Satellite industries at the turn of the century*

By Ryszard Struzak

Satellite technology has changed our perception of the world. We take for granted satellites delivering daily news and weather predictions. Satellites advance exploration of the Earth s resources, air-traffic control, and precise locating persons, animals, or objects. Cosmic radiation, solar wind, and other phenomena can be studied avoiding distortions by the Earth's atmosphere. Satellites monitor if treaty obligations are really followed, which contributes to avoiding major conflicts. Space vehicles opened new vistas in the exploration of the Moon, Mars, Venus, other planets, and the Universe, leading to phenomenal discoveries. This article offers a short review of some current issues related to satellite-related industries.

Introduction

To understand better the status and perspectives of satellite industries, we shall first look at the past. The Space Era began when Sputnik 1, the first artificial earth satellite, was launched by the Soviet Union in October 1957. The Soviet s monopoly did not last for long. The first American satellite, Explorer 1, was put into orbit in January 1958, only a few months after Sputnik 1. However, the Soviets were able to put the first man in space (1961), the first woman (1963), launched the first (unmanned) Moon exploration mission, and arranged for the first Moon landing (1959) before finally the Americans took the lead.

The Space Era was a consequence of the progress made in science and technology, as predicted by Arthur C. Clarke of Great Britain, Herman Potocnik (1892-1928), an Austro-Hungarian of Slovene origin, and Konstantin Tsiolkovsky (1857-1935), a Russian scientist of Polish origin. As with many inventions, the first satellites were products of military research. Explorer 1 was designed, built, and launched under the direction of Wernher Von Braun, the ex-prisoner-of-war and the creator of the famous German missiles that were used in attempt to destroy London during World War II.

The first satellites were small and short living, in comparison with the International Space Station (ISS) of today. Table 1 illustrates the progress made, and Figure 1 shows the ISS orbiting above clouds. The satellite lifespan increased a few hundred times, and the mass - more than a thousand times! The ISS is the largest and most complex international scientific project in history. It serves as an Earth-orbiting laboratory drawing upon the scientific, technological and financial contribution of 16 nations: Brazil, Canada, the eleven members of the European Space Agency, Japan, Russia, and the USA. With its lifetime cost estimated for US$100 billion, it is also the most expensive and most controversial project.[1] However, the future of the ISS became unclear after a series of budget cuts and program reductions.

Figure 1: Artist s rendering of the International Space Station following the undocking of the Space Shuttle Atlantis. Still being built, the station will accommodate six astronauts making scientific experiments at an altitude of 200 to 600 km. Courtesy of NASA. Photo NASA jsc2001e00360

Table 1. The first and the largest artificial satellites of the Earth

	Sputnik 1 (USSR)	Explorer 1 (USA)	ISS (International)
Launch date	4 October 1957	31 January 1958	31 October 2000
Form	Sphere	Cylinder	Complex
Diameter, m.	0.58	0.15	---
Length, m.	---	~2	~88
Width, m	---	---	~108
Mass, kg	83	14	~430 000*
Min altitude above Earth, km.	227	358	~200
Max altitude above Earth, km.	945	2550	~600
Orbit period, min.	96	115	90
Mission length	21 days	112 days	25 years*

* The ISS hardware has not yet been completed at the time of writing

During the first nine years of space history, 1957 to 1965, only two countries were able to launch satellites: the United States and the USSR. They collected invaluable data on the space environment and its effects on equipment and living organisms. For instance, the Explorer 1 discovered an unusual concentration of cosmic radiation in some region around the Earth. These have been called later the Van Allen radiation belts, after the name of the scientist who designed the experiment. This discovery has been of great importance. The satellite orbits are designed to avoid the belts since satellite electronics, and hence their operation, are strongly affected by the radiation. Millions of dollars are at stake.

Relations among nations change. We have seen throughout history how often and how easily the cooperation changes into competition, and peace into war. The USSR and the USA, close allies during the World War II, become enemies when the war was over. Ironically, the Cold War started just after the Charter of the United Nations was approved, calling for new world order and peaceful and friendly relations among nations. During the Cold War, each superpower was developing new weapons that could assure its world dominance. In that competition, satellites served as a heavy argument. A bigger satellite in the sky meant a bigger nuclear bomb carried at greater distances to kill more people faster and cheaper...

Breaking the Duopoly

The foolish arms race led quickly to an arsenal that was sufficient not only to kill the whole of humanity several times but also to wipe out all life on Earth. The menace of mutual annihilation combined with population pressure forced the world leaders to reflect. Treaties assuring survival have been negotiated and signed. At the same time, spy satellites were developed allowing safe monitoring of military activities at a distance and checking if treaty obligations were really followed. It contributed greatly to avoiding major conflicts and augmented mutual confidence. A degree of cooperation in space became both possible and necessary to solve problems the Space Era brought with it. For instance, a satellite, its crew, or its component parts could land on foreign territory, under foreign jurisdiction. Such situations never happened before and thus mutual responsibilities and obligations of the states were undefined.

The USA-USSR space domination did not last long; other nations also began space activities in the meantime. France launched its first satellite in November 1965, using its own rocket and becoming thus the third space power in the world. Later, China, India, and other countries joined the exclusive club of space technology leaders. A satellite becomes a symbol of national pride and a political/military goal in many countries, even those with populations suffering from extreme poverty. On the both sides of the Iron Curtain, the superpowers made some know-how accessible, and wider international cooperation in space has accelerated. In 1971, each of the two blocks involved in the Cold War created an intergovernmental satellite operating organization. Intelsat and Intersputnik were the first, and soon, other similar organizations appeared, see Table 2.

Table 2. Chronology of International Agreements on Space-related Institutions

1971	Intelsat	Agreement Relating to the International Telecommunications Satellite Organization

		(http://www.intelsat.com/)
1971	Intersputnik	Agreement on the Establishment of the Intersputnik International System and Organization of Space Communications (http://www.intersputnik.com/)
1975	ESA	Convention for the Establishment of a European Space Agency (http://www.esa.int/)
1976	Arabsat	The Agreement of the Arab Corporation for Space Communications (http://www.arabsat.com/)
1976	Intercosmos	Agreement on Cooperation in the Exploration and Use of Outer space for Peaceful Purposes (Intercosmos)
1976	Inmarsat	Convention on the International Maritime Satellite Organization (http://www.inmarsat.org/)
1982	Eutelsat	Convention Establishing the European Telecommunications Satellite Organization (http://www.eutelsat.org/
1983	Eumetsat	Convention for the Establishment of a European Organization for the Exploitation of Meteorological Satellites (http://www.eumetsat.de/)

Breaking the State Monopoly

The first satellites were developed for governmental purposes, and that monopoly lasted for several years. The state monopoly was broken in July 1962, when Telstar I, the first non-governmental satellite, was launched in the USA. Developed by the AT&T Company, Telstar I was the prototype for a constellation of satellites that AT&T intended to develop and operate. The constellation would consist of 50 to 120 satellites at random orbits at altitudes of the order of 10,000 kilometres. It would provide service 99.9 per cent of the time between any two points on earth. The cost of the space part of such a system was estimated in 1961 at US$500 million.[2] The project was halted when the Kennedy Administration decided to give the monopoly on satellite communications to Comsat.

Telstar I was the first telecommunication satellite with transponders, and the first satellite that transmitted the live broadcasts between the United States and Europe. At that time, a satellite provided almost 10 times the capacity of submarine telephone cable for about 1/10th the price. That price relation lasted until the first fibre-optic cable has been laid across the Atlantic in the late 1980s, when the relation has been reversed in point-to-point communication. However, satellites have still been competitive in point-to-multi-point communications. Canada began domestic satellite service in 1972. It was joined by the United States (1974), Indonesia (1976), Japan (1978), India (1982), Australia (1985), Brazil (1985), Mexico (1985), and others.[3] The satellite industry began to move towards free market. At the turn of the century, even Intelsat, Eutelsat, and Inmarsat, originally created as intergovernmental entities, have been reconstituted as private companies.

Boom

Space-related industries have been growing without interruption since the beginning of the Space Era. Figure 2 shows the revenue and employment history in the satellite -related industries during five years between 1996 and 2001. The revenue increased nearly twofold, from US$45 billion in 1996 to US$85 billion in 2001, according to recent studies.[4] It is almost three times the 1995 Gross Domestic Product of Bangladesh. For the next period 2001-2007, the expected global revenue from space related activities is some US$770 billion, according to Joseph Pelton, Director of Space and Advanced Communications Research Institute at George Washington University.[5] The employment increased from 97 thousand people in 1996 to 158 thousand in 2001. This contrasts with the general decline. For instance, in the telecommunication sector some 470 thousand jobs have been lost during the calendar year 2001 alone. [6]

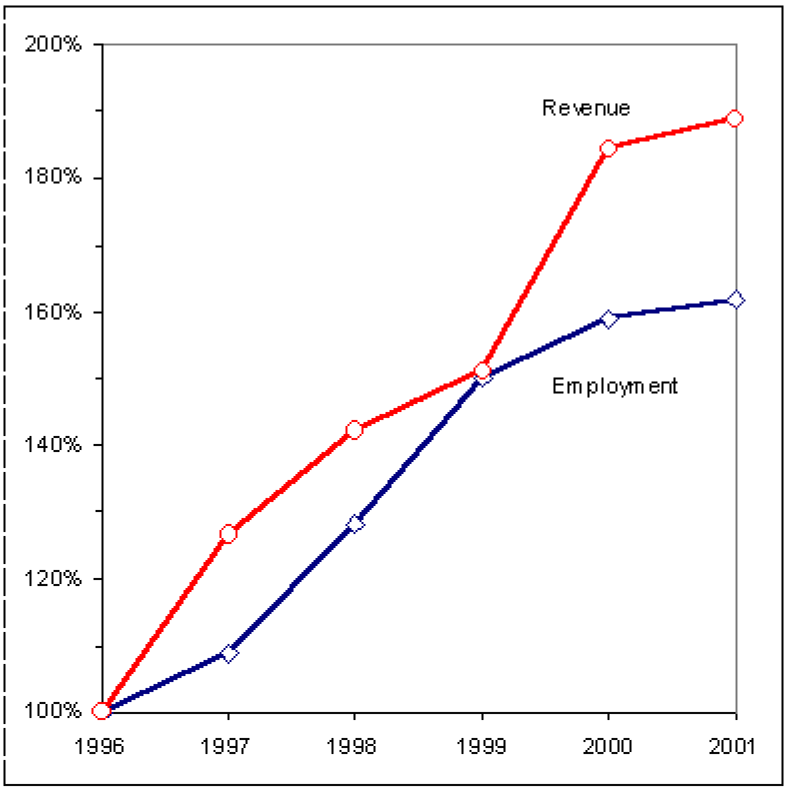

Figure 2. Worldwide space-related industry revenues and employment in the years 1996-2001. In 1996, the employment was 97 000 people and the revenue was US$45 billions. (Sources: A. Maléter, PTR 1/2002 p.8 and J.N. Pelton, PTR 1/2002 p. 26)

Satellite construction and earth segment became multi-billion dollar businesses. The size of launch vehicle industry is also large, as Figure 3 illustrates. The figure shows the relative contribution of these sub-sectors to the total value of the satellite business in 2000, according to Julián Seseña, Vice-Chairman of ITU-R Study Group 4 [7]. The lifetime benefits due to the European Galileo global positioning system are estimated for US$74 billion or more, according to The European Space Agency (ESA).[8] Similar benefits may be expected from the two other similar, already existing, systems, the American GPS and Russian GLONASS.

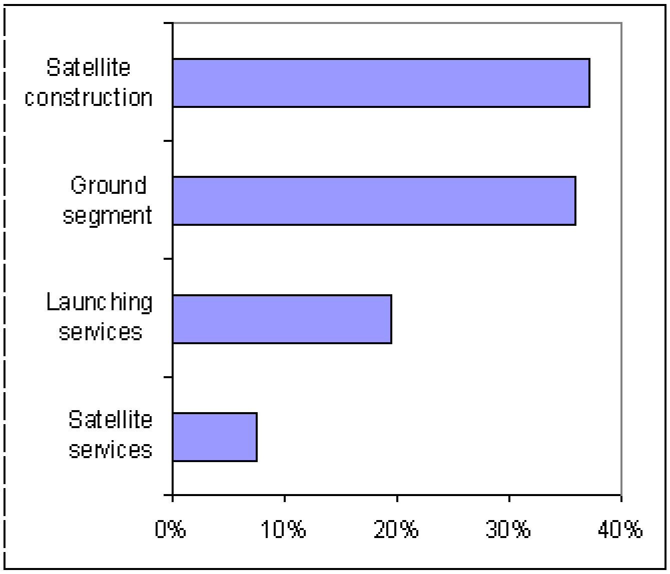

Figure 3. Relative contribution of satellite construction, ground segment, launching services and satellite services to the total value of satellite-related industries in 2000. (Source: J. Seseña: IP and Data Provisioning Via Satellite. ITU Workshop on Satellites in IP & Multimedia, Geneva 9-11 Dec. 2002)

Ten to twenty communications satellites, each valued at about US$75 million, are launched yearly, according to David J. Whalen of NASA. Figure 4 illustrates the increase of the number of satellites in the orbit in the years 1996-2000. In 2000, the total number of operational satellites exceeded 600, according to Seseña. During the first half of 2002, twelve commercial geostationary satellites were placed in orbit offering an equivalent of almost 630 standard transponders, each of 36 MHz bandwidth. With fifteen satellites expected by the yearend, it would make more than one thousand new 36 MHz transponder equivalents for the year. [9]

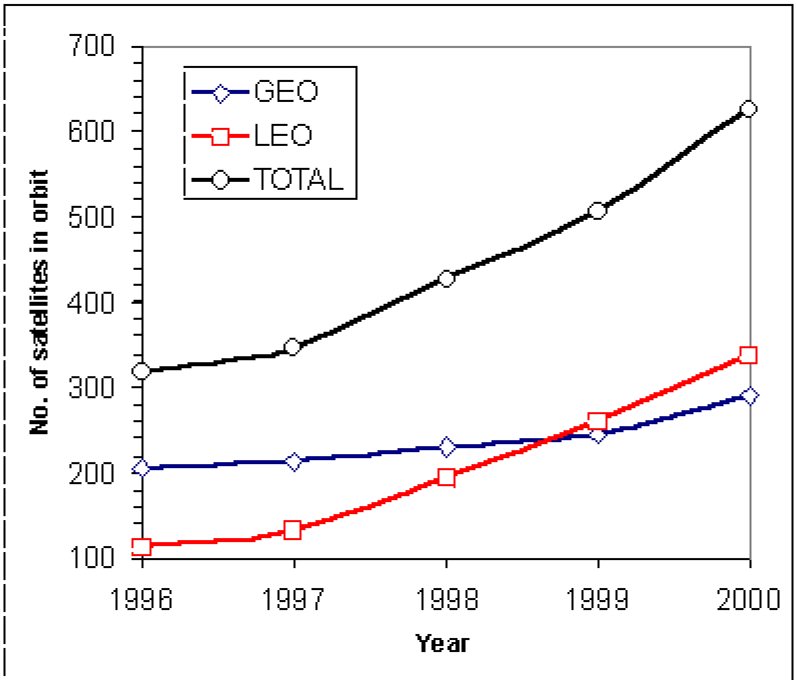

Figure 4. Increase of the number of satellites in the orbit in the years 1996-2000. (Source: J. Seseña: IP and Data Provisioning Via Satellite. ITU Workshop on Satellites in IP & Multimedia, Geneva 9-11 Dec. 2002)

A modern satellite system can retransmit speech, music, graphics, video, and digital data, anywhere and anytime. In recent years, Internet transmissions became more and more important. According to some analysts, the Internet traffic over satellites almost doubles every six months, and Internet transmissions represent the fastest growing segment of the fixed-satellite service (FSS).

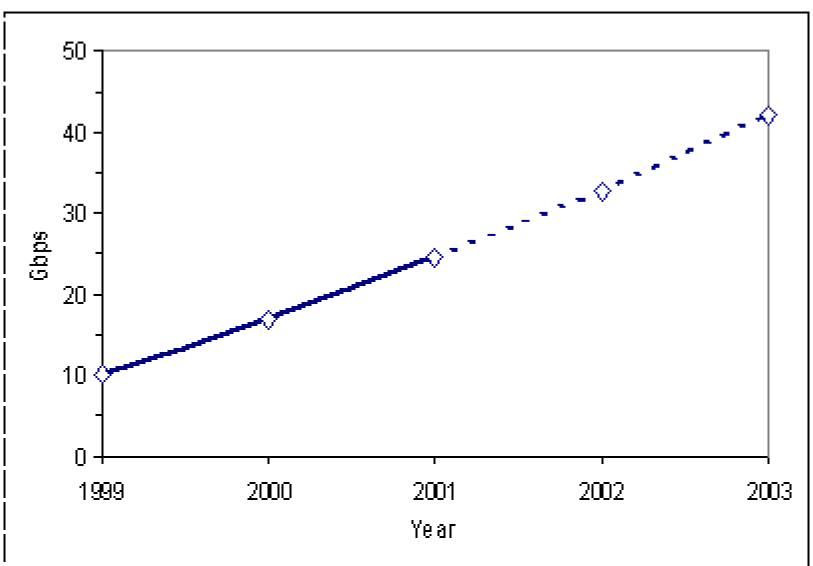

Figure 5. Growth of Internet traffic via satellites in years 1999-2001, extrapolated up to 2003. (Source: J. Seseña: IP and Data Provisioning Via Satellite. ITU Workshop on Satellites in IP &

Multimedia, Geneva 9-11 Dec. 2002)

Satellites represent the only Internet access alternative in many remote, rural, or underdeveloped regions. They provide instant infrastructure to Internet service providers (ISP) and a cost advantage over wire-line networks in sparse-populated areas. Figure 5 illustrates the growth of Internet traffic via satellites worldwide in the years 1999-2001. Figure 6 shows how that traffic is distributed geographically. The largest part of it is associated with Asia, which may be explained by a large proportion of population on isolated islands in that region. Relatively low satellite traffic in North America may in turn be explained by highly developed terrestrial infrastructure and disadvantageous transmission fee structure. In the early years, the satellite system availability was often unsatisfactory. Later it was improved to exceed 99.99% recently, far better than fibre-optic or coaxial cable systems, according to Pelton.

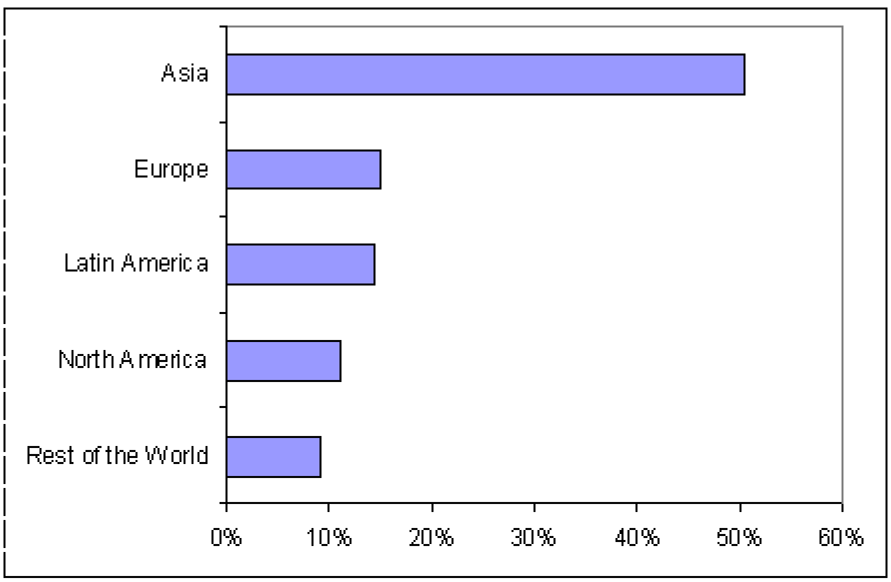

Figure 6. Geographical distribution of Internet traffic via satellite in 2001. (Source: J. Seseña: IP and Data Provisioning Via Satellite. ITU Workshop on Satellites in IP & Multimedia, Geneva 9-11 Dec. 2002)

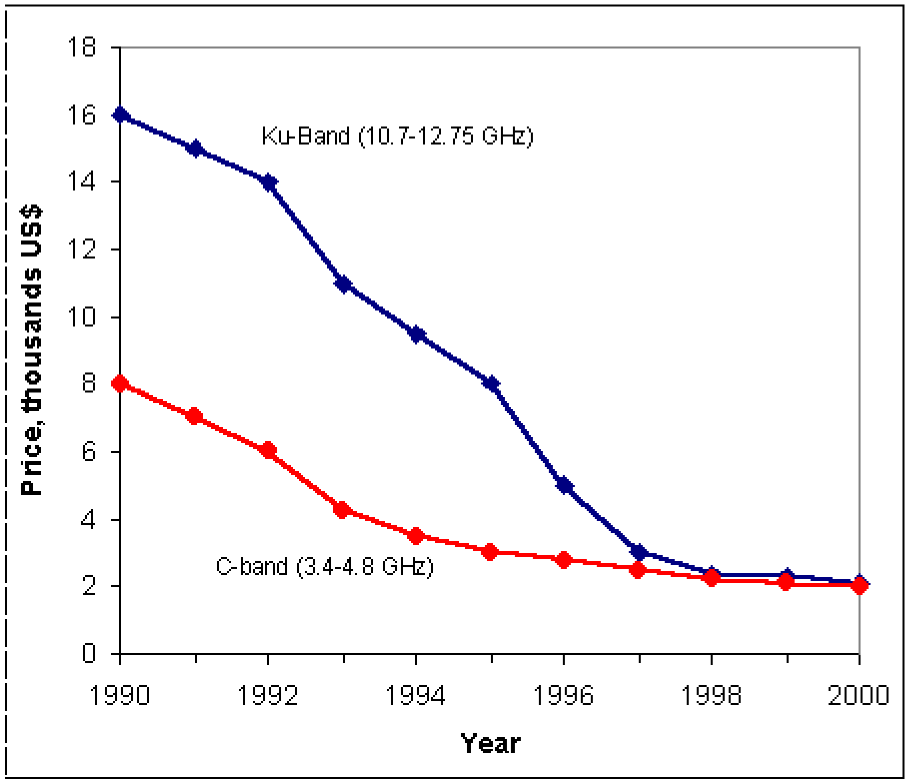

Figure 7. VSAT terminal pricing trends 1990-2000. (Source: D. Hartshorn, PTR 1/2002 p.22)

Very Small Aperture Terminals (VSAT) can be used everywhere to make broadband multimedia connections with the rest of the world via the geostationary satellites. Today, there are more than one million of VSAT systems operating in more than 120 countries throughout the world. With falling prices, the VSAT technology rises from being a niche technology to become a mainstream of IP-based telecommunication services. Figure 7 shows the price trend during the period 1990-2000.

In the recent few years, the capacity of VSAT systems was utilized in 75% only, according to David Hartshorn, Secretary General of the Global VSAT Forum. Figure 8 shows the transponder utilization in various regions. The utilization of space telecommunications is closely related to the cycle of global economy: it increases in times of economic boom and falls with global recession.

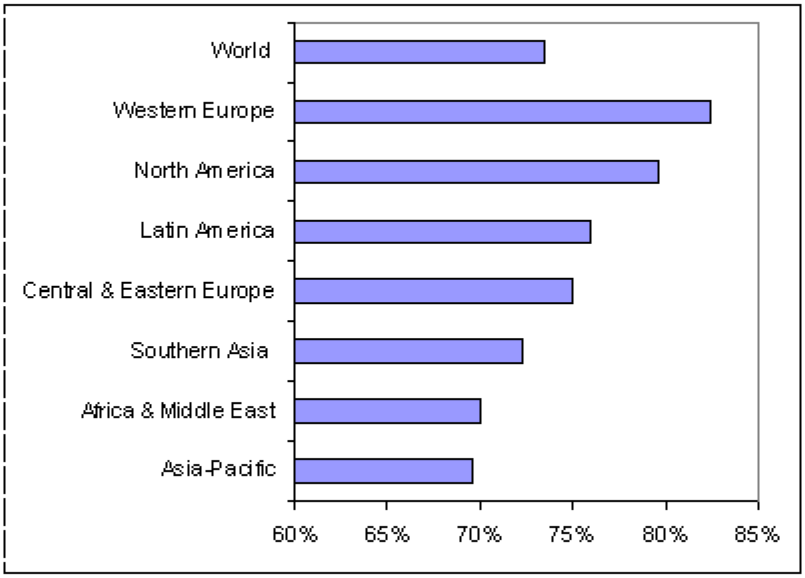

Figure 8. Satellite transponder utilization 1999-2000 (Source: D. Hartshorn, PTR 1/2002 p.21)

In spite of the phenomenal success of the space sector in general, a number of satellite projects have failed, especially those related to low-earth orbiting (LEO) systems. The case of the Teledesic is the most spectacular. Over the past ten years, the company spent hundreds of millions of dollars on the design and development of the first global broadband LEO satellite system to provide broadband multimedia communications to any part of the globe. In 1995, Teledesic received global license for a 1 GHz-wide frequency band, which was widely viewed as a significant regulatory achievement not likely to be duplicated. Designed to support millions of simultaneous users in rural, remote, and sparse-populated regions lacking terrestrial communication infrastructure, it enjoyed enthusiastic support from developing countries. Promising a full access to ultra-modern global telecommunications (internet in the sky), the project created hopes to bridge the digital gap in a span of few years time only. In 1998, the first experimental satellite T1 was launched[10] , and two years later, in 2000, Teledesic engaged Alenia, an Italian company, to build the first operational satellites of the planned satellite constellation.

Few months later, in September 2002, the company decided to suspend the works necessary to launch the satellites within the tight time limits imposed by the regulatory requirements.[11] Our decision to suspend our activities results from an unprecedented confluence of events in the telecommunications industry and financial markets. We do not presently see elements in place that would result in returns to our shareholders that are commensurate with the risk. We continue to believe that the Teledesic service would ultimately provide unique and measurable benefits to the world, and we are looking at scenarios to preserve the ability for that service to be realized , said the Teledesic Chairman and Co-CEO, Craig McCaw. His Co-CEO, William Owens, added: We continue to believe that the Teledesic system would be useful to governments around the world in connection with disaster relief, anti-terrorism, defence services and other critical government activities. We also believe that providing ubiquitous, quality broadband service to the world, including those three billion people who have never had service, will be a viable business and remains a worthy mission.

Challenges

It is impossible to discuss all satellite applications in the space available here. We shall therefore limit this short review to a few issues only.

VSAT and Elections

The VSAT technology is changing many aspects of our life, including political activities. In 2000, Prof Youri Zubarev, Director of Radio R&D Institute, Moscow, presented a satellite-based multi-media system used in the presidential elections in Ukraine. A new system was developed, called Street TV, which combined elements of videophone, video conferencing, TV news gathering, and interactive digital television, with satellite technologies. The easiness of interacting with voters increased significantly. The new system allowed multiple meetings (up to 30 meetings) with voters to be held simultaneously in a number of separate places around the country, no matter how distant from each other.

Benefits of the system are numerous, comparing to the traditional campaign, according to its creators. The new system facilitates greatly the discussions and direct contacts between the voters and electoral candidates. The candidates do not need to go in person to meet the electorate in a series of consecutive meetings. Voters from big cities and from remote areas have (almost) equal chances to discuss their problems with the candidates. The size of meeting rooms and number of meetings possible in a short time of the election campaign no more are limiting factors. With reduced travelling, the candidates time is used more efficiently and the disturbing effects of the campaign on the candidates normal duties are minimized. The candidates safety, security, and comfort are greatly improved. The candidates can substitute non-stop flying all around the country with a comfortable chair in a TV studio. Finally, it is cost-effective and environmental friendly, as most of normally planned air travels are redundant. The technology is applicable in tele-education, tele-medicine, and in other areas. [12]

Differential GPS

The Global Positioning System (GPS) was designed for military purposes. The first of its 24 satellites was launched in 1978, and the system was declared fully operational in 1995. A similar system was built by Soviet Union, and the European Union is just planning another one. Applications of these systems range from land, air, and maritime transportation to surveying and mapping; from constructions, mining, and agriculture to earth exploration; from telecommunications to outdoor recreational activities. Today, the GPS serves 20 million military and civilian users, with over 100 000 GPS receivers shipped every month[13]. With decreasing price, one may expect that GPS receivers will eventually become as popular as watches, and global GPS coordinates will replace street address to define the location of home or business, as Thomas A Stansell predicted twenty years ago, in 1983.[14]

With four or more GPS satellites visible, a user can estimate his/ her absolute position with a 10 to 100 m error. However, the relative position of two GPS receivers operating simultaneously can be estimated with centimetre precision. Such a precision is available, if the two receivers are not too distant one from another, so that satellite signals received experience the same propagation delay. If the exact position of one of the receiver pair is known, the position of the other receiver can be determined with almost the same precision. This is known as augmentation system, or differential GPS. An essential characteristic of such systems is an error-correction signal. Such a signal must be generated and disseminated as a complement to the standard GPS signals. Differential GPS systems are being deployed for aircraft navigation and for mobile communications.

Local area augmentation system (LAAS) provides precision horizontal and vertical guidance to aircraft approaching an airport. Such guidance, known as precision approach, is not available in many airports today. The pilot must follow a non-precision approach, which is more difficult and more dangerous. A number of air crashes have been attributed to the difficulty associated with non-precision approaches. It is expected that in 2003, GPS will begin to obviate the non-precision approach. Whereas a LAAS serves one airport at a time, a wide area augmentation system (WAAS) serves continental areas. Both are differential GPS systems. The International Civil Aviation Organization (ICAO) refers to the LAAS as a ground-based augmentation system and to the WAAS as a space based augmentation system.

Another perspective of augmented GPS relates to mobile telecommunications. In a number of countries, the law enforcement authorities require that the location of a mobile cell phone user can be determined with specified precision. For instance, in the USA the required precision is 50 m for 67% of the calls and 150 m for 95% of the calls, or better. In many cases, this implies the use of differential GPS.

UWB Systems

Traditionally, when two radio systems share the same service area, they have to operate at different bands or at different times to avoid mutual interference. When they operate at the same time within the same service area, they use different frequency bands. This arrangement is to be changed by ultra-wideband (UWB) systems, recently proposed. The new systems are to radiate intentionally signals on an unlicensed basis in bands previously allocated to other services. It will be thus necessary for satellite and UWB systems to share simultaneously common frequency bands and service areas. According to some opinions, this may create unacceptable interference at least to some satellite services.

The UWB proponents promise a vast array of new products that have the potential to provide significant benefits for public safety, business and consumers. Some of the applications for this technology include radar imaging of objects buried under the ground or behind walls, short-range high-speed data devices, and vehicle radar systems.[16]

The proponents claim their technology to be compatible with all of the current services because the UWB signals spectrum is so broad, that only an unnoticeable part of its energy falls into the frequency band used by any of the existing systems. Not all users of the radio frequency spectrum share that view. The UWB equipment can radiate not a small amount when compared to power received from GPS, passive Earth exploration and radio astronomy systems, etc. in frequency bands allocated to these services, as Dr. Per Enge, a Stanford University professor, underlines.[16] For these reasons, UWB emissions have to be limited, and appropriate studies have already been initiated in the USA and other countries, as well as in the ITU. Figure 9 shows the first emission limits imposed by FCC on UWB indoor equipment and on vehicular radar. The issue will certainly be discussed at the forthcoming WRC 2003 in Geneva.

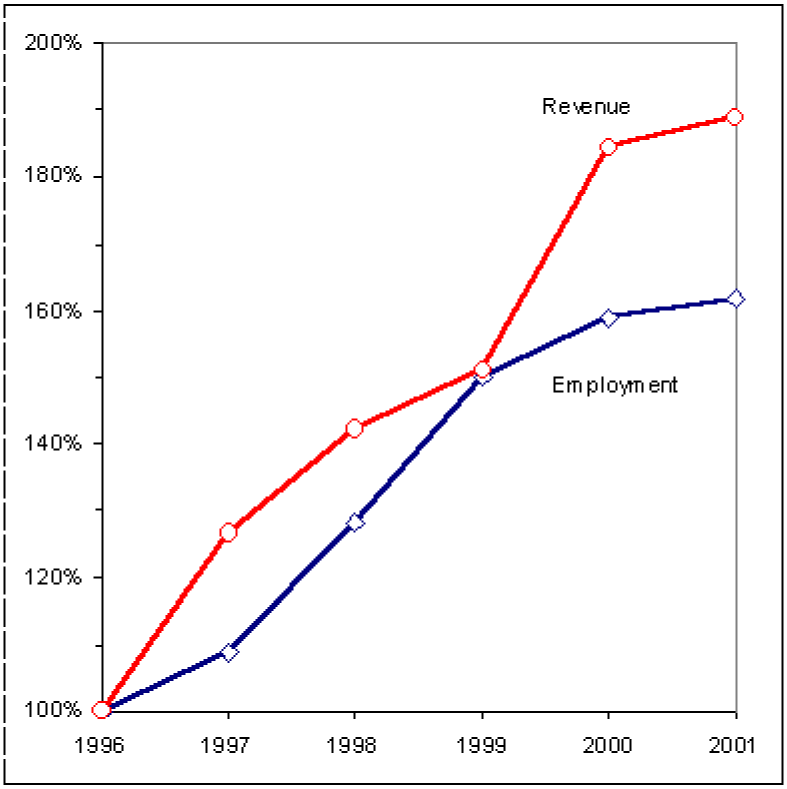

Figure 9. Example of FCC UWB emission limits imposed on indoor applications (purple) and on vehicular radar (blue). Below 960 MHz and above 29 000 MHz the two limits coincide.[17]

Space Debris

During the forty years of space exploration, the near-Earth environment has served not only for science and business, but also as a rubbish collector. Almost all objects that have been launched in outer space are still there and will remain for many years to come. Only few escaped towards other celestial bodies, felled on the Earth, or burned in the atmosphere. What forces satellite to fall down is the air drag, but the drag decreases with altitude, and at high altitudes is negligible. Table 3 lists orbital lifetimes for selected circular orbits. At the geostationary altitude, no effective natural removal mechanism exists, except for solar radiation pressure. Practically, objects located in the geostationary orbit will remain there indefinitely, unless moved to another orbit at the end of mission.

A few countries do radar, optical, and infrared surveillance of space for national security reasons. The smallest tractable objects are of about 10 cm in diameter at low altitudes and about 1m at the geostationary orbit. They are dead satellites (21%), upper stages (16%), fragments of upper stages and fragments of satellites (45%), and other abandoned objects (12%), according to Walter Flury of European

Space Operations Centre. They all move at hyper-velocities averaging 36 thousand km/h (10 km/s). The total number of these objects is counted in the millions of pieces, increasing with every new launch of space objects and with each new satellite explosion and fragmentation accidental or due to anti-satellite tests in outer space. Some of the objects launched come back to the Earth, especially after the invention of re-utilizable space vehicles, but the creation rate of debris has outpaced the removal rate. The debris population in low Earth orbit grows at an average rate of approximately five percent per year, according to NASA estimations. Table 3. Circular orbits lifetime

Orbit altitude (km)	Lifetime
200	1-4 days
600	25-30 years
1000	2000 years
2000	20 000 years
30 000 (GSO)	Indefinite

(According to W. Flury, The Space Debris Environment of the Earth, in D. McNally: The Vanishing Universe, Cambridge University Press 1994, p. 128, 130)

The threat of debris impact damage on satellites and spacecraft is a major growing concern. Medium size objects (0.1-10 cm in diameter) are the greatest challenge because they are not easily tracked and have kinetic energy high enough to cause catastrophic damage to spacecraft and satellites. For instance, a particle of 1 cm diameter and weight 10 gram moving 10 km/s has the equivalent energy of a 1.3 ton car running at the speed of 100 km/h, as the kinetic energy of an object is proportional to its mass and velocity squared. Penetration even a small particle through a critical component, such as the flight computer or propellant tank, can result in loss of the spacecraft.

If a 10 cm object, weighing 1 kg collides with a typical 1,200 kg spacecraft, over one million fragments 1 mm in size and larger can be created, according to the NASA. This collision results in formation of a debris cloud, which poses a magnified impact risk to any other spacecraft in the orbital vicinity. Mutual collisions can multiply that number further. Encounters with clouds of smaller particles can also be devastating, as evidenced by the damages made to the Hubble Space Telescope. The debris tends to concentrate in some regions in space and, ultimately, these regions may become dangerous for future missions. They also may efficiently block the astronomical observations of some regions in the sky. Maintaining the current design and operational practices could ultimately render some regions in space useless and even dangerous. Ultimately, international regulations are needed concerning debris management and debris control.

Passive Services

All satellites have been sources of major concern for passive services, and especially for radioastronomy. Satellites and satellite constellations such as the Iridium system produce signals that may be billions times stronger than those exploited by radio astronomy. They can block the normal operations of sensitive sensors, or even damage them. Passive services benefit from some provisions of outer space law and Radio Regulations, but the degree of protection is insufficient. For instance, the Radio Regulations stipulate protection from services in other bands to be afforded the radioastronomy service only to the extent that such services are afforded protection from each other (RR 4.6). This nullifies the principle of electromagnetic compatibility.

The way the unintended emissions due to unavoidable imperfections of equipment are treated often favours the offending system at the expense of the victim one. These emissions include out-of-band emissions and spurious emissions (including unintended antenna sidelobes and reception mechanisms). None of them carries useful information and the intended transmission would not loose any single bit if they were eliminated. The problem is that such elimination involves additional efforts and considerable costs.

Out-of-band emissions, a by-product of the modulation and encoding/decoding process, spill over frequency bands immediately adjacent to the band used by the intended transmission. Spurious emissions include harmonic emissions, parasitic emissions, intermodulation products, etc. (excluding out-of-band emissions) and their products fall into bands that may be far away from the assigned frequency band. Such products can be generated not only within the transmitting equipment, but also due to non-linearities in the neighbourhood of transmitting antenna and in the propagation medium (e.g. in the ionosphere). Comparing with the intended transmission, usually only a tiny part of the power escapes this way, but the escaped portion can be several billion times stronger than signals used in the victim bands, jamming or blocking the victim service.

Many passive services, like radioastronomy, do not make any monetary profit. They lose each time when involved in a conflict of interest with military or commercial activities as the following example illustrates. A military satellite launched in 1990 ended its mission in 1991, and its onboard transmitter was expected to cease its operation at the same date. However, the satellite has continued to radiate useless signals because the transmitter has not been equipped with the off switch and the power system has continued to work longer than planned. This polar-orbit satellite has visited every place on Earth at least twice every 24 hours at an altitude of about 700 km, and its radiation blocked the radio astronomical observations in the 322.0-322.5 MHz. As the satellite decay at such altitudes is about one km every two years, it would take more than one thousand years until it falls and burns in the atmosphere. It took six years, much effort, and international cooperation until the defective satellite was finally traced in 1998, and its silencing arranged. To keep it silent, the company responsible for the system must employ a work force and tracking station, and regularly provide the satellite with special commands. Should the satellite designers follow the Radio Regulations, they certainly would add a simple switch.[18] A number of other examples can be found in the recent CRAF handbook. [19]

Paper satellites

Paper Satellites is the name invented in the ITU for satellite systems that are submitted for notification in the ITU but will never operate in the orbit. This results in a significant waste of time and effort spent on the coordination, examination and notification process in the ITU and in administrations and satellite operators involved. It also blocks access to spectrum and orbital resources and produces their virtual scarcity. The ITU receives 400 to 500 requests for coordination and notification each year whereas only 10 to 20 satellites are actually launched yearly. About 1,200 satellites are awaiting coordination (as of September 2002), according to the Director of the ITU Radiocommunication Bureau. With such a long queue, processing delays can last up to 6 years or so. It is rather a long time if compared with the lifespan of integrated circuit technology that, according to Moore s Law, changes every 18 months (in that time the number of transistors on integrated circuits a rough measure of computer processing power approximately doubles). Satellite business sometimes cannot wait so long. Consequently, some satellites are coordinated outside the ITU process, or launched before the process is concluded, which may lead to chaos. The Radio Regulations allow for such a practice on the express condition that it shall not cause harmful interference to, and shall not claim protection from harmful interference caused by, a station operating in accordance with the provisions of [...] these Regulations.

The huge world demand for satellite services has seen steady increase, reflecting the growing economic value of the spectrum/orbit resources. It has resulted in increasing competition, spectrum/orbit congestion, and in a scramble for desirable orbital slots. This rush could increase further with new services planned such as the third generation mobile telephony or broadband access systems. There may be various reasons behind the overfilling . A satellite operator may submit multiple variants of the planned system for coordination as it increases chances of favourable findings, and it costs nothing or near to nothing. Finally, only one of them will actually be launched, whereas the remaining will become paper satellites . As a number of years may pass between the submission date and the launch date, many things may happen in the meantime, on which the operator may have no influence. The case of failed satellite systems, such as the Teledesic quoted earlier, are examples. When the investors withdrew, all these satellites became paper satellites . Finally, there may be also other reasons why the coordinated and notified satellite is actually not launched.

The problem of satellite notification backlog has been known within the ITU for years, and various remedies were sought. However, discussions focused on how to limit the number of submissions received, instead of improving the process. One proposal was to discourage overfilling by charging processing fees. In spite of the protests of satellite operators and some developing countries, the plenipotentiary conference in Minneapolis approved the fee principle in 1998. However, if the fee is small in comparison with the other costs to be borne before the satellite finds its place in the orbit it cannot have any practical impact. If, on the contrary, the fees will constitute a substantial part of the total costs, they will restrict the free access to spectrum/orbit resources, which is now guaranteed in the ITU Constitution, Convention, and Radio Regulations.

Ten years ago, just before the World Radiocommunication Conference Geneva 1993, I suggested[20] that automation could solve the problem, but automation is being introduced slowly. I also proposed fees for spectrum occupation/reservation, that would depend on the frequency band and would increase with the bandwidth and time reserved for specific use.[21] The fees, collected by the ITU, could be used to cover the cost of ITU conferences and staff, and to finance large international projects such as a global LEO wideband communication network, offering wireless Internet and emergency networks everywhere, including sparsely populated and under-developed regions. A similar idea was proposed formally at the WRC-97. Although there are technical means ready to be used for that purpose, these proposals did not receive sufficient support. What was missing was the political will of the ITU member countries.

Space Tourism

An idea of extending tourist activities into space has been nurtured in business circles since the 1950s.[22,23], However, its practical implementation waited until 2001, when first an American, Dennis Tito, and then Mark Shuttleworth, a South African, arranged for their tourist visits to the International Space Station on board a Russian vehicle. According to the press, the cost of such a journey was only US$20 million. Clearly, space travel is not one of the basic needs necessary to survive, and the potential market is limited to the richest people on the planet. However, some American and Japanese predictions suggest that space tourism could be a US$10 billion-per-year industry within two decades or so. Millions of dollars have already been invested in projects of suborbital tourist vehicles, orbital hotels and lunar pleasure cruise ships.

Electricity from Space

New cheap and environmentally friendly electricity sources are being sought in several countries [24]. The world's population is expected to reach 10 billion people by the year 2050, and the present energy sources will be insufficient to satisfy its needs, according to current projections. Among various ideas, the Space Solar Power (SSP) concept has been studied. In the USA, the studies started during the oil crisis in the seventies, aiming at limiting the dependence of national economy on foreign oil. In 1974, a patent was granted in the USA for a solar power satellite. A satellite platform would collect energy from the sun and transmit it down to Earth. The original patent indicated the microwave beam as the transmission medium. Later, the laser beam alternative was also taken into consideration. Both alternatives have been tested. For the conversion of sunlight to electricity, huge arrays of photovoltaic cells would be placed in a geostationary Earth orbit or on the Moon. Such arrays would be unaffected by cloud cover, atmospheric dust or by the Earth's twelve-hours day-night cycle. To reduce the surface of costly solar arrays, sunlight could be concentrated using giant mirrors or lenses. The current photovoltaic technology offers energy conversion with efficiency rate reaching 50 percent or so, according to the NASA studies.

With such efficiency, about half of the absorbed Sun radiation could be converted into electricity. A large part of the remaining half, which would manifest itself as heat, could also be converted into electricity using thermoelectric devices. These would serve as thermal pumps removing heat from the photovoltaic panels and lowering their temperature. The electricity would then be converted to microwaves and beamed by composite space antenna towards a huge Earth antenna. The latter would contain a large number of receiving antennas combined with rectifiers and filters (called a rectenna) that would convert the microwave power into electrical current injected into the power network. To limit the health danger, the receiving antenna would be located in the desert or in the mountains far away from populated areas. According to the proponents, the size of the microwave beam could be large enough to keep the power density within safe limits. High-power laser beams have also been under study as a potential candidate to transport energy from the space system. According to NASA, a space solar power system using today's technology could generate energy at a cost of 60 to 80 cents per kilowatt-hour, about ten times the current market price. They estimate that it would take 15 to 25 years of further research to nullify that difference. In 2001, Japan announced plans to launch a giant solar power station by 2040.

However, both, the high-power microwave beam and laser beam can create health and environmental problems, not solved yet. Moreover, both are potentially double-application technologies. An SSP station could easily be converted into a dangerous weapon and the current treaties prohibit weapons in outer space. Space weapons using solar energy are not a new idea. During World War II, some German scientists were speculating that the use of gigantic mirrors could concentrate solar energy to set fire to the enemy s forests, crop fields and cities. The size, complexity, environmental hazard, and cost of an SSP undertaking are daunting challenges.

Concluding Remarks

At the present time, satellites represent the only Internet access alternative in many rural areas and a cost advantage over wire line networks in sparsely populated areas. They allow business and residential customers to bypass the local loop with speeds higher than the standard phone-line transmission rate. Internet transmission represents the fastest growing segment of the FSS industry, and the Internet traffic over satellites doubles every six months.[25] The Internet traffic is expected to constitute a major revenue stream for the new generation of satellite systems. Stratospheric-altitude communication platforms (HAPS), now under development, could be another alternative to terrestrial systems .[26]

Satellite-related industries are now multi-billion-dollar business affecting the lives of people all over the planet. Many of the spectacular satellite applications we witness today were considered science fiction not so long ago. New inventions and new applications are emerging continuously. At the same time, the trend of liberalization and privatization is progressing. The current space treaties and radio treaties were negotiated when only the governmental entities were involved in all space activities. In today s new environment, they may need to be reviewed.

(*First published in Intercomms - International Communications Project, 2003 http://www.intercomms.net*)

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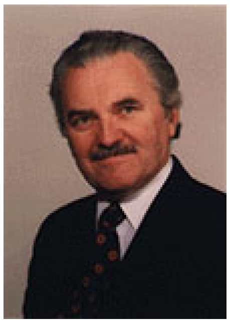
List of Abbreviations

CRAF	Committee on Radio Astronomy Frequencies
EMC	Electromagnetic Compatibility
ESA	European Space Agency
FCC	Federal Communication Commission
GPS	Global positioning System
IEEE	Institute of Electrical and Electronic Engineers
ISS	International Space Station
ITU	International Telecommunication Union
LAAS	Local Area Augmentation System

NASA	National Space Agency
UWB	Ultra Wide Band
VSAT	Very Small Aperture Terminal
WAAS	Wide Area Augmentation System

About the Author



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