DISS 740 Term Report: Satellite Broadband Communication Networks

by

Ronald G. Wolak
wolakron@scis.nova.edu

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School of Computer and Information Sciences
Nova Southeastern University

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Broadband technologies for LANs and WANs are evolving at a dramatic pace. The competing technologies include cable modem, xDSL, LMDS, all-optical, and broadband satellite. Broadband satellites are the dark horse in this race having the potential to quickly provide uniform global coverage at bi-directional access speeds in excess of 1 Mbps. Over the next five years, satellite broadband communication networks will begin global operation. These networks will have a significant impact on data communications in the 21st century. The enormous demand for high-speed networking, recent advances in technology, and new regulations are expediting the implementation of high-speed satellite networks. In the following pages, this paper began with a background discussion of satellite communication technology and services as they currently exist along with a look at where the technology is heading. The paper also highlighted the effect of NASA's Advanced Communication Technology Satellite Project on the communication satellite industry. Next, a detailed look at the emerging broadband satellite networks was presented. Upcoming geostationary or geosynchronous earth orbit, medium earth orbit, and low earth orbit satellite networks were discussed. These included Astrolink, CyberStar, Spaceway, SkyBridge, and Teledesic/Celestri. Finally, deployment issues facing broadband satellite service providers were explored. Issues of concern included latency and quality of service, network security, loss of service, congestion, and interoperability.

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Broadband technologies for LANs and WANs are evolving at a dramatic pace. The competing technologies include cable modem, xDSL, LMDS, all-optical, and broadband satellite. Broadband satellites are the dark horse in this race having the potential to quickly provide uniform global coverage at bi-directional access speeds in excess of one megabit per second (Mps) (Pioneer Consulting, 1998). Over the next five years, satellite broadband communication networks will begin global operation. These networks will help redefine high-speed networking in the next century by providing point-to-point data transfer rates of 2 Mbps, 20 Mbps, and even 155 Mbps anywhere on Earth.

Satellite broadband communication networks will have a significant impact on data communications in the 21st century. The enormous demand for high-speed networking, recent advances in technology, and new regulations are expediting the implementation of high-speed satellite networks. In well-developed areas such as the U.S. and Europe, satellite systems will compete primarily in the "last mile" where very little high-speed infrastructure exists today. However, in underdeveloped and rural areas, broadband satellite systems will provide the total network infrastructure. Conservative estimates suggest that more than 500 broadband satellites will be in service in the next 10 years. The bulk of these satellites will operate in the newly released Ka-band.

In the following pages, this paper begins with a background discussion of satellite communication technology and services as they exist today along with a look at where the technology is heading. This section also highlights the effect of NASA's Advanced Communication Technology Satellite Project on the communication satellite industry. Next, a detailed look at the emerging broadband satellite networks is presented. Upcoming geostationary or geosynchronous earth orbit (GEO), medium earth orbit (MEO), and low earth orbit (LEO) satellite networks are discussed. These include Astrolink, CyberStar, Spaceway, SkyBridge, and Teledesic/Celestri. Finally, deployment issues facing broadband satellite service providers (SSPs) are explored. Issues of concern include latency and quality of service, network security, loss of service, congestion, and interoperability.

Background

In 1993, NASA launched its Advanced Communication Technology Satellite (ACTS). The ACTS project provides for the development and flight test of high-risk advanced communications satellite technology. ACTS systems use advanced antenna beams and advanced on-board switching and processing systems. The NASA ACTS Project pioneered the testing of an all-digital, Ka-band, spot-beam GEO satellite system. This early research was responsible for the broadband satellite systems that will shortly go online (McMasters, 1998). ACTS is currently developing communications satellite technology for:

- Operating in the Ka-band (30/20GHz) where there is 2.5 GHz of spectrum available.

- Very high-gain, multiple hopping beam antenna systems which permit smaller aperture Earth stations.
- On-board baseband switching which permits interconnectivity between users at the circuit level.
- A microwave switch matrix which enables gigabit per second communication between users.

As a result of NASA's pioneering research and the interest it stimulated, the FCC granted orbital locations and Ka-band licenses to 13 companies in early 1997 (Montgomery, 1997). A few of those companies were EchoStar, Hughes, Loral, Motorola, Ka-Star, NetSat 28, PanAmSat, and Teledesic.

Worldwide broadband satellite services are on the verge of a colossal growth period, according to research conducted by Frost & Sullivan. Corporate use of the technology to support enterprise networks will drive the market to $9.4 billion in worldwide service revenues in 2004 alone (Frost & Sullivan, 1998). In addition, the emergence of the new satellite service providers will significantly increase sales of satellites and satellite earth stations. Frost & Sullivan estimates that cumulative investment in broadband satellites will be greater than $18 billion from 1998 to 2004. In addition, the total investment in ground systems is forecasted to reach $7 billion from 1998 to 2004.

Although widespread deployment of GEO and LEO Ka-band satellites will not take place until early in the next decade, implementations using conventional satellite technology have emerged. The best example is the growing use of satellites by Internet service providers (ISPs) outside the United States. These ISPs use satellite links to bypass the multiple router hops and overseas fiber bottlenecks that normally impede overseas data communications. For example, Eutelsat (Europe's largest satellite operator) is in the process of launching a new generation of telecommunications, television, and multimedia satellites (Eutelsat, 1998).

Another growing use of satellites is for local loop bypass. Corporations and consumers currently use satellites to bypass the congestion of the public telephone network. This application competes with ISDN, cable modem, and xDSL technologies. DirecPC (Hughes Network Systems), ESS Network and Dish Network (EchoStar Communications) are examples of this service. These services typically require the installation of a satellite dish cabled to an expansion board plugged into a personal computer. The downlink from the satellite to local dish typically achieves transfer rates of up to 400 Kbps, while the uplink (made through a local ISP) is greatly reduced and dependent upon the medium used (Brownstein, 1997).

Broadband GEO/MEO Satellite Service Providers

GEO satellites orbit 22,282 miles above the equator while MEO satellites orbit 6,000 miles above the earth. Unlike GEOs, which travel at earth speed and appear fixed over the same spot, MEOs revolve around the globe. Virtually all satellites used today for corporate networks are GEOs (Gareiss, 1997). The main application deployed on these satellites is one-way broadcasting. Companies are increasingly relying on GEO satellites for point-to-multipoint transmissions. GEOs are also used for point-to-point communications in order to augment and backup private networks.

The most common GEO data service is VSAT (very small aperture terminal). VSAT networks are quite simple. Typically, customers install a router that's connected either to a satellite dish on site or to landlines leading to a gateway managed by a satellite service provider. At remote sites, a small dish (one and a half feet high by three feet wide) is connected via coax to a digital interface unit (DIU). The DIU acts like a router and connects to an Ethernet or token ring LAN. Comsat, Panamsat, Hughes, GE Spacenet, Telesat, and Orion are examples of GEO VSAT satellite service providers.

In the next five years, major broadband GEO and MEO satellite networks will be going online. These networks will support bi-directional data rates far greater than today's VSAT services. Astrolink, CyberStar, and Spaceway are broadband GEO and MEO systems that will be deployed in the near future. The following is closer look at these satellite services.

Astrolink

Astrolink is a $4 billion initiative that is jointly owned by Lockheed Martin and international network operators. Astrolink will be an ATM-based, Ka-band, GEO satellite system. Nine satellites are planned, but only a total of five are needed for global connectivity. The service will offer broadband data services from 128 Kbps to 155 Mbps starting in 2001 (Salamone, 1997).

The Astrolink system will include advances such as on-board processing and spot beam technology. System security will be assured through public key and smart card technology. Optional session encryption will be available depending on local regulation. Up to 100 gateways will connect Astrolink to terrestrial networks worldwide. Intersatellite with data rates of 440 Mbps will be employed.

CyberStar

Loral Space & Communications' CyberStar satellite network announced the commercial availability of its broadband satellite service in October 1998 (Clonan, 1998). The $1.6 billion system is a GEO-based open protocol, digital system that offers a variety of low-cost, high-speed, data and telecommunication services from Ku-band satellite transponders. CyberStar services currently support high bandwidth IP-multicast solutions for intranets, extranets, and virtual private networks via the Loral Skynet operated Telstar 5 satellite. CyberStar is the only provider with plans to concentrate exclusively on direct sales to large and small businesses as well as consumers (Hudgins-Bonafield, 1998)

In late 1999, service will migrate to a dedicated constellation of Ka-band GEO satellites. CyberStar's Ka-band satellites will each have 72 independent spot beams, according to Herschel Stiles, executive director for advanced CyberStar development. This is more than any other communications satellite, including NASA's Advanced Communications Technology Satellite. Unlike other satellite systems, CyberStar satellites will not communicate with one another. They will communicate only with users and gateways on Earth.

CyberStar is also promoting the use of its system to distribute motion pictures with direct digital distribution via IP multicasting. The company was the first to distribute a full-length movie directly to theaters in five U.S. cities over its Digital Distribution Service in October 1998 (Cholewka, 1998).

Spaceway

The Hughes Communications', Inc. (HCI) Spaceway global broadband communications system is a combination of 8 GEO satellites and 20 MEO satellites (Greene, 1997). Both systems will operate in the Ka-band frequency range. As proposed the Spaceway system will provide 100 percent coverage in four regions: North America, Asia Pacific, Latin America, Europe, Africa, and the Middle East. Service in the first region will begin in 2002. The other three regions will be online by 2004.

Spaceway's "bandwidth-on-demand" capability will provide consumers and businesses with fast access to terrestrial networks (e.g. the Internet, Intranets, and LANs). The system's Ultra Small Aperture Terminal (USAT) receivers will be 26 inches in diameter and provide uplink speeds up to 6 Mbps. Downlink speed will be 108 Mbps. In addition, the system is fully compatible with a wide range of terrestrial transmission standards such as ATM, ISDN, Frame Relay, and X.25.

The Spaceway GEO constellation will focus on high data rate transport market and will operate from four orbital locations. In contrast, the Spaceway MEO constellation will provide interactive broadband multimedia communications services in high traffic markets globally. Spaceway's MEO constellation will consist of four planes with five satellites in each plane. Orbits will be circular at 6,433 miles. Spaceway satellites will use multiple-beam antennas, and intersatellite links (ISLs). A signal received by one satellite could be relayed directly back to the same beam, switched to another beam, or relayed by intersatellite links to other satellites.

Broadband LEO Satellite Service Providers

LEO satellites orbit 500 to 600 miles above the earth. Since they are much lower than the 22,282 mile-high GEO satellites, LEO signals make the round trip from earth much faster. In addition, low-powered pizza-sized dishes and hand-held devices may be used. LEOs are better suited to interactive voice and data applications. Unlike GEOs, which travel at earth speed and appear fixed over the same spot, LEOs revolve around the globe every couple of hours. Therefore, the same satellite that offers telecommunications services to people in New York and Paris as it passes overhead can offer those same services to remote areas it passes over (Sykes, 1998).

Since a single LEO satellite is in view for only 20 to 30 minutes, multiple LEOs must be used and each must be acquired and tracked by ground stations (Montgomery, 1997). Phased-array technology is used for aiming antennas at these fast moving LEOs. Unlike a satellite dish, which mechanically tracks satellite locations, phased-array antennas are self-aiming boxes consisting of many smaller antennas. They are able to track several satellites using the slightly different signals received by the array of antennas (without physically moving). The problem of keeping a link active when the satellite disappears every half hour is overcome by keeping at least two satellites in view overhead at all times (Teledesic plans to keep three or more in view). The phased-array antenna is aware of the positions of all the satellites and starts a new link before it severs one.

LEO satellite service providers are classified in three major groups, which are distinguished by the terrestrial services each provides. These groups are little LEOs, big LEOs, and broadband LEOs (Kohn, 1996). Little LEOs (e.g. Orbcomm) provide satellite paging services. Their networks operate below one GHz and use store-and-forward messaging. They provide services requiring only low data rates such as paging, remote monitoring, and vehicle tracking. Big LEOs (e.g. Globalstar, ICO, and Iridium) offer the satellite equivalent of cellular telephone service. They operate in the spectrum between one and three GHz.

Broadband LEOs, once operational, will provide service equivalent to fiber-based broadband. The spectrum in which they operate is the Ka-band (17.7 - 30.0 GHz). This frequency band was allocated in 1995 by the ITU - World Radio Conference for use in non-geostationary satellite systems (NGSO). The Ka-band, with its millimeter-sized wavelengths, provides the spectrum required to support broadband data rates. In addition, the Ka-band requires line-of-sight from the user terminal to the satellite. Consequently, broadband LEO-based networks are more suited for fixed, maritime, and aviation applications where line-of-sight is not a problem. SkyBridge and Teledesic are broadband LEO systems that will be deployed in the next decade. The following is closer look at these revolutionary satellite services.

SkyBridge

SkyBridge is the Alcatel Espace SA-led $4.2 billion satellite venture that is expected to be operational by 2001 (Slater, 1997). Partners include Lorel Space & Communications, Toshiba, Mitsubishi, Sharp, Spar Aerospace, and Aerospatiale. SkyBridge will offer Internet access, videoconferencing, LAN and WAN connections, and interactive entertainment services with data transfer rates as fast as 20 Mbps downstream and two Mbps on the uplink. System capacity of 200 Gbps is expected to meet the needs of 400 million users anticipated by 2005 (Dietrich, 1998).

SkyBridge officials recently expanded the system from 64 to 80 LEO satellites. The network now consists of two constellations of 40 satellites orbiting at an altitude of 913 miles. Each satellite illuminates an area of 1,864 miles in radius. There is at least one satellite visible within the coverage area of each terrestrial gateway. However, most of the time at least two and up to four are visible and available to receive traffic.

Unlike other broadband LEO systems, SkyBridge selected the Ku-band (10 - 18 GHz) instead of the Ka-band (Montgomery, 1997). According to Mark MacGann, director of SkyBridge public affairs, the lower Ku frequency band lets SkyBridge be the “cheapest system in low earth orbit." At the lower frequency, SkyBridge is able to use less powerful (and less expensive) transmitters. However the Ku-band is also very crowded, and many GEOs already use the spectrum. SkyBridge satellites will be susceptible to increased interference from these GEOs when they are over the equator. SkyBridge will solve this problem by shutting off transmission when a satellite is plus or minus 10 degrees from this zone. Ground terminals will then switch to another satellite.

SkyBridge will also bring down costs by using a combination of transmission methods (i.e. satellite links for local access and existing terrestrial broadband networks for long-distance connections). The use of satellite links only when absolutely necessary reduces the overall end-to-end costs.

Teledesic/Celestri

Teledesic is a privately held satellite service provider that was spun off from McCaw Cellular in 1994 in order to creating a high-speed, wireless, switched global network designed to handle two-way voice, video, and data traffic. Teledesic's web site best sums up its corporate vision with the following broad and rather amazing statement:

> "Teledesic is building a global, broadband "Internet-in-the-Sky." Using a constellation of low-earth-orbit satellites, Teledesic and its partners will create the world's first network to provide affordable, worldwide, "fiber-like" access to telecommunications services such as broadband Internet access, videoconferencing, high-quality voice and other digital data needs. On Day One of service, Teledesic will enable telecommunications access for businesses, schools, and individuals everywhere on the planet."

The Teledesic network is configured with a constellation of 288 LEO satellites. These satellites will blanket the earth and transmit in the 18 GHz and 28 GHz range and provide the equivalent of 20,000 T1 lines to 100% of the Earth's population and 95 percent of the landmass (Teledesic, 1998). Qualities of Service levels are expected to equal fiber-based terrestrial networks. Data will be switched from one satellite to another at rates of one Gbps, simulating an Internet in the sky. Corporations and consumers in third-world countries will have the same accessibility as those in developed countries. The service is expected to be operational in 2003 at a cost of $9 billion. It will be the single largest and most ambitious communications project ever undertaken.

Teledesic's major investors include Craig McCaw, Bill Gates, AT&T Wireless Services, Boeing, and Motorola. Motorola's plans to compete with Teledesic were changed recently when the two companies announced that Motorola's Celestri project would be folded into Teledesic. As part of the merger agreement, Motorola received a 26 percent stake in Teledesic. Motorola is now responsible for the design and engineering of the 288-satellite system. Also included are the groundstations and the network, according to Steve Hooper, co-chief executive officer of Teledesic (Sykes, 1998).

The Teledesic network will consist of a ground segment (e.g. terminals, network gateways, and network operations and control systems) and a space segment (e.g.

satellite-based switch network). Teledesic terminals will interface with the standard network protocols (i.e. IP, ISDN, and ATM). The network will be optimized for fixed-site terminals but will work with mobile applications (e.g. aviation and maritime). Standard terminals will have two-way connection rates of up to 64 Mbps on the downlink and up to two Mbps on the uplink. High-speed broadband applications will have bi-directional 64 Mbps connections.

Within Teledesic's satellite constellation, each satellite is a node in the fast-packet-switch network. Satellite nodes also have intersatellite communication links with other satellites in the same and adjacent orbital planes. Interconnection in this manner provides a robust non-hierarchical mesh, or "geodesic," network that is fault tolerant. The Teledesic network combines the advantages of a packet switched network with those of a circuit switched one.

Teledesic's marketing plans do not include competing with terrestrial companies. "Our main objective is to connect users to the nearest available fiber," commented David Twyver, company president (Gareiss, 1997). Twyver also estimated that at least 20 percent of the world would not have any fiber access. Teledesic plans to work with one or more service providers in each country. The providers will resell the service. Twyver also commented that service costs would be comparable to or below terrestrial offerings.

Issues

As broadband SSPs begin launching satellites and activating their networks during the next few years, they will have many technical obstacles to overcome. Issues of concern include latency and quality of service, network security, loss of service, congestion, and interoperability.

Latency and Quality of Service

GEO satellites orbit 22,282 miles above the equator. At that height, GEO satellites travel at the same speed as the earth's rotation, thus appearing stationary. GEOs are excellent for multicasting, but produce unacceptable half-second delays in interactive voice and data communications. This latency (inherent in GEOs) is the source of the delay experienced in many intercontinental telephone calls. Since users are not willing to accept this annoyance, many of these systems are being phased out. Latency is noticeable in voice communications when the round-trip delay is greater than 100 to 200 msec.

In fact, the greater this delay becomes the lower the bandwidth the system is able to support. The severity of the delay is also dependent on the size of the buffers used to store transmitted data. Buffer sizes are typically determined by the transmission protocol. MEO satellites orbit 6,000 miles above the earth. Signal delay times are significantly reduced as a result of their lower orbits. However, they do not remain stationary over the same spot and are in view for a couple of hours.

Originally, engineers thought that buffers would severely limit the bandwidth that would be possible in satellite ATM and TCP/IP networks. However, NASA demonstrated in

1997 that TCP/IP over satellite is capable of data rates of 622 Mbps (Salamone, 1997). The team of engineers, working at NASA Lewis Research Center, has proposed TCP over satellite (TCPSAT) to fix inherent flaws in the TCP protocol (Lange, 1998).

For GEO systems, a priority will be given to solve the problems caused by long-delay transmission paths from their satellites, along with the performance of the TCP standard in that environment. TCP uses an algorithm called "slow start" to make sure a new TCP transmission does not overload a path. This doubles the bandwidth used after each round trip through the network. The vast distances covered by GEO satellite links cause longer transmission delays because it takes more time for TCP to get up to speed (Gillespie, 1997).

When the round-trip is 500 msec or more, as in GEO systems, the communication session often ends before the connection ever reaches the full bandwidth of the link. GEO satellite provides are attempting to solve this problem with a technique called "spoofing." Spoofing involves sending fake responses in order to keep the TCP session active and prevent timeouts. However, spoofing is not effective with interactive real-time applications.

For example, a typical client/server transaction such as updating a customer record from an SQL Server across the country may take 20 round-trip transactions. This transaction over a fiber or LEO connection typically takes.75 to 1.5 seconds. Over a GEO network, the same transaction would take at least 10 seconds. Although both LEO and GEO networks may offer the same nominal bandwidth, the GEO communication much longer because of the inefficiency many small transaction required by the high-delay GEO network.

On the other hand, LEO systems do not have a problem with transmission latency, but have to address the issue of matching the bit-error performance of currently deployed terrestrial network facilities. Matching land-based system quality is important since these performance expectations are an integral part of the design of common protocols such as TCP and ATM (Gillespie, 1997).

LEO systems use small, low-powered satellites that transmit to remote computers that have little power themselves. This low transmitter power, combined with high data rates, increases the probability that data will be lost in transit. According to Hans Kruse, associate professor at the McClure School of Communication System Management at Ohio University, "Ultimately, it's all a power problem. LEOs may have to match the bit-error probability of terrestrial lines before they can match the performance possible with those terrestrial lines."

Network Security

In a recent survey of leading broadband satellite companies, most were unwilling to discuss security (Bonafield, 1998). The main reason for the secrecy is that their systems switch traffic across national borders. In addition, the majority of these providers fall under U.S. restrictions on the export of strong encryption. Another factor complicating the security issue is that broadband GEO systems will have great difficulty solving the technical requirements of low latency combined with end-to-end encryption.

Although most businesses with sensitive data will secure their transmissions end-to-end, they will also want satellite service providers to employ strong link encryption to prevent a satellite takeover and to protect critical network information. Winning approval from the U.S. government to use the strong encryption required will not be easy. Charles Smith, president of security consultancy Softwar, suggested one possible outcome is that U.S.-based constellations would launch with strong encryption used only within U.S. boundaries.

Under this scheme, broadband satellite providers would encrypt uplinks to satellites over the U.S., but downlinks to other nations would not be encrypted. Recently Motorola was able to gain permission to encrypt its Iridium wireless telephone traffic in China because it hired a well-known former National Security Council member to work for the company. This accomplishment demonstrates how the vagueness of current encryption laws allows their implementation to become a matter of bureaucratic discretion.

GEO satellite system security will be further complicated due to the incompatibility of end-to-end security schemes like standards-base IPSec (IP Security) and the TCP spoofing required to bring GEO transmissions up to speed. Security experts indicate that IP spoofing and IPSec are incompatible because once a transmission is encrypted, it is impossible for an outside entity such as a satellite service provider to see into the packets to perform spoofing. This is also true when TCP is encapsulated in ATM.

Another security issue for broadband satellite providers lies in their widespread use of ATM. Link encryption is possible on ATM, however a standard for end-to-end cell-based encryption is still evolving. When asked about the technical problems faced by the next-generation satellite companies, NASA officials say they believe that the Department of Defense (DOD) has already solved many of these problems. Existing DOD technology allows for extremely high throughput rates at low power.

Loss of Service

While satellite service providers typically guarantee 99.5 to 99.9 percent availability, solar interference, heavy storms, and equipment failures do affect uptime. For example, during heavy rains, satellite signals degrade and cause service interruptions that typically last five or ten minutes. Equipment failures, though uncommon, can have a major impact on communication system subscribers. In May 1998 when the PanAmSat Galaxy IV satellite had problems, 90 percent of American pagers were disconnected (Craig, May 1998). The event was the first time in 35 years that pagers were silent and virtually all paging companies were affected.

Another threat to the increasing number of satellites is meteor showers. One example is the Leonid meteor shower that occurred in November 1998 (Craig, October 1998). Leonid is a meteor shower that trails the Temple-Tuttle comet as it passes the earth every year. Although the majority of the shower's particles were smaller than a grain of sand, they were traveling at more than 200 times the speed of sound. At that speed, the particles vaporize material on impact. This would devastate the electronics on board the hundreds of broadband satellites that will soon be orbiting the earth. In anticipation of the Leonid shower, operators of existing satellite systems took precautions such as adjusting solar arrays.

Loss of service, regardless of the cause, is prompting satellite service providers to add in-orbit spares to their networks. The number of satellites required by the LEO, MEO, and GEO systems varies with altitude (Miller, 1998). The lowest altitude LEO system (Motorola's Iridium) plans on 66 satellites plus six in-orbit spares. The typical MEO system (Hughes' Spaceway) requires ten satellites plus two spares. Atmospheric drag and radiation from the inner Van Allen radiation belt are expected to limit the orbital life times of LEO satellites (i.e. five to eight years). Therefore, LEO systems will need replacements more often than will MEO satellites, which are expected to last for at least 12 years. However, the cost of launching a smaller LEO satellite into a lower orbit will be less than for the heavier, higher-altitude MEO satellites. The heavier GEO satellites cost the most to launch and build. They also have the longest lifetime (12 to 15 years).

Congestion

As satellite service providers begin the process of launching the hundreds of GEO, MEO, and LEO satellites required to make their networks functional, the potential for congestion (both for orbital slots and for bandwidth) is very real. Each of the satellite networks will have duplicate gateway stations on earth. Each provider will also have to negotiate interfaces between its gateways and the public. The result will be enormous redundancy and the possibility of extensive spectral interference among the various satellite systems and land-based LMDS systems (Cooper & Bradley, 1998).

One solution is a proposal by Paul Cooper and James Bradley. Their proposal calls for the creation of an international Internet organization called the Internet Satellite Access Commission (Internet SAC). Internet SAC would deploy and operate a global satellite network of gateways. Through these gateways, satellite systems would gain access to the Internet. The Internet terrestrial network would interface only with the Internet SAC's satellites. Thus, the gateways could use one simple, fixed, and private protocol and interface architecture.

Interoperability

Government and industry teams in Japan and the U.S. are conducting experiments to develop and demonstrate the role of satellites in the global telecommunications infrastructure (Edelson, 1997). The experiments will help develop satellite transmission techniques, standards, and protocols to determine the best method of integrating satellite links with fiber-optic cables to form high-performance global networks. These trans-Pacific experiments will carry high-speed computer data, high-resolution images, and video for applications such as astronomy, telemedicine, tele-education, digital libraries, and electronic commerce. In addition, engineers conducting the experiments have incorporated them into an international project known as Global Interoperability for Broadband Networks, sponsored by the G-7 leading economic nations.

Conclusion

In previous pages, this paper discussed current satellite technologies and the role NASA's ACTS project played in stimulating broadband satellite technology. Upcoming GEO, MEO, and LEO satellite networks were also discussed. Included were Astrolink, CyberStar, Spaceway, SkyBridge, and Teledesic/Celestri. Finally, deployment issues facing broadband SSPs were explored. Issues included latency and quality of service, network security, loss of service, congestion, and interoperability.

According to analysts conducting research for Motorola, the total telecommunications market is about $650 billion, and it is going to double in the next 10 years (Montgomery, 1997). The enormous demand for bandwidth shows no signs of subsiding. Broadband telecommunications systems (i.e. cable modems, xDSL, LMDS, all-optical technologies, and broadband satellites) will compete in terms of their availability, price, and speed. Broadband satellite networks will play a significant role in this competition and expansion. Gartner Group and Pioneer Consulting both predict that up to 15 percent of all business bandwidth will eventually come from broadband satellites (Hudgins-Bonafield, 1998).

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