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NATIONAL COMMUNICATIONS SYSTEM

TECHNICAL INFORMATION BULLETIN 98-4

SELECTED ASYNCHRONOUS TRANSFER MODE/EMERGING SATELLITE COMMUNICATIONS TECHNOLOGY INTERFACE ISSUES

JUNE 1998

OFFICE OF THE MANAGER
NATIONAL COMMUNICATIONS SYSTEM
701 SOUTH COURT HOUSE ROAD
ARLINGTON, VA 22204-2198

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PROJECT OFFICER:	APPROVED FOR PUBLICATION:
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FOREWORD

Included within the responsibilities of the Office of the Manager, National Communications System (NCS), is the management of the Federal Telecommunications Standards Program. In support of this program, the NCS, with assistance of the Federal Telecommunications Standards Committee, identifies, develops, and coordinates proposed Federal Standards which either contribute to the interoperability of functionally similar Federal telecommunications systems or to the achievement of a compatible and efficient interface between computer and telecommunications systems. These systems constitute a significant element of the overall infrastructure upon which the functioning of Government and the nation's economy is dependent. With increasing frequency, integrated network approaches involving a mixture of both terrestrial and non-terrestrial communications technologies are being used to provide system solutions. Because of fundamental differences between the two environments, frequently interface issues are likely to arise. This report examines from a national security and emergency preparedness (NS/EP) perspective selected Asynchronous Transfer Mode (ATM)/emerging satellite communications technology interface issues. Comments or statements of requirements which may assist in the advancement of this work are solicited and should be addressed to:

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ABSTRACT

Due to its capability to accommodate a broad range of traffic from diverse sources, support high data rates, and provide gains in bandwidth use efficiency, Asynchronous Transfer Mode (ATM) is gaining broad acceptance as the preferred transport mode for broadband terrestrial communications. With increasing frequency, broadband communications solutions are now involving an integrated network approach in which satellites are playing an increasingly significant role. Due to their unique operating environment, satellites offer a number of challenges when used to provide broadband telecommunications support in an integrated ATM network environment. For the most part, current challenges in this arena are the result of fundamental differences that exist between the satellite environment and the influences of the optic fiber environment upon which the development of ATM was initially based. This report presents the results of an examination from a national security and emergency preparedness (NS/EP) perspective of selected ATM/emerging satellite communications technology interface issues.

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EXECUTIVE SUMMARY

PURPOSE

This report presents the results of an examination from a national security and emergency preparedness (NS/EP) perspective of selected Asynchronous Transfer Mode (ATM)/emerging satellite communications technology interface issues.

BACKGROUND

The explosive growth of a wide range of Internet, and other broadband voice, data, and video services and increasing support of the concept of “universal service”ÄÄÄmaking telecommunications universally available at reasonable and affordable ratesÄÄÄare having a major influence on the direction new and emerging telecommunications networks are taking. From an NS/EP perspective, integrated high-capacity transmission networks, which provide speed, accuracy, security, and flexible access to bandwidth-on-demand, are essential requirements for effective multimedia service support. Because of its capability to accommodate a broad range of traffic from diverse sources, support high data rates, and provide gains in bandwidth use efficiency, ATM is gaining broad acceptance as the preferred transport mode for broadband terrestrial communications. However, with increasing frequency, broadband communication solutions involve an integrated network approach in which satellites are playing an increasingly significant role. Due to their unique operating environment, satellites offer a number of challenges when used to provide broadband telecommunications support in an integrated environment. For the most part, the challenges are the result of fundamental differences that exist between the satellite environment and the optical fiber environment upon which the development of ATM was initially based. Specific differences examined in this report include issues of delay, errors, bandwidth limitations, and availability.

OVERVIEW: EMERGING SATELLITE TECHNOLOGY

The ATM-based terrestrial public switched telephone network (PSTN) of the future will continue as the primary means of satisfying the broadband connection needs of the largest percentage of users. Capabilities provided by new and emerging satellite communications systems incorporating advanced technology will play an increasingly significant role as a complement to the PSTN, and in supporting the needs of users for whom direct access to the terrestrial network is not an option. To ensure that the end-to-end transmission path of an integrated ATM-based/satellite network is transparent to the user, it is expected that such systems serving the general public will be fully integrated with the PSTN and the public Internet at the network level. The new generation of satellite systems may be divided into three broad categories on the basis of orbital radius: geostationary (or geosynchronous)-earth-orbit (GEO) satellites, non-geostationary medium-earth-orbit (MEO) satellites, and low-earth-orbit (LEO) satellites. The three types of satellite systems deliver communications services in fundamentally different ways. Their resource management requirements are also different. However, certain parameters such as errors, delay, bandwidth limitations, availability, and the quality of the signal at the terrestrial-satellite system interface are major concerns of all systems in integrated terrestrial/satellite networks. Most of the two-way voice, video teleconferencing, data, and other interactive services currently transmitted commercially by satellite are transmitted by GEO satellites. The circular and direct orbit of GEO satellites lie in the earth's equatorial plane at an altitude of 22,300 statute miles above the earth's equator. While GEO satellite systems have long dominated both the commercial and government communications satellite arena, LEO satellite systems are now emerging as attractive alternatives.

Major factors contributing to the emergence of LEO systems are crowding at geostationary orbital altitudes, propagation delay considerations, advancements made in satellite crosslinking/onboard processing, and the lower costs associated with their launch. LEO satellite systems are designed to provide many of the same kinds of service as GEO systemsÄÄÄe.g., wide area coverage, direct radio path, and a flexible network architecture. However, their orbital altitude is only 500-1,400 miles above the earth as opposed to 22,300 for GEO satellite systems. MEO satellite systems are also non-geostationary. They occupy an orbit between GEO and LEO satellites several thousands of miles above the surface of the earthÄÄÄroughly 2,900 to 7,500 miles. Because of their intermediate orbital altitude, MEO systems are able to provide coverage over a wider area than LEO systems. However, the propagation delay associated with such systems is higher than that associated with LEO systems, but less than the delay experienced by GEO systems. At the 1997 World Radiocommunications Conference, national representatives unanimously approved a global allocation of 600 MHz of spectrum for use by a new telecommunications technology which features lighter-than-air communications stations located at fixed points in the stratosphere. Although such systems are not considered satellites, they are important to the NS/EP community because they offer additional options for extending the capabilities provided by terrestrial-based telecommunications networks.

COMMUNICATIONS SATELLITE MULTIPLE ACCESS FORMATS

Multiple access may be defined as the ability of a number earth stations to interconnect their respective communications links through a common satellite. Several access formats are currently being deployed or scheduled for deployment on new and emerging satellite networks where several earth stations require access to the same bandwidth of a satellite transponder. Networks within the same transponder must use the same format. However, a high-capacity earth station accessing more than one transponder in the same satellite could be configured so as to transmit and receive satellite signals in each format, or a combination of formats. Because of the increased efficiency in frequency and bandwidth utilization offered by time division multiple access (TDMA), code division multiple access (CDMA), and demand assignment multiple access (DAMA) technology, the general trend in current planned deployments appears to reflect movement away from the older frequency division multiple access (FDMA) format to TDMA, CDMA, and DAMA. All are capable of accommodating multirate services, a principal requirement of future multimedia communications.

SELECTED ATM/EMERGING SATELLITE TECHNOLOGY INTERFACE ISSUES

In integrated ATM/satellite communications networks, the interface between the terrestrial ATM network and the satellite network has the function of adapting incoming data to a proper format for transmission via satellite when entering the satellite portion of the integrated network, and vice versa when entering the ATM network portion. The primary requirements for successful transmissions in ATM networks are nearly error-free links, a fixed cell size of 53 bytes or octets, and the maintenance of cell order. Integrating satellites into terrestrial networks is often hindered by qualities that are integral parts of satellite networks. Because of these qualities, a number of technical challenges arise in providing broadband telecommunications support in such integrated environments. For the most part, the challenges are the result of fundamental issues of delay, errors, bandwidth limitations, and availability in the satellite portion of the integrated network. Salient features of each issue are discussed below.

DELAY

The effects of signal delay on the quality of communications is a major consideration in an integrated broadband ATM/satellite networkÄÄespecially for satellites in geostationary orbits. Although propagation delay is the dominant variable in computing total delay in an integrated ATM/satellite communications network, the total delay in such networks is the sum of the delay incurred at user devices, switches, and on both satellite and terrestrial communications links. Delay in the satellite portion of the network is generally large relative to that in the terrestrial portion of the network. The minimum round-trip delay between two earth stations via a GEO satellite connection is approximately 500 ms. Most industry experts agree that the current propagation delay on GEO satellite connections does not affect the accuracy of data transmissions directly. However, it is generally agreed that for optimal real-time voice applications, the maximum round-trip delay between terrestrial endpoints, including hops across satellites, should not exceed 400 ms. Longer delays in such networks can be noticeably distracting to users of some voice applications and during two-way video-conferencing communications.

Long delays may also be detrimental to the performance of some congestion control functions in ATM networks, and some conventional data-related error correction protocols used in satellite networksÄÄÄe.g., the automatic-repeat-request (ARQ) protocol discussed in Section 4.2 of this bulletin. Since at broadband rates, finite-sized queues may quickly overrun buffers during congested conditions, congestion control measures must be executed rapidly in order to be successful. In ATM networks, the two mechanisms used are based on the principles of cell discard and feedback. Selective cell discard allows a congested network element to selectively discard cells identified as belonging to a non-compliant ATM connection and/or cells having the cell loss priority (CLP) bit in the ATM cell header set to 1. While this approach appears to be rather simple from a control standpoint, it has some disadvantages in some situations. The dropping of data on assured connections will require that retransmissions be made. While cell discard may be an efficient process if selective retransmission is used, retransmission on a non-selective basis can be expected to delay the delivery of a substantial number of packets due to the satellite-induced delay that will be added to the network. Additionally, in integrated networks, it appears that it might be difficult to provide quality of service (QoS) guarantees for CLP=1 traffic flows under less than optimal conditions. The objective of congestion control mechanisms based on feedback is to provide the sources of the traffic causing the congestion with sufficient information about the congestion event so that the sending sources can take action to temporarily reduce the traffic load.

Because of the effect delay has on the flow control mechanisms of certain Internet transmission protocolsÄÄespecially the Transmission Control Protocol (TCP), long delays become especially significant in satellite-delivered Internet services. Generally, for real-time communications the shorter the signal delay, the better the performance. The lower delay incurred via LEO/MEO systems will reduce significantly many of the problems of long propagation delay that has become synonymous with GEO satellite communications systems.

ERRORS

In communications networks, error rates are measured in terms of the ratio of the number of bits in error received to the total number of bits transmitted over a stipulated period of timeÄÄÄthe bit error rate (BER). BER is usually expressed as a number and a power of 10ÄÄÄe.g., 2.5 erroneous bits out of 100,000 bits transmitted would be 2.5 x 10^{-5}. Errors can be random or bursty in nature. Random errors are errors distributed over the digital signal in such a manner that they can be considered statistically independent of one another. They are caused by the presence of random noise and low signal-to-noise ratio in a communications link. An error burst is a string of contiguous bits with a very high probability of being in error. Because the extremely low BER characteristics of optical fiberÄÄÄbetter than 10^{-10}ÄÄÄwere assumed when ATM parameters were defined, minimum error correction mechanisms have been included in the ATM protocol. ATM networks do not execute retransmission schemes. They correct cell headers with one-bit errors and discard headers with multiple bit errors. At the expected low BER of optical fiber, the header error control (HEC) field in the ATM cell header is sufficient to correct single bit errors in the header, or detect multiple errors. No error correction is allowed in the ATM cell payload by the core network. When errors are introduced in the payload by the core network, retransmission, if required, is accomplished by the ATM Adaptation Layer (AAL) protocol stacks at the originating endpoint termination equipment.

On satellite communications links, burst errors resulting in large groups of bit errors are common. Bursts of errors are a major concern in integrated ATM/satellite networks. Burst errors on satellite links impact the operation of both the ATM and the AAL protocol layers and their transportation in the Synchronous Optical Network/Synchronous Digital Hierarchy (SONET/SDH) frames. Due to the frequency of occurrence of errors, a number of error correction techniques have been tested on such links. Basically, the techniques tested fall into the categories of forward-error-correction (FEC) and automatic-repeat-request (ARQ). FEC uses certain binary codes that are designed to be self-correcting for errors introduced by the intervening transmission media. In this form of error correction, the receiving station has the ability to reconstitute messages containing errors. However, FEC as currently used works on random errors only. It is generally not effective with burst errors. ARQ is a two-way error correction technique based on feedback. Using this method, data is broken into packets. Within each packet is included an error checking keyÄÄÄoften a mathematical algorithm that computes a numerical value based on the bits in a block of data. If the error code reflects a loss of integrity in a packet, the receiver can request the sender to resend the packet. ARQ requires relatively noise-free channels to be effective. ARQ is not very effective in a channel with high noise levels because the noise that corrupted the initial packets will likely also cause corruption in subsequent packets, thereby requiring repeated retransmissions of the same data.

BANDWIDTH

Because of differences between the extremely high bandwidth offered by optical fiber and the relatively limited bandwidth offered by satellite links, bandwidth management is a significant issue in integrated ATM/satellite communications networks. While satellite links offer bandwidth that is as great or greater than most other transmission media, a satellite's channel capacity is still rather limited compared to the capacity of optical fiber-based ATM networks. In satellite networks, the bandwidth of each channel is fixed, thus requiring the employment of stringent access control techniques for bandwidth management to enable different users to share usage of a common channel or transponder. ATM is basically a connection-oriented system, requiring only the establishment of a connection between two endpoints before data can be transferred between them. In ATM networks, the transmission path is specified during call-establishment, enabling ATM cells to self-route through the network based on information contained in the ATM cell header. Being connection-oriented also allows ATM to specify a guaranteed QoS for each connection, and to efficiently support a network's aggregate demand by allocating bandwidth on demand based on immediate user need. The bandwidth management approach used in ATM networks is a combination of managing and controlling traffic flow, and the statistical multiplexing of ATM cells to accommodate varying traffic submitted to the network.

In satellite networks, supporting different classes of service directly impacts the choice of a channel access/sharing mechanism. Access to any shared satellite channel can be of three typesÄÄÄfixed assigned, contention/random access, or reservation/controlled access. There are also several hybrid access schemes between contention and reservation. However, none of the existing access schemes appear to be optimized for ATM technology. Fixed assigned multiple access schemes such as FDMA and CDMA are comparatively inefficient in a bursty environment with hundreds or thousands of potential users. Contention/random access schemes such as the ALOHA protocolÄÄan access technique named by the University of HawaiiÄÄand the selective reject (SREJ) ALOHA, both require some form of collision resolution, and may be a poor choice for delay-sensitive traffic such as voice/video. In ALOHA, stations transmit new messages on the channel as they are generated. If a collision occurs, the colliding packets are simply retransmitted with random delay, resulting in low efficiency of channel use. With SREJ ALOHA, data are formed into a contiguous sequence of independently detectable fixed-length subpackets, each with its own header and acquisition preamble. The thinking behind this strategy is that most collisions in an asynchronous channel result in partial overlap of contending packets; therefore, only small portions of the subpackets encounter conflict and must be retransmitted. Reservation/controlled access schemes such as DAMA, where reservations can be made by either a contention process or a fixed assigned process, appears to offer several advantages over the other types of access schemes. Specific advantages are: (1) data messages can be scheduled in a conflict-free manner, and (2) well designed DAMA systems can support variable-length message traffic with relatively high overall channel throughput. However, due to the reservation mechanism, the higher throughput is accompanied by a relatively large minimum latency (>0.500 ms) delay. Because of the disparity in bandwidth and data rate which could be serviced in separate parts of an integrated network, the role of buffersÄÄÄroutines or temporary storage used to compensate for a difference in rate of flow of data, or time of occurrence of events, when transferring data from one device or system to anotherÄÄÄis an increasingly important one. Buffering permits traffic shaping, and at the expense of delay, can help to make congestion problems less severe. The ATM Forum Traffic Management Working Group has an ongoing effort to determine the amount of delay incurred in LEO and GEO satellite networks for various buffer sizes and number of sources.

AVAILABILITY

Readiness and dependability of satellite links is generally described by two basic criteria: reliability and availability. Reliability is the ability of a system or subsystem to perform within prescribed QoS parameters. Reliability is often expressed in a more restrictive way to indicate the probability that the system or subsystem will perform its intended function for a specified interval under stated conditions. Availability is a measure of the degree to which a system, subsystem, or equipment is operable and not in a state of congestion or failure at any point in time. High availability from the network user's perspective depends not only on the availability of the equipment comprising the network, but also on the resilience of network routing and data transfer protocols, and sufficient path diversity to ensure accurate and timely information transfer if equipment or transmission path failure occurs. Typically, high-availability satellite systems employ a combination of hardware and software redundancy to recover from system faults and to maintain availability. However, utilization by some emerging communications satellite systems of carrier frequencies above 10 GHz has significant availability implications for satellite links. At such frequencies, satellite links are considered propagation-limited, and the effects of precipitation and other environmental factors must be taken into account. Telephone switching provides an availability benchmark against which the performance of other systems can be measured. A general availability target for telephone switching systems is 99.9999%. This target allows a switch to be out of service for no more than a few minutes each year. Optical fiber-based ATM networks are expected to meet or exceed this availability target.

Satellite providers typically guarantee 99.5% to 99.9% availability. Emerging systems such as Globalstar, promise an uptime of 99.9%. Teledesic and Iridium constellation providers have not set system availability guarantees. However, because of factors such as: (1) reductions in the amplitude of the transmitted signal caused by rain-induced absorption and scattering, or changing path characteristicsÄÄÄe.g., multipath reflections, shadowing, and fading due to satellite hand-off periods; (2) the use of frequency reuse techniques with the potential to cause interference between channels through a transfer of energy from one polarization state to the other orthogonal state (e.g., SDMA); and (3) increased intersatellite interference caused by narrower spacing of satellites due to the limited number of orbital positions available for satellites in geostationary orbit, the availability of satellite links at the planned carrier frequencies is not likely to match the expected availability performance of optical fiber-based ATM networks.

SECTION 1.0

INTRODUCTION

1.1 PURPOSE

This report presents the results of an examination from a national security and emergency preparedness (NS/EP) perspective of selected Asynchronous Transfer Mode (ATM)/emerging satellite communications technology interface issues.

1.2 SCOPE

This report contains a brief overview of emerging satellite communications technology developments, and an examination of selected ATM/emerging satellite communications technology interface issues.

1.3 BACKGROUND

The explosive growth of a wide range of Internet, and other broadband voice, data, and video services and increasing support of the concept of “universal service”ÄÄÄmaking telecommunications universally available at reasonable and affordable ratesÄÄÄare having a major influence on the direction new and emerging telecommunications networks are taking. From an NS/EP perspective, integrated high-capacity transmission networks, which provide speed, accuracy, security, and flexible access to bandwidth-on-demand, are essential requirements for effective multimedia service support. What the users of such integrated networks want and expect is assured access to diverse services via a single, simple interface, and reliable provisioning by the network of agreed upon quality of service (QoS) parameters for the duration of the transmission or transaction. One of the greatest challenges of such networks is to manage user traffic in such a manner that: (1) the network is capable of rapidly and reliably supporting the QoS requirements of a wide range of diverse applications; (2) network QoS guarantees such as minimum error rate, delay, bandwidth, and availability are met; and (3) the use of multiple networks to provide end-to-end transmission paths is transparent to the user.

Because of its capability to accommodate a broad range of traffic from diverse sources, support high data rates, and provide gains in bandwidth use efficiency, ATM is gaining broad acceptance as the preferred transport mode for broadband terrestrial communications. However, with increasing frequency, broadband communication solutions involve an integrated network approach in which satellites are playing an increasingly significant role. There are currently a number of commercial communications satellite systems under development or planned for deployment. This pending deployment of satellite systems will provide an enhanced global, instantaneous, telecommunications infrastructure that will be accessible from virtually any place on the surface of the earth. Satellites offer unique benefits to integrated telecommunications networks. Among the benefits offered are ubiquitous wide area coverage, rapid service installation or connection, topological flexibility, point-to-multipoint and broadcast capabilities, and mobile access enhancements. However, because of their unique operating environment, satellites also offer a number of challenges when used to provide broadband telecommunications support in an integrated ATM network environment. For the most part, the challenges are the result of fundamental differences that exist between the satellite environment and the optical fiber environment upon which the development of ATM was initially based. Specific differences examined in this report include issues of delay, errors, bandwidth, and availability.

1.4 ORGANIZATION

This document is further divided into the following subsequent sections:

- Section 2.0, *Overview: Emerging Satellite Technology*, provides a brief overview of emerging satellite technology developments with potential impact on ATM network interfaces
- Section 3.0, *Asynchronous Transfer Mode*, provides a brief discussion of the composition and routing of the ATM Cell, and salient features of the Synchronous Optical Network (SONET)/Synchronous Digital Hierarchy (SDH)
- Section 4.0, *Selected ATM/Emerging Satellite Technology Interface Issues*, examines from an NS/EP perspective selected ATM/emerging satellite technology interface issues.

1.5 REVISIONS

Comments and recommendations should be forwarded to:

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SECTION 2.0

OVERVIEW: EMERGING SATELLITE TECHNOLOGY

Optical fiberÄÄa principal replacement for the millions of miles of copper cable currently installed worldwideÄÄis intended to provide the primary transmission medium for terrestrial ATM networks. However, because of factors such as (1) cost, (2) accessibility, and (3) the lack of a terrestrial telecommunications infrastructure in certain areas, satellites are becoming an increasingly crucial component in today's terrestrial long-distance communications infrastructure. The ATM-based terrestrial public switched telephone network (PSTN) of the future will continue as the primary means of satisfying the broadband connection needs of the majority of users. Capabilities provided by new and emerging satellite communications systems incorporating advanced technology will play an increasingly significant role as a complement to the PSTN, and in supporting the needs of users for whom direct access to the terrestrial network is not an option. To ensure that the end-to-end transmission path of an integrated ATM-based/satellite network is transparent to the user, it is expected that such systems serving the general public will be fully integrated with the PSTN and the public Internet at the network level.

Most current communications satellites are radio frequency (RF) repeatersÄÄthat is, they receive signals from earth stations, change their frequency band, amplify them by means of a transponder, and retransmit them onward to other earth stations. Such satellites are frequently referred to as "bent pipes" as opposed to processing satellites. Processing satellites are also RF repeaters. However, they also provide additional capabilities. When processing satellites receive signals, as a minimum they regenerate the received digital signal to remove distortion, and retransmit the corrected version of the original signal. In addition to decoding and recoding a digital bit stream, a processing satellite might also have the capability to perform bulk switching to crosslinks connecting to other satellites. Theoretically, three such processing satellites placed in geostationary (or geosynchronous) earth orbitÄÄ22,300 statute miles above the earth's equatorÄÄcould provide communications from one earth station to any other earth station located virtually anyplace on the surface of the earth, except the polar regions. Such satellites orbit the earth in a 24-hour period. Thus they appear stationary over a particular geographic location on earth. For satellites in lower non-geostationary low earth orbit, the orbital period is less than 24 hours. Consequently, such satellites do not appear stationary to earth stations, and the period in which an earth station is in contact with a single such satellite is correspondingly reduced.

2.1 COMMUNICATIONS SATELLITE SERVICES

To increase gain (the ratio of output to input power), and to avoid interference with adjacent satellites, earth station antenna beams (the lobes of radio power emitted by the transmitter to the satellite) are generally kept narrow. By contrast, since communications satellites generally provide service to and from a large area, the antenna beams from the communications satellites to the earth stations usually have rather broad beams. However, some satellites employ narrow beams to provide specialized service to limited areas. A new generation of smart satellite systems featuring multiple spot beams and high gain antennas are supplanting older satellite systems that feature simple pass-through transponders. The spot beams narrow and focus downlink transmissions to allow the satellite to use different frequencies, or reuse the same frequencies in other downlinks. Dynamic reconfiguration of the spot beams is used to optimize coverage and the use and reuse of available frequencies.

The Federal Communications Commission (FCC) divides the services provided by communications satellites into three classes: Fixed Satellite Service (FSS), Mobile Satellite Service (MSS), and Direct Broadcast Satellite (DBS) Service. FSS is a radio communication service established between fixed earth stations where one or more satellites are used. FSS satellites broadcast their signals over relatively large areas. In some deployments, FSS satellites employ satellite-to-satellite links to extend the range of coverage. The vast majority of voice, video, and data services provided today by commercial satellites fall into this category.

MSS satellites provide seamless data or voice communications services to maritime, land, and aeronautical mobile users to support a variety of voice and data applications. The services supported by MSS satellites include position location, search and rescue communications, disaster management communications, and messaging services. Mobile users employing mobile terminals, transportable terminals, or handheld devices are provided direct access to MSS satellites. However, MSS satellites may also be used to support FSS users. DBS ServiceÄÄor Broadcast Satellite Service (BSS) as it is referred to internationallyÄÄis a direct-to-home service that uses geostationary satellites to transmit television programming service intended for direct reception by the general public. These services allow households to receive television programming directly from geostationary satellites on small satellite dishes that are not movable but aimed at a specific position in the sky.

2.2 FREQUENCY BANDS OF PROPOSED SATELLITE SYSTEMS

Bandwidth is the range of signal frequencies that can be transmitted by a communications channel with defined maximum loss or distortion. It indicates the information carrying capacity of a system or channel. Generally designers use two techniques to increase a satellite's available bandwidthÄÄfrequency reuse and beam polarization. Frequency reuse is the aiming of separate signals in different directions at the same frequency. The satellite's antennas are able to shape and direct narrow spot beams at separate angles to different areas of the earth to provide a form of space division multiplexing. Since the separate signals carrying different information are aimed in different directions, they cannot interfere with each other. Beam polarization employs a property of electromagnetic signals called polarity to eliminate interference. Beams of the same frequency, but of different polarityÄÄi.e., vertical or horizontal polarityÄÄcan travel along the same path without interfering with each other. At the receiver, polarizing filters are used to separate the two beams or to screen out the signal not intended for a given receiver.

Because communications satellites must convert the frequency of the signals they receive before transmitting those signals to earth, they require two frequencies for operation. Due to this conversion, the spectrum of frequencies used is expressed in frequency pairsÄÄor bands. The lowest frequency in the band is used for the downlinkÄÄthe path of the signal from the satellite to the earth. The higher frequency is used for the uplinkÄÄthe path of the signal from the earth to the satellite.

Because of attenuation and noise, all signals degrade over distance. The most desirable frequency bands for commercial communications satellites are in the upper portion of the ultra high frequency (UHF) and lower portion of the super high frequency (SHF) segment of the radio spectrumÄÄthat is from 1 to 10 Gigahertz (GHz). The reason these bands are so desirable is that at these frequencies, there is less loss of signal strength due to atmospheric absorption, galactic and man-made noise, and free-space lossÄÄsignal attenuation that would result if all obstructing, scattering, or reflecting influences were sufficiently removed so as to have no effect on propagationÄÄthan at higher frequencies. Additionally, communications satellite technology at these frequencies is well-understood and developed. Above 10 GHz, signal attenuation caused by rainfall, scattering, and other moisture and gaseous absorptions must be taken into consideration. However, a considerable portion of the radio spectrum from 1 to 10 GHz is shared with terrestrial servicesÄÄespecially terrestrial microwave services. Because of potential interference from stronger microwave signals, sharing places certain limitations on the power and location of some satellite systems using a shared frequency band. This is a significant factor in the current shift in focus to the use of higher frequencies for emerging communications satellite system deployments. Table 2-1 shows current FCC-defined frequency bands for commercial satellite communications systems.

Table 2-1. Commercial Communications Satellite Frequency Bands

Band	Range	Available Bandwidth
L	**1.6/1.5 GHz**	**15 MHz**
S	**4/2 GHz**	**30 MHz**
C	**6/4 GHz**	**500 MHz**
Ku	**14/11 GHz**	**500 MHz**
Ka	**30/20 GHz**	**2,500 MHz**
Q	**50/33 GHz**	**3,500 MHz**
V	**75/50 GHz**	**5,000 MHz**

The L-band and S-band frequencies have low signal levels, but allow the use of very small transportable hand-held antennas. The original allocation of the frequency spectrum for satellite communications was C-band. However, most communications satellite systems providing transmission networks and support to the public network now operate in both the C- and Ku-bands. Among the unique properties of the C-band portion of the spectrum is that it is not unduly affected by atmospheric conditions. C-band signals are relatively immune to atmospheric noise. The earth’s atmosphere is almost transparent to signals in the 6/4 GHz range, and such signals are not affected by fog and rain. However, because of the tendency of the signal to spread at geostationary orbit, a reasonable size spacecraft antenna is requiredÄÄcreating potential spacecraft weight considerations. Additionally, because some terrestrial communications systemsÄÄespecially point-to-point microwave transmissionsÄÄalso use C-band, this can also cause interference problems in some locations. Ku-band systems have higher signal levels and gains for the same size antenna, and are immune from microwave signals. However, because of the higher frequencies, they are affected more by atmospheric conditions.

Most of the proposed broadband geostationary satellite systems now at different stages of development, plan to operate in the Ka-band frequency range. Ka-band systemsÄÄlike the Ku-band systemsÄÄhave very high signal levels and gains for the same size antenna, but are also affected by rain attenuation and other atmospheric conditions. The Q- and V-bands as defined by the FCC, have small wavelengths and allow the use of high-gain antennas with small physical apertures. Although the Ka-, Q- and V-bands provide large bandwidth, their use has some disadvantages. Signal attenuation caused by rain may be significant at these frequencies, especially on the uplink. This condition forces systems to incorporate either large margins to compensate for possible attenuation, or uplink power control. Also at these bands, significant depolarization can occur during rain, thus resulting in rapid degradation of cross polarization isolation. For a given attenuation allowance, the availability at V-band is simply not as high even as Ka-band.

2.3 TYPES OF SATELLITE SYSTEMS

The new generation of satellite systems may be divided into three broad categories on the basis of orbital radius: geostationary (or geosynchronous)-earth-orbit (GEO) satellites; non-geostationary medium-earth-orbit (MEO) satellites; and low-earth-orbit (LEO) satellites. Figure 2-1 shows the relative orbital positions of satellites for each category. Each of the systems and orbital positions is designed to capitalize on the advantages offered by the physics of the orbital altitude, and the technological advances made in areas such as onboard processing, switching, micro-circuitry, and antenna design technology. The three types of satellite systems deliver communications services in fundamentally different ways. Their resource management requirements are also different. However, certain parameters such as errors, delay, bandwidth limitations, availability, and the quality of the signal at the terrestrial-satellite system interface are potential concerns of all systems in integrated terrestrial/satellite communications networks.

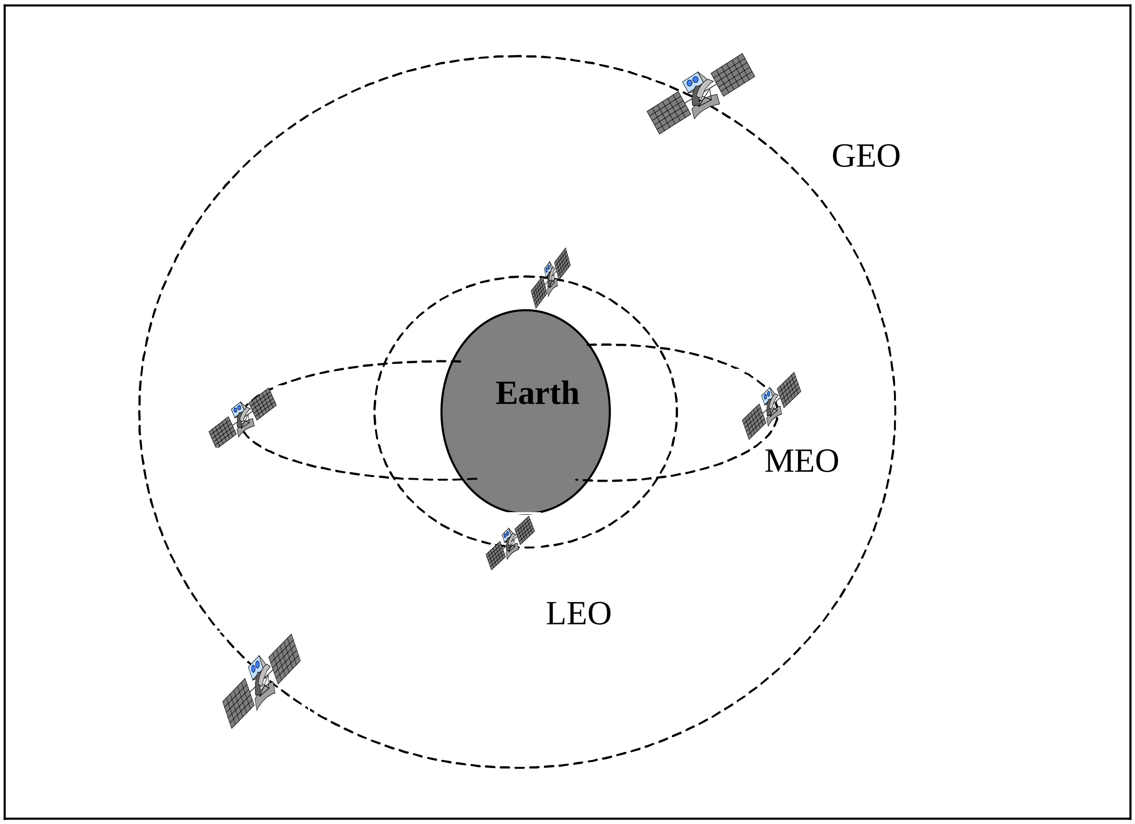


Figure 2-1. Satellite Relative Orbital Positions

2.3.1 GEO Satellite Systems

Most of the two-way voice, video teleconferencing, data, and other interactive services currently transmitted commercially by satellite are transmitted by GEO satellites. The circular and direct orbit

of GEO satellites lie in the earth's equatorial plane at an altitude of 22,300 statute miles. The slant range from the antenna of an earth terminal to the satellite is considered to be the same as the satellite altitude. Distance increases as the pointingÄÄor elevationÄÄangle to the satellite decreases. Since GEO satellites orbit the earth at the same speed as the earth turns, they remain fixed relative to the earth. The longitudes of the satellites are closely monitored and maintained to ensure that the satellites do not drift from their assigned positions on the orbital arc. This aspect allows the orientation of earth station antennas to remain fixed on the satellite once it has been acquired.

The speed of electromagnetic waves in open space is 3 x 10^8 meters-per-second (m/s)ÄÄthe speed of light. The signal delay caused by propagation is a function of the location of the earth stations at each end of the satellite links. Because of the distance between a GEO satellite and the nearest earth terminalÄÄthat is an earth terminal located directly under the satelliteÄÄthe shortest propagation time required for a signal to travel between an earth station and a GEO satellite is approximately 125 milliseconds (ms). This propagation time is greater than that generally encountered on conventional terrestrial systems. The minimum two-way path delay from earth station to earth station via a GEO satellite is four times the above propagation delay, or 500 msÄÄplus satellite processing time, if required. For earth stations with longer slant ranges to the satellite, that is those with smaller elevation angles, the delay would be greater because of the longer slant path. For certain earth stations, long terrestrial paths to the user's terminal equipment can also cause additional delay.

2.3.2 LEO Satellite Systems

While GEO satellite systems have long dominated both the commercial and government communications satellite arena, LEO communications satellite systems are now emerging as attractive alternatives. Major factors contributing to the emergence of LEO systems are crowding at geostationary orbital altitudes, propagation delay considerations, advancements made in satellite crosslinking/onboard processing, and the lower costs associated with their launch. LEO satellite systems are designed to provide many of the same kinds of service as GEO systemsÄÄÄe.g., wide area coverage, direct radio path, and a flexible network architecture. Their orbital altitude is only 500-1,400 miles above the earth as opposed to 22,300 miles for GEO satellite systems. Because of their closer proximity to earth, signals from such satellites experience lower delay and loss due to propagation. Because the satellites move relative to a fixed spot on the surface of the earth, a single LEO satellite is only able to provide coverage of any particular area of the earth's surface for a relatively short time. Therefore, multiple satellites arrayed in constellations are required to maintain continuous communications and to achieve wide area coverage. To maintain uninterrupted service over long distances, LEO satellites employ intersatellite links (ISLs) to hand off signals from one satellite to another. Because of their closer proximity to earth, LEO satellite systems are also able to provide reduced propagation delay and propagation loss. Also, since LEO satellites require less power to send and receive signals, smaller antennas, mobile/portable terminals, and low-powered handsets may be used.

2.3.3 MEO Satellite Systems

MEO satellite systems are also non-geostationary. They occupy an orbit in between GEO and LEO satellites several thousands of miles above the surface of the earthÄÄÄroughly 2,900 to 7,500 miles. Because of their intermediate orbital altitude, MEO systems are able to provide coverage over a wider area than LEO systems. The propagation delay associated with such systems is higher than that associated with LEO systems, but less than the delay experienced by GEO systems. As with LEO systems, MEO systems are in various stages of development. When deployed they will also provide continuous service for mobile voice and data service users equipped with a variety of mobile/portable terminals and hand-held devices.

2.3.4 Stratospheric Telecommunications Service

At the 1997 World Radiocommunications Conference, national representatives unanimously approved a global allocation of 600 MHz of spectrum for use by a new telecommunications technology which features lighter-than-air communications stations located at fixed points in the stratosphere. The worldwide allocation of spectrum complements the FCC's recent authorization of spectrum for use of stratospheric stations in the United States. The following is a description by Sky Station International, Incorporated (Inc.) of its planned Stratospheric Telecommunications Service [31]:

> "Sky Station's Stratospheric Telecommunications Service utilizes lighter than air platforms which will remain geostationary above major metropolitan regions using recently developed technologies, including super-efficient solar cells, new lightweight composite material, advanced fuel cells and propulsion systems, and global positioning systems. Located in the stratosphere 22 kilometers above the earth, each Sky Station platform will provide high density, high capacity, high speed service with low power requirements and no latency to an entire metropolitan and suburban area extending out into rural areas. Users will access the Sky Station system with common user terminals including modems, laptops, desktops, set top boxes, screen phones, and smart phones. The payload will provide instant T1/E1 access to users in each service area. The service possibilities [include]: real-time data communications, video phone service, full motion video conferencing, high speed commercial data transfers, automatic meter reading, telemedicine, and distance learning."

2.3.5 Communications Satellite Multiple Access Formats

Multiple access may be defined as the ability of a number of earth stations to interconnect their respective communications links through a common satellite. Satellite access may be categorized by assignment or domain. By assignment, multiple access may be defined as to whether the assignment is quasi-permanent or temporaryÄÄÄe.g., preassigned multiple access, or demand-assigned multiple access (DAMA). By domain, multiple access may be defined as to whether the assignment is in the frequency, time, space, or some other domainÄÄÄe.g., frequency division multiple access (FDMA), time division multiple access (TDMA), and space division multiple access (SDMA). Several access formats are currently being deployed or scheduled on new and emerging satellite networks where several earth stations require access to the same bandwidth of a satellite transponder. Networks within the same transponder must use the same format. However, a high-capacity earth station accessing more than one transponder in the same satellite could be configured so as to transmit and receive satellite signals in each format, or a combination of formats. A brief discussion of each of the principal formats is provided below. Because of the increased efficiency in frequency and bandwidth utilization offered by TDMA, code division multiple access (CDMA), and DAMA technology, the general trend in current planned deployments appears to reflect movement away from the older FDMA format to TDMA, CDMA, and DAMA. All are capable of accommodating multirate services, a principal requirement of future multimedia communications.

2.3.5.1 Frequency Division Multiple Access (FDMA)

This type of access is characterized by the separation of signals by frequency. A single transponder can support several carriers each simultaneously accessing different frequencies within the transponder's available bandwidth. The transponder is operated in a near linear mode so that the power obtained by each access is approximately proportional to its uplink power. Each earth station is assigned specific uplink and downlink frequencies. Since each earth station has its own private frequency band to use, there is no interference between earth stations and the system may operate without error or collision. If the frequencies assigned to each earth station are too close to each other in the satellite transponder and the power levels of each station are not uniform, the non-linearities in power levels may lead to intermodulation noise. Such noise reduces the capacity that can be supported by the transponder. FDMA requires no real time coordination among the accesses and can be used to transmit either analog or digital signals. Another advantage provided by FDMA is that smaller antennas can be used. FDMA requires guard bands to keep the signals well separated, and there is little flexibility.

2.3.5.2 Time Division Multiple Access (TDMA)

This type of access is characterized by the separation of signals by time. Individual time slots are assigned to earth stations in a sequential order. TDMA allows each station to use the entire bandwidth of the transponder within a specific time segment with minimal need for power controlÄÄsince only one earth station carrier is providing input to the satellite transponder at any one instant. This temporal sharing usually implies a requirement for timing among earth station and the transmission of information in bursts, as contrasted to transmitting on a continuous basis. The duration of the burst may last only for the time period of the assigned slot. Timing is crucial to effective TDMA operation. A synchronizing master earth station assigns precise time intervals to participating earth stations. Because of its bursty nature, TDMA is used primarily for the transmission of digital information.

2.3.5.3 Adaptive Time Division Multiple Access (ATDMA)

The ATDMA protocol has the same frame and slot structure as the TDMA protocol. However, each uplink frame contains a number of reservation [R] slots and a number of traffic [T] slots. Stations wanting to transmit information must first send a request packet via an R slot to the satellite and are therefore subject to collisions. When collisions occur because of R messages arriving at the same time, the capture effect will either allow one station to gain access or no station will be successful. The successful station will be assigned a T slot for transmitting information packets. The stations which were unsuccessful in gaining access will enter a collision resolution phase. Collision resolution involves unsuccessful stations retransmitting on the next available R slot with preferential permission specified.

2.3.5.4 Code Division Multiple Access (CDMA)

This type of access also permits multiple signals to simultaneously access the satellite's transponder. Each earth station uses the same carrier frequency and occupies the full carrier bandwidth. However, each carrier is identified by unique coding. The data is superimposed onto a specific coded address waveform. The combined signals are then modulated onto an RF carrier. The resulting signals are spread across the bandwidth of the transponder. The receiving earth station is programmed to ignore all signals except the unique signal carrying the desired code. This technique is often also referred to as Spread Spectrum Multiple Access. In addition to its multiple access capabilities, CDMA is also commonly used in military satellite systems to combat jamming.

2.3.5.5 Space Division Multiple Access (SDMA)

This type of access also permits multiple signals of different polarization to simultaneously access the same satellite transponder. Users share a common frequency, but are separated by spatial processing. With SDMA, satellites may achieve signal separation by using beams with horizontal, vertical, or circular polarization. This technique allows multiple beams to cover the same earth surface. Additionally, the satellite could achieve spatial separation by using separate antennas or a single antenna with multiple feeds. For multiple satellites, spatial separation can be achieved with orbit longitude and latitude, and for intersatellite links, using different planes. The use of SDMA allows for frequency reuse and onboard switching which, in turn, enhances channel capacity. Additionally, the use of narrow beams from the satellite allow the earth station to operate with small antennas and produce a higher capacity power density per unit area for a given transmitter. SDMA is usually employed in conjunction with other types of multiple access such as TDMA, FDMA, and CDMA.

2.3.5.6 Demand Assignment Multiple Access (DAMA)

This type of access is characterized by having a pool of single voice channels available, and making assignments from the pool on request. Using this method, DAMA allows the dynamic allocation and reallocation of satellite power and bandwidth based on the communications needs of network users. For applications where high-speed connectivity is required, but may not be required full-time, it may be more cost effective to employ DAMA techniques rather than a full-time tie up of a full-period circuit. The three methods available for handling DAMA in a satellite system are polling, random access-central control, and random access-distributed control. With the polling method, a master station polls all other stations in the system sequentially. When a positive reply is received, a channel is assigned accordingly. With the random access-central control method, the status of channels is by a central computer. Call requests are passed to the central processor by a digital order wire, and a channel is assigned if available. With the random access-distributed control method, a processor control is located at each earth station. All earth stations in the network monitor the status of all channels. Channel status is continually updated via a digital order wire. When a channel has been seized, users are informed that the circuit has been removed from the pool. Many systems use a mix of preassigned channels on an FDMA basis and DAMA channels.

2.3.5.7 Time Domain Duplex (TDD)/Frequency Domain Duplex (FDD)

Duplex transmissions are simultaneous two-way and independent transmissions in both directions. For duplex operations over satellite TDD seems to be gaining over the more broadly used FDD mode. The primary difference between the two modes is that for the TDD mode, duplex transmissions are carried in alternate time slots, whereas FDD uses two separate channels for continuous duplex transmissions. FDD systems require a guard frequency between frequencies allocated to the forward and reverse links to minimize mutual interference. In TDD systems, a guard time is used to reduce interference between the links. The most significant advantages of using TDD over FDD is that since the same frequency channel is used, reciprocity exists between the link channel characteristics. This advantage can be used to implement a number of highly desirable open loop functionsÄÄÄe.g., power control, signal pre-emphasis and shaping, and diversity transmission to respond to unfriendly transmission conditions.

2.3.6 Selected Near-term Communications Satellite System Deployments

Several global satellite systems for various forms of communications are scheduled to be deployed over the next five years. Table 2-2 provides selected summary data on several of these systems.

- **Iridium** is designed to provide voice, data, facsimile, messaging, and position location services on a global basis. Voice services are provided at a rate of 2.4 and 4.8 Kbps, and data services at 2.4 Kbps. The global connectivity provided via intersatellite links will provide significant support for users such as disaster-relief teams located in rural or undeveloped areas who need the features and convenience of rapid and reliable access via handheld telephones and portable data terminals to the worldwide terrestrial communications infrastructure. The Iridium network is nearing the end of its launch schedule with about 90 % of the constellation deployed.

- **GlobalStar** is designed to provide voice, data, facsimile, video, short messaging and position locations services between 70^o South and 70^o North latitude. The system will provide voice services at 2.4 Kbps, 4.8 Kbps, or 9.8 Kbps and data services at 7.2 Kbps. Users of GlobalStar will be able to employ both handheld or vehicle mounted terminals low-cost, reliable satellite-based wireless communications on a worldwide basis. GlobalStar satellites do not directly connect one GlobalStar user to another. Rather, they relay communications between the user and a Gateway. GlobalStar's architecture requires that all calls be routed through existing wireless and wireline infrastructures. The GlobalStar system is intended to complement and extend, not replace, the existing PSTN and Public Land Mobile Network (PLMN) infrastructure.

- **Constellation (formerly called Aries)** is designed to provide a full range of business and personal communications services, including affordable voice, data, facsimile, and position location services to mobile and fixed-site users on a global basis. The satellites will transmit directly to mobile and fixed-site users in the 2483.5-2500 MHz band and receive directly from the users in the 1610-1625.5 MHz. The system will provide voice and data service at 4.8 and 2.4 Kbps rates, respectively.

- **Ellipso** is a global telecommunications system designed to extend and complement existing telephone and data networks. Ellipso uses a constellation of elliptical satellites to connect user handheld, mobile, or fixed terminals directly to gateways within the existing regional telecommunications networks. It is designed to provide voice, data, facsimile, and position location services north of 50^o South latitude. The satellites will provide voice services at 4.2 Kbps and data services at rates ranging from 0.3-9.6 Kbps.

- **Astrolink** is a global constellation of nine Ka-band satellites designed to provide a broad range of multimedia services over virtual private networks on a global basis. The network incorporates advances in on-board processing and the use of spot beam technology demonstrated in the Advanced Communications Technology Satellite (ACTS) programÄÄi.e., resource control, channelization, demodulation, encoding/encodingÄÄand intersatellite crosslinks demonstrated in the Milstar program. The network is intended to have the flexibility and capacity to support user applications at rates ranging from 384 Kbps to 155 Mbps based on user requirements..

- **Celestri** is designed to offer a broad range of Fixed Satellite Service real-time broadband communications multimedia video, voice, and data services on a global basis. The Celestri network proposes to provide users real-time communications services over intersatellite links with delay essentially equivalent to terrestrial communications systems. The Celestri architecture achieves global interconnection by enabling a signal received by a satellite to be transmitted directly back to earth in the same or a different beam, or relayed by intersatellite links through other satellites and then transmitted to earth.

- **ICO (formerly called Inmarsat-P)** is designed to provide voice, data, facsimile, and paging on a global basis. The satellites are designed to use small dual-mode pocket-size cellular units capable of working with satellites, cellular and PCS systems. The ICO system will consist of a space segment and a dedicated ground network called the ICONET. The ICONET will provide the link between the satellites and the PSTN. The satellites will provide voice and data services at the rates 4.8 Kbps and 2.4 Kbps, respectively.

- **Teledesic** is designed to provide voice, data, facsimile, paging and video on a near global basisÄÄexcept for 2 degrees of non-coverage at each pole. Teledesic satellite links will serve as access link between users and gateways/networks. However Teledesic does not intend to market services directly to end-users. Rather, it will provide an open network for the delivery of such services by local companies and Government authorities in host countries to extend their network. Teledesic satellites will provide two-way communications at 64 Mbps on the downlink and up to 2 Mbps on the uplink. Customer voice services will be provided at 16 Kbps and data services will range from 16-2,048 Kbps.

- **Sky Station** is a proposal of Sky Station, International, Inc. to employ 37-ton global, stratospheric telecommunications service (GSTS) platforms hovering 22 kilometers above 250 major metropolitan areas around the world. Sky Station is intended to offer broadband personal communications services (PCS), with video and Internet access capabilities. The platforms are to be connected to the public switched telephone system and are designed to provide broadband telecommunications services at 2 Mbps-10 Mbps.

Table 2-2. Selected Communications Satellite/Sky Station Summary Data

System	Orbital Class	No. Satellites	Access Format	On-Board Processing	Scheduled Operation
Iridium	LEO	66	TDMA, TDD, FDMA, FDD	Yes	1998
GlobalStar	LEO	48	CDMA, FDMA, FDD	No	1998
Constellation	LEO	48	CDMA	No	2001
Ellipso	MEO	14	CDMA	No	2000

Astrolink	GEO	9	TDMA	Yes	2001
Celestri	LEO	63	TDMA, DAMA	Yes	2002
ICO	MEO	10	TDMA, FDMA, FDD	Yes	2000
Teledesic	LEO	288	TDMA, SDMA, FDMA, ATDMA	Yes	2002
Sky Station	Airships in Stratosphere	40 37-ton Airships	FDMA, TDMA	No	2000

SECTION 3.0

ASYNCHRONOUS TRANSFER MODE

The Broadband Integrated Services Digital Network (B-ISDN) reference architecture is vertically layered and covers transport, switching, signaling and control, user protocols, and applications of services. ATM is the underlying switching and multiplexing technology of the B-ISDN reference architecture. ATM technology provides a cell based integrated transport network for all services. The ATM approach provides a flexible way to dynamically allocate bandwidth and to support various services in an integrated fashion. The three primary layers of the ATM portion of the B-ISDN reference architecture are the Physical Layer, the ATM Layer, and the ATM Adaptation Layer (AAL).

Physical Layer: The Physical Layer is the lowest layer of the reference architecture. It provides for the transmission of cells over a physical medium connecting two ATM devices. This layer interfaces with the actual physical medium, extracts and inserts ATM cells within Time Division Multiplexed (TDM) frames, and passes these to and from the ATM Layer. The principal functions performed by this layer is the generation and reception of waveforms suitable for the medium, the insertion and extraction of bit timing information, and line coding where required. Sub-functions performed by this layer include bit transfer, electrical-optical transformation, cell rate decoupling, header error control (HEC), header sequence generation/verification, and the adaption, generation and recovery of transmission frames.

ATM Layer: The ATM Layer is the second layer of the reference architecture. It is independent of the Physical Layer. One important function of this layer is encapsulationÄÄin the transmit direction, taking higher layer PDUs mapped into the information field of the ATM cell in the AAL and generating an appropriate ATM cell header. In the receive direction, the de-encapsulation, or cell extraction function of this layer removes the ATM cell header and passes the cell information field to the AAL. Other functions performed in this layer are generic flow control (GFC), translation of virtual path identifiers (VPIs)ÄÄan eight-bit field in the ATM cell header which indicates the virtual path over which the cell should be routedÄÄand virtual channel identifiers (VCIs)ÄÄa unique numerical tag in the ATM cell header that identifies the VC over which the cell is to travelÄÄand cell multiplexing/demultiplexing.

AAL: The AAL passes protocol data units (PDUs)ÄÄmessages composed of payload and protocol-specific control informationÄÄbetween the ATM Layer and the higher layers. PDUs may be of variable length, or may be of fixed length different from the ATM cell length. When a VC is created, a specific AAL type is associated with the VC. The basic function of the AAL is to translate higher layer services into the size and format of an ATM cell, and to map higher layer PDUs into the information field of the ATM cell and vice versa. The AAL at the originating endpoint segments PDUs into ATM cells and marks the last cell of each PDU. At the destination endpoint, the AAL at that location uses the end of packet marker to reassemble the data from the cells received.

3.1 THE ATM CELL

ATM networks require that an end-to-end VC be established prior to the transmission of user data. A VC is a communications channel that provides for the sequential transport of ATM cells across multiple nodes and possibly multiple networks for reconstruction as a continuous stream of information at the destination. ATM cells are formatted packets of variable-length user information organized into fixed-length slots. An ATM cell consists of a 5-byte header containing information used to route the cells in the ATM network, and a 48-byte information field containing payload information that is transported transparently by the network. ATM is asynchronous in the sense that the recurrence of cells containing information from an individual user is not necessarily periodic.

3.1.1 ATM Cell Header

The ATM cell header containing the protocol control information is located at the beginning of an ATM cell. There are two standardized ATM cell structure coding schemes used in the cell header. The user-to-network interface (UNI) coding scheme is used for the interface between the user or customer premises equipment (CPE) and the network switch. The network-to-network interface (NNI) coding scheme is used for the interface between switches or between networks. The format for both coding schemes is identical except for an additional field in the UNI coding scheme header for providing: (1) local contention resolution and simple flow control for shared medium-access arrangements at the CPE, and (2) an increase in the number of bits in the VPI fieldÄÄan eight-bit field which indicates the virtual path (VP) over which the cell should be routedÄÄfor the NNI coding scheme. Figure 3-1 shows the six fields of the ATM cell header for the UNI coding scheme. A description of each field is provided below.

- **Generic Flow Control (GFC):** This field provides local contention resolution and simple flow control for shared medium-access arrangements at the CPE. The value encoded in this field is not carried end-to-end.

- **Virtual Channel Identifier (VCI):** This field is used to provide a unique numerical tag that identifies a virtual channel over which the cell is to travel. It is used to establish connections using translation tables at switching nodes that map an incoming VCI to an outgoing VCI.

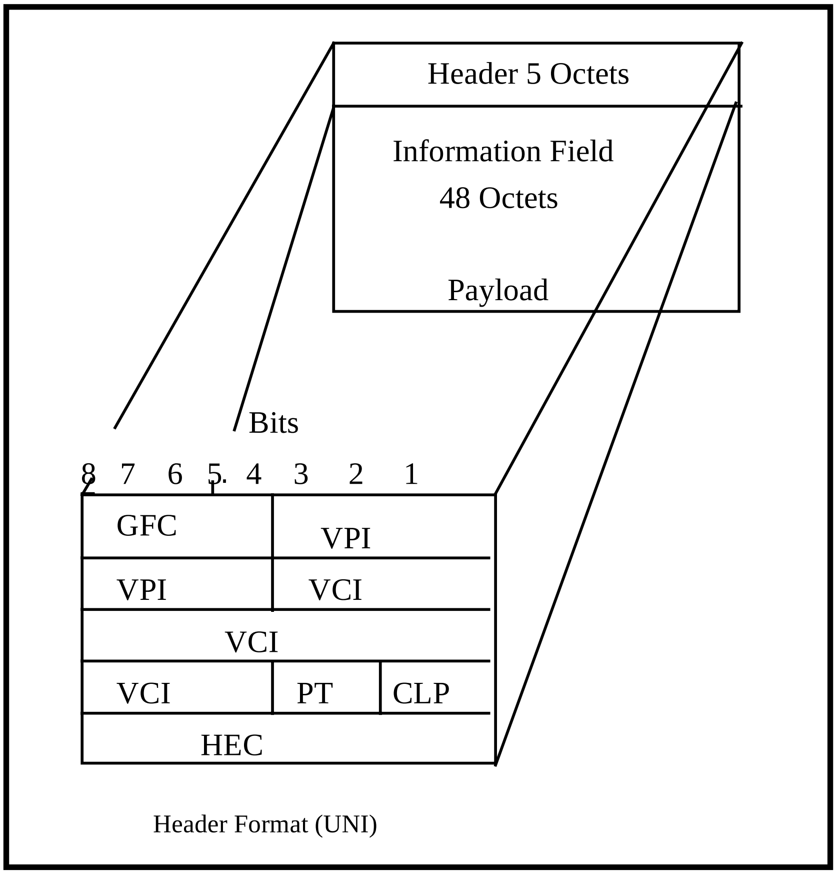


Figure 2-3. ATM Cell Header

- **Virtual Path Identifier (VPI):** This field is used to indicate the VPÄÄlogical association or a bundle of VCsÄÄ the cell is to be routed over.

- **Payload Type (PT):** This field is used to differentiate cells that traverse the same virtual circuits.

- **Cell Loss Priority (CLP):** This field is used to indicate two levels of priority for ATM cells. Depending on network conditions, cells with CLP set to CLP=1 may be discarded to preserve the cell loss ratio of cells with CLP set to CLP=0.

- **Header Error Control (HEC):** This field is used to perform a cyclic redundancy check (CRC) calculation on the header to detect and correct errors.

3.1.2 ATM Cell Routing

ATM networks are connection-orientedÄÄÄthat is an end-to-end VC must be established prior to the transmission of user data. To ensure that ATM cells are received in the proper sequence at the destination endpoint, the connection remains in effect for the duration of the service contract. The two types of VCs are permanent virtual circuits (PVCs) and switched virtual circuits (SVCs). A PVC is a link with static route defined in advance, usually by manual setup. Under this arrangement, capacity for the connection is fixed, not variable. Connection management is minimal beyond establishing the carriers and reconfiguring the ATM switch matrix. An SVC is a connection established via signaling. The user defines the endpoints when the call is initiated. Connection management involves establishing the route needed to transport ATM cells on a dynamic basis via signaling.

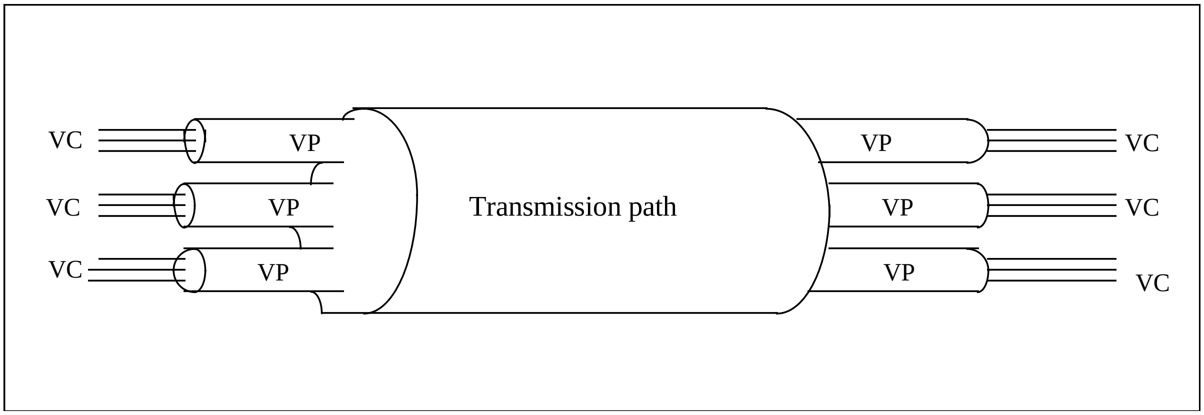
Routing functions for PVCs and SVCs are performed at ATM switches or points of cross-connection. VCI and VPI values contained in the ATM cell header contain information that uniquely identifies the connection throughout the network. Routing within the ATM network is based on the translation by ATM switches of the VPI and VCI values. When a VC is created, the ATM switch creates and maintains a table entry that maps inbound VCIs on an inbound port to an outbound port.

At switching nodes, the VCI values and translation tables are used to establish connections. The VPI value is used to establish a virtual path connection (VPC) for one or more logically equivalent VCIs in terms of route and service characteristics. Based on assigned VCI/VPI values, a virtual channel connection (VCC), a concatenation of VC links (VCLs), is established. Cell sequence integrity is preserved by the ATM layer for cells belonging to the same VPC.

The ATM SVC concept simplifies path network design and increases flexibility of path management for routing and capacity allocation. Traffic management consists of properly allocating network resources to accommodate dynamically varying virtual traffic within these connections. Because ATM multiplexing is non-hierarchical, path capacity does not need to be explicitly assigned at the VPC point at VP establishment time, but is handled by separate management procedures such as connection admission control (the set of actions taken by the network during the call setup phase in order to determine whether a connection request can be accepted or rejected) and usage monitoring (functions carried out at the ingress VPC endpoint). Consequently, VPC points along the VP route are not affected by changes in VP capacity allocations which may be initiated by capacity management procedures. The independence of route and capacity management leads to two important features of ATM networks: adaptive network reconfiguration and dynamic bandwidth allocation, both of which are important in executing restoration strategies. Figure 3-2 shows a conceptual VC, VP, and transmission path relationship.

ATM is a transfer m

3.2 SONET/SDH



ATM is a transfer mode designed with low-loss, low-delay, high bandwidth optical fiber as the expected transmission medium. In principle, ATM cells may be transported using any digital transmission formatÄÄe.g., E1/T1, and other digital formats. ATM cells may also be transported contiguously without an underlying digital network format. However, for purpose of standardization, the Synchronous Optical Network (SONET)ÄÄan American National Standards Institute (ANSI) standard for transmitting information over optical fiberÄÄand the Synchronous Digital Hierarchy (SDH)ÄÄthe International Telecommunications Union international standard for transmitting information over optical fiberÄÄare the digital transmission formats generally used for the transport of ATM cells. Although originally intended for transmission over optical fiber facilities, both formats can be accommodated on any transmission medium that meets the bandwidth requirements. The two formats are very similar. Currently, both are based on the assumption that transmission bit errors are randomly distributedÄÄthat is having no particular pattern, organization, or structure. While generally valid for optical fiber-based systems, this assumption is not necessarily valid for satellite links. On satellite links, non-random error burstsÄÄstrings of contiguous bits with a high probability of being in errorÄÄare more common. On certain satellite links, error bursts may be caused by signal fading during heavy rainfall events, or by other conditions such as crosstalk. Additionally, on satellite links, background Gaussian noiseÄÄnoise with a random distribution of frequency components centered on a specified frequencyÄÄcould also introduce a different type of error distribution than that expected from optical fiber cable.

SONET's synchronous hierarchy has sufficient flexibility and payload capacity to carry signals other than ATM. SONET transports payloads without regard to their exact structure. The interface between a payload and the SONET network is defined by a SONET standard mapping into the appropriate payload envelope. This is accomplished by use of a basic transmission module with a bit rate of 51.840 megabits per second (Mbps) and a byte interleaving multiplex scheme to produce a family of signals with N times 51.840 Mbps, where N is an integer.

The basic transmission module for SONET is the Synchronous Transport Signal level 1 (STS-1)ÄÄthe SONET standard for transmission over Optical Carrier level 1 (OC-1). STS-1 is comprised of 8-bit bytesÄÄor octetsÄÄthat are transmitted serially on the transmission medium. The payload envelope consists of a portion assigned to overhead and a portion that carries the payloadÄÄthe synchronous payload envelope (SPE). The first three columns of the frame containing transport overhead, is divided into 27 bytesÄÄ9 bytes allocated for section overhead, and 18 bytes allocated for line overhead. The other 87 columns comprise the SPE. The STS-1 envelopes are sent contiguously and without interruption. The payload is inserted into the envelopes under stringent timing rules. Because B-ISDN signals, such as ATM, require transport at rates higher than the basic rate, a technique is provided for linking several STS-1 modules together to build a transport signal of increased capacity. SDH starts at the STS-3 level. It consists of three STS-1 envelopes. ATM cell transmission via SDH also incorporates a cell delineation mechanism for the acquisition and synchronization of ATM cells on the receive side of the network. Figure 3-3 depicts the SONET STS-1 envelope.

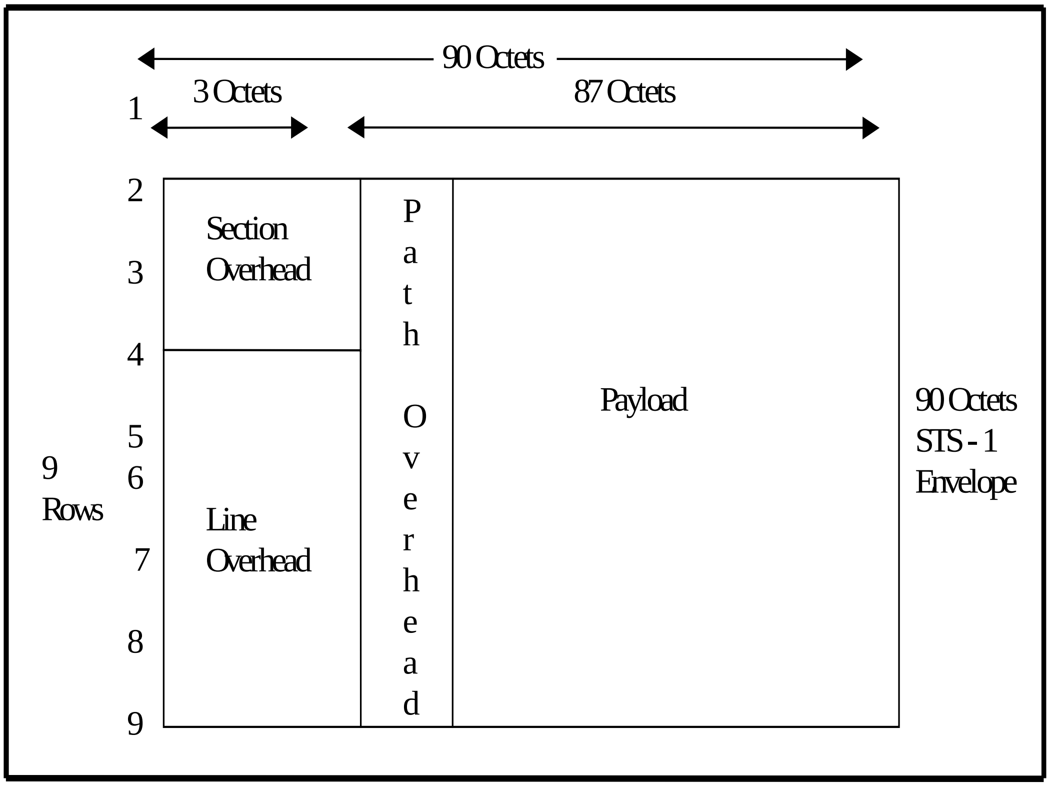

90 Octets
3 Octets
87 Octets
1
2
3
4
5
6
7
8
9
9
Rows
Section
Overhead
Line
Overhead
P
a
t
h
O
v
e
r
h
e
a
d
Payload
90 Octets
STS - 1
Envelope

Figure 3-3. Synchronous Transport Signal 1 (STS-1) Envelope

SECTION 4.0

SELECTED ATM/EMERGING SATELLITE TECHNOLOGY INTERFACE ISSUES

In integrated ATM/satellite communications networks, the interface between the terrestrial ATM network and the satellite network has the function of adapting incoming data to a proper format for transmission via satellite when entering the satellite portion of the integrated network, and vice versa when entering the ATM network portionÄÄÄsee Figure 4-1. The primary requirements for successful transmissions in ATM networks are nearly error-free links, a fixed cell size of 53 bytes or octets, and the maintenance of cell order. Integrating satellites into terrestrial networks is often hindered by qualities that are integral parts of satellite networks. Because of these qualities, a number of technical challenges arise in providing broadband telecommunications support in an integrated ATM/satellite network environment. For the most part, the challenges are the result of fundamental issues of delay, errors, bandwidth limitations, and availability in the satellite portion of the integrated network. Salient features of each issue are discussed below.

4.1 DELAY

The effects of signal delay on the quality of communications is a major consideration in an integrated broadband ATM/satellite networkÄÄespecially for satellites in geostationary orbits. Although propagation delay is the dominant variable in computing total delay in an integrated ATM/satellite communications network, the total delay in such networks is the sum of the delay induced by user devices, transmission systems, propagation, and fixed switch processing components in both the satellite and terrestrial portion of the network. Terrestrial ATM networks introduce a measure of variable delay due to: (1) the performance of traffic translation functions by the AAL convergence sublayer (CS) to convert between ATM and non-ATM formats, (2) performance of packet segmentation and reassembly (SAR) functions by the AAL SAR sublayer to segment and reassemble arbitrarily sized packets, and (3) cell loss due to congestion and misdelivery of cells due to errors in the ATM cell header. At ATM switches, the two forms of delay incurred are queuing and switching delay. Since the switches perform statistical multiplexing operations and traffic arrives asynchronously at the switches, queuing delays are caused by the building of queues to accommodate peaks in traffic. The second type of

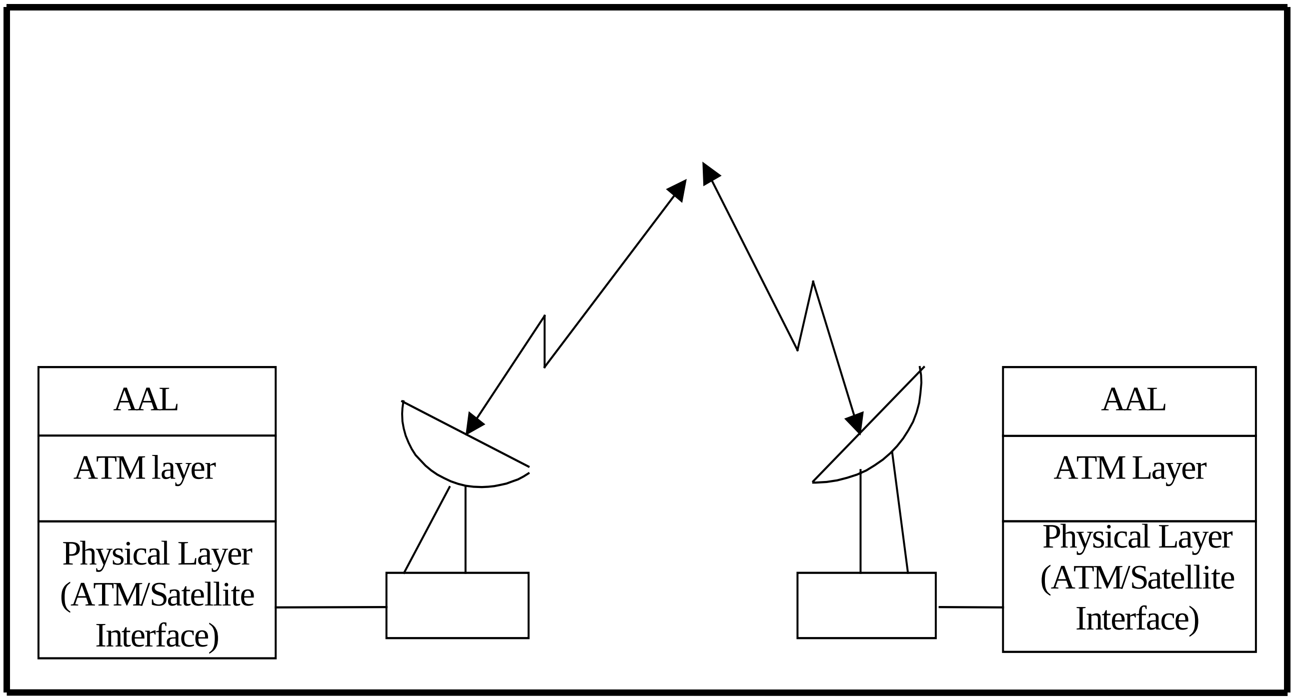


Figure 4-1. ATM/Satellite Interface

delayÄÄswitching delayÄÄis a fixed delay that varies depending on the type of switching operation employed, and the speed at which the traffic is relayed through the switch.

Delay in the satellite portion of the network is generally large compared to that in the terrestrial portion of the network. The minimum round-trip delay between two earth stations via a GEO satellite connection is approximately 500 ms. Most industry experts agree that the current propagation delay on GEO satellite connections does not affect the accuracy of data transmissions directly. However, it is generally agreed that for optimal real-time voice applications, the maximum round-trip delay between terrestrial endpoints, including hops across satellites, should not exceed 400 ms. Longer delays in such networks can be noticeably distracting to users of some voice applications and during two-way video-conferencing communications. This constraint limits the hop count for systems that support such applications using intersatellite links.

Long delays may also be detrimental to the performance of some congestion control functions in ATM networks, and some conventional data-related error correction protocols used in satellite networksÄÄÄe.g., the automatic-repeat-request (ARQ) protocol discussed in Section 4.2 below. Since at broadband rates, finite-sized queues may quickly overrun buffers during congested conditions, congestion control measures must be executed rapidly in order to be successful. In ATM networks, the two mechanisms used are based on the principles of cell discard and feedback. Cell discard allows a congested network element to selectively discard cells identified as belonging to a non-compliant ATM connection and/or cells having the CLP bit in the ATM cell header set to 1. While this approach is rather simple from a control standpoint, it appears to have some disadvantages in certain situations. The dropping of data on assured connections will require that retransmissions be made. While cell discard may be an efficient process if selective retransmission is used, retransmission on a non-selective basis can be expected to delay the delivery of a substantial number of packets due to the satellite-induced delay that will be added to the network. Additionally, in integrated networks, it appears that it might be difficult to provide QoS guarantees for CLP=1 traffic flows under less than optimal conditions.

The objective of congestion control mechanisms based on feedback is to provide the sources of the traffic with sufficient information about the congestion event, so that the sending sources can take action to temporarily reduce the traffic load and minimize the spread and duration of the congestion. Credit-based and rate-based approaches are the two types of approaches considered by the ATM Forum to provide the required feedback. Credit-based approaches consists of per-link, per-VC window flow control. The receiver monitors queue lengths of each VC and extends to the sender a “credit” for the number of cells the sender can transmit on that VC. The sender transmits only as many cells as allowed by the credit. Rate-Based approaches control the rate by which the source can transmit. If the network is lightly loaded, the source is allowed to increase its cell rate. If the network is congested, the source is directed to decrease its transmit rate.

A typical rate-based flow-control approach is an end-to-end feedback mechanism, consisting of a source end-station, a destination end-station, and intervening switches. Within the feedback loop, the switches and/or destination end-station use resource management (RM) cells generated by the source end-station, and/or the Explicit Forward Congestion Indication (EFCI) bit in the payload-type coding of the ATM cell header to convey to the source network status information needed to adaptively adjust transmission rates.

After considerable discussion among ATM community members concerning the best approach to implementing the required flow-control feedback loop, the ATM Forum recently settled on a “rate-based” approach and rejected the credit-based approach. The main reason for the credit-based approach not being adopted is that it is not scalable and requires per-VC queuing. This would cause considerable complexity in large switches which support millions of VCs. Rate-based approaches can work with or without per-VC queuing.

In integrated networks where satellites are a component, EFCI or any other type of feedback mechanism, necessarily incurs at least a one-way propagation delay in notifying the source to adapt its transmissions to current network conditions. Due to the additional delay incurred on such networks, by the time the source end-station could react to congestion information conveyed in this manner, it is possible that the switch might already have begun to discard low priority cells. While the loss of an occasional cell would not necessarily have a devastating impact on voice or video traffic, it could lead to significant problems for other data traversing integrated networks. If even one cell is lost, the entire packet must be retransmitted. Consequently, because of repeated retransmissions, the loss of a small number of cells could have a significant impact on the network at a time when it might already be operating in a congested or impending congestion state.

Because of the effect delay has on the flow control mechanisms of certain Internet transmission protocolsÄÄespecially the Transmission Control Protocol (TCP), long delays become especially significant in satellite-delivered Internet services. The TCP provides end-to-end, connection-oriented, reliable transport layer functions over IP networks. TCP builds its services on top of the network layer's services with mechanisms such as error detection, positive acknowledgment, sequence numbers, and flow control. The flow control mechanism used by TCP is based on a window which defines a continuous interval of acceptable sequence-numbered data. The window enables a TCP at a receiving location to govern the amount of data sent by a TCP at a sending location. The TCP requires each data packet to be acknowledged by the receiving TCP as received intact before sending further packets. As data is accepted, TCP slides the number upward in the sequence number space. The TCP protocol requires quick acknowledgments that packets have been received. When a sending device does not receive the expected acknowledgment, it starts retransmitting packets it assumes have been lost. While designed to operate efficiently in low-delay, terrestrial networks, TCP does not perform as well over satellites where the round trip delay can exceed 500 milliseconds. In an article in the November 1997 issue of *Via Satellite* [7], Cynthia Boeke proposed several techniques for overcoming the limitations of TCP when used in a satellite environment. The techniques cited were: (1) using techniques such as acknowledgment compression and protocol emulation to reduce the amount of acknowledgment traffic, (2) providing a bigger window, and (3) simply replacing TCP with a more efficient protocol for use with the unique characteristics of satellite networks.

The long propagation delay associated with GEO satellite systems is a significant factor behind the move to non-GEO satellite systems. Because of the relatively low altitudes of LEO/MEO satellites, the speed of electromagnetic propagation via such satellites is faster than by terrestrial optical fiber cable for a comparable distance. With LEO systems, it is possible to achieve a significant reduction in signal propagation delay. The typical signal delay, or latency, from earth station to earth station for a single LEO satellite system hop (1600 kilometers (Km)) is about 5-10 ms. Latency may easily increase to 100 ms if intersatellite links or multiple hops are used. The signal delay from a MEO satellite network is less than the delay experienced in GEO systems but greater than that experienced by LEO systems. The MEO system signal delay is around 110-130 ms. Generally, for real-time communications the shorter the signal delay, the better the performance. The lower delay incurred via LEO/MEO systems will reduce significantly many of the long propagation delay problems that have become synonymous with GEO satellite communications systems.

4.2 ERRORS

In communications networks, error rates are measured in terms of the ratio of the number of bits in error received to the total number of bits transmitted over a stipulated period of timeÄÄÄthe bit error rate (BER). BER is usually expressed as a number and a power of 10ÄÄÄe.g., 2.5 erroneous bits out of 100,000 bits transmitted would be 2.5 x 10^{-5}. Errors can be random or bursty in nature. Random errors are errors distributed over the digital signal in such a manner that they can be considered statistically independent of one another. They are caused by the presence of random noise and low signal-to-noise ratio in a communications link. An error burst is a string of contiguous bits with a very high probability of being in error. Because the extremely low BER characteristics of optical fiberÄÄÄbetter than 10^{-10}ÄÄÄwere assumed when ATM parameters were defined, minimum error correction mechanisms have been included in the ATM protocol. ATM networks do not execute retransmission schemes. They correct cell headers with one-bit errors and discard headers with multiple bit errors. At the expected low BER of optical fiber, the HEC field in the ATM cell header is sufficient to correct single bit errors in the header, or detect multiple errors. No error correction is allowed in the ATM cell payload by the core network, this is left to the end-to-end termination equipment. When errors are introduced in the payload by the core network, retransmission, if required, is accomplished by the AAL protocol stacks at the originating endpoint.

On satellite links burst errors which result in large groups of bit errors are common. Bursts of errors are a major concern in integrated ATM/satellite networks. The overall BER performance of satellite links is usually about 1 x 10^{-7}. However, quality of service is application dependent. For some voice applications the quality may be acceptable with a BER of 1 x 10^{-6} or higher. Some operations, such as medical imaging which relies heavily on non-delay sensitive file transfer applications, may find 1 x 10^{-7} acceptable by relying on the high-level protocols to resolve any problems resulting from non-error-free transmissions. Two major causes of the errors is Gaussian noiseÄÄnoise with random distribution of frequency components centered on a specified frequencyÄÄand the convolutional coding used in satellite networks to achieve high throughput while lowering the antenna size and/or power requirements to contain costs. However, other conditions may also degrade the quality of satellite links, causing an increase in the BER. Specific conditions which could cause other errors include multipath reflections, shadowing, and fading due to hand-off periods with LEO/MEO systems. In geostationary orbit, attenuation due to condensed water vapor existing in the atmosphere (i.e., rain, fog, ice, clouds, or snow) might also produce additional errors on the links.

Burst errors on satellite links impact the operation of both the ATM and the AAL protocol layers and their transportation in the SONET/SDH frames. Due to the frequency of the occurrence of errors, a number of error correction techniques have been tested on such links. Basically, the techniques tested fall into two categories: forward-error-correction (FEC) and ARQ. FEC uses certain binary codes that are designed to be self-correcting for errors introduced by the intervening transmission media. In this form of error correction, the receiving station has the ability to reconstitute messages containing errors. However, FEC as currently used works on random errors only. It is generally not effective with burst errors. ARQ is a two-way error correction technique based on feedback. Using this method, data is broken into packets. Within each packet is included an error checking keyÄÄÄoften a mathematical algorithm that computes a numerical value based on the bits in a block of data. If the error code reflects a loss of integrity in a packet, the receiver can request the sender to resend the packet. ARQ requires relatively noise-free channels to be effective. It is not very effective in a channel with high noise levels because the noise that corrupted the initial packets will likely also cause corruption in subsequent packets thereby requiring repeated retransmissions of the same data.

Additionally, in the ATM portion of an integrated network, performance is dependent on the nature of the bit errors encountered. Since the ATM cell HEC is capable of correcting only single bit errors, burst errors cannot be corrected by the ATM cell header HEC field. Consequently, the probability that satellite-transmitted data entering the ATM portion of an integrated network will be discarded is orders of magnitude higher than that over links with random errors. While efficient from a control standpoint, this discarding of cells could also lead to repeated retransmissions and a corresponding increase in network loading at a time when the network is already operating in a degraded mode.

4.3 BANDWIDTH

Because of differences between the extremely high bandwidth offered by optical fiber and the relatively limited bandwidth offered by satellite links, bandwidth management is a significant issue in integrated ATM/satellite communications networks. While satellite links offer bandwidth that is as great or greater than most other transmission media, a satellite's channel capacity is still rather limited compared to the capacity of optical fiber-based ATM networks. In satellite networks, the bandwidth of each channel is fixed, thus requiring the employment of stringent access control techniques for bandwidth management to enable different users to share usage of a common channel or transponder. ATM is basically a connection-oriented system that requires only the establishment of a connection between two endpoints before data can be transferred between them. In ATM networks, the transmission path is specified during call-establishment, enabling ATM cells to self-route through the network based on information contained in the ATM cell header. Being connection-oriented also allows ATM to specify a guaranteed QoS for each connection, and to efficiently support a network's aggregate demand by allocating bandwidth on demand based on immediate user need.

The bandwidth management approach used in ATM networks is a combination of managing and controlling traffic flow, and the statistical multiplexing of ATM cells to accommodate varying traffic submitted to the network. Traffic flow/congestion control measures currently being implemented in ATM networks may generally be classified into two categories: preventive controls and reactive controls. Preventive controls are used to prevent congestion from occurring by limiting the total amount of traffic admitted to the network. Reactive controls are used to recover from congestion once it occurs. In broadband networks, reactive controls are generally effective only over short distances due to inherent difficulties of high transmission rates, and delays induced by transmission systems, propagation, and fixed switch processing components. For most QoS classes, the traffic flow/congestion control measures being implemented in ATM networks fall largely in the preventive category. For additional discussion of this aspect, please refer to reference 36 (page 30) of this bulletin.

Statistical multiplexing enhances bandwidth efficiency by eliminating "idle time" allocations to inactive terminals, and padded blanks or null characters in the composite message blocks. With statistical multiplexing, channels are allocated time slots dynamically according to actual demand rather than on a predefined basis. ATM network nodes do not distinguish between information packets. All PDUsÄÄmessages composed of payload and protocol-specific control informationÄÄarriving at the node from whatever source or data rate, is multiplexed to fixed sized cells and encapsulated for transmission through the network. The interface between the terrestrial public ATM network and the satellite system has the function of adapting data from the ATM portion of the integrated network to a proper format for transmission via satellite and formatting satellites packets for transmission to the ATM network.

In satellite networks, supporting different classes of service directly impacts the choice of a channel access/sharing mechanism. Access to any shared satellite channel can be of three typesÄÄÄfixed assigned, contention/random access, or reservation/controlled access. There are also several hybrid access schemes between contention and reservation. However, none of the existing access schemes appear to be optimized for ATM technology. Fixed assigned multiple access schemes such as FDMA and CDMA are comparatively inefficient in a bursty environment with hundreds or thousands of potential users. Contention/random access schemes such as the ALOHA protocol and the selective reject (SREJ) ALOHA protocol, both require some form of collision resolution, and may be a poor choice for delay-sensitive traffic such as voice/video.

In ALOHA, stations transmit new messages on the channel as they are generated. If a collision occurs, the colliding packets are simply retransmitted with random delay. This approach results in low efficiency of channel use. With SREJ ALOHA data are formed into a contiguous sequence of independently detectable fixed-length subpackets, each with its own header and acquisition preamble. The thinking behind this strategy is that most collisions in an asynchronous channel result in partial overlap of contending packets. Therefore, only small portions of the subpackets encounter conflict and must be retransmitted. Reservation/controlled access schemes such as DAMA, where reservations can be made by either a contention process or a fixed assigned process, appears to offer several advantages over the other types of access schemes. Specific advantages are: (1) data messages can be scheduled in a conflict-free manner, and (2) well designed DAMA systems can support variable-length message traffic with relatively high overall channel throughput. However, due to the reservation mechanism, the higher throughput is accompanied by a relatively large minimum latency (>0.500 ms) delay. Because of the disparity in bandwidth and data rates which could be serviced in separate parts of an integrated network, the role of buffersÄÄÄroutines or temporary storage used to compensate for a difference in rate of flow of data, or time of occurrence of events, when transferring data from one device or system to anotherÄÄÄis an increasingly important one. Buffering permits traffic shaping, and at the expense of delay, can help to make congestion problems less severe. The ATM Forum Traffic Management Working Group has an ongoing effort to determine the amount of delay incurred in LEO and GEO satellite networks for various buffer sizes and number of sources.

4.4 AVAILABILITY

Readiness and dependability of satellite links is generally described by two basic criteria: reliability and availability. Reliability is the ability of a system or subsystem to perform within prescribed QoS parameters. Reliability is often expressed in a more restrictive way to indicate the probability that the system or subsystem will perform its intended function for a specified interval under stated conditions. Availability is a measure of the degree to which a system, subsystem, or equipment is operable and not in a state of congestion or failure at any point in time. High availability from the network user's perspective depends not only on the availability of the equipment comprising the network, but also on the resilience of network routing and data transfer protocols, and sufficient path diversity to ensure accurate and timely information transfer if equipment or transmission path failure occurs. Typically, high-availability satellite systems employ a combination of hardware and software redundancy to recover from system faults and maintain availability. However, utilization by some emerging communications satellite systems of carrier frequencies above 10 GHz has significant availability implications for satellite links. At such frequencies, satellite links are considered propagation-limited, and the effects of precipitation and other environmental factors must be taken into account.

Telephone switching provides an availability benchmark against which the performance of other systems can be measured. A general availability target for telephone switching systems is 99.9999%. This target allows a switch to be out of service for no more than a few minutes each year. This high availability rate assumes that active calls are not lost during switching system failure, and that less than 0.01% of calls in progress are handled incorrectly. Optical fiber-based ATM networks are expected to meet or exceed this availability target.

Satellite providers typically guarantee 99.5% to 99.9% availability. Emerging systems such as Globalstar, promise an uptime of 99.9%. Teledesic and Iridium constellation providers have not set system availability guarantees. However, because of (1) reductions in the amplitude of the transmitted signal caused by rain-induced absorption and scattering, or changing path characteristicsÄÄÄe.g., multipath reflections, shadowing, and fading due to satellite hand-off periods; (2) frequency reuse techniques with the potential to cause interference between channels through a transfer of energy from one polarization state to the other orthogonal state (e.g., SDMA); and (3) increased intersatellite interference due to the narrower spacing of satellites due to the limited number of orbital positions available for satellites in geostationary orbit, the availability of satellite links at the planned carrier frequencies is not likely to match the expected availability performance of optical fiber-based ATM networks.

4.5 IMPACT ON NS/EP OPERATIONS

During the early stages of major natural disasters or emergencies, the effects of satellite-induced delay, errors, bandwidth limitations and availability could adversely impact the ability of Government relief agencies to coordinate delay-sensitive services. At such times the key focus of Government disaster relief agencies is on National, State, and local level coordination of the resources required to save lives, alleviate human suffering, and reestablish control in the disaster area. Because of the immediacy of the need for information, voice and video-based applications play a major roles in providing Governmental authorities and providers of delay-sensitive services at all levels, the accurate and timely information needed to coordinate decisions and focus response actions. Such applications are highly sensitive to delay and other properties. Depending on the severity of the disaster, widespread collateral damage to the normal commercial telecommunications infrastructure in the disaster area is also probable. Consequently, because of the rapid response capabilities inherent in satellite networks, it can be expected that where such capabilities exist, they will be fully exploited. Correspondingly, any satellite-induced degradation in the QoS normally provided by the network can be expected to have a noticeable impact on the overall capability of emergency service managers to coordinate response operations in a degraded network environment.

LIST OF REFERENCES

1. Federal Emergency Management Agency, *Federal Response Plan (For Public Law 93-288, as amended)*, April 1992.

2. Black, U., 1997, *Emerging Communications Technologies - Second Edition*, Prentice Hall PTR, Upper Saddle River, NJ.

3. Freeman, R., 1996, *Telecommunications System Engineering - Third Edition*, John Wiley & Sons, Inc., New York, NY.

4. Inglis, A. and Luther, A., 1997, *Satellite Technology: An Introduction -Second Edition*, Focal Press, Boston, MA.

5. Richharia, M., 1995, *Satellite Communication Systems: Design Principles*, McGraw-Hill, New York, NY.

6. Mural, G. and Bousquet, M., 1996, *Satellite Communications Systems,* John Wiley & Sons, Inc., New York, NY.

7. Boeke, C., November 1997, “Surfing Among the Stars 3: The Satellite Solution for Internet, Intranet, and Extranet Applications,” *Via Satellite*, Phillip Business Information, Inc., Rockville, MD.

8. Price, K., et al, March 1992, *Final Report for Task Order 6: Applications of Satellite Technology to Broadband ISDN Networks*, NASA Contractor Report 189199, Space Systems/LORAL, Palo Alto, CA.

9. ATM Forum Technical Committee, April 28 - May 2, 1997, *Satellite ATM Utilization,* ATM Forum/97-0358, The ATM Forum, Chicago, IL.

10. Campanella, S., et al, February 1995, *Faster Than Fiber: Advantages and Challenges of LEO Communications Satellite Systems*, University of Maryland, College Park, MD.

11. Alonso, J., and Benedicto, F., February 28 - March 3, 1994, “A K/KA Band Satellite System Providing Personal and Mobile Multimedia Telecommunications Services,” *15th AIAA International Communications Satellite Systems Conference*, The American Institute of Aeronautics and Astronautics, Washington, DC.

12. Marven, C. and Ewers, G., 1996, *A Simple Approach to Digital Signal Processing*, John Wiley & Sons, Inc., New York, NY.

13. Freeman, R., 1995, *Practical Data Communications*, John Wiley & Sons, Inc., New York, NY.

14. Howes, K., January 1997 “Satellites In the Age of Interactivity: A Space-based Platform for Multimedia and High Data Rate Services,” *Via Satellite*, Phillip Business Information, Inc., Rockville, MD.

15. Chitre, D., et al, February 28 - March 3, 1994, “Broadband ISDN (B-ISDN) Via Satellite: Issues, Challenges, and Resolution,” *15th AIAA International Communications Satellite Systems Conference*, The American Institute of Aeronautics and Astronautics, Washington, DC.

16. Lubar, D. and Romano, D., March 1997, “Harnessing the Power of Smart Satellites,” *Satellite Communications*, Intertec Publishing, Inc., Overland Park, KS.

17. Nelson, R., February, 1998 “V-Band; Expansion of the Spectrum Frontier,” *Via Satellite*, Phillip Business Information, Inc., Rockville, MD.

18. Datapro Research Group, 1991, *An Overview of Satellite Communications*, McGraw-Hill, Inc., Delran, NJ.

19. Roddy, D., 1989, *Satellite Communications*, Regents/Prentice Hall, Englewood Cliffs, NJ.

20. Honcharenko, W., et. al., January 1997, “Broadband Wireless Access,” *IEEE Communications Magazines,* New York, NY.

21. Murphy, J., et. al., 1993, Technical Report: *ATM Service-Based Selective Retransmission over DSN Satellite Link, (TR-DSN-ISE-93-4)*, http://thorung.eeng.dcu.ie~murphyj/the/teh/node57.html.

22. ATM Forum Technical Committee, October 1996, *Satellite Access Services Descriptions*, ATM/Forum/96-1452, Montreux, Switzerland.

23. Kota, S., et. al., September 1997, *Satellite ATM network Architecture Considerations And TCP/IP Performance,* http://www.cis.ohio-state.edu/jain.

24. Jamalipour, A., et. al, February 1997, “Traffic Characteristics of LEO-Based Global Personal Communications Networks,” *IEEE Communications Magazine*, New York, NY.

25. Seidman, L., October 1996 “Satellite for Wideband Access,” *IEEE Communications Magazine,* New York, NY.

26. Office of the Manager, National Communications System, December 1997, *Telecommunications/Information Systems Industry Analysis Report (TISA)* (Draft), Office of the Manager, National Communications System, Arlington, VA.

27. ATM Forum Technical Committee, December 1996, *A Candidate Distributed MAC Protocol for WATM,* ATM/ Forum 96-1574, Vancouver, Canada.

28. Sackett, G. and Metz, C., 1996, *ATM and Multiprotocol Networking*, McGraw-Hill, New York, NY.

29. SETA Corporation, December 1997, *Analytic Update on Telecommunications Industry Initiatives and Developments: 1997,* SETA Corporation, McLean, VA.

30. Office of the Manager, National Communications System, January 1998, *Technical Information Bulletin 98-2: Selected ATM/Internet Protocol (IP) Technical Interface Consideration*, Office of the Manager, National Communications System, Arlington, VA.

31. Sky Station International, Inc., Undated, *The Technology: Stratospheric Telecommunications Service*, http://www.skystation.com/sts.html, Sky Station International, Inc., Washington, DC.

32. Nakamura, H., et. al., February 1998, "Applying ATM to Mobile Infrastructure Networks," *IEEE Communications Magazine*, New York, NY.

33. Chistyakov, L., March 1998, "Top Ten: High Availability," *Communication Systems Design,* Miller Freeman, Inc., San Francisco, CA.

34. Esmailzadeh, R., et. al., April 1997, "Time-Division Duplex CDMA Communications," *IEEE Communications Magazine*, New York, NY.

35. Ali, S., et. al., April 1997, White Paper: *EE 4984: Digital Satellite Systems for Internet Access*, http://fiddle.ee.vt.edu/courses/ee4984/Projects1997/ali_peter_white.html.

36. SETA Corporation, June 20, 1997, *High Speed Networks Analysis Report: Call/Connection Establishment and Congestion Control in ATM Networks,* SETA Corporation, McLean, VA.

ACRONYMS

AAL	ATM Adaptation Layer
ANSI	American National Standards Institute
ARQ	Automatic Repeat Request
ATDMA	Asynchronous Time Division Multiple Access
ATM	Asynchronous Transfer Mode
BER	Bit Error Rate
B-ISDN	Broadband Integrated Services Digital Network
BSS	Broadcast Satellite Service
CBR	Constant Bit Rate
CDMA	Code Division Multiple Access
CLP	Cell Loss Priority
CPE	Customer Premises Equipment
CRC	Cyclic Redundancy Check
CS	Convergence Sublayer
DAMA	Demand Assignment Multiple Access
DBS	Direct Broadcast Satellite
EFCI	Explicit Forward Congestion Indication
FCC	Federal Communications Commission
FDD	Frequency Domain Duplex
FDMA	Frequency Division Multiple Access
FEC	Forward Error Correction
FECN	Forward Explicit Congestion Indication
FSS	Fixed Satellite Service
GEO	Geostationary Earth Orbit
GFC	Generic Flow Control
GHz	Gigahertz
GSTS	Global Stratospheric Telecommunications Service
HEC	Header Error Control
IP	Internet Protocol
ISL	Intersatellite Link
Km	Kilometer
LEO	Low Earth Orbit
Mbps	Megabits per second
MCPC	Multiple-Channel-Per-Carrier
MEO	Medium Earth Orbit
ms	millisecond
m/s	meters-per-second
MSS	Mobile Satellite Service
N6	Technology and Standards Division
NNI	Network-to-Network Interface

NS/EP	National Security and Emergency Preparedness
OC-1	Optical Carrier level 1
OMNCS	Office of the Manager, National Communications System
PCS	Personal Communications Services
PDU	Protocol Data Unit
PSTN	Public Switched Telephone Network
PT	Payload Type
PVC	Permanent Virtual Circuit
QoS	Quality of Service
RF	Radio Frequency
RM	Resource Management
SAR	Segmentation and Reassembly
SCPC	Single-Channel-Per-Carrier
SDH	Synchronous Digital Hierarchy
SDMA	Space Division Multiple Access
SHF	Super High Frequency
SONET	Synchronous Optical Network
SPE	Synchronous Payload Envelope
SREJ	Selective Reject
STS	Synchronous Transport Signal
SVC	Switched Virtual Circuit
TCP	Transmission Control Protocol
TDD	Time Domain Duplex
TDMA	Time Division Multiple Access
UHF	Ultra High Frequency
UNI	User-to-Network Interface
VC	Virtual Channel/Circuit
VCC	Virtual Channel Connection
VCI	Virtual Channel Identifier
VCL	Virtual Channel Link
VP	Virtual Path
VPC	Virtual Path Connection
VPI	Virtual Path Identifier