SATELLITE COMMUNICATIONS: SERVICES, SYSTEMS & TECHNOLOGIES

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INTRODUCTION

Telecommunications networks have experienced an explosive growth in traffic over the last several decades, largely due to a rapid increase in global demand for voice, video, and data services. Developments in satellite-based fixed and mobile services, the advent of optical fiber networks, growth of cellular networks, the emergence of new standards for wireless mobile and personal communications, and new spectrum allocations have all contributed to this ongoing information and telecommunications revolution. Significant growth has occurred in the cellular industry, with cumulative annual growth rates in excess of 30 percent. Today there are more than 100 million cellular phone subscribers worldwide, compared to approximately 4 million users in 1988, and the number is expected to more than triple by the turn of the century. However, during the same time period, between 50 and 60 percent of world's population is estimated to live in areas with no land-based cellular coverage. The proposed satellite-based personal communications systems (PCS) seek to extend telecommunications access to these areas. By the year 2002, the global mobile satellite services market is expected to serve more than 40 million subscribers.

Similarly for fixed networks, the rapid growth in Internet traffic requires an exponential increase in transmission bandwidth. There is a seemingly insatiable demand among end users for new and enhanced services, stimulated by technology improvements that have allowed operators to deliver telecommunications services at a cost up to 1,000 times lower than 30 years ago. Enormous strides in digital technology and its applications have changed the way information is generated, processed, stored, and transported. The resulting information infrastructure will profoundly affect all facets of life, in areas such as electronic commerce, health care, education, crisis management, and environmental monitoring. Telecommunications networks capable of transporting large volumes of information will form the arteries of this infrastructure. The use of communications satellites at higher bands (Ka- and V-bands, for example), where large bandwidths are available, provides an attractive solution for rapid deployment of this broadband wireless communications infrastructure.

TELECOMMUNICATIONS NETWORK EVOLUTION

As new services are being introduced, the public switched telephone network (PSTN) is evolving to the narrowband integrated services digital network (ISDN), synchronous optical network (SONET), asynchronous transfer mode (ATM), and synchronous digital hierarchy (SDH). Data networks are moving from traditional protocols such as X.25 to more efficient, higher speed fast-packet protocols such as frame relay. Data and voice services are migrating to the unified structure of ATM, which is a cell- or packet-based system that can efficiently carry voice, high-speed data, and video information. The convergence of voice and data applications on packet networks is driven by cost considerations and the new multimedia applications. The trend is toward SONET/SDH with ATM switching forming the core of a carrier network. Mobile networks are also evolving from analog voice systems like AMPS to digital cellular systems like IS-54 and GSM, and in the future to a universal mobile telecommunications system (UMTS) and IMT-2000. In parallel with these trends, there has been a rapid evolution in satellite networks.

Communications satellites have been traditionally used for fixed services to provide “bent pipe” interconnections between terrestrial networks or, through very small aperture terminals (VSATs), to end users. Recent growth areas have been direct broadcast and mobile services. Direct broadcast services use relatively high-power satellites to distribute television programs directly to homes (DTH). For mobile satellite services, communication takes place between a large fixed earth station and a number of smaller earth terminals installed on vehicles, ships, boats, and aircraft. A good telecommunications infrastructure has been recognized as a critical element for economic development. Many developing countries which lack a domestic telecommunications infrastructure have deregulated satellite-based and other telecommunications services as a means of stimulating and sustaining economic growth. For example, a recent International Telecommunications Union (ITU) report (March 1998) states that 75 percent of all communications traffic today is provided under competitive market conditions, compared with just 35 percent in 1990. The growth in traffic as world economies become truly global has attracted many private and regional satellite operators, with several new systems being planned for operation beyond the year 2000.

The INTELSAT satellite system provides the best example of the historical evolution of a satellite network. For example, the first generation of satellites (INTELSAT I), which was launched in 1965, could only support 240 voice circuits or one black and white video signal. In contrast,

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the latest generation of INTELSAT satellites (INTELSAT VIII) contains more than 44 transponders and provides a traffic-carrying capacity of 60,000 to 80,000 two-way telephone channels, together with multiple video channels. In parallel with this impressive capacity increase, global satellite network services have evolved toward a complete digital network, accompanied by improvements in the quality of service. These advances have been driven by the need to increase bandwidth utilization efficiency, innovations in coding and compression techniques, the trend toward intelligent networks, and the overall digitization of terrestrial networks.

Time-division multiple access (TDMA) techniques were first applied in the early 1980's with the INTELSAT V series of satellites, to increase bandwidth efficiency. TDMA is a very flexible technique in which information is sent in bursts to the satellite in a time-sequenced fashion, so that no bursts overlap when they arrive at the satellite. The duration of the bursts can be assigned based on the traffic needs of each user. Satellite-switched TDMA (SS-TDMA) operation was introduced in the next series of satellites (INTELSAT VI) to achieve cyclic and dynamic interconnections among six isolated coverage beams—further enhancing bandwidth efficiency and frequency reuse. Advances in digital device technology have made TDMA terminals low-cost, and easy to use and maintain.

Another significant development has been the emergence of very small aperture terminals (VSATs), located close to customer premises for thin-route and fixed dedicated services. These terminals have traditionally been operated as single, fixed, assigned-bandwidth carriers, with cost being assessed on a monthly fixed-bandwidth basis. Recently significant progress has been made in developing VSAT products which can provide service to customers at a cost based on the use of capacity in bit increments. For example, the LINKWAY 2000™ technology developed at COMSAT Laboratories enables single-hop mesh satellite networks with switched bandwidth-on-demand services for voice, video, data, and multimedia applications. Unlike conventional VSAT systems, system capacity is allocated for both circuit- and packet-switched traffic in a dynamic fashion, providing bandwidth on demand. The system uses multifrequency TDMA to achieve very high efficiency and flexibility in satellite bandwidth management. In the near future, systems like LINKWAY 2000 will provide ATM, frame relay, ISDN, and Signaling System #7 (SS#7) interfaces for state-of-the-art mesh network connectivity.

For the new satellite systems, both earth stations and satellites must provide enhanced processing and switching so that the satellite networks are fully integrated with terrestrial networks. Ultimately the demarcation between satellite and terrestrial networks will fade, and the resulting seamless integration between the two systems will provide the infrastructure for a global information highway.

ADVANCED COMMUNICATIONS TECHNOLOGY SATELLITE (ACTS)

Many technologies adopted by emerging advanced satellite communications systems may be traced back to NASA's Advanced Communications Technology Satellite (ACTS) program. The ACTS system was developed by GE Astro Space (for the spacecraft bus), Motorola (for the onboard baseband processor), and COMSAT Laboratories (for the ground segment) in the 1980s, and the spacecraft was launched in September 1993. It has since been used successfully as a platform for numerous experiments and demonstrations by U.S. industries, universities, government agencies, and foreign organizations.

The ACTS system incorporates several advanced payload technologies that demonstrate new system concepts, including the use of Ka-band spectrum (30-GHz uplink and 20-GHz downlink), narrow spot beams with beamwidths ranging from 0.25° to 0.75° (at 30 GHz), two independently steerable hopping beams for uplink and downlink, an onboard baseband processor (BBP), a wideband dynamic microwave switch matrix, and real-time BBP control by TDMA bursts. The BBP performs demodulation and forward error correction (FEC) decoding of uplink TDMA signals, circuit-switching of individual 64-kb/s traffic channels, multiplexing, FEC encoding, and remodulation for high-speed downlink transmission. The system also provides demand assignment of bandwidth for individual calls, as well as dynamic rain fade compensation using adaptive FEC coding and rate reduction. These features are implemented by precise timing coordination among the Master Control Station, reference station, onboard BBP controller, and user terminals.

In recent years, numerous experiments and demonstrations have been performed using the ACTS system. These include ISDN, frame relay, and Internet using T1 VSATs; high-definition video transmission; global broadcast services; health care; long-distance education and training; emergency and disaster recovery operation; gigabit networking at 622 Mb/s; and high-speed aeronautical, maritime, and land mobile communications. In addition, extensive Ka-band propagation measurements have been made to quantify the effects of Ka-band rain fade on signal performance and assess the advantages of rain fade mitigation techniques. The ACTS program is expected to continue with new planned experiments and demonstrations until at least the year 2000.

The success of the ACTS technology demonstration program has provided an impetus for the development of a myriad of new-generation satellite systems by commercial organizations. Examples include the use of a large number of narrow spot beams by virtually all proposed PCS, Ka-band, and Q/V-band systems. Some systems use over 300 beams per satellite. Teledesic employs 64 hopping beams, each covering nine dwell areas. Onboard baseband processing has been adopted by Iridium, ICO, ACeS, Astrolink, Teledesic, Spaceway, Celestri, and many other emerging satellite systems. New processing technologies such as multicarrier demultiplexing and demodulation of a large number of carriers, fast packet switching based on header information from individual packets, and digital beamforming networks have been proposed. These technologies inherit or extend those used in the ACTS system.

SATELLITE SYSTEMS FOR PERSONAL COMMUNICATIONS

Satellite-based PCS are designed to provide narrowband voice and data services to small handheld terminals. This concept evolved from the highly successful Inmarsat system, which began in 1980 by providing communications through low-power global geostationary orbit (GEO) satellites and 1- to 1.5-m mobile antennas, and then to briefcase-size terminals using the Inmarsat 2 series of satellites launched in 1990. In addition, many regional systems such as those in Mexico, Australia, Europe, North America, and India provide communications to small mobile terminals. Currently the Inmarsat system can provide communications via the high-power Inmarsat 3 series of GEO satellites, launched in 1996, to mini-terminals as small as laptop computers.

The recent introduction of these small terminals can be considered the precursor to systems that can communicate directly with cellular-type handheld telephones. For satellites to provide link margins of some 10 to 16 dB to low-gain handheld terminals, the satellite antennas must focus very narrow-diameter (300- to 400-km) spot beams on the earth's surface. This translates into satellite antenna diameters that range from 1 m at a low earth orbit (LEO) of 700- to 1,800-km altitude, to 3 to 4 m for medium earth orbit (MEO) of 9,000 to 14,000 km, to 12 m for GEO at 35,760 km.

In 1990, Motorola took the lead toward providing PCS services by announcing the Iridium system of 77 LEO satellites, which was subsequently reduced to a 66-satellite system. This announcement initiated a flurry of activity in the communications satellite industry, resulting in a large number of systems being proposed with orbits ranging from LEO, to MEO, to GEO. Some of these systems are now in the advanced stages of either development or deployment, with the Iridium system due to begin operation in September 1998. The Globalstar LEO system of 48 satellites is targeted for operation in 1999, and the ICO Global MEO system of 10 satellites is scheduled for operation in the third quarter of 2000. In addition, both the Asia Cellular Satellite System (ACeS) and Thuraya GEO regional systems are currently under development, with ACeS scheduled for deployment in 1999 and Thuraya for the year 2000.

BROADBAND SATELLITE COMMUNICATIONS SYSTEMS

In contrast to handheld PCS systems, broadband satellite communications typically operates at bit rates ranging from hundreds of kilobits per second to hundreds of megabits per second, and is primarily targeted for business and home users with low-cost fixed user terminals. Mobile applications are also being considered by some systems. Service applications include high-speed Internet access, intranet communications, home shopping, software downloading, multimedia communications, telecommuting, distance learning, telemedicine, and other voice/data /audio/video/image-based communications services.

In the past, because of its relatively high cost, broadband satellite communications has been limited to large business users and international carriers. This situation will change dramatically in the near future with the introduction of a number of Ka-band (30/20 GHz) and V-band (50/40 GHz) satellite communications systems. These frequency bands are currently in very limited use worldwide, and hence are easier to coordinate with existing systems. Also, a large bandwidth (exceeding 1 GHz) is available for new services. In the U.S. alone, more than 10 Ka-band satellite systems (more than 70 worldwide) have been proposed, including Astrolink by Lockheed Martin, Cyberstar by Loral Space and Communications, Spaceway by Hughes Communications, Millennium by Motorola, and Teledesic by Teledesic Corporation. All but Teledesic are GEO-based worldwide systems, whereas Teledesic provides global coverage using 288 LEO satellites. Motorola has recently proposed a new system called Celestri which combines Millenium (Celestri GEO), Ka-band Celestri LEO, and V-band M-Star systems. All of these systems require large investments. For example, the construction and launch costs of Celestri LEO and four Millennium satellites are estimated to be in excess of US$10 billion.

More recently, 15 V-band systems (in addition to M-Star) were filed with the U.S. Federal Communications Commission (FCC), including CyberPath by Loral Space and Communications; Expressway, SpaceCast, and StarLynx (three systems) by Hughes Communications; GESN by TRW, GE*Star Plus by GE Americom; GS-40 by Globalstar L.P.; Orblink by Orblink, LLC; Pentriad by Denali Telecom; Q/V Band by Lockheed Martin; VBS (V-Band Supplement) by Teledesic Corporation; and V-Stream by PanAmSat. These systems employ a variety of orbits (GEO, MEO, LEO, and hybrid), and most utilize onboard RF switching or baseband processing, and microwave or optical intersatellite links.

Some notable non-U.S. systems currently under consideration are Euroskyway (Ka-band GEO) by Alenia Spazio of Italy, SkyBridge (Ku-band LEO) by Alcatel of France, WEST (Ka-band GEO/MEO) by Matra Marconi of France, and Astra K by SES of Luxembourg. Sky Station International, based in Washington, D.C., proposes to use a balloon in the stratosphere (at approximately 23-km altitude) to provide low-cost multimedia communications services in the V-band.

Successful development and operation of the proposed broadband satellite systems must overcome numerous technical and financial challenges, such as the design of multibeam antennas, onboard baseband processors, and optical intersatellite links; frequency coordination; landing rights; financing; and marketing. In addition, the development of user terminals costing around US$1,000 will be critical to the success of the systems. Another factor is the size of the market, which may be large enough to accommodate only a few global systems. Nonetheless, significant advances in satellite communications technology will be made in the next few years.

KEY TECHNOLOGIES

The large increases in capacity attained for early INTELSAT satellites were made possible by innovations in lightweight filter technology for contiguous transponder channelization, frequency reuse through polarization and spatial isolation, and advances in beam-forming networks (BFNs) and shaped reflectors for narrow beams with increased gains. The success of future satellite systems will be critically dependent on the development of multibeam satellite antennas systems with large (10 to 12-m) deployable reflectors, as well as active phased-array antennas with beam steerability and hopping to provide flexible capacity and power-sharing among the beams.

In recent years, the miniaturization of RF subsystems through the use of gallium arsenide (GaAs) monolithic microwave integrated circuits (MMICs) has made practical the manufacture of space-qualified, lightweight, active phased-array antennas with flexible scanning and steering of multiple spot beams. However, power dissipation and heat removal from these arrays presents a major technological challenge for many of the proposed LEO, MEO, and GEO satellite systems. Technologies that can perform more onboard beam-forming, connectivity, and processing functions with less power, mass, and size will become increasingly important. To this end, low-loss RF integrated circuit (RFIC) control components and power-efficient gain blocks, as well as highly efficient linearized solid-state power amplifiers (SSPAs), are extremely important. Developments in optical techniques for beam-forming and intersatellite links also hold promise. Onboard digital processing technology is very critical for signal demultiplexing and demodulation of a large number of carriers, onboard routing of individual ATM cells according to destination beams, and high-speed downbeam multiplexing and modulation. Development of low-power application-specific integrated circuits (ASICs) with high integration densities and radiation tolerance is critical to the realization of several on-board digital signal processing and control functions.

Terrestrial communications networks are evolving rapidly in response to the complex and stringent requirements of new services. A new generation of satellite ground infrastructure is being developed to exploit the unique advantages of satellite systems, such as the ability to provide broadcast coverage, bandwidth on demand, and rapid deployment. Along with these technology developments, reduction in the cost of terminal equipment will be critical to the business success of many of the proposed systems. The developments in low-cost, flat-panel printed antennas, that are easy to manufacture, is critical to meeting cost-reduction goals. In addition, low-cost and low-power-consumption RF integrated circuits at Ku-band, Ka-band, and higher bands, together with low-cost digital processors with integrated functionality, are needed to substantially reduce the cost of user terminals.

SUMMARY & CONCLUSIONS

Satellite communications is thriving in today's telecommunications market and will continue to interoperate with other transmission media to achieve the grand vision of a global information highway. Satellite systems will employ increasing levels of digital signal processing, in both the space and ground segments, to efficiently and cost-effectively provide the broad spectrum of services demanded by end users. Geostationary and non-geostationary satellite systems—using technologies such as bandwidth on demand, TDMA, onboard processing, switching and large multibeam antennas with hopping spot beams will work seamlessly with terrestrial systems to offer the very best in systems and services to consumers.