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1 Introduction

The basic advantages of satellite transmission are flexibility, speed of deployment and a considerable reduction in ground infrastructures.

Only satellite transmission permits the low-cost, immediate connection of subscribers in areas where communication infrastructures are totally or partially lacking. For public and private users, satellite communication networks offer numerous decisive advantages, such as:

- speed of deployment, extension or modification of network topology;
- flexibility thanks to the transportability of some types of earth stations and to the network's ability to absorb sudden traffic increases;
- security and reliability thanks to the network's independence from existing communication infrastructures;
- complementarity with other networks (e.g. radio relay systems, cable) giving the user access to a global telecommunication network.

Since their debut in 1965, satellite telecommunication systems have used geostationary orbits with global coverage for both fixed and mobile applications and for "traditional" public (and subsequently private) requirements (voice, data and image transmission).

Technical and technological developments are now making it possible to meet the explosion in demand, particularly in the field of mobile communications, with increasing use of satellite transmission systems for global coverage.

Thus it is that various projects have appeared and continue to appear, based on the use of satellite constellations in low orbit (LEO: altitudes between 700 and 1 500 km) or medium orbit (MEO: altitudes around 10 000 km).

The satellites comprising such systems are not stationary with regard to the Earth, and must therefore be launched in large numbers in order to ensure continuity of service over a given area (the time of passage of a satellite is a few minutes for LEOs and several hours for MEOs).

However, such systems make for a considerable reduction in the satellite's required radio power, as well as for a reduction in the response time (delay between transmission and reception of a message), thanks to the virtual elimination of the propagation time.

Non-geostationary satellites, especially LEOs, are the most suited to communications using small terminals with a power level equivalent to that of GSM terminals: where a satellite is closer to Earth, the energy dispersal, and hence the power required to ensure a good connection, is minimized.

Even though geostationary satellites are limited in terms of their number of channels and re-use of frequencies, ambitious projects using the geostationary orbit continue to appear, sometimes even in association with low-orbit systems (e.g. Skybridge, Cyberstar, Celestri).

Before describing the many programmes that are planned or under development, attention is drawn to the following factors justifying such programmes:

- the need to make basic services generally available in the developing countries (voice, data, facsimile, broadcasting, television);
- the globalization of data exchange and multimedia;
- the development of digital television (appearance of satellite "digital packages", made possible through progress in digital compression);
- the development of personal communication services for subscribers worldwide.

Also worth mentioning is the fact that there are currently over 25 new satellite projects, including:

- five LEO- or MEO-type "global" systems for voice and data transmission;
- three LEO-type "global" systems for data and messaging transmission;
- one GEO-type "global" system for voice and data transmission;
- eight GEO-type "regional" systems for voice and data transmission;
- three LEO-type "global" systems for multimedia;
- three GEO-type "global" systems for multimedia;
- one GEO-type "regional" system for multimedia;
- one GEO-type "regional" system for sound broadcasting.

Over the coming decade, total sales will amount to $US 80 billion for the space segment (manufacture and launch of satellites, etc.) and $US 100 billion for the ground segment (stations, equipment and terminals).

The services market could reach $US 450 billion.

2 Satellite systems for mobile networks

These systems, designed to provide mobile (and fixed) radiotelephony services to the entire planet, including remote or inaccessible areas, are particularly well-suited to very large countries. The biggest and best-known projects in this field are based on the use of low (LEO) or medium (MEO) orbits.

According to certain studies, over half the market should be concentrated in the six largest countries of the world, namely Australia, Brazil, Canada, China, Russia and the United States.

Satellite mobile communication networks provide the user with the same freedom as do current cellular networks, but with a further major advantage: a single number, terminal and service worldwide no matter where the user is (town, country, desert, ocean, …).

The price of this freedom is that such networks are technologically by far the most complex to manage. The management and control of these space information highways have given rise to technological challenges stemming, on the one hand, from user and satellite mobility and, on the other, from the scarcity of frequencies and short visibility periods of the satellites.

Optimization software developed from operational research and artificial intelligence, for example, makes it possible to resolve the complex problem of allocating shared resources, which is a very basic problem for mobile communication by satellite operators seeking to maintain a major competitive edge.

The best-known projects are currently:

- **GLOBALSTAR** (Loral/Qualcomm, Alcatel)
  - a mobile radiotelephony network (LEOs) providing global coverage;
  - voice, data, facsimile, messaging, positioning, paging;
  - 48 satellites - altitude 1 414 km,
    8 orbital planes at 52° inclination;
  - mobile-satellite service (MSS) frequency bands: 1 610.0 - 1 626.5 MHz (Earth-to-satellite) and 2 483.5 - 2 500.0 MHz (satellite-to-Earth);
  - access mode: CDMA;
  - no intersatellite links (transparent satellites);
  - use of satellite diversity to improve service availability and quality;
  - 50 - 100 gateways making it possible to distribute the signals received by the satellites from portable terminals to public telephone networks;
  - Alcatel's participation: satellite payloads and gateway antenna systems;
  - dual-mode terminals;
  - cost of project: $US 1.8 billion;
  - financed through participation of major global manufacturers and operators: TE.SA.M. (JV Alcatel/France Telecom); Vodaphone (UK); Airtouch Communications, Loral Corporation, Qualcomm (USA); DaCom Corp., Hyundai, Electronics Industries Co. (Korea); Alenia (Italy); Deutsche Aerospace (Germany); and Space Systems/Loral (international alliance comprising Aerospatiale, Alcatel Espace, Alenia and Deutsche Aerospace);
  - contracts with over 90 countries;
  - launch of first four satellites in February 1998;
  - commencement of service: 1999;
  - foreseeable costs: $US 1 000 - 2 000 per terminal, $US 1 - 1.165 per minute,
- **IRIDIUM** (Motorola)
  - global mobile communication system (LEOs);

– voice, data, facsimile, messaging;
– 66 satellites - altitude 780 km;
– 11 orbital planes with 86° inclination;
– frequency bands:

  1 610.0 - 1 626.5 MHz (Earth-to-satellite),
  1 613.8 - 1 625.5 MHz (satellite-to-Earth);

– access mode: TDMA;
– use of intersatellite links and on-board processing (more sophisticated satellites);
– nine gateways (connection stations);
– three call-centre network: Sydney - Australia (Asia Pacific area), Orlando - USA (Americas area), and Zöetermeer - Netherlands (Europe, Africa and Middle East area);
– dual-mode terminals;
– partners: United States (Lockeed Martin, Raytheon, Sprint), Germany, Canada, Venezuela, Russia, Saudi Arabia, Italy, China, South Korea, India, Japan, Thailand, etc.;
– cost of project: $US 4.2 billion;
– operation planned as from 1998;
– 58 satellites in orbit at end of March 1998,
– foreseeable costs: approximately $US 2 500 per terminal and $US 3 per minute average,

• **ODYSSEY** (TRW + Teleglobe)

– voice, data, facsimile;
– 12 satellites at an altitude of 10 354 km (MEOs);
– access: CDMA;
– no intersatellite links (transparent satellites);
– seven connection stations (Harris with TH-CSF and Nortel for the automatic exchanges);
– dual-mode terminals (Odyssey + cellular);
– cost of project: $US 2 billion (financing difficulties);
– operational in 2000/2001;
– foreseeable costs: $US 500-700 per terminal and $US 1 per minute;
– ***project abandoned - TRW joins Inmarsat for ICO Global network (see below),***

• **ICO Global** (Inmarsat + TRW)

– voice, data, facsimile, messaging;
– 12 satellites (Hughes) at an altitude of 10 355 km (MEOs);
– frequency bands of future mobile systems: 1 980 - 2 025 MHz and 2 170 - 2 200 MHz;
– access: TDMA;
– 12 nodal connection stations (gateways) and additional national stations;

  - a consortium comprising NEC, HNS and Ericsson has been set up to provide stations for installation in Brazil, Chile, China, Germany, India, Indonesia, Mexico, South Africa, South Korea, United Arab Emirates and the United States;
  - in addition, Deutsche Telekom has been chosen to construct a relay station serving Europe, Asia Minor and a large part of Africa;
  - KDD and Satellite Phone Japan (SPJ) (a consortium of 25 Japanese companies including KDD, N2T DoCoMO, Japan Telecom, Sumitomo, Marubeni and Toyota) have been chosen to set up and operate, in Japan, a Network Management Centre (NMC) and a Back-up Satellite Control Centre (BSCC), with the primary Satellite Control Centre to be set up in the United Kingdom;
  - organization of project and partnerships: 58 investors from 51 different countries and distribution agreements in 91 countries;
  - 14 million users targeted by 2005;
  - dual-mode terminals;
  - cost of project: $US 2.6 billion;
  - operational in 2000;
  - objectives: 14 million terminals by 2005;
  - foreseeable costs: $US 1 000 per terminal and $US 2 per minute,

- **ORBCOMM** (Orbitial Sciences Communications Corp/OSC - USA, Teleglobe Inc. - Canada and Technology Resources Industries Bhd - Malaysia)
  - data, messaging, radiolocation
  - 36 microsatellites, 30 kg each;
  - circular orbits at 765 km (small LEOs);
  - frequency bands 137, 148 and 400 MHz;
  - cost of project: $US 100 million;
  - satellites constructed and launched by OSC, 10 gateway connection stations provided and installed by Scientific Atlanta;
  - launch in 1995 of two satellites to test the land segment;
  - partial service in United States in 1996;
  - fully operational as of 1997 (covering 70 countries);
  - foreseeable costs: $US 600 per terminal - $US 15-30 per subscription - $US 0.07 per bit.

In some countries, however, mobile telecommunication services by satellite are or will be provided using traditional **geostationary** satellites. The service will of course be restricted to subscribers located within the coverage area of the satellite(s).

An example of this is the **ACeS** (Asia Cellular Satellite system) project initiated by Asian operators (Indonesia, Philippines, Thailand) for voice, data and fax transmission.

The system will use two satellites furnished by Lockeed Martin and will cover India, China, South East Asia and Japan.

The ACeS project should cost $US 700 million and be operational in 1998.

Alcatel, under sub-contract from Lockeed Martin, will provide A1000 E10 MSC switching equipment.

A further project of the same kind, **Agrani**, piloted by African-Asian Satellite Communications Ltd. (ASC) based in Bombay, plans to launch two geostationary satellites (Hughes) to cover Asia and Africa. The system will provide voice, data and fax transmission and should be operational in 1998.

In addition, the Ministry of Transport of Japan began development in 1995 of the **MT-SAT** satellite system for air navigation applications including global navigation satellite system (GNSS) functions and the relaying of ground-to-aircraft communications between pilots and air traffic controllers. Under this project, Alcatel has been entrusted with designing and producing the satellite's air navigation payload as well as with the design and installation of the connection station and the remote control and remote monitoring station.

The connection station will provide transmission of the GNSS signal as well as that of voice and data between the airliners and the ground; it will also route these communications to the civil aviation land networks.

THURAYA is an Etisalat project (United Arab Emirates) that will serve 1.75 million users in the Middle East, Iran, India, Pakistan, Turkey and North Africa. Three geostationary satellites will be placed in orbit above the Indian Ocean for voice, data and fax transmission.

The contract is estimated at $US 1.2 billion, and Hughes Space & Communications has been chosen to construct the first satellite.

The telecommunication company Euro African Satellite Telecommunications Ltd. (**EAST**) was set up at the end of 1997 to establish a geostationary satellite telecommunication system for the relay of mobile communications in Eastern Europe to part of Asia via Africa and the Middle East. It was set up by Digimed, which is a 100% subsidiary of the Cyprus Telecommunications Authority (CYTA) and Matra Marconi Space.

Matra Hautes Technologies, which belongs to the Lagardère Group, and the Norwegian company Nera have joined forces with EAST as members of its industrial team, which will come under English law.

The system will comprise two satellites in orbit, a network control centre and points of access to the existing networks.

It is intended to be compatible with GSM- and DCS-standard land cellular networks and to allow national and regional telecommunication operators within the coverage area to improve their mobile and rural telephony and data transmission capacities.

The terminals will be dual mode (space and terrestrial) or single mode (space). The mobile communications are expected to cost the user around $US 0.8 per minute, and the cost of the portable terminal to be slightly higher than that of a cellular telephone.

The cost of the project is around $US 1 billion, and its bringing into service is planned for around 2001.

3 Future of satellite systems for mobile networks

There is a huge market made up of areas not covered by cellular and by developing countries in which the telephone network is still virtually non-existent.

It is currently estimated that some 50 million people in the developing countries are on the waiting list for a telephone line.

In Asia in particular, many people could afford cellular telephones as an alternative to the shortcomings of a wired service that would take too long to set up.

These satellite systems will enable them to communicate at last. Along with business travellers who wish to be contactable on their trips abroad or to rural areas, they will constitute the bulk of the user base.

Around 150 million subscribers are forecast for 2000 for cellular telephony services. If the new projects were to win over only 10-15% of that number, they could still be profitable.

Indeed, the potential market for mobile voice-data services by satellite is estimated at 8 million subscribers in 2002 by the British research company Ovum. Turnover in the same year could amount to $US 8.5 billion, with $US 3.7 billion for operators and $US 3.3 billion for terminal manufacturers.

There are still some difficulties to be overcome, however; for example competition (charging) between the new systems and national operators, and negotiations between individual countries are complex. But work is under way in ITU to establish suitable regulations.

Finally, at the technical level, it should be noted that some systems require intersatellite links, which would make the design of on-board equipment more complex (signal processing), and might as a consequence reduce the reliability of the space segment.

To sum up, these are ambitious projects, the techniques and technologies are for the most part mastered, and demand is solvent; however, as with satellite access systems (see below), the problem of financing the projects remains the greatest hurdle.

For the next millennium, mobility will be "universal" and sets will most certainly be "portable" (pocket sized) and dual mode (cellular + satellite).

4 Satellite broadband access systems

The birth of the concept of information highways and the development of digital television (with the appearance of satellite "digital packages" thanks to progress made in digital compression), coupled with the need to make basic services generally available in the developing countries (voice, data, facsimile, broadcasting, television, …) have led some industrialists to conceive of satellite access systems.

The best known such projects are currently SKYBRIDGE, designed by Alcatel, and TELEDESIC, piloted by Microsoft, each of which has its own specific and original features.

To these we must add Motorola's CELESTRI and Loral's CYBERSTAR projects.

- **SKYBRIDGE** (Alcatel)
  - partnership with Loral (Cyberstar), Spar Aerospace, CNES, Aérospatiale, the *Société Régionale d'Investissements de Wallonie*, Mitsubishi, Sharp, Toshiba;
  - satellite version of information highways (online services, high-speed Internet access, teleworking, tele-education, LAN and WAN connections, video games, …), for users (professional and residential) living in urban or sparsely-populated areas, plus additional services: narrow-band (voice, videoconferencing, data) and infrastructure (connection of base stations for radio local loop);

- 64 low-orbit satellites (LEOs) at an altitude of 1 457 km;
- nx20 Mbit/s for reception and nx2 Mbit/s for transmission;
- over 144 Gbit/s for the constellation as a whole;
- 200 connection stations (gateways);
- connection of user to nearest land-line network;
- Ku frequency band (11/14 GHz);
- CDMA access;
- client/server-type ATM architecture;
- a licence has been requested from the Federal Communications Commission (FCC) for the space segment and associated ground control segment;
- specific frequency bands were allocated at the last World Radiocommunication Conference (WRC-97);
- 15 - 20 million potential users;
- cost of project: $US 3.5 billion;
- cost of terminal: $US 700;
- operational as of 2001;
- marketing integrated with that of Loral's Cyberstar, opening the way for complementary services (radio and television broadcasting).

• **CYBERSTAR** (Loral Space & Communications)

- high-speed multimedia network (data and video);
- three interconnected geostationary satellites;
- Ku (initially) and Ka bands;
- capacity: 400 kbit/s in Ku band, subsequently 30 Mbit/s in Ka band;
- FDMA and TDMA access;
- cost of project: $US 1.6 billion;
- cost of terminal: $US 800 (Ku initially) and $US 1 000 (Ka);
- operational as of 2001;
- marketing integrated with that of SKYBRIDGE.

• **TELEDESIC** (Microsoft + Craig MacCaw + Boeing, new general contractor)

- basic telephone services for developing countries (16 kbit/s at 2 Mbit/s);
- "high-speed" services (155 Mbit/s at 1.24 Gbit/s);
- access to Internet, corporate networks;
- fixed or mobile terminals (low bit rate);
- 288 satellites at an altitude of 700 km (LEOs);
- Ka band (20/30 GHz);
- access: MF-TDMA, ATDM;
- high-speed intersatellite links at 60 GHz, "green light" from FCC;
- cost of project: $US 9 million;

– operational as of 2002.

- **CELESTRI** (Motorola)
  - high-speed data transmission network (64 kbit/s at 155 Mbit/s) - applications: multimedia, with high-speed Internet access, video, data;
  - 63 LEO satellites (1 400 km) allowing interactivity on demand + five GEO satellites providing global coverage;
  - intersatellite links;
  - frequency bands: 18.8 - 20.2 GHz for uplinks and 28.6 - 30.0 GHz for downlinks;
  - access: FDMA and TDMA;
  - Matra Marconi Space (Lagardère group + GEC) has been chosen to provide the satellite platforms (LEOs and GEOs);
  - cost of project: $US 14 billion;
  - cost of terminal: $US 750 initially;
  - launch of first satellites in 2001;
  - bringing into service in 2002.
- **ASTROLINK** (Lockheed)
  - data transmission, video and rural telephony network;
  - nine GEO satellites;
  - intersatellite links;
  - Ka band;
  - FDMA and TDMA access;
  - capacity: up to 9.6 Mbit/s;
  - cost of project: $US 4 billion;
  - cost of terminal: $US 1 000 - 2 500;
  - bringing into service in 2000.
- **SPACEWAY** (GM-Hughes)
  - network for high-speed data transmission and multimedia applications;
  - eight GEO satellites;
  - intersatellite links;
  - Ka band;
  - FDMA and TDMA access;
  - capacity: up to 6 Mbit/s;
  - cost of project: $US 3.5 billion;
  - cost of terminal: less than $US 1 000;
  - bringing into service in 2000.

5 Other projects

- **WORLDSTAR** (project of WorldSpace Corporation, a company specialized in direct digital audiovisual broadcasting by satellite):
  - three geostationary satellites;
  - global digital broadcasting service offering multimedia programmes (sound, text and images) such as health, information, education or entertainment programmes for the public at large, as well as training or databased services for public organizations (universities, etc.);
  - receipt of information on a new generation of portable, low-cost terminals ($US 100-200) called "StarMan" (developed by Motorola - manufactured in Asia: Hitachi, Matsushita, JVC, Sanyo);
  - over 100 programmes from all parts of the globe;
  - services basically intended for the developing countries (Asia, Africa, Middle East, Mediterranean Basin, Latin America and the Caribbean);
  - potential market: $US 4.6 billion people in 116 countries;
  - today's estimate is for 183 million potential purchasers of a radio receiving station in the first ten years of this system's operation;
  - AfriStar-1 will be launched over Africa in mid-1998;
  - AsiaStar-1 will be launched in mid-1999 and CaribStar-1 at the end of 1999;
  - Alcatel is project leader for delivering the entire system ready to use (excepting the portable receivers), for the placing in orbit of the three satellites and for the installation of traffic management and control centres on five continents;
  - other partners: Arianespace, Matra Marconi Space, SGS-Thomson, TIW, ITT Intermetall and the German Fraunhofer Institute;
  - the service will commence in 1998 and will enable users, no matter where they are on the planet, to use portables and mobiles (portable radios, portable computers and car radios) to listen to music at different digital audio compression rates and view associated images on a hundred different channels direct from the satellite without the need for a dish;
  - cost of project: $US 850 million.

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