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GEOLOCATION APPLICATIONS of the GONETS LEO MESSAGING SATELLITES

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V.N. Vlasov, NPO-PI, Moscow, Russia
Javad Ashjaee, Ashtech
1170 Kifer Road
Sunnyvale, CA 94086
(408) 524-1400
FAX (408) 524-1500

INTRODUCTION

Geostationary satellites carry a majority of the international telecommunications traffic not carried by transoceanic cable. However, because the radio path links to and from geostationary satellites total at least 70,000 km and because of inherent on-board spacecraft power limitations, earth stations used in conjunction with geostationary satellites are usually large and expensive. This limits their installation to areas with a well-developed industrial and economic infrastructure.

This reality helps perpetuate a chicken-egg dilemma for the developing countries and isolated regions. Economic integration with the developed world requires being "networked". But for many developing entities, even the initial price of entry exceeds their modest resources.

Exclusion from the global information highways virtually assures retardation of economic growth for developing nations, remote and isolated areas.

Very Small Aperture Terminal (VSAT) earth stations are often thought of as a solution for networking developing regions. But economic considerations often forecloses this option. If VSAT size and cost is to be minimized, powerful spot beams from the satellite need to be focused on relatively small regions. This is not often feasible because of the high cost of the satellite itself. To dedicate a high power spot beam to a small region is usually not economically feasible.

Further improvement of the space segment could provide some relief for cash-strapped, low-density user populations. Some visions have been put forth of massive spacecraft with 30 m antennas, huge solar arrays generating several kilowatts and spacecraft masses exceeding 4 to 6 metric tons. Realistically however, the costs of building and launching such massive, complex payloads renders this possible approach to some future era. It will clearly be impractical for the near term.

Low Earth Orbiting (LEO) satellites offer a practical solution to this dilemma for many potential applications.

All LEO communications fall into one or two categories depending on the services they provide and their technical sophistication:

- data transmission
- voice communications

GONETS PACKET DATA RELAY LEO SYSTEMS

The category including projects such as Gonets, Leosat, Orbcomm, Starsys, Vitasat [1-2] can provide the following services:

- Digital data transmission of: text, imagery, databases, environmental data to/from control and sensors; Supervisory Control and Data Acquisition (SCADA)
- Paging
- Remote geolocation

Many applications do not require

uninterruptable links. Unlike a voice telephone conversation wherein a real-time link is essential, many data transmission applications allow for some enroute delay. Non-realtime data forwarding is vastly more cost-effective than providing realtime links.

All this considered, a practical, useful, low-cost, packet LEO data transmission network needs to be based on the following principles:

1. The use of a quasi-random constellation of satellites each of which has attitude control mechanisms but no station/orbit keeping facility. The number of satellites then depends on the specific orbital parameters and the allowable message delivery transit time from originator to addressee.

2. The use of VHF/UHF links (130-400 MHz) allocated for mobile satellite communications together with polar, circular orbits (700-1500 km). This allows global coverage and the use of simple, 0-3 dbi, low gain "omni" antennas, 2-10 W transmitters and very simple (gravitational) quasi-passive spacecraft attitude control.

3. The use of packet transmission mode to minimize power consumption of both the earth and space segments and to allow effective spectrum sharing by multiple users. The packet protocol minimizes channel contention and reduces overhead by simplifying channel control and supervisory intervention.

4. The use of an orbital constellation with quasi-random access windows is extremely easy to control and operate using a single master control center.

When realized in a practical network, these basic principles yield the following results:

1. Satellites can be very small (50-200 kg) and inexpensive capitalizing on the latest achievements in micro-miniaturization and satellite technology. Relatively low spacecraft mass and low orbital altitude allows a single launcher to carry several spacecraft thus reducing the overall cost of the space segment.

2. Ground terminals can be small, simple, inexpensive and user-friendly devices lowering maintainability requirements and the training of the "maintainers" themselves.

Thus, the foregoing principles allow the development of affordable LEO satellite networks for packet data transmission at an estimated cost of between $50 and $200 million depending on the range and complexity of services provided. Such networks are end-user oriented and do not require developed terrestrial land-line infrastructure. They thus provide instant network connectivity in "islands" of often urgent communications requirements. The time required to establish a node on any square meter of earth is the time needed to open an attache case and turn on a switch.

The "Gonets" LEO system is thoroughly based on the foregoing design philosophy and first principles. Gonets is programmed to be operational with an eventual total of 36 satellites organized as six planes of six satellites beginning in 1994 and building to a 1996 full operational constellation.

In the current system development phase, the "demonstration" phase called "Gonets-D" has already been placed in orbit. Two Gonets-D satellites were launched in July, 1992 and have since provided scores of demonstrations around the world.

Gonets-D has been demonstrated to various governments, industry, and financial institutions in Russia, other CIS countries, as well as in Australia, India, Africa, and elsewhere. A major series of Gonets-D demonstrations is planned in Western Europe later in June and South Asia in the July-August time frame.

The demonstration system will be expanded by Smolsat later in November or December 1993 to include an additional 6 satellites with 3 in each of the two orbital planes. That system, called Gonets D-1, will be capable of supporting up to 30,000 portable transceive terminals and a virtually unlimited number of SCADA terminals.

The Gonets-D1 advanced development demonstration system has the following performance values:

- 2 hours maximum access wait at the 0.8 probability level
- 3-6 hours average maximum message in-transit delays depending on the system completeness (number of spacecraft in service at that point

The above limitations resulted in the following communications protocol.

Communication between any two stations simultaneously in the 5000 km diameter footprint is quasi-realtime, quasi-bent-pipe mode.

The satellite periodically sends a preamble signal carrying data necessary to establish radio contact with a user. Users can exchange information when they are both in the footprint of the satellite using the preamble which contains the necessary subscriber identification information (callsign) and the particular geographic area information. The geographic area identification can be both satellite and Area Station (AS) generated. The latter is simpler and therefore employed by the Gonets system.

Various types of data transfers between User Terminals (UT) (UT1-satellite-UT#) and to a Stationary User Terminal (SUT) linked to the Area Station (UT2-satellite-AS1 SUT).

Users not simultaneously in the footprint of a satellite use the store-and-forward mode for communication. Data received by the satellite is stored in the on-board memory. When the message addressee is heard by the carrying satellite, the message addressed to him is downlinked to that station.

Even in its late developmental phase (1993-94), Smolsat will be offering precise geolocation services for mobile users by relaying Global Positioning System (GPS)/Global Navigation System (GLONASS) derived vehicle position data to corresponding central service stations via Gonets-D1 by using a synthesis of Gonets and GPS terminals in a convenient package.

Vehicles and other mobile platforms (be they icebergs or high-value cargo) which require highly accurate location determination reporting will use a synthesis of GPS/Glonass receivers and GONETS transceivers to provide this information to managers. The GPS/Glonass-Gonets synthesis will provide the facility to accurately and quickly telemeter the location and status of a vehicle anywhere on earth to a command center with an accuracy within several meters.

While these terminals locate the vehicle (or other mobile object), status and/or message traffic is transferred to central stations via Gonets user terminals. A standard RS-232C interface is used to connect the various equipment.

DIFFERENTIAL NAVIGATION

Commercial GPS/Glonass navigation receivers are limited to the GPS standard position service (SPS) accuracy of 100 meter available worldwide for civil use and similar accuracy for the Russian Glonass system.

Navigation receivers which use differential corrections can significantly improve performance. Typical differential GPS accuracy is from 0.5 to 5 meters. Differential Glonass accuracy can expect similar improvements over autonomous receiver operation.[4]

The accuracy of differential navigation

is limited by the distance between the base station and remote receiver, the age of the differential correction data (update rate), and the differential data link.

The corrections remove most of the error from the major error sources affecting the accuracy of satellite-range measurements: satellite orbit estimation, satellite clock estimation, ionospheric error, and tropospheric error. After the correction is applied, the residual error is on the order of one millimeter for every kilometer of separation between the base and remote receiver.[5]

It is estimated that over 500 base differential stations would be required to cover the United States. Techniques are being investigated which may reduce the number of base stations required to provide differential range corrections for a wide area.[6][7]

The differential corrections must be transmitted to the remote receiver at a data update rate sufficient to eliminate the effects of time varying satellite errors and atmospheric effects. Update rates from two to six seconds are sufficient to minimize these effects.

The differential data message can also include information on the integrity of the differential corrections and the real-time health of the navigation satellites which is critical for some applications.

The differential data link requires selection of an appropriate transmission frequency to assure reception at the remote receiver and meet local governmental licensing requirements. The selection of a Gonets system as the data link provides an ideal solution to these problems.

GEOLOCATION APPLICATIONS

Applications for differential navigation encompass a wide range of user needs and uses. Equipment complexity is dictated by user requirements. Some applications require continuous reception of differential corrections and other applications need a correction at a distinct location or time. Some users require knowledge of the position of the remote units.

These user requirements can be met simply with just a GPS/Glonass receiver and Gonets user terminal. Gonets protocol is built into the standard interface of the Ashtech GPS/Glonass-Gonets capable receiver.

Users requiring map or navigation displays can add a common personal computer to the basic configuration. Geographic information systems (GIS) could use a bar code reader to easily enter attribute information for the landmark.

Typical applications include: worldwide accident investigation (aircraft, ship, oil spills, earthquakes, hurricanes, and other infrastructure damage), worldwide rescue operations, locating & tracking icebergs, exploration geophysics, oil rig positioning, vessile docking, channel dredging, installing remote communications sites, harbor depth mapping, and a host of many other GIS applications.

Vehicle tracking systems or fleet management systems could perform worldwide tracking and route management control of vehicles (ship, truck, automobiles, and aircraft). It is even possible to apply this technology to unmanned ships traversing the oceans. The system could then be used by a pilot to safely navigate the harbors.

Agricultural equipment would benefit from accurate position data for planting, applying fertilizers and pesticides leading to improved yields. Navigation and control of unmanned combines and tractors may also be feasible.

All users would have confidence they can depend on the accuracy of the GPS/Glonass-Gonets position data from the health data built into the satellite differential correction messages.

Table 1. GONETS Technical Data

GONETS Orbital Specifications
General Orbital Characteristics:
Type:LEO, polar
Inclination angle: 82.6degrees
Period: 114minutes
Apogee:1420km
Perigee:1420km
Footprint:5000km
Characteristics of the GONETS-D Orbits
Number of satellites: 2
International Designators:
Cosmos 2199, Object 22036
Cosmos 2201, Object 22038
Launched: 13 Jul 92 from Plesetsk

GONETS Spacecraft General Specifications
Bus Description:
Mass:225kg
Dimensions: Length150cm
Diameter100cm
Max span, antennas deployed: 140 cm
Attitude control: Gravity gradient boom, magnetic assisted
Attitude accuracy:5 - 10degrees
Power:
Orbital average power: 45W
Peak power available:160W
Thermal control:Maintains 0 - 40 °C
Launcher:Cyclone 6 per launch

GONETS Communications Characteristics
Subscriber/user terminal characteristics
Earth-to-Space Direction
Maximum gain:+2.0dBi
Polarization:RHC
Service area:Regions 1, 2, 3
Class of station: CP, TG, TU
Receiving system noise temp: 700 °K
Frequency range:259.450 - 259.550 MHz†
261.850 - 262.150 MHz†
264.375 - 264.525 MHz†
387 - 390 MHz
Emission designator:20K0G1W
Total peak power:+10.0 dBW
Maximum power density:-37.8dBW/Hz
EIRP:+5.19 dBW
Typical earth station:Type UT-P

Space-to-Earth Direction
Spacecraft Characteristics
Maximum gain:+2.0dBi
Polarization:RHC
Service area: Regions 1, 2, 3
Type of service: EG, EU, CP
Frequency range: 258.900 - 259.100 MHz†
261.085 - 261.1350 MHz†
262.900 - 263.100 MHz†
264.400 - 264.600 MHz†
312 - 315 MHz†
Emission designator: 20K0G1W, 10K0G1W
Total peak power: +10.0 dBW
Maximum power density: -37.4 dBW/Hz
Space station EIRP +7.6 dBW
Receiving system noise temp: 490 °K

Communications Link Parameters
General:
UHF uplink, UHF downlink
Signaling rate: 2.4 kbps†
2.4, 9.6, 64 kbps‡
Modulation: DPSK
Coding: Reed-Solomon coding (32,38), M=8
Decoding: Viterbi (R=1/2, K=3)
Link Margins:
Portable terminal UT-P 5-7 dB
Fixed terminal UT-S 5-7 dB
Link control protocol: DAMA using FDMA/TDMA
Marker signal present
Aloha mediated assignment channel
Channelization (36 satellite network system):
Preamble signals: 72 physical chan
Signal communications: 10,800 TDMA chan
Data channels: 72 physical chan
Packet transmission: 21,600 16kbit slots/min

Network Performance:

System Throughput at 13% 3x10E04 Mbit/day

or 3x10E06 pages/day (GONETS)

Number of users: Up to 1,000,000

Wait time: 20 minutes @ 0.8 probability

Delivery time (worst case): 1 hour

† GONETS-D only

‡ GONETS-D1 only

Program Phasing:

Phase Event	Schedule	Capacity (pages/day)	On-board memory (MByte per satellite)
Launch of two Gonets-D (demonstration)	13Jul92	3x10E2	0.019
Launch of 6 Gonets D-1 (isolated user groups)	Nov.1993-Jan.1994	1.2x10E4	2
Full GONETS constellation	1994-1996	3x10E6	8/16
Start of commercial use	1994/5		

Programmatics:

Organizations in consortium:

- SMOLSAT (Moscow): Program management
- NPO AM (Krasnoyarsk): spacecraft bus; system/launch integration
- NPO PI (Moscow): spacecraft subsystems
- Izhevsk Radio Manufacturer: communications payload, user terminals
- Kievpribor Manufacturer: communications payload

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[7] Dariusz Lapucha, *Multi-Site Real-Time DGPS System Using Starfix Link; Operational Results*, Proceedings of ION GPS-92, September, 1992.