1

INTRODUCTION TO SATELLITE COMMUNICATIONS

1.1 A BRIEF HISTORY OF SATELLITE COMMUNICATIONS

1.1.1 Origins of Communications Satellite Technology

The advent of satellite communications has revolutionized the world's ability to communicate. The modern age of space-based communication probably began in 1945, when Arthur C. Clarke, then secretary to the British Interplanetary Society and later the author of such popular works of science fiction as *2001: A Space Odyssey*, wrote an article entitled "Extraterrestrial Relays" for *Wireless World*. In it, Clarke described his idea for a worldwide satellite communications system that would be based on three satellites positioned equidistant from each other in orbit over the equator at an altitude of 22,300 mi/36,000 km. Each satellite would be linked by radio to the two others and to the ground, thereby allowing anyone on earth to reach anyone else in the world—wherever that person would be located—by tapping into this radio network. Clarke described the orbital path as a geosynchronic orbit, referring to the fact that a satellite at that specific altitude above the equator could orbit the earth at precisely the same speed as the earth itself rotates, thereby making it appear to be stationary from the perspective of someone on the ground. Because such a satellite would stay above the same spot in the sky at all times, radio signals could be relayed through it without interruption. This orbit today is normally called *geostationary, geosynchronous*, or *geosynchronous equatorial orbit (GEO)*.

Mobile Satellite Communications Handbook, Second Edition. Roger Cochetti.

Geostationary satellites are by no means the only type that can be used for communications (as we see in later chapters), but their development served as a foundation for most modern satellite technologies. Two supporting technologies during the 1950s led to the development of communication satellites. The invention of the transistor made unattended, long-endurance satellites possible because, unlike vacuum tubes (typically, small vacuum-sealed, glass cylinders with filaments inside), transistors do not require frequent replacement—which is a difficult task when a satellite is 22,000 mi away. Second, advances—mainly military—in rocketry and rocket guidance systems made the deployment of a satellite at high altitudes feasible.

Although many theorists imagined satellite communications applications during the decade after World War II, a link from the United States to Europe was probably the first application in which the possibility of using satellites was seriously considered. An undersea telephone cable to Europe was also being considered at this time. Ten years after the end of World War II, the first transatlantic voice cable linking the United States and Scotland was completed. This transatlantic telephone cable, TAT-1, went into use in 1956. It replaced radio telephone technology and provided reliable voice connections between the United States and Europe for the first time. A major drawback was its limited capacity: It was designed to handle only 36 telephone calls at one time, and no television at all. More important, cables then were designed to connect a small number of points, often only two, with each other (from which they could branch out to large cities). Consequently, they did not reach beyond the countries with the largest cities in Europe and North America.

Following World War II, the United States and Soviet militaries had thought about building and launching reconnaissance and communications satellites, but both military establishments were more interested in guided missiles. Their work on ballistic missiles would eventually make satellite launches possible.

Most US plans for communications satellites (sometimes called *satcoms* or *comsats*) remained on the drawing boards, or the seminar table, however, until news of Sputnik splashed across the headlines in October 1957. As part of its contribution to the International Geophysical Year (July 1957 through December 1958), the Soviet Union launched a 184-lb sphere into a 560-mi orbit above the earth. The satellite carried two small radio transmitters, which lasted for 22 days. As a form of propaganda, Sputnik represented an attempt by the Soviets to demonstrate to the world the superiority of Soviet over US technology, power, and perhaps even ideology.

The impact of this point was not lost on the US government; each of the three US armed services had developed their own low-to-mid-level-priority satellite program prior to 1957 on the grounds that satellites were of debatable military value. In rapid order, the US satellite program was given a very high priority by each of the services. Two months after the launch of Sputnik I, the US Navy attempted and failed to launch a satellite on a Vanguard rocket in a spectacular launch explosion. About 4 months after the launch of Sputnik I, the US Army launched the first US artificial satellite, Explorer I, on a Jupiter rocket. In July 1958, the National Aeronautics and Space Administration (NASA) was established to pursue a civil space program. The so-called *space race* was on.

From this point forward, most satellite programs, industries, and technologies in the United States began to diverge into two distinct groups: military and civil/scientific. Later, a third group—namely, commercial satellites—emerged, and military satellites further divided among communications, reconnaissance (sometimes called *remote sensing* or *spy*), and navigation, which is sometimes called *radio determination satellite services* (RDSS) such as the global positioning system (GPS).

The first true communications satellite, the US Army's experimental SCORE (Signal Communications by Orbiting Relay Equipment), was developed by the Defense Department and launched on December 18, 1958 into an elliptical orbit ranging in altitude from about 100 to 900 mi. It contained a very high frequency (VHF) radio receiver/transmitter and a tape recorder to receive and store messages from the ground as the 99-lb satellite passed overhead on its orbit. The transmitter/receiver also permitted the satellite to serve as a real-time relay between two ground stations below. The store-and-repeat mode was considered useful for military purposes because it would permit a satellite to transmit orders from the Pentagon to a commander in some distant region and to carry intelligence in the opposite direction. SCORE proved that Atlas rockets could be used to launch satellites, but it lasted just 12 days. It was, however, an experimental success and was perhaps best known for proving that communication via satellite was possible as well as for the Christmas greetings it carried from President Eisenhower in 1958.

Following the success of SCORE, the US Department of Defense (DOD) assumed responsibility for satellite programs. DOD's Advanced Research Projects Agency (DARPA) set up three study panels and through the US Army it deployed Courier in 1960. This 500-lb satellite (there were two, but the first failed on launch) lasted only a few weeks, but demonstrated the use of solar cells for electric power in an active repeater satellite. This meant that a satellite could last longer than its onboard batteries. Its success led the US military to devote significant resources to develop satellite communications technology by the creation of Project Advent, which was assigned to the Army as the lead agency for the project. (Among other related technologies in which experiments were conducted was Project Westford from around 1961 through 1963. In this experiment, which was conducted for the US military by MIT's Lincoln Laboratory, a ring made up of almost 500 million copper needles was placed in a 2400 mi/3800-km-high orbit and used as a reflector for long distance, military communications. Westford-type "ring the earth" technologies were far surpassed by satellites and not pursued.)

On the civil side, virtually from NASA's birth, it assumed federal responsibility to develop civil communications satellites. During the early 1960s, NASA worked closely with ATT, Radio Corporation of America (RCA), Hughes Aircraft Company, and many other companies to define the technologies that would make communications satellites viable. This led to the development of several NASA experimental and demonstration satellites that tested different techniques. In August 1960, the first of two Echo satellites, for example, tested a passive satellite communications technique by launching a 100-ft diameter balloon into a 1000-mi orbit.

Ground transmitters would literally bounce signals off the balloon's aluminum mylar skin so that receivers could catch the VHF and UHF (ultrahigh frequency) signals at some distant location. The next, and probably the most famous, satellite experiment involved two 1962/1963 satellites developed by ATT's Bell Laboratories and NASA called *Telstar*. Like SCORE and Courier, Telstar was a solar-powered, active satellite, but it carried live television or multiple channels for voice. It was placed in an inclined elliptical orbit about 600 mi from the earth's surface at its low point, which is its perigee, and 3500 (almost 7000 mi for Telstar No. 2) miles away at its high point, which is its apogee. Telstar weighed about 170 lb and was about the size of a large beach ball. It circled the earth about every 3 hours, making a live C-band [6 and 4 GHz] communications link available at any one time for about 10 min before the satellite passed overhead. More than any previous satellite, Telstar brought satellite technology to the public's attention through its live international television transmissions. The third early NASA experimental satellites were called *Relay*. Built by RCA, these two elliptically orbiting satellites were launched in 1962 and 1964. They tested redundant systems and demonstrated that satellites could operate at the C-band without interfering with terrestrial microwave systems.

None of these early experimental communications satellites led directly to an operational system, but they did provide important engineering data on various factors necessary for an operational communications satellite. Telstar and Relay shared a common technical limitation, however. Because of their orbit and because the speed of their rotation was faster than the rotation of earth, they appeared to an observer on the ground to move eastward across the sky. So it did not take long for one of these satellites to move out of position to hold a continuous communications link. Such elliptically or medium earth-orbiting (MEO) satellites were gone from sight within 10 min of their appearance, and it would be hours before they reappeared. The only way to offset this limitation was to deploy a ring of such MEO satellites, so that as soon as one began to move out of sight, another would enter. But, in the early 1960s, this was a financially and technically daunting task for both the government and industry.

Although most of the focus of NASA's early attention to communications satellites was on low and medium altitude technologies, DARPA and the Army focused on the idea of a large geostationary (GEO) communications satellite, called *Advent*. However, after several years of developmental effort, and much interservice wrangling, Advent was canceled. As a result of a growing list of demands from each of the military services, the planned GEO military satellite had grown to such a size that there was no rocket system powerful enough to launch it in the early 1960s.

While Advent stalled, Hughes Aircraft Company proposed to the US military and NASA a much smaller (86 lb) geostationary communications satellite that would spin like a top to give it stability. After some resistance, and with Advent experiencing continued delays, NASA and DOD decided to provide the necessary support for three such satellites. They were called *Syncom*, and they were the first geostationary communications satellites. DOD supplied the ground stations and NASA developed the satellites. In the beginning of 1963, the Syncom series proved the viability of geostationary communications satellites. Although

Syncom I failed, Syncom II and III were successfully placed in orbit in 1963 and 1964, providing live TV transmission of the 1964 Tokyo Olympics. The joint NASA–DOD satellites used military frequencies of 7.36 GHz from the ground to the satellite and 1.815 GHz from the satellite to the ground, and they operated until 1966. (See Figure 1.1 for the geostationary orbital arc.)

Syncom II and III demonstrated the value and reliability of GEO satellite technologies and set the stage for the domination of satellite communications by geostationary techniques for some time to come. Syncom's success was also instrumental in gaining worldwide agreement in 1963 to allocate 2.8 MHz of radio frequency at the 6- and 4-GHz bands (called the *C-band*) for satellite communications, which was an essential prerequisite for the later commercialization of satellite communications. They demonstrated that, as Arthur Clarke had predicted, as long as a dish antenna could get an unobstructed look at a GEO satellite as the satellite hovered above the equator, near-worldwide communications coverage was possible.

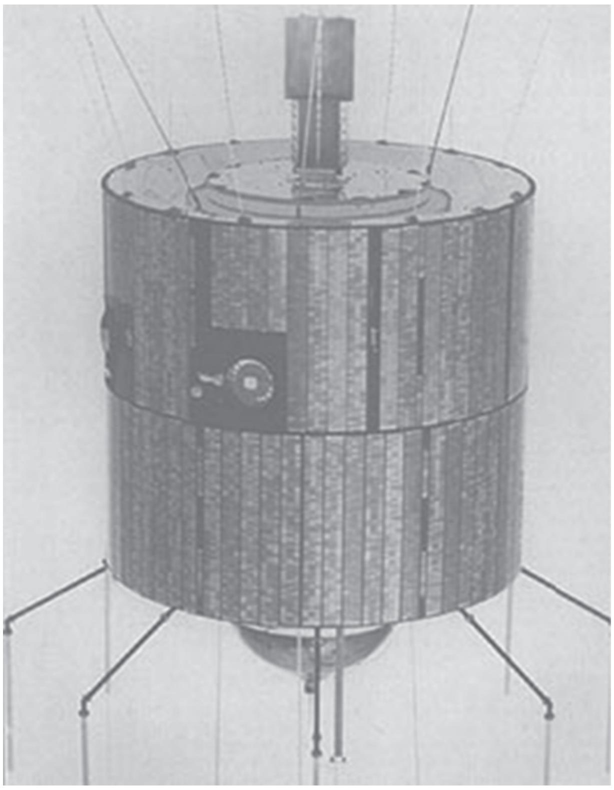

Figure 1.1 ATS-1 VHF communications. NASA's mid-1960s tests and demonstrations of aeronautical mobile satellite communications. Courtesy of NASA, Washington, DC.

1.1.2 Origins of the Communications Satellite Legal Structure—International

Aside from the US government's military and civil satellite programs, as early as 1960, President Eisenhower had articulated a national policy to establish a *commercial* communications satellite system. With the advent of the Kennedy administration, federal satellite policy shifted, however. In his 1961 State of the Union message, President Kennedy invited all the countries to join with the United States in developing a communications satellite program, thus giving greater emphasis to the *foreign policy* (vs the commercial) nature of the powerful new technology. Kennedy's initiative was clearly intended to support the US in its growing rivalry with the Soviet Union.

Partly because of the Kennedy and Johnson administrations' emphasis on the foreign policy aspects of satellite policy, a lengthy debate took place in the Congress over how the government-developed satellite communications technology should be used for communications. Some felt that the US government should take on the task of developing an international satellite communications system; others that it should be taken on by telephone companies and other common carriers; and still others that it should be taken on altogether by new organizations. Acting on a request from President Kennedy in 1962, the Congress decided to follow the last course and create a new organization, a shareholder-owned company, to commercialize international communications satellite technology through an international effort. This company, Communications Satellite Corporation, or COMSAT (later COMSAT Corporation), was intended to be nongovernmental but operating under certain controls of the State Department, the Commerce Department, and the Federal Communications Commission (FCC). COMSAT was designed to be the US part of a multinational effort led by the United States to develop satellites for international communications, intending to demonstrate the superiority of US technology and ideology over Soviet alternatives. The multinational effort came to be known as *INTELSAT* (International Telecommunications Satellite Organization), and COMSAT was the US-operating participant in it.

Between 1962—when COMSAT was formed as a shareholder-owned company under the terms of an Act of Congress—and 1964, the initial agreements to create INTELSAT were negotiated and the first satellite was procured. Like Syncom, it was a geostationary satellite placed 22,300 mi over the Atlantic Ocean. This first operational communications satellite was built by Hughes and named Early Bird. Its technical success helped to propel the INTELSAT system to commercial success, as well as official status, which it reached in 1969.

Partly in response, and partly for its own civil and military needs, the Soviet Union developed its own series of communications satellites and its own counterpart to INTELSAT. The first Soviet communications satellites were not placed into the GEO orbits that became popular in the United States, however. The Soviets found that the very northern location of their territory made geostationary satellites that were positioned above the equator difficult to use because in many locations the satellite would be so low on the southern horizon that a unobstructed "look" at it by an antenna would be blocked by mountains, trees, buildings, or the horizon. So, the Soviets concentrated on an elliptical orbit (roughly above the poles) for communications satellites.

In this orbit, the satellite comes low to the earth on one end (perigee) and far from the earth on the other (apogee). It is used for communications while near its apogee because during that period the satellite moves across the sky slowly. The particular elliptical orbit used by the Soviets is known by the Russian name of its satellites, Molniya ("lightning"). It stretches typically from about 25,000 mi at its apogee to 300–600 mi at its perigee. Molniya (sometimes spelled Molnya) satellites were launched starting in 1964, and they required complex ground stations. Because the satellites would move slowly across the sky, a tracking or moving dish-shaped antenna was needed, and because one satellite would go out of sight as another came in, two moving antennas were needed for a continuous communications link. In 1975, the Soviets began to add geostationary communications satellites to their fleet, including a series called *Statsionar*, which consisted of Raduga ("rainbow"), Ekran ("screen"), Gorizont ("horizon"), and Louch ("light") GEO satellites.

Based on the technical success of its elliptical satellites in the Soviet Union, the Soviets led the creation in 1971 of the International Organization of Space Communications (INTERSPUTNIK or Intersputnik), a much smaller organization than INTELSAT that provided international communications satellite services mainly among the closest of the then Soviet-aligned countries. Following the collapse of the Soviet Union, Intersputnik continued as an intergovernmental organization with the Russian Federation assuming the role of the former Soviet Union. By 2013, the Organization included 26 countries and provided access to fixed users from 16 GEO satellites for which it had access.

Throughout the 1960s, however, the main focus of commercial communications satellite activity was INTELSAT, which relied entirely on GEO, C-band satellites. Created as a treaty-based, user-owned cooperative to which national governments became a party by treaty, INTELSAT began an ambitious program to deploy GEO satellites over each of the three main oceans. But these were not intended to be government-owned, civil satellites. Once a country became a Party to the INTELSAT treaty, then its government (usually represented by its foreign ministry) designated an operating organization to invest in the satellite system and manage the usage of the INTELSAT satellite circuits within their country. These operating organizations, called *Signatories*, normally were the telephone network operators from the member countries, sometimes called *PTTs* after the European style of centralizing their post office, telegraph, and telephone networks into a single government ministry of Posts, Telegraph and Telephone (PTT).

During the negotiations to establish the INTELSAT system, the United States had advocated that INTELSAT should have a virtual monopoly on all international communications via satellite among the countries that ratified the INTELSAT Agreements, mainly to avoid the emergence of satellite systems that might undermine the economic integrity of or the Western alliance flavor to INTELSAT. Many European countries wanted a looser arrangement, and what emerged was an arrangement under which non-INTELSAT satellite systems that provided international services were permitted, but they first had to be coordinated with INTELSAT to demonstrate that they would not economically harm the INTELSAT system. In addition, ground stations that linked to all international satellite systems would be licensed and regulated by the country in which the ground station was located. These rules had the intention and effect (through the 1980s at least) of making it difficult for anyone to establish an international communications satellite system other than INTELSAT.

Also, under the early Kennedy/Johnson administration policies, communications satellite systems that provided purely domestic services did not have to be advance-coordinated at a policy/economic level with INTELSAT, although all satellite frequency and orbital slot assignments became the responsibility of the United Nations' International Telecommunications Union (ITU). This early distinction between a more flexible legal structure for domestic communications satellites than for international communications satellites proved mainly important for large countries like the United States and Canada, where purely domestic systems developed during the 1970s and 1980s to serve such markets as cable television program distribution, remote transmission of television feeds into network operation centers, and domestic voice or data networks. As the costs of deploying satellites came down, domestic communications satellites—including "domestic packages" on board other satellites—emerged in many countries of all sizes.

In the United States, the Kennedy-era idea of a US-led international system for international services evolved into a multitiered structure of US involvement in INTELSAT. The US "Party" was normally represented by the State Department, but with active involvement from the Federal Communications Commission and the Commerce Department's National Telecommunications and Information Administration (NTIA). COMSAT Corporation was the US Signatory and the provider of INTELSAT space segment services in the United States. A large number of organizations, many of them long distance or international telephone companies or special satellite antenna (called *telport*) operators, were licensed to provide ground segment service through satellite antenna complexes, which are called the *earth stations*, around the country.

Beginning in the early 1980s during the administration of President Ronald Reagan, in a reversal of its original approach, the US government became an active proponent of opening up competition in international satellite systems by encouraging the development of privately owned satellite systems that would compete with the INTELSAT network in offering international satellite links. This policy found some support in Europe and elsewhere and by 1988, both Luxembourg-based Societe Europeenne des Satellites (SES) and US-based PanAm Sat had deployed GEO, international, communications satellites. Both of these companies eventually grew to become major, global, providers of communications satellite services (until PanAmSat was acquired by Intelsat, Ltd. in 2006).

By the late 1980s, however, all of the satellite systems that offered international communications services, including INTELSAT, began to come under increasing pressure from competitors using efficient, high speed, fiber optic cables.

During the 1990s, the process of introducing competition to commercial, international, communications satellite services took a dramatic turn. Many competitors of INTELSAT and supporters of competition between INTELSAT and so-called “separate systems” concluded that competition could not be fair as long as INTELSAT enjoyed its special intergovernmental status. And many supporters of INTELSAT concluded that INTELSAT’s intergovernmental structure prevented the organization from being competitive and agile in the marketplace. In fact, in 1999, INTELSAT announced its intention to “privatize” by becoming a shareholder-owned, business corporation. These concerns and developments led the US Congress in 2000 to enact the Open-market Reorganization for the Betterment of International Telecommunications Act, the ORBIT Act. This Act made it United States policy that INTELSAT should be transformed from an intergovernmental organization into a private sector, for-profit corporation with virtually no intergovernmental status and few ties to the existing Signatory owners of INTELSAT. In 2001, INTELSAT transferred virtually all of its assets to Intelsat, Ltd., a Bermuda-registered holding company, which in turn established several subsidiaries, including US-based Intelsat, LLC, that operated what had been the INTELSAT satellite system. Although most of the “Signatories” of INTELSAT became shareholders of Intelsat Ltd., by 2006, Intelsat Ltd. had acquired ground stations so that it could offer end-to-end satellite links; merged with PanAm Sat, a major international competitor; and acquired the Telstar communications satellites of Loral Skynet, a major provider of domestic communications satellite services in the United States. Intelsat, Ltd. was soon thereafter acquired by private investors. In 2009, Intelsat, Ltd. changed its domicile to Luxembourg and as a result changed its formal name to Intelsat, SA.

Throughout this period, all of the various INTELSAT/Intelsat systems have relied on geostationary satellites, typically positioned over ocean regions to exploit the satellites’ giant “footprint” (the area of the earth’s surface that is within sight of the beams from the satellite’s antennae). These satellites have grown in size and capacity, with the intention of both increasing the economic efficiency and permitting the use of smaller satellite ground stations. By the 1990s, it was possible to access an INTELSAT satellite with an earth station whose dish antenna measured from 4 to 10 ft in diameter, compared with antennas that measured 50–90 ft in diameter during the 1960s. And by the 2000s, Intelsat was offering service to even smaller ground stations and ground stations mounted on board ships at sea. In the use of radio frequencies, INTELSAT’s satellites have evolved from an exclusive use of the 6- and 4-GHz bands (C-band), to a mixed use of both C- and Ku-band (14 and 12 GHz).

1.1.3 Origins of the US Communications Satellite Legal Structure—Domestic

The first and most important implementation of President Eisenhower's 1960 national policy to develop commercial communications satellite technology was in the international arena, and there it evolved significantly. From a 1960s foreign policy initiative to a 1990s complex mosaic of private and public enterprise to a purely private sector-driven market in the 2010s, the international structure started rapidly and evolved slowly. But the US domestic structure for satellite communications was to start slowly, develop rapidly, and then evolve.

In the absence of a major presidential initiative of the sort launched by President Kennedy for international satellite communications, the legal structure for domestic satellite communications emerged slowly, largely as a result of numerous, conflicting interests. Many US communications carriers with investments in cables or terrestrial microwave downplayed the value of satellite communications, in effect discouraging prompt federal action to license satellites for domestic use. On the other hand, most of the national television networks encouraged the rapid introduction of satellite communications domestically, mainly to lower their costs for the distribution of network feed to affiliate stations around the country. Major proposals were put forward by charitable foundations, hospitals, and universities that domestic satellite communications should be managed by a nonprofit organization that would assist the charitable and educational communities. Alternative proposals were made that the field should be regulated as little as possible and left entirely to the commercial marketplace to develop.

Importantly, as noted earlier, in face of American views that INTELSAT should be a virtual monopoly provider of international communication satellite services and European views that there should be multiple international communications satellite systems, there was consensus that domestic communications satellite services should not be effected by the "coordination" procedures required of international satellite operators. In other words, except for the frequency and orbital slot coordination required with the ITU, domestic satellite services were up to each country and its own regulations and licensing. A corollary of this has been the principle that ground stations that are used to connect to communications satellites—whether those satellites are used for domestic or international services—are entirely subject to the domestic regulation and licensing of the nation within which the ground station is located.

It was not until 1966, well after the international satellite communications system had gotten under way, that the Federal Communications Commission began a formal investigation into how the domestic satellite communications industry should be structured. This FCC inquiry was to continue in one form or another for almost 7 years, until 1972. The final structure, commonly called *open skies*, embodied a marketplace approach to domestic satellite communications. The policy was based in part on the technological assumption that such domestic satellites would be geostationary. Under it, there were no limits—other than that the owners must be sound and principally American—on who might operate a communications satellite for domestic services. The technological complexity, requirements for close cooperation with NASA, and the costs and risks of satellite communications (a single satellite failure normally results in at least a $100 million loss and a 2- to 3-year delay until another satellite is built and launched) were sufficient to limit the initial competition, however, to a small group of then major telecommunications companies: RCA, Western Union, and a joint effort by ATT and COMSAT.

The first domestic commercial communications satellites to be launched for the United States were Western Union's "Westar" satellites in 1974, followed by COMSAT's (with ATT) "Comstar" and RCA's "Satcom" satellites in 1976. The Westars and Comstars were built by Hughes and the Satcoms by RCA. When these satellites were designed, their owners had sales plans and forecasts, but only a limited idea of how they would actually be used. ATT, Western Union, and RCA each operated sizable domestic, terrestrial networks and each planned to use some of their available capacity for their ongoing businesses. Each planned some expansion into new markets, primarily the distribution of network television.

Television has indeed been the major user of domestic communications satellites in the United States, but not just broadcast network television. The major US broadcast networks continued to primarily use terrestrial (cable and microwave) links for their feeds from their network operations centers to their broadcast affiliates well into the 1980s. A then-little-known supplier of movies to then-often-rural, cable TV stations called *Home Box Office* (HBO) decided in the 1970s to lease capacity on an RCA satellite and transmit via satellite (instead of ship by package delivery) movies to local cable television stations around the United States. The success of HBO and RCA in distributing movies to cable TV "head ends" paved the way for the eventual and linked success of the US domestic satellite communications and cable television industries; and for similar industries in Europe and throughout the world. In addition to cable television, other prominent customers for domestic satellites have been broadcast radio network operators; large organizations that require data networks; television news and sports departments that want to transmit from remote locations back to their studios; and eventually direct broadcast satellites (DBSs), which transmit television, Internet, and radio directly from a satellite to a home, office, or automobile.

Over time, a variety of purely domestic geostationary communications satellite systems have come and gone in the United States, mostly as a result of the emergence of DBS and business restructuring in the industry. By the mid 1990s, six commercial satellite operators offered service, very often through a plethora of resellers; and by the 2010s, that number had dropped to two (or three, depending on how one calculates) integrated domestic and international service providers. In addition, by 2013, there were three principal DBS providers in the United States, which often also serve customers in Canada, Mexico, the Caribbean, and Central America. Consequently, the era of strictly domestic communications satellites for the United States has nearly come to an end since most communications satellites used in the United States also provide services to other countries, to international routes or are available to do so. Finally, as with international communications via satellite, the advent of efficient and high speed, fiber optic cables in the 1980s and

1990s put competitive pressure on domestic satellite services in the United States and within other countries.

Because nearly all of the United States, with the exception of some parts of Alaska, lies within easy "look" at a GEO satellite hovering above the equator, until the advent of land mobile satellite communications in the 1980s, all domestic communications satellites in the United States used GEO platforms.

1.1.4 The Merger of Domestic and International Communication Satellite Legal Structures

With the privatization of Intelsat in 2001 and the advent of international trade agreements in the 1990s that make it easier in most countries for domestic and international communications satellite services to address both markets, the distinctions between domestic and international communications satellite services have faded significantly. Since the World Trade Organization (WTO) was established in 1995, over 100 countries—notably including the United States—have agreed to allow foreign operators of telecommunications services to provide telecommunications services to their domestic markets; and most of these commitments have included satellite communications. If an international communications satellite operator does not need to advance-coordinate with INTELSAT and is allowed under international trade commitments to provide domestic or international services to over 100 countries, then many major barriers between international and domestic communications satellites services have been removed. The principal approvals that any domestic *or* international communications satellite operator needs have evolved to be much the same: orbital slot and frequency assignments from the host country and the ITU; and licenses to operate ground stations from each country in which they operate. And while by 2013, there remained many countries that did not readily allow foreign communications satellite service operators to address their domestic markets, that list is shrinking. By exactly the same token, without the burden of advance coordination with INTELSAT and with foreign regulations reduced, domestic communications satellite service providers of all countries have been freed up to more readily offer communications satellite services to cross border markets as well as to the domestic markets of other countries.

1.1.5 NASA and Civil Communications Satellites

To a large extent, the geostationary technology that supports both domestic and international communications satellites has been built on the same NASA and US military technological foundation. Building on its success with Syncom, between 1966 and 1974, NASA launched and operated six test and demonstration geostationary communications satellites, called *Applications Technology Satellites* (ATS). These satellites helped to develop a variety of critically important satellite communications techniques, most importantly for television transmission. ATS-1, 3, 5,

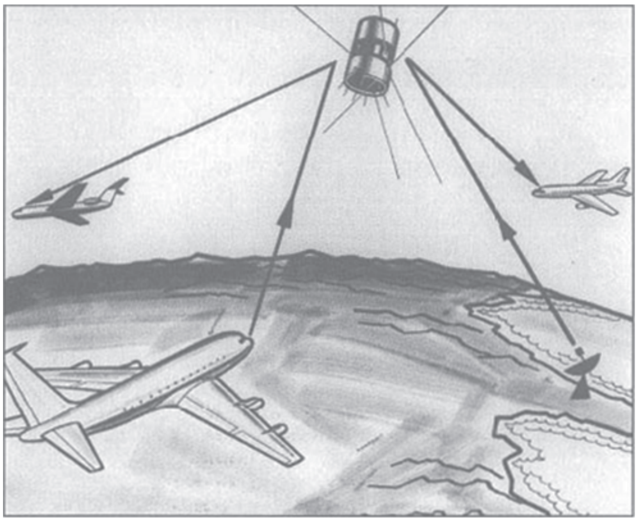

Figure 1.2 NASA began the development of mobile satellite communications technology in the mid-1960s and has continued to invest in the development of mobile satellite technology through the mid-1990s. Courtesy of NASA, Washington, DC.

and 6, however, were all designed specifically to experiment and test mobile satellite communications. ATS-1 (1966), ATS-5 (1969), and ATS-6 (1974) tested and demonstrated the use of the L-band (around 1.5 GHz) for mobile satellite communications, specifically for aircraft (see Figure 1.1) and ships (see Figure 1.2). This paved the way for all future L-band mobile communications satellites. The ATS series was followed in 1976 by a joint US-Canadian Communications Technology Satellite (CTS), which tested new satellite designs and, perhaps most importantly, the use of small television receive-only antennas and frequencies at the 12-GHz and 14-GHz bands (called *Ku-band*) for satellite communications. This in part led to the commercialization of the Ku-bands by the 1980s and the widespread availability of Ku-, C-, and S-band satellite services in the United States.

Continuing its role in developing new technologies, NASA deployed its largest and most complex experimental communications satellite from 1993 through 2004, the Advanced Communications Technology Satellite (ACTS). ACTS tested the use of very high radio frequencies, called the *Ka-band* (30 and 20 GHz) for fixed and mobile satellite communications, and in doing so set the stage for future satellites that operate at frequencies never used before.

1.2 CURRENT MAJOR COMMUNICATIONS SATELLITE SYSTEMS

It is impossible to say exactly how many communications satellites are in operation in 2013, in part because some of these satellites are continuously being retired as they reach the end of their lifetime and others are being constantly deployed. Moreover, when one considers spare satellites, scientific satellites, government satellites, military communications satellites, and multipurpose satellites, problems of definition arise. Nonetheless, it is safe to say that over 600 communications satellites were in one or another stage of service by the end of 2012. Around two-thirds of these were commercial communications satellites, split mainly between geostationary (GEO) and low earth orbiting (LEO). These were complemented by around 100 military and 100 civil government communications satellites, most of which were GEO.

1.2.1 Military Communications Satellites

All satellites used for military communications are not publicly announced, and the military forces of the United States and most other countries make considerable use of commercial communications satellites for both fixed and mobile services. Frequently, a military communications package is placed on a satellite used by a government for other purposes, thus avoiding the satellite's classification as purely a military communications satellite. Consequently, a thorough and accurate picture of the military segment of the communications satellite market is not publicly available.

While virtually every military organization in every nation makes use of communications satellites services today, public records indicate that the United States, Russia, China, Britain, France, Germany, Italy, Spain, the North Atlantic Treaty Organization (NATO), and Brazil currently operate some type of military communications satellite system. As of 2012, Japan, India, and Israel had announced plans to do so in the near-future as well. The US armed services have access to around 50 NATO, WGS (Wideband Global Satcom), AEHF (Advanced Extremely High Frequency), UHF Follow On (UFO), Milstar, Mobile User Objective System (MUOS), XTAR, SMDC, and Tactial Microsatellite Innovative Naval (TACSAT) satellite systems and leased capacity on commercial satellites. Other large operators of military satellite communications systems include Britain (Skynet), China (Chinasat, Shijian, and Zongzing), and Russia (Cosmos, Meridian, Molniya, and Raguda/Globus; Figure 1.3).

Military communications satellites generally operate in the VHF, UHF, EHF, and SHF bands and can use GEO, MEO, elliptical, and LEO orbits, although most use GEO orbits. These systems tend to be out of public view and designed to provide secure communications for fixed, transportable, maritime, aeronautical, and land mobile military and intelligence ground stations. They are examined later because of their relevance to mobile satellite communications.

1.2.2 Civil Communications Satellites

Related to the military systems (in fact, in some cases overlapping with them) are communications satellite systems operated by or for civil government agencies, sometimes for governmental use, sometimes for test and demonstration, sometimes for experimentation, sometimes for commercial communications, and most often for a combination of these functions. While civil agencies of virtually all national

Figure 1.3 Early US Army transportable satellite communications system. Courtesy of US Army.

governments make frequent use of commercial communications satellite services, over a dozen countries operate civil government, satellite programs of one sort or another; most of which include weather or remote sensing satellites. Several of these include experimental or operational communications satellites as well. The oldest of these is in the United States, where the NASA has operated the Tracking & Data Relay Satellite System (TDRSS) since 1983, which has been used for high speed communications for a wide range of NASA programs, including the International Space Station.

In Japan, the Japanese space agency, the Japan Aerospace Exploration Agency, JAXA, in 2012, operated several, experimental communications satellite systems, including KODAMA for intersatellite relays, KIZUNA for wideband internetworking, and KIKU/ETS VII for mobile and engineering tests. In Europe (with Canadian cooperation), the European Space Agency, ESA, began deploying scientific and experimental satellites in the 1970s and by 2012 operated a variety of civil communications satellites or packages on board others' communications satellites, including the European Data Relay Satellite (EDRS), Artemis, and Alphasat.

Experiments, tests, and demonstrations of communications satellites were at one time a major part of the government space programs of the United States, Russia, Europe, and Japan. But as satellite technology has matured, civil government systems—with some notable exceptions in Europe and Japan—have tended to be more operational, with experimental satellites reserved for such new areas as the use of higher frequencies or intersatellite links. Now, even these experiments are often conducted through a package on board a general-purpose or even an operational satellite.

1.2.3 Commercial Satellites

Around 400 communications satellites provided commercial services in 2012, with the largest single group providing service to international or global markets. Since the privatization of INTELSAT and INMARSAT around the turn of the century, the distinction between a communications satellite providing domestic services and a communications satellite providing international services has faded and most communications satellites today do, or are available to do, both. As noted above, around half of these are GEO and half are LEO and they operate in the C-, Ku-, S-, L-, and Ka-bands. We shall briefly examine the international, then the regional, and then the domestic satellite communications systems in operation in 2012.

1.2.3.1 Global Systems The largest single owner and operator of international, commercial communications satellites for much of the past four decades has been INTELSAT and its successor, Intelsat, SA, which in 2012 was primarily owned by BC Partners and Silver Lake Partners, which are private equity firms. While Intelsat's legal domicile is in Luxembourg, its principal marketing operations are in London, United Kingdom, and its principal operations are in the United States. As noted above, Intelsat, SA, began as a treaty organization because it was created by, and operated until 2001 under, an international treaty ratified by the governments of more than 125 countries. Until 2001, INTELSAT was a user-owned cooperative in which its owners (called *Signatories*), were also its users in providing international satellite space segment services. At its peak, in this now discontinued and highly regulated structure, around 300 US-based earth stations looked at INTELSAT satellites, and about 1700 such stations did worldwide.

Today, Intelsat, SA, is a privately held corporation that in 2012 operated 52 GEO satellites that operated primarily in the C- and the Ku-bands and it employed over 1000 people. Most of its global satellite communications services were provided to fixed earth stations, although over the past few years the company has announced increased interest in serving such mobile markets as maritime and aeronautic (see later section on Intelsat's mobile satellite communications services.) Around half of Intelsat's services are provided to large, often global, telecommunications network operators; around a third to a wide range of video customers; and the balance generally to government customers. These services range from satellite transponder capacity to end-to-end, fully managed domestic or international networks. Integrated space and ground services are often provided through subsidiaries such as Intelsat General Corporation and through a variety of resellers, partners, and joint ventures. Intelsat is the largest provider of communications satellite services within the United States and between the United States and other countries, and its principal focus throughout its varied history has been to offer global as well as local satellite connectivity for users in fixed locations.

SES (founded in 1985 as Societe Europeenne des Satellites and renamed as SES), in 2013, was the second largest operator of communications satellites. SES is a Luxembourg-based, publicly traded company (it trades as SESG, although a majority of its shares are held by a few institutions) that currently operates 52 C- and Ku-band GEO satellites around the world. It began its operations in 1988 with a series satellites called *Astra* that pioneered in providing direct-to-home (DTH), digital and high definition television services primarily to millions of homes in Europe that were equipped with small, dish antennae pointed at the Astra GEO satellites. SES began a rapid expansion beyond Europe in 1999, leading to its acquisition, among many others, of GE Americom (a major provider of communications satellite services within the United States and to the United States government). SES also acquired the six satellites of New Skies Satellites, which had been divested from INTELSAT.

Importantly, SES offers its customers a full range of services from transponder access to fully integrated network services and these can range from local to global. Integrated ground and satellite services are generally provided through such SES subsidiaries as SES Government Solutions and through a variety of joint ventures, partners, and with regional communications satellite operators. SES is the largest provider of communications satellite services within Europe and it operates through regional offices in 18 countries around the world. While nearly all of SES' communications satellite services are provided to fixed users, it serves a small but growing number of large ships at sea.

Eutelsat Communications, like Intelsat, began as a treaty organization and evolved into a shareholder-owned, business corporation. When EUTELSAT was established in 1977 by treaty 17 nations who were members of the European Conference of Postal and Telecommunications Administrations, or CEPT, came together to create an inter-European communications satellite system. National governments were Parties and national telecommunications administrations, sometimes called *ministries of posts and telecommunications*, or PTTs, were operating Signatories. The EUTELSAT treaty entered into force in 1985 but the Paris-based Organization had actually begun deploying GEO communications satellites over Western Europe by 1983. EUTELSAT saw rapid growth in membership as the European Union expanded and by 2001, 48 countries were members and the organization that operated six GEO satellites.

At that time, EUTELSAT underwent a significant change. As had been the case with INTELSAT and INMARSAT, EUTELSAT in 2001 was privatized and converted to a shareholder-owned, Paris-based business, initially named Eutelsat, SA and later converted to Eutelsat Communications. By 2005, Eutelsat Communications was listed on the Euronext Paris stock exchange (formerly the Paris Bourse) and its satellite fleet had more than doubled. In 2012, Eutelsat Communications operated 29 GEO, Ku and C-band satellites, with coverage concentrated on Europe and the Middle East, but extending throughout Asia and to Africa and the East Coast of North and South America. Eutelsat offers both basic transponder capacity and fully integrated services either directly or through a variety of partners. The largest part of its services are in video distribution.

Given the size, geography, demographics, and proximity to the United States of Canada, it should come as no surprise that the Canadian government took a great interest in the use of satellites for communications as soon as the first experimental communications satellites were deployed by the United States in the 1960s. With many small towns located across its large territory and a constant threat that Canadians living near the US border would tune into American broadcasters, Canadian officials recognized early on that communications satellites could create cost-effective, nationwide telecommunications and television distribution networks. This led to both close cooperation between the Canadian government and NASA during the 1960s and the establishment by Act of Parliament in 1969 of Telesat Canada Corporation, partly owned by the Canadian government and partly by key Canadian telecommunications companies. In 1972, Telesat deployed its first communications satellite, called *Anik*, a C-band GEO that demonstrated that satellites could be used to distribute television throughout Canada and provide telephone service to remote communities. By the mid-1980s, after restrictions on the use of Telesat satellites for television distribution had been lifted, Telesat had become a leader in the use of higher powered, Ku-band satellites to distribute television to small dish-shaped ground terminals, which were soon found throughout Canada. In 1998, Bell Canada Enterprises (BCE) acquired Telesat and the company's quasigovernment status was ended. In 2006, BCE sold Telesat to a partnership led by Loral Space & Communications, Inc. of the United States.

By the end of 2012, Telesat operated a fleet of 13 GEO communications satellites that operated at the C-, Ku-, and Ka-bands. It divided its satellites into three categories: *Nimiq* Ku-band satellites (of which in 2012 there were five) that were used primarily for DTH or DBS throughout North America; *Telstar* Ku-band satellites (in 2012, there were four) that were used primarily for telecommunications networks and video transmissions on a global scale; and *Anik* C-, Ku-, and Ka-band satellites (of which there were four in 2012) that were used for telecommunications networks and video transmissions in North and South America. Telesat has been integrated with Loral Skynet and it offers both transponder capacity and fully integrated network services either directly or through its partners.

Finally, as noted previously, the INERSPUTNIK Organization that was created by the former Soviet Union as a counter to the US-led INTELSAT continues today as an intergovernmental organization in which the Soviet role has been filled by the Russian Federation. Located in Moscow, INTERSPUTNIK has 26 member countries, including several former Warsaw Pact countries, most of the former Soviet Republics, Syria, Laos, North Korea, Yemen, India, Vietnam, Afghanistan, Germany, Cuba, and Nicaragua. INTERSPUTNIK principally offers capacity on Express satellites operated by the Russian Satellite Communications Company, Eutelsat satellites, Measat satellites, and even Intelsat satellites. INTERSPUTNIK offers limited technical assistance and support for users.

There are currently five global communications satellite systems that essentially serve mobile customers through L-band satellites: Inmarsat, Iridium, Globalstar, Thuraya, and Orbcomm. Since these five systems are addressed more fully elsewhere in this book, they will be only noted here as important, global communications satellite systems.

1.2.3.2 Regional Communications Satellite Systems As the technology, regulation, and economics of satellite communication has evolved, the role of regional communications satellite systems has grown dramatically. Through the first three decades of satellite communications, from the 1960s through the 1980s, there was one principal, communications satellite system that was designed as a regional system, EUTELSAT, which as we have seen above evolved into a global, corporate communications satellite services provider, Eutelsat Communications. One other, much smaller, regional system, ARABSAT, was deployed by governments to offer services to its member countries in the Middle East. This formative period in satellite communications was generally characterized by (i) a rigid regulatory distinction between domestic and international satellite services, with domestic service reserved exclusively for government-owned operators and strong regulatory limits placed on satellite technology everywhere; (ii) a very high cost of building, launching, and maintaining a communications satellite with a substantial risk of launch or other failure; and (iii) a demand for satellite communications services, both domestically and internationally, consisting mainly of long distance telephony, large computer networks used by very large organizations and the transmission of video for centralized broadcasters.

During the 1990s, all of these characteristics began to change: (i) The end of the Cold War both relaxed the availability of satellite technology and brought a wide range of new, lower cost rocket launch services to the market, notably including Russian, European and business rocket launch services; (ii) the evolution of international trade agreements and the privatization of INTELSAT (and other intergovernmental satellite ventures), allowing investors to readily invest in the satellite communications industry, entrepreneurs to innovate, and communications satellite operators of every type to provide services within and between countries without having to deploy separate satellites for each country or each route; (iii) the evolution of technology permitting satellite operators to add coverage beams to multiple, defined areas (spot beams), to move the coverage beam to a new spot on the ground (steerable beams), to more readily relocate a communications satellite to a new orbit so that it could serve a new area on the earth's surface, and to increase satellite power and antenna size so that the ground earth station antennas could shrink to the size of a dinner plate or even a pencil; and (iv) an explosion in the demand in every country for video of all sorts, followed by an explosion of demand for Internet-based services; often in previously remote areas.

Combined, these factors led to a climate in which, for the most part, it no longer made sense for a business to invest in a strictly domestic communications or single-purpose satellite system. At modest additional cost and with modest additional licenses, the business could offer services to nearby or distant other countries or for international services. Similarly, at a modest additional cost, a satellite could be designed to serve multiple services. As a result, during the 1990s, billions of dollars were invested in hundreds of communications satellite ventures and most of these were for regional, global services but mostly for multiple services. This in turn led to the creation of a competitive, communications satellite marketplace in which support services that had at one time been one-off and unique—such as satellite market research, design, manufacturing, launches, insurance, or management—began to be offered by competing service providers with standardized "products." Equally, depending on the exact locations and timing, as competition between satellite operators has grown, the market for satellite communications services has generally become more standardized and price-sensitive.

The result by 2013 has been an explosion in regional communications satellite systems that serve multiple countries both American and non-American, particularly for the distribution of video. Many new communications satellite operators have entered the market since the 1990s, and most offer international regional communications satellite services, even if their principal market is domestic. Many are also either affiliated with a global or other service provider or have received investments from foreign investors or partners. By 2013, around two dozen non-American, regional communications satellite systems provided services to multiple countries, including

Yamil by Gazprom Space Systems of Russia
THOR by Telenor Satellite Broadcasting of Norway
RASCOM by the Regional African Satellite Communications Organization
Nilesat by Nilesat The Egyptian Satellite Company of Egypt
BSAT by the Broadcasting Satellite Corporation of Japan
MEASAT by the Malaysia East Asia Satellite Company
Express by the Russian Satellite Communications Company
AMOS by Spacecom of Israel
Hellassat by the Hellas-Sat Consortium, Ltd. of Greece
ABS by the Asia Broadcast Satellite Corporation of Hong Kong
ARABSAT by the Arab Satellite Communications Organization
OPTUS by the Optus Corporation of Australia
Thaicom by the Thaicom Public Company, Ltd. of Thailand
APSTAR by APT Holdings of Hong Kong
SATMEX by Satellites Mexicanos of Mexico
Turksat by Eurasiasat of Turkey
StarOne by Embratel of Brazil
Hispasat by HISPASAT of Spain
INSAT by the INSAT consortium of India
Chinasat by the China Satellite Communications Company of China

Although the number of communications satellites operated by these regional service providers is constantly changing (GEO satellites typically stop functioning when their station-keeping fuel runs out and new satellites are constantly being launched), by 2013, it included well over 60.

While business failures and mergers and acquisitions are inevitable based on events, business cycles, or management judgements (or mis-judgements), as time goes on, this segment of the communications satellite market is likely to grow. As technological advances drive the component costs of satellite communications down and market demand for video and Internet services in previously remote areas draw investors to provide satellite connectivity, one can expect new, more innovative, and lower cost regional, communications satellite systems to emerge.

There are currently two regional communications satellite systems that are designed for mobile services, principally using the L-band: Thuraya in the Middle East and LightSquared in North America. (A mobile satellite communications system is planned for Europe by the European Union as well.) These are described in detail in later chapters.

1.2.3.3 Domestic Communications Satellite Systems As explained above, by 2012, the distinction between domestic and regional communications satellites had significantly faded, since most operators of “domestic” communications satellites had become either businesses or revenue-seeking government organizations and communications satellite services to multiple countries could usually be provided at modest incremental investment over the investment needed to provide strictly domestic services. Nonetheless, for a variety of market, regulatory, and technical reasons, by 2013, there were around a dozen communications satellite systems that were reserved for purely domestic services. Accounting for these with exactness is difficult because many of these domestic-use satellites are parts of satellite fleets that otherwise offer regional, international, or even global communications satellite services. So, in these cases, a domestic-only satellite is in effect buried within a regional or a global fleet.

In other cases, a communications satellite may be capable of providing services either regionally (to multiple countries) or domestically; and the regional capability is not in use—either because of lack of demand, technical difficulty, or regulatory issues. And finally, given the competitiveness and fluidity of the industry, communications satellites are continuously repurposed and sometimes relocated. Altogether, this makes describing the purely domestic satellite communications industry in 2013 a difficult task.

Nonetheless, it is clear that there are some communications satellites that are more-or-less reserved for domestic use. Many of these are for DTH or DBS video and others are for government or commercial communications. Some, as in India, Pakistan, and Indonesia, are exclusively designed and authorized for domestic service, while others, as in the United States, Russia, China, Canada, Korea, and Australia seem to be used for domestic service but appear to be available for use in other countries or, in some cases, for international services. Altogether, however, these domestic-only, commercial communications satellites seem to amount to a few dozen satellites or less.