Fixed Satellite Communications: Market Dynamics and Trends

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Contents

Abstract

The history of fixed satellite services (FSS) systems, in terms of technological and institutional development, has been previously provided in chapter “▶ History of Satellite Communications” of this handbook to a very large extent. Thus, this chapter addresses the market trends related to FSS systems and also discusses how a variety of new types of satellite services has evolved out of the initial FSS networks over time.

The market dynamics and trends of FSS systems are particularly addressed in terms of four main factors: (1) the competitive impact of high-efficiency fiber-

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optic terrestrial and submarine cable communications networks; (2) the conversion of FSS systems from analogue to digital services that allowed FSS systems to be more cost-efficient and use spectrum more efficiently as well as migrate to spectrum in higher bands more effectively; (3) the move of FSS systems toward deployment of smaller and lower cost ground systems (variously called VSATs, VSAAs, USATs, and microterminals) that allowed services to migrate closer to the "edge" of telecommunication user networks (i.e., satellite services directly to end user facilities); and (4) a shift in regulatory policy that allows FSS systems to compete directly for services that has generally served to reduce cost and spur innovations in services and applications.

These four trends have combined to contribute to what has been previously described in chapter "▶ History of Satellite Communications" as "technology inversion." This "technology inversion" has thus seen FSS systems in space become larger, more complex, longer-lived, and more powerful as ground systems have become more user-friendly, lower in cost, and are designed to interface directly with users at localized office facilities or even small office/home office (SoHo) VSATs or microterminals. These technological, regulatory, and market-based trends have shaped the FSS networks and related market dynamics. All four of these trends have dramatically reshaped the nature of FSS services for both commercial markets and defense-related satellite networks around the world.

The historical trend in FSS markets has been the initial development of global networks since global connectivity was the highest value market and the most underserved by terrestrial telecommunications networks available in the 1960s. Over time, satellite technology matured and the economical viability of regional and domestic satellite systems evolved in the years that followed. Today there are some 300 FSS satellites, essentially all in GEO orbit where these systems provide a complex combination of global, regional, and domestic satellite services. Although broadcast satellite services have outstripped FSS in terms of market value and sales, the FSS is still a very large and growing multibillion dollar industry.

Keywords

Analogue to digital conversion • Bit error rate • C-band • Digital satellite services • Domestic satellite systems • Fixed satellite services • Frequency bands of satellite service • International Telecommunication Union (ITU) • Internet protocol over satellite (IPoS) • Ka-band • Ku-band • Microterminal • Quality of service (QoS) • Regional satellite systems • Satellite markets • Spectrum allocations • Spectrum efficiency • Submarine cable systems • Ultrasmall aperture terminal (USAT) • Very small aperture antenna (VSAA) • Very small aperture terminal (VSAT)

Introduction

This chapter notes how this first type of communications satellite service was defined by the International Telecommunication Union as fixed satellite service (FSS). With the maturation of satellite technology over the years that followed, the development of lower cost and easier to use ground systems, together with regulatory shifts, allowed the further development of direct broadcast satellite services, mobile satellite services, and even store and forward data relay or machine-to-machine type services. FSS services, as the oldest and most mature of the satellite services, is the father and in some cases the grandfather of all the various satellite communication services that have followed since the start of commercial services in the 1960s. Both mobile satellite services, which evolved in the 1970s, and direct broadcast satellite services that date from the 1980s have benefited from the initial technology first developed for commercial FSS systems (Chartrand 2004).

The development of these additional services as well as defense-related satellite services is discussed in detail in chapters "▶ Satellite Communications Video Markets: Dynamics and Trends," "▶ Mobile Satellite Communications Markets: Dynamics and Trends," "▶ Store-and-Forward and Data Relay Satellite Communications Services," "▶ Broadband High-Throughput Satellites," "▶ Distributed Internet-Optimized Services via Satellite Constellations," and "▶ An Examination of the Governmental Use of Military and Commercial Satellite Communications."

The key market dynamics for FSS are discussed in this chapter in terms of six predominant trends that can be concisely stated as: (1) evolution of service capabilities and related competition from terrestrial communications systems; (2) digital satellite communications and the move to higher frequency bands; (3) decentralization of FSS services as small ground systems move to the "edge" of global networks; (4) regulatory shifts with regard to FSS systems to make them openly competitive around the world; (5) the shift of FSS systems from primarily serving global markets to more and more satellite networks serving regional and domestic markets; and (6) key new trends in satellite system design that are rapidly changing the traditional forms of communications satellite system services and economics. These key interrelated trends are discussed and analyzed in terms of their impact on the FSS markets.

The pattern for FSS markets was for networks designed for global services to evolve first because this was the highest value type service. Regional and domestic FSS systems followed thereafter. This was a logical consequence as satellite technology matured and market demand allowed these regional and domestic systems to become economic around the world, particularly as lower cost satellite antennas and terminals became available. The development of military and defense-related traffic has represented yet another dimension of the market for FSS networks around the world. These market trends and dynamics are addressed separately in chapter "▶ An Examination of the Governmental Use of Military and Commercial Satellite Communications."

Evolution of FSS Services and Competition from Terrestrial Communications Systems

The evolution of fixed satellite services (FSS) in the earliest days of satellite communications was largely the history of the Intelsat satellite system in the period from 1965 through the early 1970s. The first Intelsat satellite, known as "Early

Bird," was essentially a "cable in the sky" that could only connect point-to-point service. Then came the Intelsat II series which was able to provide multidestination service and connect several points at once. This satellite was designed and built with US government funding to support the US manned space program Gemini so that ships at sea could maintain communications with the crew in the space capsule. The Intelsat III series that was launched in the 1968/1969 time period were the first commercial satellites to provide a full range of satellite services similar to today's satellites in terms of providing multidestination services to many points with the capability to provide voice, data, color television, and high-quality radio channels.

It was this Intelsat III series that in July 1969 was able to provide global coverage of the Moon landing by Apollo 11. It was only a few weeks before the Moon landing that true global connectivity via satellite was established. As of 1970, satellite communications had become the predominant form of international communications as this technology provided broader band and lower cost connectivity than the coaxial submarine cables of the day. Further, multidestination satellites were able to connect any country in the world to a globally interconnected network by constructing and operating only a few Earth stations. As the first Director General of the Intelsat and former head of Entel Chile once said:

Communications satellites changed almost everything for our country. For the cost of one Boeing 707 airplane, we could build and operate a satellite earth station that could allow Chile to be fully connected to the rest of the world (Interview with Santiago Astrain 1974).

The cost of international telephone calls from remote areas of the world could exceed $50 a minute prior to the advent of satellite communications. However, since the arrival of global satellite systems and ever more efficient submarine cable systems, the cost of an international call has dropped to a level that is little different from the cost of a long distance call within a country. Prior to the advent of satellite communications, the global delivery of live television was simply not possible. Today over 18,000 video channels are available worldwide via satellite connections (Pelton 2006).

For over a century, there has been an ongoing rivalry between terrestrial submarine cables and wireless communications systems to provide better, lower cost, and more reliable communications for overseas communications. In the middle of the nineteenth century, telegraph submarine cable systems began to provide limited international communications service. These cables had limited capacity and were subject to disruptions and failures due to storms, trolling fish vessels, and other factors. The invention of shortwave radio provided a way to provide overseas voice and data services at lower cost and with greater throughput capability. However, shortwave radio was subject to disruptions as the result of space weather interference with the ionosphere. The invention of coaxial cable systems capable of carrying voice traffic in the 1940s and 1950s moved international voice and data traffic back toward terrestrial technology. The resulting submarine cable systems, even with 3 KHz telephone channel spacing and the so-called time assignment speech interpolation (TASI), still had very limited capacities of only 72 voice circuits in the mid- to late 1950s. The advent of satellites such as the Intelsat I with 240 voice circuits in

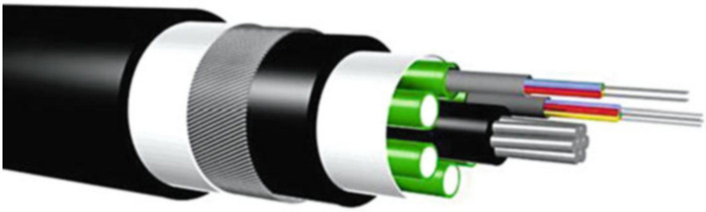

Fig. 1 Fiber-optic submarine cables have become predominant for the heaviest transoceanic routes

1965 and then Intelsat III with 1,200 voice circuits plus two color television channels sharply shifted international telecommunications traffic to satellite connections. Satellite circuits were lower in cost and allowed much more voice and data traffic to be provided between the continents and enabled international television transmissions to be provided, both technically and economically (Pelton and Alper 1986).

Beginning in the 1980s with the advent of new fiber-optic submarine cable technology, the international telecommunications market shifted focus once again. Fiber-optic submarine cables became more and more cost-effective, broadband, and higher quality and thus quickly began to reclaim international telecommunications services, at least on the heaviest transoceanic links (see Fig. 1 above). This shift from satellite telephone and data back to submarine cables, particularly for trans-Atlantic and trans-Pacific Ocean traffic through the 1990s and up to the present time, was hastened by several factors:

- *Quality of service*: Transmission via fiber-optic submarine cables, as measured in bit error rate, could be very low and typically could be in the range of only 10^{-10} or even 10^{-12}. This was an unprecedented level of transmission quality. Further transmission times were typically less than 100 ms as opposed to the 250 ms of transmission delay associated with geosynchronous satellite transmission. This shorter latency or transmission time made fiber the preferred choice for telephone service.
- *Cost of service*: The very heaviest routes, such as between the United States and Europe, could be considerably lower than the costs associated with international satellite connections. Satellites remained cost competitive for more remote locations with thinner routes of traffic or to locations not served directly via fiber-optic networks. Satellites also remained cost competitive for television distribution services.
- *Structure of service provision and ownership*: Submarine cable services were provided as if they were actually owned and capitalized by telecommunications service providers under what were called “indefeasible rights of use” (IRUs) that made provision of service more cost-effective and profitable under current regulatory policies then in effect.

The cost efficiencies of both fiber-optic submarine cables and satellites have continued to plummet as both of these technologies have matured. The improvement of the technology, the extension of the lifetimes of these systems and more have now been so dramatic that the “capital cost” of a single voice circuit might be as low as $5 per voice circuit on a submarine cable and under $50 a voice circuit on an advanced communications satellite.

The economics are such that other costs associated with international telecommunications, such as marketing and sales, advertising, billing, and operations, now tend to be predominant over the creation of the international link itself. Thus, issues such as quality of service, lack of transmission delay, redundancy of service links, network design and complexity, and the ability to establish links to particular locations with great speed often tend to dominate the decision as to whether or not a link is established via satellite or submarine cable. In general, it can be said that most heavy route traffic between countries or even within countries today are carried by fiber-optic networks. Satellite communications networks thus tend to carry medium to thin route voice or data traffic to supplement fiber-optic networks and a variety of different types of television services where distribution to widely distributed audiences of business networks may be involved.[1]

The need to create integrated global telecommunications networks to serve the “enterprise networks” of multinational enterprises, national governments, international organizations, and military systems has seen a growing trend toward forming combined and seamless networks. These combine fiber and coaxial fiber networks, broadband terrestrial wireless networks, and satellite systems under unified ownership. This is, in part, the result of the growth of Internet, intranets, virtual private networks, and digital networks that provide broadband to support voice, data, video, and audio services on demand. The digital satellite revolution and the provision of voice and other services over IP are discussed immediately below.

Digital Satellite Communications and the Move to Higher Frequency Bands

The provision of satellite services for the initial two decades was essentially via analogue-based services. Analogue services and multiplexing systems using frequency division multiple access (FDMA) were inefficient in several ways. The amount of information that was sent via satellite was inefficient in terms of information transmitted per Hertz (or information sent per cycle per second). Also, there were just a limited number of carriers of set size for everything from small routes to very large routes. The information throughput density was progressively lower for smaller and smaller carriers for thin routes of traffic because of the need to separate the carriers with guard bands and because the carriers were only efficient when completely filled with actual active voice traffic. Once a carrier was filled with traffic, however, there was a need to jump to a larger fixed carrier size to accommodate growth. In all of these ways, the analogue satellite service was inefficient. In the

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[1] Op cit, Chartrand, pp. 9–20.

1980s and 1990s, there was a digital revolution in satellite communications and most space traffic was converted from analogue transmission using FDMA multiplexing to either time division multiple access (TDMA), code division multiple access (CDMA), or a special system developed for very thin routes of traffic known as the SPADE system that allowed single channels to be used on the satellite on a demand-assigned basis.

Some ways by which digital satellite communications can be considered superior to analogue satellite service include the following:

- Greater ability to operate at higher transmission speeds
- Improved quality of service – especially in a high noise environment
- Greater compatibility with terrestrial digital switches – that now predominate
- Greater compatibility with digital fiber-optic systems
- Easier to allow accommodation of encryption/decryption systems
- Easier accommodation of digital signal compression techniques
- Easier accommodation to onboard digital switching and onboard signal processing to overcome rain attenuation and other forms of interference
- Greater compatibility with all other forms of digital transmission services – coaxial cable, fiber, mobile cellular (4G, LTE, 5G), etc., (Lewis 1988)

In terms of market efficiency, the conversion to digital satellite services allows very high new efficiencies to be achieved. A 72 MHz transponder using analogue technology for high-quality television was typically able to derive two color television channels of reasonably high signal to noise (S/N) quality while operating to very highly sensitive Earth stations of 18 m or larger. In contrast, using digital TDMA or other digital multiplexing technology and MPEG compression, on the order of 14-18 digital television channels could be derived from a 72 MHz transponder while also using smaller antennas to uplink the video signals. The improved throughput for voice channels and data transmission was not as dramatic as was the case for digital television, but there were nevertheless considerable gains.

The gains in efficiencies were approximately four to six times depending on a variety of factors such as the volume of traffic, the size of Earth station antennas, etc. These gains created market disruptions during the transition because the dramatic gains in efficiencies offered by digital services could not easily be reflected in pricing policies without creating a shortfall in revenues.

Also, because the ownership of the satellites and the space segment was divided from the ownership of the Earth stations within the structure of the Intelsat organization, there was a division of interests involved in terms of seeking the benefits from digital satellite services. The owners of the ground stations, especially those with low volumes of traffic, questioned why they should invest in the new digital equipment after having invested in analogue equipment only a short time before. Their position was that the benefits, which would flow from digital efficiencies, went primarily to the largest users and owners of the space segment and not to the smallest users – particularly if they continued to use analogue equipment. Many of the smallest users of the space systems, especially the developing countries, thus had the least incentive to convert to the more efficient digital equipment.

The resulting decision that ensued from this dilemma of what might be called conflicting interests of conversion to the more efficient digital technology was a compromise within the Intelsat Board of Governors. This compromise decision was to phase in the "efficiency pricing" for digital services over a series of years. In short, the plan was to phase in the new pricing for digital services and not to seek to reflect immediately all of the gains achieved by rapid, high-efficiency digital throughput all at once, but to gradually reflect the digital efficiency as TDMA systems were introduced. This was known within the Intelsat organization (the organization that dominated international satellite communications up through the 1980s and was the first to introduce commercial digital services) as the decision in the "spirit of Chang Mai." This was so-named because the Intelsat Board meeting that reached this compromise decision was held in Chang Mai, Thailand, where the local markets were known for their intensive bargaining over price.

In the years that followed, digital conversion continued apace in international, regional, and domestic satellite systems. In many of these systems, networks began with digital systems and thus there was not a question of analogue to digital conversion or the need for a transitional pricing scheme as the switchover occurred.

The competitive processes that were set in motion with the divestiture of AT&T in the United States in 1984 and the liberalization of telecommunications competition within Europe and Japan in the following years helped to speed the conversion to the more efficient digital technology in the form of TDMA and SPADE and subsequently CDMA and spread spectrum services. (This relationship between and among the technology, the market dynamics, and the regulatory process are discussed later in this chapter.)

Ironically, the greater efficiencies of digital satellite services and the reduced cost of service led to a rapid surge in demand. International satellite communications and international submarine transmission capabilities in the 1960s and 1970s were miniscule in comparison to national telecommunications networks. The dramatic decrease in cost for telecommunications and IT systems that occurred in the 1980s, further driven by competition and the spread of multinational enterprises, led to a dramatic increase in demand for international communications. Thus the digital satellite revolution that was thought would create excess satellite system capacity had almost the reverse effect. The net result was that the communications satellite spectrum that had been the mainstay of the satellite industry in the 1960s, 1970s, and 1980s was almost saturated even with the efficiencies that digital communication satellite services engendered. In key locations for geosynchronous satellites, providing for relay over the Atlantic, Pacific, and Indian Oceans, the C-band spectrum was fully consumed.

The new growth of regional and domestic satellite networks further compounded the problem of limited available spectrum for geosynchronous FSS services. The result was to push forward to exploit higher frequencies and also to seek more efficient designs for FSS satellites to allow more reuse of available frequencies. Both solutions were needed to keep up with rapidly growing market demand.

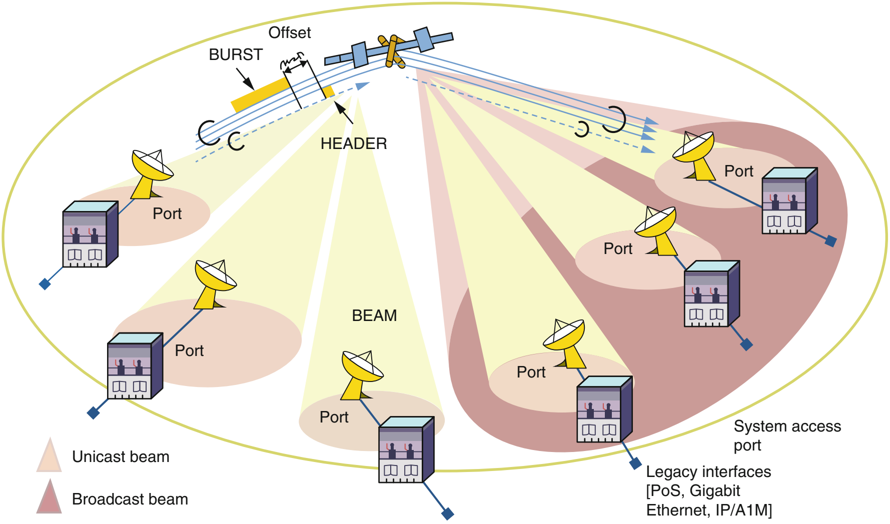

Fig. 2 Multibeam ARTES satellite showing digital spot beams and onboard beam interconnection between beams (Illustration courtesy of ESA)

Technical innovation led to the creation of more efficient designs with FSS satellites deploying many more spot beams that allowed frequency reuse. Spot beams that were sufficiently isolated from one another allowed the same frequencies to be used over again, just as was being done with terrestrial cellular systems. Digital switches on board the satellites allowed these various spot beams to be interconnected. A signal could thus go up to the satellite in a spot beam at one location and then be switched to another spot beam for the downlink connection.

If these spot beams illuminated different parts of the Earth's surface, then the same spectrum could be used without interference. This type of multibeam satellite that uses high-speed onboard spot beam digital switching thus can provide interconnection as illustrated in Fig. 2. This illustration shows the ARTES satellite, which has been developed by the European Space Agency to provide flexible interconnection of many different VSAT ports. This design allows the efficiency of multiple reuse of the same spectrum, and the high-efficiency spot beams can support more rapid throughput within the high-powered beams. These higher-powered spot beams allow smaller aperture antennas to operate to the satellite and also allow for more margin against rain attenuation.

The migration of more and more traffic from the "C"-band spectrum (i.e., 6 GHz uplink and 4 GHz downlink) to the "Ku"-band spectrum (i.e., 14 GHz uplink and 12 GHz downlink) thus accommodated new growth associated with more and more regional and domestic systems and more demand for international services. The Ku-band was in many ways well suited to spot beam operation since the higher frequencies and thus smaller wavelengths were suited to creating higher and higher gain spot beam antennas that could be smaller yet have higher gain just because of the physics of radio waves. A Ku-band antenna could be four times smaller in aperture size but has the same gain as a C-band antenna.

The transition to higher frequencies was not without its difficulties. The new and more demanding higher frequency transmission equipment (on the ground and in space) was more difficult to engineer and build and was thus more expensive. Further, rain attenuation problems that were minimal at C-band increased as one moved up the microwave band to the higher frequencies. The closer the wavelength of radio waves approaches the size of raindrops, the greater the problem of heavy rain acting as a sort of lens to distort the pathway of radio wave transmissions to and from the satellite. Thus, more power margin had to be added to overcome these rain attenuation problems at the higher frequencies.

Most recently, the demand for additional satellite capacity has driven satellite services toward even more powerful and narrow spot beams interconnected by digital switching technology to allow even more frequency reuse. Market demand has also supported the move upward to the still higher “Ka-band” frequencies (i.e., 30 GHz uplink and 20 GHz downlink). The rain attenuation issues associated with “Ku-band” are even more present with “Ka-band” frequencies and the much higher frequency equipment is even more difficult to design and build. Thus, the cost of the Ka-band equipment is still higher than the Ku-band equipment. There is also a need for greater power margins to protect against heavy rainfall (i.e., rain attenuation).

One might ask why not accommodate traffic growth and new market demand by simply allocating new frequencies in lower bands? The problem is that the demand for terrestrial mobile wireless communications has outstripped all other demands for over a decade. There is no realistic hope of new satellite communications allocations for FSS requirements in lower frequency bands. The likelihood of new allocations for FSS services in the microwave band for instance is almost none. This is particularly true since broadcast satellite services (BSS) and mobile satellite services (MSS) are also seeking new allocations as well. The BSS systems, because they provide direct-to-home services to millions of customers, and MSS systems, because also serve millions of customers directly at locations on land, the sea, and the air, are likely to receive priority for obtaining new frequency allocations over FSS systems because of considerations related to rain attenuation and consumer costs.

The bottom line, as noted in more detail above, is that digital services are more efficient than analogue systems in being able to overcome noise and interference. They are certainly better suited to rapid switching of digital traffic between numerous spot beams on the satellite. This factor alone has been critical to the growth of both FSS and MSS satellite systems. Digital satellite systems have also been critical to the effective use of small VSAT and microterminals on the ground. The efficiency of digital satellite services and the resulting reduction in the cost of services stimulated the rapid growth of global, regional, and domestic demand and has also seen a shift of space-networked FSS offerings to ever higher frequencies. Thus FSS offerings are now in the C-band, Ku-band, and Ka-band and there could conceivably be use in future years in even higher bands such as the so-called Q, V, and W bands in the millimeter wave frequencies.

Decentralization of FSS Services as Small Ground Systems Move to the "Edge" of Global Networks

The early days of satellites were controlled by the large telecommunications monopolies that saw fixed satellite services as a means to interconnect national communications with overseas countries because of the limited capacities of the submarine cables of the day. In this early satellite market, large national Earth stations connected to satellites of still limited capacity and therefore it was the national telecommunications terrestrial networks that controlled all international traffic. The subsequent emergence of national satellite systems and national television satellite distribution changed not only the market structure, but also spurred the rise of new satellite systems to compete with national terrestrial networks.

Once this trend started, it created increasing pressure to design smaller and more cost-efficient satellite Earth stations that could bring traffic connectivity closer and closer to the headquarters of large businesses, to satellite broadcasters, and to cable television networks. It likewise created the demand to design and build very low-cost, small, receive-only satellite ground stations for consumers to get television and radio programming. This trend started with the early national satellite systems in Canada, the Soviet Union, the United States, and Indonesia and then spread to dozens of countries around the world. In turn, this spawned what might be called the VSAT (or the very small aperture terminal) revolution. Instead of hundreds of Earth stations to connect the countries of the world, there were, over time, hundreds of thousands of transmit and receive small satellite antennas located at businesses and eventually many millions of television receive-only (TVRO) terminals.

This trend started during the analogue era of satellite communications but mushroomed with the dawn of the era of digital satellite communications. Digital transmission, with its more efficient use of limited satellite bandwidth and allocated frequencies, made the system efficiencies of satellite communications that connected much smaller antennas ever more attractive. Instead of 30 or even 10 m Earth stations, there were now two-way transmit and receive VSATs that were 3 m or smaller in diameter. As satellites became larger and more powerful, the system economics and evolving technology encouraged the building of even smaller microterminals which were also cost-efficient. Thus, there was a series of technological advances such as 3-axis stabilized satellites with higher gain antennas; more powerful satellites; the deployment of satellites in new higher frequency bands such as Ku-band and Ka-band; the conversion to digital satellite services; and onboard intelligence, switching, and processing. These advances not only allowed higher capacity satellites but also satellites capable of working to even smaller and more cost-effective ground antenna systems. The NASA program in the United States to develop the Advanced Communications Technology Satellite (ACTS) that demonstrated the use of Ka-band frequencies and onboard processing helped to move this process along during the late 1980s (Fig. 3).

The most remarkable aspect of the new technology made possible by experimental satellites such as the ACTS satellite in the United States, the ETS VI satellite in

Fig. 3 The advanced communications technology satellite developed by NASA in the 1980s to promote new digital capabilities and Ka-band utilization (Graphics courtesy of NASA)

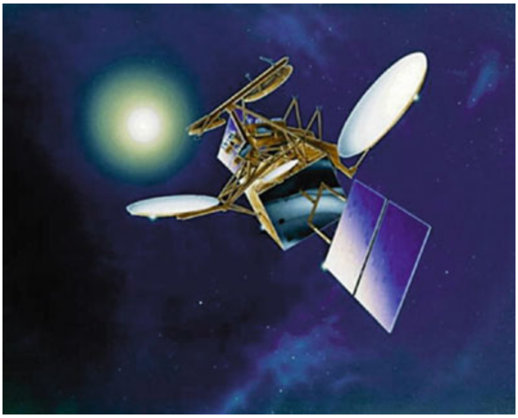

Fig. 4 The ACTS smallest user terminal was only 60 cm in diameter (Graphics courtesy of NASA)

Japan, and the ARTES satellite in Europe was actually realized on the ground. These new satellites demonstrated very broadband capabilities that could be accomplished to small and compact ground antenna systems. The ACTS ultrasmall aperture terminal (USAT) pictured below had only a 60-cm (about 2 ft) aperture yet could receive data rates of 45 Mbits/s with a lower upstream return rate of 1.5 Mbits/s (Fig. 4).

This research program hastened the conversion of the FSS industry to digital video broadcasting services. The digital broadband distribution function could send high-speed data to support television, voice, or data services, which could be used to download new computer software, validate a credit card, or update a global corporation's inventory at thousands of outlet stores. In the age of the Internet, this has perhaps been the most significant stage in the evolutionary process for today's FSS digital networking services. The latest stage in this evolution has been the increasing shift by businesses and private users to employ Voice over IP (VoIP) services regardless of whether the data stream might be going over satellite, fiber, coax, or microwave relay.

The international standards to allow this digital broadcast service to be interactive with downstream rates have now fully evolved. This digital broadcast service is often in the 36–72 Mbits/s range downstream, with thinner stream response uplink rates that originate from 1 m microterminals. This shift to digital broadcast services have thus served to move FSS services closer and closer to end users. Large multinational enterprises with enterprise networks can thus use such digital broadcast satellite networks to connect efficiently with thousands of node points. For example, large oil companies can use these networks to link with all their service stations and automobile companies can link to all their dealerships. Global department stores, insurance companies, banks, and airlines can also connect with great flexibility to thousands of locations worldwide.

The two most predominant standards that allowed the development of this type of asymmetrical global satellite digital networking (i.e., a heavy stream of data out from corporate headquarters and thin route return data service) are known as: (1) Digital Video Broadcasting with Return Channel Service (DVB-RCS) and (2) Digital Over Cable System Interface Standard (DOSCIS). In the case of DOSCIS, this service was first developed for cable television networks on terrestrial systems, but then adapted to use on satellite networks as well.

This new type of digital broadband satellite service has truly allowed satellites to support global networks with thousands or even tens of thousands of nodes very cost-effectively.

The shift to large-scale digital networks via satellite has, however, presented a great challenge to the fixed satellite service (FSS) industry. The problem is that most large-scale digital networks today operate using the Internet Protocol. However, the original IP interface connections were established on the basis of terrestrial networks where the issue of satellite transmission delay and the IP Security (IP Sec) procedures did not take into account the particular characteristics of satellite transmission. These two issues initially made it very difficult to use satellite-based digital networks using TCP/IP (Transmission Control Protocol/Internet Protocol) efficiently. Satellite transmission delay was mistakenly interpreted as network congestion and led to slow recovery procedures. In time, the clock for detecting congestion was reset to take into account satellite transmission times and the so-called spoofing methods compensated for geosynchronous satellite-related transmission times. Also the problem of IP Sec procedures, that stripped off key routing header information needed for effective satellite transmission, has also been largely rectified by the

Internet Expert Task Force (IETF) Request For Comment (RFC) processes. The result is the now widely adopted Internet Protocol over Satellite (IPoS) transmission standard. Thus, today large-scale digital satellite networks using IP-based interface standards can operate with much higher efficiency and are typically within 80 % of the efficiencies achievable on terrestrial networks (Kadowaki 2005).

Regulatory Shifts Concerning FSS Systems to Make Them Openly Competitive

The regulatory environment in which telecommunications and IT services are provided on a global basis has shifted dramatically since the 1980s. It was in this decade – especially in 1983–84 with the divestiture of AT&T and its loss of near monopoly status in the U.S. that the satellite market began to shift rapidly. This was when "liberalization" or competitive services began to replace the so-called rate-based regulation of monopoly carriers. This occurred first in the United States, then Europe and Japan, and then around the world.

The inital step in this process actually began in the United States in the 1970s when the MCI Corporation challenged the monopoly status of AT&T in courts by claiming anticompetitive actions. It was also in the early 1970s during the Nixon administration that the US Justice Department opened an investigative process against both AT&T and IBM, charging that there was evidence of anticompetitive practices by both firms. In time, the proceeding against IBM was dropped but the action against AT&T continued. In fact, there were two different but related proceedings. There was the MCI suit against AT&T seeking damages for anticompetitive practices that was ultimately successful. And then there were the antitrust charges brought by the Justice Department which continued through the Ford and Carter administrations until the very waning days of the Carter administration.

At that time, Federal Judge Harold Greene adjourned the proceedings on January 16, 1981 to let the Justice Department and AT&T to see if they could reach a final negotiated settlement. After months of negotiations that went many months into the Reagan Administration, a negotiated final settlement was reached between the Justice Department and AT&T and approved by Judge Harold Greene.

Under the terms of this negotiated final agreement, planning was undertaken to begin the restructuring of AT&T with the divestiture of AT&T actually occurring as of January 1, 1984. Under this negotiated final agreement, the divested AT&T would continue its long distance and international services but it would give up ownership of its various local Bell Operating Companies, which were reconstituted as a series of new regional corporations. AT&T, as of 1984, faced competition for its telecommunications services for long distance and overseas services and it also faced competition in the design and installation of telecommunications facilities. In order for AT&T and its Bell regional operating companies to reliably interconnect, the FCC established rules called "open network architecture" (ONA). This allowed these various systems in the United States to interconnect to common digital standards (MacAvoy and Robinson 1983/1984).

The negotiated agreement changed the entire regulatory structure for telecommunications in the United States. In the past situation, the Federal Communications Commission regulated AT&T by explicitly approving new facilities for telecommunications services that went into an “official rate base.” This rate base of approved facilities allowed AT&T to make a certain amount of profit or rate of return on this “officially approved” investment. Critics of this arrangement included those who were heavy users of telecommunications such as banks, insurance companies, airlines, etc. They argued that this “rate base” system for regulating monopolies created the wrong incentives and that it led to wasteful investment in unnecessary telecommunications facilities (switches, microwave relays, coaxial cables, satellites, Earth stations, etc.) and thus stymied innovation and cost efficiency. Under the new FCC regulatory regime, US telecommunications providers were given incentives to make higher profits if they could lower investment costs and lower their prices to business and consumers.

In Europe, the newly formed European Union was beginning to wrestle with a different but somewhat parallel problem. Its objective was to create an integrated telecommunications system that could allow all of the networks within Europe to be compatible with one another and connect seamlessly as if it were one system. The concept for digital communications under development at that time, called Integrated Services Digital Network (ISDN), allowed largely compatible digital networking and served to provide part of the solution. The major breakthrough was to adopt what they called “Open Network Provisioning” (ONP). The bottom line in Europe was that ONP not only allowed national networks to interconnect seamlessly, but it set the stage for national telecommunications to start competitive telecommunications networks in neighboring countries.

In Japan, there was also interest in the competitive approach to regulation of telecommunications and they sent observers to the United States to monitor the divestiture of AT&T. The result was that the Japanese Diet (the legislative branch for Japan) passed two new telecommunications laws – one dealing with domestic telecommunications and other dealing with international telecommunications. These laws authorized competition for telecommunications services in Japan but restricted ownership of competitive networks to Japanese-owned entities.

Thus from 1984 through 1992 there was a major shift in many of the so-called developed economies to “liberalize” telecommunications regulation and create a regulatory process under various types of open network standards to allow the efficient interconnection of competitive networks.

The situation for satellite communications was complicated in that the Intelsat Agreements that acted very much like a treaty among all member countries and territories (almost 200 in number) specified that there should be a single global satellite network with a mission to provide services at low cost to developing nations. These Intelsat Agreements had been set up under US initiatives starting from the Kennedy Presidential administration. The United States was caught in a difficult situation. The single Intelsat Global Satellite System had been the brainchild of the United States and the Communications Satellite Corporation (Comsat) that had been created by the 1962 Communications Satellite Act by the US Congress.

The United States was the predominant member and owner of the Intelsat system and from 1965 to 1975 Comsat had been the system manager.[2]

In 1983, several filings were made to the FCC to build and deploy new satellite systems that would provide international links in competition with Intelsat. This left US policy makers caught up in a dilemma. Article XIV of the Intelsat Agreement specified that any member country of Intelsat that wished to deploy and operate a separate satellite system must technically coordinate it with Intelsat and if it wished to carry international traffic then it must "economically coordinate" with Intelsat under Article XIV(d) of the Agreements to show that such removal of international traffic did not create "economic harm" to Intelsat.

This economic coordination was successfully carried out by the "Eutelsat" organization for regional traffic essentially within Europe and involved traffic that Intelsat was for the most part not carrying. The Reagan administration favored competition and believed that competitive satellite systems would serve to reduce prices to businesses and consumers. It nevertheless proceeded slowly. It authorized several competitive systems to proceed, but on the basis that the competition would only be to serve large corporations on dedicated "enterprise networks" and not to be competitive for publicly switched telephone traffic. In time, the emergence of regional satellite networks such as Eutelsat, Arabsat, and proposals for an Africasat that proved to be economically viable, as well as a growing number of domestic satellites, created a groundswell of opinion within governments around the world to abandon the concept of monopoly satellite systems owned by governments. There were meetings of the Intelsat Assembly of Parties that allowed the Agreements that had been negotiated originally in 1963–1965 and adopted in definitive form in 1983–1986 to be abandoned with the result that Intelsat was "privatized" and part of the monopoly system spun off as the New Skies organization of The Hague, The Netherlands.

This shift to "privatize" Intelsat and take away its intergovernmental status affected not only Intelsat. The Inmarsat organization for mobile satellite communications and Eutelsat for European and other international services proceeded toward privatization as well. In fact, Inmarsat, of London, United Kingdom was the first to complete the privatization process. Today everything concerning Inmarsat has been "privatized" except for a small unit to assist with public safety for ships and aircraft and a unit to provide assistance for developing countries to obtain satellite services (GAO Telecommunications 2004).

There are several ironic results with regard to the global privatization process for satellite services and the opening of international satellite services to competition. The prime competitor to Intelsat in the 1980s was the so-called Panamsat organization. In the aftermath of privatization, Intelsat has now totally acquired Panamsat through merger arrangements. Thus, the competitor that played a prime role in forcing the privatization of Intelsat has essentially disappeared while Intelsat is as large as ever with ownership and investment in some 80 satellites and is earning the

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[2] Op cit, Pelton and Alper.

largest amount of revenues ever in its history. The entity named New Skies that was spun off to compete with Intelsat has been acquired by the SES Global organization of Luxembourg and thus has also essentially disappeared as well. Privatization, followed by a number of acquisitions and mergers in the past decade, has seen the reemergence of just a handful of dominant carriers.

The good news for consumers is that this global competitive process has largely seemed to accomplish the goal of lowering the cost of television, data, and voice services via satellite. The price of international connections via both fiber-optic cable and communications satellites are at an all time low. The very largest carriers, namely Intelsat, SES Global, and Eutelsat, have also tended to form alliances with regional carriers in many instances (Pelton 2005). The Appendices to this Handbook indicate the various international and regional systems and the many alliances and partnerships that now exist around the world in the field of satellite communications.

Evolution of FSS Markets from Global Networks to Regional and Domestic Satellite Systems

As described earlier, the first major FSS system was the Intelsat global network that was established to provide international connectivity in 1964 with the first satellite going up in 1965. Intelsat first provided connectivity across the Atlantic Ocean and then followed with connections across the Pacific Ocean. Global connectivity across all three major oceans was not established by Intelsat until 1969, just before the Moon landing.

The success of these early international satellite services stimulated all other uses. The enthusiasm to employ satellites for regional and domestic national services thus also grew apace. By the early 1970s, Intelsat began to lease capacity to countries for domestic services. Even in the late 1960s, dedicated national satellite systems began to be deployed. The Soviet Union and Canada led the way and then the United States adopted an “open skies” policy. This new policy adopted during the Nixon Presidency urged the development of national satellite systems. Shortly thereafter, multiple national satellite networks began to emerge in the United States for fixed satellite and especially for satellite television distribution services. In time, other nations and regions allowed multiple satellite systems to be financed and deployed as well even though the US market remains the most dynamic in this respect.

The United States shifted quickly toward more competitive telecommunications markets and the so-called liberalization process also ensued in Europe, Japan, and elsewhere around the world, particularly within the OECD. This process has continued under a competitive process backed by the World Trade Organization (as discussed in the previous section) and these factors all served to spawn more and more satellite systems at the international, regional, and national levels. This openly competitive process, however, has also led to consolidation. Mergers, competitive failures, and/or outright acquisitions of other satellite systems have also served to narrow the range of competition. Today, there appears to be a narrowing range of global networks as Intelsat has acquired its chief competitor Panamsat and

SES Global has acquired New Skies and bought an interest in many other regional systems. Today Intelsat, SES Global, and Eutelsat are the most prominent globally ranging systems, although there are also many vibrant regional systems and of course an even larger number of domestic systems.

In the appendices to this Handbook, there is an extensive listing of the various national, regional, and international communications satellite systems that exist around the world today. The shift in FSS markets in the past nearly 50 years have been dramatic in terms of the range and volume of services. The Early Bird or Intelsat I satellite that started commercial satellite services had but 240 voice circuits of capacity using analogue technology and had both very low power and low gain antenna. Today's satellites using digital technology and deploying as many as 100 transponders (such as on the Intelsat 8 satellite) can have the capacity of millions of voice circuits or over a thousand video channels. The remarkable thing is that not only do the satellites now have tremendously larger throughput capacities, but the ground antennas are no longer huge, multiton structures but can be only 1 m or less dishes. Despite their small size, these dishes – thanks to digital video broadcast standards – can still support fast, broadband data rates. As of 2012, upward of 18,000 video channels are available via FSS networks for television distribution around the world on a 24 h a day and 7 days a week basis. These FSS networks can be used in very flexible ways to support corporate enterprise networks, data networking, and multicasting, as well as a flow of traffic that can dynamically shift from voice, data, audio, video, or videoconferencing depending on consumer demand.

New Trends in Satellite System Design

Finally there are several important new trends that are creating major shifts in the economics and the overall market dynamics of global satellite communications. The first of these trends that has made a large impact on service costs is the deployment of so-called High Throughput Satellites (HTS). New satellites such as ViaSat 1 & 2, Intelsat Epic, and Hughes' Jupiter are providing major increases in satellite throughput capabilities.

These new types of high throughput satellites represent at least as much as a tenfold increase in data throughput over conventional FSS satellites. This has led to an impulse jump in available satellite capacity that is only increasing. This will impact satellite pricing and destabilize markets in the 2016–2020 time period. The ViaSat 1 and 2 high throughput satellites with a throughput capability of 140 gigabit/second are clearly already changing the pricing structure for video and broadband satellite services in the North American markets. The launch of the Intelsat Epic and the Hughes Jupiter also serves to accelerate the downward movement of transponder pricing. (See Fig. 5).

Another new trend is the deployment of satellites in medium and low earth orbit that are optimized to provide Internet-based services – particularly for underserved areas such as countries with developing economies in the equatorial regions of the world. To date, the 03b (i.e., "Other three billion") satellite system that is deployed in

Fig. 5 The ViaSat-2 that will soon accompany the ViaSat-1in orbit

medium earth orbit is already in service. Planned services such as One Web, Leo Sat and Commstellation would deploy perhaps hundreds of satellite in new types of global LEO constellations for Internet-optimized broadband services. This could well represent “game changing” and “disruptive” technology” in the global satellite business. If Space X, in even more extreme fashion, were to deploy LEO constellations with perhaps thousands of small satellites in such a network this could lead to new economies but also heightened concerns about orbital debris.

Further, it is possible that new capabilities to refuel and provide on-orbit servicing, particularly to high throughput satellites, could further change the economics of the industry. The capabililty to do on-orbit servicing could ultimately help provide relief to orbital debris build-up as well. All of these new trends are addressed in subsequent chapters.

Conclusion

The FSS satellite systems that started the satellite communications in the mid-1960s nearly 50 years ago were the “grand-daddies” of the satellite industry. As the technology matured and the range of services that satellite could deliver expanded, new types of satellite services were developed and systems were adapted to this growing market in a diversity of ways. Today, FSS has spun off direct broadcast satellite systems (known in ITU as BSS networks), mobile satellite systems (known as MSS networks), store and forward data relay (or machine-to-machine networks), and specialized defense and strategically oriented satellite networks. These latter two types of satellite networks actually use different spectrum bands. Even within the mainstream FSS services there are global, regional, and domestic networks and even within these there are networks that specialize in data networking, video distribution, or emphasize highly connective "mesh networks" versus those that use a star (or hub and spoke) architecture. This market specialization tends to affect the technical design of the satellites, the user antennas and terminals, and the interface standards. These specializations can at times complicate the ease and quality of interconnectivity with terrestrial or even other satellite networks. The evolution of IP-based standards, however, continues to serve as the key "glue" that allows all forms of global communications and IT systems to connect together as seamlessly as possible.

The long-term progress made in satellite communications seems likely to continue, but there remain key challenges for the future. The challenges that are discussed throughout the chapters of the Handbook and that consider satellite communications and related spacecraft and launcher needs include:

- Expanding or at least preserving satellite communications spectrum allocations and the need for effective migration to the use of higher frequencies in the millimeter wave band in overcoming precipitation attenuation issues in these new bands.
- Access to adequate GEO orbital positions and minimizing intersystem interference. Closely related to this issue is the effective management and deployment of LEO satellite constellations so as to minimize interference and coordinate between GEO, MEO, and LEO systems.
- Coping with the problem of orbital debris.
- Technical standards to achieve seamless connectivity between FSS and terrestrial networks and even other types of satellite networks – especially related to completely fluid IP interfacing.
- Coping with the issue of satellites constantly changing role as a complement to terrestrial networks, as a potential restorer of terrestrial networks, and at times a direct competitor. (The satellite use of CDMA and TDMA multiplexing vs. fiber-optic systems using DWDM creates an ongoing compatibility issue beyond that of satellite latency and IP Sec-related disruptions.)
- Developing improved satellites, lower cost and more compact ground antenna, and lower cost launch systems to keep the cost of satellite networking moving to even more competitive levels.

The remarkable growth of computer and IT systems and fiber-optic networks worldwide has been so dramatic that they have at times overshadowed the rapid expansion of satellite technologies and markets. Few industries in the history of humankind have expanded more than a 1,000-fold in less than a half century, but the satellite industry in general and the FSS networks around the world have exceeded even this rate of expansion. Now, something approaching 20,000 satellite television channels have replaced the single low-quality black-and-white television channel that Intelsat I was able to achieve in 1965. Instead of satellites with hundreds or thousands of equivalent voice circuits, there are today satellites equivalent of millions of voice circuits. Just one of these massive satellite networks could transmit the equivalent of the Encyclopedia Britannica in a few seconds and the equivalent of the Library of Congress in a matter of hours. New capabilities such as intersatellite links, onboard processing, active rain attenuation response capabilities, extremely high-gain multibeam antennas, exploitation of additional spectrum in the Ka-band frequency bands, and new digital interface standards will allow satellites to improve their performance to even higher levels during the twenty-first century to keep pace with new user and institutional demand for communications and IT services.

Cross-References

- ▶ An Examination of the Governmental Use of Military and Commercial Satellite Communications
- ▶ Broadband High-Throughput Satellites
- ▶ Distributed Internet-Optimized Services via Satellite Constellations
- ▶ Mobile Satellite Communications Markets: Dynamics and Trends
- ▶ Satellite Communications Video Markets: Dynamics and Trends
- ▶ Store-and-Forward and Data Relay Satellite Communications Services

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