The Potentiality of Commercial Satellite-Based Communication Networks for Telemetry and Commanding of Small Satellites

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Abstract. Within the next few years the emergence of satellite-based personal communication networks operating from small low earth orbits to geostationary orbits offers viable solutions for contacts between two points on Earth. The idea is to use the same networks for communications links between small satellites and their ground stations. Will it be possible to call a satellite from a PC, e.g., like an answering machine from a phone?

The paper presents concepts for the transfer of data between ground stations and low Earth orbiting small (scientific) satellites via a) commercial satellite-based communication networks, e.g. IRIDIUM, ORBCOMM, GLOBALSTAR, SIGNAL and b) geostationary communication satellites, e.g. INMARSAT. The potentialities which lie in these concepts will be discussed. Operational and technical constraints will be pointed out.

The results are the outputs of a study sponsored by the German Space Agency DARA to analyze the potential of cost reduction in mission operations for small satellites as part of its effort to reduce the overall mission cost.

Introduction

Within the next few years, satellite consortia are planning to invest billions of dollars in mobile global telecommunication services (mobile satellite services - MSS) based on the communication between user terminals on the ground and satellites. The user terminals range from hand-held devices to mobile and fixed stations. INMARSAT (International Maritime Satellite Organisation) pioneered this service in 1982 providing world-wide satellite communications for the maritime community. About 10 years ago, MOTOROLA analysed a concept for a satellite-based, global and mobile communications network. These analyses resulted in the birth of IRIDIUM who started launching the first satellites in June 1997. Other competitors are also trying to get a share of the market, like GLOBALSTAR, ICO, ODYSSEY.

The orbital configuration for providing communication services to hand-held satellite phones depends on a trade-off between coverage, link budget and number of required satellites. For MSS constellations the technically feasible options are:

1. low earth orbit (LEO) - up to 2000 km altitude

2. medium earth orbit (MEO) - between 8000 and 20000 km altitude
3. geostationary orbit (GEO).

In order to achieve global coverage of the earth, a LEO constellation has to consist of about 40-70 satellites, a MEO constellation between 6 and 20, and a GEO constellation between 3 and 6.

A study sponsored by the German Space Agency DARA (Deutsche Agentur für Raumfahrt-Angelegenheiten GmbH) was conducted to analyse the cost-saving potential for operations of small satellites using mobile communication services instead of conventional ground stations. Typical concepts for data transfer were defined based on representative MSS implementations: IRIDIUM and GLOBALSTAR for LEO constellations, ICO for MEO and INMARSAT for GEO.

The investigated MSS primarily offer voice and low-rate data and fax communication services. Concepts for global broadband networking are emerging that will allow high-rate data transfer. These systems were not included in the study because they are still in their early phases and the required frequencies have not been allocated yet. In contrast, the first LEO MSS is planned to become operational in 1998, INMARSAT is already operational.

The paper does not include detailed technical evaluations but rather a proof-of-potential for cost reductions.

Idea: Data Transfer Concept with MSS

The idea is intriguing. A small, scientific satellite (referred to hereafter as "SmallSat") in low-earth orbit is configured as an MSS user terminal (also referred to as subscriber), i.e. it provides the functionality of a mobile phone in space. It receives and transmits data via an MSS satellite constellation. The user on the ground can communicate using a hand-held, mobile or fixed terminal. The concept is sketched in Figure 1. The implementation of this concept would eliminate the need for expensive ground stations.

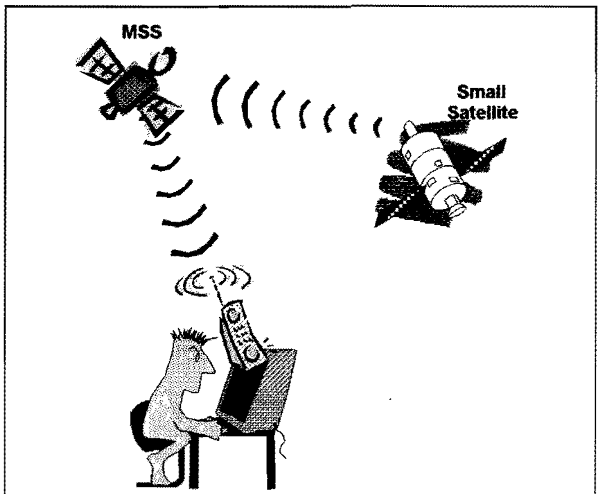

Figure 1: Data Transfer Concept

Moving Systems

The concept for transferring data or voice between a user terminal on the ground or a low-earth orbiting satellite and an MSS is governed by the orbit geometry. LEO- and MEO-MSS are so-called moving systems, i.e. the MSS constellation is in constant motion with respect to the surface of the earth and other orbiting spacecraft. GEO-MSS, however, can be regarded as stationary.

LEO-, MEO- and lately GEO-MSS use the spot-beam technology to optimise the link budget and maximise channel allocations for the transfer of data. Spot-beams split the satellite footprint into a number of overlapping beams. The satellite constellations have to be designed in a way that the transfer of circuits from one beam or satellite to another does not interrupt the transfer of information. This is achieved by means of hand-over or soft hand off.

The problems that manifest themselves when dealing with fast flying satellites below the orbit of the MSS are shown in Figure 2. It becomes evident that the contact periods for the transfer of data between SmallSat and the MSS depend on several factors:

- altitude and orbit of the MSS constellation;
- number of spot beams per satellite and their respective footprints and number of satellites in the constellation - this determines the number of hand-overs;
- altitude and orbit of SmallSat.

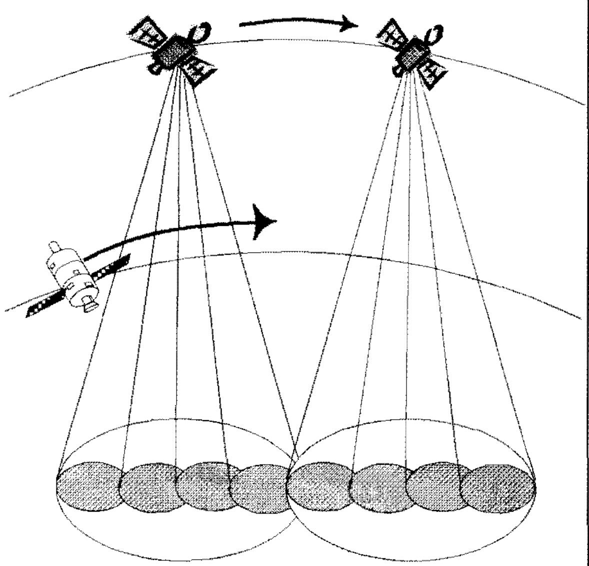

Figure 2: Moving Systems and Spot-Beams

Hand-overs require additional processing on board the satellite. It can be expected that the frequency of the hand-overs affects the achievable coverage period.

Data Transfer Concepts Based on LEO-MSS

The concepts for transferring data utilising the LEO-MSS IRIDIUM and GLOBALSTAR are presented in the following. It is assumed that the data transfer mechanisms for other competing LEO constellations do not differ substantially from the above. IRIDIUM and GLOBALSTAR have been chosen because they are based on radically different implementation approaches and seem to be the furthest advanced in development / service implementation.

IRIDIUM

The IRDIUM constellation consists of 66 operational satellites (plus 11 in orbit spares) deployed in 780 km altitude. The satellites are arranged in 6 near polar orbital planes with 11 satellites each. The system provides total global coverage by means of crosslinking the satellites in the constellation. It is, however, switched off over the polar regions. IRIDIUM is the only MSS using crosslinks to hand off calls and data transmissions between satellites in the same or adjacent orbiting planes. Steerable antennas are required to maintain the crosslink to satellites in adjacent orbiting planes. The crosslinks are interrupted between satellites moving in opposite directions, i.e. the "seam" is defined where satellites in an ascending plane are next to satellites in a descending plane. Crosslink data rates are 12.5 Mbps using Ka-band. The exchange of data between the satellites and the mobile terminals takes place in L-band. The achievable data rate is 2400 baud. Ground gateways provide Ka-band uplink and downlink capabilities and are used to interconnect the IRIDIUM constellation to public switched networks. The first 17 satellites were launched by July 1997, the system is planned to become fully operational in 1998.

The analysis of implementation options for the transfer of data between SmallSat and IRIDIUM shows a number of technical, operational and general constraints:

1. Because of the orbit characteristics and spot beam geometry, drop-out periods between hand-overs and a high hand-over rate can be expected. Also, achievable data rates are very low. Communication via user terminals is therefore not feasible.
2. Communication via crosslinks and ground gateways (as depicted in Figure 3) supports high data rates (12.5 Mbps). However, a number of constraints have to be taken into consideration:
   - SmallSat has to be more or less identical to an IRIDIUM satellite with respect to orbit requirements and communication equipment.

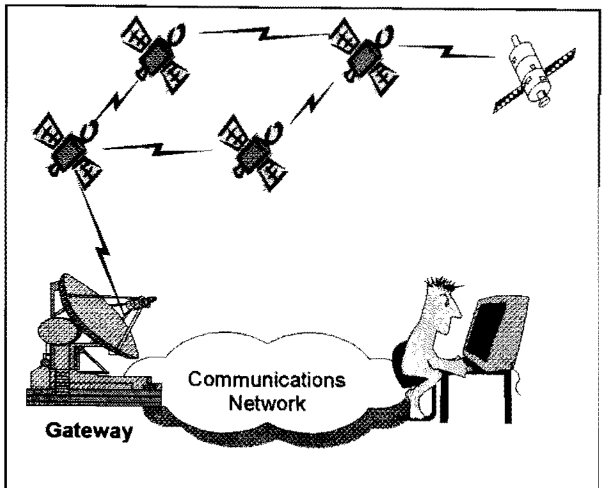

Figure 3: Data Transfer Concept with IRIDIUM Based on Crosslinks

- Communication will only be possible if SmallSat flies in the "seam" or in the polar regions where the IRIDIUM system is normally switched off for mobile communications.
- The communication takes place via steerable Ka-band antennas. (It is expected that the Ka-band communications equipment can be procured from IRIDIUM at low cost because of the amount of equipment produced).

3. Detailed knowledge of SmallSat's own orbital position and attitude as well as those of IRIDIUM is necessary. This necessitates the implementation of a satellite navigation system, e.g. GPS, and close co-operation with the IRIDIUM control centre.
4. The operation scenarios will be complex because of the need to co-operate with the IRIDIUM control centre with regard to seam communication and/or arctic region switching as well as the exchange of orbital parameters of the IRIDIUM constellation.
5. The IRIDIUM concept contains unproven technology and advanced operations concepts.
6. Information about cost is not available.

GLOBALSTAR

GLOBALSTAR can be considered as one of the strongest competitors of IRIDIUM. The GLOBALSTAR constellation consists of 48 operational satellites (plus 6 in orbit spares) orbiting in 8 orbital planes with 6 satellites each. The orbital planes are inclined at 52 degrees. The chosen altitude is 1414 km. The satellite communications architecture is based on the "bent pipe" data relay principle rather than crosslinks, i.e. data is relayed through the satellite constellation to a ground station and then through local communication networks to the end destination. The system is to become operational after 1998.

The analysis of implementation options for the transfer of data between SmallSat and GLOBALSTAR (as depicted in Figure 4) shows a number of technical, operational and general constraints:

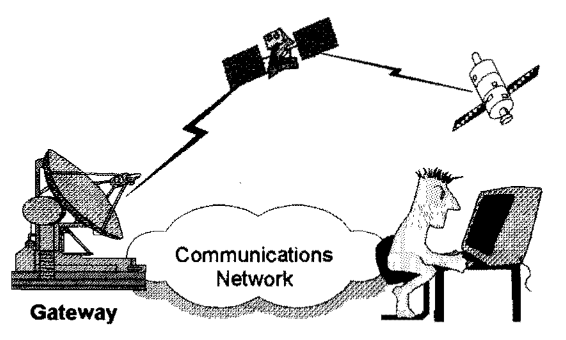

Figure 4: Data Transfer Concept with GLOBALSTAR

1. SmallSat is registered as a subscriber in the GLOBALSTAR system. It transmits data via L-band and receives data via S-band using a terminal whose functionality is identical to that of a subscriber on the ground. The forward and return data is relayed to a gateway and routed to and from the SmallSat control centre via a communication network.

2. SmallSat is required to present itself to the GLOBALSTAR system like a mobile subscriber on the ground thus necessitating the compensation for Doppler shift when receiving and transmitting data.
3. This in turn requires SmallSat to have its own orbital parameters and those of the GLOBALSTAR constellation available on board the spacecraft.
4. A satellite navigation system like GPS has to be used to determine SmallSat's position.
5. GLOBALSTAR's primary mission is to transfer real-time voice. The maximum achievable data rate for the transfer of data is therefore very low (2400 baud).
6. GLOBALSTAR also makes use of the spot-beam technology. Because of the constraints imposed by the geometry of the orbit and the hand-over procedure (see discussion above), the effective coverage period is determined by the velocity vector of both systems, i.e. it is increased if both systems have similar velocity vectors.
7. Operations will be very complex because of the coverage limitations and also because of the need to work in close co-operation with the GLOBALSTAR control centre for the exchange of orbit parameters.
8. The cost for transferring data is believed to be in the same range as offered by other MSS providers ($3-5 per minute).

Data Transfer Concept Based on the MEO-MSS ICO

The ICO mobile communication system was derived from the INMARSAT-P project to use mobile terminals for satellite-based communication and has since been marketing under its own name.

The ICO system comprises a constellation of 10 active satellites orbiting in 10 355 km (MEO) split in two orbital planes. The orbital planes are inclined ± 45 degrees to the equator. ICO could be operational in 2000. The ICO system integrates mobile satellite communications capability with terrestrial public-switched networks.

The analysis of implementation options for the transfer of data between SmallSat and ICO shows a number of technical, operational and general constraints (The data transfer concept is in principle similar to that with GLOBALSTAR; see Figure 4):

1. Commands are forwarded from the SmallSat control centre via a ground communications network to an ICO ground station which will select a satellite through which the data will be transmitted.
2. Satellite telemetry is forwarded through the ICO constellation to a gateway which routes the data to the SmallSat control centre.
3. SmallSat has to behave in the ICO constellation like a mobile subscriber on the ground. It transmits and receives data via two separate antennae operating in L-band. It is therefore required to compensate for Doppler shift when receiving and transmitting data.
4. This in turn requires that SmallSat has to have its own orbital parameters and those of the ICO constellation available on board the spacecraft.
5. A satellite navigation system like GPS can be used to determine SmallSat's position.
6. ICO's primary mission is to transfer real-time voice. The maximum achievable bit rate for the transfer of data is therefore very low (2400 baud).
7. Like GLOBALSTAR, ICO makes use of spot-beam technology with the corresponding constraints regarding the achievable coverage period. Since ICO is a MEO system, it has a larger ground coverage resulting in less hand-overs.
8. Operations will be complex because of the need to schedule coverage periods as well as communicating with the ICO control centre for the periodic exchange of orbital data.
9. The cost for transferring data is believed to be in the same range as offered by other MSS providers ($3-5 per minute).

Data Transfer Concept Based on the GEO-MSS INMARSAT

INMARSAT is an international organisation with 79 member countries to provide world-wide mobile satellite communications for the maritime community.

The INMARSAT satellite system comprises geostationary satellites distributed around the world to provide global coverage. The system is operational and provides various types of services, e.g. INMARSAT-A is the original analogue ship-borne, INMARSAT-B the digital, and INMARSAT-M the mobile user service. Satellites of the 3rd generation are being launched and introduce spot-beam technology supporting mobile-to-mobile links.

The analysis of implementation options for the transfer of data between SmallSat and INMARSAT (as depicted in Figure 5) shows a number of technical, operational and general constraints:

1. SmallSat is registered as a mobile subscriber in the INMARSAT environment. It transmits and receives data via an INMARSAT-compatible transponder. Commands are routed from the SmallSat control centre to the satellite
   - via a gateway earth station and an INMARSAT satellite
   - directly via a mobile user terminal if the control centre and SmallSat are within the field of view of the same INMARSAT satellite.
2. SmallSat telemetry is transferred via an INMARSAT satellite to a gateway earth station from where it is re-routed to the SmallSat control centre through a communications network.
3. SmallSat has to compensate for Doppler shift when receiving and transmitting data.
4. INMARSAT is the only mobile satellite communication system that is available for services at this point in time.
5. As INMARSAT satellites are susceptible to RF-interference, the SmallSat antenna has to have directional beam characteristics.
6. This in turn requires SmallSat to have its own orbital position and attitude and those of the INMARSAT system available on board the spacecraft.
7. A satellite navigation system like GPS could be used to determine SmallSat's position.
8. The maximum achievable data rate is 9.6 kbps, a 64 kbps option is also available.
9. The digital service costs about $4 to $6 per minute.
10. Voice contact via the INMARSAT-M system will be demonstrated on a Space Shuttle mission in the near future.
11. The British "Space Technology Research Vehicle" STRV-1d will demonstrate the PHLASH (Phone Home Link for Autonomous Spacecraft Handling) concept [1] in early 1999. The concept includes data and command transfer via the INMARSAT system similar to that described above.

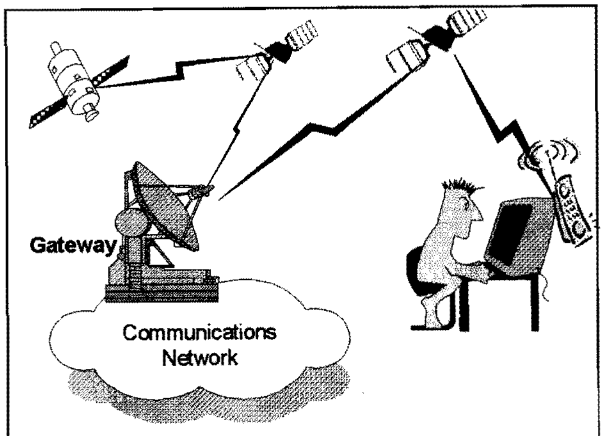

Figure 5: Data Transfer Concept with INMARSAT

Conclusion

Concepts for the transfer of data between a small, scientific satellite and mobile satellite services that are already operational or very close to it have been analysed. There is a potential for cost reductions operating a small satellite in an MSS environment and omitting dedicated ground stations.

All MSS are primarily designed to support voice services. Achievable data rates are therefore low. As this may be acceptable for spacecraft housekeeping, monitoring and commanding it is prohibitive for the transfer of higher-rate payload data.

Because of the constraints imposed by the orbit and antenna geometry of the LEO and MEO MSS, the contact period is limited due to the usage of spot-beam technology and the resulting hand-over rate.

Operating a small satellite in an MSS environment results in complex operations scenarios.

The small satellite is required to have knowledge of its own orbital position and in some cases also of its own attitude and of the orbital elements of the MSS.

An exception to all rules is IRIDIUM. The system supports high data rates and contact periods. This is, however, only possible by accepting constraints in the mission profile and specific requirements for the data transfer equipment, i.e. effectively become an IRIDIUM satellite.

INMARSAT has a potential for further investigations, as

- INMARSAT is operational;
- the geostationary orbit renders the problems involved with hand-over negligible thus resulting in longer contact periods;
- other agencies are investigating similar concepts.

Generally, the MSS concepts contain high risk areas. Frequency bands are becoming more and more cluttered. The technology for the MSS is generally new and unproven in space. Schedules are ambitious and funding the necessary development, launch and operations is a major task.

LEO and MEO MSS-providers claim that they have systems with shorter delay times, less energy requirements and less complex satellites compared to GEO systems. On the other hand, LEO & MEO systems require a high number of satellites. This is expensive and can only be realised by international co-operation.

Also, the high number of communication satellites planned to be launched in the next few years increases the problem of space debris and poses a potential danger for low-earth orbiters.

Acknowledgements

This paper is based on a study sponsored by the German Space Agency (DARA) under contract number 50 TB 9608.

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