Future Satellite Services, Concepts and Technologies

A. Martínez de Aragón
ESA Directorate for Industrial Matters and Technology Programmes, ESTEC, Noordwijk, The Netherlands

F. Mura
Alenia Aerospazio, Turin, Italy

C. Dionisio
Alenia Aerospazio, Rome, Italy

S. Howes
ESYS, Guildford, United Kingdom

R. Slim, P.D. Erickson
MacDonald Dettwiler (MDA), Richmond, Canada

In a competitive global environment, the space sector has to target part of its R&D towards service-oriented missions where the specific characteristics of space-based systems can be of advantage. Several markets have been analysed, and a preliminary design study performed for two of the most promising missions for the future in terms of returns and appeal to users. The studies have shown that the predominant space-segment architectures will be satellites as large as the launchers allow, relatively small activity-oriented spacecraft, and satellite constellations. An important finding is that, to capture a significant share of the corresponding markets, the space-segment costs have to be reduced to less than 1/5 of current costs, which is not possible with existing technological solutions and production methods. Technology development thus lies at the foundation of successful future space systems, as it is perceived as the way to reduce life-cycle cost and time-to-market and to provide increased performances per unit of cost/mass/volume/power. Applied research must be encouraged in Europe, and ESA needs to foster those developments directly applicable to space and to provide opportunities for their demonstration in orbit.

Introduction

Thirty years ago, the objective of the space sector was to be in space. Now, the main drive is to use space, to sell it, and to profit from it. The space sector is currently in the transition phase from being funded mostly by the public sector to raising funds from private shareholders; from being a purely research-oriented activity to a commercial venture with such successful applications as satellite television, satellite navigation and satellite-based mobile communications. This state of transition creates unrest, since structures are transformed, alliances modified, users become customers and their requirements change and have to be satisfied quickly.

The space sector begins to fall under the strong influence of market forces. That market is formed by investors and customers for whom space is just another means of providing a certain type of service. What interests them are the services, their costs and quality, rather than the means used to provide those services. The space sector therefore has to fight for its place in competition with other industrial sectors capable of supplying alternative solutions for the provision of the same, or at least very similar services. Space-based systems are also increasingly forming just a part of much larger systems, where space's role varies in significance depending on the particular application. The main advantage of spacecraft is their location in orbit and, as history shows, the highest location has strategic importance due to its wider areal coverage, be it for communications, observation or navigation.

In what follows, the discussion revolves around market-oriented services that have a space infrastructure as a major component. Life-cycle costs, compared to those of alternative solutions, are the main reason for commercial companies to include or exclude space-based systems in their production processes. Current technologies and manufacturing methods common to the space industry result in very high life-cycle, end-to-end costs, which results in a limited number of competitive niches for the space sector.

Under ESA's General Studies Programme, a study on 'Future Satellite Concepts, Architectures, Technologies and Service Capabilities' was performed by Alenia Spazio, in cooperation with ESYS and MDA, to analyse the main future markets in which space could intervene, the roles that space could play, and the conditions for playing those roles.

Services

The market study part of the above analysis covered satellite communications, Earth observation and navigation, and also considered several other minor markets. Its main findings can be summarised as follows:

Satellite communications

The demand for satellite services is estimated to grow from 10 billion ECU in 1990, to over 30 billion ECU per year by the year 2000, with demand almost doubling every five years. Many of the satellite services driving growth are the result of commercial pressures to complement fibre-optic cable. The current demand for satellite communications is about 2% of the world-wide demand for communications. Although a niche sector, satellite communications represent a substantial market. The service with highest demand is currently direct-to-home television. Its growth will continue but, world-wide, by 2005 it is expected to share leadership with mobile satellite and bandwidth-on-demand services.

For future satellite-based services, the price to the end user should be reduced by a factor of 5 to 10, while maintaining or improving the quality of service. All current types of service would benefit significantly from those price reductions. In a number of cases, they would enable satellite services to begin to compete directly with terrestrial-based services. Conceptually, all current services could be achieved through the deployment of broadband systems which 'leapfrog' present capabilities. The three distinct types of broadband services identified as targets are: mobile asymmetric (10 kbps up, 10 Mbps down), mobile two-way (over 100 kbps both ways), fixed/semi-fixed two-way (about 100 Mbps both ways). The addressable market for such services is estimated to be at least in the range of up to 5 billion ECU/year, based on terminal prices of 500 to 1000 ECU and tariffs commensurate with current telephony.

Satellites are ideally suited to linking organisations in rural or remote regions to the information highway. Satellite technology provides the capability for fully mobile, personal broadband services.

Earth Observation

The world-wide revenue from space-based Earth-observation (value-added) products in 1995 was about 600 MECU, with about 200 MECU going to European suppliers. Of those, only 60 MECU were satellite raw-data sales (the European share being 17 MECU). Demand in the year 2000 is expected to increase by about 15% compared with 1995. The Earth-observation market is therefore still very small compared to the communications market and most of its revenues go to value-adding providers. From the number of planned missions, there seems to be a latent mass market, but it has to be noted that a majority of applications are not commercially viable in a strict sense: they would provide data of public interest and thus would be based on public funding (environmental research, climate change, disaster monitoring, support to peace-keeping operations).

The transition to full operation and mass-market applications will call for radical changes in the supply of data compared to today's situation. The value of the data is inversely proportional to its age and its spatial/spectral resolution. Prerequisites are a high revisit frequency and affordable, near-real-time and easy-to-access data-distribution services. These could be satisfied by a constellation of specialised Earth-observation satellites linked to the high-speed communications infrastructure (ground- and space-based) which is becoming available. Most Earth-observation services can be addressed with such an architecture, whereby the number of satellites and their sensor types increase as a function of the market's development. Assuming a price structure and characteristics appropriate to the user's needs, the addressable market could be of the order of 1 to 2.5 billion ECU/year, as a rough order of magnitude. Prime markets would be digital mapping (for GIS, mobile services, cars), followed by resources monitoring, all-weather mapping, and disaster detection.

The 'Report of the ESA Ad-hoc Industrial Working Group on Earth Observation', prepared by Eurospace, provides a comparable analysis, namely:

The European Earth-observation market is fragmented and unstructured, dominated by public-sector users, with a strategic value that should be duly considered, and is being captured by non-European providers. Data distribution has to be improved, since it has not achieved the levels expected; this demands a restructuring of the sector.

Navigation

The Global Positioning System (GPS) has

generated a market of around US$ 20 billion, with an investment in satellites, their launch, ground segments and operations of about US$ 3 billion. The current market is about 1.6 billion ECU/year, with GPS finding application in an increasing number of areas, including satellite orbit and attitude reconstitution. The core of the market consists of user terminals and value-added services such as differential corrections or position data. The existence of GPS and Glonass limits the possibilities for a new dedicated commercial service. Nevertheless, a European alternative of regional scope, with enhanced capabilities, would be facilitated by future satellite technologies and architectures. The greatest opportunities seem to lie in the user segment.

Other markets
Materials processing, waste disposal in space, Earth-crossing asteroid monitoring and deflection, and space tourism are among other possible commercial services. They may represent lucrative opportunities at some point in the future. Exploiting these opportunities requires a radically more reliable and cheaper means of accessing space, with cost reductions of several orders of magnitude.

Concepts
For most of the services discussed above, the space-related infrastructure amounts to less than 15% of the total investment, with the major expenditure corresponding to value-adding activities (extraction of specific information from the data, TV programmes, etc.) and the user segment (hand-held terminals, navigation devices for the car, etc.). It may be said that leverage has been high in those areas where space has created new markets, their value being over 6 times larger than the related space investments.

Further reduction in the costs of, and increased performance of the space segment and its related (ground-) infrastructure is essential to generate revenues in the future, whether by expanding existing markets or by opening up new ones. The final products have to be competitively priced and turnaround times must be short.

To participate in space ventures, commercial investors require a high rate of return, to compensate them for the high risks and long waiting times associated with many space projects (the net present value of a series of cash-flows is dependent not only on the cost of capital, but also on its distribution over time). Users also demand increases in performance before accepting space-based services and products (e.g. most users still prefer a small cellular telephone to a larger Inmarsat terminal, even though the former has poorer coverage).

Absolute cost is the factor that must be most improved to make a service economically attractive. Space-based service providers need high ratios between performance and cost, resulting in cost/benefit ratios comparable to or better than those for similar ground-based services. Today, the spacecraft is the most expensive component in most space-based systems (user segment excluded), followed by the launcher and launch services (20 to 50% of the total cost), ground segment and operations (up to 15%) and management and technical support. The spacecraft is an industrial cost and in new projects around 30% of it corresponds to engineering, followed by development hardware, management, AIV, support equipment, and product assurance. The cost of the actual flight model in a new project could be as low as 15%. This means that costs are reduced dramatically when a design is reused, and the recurrent unit cost may be as low as 20% of that of the prototype. Looking within the platform itself, the attitude and orbit control system (AOCS) is the most expensive subsystem in all modern spacecraft. Next come the power system and solar arrays (with strong differences between projects), the structure, on-board data handling and harness, reaction control, thermal, and command and control (TT&C) systems. Payload costs vary widely, depending on the application, degree of maturity, etc., and may exceed those of the platform if new developments are required (such as for Earth-observation instruments).

One of the basic requirements that a competitive product must satisfy is to be on the market at the right time. For space to compete with the ground, reductions in development and deployment times are a must. All parameters specifying the merit of a commercial initiative (e.g. net present value, internal rate of return, actualised payback) include a time element in their definition, as cash-flow distributions over time (payments and income profiles). On the one hand, revenues from space come very late with respect to those in other sectors. On the other hand, innovation cycles for new products and key technologies are becoming ever shorter.

Since a satellite does not provide services (and thus generate income) until after it has been commissioned in orbit, timing is a critical factor to be addressed. From idea to commissioning, the satellite and its associated infrastructure are solely incurring costs. Therefore, the shorter this time span, the lower the overall costs (including the financial charges for the capital raised). Time is not only important financially, but also strategically: changes happen fast, as has already been seen with microprocessors (a new generation every three years) and mobile telephony (very fast growth, and the transition from analogue to digital), and is currently happening for satellite TV with the rapid introduction of digital direct-to-home broadcasting. The space sector therefore has to develop fast-reaction capabilities and has to be adaptable to the non-space world, if it is not to be left behind.

European industry has well-recognised experience in the space segment, and has also had extraordinary successes in the user segment (e.g. home terminals for satellite TV, GSM telephony). Space industry, alone or through partnerships, should strive to increase its involvement in this segment, given its strategic and commercial importance. The space agencies and regulators should be more concerned about the end users, their demands and evolution.

As far as the launch segment is concerned, Europe has Ariane and its Kourou launch base, which are optimal for launches into geostationary orbit, but less so for polar orbits or orbits with high inclinations. As a result, no satellite-constellation launches have yet been contracted to Arianespace.

Europe is one of the largest and more developed world markets, with both a population and a Gross Domestic Product (GDP) greater than those of the USA. It therefore has an important role to play in regulatory matters in that, for example, authorisation to use allocated frequencies over European territory is a European prerogative. This explains the interest of some American initiatives in adding European industries as partners, in the hope of thereby obtaining licences to operate their services over Europe.

Architectures

The main trends in space-based architectures, for services where the space sector is more active, are currently the following:

- constellations of satellites, mostly in low Earth orbit but also in medium-altitude orbits, for services where the distance to the user cannot be large and coverage must be frequent or permanent (mobile communications, operational Earth observation); the global performance of the system is spread amongst the constellation's satellites, which may become smaller
- big satellites, as large as the launcher allows, mostly in geostationary orbit, where it is economically interesting to concentrate as much as possible of the system performance into just a few satellites (communications, low-resolution but permanent Earth observation)
- small satellites for activity-specific missions, built around a primary instrument or task (science, demonstrators).

There are several considerations that can help us to understand better the possible evolutions of these system architectures:
- The communications demand is in a permanent state of growth. In order to satisfy this ever-increasing market, terrestrial-based systems are constantly improving their capabilities and performances by means of equipment and architecture upgrades. Satellites could easily find a role in this global scenario, but space alone cannot become 'a global service': even under the most optimistic hypothesis, it would be difficult to achieve a penetration of more than 5% into the global communications market by the year 2010, basically for technical reasons.
- The Earth-observation market, to achieve significant growth, requires a very short turnaround between the user request and image delivery, which implies not only that the EO constellation must be able to access any point on Earth very quickly (maximum of 6 h revisit period), but also the ability to transmit the data to ground, process it, and deliver the final product to the user within that period.

From the above, we can conclude that space-based infrastructures will rather form a part of the global architecture in which the user, ground and space segments play their own specific but integrated roles.

Successful constellations will define future space-equipment standards, with their manufacturers influencing, and probably dominating, the subsystem and equipment markets. Although not large enough to be considered mass markets in the sense of the automotive or consumer electronics sectors, constellations are expected to become the paradigm for space utilisation and exploitation, and to be part of the key to reducing the cost of space hardware. Constellations represent a quantum leap in the way space-based systems are conceived, and require adaptation of processes, technologies and sectorial structures for their successful manufacture, deployment in space and exploitation.

Constellations, and their future functional expansion into networks, are certainly becoming the new model for commercial space systems for navigation (GPS, Glonass), mobile telephony (Globalstar and Iridium), and many other planned telecommunications-type applications. Since a large number of satellites have to be deployed before the particular service can start, it is essential to reduce the production and deployment times, during which huge amounts of capital are tied up and interest payments are accruing. The Island Integration approach — already being used for Globalstar — allows the simultaneous assembly, integration and verification (AIV) of several satellites, each of which is in a different AIV phase (corresponding to a particular 'Island') at a given moment. This approach requires a higher initial investment than traditional approaches, to build the larger integration facilities needed and to duplicate the necessary test equipment.

In the framework of the Alenia Spazio, ESYS and MDA study, mentioned above, two services, one related to telecommunications and one to Earth observation (see the accompanying panel for details), were analysed. Alenia performed a preliminary design of the missions required to provide the respective services operationally with the quality levels demanded. State of the art technologies (as per 1997) and current manufacturing (design, assembly, integration, verification) methods were used in both cases, resulting in high space-segment costs and long manufacturing times, incompatible with commercial success.

After an evaluation of demands and trends in applied research for space-related technologies, a second design study was performed assuming that a number of new technologies (Table 1) would be available in the required time frame. Shorter production times, together with increased performances per unit mass/volume/power, resulted in reasonable spacecraft and financially feasible missions.

The main conclusion is that several new technologies have to be developed, together with new AIV methods, and must reach maturity for space-based services to become commercially viable. Even so, the market share that can be captured by space in the most dynamic sectors would be minor (although important in terms of volume of funds).

Methods: reducing the time to market

Spacecraft manufacture is a highly specialised and labour-intensive task. It is expected that in the future extensive use will be made of recurrent equipment. The methods adopted in its design and production will influence the time-to-market of any space-based system:

Project management

Cost and schedule reductions can be achieved by adapting the way in which the space-system development effort is managed, in terms for instance of the organisation of the project team, the documentation management and information technologies used in support of that team, and the manner of interaction with the subcontractors and suppliers. Potential reductions in Life-Cycle Costs (LCC) and schedule may be found among methods that:

– reduce the number of team members
– simplify the activities to be performed during the programme life cycle
– reduce and simplify the interfaces between the various activities and/or groups
– simplify the procurement and integration of parts and equipment.

Two factors that need to be considered carefully in sizing the team are: (a) the ability to solve problems in minimum time, and (b) the ability to do so at minimum cost.

System engineering

This area involves several disciplines that are needed during the lifetime of a space system development. Their impact on LCC and schedule may be very strong. System-engineering activities cover all aspects of a project, from the definition of mission requirements to in-orbit operations, passing through requirements definition at subsystem/equipment level, methods for verifying that the requirements are met, assembly, integration and verification (AIV) and testing, and the launch campaign. The AIV approach selected for series production is very important for commercial systems based on constellations of satellites, which represent a new challenge for the space industry.

Technologies: increasing performances

Advances in technology are important for the payload, the platform and the user/ground segment. In addition to improvements in the fields directly related to the technology, they may have lateral impacts by affecting other disciplines, equipment and subsystems. This is the case for structural ultralights, which are very strong and stiff materials that allow one to reduce the structure's mass, but which simultaneously affect the requirements definition (due to the higher margins allowed), the design (simpler analysis due to the high margins), and the verification process (simplification and reduction in the number of tests due to higher design margins). Today's technology allows one to achieve with small satellites performances that were considered exceptional for any satellite just a few years ago.

Commercial comparisons are usually based on cost/benefit ratios, whilst in the public sector cost/utility or cost/performance criteria are often preferred. To reduce total life-cycle costs, technologies need to be developed which can increase the performance-to-cost ratio in as many areas as possible.

At satellite level, improving the benefits derivable from a space-based service means increasing both the payload capabilities and the corresponding platform performances, which are directly related to lifetime, simplicity of operation, electrical power available, processing power, etc. To reduce costs, the volume, mass and power requirements of the overall satellite, and hence those of its individual equipment items, have to be reduced. High priority should therefore be given

Table 1. Technologies for commercial space services

Space Segment (platform and payloads)

• *Propulsion and Power*

Electric propulsion

Solar Generators:
- Thin GaAs/Ge Solar Cells (mass saving)
- Multi-Junction GaAs Solar Cells, Indium Phosphide Solar Cells
- Concentrators for GaAs/GaSb Solar Cells and Solar Arrays
- Lightweight Solar Arrays (cells on flexible Kapton substrate and inflatable Torus solar array)
- Micromachined Blue-Red Reflective Cover Glasses (increased solar cell efficiency)

Power Storage:
- Nickel-Metal-Hydride Battery Cells
- NaS Battery Cells

Power Control:
- Peak-Power Tracking Power Control
- Direct Energy Transfer (use of processor and software).

• *Thermal Control*

- Two-phase Mechanically Pumped Loops, Capillary Pumped Loops
- Advanced Radiators (variable radiating area)
- Heat Pumps
- Integrated Spacecraft Thermal Bus

• *Microwave and Telecommunication Equipment*

- High Power Amplifiers (SSPA, MPM, TWTA)
- 3D-VLSI, 3D-MCM, MMIC, MHCM
- Rain Fading Compensation Techniques
- High-Temperature Superconductors
- Ku/Ka Band Technologies for Receivers, Down-converters (low noise amplifiers,...)
- Multi-Beam Antenna
- Optical Technologies for Beam Forming Networks, Switching

• *On-Board Processing and Data Compression*

- Data-Compression Techniques
- Processors: general purpose and telecommunications payload management

• *Mechanical Systems (antennae, solar panels)*

- Micro/nano-Technologies and Micro-electro/mechanical Systems
- Smart Structures (antenna reflectors)
- Large Aperture Antennas
- Ultra-light Antenna Reflectors
- Electron Beam Curing

• *Optical Equipment*

- Cryo-Coolers
- Focal-Plane Equipment

Ground and User Segment

• *Telecommunications*

User terminals:
- Miniaturisation
- Handwriting/Speech/Vision Recognition, Pen-Based Interfaces, Integrated Voice and e-mail
- Nomadic Computing
- Integration in Networks and Communications with Other Computers

Terrestrial Networks:
- Modulation and Access Schemes
- Security
- ISDN, ATM, Network Integration and Protocols to Incorporate the Space Segment
- High-Speed Infrastructures

• *Earth Observation*

Cataloguing/Archiving:
- Multi-database Management Systems
- Metadata Standards and Catalogues

Automated Information Extraction:
- Distributed Object Based Computing
- Object Based Geographic Information Standards
- Qualitative Reasoning Systems

Automated Order Handling:
- Order Entry
- Processing and Product Distribution
- Data Acquisition Planning

to technologies that reduce such requirements whilst still maintaining or even improving upon the performances delivered (e.g. micro/nano-technologies, deployable/ inflatable structures for large apertures) and that improve the electrical power generation and storage capabilities, on-board computational power, payload performances, autonomy, etc.

At the user and ground-segment level, technologies for data compression, communication standards for integration of terrestrial and space networks, nomadic computing and automated information extraction will be needed to maximise user access and minimise operating costs. User and ground segments must be developed to support the role of the target market, and to provide seamless access to both space-based and terrestrial service providers.

Table 1 lists technologies that need to be developed to make the telecommunications and Earth-observation services discussed above commercially viable. Other lists have also been drawn up based on different criteria. Eurospace, for example, has proposed 10 major technology areas which Europe should develop to increase its worldwide competitiveness. ESA's Basic Technology Research and Development Programme (1997 – 1999) is structured along 13 major technology axes, plus 16 specific and complementary axes, and it is oriented to generate innovative ideas in supporting industry and ESA programmes. Other ESA programmes include application-specific research (e.g. ASTE for telecommunications, FLTP for launchers, SSU for the Space Station).

Recommendations

Europe has to look for specific sectors in space – in line with its goals and commensurate with its capabilities – in which it could excel. The space sector has to concentrate on those activities where it has the potential to prevail over solutions provided by other means. The European space sector needs to establish long-term strategic alliances of world proportions. The maturity already reached by European markets in most growth sectors means that the further growth potential is small compared to that in other geographical areas still under development. Europe therefore has to look not only to its own internal markets, but must also seek to expand in other directions and geographical areas, focussing on activities with high potential for attracting paying users.

New technologies are the key to long-term competitiveness. Technology development is essential to achieve the cost and time-to-market reductions and performance increases characteristic of other competitive sectors. Common-interest technologies are being developed by non-space groups and space industry can profit from these developments (micro/nano-technologies, electronics, processors). The space sector must establish alliances with complementary sectors, with the objective of sharing technologies, and also foster the development of space-specific technologies and technologies oriented towards the solution of space-specific problems, so that total integrated solutions are available on time and at viable cost.

Europe's level of achievement in basic research is high. Unfortunately, transfer to industrial applications is slow, to the advantage of other geopolitical regions that are more aware of the market implications of that transfer. Applied research has to be encouraged in Europe and a technology harmonisation process urgently needs to be initiated, with ESA promoting developments directly applicable to space. More effective coordination is needed between ESA, the national agencies, European institutions and industry to minimise redundancies and overlaps and achieve efficient utilisation of the scarce resources devoted to space. Priority should be given to lines of research where significant increases in performance per unit cost/mass/volume/power can be foreseen. Lines where only minor improvements are to be expected should be abandoned, unless they require only minor levels of resources to accomplish the goals and the inherent development risk is minimal.

The presence of European space industry in the world has to be fostered, and measures contributing to the development of a competitive Europe supported. A global end-to-end approach to technology research and development, open and attentive to the changing world situation and demands, should be adopted. The short- and medium-term importance of marketing has to be exploited. Industry has to be encouraged to be more innovative, to invest more heavily in research and development, to accept risk, and to enter the free market competition.

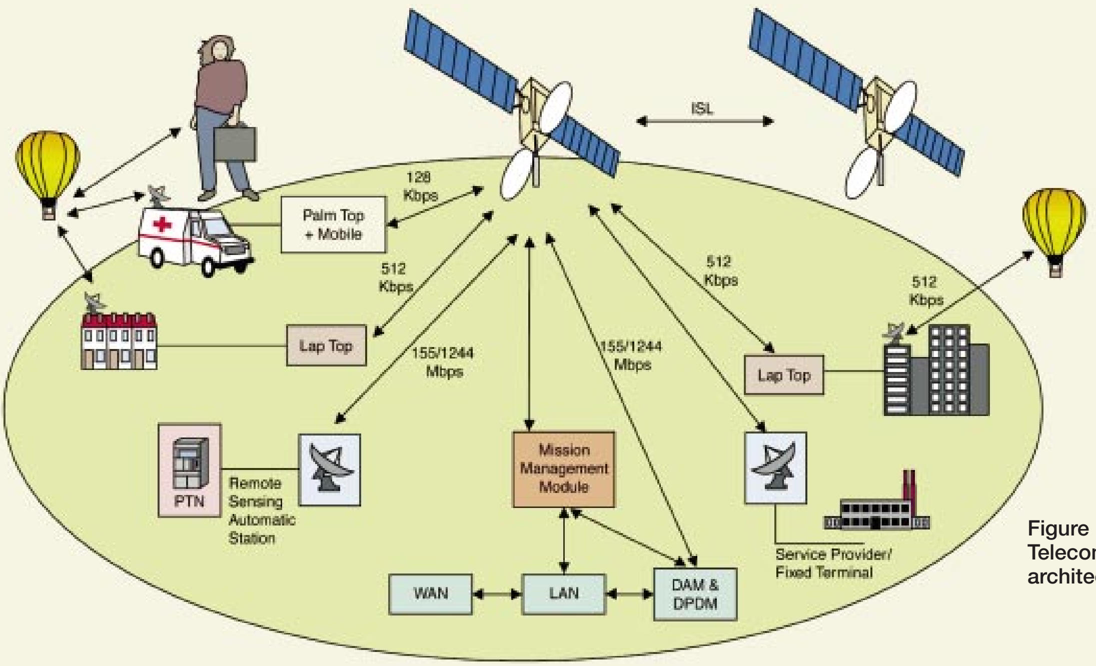
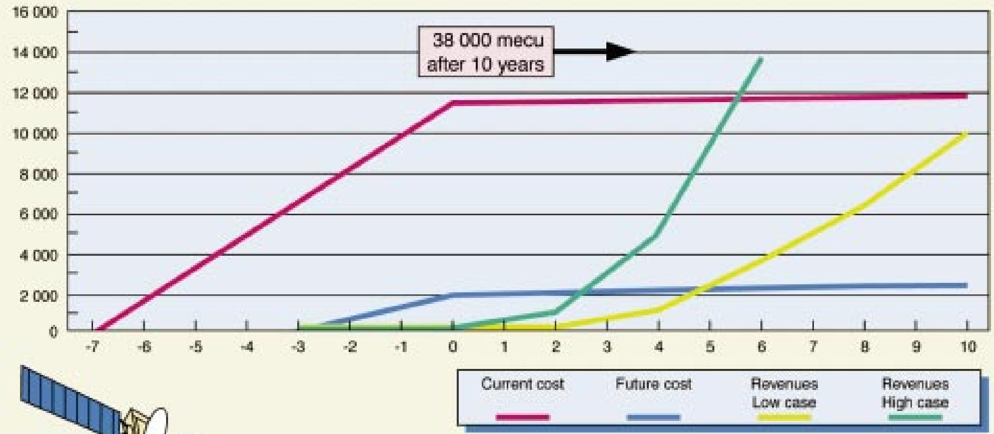


Figure 1. Overall Telecommunications System architecture

Figure 2. Projected cumulative costs/revenues (MECU vs Year) for the Telecommunications Service



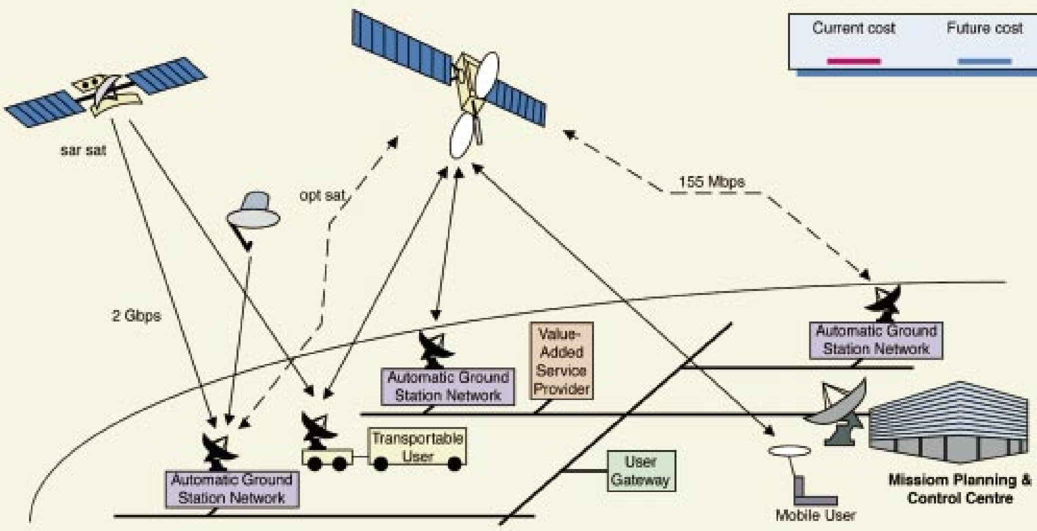
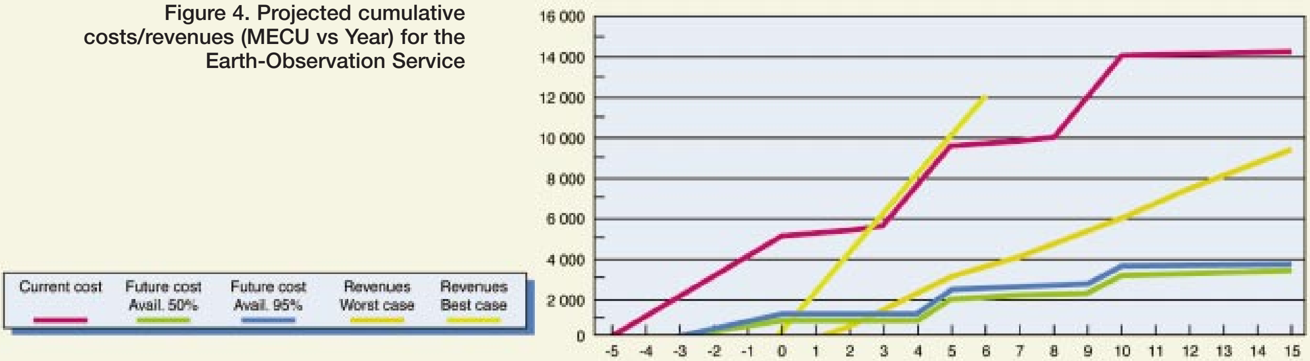


Figure 3. Overall Earth-Observation System architecture

Figure 4. Projected cumulative costs/revenues (MECU vs Year) for the Earth-Observation Service



Examples of Future Service Capabilities

Most of the concepts and approaches described in the accompanying article were considered in modelling two space-based services to be deployed in the 2010 - 2015 time frame, when all of the necessary technologies (Table 1) are expected to be available and consolidated. The two 'model services' analysed were:

A MULTIPURPOSE TELECOMMUNICATIONS SERVICE (Figure 1)

Based on large satellites in geostationary orbit and supporting mobile, fixed/semi-fixed terminals with several media products, the mission would consist of full-duplex services to low-cost user terminals providing:

- low data rates up to 384 kbps accessible by 'palmtop' terminals
- medium data rates, in the 2 Mbps range, accessible by 'laptop' terminals
- high data rates up to 1.2 Gbps accessible by 'fixed' terminals.

Six satellites would be necessary to provide a global service with the availability required, each with a mass of 7000 kg. Each of these satellites would be comparable in performance to three of today's satellites in the 3500 kg and 14 kW class.

The revenues have been estimated on the assumption that the maximum number of users per day per satellite matches the maximum capability of the satellites (in terms of number of channels) at the end of the last year. For each service type, a utilisation price and rate (hours/day) is assumed (optimistic scenario) and then the price and rate of use are reduced by a factor of 2 (revenue per user reduced by 4) (pessimistic scenario). The resulting market penetration would not exceed 2% (6 million palmtop, 2600 desktop users).

Figure 2 summarises the most important results in terms of cumulative costs and revenues (optimistic and pessimistic cases). They show that the proposed communications service, sized and costed on the basis of current parameters and methods is not commercially viable (except by raising the fees charged to the users, which results in the service not being competitive with ground-based services). A service designed around emerging technologies, however, appears very profitable, so that even with a very low market penetration, it is possible to generate profits with rates comparable to those of currently planned ground-based services.

Satellite applications for global purposes will not be possible unless several hundred 7 ton/70 kW satellites are deployed in geostationary orbit and integrated into global information systems.

Optimised use of future large geostationary satellites could be achieved in the framework of 'fixed desktop services', for second-level customers such as Internet-like service providers, or for private Intranets with geographically sparsely distributed users. With satellites resources fully dedicated to these kinds of customers (palmtop and laptop users could be served by other space-based services like LEO or MEO constellations, thereby reducing delay problems), a market penetration of more than 5% could be achieved. Satellites could then compete directly with terrestrial services, especially for small organisations who need limited or only occasional access to high-speed networks, and for developing nations on the verge of significant economic expansion. In both cases, there is a window of opportunity for satellite services to secure a significant market share before the competing terrestrial services become available. Once affordable terrestrial services are in place, it is difficult to displace them, except by providing radically better services. The fixed Gbps service could displace terrestrial services for certain users.

For palmtop and laptop services, the main competitor is likely to be terrestrial Local Multi-point Distribution Systems (LMDS). A different type of competitor could be stratospheric-airship systems, such as the proposed Sky Station. However, neither the LMDS nor airship systems seem to be able to provide a complete solution, thereby still leaving room for satellite services.

AN EARTH-OBSERVATION SERVICE (Figure 3)

With near-real-time and global access and an all-weather capability, this service would be based on a small constellation of satellites in low Earth orbit, with six in a near-noon 280 km-high orbit having an optical payload, and twelve with a microwave (SAR) payload, six of them in a near-noon and six in a dawn-dusk orbit of 410 km altitude.

The high-level mission requirements are:

- all-weather and day-and-night observing capability (microwave)
- high spatial resolution, ~0.5 m for optical and ~1 m for microwave
- multispectral capability
- global access time shorter than 8 hours for end users.

Employing current technologies, each satellite would have a mass of around 1650 kg and a power demand of up to 1000 W. Technologies under development would allow similar performances to be achieved with satellites weighing around 230 kg and with power demands of approx. 800 W (microwave payload).

The analysis has shown that the addressable market is between 4000 and 13 000 MECU by the year 2010; assuming that 50% (conservative assumption) of it is captured by non-space approaches such as air-based systems, and the other 50% is shared by 3 competitors, by 2010 the revenues would be in the range of 600 to 2000 million ECU/year. Figure 4 shows the cumulative costs assuming infrastructures based on current and on future technologies and methods, together with the cumulative revenues for the worst- and best-case scenarios.

It can be seen that:

- in economic terms, the difference between an availability of 50% (no spare satellite in orbit) or 95 % (with in-orbit spares) is not significant, so that the latter should be taken as the baseline
- the Earth-observation infrastructure sized and costed on the basis of current technologies and methods is not commercially viable, except under the most optimistic assumptions, and even then with low rates of return
- the expected future technologies and methods would result in space systems generating an internal rate of return ranging between 25 and 70%, depending on the market assumptions.