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Position Reporting System Using Small Satellites

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ABSTRACT

The demand for mobile communications is growing in the world. Satellites systems can be a candidate solution to supply some of these services. In this context, a system able to provide position reporting and monitoring services for mobile applications represents a natural complement to GPS navigation system.
This service could be managed by public organization or by private groups. Private organizations can operate through Closed User Groups (CUG) and optimize the use of the own assigned satellite capacity.
In order to reduce the costs and the time necessary to implement the system, small satellites can be used, launched in piggy-back mode or by small launcher.
The system architecture is defined on the basis of the communications requirements derived by user needs, allowing maximum flexibility in the use of channel capacity and very simple and low cost mobile terminal.
The payload is sketched outlining the blocks modularity and the use of qualified hardware. The global system capacity is also derived.
The spacecraft characteristics are defined on the basis of the payload requirements.
A small bus optimized for Ariane IV, Delta II vehicles based upon the modularity concept is presented. The design takes full advantage of each launcher with a common basic bus or bus elements for a mass production.

1. INTRODUCTION

Satellite mobile communications together with position reporting are requested for several reasons and constitute a valuable market.
The aim of this paper is to propose a low cost system architecture which can be convenient for private networks, for land mobile and aircraft applications.

Land mobile users are requesting:

- two-way data messages,
- localization and position reporting,
- alarm services for security and safety of transported goods,
- emergency,
- interactive services.

Target customers are trunking organizations, tour-operators, governmental agencies, surveillance and rescue service providers.

The system architecture adopts message transceivers suitably integrated with localization equipment. The transceivers communicate with the control gateway stations, sending and receiving messages to/from the satellite.

The key element for a successful application of this scheme is the high-value service, when provided in a cost-effective manner. Low costs are associated to the concept of private use. Thus, data messages, position determination and position reporting can be a promising business for closed user groups operating through their own private networks.

Direct access to data bases, together with vehicle management and control are additional features offered by this system. Automated or on demand updating messages with vehicle geographical location can be beneficial in controlling ad-hoc dispatching, and in scheduling travel management.

The flexibility of the system and the possibility of enhancing the capacity according to the communication traffic or the number of mobiles are other significant advantages. This modularity will allow gradual investments for private networks, which can begin their operations dimensioned as needed.

For the aircraft the most demanding service is the support to ATC (Air Traffic Control) with ADS (Automatic Dependent Surveillance) services.

The adoption of satellite-based system for air traffic ADS is mainly driven by the need to improve the Communication, Navigation and Surveillance services. According to ICAO requirements, the ADS will support aircraft position monitoring with high frequency of updating. The requirements for ADS service are:

a) the ADS data acquisition has a minimum periodicity of 10 sec, with a message length of 144 bits;
b) typically on long route application an ADS message is requested every 5 minutes with a message length of 330 bits (including basic ADS report, extended ADS report and associated ADS report data).

For case a) 1 message of 144 bits each 10 sec is equivalent to an information of 864/minute. Up to 40 users can be served by one channel rated at 600 bps.

For case b) 1 message of 330 bit each 5 min. allows to serve more than 500 users through one channel, rated at 600 bps.

The traffic we assumed considers 85% of the traffic due to the high frequency updating and the remaining for the complete message updating each 5 min. In this way, we can consider that each channel can serve 36 users with updating message every 10 sec, and 85 users with updating messages every 5 min that is equivalent for each channel to a 1 min. of updating for a message of 330 bits for 100 users each hour.

2. SYSTEM CHARACTERISTICS

A system capable to provide position determination service, position reporting and data message services can be implemented in a selected zone using a reduced constellation of satellites. The proposed configuration is a constellation of two small satellites positioned in Tundra orbits plus 3 small geostationary satellites.

All satellites are provided with navigation packages, GPS compatible. In addition, the GEO satellites are provided with communication payloads for position reporting and data message services. The revenues of the overall system are obtained through the communication services.

The major system features are:

- complementary to GPS-NAVSTAR;
- use of same GPS-NAVSTAR navigation message structure, but with different sets of PRN codes;
- unlimited number of users for position determination;
- gap filler in zones of poor GPS availability;
- 20 to 50 thousand users for position reporting at 600 bps;
- TDMA scheme for position reporting.

We envisage the following organization for position reporting:

- use of one GEO-satellite for aircraft services in connection with user's terminals of enhanced type,
- use of two GEO-satellites for land mobile services.

The HEO satellites will carry the navigation payload only.

Satellite Payload Configuration Outline

The payload is composed of:

- one transparent transponder receiving at C or Ku-band (or another band to be specifically allocated) the navigation signal from a feeding station part of a fiducial system supporting the service and retransmitting at L-band, at the same frequencies of operation of the GPS-NAVSTAR;
- one transparent transponder receiving messages from mobile users at L-band (in the range allocated to mobiles) and retransmitting down to the earth stations at C or Ku or another band and vicecersa.

The major navigation payload parameters, for a margin of about 5 dB in GPS signals reception, are:

	GEO	TUNDRA
. Satellite EIRP	26.8 dBW	28.7 dBW
. Antenna gain (EOC)	16 dB	16.5 dB
. HPA RF power	12 W	16.6 W

The navigation payload mass is about 35.9 Kg with a power consumption of 60 W for GEO payload and 74 W for HEO payload.
Only C/A code is envisaged for this type of civil service. Thus, the frequency used will be 1.57545 GHz

The major parameters of the data service are:

		AIRC/FWD	AIRC/RET	LMOB/FWD	LMOB/RET
. N. of carriers/ transponder		2	20	4	30
. Access/modul.		TDMA/ QPSK	TDMA/ QPSK	TDMA/ QPSK	TDMA/ QPSK
. BW per carrier		81 KHz	8 KHz	30 KHz	4 KHz
. Total bandwidth		162 KHz	160 KHz	120 KHz	120 KHz
. Power per carrier	L-band	40 W		15 W	
	C-band		0.5 mW		0.16 mW
. Total power	L-band	80 W		60 W	
	C-band		10 W		5 W
. Output back-off		1 dB	3 dB	2.2 dB	6 dB
. Satur. power	L-band	100 W		100 W	
	C-band		20 W		20 W
. Ch.s per carrier		40	4	15	2
. Channels		80	80	60	60

A two way service is established with:

- L-band, for down links from the traffic control centers (Forward link),
- C-band, for down links from the users (Return link).

The position reporting payload mass is about 40 Kg, excluding the antenna system which is part of the navigation payload while the power consumption is about 285 W.
The frequencies of L-band are in the same range of aeronautical and land mobile communications. The frequencies of C-band (or Ku-band) are in the conventional band allocated to feeder links.

The payload budget for navigation and position reporting are as follows:

PAYLOAD BUDGET FOR NAVIGATION SERVICES

	MASS (Kg)	POWER (WDC)	POWER (WDC)
	GEO-HEO	GEO	HEO
Amplifiers	3.5	35	47
Receiver section	5	10	10
Up-down converter IF transp. section Filters and switches	10	10	10
Antenna system L-band C-band	12 2.5		
Margin	3	5	7
Total	36	60	74

PAYLOAD BUDGET FOR POSITION REPORTING SERVICES

	MASS (Kg)	POWER (WDC)
	GEO	GEO
Amplifiers L-band C-band	14 7	180 + 60
Receiver section & dipl.	5	10
Up-down converter IF transparent section Filters and switches	10	10
Antenna system L-band C-band		
Margin	4	25
Total	40	285

The overall payload mass is estimated 76 Kg about, and the power consumption is about 345 W (DC).

The earth segment for navigation service will be composed by:

. Navigation fiducial network: four stations
. Master control station: one main center, at least
. Mobile terminals: GPS receivers, or similar

The typical features of the ground segment for the message communications are simplicity and low cost. A large scale production of the mobile terminals, will allow the low cost characteristics. The major characteristics of data message communication earth segment are:

GROUND STATIONS GATEWAY

. Frequency	C-band
. Antenna size	3 m diameter
. Antenna gain	39/42.6 dBi Rx/Tx
. EIRP (for 1 carrier)	40 dBW
. G/T	12.1 dB/K

MOBILE TERMINALS DATA MESSAGE

	AIRCRAFT	LAND MOBILE
. Frequency	1.5 GHz Rx, 1.6 GHz Tx	1.5 GHz Rx, 1.6 GHz Tx
. RF Tx power	15 W	10 W
. Antenna gain	3 dBi	3 dBi
. G/T	-21.5 dB/K	- 21.5 dB/K

The number of user's terminals will be several thousands.

3. THE USE OF LOW COST SMALL SATELLITE

In order to implement these systems it is necessary to reduce the high costs involved with satellite development and launch, a small bus capable to fly at marginal cost on a piggy-back mode can provide an alternative access with respect to other bigger satellite families.

A such kind of satellite shall be developed, tested and launched in a short period with a low launch cost, it shall be also lightweight, manufactured with mass production techniques, having some relaxation in failure rate and reliability requirement.

In the following table the principal cost reduction areas are presented for a small satellite with respect to a typical allocation cost for a communication satellite. As it can be noted the major areas candidate for cost reduction are administration, system engineering, product assurance, a launch.

	ALLOCATION
Program Administration	16.4%
System Engineering	8.2%
Product Assurance	10.3%
Assembly Integration test	10.5%
TT&C and DH	3.5%
AOCS	6.3%
Propulsion	6.3%
Solar Array	3.8%
Power Control	4.1%
Structure	5.2%
Thermal	1.3%
Communications Antenna	8.1%
Communications Transponder	16.0%
	100%

Launch cost with respect to satellite cost	100%
Launch Insurance with respect to Satellite cost	25%

Cost Reduction Areas

The administrative costs can be reduced by negotiating contract conditions directly with the equipment vendors. Co-responsibility and incentive can be used to reduce sub-system contract costs.

Further reductions are possible incorporating several functions in single units, with reduction of number of contracts to be managed.

The system engineering costs can be reduced involving the system team during all activities across the program, to cope also some specialistic efforts and minimizing the subcontracted items.

Another area for cost reduction concerns the design, manufacturing, integration, testing techniques and product assurance procedures.
The primary reasons for high cost of satellites are the small number of units produced and the high single-satellite reliability required.
It is evident that systems employing larger number of moderate capacity platforms can be more economical than high performance platforms, reducing a significant amount of production cost.
The current methods to enhance reliability are extensive testing and equipment multiple redundancy. In the case of a small satellite, the low level of interconnection and the units integration allow to significantly reduce the test procedures, taking also into account limited redundancies.

As regards the launch the primary payload usually does not exactly fit to the launcher capability, so additional mass is available for secondary payloads. Taking also into account that the Ariane and Delta II launchers can increase the length of fairing and make available small additional volumes for a piggy-back passenger sandwiched between the launcher interface ring and spacecraft adapter (Fig. 1). It is clear the possibility of launching at a marginal cost the additional passenger.

4. SMALL BUS FOR GEO AND HEO MISSION

For the basic configuration of "MINISTAR" satellite, a sun pointing attitude concept has been selected, that with some modifications permits to support both HEO and GEO missions (Fig. 2).

The satellite design adopts an inter-passenger approach.
The external structure is dimensioned to support the upper passenger during the launch and have in the upper part a ring for the attachment of primary passenger adapter and in the lower part a circular junction with the launcher.
In the lower side of spacecraft there is a racks where the tanks for pressurization are placed. At the center of the structure is positioned a central tube that support the bapta for the payload platform and the bipropellant motor. Four vertical plates attached at the tube support the propulsion tanks.

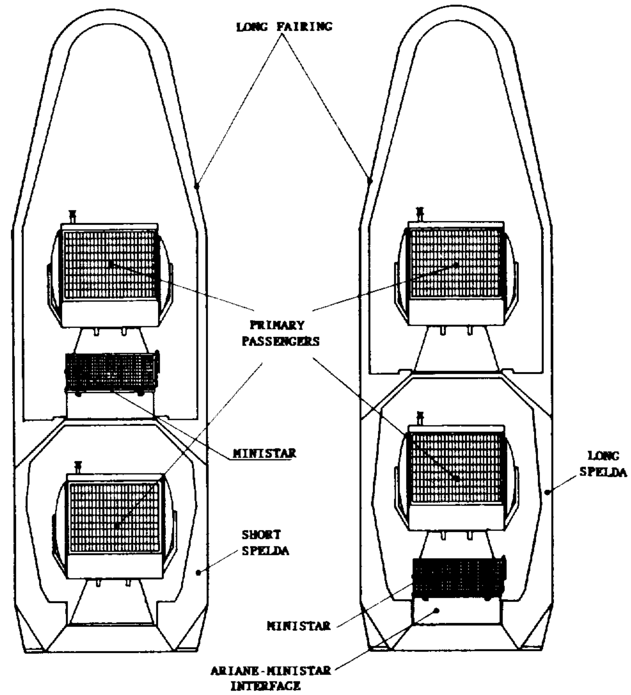

FIGURE 1 - "MINISTAR" IN ARIANE IV LAUNCH CONFIGURATION

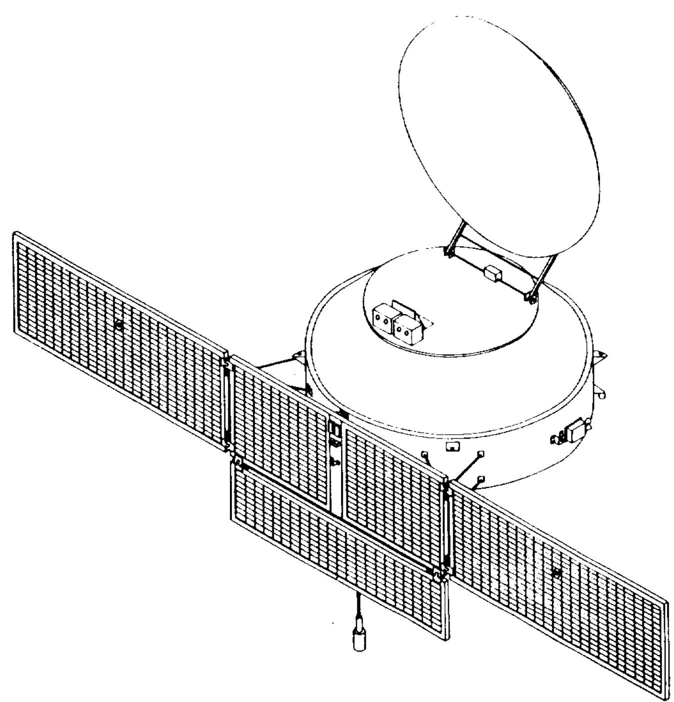

FIGURE 2 - MINISTAR CONFIGURATION

The solar panels, once deployed, are rigidly fixed to the spacecraft and during the launch are wrapped around the spacecraft structure.
The payload is positioned on a platform rotating at one revolution per day and allows to accommodate a 1.8 m reflector communication antenna.

The main differences between HEO and GEO are the antenna pointing mechanism and the attitude and orbit control system. In fact, in the GEO case the antenna is fixed on the rotating platform and the yaw pointing is assured by the control loop using momentum wheel and thrusters, while in the HEO case it is necessary a further pointing mechanism which allows the variation of antenna elevation with an angular displacement proportional to the latitude of earth covered zone.

The relative velocity between service module and payload module is one revolution per day in both GEO and HEO. In the HEO case, the velocity rate is variable and make more complex the attitude control procedure.

System Management Processor

The satellite functions and operation coordination are performed by an on-board central computer which can be programmed for each mission and for each configuration. This microcomputer derives from the current technology, it has a multitask operating system and it is substantially a supervisor of attitude control system and perform the TT&C functions managing also the periodic control of other satellite subsystems and activating particular sequences as separation and apogee motor firing.

Telemetry and Command

It performs three main functions:

- the telemetry function (a reduced rate in the order of 200 bps could be used in this case),
- the command function,
- the tracking function.

In stationary conditions, the payload antenna system, is used. In the emergency and launch conditions, when the attitude of the satellite is not fixed, the TT&C will operate through the omnidirectional antenna.

Propulsion

The motor used for the apogee maneuvers will be a liquid propellant.
This seems a suitable solution in the case of "MINISTAR", even if the use of liquid bipropellant technology will lightly increase the cost.

The first advantage is that multiple burns are possible, permitting higher injection accuracy. Besides, it is not necessary to spin-up the satellite at high spin rate during the maneuver.

The second advantage is that bipropellant facilitates the accommodation of the tankage structure into a small structure.

A third advantage resides on the motor control electronic unit, which remains the same while the tanks can be tailored for each mission and for each spacecraft weight.

Attitude Control

The main element for attitude recon-sititution are a two axis infrared earth sensor mounted on the payload platform and a sun sensor positioned on the solar panel. This sensing principle, together with a significant momentum bias provided by a momentum wheel positioned along S/N direction, provides the nucleus of the attitude control system.
The momentum bias needs to be adjusted in length and direction in regular intervals of days. To execute the correction maneuvers 6 thrusters (12 for redundancy) are adopted also for orbit control.

Thermal

The thermal control of "MINISTAR" uses only passive techniques. Electric heaters with automatic control capability could also be included. This means that the temperatures of the components have to be maintained within their limits by:

. controlling conductive and radiative heat paths,
. selecting a suitable geometrical configuration of the equipment,
. selecting thermal coating (i.e. thermo-optical properties of the surfaces),
. using thermal insulations for selected zones of the satellite in order to reduce both heat flow to or from component and temperature fluctuations of component due to time varying external heat flux.

In addition, electric heaters could be required for some particular component (e.g. battery).
A design margin of 10 degrees centigrade has to be maintained between operating in orbit temperature limits of the equipments and the limits over which they are to be qualified.

Power and Mass Budgets

In the following tables are presented some preliminary estimation of mass and power for the selected satellite options.

SATELLITES POWER BUDGETS

	GEO	HEO
	COMMUNICATION & NAVIGATION	NAVIGATION
Payload	345 W	74 W
Propulsion	12 W	12 W
System manag. processor	25 W	15 W
Telemetry and command	20 W	20 W
Attitude control	22 W	12 W
Thermal	7 W	3 W
Harness loss	5 W	3 W
Battery charge	60 W	-
Margin	20 W	10 W
TOTAL	516 W	149 W

SATELLITES MASS BUDGETS

	GEO	HEO
	COMMUNICATION & NAVIGATION	NAVIGATION
Payload	76 Kg	36 Kg
Electric power	42 Kg	10 Kg
Structure	50 Kg	25 Kg
Propulsion	16 Kg	16 Kg
System manag. processor	18 Kg	14 Kg
Telemetry and command	10 Kg	10 Kg
Attitude control	20 Kg	18 Kg
Thermal	5 Kg	3 Kg
Mass margin	30 Kg	25 Kg
Dry spacecraft mass	267 Kg	157 Kg
Propellent	26 Kg	10 Kg
Apogee motor expendable	118 Kg	50 Kg
TOTAL	411 Kg	217 Kg

These mass and power budgets are derived considering:

. for the GEO satellites: Ariane IV launch, 50 m/s per year for station keeping, 5 years of life plus 1 year of margin;

. for HEO satellites: Delta II launch, 30 m/s per year for station keeping (Ref. 1, 2, 3), 5 years of life plus 1 year of margin, no eclipse during operational phase.

Economic analysis

A cost/revenue model has been applied to this configuration. The case of small satellite allows the following economical considerations:

. low cost per Kg of the payload,
. quick saturation of the available capacity,
. low cost of the launch,
. two operational Tundra satellites plus one spare satellite, launched all together with a single launch with Ariane,
. three GEO satellites launched in Ariane piggy-back,
. reduction of the system organization cost due to the low complexity of the management of the overall mission.

The assumptions for cost of the organizations are:

Inflation rate	3.5%
Discount rate	
. Capital investor	9%
. Service provider	9%
. Ground segment prov.	9%
Profit	
. Space Corporation	10%
. Service Provider	14%
. Ground Segment prov.	12%
or	
. Unified corp. earnings (Space Corp.+Serv. Prov.)	24%
. Banking system	9%
Cost	
. Administration (MAU/yr)	0.05
. Investment cost (MAU)	2.5
. Operation cost (MAU/yr)	0.15

The revenues are derived as output from:

- number of channels used or number of users, according to the service penetration profile during the mission,
- cost per unit, which is the cost per number of bits transmitted each second.

The navigation service is offered free of charge while the channel occupancy is charged with a cost per message.

The navigation and position reporting system recovers the cost from the message transmissions. The messages mainly concern with the position of the user, but other information can be transported by the system. The system provides a two-way message capability.

The references costs are:

- 0.7 USD per 1 Kbit message,
- 0.1 USD per messages of blocks of 256 bits, (Geostar).

In making the comparison, we consider the channel cost per year as results from the model runs which is 0.315 MAU/ch/year and consider a channel utilization of 6 hours per day during the working days, which corresponds to 93960 min/year.

For the 1 Kbit messages we obtain: 0.093 AU and 0.081 AU, respectively for the case of full insurances of the system elements and the case of absence of insurances.
The Space company and the Service-providers are considered as different organizations.

In the case of only one Actor, the cost per 1 Kbit message is 0.084 AU.

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