for low cost, instantaneous information transfer, they compete to operate transponders in GSO. Benefits to the public, not only in terms of economic stimulation, but also in opening the world to instantaneous television and other modern forms of communication have been spectacular. They have created a whole new industry in providing low-cost long distance communication.
Over 140 communication relay satellites, many of them privately owned and operated are presently in GEO. They provide many thousands of communication circuits which facilitate the exploding rate of information exchange, the use of the internet and the weaving of the worldwide web. Investments in these satellites amount to several billion dollars with many millions more spent on supporting facilities. The clamor for "slots" by would-be users continues to increase. With the demand for means of rapid information transfer expanding at an exponential rate, and geostationary satellites the most successful way to satisfy long distance communication needs, economic forces are expected to be one of the major drivers in the development of new and better ways of utilizing the capability.

6. ENGINEERING PROGRESS

The economic impetus to accomplish faster, better, cheaper long distance communication will compel higher data rates for GSO satellites, and the freedom to compete will demand more of them. Innovations in position control, attitude control (such as the three-axis stabilization on Intelsat 8), thrusters, beam pointing, beamwidth control, antenna efficiency, modulation techniques, signal and noise filters, amplifiers, transponders, frequency control, photovoltaic devices, solar array orientation, and other hardware subsystems will occur, motivated by profit incentives. The tremendous new design capabilities provided by computers in fields such as finite element analysis and rapid prototyping, will be employed to achieve these advancements economically and relatively quickly.

Computers will also be used to create far more capable, albeit more extensive, software for operation of systems and subsystems. As understanding of the perturbing effects on satellite orbits grows and precise position control becomes possible, computers may make it possible to operate several satellites simultaneously in a figure eight pattern based on a node in a singly allocated GSO slot. In the course of the next century engineering progress will permit better satellite positioning, reduce concerns about interference among GSO satellites, allow many more satellite slots to be occupied, and permit resources to be more beneficially utilized.

New means of providing power for both propulsion and orbital operations will be investigated and developed. Besides solar power, nuclear thermal and ionic systems , which have potential for manned voyages, will be evaluated. Fuel cells have offered promise as sources of spacecraft power, but have needed further development. This is now fortuitously occurring as a result of high gasoline prices and taxes in Europe, where fuel cells are being utilized in automobiles. Use in such a large market will surely accelerate fuel cell development and facilitate their eventual application in space.

7 . SPACE STATIONS

Closer monitoring of relay satellites will be an important step toward reducing the threats of interference. Present monitoring of GSO position and attitude by radar or optical telescopes is quite coarse. When clear visual monitoring becomes possible, better position control will follow. Visual monitoring may be done through advances in optical detection and resolution on space telescopes like the Hubble, or it may be accomplished by robotic spacecraft sent specifically to scan the GSO belt, or it may be done by manned orbital transfer vehicles visiting GSO from a space station. Conceptual studies of vehicles to visit GSO have been made but not advanced into implementation stages, mainly because of the higher priorities of projects like the international space station.

When Station Freedom is in operation it will serve as a staging platform for further voyages into space. These may include missions to deliver, observe, repair, retrieve or replace GSO spacecraft or to clear debris. A small manned shuttle operating between the space station and GSO has been proposed for these purposes. Spacecraft which have propulsion fuel left after they terminate their missions can be boosted out of orbit like GOES-4 was in 1986. Other satellites may be deliberately allowed to drift in orbit to study perturbational effects, but unwanted hardware which is hazardous to active spacecraft may have to be physically removed from orbit through capture by a vehicle nicknamed the "space tug."

Other voyages from Freedom will involve returning to the Moon. This will be necessary if the important and popular goal of sending men to Mars is to be achieved. An American president, George Bush, has identified a return to the Moon to stay and a manned mission to Mars as objectives of the space program. The Moon provides an ideal test range for the development of propulsion, automation, life support, flight control and other systems needed for a manned Mars mission.

As traffic outside the Earth's atmosphere increases in the twenty-first century, it may become desirable to communicate in space via frequencies of the electromagnetic spectrum which have been unusable at lower altitudes because of atmospheric attenuation. Portions of the S, X, C, and K bands presently used for Earth-to-space communication may approach saturation. Allocated portions of the V and W bands of extremely high radio frequencies (EHF) and laser bands are possiblities for space-to-space. Such communication would be in keeping with the long-term trend toward shorter wavelengths, would avoid congestion in the lower bands, permit security, and conserve power. Satellites in GSO are in position to receive such signals and convert their frequencies for downlinking to Earth. They could similarly process and transmit uplinks to space.

Later in the century a space station may be built in geostationary orbit. Being manned it would have many advantages beyond those of unmanned satellites. Monitoring and servicing of spacecraft in its portion of the GSO belt could be performed readily. Being completely above the atmosphere it would have advantages in astronomical observation exceeding those of Hubble, Freedom, and other low orbit satellites, which although above the troposphere and stratosphere are still within the Earth's thinly gaseous thermosphere.

A GSO station will be out where space is truly "black" This can be an advantage in observing the planet Mars, a target of twenty-first century exploration. For most of its 687-day orbit around the Sun, Mars is at a sun-avoidance angle from Earth of less than ninety degrees. This means that telescopes looking at Mars from Earth must look through the sunlit, i.e. "daytime", atmosphere, which makes viewing difficult. Outside the atmosphere in "black" space, without as much attenuation, refraction, scintillation or glare, telescopes can see clearly down to sun-avoidance angles of twenty degrees or less. Consequently they can observe Mars for most of its orbit. A similar effect applies to observations of other planets, comets, and asteroids as they approach the Sun.

8 . SCIENCE FROM GEO

One of the most dramatic pictures taken from space demonstrated the unique view of Earth obtainable from GSO. It was a daytime view in color taken by ATS-3 in 1967. For the first time it showed the fragile beauty and some of the complexity of our home planet when seen as a single entity. The picture is credited for impressing many who saw it with the realization that humans live in one relatively small world, and that it has an environment deserving careful preservation.

Viewing the Earth from GSO provides a perspective which is different from that obtained from low earth orbit or from lunar orbit. From low earth orbit, say 300 kilometers, the Earth subtends an angle of approximately 143 degrees, from GSO approximately 17 degrees, and from the Moon approximately 2 degrees. Each of these perspectives provides a distinct view with some unique information. The view from low earth orbit with relatively high resolution provides considerable detail. The view from the Moon is comprehensive and integrated providing a synopsis of the Earth's radiation, albedo and other overall features. The view from GSO is intermediate, providing useful views of cloud patterns, weather, ocean conditions, polar ice, vegetation, deserts, etc. The geostationary and lunar perspectives are capable of revealing new information when viewing the Earth and its atmosphere from the dark against the Sun's corona, e.g. from eclipse situations, during the coming century.

Motion of satellites in geostationary orbit is highly regular. Unlike satellites in eccentric orbits, geostationary satellites travel at a velocity considered constant at approximately 3 km/s. Their orbital planes are reported to oscillate periodically in a north-south direction under the influence of solar/lunar gravity causing a lengthening and shortening of a figure 8 of their ground track. If station-keeping adjustments are not made, measurements of natural perturbation can be used to evaluate solar and lunar gravitational forces. The east-west component of perturbations is attributed mainly to noncircularity of the Earth, i.e. its triaxiality. Some geosynchronous satellites whose station-keeping ability was exhausted have drifted into clusters at certain longitudes. Analysis of lunar orbits led to the discovery of mascons in the Moon's crust. If the Moon has mascons, it seems likely the Earth would have something similar. Identification of uneven mass distribution in the Earth's tectonic plates would assist understanding of terrestrial crustal dynamics, including earthquake mechanisms. Analysis of geosynchronous orbit data in the 21st century may lead to significant discoveries.

9 . CONCLUSION

Coming generations - the people of the twenty-first century - will be better educated and have a more global view of society. They will also have a better understanding of the need for human expansion into space and of priorities in industry and technology. These will extend to geosynchronous spacecraft and elsewhere. Many of the present barriers associated with funding constraints and international politics will be reduced. Faith in technical progress and in man's reasoning ability suggest that the next century may be as interesting a time to be alive as the twentieth century has been.

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