terminals and devices attached to the ends of the network as reliable and trouble-free as the network itself. For instance, fire and burglar alarm systems that send warning signals through the telecommunications network have great potential for improving home security. But fire and police departments cannot tolerate a large percentage of false alarms, so alarm systems must be intelligent enough to distinguish real emergencies from false ones. The same kind of careful systems engineering and the same approach to reliability that helped build the intelligent network must be applied to the intelligent terminals and sensors that interact with it.

The capabilities of the intelligent network have evolved in close synchronization with advances in science and technology. But in recent years the merging of telecommunications and computer technologies has raised difficult regulatory issues with potentially profound effects on the evolution of the network. There are many points of view on these issues. But on at least one point there seems to be consensus: that the benefits of rapid technological progress—new products and services—must continue to become promptly and widely available.

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# Business Use of Satellite Communications


Burton I. Edelson and Robert S. Cooper


The first commercial satellite communications system, INTELSAT, has been in operation since 1965. Growing at an annual rate of more than 20 percent, INTELSAT has progressed through five generations of satellites to provide global coverage devoted mostly to long-distance trunks for telephone circuits (*1*). The present system has 12 operational and standby satellites interconnecting 300 earth stations on six continents through a network of 800 links. The traffic load now exceeds 20,000 two-way telephone circuits, plus television and data. In addition to international communications, INTELSAT leases capacity to 20 countries for domestic communications.

INTELSAT has been a significant business success, over the years providing service of increasingly higher quality at lower cost. Its charge for a telephone circuit in 1981 ($4680 per channel) is one-sixth of its original charge. Moreover, INTELSAT is profitable for its members as well as its users—the communications carriers. From its revenues of $213 million last year, it will pay its members about a 14 percent return on their investments.

Several nations, including the United States, launched satellites to provide their own domestic communications services starting in the middle 1970's (*2*). Many of the same technologies that provide good communications links between countries across oceans have served as well to connect cities and towns, or even individual buildings, within a single nation. Special technology had to be developed for domestic systems to meet national and local requirements—for example, satellite antennas to provide high-power, limited-area coverage (Fig. 1) and small earth stations, which are particularly adaptable to user requirements in urban areas (Fig. 2).

Although it was thought that domestic systems would, like INTELSAT, be used mostly for telephone trunking, their major application has been for television program distribution to broadcasters and cable systems and, increasingly, for data transmission. In the United States, domestic satellite system traffic is projected to grow at the rate of 15 percent or more per year through the rest of this century (*3*) (Fig. 3).

Today, 22 separate satellite communications systems are operational worldwide, with a combined commercial revenue approaching $2 billion per year (*4*), and 30 additional systems are being built or planned. In this article we briefly review business communications development and then discuss business applications of satellite communications, systems technology, and prospects for future developments in digital transmission systems.

## Business Communications

Paralleling the expansion of satellite communications has been the information explosion in business operations and management, particularly in the United States. The number of white-collar workers is growing rapidly and their time is being devoted increasingly to the tasks of generating, storing, retrieving, manipulating, and transmitting information. The effectiveness of the white-collar work force now depends heavily on man-


Burton Edelson is senior vice president of COMSAT General Corporation, Washington, D.C. 20024. Robert Cooper is director of the Defense Advanced Research Projects Agency, Department of Defense, Arlington, Virginia 22209.




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agement's intelligent use of computers and terminal equipment. Since business expenses in these areas are grouped with general overhead, they are reflected almost directly in a company's profits and losses. Therefore, interest in technical innovations that reduce these expenses is high.

*Summary.* The development of satellite communications over the past two decades has been very rapid. At the same time, space and electronics technologies have progressed sufficiently to allow satellite systems to keep pace with user requirements and to expand in several dimensions, including capacity, coverage, performance, reliability, and variety of services. The principal services provided by satellite systems have been long-distance trunks for telephone circuits and television program distribution. Recently, data transmission and network services have been added to meet emerging requirements for "office of the future" and other business applications. Data services are now expected to be the most rapidly expanding element of satellite communications.

Historically, business communications have been carried over analog communications channels, whether the transmission medium was terrestrial microwaves, coaxial cables, or satellites. With the increasing importance of digital data in business and government, special digital communications systems are emerging in both terrestrial and satellite networks. Computer-controlled electronic switches and digital transmission equipment are being installed at an accelerating rate as replacements for outmoded electromechanical equipment in the terrestrial net. All-digital satellite systems are just now being put into service.

The architecture of this emerging communications network, known as the Integrated Services Digital Network, is transforming and supplementing previous analog facilities. The all-digital network approach provides compatibility between digital computers and office equipment and the channels by which they communicate. Regardless of the nature of the original message—voice, data, facsimile, video, or industrial control—information can be routed and transmitted in digital form over wideband channels with high efficiency. Domestic satellite systems are well matched to the transmission of these digital signals, providing high-quality, wideband channels at low cost. Connectivity is established throughout the area of coverage with the satellite serving as a central node.

## Business Applications

As factory automation and mass production techniques improve, management costs rise to become a larger portion of overall business expenses. The management costs related to information systems and services borne by U.S. businesses in 1980 were over $200 billion. Table 1 shows the breakdown of those costs among four major categories (*5*). About 55 percent of the costs, or $111 billion, is attributable either to communications or to travel and mail, both of which categories can be displaced by effective application of advanced telecommunications.

A further breakdown of the communications category in Table 2 shows that 62 percent of these costs is for transmission (line charges), and by far the largest share of this cost (84 percent) can be attributed to telephone traffic. It is in this area of low-cost, high-quality transmission that satellite links are most competitive, even for domestic use. Terrestrial transmission systems, such as microwave relays, coaxial cables, and optical fiber cables, can also provide good transmission quality. It will be years, however, before these systems are extensive enough to provide the broadband connectivity that is already available with satellites, and it is doubtful whether they will ever compete in cost over long distances.

Table 1. Business costs related to information systems and services (*5*).

| Category | Cost ($ billion) | Percent of overall expenses |
|---|---|---|
| Data processing | 62 | 31 |
| Office expense | 27 | 14 |
| Travel and mail | 75 | 37 |
| Communications | 36 | 18 |
| Total | 200 | 100 |

Table 2. Business communications costs (*5*).

| Category | Cost ($ billion) | Percent of overall expenses |
|---|---|---|
| Equipment | 7.9 | 22 |
| Labor | 3.7 | 11 |
| International | 1.7 | 5 |
| Line charges | 22.7 | 62 |
| Total | 36.0 | 100 |

Table 1 shows that $75 billion, or 37 percent of overall business expenses, is related to travel and mail. Digital data transmission by satellite now provides a number of interesting alternatives to these traditional expenses. Teleconferences, for instance, are expected to reduce the need for business travel. Color video encoders for teleconferences, which operate at speeds from 6.3 down to 1.5 megabits per second and have adequate color and motion fidelity, are now commercially available. Full privacy can be maintained through encryption of the digital bit stream.

Mail costs can also be displaced to a significant extent through facsimile telecommunications. Facsimile scanning and printing equipment provides several grades of service. Relatively slow analog equipment (several minutes per page) of moderate quality (100 to 200 lines per inch) has been available for use over telephone lines for a decade.

Higher speed, higher resolution digital equipment (several seconds per page and 200 to 400 lines per inch) is now available for use over data networks at channel speeds of 9.6 to 224 kilobits per second. The U.S. Postal Service is developing an international electronics postal system, INTELPOST, which uses such equipment. At present, six nations are involved in the system, with mail processing centers in Washington and New York and in Argentina, Canada, England, the Netherlands, and Switzerland. This system is expected to grow rapidly over the next few years, with more countries entering and most countries extending their domestic service.

Specialized, very high resolution facsimile equipment (800 to 1000 lines per inch) suitable for remote composition and makeup in the publication industry has recently come into service. The *Wall Street Journal* is now printed in nine plants across the United States solely by satellite facsimile transmission, and the *New York Times*, Gannett publications, and several magazines are also establishing publication networks by satellite. The copy for an entire magazine, including text and graphics (in color if desired), can be transmitted from composition site to an automated printing plant at a speed of 1.5 Mbit/sec within 1 hour.

A large nationwide retail chain creates about $10^9$ bits of sales information per day. Much of this must be exchanged among many locations, including company headquarters for management, inventory, and procurement control. Instead of letter and parcel mail, wideband satellite links during nonpeak traffic periods provide an ideal way to transfer routine data rapidly and efficiently.

Real-time uses for wideband satellite links include interactive communications between "smart" digital terminals, remote job entry to large mainframe computer centers, document distribution, and hotel and airline reservation services. High-speed satellite communications links, which are easily internetted and which operate with advanced burst modulation schemes, are particularly well suited to these emerging business applications.

In the following sections, digital transmission techniques and their applications to satellite communications systems for business needs are examined.

### Digital Transmission Systems

Communications satellites were first used to provide long-distance trunks for telephone circuits. INTELSAT started with one trunk of 60 telephone circuits connecting North America with Europe. As improved satellites with wider bandwidths and multiple-access capability became available, links were added to the system. Several frequency-modulated (FM) carriers were transmitted through the satellite on separate frequencies, a technique known as frequency division multiple access (FDMA). This FM/FDMA technique is still in primary use in INTELSAT today.

Digital techniques were first introduced to INTELSAT in 1973 for demand assignment in the so-called SPADE system, which allowed earth stations to "call up" channels as required with only the minimum power for each channel. Voice channels in the SPADE system were coded by pulse code modulation (PCM) and transmitted by phase shift keyed (PSK) modulation at 64 kbit/sec. Since there was only one channel on each carrier, the voice channels were transmitted through the satellite by FDMA. The SPADE system, which is ideal for a network of many lightly loaded telephone trunks, has been in continuous service since 1973.

The Canadian Telesat domestic system introduced the technique of time division multiple access (TDMA) in order to gain the maximum capacity for telephone circuits in one transponder. This overcame an inherent problem of nonlinear power amplifying devices in satellite transponders. Such transponders can operate at maximum power only if one radio-frequency (RF) carrier is present. If two or more carriers are present simultaneously, the power to the transmitter must be operated in a "backoff" mode, reducing its total capacity by 50 percent or more.

Domestic communications satellite systems are not configured primarily as trunking systems, as is INTELSAT, but as networks intended to carry medium- and high-speed data as well as voice traffic. With digital transmission techniques, several services may be provided concurrently. Signals that originate in analog form, such as voice and video, may be digitized and combined in the same bit stream as original digital signals, such as telex and computer data.

### Digital Transmission Processes

Several combined processes make up the all-digital transmission system in satellite communications. These include source and channel coding, multiplexing, modulation, and multiple access, all of which present advantages in efficiency and performance when combined digitally.

Source coding, the processing of signals at their origin for outward transmission, allows removal of redundant information. A good example is digital facsimile, which eliminates large amounts of "white space" for transmission. Also, voice and television signals may each be compressed by factors as great as 10 when converted into digital form.

Channel coding, the processing of signals en route within a network, may increase efficiency. Many types of digital signals are coded for error control and correction and for an efficient trade-off of satellite power and bandwidth. Encryption is also a form of channel coding.

Multiplexing, the combining of individual signals to form a trunk, is accomplished sequentially in the time domain more easily than in the frequency domain. As in almost all digital techniques, the hardware is simplified through the

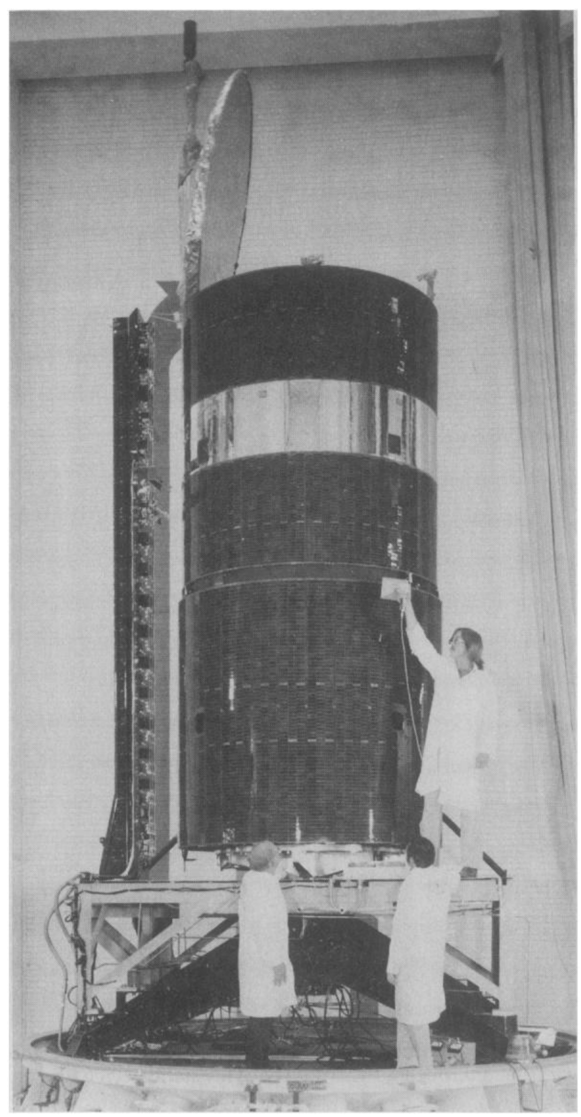

Fig. 1. Satellite Business Systems satellite in test chamber at the Hughes Aircraft Company plant; Hughes manufactures the satellite. This satellite weighs about 550 kilograms in geostationary orbit and has a capacity of 15,000 voice channels or 300 teleconferences.

use of solid-state devices, which are inherently bistatic and have the advantage (especially for spacecraft) of light weight.

Digital modulation (such as PSK) has advantages over analog modulation (such as FM) in its greater flexibility and resistance to interference.

Digital multiple access (TDMA) has two important advantages over analog multiple access (FDMA). In TDMA only one RF carrier need be present at a time in the satellite transponder; this allows the transponder output amplifier to operate at saturation without cross-carrier mixing, which can result in interference between channels. FDMA, in which several carriers are present simultaneously, requires back-off from maximum power to avoid this interference and therefore provides less capacity through the transponder. The second major advantage of TDMA is that only one receiver is required in each earth station for communications with many other earth stations; in FDMA the earth station requires a separate receiver for each of the earth stations from which it receives transmissions.

When the satellite transmission system is all digital, each of the processes indicated above can contribute to overall system efficiency and flexibility and lead to greatly enhanced capabilities.

## Domestic Systems

The three U.S. domestic satellite communications systems established in the middle 1970's—WESTAR (Western Union), SATCOM (RCA), and COMSTAR (AT&T)—all use the 6/4-gigahertz frequency band, as did INTELSAT until the introduction of INTELSAT V satellites in 1981. Although these systems mostly provide analog transmission service, some high-performance digital transmission links have been established, particularly by the American Satellite Corporation, using the WESTAR satellites. Both American Satellite and Western Union are now modifying their existing 6/4-GHz earth stations to accommodate high-speed digital services through TDMA.

Several U.S. domestic satellite systems are being developed for operation in the 14/12-GHz frequency band, which has the advantages of being available without interference and not requiring coordination to obtain site clearance for earth stations, and which therefore allows positioning of earth stations in congested metropolitan areas (for instance, on the roofs of buildings, as shown in Fig. 2). Satellite Business Systems (SBS) inaugurated service in the 14/12-GHz frequency band in early 1981. General Telephone and Electronics and Southern Pacific are also developing new systems that will use this band.

The combination of the wide bandwidth available in the 14/12-GHz frequency band, all-digital transmission systems, and smaller earth stations on customer premises is expected to be very effective in a wide range of business services. The SBS system, depicted in Fig. 4, illustrates an all-digital, 14/12-GHz system designed primarily for business purposes (*6*). It consists of a number of dedicated networks of earth stations, using the ten 50-megahertz bandwidth transponders in each satellite. Although each earth station operates autonomously while it is connected to all others in its network, TDMA transmissions in each satellite transponder are automatically coordinated from a communications master station. The satellite is controlled from one of two tracking and telemetry sites, where communications monitors also check the functioning of all earth stations that use the satellite. Finally, a System Management Facility monitors and tests the subsystems of all remote communications terminals, and dispatches maintenance personnel to upgrade redundancy after component failures.

Fig. 2. Satellite Business Systems earth station with aperture 5 meters, transmitted power 500 watts, and throughput 12 Mbit/sec. This station is located on the roof of One State Street, New York City.

The earth station, designed to operate unattended on the customer's premises, consists of a 5.5- or 7.7-meter antenna combined with receiving and transmitting equipment in a small fiberglass shelter, often placed on a building roof (Fig. 2) or in any convenient nearby ground location. The Satellite Communications Controller

(SCC), which is located in a room near the RF terminal, serves to receive analog and digital signals from various types of equipment in the terminal, convert and reformat them to a coded sequence of interleaved messages, add appropriate identification and routing information, and send a coded burst of information at a data rate of 48 Mbit/sec to the modem. The modem converts the pulse coded burst to an intermediate-frequency, phase-modulated signal, which it sends to the transmitter. The burst is then converted to radio frequency and transmitted to the satellite. Received signals follow the reverse path, with the SCC automatically routing the de-interleaved messages to the proper terminal equipment. Bulk encryption is added for data security as desired.

Each SBS terminal has a throughput capability of 12 Mbit/sec. One terminal can transmit simultaneously about 375 delta-modulated voice channels at 32 kbit/sec or eight video teleconferences at 1.5 Mbit/sec. The bit stream is transmitted through the satellite with an efficiency of about 1 bit per hertz; therefore, the capacity of each satellite is about 15,000 simplex voice channels or 300 video teleconference channels in the 500-MHz bandwidth.

Several companies are developing voice bandwidth compression equipment, which could reduce the data rate required to transmit toll quality speech to 16 kbit/sec or less. This is done by use of microprocessor-controlled coding devices with linear predictive algorithms. These techniques could double or quadruple the voice channel capacities of satellite communications networks at small incremental costs in the next few years.

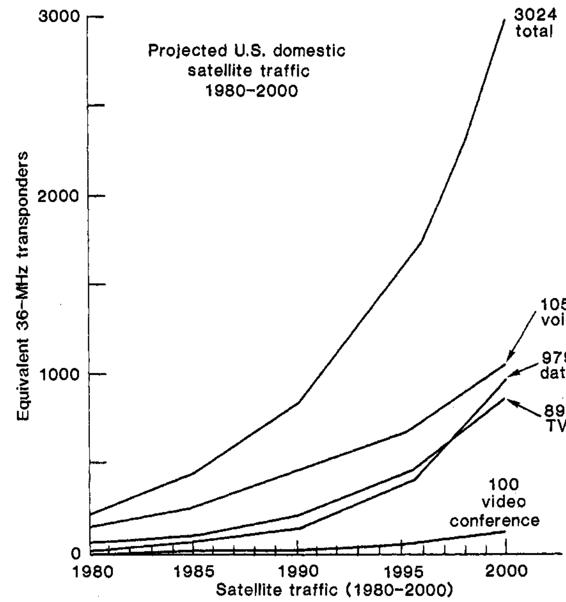


Fig. 3. U.S. domestic satellite communications traffic projected to the year 2000. The unit is equivalent to 36-MHz transponders. U.S. domestic satellites now have 10 to 24 such transponders. The average rate of traffic increase is projected at 15 percent per year.

## Future Trends

The trend toward larger, more powerful, and more complex satellites, smaller and less costly earth stations, and all-digital transmission systems is expected to continue through this century. Greater satellite system capacity will be obtained through the use of new frequencies, multiple frequency reuse, and efficient modulation and multiple-access techniques. Since orbital positions are limited, increased capacity must be achieved through the maximum utilization of each position. Very large spacecraft are expected to be launched by the end of this decade with the space shuttle, which will be able to transport large antennas (10 to 12 meters in diameter) with extensive feed systems and multiple frequency reuse. The increased weight potential will provide the opportunity for onboard processing and for greatly increased capacity. Satellites of the present generation (about 1000 kilograms) can provide capacities equivalent to about 12,000 two-way telephone circuits. Those of the next decade (about 5000 kilograms) are expected to provide the equivalent of about 250,000 telephone circuits.

In future generation satellites, TDMA will allow switching in the satellite at microwave frequencies, so that earth stations located in different satellite beams may communicate with each other. In each beam the same frequency band will be used, so that with many beams the frequency may be reused a large number of times to obtain high capacity (Fig. 5).

A further development would be demodulation of the received signal in the satellite, which could then be processed and switched at baseband. Signals could then be regenerated, remodulated, and finally transmitted from satellite to the earth. Such advanced processing satellites have been termed "switchboards in the sky."

As satellites increase in power and

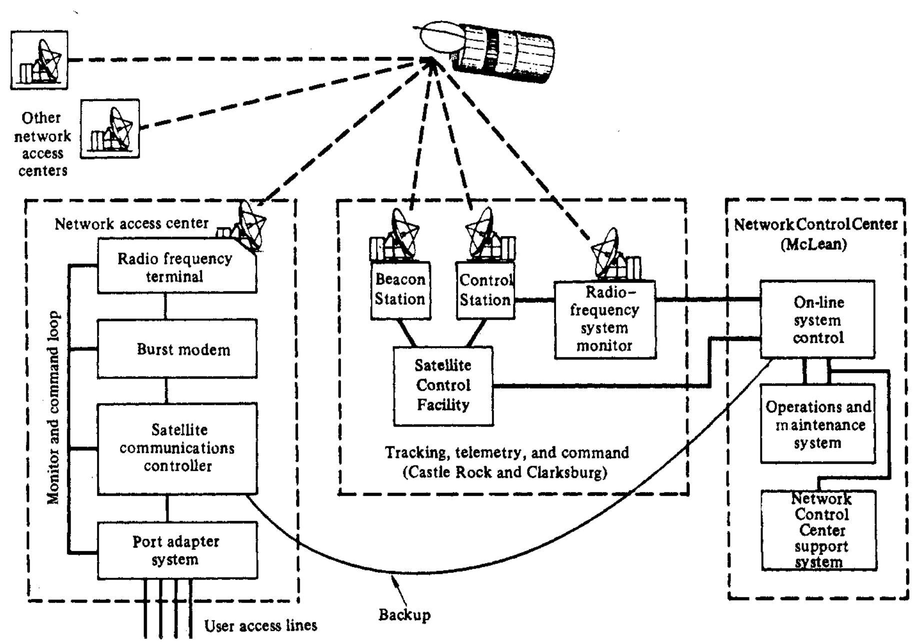


Fig. 4. Satellite Business Systems system schematic. Each satellite provides connectivity for a number of all-digital networks. Access to the networks is through earth stations, shown on the left. The control center (right) monitors the performance of all network operations and controls the satellites through the control facility (center).

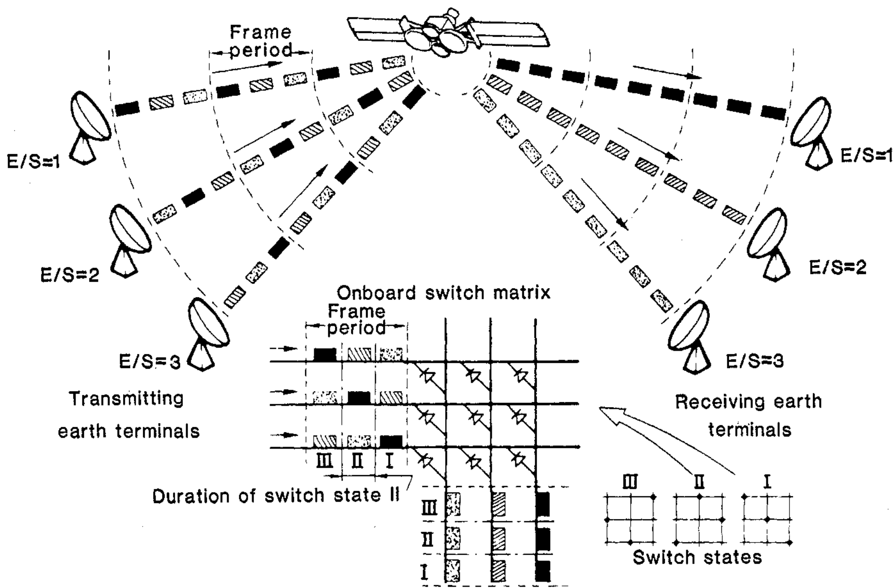


Fig. 5. In satellite-switched time division multiple access (SS/TDMA) operation, several earth stations in different beams communicate with each other through a microwave switch in the satellite. As shown here, a 3 by 3 switch matrix remains in one position for the duration of a burst, long enough for one combination of connections to be made (for example, station 1 to station 2, station 2 to station 3). Then in a few milliseconds the matrix switches to a new position, so that a new combination of connections is made (station 1 to station 3, station 2 to station 1) and so on. The great advantage of SS/TDMA is its very high capacity achieved through multiple frequency reuse.

transmission systems become more efficient, it will be possible to use smaller, less costly earth stations that are more adaptable to user requirements. Improvements in materials and computer-aided design and manufacturing will lead to high-performance, low-cost electronics both for digital circuits, as in very large-scale integration, and for microwave integrated circuits. Also, widespread use of computers will allow rapid reconfiguration to accommodate changes in traffic type or volume. This is particularly relevant to business users, who might require multichannel voice, video, teleconference, electronic mail, and computer interconnection, simultaneously or sequentially over the same network.

Since smaller earth stations can reside on the customer's premises, the requirements for terrestrial service extensions or so-called tail circuits will be reduced and there will be less dependence on interconnection facilities. However, earth stations may easily be shared among users in one vicinity through local networks consisting of cable or cellular radio communications.

As new business systems such as electronic mail, electronic funds transfer, facsimile publication distribution, and video teleconferencing come into use, satellite systems will be available to link them nationally—and eventually internationally—through direct user connections. Alternative terrestrial systems such as microwave links and fiber optic cables, although capable of carrying high-capacity digital circuits, have difficulty in providing direct connectivity and, further, use multiple tandem links, which complicates the error control problem. In general, terrestrial systems also have the disadvantage of requiring replacement of plant facilities. For these reasons, the growing demand for business services is expected to be met largely by satellite systems.

Business uses for satellite communications, now really in their infancy, should grow very rapidly during the decade. Satellite systems will provide the interconnections and networking capability required to make them practical and profitable.

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