System Design for Commercial Microsatellite Missions

Dr. Dino A. Lorenzini
Executive Vice President, Interferometrics Inc.
Vienna, Virginia 22182

and

Dr. Vincenzo Violi
Head, Space and Orbit Support System Division
Telespazio S.p.A, Rome, Italy 00156

This paper presents the results of a Microsat Feasibility Study conducted by Telespazio S.p.A and Interferometrics Inc. The study examined the feasibility of three possible near term space missions: (1) data collection and relay for environmental monitoring, (2) mobile messaging and digital communications, and (3) remote sensing of sulfur dioxide content in the atmosphere and detection of wild fires. The generalized system architecture consists of a network of low Earth orbit microsatellites, an array of low cost fixed and mobile User Terminals for either communications or data collection, and a Mission Control Center tailored to the specific mission. A prototype system consisting of four or more microsatellites could perform a combined environmental data relay mission and a limited communications mission in the 1994 - 1999 time frame. An operational system based on the experience gained during the prototype phase could be designed for both a remote sensing and a communications mission for the 1997 - 2004 time frame. The study examined the technical, programmatic and financial aspects of the selected missions. The objective of this effort was to establish the design parameters for evaluating the profitable introduction of these new microsatellite missions during the time frame of interest. The paper presents the mission designs, system concepts and programmatic aspects of selected microsatellite opportunities.

Background

Recent initiatives for low cost communications satellites that operate in low Earth orbit suggests the possibility of using a network of these satellites to create a commercially profitable communications service. Consideration by the 1992 WARC for allocating new spectrum for use by low Earth orbit communication satellites has opened the way for a lower cost entry into the satellite communications market. The expected advantages of these systems, including the use of low cost, low power, flexible and portable terminals, has prompted several companies to submit applications to the Federal Communications Commission for satellite construction and operating licenses.

Telespazio, in cooperation with Interferometrics, conducted a three month Microsat Feasibility Study in order to identify appropriate Microsat missions and to assess the economic feasibility of introducing a new space communications service based on the use of small, inexpensive, low Earth orbiting satellites.

Microsat Characteristics

The important characteristics of a low Earth orbit (LEO) microsatellite that distinguish it from a large geosynchronous (GEO) satellite are its regional coverage and its communications links. A GEO satellite will cover a fixed region of the Earth. This provides continuous satellite coverage to a user at a fixed azimuth and elevation angle. Because a GEO satellite is approximately 36,000 km from the user it requires large transmitter power and/-or high antenna gain in order to establish the communications link. These characteristics generally limit the use of GEO satellites to fixed installations with a high data transfer rate, although there are several examples of GEO satellites that are used with small or mobile terminals.

Typically, a single LEO satellite provides only intermittent coverage over the entire Earth several times a day depending on the inclination of the satellite and the latitude of the user. For a satellite in polar orbit a typical mid-latitude user would see about six passes of the satellite each day. Each pass would last approximately 8 to 20 minutes depending on the satellite's orbital altitude and the elevation of a particular pass. Thus, a user would have about 1 to 2 hours of visibility each day to a single satellite. Multiple satellites in LEO would increase the visibility period depending on their relative position in orbit.

Figure 1 is a plot of elevation angle versus time for a typical 24 hour period. It is generally possible to communicate with most LEO satellites when they are at an elevation angle of 5 to 10 degrees above the horizon. Again, depending on the satellite's orbital altitude, the satellite visibility footprint above 10 degrees elevation from the user may range from 4,000 to 6,000 km in diameter. Figure 2 depicts a typical LEO satellite footprint over Europe.

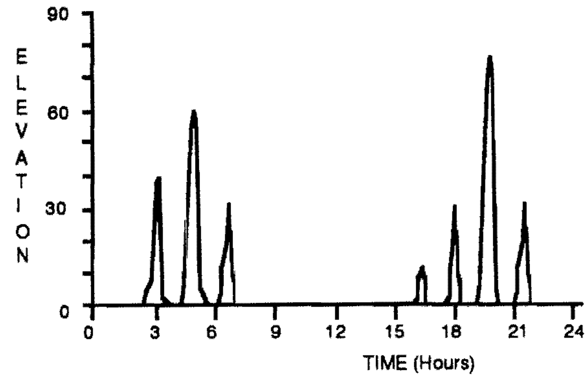

Figure 1. Satellite Elevation vs. Time.

Figure 2. Typical Satellite Footprint

Because of its closeness to the user, a LEO satellite can connect with a user at modest data rates up to 9600 bps with only a few watts of transmit power using a hemispherical antenna pointing toward the Earth. A user with a compact, lightweight transceiver operating at a few watts of power can communicate with the satellite when it is visible in his region. The ability to use these low-cost, low-power communications terminals opens up many new applications for using LEO satellites.

System Description

A complete satellite system would consists of the four major segments shown in Figure 3. The space segment would include one or more satellites in low earth orbit. The launch segment used to get the satellites into their desired orbit could be provided by a dedicated vehicle, a shared ride with another satellite, or a piggyback launch with one or more primary payloads. The ground segment would consist of: (1) an Operations Control Center to monitor the health of the satellite and and to control it on-orbit functions, and (2) a Mission Control Center to handle the mission data and to interface with the users. The user segment includes all of the fixed, mobile and remote terminals that communicate through the satellite link.

Mission Selection and Rationale

The special characteristics of a LEO microsatellite system, such as global coverage, low power transmitters, omnidirectional antennas, small inexpensive terminals, global digital data relay, and relatively low cost, could create new opportunities for addressing a number of different communication requirements.

Among these opportunities are:

- Digital messaging services for government agencies or construction firms.
- Data collection for scientific research or environmental monitoring.
- Data distribution for religious organizations or private companies.
- Mobile communications for business travelers or exploration groups.
- Position location for fishing fleet or floating buoys.
- Remote sensing with small sensors.

The size of the potential addressable market in the U.S. for these satellite services is given in Figure 4. Because of the size of the potential market, only a small penetration into selected areas is required to recover the cost of an initial microsatellite system.

The cost and complexity of selected missions are shown as a function of mission availability in Figure 5. The missions which could be implemented in the next few years using existing technology are highlighted in the figure. The more challenging missions, because of their technical complexity or high investment cost, are found in the upper right portion of the figure.

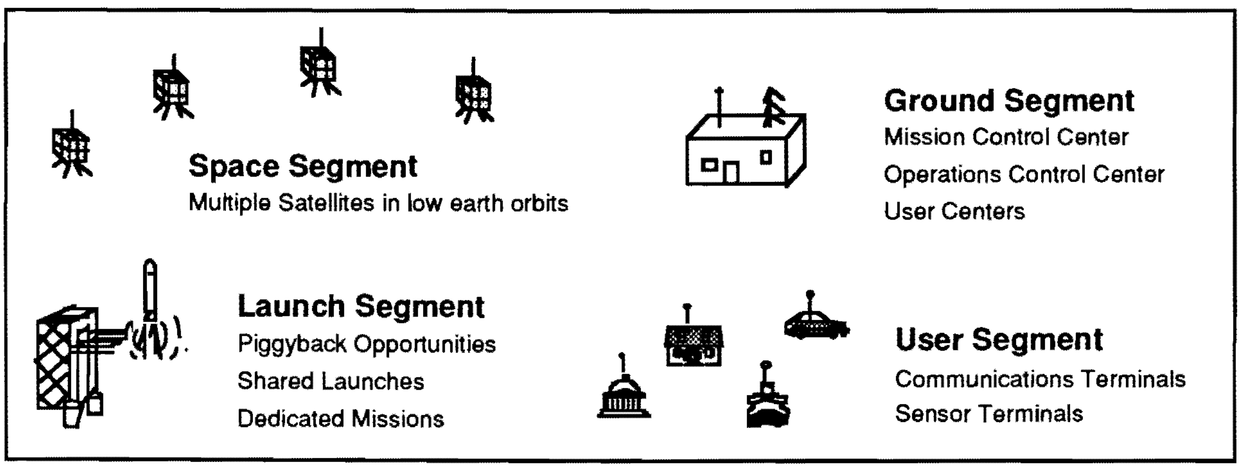

Figure 3. System Architecture

SERVICE	APPLICATION	SIZE OF MARKET
DATA ACQUISITION	Environmental Monitoring Industrial Monitoring Remote Asset Monitoring	100,000 Government data stations 151 million electric meters 270,000 vacation homes
MESSAGING	Personal & Business Handicapped Trucking Hazardous Material Transport	7.5 million pagers 2 million deaf persons 1.3 million long haul trucks 18,000 shipments per year
TRACKING	Boxcars & Containers Stolen Property Recovery Customs Security Transmitter Tracking	5 million boxcars 182 million licensed vehicles 500,000 U.S. Containers 5,000 ARGOS terminals sold
EMERGENCY SERVICE	Emergency Road Service Search & Rescue Emergency Medical	48 million subscribers 22 million park visitors 12 million people over 65 with health problems

Figure 4. Size of Addressable U.S. Market for Microsatellite Services

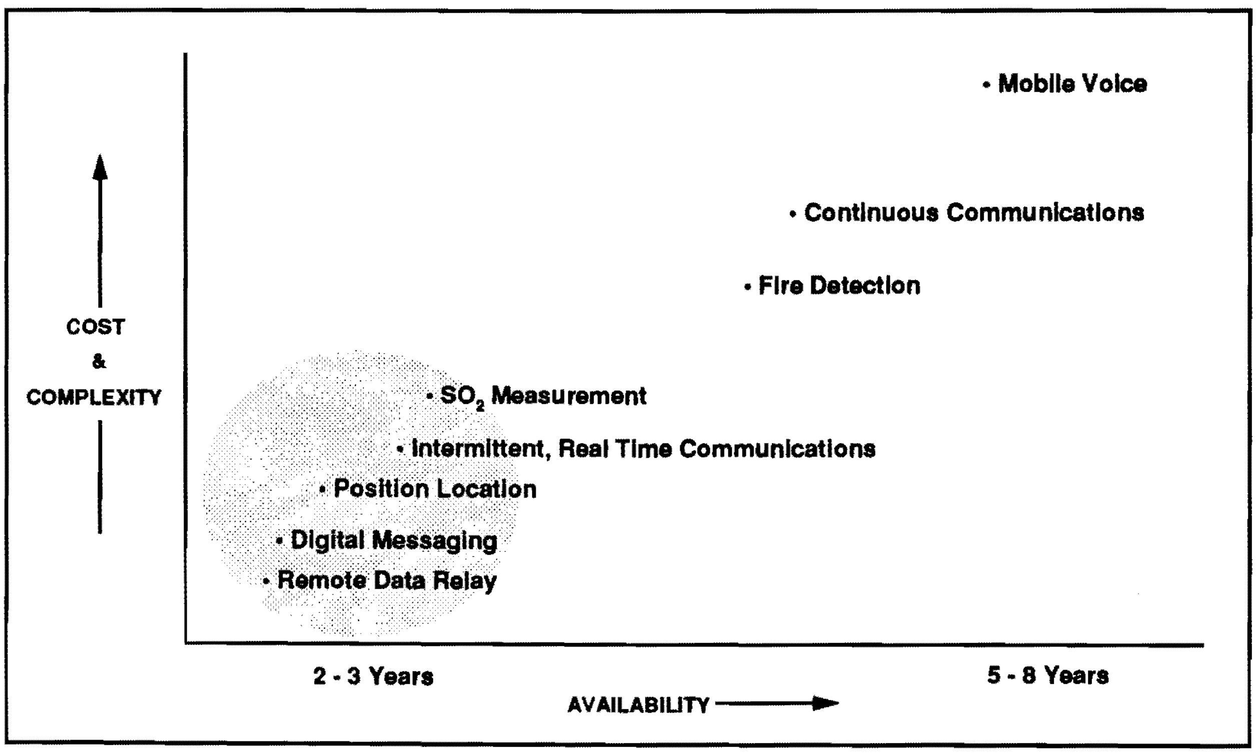

Figure 5. Mission Complexity vs. Availability

Program Objectives and Strategy

From an examination of the applications having the most commercial profit potential, four possible microsatellite missions were selected for further investigation. The names and objectives of these missions are:

- Initial Mission: Provide environmental data relay services and establish a space test bed to investigate future missions.
- Prototype Mission: Provide limited digital communications services, validate operations and system management concepts, and demonstrate satisfactory profitability at acceptable prices.
- Operational Mission: Maintain compatibility with the prototype mission while providing continuous global coverage.
- Remote Sensing Mission: Measure the sulfur dioxide content in the atmosphere and/or detect and report forest fires.

To achieve these program objectives with modest investment capital, limited risk, and competitive positioning the following business strategy was devised:

- Capitalize on small satellite technology and new LEO frequency allocations.
- Find niche markets that satisfy real user requirements.
- Take advantage of inexpensive microsatellites and low cost launch opportunities.
- Limit initial investments, but seek reasonable financial returns.
- Focus initially on regional customers, but expand operations to global areas to improve economic viability.
- Use incremental program stages and build on previous experience.
- Insure that each stage is profitable and self-contained.
- Plan for exit if market does not materialize.

Initial Mission Concept

The Initial Mission consisting of two microsatellites could be launched as early as 1992 on the Ariane IV vehicle. To comply with the table of satellite frequency allocations for meteorological data relay and satellite operation, an earth-to-space frequency of 402 MHz and a space-to-earth frequency of 137 MHz would be used.

Each satellite would have four data channels operating at 2400 bps and one telecommand channel. One mission transmitter and one satellite telemetry transmitter would operate at 9600 bps in order to relay all of the environmental data to the Mission Control Center in real time while at the same time monitoring the satellite health status. Each transmit channel would have an output power of 4 watts. An FSK modulation scheme would be used for both the uplinks and the downlinks to simplify signal acquisition and lock.

The initial mission can also provide a position location capability by measuring the Doppler shift in the transmit frequency of the sensor terminal. By making several successive Doppler measurements over an entire pass of a single satellite, transmitter position measurement accuracy approaching 350 meters can be achieved. This capability can be quite valuable in tracking free floating sensor buoys.

Potential customers for the initial system include research institutions, environmental agencies, government organizations, and private oil, fishing or shipping firms. A typical user would deploy a number of remote sensor terminals that instrument and monitor environmental parameters. More than 2000 terminal can be supported in a single region with each terminal transmitting 3 KBytes of environmental data per day to the Mission Control Center. The price of the communications terminal is expected to be about $1200, while the monthly satellite usage fee is expected to run about $90 per terminal.

Prototype Mission Concept

The Prototype Mission consists of four satellites that are equally spaced in a single orbit. These satellites could be launched in early 1995 on an Ariane booster. The satellites will be gravity-gradient stabilized, have a station-keeping capability using cold nitrogen gas, and will employ eight two-way communications channels operating at 9600 bps.

With a system data capacity of 115 MBytes per day per region, up to 16,000 user terminals transmitting 10 KBytes of data per day in two regions could be supported. User fees of $.40 per kilobyte would result in a profitable operation for the seven year lifetime of the spacecraft.

The digital data messaging service provided by the prototype system would be intermittent with four equally-spaced satellites in a single orbit plane. A customer would experience about four hours of good satellite visibility each day. This time can be used for real time data relay within the region covered by the satellite footprint, or for store-and-forward messaging to any worldwide ground station.

The preferred frequencies for this mission are in the UHF band, but final selection will be made after WARC 92. The system design is capable of operating in the L-band, however the cost of the satellite and the user terminals will be greater.

Operational Mission Concept

The Operational Mission consists of a full constellation of satellites. Using four circular orbits with an inclination of 63.4 degrees and an altitude of 1600 km, six satellites in each plane would be sufficient to provide continuous coverage to most regions of the Earth. The planned constellation would be gradually expanded to meet customer demand using revenues generated from user fees. The operational spacecraft would be enhanced to include 16 simultaneous user communication channels.

The operational system will use the same frequencies, modulation scheme and access protocol as the prototype system so that prototype users can take advantage of the greater capacity provided by the operational system without having to purchase new terminals. The full complement of 24 satellites will provide more than 1.5 gigabytes of data transfer per day in each operational region. A service fee of less than $.10 per kilobyte is projected for a user population of 80,000 terminals in four regions with an average terminal use of 50 kilobytes per day.

Remote Sensing Mission Concepts

Two separate remote sensing missions were considered: the measurement of SO_2 in the atmosphere and the detection of forest fires. The SO_2 mission requires only one or two spacecraft to monitor the level of sulfur dioxide around major metropolitan areas on a daily basis. A lightweight, narrow-band UV instrument must be developed and tested for inclusion on a microsatellite bus before this mission can be implemented. Three years are required for this development leading to a possible launch as early a 1994. The estimated cost for two spacecraft in low earth orbit and the necessary ground segment is $15 million. Most likely there would be a single sponsor for this mission, either a government organization or an environmental agency.

The fire detection mission consists of 12 satellites with scanning infrared sensors. Although the component technology currently exists for these IR sensors, the instrument would have to be made smaller, lighter and cheaper, and consume much less power to be compatible with the use of a microsatellite bus. The larger number of satellites which are needed to provide frequent updates of forest fire conditions results in a higher cost than for the SO_2 mission. In this case several national customers would be needed to absorb the cost of system deployment.

Program Description

A summary of the main features associated with each of the selected missions is given in Figure 6. A phased program schedule allows the overall system capability to grow as market demands dictate, yet each mission is designed to stand or fall on its own merits.

Features \ System	Initial Data Relay	Prototype Communications	Operational Communications	Remote Sensing
Mission	Environmental Data Relay	Limited Digital Data Messaging	Mobile Communications and Global Store/Forward	Measure SO_2 Detect Wildfires
Number of Satellites	2	4	6 to 24	2 for SO_2 12 for Wildfires
Regions Served	Italy and Coastal Waters	Italy and Another Region	Italy, Europe & Worldwide Regions	Global
Orbit	TOPEX Orbit 63.5° 1300km	Sun-Synchronous	Circular - 2 hour 63.5° 1600 km	Circular
Schedule	12 - 18 Months	24 - 30 Months	36 Months	36 Months
Launch Date	1992	1994 - 1995	1997	1994 - 1997
Launch Vehicle	Ariane	Ariane Pegasus	Taurus Scout IV	Pegasus
Spacecraft Features	Basic Eyesat VHF Uplink UHF Downlink GaAs Solar Cells	Enhanced Eyesat GG-Boom L-Band Up & Down 8 Channels Station Keeping	Extended Bus Momentum Wheel L-Band Up & Down 16 Channels Station Keeping	New Bus Earth Stabilized Momentum Wheel 150 Watts Power
Spacecraft Weight & Transmit Power	25 lbs 8 Watts	35 lbs 16 Watts	70 to 100 lbs 64 Watts	250 lbs 10 watts

Figure 6. Program Summary of Selected Missions

The key implementation issues that need to be resolved are:

- Obtaining approval for operating frequency allocation in Italy and other regions, and the availability of sufficient spectrum to support long term operational needs.
- Obtaining a commitment from launch vehicle providers to launch the space segment for each of the proposed systems.
- Development of low cost communications terminals and remote sensing instruments.
- Identification of the market potential for each mission and obtaining initial commitments from key customers.

Financial Analysis

A financial model was developed to analyze each of the selected missions. The primary cost elements include:

- Spacecraft hardware and software development
- Operational Control Center development
- Mission Control Center development
- Launch Services
- Insurance
- Customer service centers
- User Terminal development and manufacture
- Marketing and sales
- Operating expenses
- Management
- Contingency/Reserves (20%)

The cost model includes potential revenues that could be obtained for each of the proposed missions based on such factors as:

- User prices
- Number of regions served
- Number of operating spacecraft
- Spacecraft capacity
- Average user data transmission rates
- Annual satellite capacity utilization

Using reasonable assumptions for the cost and revenue factors the following parameters were computed for each mission:

- Annual Operating Expenses
- Annual Revenue
- Annual Pretax Profits
- Cumulative Revenues
- Cumulative Pretax Cash Flow
- Internal Rate of Return

The results obtained depend on the input assumptions with regard to the prices charged for satellite services, the capacity utilization of the system, the timing of needed investments, satellite lifetime, depreciation schedule, number of regions served, marketing, sales and customer service expenses.

Based on a preliminary financial analysis it was determined that a profitable business operation can be established for a microsatellite space communications system. Under the right circumstances the business can be extremely profitable if customers can be found and brought on line quickly. The financial model identified critical program investment factors and the sensitivities to model assumptions.

Findings and Conclusions

A overall findings of the study are summarized below:

Initial Mission:

- Environmental data relay offers a competitive niche and can be implemented using existing technologies.
- The initial system can be used as an experimental test bed for the prototype system design.
- The addition of position location greatly enhances the attractiveness of the mission.
- Italy, by itself, is insufficient to justify satellite data relay for fixed meteorological sensors.
- A global perspective increases profit potential and enhances overall price and/or service competitiveness.
- A proven microsatellite design with only minor changes can be used to perform the initial mission.
- A prototype sensor terminal has been built and demonstrated.
- Suitable frequency bands for satellite operation are available.
- An Ariane launch opportunity exists in late 1992.

Prototype Mission:

- Limited mobile communications services can be provided to a variety of users.
- In addition to its primary mission, the prototype system can extend the useful service of the initial mission.
- The prototype mission creates an opportunity to make effective use of the WARC 92 allocation of UHF frequencies for LEO satellite services.
- Piggyback launch and low cost satellite design could provide entry into new satellite communications market with an investment of about $20 million.
- Multiple regions are essential to exploit inherent system advantages.
- Technical, schedule and cost risks appear low, but market and regulatory risks are uncertain.

Operational Mission:

- Twenty-four operational satellites can provide continuous real time coverage throughout the world.
- Investment costs are significantly higher that the prototype system due to the need for expensive, dedicated launch vehicles and the large number of satellites.
- Technical challenges exist with the development of L-band terminals and spacecraft electronics.
- Although a wide range of communications services are possible, specialized applications must be identified to establish and maintain a competitive niche.

Remote Sensing Mission:

- Small, low cost sensor payloads for SO_2 measurement and forest fire detection are not currently available.
- Instrument component technology is mature.
- The required sensor systems can be constructed by integrating existing, space-qualified components.
- Remote sensing using microsatellites will require from 18 to 42 months for the development of small space sensors.
- A low cost SO_2 sensor mission is possible in late 1994.