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MARKET CAPTURE BY 30/20 GHz SATELLITE SYSTEMS

by: R. B. GAMBLE,
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15. Supplementary Notes

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16. Abstract

THIS REPORT PROJECTS DEMAND FOR 30/20 GHz SATELLITE SYSTEMS OVER THE NEXT TWO DECADES. TOPICS INCLUDE A PROFILE OF THE COMMUNICATIONS MARKET, SWITCHED, DEDICATED AND PACKET TRANSMISSION MODES, DEFERRED AND REAL-TIME TRAFFIC, QUALITY AND RELIABILITY CONSIDERATIONS, THE CAPACITY OF COMPETING TRANSMISSION MEDIA, AND SCENARIOS FOR THE GROWTH AND DEVELOPMENT OF 30/20 GHz SATELLITE COMMUNICATIONS. VOLUME 1 (REPORT NO. CR165231) PROVIDES AN EXECUTIVE SUMMARY OF THIS MATERIAL.

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TABLE OF CONTENTS

VOLUME I
EXECUTIVE SUMMARY

PAGE

VOLUME II

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

1.0 INTRODUCTION

This report presents the results of a study of telecommunications demand performed under NASA Contract Number NAS3-21366. The report consists of this volume, and a separately bound Executive Summary. The work described in this report is a continuation of a previous study performed under the same contract number and identified in Reference 1.

1.1 PURPOSE

Previous studies (Ref. 1, 2) have forecast the emergence over the next two decades of a greatly expanded demand for communications services. The present study assesses the degree to which Ka band (30/20 GHz) satellite systems can satisfy a significant portion of this demand so that necessary satellite technology can be developed on a timely basis.

1.2 SCOPE

The report forecasts demand for 30/20 GHz satellite systems, and the expected build up of traffic on these systems, as a function of time for each of several operational scenarios. The following major topics are covered.

<u>PROFILE OF THE COMMUNICATIONS MARKET</u>

The characteristics of the major terrestrial and satellite transmission media are discussed in terms of the capability of each to support the communications applications expected to be of importance over the next two decades.

<u>NETWORK OPERATING MODES</u>

The suitability of switched, dedicated, and packet network operating modes are discussed with respect to the communications applications projected. For satellite communications, the demand for Customer Premises Services (CPS) as opposed to Trunking Service is also estimated.

<u>TIME VALUES</u>

The degree of improvement in network efficiency permitted by the existence of an appreciable component of deferrable traffic is explored. The percentage of traffic in each communications category that is expected to require real-time as opposed to deferred transmission is estimated, as are peak factors appropriate to each of the various traffic categories.

QUALITY AND RELIABILITY

The quality and reliability expected for 30/20 GHz satellite communications systems is discussed relative to that of competing transmission media. Estimates of demand for services as a function of reliability are developed.

CAPACITY OF COMPETING SYSTEMS

Ka satellite systems will compete with those using terrestrial, C, and Ku band transmission media for a share of the communications market. The traffic carrying capacity of these systems is estimated.

ECONOMIC COMPARISONS

The relative costs of communications using a variety of terrestrial and satellite media are discussed.

Ka BAND MARKET CAPTURE

Several scenarios are postulated in which Ka satellite communications play an important role in satisfying projected demand. The build up of traffic on Ka systems is projected for each scenario.

1.3 CATEGORIES OF TRAFFIC DEMAND

Prior work, reported in Reference 1, divided traffic demand into a number of categories and subcategories and provided estimates of the long distance traffic demand for each subcategory of traffic. Table 1-1 represents a compact version of these results with the original categories and

TABLE 1-1 TRAFFIC DEMAND BY COMMUNICATION CATEGORY (TRAFFIC TRAVELLING 200 MILES OR MORE)

CATEGORY	COMMUNICATIONS SUBCATEGORY	TRAFFIC DEMAND (BITS PER YEAR$\times 10^{15}$)		
		1980	1990	2000
VOICE	RESIDENTIAL (SWITCHED SVC.)	81	197	378
	BUSINESS (SWITCHED SVC. INC. WATS)	248	600	1076
	BUSINESS (PRIVATE OR LEASED LINE)	561	1453	3440
	SUBTOTAL	890	2250	4894
VIDEO	NETWORK TV	13	16	11
	CATV	46	33	27
	EDUCATIONAL VIDEO	20	38	113
	VIDEOCONFERENCING	3	84	268
	SUBTOTAL	82	171	419
DATA	FACSIMILE	.3	2	4
	ELECTRONIC MAIL	-	6	7
	COMPUTER	111	272	423
	SUBTOTAL	111	280	434
	TOTAL	1083	2701	5747

subcategories slightly rearranged for convenience in presenting the scenarios appearing later in this report. Some minor subcategories of traffic introduced in Reference 1 have been combined with other, larger, subcategories. The subcategory of TWX/Telex has been included in Electronic Mail, Freeze Frame TV has been combined with Switched Business Voice, and Health and Public Affairs Video has been combined with Educational Video. The combination of these minor volume subcategories with related, larger, traffic components results in a more compact list with negligible impact on subsequent traffic projections. The traffic estimates for the private or leased line business voice service have also been updated to reflect information obtained subsequent to publication of Reference 1. The traffic demand in Table 1-1 is presented in terms appropriate for transmission via digital facilities by converting each component of demand to bits per year. For a discussion of the basis for these estimates and conversions, see Reference 1.

1.4 RANKING OF COMMUNICATIONS APPLICATIONS

Since the Ka band satellite facilities which are the prime focus of this report are not likely to be developed for commercial use until late in the present decade, interest centers on demand volumes projected for 1990 and the year 2000. As may be seen from Table 1-1 demand varies considerably from application to application, and from year to year. However, the relative rankings of demand for each application remain constant between 1990 and 2000.

Table 1-2 rearranges the data contained in Table 1-1 according to demand volume during the 1990-2000 decade. The first column under each year presents the demand for each subcategory of traffic in bits per year. The second column shows each subcategory's percentage of total demand and the third column cumulates this percentage by adding the demand for each subcategory down to, and including, the one in question.

Table 1-2 indicates that the major portion of projected long distance traffic demand is contributed by a relatively few, large applications. The first four, comprising the business and residential voice subcategories plus computer traffic (almost entirely terminal-to-computer data base traffic), account for more than 90% of total demand. With the addition of Videoconferencing more than 95% of demand is accounted for. Three video applications (Educational, Network TV, and CATV) account for most of the remaining few percent and the last two applications, Electronic Mail and Facsimile, amount to only a few tenths of one percent.

TABLE 1-2 TRAFFIC DEMAND IN RANK ORDER
(TRAFFIC TRAVELLING 200 MILES OR MORE)

COMMUNICATIONS SUBCATEGORY	1990			2000		
	BITS/YR. x 10^{15}	% OF TOTAL	CUM. %	BITS/YR. x 10^{15}	% OF TOTAL	CUM. %
1. BUSINESS VOICE (PRIVATE OR LEASED LINE)	1453	53.8	53.8	3440	59.9	59.9
2. BUSINESS VOICE (SWITCHED SVC. INCL. WATS)	600	22.2	76.0	1076	18.7	78.6
3. COMPUTER	272	10.1	86.1	423	7.4	86.0
4. RESIDENTIAL VOICE (SWITCHED SVC.)	197	7.3	93.4	378	6.6	92.5
5. VIDEOCONFERENCING	84	3.1	96.5	268	4.7	97.2
6. EDUCATIONAL VIDEO	38	1.4	97.9	113	2.0	99.2
7. CATV	33	1.2	99.1	[illegible]	0.5	99.6
8. NETWORK TV	16	0.6	99.7	11	0.2	99.8
9. ELECTRONIC MAIL	6	0.2	99.9	7	0.1	99.9
10. FACSIMILE	2	0.1	100.0	4	0.1	100.0
TOTALS	2701	100%	-	5747	100%	-

1.5 PRIMARY ROLE OF Ka SATELLITE SYSTEMS

Some of the lesser magnitude applications, while representing only a small percentage of the total, nevertheless amount in absolute terms to respectable traffic volumes. For example, a Ka band satellite system that captured much of the traffic predicted for Educational Video, Network TV and CATV might require several satellites to satisfy the demand indicated in Table 1-2. A Ka band satellite system oriented to this specialized video service, if suitably designed and priced, might therefore attract enough traffic to become an economically viable venture. However, the most important feature of Ka satellite systems is their ability to provide very high capacity in an uncrowded region of the spectrum. To make effective use of this capacity, and to best amortize the substantial costs likely to be required for the development of an advanced Ka band satellite communications network, it is desirable to address as many of the high traffic volume applications as possible. Emphasis in this report, therefore, centers on general purpose satellite systems capable of serving a wide variety of uses in the heavy volume applications. Once such a system is established in this high volume marketplace, further extension of service to specialized lesser volume applications can be considered on an incremental basis.

REFERENCES

1. "30/20 GHz Fixed Communications Systems Service Demand Assessment," NASA Report No. CR 159620, Prepared by ITT U.S. Telephone and Telegraph Corp. (Aug. 1979).

2. "18/30 GHz Fixed Communications Systems Service Demand Assessment," NASA Report No. CR 159546, Prepared by Western Union Telegraph Company (July 1979).

2.0 PROFILE OF THE COMMUNICATIONS MARKET

This section presents a profile of the communications market that is expected to develop over the next two decades, and of the terrestrial and satellite communications media suited to the satisfaction of this market.

In meeting the demand for communications services the telecommunications plant will use a wide array of terrestrial and satellite based technology. But, in the face of rapidly expanding traffic loads, it is likely that some technologies will be better suited than others for particular applications and will, as a result, capture correspondingly larger shares of the emerging market.

The section begins by briefly discussing some of the characteristics of existing and developing communications technologies that tend to encourage or discourage their use in various applications. The background thus provided is then used to assist in the assignment of traffic demand to those communications media aptly suited to accommodate it.

2.1 MEDIA CHARACTERISTICS

Each type of transmission medium has special characteristics which influence its competitive position and potential for use in particular applications. The following discusses the more important of these characteristics and establishes a background for later assessment of the degree of market penetration likely to be achieved by each medium.

2.1.1 CAPACITY FOR EXPANSION

The continued rapid growth of communications demand over the next decades appears to be a well established trend. In order to meet this demand, communications capacity will have to expand to several times its present value (Ref. 1,2). It is therefore pertinent to consider the ability of available long haul communications media to respond to these growth trends. Those media unable to respond to anticipated traffic volumes will clearly be limited in their ability to capture a proportionate share of the market.

2.1.1.1 MICROWAVE

The existing terrestrial long haul network is implemented largely through microwave line-of-sight radio transmission. A typical long haul route is capable of supporting 12,000 two-way voice circuits per route. The spectrum allocated to common carrier use is already subject to severe frequency congestion in many urban locations. Unless new bands are introduced for microwave radio systems (for example, as contemplated under the XTEN application) frequency congestion is likely to establish an important barrier to major increases in the capacity of microwave radio systems (Ref. 3).

2.1.1.2 COAXIAL CABLE

An important portion of bulk long haul transmission is provided by coaxial cable. Using AT&T's analog L5 carrier system, a coaxial cable (typically a 4" bundle of 22 individual tubes) can have very high capacity and can provide as many as 108,000 two-way circuits (Ref. 3). The newer T4 carrier system is basically digital and will support 274 million bits per second (roughly 2,000 two-way digital voice channels).

Coaxial cables require amplifiers every mile or so. A coaxial cable circuit across the United States might therefore have over 1,000 amplifiers (as compared to perhaps 100 for microwave) and in addition to being costly, this represents a disadvantage for some applications. Primarily as a result of right-of-way requirements, coaxial systems tend to be several times more expensive than microwave systems and major network expansions into new geographical regions are difficult to arrange.

2.1.1.3 WAVEGUIDE

Waveguides, like coaxial cable, are right-of-way dependent systems. The AT&T experimental WT4 helical waveguide system is designed to provide long distance communications service at a lower per circuit cost (when fully loaded), and with an order of magnitude improvement in reliability over other right-of-way systems (Ref. 4). The system is basically digital with repeater spacings of 30 to 40 miles. Nominal capacity is 240,000 two-way voice channels. While experimental results are impressive, waveguide systems have not yet been demonstrated as a working part of the long haul telecommunications plant. It appears likely that waveguide systems will be supplanted by emerging fiber optics technology and for this reason do not receive further discussion in this report.

2.1.1.4 FIBER OPTICS

The most promising of the new terrestrial communication media is fiber optics. Like waveguide and cable, fiber optics is right-of-way dependent, but the small diameter and flexibility of the fibers in many cases permits installation in existing ducts. Repeater spacings every four miles are also favorable in comparison with coaxial cable.

Following demonstration installations in Atlanta and Chicago (Ref. 5, 6), AT&T early in 1980 disclosed plans for the construction of a major fiber optics pipeline linking Washington, D.C., Philadelphia, New York, and Boston. The system is slated for start-up between Washington and New York in 1983 and will be extended to Boston the following year. Capacity of this digital link will be 80,000 two-way voiceband circuits. The system will cover 600 miles at a cost of 79 million dollars, and will link 19 digital Electronic Switching System (No. 4 ESS) offices in seven states and the District of Columbia. All but 97 miles of the half-inch diameter cables will be placed in existing Bell System conduits. AT&T estimates that construction costs for lightwave systems will be about $9.00 per circuit-mile in contrast with $13.00 per circuit-mile for older systems, and considers these systems to be the most economical means of adding new capacity to the network (Ref. 7, 8).

2.1.1.5 SATELLITE COMMUNICATIONS

The capability of satellite systems to add substantially to existing long haul telecommunications capacity involves complex technical, economic, and regulatory considerations. It is likely that the capacity of the 6/4 GHz domestic satellite frequency band, and the shortly to be available 14/11 GHz band, will become saturated in the next few years. There are also limitations imposed by problems of interference with terrestrial microwave systems. However, substantial spectrum resources are available at 30/20 GHz, and technical advances promise to multiply the utility of existing allocations in all bands.

Insofar as a typical design can be said to prevail, a satellite may contain 24 transponders, each having a 36 MHz bandwidth with a total satellite capacity of 14,000 to 18,000 two-way voice channels. The number of satellites that can be disposed at convenient positions in the orbital arc is limited by mutual interference effects and is subject to international agreements developed at the World Administrative Radio Conferences (WARCS). These factors establish an upper bound to the number of channels that can be deployed. However, various spot beam, scanning beam, and other approaches show promise in permitting a high degree of frequency re-use. These factors are discussed in greater detail in Chapter 6 of this report.

Satellite communications has the important virtue of flexibility. Subject to frequency coordination considerations, earth stations can be installed where needed, without the attendant problems of right-of-way acquisition characteristic of most terrestrial communications media. A network can thus be formed and reformed with relative ease as demand patterns evolve.

2.1.1.6 SUMMARY

All of the major long haul media discussed in the previous paragraphs are capable of high capacity transmissions. However, when scenarios implying growth of the existing nationwide telecommunications plant to several times its present size are considered, certain media are more likely to prove more cost effective than others.

Coaxial cable and waveguide, both highly right-of-way dependent, are likely to be confined to back-bone routes, with lateral extension to moderate or low population regions being less likely. The installation of these systems is heavily labor intensive and requires the burial of substantial quantities of copper. The costs of both these ingredients are rapidly increasing.

Microwave line-of-sight is also right-of-way dependent, but to a lesser degree. Frequency congestion is a current problem in urban areas, but it is possible that new frequency bands will be opened if the pressure of demand becomes sufficiently intense. However, making a major increase in the capacity linking two distant cities requires the installation, or modification, of many intermediate relay links.

Fiber optics can provide large capacity links over long distances as well as in the local area. Installation problems similar to those of coaxial cable apply, except where existing ducts provide a cost effective means of greatly increasing capacity.

Satellites are unique in their ability to provide large capacity links to widely separated points. The satellite medium is extremely flexible, and links can be formed and reformed by placing earth stations at points where communications needs develop. In some configurations, communication is brought directly to the user via a user-site earth station. In other configurations, a centrally located site becomes a distribution point for further extension of the links via terrestrial facilities. The use of satellites to provide wideband links to widely dispersed locations is likely to be complemented by fiber optics extending the communications to local users.

2.1.2 TIME DELAY AND ECHO EFFECTS

All long distance transmissions involve a certain amount of time delay due to the finite propagation speed of the signal, and this is an important consideration with respect to the suitability of the medium to particular communications applications. For terrestrial links, a conservative estimate for calculating propagation delay may be arrived at by assuming a circuit mileage which is 2.5 times the airline mileage. This accounts for communication paths being generally longer than the airline distance, and for the fact that propagation speeds on some transmission media are lower than the free-space speed of light. A typical crosscountry terrestrial link, by this estimate, introduces a round-trip delay of 67 milliseconds. In comparison, a transmission link through a geosynchronous satellite typically has a much higher round-trip delay of about 540 milliseconds.

The following paragraphs consider the effects of echo and time delay on voice and data traffic. Video transmissions are unidirectional and therefore are not seriously affected by echo. In most instances the fractional-second time delays involved are of no practical consequence for video transmissions, though they may be noticeable by participants in video conferences.

2.1.2.1 EFFECTS ON VOICE TRAFFIC

Time delay alone is not a serious problem for voice communications, but it may result in a loss of efficiency for certain types of data transmissions. Most studies of the subjective effects of time delays on speech have concluded that even the long delays associated with round-trip satellite links go undetected by many users and are unobjectionable to most (Ref. 9). However, when the long delays are accompanied by appreciable echoes, the effect on voice communications is disruptive. As discussed later, however, the development of new, economical, echo canceller circuitry is expected to greatly reduce the impact of echoes on satellite voice transmissions.

Studies of subjective reactions to echoes have shown that it is difficult to conduct a conversation when one's own voice returns with a delay of more than a few tens of milliseconds. Even when the long delayed echoes are as much as 40 dB below the transmitted voice, some speakers find the transmission unsatisfactory (Ref. 10).

It was recognized early that a method of dealing with echoes was needed. Relying on the fact that most conversations consist largely of single talking (one person speaking at a time) and that double talking (both persons speaking simultaneously) takes place only a small fraction of the time, voice-actuated switches were developed to insert attenuators in the path carrying the echo returning to the speaker. Special provision is made to permit transmission in both directions during the brief periods when double talking does occur.

These voice-actuated switches, referred to as echo suppressors, have been in general use in the United States since the late 1920's. While echo suppressors sometimes chop or clip portions of the speech, particularly at the beginning of an utterance or during rapid back and forth conversation, users have found them to be a satisfactory solution for circuits where the round-trip delay is under 100 milliseconds. General practice in the United States recently has been to use echo suppressors on terrestrial links longer than 1,800 miles.

On circuits with long delays, such as those routed through satellites, the distorting effects of the echo suppressors are much more pronounced and many users find these circuits unacceptable (Ref. 11). As a result, the common carriers largely favor the terrestrial network for the very large portion of traffic associated with voice transmissions, and, at most, limit voice transmission via satellite to a single one-way hop, with the return path being established through terrestrial links.

Some recent technical developments, however, have begun to reverse this situation and it is now generally accepted that voice traffic will be routed round-trip via satellite without major difficulty. The new technology referred to involves the replacement of echo suppressors with echo cancellers.

Echo cancellers first emerged in the early 1960's and were rapidly recognized as a superior method of echo control. They operate by adaptively modeling the channel so that the echoes can be predicted. The modeled echoes are then subtracted from the real echoes while leaving the speech paths unaffected for through transmission. Adaptive echo cancellers, however, are much more complex than echo suppressors. Early models had component costs of about $20,000, placing them out of bounds for widespread use on the switched network. More recently, however, costs have been drastically reduced. Comsat General's TeleSystems subsidiary has placed a unit on the market which sells in large quantity for under $600. Generally two such units are required for each link. Western Electric is now manufacturing an echo canceller integrated circuit chip developed by Bell Laboratories for use in satellite links. The chip permits replacement of seven fully loaded circuit boards with components costing one-tenth as much. With it, Bell expects to obtain approximately the same voice quality with two-way satellite transmission as is now achieved with terrestrial links. The price performance of the chip allows volume introduction into the telephone network (Ref. 12, 13).

While echo cancellers have not yet been widely installed, the economic barrier to their use has been overcome. It appears therefore that this superior method of echo control will make satellite communications a much more attractive vehicle for voice traffic, with a consequent continuing improvement in the ability of satellite systems to capture a significant portion of the voice communications market.

2.1.2.2 EFFECTS ON DATA TRAFFIC

Time delay and echo effects also have an impact on data transmission and influence the potential ability of satellite systems to capture portions of the data traffic market. In contrast to the situation for voice, data traffic is affected more by the time delay itself than by the delayed echo. As discussed later, new data transmission protocols are being introduced which lessen the impact of satellite time delays on data transmissions.

The main effect of time delay on data transmissions is to degrade throughput when certain common types of error control, which require responses from the receiver before sending the next block of data, are used. An important example of this type of stop-and-wait transmission is IBM's widely used binary synchronous communications (BSC) protocol, often referred to as Bisync. The transmitter under this protocol waits for an acknowledgment of correct reception and requests a repeat of any block in which an error is observed before it sends the next block.

With round-trip delays on satellite links of over one-half second, the idle time, while waiting for acknowledgments, can easily approach or even exceed the duration of the transmitted block. The result is a substantial decrease in throughput. If there are many errors on the circuit, additional loss of throughput occurs because of the need to wait for a repeat of any blocks in which errors have been detected.

Similar difficulties result from long path delays in many systems which use polling of distant terminals, and in systems using "Echoplex" in which each character transmitted from a terminal is echoed back to that terminal from the receiving end. In each case the need to wait for a response results in a considerable deterioration of the effective rate at which the data can be transmitted (Ref. 14).

Protocols using continuous repeat-request, rather than stop-and-wait transmissions, are becoming more common and avoid the loss of efficiency resulting from long time delays. High-Level Data Link Control (HDLC) and Synchronous Data Link Control (SDLC) are examples of this type of protocol. In continuous repeat-request transmissions the transmitter does not wait for an acknowledgment, the transmitting terminal (depending on the protocol) will back up to the block in question and recommence transmission, repeating that block and all subsequent blocks. Even more efficiency can be obtained by procedures that repeat only the block or blocks in error (Ref. 15).

All of these methods are effective in permitting efficient operation over data circuits with long delays. However, they require terminals with buffers capable of locally storing the data blocks that are in the round-trip "pipeline" so that a repeat can be supplied on demand. They also require that the software and hardware necessary to operate under the more efficient protocols be on hand.

An alternative approach, which allows users to retain their existing stop-and-wait procedures without converting their equipment to the newer protocols, is to use an add-on device referred to as a Satellite Delay Compensation Unit (SDCU) to achieve the same effect. Figure 2-1 illustrates the placemen' of these units in a satellite link. Each SDCU

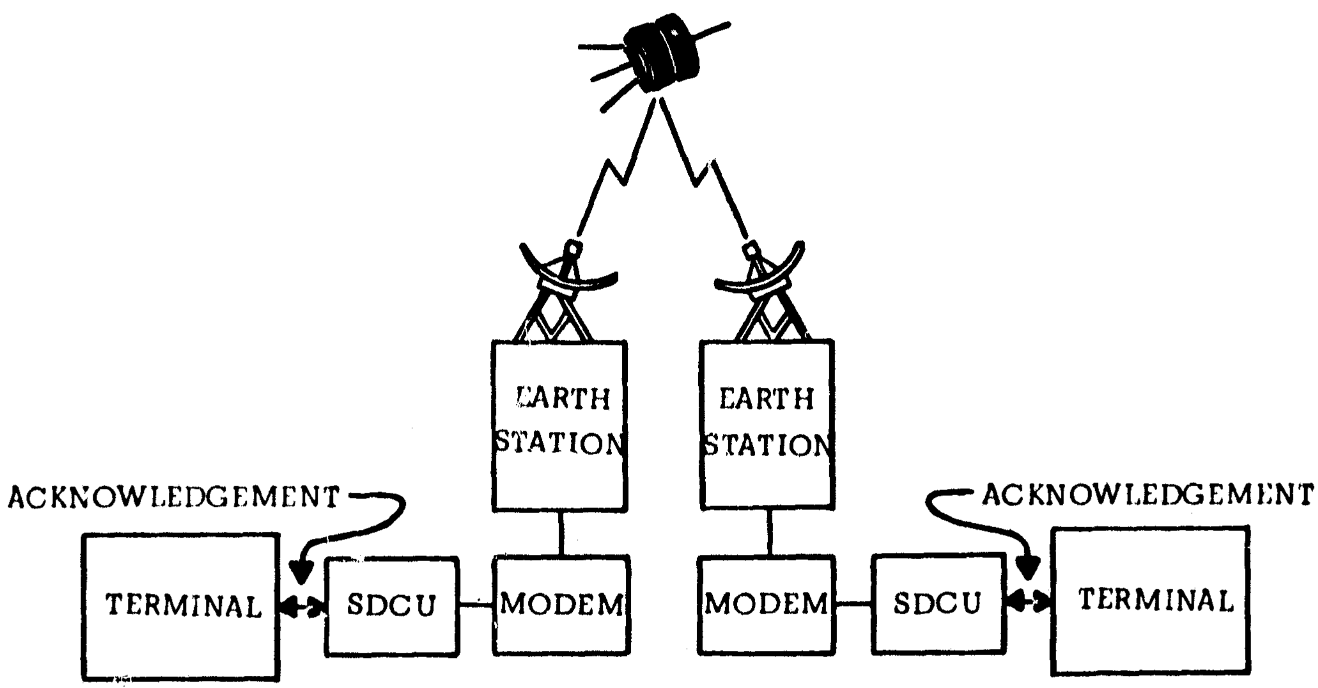

FIGURE 2-1 SATELLITE DELAY COMPENSATION UNITS (SDCU) IN DATA TRANSMISSION APPLICATION

accepts data blocks from its nearby terminal and responds to that terminal with the appropriate acknowledgments, thereby permitting the rapid release of subsequent blocks. The SDCU buffers these blocks and transmits them to the opposite end of the link, using a protocol that does not lose efficiency when operating with long delays. Provision is usually made to supply a "wait" signal to the local terminal if the buffer becomes full. The net result is a large increase in efficiency when using delay-sensitive protocols like Bisync. Satellite delay compensators can be purchased by the users or are offered on a rental basis by some of the Satellite Common Carriers (Ref. 15).

Overall, the time delay encountered on satellite circuits is a disadvantage in many near term data communications applications. However, interim solutions to this problem are at hand and, as the more advanced protocols become widespread, this disadvantage will become of diminishing significance.

2.1.2.3 SUMMARY

Time delays and echo problems introduced by transmissions over synchronous satellites have been a deterrent to the widespread adoption of satellite communications for both voice and data. However, economic technical solutions now exist. The barriers to widespread use of satellite communications may therefore be expected to dissipate as these solutions begin to receive widespread implementation. The following progressions are likely:

(a) Voice

Present: Preference for terrestrial paths predominates. Satellites used in single direction with return through terrestrial network.

Interim: Use of echo cancellers on special networks makes satellite links acceptable for voice in both directions.

Future: Widespread implementation of echo cancellers in the telephone network makes routing via satellite or via terrestrial networks equally acceptable.

(b) Data

Present: Some of the most commonly used data communication protocols are poorly suited to satellite transmission, restricting these signals to terrestrial paths.

Interim: Use of satellite delay compensator units permits these protocols to be maintained while eliminating the disadvantages of satellite transmission.

Future: New protocols better suited to satellite transmission replace the older less efficient protocols.

2.1.3 ANALOG AND DIGITAL TRANSMISSION

Both analog and digital transmission links are widely encountered in today's telecommunications plant. Each of those transmission methods influences the efficiency with which voice, video and data traffic can be transmitted, and therefore determines the telecommunications resources needed to carry each type of signal.

Most transmission facilities (i.e. cable, microwave, satellite, etc.) can be implemented on either an analog or a digital basis. The telephone network originated as an analog system, but since the introduction in 1962 of the Bell System's T1 carrier*, the proportion of digital facilities has been steadily rising. More than one-third of the trunks connecting Bell local offices are now digital, but growth in the long haul plant has been slower (Ref. 16).

Signals which originate in either analog form (e.g. voice) or in digital form (e.g. data) may each encounter transmission links that may themselves be either analog or digital. Special interface equipment is used to convert the signals to the appropriate form for passage through each type of link. It is also common for signals of either type to pass sequentially through several analog and digital links, requiring multiple conversions and re-conversions. For example, a speech waveform may be transmitted over terrestrial wire pairs and microwave links in its original analog form, and then be converted to digital form prior to entering a digital satellite link. At the output of the digital link the voice signal usually requires reconversion to analog form for transmission, through

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*The T1 carrier system uses 1.544 Mbps digital transmissions to provide 24 one-way voice channels on a twisted pair of copper wires normally reserved for single analog voice channel.

analog links, to its final destination. In much the same way, a data signal originating in digital form at a terminal may be converted to an analog waveform suitable for transmission over analog links.

The way in which the necessary interface conversions between analog and digital forms are accomplished has an important influence on the efficiency with which various communications applications are handled and on the types of service offerings likely to be established by common carriers. Each of the most important interface possibilities are briefly discussed below.

2.1.3.1 TRANSMITTING ANALOG SIGNALS VIA ANALOG LINKS

The most commonly encountered situation involving the transmission of analog signals over analog links is the transmission of speech over the conventional telephone network. The analog links provided in the network are designed to accept these speech signals directly and no special interface conversion is required.

2.1.3.2 TRANSMITTING DIGITAL SIGNALS VIA DIGITAL LINKS

Digital links and complete digital networks for the transmission of data are less common then analog, but are becoming increasingly popular. Many of the new services offered by AT&T (e.g. Dataphone Digital Service) and other common carriers are based on digital transmission. The interfacing of data signals to digital links is relatively straightforward. Generally a service unit is used to couple the terminal to the network. It provides network protection and supplies buffering and clocking capabilities.

2.1.3.3 TRANSMITTING DIGITAL SIGNALS VIA ANALOG LINKS

Digital signals are also commonly transmitted over analog links by means of modems, which convert the digital signal (e.g. a data sequence generated at a terminal) to a waveform which propagates over the link. Rates up to 9600 bps are common over dedicated voicegrade lines, and rates up to 4800 bps are common over the switched telephone network. Much higher rates are also possible over wideband analog transmission facilities by using appropriate modems.

2.1.3.4 TRANSMITTING ANALOG SIGNALS VIA DIGITAL LINKS

It is commonplace today for voice transmission to travel over digital links for some portion of their path, the predominant example being the previously mentioned T1 carrier which is heavily used for the Bell System's interexchange trunks.

A large volume of research has been devoted to the development of efficient coders and decoders for the conversion of voice signals to digital form and their later reconversion to analog form. Speech waveform coders and decoders (codecs) designed for voiceband signals operate at bit rates from about 64 Kbps (using standard PCM) down to 16 Kbps (using certain types of adaptive delta modulation). While the lower bit rates are possible for individual links, and in specialized applications, it is likely that codecs using the 64 Kbps rate for a one-way speech signal will prevail for general use in the long haul network (Ref. 17). This means that the nominally 3.5 KHz channel used for speech will require 64 Kbps in each direction, or a total of 128 Kbps in the digital bit stream. Figure 2-2(a) is a simplified illustration of the connection of a telephone through a codec to a digital link.

Data signals, of course, originate as digital bit streams but may, in order to traverse intervening analog links, be first converted to analog form by means of a modem. When this analog data waveform reaches the digital link, there are two commonly used methods used to reconvert them to digital form so that they can be transmitted over the digital link.

The first method illustrated in Figure 2-2(b) treats the analog voiceband data signal generated by the modem exactly as it does a speech signal. That is, prior to entering the digital multiplexer, the signal is processed by a codec which converts it to a digital form suitable for transmission over the digital link. This digital encoding bears little relation to the form of the original data transmission as it left the terminal. While the original data may have a speed in the range of 300 to perhaps 9600 bits per second, a codec operating at 64,000 bits per second will convert the input to 64,000 bits per second without regard for the underlying data rate. This results in a high degree of inefficiency since a one-way data signal at 300 bits per second may occupy 64,000 bits per second of capacity in the output link. Furthermore, each passage through a codec unavoidably adds a certain amount of noise and distortion to the signal. Despite these disadvantages, this method of handling data signals is an important one. It offers a high degree of flexibility by treating speech and data signals

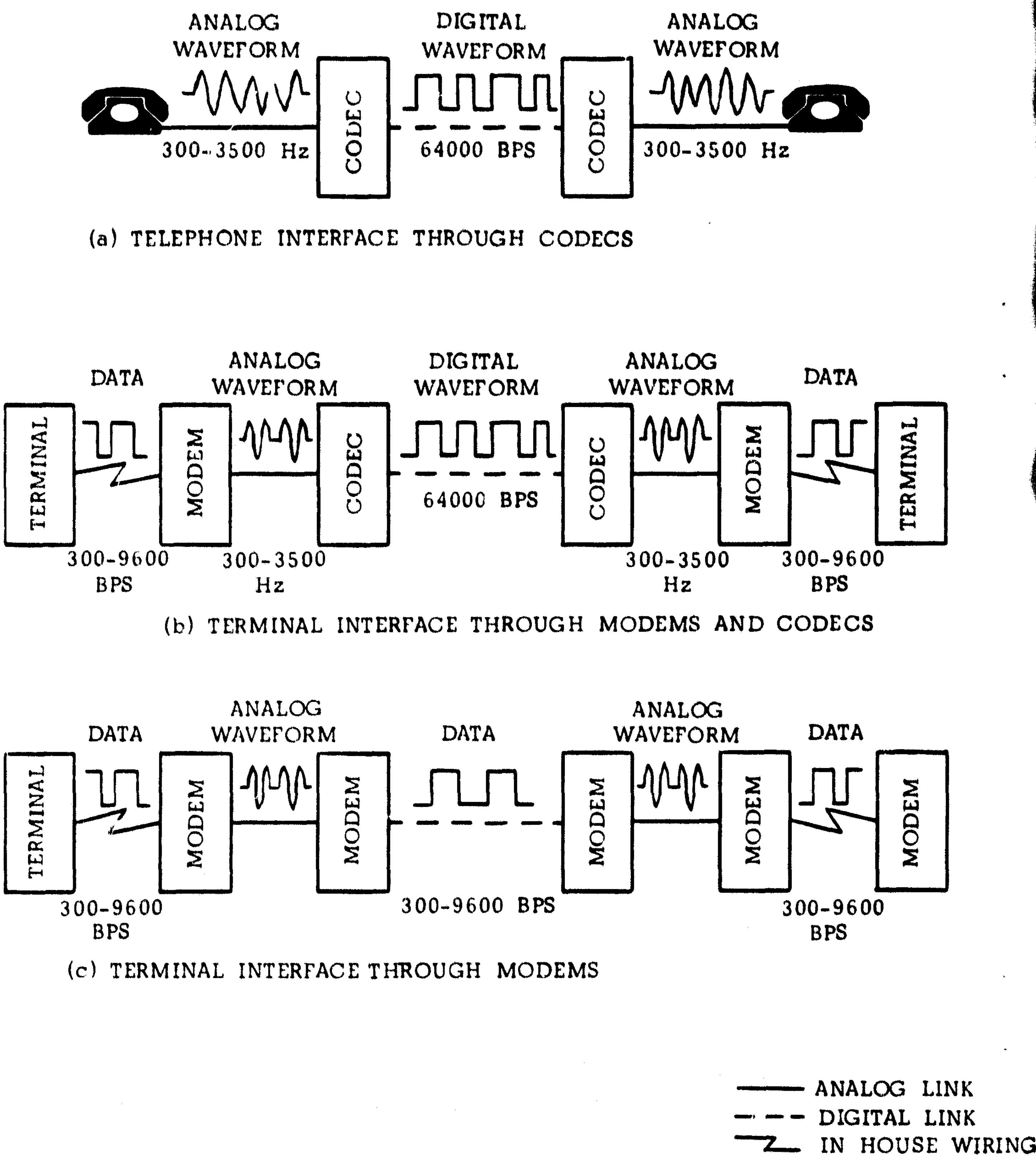


FIGURE 2-2 TYPICAL INTERFACES WITH DIGITAL LINKS

identically. Thus there is no need for the codec to recognize whether speech or data is being presented to it, and in the case of data it is not necessary to respond to the particular waveform and speed of the originating modem.

The second method, Figure 2-2(c), of handling data signals arriving at a digital link in analog form is to restore the signal to its original digital form by the use of a modem corresponding to that at the originating end of the path. A 300 bit per second data signal is restored to 300 bps and a 9.6 Kbps signal is restored to 9.6 Kbps by the appropriate compatible modems. The digital multiplexer at the input to the link accepts the signal at its original rate and assigns the corresponding capacity in the link. Clearly, this makes more efficient use of link capacity but requires that the carrier operating the link be able to recognize which incoming lines have data signals and be prepared to instrument these lines with a modem matching that used at the originating end. This is a much less flexible mode of operation and is only appropriate in certain specialized situations where the needed compatability can be prearranged.

2.1.3.5 SUMMARY

Over the next two decades it is expected that digital transmission facilities will become increasingly widespread, but both analog and digital facilities will remain in common use.

Whether a transmission facility is implemented on an analog or a digital basis, interface devices exist which are capable of transforming voice and data signals to the form appropriate for transmission over the facility.

The method used to interface voice and data signals to the transmission facilities has a strong influence on the communications capacity required. Voice signals when digitized for transmission on digital links are likely to require 64 Kbps for each direction, though lower rates are possible in some applications and over specialized networks.

The link capacity required to handle voiceband data signals (300 to 9600 bps) is very dependent on whether or not these signals are class marked for separate handling. If they are to be able to pass successively through analog and digital links, without being distinguished from coexisting voice signals, they too are likely to require one-way transmission through digital links at 64,000 bps, even though the original data rate may be very low. Specialized networks for data can avoid this inefficiency by accepting the data signals at their original bit rates and providing only the capacity called for by that bit rate. Though less flexible these special networks should, because of their higher efficiency, be able to offer cost advantages for data messages.

2.1.4 END USER ACCESS

The problem of supplying local end loops for access to long haul communications has frequently proven to be a difficult one, particularly for Specialized Common Carriers (SCCs) offering innovative services. Where satisfactory arrangements have not been achieved, a large portion of the potential utility of these services has been eroded.

2.1.4.1 PROBLEMS OF CONNECTING TO SPECIAL NETWORKS

Consider the case of a long haul network operating in digital mode intended to serve data users. A digital network of this type offers several special advantages to data users if they can connect directly to the network:

(a) Expensive modems are eliminated;

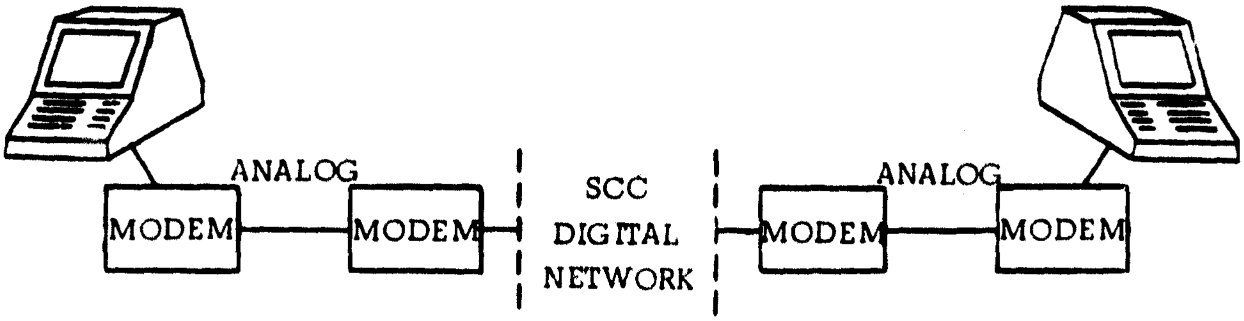
(b) Transmission capacity is efficiently utilized;

(c) Generally higher quality (lower error rate).

Figure 2-3(a) illustrates the connection of a pair of data terminals where direct access to the digital network can be achieved. Figure 2-3(b) shows some of the difficulties that occur when access is required through standard analog, leased or dial-up, telephone links.

When direct connection to the network cannot be achieved it is necessary to use modems on the analog end loops. To complete the path four modems are required. (Only two would be needed to establish a similar path through the conventional analog network.) Thus, unless provision for direct access is made the specialized digital network actually winds up requiring twice as many modems as the conventional analog network.

(a) DATA TERMINALS DIRECTLY CONNECTED TO DIGITAL NETWORK



(b) DATA TERMINALS CONNECTED THROUGH ANALOG END LOOPS

FIGURE 2-3 DIRECT AND INDIRECT ACCESS TO NETWORK

It would be possible under some circumstances to eliminate the modems at the digital network interface but then codecs would be required and, as discussed in Subsection 2.1.3, the bit rate on the digital network would be high, resulting in a loss of transmission efficiency. Furthermore, the end loops often pass through electrically noisy environments in switching centers. This may contribute substantially to the end-to-end error rate, even though the distances travelled on the end loops may be insignificant in relation to the overall path length.

Similar problems exist with respect to networks offering wideband services, or special features such as four-wire circuits (separate receive and transmit paths), packet transmission, or store-and-forward service. If a customer is a significant distance from a service access point, it may be difficult and very expensive to develop a communications path to enter the network (Ref. 18).

In some cases the end loop problem may be avoided by providing service directly to the user. Such Customer Premises Service (CPS) is used today in applications such as the transmission of typeset newspaper pages and in CATV. Customer Premises Service is also an important feature of both the

Satellite Business System (which will place satellite earth stations at the plants of large communications users) and XTEN (which plans to use roof-top mounted microwave radio to link users directly with area nodes).

2.1.4.2 SUMMARY

The viability of offered services may be highly dependent on problems of local area access. This is particularly the case for wideband and other specialized transmissions for which the existing local telecommunications plant is not well adapted. One of the important advantages of satellite service directly to the customers' premises is that the problems and costs of local access are avoided.

2.2 MARKET PROFILE BY TRAFFIC CATEGORY

This section briefly discusses the traffic categories introduced in Table 1-1 and comments on the suitability of the various terrestrial and satellite media to accommodate each category of traffic.

In many cases the differences among transmission media are not of great significance from the viewpoint of an end user. With few exceptions each of the major transmission technologies can be (and frequently are) used for the listed traffic categories. Where media limitations do exist, technical solutions to these difficulties can often be found, or usage scenarios can be postulated, which considerably reduce their significance. Thus, in estimating the degree of market penetration that may be expected for each medium of transmission, its technical advantages and limitations must be weighed together with a host of other considerations. The most important of these are cost, timely availability of the service, the existence of capacity on competing transmission modes, and the pressure of expanding demand on limited communications resources.

2.2.1 VOICE TRAFFIC

Echo effects will limit the acceptability of satellite media for voice transmissions through much of the present decade, with satellite usage limited to one direction of the needed bidirectional path. Although echo cancellers capable of removing this restriction can now be produced at a cost which permits economic usage, it will be some time before their widespread installation and complete acceptance can be expected. It does not appear likely that differential pricing policies will be offered to residential telephone users as a motivation for accepting poorer transmission quality in place of the existing high quality terrestrial service they have become accustomed to. Thus it will be necessary to more or less completely upgrade satellite voice quality (by bulk installation of echo cancellers) before placing these channels into common residential telephone use.

It is possible, however, that such differential pricing structures will be offered to business users, particularly via SCC offerings seeking to compete on a price basis. Since business users are likely to be more familiar with, and more tolerant of, echo problems, the use of two-way satellite channels for voice will gain acceptance more rapidly among business users, particularly if pricing advantages are offered.

To the extent that rain outage results in some Ku and Ka band satellite configurations offering less reliable service than other communications modes (see Section 5.2), the use of these bands for telephone service is likely to remain limited, even when successful solutions of the echo problem have been implemented. However, private line telephone service will be less subject to this limitation if the means exist to back-up priority calls through more reliable switched services. This mode is quite common today in leased line data service where dial back-up is a common method of enhancing communications reliability. The use of similar strategies for private line voice is a possible way of making less reliable satellite channels acceptable for many voice applications.

The situation relative to rain outage limitations in voice applications is somewhat different when the viewpoint of a large common carrier is considered rather than that of the end user. For the common carrier, Ku and Ka band satellite links can provide one of many modes of supplying bulk communications between city pairs. With suitable flexibility in the control of network configuration, additional capacity through terrestrial or C band links can be supplied to cities experiencing rain outages, and the affected Ku or Ka band capacity can be temporarily redirected to cities where propagation conditions are more favorable.

Thus, despite rain outage disadvantages to the use of the higher frequency satellite bands for voice, under the appropriate deployment scenarios these bands can provide useful capacity. However, all other factors being equal, terrestrial links are superior to satellite links for voice applications, and C band is superior to Ku, and Ka. Therefore, factors such as cost or capacity arguments must be invoked to motivate any significant departure from the use of more traditional channels.

2.2.2 VIDEO TRAFFIC

Video traffic is primarily unidirectional so that echo effects are of little consequence for these applications. This holds true even in the case of videoconferencing where two-way conferences are generally implied. Such conferences are likely to be implemented via two separate one-way links (one for each direction) or by means of half-duplex sharing of a common path by each user in turn (but not simultaneously), so that transmission remains essentially unidirectional. There is, therefore, no return path for echoes to reach the originator. However, time delay will be apparent and may be mildly disturbing to video conference users engaged in rapid exchanges.

Satellite media are well suited to long distance video applications, but Network TV users are likely to take some time before accepting any but the most conservative and traditional approaches to communications. CATV program originators and distributors have shown a much higher degree of acceptance of satellite transmission where the capability for wideband broadcast to many receive-only earth stations is a valuable feature.

Rain outage problems are likely to remain a barrier to widespread adoption of Ku and Ka band satellite links for Network TV, and to a lesser extent to CATV. It appears likely, however, that in many cases a form of time diversity could be used to partially overcome this disadvantage. Pre-recorded programs scheduled for transmission at a given time could be broadcast several hours earlier and stored locally on tape, avoiding some of the concerns over outages associated with real-time broadcasts. As demand for wideband channels expands, this type of solution will become more attractive to those users who can accept deferred modes of video transmission by use of storage as discussed above, or by other strategies.

A growing market is projected for videoconferencing, educational, and other specialty applications of video. Escalating costs will make business travel a less desirable activity, and video technology is rapidly becoming an accepted part of social interactions. In many cases reliability requirements for these transmissions are moderate, and the flexibility of satellites in establishing or reconfiguring wideband long haul circuits with relative ease is an important advantage. The additional capacity available via Ku and Ka band satellites make these an attractive mode for the satisfaction of emerging demand for these applications. The smaller antennas associated with Ku and Ka bands also simplify Customer Premises Service and make the design of small size transportable earth stations practical.

Fiber optics links are also expected to be of importance in these video applications, but are better suited to short haul and urban environments. The ability of satellite circuits to avoid end loop problems through Customer Premises Service is particularly valuable for wideband transmissions. Alternatively, fiber optics and satellites can successfully complement each other for video applications, with satellites providing the long haul portions of a link, and fiber optics completing the wideband path from earth station to user.

2.2.3 DATA TRAFFIC

Data traffic spans a wide variety of applications and places diverse requirements on the communications plant.

Much of the message traffic that is expected to be sent by facsimile methods, and most of that projected for postal service type electronic mail, is able to tolerate moderate time delays. Short periods of rain outage are not therefore major impediments for these applications. Thus the higher band satellite channels, as well as C band and the terrestrial media, are all well suited to these forms of message traffic. However, as growing demand exerts pressure on communications resources, it is likely that off loading of this deferrable traffic to Ku and Ka band satellites would be a cost effective strategy for releasing the more reliable channels for real-time applications.

Computer traffic, particularly terminal-to-computer inquiry mode traffic, is an important element of demand. Time-delay limitations inherent in satellite links make these links unfavorable for some currently popular data protocols, but these limitations will disappear as newer more efficient, protocols become widespread.

Satellite technology is likely to become increasingly dominated by digital transmission, though most existing capacity is analog. The efficiency with which data signals can be handled on digital links (whether satellite or terrestrial) varies greatly, depending on the way in which these links are interfaced with the data sources. The most efficient usage of digital transmission capacity requires that data signals be classmarked so that they can be recognized as such prior to acceptance by the digital facility. Though much flexibility is lost by this requirement, the efficiency of the transmission can be enormously increased. This efficiency is also dependent on whether the transmission is organized on a packet switched, circuit switched, or dedicated line basis. The packet mode is generally the most efficient, and dedicated modes are least efficient. Those arrangements which permit efficient transmission of data signals (for example, a packet network using digital satellite transponders exclusively for data) will presumably be able to translate this efficiency into highly competitive cost reductions.

The alternative scenario for digital transmissions via digital satellite (or terrestrial) links exchanges efficiency for flexibility. Data and voice are treated on a common basis as they are, for example, on today's switched telephone network. When digital links are encountered the signal (data or voice) is converted to a suitable waveform by means of codecs. The resulting loss of efficiency for data can be very large and can greatly magnify the transmission capacity needed to satisfy a given demand. These approaches are nevertheless viable, and necessary, when practical considerations of interfacing with existing analog facilities are taken into account. Thus a large and perhaps major portion of data demand will be transmitted by very inefficient modes, and a corresponding increase in plant capacity will be called for to accomodate these transmissions.

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3.0 NETWORK OPERATING MODES

The terrestrial and satellite transmission media discussed in the previous chapter provide facilities for the bulk transmission of information. The present chapter is concerned with the methods used to organize these transmission facilities into networks in order to provide practical and economic means for users to share the bulk capacity provided.

The most important network operating modes are:

(a) Switched
(b) Dedicated
(c) Packet

Networks operating in any of these modes may be established using the various transmission media discussed earlier. The mode established for a particular network will influence the types of communications applications likely to be routed through that network, the efficiency and convenience of the service provided, and the cost.

With few exceptions, terrestrial networks operate in a "trunking" mode in which long haul facilities are brought to a termination point from which they are broken down for further distribution to local users. However, in the case of satellite networks, the alternative also exists to place an earth station at a user's location and to deliver "Customer Premises Service" (CPS) directly to the user.

The following discusses each of these network approaches and develops a profile of traffic demand as influenced by network operating mode. Sections 3.1 through 3.4 deal with switched, dedicated and packet network modes, and Section 3.5 discusses trunking and CPS considerations.

3.1 SWITCHED NETWORKS

A large fraction of long distance communication traffic is, and will continue to be, routed via switched networks. The Bell System's switched network carried 16.2 billion toll messages and 4.2 billion WATS messages in 1979 (Ref. 1). Revenues for these two switched services are more than nine times those associated with Bell System provided private lines.

Switched networks offer three major advanges to users:

(a) SHARING - Expensive long haul transmission facilities are shared on a time-usage basis by users whose traffic may not justify full time dedication of the channel. In general, subscribers whose line usage totals less than two to four hours per day find switched service less costly than private line service.

(b) FLEXIBILITY - Any of the many subscribers to the system can be reached by simply dialing the appropriate number. Dedicated service in contrast, limits access to only the users on that line.

(c) RELIABILITY - Due to the large number of alternative routes through the network, two distant points can be connected even though specific intermediate transmission links may be out of service.

3.1.1 VOICE

The switched telephone network was designed primarily for voice transmission and is admirably suited for this purpose. As discussed earlier, a trend exists toward the installation of digital switching facilities both within the common user network and at customer site switchboards. The probable long range outcome of this trend will be a completely digital common user switched network, but for many years new communication offerings will have to be able to work with a hybrid communications plant containing a variety of analog and digital switching nodes linked by analog and digital transmission facilities (Ref. 2, 3).

3.1.2 VIDEO

Switched video services are technically difficult to supply and have not so far proved economically viable. However, if full motion videoconferencing becomes widespread, those transmission and network configurations able to supply switched video services (for example, CPS satellite networks) may find a significant amount of demand in this area (Ref. 4).

3.1.3 DATA

Data signals as well as voice signals are often routed through switched network facilities. Data speeds up to 9600 bits per second can be transmitted over voice grade analog circuits, but more commonly speeds range between 300 and 4800 bits per second. TWX and Telex offer examples of switched network operation primarily directed toward low speed message and data service at speeds below 300 bits per second. To a limited extent, wideband switched data service is also available with data speeds as high as 50,000 bits per second.

3.2 DEDICATED SERVICE

Dedicated communications links or networks provide transmission facilities reserved on a full time or part time basis for the sole use of the purchaser. Facilities of this type may be owned by the organizations using them (private facilities), but more commonly are obtained from a common carrier on a monthly lease basis. The largest suppliers of voice band leased lines (often interchangeably referred to as private lines) are AT&T and other Telcos who collectively account for about 90 percent of the market.

Dedicated facilities are used in a wide variety of point-to-point and fixed network configurations, and for voice, video and data applications. The primary impetus toward the use of dedicated facilities is cost. Generally, line occupancy of more than a few hours per day is sufficient to make the dedicated lines the lower cost choice. However, as discussed in the following subsections, there are other technical and operational characteristics that also influence a choice between dedicated and switched communications modes.

Statistics on the numbers, lengths and applications for dedicated facilities are not as widely reported as for the switched network, but the best available estimates indicate that there are at present approximately 435,000 full duplex lines in service, about 290,000 of which are longer than 50 miles and 139,000 of which are longer than 200 miles.

3.2.1 VOICE

Many companies use dedicated lines to link their major installations, the lines being terminated on private branch exchanges (PBXs) which switch the calls to the appropriate instrument within the building. Companies with large amounts of traffic between two or more fixed points find that the bulk installation of leased line facilities leads to cost economies.

The distinction between dedicated and switched operation is sometimes blurred. Many carriers lease dedicated facilities from other carriers and add value to these facilities by assembling them into a network linking carrier provided switching centers. Switched service may then be offered as a value-added service to the public. From the viewpoint of the end user, the transmission lines are part of a switched network, but from the viewpoint of the original carrier dedicated lines have been supplied to the value-added carrier.

Recently another mode of operations known as "off-net" service has been authorized by the FCC. This service permits private users and specialized common carriers to interconnect their networks with the switches and local transmission facilities of the public network. ITT's City Call, MCI's Execunet and SPC's Sprint networks offer examples of this mode of operation.

3.2.2 VIDEO

Video communications are essentially all accomplished on a dedicated facility basis, but can be purchased by prearrangement in short time blocks (one hour minimum under ATT's series 7000 TV channel). At present the CATV industry is the chief user of these services, with network TV and educational video adding smaller but significant demand. It is likely that newer uses in education, videoconferencing, health and public affairs will develop into major markets over the next decades. The Bell System is currently providing its Picturephone Meeting Service (PMS) at tariffed, time and distance sensitive, rates from public PMS videoconference centers in several major cities.

The satellite has been the key to accelerating growth in CATV. Cable systems were originally established to improve TV reception in local areas of poor signal strengths. However, once the thousands of scattered cable systems were able to acquire satellite signals via receive-only earth stations, CATV became a national medium instead of strictly a local one. The abundance of available programming has stimulated high levels of interest in the viewing public, who now contribute revenues to a 1.9 billion dollar industry. Home Box Office, the oldest and largest of the pay-cable networks, now has more than 4 million subscribers nationally. The nearest competitor, Showtime, has recently reached the one million subscriber level and the Movie Channel has close to 200,000 subscribers (Ref. 5).

Since a program is broadcast from a single transmitter through the satellite to many receive-only CATV earth stations, a single video channel (usually a full transponder) can simultaneously serve millions of people. Demand for satellite capacity is therefore much less dramatic than might be assumed on the basis of number of subscribers (millions) or earth stations (thousands) even though, as a rough measure, each video transmission requires a capacity equivalent to approximately 500 two-way voice channels. With current CATV usage estimated at roughly 35 full-time channels, the equivalent 17,500 duplex voice channels represented is still a small fraction of the 139,000 private lines estimated to be in long haul use (200 miles or more). CATV traffic, however, is ideally suited to satellite transmission with little competition offered by terrestrial facilities, whereas private line voice and data have well established alternative transmission modes available. CATV, therefore, is an important and growing generator of demand for satellite capacity.

Similar considerations apply to video applications in education and in other special video applications such as telemedicine and public affairs. Dedicated facilities will be required, but in many cases flexible reconfiguration will be needed as classroom schedules or public meetings place changing demands on transmission facilities. Channels will often be point-to-point but will also frequently require multipoint configurations. In some cases a return channel, most often voiceband only, will be needed.

If predictions of increasing cost and difficulty of business travel prove correct, videoconferencing may evolve to become the largest of the video services. Point-to-point or multi-point dedicated service between pre-selected sites will be suitable for a large portion of this demand in applications linking video meeting rooms established in population centers or in remote offices of nationwide corporations. However, a demand for intercompany conferencing may also develop if the means for establishing video channels on an on-demand or switched basis can be offered. Videoconferencing will require two-way channels, but in many cases less than full motion capabilities will be acceptable allowing bandwidth compression and consequent economy in communication costs.

3.2.3 DATA

Many data networks and individual links are implemented with dedicated lines. As in the case of voice, the decision to use dedicated facilities for data applications, in preference to switched network service, is basically determined by whether sufficient traffic volume exists to justify the cost of dedicated circuits, and whether the transmission is between a few locations or must address many remote locations with a minimum amount of pre-arrangement. However, for data applications, there are also many other reasons why leased lines may be required in particular circumstances. Some of these are discussed below.

CONNECTION TIME

Many data messages are brief. It frequently takes longer to establish a dialed connection than to transmit the actual message. This difficulty is often compounded by pricing policies that establish a minimum one-minute charge for a call. Some specialized common carriers (for example, SPC) have partially eliminated this disadvantage by providing fast-connect features which establish a connection in a fraction of a second, and by reducing the minimum billing interval to one second.

FOUR-WIRE SERVICE

Commonly, switched networks provide two-wire service (bidirectional on a single pair of wires) to the end user even though the long haul plant actually establishes the call on a four-wire basis (separate transmission channels in each direction). This is often a disadvantage for data communication users since the two-wire end loops, while bidirectional for voice signals, cannot be used bidirectionally at full capacity for data. The result is that data speeds must either be reduced so that simultaneous transmission in both directions (full duplex) can take place, or the transmission must be confined to a single direction at a time with the line being "turned around" each time the direction of transmission reverses (half duplex). Some carrier offerings (for example the ITT Switched Private Network Service) avoid this limitation and offer a switched four-wire service end-to-end, but in most cases four-wire service can be obtained only through dedicated facilities.

ELIMINATION OF ECHO SUPPRESSORS

Echo problems on long distance circuits, and the use of echo suppressors and cancellers to make long distance connections more palatable to voice users, were discussed earlier. While echoes themselves are not usually a severe problem for data communications, the echo suppressors installed to improve voice quality are an inconvenience. They prevent simultaneous two-way transmission of the data, and take time to turn around if half-duplex (one way at a time) data transmission is used. On the switched public network, the same long distance lines are used for both voice and data. Special provision must therefore be made to disable the echo suppressors (by the use of special tones generated by the data modem). This adds a degree of complexity to the transmission and in some applications reduces efficiency. Dedicated facilities reserved for data use are installed without echo suppressors, thereby avoiding these problems.

NETWORK CONTROL SIGNALING

Switched networks often require signaling tones within the bandwidth of the channel for the control of the network. This again adds a complication to the design of modems for use on the switched network, since they must avoid interference with the network signaling. These problems do not arise with dedicated facilities.

EQUALIZATION

To obtain the higher transmission speeds in data transmission, the characteristics of the particular link have to be shaped to match the waveform generated by the modem. Equalization of this type is generally required in order to achieve speeds of 4800 bits per second or above, and is sometimes required even for speeds as low as 2400 bits per second. Equalization is a simple matter for dedicated facilities, and, if required, is included as part of the circuit at the time the line is installed. With switched facilities, however, the path connecting two points is re-formed each time a new connection is made. An equalizer preset to one path through the network will not be suitable for another. As a result the equalizers have to be adaptive, with capability to "learn" the characteristics of the line and compensate for its deficiencies. These adaptive equalizers are built into most modern high speed modems intended for switched network applications, but they are complex and add appreciably to the cost of the modem.

QUALITY

Equalization, as discussed above, is one aspect of line quality. Others such as noise, jitter, gain hits, etc. also influence the error rate obtainable on the line. In general, the quality of dedicated facilities for data applications can be more closely monitored, and tends to be higher than that provided by switched service.

3.3 PACKET NETWORKS

Rapid advances in computer technology have made practical a new approach to communication network design which offers substantial economic and performance advantages over conventional systems. Over the last decade this new communication technology, referred to as packet switching, has received worldwide acceptance in public and private data communication networks. Its chief application has been in the transmission of interactive data traffic. There is also a high level of interest in using packet techniques for voice, or integrated data and voice, applications, but as yet the viability of these approaches has not been established.

In packet switching, the input flow of information (in digital form) is divided into small segments or packets which move through the network at high speed. The packets are assembled at switching nodes where computer controlled switches sort, check, and route the packets toward their destination. The result is that traffic that tends to occur in bursts, such as that due to interactive terminal to computer inquiries, can be handled with high efficiency and with economical usage of expensive transmission facilities.

The way in which packet approaches lead to economy in transmission plant usage is shown in Figure 3-1, which illustrates a typical on-line terminal to computer session and the resulting occupancy of the communications facility for three types of transmission.

Figure 3-1(a) shows the periods of activity in a typical data communication application involving interactive terminal to computer data base access. The session begins with the terminal being turned on. Each brief inquiry message from the terminal typically results in a burst of data which is responded to a short time later by a computer transmission back to the terminal. A period of inactivity may then follow while the next inquiry is prepared, after which the inquiry response cycle is repeated. After a number of such transactions the session may be terminated by turning off the terminal. The transmissions then cease until a new session is begun, minutes or hours later. This characteristic on-off behavior is actually much more bursty than the illustration implies, the periods of activity being narrower in comparison with the much longer periods between transmissions.

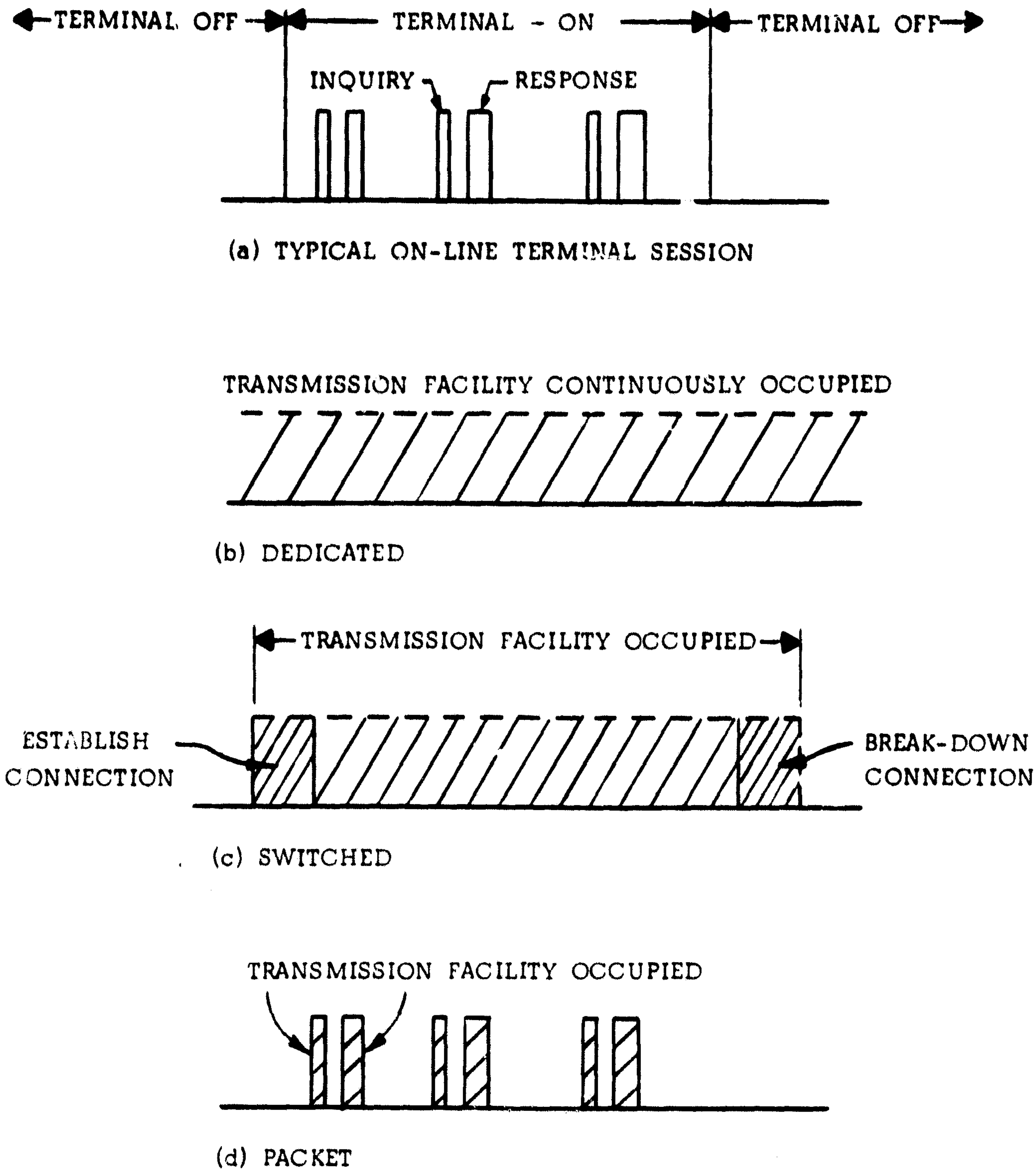

FIGURE 3-1 A TYPICAL ON-LINE TERMINAL/COMPUTER SESSION, AND FACILITY USAGE FOR DEDICATED, SWITCHED AND PACKET TRANSMISSIONS.

Figures 3-1(b), (c) and (d) show the communication facility occupancy resulting from the data application illustrated in Figure 3-1(a). As shown in Figure 3-1(b), dedicated facilities are continuously occupied. That is, transmission capacity is reserved for the application even when the terminal is off. Clearly this is a very inefficient use of transmission capacity but, as discussed in Subsection 3.2.3, may under the appropriate circumstances be economically and technically justified. Switched facilities (Figure 3-1(c)) make more effective use of the transmission plant by occupying the transmission facility only during the session and releasing it for use by others when the terminal is switched off. With brief terminal sessions, however, the time to establish and break-down the connection may be an appreciable fraction of the occupancy time, leading to a loss of efficiency. Fast-switched approaches (not illustrated) avoid this by reducing the connection and breakdown times so that it is possible to release the facility between successive inquiries and responses. While this further improves efficiency, the call establishment and break-down time still results in an unwanted line overhead.

Packet switched approaches (Figure 3-1(d)) provide the most efficient response to burst transmissions of the type illustrated in Figure 3-1(a). The packet switch collects a burst of data (usually 1000 to 8000 bits) and processes it for transmission. An identifying header and some error control characters are added and the packet is transmitted to the destination switch which reprocesses it for delivery to the end user. The transmission facility is occupied only during the packet, and the overhead imposed by the header and control characters can be kept small, making the facility utilization very efficient.

3.3.1 VOICE

Packet network efficiency derives from the ability of the network to dynamically allocate transmission resources when needed, and to release these resources for other users when they are no longer required. This is accomplished by using buffer storage and relatively complex processing capabilities at the network nodes. Thus there is an economic trade-off between processing costs at the nodes and transmission costs for the links. Since processing costs have been decreasing more rapidly than transmission costs, the trade-off has been increasingly in favor of packet approaches.

Packet switching can improve line utilization efficiency for digitized voice since in normal conversation each speaker is only talking about one-third of the time (Ref. 6). While much less dramatic than the equivalent improvement for interactive data, the rapidly decreasing cost of packet hardware makes it likely that packet transmission of voice will evolve over the next decade as a viable competitor to more conventional circuit switched approaches (Ref. 7).

The most likely form of this evolution is an integrated packet network providing both voice and data services. However, in view of the heavy investment in existing voice facilities and the fact that the improvement for voice is less than that for data, the transition to packetized voice is likely to proceed at a slower pace.

3.3.2 VIDEO

Packet approaches have not been seriously considered for video applications. The relatively continuous loading presented to the network does not allow any special efficiency benefit to be derived from packet approaches, and the wide bandwidths involved further complicate the technology needed.

3.3.3 DATA

Packet networks are most effective for certain important sectors of data traffic. Depending on the nature of the data being transferred, packet techniques can achieve efficiencies up to several hundred times higher than conventional circuit-switched approaches. Bulk data traffic benefits from packet technology to a much smaller extent than interactive computer traffic. Applications involving near continuous transmission of large quantities of prestored data (e.g. postal service and funds transfer applications) may actually achieve higher efficiencies using dedicated facilities than can be obtained with packet transmission. Similarly, most remote job entry applications are equally well handled on a circuit-switched basis and any improvement via packet operation is likely to be slight.

While transmission efficiency is an important advantage of packet networks for interactive traffic, there are other advantages as well. In packet networks, users access the network through a packet switch at their local node. The switches can effect code and speed conversions which enable users with otherwise incompatible terminals to communicate with each other through the network. This feature has proven to be a valuable one in resource-sharing computer networks. Many different types of computers can be linked and made accessible to users having many different types of terminals. The ability to interface diverse terminal types is also likely to be of importance in electronic mail applications. The lack of compatibility between communicating word processors produced by different manufacturers has been one factor in slowing the widespread use of these devices for general electronic mail applications. Similar problems exist in postal system uses of electronic mail, where messages may have to be delivered to a wide variety of terminals, and in facsimile networks where the incompatability of end user equipment has long been a problem.

3.4 TRAFFIC DEMAND VS NETWORK OPERATING MODE

Table 3-1, discussed below, presents estimates of the traffic demand for switched, dedicated and packet modes of network operation. The estimates are based on the considerations discussed in the previous sections and the traffic estimates presented in Table 1-1.

3.4.1 VOICE

The traffic estimates for the voice category shown in Table 1-1 fall directly into the switched (Residential and Business Switched Services) and dedicated (Business Private or Leased Line Services). Since there is no packet voice service in present commercial operation, these estimates lead immediately to the values shown in Table 3-1 for Voice in the year 1980. For the years 1990 and 2000, however, some small amounts of packetized voice traffic are anticipated, chiefly due to the hybrid use for voice transmission of packet networks established primarily for data. The switched and dedicated voice traffic estimates of Table 1-1 are each decremented by 2.5 percent to account for the corresponding amount of packetized voice traffic expected for 1990. For the year 2000 this estimate is increased to 5 percent and the same procedure is used to arrive at the values in Table 3-1.

3.4.2 VIDEO

As indicated in Table 3-1 the packet mode transmission of video signals is not anticipated during the time frame of this study. Furthermore, with the exception of videoconferencing, video transmissions are expected to use only the dedicated transmission mode.

Videoconferencing will also use the dedicated transmission mode to satisfy that larger portion of demand occasioned by intracompany teleconferencing. However, as the state of the art progresses, and as public reliance on videoconferencing grows, a moderate but increasing component of demand for switched mode videoconferencing is anticipated in response to demand for ad hoc videoconferencing between companies. The percentage of videoconferencing expected to use dedicated transmissions is estimated for

TABLE 3-1 TRAFFIC DEMAND BY NETWORK OPERATING MODE

	TRAFFIC VOLUME * BITS/YR x10^15	SWITCHED BITS/YR x 10^15	SWITCHED PERCENT	DEDICATED BITS/YR x 10^15	DEDICATED PERCENT	PACKET BITS/YR x 10^15	PACKET PERCENT
1980							
VOICE	890	329	37.0%	561	63.0%	0	0%
VIDEO	82	0	0 %	82	100.0%	0	0%
DATA	111	22	20.0%	89	80.0%	0	0%
TOTAL	1083	351	32.4%	732	67.6%	0	0%
1990							
VOICE	2250	777	34.5%	1417	63.0%	56	2.5%
VIDEO	171	8	4.8%	163	95.3%	0	0%
DATA	280	55	19.5%	224	80.0%	1	0.5%
TOTAL	2701	840	31.1%	1804	66.8%	57	2.1%
2000							
VOICE	4894	1381	28.2%	3268	66.8%	245	5.0%
VIDEO	419	54	12.9%	365	87.1%	0	0%
DATA	434	83	19.0%	347	80.0%	4	1.0%
TOTAL	5747	1518	26.4%	3980	69.3%	249	4.3%

*FROM TABLE 1-1

the years 1980, 1990 and 2000 as 100, 90, and 80 percent respectively. The remainder, namely 0, 10, and 20 percent, will use the switched transmission mode. The entries in Table 3-1 for dedicated mode video transmission in each year are therefore arrived at by summing the values presented in Table 1-1 for Network TV, CATV, and Educational Video, and adding to this the percentage of Videoconferencing appropriate to each year. The switched mode component is simply 0, 10 or 20 percent of the videoconferencing traffic.

3.4.3 DATA

The efficiency with which data traffic is handled has a large impact on the communications resources needed to satisfy demand. The highest efficiencies are expected for packet modes, while switched modes are less efficient and, when due account is taken of the fact that leased lines require the reservation of capacity even when not in active use, leased lines are the least efficient mode. All three operating modes are expected to be of importance for data transmission throughout the time frame of this study. Packet modes, which are not yet in widespread use, are expected to have a rapidly expanding role due to their high efficiency.

While high efficiency is one of the factors which tends to encourage usage of a network operating mode, it also acts to reduce the number of bits transmitted for each data transaction. As a result the operating modes with higher efficiencies have a correspondingly lower impact on the facilities needed to satisfy communications needs. For example, a typical interactive terminal to computer communications application may be handled under packet modes with an efficiency of facility usage on the order of 100 times higher than can be achieved for the same application using traditional circuit switched modes. It would therefore take, on the average, 100 packet mode transactions to generate the same traffic load on communications facilities as a single switched mode transaction. The same considerations apply to the use of dedicated transmission modes which, for most interactive data applications, are even less efficient. The lack of efficiency results in a magnification of the demand for transmission plant capacity.

Thus, while measures of activity such as the numbers of users, terminals, or messages using each operating mode are likely to be of comparable magnitudes over the 1990 to 2000 decade, facility usage, which is the measure of most concern in this study, will tend to be biased strongly toward the less efficient modes. As indicated in Table 3-1, dedicated modes are expected to account for 80 percent of the actual bits transmitted in 1980, 1990 and 2000. Switched mode traffic is projected to account for 20 percent in 1980, decreasing to 19 percent by the year 2000. Packet mode transmission, initially at negligible values as far as facility occupancy is concerned, will grow to about 1 percent by the year 2000. This relatively small value, however, is a result of the high efficiency of packet transmissions. When impact on users and applications is considered, packet modes will be of considerably greater importance than the demands for capacity reflected above would indicate.

3.5 TRUNKING MODE AND CUSTOMER PREMISES SERVICES

In trunking mode operation, bulk long haul transmission capacity established by a terrestrial or satellite link terminates at a network node, and then is further distributed by end loops to the user's location. Satellites can offer an additional distribution mode, referred to as Customer Premises Service (CPS), by locating an earth station at the user's site. In this report Customer Premises Service refers to CPS connection at both ends of the link. Transmission can then be direct to the user, and end loops can be avoided. This can be of particular importance when wideband or specialized services are required. Other definitions of CPS which allow for trunking at one end of the link, or shared earth station usage at one or both ends of the link are possible but unless otherwise noted the more restrictive definition applies.

Satellite provided CPS service opens some options of interest for certain communication applications that are otherwise difficult to achieve. Wideband services, such as those required for video or high speed data, are generally difficult to extend from a trunking node to the user's location. Coaxial cables, microwave or laser links, and fiber optics are some of the technologies capable of providing the wideband end loops needed in trunking configurations, but these are all costly and cannot be rapidly reconfigured as needs change. Furthermore, switching of these wideband services is not generally available so that networks must be established, via dedicated links, to prearranged communities of interest.

Customer Premises Services, particularly at the higher satellite frequency bands where antennas are small, can provide high flexibility in the establishment and reconfiguration of communications capacity. Small transportable earth stations can be quickly moved into place to establish communications where needed. In addition, the broadcast nature of the signal from the satellite to earth allows the equivalent of switched wideband operation by addressing the transmission to the desired recipient or recipients.

Customer Premises Services can also be of importance in solving the access problems of users of special purpose networks (see Subsection 2.4.1). In many cases the special features of the networks are partially or wholly negated for users who must reach the access points of the special network through the common telephone plant. The ability of satellites using CPS to extend the special features directly to the user's site avoids the difficulties and expenses of establishing and interfacing with local distribution facilities.

While Customer Premises Service offers some important benefits, as discussed above, application is limited by the following considerations:

(a) Traffic Volume - An establishment using CPS must have a sufficient volume of communications to offset the cost of installing and operating a dedicated earth station. While earth station designs and costs can vary widely, depending on frequency band and application, some indication of volume requirements is offered by the Satellite Business Systems (SBS) projected CNS-A service. SBS CNS-A service will provide customer site earth stations for business communications (see Subsection 7.2.2). The prime customers for this service are businesses spending \$3.6 million to \$6.9 million per year on communications. A typical customer network would have three to six earth stations, so that each prime target establishment supporting an earth station in this Ku band system might be expected to spend over a million dollars per year for communications. SBS is also offering a shared earth station service (CNS-B) which reduces the costs to participants sharing the earth station, but this type of operation implies a broadening of the more limited, on site, definition of "Customer Premises Service" adopted in this study.

(b) Need for Widespread Distribution - CPS has its main application in intracompany dedicated service. It is also possible for establishments of one company to communicate with establishments of another company via CPS provided that both establishments are equipped with earth stations addressing the same satellite system. However, if communications are needed to an establishment that is not equipped with a compatible CPS earth station, it becomes necessary to establish the link via trunking. This may be done by direct access to trunking facilities at both ends of the link or, in suitably designed systems, by allowing a CPS equipped establishment to use its earth station to address a remote common-user earth station which, in turn, provides the trunking connection to the desired non-CPS equipped user. However accomplished, those applications requiring widespread distribution to many small as well as large users are best served by trunking.

(c) Reliability - As discussed in Subsection 5.2.2, rain induced outages will lower the reliability of satellite communications in the higher frequency bands. While this effect can be countered in trunking systems by using separated earth stations to provide space diversity, the use of space diversity is not generally applicable to CPS operation. Thus, CPS operation at Ka band, and to a lesser degree at Ku band, is expected to be less reliable than service provided through competing terrestrial and C band satellite systems. It will also be less reliable than trunking service using diversity earth stations. Those applications for which high reliability is important will therefore find the lower reliability CPS transmissions less desirable than those of alternate methods of communications.

Table 3-2 provides a profile of the communications market for Customer Premises Service in satellite frequency bands such as Ka for which CPS reliability is expected to be lower than that available with other communications approaches. Each of the communications categories and subcategories listed in Table 1-1 are considered in terms of the previously discussed limitations imposed by traffic volume, need for widespread distribution, and reliability. The entries in Table 3-2 are discussed in Subsections 3.5.1 to 3.5.3. A table similar to Table 3-2 can be constructed for C band satellite CPS and to a first approximation the entries would be the same with the exception that all entries in the column labled "Reliability Considerations" would be increased to 100 percent to reflect the high reliability performance obtainable with C band CPS. Ku band CPS service, depending on the system design, will have a reliability intermediate between that of C band and that of Ka band, and the traffic addressable by CPS will fall between the values for C and Ka band.

3.5.1 VOICE

Individual residential voice subscribers clearly have insufficient traffic volume to justify CPS service. This is indicated in Table 3-2 by the zero entered under Traffic Volume for this subcategory of traffic.

About 30 percent of long distance business switched voice traffic is estimated to arise from business establishments whose volume can justify CPS. CPS, however, does not provide the capability of widespread distribution to both large and small users essential to switched voice traffic. Thus, the 30 percent of traffic, indicated in the first column as a candidate for CPS is further disqualified by the zero entered in the column headed "Widespread Distribution."

About 30 percent of long distance dedicated (private or leased line) business voice traffic is also estimated to arise from sources with sufficient traffic volume to justify CPS service, but in this case a large fraction of this (estimated to be 50 percent) remains within the narrow distribution confines of the high volume CPS user community. The entry of the 20 percent value in the column headed "Reliability" indicates that only 20 percent of the candidate traffic in the dedicated business voice subcategory will find the lowered reliability of CPS service acceptable. The net result, as shown in the last column, is that only 3 percent (.3x.5x.2x100) of the traffic in this subcategory is a candidate for CPS service.

3.5.2 VIDEO

A similar procedure is followed in Table 3-2 for the Video category. Network TV, CATV, and Educational TV to a lesser extent, are applications which generally can justify dedicated earth station costs since distribution of the signal is in broadcast mode to many relatively inexpensive receive-only sites. Furthermore, the competing alternative terrestrial or satellite trunking options also involve expensive local distribution costs. CPS is therefore assumed to be fully qualified for the Network TV and CATV subcategories as far as "Traffic Volume" is concerned. The 95 percent entry under "Widespread Distribution" allows for those few instances where considerations such as radio frequency interference preclude use of CPS. The lower reliability offered by CPS, however, limits these transmissions to that percentage of traffic which can be prerecorded for later transmission and, therefore,

TABLE 3-2 ADDRESSABLE TRAFFIC PERCENTAGES FOR Ka BAND SATELLITE CUSTOMER PREMISES SERVICE**

	COMMUNICATIONS SUBCATEGORY	PERCENT FOR CPS AFTER LIMITATION DUE TO:			
		(1) TRAFFIC VOLUME	(2) WIDE DISTRIB.	(3) RELIAB. CONSID.*	(4) OVERALL PERCENT
VOICE	RESIDENTIAL	0	0	35	0
	BUSINESS (SW.SVC.)	30	0	20	0
	BUSINESS (PVT. OR LEASED LINE)	30	50	20	3
VIDEO	NETWORK TV	100	95	40	38
	CATV	100	95	50	48
	EDCA. VIDEO	80	95	45	34
	VIDEOCONFER.	80	95	40	30
DATA	FACSIMILE	30	50	50	8
	ELECT. MAIL	85	90	90	69
	COMPUTER	30	50	20	3

*BASED ON SUM OF LAST TWO COLUMNS IN TABLE 5-8

**ASSUMES CPS AT BOTH ENDS OF LINK

is not seriously affected by rain outages. Similar considerations are used in arriving at estimates appropriate to the Educational Video category.

Videoconferencing is assumed to prefer CPS operation for 80 percent of the volume. This includes the use of dedicated CPS earth stations by the larger users and centrally located, CPS equipped, studio facilities in shared use by smaller users. The remaining 20 percent accounts for users with insufficient volume for CPS who consequently may be served by dedicated lines derived through trunking. Most videoconferences are assumed to be intracompany between preselected locations, or, if established on an ad hoc intercompany basis, to be switched via satellite multiple access technology. Thus, wide distribution requirements are not an impediment for most of this traffic category. However, only about 40 percent of videoconferencing users are expected to find the lowered reliability of CPS service satisfactory.

3.5.3 DATA

Following the procedure used above, about 30 percent of Facsimile traffic is estimated to be generated by establishments with traffic volumes high enough to justify an earth station. Of this percentage, 50 percent is estimated to remain within the community of CPS users.

Immediate delivery is not usually of great concern for that fraction of facsimile traffic using bulk mailroom facilities. About 50 percent of facsimile traffic is estimated to be of this type for which the lower reliability levels of Ka band CPS is acceptable. The remainder, generated by convenience facsimile machines located in the office, is generally transmitted via ordinary telephone facilities at reliability levels typical of current voice service.

The major component of Electronic Mail traffic is projected to be Postal Service oriented bulk traffic between major postal centers, almost all of which is well suited to CPS modes. That smaller portion of electronic mail generated by communicating word processors and related message systems is expected to have a substantial component of dedicated traffic, part of which will originate with establishments equipped for CPS. Combined, these components are estimated at 85 percent as indicated in the first column of Table 3-2. Because of the large postal service component, 90 percent of this is expected to remain within the CPS community. Reliability considerations are of importance to only a small fraction contributed by priority electronic mail. About 90 percent of the electronic mail traffic is expected to find the reduced reliability levels of Ka band CPS satisfactory.

Computer traffic represents, by far, the largest of the data communications subcategories. An estimated 30 percent of Computer traffic originates with establishments generating sufficient volume to justify CPS, and 50 percent of this traffic is expected to remain within the CPS community. Reliability is an important issue for most data communications and only 20 percent of the potential traffic is expected to find the lower reliability of Ka band CPS acceptable.

3.5.4 SUMMARY

Table 3-3 summarizes the results of Table 3-2 by weighing each traffic category with the traffic volumes projected in Table 1-1 for the years 1980, 1990 and 2000. The entries in the columns labled "%" refer to the percentage of the traffic projected in Table 1-1 for the indicated year in each traffic category.

TABLE 3-3. SUMMARY OF CPS ADDRESSABLE TRAFFIC FOR Ka BAND SATELLITES

	1980		1990		2000	
	BITS/YR x 10^{15}	%*	BITS/YR x 10^{15}	%*	BITS/YR x 10^{15}	%*
VOICE	17	2	44	2	103	2
VIDEO	36	42	63	35	131	32
DATA	3	3	13	4	18	4
TOTAL	57	5	120	4	252	4

*Percent of VOICE, VIDEO, DATA and TOTAL TRAFFIC addressable by Ka Band CPS.

Only 2 percent of voice traffic, and 3 to 4 percent of data traffic is estimated to be addressable via the less reliable CPS services expected to be provided by Ka satellites. Video applications account for the largest component of CPS addressable traffic, both in absolute values and in terms of the percentage of total video demand. Overall, only 4 to 5 percent of total traffic is estimated to be addressable by CPS facilities of this type. The volume of traffic estimated for CPS, however, may be expected to increase if less restrictive CPS approaches are adopted which permit easy access to trunking and allow shared use of earth stations. It should also be noted that 4 to 5 percent of the total traffic in absolute terms amounts to a sizeable traffic volume and may represent an attractive target for some common carriers.

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4.0 TIME VALUES

Communications response time needs vary over a wide range: from the real-time requirements of voice to the overnight requirements of low priority electronic mail. This section discusses the response time requirements of various communications applications and develops a profile of traffic type versus acceptable delivery delay. Those traffic components capable of tolerating delay permit more efficient utilization of communications capacity and are of particular significance to media, such as Ka band satellite, where outages due to rainstorms may make real-time delivery of traffic difficult to guarantee.

4.1 COMMUNICATIONS DELAY CATEGORIES

Most communications traffic exhibits heavy peaking at particular hours of the day, and in addition shows substantial day-to-day and seasonal variation. Transmission facilities must be designed to provide satisfactory performance during peak loading periods and, as a result, are often left with idle capacity during off-peak hours. Traffic that is capable of accepting delays in transmission can employ this idle capacity with resulting cost beneficial improvements in plant utilization. In the following pages response time is discussed under the real-time and deferred categories defined in Table 4-1.

Real-time response generally implies a transmission delay of well under a second, but in some interactive data applications response times of several tens of seconds are often also considered to be real-time. The satisfaction of real-time demand requires the immediate delivery of communications resources even though facilities may be overloaded. However, it is often possible to encourage the transfer of real-time traffic to off-peak hours through appropriate pricing policies.

Deferrable traffic, able to accept short delays of up to several minutes, is common in many facsimile applications and in applications involving inquiries to remote data bases. Short delays of this type can permit buffering

TABLE 4-1. RESPONSE TIME CATEGORIES

CATEGORY	DESCRIPTION
REAL-TIME	Generally implies response times of under one second but in some data applications may be several tens of seconds.
DEFERRED	
SHORT	Up to several minutes delay. Short delays are not effective in reassigning traffic to less busy hours but permits various buffering and queuing methods to improve link efficiency.
MEDIUM	Up to several hours of delay. Can result in better resource utilization by off-loading peak hour traffic.
LONG	Up to twenty-four hours of delay. Permits high flexibility in reassigning traffic to make effective use of idle capacity.

and queuing procedures to be used to improve the efficiency of line utilization, but are not effective in transferring traffic from peak hours to less busy times. Aside from the above mentioned facsimile and data base access applications, delays of several minutes have few applications. Most applications either require real-time service or, if they are capable of accepting deferred service at all, can accept delays of considerably larger magnitude.

Medium delays are applicable to many message delivery systems for which a response faster than that provided by postal mail service is desired. Delays ranging from one to eight hours typify this category. At the longer end of this range, off-loading of traffic can prove very effective in permitting efficient utilization of network resources.

Long delays, extending to twenty-four hours, allow the transfer of traffic to lightly loaded night-time hours and permit optimum flexibility in resource utilization. While delays longer than twenty-four hours are possible in some instances, electronic transmission modes begin to compare unfavorably with the lower costs of physical delivery of documents and magnetic tapes or discs.

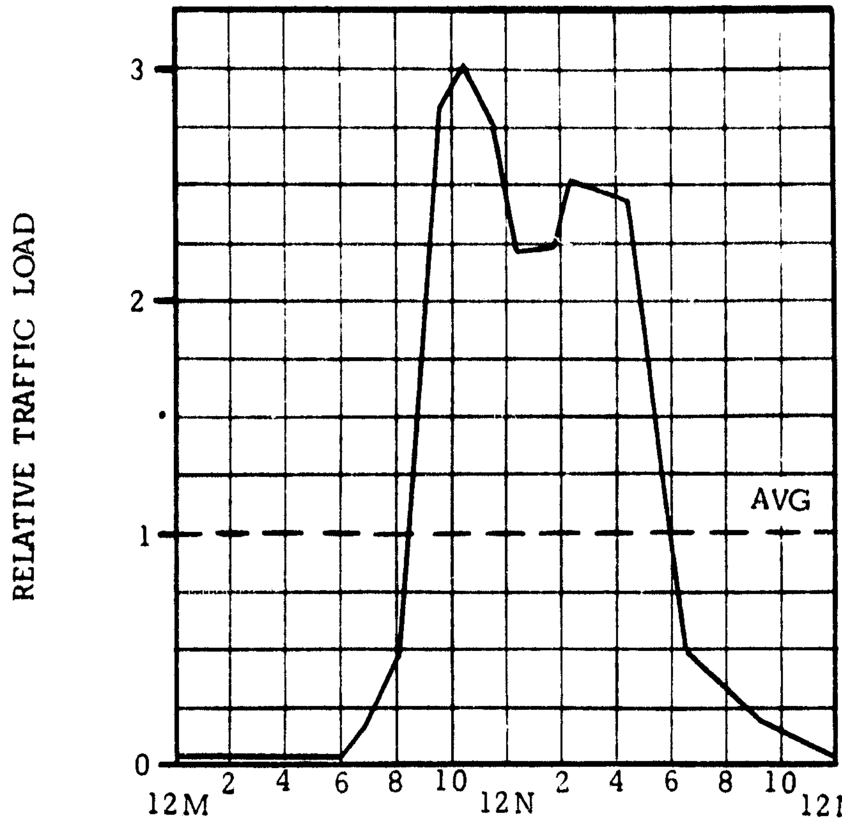
4.2 FACILITY UTILIZATION VS DEFERRED TRAFFIC VOLUME

A traffic mix which contains a substantial fraction of deferred traffic allows more efficient utilization of available communications facilities than one which has only real-time components. The following discusses the desirable balance between real-time and deferred traffic volumes and examines pricing strategies that encourage the development of a satisfactory balance.

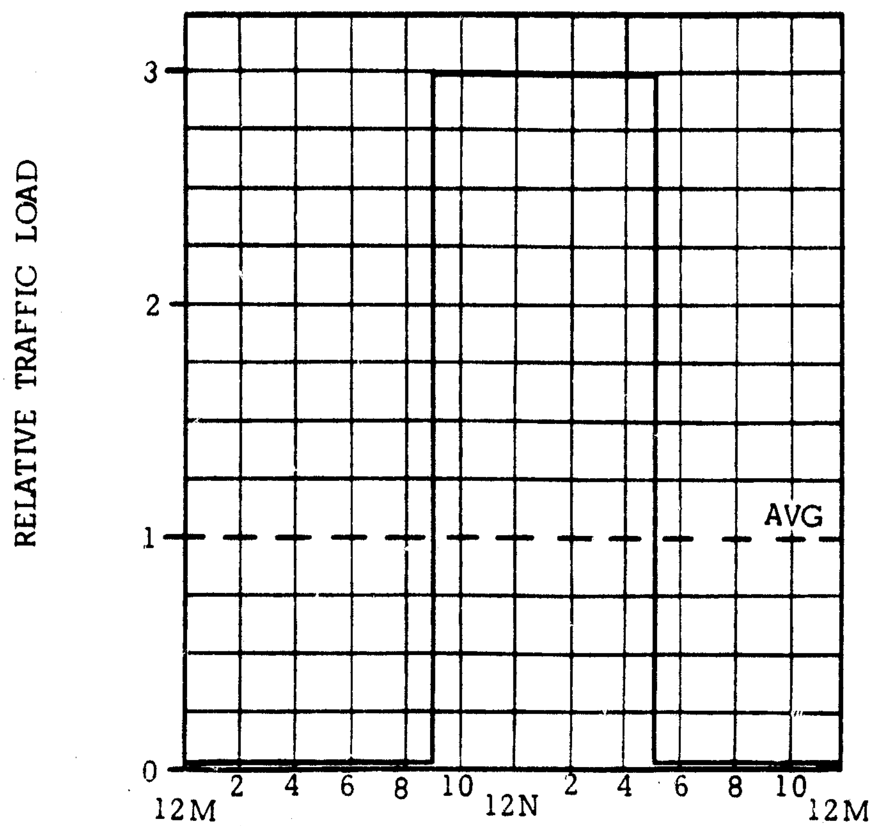
4.2.1 TRAFFIC LOADING MODEL

The actual traffic loading patterns of practical communications systems are complex. Traffic in general builds up rapidly during daytime hours and often has both a morning and afternoon peak. Figure 4-1a shows a typical loading pattern for a telephone central office in which real-time business voice traffic predominates (Ref. 1). The corresponding loading pattern for a central office serving residential traffic would be slightly broader and shifted toward the evening hours. Such patterns are subject to change as different price incentives are instituted to encourage off-peak hour use. Traffic loading patterns also depend on the mix of local traffic versus that spanning several time zones, and can be expected to change as emerging applications such as electronic mail become increasingly significant.

For the purposes of the following discussion the highly simplified model shown in Figure 4-1b provides a rough but adequate approximation to typical real-time demand loading. All traffic is concentrated in an eight hour day, and the peak-to-average value of three is close to that applying to the central office traffic illustrated in Figure 4-1a. The simplified model, however, has a flat top without the ripples exhibited in Figure 4-1a. The model, therefore, will not accurately represent some of the fine grained effects of deferring traffic, such as the possible relocation of the 9:30 to 11:30 a.m. peak into the 12:00 to 2:00 p.m. valley. However, for communications facilities with nationwide capabilities, the time zone differences make such effects less pronounced. In addition, other factors, such as the day-to-day variability of traffic, also tend to make the existence of such fine grained ripples of little consequence in gaining insight into the effects on network operation of various mixes of real-time and deferred traffic.



(a) TYPICAL BUSINESS CENTRAL OFFICE TRAFFIC LOADING PATTERN



(b) SIMPLIFIED TRAFFIC LOADING MODEL

FIGURE 4-1 TRAFFIC LOADING PATTERNS

4.2.2 EFFECT OF DEFERRED TRAFFIC ON PEAK-TO-AVERAGE RATIO

In the traffic model illustrated in Figure 4-1b only eight hours out of the twenty-four hour day are occupied with traffic and during the remaining sixteen hours the facility is idle. If two-thirds of the traffic is removed from the 9:00 a.m. to 5:00 p.m. peak period and redistributed over the remaining sixteen hours of the day, the peak traffic becomes equal to the average traffic and the peak to average ratio decreases from three to one. This three-fold reduction in the peak-to-average ratio allows a much smaller communications facility to carry the same daily traffic. Alternatively, it allows the daily traffic carried by facilities with a fixed peak capacity to be increased by a factor of three.

The three-fold improvement in the peak-to-average ratio discussed above permits a major improvement in the efficiency of plant operation. However, it requires that fully 66.6 percent of the traffic arriving during the 9:00 a.m. to 5:00 p.m. peak hours be deferrable for periods as long as 16 hours. A traffic mix this rich in deferrable, long-delay, traffic is unrealistic under most scenarios for the development of general purpose communications systems, though such a mix may occur under some special purpose scenarios. In most cases of practical interest the percentage of deferrable traffic presented during the peak period will be much smaller, and there will be limits to the number of hours of delay that are acceptable. The effects of these limitations on peak-to-average ratios are discussed below.

Figure 4-2 illustrates the improvement in peak-to-average ratio that can be achieved for various acceptable delays, and as a function of the percentage of traffic that can be deferred. These results (based on the simplified traffic loading of Figure 4-1b) show, for example, that if 20 percent of the traffic presented in each of the hours between 9:00 a.m. and 5:00 p.m. could be deferred up to, but no more than, two hours, the peak-to-average ratio would be reduced from three to 2.85. To accomplish this, the deferrable 20 percent of the traffic in the 3:00 p.m. to 5:00 p.m. period is relocated to the 5:00 p.m. to 7:00 p.m. period, and the traffic remaining in the 9:00 a.m. to 5:00 p.m. period is smoothed by using the remaining deferrable traffic to fill the space created by the relocation. If the number of hours of delay acceptable for this 20 percent of deferred

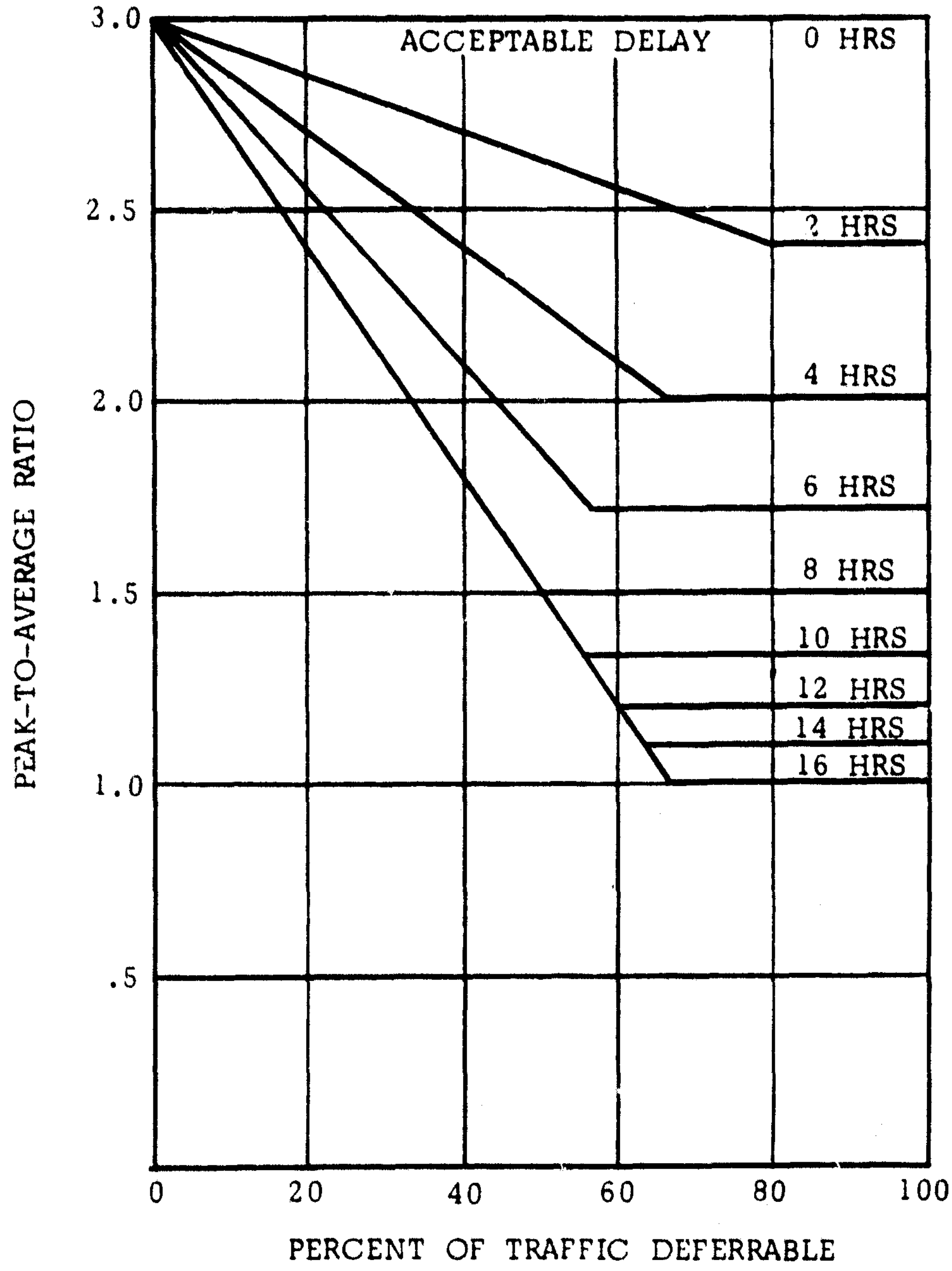


FIGURE 4-2 PEAK-TO-AVERAGE RATIO AS A FUNCTION OF PERCENT OF TRAFFIC DEFERRABLE

traffic is increased to eight, a further reduction in the peak-to-average ratio to 2.4 is obtained. Additional delay beyond eight hours is not effective in achieving further reductions in the peak-to-average ratio because all of the deferred traffic (20 percent of the total in this example) can be relocated within the eight hour delayed window without creating an excessive traffic build-up in the delayed period.

It is apparent from Figure 4-2 that relatively large amounts of delay and/or large components of deferrable traffic are needed to achieve appreciable improvements in the peak-to-average ratio. Small delays, or small percentages of deferrable traffic do not result in much improvement in facility utilization.

4.2.3 PRICING OF DEFERRED TRAFFIC

Deferred traffic reduces the peak-to-average traffic loading and thus permits more efficient use of communications facilities. It is reasonable, therefore, to charge less for deferred traffic than for real-time traffic in order to equitably distribute costs, and to encourage users capable of accepting delayed transmissions to use this more efficient mode of operation.

The traffic loading model discussed in the previous sections, and the results presented in Figure 4-2, permit the estimation of reasonable cost allocations to various components of real-time and deferred traffic. For example, in the discussion of Figure 4-2 it was noted that a 20 percent component of deferred traffic, capable of accepting two hours of delay, reduces the peak-to-average ratio from 3 to 2.85. Assuming that sufficient real-time and deferred traffic is available to fully load the facility during the peak hours, the total daily traffic volume increases by a factor of 3:2.85 = 1.053. Since this 5.3 percent increase in volume occurs with little or no increase in facilities needed, earnings from the operation of the facilities remain unchanged if pricings are adjusted to maintain a balance between the total relative values shown in Cases A and B below.

A. <u>Real-Time (80%) and Deferred (20%) Traffic Mix</u>

Relative traffic volume 1.053

Real-time traffic value 1.053x80% @ \$1.00 = \$.842

Deferred traffic value 1.053x20% @ \$C = .211C

Total Relative Value (Dollars) = \$.842 + .211C

Where C is the price charged for a unit of deferred traffic relative to a \$1.00 charge for a unit of real-time traffic.

B. <u>Real-Time Traffic Only</u>

Relative traffic volume 1.00

Real-time traffic value 1.00x100% @ \$1.00 = \$1.00

Deferred traffic value None 0

Total Relative Value (Dollars) = \$1.00

A balance between these two cases occurs when the total relative values are equal, (i.e., when \$.842 + .211C = \$1.00) resulting in a break-even price for the deferred traffic of C = \$0.749. Thus, with a given peak capacity it should be possible to offer either 100% real-time service at a relative cost of \$1.00 or an 80/20 percent mix of real-time and deferred service at relative costs of \$1.00 for the real-time components and \$0.749 for the deferred components.

A similar analysis may be carried out for each mix of deferred and real-time traffic, and for each acceptable delay. Results are presented in Figure 4-3 which shows the break-even price of deferred traffic (relative to real-time traffic) as a function of the percent of total traffic that is deferrable, and with acceptable delay as a parameter.

Such curves present broad guidance in the formulation of pricing policy for deferred traffic. For example, the curves indicate that if deferred service with four hour delay is offered, a rational charge for the deferred traffic would be one-half that charged for real-time service. The flatness

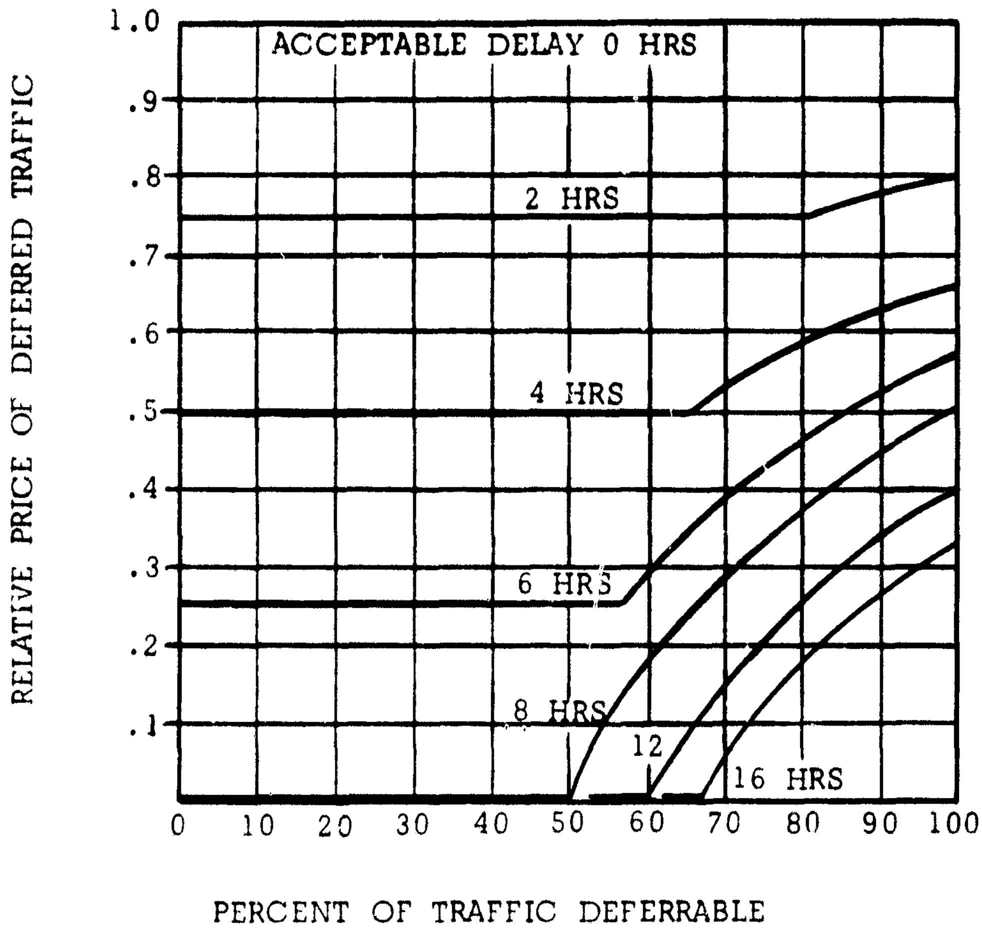


FIGURE 4-3 BREAK-EVEN PRICE OF DEFERRED TRAFFIC VS. PERCENT OF TRAFFIC DEFERRABLE

of the left hand region of the curve indicates that, up to a point, the offerer of the service can be relatively indifferent to the mix of traffic. That is, the facility will earn the same amount whether the traffic is almost all real-time traffic or whether a relatively large component of deferred traffic (at the reduced price but with an overall increase in total daily traffic carried) is included. When the percentage of deferred traffic becomes very high, however, (67% in the four hour case) the deferred traffic begins to interfere with the ability of the facility to handle the higher priced real-time traffic within peak capacity constraints. As a consequence it is necessary for the price charged for deferred traffic to increase so as to compensate for the loss in real-time revenues.

Actual pricing structures of real communications services are, of course, highly dependent on many interrelated factors. The values developed using the simplified model discussed in this section provide only a single viewpoint, that of potential earnings from a communications plant of fixed peak capacity with zero cost for the use of idle capacity. The consequences of some of these simplifications are apparent in Figure 4-3, in that some deferred traffic, capable of accepting eight or more hours of delay, places no demands on peak capacity and is therefore priced at zero. In practice there are some operating costs for the additional services, and pricing reflects a compromise between utility to the user and cost to the supplier. The results presented, however, serve to illustrate the general trends and relationships among the variables introduced.

4.3 REAL-TIME VS DEFERRED TRAFFIC DEMAND

This section discusses the demand for real-time vs deferred transmission capabilities for each of the Voice, Video and Data traffic categories.

4.3.1 VOICE TRAFFIC DELAY CHARACTERISTICS

Substantial contributions to real-time demand arise from teleconferencing, live television programming, and interactive data traffic, but voice transmissions present the largest component of traffic demand for real-time service.

While voice and other real-time transmissions require immediate service and may therefore add to peak hour loading, it is possible to encourage users to defer their real-time demands to hours when the communications facility is less heavily loaded. For example, reductions in the charges for telephone calls placed during evening and weekend hours have proved very effective in diverting traffic to these hours. Following a 1963 rate reduction of 18 to 24 percent for evening hour calls in the 221 to 506 mile band, there was a virtual doubling of evening hour volume. In the 507 to 3000 mile band, where evening rates were reduced by 34 to 44 percent, message volume roughly quadrupled (Ref. 2). Not all of these increase can be ascribed solely to the rate reductions, but the effectiveness of pricing policy in deferring large segments of voice traffic to non-peak hours is clearly evident.

There has also been some recent interest in deferred modes of voice traffic related to office of the future concepts and as a custom feature for residential callers. The Bell System recently proposed two new services of this type known as "Call Answering," and "Advanced Calling" (Ref. 3). Call Answering performs much the same function as a telephone answering machine, but in this case, the telephone company central office automatically intercepts the call after a certain number of unanswered rings, and records the caller's message for later retrieval. Advanced Calling permits a user to record a message for later delivery to one or more recipients at specified times. While such deferred mode voice services will undoubtedly be available in the future, their impact on traffic loading will be slight.

4.3.2 VIDEO TRAFFIC DELAY CHARACTERISTICS

Most of the video traffic categories include a significant fraction of traffic that can profitably employ deferred modes of transmission. The major exception to this is videoconferencing which, because of its two-way interactive character, requires real-time transmission.

The key to accommodating deferred transmission modes in most video applications lies in the provision of suitable wideband recording media at the receiving site. Programs scheduled for broadcast in a local area are transmitted some time in advance from the originator to the local area, and are stored for transmission at the appropriate hour.

Rapid progress in video recorder design has reduced the costs of video recording equipment to relatively modest levels and the technology is well developed and reliable. Other than for certain televised events such as sports which require live coverage, it is likely therefore that a large portion of CATV and Network TV programming will make use of deferred transmission. The same is true for many educational uses of video and, to a smaller extent, for health and public affairs transmissions.

It appears that once facilities and procedures for accommodating deferred video transmissions have been installed, acceptable delays will fall into the medium (several hours) to long (up to one day) delay categories with no particular operational advantage being afforded by shorter delays. The off-loading of traffic from peak hours will, as discussed earlier, permit network economies and pricing benefits and at the same time provide a partial solution to the outage problems that characterize certain modes of K Band transmission.

4.3.3 DATA TRAFFIC DELAY CHARACTERISTICS

Many data communications applications can make effective use of deferred modes of communication, and in some cases deferred transmission is actually preferable. An example is provided by messages destined for an office which, because of time zone differences will not be open for some hours.

Figure 4-4 shows typical response or delivery time requirements plotted against the quantity of data to be transmitted for various data transmission applications. The dashed

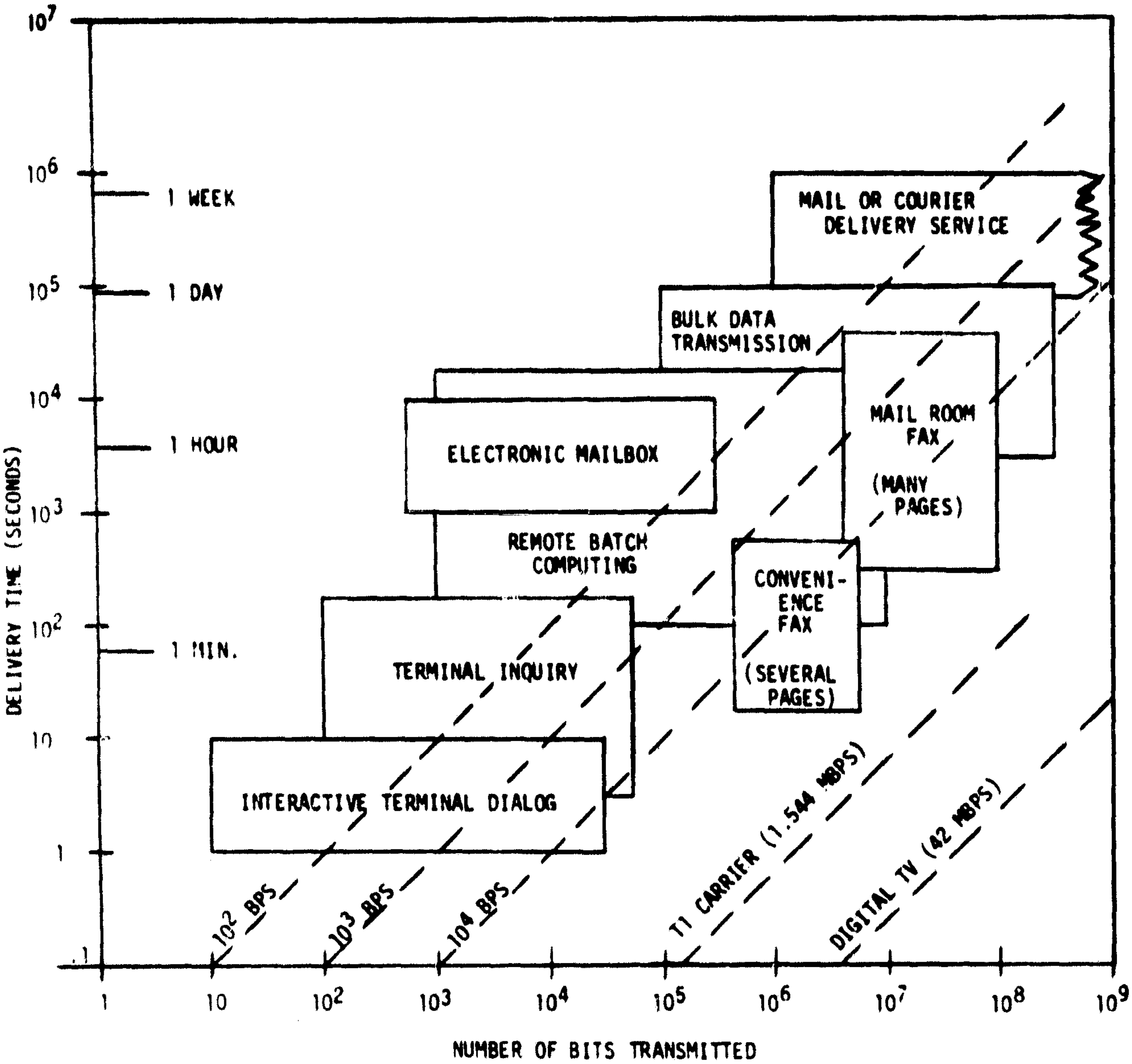


FIGURE 4-4 DELIVERY TIME AND VOLUME REQUIREMENTS OF TYPICAL DATA APPLICATIONS

lines show the time it would take to complete the transmission of the quantity of data represented by the abscissa at the average bit rates indicated. Data speeds possible on a voice grade line (up to about 9600 bps) are adequate for delivering most of the illustrated applications within the time required. Transmission rates available on the Bell System's T1 Carrier System (1.544 Mbps), or on a typical digital TV channel (42 Mbps), provide much higher capacity than is likely to be needed for any single installation of these data applications.

The shortest delivery times illustrated in Figure 4-4 are associated with interactive terminal dialogs. These may be person-to-person via Telex terminals, communicating word processors, or other terminal types, or they may be person-to-computer transactions. Typically, delays of one to ten seconds are acceptable to most persons seated at a terminal for this type of interactive communications.

Terminal-to-computer data base inquiry operations are common in airline passenger reservation systems, law enforcement, inventory control and general business applications. Acceptable delays range from several seconds to several minutes.

Delays ranging from minutes up to perhaps half an hour are acceptable for many office facsimile applications utilizing light-duty, convenience, facsimile machines. Messages for which longer delays are acceptable are more likely to be handled on a batch basis via heavy duty facsimile machines in the company mailroom.

Remote batch computing generally involves turn around times ranging from several minutes to three or four hours. A large printout to a remote site may involve the transmission of millions of bits and may occupy a transmission link for several hours.

Electronic mailbox operations involve the transmission of memos, letters and reports to a local memory store for later access by the recipient. This advanced office procedure replaces conventional interoffice mail by more convenient electronic technology. Messages tend to be brief (a few pages of text), with delivery requirements between one-quarter of an hour to several hours.

Bulk data transmissions are typical of advanced postal service approaches and electronic funds transfer operations. Government networks such as the Advanced Record System (ARS) also are generators of bulk data transmissions. The ARS network, operated by the General Services Administration, with Social Security and the Veterans Administration being the heaviest users, is currently carrying about 40 billion characters per year (1.6 billion bits per day) (Ref. 4).

With response times much longer than a day electronic data transmission begins to suffer in comparison to the physical transportation of magnetic tape or discs by truck or plane. A 100 megabit magnetic tape can be delivered by airmail at a cost of about 5 cents per megabit in comparison with leased line or packet network costs of 50 cents to one dollar per megabit.

4.3.4 PROFILE OF REAL-TIME AND DEFERRED TRAFFIC APPLICATIONS

Under an earlier phase of this study (Ref. 5), estimates were formed for the percentages of real-time and deferred service acceptable for each communications application. These results, with some slight revisions, are summarized in Table 4-2 using the categories of traffic introduced in Table 1-1.

TABLE 4-2. SUMMARY OF DEMAND FOR REAL-TIME AND DEFERRED TRAFFIC (PERCENT OF TRAFFIC FOR EACH APPLICATION)

		REAL-TIME	DEFERRED		
			SHORT	MEDIUM	LONG
VOICE	RESIDENTIAL SWITCHED SVS.	100	0	0	0
	BUS. SW. SVS. INCL. WATS)	100	0	0	0
	BUSINESS (PVT. OR LEASED SVS.)	100	0	0	0
VIDEO	NETWORK TV	60	0	20	20
	CATV	50	0	10	40
	EDUCATIONAL VIDEO	50	0	20	30
	VIDEOCONFERENCING	100	0	0	0
DATA	FACSIMILE	50	20	10	20
	ELECTRONIC MAIL	10	10	40	40
	COMPUTER	60	20	20	0

These results can be combined and summarized by weighing each of the applications in accordance with their estimated overall traffic volumes as obtained from Table 1-1. The results are shown in Table 4-3.

TABLE 4-3. PERCENTAGE OF REAL-TIME AND DEFERRED TRAFFIC DEMAND, WEIGHTED ACCORDING TO OVERALL TRAFFIC VOLUME

CATEGORY	1980		1990		2000	
	REAL-TIME	DEFERRED	REAL-TIME	DEFERRED	REAL-TIME	DEFERRED
VOICE	100	0	100	0	100	0
VIDEO	53	47	75	25	82	18
DATA	60	40	59	41	59	41
WEIGHTED AVG.	92	8	94	6	96	4

In each service category, real-time demand is the largest component, and because of the large weight of real-time voice traffic, the overall weighted average heavily favors real-time. While the deferred traffic does not amount to a large portion of the total, to the extent that this traffic can be captured, it is useful, as discussed earlier in this chapter, in permitting some degree of improvement in the efficiency with which communications facilities can be utilized. In addition, for media such as Ka band satellites, the deferred component of traffic can be carried without requiring the back-up capabilities needed to protect the more critical real-time components against rain induced communications outages.

4.4 PEAK FACTORS

As discussed in Section 4.1, communications traffic volumes exhibit substantial variations according to the hour of the day, and from season to season. Generally communications facilities are designed to handle, at a satisfactory level of performance, the volume presented during the peak hour of the average day. As a design economy the specially high peaks occurring on certain holidays and during emergencies are handled on an overload basis. In order to relate the average day peak capacity at a communications facility to its overall average capacity, a peak factor is used. The peak factor is defined as the traffic volume during the peak hour of the average day divided by the average hourly traffic.

Peak factors for various communications applications were developed in Reference 5. These have been adapted to the traffic categories and volumes defined in Table 1-1 and are summarized in Table 4-4. A nominal peak factor of two is used in later sections of this report where conversion between average values and peak values of capacity, or demand, are required.

TABLE 4-4. PEAK FACTORS BY TRAFFIC CATEGORY

	1980	1990	2000
VOICE	1.71	1.68	1.57
VIDEO	1.07	1.97	2.20
DATA	3.96	3.93	3.90
WEIGHTED AVERAGE	1.96	2.00	1.85

REFERENCES

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3. "Bell's Newest Phone Service, "New York Times (May 8, 1980).

4. "Government Opts to Fine-Tune Existing Network," Data Communications (April 1980).

5. "30/20 GHz Fixed Communications Systems Service Demand Assessment," NASA Report No. CR159620, Prepared by ITT U.S. Telephone and Telegraph Corp. (Aug. 1979).

5.0 QUALITY AND RELIABILITY

This section addresses the issues of signal quality and reliability as they influence the capabilities of Ka satellites relative to other communications media. The following discussion indicates that signal quality on Ka satellite systems is expected to be excellent for voice, video and data services, but that reliability considerations are less favorable and have important consequences on system design and the ability to address these services.

5.1 SIGNAL QUALITY

Signal quality, as used here, refers to the normal performance of the communications channel, with all equipment functioning properly, and under good propagation conditions. Quality, of course, degrades during propagation fades caused by rainstorms, or as a result of equipment malfunctions, but these effects are ascribed to the category of reliability and are treated later in this chapter.

5.1.1 VOICE

The most important quality related parameters for voice transmissions are noise, crosstalk, and amplitude-frequency response. Noise, or more properly signal-to-noise-ratio, is determined by the design of the communications link. For satellite links, it is dependent on factors such as antenna size, radiated power, modul ion scheme, etc. Ka satellite links are likely to be engineered to allow substantial signal power margins to allow for rain attenuation. Therefore, during the majority of the time, in which good weather prevails, Ka satellite links should have excellent signal-to-noise ratios. In addition, manmade interference from electrical machinery, automobile ignition systems, and various other sources of radiation tend to be less disturbing at Ka band then at lower frequencies. The orientation of satellite antennas toward the sky, and away from these noise sources, also helps in achieving high quality.

If the satellite link is digital, as is likely to be the case for the Ka satellite systems of interest, the measure of interest switches from signal-to-noise-ratio to error rate.

Practical digital link designs almost always result in error rates much better than those needed for excellent voice performance. Other disturbances, however, are introduced into the signal path by the sampling and quantizing processes needed to digitize the voice signal for transmission over the digital link but, at the 64 Kbps sampling rate likely to prevail, quality will remain excellent.

Amplitude-frequency distortion and crosstalk also cause deterioration of the quality of voice signals. The wide, flat spectrum available at Ka band tends to permit engineering designs which minimize these difficulties. The large distance covered in a single satellite hop also avoids the accumulation of signal impairments introduced by the many repeaters, amplifiers and other electronic equipment encountered in a terrestrial path of similar length.

Many other factors, of generally lesser significance, also affect the quality of voice transmissions. In most instances it is likely that the performance of Ka satellites with respect to these will be equal to or better than that of other media.

5.1.2 VIDEO

The most critical quality determining parameters for television signals are:

Amplitude-frequency response
Envelope delay distortion
Transient response
Noise (thermal, intermodulation, crosstalk and impulse)
Differential gain
Differential phase

The last two of these are of lesser importance for black and white television but are important for color.

Because video transmissions require bandwidths that are much wider than those required for voice channels, and because the quality of the picture is critically related to some of the parameters listed above, the characteristics of the video channel have to be carefully controlled. Control of these parameters during the transmission of video signals via terrestrial media is made more difficult by the need for multiple hops. Many of the transmission impairments accumulate from hop to hop and therefore each link in a cascaded system of links has to be held to rigid specifications in order to obtain the desired end-to-end results. Satellite media have an advantage in this respect, and, in addition, Ka band transmissions are less likely to suffer from many of the interference problems that exist at the lower frequencies.

An important issue for the wideband links needed for video applications is the amount of compression in bandwidth, or data rate, that can be achieved without introducing quality degradations beyond those acceptable in each application. A large amount of work is currently underway in this area.

A typical approach uses the fact that a television picture does not completely change from line-to-line or from frame-to-frame, and in the extreme, a picture of a scene without motion does not change at all. The transmission of information relative to only the line-to-line changes (intraframe coding) or the frame-to-frame changes (interframe coding) therefore takes fewer bits than would be needed to completely repeat each frame. Table 5-1 (Ref. 1) provides an estimate of the data rates required to transmit network quality video images using conventional 7 to 8 bit Pulse Code Modulation (PCM), as compared to typical intraframe and interframe systems. Also presented are bit rate projections for several progressively lower quality videoconferencing systems.

The bit rate requirements shown in Table 5-1 may be compared with the digital capacity of a typical 36 MHz transponder which, under current technology, generally is considered to range from about 40 Mbps to 60 Mbps. With this transponder throughput it is not possible, using PCM, to transmit even a single network quality digital color TV signal, whereas one or two such signals can be supported with the more sophisticated encodings. For the lesser picture quality generally appropriate to videoconferencing, 10 to 40 one-way signals are possible within the capacity constraints of the transponder, depending on the quality desired, and on the degree of success encountered with

TABLE 5-1 BIT RATES PROJECTED FOR VIDEO TRANSMISSIONS USING VARIOUS DIGITAL ENCODINGS

QUALITY	ENCODING	BIT RATE (Mbps)	COMMENTS
NETWORK	PCM (7-8 BIT)	75-86	EXCELLENT QUALITY OR TV
	INTRAFRAME	32-45	"
	INTERFRAME	20-30	"
VIDEO-CONF.	INTRAFRAME	6	QUALITY GOOD
	INTERFRAME	3	SOME JERKINESS & OCCASIONAL PICTURE FREEZING.
	INTERFRAME WITH MOTION COMPENSATION	1.5	EXPERIMENTAL, CAN USE T-1 TRANSMISSION RATES.

operational versions of some of the currently experimental approaches.

Many video applications require only one-way transmission. Others, such as videoconferencing, which may require simultaneous two-way transmissions are expected to be configured as two separate one-way paths so that echo problems are minimized. The appreciable time delay experienced on satellite links will be noticeable to the users in two-way conferencing but is not a very disturbing effect.

Overall, it appears that video quality available via Ka satellite systems will be very good and will be equal to or better than that provided by other transmission media.

5.1.3 DATA

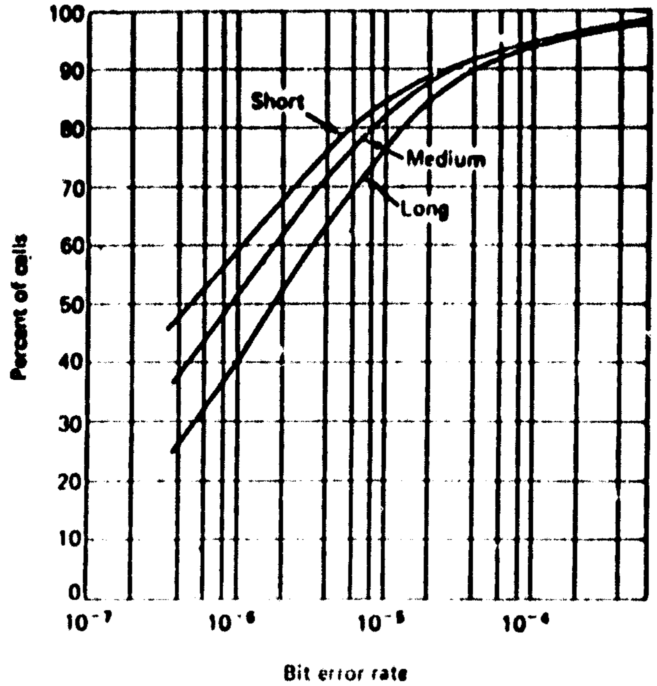
Most of the previously discussed parameters which influence circuit quality for voice and video are also of concern for data signals. Among the most important of these are amplitude-frequency response, delay distortion, and noise. The first two of these are closely related to the data rates which can be supported on the channel. Various channel adjustments (conditionings) are used to compensate for these effects and to allow higher data speeds. All three of these critical parameters influence the error performance of the channel.

In addition to the above, the quality of the channel for data communications purposes is also influenced by factors such as phase jitter, sudden amplitude and phase jumps, brief dropouts of transmission, crosstalk from other channels, non-linear distortion, and many other effects.

The net effect of the many channel disturbances to which data transmissions are susceptible is not apparent to the end user in the form of errors scattered among the bits of information being received. A high error rate causes the receipt of incorrect characters, garbled messages, loss of synchronization and other undesirable effects. Depending on the application, error rates as poor as one error in one thousand bits received may be tolerable to the data user but the usual application requires error performance 100 to 1000 times better than this, and some applications demand error rates of one in 10^8 or better.

Three important experimental surveys have provided most of the available information about the error performance of the terrestrial telephone network. The first of these, conducted by Alexander, Gryb and Nast in 1958-1959 (Ref. 2), presented the results obtained in approximately 1,100 dial-up data calls at 600 to 1200 bits per second. The second survey was conducted by Townsend and Watts in 1962 (Ref. 3) at speeds of 2000 bits per second. The most extensive survey of dial connections was performed during 1969-1970 at speeds of 1200, 2000, 3600 and 4800 bits per second by Balkovic, Klancer, Clare and McGruther (Ref. 4). Typical error performance as reported in the 1969-1970 survey is shown in Figure 5-1 for short haul (0-180 miles), medium haul (180-725 miles) and long haul (725-3000 miles) connections. As might be expected performance on the short haul connections was better than that obtained for long haul.

There has been a continuing program by the telephone companies to eliminate the major sources of error. Some evidence of the effect of this program may be apparent by observing that 77 percent of the long haul connections in the 1969-1970 survey illustrated in Figure 5-1 have an error rate less then 10^{-5}.



SOURCE:
REF.4

FIGURE 5-1 ERROR PERFORMANCE OF SWITCHED TELEPHONE NETWORK AT 1200 BPS FOR SHORT HAUL (0-180 MI.), MEDIUM HAUL (180-725 MI.), AND LONG HAUL (725-3000 MI.) CALLS

The survey performed eleven years earlier by Alexander, Gryb and Nast reported that only 60 percent of the long haul connections had this level of error performance. The evidence of improved performance, however, is not conclusive since the more recent tests were on lines linking central offices and did not include the local subscriber loops that were part of the earlier tests.

It is generally expected that satellite bit error rate performance is at least two orders of magnitude better than that typical of the terrestrial long haul plant (Ref. 5), and this observation may be expected to apply to Ka band satellites as well. This is important in providing high quality data channels, and also in minimizing the loss in throughput efficiency caused by the satellite path delay under high error rate conditions. This loss of efficiency comes about because most data communications protocols protect against errors by automatically requesting the repeat of a block of data whenever the error control code detects an error in the block. The time lost in waiting for an acknowledgment, or repeat request, to propagate back to the source causes a serious decrease in throughput for high speed data if the link error rate is high. While the trend is toward the use of protocols that avoid this difficulty, it is nevertheless particularly desirable that satellite link error performance be good, and it appears that this goal is one which will be successfully achieved in practical Ka satellite system designs.

5.2 RELIABILITY

This section discusses the reliability of Ka satellite communications, as compared with that of other communications media, and estimates the levels of reliability acceptable for the various communications services. A convenient measure of reliability for communications is the percentage of time for which the link achieves some specified minimum level of performance. This measure is defined as the "Availability" of the link and is calculated as follows:

$$\text{Availability (\%)} = 100 - 100 \times \frac{\text{Accumulated Outage Time}}{\text{Total Time}}$$

where the accumulated outage time refers to the summation of those time intervals during which performance falls below the specified minimum level. The complement of the Availability (i.e. 100% - Availability) is referred to as the unavailability. Availability and unavailability, as defined above, are the reliability measures used throughout this report.

There are many causes of the outages which contribute to the overall unavailability of a communications link. These can be classified as either due to equipment failures, or due to propagation effects. Both types of outage are significant in terms of the reliability performance experienced by the end user.

5.2.1 TERRESTRIAL CIRCUITS

Equipment failures are of greater importance for terrestrial long haul communications than are propagation effects, though both factors are of significance. The large number of hops needed in a terrestrial long haul path introduces many repeater points at which equipment failure can occur. In contrast, satellite links reach the earth station with only a single repeat in the spacecraft. Furthermore, for those satellite earth stations handling high traffic volumes at major network nodes, the engineering, maintenance, and back-up provisions are likely to be of the highest order.

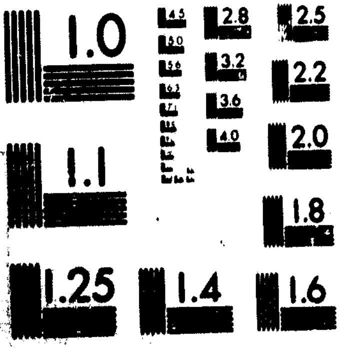
In terrestrial circuits, frequent short outages result from bursts of noise, disturbances caused by repair work, occasional intermittent equipment, and automatic switching from one channel to an alternative channel in the same cable or radio system. Most of these brief outages are self repairing, and while sometimes a source of difficulty, particularly in data transmissions, they are not generally too serious.

In addition to outages related to equipment failure, terrestrial microwave radio systems are also subject to short propagation outages due to fading of the signal. These typically last from a few seconds to a few hundred seconds. Such fading affects only a few radio channels but each of these radio channels contains the equivalent of many voiceband channels. Most microwave radio systems therefore include the capability to switch automatically to spare radio channels on the same radio path to minimize the effects of these propagation fades. On occasion, however, propagation conditions in certain localities do cause microwave outages that can last as long as several hours and that simultaneously affect all of the radio channels in the link. To the extent possible, radio links are sited to avoid this difficulty and are designed to minimize the fades. Alternate routing of the signal through different paths may also be used to bypass the affected link. Overall, with careful design and siting of microwave systems, the long haul propagation reliability achieved by terrestrial systems is generally excellent.

The main source of long outages on the terrestrial network is equipment failure. The time taken to repair these failures, once reported, is highly variable but typically ranges from one to four hours. A review of telephone company repair records for a large sample of data links indicates that 30 percent of all reported failures take longer than two hours to repair (Ref. 6). The average time to restore a microwave channel after an equipment failure is quoted by AT&T to be 2.25 hours (Ref. 7).

An average availability of 99.8 percent is generally regarded as typical of the performance of terrestrial leased lines (Ref. 6). Measures of performance for the dial-up network are more complex since a call can be redialed if a bad connection is received, but levels of performance similar to those of leased lines may be expected.

It appears that a large portion of the longer outages are due to local loop problems. These may be the result of tree branches falling on overhead cables, construction work, vehicle



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

crashes, ice storms, flooding of underground ducts and many other causes. Since there is generally no alternate path by which the local communications can be re-routed, the restoral of service must wait for service crews to repair the damage. Comparisons show that outages on long circuits are not proportionately greater than those on short circuits, indicating that a large portion of the problems are in the local area.

5.2.2 SATELLITE CIRCUITS

Long haul satellite circuits are expected to exhibit fewer outages as a result of equipment failures than terrestrial circuits of equivalent length. However, propagation effects become a more significant cause of outages. For the higher frequency satellites of prime concern in this study, attenuation of the signal by heavy rain is expected to be the major contributor to outages, but other effects, such as sun eclipse discussed below, must also be considered.

5.2.2.1 SUN ECLIPSES

During two periods each year, each of about six weeks in duration, a geostationary satellite enters the earth's shadow once each day with a resulting loss of solar array power. The longest eclipses of this type occur at the vernal and autumnal equinoxes (March 23 and September 23) and last 72 minutes. If outages are to be avoided, provision for energy storage in the satellite capable of working through these periods is required. Depending on system tradeoffs of cost and weight versus performance, the capability to work through the eclipse period may or may not be provided in the satellite.

If a suitable energy storage system is included to handle solar eclipse, it may also be of value in combating rain outages by allowing for adaptive increases in power during the periods of high attenuation caused by rain. For those system designs which do not include energy storage capacity capable of outlasting the maximum eclipse period, the eclipse effects are partly mitigated by the predictability of the outages. The fact that two satellites with more than 18 degrees of orbital spacing will not simultaneously undergo eclipse may also, in some multisatellite system designs, provide a means of minimizing these effects.

5.2.2.2 RAIN ATTENUATION

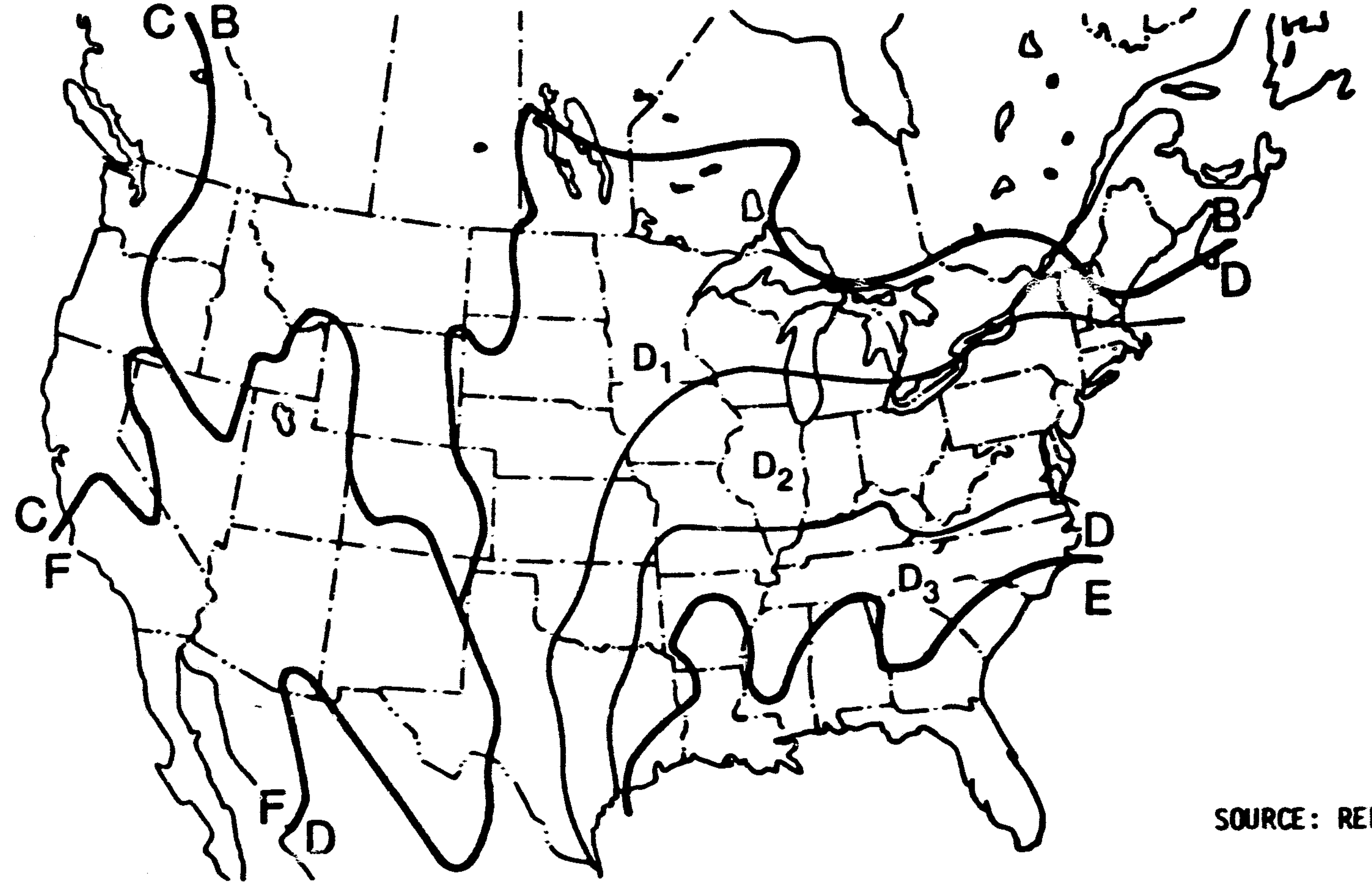
For Ka satellite systems heavy rains, usually associated with thunderstorms, are an important cause of outages. Similar problems also exist at Ku band, but are less severe.

A large body of literature exists which presents data on precipitation patterns throughout the world, and which correlates this data with radio propagation effects. The problem, however, is a complex one involving a large number of variables, and the state of the art does not permit predictions with the degree of conclusiveness that might be desired. A recently published handbook (Ref. 8) sponsored by NASA provides an up-to-date compilation of techniques and data useful in modeling the performance of earth-space radio links and is the source for the procedures used in the following discussion.

Figure 5-2 shows the contiguous forty-eight states divided into a number of rain rate climate regions. Table 5-2 presents the rain rate in each region that is exceeded for various percentages of the year. According to this table the up-link path from a city such as Miami, situated in region E, must be designed to survive a rain rate of 35 mm/hour to achieve an availability of 99.9 percent. Similarly, the down-link to Chicago, in region D_2, must be capable of maintaining satisfactory communications with rain rates of 15 mm/hour to achieve the same availability. The availability of the path from Miami to Chicago would, taking the 99.9 percent availability of both the up-link and down-link into account, have an overall value of 99.8 percent.

To translate these results into propagation data useful in designing radio links it is necessary to relate the rain rate to the specific attenuation caused by the rain. Specific attenuation is expressed in decibles per kilometer and is dependent on radio frequency as well as the rain rate. Recommended approximations for the specific attenuation, derived from empirical measurements, are presented in Table 5-3 for the frequency ranges which include Ku and Ka band (Ref. 8).

The total attenuation introduced over the space-earth path may be obtained by multiplying the specific attenuation, as calculated from the relations in Table 5-3, by the effective path length through the rain.



SOURCE: REF. 8

FIGURE 5-2. RAIN RATE CLIMATE REGIONS FOR THE CONTINGUOUS UNITED STATES SHOWING THE SUBDIVISION OF REGION D

TABLE 5-2. POINT RAIN RATE DISTRIBUTION VALUES (mm/hr) VERSUS PERCENT OF YEAR RAIN RATE IS EXCEEDED

SOURCE: REF. 8

PERCENT OF YEAR	RAIN CLIMATE REGION: B	F	C	D_1	D_2	D_3	E	MINUTES PER YEAR	HOURS PER YEAR
0.001	54	66	80	90	102	127	164	5.3	0.09
0.002	40	51	62	72	85	107	144	10.5	0.18
0.005	26	34	41	50	64	81	117	26	0.44
0.01	19	23	28	37	49	63	98	53	0.88
0.02	14	14	18	27	35	48	77	105	1.75
0.05	9.5	8.0	11	16	22	31	52	263	4.38
0.1	6.8	5.5	7.2	11	15	22	35	526	8.77
0.2	4.8	3.8	4.8	7.5	9.5	14	21	1052	17.5
0.5	2.7	2.4	2.8	4.0	5.2	7.0	8.5	2630	43.8
1.0	1.8	1.7	1.9	2.2	3.0	4.0	4.0	5260	87.66
2.0	1.2	1.1	1.2	1.3	1.8	2.5	2.0	10520	175.3

TABLE 5-3 RECOMMENDED SPECIFIC ATTENUATION APPROXIMATIONS

FREQUENCY RANGE	SPECIFIC ATTENUATION, a(dB/km) (R in mm/h, f in GHz)
10 - 25 GHz	$a = 4.21 \times 10^{-5}(f)^{2.42} R^{1.41(f)^{-0.0779}}$
25 - 54 GHz	$a = 4.21 \times 10^{-5}(f)^{2.42} R^{2.63(f)^{-0.272}}$

SOURCE: REF. 8

The determination of the effective path length is complex and various models give conflicting results. The effective path length depends on the dimensions of the rainstorm, the latitude, and the distribution of the rain intensity along the radio beam. It also depends on the elevation angle of the beam, varying in some models inversely as the sine of the elevation angle, and in other models somewhat less rapidly as a function of angle. The inverse sine relation is used in this report.

A compilation of the effective path length predicted by several different models shows that values of 4 to 5 kilometers are reasonable for elevation angles of 45 degrees at 40 degrees of latitude (about the midpoint of the contiguous United States). For an ideally located satellite most of the land area in the contiguous United States is included within an elevation angle of 30 degrees. The regions of heavier rainfall are included within 40 degrees. However, if satellites are situated unfavorably for some locations, the elevation angle may be as low as 15-20 degrees, but even in this case the heavy rainfall areas are mostly covered at 30 degrees. If it is assumed that the system concepts involved will allow earth stations to be assigned to satellites favorably located with respect to elevation angle, an angle of 30 degrees presents a reasonable compromise among the various factors involved. Using the inverse sine relationship, path lengths of 4 to 5 kilometers at 45 degrees elevation translate to 5.7 to 7.1 kilometers at 30 degrees. The more conservative value of 7.1 kilometers will be used as path length appropriate to a wide range of locations and satellite positions likely to be encountered in the Ka system under consideration.

By using the rain rate data in Table 5-2, with the specific attenuation formulas of Table 5-3, and multiplying the resulting attenuation per kilometer values by an effective path length of 7.1 kilometers, the power margins required to achieve given levels of availability for each of the climate zones may be calculated. This has been done for 30 GHz (typical of the highest frequency likely to be employed in Ka band) and for 14 GHz (typical of the highest frequency to be employed at Ku band). The results are presented in Tables 5-4 and 5-5.

The amount of margin for rain outages is a cost tradeoff option available to the designers of the satellite system. However, if 10 dB (10 times the power) is assumed to be a difficult but reachable goal for non-diversity CPS earth stations, within desirable cost constraints, it may be noted from Table 5-4 that at Ka band, almost full geographic coverage of the contiguous United States land area can be achieved at the 99.5 percent availability level, but that only regions B, F, and C, which contain 42 percent of the land area, are covered at the 99.9 percent availability level. No coverage is achieved at the 99.99 percent level.

Even if the margin is increased to as much as 20 dB (one hundred times the power) the area covered at 99.9 availability moves up to about 81 percent, failing to completely cover the contiguous states, and nowhere achieving an availability as high as 99.99 percent.

It is, therefore, likely that for most system designs CPS reliabilities of 99.9 percent or more over the contiguous states will be difficult to achieve with low cost earth stations. Furthermore, it must be remembered that this refers to the Ka band satellite up-link alone. Additional loss in availability occurs for the down-link, and as a result of equipment failures. For trunking systems the reliability performance of the local

TABLE 5-4 MARGIN NEEDED (dB) TO ACHIEVE STATED AVAILABILITY AT 30 GHz (LATITUDE 40°, ELEVATION 30°)

CLIMATE ZONE	CUMULATIVE PERCENT OF CONTIGUOUS U.S. AREA COVERED	AVAILABILITY (%)			
		99.0	99.5	99.9	99.99
B	17	2.1	3.2	8.2	24.0
F	37	2.0	2.8	6.6	29.3
C	42	2.2	3.3	8.7	35.9
D_1	62	2.5	4.7	13.5	48.0
D_2	81	3.5	6.2	18.8	64.3
D_3	91	4.7	8.5	28.0	83.5
E	100	4.7	10.4	45.3	132.2

TABLE 5-5 MARGIN NEEDED (dB) TO ACHIEVE STATED AVAILABILITY AT 14 GHz (LATITUDE 40°, ELEVATION 30°)

CLIMATE ZONE	CUMULATIVE PERCENT OF CONTIGUOUS U.S. AREA COVERED	AVAILABILITY (%)			
		99.0	99.5	99.9	99.99
B	17	0.3	0.6	1.6	5.2
F	37	0.3	0.5	1.3	6.5
C	42	0.4	0.6	1.7	8.2
D_1	62	0.4	0.9	2.8	11.3
D_2	81	0.6	1.2	4.0	15.6
D_3	91	0.9	1.7	6.2	20.8
E	100	0.9	2.1	10.6	34.6

distribution lines must also be considered to arrive at end-to-end results.

While different design assumptions can lead to different results, the overall conclusion considered most appropriate, for use in the scenarios discussed later in this report, is that CPS availability at Ka band will be lower than that of competing terrestrial and C band systems.

The situation for Ku band up-links may be evaluated from the results of Table 5-5. Here the achievement of virtually full coverage at the 99.9 percent availability level is possible at the 10 dB rain margin level so that performance of single station (non-diversity) Ku band CPS is likely to be about equal to that of present day terrestrial channels. Full geographic coverage at the 99.99 percent level, however, appears unlikely.

5.2.2.3 DIVERSITY

Several methods have been suggested for improving the rain attenuation performance of satellite links. Among these are various adaptive approaches which direct additional power or bandwidth to the affected location. In the multisatellite environment it may also be possible to utilize angular diversity by selecting, from a given ground location, a satellite for which the earth to space beam does not pass through a heavy rain cell. Recent results, however, indicate that angular diversity is not very effective (Ref. 9).

The most thoroughly studied approach, and the one most likely to be employed, uses space diversity, operating on the principle that earth stations spaced sufficiently far apart are not likely to be simultaneously affected by major fading. The reliability increases rapidly as separation between the stations is increased and levels off at spacings in the 10 to 30 kilometer range. The final value approached is usually quite close to the value achieved under uncorrelated fading conditions.

Assuming adequate separation, the performance of a space diversity link is readily calculated from the percent of time versus attenuation relation for each individual station. If, for example, a given level of attenuation for each station is exceeded 1 percent of the time, both stations may be expected to simultaneously exceed that attenuation level only .01 percent of the time.

The improvement in performance by introducing space diversity can be very great. The net effect on the margin requirement, as stated in Table 5-4 and Table 5-5 for the non-diversity case, is to move the margin values presented under the 99.0 percent availability column to the 99.99 percent column. Thus, even for climate region E, the use of space diversity would allow 99.99 percent availability over the contiguous United States using only 4.7 dB of rain margin.

5.2.2.4 IMPLICATIONS FOR CPS AND TRUNKING MODES

Space diversity requires separated earth stations, on the order of 10 to 30 kilometers apart, plus a terrestrial link between these stations. A means for rapidly switching traffic to the best performing earth station is also needed. The dispersed site location requirements, and the additional equipment needed for the implementation of space diversity, are not consistent with the typical concept of simple, inexpensive, CPS stations located on a customer's roof-top or parking lot. For this reason the scenarios discussed in later sections of this report make the following assumptions:

(a) Ka band CPS satellites in the modes considered in this study will not use space diversity or other costly reliability enhancements and are therefore likely to have a level of availability lower than that of competing communications media.

(b) Trunking satellite modes at Ka band will use space diversity as needed, and, when due account is taken of all contributions to outages, will achieve a level of performance approximately on par with that of competing communications media.

5.2.2.5 RAIN OUTAGE DURATION VS FREQUENCY

In many communications applications concern exists over the number and duration of outages as well as the aggregate of outages as expressed by the availability measure. For example, 99.9 percent availability means, that of the 8760 hours in a year, communications will be inoperative for a total of 8.76 hours but this aggregate outage may equally well be the result of many brief outages or a few lengthy outages.

In some applications, such as dial-up voice, the relatively frequent occurrence of many short interruptions (for example, a one or two minute outage each business day) may be considered a nuisance rather than a serious inconvenience while, at the same availability level, one or more day-long outages each year may severely interrupt business operations. In other applications the reverse is true. For example, in some data applications each outage, even if brief, may necessitate lengthy procedures to confirm or update the validity of the data base and to re-establish connections to many remote users. Under these circumstances, a few long outages are preferrable to a multiplicity of short outages.

The rain propagation data dealing with the distribution of fade durations is scanty. Figure 5-3 presents Weather Bureau data showing the average number of days with thunderstorms in the United States (Ref. 10), which provides some idea of the frequency with which heavy rainstorms occur but does not indicate the intensity of the storms. The State of Florida has the largest

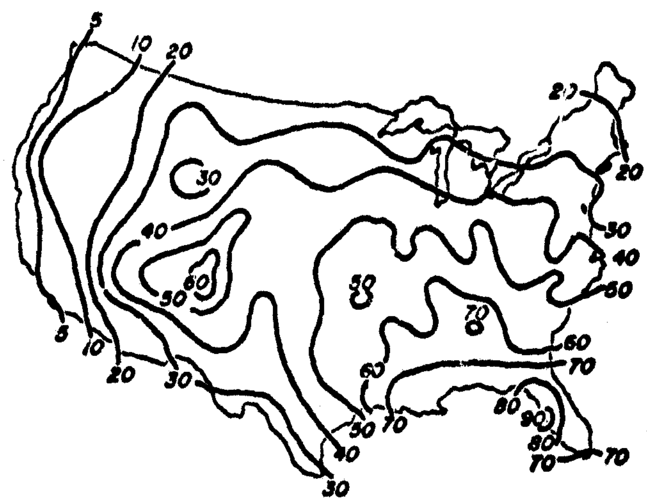


FIGURE 5-3 AVERAGE NUMBER OF DAYS WITH THUNDERSTORMS IN THE UNITED STATES (SOURCE: REF. 9)

number of thunderstorms, ranging between 70 and 90 per year at various points over the state while the West Coast typically has only 5 per year.

Figure 5-4 presents illustrative data for the U.K (climate zone C) relating the duration of rainfall to frequency (Ref. 11). The left-hand scale shows the rainfall rate, and the horizontal dotted lines terminating at the right-hand scale show the attenuation expected at 30 GHz, as calculated from the formulas in Table 5-3 and using an effective path length of 7.1 km.

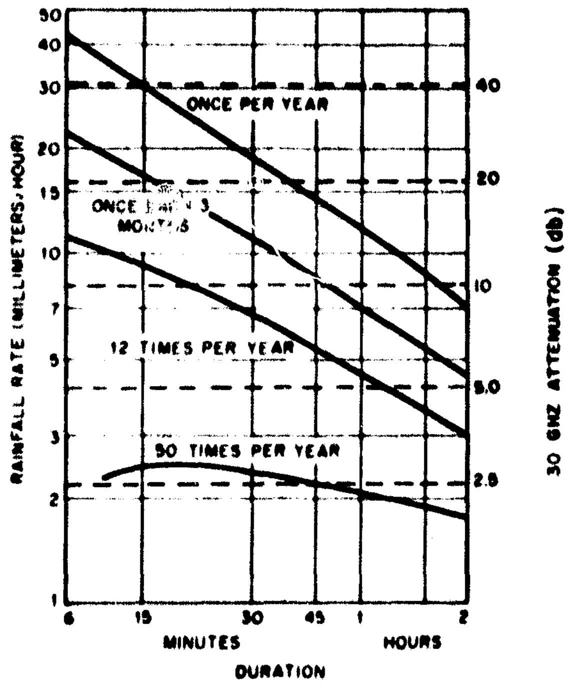


FIGURE 5-4 RAINFALL DURATION, U.K. DATA (REF. 11)

The figure shows fades below 10 dB occurring twelve times per year at about 20 minutes duration for each fade, four times a year at 50 minutes per fade, and once a year at 100 minutes per fade. Note that if the system margin increases (for example, to 20 dB) both the frequency of fades and their durations decrease, confirming the expectation that links designed to higher availability criteria will less often encounter rain of a given duration capable of exceeding the link's penetrating capabilities.

Detailed outage duration statistics covering the United States are not available in a form useful for the evaluation of the impact of rain outages on user acceptance of the communications service. However, typical values have been suggested in Reference 12 and appear to be reasonably consistent with the limited amount of data available from other sources. Table 5-6 presents these values, which will be used as a guide in evaluating the potential effect of rain outage at different levels of availability, for the various communications applications that have been defined.

TABLE 5-6 TYPICAL OUTAGE FREQUENCY AND DURATION FOR DIFFERENT AVAILABILITIES

AVAILABILITY (PERCENT)	99.99	99.9	99.5	99.0
AGGREGATE OUTAGE (HOURS PER YEAR)	0.9	9	44	88
TYPICAL FREQUENCY (OUTAGES PER YEAR)	11	35	105	175
TYPICAL DURATION (MINUTES)	5	15	25	30

The first two columns are typical of the range of performance expected for trunking systems using space diversity. Performance may be characterized as resulting in 5 to 15 minute outages once every few weeks. The last two columns are representative of the range of performance expected with low cost CPS stations where no diversity is provided. Performance in this case may be characterized as resulting in roughly half hour outages every few days.

5.2.3 SERVICE ACCEPTABILITY VS. AVAILABILITY

The degree of user acceptance of Ka satellite communications is highly dependent on the reliability of the service provided. Whether service at a particular reliability level will or will not be accepted by the majority of users depends on a number of factors including:

(a) The requirements of the particular communications application;

(b) The frequency and duration of the outages encountered;

(c) The level of reliability to which users have become accustomed;

(d) The existence of alternative communications media with possibly better characteristics; and

(e) The cost of the service.

Availability levels for communications are generally quite high when compared to the performance of many other areas of technology. Outages totaling one percent of the total time are considered to be at the lower end of the acceptability range for most communications applications. In contrast the performance expected from other technology areas, such as transportation, computers, and consumer products, are generally considered excellent if their availability approaches 99.0 percent and performance at the 99.9 or 99.99 percent levels would be exceptional.

The consequence of lengthy communications outages on many types of business can be severe. A large airline reservation office, for example, if unable to accept reservations for the better part of a day, incurs high cost penalties through the loss of potential business and the disruption of the working patterns of reservation personnel.

In the banking industry large amounts of money are transferred via electronic systems highly dependent on data communications. Failure to meet transfer deadlines may result in heavy loss of interest payments.

Many businesses are critically dependent on real-time access to central computer facilities to carry out their daily operations. A communications outage interfering with this access can result in cost penalties far in excess of the cost of the lost communications time itself. The fact that many companies go to considerable expense to guard against outages by using redundant data communications lines (and computers) is an indication of the importance of reliability to their operations.

With respect to residential communications, which primarily involve switched voice applications, the urgency of many calls is probably not high. However, users in the United States have become accustomed to very good telephone service and are usually highly critical of the poorer service they sometimes encounter during foreign travel. Availability of 99.0 percent would not be classified as good by most users. Typically 99.0 percent availability might involve denial of the use of the phone for both incoming or outgoing calls for perhaps one-half hour or more every two or three days. Furthermore, in most areas rain outages concentrate in the late afternoon hours causing a greater impact, particularly on business users, than if the outage concentrations were to occur in the post midnight hours.

The degree to which lower costs might motivate the acceptance of less reliability by residential users is difficult to assess. It is not always the case that telephone users opt for the lower cost product, as witness the popularity of touch tone service, designer phones and other higher priced accessories. On the other hand, reductions in long distance rates for evening and weekend hours have resulted in substantial increases in traffic during these hours. The willingness on the part of the public to delay calls, in order to take advantage of the lower rates, is perhaps indicative of a potential willingness to also accept delay as a result of communications outage if sufficient cost inducements are offered. However, in the case of evening or weekend calls, the delays are accepted at the customer's option while delay as a result of communications failure is unscheduled and cannot be avoided.

Broadcast TV imposes stringent reliability requirements. Significant revenues may be lost, and large numbers of viewers inconvenienced, by inopportune communications outages. The Network TV category is most subject to such considerations but CATV also has high reliability requirements. These reliability needs are likely to preclude the use of Ka band CPS for real-time broadcast TV, but an appreciable amount of program material can be pre-recorded for later broadcast so that the possibility of deferred modes for some transmissions exist.

Videoconferencing shares many of the considerations of business voice traffic. Video conferences, however, usually involve more people than do voice calls and the people involved tend to be at higher executive levels. From this viewpoint more reliable communications is desirable. However, videoconferencing is an expensive service with difficult to achieve wideband transmission needs. Furthermore, the service has not yet become widespread so that user expectations are still unformed. If relatively unreliable service is all that is available at reasonable price levels, the business community is likely to find ways to adapt to the characteristics of the offered service, in much the same way that accommodation is made to disruptions of air travel resulting from weather and equipme problems.

The applications most tolerant of outages are the deferred mode, bulk transfer communications, associated with some sectors of electronic mail and the less urgent portions of electronic funds transfer.

The following section summarizes these considerations by providing estimates of the availability requirements appropriate to each communications service and indicates the effect of cost tradeoffs on user acceptance of reduced levels of availability.

5.2.3.1 PROFILE OF TRAFFIC VS. AVAILABILITY AND COST

This section provides quantified estimates of the degree of acceptance expected for the communications services defined in Table 1-1 and Table 1-2 at various levels of availability and cost. A large number of factors enter into such an evaluation, many of which are only partly definable. Furthermore, each communications application includes the composite requirements of many individual uses and users. The following estimates represent a consensus of opinions, arrived at in discussions among communications specialists, which attempts to evaluate as many of these factors as possible.

The four communications offerings defined in Table 5-7 were chosen as presenting a suitable range of availabilities and costs on which to base the evaluations. The typical outage descriptions in this Table are representative of those due to

TABLE 5-7 COMMUNICATIONS OFFERINGS

OFFERING	AVAIL. (%)	TYPICAL OUTAGES	RELATIVE COST
1	99.99	5 MIN. EVERY MONTH	20% HIGHER
2	99.9	15 MIN. EVERY 2 TO 3 WEEKS	REFERENCE
3	99.5	25 MIN. EVERY 3 TO 4 DAYS	30% LOWER
4	99.0	30 MIN. EVERY 2 DAYS	35% LOWER

rainstorms at Ka band frequencies as presented in Table 5-6. Other communications media, at the same level of availability, may have a different distribution of outage frequency and duration. Costs are presented relative to offering Number 2 since, for the important voice and data components, the 99.9 percent level is close to that provided by today's telecommunications plant. For conventional voice and data signals, the cost of offering Number 2 would therefore logically have to be close to that of the rest of the communications plant. Otherwise, in the absence of other distinguishing characteristics (an assumption needed in order to isolate the effects of reliability variations) large scale migrations of the customer base in one direction or the other would result. Thus, for the purposes of this analysis, offering Number 2 may be categorized as providing voice and data services at reliability levels comparable to today's communications plant at a comparable cost, while offering Number 1 provides substantially superior reliability at a 20 percent cost premium, and offerings 3 and 4 provide substantially poorer reliability at cost reductions of 30 and 35 percent.

The reliability level offered by competing transmission media for the expensive, wideband transmissions used in broadcast TV applications is much higher than that of offering Number 2. Furthermore, less conventional applications, such as videoconferencing, or postal service electronic mail, have not yet become sufficiently widespread to establish competitive levels of reliability or cost. For these traffic components the relative cost values in Table 5-7 represent only the costs of offering 1 through 4 relative to each other, but not necessarily to other competing media.

Table 5-8 shows the estimated user preference in each communications subcategory for each of the offerings in Table 5-7. It is assumed that all offerings exist simultaneously so that a free choice is available to the users, and that technical and operational characteristics other than reliability, are satisfactory for the applications in question. The following brief comments present the chief rationale for the entries in the Table.

1. Residential Voice (Switched Service) - This is the least critical of the voice services. Most users are satisfied with present service and only a small percentage would choose the "luxury service" of offering 1. However, a large number of economy minded users are candidates for the lower reliability offerings as reflected in the entries in columns 3 and 4 of Table 5-8. The sum of these two entries, 35 percent, represents a moderate upward revision of demand for lower cost, lower reliability, service over that previously estimated in Reference 12.

TABLE 5-8 ESTIMATED PERCENT OF LONG DISTANCE TRAFFIC PREFERRING EACH OF FOUR COMMUNICATIONS OFFERINGS

	COMMUNICATIONS SUBCATEGORY	1 AT 20% COST PREMIUM 99.99% AVAIL.	2 REFERENCE COST 99.9% AVAIL.	3 AT 30% COST REDUCTION 99.5% AVAIL.	4 AT 35% COST REDUCTION 99.0% AVAIL.
VOICE	RESIDENTIAL (SWITCHED SVC.)	5	60	20	15
	BUSINESS (SWITCHED SVC.)	5	75	12	8
	BUSINESS (PRIVATE OR LEASED LINE)	5	75	12	8
VIDEO	NETWORK TV	60	0	0	40
	CATV	40	10	0	50
	EDUCATIONAL VIDEO	5	50	25	20
	VIDEOCONFERENCING	10	50	20	20
DATA	FACSIMILE	0	50	0	50
	ELECTRONIC MAIL	0	10	0	90
	COMPUTER	15	65	10	10

2. Business Voice (Switched Service) - Few users would pay for better service than presently provided. A moderate number, in businesses where telephone usage is not critical, may elect the lower cost offerings.

3. Business Voice (Private or Leased Line) - Most users find present service satisfactory. Only a few users would need or pay for the premium service of offering 1, particularly if dial back-up service through other media is available. Leased line networks are primarily established as a means of saving communications costs and therefore some users may accept the lower cost, low availability of offerings 3 and 4, under the assumption that back-up is possible.

4. Network TV - Assuming that procedures are established for the recording of program material for later transmission, perhaps 40 percent of Network TV could use low reliability deferred transmission modes and would choose the lower cost offering. The remaining 60 percent, representing real-time broadcast material, would require the highest reliability levels. The assumed use of video recording to permit the deferred transmission of this category of traffic permits an upward revision of demand for the lower reliability services over that previously projected in Reference 12.

5. CATV - An estimated 50 percent of pre-recorded deferred transmission will use the least expensive offering. The real-time component would divide between offerings 1 and 2 with most preferring the more reliable service of offering 1. The use of pre-recorded video accounts for an upward revision of demand for the lower reliability offerings over that projected in Reference 12.

6. Videoconferencing - Most users will accept offering 2, but, in view of the inconvenience to many high level conference participants that may be occasioned by an outage, some companies will choose the more reliable offering. However, this is a relatively expensive service without pre-established patterns of user expectations. If properly marketed, a substantial number of budget minded companies may opt

for the lower reliability offerings, accepting occasional conference disruption or rescheduling as a necessary characteristic of economical service. Under this assumption the estimated demand for the two lower reliability categories has been revised upward.

7. Educational Video - Users of this service are expected to be budget minded with preferences about evenly divided between offering 2 and the lower reliability categories. Only a few specialty uses are expected to require the higher reliability of offering 1. An increased probability of the use of pre-recorded program material is the basis for an upward revision of demand for the lower reliability offerings.

8. Facsimile - Bulk mailroom facsimile is tolerant of delay and can utilize the lower reliability offering. Lower volume convenience facsimile often uses dial-up voice lines on an alternate voice/facsimile basis. Reliability levels typical of presently available voice service is considered appropriate for this usage.

9. Electronic Mail - Bulk mail in support of postal service will use the lowest cost service. The remainder, involving applications such as communicating word processor and more urgent message traffic will find offering 2 satisfactory.

10. Computer - Present service is adequate for the bulk of this traffic but a substantial number of applications would benefit from the higher reliability of offering 1. There are also many applications which are not critical and which would call for offerings 3 and 4.

The estimates presented in Table 5-8 are weighted according to the year 1980, 1990 and 2000 traffic demand presented in Table 1-1 to arrive at the percentage of long haul traffic preferring each of the offerings defined in Table 5-7. Results are shown in Table 5-9. Overall about 70 percent of traffic is estimated to require a reliability level of 99.9 percent. Only 6 to 8 percent of traffic would prefer the higher 99.99 percent offering at a cost premium of 20 percent, and about 23 percent would chose one or the other of the two lower reliability offerings at cost savings of 30 to 35 percent.

TABLE 5-9 PERCENTAGE OF TRAFFIC PREFERRING VARIOUS COMMUNICATIONS OFFERINGS

	TRAFFIC VOLUME* BITS/YR x 10^{15}	1 99.99% AVAIL. @ 20% COST INCREASE	2 99.9% AVAIL. @ REFERENCE COST	3 99.5% AVAIL. @ 30% COST DECREASE	4 99.0% AVAIL. @ 35% COST DECREASE
1980					
VOICE	890	5.0	73.6	12.7	8.6
VIDEO	82	33.5	19.6	6.8	40.0
DATA	111	14.5	65.5	10.0	10.0
TOTAL	1083	8.1	68.7	12.0	11.2
1990					
VOICE	2250	5.0	73.7	12.7	8.6
VIDEO	171	19.4	37.6	15.4	27.7
DATA	280	14.6	63.7	9.8	12.0
TOTAL	2701	6.9	70.4	12.6	10.2
2000					
VOICE	4894	5.0	73.8	12.6	8.2
VIDEO	419	11.9	46.1	19.5	22.5
DATA	434	14.6	64.0	9.8	11.7
TOTAL	5747	6.2	71.1	12.9	9.5

*FROM TABLE 1

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6.0 CAPACITY OF COMPETING SYSTEMS

Domestic satellite communications at C band is an already well established service, and transmissions at Ku band will shortly join those at C band in becoming a significant competitor in the communications marketplace. Ka band systems will take a longer time to develop and, therefore, will enter a market already being served by both C and Ku band. The capacity of these lower frequency satellite systems to satisfy demand is consequently an issue that must be taken into account in estimating the market share expected for Ka band.

The capability of a spectrum band to supply transmission capacity depends on the interaction of many technical and regulatory issues. Underlying these issues are three fundamental considerations:

(a) The amount of frequency spectrum and the orbital arc allocated;

(b) The degree of re-use of the allocated spectrum; and

(c) The efficiency with which the radio frequency bandwidth is used to provide useful communications channels.

All of these factors are subject to wide variations as the result of ongoing technical and regulatory developments. The following discusses each factor and presents current best estimates for the capacity of C and Ku band systems.

6.1 FREQUENCY AND ARC ALLOCATIONS

The 1979 World Administrative Radio Conference took a number of actions relating to the Fixed Satellite Service (FSS) in Region 2 (which includes North and South America). Additional actions are slated for consideration at subsequent meetings scheduled for the next few years.

6.1.1 FREQUENCY ALLOCATIONS

Figure 6-1 shows the Region 2 FSS allocations for C band.

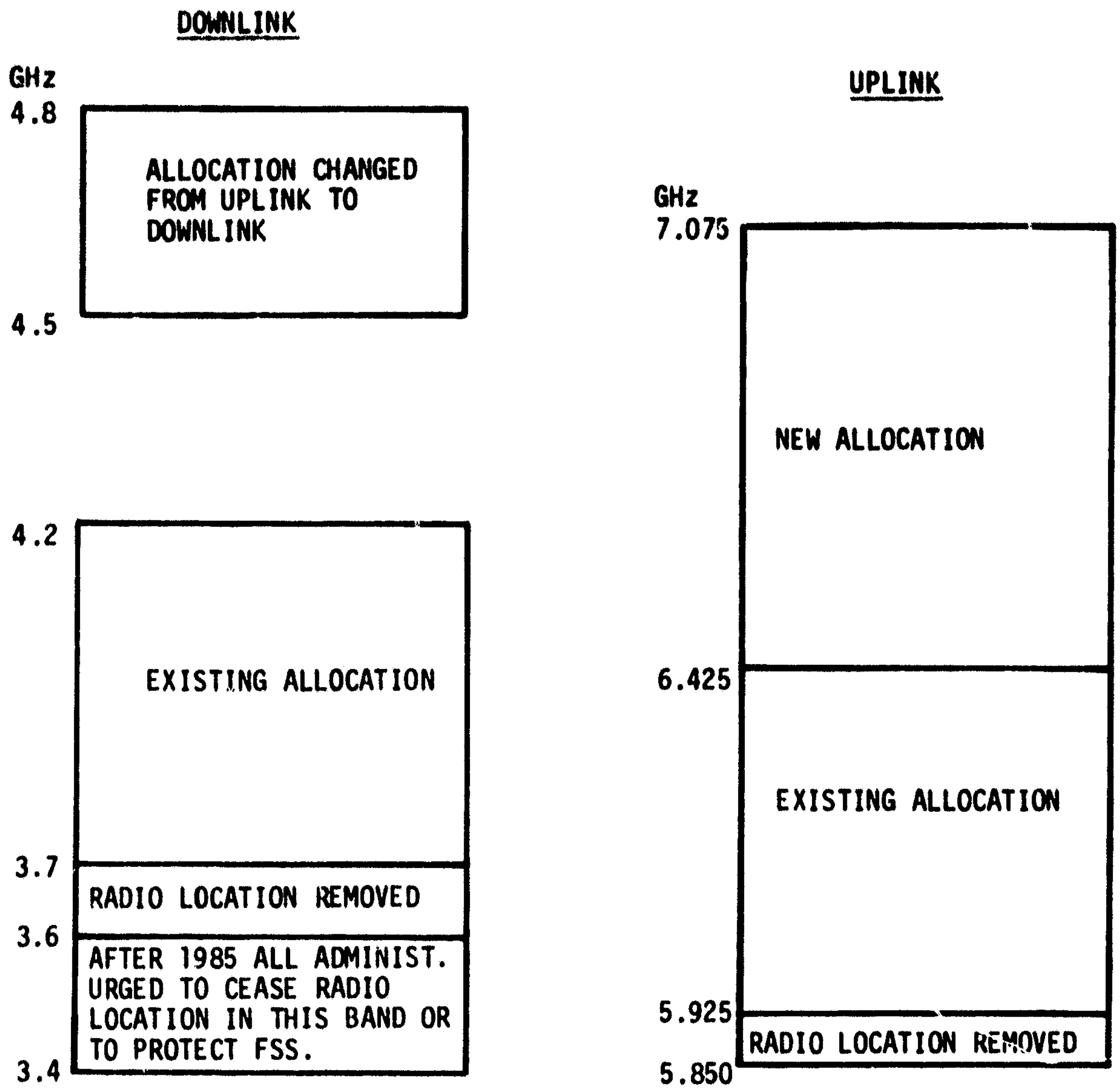

FIGURE 6-1 REGION 2 FIXED SATELLITE SERVICE ALLOCATION IN C BAND

The down-link allocations encompass 1100 MHz of spectrum. However, the 300 MHz band from 4.5 to 4.8 GHz is subject to potential interference from DoD troposcatter systems and will probably not be used by Domsats to increase U.S. Fixed Satellite Service capacity. Similarly, in the 200 MHz between 3.4 and 3.6 GHz a conflict exists with radio location uses. A compromise position was worked out at the WARC which preserves the status of important U.S. military radars in this band while taking practicable steps to protect FSS. The net result, however, is likely to be the avoidance of this range by U.S. Domsat carriers, at least in certain regions of the country. Overall, it appears that the prime C band spectral range available for FSS down-links will be the 600 MHz band between 3.6 and 4.2 GHz with possible downward revision to the 500 MHz (3.7 to 4.2 GHz) now in common usage.

The C band up-link allocation of 1225 MHz is slightly more than two times as wide as that likely to be used for down-link bands. In most systems, however, there is little need for up-link capacity far in excess of that available on the down-links, so that overall C band capacity is likely to remain limited to that of the 500 to 600 MHz bandwidth established by the down-links.

Figure 6-2 shows the FSS Region 2 allocations in Ku band. FSS is permitted in the 12.3 to 12.75 GHz range but this range is primarily allocated to Broadcast Satellite Service (BSS). In the 11.7 to 12.1 GHz range, now primarily allocated to FSS, the 1979 WARC also removed orbital restrictions that previously limited FSS to only 40 degrees of arc.

The division between Fixed Satellite Service and Broadcast Satellite Service in the down-link band between 12.1 and 12.3 GHz has not yet been decided, and the task of making this division has been assigned to the Region 2 conference scheduled for 1983. Assuming that this band is evenly split between FSS and BSS, the probable range of frequencies usable for Region 2 FSS down-links at Ka band is 1500 MHz. Up-link Ku allocations exist in two separated 500 MHz bands totaling 1000 MHz. Under the assumption that throughput of the satellite will be limited by that of the lowest of the two links, the capacity of Ku band systems will be determined by the 1000 MHz up-link allocation. This, however, is a probable upper limit. Portions of this bandwidth will be shared with terrestrial applications, and

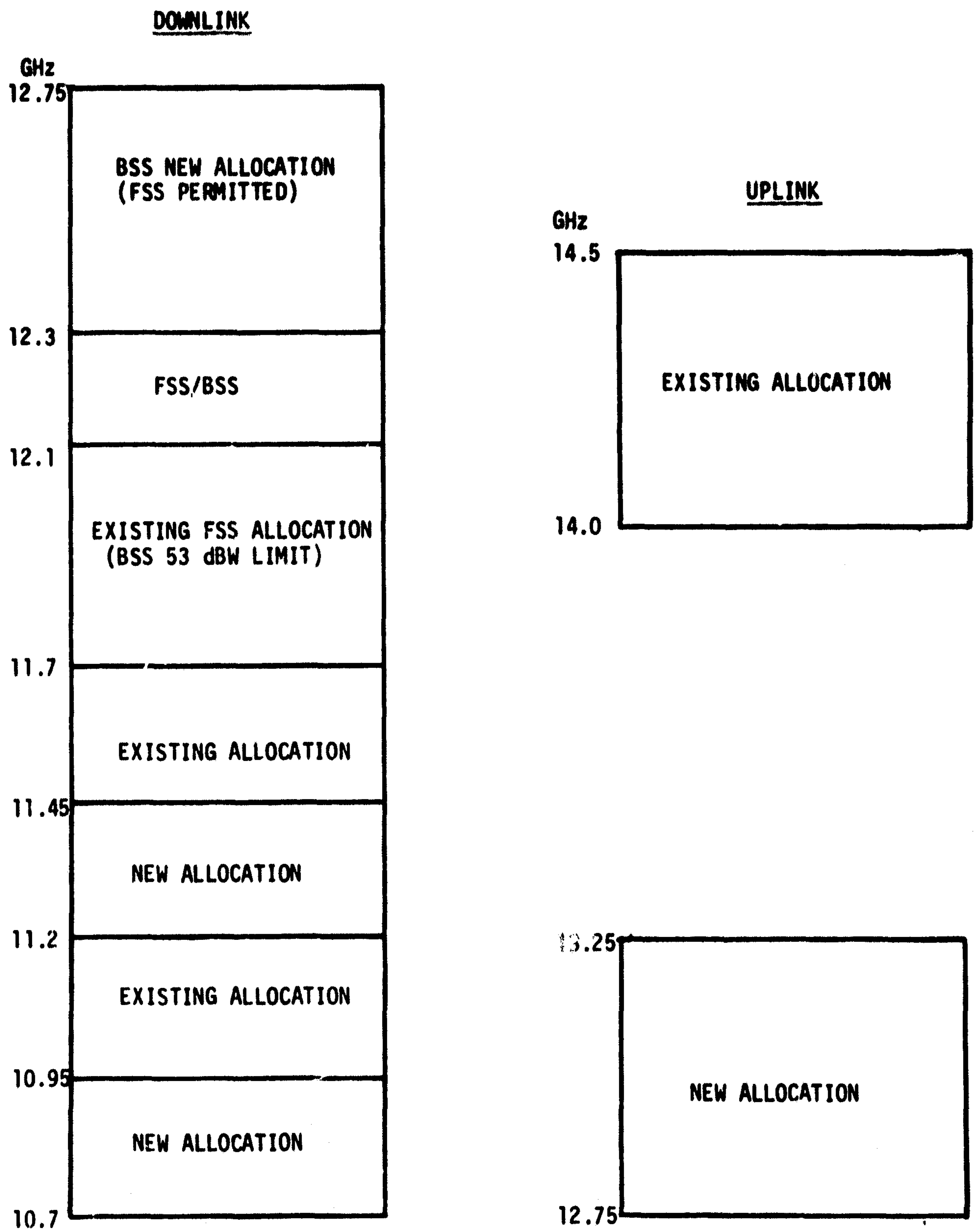

FIGURE 6-2 REGION 2 FIXED SATELLITE SERVICE ALLOCATION AT Ku BAND

the effective bandwidth available for Fixed Satellite Service Domsat operation may remain close to the 500 MHz existing prior to the 1979 WARC.

Thus, with some possible variations as a result of decisions yet to be adopted, it appears that FSS C band and Ku band capacities should be based on spectrum bandwidths of 500 to 600 MHz for C band, and 500 to 1000 MHz for Ku band. As further discussed in the next section, satellites will be able to be distributed over the full orbital arc useful for coverage of the contiguous 48 states.

6.1.2 ORBITAL ARC CONSIDERATIONS

Figure 6-3 shows the orbital positions of satellites visible from extreme positions in the contiguous states for different elevation angles up to 15 degrees. The most easterly satellite longitude is determined by visibility requirements for locations in the State of Washington, while the most westerly longitude is determined by visibility requirements for the State of Maine. Also shown in Figure 6-3 is the width of the orbital arc that is simultaneously visible from all points within the contiguous states, as obtained by subtracting the eastern longitudinal location from the western longitudinal location.

The use of too low an elevation angle results in increased radio interference from sources located at the horizon, and also lengthens the slant range through the atmosphere with consequent undesirable increases in atmospheric disturbances and rain attenuation. Practical minimum elevation angles range from 5 to 10 degrees depending on antenna size and design, and on local site conditions. A nominal arc length of 73 degrees, which is consistent with elevation angles in the middle of this range, represents a reasonable estimate of the extent of orbital positions simultaneously visible over the contiguous United States. While the use of egional systems serving only the East or West coasts could expand this range, satellite positions are restricted to approximately these 73 degrees for fullest coverage and flexibility in establishing connectivity.

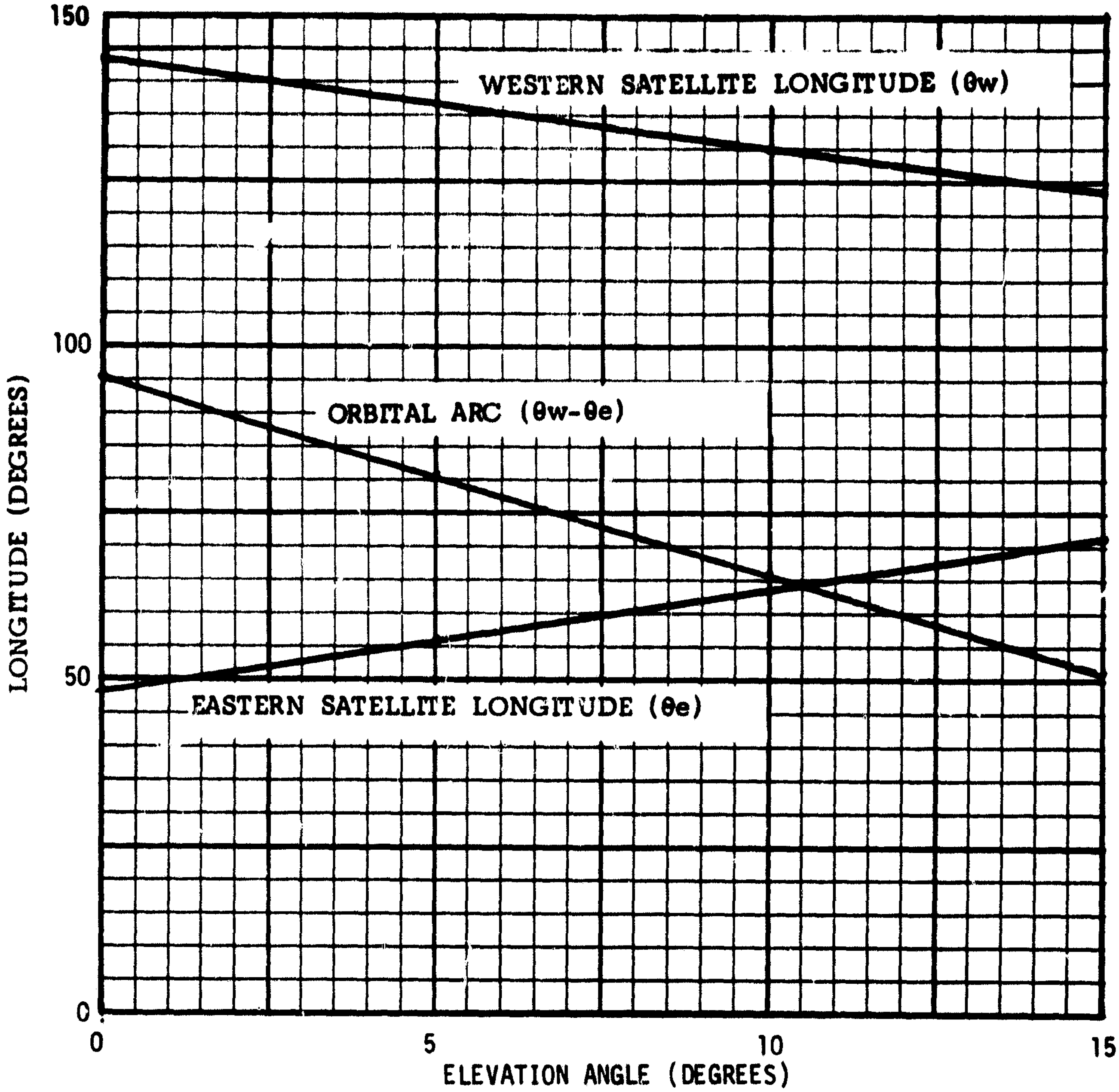

FIGURE 6-3 ORBIT LOCATIONS SIMULTANEOUSLY VISIBLE FROM ALL POINTS IN THE CONTIGUOUS UNITED STATES

6.2 RE-USE OF SPECTRUM RESOURCES

The capacity of the orbital arc to support communications can be greatly increased by the re-use of available spectrum. The following discusses the methods of frequency re-use that permit expanded capacity within the spectrum and arc limitations imposed.

6.2.1 ORBITAL SPACING

The most common method of effecting spectrum re-use involves the placement of multiple satellites in orbit with sufficient spacing to permit each to be accessed by its own community of earth stations, without interfering with other earth station communities accessing other satellites. The number of satellites that can be distributed within a given sector of the orbital arc is limited primarily by radio interference arriving through sidelobes of the earth station antennas. Satellites receiving or transmitting at the same frequencies must be placed sufficiently far apart to allow an earth station to look at the desired satellite without receiving or transmitting an undue amount of energy to, or from, all nearby satellites.

While the capacity of the earth station antenna to reject off-boresight radiation is the prime consideration in determining how far apart the satellites must be placed, entering into this determination are also factors such as the station keeping abilities of the satellites and the interference noise allowance of the receivers. Withers (Ref. 1) estimates an improvement in arc utilization of 20 to 25 percent if the previously allowed ± 1 degree East-West station keeping excursions are reduced to the ± 0.1 degrees now mandated by the 1979 WARC. The same reference also points out that present CCIR recommendations for analog satellite systems allow for 10 percent of all channel noise to be caused by interference from other satellite networks and an additional 10 percent for interference from terrestrial systems. In designing for an environment in which interference becomes a major consideration, upward revision of these limits may have beneficial effects on orbital arc utilization.

Despite possible changes of the type discussed above, the FCC policy of about 4 degrees of spacing, as set forth in the Declaratory Ruling and Order RM 2614/2725, will probably remain in effect for C band. This protects existing C band systems based on interference levels consistent with this spacing. The current FCC staff view, however, is that 3 degrees can be achieved for systems in the 12 GHZ band (Ref. 2). These spacings would permit about 18 satellites at C band and 24 at Ku band within 73 degree orbital arc. However, these slots will be shared among all of the Western Hemisphere countries. If it is assumed that about one-third of the slots will be used by other countries, a maximum of 12 slots at C band, and 16 slots at Ku band remain for use by the United States.

6.2.2 POLARIZATION DISCRIMINATION

The distribution of multiple satellites along the arc, as previously discussed, provides one of the more important means of frequency re-use. With 12 satellites at C band and 16 at Ku band for U.S. use, the bandwidth available in each band can be simultaneously used by 12 and 16 separate communities of earth stations, each community transmitting to, or receiving from, a given satellite. An additional degree of frequency re-use can be obtained, in some regions of the spectrum, by relying on polarization to discriminate between independent signals simultaneously transmitted in the same frequency range and in the same antenna beam width. Since there are two independent polarizations, this approach permits a potential second use of each frequency band with a resultant doubling of capacity.

Frequency re-use via polarization discrimination is in current use in C band and will receive increasing employment in this band as competition for available slots increase.

The applicability of this technique at Ku band frequencies, however, is less clearly established. At the higher frequencies various propagation effects, chiefly associated with ice and rain, produce depolarization of the signals and result in crosstalk between the polarization pairs. Plans for Advanced Westar, however, include partial use of polarization discrimination at Ku band as a means of improving isolation between spot beams. The recent GTE applications to the FCC for a domestic satellite system also refers to the employment of cross-polarization in the 14 and 12 GHz bands to enable each up-link and down-link frequency to be used twice (Ref. 3).

Further experimental and operational experience is needed before the validity of this approach can be relied on for general application in the higher frequency bands.

6.2.3 SPOT BEAM TECHNOLOGY

The use of multiple spot beams to illuminate separated areas on the earth provides another form of frequency re-use and the re-use capability provided by this approach is potentially very high.

The earliest synchronous satellites used broad beam antennas to achieve global coverage. The next generation of domestic satellite systems restricted coverage to the 48 contiguous states, sometimes supplying spot beams to illuminate Alaska, Hawaii, and Puerto Rico. The re-use of the frequency spectrum in each spot beam expands the satellites capacity and at the same time results in significant power savings.

A number of more advanced proposals for spot beam systems have been set forth, which offer greatly expanded re-use capabilities. Reudink and Yeh (Ref. 4) of the Bell Telephone Laboratories have suggested the use of rapidly scanned narrow spot beams on one polarization to provide area coverage together with 10 fixed spot beams on the second polarization to serve major population centers. As many as ten frequency re-uses are envisioned. Edleson and Morgan (Ref. 5) of the Comsat Laboratory propose a large orbital platform with on-board switching between beams. In discussing the use of such a platform Fordyce and Jaffe (Ref. 6) project the orbiting of a 30 meter C band antenna producing 40 spot beams and allowing as many as 40 frequency re-uses.

6.2.4 PROJECTED RE-USE OF C AND Ku BAND SPECTRUM

All three methods of frequency re-use (i.e. by orbital spacing, by polarization discrimination, and by the use of spot beam technology) have been demonstrated in space, at least to a limited extent, and offer the capability of greatly expanding the capacity of the C and Ku spectrums. In principle, it is possible to use all of these approaches simultaneously to achieve enormous increases in spectrum and orbital capacity. However, system complexity grows at the same time, and many problems of coverage and connectivity are introduced and remain to be solved.

Solutions to these problems are likely to be made difficult by the fact that present technology in C and Ku band is rapidly receiving practical embodiment in hardware. Capacity is, and will remain, fragmented among the numerous Domsat carriers and the various nations, each with vested interests to protect. The close coordination, and the unified system approach necessary to bring about the fullest exploitation of spectrum re-use at C and Ku band are therefore likely to be neglected until spectrum scarcity in both C and Ku band becomes truly pressing. By the time this occurs, however, the existing extensive investments in space and terrestrial hardware will make it difficult to reform the communications plant along spectrally more efficient lines.

In view of the above, frequency re-use for C and Ku band is projected to remain modest in the time frame prior to the expected introduction of Ka band systems early in the 1990 to 2000 decade. The most likely scenario will be the filling of the C and Ku band orbital arcs (already near at hand for C band), with an additional re-use factor of two being achieved on the average by combinations of spot beam and dual polarization technology. The net effect projected for the contiguous United States is described in Table 6-1.

TABLE 6-1 FREQUENCY RE-USE FOR C AND Ku BAND PROJECTED FOR THE CONTIGUOUS U.S. CIRCA 1990-2000

FREQUENCY BAND	C BAND	Ku BAND
SPECTRUM AVAILABLE	500-600 MHz	500-1000 MHz
RE-USE THROUGH ORBITAL SPACING	12 Times	16 Times
ADDITIONAL RE-USE THROUGH POLARIZATION AND/OR SPOT BEAM TECHNOLOGY	2 Times	2 Times
TOTAL RE-USE	24 Times	32 Times
EFFECTIVE SPECTRUM	12-14.4 GHz	16-32 GHz

6.3 EFFICIENCY OF BANDWIDTH UTILIZATION

The number of usable communications circuits that can be supported in a given spectral bandwidth has an important influence on the capacity of C and Ku band satellite communications, and is discussed in the following sections.

6.3.1 SUBDIVISION OF SATELLITE CAPACITY INTO TRANSPONDERS

The bandwidth available to each satellite at C band and Ku band (with potential re-uses as discussed in the previous section) is conventionally divided into smaller frequency segments, each of which is assigned to a separate transponder. While not strictly essential in configuring a satellite system, or in analyzing the overall communications capacity of the available spectrum, it is convenient to consider the problem in terms of the number of transponders that make up a satellite and the mix of traffic that can be assigned to each of the transponders.

The number of transponders that can be placed in a given satellite is a variable of the design but, aside from possible re-uses, the transponder bandwidth allocations add up to the total satellite spectrum occupied. In some approaches it may be beneficial to have only a single wideband transponder with access to the full bandwidth assigned to the satellite. Other approaches use several, narrower bandwidth transponders. Historically, however, the most common frequency plan has used an overall transponder spectrum of 500 MHz divided as shown in Figure 6-3, or some similar variant thereof.

In the frequency plan illustrated, the 500 MHz bandwidth up and down-links are divided into twelve 40 MHz subbands. A 40 MHz guard band separates each subband so that each transponder is assigned 36 MHz of bandwidth. A convenient 20 MHz band at the top of the spectrum remains for telemetry and command uses. Essentially the same plan is followed in existing satellites which include 24 rather than 12 transponders of 36 MHz bandwidth, the duplicate use of the spectrum being accommodated by polarization or spot beam frequency re-use.

Since twelve, 36 MHz transponders, as used in the frequency plan of Figure 6-3, occupy 432 MHz of bandwidth, the

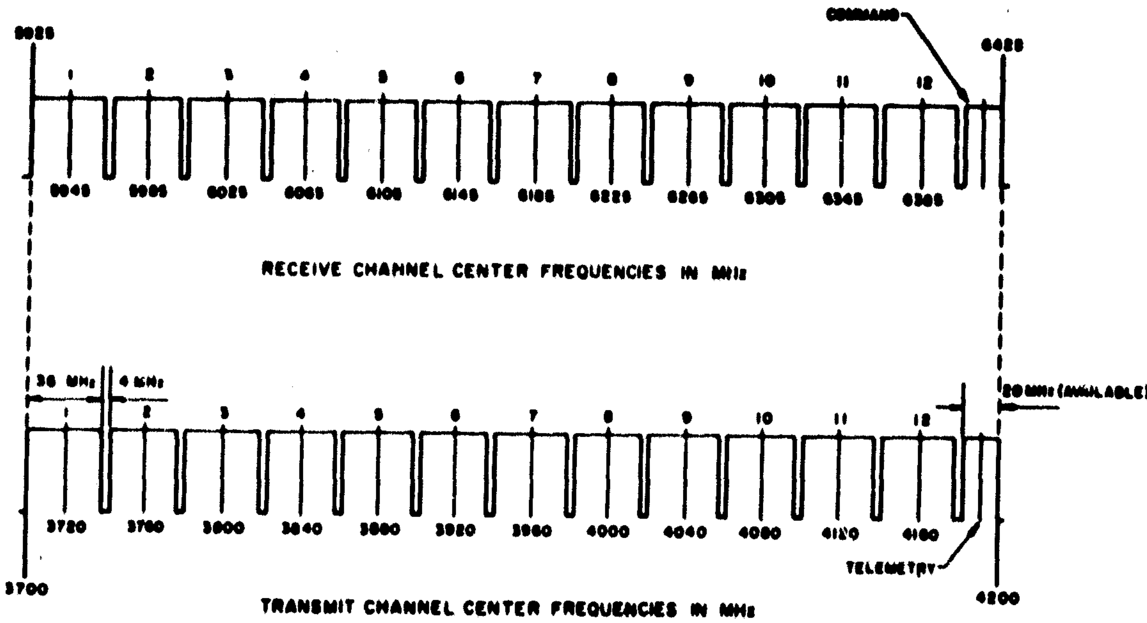

FIGURE 6-3 TYPICAL C BAND SATELLITE FREQUENCY PLAN

full 500 MHz allocation is used with 86.4 percent efficiency, the remainder of the allocation being devoted to overhead functions. If it is assumed that future satellites, which take advantage of the wider spectrum allocations, retain the nominal 36 MHz transponders and require the same 4 MHz for guard bands, and 20 MHz for telemetry and control, the 500 to 600 MHz postulated for C band will support 12 to 14.5 transponders in each satellite, and the 500 to 1000 MHz postulated for Ku band will support 12 to 23.5 transponders. With two times frequency re-use by means of polarization discrimination and/or spot beams, the typical C band satellite will therefore contain 24 to 47 transponders.

The number of transponders per satellite may be limited to lower values than the above by practical constraints of launch vehicle capability and solar array power availability. In actual practice, limitations such as these may necessitate fewer, but wider, bandwidth transponders in the satellite. Another possibility is the orbiting of double the number of satellites with half the orbital separation, each satellite using only one of the two frequency re-uses. The effective capacity of the band, however, remains unchanged, and it is convenient to carry out the discussion based on each satellite addressing the full bandwidth and re-uses available, and being subdivided into standard 36 MHz nominal transponders.

Based on nominal 36 MHz transponders, and the frequency re-use projections presented in Table 6-1, the transponder capacity of C and Ku band is summarized in Table 6-2.

TABLE 6-2 PROJECTED TRANSPONDER CAPACITY OF C AND Ku BAND FOR THE CONTIGUOUS UNITED STATES CIRCA 1990-2000

FREQUENCY BAND	C BAND	Ku BAND
SPECTRUM AVAILABLE	500-600 MHz	500-1000 MHz
FREQ. RE-USES THROUGH POLARIZATION AND/OR SPOT BEAMS	2	2
NO. OF TRANSPONDERS PER SATELLITE	24-29	24-47
NO. OF U.S. DOMSATS IN ORBIT	12	16
TOTAL TRANSPONDERS	288-348	384-752

NOTE: NOMINAL 36 MHz TRANSPONDERS ; 73 DEGREE ORBITAL ARC

6.3.2 CHANNEL PACKING DENSITY

The number of voice, video or data channels that can be supported by a 36 MHz transponder is highly dependent on the design of the system, and is subject to wide variation as a result of emerging technology. The influence of the factors is briefly discussed in the following subsections and is summarized in Table 6-3.

6.3.2.1 TRANSPONDER DIGITAL THROUGHPUT

During the time frame of interest both analog and digital transponders will be operational in C and Ku band. The capacity of a nominal 36 MHz transponder to establish voice, video and data channels depends on which type of transponder operation is used, and in the case of digital operation, on the bit rate that is achieved within the 36 MHz transponder bandwidth.

A large technical effort continues to be devoted to spectrally efficient digital transmissions with the intent of achieving high bit rates with acceptable error performance, within a given bandwidth. Depending on the type digital modulation employed, transmission efficiencies ranging between one and four bits per hertz of bandwidth have been used, or proposed, for transmissions of this type (Ref. 7). In a high interference environment, however, the packing of higher digital transmission rates into a given transponder bandwidth may be self-defeating. The higher efficiency transmissions are more susceptible to interference from adjacent systems, thereby reducing the potential for frequency re-use and achieving little or no overall gain. Reasonable average values during the period 1990 to 2000 are estimated to be two bits-per-hertz at C band, and three bits-per-hertz at Ku band where narrower antenna beams more readily control radio frequency interference, and where the introduction of new technology will face a less highly developed existing plant.

With these values, the 1990 and 2000 time frame capacity of nominal 36 MHz transponders is, as indicated in Table 6-3, projected to average 72 Mbps for C band and 108 Mbps for Ku band. These values are used in estimated transponder capacity for these voice, video or data signals making use of digital transmission formats.

TABLE 6-3 PROJECTED COMMUNICATIONS CAPACITY OF C AND Ku BAND TRANSPONDERS CIRCA 1990-2000

SERVICE	C BAND	Ku BAND
TRANSPONDER THROUGHPUT		
ANALOG	36 MHz*	36 MHz*
DIGITAL	72 MBPS*	108 MBPS*
VOICE TELEPHONE ONE WAY CHANNELS		
ANALOG	1200*	1200
DIGITAL	1200	1800 *
WITH DIGITAL SPEECH INTERPOLATION	2400	3600
VIDEO, ONE WAY CHANNELS		
BROADCAST QUALITY - ANALOG	1-2	1-2
- COMPRESSED DIGITAL	2	3
- WEIGHTED AVERAGE	1.5*	2.5*
VIDEOCONFERENCING AND OTHER REDUCED QUALITY/MOTION VIDEO WITH DIGITAL COMPRESSION	12*	18*
DATA, ONE WAY CHANNELS		
DERIVED FROM ANALOG VOICE CIRCUITS USING RATES UP TO 9.6 KBPS	1200	1200
DIGITAL TRANSPONDER - COMBINATIONS OF RATES BELOW	*	*
6.3 MBPS	11	17
1.544 MBPS	47	70
64 KPBS	1100	1600
9.6 KBPS	7500	11,250
4.8 KBPS	15,000	22,500
2.4 KBPS	30,000	45,000

* DENOTES AVERAGE VALUES EXPECTED FOR 1990-2000 PERIOD.

6.3.2.2 VOICE

The capacity of the nominal 36 MHz transponder to provide voice channels is dependent on whether the satellite link is established on an analog basis or on a digital basis, the number of accesses required, and whether access is via FDMA or TDMA. TDMA generally offers a considerable capacity advantage over FDMA when sharing of the transponder among many earth stations is required. An example of this is provided by a comparison of the FDMA and TDMA channel capacities of an INTELSAT IV global beam transponder operating with standard INTELSAT 30 meter stations. With 10 accesses, the capacity using FM/FDMA is about 450 one-way voice channels. In comparison, using standard 64 Kbps PCM for voice encoding with TDMA, the same transponder has a capacity of about 900 one-way voice channels (Ref. 8).

On the other hand, where the full transponder capacity is likely to be devoted to point-to-point use between only a few earth stations which serve major population centers, the inefficiencies associated with multiple access are reduced and both digital and analog approaches are capable of high capacities, in the range of 1000 to 2000 one-way voice channels.

Various speech processing techniques such as Digital Speech Interpolation, which uses the pauses that occur in normal speech as a means of obtaining additional channel capacity, can add an additional factor of two to transponder capacity (Ref. 9), and various other speech processing approaches such as adaptive delta modulation techniques can further improve voice channel packing density.

Table 6-3 indicates the number of voice channels expected for C band and Ku band for various types of transmission technology. The asterisks indicate the average values expected to be applicable during the period 1990 to 2000. For both C and Ku band transponders, 1200 one-way voice circuits is suggested as a reasonable estimate for systems using analog transmissions. For digital systems, a nominal value of 1200 one-way digital circuits (64,000 bps) per transponder is projected for C band while for Ku band, this projection is increased to 1800 digitally derived one-way voice circuits per transponder, taking into account the higher transponder digital throughput expected for this band.

6.3.2.3 VIDEO

The capacity of a transponder to support video channels depends on the quality of the image required, as well as on the type of transmission provided.

Analog broadcast quality color TV signals generally occupy a full transponder in U.S. domestic transmission, but the use of two analog TV signals per transponder, at a reduced signal to noise ratio, is common in international satellite transmissions. Recent commercial broadcast experiments in North America include the STRAP system (Simultaneous Transmission and Reception of Alternate Programs). Both RCA and CRS-Thompson have developed systems of this type, now in experimental use between California and Alaska, to multiplex two program sources on a single transponder maintaining broadcast quality.

Digitized broadcast TV transmissions are not yet widespread, but Table 5-1 provides estimates of the bit rates needed with various digital encodings. Based on a moderate amount of digital compression, such as that afforded by intraframe techniques (see Subsection 5.1.2), the capacity of a nominal transponder for digital broadcast TV is indicated in Table 6-3 as 2 channels in C band and 3 in Ku band. Under the assumption that a mix of transmission technologies will exist, average values of 1.5 and 2.5 digital broadcast TV channels per transponder, identified by asterisks in Table 6-3, have been selected as likely estimates for the 1990 to 2000 period.

For the lower quality, limited motion, transmissions appropriate to videoconferencing, and other less demanding video applications, various experimental systems, requiring as low as 1.5 Mbps per one-way channel have been demonstrated (See Table 5-1). In May 1980, AT&T adopted for its Picturephone Meeting Service (PMS) a 6.3 Mbps standard using video compression techniques. The 6 Mbps transmission rate typical of the more moderate compression techniques shown in Table 5-1 is considered probable for the time frame contemplated, resulting in the estimates of 12 and 18 videoconferencing channels per transponder presented in Table 6-3 for C and Ku bands, respectively.

6.3.2.4 DATA

The data traffic capacity of a 36 MHz transponder is particularly sensitive to whether the basic transmission is analog or digital. Data channels derived from an analog voice channel, with appropriate line conditioning, can provide about 9600 bits per second, while a 64 Kbps, digital voice channel can support a full 64 Kbps of data transmission, under appropriate configurations.

Based on subdivision into analog voice channels, the 1200 voice channels indicated in Table 6-3 would permit a corresponding 1200 data channels at data rates up to 9.6 Kbps. It is interesting to note that overall transponder throughput on this basis would have a maximum value of only 11.5 Mbps as compared with the projected 72 and 108 Mbps throughput potential of C and Ku band digital transponders.

Assuming, as is likely to be the case, that digital transponders are used for data transmission, the 72 and 108 Mbps throughput projections are subdividable in many ways to produce lower speed channels. Some typical subdivisions resulting in data rates of interest in various transmission plans are presented in Table 6-3. Combinations of these rates, adding up to the digital transponder throughput, are likely to be offered.

6.4 OVERALL CAPACITY OF C AND Ku BANDS

Table 6-4 combines the results presented in Table 6-2 and Table 6-3 and summarizes the average capacity projected for C band and Ku band in the 1990-2000 time frame. The table entries are the capacities that would pertain if each band were to be solely dedicated to the service indicated In practice, various mixes of service will be provided.

The values listed in Table 6-4 under the "Per Transponder" heading are the anticipated average values identified by asterisks in Table 6-3. The values shown for Data, correspond to the peak digital transponder throughput rates of 72 Mbps and 108 Mbps projected for C and Ku bands respectively in Table 6-3. Also presented is the translation of these peak digital capabilities to average annual throughput based on 24 hours per day, 365 days per year, operation with a peak-to-average ratio of 2.0 (see Section 4.4) and a nominal fill factor of 75 percent. The fill factor takes into account items such as customer turnover, off line testing of satellites newly inserted in orbit, etc. which reduce the usage of otherwise available capacity.

The "Per Satellite" values in Table 6-4 assume a frequency re-use of two times resulting in 24 to 29 and 24 to 47 nominal 36 MHz transponders per C band and Ku band satellite respectively, as per Table 6-2. The last column, showing the total capacity available for the contiguous U.S. includes the orbital considerations leading to Table 6-1 and is based on the availability of 73 degrees of orbital arc with 4 and 3 degree satellite spacings at C and Ku bands respectively.

TABLE 6-4 PROJECTED CAPACITY OF C BAND AND Ku BAND

C BAND

SERVICE	PER TRANSPONDER (36 MHz)	PER SATELLITE (24-29 TRANSPONDERS)	TOTAL CONTIGUOUS U.S. (12 SATELLITES)
VOICE (ONE-WAY CTS)	1200	28,800 to 34,800	346,000 to 418,000
BROADCAST TV (COLOR CHANNELS)	1.5	36 to 44	432 to 522
VIDEOCONFERENCING (ONE-WAY CTS)	12	288 to 348	3456 to 4176
DATA OR DIGITAL THROUGHPUT			
PEAK (Mbps)	72	1728 to 2088	20736 to 25056
AVG. (BITS/YR$\times 10^{15}$)	.851	20.4 to 24.7	245 to 297

Ku BAND

SERVICE	PER TRANSPONDER (36 MHz)	PER SATELLITE (24-47 TRANSPONDERS)	TOTAL CONTIGUOUS U.S. (16 SATELLITES)
VOICE (ONE-WAY CTS)	1800	43,200 to 84,600	691,000 to 1,353,000
BROADCAST TV (COLOR CHANNELS)	2.5	60 to 118	960 to 1880
VIDEOCONFERENCING (ONE-WAY CTS)	18	432 to 846	6912 to 13536
DATA OR DIGITAL THROUGHPUT			
PEAK (Mbps)	108	2592 to 5076	41472 to 81216
AVG. (BITS/YR$\times 10^{15}$)	1.28	30.7 to 60.0	490 to 961

6.5 CAPACITY COMPARISONS

The preceding discussion results in estimates, within broad limits, of the capacity of C and Ku bands to support various types of communications. This section compares these estimates with projected demand, and with the capacity expected for terrestrial and Ka media. Estimates of this type are highly dependent on the assumptions made and are subject to wide variability, but can provide order of magnitude guidance in planning for future communications needs.

Table 1-1 estimates that the total voice, video and data traffic addressable in 1980 is 1083 x 10^{15} bits per year. It is reasonable to assume that this demand is presently being satisfied by existing capacity, chiefly provided by the terrestrial networks. Assuming that terrestrial capacity grows moderately from this base, so as to multiply by a factor of 2.5 by the year 2000, it would reach a value of 2708 x 10^{15} bits per year. This amounts to about 47 percent of the total annual demand of 5747 x 10^{15} bits per year projected for the year 2000.

Similar estimates can be developed for C and Ku band systems based on the projections summarized in Table 6-4. The rows of Table 6-4 labeled "Data or Digital Throughput" estimate the overall digital throughput that could be supported by C and Ku band orbital capacities, if they were completely devoted to transmissions in digital form. At the upper end of the ranges shown, the average annual capacities of C band and Ku band are estimated as being equivalent, respectively, to 297 x 10^{15} and 961 x 10^{15} bits per year. These values result in a capacity estimate for C band satellite systems on the order of 5 percent of total annual demand in the year 2000. The corresponding capacity of Ku band is about 17 percent of demand.

The total capacity that will be available from future Ka band satellite systems is highly speculative since these systems have not yet reached sufficiently detailed levels of development. However, the spectrum allocated to Ka band is about 3.5 times that of the 1000 MHz, which represents the higher end of the range of values postulated for Ku band. On this basis it is reasonable to assume that the capacity of Ka band systems, if fully implemented, would be at least 3.5 times that of Ku. This amounts to approximately 60 percent of the year 2000 total annual demand.

Table 6-5 summarizes the capacity estimates referred to above. While subject to considerable variation depending on technical and regulatory developments and assumptions, the values presented in this table indicate that Ka systems are needed to satisfy projected demand and that if fully implemented the capacity of all media combined will provide about 29 percent margin for further growth beyond the year 2000.

TABLE 6-5 ESTIMATED CAPACITY OF TELECOMMUNICATIONS SYSTEMS CIRCA 2000

	PEAK CAPACITY Mbps x 10^3	ANNUAL CAPACITY BITS/YR x 10^{15}**	% OF YEAR 2000 ANNUAL DEMAND*
TERRESTRIAL	-	2708	47
C BAND	25.1	297	5
Ku BAND	81.2	961	17
Ka BAND	284.2	3364	60
TOTAL	-	7330	129

* BASED ON YEAR 2000 DEMAND OF 5747 x 10^{15} BITS PER YEAR

** INCLUDED EFFECTS OF 75 PERCENT FILL FACTOR AND PEAK-TO-AVERAGE RATIO OF 2.

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9. S.J. Campanella, "Digital Speech Interpolation," Comsat Technical Review, (Spring 1976).

7.0 ECONOMIC COMPARISONS

This section discusses the costs of Ka satellite systems and other transmission media and discusses the extent to which economic factors are likely to influence the market potential of Ka band systems.

7.1 COSTS OF TERRESTRIAL COMMUNICATION

As described in Chapter 2, a wide variety of communications media, with differing characteristics and capacities, are used in the terrestrial communications plant. The Bell network accounts for roughly 90 percent of the existing terrestrial communications plant and therefore presents an appropriately weighted mix of media types on which to base cost estimates for terrestrial communications.

Based on the 1979 AT&T Annual Report (Ref. 1), Bell System revenues totaled 45.4 billion dollars, about evenly divided between local and toll services. Operating expenses in 1979 amounted to 30.2 billion. Figure 7-1 provides estimates of the major elements making up these operating expenses. The largest portion of the operating expenses, roughly 16 billion, or 53 percent, went to employee expenses. Other expenses involved in maintenance, network and operator services, marketing, financial operations, etc., account for about 27 percent of operating expenses. Only 6.13 billion, or about 20 percent, of the operating costs went to depreciation of the communications plant. This value is roughly indicative of the average annualized replacement cost of the physical communications plant. The costs of the physical plant equipment, therefore, impact only moderately the costs of operating the terrestrial network.

This is further emphasized when the long haul transmission plant alone is considered. The 1979 depreciation for the long haul transmission plant was about 0.25 billion which is only 0.8 percent of the $30.2 billion total operating expenses.

An important conclusion that can be drawn from Figure 7-1, therefore, is that annualized long haul transmission plant costs have only a small impact on the overall costs of terrestrial

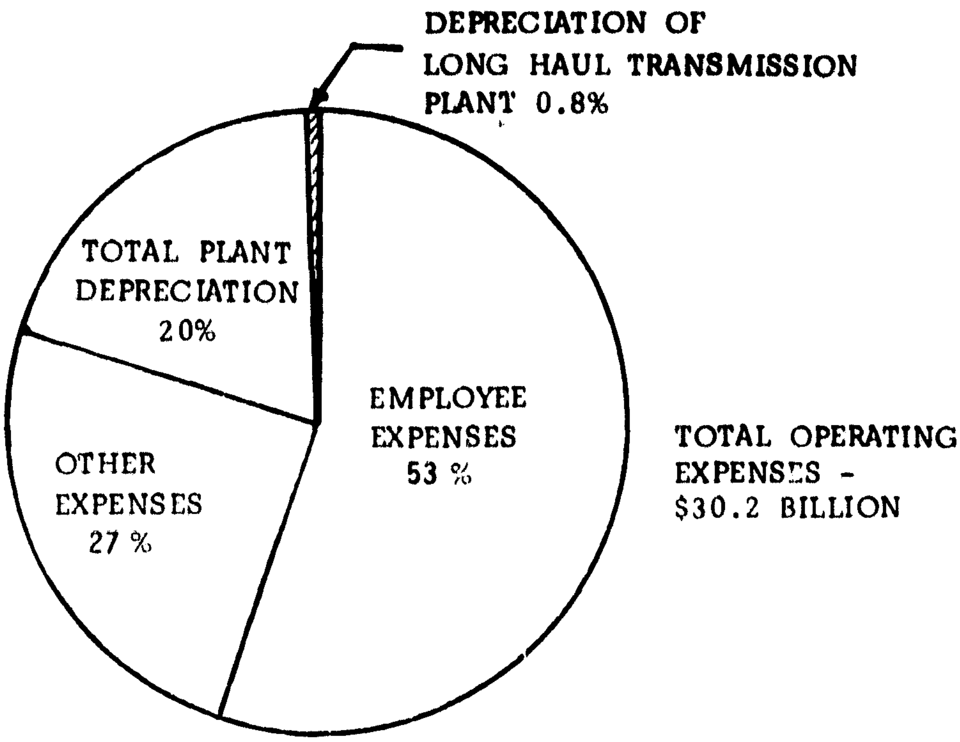

FIGURE 7-1 AT&T EXPENSES FOR 1979

communications. Dollars spent on personnel, maintenance, marketing, etc. add up to a much larger portion of the total.

The investment needed to establish a voiceband circuit-mile of interstate telecommunications plant has been steadily decreasing. Figure 7-2 shows an investment cost of $11.94 for a voiceband circuit-mile for 1979, down from $15.76 in 1975 (Ref. 2).* Assuming an average asset lifetime of about 18 years, (consistent with a 5.6 percent straight line depreciation of average depreciable plant as per Reference 2) the current $11.94 investment cost of a voiceband circuit-mile would, on an annualized basis, be about 66 cents per circuit-mile per year. This estimate refers only to the cost of establishing the necessary physical long haul plant. When other operating expenses, for personnel, taxes, interest, etc., are included, the per circuit-mile costs are much higher and the rate at which costs have been decreasing is much smaller. At present the AT&T interstate voiceband private line tariff for each incremental mile above 1000 miles is $5.04 per mile, per year (Ref. 3).

Thus, a reasonable estimate for the annualized investment cost of a circuit-mile of voiceband capacity is 66 cents per year, while the overall cost to the end user of both establishing and operating the same facility, as reflected in tariffs, has the much higher value of $5.04 per year. Annualized investment cost based on this analysis is only 13 percent of long haul costs to the end user. Over the next two decades, the overall costs of a terrestrial voice circuit are projected to decline at a rate of about one percent per year (Ref. 9).

Video channels are tariffed under the Series 7000 private line service (Ref. 3). The type 7004 channel is intended for interexchange use on a full-time monthly rental basis. The monthly tariffed rates result in a cost of about $380 per mile per year for a color channel. A second color channel can be added at a reduced rate of $180 per mile per year. Full-time station connections are $18,000 per year per connection. Video channels can also be leased on an hourly basis. Hourly charges are $.75 per hour per mile and each station connection costs $80 per hour. Economies of scale are important in terrestrial video communications, as indicated by the fact that a second video channel may be added at a cost roughly one-half that of the first.

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*Cost values are actual costs current in year cited without correction for inflationary factors.

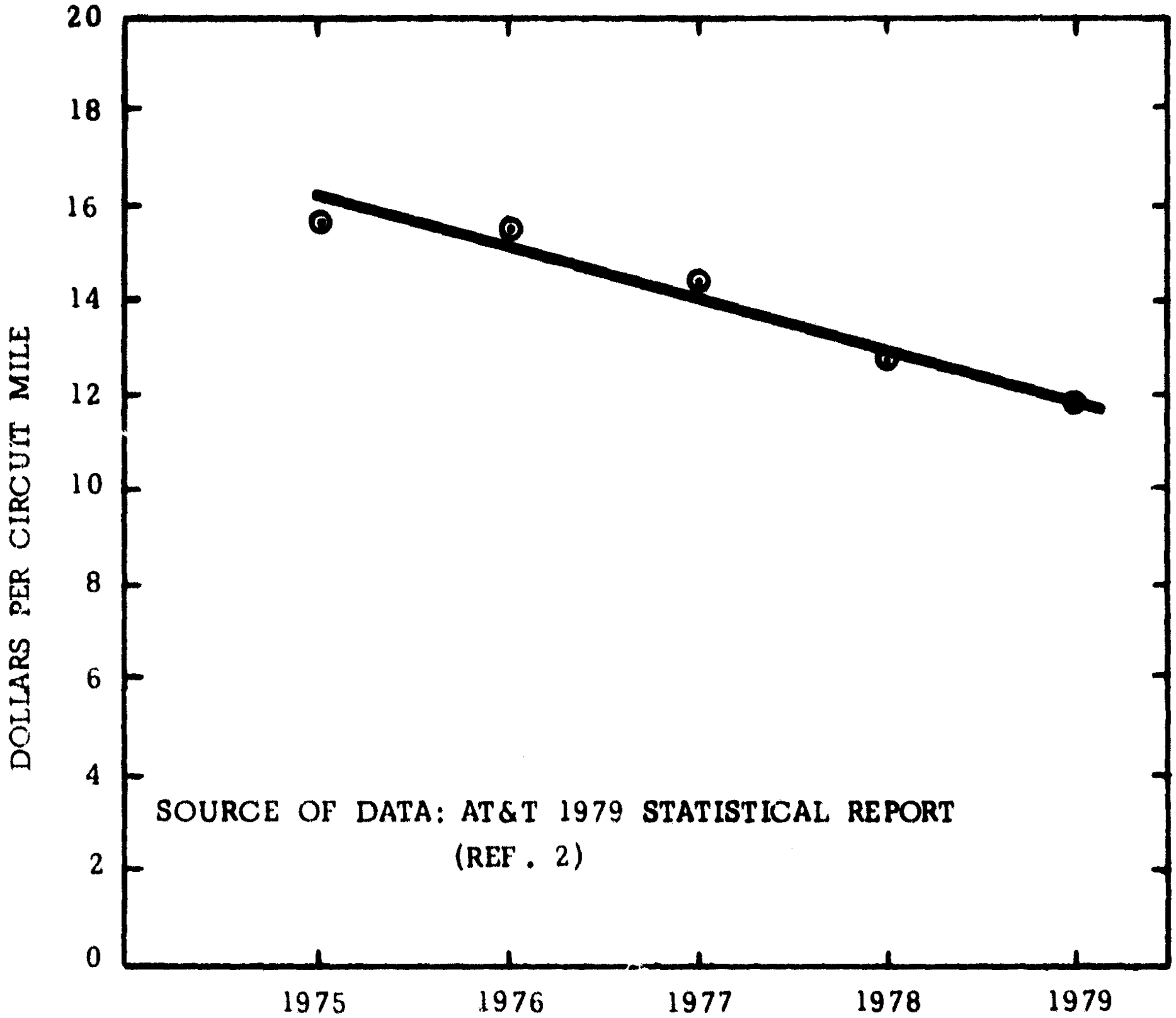

FIGURE 7-2 AVERAGE INVESTMENT PER CIRCUIT MILE (INTERSTATE STATISTICS)

7.1.1 FIBER OPTICS

Fiber optics do not as yet constitute an appreciable portion of the terrestrial network. However, the potential of fiber optics for providing high capacity, wideband communications links, at low cost, without the frequency congestion problems that limit some terrestrial media, is of special interest in the 1990 to 2000 time frame. Fiber optics may constitute an important competitor to long haul communications provided by satellites. However, fiber optics may also contribute to the viability of high volume long haul satellite transmission by providing an effective method for the local distribution of wideband signals from the earth station to the users.

The projected 1983 implementation by AT&T of a 600 mile fiber optics highway in the high density Boston-Washington corridor offers an opportunity for some cost comparisons with other terrestrial media. Most of the fiber optics cable will be installed in existing Bell System conduit with repeaters spaced every four miles. The system is projected to cost $79 million dollars and will carry 80,000 simultaneous voice calls (Ref. 5).

Mr. Robert Kleinert, President of AT&T Long Lines, estimated that the cost of the fiber optics system would be about $9.00 per voice circuit-mile and compared this with an estimate of $13.00 per voice circuit-mile for other terrestrial media (Ref. 6). The latter value is close to the investment per circuit-mile presented in Figure 7-2 for 1978.

Using the 18 year straight line depreciation assumed earlier for other terrestrial plant equipment, the annualized investment cost of fiber optics is 50 cents per voice circuit per mile, which is about 25 percent less than the 66 cents per mile estimated for other terrestrial media. As before, however, the cost of establishing the communications plant is only a small portion of overall annual operating costs. Under the conservative assumption that these additional factors are incrementally the same for fiber optics as for other terrestrial media, a proportional tariff for fiber optics voiceband circuits becomes $4.88 amounting to a reduction of only about 3 percent in the annual tariff of $5.04 per circuit-mile discussed earlier for other terrestrial media. Thus, the relatively large change in investment cost represented by the reduction from $13.00 per circuit-mile to $9.00 per circuit-mile would, if translated into tariffs, be likely to result in only minor cost reductions to the end user.

7.2 COSTS OF SATELLITE COMMUNICATIONS

This section discusses the costs of C, Ku and Ka band satellite communications and compares these costs with those of terrestrial media.

7.2.1 C BAND SATELLITE COMMUNICATIONS COSTS

The per channel cost of satellite communications, like that of other communications media, is influenced by economies of scale and thus is strongly dependent on the capacity of the system. This fact is illustrated by the pattern of increasing capacity, and decreasing cost, evident in the 15 year evolution of the Intelsat series of international communications satellites, which to date have utilized C band transmissions. Table 7-1 presents capacity and cost data for Intelsats I through V (Ref. 7).

TABLE 7-1 CAPACITY AND SPACE SEGMENT COST OF INTELSAT SYSTEMS

SATELLITE SERIES	I	II	III	IV	IVA	V
YEAR OF FIRST LAUNCH	1965	1967	1968	1971	1975	1980
NO. OF TRANSPONDERS	2	1	2	12	20	27
TOTAL USABLE BAND-WIDTH (MHz)	50	130	500	500	800	1200
TWO-WAY TELEPHONE CIRCUITS	240	240	1200	4000	6000	12500
COSTS/CIRCUIT YEAR	$30,000	$10,000	$2,000	$1,000	$1,000	$700

Intelsat I (Early Bird) was launched in 1965 and had a capacity of only 240 two-way voice circuits and on an annualized basis, cost $30,000 per circuit. By 1975, with the launching of INTELSAT IV-A, capacity had increased to 6000 circuits with an annualized cost of only $1000 per circuit. INTELSAT V will use both C and Ku bands plus polarization diversity and spot beam technology to provide 12,500 voice channels at an annualized cost of $700 per channel.

The costs discussed above are annualized investment costs needed to establish the channel. As in the terrestrial cases discussed earlier, annualized investment cost is only a small part of total costs as evidenced by the fact that the present cost to the international carriers who lease INTELSAT channels from COMSAT Corporation is much higher than the above (Ref. 8).

The evolution of domestic C band satellite communications has both a shorter, and more diverse, history so that cost trends equivalent to those cited for the INTELSAT series of satellites are not as readily apparent. There is no doubt, however, that comparable cost reductions, and capacity increases, apply to domestic as well as to international satellite technology.

Some representative estimates of the costs per circuit-mile for domestic C band satellite systems were projected for the years 1980, 1990 and 2000 in Reference 9. The C band system was assumed to be an FDM/FDMA trunking system with characteristics and projected costs summarized in Table 7-2. These costs

TABLE 7-2 ANNUALIZED C BAND COSTS PER VOICE CHANNEL
(SOURCE: REF. 9)

CONFIGURATION	TRUNKING
ACCESS METHOD	FDM/FDMA
SATELLITES	2 OPERATIONAL, 1 SPARE
NO. OF 36 MHz TRANSPONDERS	24
VF CHANNELS/TRANSPONDER	1000
AVG. EARTH STATION CAPACITY	240 CHANNELS
ANNUAL COST PER DUPLEX CHANNEL:	
1980	$5,669
1990	$5,014
2000	$4,629

NOTE: Utilization 75%

are based on a cost model which includes capital costs, operations and maintenance, return on investment, system lifetime and loading; adjustments are needed when comparing with other costs which do not include these factors.

C band domestic satellite communications is presently offered by three domestic common carriers, American Satellite Corp., RCA Americom, and Western Union. Tariffs among these carriers are comparable, and competitive with the distance dependent tariffs applicable to terrestrial service. Westar transmission service provided by Western Union, for example, is offered at a basic rate for a full time leased voice channel of $8160 per year for Zone 1 covering 1075 miles, $9840 per year for Zone 2 covering up to 1875 miles, and $13,200 per year for Zone 3 covering 1876 miles or more (Ref. 10). Substantial quantity discounts are available. Figure 7-3 provides a comparison between voice grade tariffs for Westar Satellite leased line service and AT&T terrestrial channels.

Satellite facilities are often leased on a full transponder basis. A full 36 MHz C band transponder, for example, is offered by Western Union under several tariff arrangements. Some typical costs are presented in Table 7-4 (Ref. 11).

TABLE 7-4 WESTAR TRANSPONDER COSTS
(Millions of Dollars Per Year)

	Month-To-Month Transponder Service	Fixed-Term Transponder Service
Protected	2.4	1.8
Unprotected	1.44	1.0
Unprotected, Interruptible	1.2	0.8

Some additional C band transponder cost data was recently reported relative to an agreement between RCA and AT&T (Ref. 12). Under this agreement RCA will lease transponders on AT&T's back-up Comstar satellite, with AT&T retaining the right to reclaim or pre-empt these channels if any of its own primary transponders should fail. The transponders are being leased from

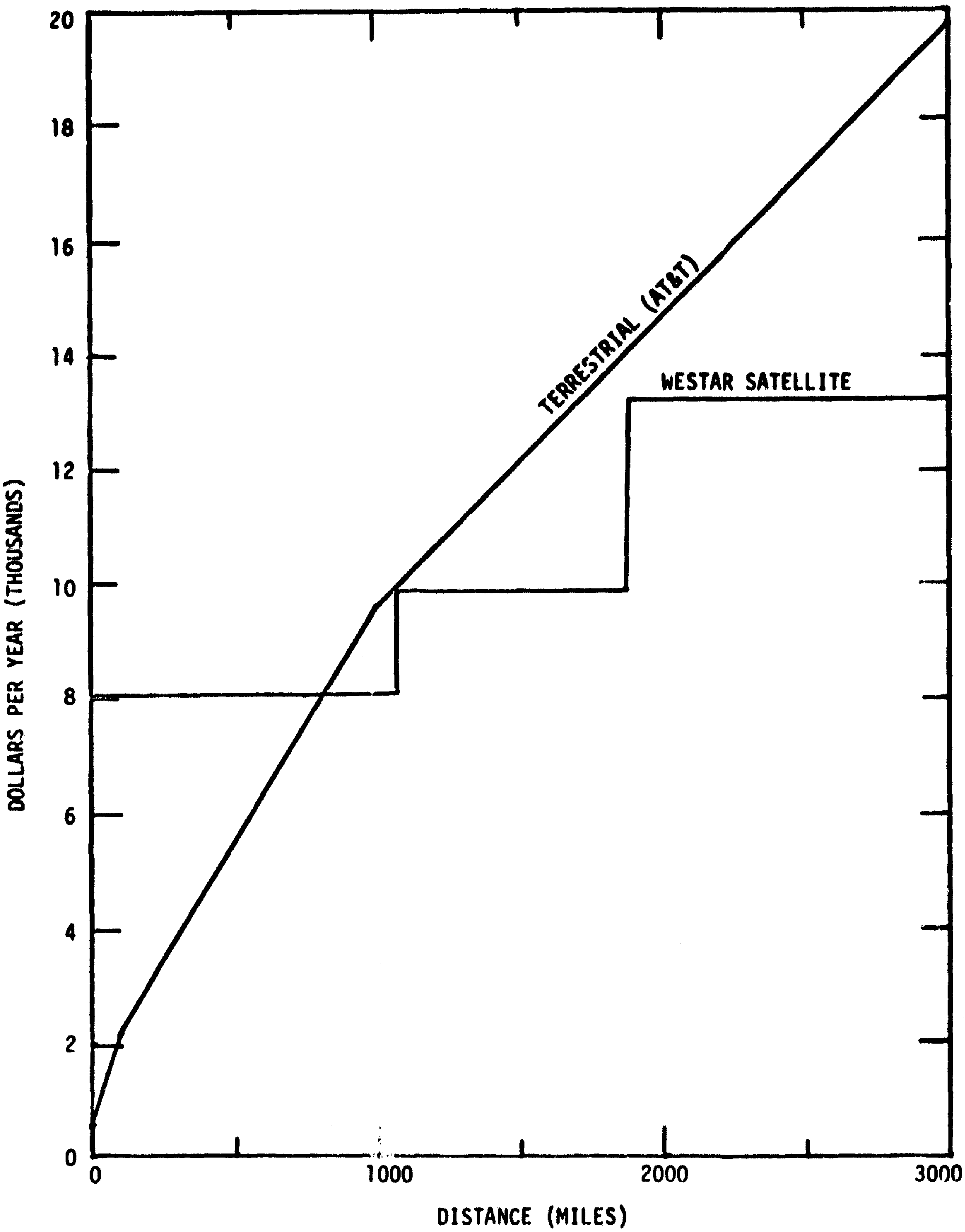

FIGURE 7-3 TERRESTRIAL AND SATELLITE LEASED LINE VOICEBAND CIRCUIT TARIFFS

AT&T at $70,000 per montn ($0.84 million per year) each, and will be used as temporary replacements for transponders in an RCA satellite that failed to achieve successful orbit after launch in December of 1979. RCA will in turn lease the transponders to its customers at a previously agreed upon price of $40,000 per month ($0.48 million per year).

Some cost comparisons between video services on terrestrial facilities relative to those on C band satellites were presented by Mr. J. T. Ragan, Vice-President of Broadcast Services for the Western Union Telegraph Company in a paper presented in April, 1980 (Ref. 13). One hour of prime time, coast-to-coast, transmission via land lines is estimated to cost $1,839 as compared to a $580 cost via Westar satellite to the occasional user and $390 to a high volume user. Some typical multipoint video broadcast cost comparisons are presented in Table 7-5.

TABLE 7-5 TYPICAL TV BROADCAST NETWORK DISTRIBUTION COSTS FOR ONE HOUR OF PRIME TIME (SOURCE: REF. 13)

	TERRESTRIAL	SATELLITE
Top 25 ADI Markets	$ 4,590	$1,136
Top 50 ADI Markets	6,318	1,800
Top 100 ADI Markets	15,714	3,100

7.2.2 Ku BAND SATELLITE COMMUNICATIONS COSTS

There are at present no domestic operational capabilities offered at Ku band, and as a result costs are not as well established as for the older C band satellite services. Some projections for the costs of Ku band satellite systems are presented in Reference 9 and others are available from SBS tariff filings as discussed later. The system characteristics and costs are summarized in Table 7-6, and as for the C band costs presented in Table 7-2, include allocations for capital costs, operation and maintenance, return on investment, system lifetime, and loading.

TABLE 7-6 ANNUALIZED Ku BAND COSTS PER VOICE CHANNEL
(SOURCE: REF. 9)

CONFIGURATION	TRUNKING
ACCESS METHOD	TDMA
SATELLITES	2 OPERATIONAL, 1 SPARE
NO. OF 36 MHz TRANSPONDERS	12
VF CHANNELS/TRANSPONDER	1000
AVG. EARTH STATION CAPACITY	240 CHANNELS
ANNUAL COST PER CHANNEL:	
1980	$8,177
1990	$7,667
2000	$7,345

NOTE: UTILIZATION 75%

The higher costs for Ku band transmission, in comparison to those presented in Table 7-2 for C band, are primarily the result of the assumptions that fill factors in the early years will be less for Ku than for C band, and that the Ku satellite would contain only 12 transponders compared to the 24 assumed for C band. Here is another instance in which communications costs are highly volume sensitive.

The earliest domestic operational Ku band satellite services are expected to be offered by SBS with a scheduled service cutover date of January 1, 1981. The first SBS operational tariff was filed with the FCC in June of 1980 (Ref. 14) and additional filings are expected in 1981.

SBS will initially offer a service referred to as "Communications Network Service-A, (CNS-A)." This service is oriented toward the larger customers who are expected to use a minimum of three CPS earth stations called Network Access Centers at a unit cost of $12,500 per month. Interface between the Network Access Centers and customer equipment such as PBXs or computers will be via different types of Connection Arrangement Units (CAUs). CAUs for voice channels range in price from $50 to $110 per month depending on the number of channels installed, and up to $3,000 per month for various wideband channels. Satellite transmission capacity, assigned in 224 Kbps blocks, will cost $2,100 per month if leased on a full time basis, or $40 per hour on demand.

SBS will use digitized voice channels based on a digitization rate of 32 Kbps for a simplex voice channel. This allows the packing of seven such channels in each 224 Kbps capacity block. Based on this digitization rate, the cost elements discussed above, the annual per channel costs for a minimum three earth station CNS-A configuration are as shown in Figure 7-4. For CNS-A's prime target users, whose long distance communications expenditures exceed $300,000 per month (Ref. 15), the cost of a simplex voice channel ranges from about $5,000 to $6,500 per year.

Some care must be exercised in comparing these voice channel costs with those of other media. The digitization rate for SBS results in a 32 Kbps simplex channel while most of the projections for other digital satellite media discussed in this report are based on a 64 Kbps simplex channel. The latter allows greater latitude in extending the voice channel through additional terrestrial links, where further conversions from analog to digital form may be encountered. SBS also intends to use additional voice compression (a form of digital speech interpolation) to make more efficient use of the silent periods characteristic of voice conversations. With this additional compression, the 64 Kbps of capacity that would ordinarily be required to get a duplex channel at a 32 Kbps digitization rate is cut approximately in half. Under these circumstances the cost of a duplex voice channel for SBS becomes equal to that shown in Figure 7-4 for a simplex voice channel. Again, to make valid comparisons with the costs of a duplex voice channel on other transmission media it is necessary to note whether such additional compression technology has been assumed.

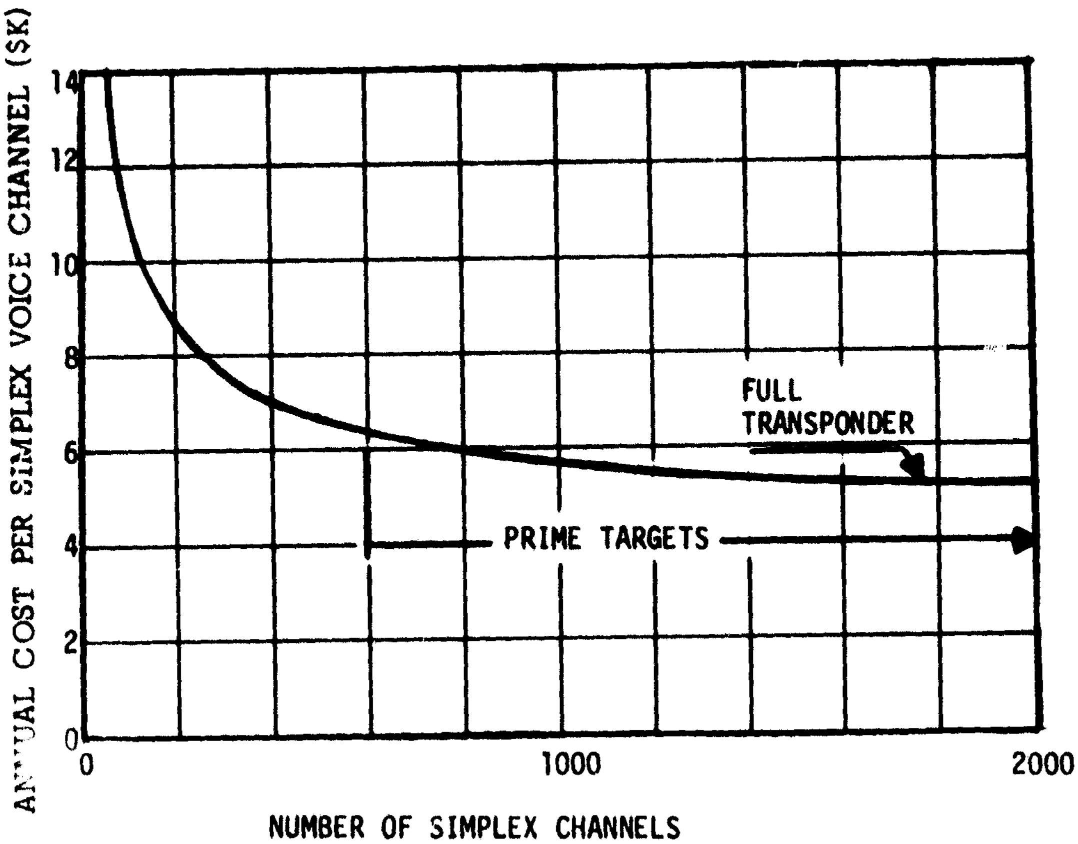

FIGURE 7-4 ESTIMATED ANNUAL COSTS PER SIMPLEX VOICE CHANNEL
FOR SBS CNS-A SERVICE

A second SBS service offering, referred to as "Communications Network Service-B (CNS-B)" is planned for 1982 and will provide for shared use. Costs are expected to be $7,500 per month for each of three earth stations plus $250 per month for each duplex voice circuit. In a related filing SBS also requested authorization to permit CNS-B users to place voice calls to off-net stations. Anticipated charges are $9.00 per hour for the first 120 hours of usage each month, dropping to $6.00 per hour for the next 480 hours, and $5.70 per hour thereafter.

Since the types of services offered by SBS differ from more conventional leased line and dial-up services, and are highly dependent on the user configuration, it is difficult to make direct cost comparisons. The previous discussion tends to indicate that SBS costs for the larger users will be in the same range as those of conventional services. In a December, 1979 interview Mr. Robert C. Hall, President and chief officer of SBS, confirmed this by stating that he expected competitive pricing responses to SBS offerings from the phone company, but is confident that SBS can provide equal facilities at lower costs. Mr. Hall referred to 10 to 20 percent savings in both the voice and data areas compared with competing services (Ref. 16).

7.2.3 Ka BAND SATELLITE COSTS

This section discusses cost projections for Ka band satellite communications. The main sources of information are two 1979 design studies performed respectively by the Ford Aerospace Corp. (Ref. 17) and the Hughes Aircraft Corp. (Ref. 18). Some additional cost data based on an analysis of higher frequency satellite systems as reported in a 1980 study by the Georgia Institute of Technology (Ref. 19) is also presented.

The 1979 report by Ford Aerospace and Communications Corp. (Ref. 17) developed Ka band satellite trunking and CPS baseline configurations and estimated the cost impact of several alternative designs. The baseline trunking system configuration and costs are presented in Table 7-7. These cost estimates consider the satellite system alone and do not include local distribution lines, the cost of which may be substantial.

TABLE 7-7 Ka BAND BASELINE FDMA TRUNKING SYSTEM AS PER REFERENCE 17

BASELINE CONFIGURATION		
10 Diversity Earth Station Pairs with 12 M Antennas		
1 Prototype plus 3 Flight Model Spacecraft		
25 Gb/s System Capacity		
10 Site Coverage with 0.3° Antenna Beams		
99.9% Availability		
TEN YEAR SYSTEM COSTS		
Spacecraft		\$195M
Launch and TT&C		95M
Earth Stations		78M
Operation Costs		57M
	TOTAL	\$425M
ALLOCATED CIRCUIT COSTS		
Duplex 64 Kbps Channel		\$ 300/Year
Simplex 1.5 Mbps Channel		\$3600/Year

NOTE: UTILIZATION 100%

Since large fixed costs are expected in the early years of the program, with revenues spread over the full program period, the costs of money add significantly to the other program costs. The \$300 per year for a duplex 64 Kbps channel and the \$3,600 per year cost for a simplex 1.5 Mbps channel are the estimated yearly revenues needed, to offset the costs of the satellite communications system, including the cost of money.

An alternative trunking system using TDMA was also investigated. The ten year cost for this alternative, with characteristics similar to those defined in Table 7-7 is $366 million. Removing the diversity earth stations, but upgrading the baseline design to retain the same 99.9 percent availability level, was found to result in an additional net cost increment of $5 million. Allowing the availability to degrade to 99.5 percent resulted in no change to the baseline costs.

Reference 1[7] also provided cost estimates for Ka band CPS service. The baseline system characteristics are shown in Table 7-8.

TABLE 7-8 Ka BAND BASELINE CPS SYSTEM AS PER REFERENCE 17

BASELINE CONFIGURATION		
1000 Non Diversity Earth Stations with 4.5M Antennas		
Remodulation and Antenna Switching in Spacecraft		
25 Beam Full CONUS Coverage		
TDM at 150 Mbps per Beam		
3.5 Gb/s Maximum Capacity		
99.5% Availability		
TEN YEAR SYSTEM COSTS		
Spacecraft		$248M
Launch and TT&C		85M
Earth Stations		522M
Operations Costs		376M
	TOTAL	$1231M
ALLOCATED CIRCUIT COSTS		
Duplex 64 Kbps Channel		$7500/Year
Simplex 1.5 Mbps Channel		$87,000/Year
Simplex 6.3 Mbps Channel		$365,000/Year

NOTE: UTILIZATION 100%

In a parallel effort, costs for Ka band satellite communications were evaluated by the Hughes Aircraft Company (Ref. 18). The trunking system configuration includes three satellites, ten dual diversity earth stations and the terrestrial link between the earth stations, but does not include local distribution costs. Results are summarized in Table 7-9.

TABLE 7-9 Ka BAND SATELLITE TRUNKING SYSTEM INVESTMENT COSTS (SOURCE: REF. 18)

	FDMA		TDMA	
Propagation Reliability	99.9%	99.99%	99.9%	99.99%
Total Investment, $M	251	273	231	245
Capacity, Gbps	19.4	19.4	22.2	22.2
Investment Costs:				
Per Duplex 64 Kbps Channel	$1,636	$1,801	$1,197	$1,270
Per Simplex 40 Mbps Channel	$518,000	$562,000	$374,000	$397,000

NOTES: INVESTMENT COSTS ONLY.
ASSUMES 100% UTILIZATION.

These costs represent the investment needed to make the capacity available. In order to compare these with the annual circuit costs shown in Table 7-7, it is necessary to adjust for the system lifetime, and the costs of money and annual operations. A rough comparison between the two estimates may be arrived at by calculating the total costs for spacecraft, launch and TT&C and earth stations on a per unit capacity basis. For the trunking system described in Table 7-7, this amounts to $368 million per 25 Gbps or $14.2 million per Gbps. The corresponding values in Table 7-9 range from $10.4 million per Gbps to $14 million per Gbps. Thus, it is reasonable to assume that if both estimates were put on a common annual basis, by prorating according to the cost per unit capacity, the $300 annual cost of a 64 Kbps duplex channel reflected in Table 7-7 would translate to \$223 to \$304 for the same circuit, under the configurations and estimates of Table 7-9.

Reference 18 also provides some estimates for CPS service costs. The baseline CPS system uses 25 spot beams, with 400 non-diversity earth stations per beam. Costs in this case are stated as the annual revenue required per circuit, under the assumption that facilities are fully loaded. In practice, costs will be higher, reflecting the degree of utilization of the facilities. The CPS cost estimates are summarized in Table 7-10, for small, medium and large earth station configurations.

TABLE 7-10 Ka BAND CPS SATELLITE REVENUES REQUIRED PER CIRCUIT (DOLLARS PER CIRCUIT PER YEAR) (SOURCE: REF. 18)

	FDMA			TDMA		
	SMALL	MEDIUM	LARGE	SMALL	MEDIUM	LARGE
Duplex 64 Kbps Circuit	16,000	7,800	6,500	25,000	7,400	4,400
Simplex 1.5 Mbps Circuit	-	134,000	156,000	-	180,000	107,000
Simplex 6.3 Mbps Circuit	-	-	669,000	-	-	456,000

NOTE: ASSUMES 100% UTILIZATION

Some additional estimates for the costs of high frequency satellite communications systems are presented in a report describing NASA supported work done at the Georgia Institute of Technology (Ref. 19). The study deals primarily with 50/40 GHz systems with extensions of the results to the nominal 30/20 GHz range of interest in the present study.

The study (Ref. 19) uses a computerized Satellite Cost Optimization Routine (SCOR) which minimizes total capital cost, subject to constraints on the link equation and weight budget. Total optimized capital costs and annual costs per voice channel were determined by scaling results presented in Volume 2 of Reference 19 and are summarized together with key system parameters in Table 7-11.

TABLE 7-11 POINT-TO-POINT BASELINE PARAMETERS FOR HIGH FREQUENCY SATELLITE COMMUNICATIONS SYSTEMS (SOURCE: REF. 19)

FREQUENCY	30/20 GHz
SATELLITE BANDWIDTH	1000 MHz
SPOT BEAMS	6
RELIABILITY	99.9% WITH DUAL DIVERSITY
RAIN RATE	50 MM/Hr.
NO. OF GROUND STATIONS	6
NO. OF SATELLITES	3 (2 IN ORBIT)
LIFE	SATELLITE 8 YRS., GROUND SYS. 14 YRS.
TOTAL CAPITAL COST	$96.4 MILLION (SCALED FROM 50/40 GHz COSTS)
ANNUALIZED SYSTEM	$27.2 MILLION (INCL. TAXES, COST OF MONEY, RETURN ON INVESTMENT AND OPERATING COSTS) (SCALED FROM 50/40 GHz COSTS)
ANNUAL COST PER DUPLEX VOICE CHANNEL	$1640

NOTE: UTILIZATION 50%

7.3 SUMMARY OF COST ESTIMATES

The previous discussion provides cost estimates for terrestrial and satellite communications media. The estimates are derived from a variety of sources which do not always explicitly present all of the cost assumptions used in arriving at the results. Valid comparisons are therefore difficult to arrive at. To the extent possible, Table 7-12 attempts to compare these estimates and comments on the values presented.

Existing terrestrial tariffs for a duplex voice grade line result in annual costs of $9664 for a one thousand mile circuit between major city centers, and $14,704 for a two thousand mile circuit. Incremental costs for distances above 1000 miles are $5.04 per mile per year. Some small reduction may result from the slightly lower costs expected from fiber optic systems, if these systems become an important part of the terrestrial network.

The satellite system costs presented in Table 7-12 represent the estimated revenues required to support a duplex voiceband channel. The costs are for the space system alone, including, where appropriate, the costs of a wideband terrestrial link between diversity earth stations. The costs of local terrestrial links to connect the end users to the earth station are not included. Some discussion of the significant impact of these local distribution costs is presented later in this section.

C band satellite costs are estimated to range from $4,600 to $5,700 per duplex channel per year. Tariffs have been established by domestic SATCOM carriers for C band channels and these roughly parallel those of terrestrial systems with five to ten percent discounts common.

Ku band satellite costs are less well defined. The cost estimates summarized in Table 7-12 show these as slightly higher than those for C band systems. This appears to be more a result of the fact that the system configuration evaluated for Ku operation was of lower capacity than that postulated for C band, rather than to any intrinsic major cost increment of one system over the other.

The cost value shown for SBS is illustrative of the costs to a typical large user. The cost shown is based on

TABLE 7-12 SUMMARY OF COST ESTIMATES
(Annual Cost Per Duplex Voice Channel)

MEDIUM	COST	COMMENTS
Terrestrial (Wire, Coax, Microwave)	$9664 for 1000 mi. $14704 for 2000 mi.	Based on AT&T Tariff (Ref. 3). Investment cost is $12 per channel mile which for 18 year depreciation annualizes at $.66 per channel mile.
C Band Satellite	$4600 to $5700	Based on W.U. FDM Trunking System cost estimates (Ref. 9). Present tariffs are distance sensitive and approximately duplicate terrestrial tariffs.
Ku Band Satellite	$7300 to $8200	Based on W.U. TDMA Trunking System cost estimates (Ref. 9). Assumes smaller volume than C band system above. 75% utilization.
Ku Band Satellite (SBS)	$5000 to $6500	Based on CNS-A charges (Ref. 14) for 3 earth station large volume users. Assumes 32 Kbps voice channel with additional 2:1 compression. Tariffs expected by SBS to be competitive.
Ka Band Satellite	$300 ($1800)*	Based on Ford Aerospace estimates (Ref. 17) of ten year system costs for 10 spot beam FDM Trunking System with 25 Gbps capacity. 100% utilization.
Ka Band Satellite	$223 to $304 ($1338 to $1824)*	Computer from Hughes Aircraft Co. estimates (Ref. 18) for 10 spot beam trunking systems with 19.4 to 22.2 Gbps capacity. 100% utilization.
Ka Band Satellite	$1640	Based on Georgia Institute of Technology estimates (Ref. 19) for 6 spot beam trunking system with 1000 MHz bandwidth. 50% utilization.

*When multiplied by factor of six to account for utilization and non-uniform employment of spot beam capacity. See discussion in text.

pricing data presented by SBS for a typical large user configuration, divided by the assumed number of voice channels provided. On this basis costs appear to be about the same as those of current C band satellites. The CNS-A service offering by SBS, however, is basically a customer premises service so that comparison with trunking system costs are not directly applicable. Local distribution costs which would add to the end-to-end costs of channels obtained via trunking are not needed for CPS. It should also be noted that the voice digitization rate used by SBS is 32 Kbps as compared to the 64 Kbps assumed in the other satellite designs. A further 2 to 1 compression is also used in arriving at the digital rate for duplex voice channels.

The costs estimated for Ka band satellite systems are very much lower than those for other satellite systems. The estimates due to Ford Aerospace Corp. and Hughes Aircraft Company are based on 100 percent utilization of a very large capacity system. Doubling of costs to account for an average utilization of about 50 percent would probably be appropriate. An additional factor of three is probably also needed to account for uneven loading among the cities served by the separate spot beams. The Ka systems postulated provide the same capacity to each spot beam, but this capacity is sized to handle the traffic load of the largest city. Those spot beams serving smaller cities will be highly under-utilized, and this wasted capacity cannot be readily recovered without adding complexity and costs to the design.

If these additional considerations are taken into account the $300 per channel cost figures would be multiplied by a factor of six, resulting in the values indicated in parentheses in Table 7-12. These values are also comparable to those estimated for Ka band satellite systems in the Georgia Institute of Technology study.

Even with the upward revisions discussed above, the projected costs for Ka satellite systems are much lower than those estimated for competing systems. The primary reason for this is the economy of scale resulting from the very large system capacity assumed for the Ka systems as a result of the use of advance spot beam concepts. This provides a much larger number of available voice channels over which to spread the system costs.

While the wider spectrum available at Ka band makes the use of the assumed larger capacities an attractive possibility, much larger capacities could also be achieved at C band and Ku band if fuller use of spot beam technology were to be introduced in these lower frequency bands. Thus, while Ka band offers a wide spectrum, and can thus potentially make better use of economy of scale to reduce costs, the advantage is not as great as a comparison of the costs under discussion might indicate. Re-designing all systems to their maximum capacities would probably result in per channel costs among the satellite systems falling in a much narrower range.

With the exception of SBS's CNS-A service, all of the satellite systems discussed in Table 7-12 are trunking systems. End-to-end costs to the user, therefore, require the addition of local distribution lines which add significantly to end users' overall costs. Tariffs for local, leased, terrestrial voice grade lines vary from state to state, but typically are about $1,000 per year for a twenty-five mile line. Since connection to the satellite trunking system is required at each end, this adds about $2,000 per year to end-to-end costs. When these local loop costs and other terminating charges are included, the relative cost differentials among the various media are further attenuated, but would appear nevertheless, for systems of very high capacity, to favor Ka satellite solutions.

Overall the cost differentials among the various systems are expected to have a stronger impact on costs to the carriers than to the end user. This will particularly be the case in composite systems which combine the capabilities of various media, such as systems that use Ka satellites with back-up provided by lower frequency satellite or terrestrial media. Thus, while Ka satellites may provide an economic solution to a carrier wishing to make large increases in available capacity, the net cost improvement for the final user is likely to be largely negated by the accumulation of costs unrelated to the cost of the long haul transmission media itself.

The various cost estimates for the satellite systems discussed in this chapter are all highly dependent on the traffic volumes assumed. The costs developed for Ka systems are predicated on very large traffic volumes. This assumption is generally consistent with the high capacity available from these systems and leads to low per channel costs. To a lesser extent, however, it is also possible to postulate C and Ku band systems capable of carrying high traffic volumes and the costs of these systems would then be correspondingly reduced.

When all of the above factors are considered, the most reasonable conclusion that can be drawn at the present stage of development of Ka satellite systems, is that end-to-end costs to the user for Ka band service will be comparable to those of equally reliable service provided via other transmission media.

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8.0 Ka BAND MARKET CAPTURE

Ka band satellite communications, as discussed in Chapter 2, shares the advantages and disadvantages of other satellite systems, and has some special characteristics of its own. On the positive side, Ka band systems offer the potential for high volume transmissions in a frequency range as yet unaffected by traffic congestion. Because the frequencies involved are higher, Ka band antennas tend to be smaller, lighter, and more easily deployed. On the negative side, Ka band links require special measures to compensate for rain attenuation.

This section discusses the probable evolution of Ka band systems and describes likely scenarios for the implementation and traffic buildup of such systems. The scenarios selected emphasize general purpose Ka systems capable of serving a wide range of Voice, Video and Data applications rather than special purpose systems intended for a single high volume application.

8.1 SELECTION OF SCENARIOS

Ka band satellite communications systems can operate as self-contained systems, but in doing so face certain problems as a result of their relatively poor reliability. If trunking modes are involved reliability can be improved, at a price, by establishing duplicate Ka band earth stations some 10 to 30 kilometers apart (space diversity) so that the likelihood of both stations being simultaneously rained out is small (see Subsection 5.2.2.3). However, space diversity methods of this type are applicable for Customer Premises Services (CPS) only in a very limited number of situations. Consequently CPS services, if offered by an isolated Ka band system, are likely to be at reliability levels lower than those available from competing transmission facilities (see Subsection 5.2.2.4).

Because of these reliability related limitations of isolated Ka band systems, scenarios in which Ka satellites operate in conjunction with terrestrial long haul facilities, or with lower frequency satellite systems, have some attractive features. Essentially, these combined systems take advantage of the high capacity available at Ka band, while using the more reliable terrestrial or satellite systems for back-up.

In selecting scenarios in which Ka systems play a significant role, it is useful to systematically generate a wide range of alternatives and to select from them those which have a high probability of implementation. Three classes of scenarios are of interest:

(a) Those in which Ka band satellites form an independent system.

(b) Those in which Ka band is used in conjunction with long haul terrestrial facilities.

(c) Those in which Ka band is used in conjunction with lower frequency (C band or Ku band) satellites.

For each of the situations listed above trunking modes, CPS modes, or both are possible, and each mode may be implemented as a higher-cost-high-reliability link or as a lower-cost-low-reliability link. In the following subsections the various combinations possible are displayed and those of interest for further consideration are selected.

8.1.1 SEPARATE Ka BAND CONFIGURATIONS

This subsection considers those configurations in which Ka band satellite communications are established as separate facilities. That is, no alternate long haul route is available to replace the Ka link if an outage occurs. Later subsections consider Ka satellites in conjunction with terrestrial, and with lower frequency satellite systems. Table 8-1 shows various combinations of high and low cost/reliability options together with the trunking and CPS configurations possible. In the context of this Section, high reliability configurations are associated with performance levels equal to or superior to the performance of competing terrestrial communications media (nominally 99.9 percent or above) at comparable cost. Low reliability configurations refer to performance substantially lower than that of competing terrestrial media (99.5 percent or lower) together with a lower cost. As indicated by the check marks appearing in the last column, only two of the eight possible configurations are of interest for isolated Ka band configurations: high reliability trunking, and high reliability trunking in combination with lower reliability CPS. The remainder of the eight possibilities are disqualified for the reasons presented in the numbered footnotes.

TABLE 8-1. SEPARATE Ka BAND CONFIGURATIONS

	MODE		
	TRUNKING	CPS	NOTES
COST/RELIABILITY	HIGH	-	✓
	LOW	-	1
	-	HIGH	2
	-	LOW	1
	HIGH	HIGH	2
	LOW	HIGH	1,2
	HIGH	LOW	✓
	LOW	LOW	1

NOTES: ✓ Likely configuration

1 Not enough demand unless high reliability trunking is included to justify separate Ka system, but may be a possible configuration when Ka is combined with other systems.

2 High reliability CPS mode not applicable at Ka Band.

The rows identified with Note 1 require some amplification. As discussed in Subsection 5.2.3.1, only about 23 percent of overall traffic is estimated to be addressable at reliability levels substantially lower than those provided by competing transmission media, and a 30 to 35 percent cost differential would be required to motivate this degree of user acceptance. Furthermore, as discussed in Subsection 3.5.4, the market for low reliability CPS transmission is estimated to be only 4 to 5 percent of addressable traffic. As a result, in systems where Ka supplies the only long haul facility available, it is not likely that configurations with no trunking capability, or with only low reliability trunking, would attract the high volumes of traffic best suited to the high capacity characteristic of Ka satellite communications. Most of the heavy volume applications using trunking modes (e.g., voice, remote computer access, etc.) are also those requiring relatively high reliability. Those low reliability configurations indicated by Note 1 are therefore not of great interest for an isolated Ka band system where back-up through other systems is lacking. However, if Ka is combined with other trunking systems capable of providing back-up, these configurations (if not disqualified for other reasons) may be worthy of further consideration and are addressed in subsequent scenarios.

Note 2 indicates that, in most cases, real estate and economic considerations rule out the use of the widely separated dual earth stations needed to establish reliable Ka band CPS links. Though possible exceptions to this rule may exist (for example, dual CPS earth stations for Network TV or CATV distribution), widespread use of reliable Ka band CPS transmission is not considered likely.

8.1.2 Ka BAND SYSTEMS COMBINED WITH TERRESTRIAL FACILITIES

This subsection considers Ka band satellite configurations that are likely candidates for use with terrestrial facilities. The overall characteristics of terrestrial links were discussed in Chapter 2. CPS modes in the sense used in this report are not common in terrestrial communications, though some proposed systems (e.g., the rooftop microwave radio distribution system described in Xerox/s XTEN filing (Ref. 1) do fit this description. For practical purposes, however, terrestrial communications falls in the category of reliable trunking facilities.

Ka band satellites can play an important role in support of terrestrial communications. The high capacity and flexibility available with Ka links provides a valuable means of adding major transmission resources to the terrestrial network. If suitable methods of network control and traffic rerouting are employed, the Ka links do not necessarily have to be designed to a high level of reliability, though a choice in this respect remains an option open to the carrier involved. If the low reliability option is selected, the alternate routing capability of the network would be used to direct additional terrestrial facilities to a city affected by a rain induced Ka outage while reassigning to other destinations the Ka capacity normally reserved for that city. The more reliable Ka band option avoids some of these complexities, but of course bears a higher cost for the Ka links.

While the use of Ka links to strengthen the trunking capabilities of a terrestrial network bears little direct relation to CPS applications of Ka, the option of including CPS modes should remain open for two reasons. The first is that this permits the interface of users, who for one reason or another are best served by CPS facilities, with other users of the terrestrial network. Due consideration to the probably less reliable nature of the CPS link is needed and steps should be taken to avoid double satellite hop-routing for those CPS users whose applications are delay sensitive. The second reason to retain the option of adding Ka band CPS capabilities to a basically trunking situation is that a carrier having excess Ka transponder capacity available may find it profitable to seek separate CPS applications to add to the customer base.

Table 8-2 summarizes the previous discussion, and indicates the Ka band configurations most likely to be of value in combination with terrestrial facilities.

Because the primary role of Ka band satellite communications in conjunction with the terrestrial network is to add additional trunking capacity, only those configurations involving some form of trunking are included in this table. Thus the table includes high and low reliability Ka trunking modes both with and without a lower reliability CPS component.

TABLE 8-2. Ka BAND CONFIGURATIONS FOR USE WITH TERRESTRIAL NETWORKS

	MODE		
	TRUNKING	CPS	NOTES
COST/RELIABILITY	HIGH	-	✓
	LOW	-	✓
	HIGH	HIGH	1
	LOW	HIGH	1
	HIGH	LOW	✓
	LOW	LOW	✓

NOTES: ✓ Likely configuration

1 High reliability CPS mode not practical at Ka Band

Note 1 indicates that high reliability CPS modes are not a likely alternative for Ka band satellites. The check-marked configurations provide attractive combinations with terrestrial facilities and will receive further discussion in the sections dealing with scenarios.

8.1.3 Ka SYSTEMS COMBINED WITH LOWER FREQUENCY SATELLITE SYSTEMS

This subsection considers applications of Ka satellites in conjunction with C band and Ku band satellite systems. First the characteristics of C band and Ku band systems are discussed in order to select those configurations likely as possible partners for Ka band systems. The selected C band or Ku band configurations are then combined with various Ka band configurations to arrive at overall configurations that have merit as combined systems.

TABLE 8-3. C OR Ku CONFIGURATIONS SUITABLE FOR USE IN CONJUNCTION WITH Ka SYSTEMS

	MODE		
	TRUNKING	CPS	NOTES
COST/RELIABILITY	HIGH	-	✓
	LOW	-	1
	-	HIGH	✓
	-	LOW	1
	HIGH	HIGH	✓
	LOW	HIGH	1
	HIGH	LOW	1
	LOW	LOW	1

NOTES: ✓ Likely configuration

1. Low reliability systems not useful in conjunction with Ka

Thus, the only C or Ku configurations of interest for combined operation with Ka systems are high reliability trunking, high reliability CPS, or both. The last two of these (involving high reliability CPS modes) may be difficult to achieve in some Ku designs, but only those designs that do achieve the required reliability are of interest in this context.

8.1.3.1 COMBINED Ka BAND AND LOWER FREQUENCY SATELLITE SYSTEMS

Table 8-1 presented a selection of configurations for Ka band systems. With the inclusion of those options identified by Note 1 alone, there are five configurations of interest as candidates for systems which combine Ka with either C or Ku band capabilities.

Similarly, Table 8-3 presented a selection of three C or Ku band configurations of interest as possible candidates for combination with Ka systems.

This subsection considers the various combinations of the Ka and C/Ku configurations referred to above and selects from the fifteen possibilities those of highest promise as viable combined systems.

Table 8-4 presents the various combined configuration options. Across the top are the five Ka configurations selected in Table 8-1 and at the left are the three C/Ku configurations selected in Table 8-3. As in the previous tables the configurations are distinguished by whether trunking and/or CPS modes are offered, and whether these modes are provided as relatively high cost, high reliability services (comparable to existing terrestrial service), or are of lower cost and reliability. The six configurations designated by checkmarks appear to have attractive capabilities. Those configurations designated by numbered notes are of lesser interest for the reason stated in each note and as further discussed below.

Note 1 relates to the fact that the chief advantage of combining Ka systems with either C or Ku systems lies in the back-up capability provided by the presumably more reliable lower frequency band. Under the assumption that the Ka component itself has been designed to an adequately high level of reliability, a large portion of the motivation for combining systems disappears.

Note 2 indicates that unless some high reliability trunking in included in the combined system a large part of the potential market will not be addressed. This same point was made relative to the isolated use of Ka band systems in the discussion and footnotes (Note 1) associated with Table 8-1.

TABLE 8-4 COMBINED Ka AND C OR Ku CONFIGURATIONS

		COST/RELIABILITY				
	Ka-BAND TRUNK	HIGH	-	HIGH	LOW	LOW
	Ka-BAND CPS	-	LOW	LOW	LOW	-
C/Ku BAND TRUNK	**C/Ku BAND CPS**					
HIGH	-	1	3	1	✓	✓
-	HIGH	3	2	✓	2	2
HIGH	HIGH	1	✓	1	✓	✓

NOTES: ✓ Likely configuration

1 Unnecessary Duplication of High Reliability Trunking

2 Systems without some high reliability trunking are not attractive to many important applications even at reduced cost

3 Basically independent Ka and C/Ku systems.

Note 3 points out that while the indicated configurations are conceptually feasible as combined systems, in practice they have very little interrelation. For example, the technology and market base for high reliability C/Ku trunking services is so distinct from the technology and market base for Ka Band CPS that they are best considered as separate and independent systems. The same consideration applies to the combination of high reliability C/Ku band CPS with high reliability Ka band trunking. The technology and applications of the two component systems are sufficiently diverse that little benefit arises from consideration of these as a unified combined system.

8.1.4 SUMMARY OF SELECTED CONFIGURATIONS

The configurations which, based on the previous analysis, appear most attractive for potential future development are the two checkmarked stand-alone configurations shown in Table 8-1, the four checkmarked Ka/Terrestrial configurations shown in Table 8-2, and the six checkmarked combined Ka and C or Ku systems shown in Table 8-4.

These configurations are summarized in Table 8-5 and will be further discussed in the more detailed scenario development contained in the remainder of this chapter. In most of the configurations summarized in Table 8-5, where Ka supplements a similar mode supported also terrestrially or at C or Ku band, the Ka portion of the system provides high volume bulk transmission capacity to enlarge the overall capability of the combined system, while the terrestrial or lower frequency satellite component improves overall system reliability.

TABLE 8-5 SUMMARY OF ATTRACTIVE CONFIGURATIONS INVOLVING Ka-BAND SATELLITE SERVICES

SYSTEM TYPE	CONFIG. NUMBER		TERRESTRIAL OR C/Ku CONFIGURATION	Ka-BAND SATELLITE CONFIGURATION
STANDALONE Ka CONFIGURATIONS	1	a	N/A	HIGH RELIABILITY Ka TRUNKING
		b	N/A	HIGH RELIABILITY Ka TRUNKING PLUS LOW RELIABILITY CPS
Ka IN COMBINATION WITH TERRESTRIAL FACILITIES	2	a	HIGH RELIABILITY TERRESTRIAL TRUNKING	LOW RELIABILITY Ka TRUNKING
		b	"	LOW RELIABILITY Ka TRUNKING PLUS LOW RELIABILITY CPS
	3	a	"	HIGH RELIABILITY Ka TRUNKING
		b	"	HIGH RELIABILITY Ka TRUNKING PLUS LOW RELIABILITY CPS
Ka IN COMBINATION WITH C OR Ku SATELLITES	4	a	HIGH RELIABILITY C OR Ku TRUNKING	LOW RELIABILITY Ka TRUNKING
		b	"	LOW RELIABILITY Ka TRUNKING PLUS LOW RELIABILITY CPS
	5	a	HIGH RELIABILITY C OR Ku TRUNKING PLUS CPS	LOW RELIABILITY Ka TRUNKING
		b	"	LOW RELIABILITY Ka CPS
		c	"	LOW RELIABILITY Ka TRUNKING PLUS LOW RELIABILITY CPS
	6	-	HIGH RELIABILITY C OR Ku CUSTOMER PREMISES SERVICE	HIGH RELIABILITY Ka TRUNKING PLUS LOW RELIABILITY CPS

8.2 EVOLUTION OF Ka SATELLITE SERVICES

The following sections examine various ways in which Ka satellite systems may evolve, either as stand-alone facilities, or in conjunction with terrestrial or lower frequency satellite systems. For each of the configurations summarized in Table 8-5, a scenario is presented for the development of Ka band satellite facilities and the build-up of traffic on these facilities.

Ka band satellite links have technical characteristics which in general are similar to those of other satellite links. However, because of outages caused by rainstorms, the level of reliability provided may be lower than that otherwise available. In order to address the high volume of communications traffic which requires reliability levels equal to those typical of competing communications media (see Subsection 5.2.3.1), the reliability performance of Ka satellite links must be improved. This may be achieved by using separated Ka earth stations in a dual diversity mode, as discussed in Subsection 5.2.2.3, or by associating spare capacity in a more reliable system (terrestrial or lower frequency satellite) as back-up to the Ka links, as discussed in some of the scenarios presented later in this chapter. It is assumed in the following discussion that one or the other of these methods will be used to arrive at reliability levels for trunking applications equivalent to those of other competing transmission media. It is also assumed, as per the discussion in Subsection 5.2.2.4, that Ka band CPS will be of lower reliability.

While the high volume usages projected for Ka satellite systems in the following scenarios will tend to promote reduced per-channel costs, it is not possible at the present state of development of Ka satellite systems to be definitive in making cost comparisons with other systems. As pointed out in Chapter 7, when all cost factors are included, the cost to an end user of communications services is only partially determined by the cost of the long haul transmission link. A conservative approach to estimating demand for Ka satellite services, therefore, is to assume that Ka satellite costs will be comparable to those of other, more mature, systems offering competitive services at the equivalent level of reliability. The scenarios discussed in the following pages, therefore, establish factors other than cost as the basis for the postulated growth of Ka systems. The most potent factor of this type is the growing demand for communications capacity relative to the limited expansion capabilities of competing media. Limitations to the expansion of terrestrial media are discussed in Subsection 2.1.1, and those relative to the possible growth of C and Ku band satellite systems are discussed in Chapter 6. Even if the cost/reliability performance of potential Ka band systems is essentially no different than that of existing media, the continuing pressure for additional channels and services will motivate the implementation of these high capacity systems. The scenarios presented in the following sections are, therefore, predicated on the assumption that the demand for capacity will exceed that which is likely to be available through competing communications media. The traffic estimates summarized in Section 1.3 showing a five-fold growth in demand over the next two decades, and the capacity estimates presented in Section 6.5 appear to provide adequate justification for this assumption.

8.3 SCENARIO 1 - Ka SATELLITES IN STAND-ALONE CONFIGURATIONS: (a) HIGH RELIABILITY Ka TRUNKING (b) HIGH RELIABILITY Ka TRUNKING WITH CPS

This section discusses Ka satellite facilities operated as relatively isolated systems, without significant access to other long haul communications plant. It is assumed, however, that where needed, local distribution between Ka satellite earth stations and the end users can be accommodated by interconnection with various common carrier supplied local facilities.

8.3.1 DESCRIPTION OF SERVICE

Because the Ka configurations discussed under this scenario lack connection to other long haul facilities, backup of the Ka links through these other media is not possible. The reliable long haul links needed to satisfy major portions of projected communications demand (see Subsection 5.2.3.1) must be supplied by the Ka system itself and cannot be derived by alternate routing through long haul terrestrial facilities, or through lower frequency satellite systems. It is assumed, therefore, that the Ka trunking service will employ diversity earth stations to provide a level of reliability comparable to that of most existing communications. As discussed in Subsection 5.2.2.4, however, dual diversity is not a practical option for Ka band CPS, so that service to "rooftop" antennas at the customer's location will be of lower reliability.

8.3.2 MARKET POTENTIAL

This Subsection discusses the voice, video and data traffic that is suitable for, and can be addressed by, the stand-alone Ka satellite systems that are the subject of Scenarios 1a and 1b. Traffic is considered to be addressable if there is no reason which prevents, or highly discourages, the transmission of that traffic by Ka satellites under the scenario being considered.

Table 8-6 refers to the stand-alone, high reliability, trunking configuration of Scenario 1a. The first column, labeled "Target for Ka," provides estimates of the percentage of the traffic demand projected in Table 1-1 that can be effectively addressed by Ka satellites under this scenario. The basis for these estimates is summarized in the footnotes to Table 8-6 and is further discussed in Subsections 8.3.2.1 through 8.3.2.4.

TABLE 8-6 ADDRESSABLE TRAFFIC FOR Ka SATELLITES UNDER SCENARIO 1a. HIGH RELIABILITY Ka TRUNKING.

COMMUNICATIONS SUBCATEGORY	TARGET FOR Ka PERCENT	ADDRESSABLE* (BITS/YR$\times 10^{15}$) 1990	2000	COMMENTS
RESIDENTIAL	10	19.7	37.8	1,2
BUSINESS (SWITCHED SVC.)	10	60.0	107.6	1,2
BUSINESS (PVT. OR LEASED LINE)	100	1453.0	3440.0	2
TOTAL VOICE	-	1532.7	3585.4	
NETWORK TV	20	3.2	2.2	3
CATV	20	6.6	5.4	3
EDUCATIONAL VIDEO	20	7.6	22.6	3
VIDEOCONFERENCING	40	33.6	107.2	3
TOTAL VIDEO	-	51.0	137.4	
FACSIMILE	50	1.0	2.0	4
ELECTRONIC MAIL	90	5.4	6.3	5
COMPUTER	82	223.0	346.9	4
TOTAL DATA	-	229.4	355.2	
TOTAL TRAFFIC		1813.1	4078.0	

*TARGET FOR Ka TIMES DEMAND FROM TABLE 1-1

1. SWITCHED SERVICE BETTER ADDRESSED IN SCENARIOS WHERE SATELLITE LINKS ARE INTEGRATED AND MANAGED WITH TERRESTRIAL FACILITIES.
2. ASSUMES AVAILABILITY OF COST EFFECTIVE ECHO CANCELLERS.
3. WIDEBAND SERVICES UNDER TRUNKING LIMITED BY LOCAL DISTRIBUTION PROBLEMS.
4. PRIMARILY DEDICATED TRAFFIC PLUS A SMALL PERCENTAGE OF SWITCHED TRAFFIC.
5. PRIMARILY DEDICATED TRAFFIC, INCLUDING A LARGE POSTAL SERVICE COMPONENT.

TABLE 8-7 ADDRESSABLE TRAFFIC FOR Ka SATELLITES UNDER SCENARIO 1b.
HIGH RELIABILITY Ka TRUNKING WITH LOWER RELIABILITY CPS.

	TRUNKING			CPS			
COMMUNICATIONS SUBCATEGORY	TARGET FOR Ka PERCENT	ADDRESSABLE (BITS/YRx10^{15})* 1990	2000	TARGET FOR Ka PERCENT	ADDRESSABLE (BITS/YRx10^{15})* 1990	2000	COMMENTS
RESIDENTIAL	10	19.7	37.8	0	0	0	1
BUSINESS (SWITCHED SVC.)	10	60.0	107.6	0	0	0	1
BUS. (PVT. OR LEASED LINE)	97	1409.4	3336.8	3	43.6	103.2	1
TOTAL VOICE	-	1489.1	3482.2	-	43.6	103.2	1
NETWORK TV	20	3.2	2.2	38	6.1	4.2	2
CATV	20	6.6	5.4	48	15.8	13.0	2
EDUCATIONAL VIDEO	20	7.6	22.6	34	12.9	38.4	2
VIDEOCONFERENCING	40	33.6	107.2	30	25.2	80.4	2
TOTAL VIDEO	-	51.0	137.4	-	60.0	136.0	2
FACSIMILE	42	0.8	1.7	8	0.2	0.3	1
ELECTRONIC MAIL	21	1.3	1.5	69	4.1	4.8	1
COMPUTER	79	214.9	334.2	3	8.1	12.7	1
TOTAL DATA	-	217.0	337.4	-	12.4	17.8	1
TOTAL TRAFFIC		1757.1	3957.0		116.0	257.0	

*TARGET FOR Ka TIMES DEMAND FROM TABLE 1-1

1. SUM OF TRUNKING AND CPS SAME AS SCENARIO 1a. CPS PORTION AS PER TABLE 3-2.

2. TRUNKING COMPONENT SAME AS SCENARIO 1a. CPS PROVIDES ADDITIONAL CAPABILITY TO ADDRESS TRAFFIC AS PER TABLE 3-2.

By multiplying the target percentages of Table 8-5 by the demand projections of Table 1-1, the addressable traffic shown in the last two columns of Table 8-6 for the years 1990 and 2000 is arrived at. Since only trunking is available under Scenario 1a, applications that can equally well use either trunking or CPS modes are included in these estimates.

Table 8-7 accomplishes the same functions for Scenario 1b. In this case, separate estimates are provided for the traffic addressable by trunking and by CPS. Table 3-2 is used as a guide in arriving at the percentages addressable by CPS. In some traffic categories (voice and data) traffic adaptable to either trunking or CPS, which was allocated to the trunking mode in Table 8-6, has been reallocated in Table 8-7 to CPS modes to reflect user preference for this mode if it is available. In the video categories the inclusion of a CPS capability allows the Ka satellite system to address traffic that would otherwise not be carried via trunking. Further discussion of these estimates is contained in the following subsections.

8.3.2.1 VOICE

Voice applications represent the largest single component of the overall communications demand projected in Table 1-1. The largest portion of long distance voice traffic is business oriented, but a sizable component results also from residential use.

The residential component of voice traffic is almost exclusively carried on the common user switched telephone network, and is delivered to the home via dominant common carrier switches and local loops. It would be difficult for the separate long haul satellite facilities postulated in this scenario to successfully address a major portion of this residential switched voice traffic. In the long term, a satellite system closely integrated with, and managed with, the terrestrial network can best serve this switched traffic component. Arrangements of this type are discussed under Scenarios 2 and 3.

Similar considerations apply to the switched components of business voice traffic. An essential feature of this service is wide distribution and the capability of reaching a multiplicity of users through terrestrial switched telephone facilities. An isolated separately managed Ka trunking system would not be well adapted to this traffic. Thus, only a small portion (10 percent) of switched business or residential traffic is indicated in Table 8-6 as an addressable target for Ka satellite systems under this stand-alone trunking scenario. The same percentage is assumed for trunking under Scenario 1b, as indicated in Table 8-7. As discussed in Section 3.5 these switched voice traffic components are not well suited for CPS and essentially none of this traffic can be addressed in the latter mode.

A significant component of business voice traffic is carried via dedicated facilities on leased lines. Corporations and various state and federal agencies with substantial traffic volumes between their dispersed facilities find it economically attractive to link their facilities by networks of lines leased from common carriers, rather than to route these large amounts of intracompany traffic via the common user switched network. Dedicated voice service, in applications such as these, forms an excellent target for the isolated Ka facilities considered in this scenario, provided that echo cancelers are used to eliminate echoes, and that costs are competitive with those of other media. Since there is no reason preventing Ka satellite systems, under this scenario, from competing effectively on an equal basis with other transmission media, the target assigned in Table 8-6 is 100 percent. With the addition of a CPS capability in Scenario 1b, this traffic will divide between trunking and CPS modes with the limitations discussed in Section 3.5 restricting the CPS share, as indicated in Table 8-7, to only 3 percent.

8.3.2.2 VIDEO

Video signals require wide bandwidths for their transmission. As indicated in Subsection 6.3.2, depending on the application and the degree of signal compression used, a single video transmission occupies communications resources equivalent to many voice channels. The problem of local distribution is therefore a significant one for the trunking configuration of Scenario 1a. CPS modes, which avoid local distribution problems, tend to be preferable to trunking for most video applications. In view of this preference for CPS modes, the trunking configuration represented in Table 8-6 is indicated as addressing only 20 percent of the broadcast mode (Network TV, CATV, and Educational Video) video applications.

Table 8-7, referring to Scenario 1b, indicates the same addressable traffic percentage for the trunking component but supplements this with additional traffic for the CPS capability. The main limitation to the applicability of Ka band CPS for broadcast video is the limited reliability of this mode. Ka band CPS can effectively address only the deferred portion of broadcast video, using video recorders to accept the signal for later local transmission. Percentages appropriate to CPS are developed in Table 3-2 and used in Table 8-7.

For the important traffic category of videoconferencing, trunking allows greater flexibility in the establishments of the conference. The bandwidths required for videoconferencing are generally more modest than those for the broadcast video categories discussed above, which also encourages trunking approaches. In addition, as videoconferencing evolves from a dedicated intracompany service satisfactorily served by CPS, toward the more frequent use of ad hoc conferences set up between organizations not necessarily equipped for CPS, the use of trunking becomes more desirable. The addressable traffic estimates for trunking in Tables 8-6 and 8-7 have been increased to reflect these trends. The estimates for videoconferencing traffic suitable for CPS are consistent with those of Table 3-2.

8.3.2.3 DATA

Data traffic is similar to voice as far as addressability under this scenario is concerned. The switched components, requiring distribution, are not well served by the stand-alone configurations of the scenario, whereas the dedicated components, using leased line intracompany transmissions, form an excellent target.

About 50 percent of facsimile traffic is estimated to be addressable under Scenario 1a. This is primarily composed of bulk mailroom and other leased line facsimile services, and includes only a small fraction of the switched mode operation typical of in-office convenience facsimile. Under Scenario 1b this traffic divides between trunking and CPS modes with CPS receiving the percentage presented in Table 3-2.

Electronic mail, including the large component of bulk postal system transmissions between post offices predicted for the future, is well adapted to these scenarios. Some small portion of electronic mail, however, will need the wide distribution and switched capabilities more appr- priate to other scenarios. A large part of the 90 percer target estimated for trunking in Scenario 1a is expecte to be diverted to CPS modes in Scenario 1b as per Table -2.

A large portion of computer traffic requires dedicated facilities. All of this, plus a small fraction of the switched mode traffic, is considered a good target for Ka satellites under this scenario. With the added capability of CPS about 3 percent (as per Table 3-2) of the trunking traffic is diverted to CPS.

8.3.2.4 SUMMARY OF ADDRESSABLE TRAFFIC

Of the total traffic volume of 2701×10^{15} bits per year projected in Table 1-1 for 1990, 1813×10^{15} bits per year, or 67 percent, are addressable by Ka satellites in the stand-alone, high reliability trunking configuration represented in Table 8-6. For the year 2000 the addressable traffic increases to 71 percent of total projected volume.

In general, the addition of CPS to the high reliability trunking mode as reflected in Table 8-7 does not have a dramatic effect on the amount of traffic that can be addressed. The major components of CPS traffic fall in the Video categories where freedom from local distribution problems are an important advantage. However, the lower reliability levels available with stand-alone Ka band CPS permit this mode to address only the deferred, non-real-time portion of video traffic. The lower reliability level also prevents the addressing, by this CPS configuration, of most of the large volume voice and computer applications. As a result, the total traffic addressable by trunking plus CPS in this stand-alone Ka configuration is about six percent of that addressable by trunking. Overall, the addition of a CPS capability increases the total traffic addressable by only 3 percent compared to that addressable by trunking alone. It should be noted, however, that most of this CPS traffic is due to wideband video requirements that would not be readily addressable by trunking alone.

8.3.3 OWNERSHIP AND OPERATION

This section discusses the development of stand-alone Ka configurations with respect to commercial ownership and operation. Since the Ka system under this scenario will operate in a stand-alone mode, it is not necessary for a carrier contemplating its development to be able to supply alternate long haul terrestrial or satellite facilities. Thus these stand-alone configurations impose the fewest qualifying restrictions on ownership and operation.

The prime role of Ka satellite communications is the provision of bulk high volume capacity in response to the emergence of heavy traffic demand across a broad spectrum of applications. For this reason the scenarios selected for Ka satellites emphasize high reliability trunking which is capable of addressing the largest portion of the traffic projected. CPS can address only a much smaller fraction of the traffic but may be offered in addition to trunking to address those organizations with sufficient traffic to justify a dedicated earth station, or to address those applications where CPS offers a cost effective solution to wideband local distribution problems.

The traffic volume projected for CPS in Table 8-7, while only a small fraction of total volume, in absolute magnitude is large enough to justify several satellites in orbit. For example, Table 6-4 estimates that the per satellite digital throughput of Ku band transponders will range between 30.7×10^{15} and 60.0×10^{15} bits per year. If Ka satellites have comparable capacity, the CPS addressable traffic shown in Table 8-7 if fully captured would require four to eight satellites for the year 2000. Conceivably, therefore, a common carrier might choose to develop a special purpose stand-alone system to serve only this CPS market. Such a system might concentrate primarily on a limited market sector such as videoconferencing and/or deferred mode television traffic. Realistically, however, it must be recognized that competing media will also obtain their share of this market so that the Ka portion will only be a fraction of the total potential traffic. More important, the Ka resource in such a limited approach would not be employed in its prime role, that of supplying bulk high volume capacity in response to emerging heavy demand across a broad spectrum of applications. Thus a common carrier adopting this approach would be faced with the substantial costs of developing a new and high capacity medium while restricting usage to only a small fraction of its potential capacity. For this reason, the development of Ka satellite systems in restricted volume CPS configurations is not considered likely as a long term market venture, though it might provide an easy mode of entry into this marketplace as part of a plan for gradual expansion to the larger markets available to trunking systems.

If the broader market appropriate to Ka stand-alone high reliability trunking (with or without CPS) is to be addressed, it is probably necessary for common carriers considering such a development to be among the larger size organizations. Large financial resources will be needed to allow for amortization of development costs while volume grows to levels that bring economy of scale to bear.

An important distinction exists between AT&T and other common carriers because of the ownership by AT&T of extensive long haul terrestrial facilities. The present scenario does not include mutual support between the stand-alone Ka facilities and the terrestrial plant, but if AT&T were to develop a Ka satellite system it is logical to assume that the Ka system would be integrated with the terrestrial plant. As discussed later in Scenarios 2 and 3, such integration can economically solve many of the rain outage problems of Ka satellites while providing large increases in terrestrial plant capacity. Thus, if AT&T were to develop a Ka satellite system it would probably not choose the stand-alone Ka configurations being considered here.

In overall concept, and in the markets addressed, a stand-alone Ka system parallels that proposed for SBS (Ref. 3) with the transmission band relocated from Ku band (14/12 MHz) to Ka band (30/20 GHz). Emphasis on business oriented dedicated network traffic is common to both cases as a result of the inability to effectively address the common user switched voice and data component of traffic. SBS originally emphasized CPS operation and later broadened its concept by allowing shared use of earth stations in what amounts to a trunking configuration. The high capacity nature of Ka systems points to the same solution but reverses the sequence to emphasize trunking with broadening of the concept to include CPS. Another similarity between SBS and this Ka band scenario is that both use frequencies at which a reliability level comparable to other media is difficult to obtain without special effort, a factor which is of importance with respect to the ability to address various classes of traffic.

It is interesting to note that the original plans for SBS called for a pre-operational program at C band with the second phase, operational system, using Ku band. It would not be too difficult to imagine a next generation system with Ka band replacing Ku band as expanding traffic demand and technical capability might dictate.

8.3.4 GROWTH OF Ka SERVICES

This section discusses the potential development of Ka satellite communications under this scenario and provides estimates of the growth of Ka traffic as a function of time.

Tables 8-6 and 8-7 form a starting point for the analysis. These tables provide estimates of the amount of traffic that is addressable by Ka satellites. A traffic component is considered to be addressable if there are no strong technical or operational factors which prevent Ka satellites from competing for the traffic. Ka satellite systems, however, will capture only a portion of the addressable traffic since other competing terrestrial and satellite media will also address this traffic.

Furthermore, the amount of traffic captured by Ka systems will initially be low and will gradually increase over a number of years before the full capturable share is obtained. The following sections evaluate the share of traffic expected for Ka systems and the time frame for the build-up of this traffic.

8.3.4.1 GROWTH MODEL

The prediction of the amount of traffic that will be captured by Ka satellites, and the growth rate at which this traffic capture will proceed, is subject to the usual uncertainties that attend long range forecasts. Not only is a prediction of this type highly dependent on the specific technical, operational and economic characteristics of the Ka satellite system itself, but it is also highly dependent on the same factors operating with respect to the other media that compete with Ka satellites. A large increase in terrestrial capacity, for example, perhaps brought about by large scale installations of fiber optics, might dramatically influence the market share captured by Ka satellites without regard to the availability and capability of the satellite system itself.

Forecasts for the growth of Ka satellite services must therefore rely heavily on value judgments and past experience, and such forecasts unavoidably carry with them a large component of uncertainty. There are, however, some procedures or models which help in systematizing the forecasting process, and which have the virtue of making the value judgments visible and subject to sensitivity analysis. The path taken in forming the projection can be followed and repeated with modifications to improve the forecast accuracy as developing real world events may suggest.

The model used in this report is based on the Gompertz Curve (Ref. 4), a relatively simple "S" shaped function which is extensively used in modeling the growth of new technology. A recent application of the Gompertz curve to the forecasting of communications traffic volumes may be found in the 1978 Xerox Corp. Petition for Rule Making before the FCC(Ref. 1).

The basic form of the Compertz curve is:

$$Y = CA^{B^t}; \quad A<1, \quad B<1$$

where

Y is the value of the growth function being modeled. Y approaches 0 for large negative values of t and approaches C for large positive values of t.

t is the time variable.

C is a scale constant used to fit the equation to the final value approached.

A is a constant equal to the fraction of the final value that has already occurred at t=0.

B is a constant that adjusts the time scale of the growth.

Figure 8-1 shows a set of three Gompertz curves normalized by setting C equal to 1. As a result the normalized curves approach a final value of unity. In actual application C is set to whatever final value is appropriate to the growth process being modeled. For illustrative purposes, in all three cases the constant A has been given the value 0.1 so that, at time t=0, each of the curves has grown to 10 percent of its final value. Three different values of B have been selected which cause the curves to reach 90 percent of their final values at the end of five, ten, and fifteen years respectively.*

In applying the model to the forecasting of Ka satellite traffic growth under this scenario, each component of the addressable traffic listed in Tables 8-6 and 8-7 is considered in turn. A Gompertz curve is then fitted to each traffic component by assigning values to the parameters C, A and B. The curves representing the individual traffic components are then summed year-by-year to arrive at the overall evolution of traffic appropriate to the scenario.

8.3.4.2 SELECTION OF PARAMETERS

Allowing for the many engineering, test and organizational procedures necessary for the launching of a program of this size, it is assumed that Ka satellite systems will become operational around 1990. This time frame also coincides with previous estimates of the time at which other satellite media will be approaching saturation. It is reasonable to assume that by the start of operations in 1990 some pre-selling of Ka capacity will have been accomplished, and that at least a minimum penetration of the potential market will exist. For each traffic subcategory the percentage of the final long term capturable goal expected to be presold by 1990 has been estimated, thereby establishing values for the constant A in the Gompertz curves.

The constant B, which dictates the rate of growth of capturable traffic beyond the year 1990, is also individually selected for each traffic component, in each scenario, according to the technical and operational factors which pertain to

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*The value of B is related to the number of years N that are required for growth from the initial value of Ax100% to 90% of the final value by the equation:

$$B = (\log .9 \div \log A)^{1/N}$$

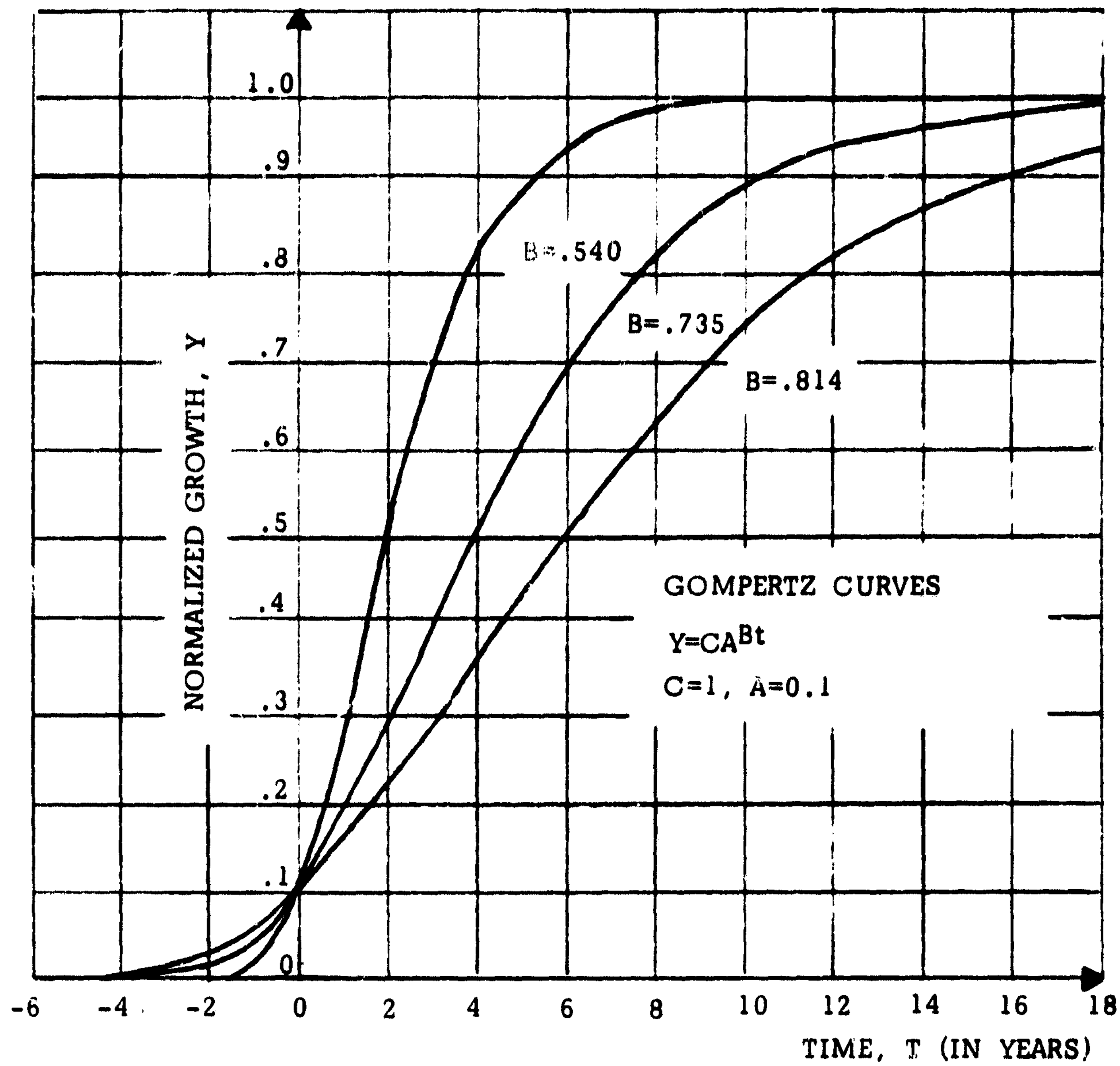


FIGURE 8-1 NORMALIZED GOMPERTZ CURVES REARCHING 90 PERCENT OF FINAL VALUE IN 5, 10 AND 15 YEARS RESPECTIVELY.

C-3

that component. In general, growth to 90 percent of the final capturable traffic will fall in the range of five to fifteen years following growth patterns exemplified by the curves in Figure 8-1.

The most critical parameter of the Gompertz curve is C which provides an estimate of the traffic volume competitively achieved by Ka satellites in the long term. The value of C is arrived at by estimating the percentage of the traffic addressable in the year 2000 deemed capturable by Ka satellites. Separate values will be selected for C for each traffic component addressable under the scenario in question.

As background for the selection of values for C, the basic role of Ka satellites in providing high volume transmission capacity should be kept in mind. As growing demand overtakes the capacity of terrestrial and other satellite media the excess traffic will tend to gravitate to Ka satellites. Table 6-5 provides rough estimates of the capacity of various communications media to support communications in the year 2000. The capacity of terrestrial, C band and Ku band systems total 69 percent of overall demand. If Ka systems capture only the overflow traffic above this 69 percent the market share for Ka in general would be around 31 percent. Furthermore, for some traffic components, Ka systems can be expected to compete on a more favorable basis with other media rather than accepting overflow traffic only. For example, if preference is given to terrestrial transmission, but all satellite media compete on an equal footing in proportion to total available capacity, the share for Ka satellites rises to about 38 percent. This value remains essentially unchanged if C band satellite transmission is included with the favored terrestrial modes. If Ka band service is able to compete for some traffic categories on a completely equal basis with all other media, the available capacity of Ka band would tend to favor capture by Ka band satellites of 47 percent of the total traffic. Lastly, for those traffic components which are not well adapted to terrestrial transmission and which are divided in proportion to capacity among satellite media only, the share for Ka may be as high as 73 percent.

While the preceding gross estimates are subject to large uncertainties, they nevertheless serve a useful function in suggesting that long term capture percentages for Ka satellites are likely to be relatively high. If a particular traffic component has no compelling technical or operational characteristics which either favors or discourages transmission by Ka satellite, capture by Ka media of 31 to 73 percent of the year 2000 addressable traffic as appropriate to each component suggests itself as a suitable estimate for long term capture. In the following pages the Gompertz curve parameter C is selected to reflect this level according to the competitive position expected for the traffic component in question. In those instances in which special reasons are adduced favoring or discouraging the use of Ka satellites, the value of C is correspondingly adjusted upward or downward from values in this range.

8.3.4.3 APPLICATION OF THE MODEL

The procedures and considerations described above are applied here to the scenario for the development of Ka satellites in stand-alone configurations. Table 8-8 refers to the high reliability trunking configurations. The first column presents the year 2000 addressable traffic for each traffic category as obtained from Table 8-6. The second column lists the percentage of this addressable traffic which is estimated to be capturable in the long term by Ka satellite systems. The combination of these two columns results in the estimated long term traffic captured by Ka satellites and corresponds to the value of the constant C to be used in the Gompertz curve. The third column provides estimates of the percentage of the long term capturable traffic captured by the beginning of operations nominally assumed to occur in 1990. The parameter A for the Gompertz curve is the fraction corresponding to this value. The last column presents estimates for the number of years, N, needed for each traffic component to grow to 90 percent of its final value. Since N is directly translatable to the parameter B of the Gompertz curve, all three needed parameters are derivable from the information presented in the table.

As discussed earlier the switched components of voice traffic, whether residential or business oriented, are not strongly addressed under this scenario, being considered more suitable to scenarios with stronger ties to terrestrial facilities. Private or leased line business voice traffic, however, is an attractive target for the stand-alone high reliability trunking configuration being considered, and represents the largest component of traffic listed in Table 8-8. Voice

TABLE 8-8 TRAFFIC CAPTURED UNDER SCENARIO 1a.
HIGH RELIABILITY Ka TRUNKING.

	COMMUNICATIONS SUBCATEGORY	YEAR 2000 * ADDRESSABLE TRAFFIC BITS/YRx10^{15}	LONG TERM Ka CAPTURABLE PERCENTAGE	% OF LONG TERM TRAFFIC CAPTURED BY 1990	YEARS AFTER 1990 TO REACH 90%
VOICE	RESIDENTIAL	37.8	38	5	12
	BUSINESS (SWITCHED SVC.)	107.6	38	5	12
	BUS. (PVT. OR LEASED LINE)	3440.0	38	10	12
VIDEO	NETWORK TV	2.2	10	15	10
	CATV	5.4	10	15	10
	EDUCATIONAL VIDEO	22.6	50	5	10
	VIDEOCONFERENCING	107.2	78	5	15
DATA	FACSIMILE	2.0	46	10	10
	ELECTRONIC MAIL	6.3	80	10	15
	COMPUTER	346.9	38	10	10

*YEAR 2000 ADDRESSABLE TRAFFIC FROM TABLE 8-6

traffic is also an attractive and significant target for terrestrial and other satellite media which are likely to be well established at the time Ka systems become operable. Thus competition for this market can be expected to be high. Furthermore, Ka satellite systems share with other satellite systems the problems of echo and time delay. While new echo canceler equipment has removed much of this difficulty, there is still some uncertainty in the degree to which the public will accept two-way satellite links using these devices.

For the reasons discussed above, terrestrial media are likely to take priority in capturing the voice market with Ka satellites tending to share the overflow with other satellite media. A division of this overflow roughly in proportion to the satellite capacities projected for the year 2000 results in the 38 percent of addressable traffic estimated in Table 8-8 as the long term capture potential of Ka media. It is projected that intensive marketing will result in a presold share of ten percent of the long term goal for the attractive dedicated business voice traffic by the start of operations in 1990. The less attractive, for this scenario, switched voice components are expected to be presold only to the five percent level. For all three voice components a twelve year development period is assumed for the capture of 90 percent of the long term goal.

The newer video applications in education (and in health and public affairs applications included in this category) are assigned capture percentages of 50 percent. Since these are new services, well adapted to the flexible capabilities of Ka satellites, the competitive position of Ka satellites is good. A five percent initial capture by 1990 and a ten year development period is estimated. A much smaller capture percentage is envisioned for the more conventional CATV and Network TV components. These will be firmly established on other competing media and may be difficult to relocate to Ka satellites. However, because these are better established and more conventional applications, a higher initial capture of 15 percent is estimated and the development period is shortened to ten years.

Videoconferencing, as a large scale activity, is a new source of traffic demand projected for the future and established markets have not yet been solidified by competing media. The chief competition is expected from Ku band satellite systems, but Ka band provides a larger reserve of the wide bandwidth capabilities needed for this type of traffic. An aggressive sales approach should therefore be successful in capturing a large portion (estimated at 78 percent on the basis of available capacities) of this traffic for Ka satellites. The wide bandwidths required put the Ka satellite medium in a good position to compete on favorable terms with other media of more restricted bandwidth. As indicated in Table 8-8 the time scale for the emergence of videoconferencing is projected to be fifteen years. This allows for slowly developing user acceptance and increased usage motivated by the escalating costs of travel and executive time. Preselling of capacity before the start of Ka operations in 1990 is estimated to amount to only 5 percent of the long term capturable traffic for the same reasons.

Long term capture by Ka satellites of deferred traffic in facsimile and electronic mail applications is estimated to be 47 percent and 80 percent respectively. Ka satellites are well qualified, as are all the other transmission media, for these technically undemanding and desirable traffic components. The value assigned to facsimile is consistent with an assumed equal competition among all media in proportion to available capacity for this traffic. The higher long term capture ratio assigned to Electronic Mail reflects a reasonable expectation that large scale postal service applications can be effectively addressed by a special purpose Ka satellite sub-network using non-peak hour capacity, and that this traffic category will form an important sales target for Ka satellites. The fifteen year development period allows for the transfer of significant portions of first class mail from present day physical transportation modes to electronic transmissions.

The relatively large volume of dedicated computer traffic forms an excellent target for Ka satellites. Delay and echo effects are not as significant a deterrent as for voice. Overall long term capture is expected to be about the same as for leased line voice. The field of data transmission is fast moving and technically advanced. New techniques and approaches are adopted with relative ease. In view of this, but with due regard to the high volumes involved, a ten year growth to 90 percent of the long term value is projected starting from an initial value in 1990 of ten percent.

Table 8-9 repeats the procedure just discussed for the case of Ka satellites with the high reliability trunking configuration supplemented with a lower reliability CPS capability (Scenario 1b). The first column represents the total addressable trunking and CPS traffic in the year 2000 as obtained by combining these components from Table 8-7. The main effect of introducing the lower reliability CPS capability is to increase the traffic addressable in the video categories where local distribution problems might otherwise be a significant deterrent. Other than this, the only change expected is the redistribution of addressable traffic between trunking and CPS modes indicated in Table 8-7 which does not affect the total addressable traffic shown in Table 8-9. The percentages of traffic capturable, initially and in the long term, and the number of years required for growth, are unchanged between Scenarios 1a and 1b.

The entries in Tables 8-8 and 8-9 are used to arrive at parameters for the Gompertz curves describing the projected growth of each traffic component. The components are then summed year-by-year to obtain the projected overall growth curves for Ka satellite traffic presented in Figure 8-2. Table 8-10 summarizes the projected growth for Scenarios 1a and 1b in tabular form and compares the traffic expected on Ka satellites with the overall addressable traffic. The years 1990, 1995 and 2000 are represented with the addressable traffic for 1995 being calculated for each traffic category as the geometric mean between that of 1990 and 2000.

TABLE 8-9 TRAFFIC CAPTURED UNDER SCENARIO 1b.
HIGH RELIABILITY Ka TRUNKING WITH LOWER RELIABILITY CPS.

	COMMUNICATIONS SUBCATEGORY	YEAR 2000 * ADDRESSABLE TRAFFIC BITS/YRx10^{15}	LONG TERM Ka CAPTURABLE PERCENTAGE	% OF LONG TERM TRAFFIC CAPTURED BY 1990	YEARS AFTER 1990 TO REACH 90%
VOICE	RESIDENTIAL	37.8	38	5	12
	BUSINESS (SWITCHED SVC.)	107.6	38	5	12
	BUS. (PVT. OR LEASED LINE)	3440.0	38	10	12
VIDEO	NETWORK TV	6.4	10	15	10
	CATV	18.4	10	15	10
	EDUCATIONAL VIDEO	61.0	50	5	10
	VIDEOCONFERENCING	187.6	78	5	15
DATA	FACSIMILE	2.0	46	10	10
	ELECTRONIC MAIL	6.3	80	10	15
	COMPUTER	346.9	38	10	10

*YEAR 2000 TRUNKING PLUS CPS ADDRESSABLE TRAFFIC FROM TABLE 8-7

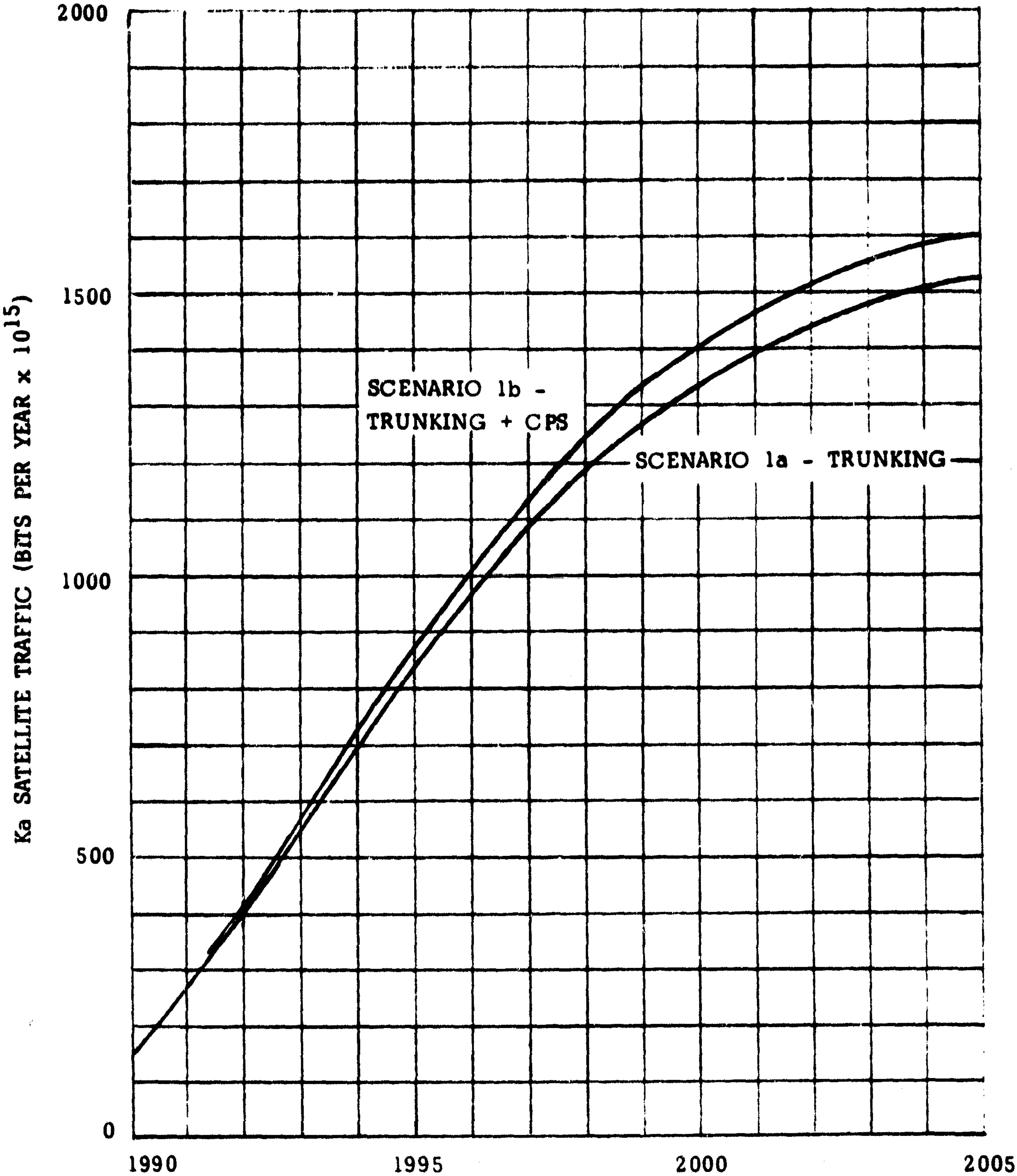


FIGURE 8-2 DEVELOPMENT OF Ka SATELLITE TRAFFIC FOR SCENARIOS 1a AND 1b

TABLE 8-10 SUMMARY OF TRAFFIC CAPTURED BY Ka SATELLITES UNDER SCENARIOS 1a AND 1b (BITS PER YEAR$\times 10^{15}$)

SCENARIO 1a

	ADDRESSABLE TRAFFIC			CAPTURED TRAFFIC		
	1990	1995	2000	1990	1995	2000
VOICE	1533	2344	3585	134	718	1142
VIDEO	51	84	137	5	39	72
DATA	229	285	355	14	84	123
TOTAL	1813	2713	4078	153	841	1337

SCENARIO 1b

	ADDRESSABLE TRAFFIC			CAPTURED TRAFFIC		
	1990	1995	2000	1990	1995	2000
VOICE	1533	2344	3585	134	718	1142
VIDEO	111	174	273	9	74	136
DATA	229	285	355	14	84	123
TOTAL	1873	2803	4214	157	876	1401

8.4 SCENARIO 2 - Ka SATELLITES IN COMBINATION WITH TERRESTRIAL FACILITIES: (a) LOW RELIABILITY Ka TRUNKING (b) LOW RELIABILITY Ka TRUNKING WITH CPS

The following discusses Ka satellites used in combination with terrestrial facilities. The Ka satellites are used in low reliability trunking modes, with and without CPS, to provide bulk transmission capacity to supplement the terrestrial network, while the terrestrial network provides alternate routing paths to back-up any satellite links experiencing rain outage difficulties.

8.4.1 DESCRIPTION OF SERVICE

Terrestrial networks use a wide variety of transmission media to interconnect their distributed nodes. As discussed in Section 2.1, each type of transmission link has its own special characteristics. As a general observation, however, it can be stated that terrestrial links tend to be significantly more reliable than Ka satellite links unless the more expensive diversity configurations are considered for the Ka links. On the other hand, the expansion potential of much of the long haul terrestrial plant is limited by right-of-way problems and by the need to install or modify large numbers of intermediate relay or repeater sites in order to achieve a substantial increase in capacity.

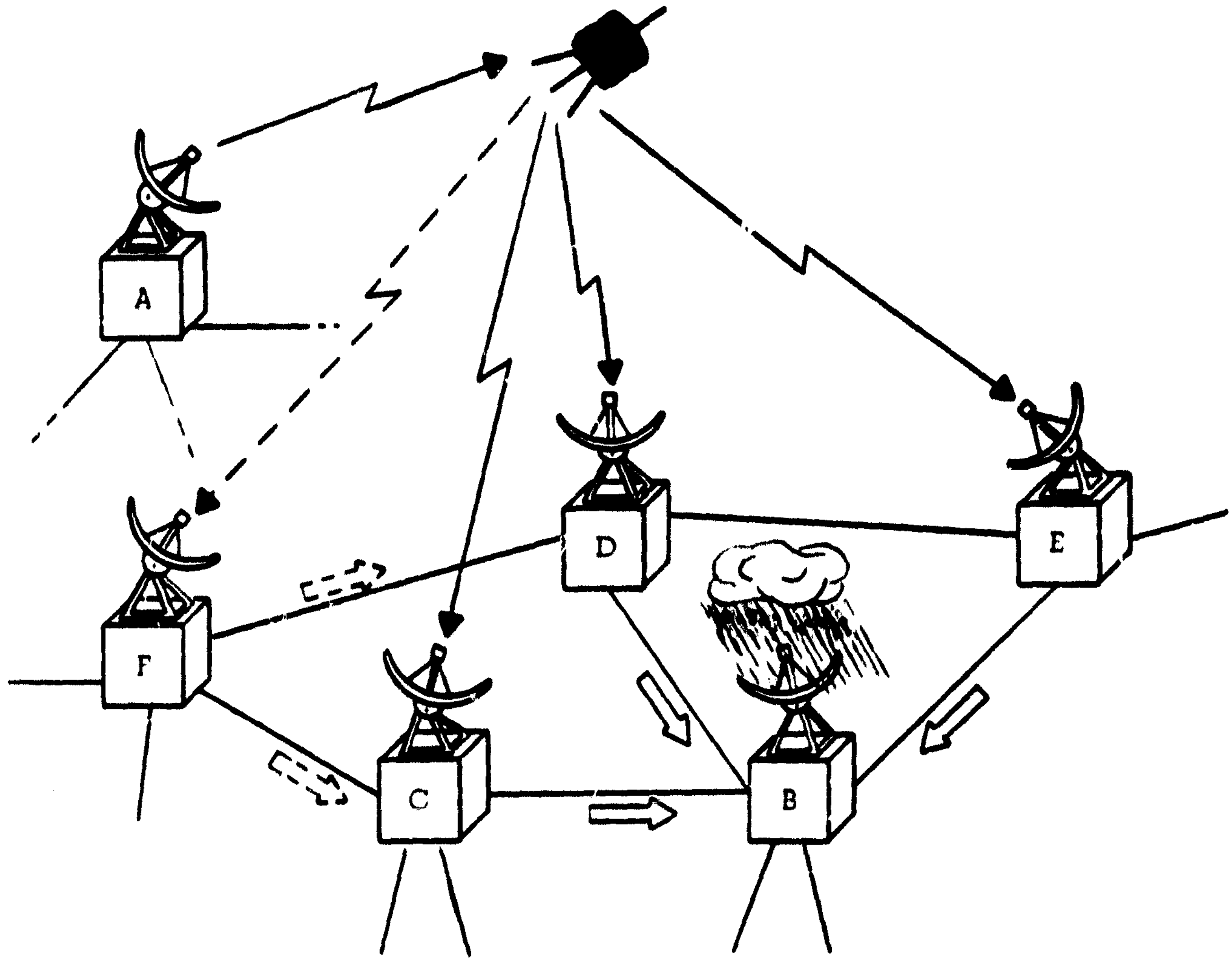
Ka satellites and terrestrial facilities are therefore well adapted to mutually supporting roles. The Ka satellite facilities can provide a practical and flexible means of greatly increasing the capacity available through the terrestrial network, while the terrestrial network effectively eliminates many of the reliability limitations of the Ka satellite links.

Terrestrial long haul links are, with few exceptions, used in trunking modes. That is, the long haul links terminate at common carrier facilities from which further distribution is made through local facilities to diverse end users. Under the present scenario, Ka satellite links add an additional transmission medium with substantial additional capacity to this trunking facility. The merits of also providing Ka band CPS facilities to supplement the trunking links will be discussed later.

Since in the present scenario the Ka satellite links will be used in their lower reliability, non-diversity configuration, back-up through the terrestrial network is essential to permit these links to address the high volume voice and computer applications that require high reliability. Back-up of the less reliable Ka satellite links through the terrestrial network is conceptually simple, but requires the solution of many practical operational problems. This is particularly the case if the Ka satellite links carry high traffic volumes. If a Ka satellite link carrying heavy traffic is interrupted by rain, it may be difficult to find the needed replacement capacity in the terrestrial links.

Figure 8-3 illustrates a region of the terrestrial network with communications capacity supplemented by Ka satellite links. Each terrestrial node is shown associated with a Ka satellite earth station, but in practice not every node will be so equipped. The figure shows transmission from a distant network node in City A to a region containing nearby cities B, C, D and E. Normally traffic from City A would find its way to City B by one or more multi-link paths through the terrestrial network, and also directly through the satellite link between City A and City B. However, Figure 8-3 illustrates a rainstorm over City B which is temporarily preventing the use of the satellite link and requires restoral through the terrestrial network of the lost Ka satellite capacity between Cities A and B.

There are several ways in which this lost capacity can be restored. The component of traffic from City A to City B normally transmitted via Ka satellite can be added directly to the multi-link terrestrial routes between the two cities. However, if the satellite component is relatively heavy this will substantially add to the loading of all of the terrestrial links used between the two cities. A preferable approach, therefore, is to route this traffic to those satellite earth stations surrounding City B, (for example, Cities C, D and E) and to use only the nearby terrestrial links to bring the traffic into City B. While it would also be possible to direct the restored traffic to the earth station at City F and then through the terrestrial network through Cities C and/or D to its final destination, this would involve unnecessary additions to the traffic loading of the terrestrial links between Cities F and C and Cities F and D, without increasing the available capacity to City B.



DESIRABLE RESTORAL PATHS

UNDESIRABLE RESTORAL PATHS

TERRESTRIAL LINKS

FIGURE 8-3 RESTORAL OF SERVICE THROUGH TERRESTRIAL NETWORK

Network reconfiguration to provide back-up routes for out-of-service links, or to achieve a better distribution of traffic between overloaded and lightly loaded links, is a standard procedure in the management of the terrestrial network. To the extent that the Ka satellite links under discussion are treated as additional links in the network, and are subject to the same network control procedures as other links, the use of Ka satellites in combination with the terrestrial network introduces no special network control requirements. In practice, however, there are likely to be additional complexities if:

(a) The satellite traffic component is large, making it difficult to provide adequate restoral capacity via terrestrial links; or

(b) The satellite traffic includes components such as wideband video that are difficult to re-route through terrestrial paths without advance preparation.

On balance it appears that difficulties such as the above can be satisfactorily resolved. Overloading of the terrestrial links can be made less severe if several of them share the traffic. Also, some relaxation of grade-of-service performance on the terrestrial links is probably acceptable during the relatively rare periods in which back-up is required. Particular traffic types that are difficult to reroute through the terrestrial network can be avoided unless lower reliability is acceptable or special prior back-up arrangements are made. Thus at some cost to the common carrier, in the form of complexity in network management and control, terrestrial links can be combined with low reliability Ka satellite links to arrive at a mutually complementary configuration. The alternative in which these complex network management procedures are avoided by the use of higher reliability Ka links is considered in Scenario 3.

8.4.2 MARKET POTENTIAL

Under this scenario Ka satellite communications is fully integrated with dominant common carrier long haul and local terrestrial facilities. In effect, the satellite system becomes one more transmission medium for use with the terrestrial network. Except for the limitations discussed in Section 2, resulting from the long time delays inherent in synchronous satellite communications, all of the traffic components normally traversing the common user network can be routed through the satellite links. In addition, other components that might be difficult to handle terrestrially because of high volume requirements, or that might benefit from the broadcast modes readily achieved with satellites, are also possible targets for the satellite links. Thus, under this scenario a very wide range of target traffic is addressable by Ka satellites. This already wide range is further broadened when the low reliability Ka trunking, which is the major component of the scenario, is supplemented by the addition of a Ka band CPS capability.

The degree to which each of the traffic components presented in Table 1-1 may be addressed by Ka satellites is described for Scenarios 2a and 2b in Tables 8-11 and 8-12, respectively. The basis for these estimates is further discussed in the following Subsections.

8.4.2.1 VOICE

As in the previous scenario in which Ka satellites were used in an isolated stand-alone configuration, dedicated voice service (primarily business oriented leased lines) is a major target for Ka satellites. If it is assumed that echo cancelers are employed to reduce the inconvenience caused by long delayed echoes, and that satisfactory overall reliability is achieved by back-up through the terrestrial network, Ka satellite trunking can address essentially all of this traffic.

The same considerations apply also to the switched voice traffic components. With the Ka links integrated with the terrestrial network these links can be used interchangeably with terrestrial links, though special provision will be needed to avoid routing of calls through two satellite hops in tandem. Thus essentially all voice traffic is addressable by Ka satellites in this configuration. This is reflected by the 100 percent target entries in Table 8-11. The inclusion of a CPS capability, as represented in Table 8-12 does not affect the switched voice components which are not well suited for CPS modes. A small fraction of the leased line voice traffic, subject to the limitations of Table 3-2 is diverted to CPS modes under Scenario 2b.

TABLE 8-11 ADDRESSABLE TRAFFIC FOR Ka SATELLITES UNDER SCENARIO 2a. LOW RELIABILITY Ka TRUNKING IN COMBINATION WITH TERRESTRIAL FACILITIES.

COMMUNICATIONS SUBCATEGORY	TARGET FOR Ka PERCENT	ADDRESSABLE* (BITS/YRx10^{15}) 1990	2000	COMMENTS
RESIDENTIAL	100	197.0	378.0	1,2
BUSINESS (SWITCHED SVC.)	100	600.0	1076.0	1,2
BUSINESS (PVT. OR LEASED LINE)	100	1453.0	3440.0	1,2
TOTAL VOICE	-	2250.0	4894.0	
NETWORK TV	0	0	0	3
CATV	0	0	0	3
EDUCATIONAL VIDEO	0	0	0	3
VIDEOCONFERENCING	40	33.6	107.2	4
TOTAL VIDEO	-	33.6	107.2	
FACSIMILE	100	2.0	4.0	1
ELECTRONIC MAIL	100	6.0	7.0	1
COMPUTER	100	272.0	423.0	1
TOTAL DATA	-	280.0	434.0	
TOTAL TRAFFIC		2563.6	5435.2	

*TARGET FOR Ka TIMES DEMAND FROM TABLE 1-1

1. BOTH DEDICATED AND SWITCHED COMPONENTS ADDRESSABLE.
2. ASSUMES AVAILABILITY OF COST EFFECTIVE ECHO CANCELLERS.
3. SPECIALTY WIDEBAND TRANSMISSIONS ON LOW RELIABILITY Ka TRUNKS ARE DIFFICULT TO BACK-UP AND INTEGRATE WITH TERRESTRIAL FACILITIES. LEFT TO SCCs TO ADDRESS AS A SEPARATE MARKET OUTSIDE THIS SCENARIO.
4. DIFFERS FROM OTHER VIDEO SERVICES IN THAT POINT-TO-POINT RATHER THAN BROADCAST MODE IS REQUIRED. ALSO RELIABILITY REQUIREMENTS ARE LOWER AND BANDWIDTH IS NARROWER MAKING VIDEOCONFERENCING MORE READILY ADDRESSED UNDER THIS SCENARIO.

TABLE 8-12 ADDRESSABLE TRAFFIC FOR Ka SATELLITES UNDER SCENARIO 2b.
LOW RELIABILITY Ka TRUNKING PLUS CPS IN COMBINATION
WITH TERRESTRIAL FACILITIES.

COMMUNICATIONS SUBCATEGORY	TRUNKING			CPS			COMMENTS
	TARGET FOR Ka PERCENT	ADDRESSABLE* (BITS/YR$\times 10^{15}$) 1990	2000	TARGET FOR Ka PERCENT	ADDRESSABLE* (BITS/YR$\times 10^{15}$) 1990	2000	
RESIDENTIAL	100	197.0	378.0	0	0	0	1
BUSINESS (SWITCHED SVC.)	100	600.0	1076.0	0	0	0	1
BUS. (PVT. OR LEASED LINE)	97	14[illegible].4	3336.8	3	43.6	103.2	1
TOTAL VOICE	-	2236.4	4790.8	-	43.6	103.2	
NETWORK TV	0	0	0	38	6.1	4.2	2
CATV	0	0	0	48	15.8	13.0	2
EDUCATIONAL VIDEO	0	0	0	34	12.9	38.4	2
VIDEOCONFERENCING	40	33.6	107.2	30	25.2	80.4	2
TOTAL VIDEO	-	33.6	107.2	-	60.0	136.0	
FACSIMILE	92	1.8	3.7	8	0.2	0.3	1
ELECTRONIC MAIL	31	1.9	2.2	69	4.1	4.8	1
COMPUTER	97	263.8	410.3	3	8.2	12.7	1
TOTAL DATA	-	267.5	416.2	-	12.5	17.8	
TOTAL TRAFFIC		2507.5	5314.2		116.1	257.0	

*TARGET FOR Ka TIMES DEMAND FROM TABLE 1-1

1. SUM OF TRUNKING AND CPS SAME AS SCENARIO 2a. CPS PORTION AS PER TABLE 3-2.
2. TRUNKING COMPONENT SAME AS SCENARIO 2a. CPS PROVIDES ADDITIONAL CAPABILITY TO ADDRESS TRAFFIC AS PER TABLE 3-2.

8.4.2.2 VIDEO

Ka satellites in this scenario are closely integrated with the terrestrial network and the prime targets for these satellite links will tend to duplicate the heavy concentration on voice and data signals typical of terrestrial traffic. Furthermore, the Ka links provided under this scenario will be of lower reliability. Back-up via terrestrial facilities is therefore of considerable importance, but is more difficult to achieve for wideband video signals than for the narrower bandwidth signals characteristic of voice and data. Thus, while there is no overriding reason for the role of video to be reduced, it is nevertheless likely that emphasis will remain with the larger voice and data components rather than with video.

It is assumed, for the trunking target estimates in Tables 8-11 and 8-12 that broadcast video traffic will be considered a specialty service with unique communications needs, wideband local distribution requirements, and more complex restoral procedures better served by smaller specialized common carrier systems. As shown in Table 8-12, however, a component of deferred broadcast video consistent with the limitations of Table 3-2 is projected.

The major exception to the low level of activity projected for video under this scenario is expected to be in the area of videoconferencing. Videoconferencing is predicted to become the largest of the video services and therefore represents an attractive target. This traffic component is more closely akin in concept to the distribution of voice traffic than are the other video components which tend to be broadcast oriented. In addition, there has been a continuing interest over many years in the development of the earlier Picturephone Service and the current Picturephone Meeting Service using terrestrial facilities. The availability of Ka satellite service in combination with terrestrial network facilities offers an effective approach to satisfying the wideband requirements of this component of video traffic. However, as in Scenario 1a, the problems of wideband local distribution tend to limit the use of the trunking only facilities available in Scenario 2a to about 40 percent of total demand. With the addition of a CPS capability in Scenario 2b, an additional 30 percent, subject to the reliability and other limitations discussed relative to Table 3-2, is projected.

8.4.2.3 DATA

The situation with respect to data traffic is similar to that for voice. All components of data traffic are fully addressable by Ka satellites under this scenario.

Close integration with the terrestrial network makes it highly probable that both dedicated and switched modes of computer traffic will be addressed. Computer traffic using dedicated lines will be shared between Trunking and CPS modes. The considerations presented in Table 3-2 serve as a guide to the percentage of traffic addressable through CPS modes. That portion of computer traffic relying on switched modes will tend to utilize trunking in preference to the more limited distribution capabilities of CPS. Where, as in Scenario 2a, CPS service is not offered, it is assumed that this component will be equally well addressed by trunking.

Electronic Mail is also expected to be 100 percent addressable by Ka satellites under this scenario. If a CPS capability is offered, the large volume of low reliability Postal Service requirements is likely to be served primarily by this mode. Other dedicated Electronic Mail will divide between CPS and trunking. The component of electronic mail involving intercompany switched traffic, such as communicating word processor generated messages to outside organizations, will require the wide distribution available through trunking. The values developed in Table 3-2 provide the basis for the CPS estimates in Table 8-12.

Facsimile traffic is similar to electronic mail with the dedicated intracompany component dividing between CPS and Trunking modes, while the switched intercompany component is addressed by trunking.

8.4.2.4 SUMMARY OF TARGET APPLICATIONS

As indicated in Table 8-11 the trunking configuration is capable of addressing a large fraction of the total long haul traffic. For both 1990 and the year 2000 slightly less than 95% of the total traffic shown in Table 1-1 can be addressed. This includes all of the voice components, computer traffic and about forty-percent of videoconferencing. The major omissions are in the area of video other than videoconferencing. The difficulties of restoring video traffic through the terrestrial network and the problems of wideband local distribution make this traffic a poor target for low reliability trunking by Ka satellites.

The addition of low reliability CPS service as per Table 8-12 does not result in any dramatic changes. The traffic volume addressable by CPS is about 5 percent of that addressable by trunking. Overall the addition of a CPS capability increases the total addressable traffic by only two to three percent compared to that addressable by trunking alone.

8.4 3 OWNERSHIP AND OPERATION

The essence of this scenario lies in close interworking between the Ka satellite links and the terrestrial network. Since the Ka links will be of relatively low reliability in both trunking and CPS modes, the terrestrial plant is relied on for back-up of the long haul transmission as well as for local distribution. Without this close integration between satellite and terrestrial media, much of the high volume voice and computer traffic is not addressable by the Ka satellite systems.

The re-routing of traffic to compensate for rain outages in the Ka links is complex and cannot be carried out effectively without up to date information on the status and traffic loading of the terrestrial links surrounding the affected city. Network control procedures to accomplish this re-routing require intricate interworking between satellite and terrestrial resources. It is unlikely that the required close coordination of resources could be achieved under separate management of the satellite and terrestrial systems. As a result this scenario implies operation of the Ka satellite system by the terrestrial carrier. In order to address the widest range of traffic, the Ka satellite system would interface with the major common user terrestrial telephone network and therefore be operated by AT&T.

With a reduction in the level of addressable traffic, it is also possible that other carriers with substantial terrestrial transmission plants could operate Ka satellite systems under this scenario. Possible candidates are Western Union, with a more limited but substantial nationwide terrestrial plant, and a possible consortium of large, independent telcos and OCCs. Ka systems could be used to increase the long haul capacity of this plant while receiving back-up from the terrestrial links. A more limited range of customers is addressable in such arrangements, but expanded customer bases might be addressable through interconnect with AT&T local distribution facilities. The fact that Western Union operates a major C band satellite network adds an extra dimension to this possibility which relates also to some of the scenarios to be considered later in which Ka and C band satellite systems are combined.

A similar example of a more restricted version of this scenario would result from operation of the Ka system by ITT in support of its USTS terrestrial microwave network which covers the southeastern and eastern region of the United States. Network control problems for this more limited regional network would be simplified but the addressable traffic would correspondingly be reduced.

In any of the above possibilities CPS service is expected to play a relatively minor role compared to the main trunking function served by the network. However, for the smaller trunking networks operated by carriers other than AT&T, the addition of CPS capabilities becomes of increasing importance in being able to address a market of suitable dimensions.

Overall, however, the most viable and significant use of Ka satellites under this scenario would result from ownership and operation of the satellite system by AT&T. Under this arrangement the fullest benefit of the potentially high capacity of Ka satellites can be realized, and the limitations of the medium minimized. The substantial technical and financial resources needed are supported in this case by a large customer base and the implementation of the Ka system can be achieved gradually with a plentiful supply of traffic to insure efficient satellite fill as each increment is installed.

8.4.4 GROWTH OF Ka SERVICES

This section discusses the potential development of Ka satellite communications under Scenario 2. The traffic growth model described in Section 8.3.5 for Scenario 1 is used here as well. The use of this model, based on Gompertz curves, to estimate the build-up of traffic for each traffic component proceeds as per Scenarios 1a and 1b, but uses as starting points the year 2000 addressable traffic listed in Tables 8-11 and 8-12.

Tables 8-13 and 8-14 present estimates of the long term and initial (1990) capture percentages for Ka satellites, and the time needed for traffic to build up to 90 percent of its long term value. Many of the considerations used in arriving at these values are similar to those pertaining to Scenario 1. The discussion in this section, therefore, centers on those elements where changes to the previous projections apply.

The most significant of these changes relate to the voice categories. The presumption under Scenario 2 is that the Ka satellite facilities are owned and operated by a carrier with an existing major terrestrial network, and in the most far reaching version of this scenario the carrier would be AT&T. The ability of Ka satellite systems to capture significant portions of the addressable voice traffic is greatly enhanced by the existing large base of terrestrial voice traffic supported by the carrier. As the traffic demand expands, it becomes possible to transfer portions of this traffic to Ka facilities by an orderly and efficient growth process. Customers already accustomed to dealing with the terrestrial carrier feel none of the dislocation, and experience none of the difficulties that might otherwise attend the relocation of their traffic to a new carrier. Where Ka satellites are the cost effective means of increasing capacity in various geographic regions, such facilities need not contend with the inefficiencies that might result from simultaneous overbuild of terrestrial facilities in direct competition for the same overflow traffic.

The considerations above relate equally well to switched as well as dedicated voice components and to residential as well as business traffic. There is no reason, other than the unlikely possibility of adverse public reaction to circuit quality, why Ka satellites under this scenario should not compete on an equal basis with other transmission media for voice traffic. Division of this traffic in proportion to the capacities of each media, as projected in Section 6.5, results in the 46 percent long term capturable estimate indicated in Tables 8-13 and 8-14. A large volume of traffic is available in the terrestrial network for transfer to Ka systems as Ka capacity becomes available. A relatively high percentage (15 percent) has therefore been estimated for initial traffic capture, with a build-up to 90 percent of the long term value taking place ten years after the inception of Ka satellite service around 1990.

TABLE 8-13 TRAFFIC CAPTURED UNDER SCENARIO 2a.
LOW RELIABILITY Ka TRUNKING IN COMBINATION WITH
TERRESTRIAL FACILITIES.

	COMMUNICATIONS SUBCATEGORY	YEAR 2000 * ADDRESSABLE TRAFFIC BITS/YRx10^{15}	LONG TERM Ka CAPTURABLE PERCENTAGE	% OF LONG TERM TRAFFIC CAPTURED BY 1990	YEARS AFTER 1990 TO REACH 90%
VOICE	RESIDENTIAL	378.0	46	15	10
	BUSINESS (SWITCHED SVC.)	1076.0	46	15	10
	BUS. (PVT. OR LEASED LINE)	3440.0	46	15	10
VIDEO	NETWORK TV	0	-	-	-
	CATV	0	-	-	-
	EDUCATIONAL VIDEO	0	-	-	-
	VIDEOCONFERENCING	107.2	78	5	15
DATA	FACSIMILE	4.0	46	15	10
	ELECTRONIC MAIL	7.0	80	10	15
	COMPUTER	423.0	46	15	10

*YEAR 2000 ADDRESSABLE TRAFFIC FROM TABLE 8-11

TABLE 8-14 TRAFFIC CAPTURED UNDER SCENARIO 2b.
LOW RELIABILITY Ka TRUNKING PLUS CPS IN COMBINATION
WITH TERRESTRIAL FACILITIES.

	COMMUNICATIONS SUBCATEGORY	YEAR 2000 * ADDRESSABLE TRAFFIC BITS/YRx10^{15}	LONG TERM Ka CAPTURABLE PERCENTAGE	% OF LONG TERM TRAFFIC CAPTURED BY 1990	YEARS AFTER 1990 TO REACH 90%
VOICE	RESIDENTIAL	378.0	46	15	10
	BUSINESS (SWITCHED SVC.)	1076.0	46	15	10
	BUS. (PVT. OR LEASED LINE)	3440.0	46	15	10
VIDEO	NETWORK TV	4.2	10	15	10
	CATV	13.0	10	15	10
	EDUCATIONAL VIDEO	38.4	50	5	10
	VIDEOCONFERENCING	187.6	78	5	15
DATA	FACSIMILE	4.0	46	15	10
	ELECTRONIC MAIL	7.0	80	10	15
	COMPUTER	423.0	46	15	10

*YEAR 2000 TRUNKING PLUS CPS ADDRESSABLE TRAFFIC FROM TABLE 8-12

Scenario 2a, lacking a CPS component, and being primarily oriented towards bulk voiceband traffic, does not address the broadcast video traffic components. These are likely to be left for other specialized carriers capable of offering reliable CPS service via C or perhaps Ku satellites. However, in Scenario 2b, where a CPS capability is included as a supplement to trunking, the deferred components of broadcast video traffic are addressed. A modest 10 percent long term capture is accorded to CATV and Network TV which are likely to be well established on lower frequency satellite media prior to the inception of Ka band service. A ten year growth to 90 percent of the long term value, from an initial value of 10 percent, is anticipated. The less well established, newer educational applications of video start from a lower value, but are potentially capable of capturing a larger share of the market. Videoconferencing growth remains unchanged from that predicted for Scenario 1 and the discussion previously presented applies here as well.

In the data categories, facsimile and computer traffic growth is expected to follow patterns similar to those for voice. For electronic mail, it is assumed, as in the case of Scenario 1, that special efforts are made to capture for Ka band the bulk postal service component which is well suited to the Ka medium. A somewhat smaller initial capture percentage, and longer development time, is estimated for this component of data traffic.

When the traffic components of Tables 8-13 and 8-14 are extended year-by-year and summed using the Gompertz curve methodology, the projections plotted in Figure 8-4 are obtained. Table 8-15 summarizes results in tabular form for the years 1990, 1995 and 2000.

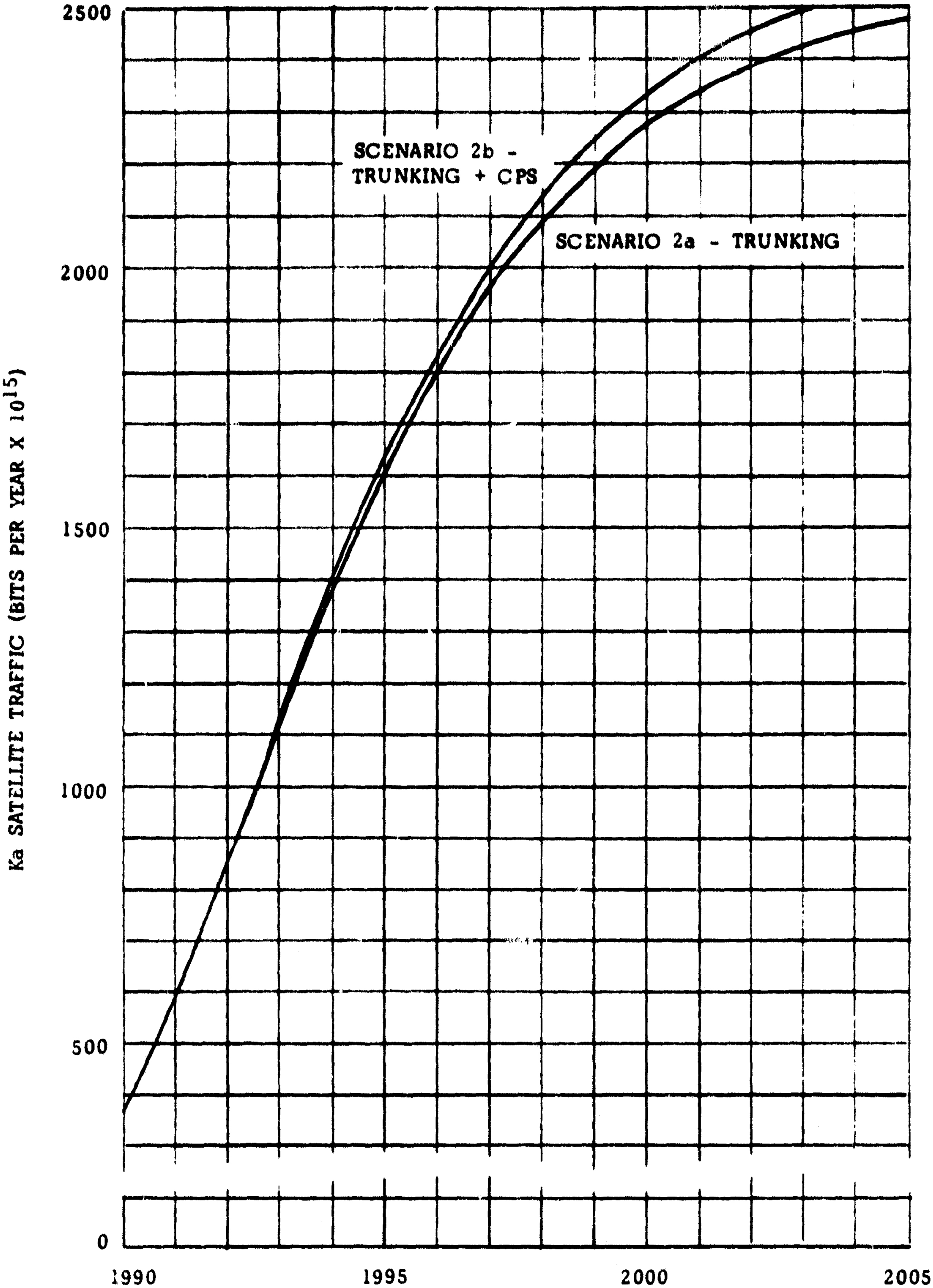


FIGURE 8-4 DEVELOPMENT OF Ka SATELLITE TRAFFIC FOR SCENARIOS 2a AND 2b

TABLE 8-15 SUMMARY OF TRAFFIC CAPTURED BY Ka SATELLITES UNDER SCENARIOS 2a AND 2b (BITS PER YEAR$\times 10^{15}$)

SCENARIO 2a

	ADDRESSABLE TRAFFIC			CAPTURED TRAFFIC		
	1990	1995	2000	1990	1995	2000
VOICE	2250	3318	4894	338	1440	2026
VIDEO	34	60	107	4	31	61
DATA	280	349	434	30	128	181
TOTAL	2564	3727	5435	372	1599	2268

SCENARIO 2b

	ADDRESSABLE TRAFFIC			CAPTURED TRAFFIC		
	1990	1995	2000	1990	1995	2000
VOICE	2250	3318	4894	338	1440	2026
VIDEO	94	151	243	9	67	125
DATA	280	394	434	30	128	181
TOTAL	2624	3863	5571	377	1635	2332

8.5 SCENARIO 3 - Ka SATELLITES IN COMBINATION WITH TERRESTRIAL FACILITIES: (a) HIGH RELIABILITY Ka TRUNKING (b) HIGH RELIABILITY Ka TRUNKING WITH CPS

This scenario discusses the use of Ka band satellites to provide high reliability trunking service in combination with terrestrial facilities. The possible addition of lower reliability CPS facilities is also considered.

8.5.1 DESCRIPTION OF SERVICE

In overall concept the service provided under this scenario is very similar to that provided under Scenario 2. The basic difference between the two is that in the previous scenario the Ka satellite links use single earth stations in a lower cost, lower reliability configuration, while in the present scenario widely separated dual earth stations are used to obtain the high reliability levels obtainable with diversity.

Integration of the Ka satellite links with dominant carrier local distribution facilities is needed to assure the ability to address the high volume switched voice and data components of traffic. However, since it is assumed under this scenario that the Ka satellite links themselves provide a reliability level equivalent to that of terrestrial service, the need for back-up by the terrestrial long haul plant is open to question. Certainly other factors being equal, this would be a useful capability. If properly used it could guarantee extra high levels of reliability, first through the diversity feature of the satellite links and then, in the event of an outage of both diversity earth stations, by providing an alternative path through the ground network. It is doubtful, however, that this extra level of performance would have any great impact in terms of addressable traffic.

The significance of integration of the Ka satellite links with the terrestrial long haul plant lies more in the ownership and operation modes implied. Full integration with both long haul and local terrestrial facilities implies operation by AT&T or at least by one of the major terrestrial carriers. Avoidance of this integration opens ownership and operation to a wider group of carriers but reduces this scenario to the stand-alone case explored in Scenario 1. Thus, this scenario implies, as does Scenario 2, operation of the Ka satellite system by a major terrestrial common carrier. Its main significance relative to Scenario 2 lies in the additional options open to the system designers and cost analysts. The more reliable diversity configuration of the present scenario entails additional costs for the extra earth stations, real estate, and the wideband terrestrial transmission required to link the two stations. The less reliable single earth station configuration of Scenario 2, however, also requires some additional costs for the network control equipment and personnel needed to permit rapid network reconfiguration as individual Ka satellite links become unavailable due to rainstorms. It also requires a higher degree of idle capacity in the terrestrial network to provide stand-by for the satellite links. Thus, each approach imposes its own cost penalties and it would be difficult to estimate at this point the relative life cycle impact of these factors. An attractive possibility is a hybrid approach using diversity earth stations in those geographic areas where rain activity is high, and relying more heavily on restoral of satellite communications through the terrestrial network in those areas of light rain activity.

8.5.2 MARKET POTENTIAL

As in Scenario 2, Ka satellite communications under the present scenario is fully integrated with both long haul and local dominant common carrier terrestrial facilities. The role of the Ka satellite links, as one among many types of communications media flexibly deployed as part of the nationwide network, is even more clear cut under the present scenario than in Scenario 2. With the higher reliability trunking afforded by diversity earth stations, the reliability of the satellite links is expected to be similar to that of the terrestrial links, so that no special provision for back-up is needed other than the alternate routing scheme conventionally employed in normal network operation.

Tables 8-16 and 8-17 present estimates of the amount of traffic addressable under Scenarios 3a and 3b. The basis for these estimates is discussed in the following subsections.

TABLE 8-16 ADDRESSABLE TRAFFIC FOR Ka SATELLITES UNDER SCENARIO 3a. HIGH RELIABILITY Ka TRUNKING IN COMBINATION WITH TERRESTRIAL FACILITIES.

COMMUNICATIONS SUBCATEGORY	TARGET FOR Ka PERCENT	ADDRESSABLE* (BITS/YR $\times 10^{15}$) 1990	2000	COMMENTS
RESIDENTIAL	100	197.0	378.0	1,2
BUSINESS (SWITCHED SVC.)	100	600.0	1076.0	1,2
BUSINESS (PVT. OR LEASED LINE)	100	1453.0	3440.0	1,2
TOTAL VOICE	-	2250.0	4894.0	
NETWORK TV	20	3.2	2.2	3
CATV	20	6.6	5.4	3
EDUCATIONAL VIDEO	20	7.6	22.6	3
VIDEOCONFERENCING	40	33.6	107.2	3
TOTAL VIDEO	-	51.0	137.4	
FACSIMILE	100	2.0	4.0	1
ELECTRONIC MAIL	100	6.0	7.0	1
COMPUTER	100	272.0	423.0	1
TOTAL DATA	-	280.0	434.0	
TOTAL TRAFFIC		2581.0	5465.4	

*TARGET FOR Ka TIMES DEMAND FROM TABLE 1-1

1. BOTH DEDICATED AND SWITCHED COMPONENTS ADDRESSABLE.
2. ASSUMES AVAILABILITY OF COST EFFECTIVE ECHO CANCELLERS.
3. WIDEBAND SERVICES UNDER TRUNKING LIMITED BY LOCAL DISTRIBUTION PROBLEMS. RELIABLE TRUNKING REDUCES PROBLEMS OF BACK-UP BY TERRESTRIAL FACILITIES.

TABLE 8-17 ADDRESSABLE TRAFFIC FOR Ka SATELLITES UNDER SCENARIO 3b. HIGH RELIABILITY Ka TRUNKING PLUS LOWER RELIABILITY Ka CPS IN COMBINATION WITH TERRESTRIAL FACILITIES.

	TRUNKING			CPS			
COMMUNICATIONS SUBCATEGORY	TARGET FOR Ka PERCENT	ADDRESSABLE* ($BITS/YR \times 10^{15}$) 1990	2000	TARGET FOR Ka PERCENT	ADDRESSABLE* ($BITS/YR \times 10^{15}$) 1990	2000	COMMENTS
RESIDENTIAL	100	197.0	378.0	0	0	0	1
BUSINESS (SWITCHED SVC.)	100	600.0	1076.0	0	0	0	1
BUS. (PVT. OR LEASED LINE)	97	1409.4	3336.8	3	43.6	103.2	1
TOTAL VOICE	-	2206.4	4790.8	-	43.6	103.2	
NETWORK TV	20	3.2	2.2	38	6.1	4.2	2
CATV	20	6.6	5.4	48	15.8	13.0	2
EDUCATIONAL VIDEO	20	7.6	22.6	34	12.9	38.4	2
VIDEOCONFERENCING	40	33.6	107.2	30	25.2	80.4	2
TOTAL VIDEO	-	51.0	137.4	-	60.0	136.0	
FACSIMILE	92	1.8	3.7	8	0.2	0.3	1
ELECTRONIC MAIL	31	1.9	2.2	69	4.1	4.8	1
COMPUTER	97	263.8	410.3	3	8.2	12.7	1
TOTAL DATA	-	267.5	416.2	-	12.5	17.8	
TOTAL TRAFFIC		2524.9	5344.4		116.1	257.0	

*TARGET FOR Ka TIMES DEMAND FROM TABLE 1-1

1. SUM OF TRUNKING AND CPS SAME AS SCENARIO 3a. CPS PORTION AS PER TABLE 3-2.

2. TRUNKING COMPONENT SAME AS SCENARIO 2a. CPS PROVIDES ADDITIONAL CAPABILITY TO ADDRESS TRAFFIC AS PER TABLE 3-2.

8.5.2.1 VOICE

Both dedicated and switched voice traffic components are fully addressable under this scenario, provided that satisfactory echo cancellers are employed. From the users point of view the voice services provided under this scenario are indistinguishable from those provided under Scenario 2. Unless a clear cut cost distinction evolves, therefore, the voice traffic addressable under this scenario is the same as that predicted for Scenario 2.

8.5.2.2 VIDEO

The reliability achievable by the Ka satellite links under this scenario allow the addressing of a wider portion of the video market. Whereas Scenario 2 implies the re-routing of substantial amounts to wideband video traffic through the terrestrial network whenever a satellite link becomes unavailable, this is avoided in the present scenario. Thus, it becomes more practical to address the Network TV, CATV and Educational Video markets via Ka satellite trunking modes, though wideband local loop distribution problems still favor CPS modes for these traffic components. The same is true for Videoconferencing, but the need to serve videoconferencing users in establishments with insufficient volume to justify CPS service provides increased impetus to trunking despite the difficulties of wideband local distribution.

Thus, video traffic under this scenario includes a portion of each video component which is addressable via trunking with a substantial additional amount addressable when a CPS capability is added, subject to the reliability and other limitations identified in Table 3-2.

8.5.2.3 DATA

Under this scenario both dedicated and switched data components are fully addressable. The discussion presented in Section 8.4.2.3 for Scenario 2 applies here as well.

8.5.2.4 SUMMARY OF TARGET APPLICATIONS

The major distinction between the addressable traffic under Scenario 3a and that under the earlier Scenario 2a is in the area of video traffic. Because the higher reliability Ka satellite trunking in Scenario 3a reduces dependence on terrestrial long haul facilities the problem of re-routing wideband, and often critical, video traffic is avoided, thereby making this traffic somewhat more desirable from the carriers' viewpoint. Nevertheless, the problem of local distribution of video signals remains a deterrent and much of the video will seek other media (C or possibly Ku band) offering CPS capability.

This latter restriction is partly removed in Scenario 3b which supplements the high reliability Ka trunking with lower reliability CPS. An additional component of video is thus addressed but the relative unreliability of Ka band CPS allows the addressing of only the lower reliability or deferred portion of this video traffic.

Overall, the additional traffic addressable in Scenario 3 is only slightly increased over that of Scenario 2, reaching a value of approximately 95 to 96 percent of total addressable traffic. The traffic volume addressable by CPS is about 5 percent of that addressable by trunking and the addition of CPS capability increases total addressable traffic by only 2 to 2.5 percent over that addressable by trunking alone.

8.5.3 OWNERSHIP AND OPERATION

Ownership and operation considerations are similar to those of Scenario 2 in that ownership and operation by a dominant terrestrial carrier under this scenario permits the addressing of the fullest complement of traffic. In Scenario 2, however, the advantage resulting from dominant carrier operation is due in part to the need for flexible network control in order to allow terrestrial back-up of the low reliability Ka trunking links. In the present scenario the diversity configuration employed for these links eliminates the need for these special back-up considerations. The main advantage that a dominant terrestrial carrier has under this scenario, in addressing projected traffic, is the difficulty that other carriers might have in addressing the large switched voice and computer traffic components in competition with the existing terrestrial network. Until an independently operated satellite network evolves to a very large size, subscribers to the network are unable to get the wide distribution capabilities expected of the telephone network. Dominant carrier ownership on the other hand permits the orderly and efficient growth of the satellite network, by degrees, as traffic build-up in various geographic regions justifies the addition of satellite links to upgrade terrestrial capacity.

If addressing a more limited portion of the potential traffic is an acceptable posture, however, then carriers such as ITT and Western Union, with substantial terrestrial networks, can employ Ka satellites under more limited versions of this scenario. If this is attempted the high reliability Ka trunking postulated under this scenario offers a certain advantage over the lower reliability trunking postulated for Scenario 2. If an existing network is to be extended to support a rapidly growing urban area, the flexibility of Ka satellites can be used to rapidly upgrade capacity without concern over the availability of terrestrial capacity capable of serving as back-up.

High reliability Ka trunking can also serve to link two geographically separated networks serving population centers in separate regions of the country without the need to acquire intervening real estate. This can be particularly effective in facilitating the merger or joint venture of regional carriers whose combined network might then provide greater utility than the sum of that provided by each as a separate entity.

In summary, it appears that AT&T, with the largest existing terrestrial plant, is in the best position to utilize Ka satellites in the configuration postulated in this scenario. Other large terrestrial carriers, however, may also be able to benefit from this mode on a more limited scale.

8.5.4 GROWTH OF Ka SERVICE

This section discusses the potential development of Ka satellite communications under Scenario 3. The procedures previously described for estimating the growth of traffic are followed, starting from the year 2000 addressable traffic defined in Tables 8-16 and 8-17.

Since from an end users viewpoint, the services provided under Scenario 3a are virtually the same as those provided under the previously discussed Scenario 2a, it may be expected that the percentage of capture, and the rate of growth, for Scenario 3a will parallel the earlier case, but starting from the appropriate addressable traffic levels. The main distinctions between the two scenarios lies in the video categories, other than videoconferencing, which were not addressed in Scenario 2a due to the difficulties of restoring these specialized wideband channels through the terrestrial network. These are, however, addressed in Scenario 3a since the high reliability trunking provided renders such restoral unnecessary. With respect to these components of video traffic, capture under the high reliability trunking configuration of Scenario 3a should be similar to that of the high reliability configuration discussed in Scenario 1a. Thus, the estimates presented in Table 8-18 for Scenario 3a are, for most categories, those presented in Table 8-13 supplemented by those of Table 8-8 for the video categories (other than videoconferencing).

The parallelism between the build-up of traffic expected under Scenario 3b and that of Scenario 2b is a close one and the capture percentages and build-up period estimated in Table 8-14 are applied to Table 8-19 as well.

Figure 8-5 shows the development of Ka satellite traffic for Scenarios 3a and 3b using the previously discussed Gompertz growth model. Table 8-20 presents results for the years 1990, 1995 and 2000 in tabular form.

TABLE 8-18 TRAFFIC CAPTURED UNDER SCENARIO 3a.
HIGH RELIABILITY Ka TRUNKING IN COMBINATION WITH TERRESTRIAL FACILITIES.

	COMMUNICATIONS SUBCATEGORY	YEAR 2000* ADDRESSABLE TRAFFIC BITS/YRx10^{15}	LONG TERM Ka CAPTURABLE PERCENTAGE	% OF LONG TERM TRAFFIC CAPTURED BY 1990	YEARS AFTER 1990 TO REACH 90%
VOICE	RESIDENTIAL	378.0	46	15	10
	BUSINESS (SWITCHED SVC.)	1076.0	46	15	10
	BUS. (PVT. OR LEASED LINE)	3440.0	46	15	10
VIDEO	NETWORK TV	2.2	10	15	10
	CATV	5.4	10	15	10
	EDUCATIONAL VIDEO	22.6	50	5	10
	VIDEOCONFERENCING	107.2	78	5	15
DATA	FACSIMILE	4.0	46	15	10
	ELECTRONIC MAIL	7.0	80	10	15
	COMPUTER	423.0	46	15	10

*YEAR 2000 ADDRESSABLE TRAFFIC FROM TABLE 8-16

TABLE 8-19 TRAFFIC CAPTURED UNDER SCENARIO 3b. HIGH RELIABILITY Ka TRUNKING PLUS LOWER RELIABILITY Ka CPS IN COMBINATION WITH TERRESTRIAL FACILITIES.

	COMMUNICATIONS SUBCATEGORY	YEAR 2000* ADDRESSABLE TRAFFIC BITS/YR$\times 10^{15}$	LONG TERM Ka CAPTURABLE PERCENTAGE	% OF LONG TERM TRAFFIC CAPTURED BY 1990	YEARS AFTER 1990 TO REACH 90%
VOICE	RESIDENTIAL	378.0	46	15	10
	BUSINESS (SWITCHED SVC.)	1076.0	46	15	10
	BUS. (PVT. OR LEASED LINE)	3440.0	46	15	10
VIDEO	NETWORK TV	6.4	10	15	10
	CATV	18.4	10	15	10
	EDUCATIONAL VIDEO	61.0	50	5	10
	VIDEOCONFERENCING	187.6	78	5	15
DATA	FACSIMILE	4.0	46	15	10
	ELECTRONIC MAIL	7.0	80	10	15
	COMPUTER	423.0	46	15	10

*YEAR 2000 TRUNKING PLUS CPS ADDRESSABLE TRAFFIC FROM TABLE 8-17

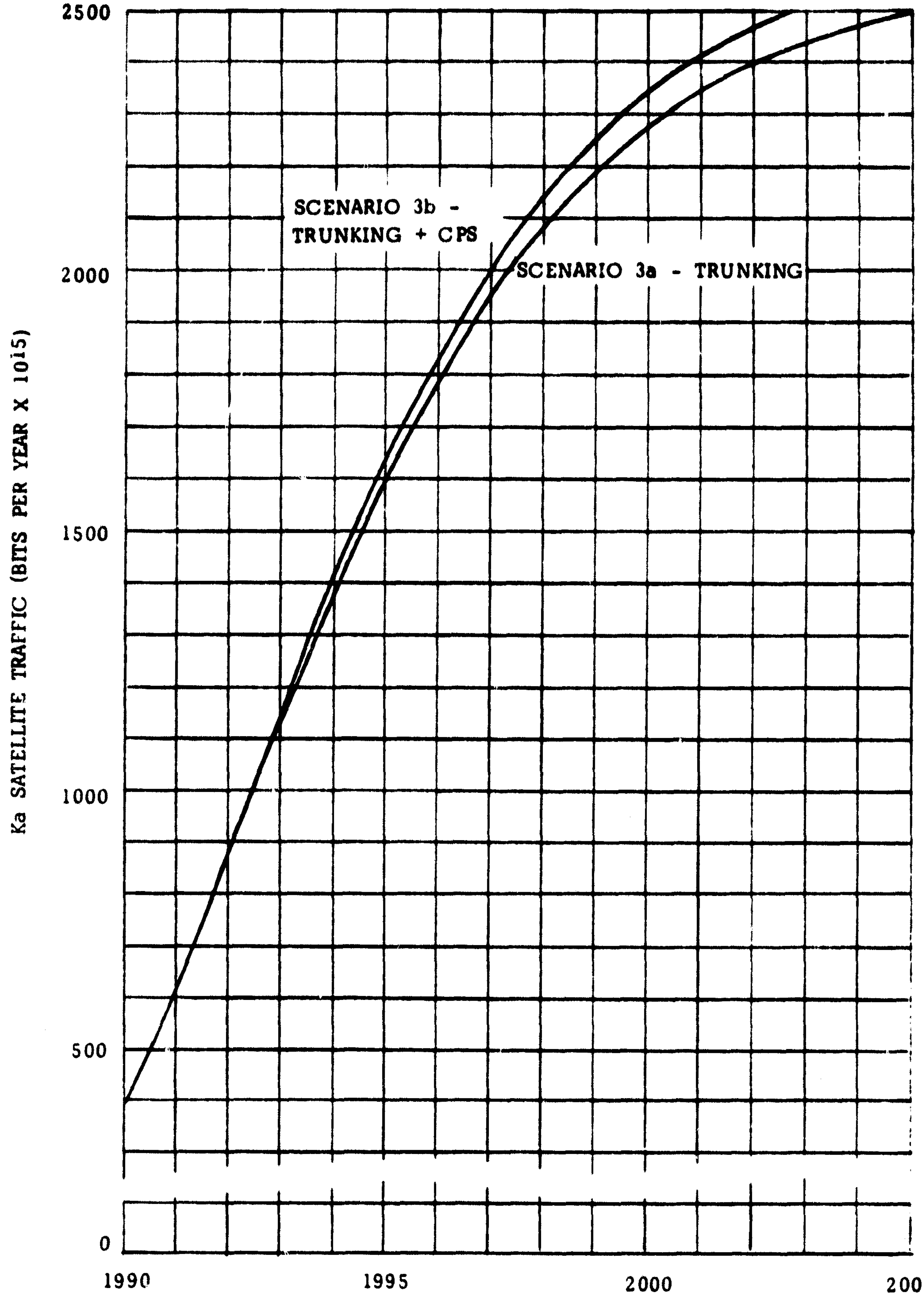


FIGURE 8-5 DEVELOPMENT OF Ka SATELLITE TRAFFIC FOR SCENARIOS 3a AND 3b

TABLE 8-20 SUMMARY OF TRAFFIC CAPTURED BY Ka SATELLITES UNDER SCENARIOS 3a AND 3b (BITS PER YEAR$\times 10^{15}$)

SCENARIO 3a

	ADDRESSABLE TRAFFIC			CAPTURED TRAFFIC		
	1990	1995	2000	1990	1995	2000
VOICE	2250	3318	4894	338	1440	2026
VIDEO	51	84	137	5	39	72
DATA	280	349	434	30	128	181
TOTAL	2581	3751	5465	373	1607	2279

SCENARIO 3b

	ADDRESSABLE TRAFFIC			CAPTURED TRAFFIC		
	1990	1995	2000	1990	1995	2000
VOICE	2250	3318	4894	338	1440	2026
VIDEO	111	174	273	9	74	136
DATA	280	349	434	30	128	181
TOTAL	2641	3841	5601	377	1642	2343

8.6 SCENARIO 4 - Ka SATELLITES IN COMBINATION WITH C OR Ku SATELLITE TRUNKING FACILITIES: (a) LOW RELIABILITY Ka TRUNKING (b) LOW RELIABILITY Ka TRUNKING WITH CPS

The following discusses Ka satellites used in combination with intrinsically higher reliability C or Ku band satellite trunking systems. In this scenario the Ka satellites are used in low reliability trunking modes, with or without a Ka band CPS component to add high volume capacity to the lower frequency satellite system. The C or Ku band trunking provides back-up capability for any Ka trunking links experiencing rain outages. The Ka band CPS capability, as in the previous scenarios, is of lower reliability and under this scenario receives no back-up from the C or Ku band system.

8.6.1 DESCRIPTION OF SERVICE

As discussed in Chapter 6, the capacity of C band and Ku band satellite systems is limited. C band, in particular, is already showing signs of overcrowding and the traffic demand projections of Table 1-1 indicate that, in the future, similar overcrowding of Ku band is likely. Carriers with demand backlogs for C and Ku circuits can be expected to look to Ka band systems for additional capacity.

It is assumed that the C band or Ku band systems are designed to levels of reliability comparable to or better than that of existing terrestrial service (see Subsection 8.1.3.1). As indicated in Subsection 5.2.2.2, this is not a difficult requirement for C band and will probably also be achieved without great difficulty with most Ku band systems. The C or Ku trunking network can therefore provide reliable alternative paths for the re-routing of Ka band trunking traffic to cities with Ka band outages due to rain. Since the C or Ku facilities under Scenarios 4a and 4b involve trunking only, the back-up capability applies to Ka trunking components only. Ka band CPS, offered under Scenario 4b is not backed-up and therefore, as in the previous scenarios, provides lower reliability service. Configurations in which back-up is provided for Ka band CPS are considered under Scenarios 5 and 6.

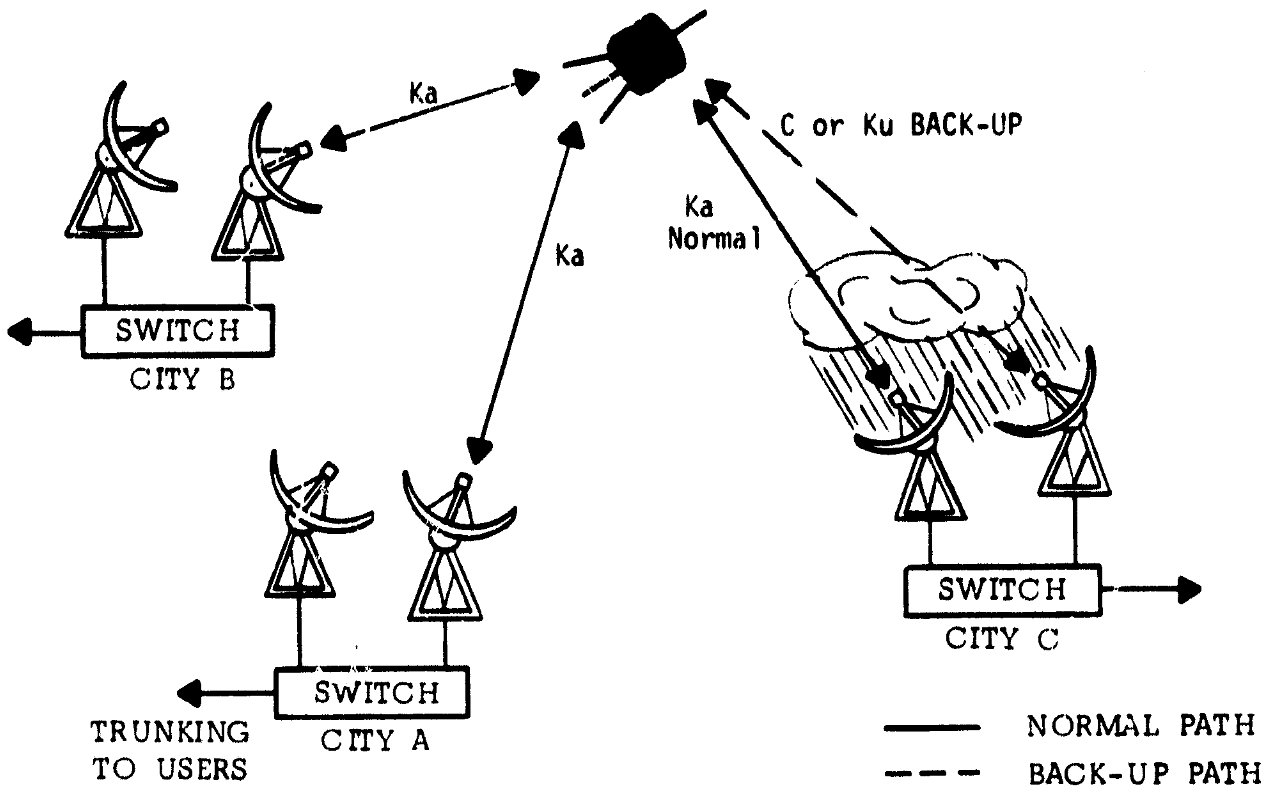
The end effect of providing back-up for the Ka band trunking links through the C or Ku network is similar to that of building the Ka links to higher reliability standards by the use of diversity earth stations. The extra costs of the diversity Ka configuration are avoided, but capacity must be reserved in the C or Ku band system to replace any rained-out Ka capacity.

The procedures needed to accomplish the restoral of lost Ka capacity through the C or Ku network, as in the case of restoral through the terrestrial network, requires careful interface and coordination between the systems involved. One possible back-up configuration is based on the use of advanced satellites containing both Ka and C or Ku band transponders which, in response to a command from the ground, can be cross-linked to achieve the desired back-up. A typical configuration of this type is illustrated in Figure 8-6(a). Traffic normally directed to and from City C via Ka facilities is cross-strapped to C or Ku band facilities when City C experiences propagation difficulties. The transmissions between the satellite and Cities A and B remain unchanged. The capability is also required, on the ground, to switch user traffic at City C from the Ka band earth station to the C or Ku earth station.

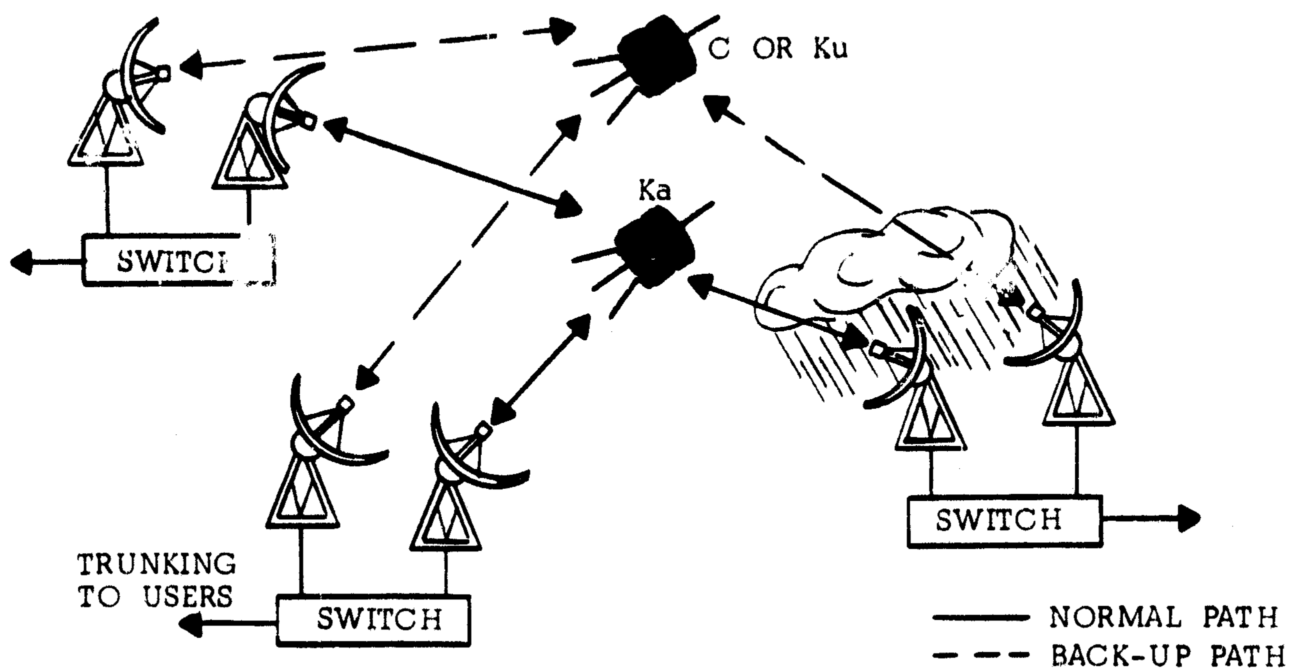
The advantage of this approach is that only the rained-out city (City C) requires reconfiguration. Cities A and B continue normal operations. On the negative side, advanced technology, involving cross-strapping on ground command, is required in the satellite.

An alternative approach, illustrated in Figure 8-6(b), accomplishes all switching on the ground, and does not require cross-strapping of transponders. When City C is affected by rain, all cities direct that portion of their traffic to or from City C to the C or Ku band facilities. The technology required is less advanced but coordinated action by all cities in communication with City C is required.

The amount of C or Ku capacity that must be reserved to bring the reliability of the Ka system up to suitable standards is a major consideration in evaluating the desirability of this type of back-up versus the option of building the Ka trunking links themselves to higher reliability specifications. A detailed analysis is beyond the scope of this discussion but some useful insight can be obtained by making some simplifying assumptions and a few basic calculations.



(a) BACK-UP USING CROSS STRAPPING IN SATELLITE



(b) BACK-UP USING SWITCHING AT EARTH STATIONS

FIGURE 8-6 ALTERNATIVE CONFIGURATIONS FOR BACK-UP OF Ka BANK LINKS THROUGH C OR Ku BAND FACILITIES

If a trunking system serving N widely dispersed, equal size, cities is assumed, connected by Ka links each designed to an availability level A, the probability that more than n cities will be subject to outages is given by the cumulative binominal distribution:

$$\text{PROBABILITY OF MORE THAN n OUTAGES} = 1 - \sum_{i=0}^{n} C_i^N \quad (1 - A)^i (A)^{N-i}$$

WHERE: N is the number of cities in the network;
n is the number of cities simultaneously experiencing an outage;
A is the link availability;
C_i^N is the number of combinations of N items taken i at a time.

The provision of spare C or Ku band capacity equal to the sum of the capacities of the Ka links to n cities would assure the ability to back-up the Ka system to the probability level defined in the above equation.

The equation shows that a network linking N = 100 cities, with individual Ka link availabilities A = .99, would need C or Ku spare capacity equivalent to the Ka capacity serving n = 5 nominal cities to insure overall Ka system availability of at least 99.9 percent. That is, with 5 percent, (5 cities out of 100) of the total Ka capacity supplied as spare back-up capacity via the C or Ku system, the relatively low availability Ka links will perform at a higher than 99.9 percent availability level, which is somewhat better than typical present day terrestrial service.

It should be noted that if the Ka system being backed-up carries high volumes of traffic, relative to the C or Ku system, five percent of the Ka capacity might be a significant portion of the C or Ku system capacity. This method of providing back-up, therefore, may be costly in terms of lost capacity on the C or Ku system. There are, however, some factors which tend to lessen this disadvantage. The calculation discussed above assumes that all Ka links are designed to low reliability levels. Many links will be located in regions of low rain activity and will, therefore, perform at higher levels of availability. In addition, it may be desirable to provide dual diversity for certain critical Ka links, namely those subject to very poor propagation conditions, and those carrying very high traffic volumes. Lastly, not all traffic components are critical. The less critical components can be dropped, rather than re-routed. Nevertheless, the issue of back-up capacity is an important one in this, and the following scenarios. Trade off against other methods achieving the desired levels of reliability is an important issue for future system designs.

8.6.2 MARKET POTENTIAL

With respect to market potential Scenarios 4a and 4b are similar to Scenarios 1a and 1b. Reliable trunking is provided in one case through dual diversity earth stations, and in the other by back-up through C or Ku facilities. CPS in each case remains a relatively isolated service with low reliability performance. Scenario 4 does not permit access to the wide distribution capabilities, and large customer base, available when Ka services are integrated with terrestrial facilities as in Scenarios 2 and 3. Thus, from a user's viewpoint the service available in Scenario 4 is close to that of Scenario 1 and is more limited in distribution capability than that of Scenarios 2 and 3.

The addressable traffic for Scenarios 4a and 4b is estimated in Tables 8-21 and 8-22, respectively, and is further discussed in the following subsections.

8.6.2.1 VOICE

Voice applications remain the largest fraction of addressable traffic. As in Scenario 1a the dedicated private or leased line voice applications are fully addressable. The switched voice applications, requiring close interface and coordination with terrestrial local distribution systems, are not considered to be a good long term target for Ka satellites under this scenario and only a small portion of this traffic is estimated

TABLE 8-21 ADDRESSABLE TRAFFIC FOR Ka SATELLITES UNDER SCENARIO 4a. LOW RELIABILITY Ka TRUNKING IN COMBINATION WITH C OR Ku TRUNKING.

COMMUNICATIONS SUBCATEGORY	TARGET FOR Ka PERCENT	ADDRESSABLE* (BITS/YRx10^{15}) 1990	2000	COMMENTS
RESIDENTIAL	10	19.7	37.8	1,2
BUSINESS (SWITCHED SVC.)	10	60.0	107.6	1,2
BUSINESS (PVT. OR LEASED LINE)	100	1453.0	3440.0	2
TOTAL VOICE	-	1532.7	3585.4	
NETWORK TV	10	1.6	1.1	3,4
CATV	10	3.3	2.7	3,4
EDUCATIONAL VIDEO	10	3.8	11.3	3,4
VIDEOCONFERENCING	40	33.6	107.2	3
TOTAL VIDEO	-	42.3	122.3	
FACSIMILE	50	1.0	2.0	5
ELECTRONIC MAIL	90	5.4	6.3	6
COMPUTER	82	223.0	346.9	5
TOTAL DATA	-	229.4	355.2	
TOTAL TRAFFIC		1804.4	4062.9	

*TARGET FOR Ka TIMES DEMAND FROM TABLE 1-1

1. SWITCHED SERVICE BETTER ADDRESSED IN SCENARIOS WHERE SATELLITE LINKS ARE INTEGRATED AND MANAGED WITH TERRESTRIAL FACILITIES.
2. ASSUMES AVAILABILITY OF COST EFFECTIVE ECHO CANCELLERS.
3. WIDEBAND SERVICES UNDER TRUNKING LIMITED BY LOCAL DISTRIBUTION PROBLEMS.
4. BACK-UP SWITCHING TO C OR Ku BAND IS A POTENTIAL DETERRENT TO RELIABLE WIDEBAND BROADCAST VIDEO APPLICATIONS.
5. PRIMARILY DEDICATED TRAFFIC PLUS A SMALL PERCENTAGE OF SWITCHED TRAFFIC.
6. PRIMARILY DEDICATED TRAFFIC, INCLUDING A LARGE POSTAL SERVICE COMPONENT.

TABLE 8-22 ADDRESSABLE TRAFFIC FOR Ka SATELLITES UNDER SCENARIO 4b. LOW RELIABILITY Ka TRUNKING PLUS CPS IN COMBINATION C OR Ku TRUNKING

COMMUNICATIONS SUBCATEGORY	TRUNKING TARGET FOR Ka PERCENT	TRUNKING ADDRESSABLE* (BITS/YRx10^{15}) 1990	TRUNKING ADDRESSABLE* (BITS/YRx10^{15}) 2000	CPS TARGET FOR Ka PERCENT	CPS ADDRESSABLE* (BITS/YRx10^{15}) 1990	CPS ADDRESSABLE* (BITS/YRx10^{15}) 2000	COMMENTS
RESIDENTIAL	10	19.7	37.8	0	0	0	1
BUSINESS (SWITCHED SVC.)	10	60.0	107.6	0	0	0	1
BUS. (PVT. OR LEASED LINE)	97	1409.4	3336.8	3	43.6	103.2	1
TOTAL VOICE	-	1489.1	3482.2	-	43.6	103.2	
NETWORK TV	10	1.6	1.1	38	6.1	4.2	2
CATV	10	3.3	2.7	48	15.8	13.0	2
EDUCATIONAL VIDEO	10	3.8	11.3	34	12.9	38.4	2
VIDEOCONFERENCING	40	33.6	107.2	30	25.2	80.4	2
TOTAL VIDEO	-	42.3	122.3	-	60.0	136.0	
FACSIMILE	42	0.8	1.7	8	0.2	0.3	1
ELECTRONIC MAIL	21	1.3	1.5	69	4.1	4.8	1
COMPUTER	79	214.9	334.2	3	8.1	12.7	1
TOTAL DATA	-	217.0	337.4	-	12.4	17.8	
TOTAL TRAFFIC		1748.4	3941.9		116.0	257.0	

*TARGET FOR Ka TIMES DEMAND FROM TABLE 1-1

1. SUM OF TRUNKING AND CPS SAME AS SCENARIO 4a. CPS PORTION AS PER TABLE 3-2.

2. TRUNKING COMPONENT SAME AS SCENARIO 4a. CPS PROVIDES ADDITIONAL CAPABILITY TO ADDRESS TRAFFIC AS PER TABLE 3-2.

to be addressable. The discussion in Subsection 8.3.2.1 applying to Scenario 1 applies here as well.

8.6.2.2 VIDEO

Because of wideband distribution problems CPS modes are desirable for most video applications. However, the low reliability of Ka band CPS limits the applicability of this mode to deferred video signals recorded for later transmission. The considerations discussed in Subsection 8.3.2.2 relative to Scenario 1 apply here as well with the following exception. The relatively small addressable component projected for broadcast video traffic using reliable trunking in Scenario 1 is further reduced under the present scenario as a result of the difficulties inherent in switching these wideband signals from Ka band to C or Ku band when back-up is required.

8.6.2.3 DATA

That portion of data traffic using dedicated modes of transmission is readily addressed under this scenario. The switched component, as in the case for voice, is less well addressed. The discussion in Subsection 8.3.2.3 applies here as well.

8.6.2.4 SUMMARY OF ADDRESSABLE TRAFFIC

Of the total traffic volume of 2701×10^{15} bits per year projected in Table 1-1 for 1990, 1804×10^{15} bits per year, or 67 percent are addressable in the trunking only configuration represented in Table 8-21. For the year 2000 the addressable traffic increases to 71 percent of total projected volume.

The traffic volume addressable by CPS is about 6.5 percent of that addressable by trunking and the addition of low reliability Ka band CPS to the trunking capability as reflected in Table 8-22, increases the total addressable traffic by only 3 percent over that projected for trunking alone in Table 8-21.

8.6.3 OWNERSHIP AND OPERATION

Ka systems under this scenario are most likely to evolve as a means of adding capacity to overloaded C or Ku facilities. A carrier with existing C or Ku capabilities, and with a backlog of demand may seek to expand capacity through the addition of Ka facilities.

The existence of a customer base for satellite services can be expected to ease the problems of maintaining adequate fill for the Ka systems. Facilities can be added as needed and traffic can be transferred from one satellite medium to another with relative ease.

The technical and operational problems involved in back-up of the Ka system through C or Ku systems, however, are complex and require close coordination of facilities. In addition, the reduction of C or Ku capacity, needed to provide spare capacity for back-up of the Ka band links, can be a significant deterrent. The new capacity gained by the addition of the Ka links must more than compensate for the loss.

8.6.4 GROWTH OF Ka SERVICE

This section discusses the potential development of Ka satellite communications under Scenario 4. The Gompertz growth model discussed in relation to previous scenarios is used with the year 2000 addressable traffic defined in Tables 8-21 and 8-22 as a starting point.

Since, from the users point of view, the service provided under Scenario 4a and 4b is virtually the same as that provided under Scenarios 1a and 1b, the market penetration parameters for the two sets of scenarios tend to be the same. Table 8-23 defines these parameters for Scenario 4a and Table 8-24 does the same for Scenario 4b. The only changes from the comparable estimates for Scenarios 1a and 1b are in the long term capturable percentages predicted for the voice and computer categories. Users in these categories may be concerned over possible discontinuities in service encountered during switch over between Ka and C and Ku service when back-up is required. Depending on how the system is engineered and controlled, the switch-over process may or may not be a smooth process without

TABLE 8-23 TRAFFIC CAPTURED UNDER SCENARIO 4a. LOW RELIABILITY Ka TRUNKING IN COMBINATION WITH C OR Ku TRUNKING.

	COMMUNICATIONS SUBCATEGORY	YEAR 2000 * ADDRESSABLE TRAFFIC BITS/YRx10^{15}	LONG TERM Ka CAPTURABLE PERCENTAGE	% OF LONG TERM TRAFFIC CAPTURED BY 1990	YEARS AFTER 1990 TO REACH 90%
VOICE	RESIDENTIAL	37.8	31	5	12
	BUSINESS (SWITCHED SVC.)	107.6	31	5	12
	BUS. (PVT. OR LEASED LINE)	3440.0	31	10	12
VIDEO	NETWORK TV	1.1	10	15	10
	CATV	2.7	10	15	10
	EDUCATIONAL VIDEO	11.3	50	5	10
	VIDEOCONFERENCING	107.2	78	5	15
DATA	FACSIMILE	2.0	46	10	10
	ELECTRONIC MAIL	6.3	80	10	15
	COMPUTER	346.9	31	10	10

*YEAR 2000 ADDRESSABLE TRAFFIC FROM TABLE 8-21

TABLE 8-24 TRAFFIC CAPTURED UNDER SCENARIO 4b. LOW RELIABILITY Ka TRUNKING PLUS CPS IN COMBINATION WITH C OR Ku TRUNKING.

	COMMUNICATIONS SUBCATEGORY	YEAR 2000* ADDRESSABLE TRAFFIC BITS/YR$\times 10^{15}$	LONG TERM Ka CAPTURABLE PERCENTAGE	% OF LONG TERM TRAFFIC CAPTURED BY 1990	YEARS AFTER 1990 TO REACH 90%
VOICE	RESIDENTIAL	37.8	31	5	12
	BUSINESS (SWITCHED SVC.)	107.6	31	5	12
	BUS. (PVT. OR LEASED LINE)	3440.0	31	10	12
VIDEO	NETWORK TV	5.3	10	15	10
	CATV	15.7	10	15	10
	EDUCATIONAL VIDEO	49.7	50	5	10
	VIDEOCONFERENCING	187.6	78	5	15
DATA	FACSIMILE	2.0	46	10	10
	ELECTRONIC MAIL	6.3	80	10	15
	COMPUTER	346.9	31	10	10

*YEAR 2000 TRUNKING PLUS CPS ADDRESSABLE TRAFFIC FROM TABLE 8-22

significant interruption. All other factors being equal, some users may prefer to be routed through the lower frequency C or Ku band system thereby avoiding even the possibility of discontinuity in service that may be present in the Ka band system. The long term capturable percentages for voice and computer traffic in Tables 8-23 and 8-24 are, therefore, based on these components giving first preferences to terrestrial, C or Ku bands, with only the overflow above the capacity of these systems migrating to Ka band.

Figure 8-7 shows the development of Ka satellite traffic for Scenarios 4a and 4b. Table 8-25 presents results for the years 1990, 1995 and 2000 in tabular form.

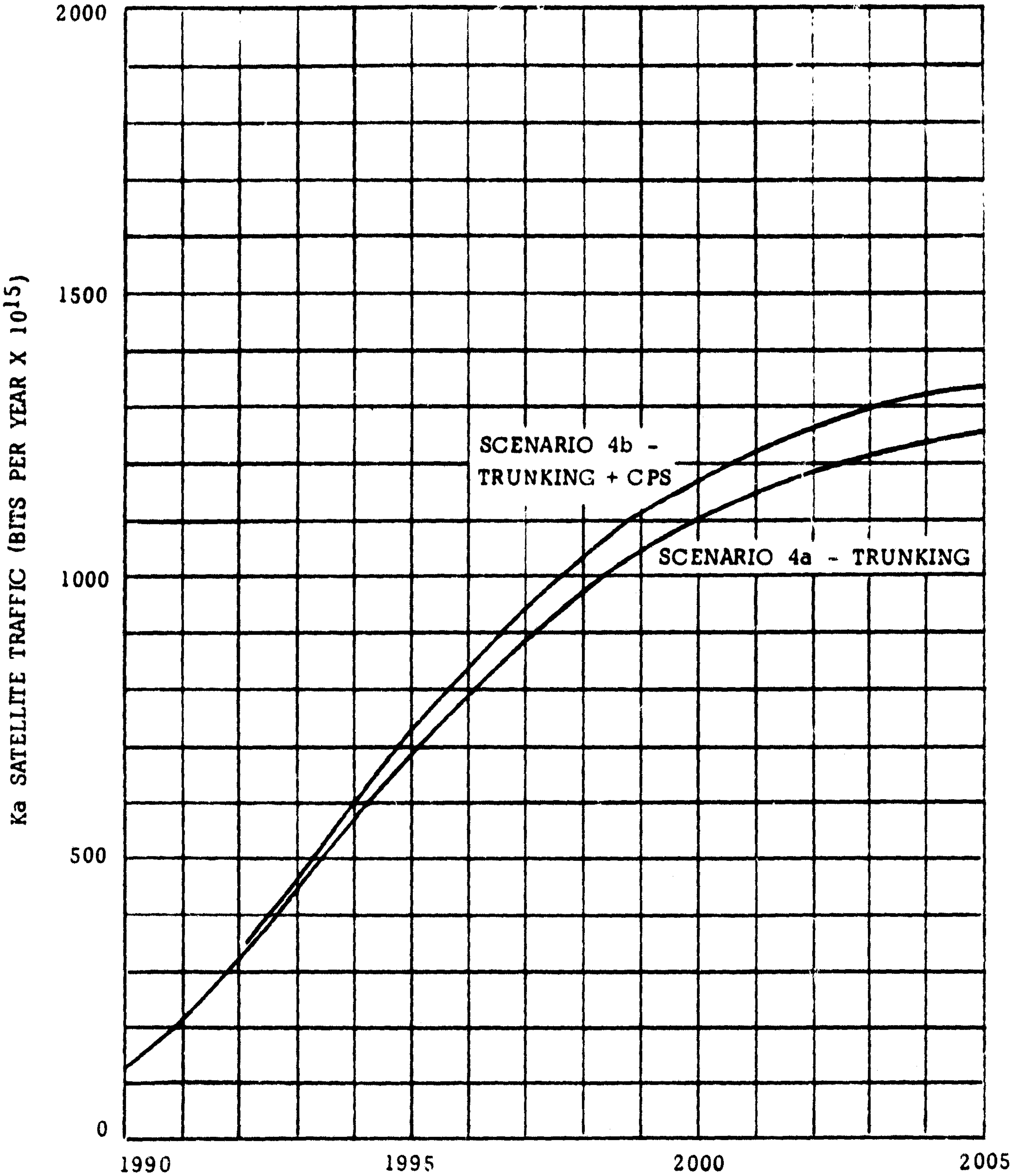


FIGURE 8-7 DEVELOPMENT OF Ka SATELLITE TRAFFIC FOR SCENARIOS 4a AND 4b

TABLE 8-25 SUMMARY OF TRAFFIC CAPTURED BY Ka SATELLITES UNDER SCENARIOS 4a AND 4b (BITS PER YEAR$\times 10^{15}$)

SCENARIO 4a

	ADDRESSABLE TRAFFIC			CAPTURED TRAFFIC		
	1990	1995	2000	1990	1995	2000
VOICE	1533	2344	3585	109	586	932
VIDEO	42	72	122	5	35	66
DATA	229	285	355	12	69	102
TOTAL	1804	2701	4063	126	690	1100

SCENARIO 4b

	ADDRESSABLE TRAFFIC			CAPTURED TRAFFIC		
	1990	1995	2000	1990	1995	2000
VOICE	1533	2344	3585	109	586	932
VIDEO	102	162	258	9	71	131
DATA	229	285	355	12	69	102
TOTAL	1864	2791	4199	130	726	1165

8.7 SCENARIO 5 - Ka SATELLITES IN COMBINATION WITH C OR Ku TRUNKING AND CPS FACILITIES:
(a) LOW RELIABILITY Ka TRUNKING
(b) LOW RELIABILITY Ka CPS
(c) LOW RELIABILITY Ka TRUNKING WITH CPS

The following discusses Ka satellites used in combination with C or Ku satellite systems. As in the previous scenarios the role of the Ka satellites is to provide large increases in communications capacity, while the lower frequency, C or Ku system, permits back-up for improved reliability. The C or Ku system in this scenario provides both trunking and CPS service. It is assumed that each of these is capable of reliability levels comparable to those of existing terrestrial service. Thus, the capability exists in this scenario for back-up of the Ka band CPS mode as well as the trunking mode. Reliable communications service can therefore be supplied in either mode.

8.7.1 DESCRIPTION OF SERVICE

As far as the Ka band trunking component is concerned, there is no significant distinction between this scenario and that of Scenario 4. The existence of a reliable C or Ku band CPS capability enhances the position of Ka band CPS offerings included in Scenarios 5b or 5c, but has little bearing on Ka band trunking operations.

The need for coordination between Ka band facilities and the C or Ku band system is similar to that required for trunking in Scenario 4, but extends in this case to CPS as well. Spare capacity must be made available at C or Ku band to accommodate possible rain outages at Ka band, both for trunking and CPS. Some examples of methods of accomplishing this back-up were discussed in Subsection 8.6.1 for trunking. The methods of accomplishing back-up in the case of CPS are in principle the same, but the economic practicality of equipping CPS earth stations with both Ka and C or Ku band capabilities requires further investigation. A possible alternative is to provide regional C or Ku band back-up facilities linked via short local trunks to the Ka band earth stations in the near vicinity. Normal Ka band operation would then be via CPS but back-up, in the event of a Ka band outage, would be through terrestrial links to the common C or Ku band earth station serving the area.

There are a number of technical and operational issues, such as the above, that will have to be addressed to establish a practical back-up capability for Ka band CPS under this Scenario. The traffic estimates discussed in the following sections assume that these issues are satisfactorily resolved and that reliable Ka CPS and trunking is achieved through back-up by C or Ku band facilities.

8.7.2 MARKET POTENTIAL

The amount of traffic addressable for Scenarios 5a, 5b, and 5c is estimated in Tables 8-26, 8-27, and 8-28 respectively, and is discussed in the following subsections.

8.7.2.1 VOICE

The traffic addressable by Ka satellites in the Ka trunking configuration of Scenario 5a duplicates that of the similar configuration of Scenario 4a. The entries in Table 8-26 are therefore the same as those of Table 8-23.

Scenario 5b refers to Ka band CPS only, with back-up through reliable C or Ku band CPS. The addressable traffic projections in Table 8-27 reflect the estimates of Table 3-2 as far as the high traffic volume and wide distribution limitations are concerned. However, the limitation due to reliability considerations in Table 3-2 is removed by the existence of reliable CPS back-up through the C or Ku band system. Thus, the target percentages for Ka band CPS in Table 8-26 are equal to the product of the first two columns of Table 3-2.

Table 8-28 presents estimates for Ka addressable voice traffic when both Ka trunking and CPS are simultaneously offered. The total traffic remains the same as in Scenario 5a, with that portion estimated for CPS in Scenario 5b being diverted in Scenario 5c from the amount that would otherwise be addressed by trunking.

8.7.2.2 VIDEO

As in the case of voice, discussed above, the video estimates presented in Table 8-26 for Ka trunking only are derived from the similar configuration for Scenario 4a represented in Table 8-21. The estimates for Ka CPS only in Table 8-27 deri[illegible] from Table 3-2 with the reliability limitation removed. The addressable traffic for combined Ka

TABLE 8-26 ADDRESSABLE TRAFFIC FOR Ka SATELLITES UNDER SCENARIO 5a. LOW RELIABILITY Ka TRUNKING IN COMBINATION WITH C OR Ku TRUNKING AND CPS.

COMMUNICATIONS SUBCATEGORY	TARGET FOR Ka PERCENT	ADDRESSABLE* (BITS/YRx10^{15}) 1990	2000	COMMENTS
RESIDENTIAL	10	19.7	37.8	1,2
BUSINESS (SWITCHED SVC.)	10	60.0	107.6	1,2
BUSINESS (PVT. OR LEASED LINE)	100	1453.0	3440.0	2
TOTAL VOICE	-	1532.7	3585.4	
NETWORK TV	10	1.6	1.1	3,4
CATV	10	3.3	2.7	3,4
EDUCATIONAL VIDEO	10	3.8	11.3	3,4
VIDEOCONFERENCING	40	33.6	107.2	3
TOTAL VIDEO	-	42.3	122.3	
FACSIMILE	50	1.0	2.0	5
ELECTRONIC MAIL	90	5.4	6.3	6
COMPUTER	82	223.0	346.8	5
TOTAL DATA	-	229.4	355.2	
TOTAL TRAFFIC		1804.4	4062.9	

*TARGET FOR Ka TIMES DEMAND FROM TABLE 1-1

1. SWITCHED SERVICE BETTER ADDRESSED IN SCENARIOS WHERE SATELLITE LINKS ARE INTEGRATED AND MANAGED WITH TERRESTRIAL FACILITIES.
2. ASSUMES AVAILABILITY OF COST EFFECTIVE ECHO CANCELLERS.
3. WIDEBAND SERVICES UNDER TRUNKING LIMITED BY LOCAL DISTRIBUTION PROBLEMS.
4. BACK-UP SWITCHING TO C OR Ku BAND IS A POTENTIAL DETERRENT TO RELIABLE WIDEBAND BROADCAST VIDEO APPLICATIONS.
5. PRIMARILY DEDICATED TRAFFIC PLUS A SMALL PERCENTAGE OF SWITCHED TRAFFIC.
6. PRIMARILY DEDICATED TRAFFIC, INCLUDING A LARGE POSTAL SERVICE COMPONENT.

TABLE 8-27 ADDRESSABLE TRAFFIC FOR Ka SATELLITES UNDER SCENARIO 5b. LOW RELIABILITY Ka CPS IN COMBINATION WITH C OR Ku TRUNKING AND CPS.

COMMUNICATIONS SUBCATEGORY	TARGET FOR Ka PERCENT	ADDRESSABLE* (BITS/YRx10^{15}) 1990	2000	COMMENTS
RESIDENTIAL	0	0	0	1
BUSINESS (SWITCHED SVC.)	0	0	0	1
BUSINESS (PVT. OR LEASED LINE)	15	218.0	516.0	1
TOTAL VOICE	-	218.0	516.0	
NETWORK TV	95	15.2	10.5	1
CATV	95	31.4	25.7	1
EDUCATIONAL VIDEO	76	28.9	85.9	1
VIDEOCONFERENCING	76	63.8	203.7	1
TOTAL VIDEO	-	139.3	325.8	
FACSIMILE	15	0.3	0.6	1
ELECTRONIC MAIL	77	4.6	5.4	1
COMPUTER	15	40.8	63.5	1
TOTAL DATA	-	45.7	69.5	
TOTAL TRAFFIC		403.0	911.3	

*TARGET FOR Ka TIMES DEMAND FROM TABLE 1-1

1. CPS TARGET AS PER TABLE 3-2 WITH RELIABILITY LIMITATION REMOVED.

TABLE 8-28 ADDRESSABLE TRAFFIC FOR Ka SATELLITES UNDER SCENARIO 5c. LOW RELIABILITY Ka TRUNKING PLUS CPS IN COMBINATION WITH C OR Ku TRUNKING AND CPS.

COMMUNICATIONS SUBCATEGORY	TRUNKING			CPS			COMMENTS
	TARGET FOR Ka PERCENT	ADDRESSABLE (BITS/YRx10^{15})* 1990	2000	TARGET FOR Ka PERCENT	ADDRESSABLE (BITS/YRx10^{15})* 1990	2000	
RESIDENTIAL	10	19.7	37.8	0	0	0	1
BUSINESS (SWITCHED SVC.)	10	60.0	107.6	0	0	0	1
BUS. (PVT. OR LEASED LINE)	85	1235.1	2924.0	15	218.0	516.0	1
TOTAL VOICE	-	1314.8	3069.4	-	218.0	516.0	
NETWORK TV	5	0.8	0.6	95	15.2	10.5	2
CATV	5	1.7	1.4	95	31.4	25.7	2
EDUCATIONAL VIDEO	10	3.8	11.3	76	28.9	85.9	2
VIDEOCONFERENCING	20	16.8	53.6	76	63.8	203.7	2
TOTAL VIDEO	-	23.1	66.9	-	139.3	325.8	
FACSIMILE	35	0.7	1.4	15	0.3	0.6	1
ELECTRONIC MAIL	13	0.8	0.9	77	4.6	5.4	1
COMPUTER	67	182.2	283.4	15	40.8	63.5	1
TOTAL DATA	-	183.7	285.7	-	45.7	69.5	
TOTAL TRAFFIC		1521.6	3422.0		403.0	911.3	

*TARGET FOR Ka TIMES DEMAND FROM TABLE 1-1

1. SUM OF TRUNKING AND CPS SAME AS SCENARIO 5a. CPS PORTION AS PER TABLE 3-2 WITH RELIABILITY LIMITATION REMOVED.

2. TRUNKING COMPONENT SAME AS SCENARIO 5a. CPS PROVIDES ADDITIONAL CAPABILITY AS PER TABLE 3-2, WITH RELIABILITY LIMITATION REMOVED.

trunking and CPS, presented in Table 8-28, assumes that the percentages addressable by CPS remain the same as those of Table 8-27, and that some of the traffic addressable by trunking in Table 8-26 moves to the CPS category.

8.7.2.3 DATA

Addressable traffic for Scenario 5a, shown in Table 8-26, duplicates that of the similar configuration of Scenario 4a. The Ka band CPS only configuration of Scenario 5b, shown in Table 8-27, is derived from Table 3-2 with the reliability limitations removed. Estimates for the traffic addressable under Scenario 5c, which includes both trunking and CPS, are presented in Table 8-28. Total traffic remains the same as in Scenario 5a, with that portion estimated for CPS in Scenario 5b being diverted from the amount that would otherwise be addressed by trunking.

8.7.2.4 SUMMARY OF ADDRESSABLE TRAFFIC

Of the total traffic volume of 2701 x 10^{15} bits per year projected in Table 1-1 for 1990, 1804 x 10^{15} bits per year, or 67 percent, are addressable in the trunking only configuration represented in Table 8-26. For the year 2000 the addressable traffic increases to 71 percent of total projected volume.

With the CPS only configuration of Table 8-27, using back-up through C or Ku band CPS, the traffic addressable at Ka band is 15 percent of total demand for 1990 and 16 percent for the year 2000. With the added reliability resulting from back-up, substantial components of traffic in the voice, video and data categories are addressable in this CPS mode. Combined Ka trunking plus CPS as reflected in Table 8-28 results in an addressable traffic equal to 71 percent of demand for 1990, rising to 74 percent in the year 2000. Even with reliable CPS operation obtained through back-up at C or Ku band the sum of trunking plus CPS addressable traffic is only 5 to 6 percent higher than that obtained by trunking alone. In part this is due to the fact that traffic carried by CPS in most categories is diverted from that which otherwise would be carried by trunking.

8.7.3 OWNERSHIP AND OPERATION

As in Scenario 4, Ka systems under this scenario are most likely to evolve as a result of Domsat carriers' needs for additional capacity to supplement existing overloaded C or Ku facilities. The technical and operational problems of providing back-up through the C or Ku network are complex, and the reduction of capacity in the lower frequency satellite system needed to provide spare back-up capacity remain a possible deterrent.

8.7.4 GROWTH OF Ka SERVICE

This section discussed the potential development of Ka satellite communications under Scenario 5. The Gompertz curve growth model discussed in previous scenarios is used, with the year 2000 addressable traffic defined in Tables 8-26, 8-27 and 8-28 as a starting point.

The trunking service provided under Scenario 5a is essentially the same as that of Scenario 4a. The market penetration parameters presented in Table 8-29 are therefore the same as those in Table 8-23.

Table 8-30 defines market penetration parameters for the Ka CPS configuration of Scenario 5b. In this case the existence of back-up through reliable C or Ku band CPS facilities results in higher long term capturable percentages than for previous scenarios involving CPS. Since it is assumed that switched traffic is not readily addressable by CPS, the capturable percentages for Residential and Business Switched Services are not applicable. A large portion of the addressable dedicated Business Voice traffic, however, is projected to be capturable in the long term. Terrestrial transmission is somewhat superior to satellite transmission for this type of traffic because of the echo and delay problems discussed in Chapter 2. The long term capture percentage reflected in Table 8-30 for the Business Private or Leased Line category is therefore based on first preference being given to terrestrial modes, with Ka satellites sharing the overflow traffic on an equal basis with other satellite media, in proportion to the available capacities postulated in Table 6-5.

The same considerations apply to the Data category. Terrestrial media are accorded a preferential role, but with

TABLE 8-29 TRAFFIC CAPTURED UNDER SCENARIO 5a. LOW RELIABILITY Ka TRUNKING IN COMBINATION WITH C OR Ku TRUNKING AND CPS.

	COMMUNICATIONS SUBCATEGORY	YEAR 2000 * ADDRESSABLE TRAFFIC BITS/YR$\times 10^{15}$	LONG TERM Ka CAPTURABLE PERCENTAGE	% OF LONG TERM TRAFFIC CAPTURED BY 1990	YEARS AFTER 1990 TO REACH 90%
VOICE	RESIDENTIAL	37.8	31	5	12
	BUSINESS (SWITCHED SVC.)	107.6	31	5	12
	BUS. (PVT. OR LEASED LINE)	3440.0	31	10	12
VIDEO	NETWORK TV	1.1	10	15	10
	CATV	2.7	10	15	10
	EDUCATIONAL VIDEO	11.3	50	5	10
	VIDEOCONFERENCING	107.2	78	5	15
DATA	FACSIMILE	2.0	46	10	10
	ELECTRONIC MAIL	6.3	80	10	15
	COMPUTER	346.8	31	10	10

*YEAR 2000 ADDRESSABLE TRAFFIC FROM TABLE 8-26

TABLE 8-30 TRAFFIC CAPTURED UNDER SCENARIO 5b.
LOW RELIABILITY Ka CPS IN COMBINATION WITH C OR Ku
TRUNKING AND CPS.

	COMMUNICATIONS SUBCATEGORY	YEAR 2000* ADDRESSABLE TRAFFIC BITS/YR$\times 10^{15}$	LONG TERM Ka CAPTURABLE PERCENTAGE	% OF LONG TERM TRAFFIC CAPTURED BY 1990	YEARS AFTER 1990 TO REACH 90%
VOICE	RESIDENTIAL	0	-	-	-
	BUSINESS (SWITCHED SVC.)	0	-	-	-
	BUS. (PVT. OR LEASED LINE)	516.0	73	10	12
VIDEO	NETWORK TV	10.5	20	15	10
	CATV	25.7	20	15	10
	EDUCATIONAL VIDEO	85.9	50	5	10
	VIDEOCONFERENCING	203.7	78	5	15
DATA	FACSIMILE	0.6	73	10	10
	ELECTRONIC MAIL	5.4	80	10	15
	COMPUTER	63.5	73	10	10

*YEAR 2000 ADDRESSABLE TRAFFIC FROM TABLE 8-27

suitable back-up, Ka satellites can compete equally with other satellite media. It is assumed that a special effort is made to capture the desirable postal service component of electronic mail, and the long term capturable percentage is increased to reflect this.

Broadcast video applications are well suited to CPS operation. Network TV and CATV, however, are well established on C band facilities and, as expansion is needed, will migrate to Ku band before Ka facilities are available. In addition, the complexity of deriving Ka band reliability through back-up in C or Ku band detracts from the position of Ka satellites in favor of approaches which are of intrinsically higher reliability. Long term capture of these traffic components by Ka CPS under Scenario 5b is therefore projected to be relatively modest. The Educational Video category is expected to be less well established on competing media, and concern over reliability is less pressing than for Network TV or CATV. A higher capture percentage is therefore indicated. Videoconferencing will also lack pre-established preferences for other media. The large volumes of wideband traffic postulated would make it most likely that Ku band satellites would be the primary competition to Ka band satellites for this traffic component. The long term capture percentage indicated in Table 8-30 reflects a division between these two media in proportion to capacity limitations.

Table 8-31 refers to Scenario 5c which includes Ka trunking and CPS, with back-up of both modes through C or Ku band facilities. The long term capture percentages shown are the weighted averages of those for the separate Ka trunking and CPS components of Tables 8-29 and 8-30. Weighting is according to the addressable traffic percentages for trunking and CPS as given in Table 8-28.

Figure 8-8 shows the development of Ka satellite traffic for Scenarios 5a, 5b and 5c. Table 8-32 summarizes results for the years 1990, 1995 and 2000 in tabular form.

TABLE 8-31 TRAFFIC CAPTURED UNDER SCENARIO 5c.
LOW RELIABILITY Ka TRUNKING PLUS CPS IN COMBINATION WITH
C OR Ku TRUNKING AND CPS.

	COMMUNICATIONS SUBCATEGORY	YEAR 2000 * ADDRESSABLE TRAFFIC BITS/YRx10^{15}	LONG TERM Ka CAPTURABLE PERCENTAGE	% OF LONG TERM TRAFFIC CAPTURED BY 1990	YEARS AFTER 1990 TO REACH 90%
VOICE	RESIDENTIAL	37.8	31	5	12
	BUSINESS (SWITCHED SVC.)	107.6	31	5	12
	BUS. (PVT. OR LEASED LINE)	3440.0	37	10	12
VIDEO	NETWORK TV	11.1	20	15	10
	CATV	27.1	20	15	10
	EDUCATIONAL VIDEO	97.2	50	5	10
	VIDEOCONFERENCING	257.3	78	5	15
DATA	FACSIMILE	2.0	55	10	10
	ELECTRONIC MAIL	6.3	80	10	15
	COMPUTER	346.9	39	10	10

*YEAR 2000 TRUNKING PLUS CPS ADDRESSABLE TRAFFIC FROM TABLE 8-28

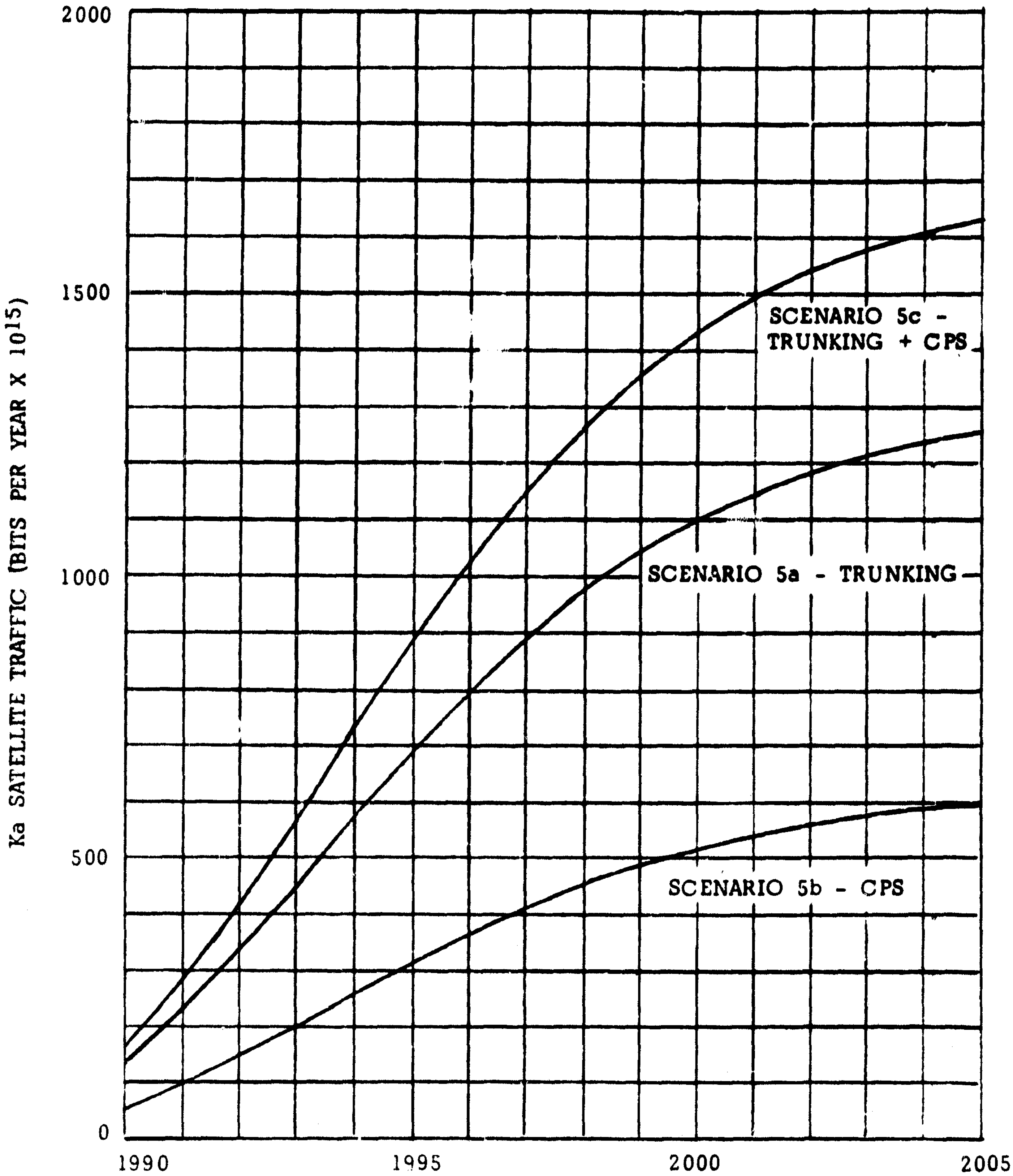


FIGURE 8-8 DEVELOPMENT OF Ka SATELLITE TRAFFIC FOR SCENARIOS 5a, 5b AND 5c

TABLE 8-32 SUMMARY OF TRAFFIC CAPTURED BY Ka SATELLITES UNDER SCENARIOS 5a, 5b AND 5c (BITS PER YEAR$\times 10^{15}$)

SCENARIO 5a

	ADDRESSABLE TRAFFIC			CAPTURED TRAFFIC		
	1990	1995	2000	1990	1995	2000
VOICE	1533	2344	3585	109	586	932
VIDEO	42	72	122	5	35	66
DATA	229	285	355	12	69	102
TOTAL	1804	2701	4063	126	690	1100

SCENARIO 5b

	ADDRESSABLE TRAFFIC			CAPTURED TRAFFIC		
	1990	1995	2000	1990	1995	2000
VOICE	218	335	516	38	199	316
VIDEO	139	213	326	11	89	161
DATA	46	57	70	5	31	45
TOTAL	403	605	911	54	319	522

SCENARIO 5c

	ADDRESSABLE TRAFFIC			CAPTURED TRAFFIC		
	1990	1995	2000	1990	1995	2000
VOICE	1533	2344	3585	130	695	1105
VIDEO	162	252	393	14	108	196
DATA	229	285	355	14	86	127
TOTAL	1925	2881	4333	158	889	1428

8.8 SCENARIO 6 - HIGH RELIABILITY Ka WITH LOWER RELIABILITY Ka CPS BACKED-UP BY C OR Ku BAND CPS

The following discusses Ka satellite configurations in which diversity earth stations or other design approaches are used to assure intrinsically reliable Ka trunking. A Ka band CPS capability is also provided and achieves reliability through back-up by C or Ku band satellite facilities.

8.8.1 DESCRIPTION OF SERVICE

The Ka trunking facilities provided under this scenario are similar in capabilities to those provided in Scenario 1a. The Ka band CPS facility with C or Ku band back-up is similar in capabilities to the CPS provided in Scenario 5b. The market performance expected under Scenario 6 can, therefore, be expected to be a combination of that of Scenario 1a and 5b.

8.8.2 MARKET POTENTIAL

The amount of traffic addressable for Scenario 6 is estimated in Table 8-33 and is discussed in the following subsections.

8.8.2.1 VOICE

As in the cases of Scenario 1a and Scenario 5b, only small amounts of switched traffic are addressed by trunking and none by CPS. The private or leased line voice traffic is primarily trunking oriented, with the sum of the trunking and CPS traffic being the same as the addressable traffic in Scenario 1a. The CPS component is derived from the estimates of Table 3-2 with the reliability limitation removed. These addressable voice traffic estimates of Table 8-33 are also consistent with those applying to the similar capabilities existing under Scenario 5c.

8.8.2.2 VIDEO

Under this scenario, the intrinsically reliable trunking and backed-up CPS allow the addressing of the complete

TABLE 8-33 ADDRESSABLE TRAFFIC FOR Ka SATELLITES UNDER SCENARIO 6. HIGH RELIABILITY Ka TRUNKING PLUS LOWER RELIABILITY CPS IN COMBINATION WITH C OR Ku CPS.

COMMUNICATIONS SUBCATEGORY	TRUNKING TARGET FOR Ka PERCENT	TRUNKING ADDRESSABLE (BITS/YRx10^{15})* 1990	TRUNKING ADDRESSABLE (BITS/YRx10^{15})* 2000	CPS TARGET FOR Ka PERCENT	CPS ADDRESSABLE (BITS/YRx10^{15})* 1990	CPS ADDRESSABLE (BITS/YRx10^{15})* 2000	COMMENTS
RESIDENTIAL	10	19.7	37.8	0	0	0	1
BUSINESS (SWITCHED SVC.)	10	60.0	107.6	0	0	0	1
BUS. (PVT. OR LEASED LINE)	85	1235.1	2924.0	15	218.0	516.0	1
TOTAL VOICE	-	1314.8	3069.4	-	218.0	516.0	
NETWORK TV	10	1.6	1.1	90	14.4	9.9	2
CATV	10	3.3	2.7	90	29.7	24.3	2
EDUCATIONAL VIDEO	25	9.5	28.3	75	28.5	84.8	2
VIDEOCONFERENCING	24	20.2	64.3	76	63.8	203.7	3
TOTAL VIDEO	-	34.6	96.4	-	136.4	322.7	
FACSIMILE	35	0.7	1.4	15	0.3	0.6	1
ELECTRONIC MAIL	13	0.8	0.9	77	4.6	5.4	1
COMPUTER	67	182.2	283.4	15	40.8	63.5	1
TOTAL DATA	-	183.7	285.7	-	45.7	69.5	
TOTAL TRAFFIC		1533.1	3451.5		400.1	908.2	

*TARGET FOR Ka TIMES DEMAND FROM TABLE 1-1

1. SUM OF TRUNKING AND CPS SAME AS SCENARIO 1a. CPS PORTION AS PER TABLE 3-2 WITH RELIABILITY LIMITATION REMOVED.
2. BETWEEN TRUNKING AND CPS 100 PERCENT ADDRESSABLE. CPS COMPONENT APPROXIMATELY AS PER TABLE 3-2 WITH RELIABILITY LIMITATION REMOVED. SOME SLIGHT DIVERSION OF CPS TRAFFIC TO TRUNKING REFLECTS THE ADDED CONVENIENCE OF INHERENT RELIABILITY AS OPPOSED TO RELIABILITY DERIVED FROM C OR Ku BAND BACK-UP.
3. BETWEEN TRUNKING AND CPS 100 PERCENT ADDRESSABLE. CPS COMPONENT AS PER TABLE 3-2 WITH RELIABILITY LIMITATION REMOVED.

range of Video applications. The sum of the trunking and CPS component is, therefore, 100 percent. The CPS components are approximately the same as those estimated in Table 3-2 with reliability limitations removed. However, for the broadcast video components, some small reductions have been made in the CPS component in favor of trunking. This recognizes and allows for the added convenience of intrinsically reliable trunking as opposed to reliability derived from C or Ku band back-up.

8.8.2.3 DATA

The sum of the trunking plus CPS traffic remains the same as the total traffic addressed under Scenario 1a. The CPS addressable traffic is consistent with the estimates of Table 3-2 with the reliability limitation removed. The overall result is also similar to the situation pertaining to Scenario 5c.

8.8.2.4 SUMMARY OF ADDRESSABLE TRAFFIC

Of the total traffic volume of 2701 x 10^{15} bits per year projected in Table 1-1 for 1990, 1933 x 10^{15} bits per year or 72 percent are addressable under this scenario. For the year 2000 this rises to 76 percent. About 21 percent of the total traffic under this scenario is addressable by CPS.

8.8.3 OWNERSHIP AND OPERATION

This scenario is most likely to evolve through the expansion of C or Ku band CPS services. In response to increasing demand a Domsat carrier may introduce Ka band CPS services as a means of obtaining needed capacity. The existence of the requisite technology and capacity may then lead to the offering of shared Ka band CPS for users unable to cost justify a fully dedicated earth station. The last step in the progression would be the offering of trunking services as well.

Since the largest portion of traffic, in the long term, is expected to occupy trunking facilities, the provision of these facilities in an intrinsically reliable configuration avoids the problem of reserving large blocks of C or Ku band capacity for back-up. Back-up is required in this scenario only for the CPS component.

8.8.4 GROWTH OF Ka SERVICES

This section discusses the growth of Ka services under Scenario 6. The parameters needed for the Gompertz growth model discussed earlier are derived from the estimates provided in Table 8-34.

The service offered under this scenario is similar to the combination of reliable Ka trunking, as considered in Scenario 1a, and backed-up Ka band CPS, as considered in Scenario 5b. The long term capturable percentage presented in Table 8-34 is, therefore, estimated as the weighted average of the long term capturable percentages in Tables 8-8 and 8-30. The weighting is according to the addressable trunking and CPS target percentages of Table 8-33.

Figure 8-9 shows the development of Ka satellite traffic for Scenario 6. Table 8-35 summarizes results for the years 1990, 1995 and 2000 in tabular form.

TABLE 8-34 TRAFFIC CAPTURED UNDER SCENARIO 6.
HIGH RELIABILITY Ka TRUNKING PLUS LOWER RELIABILITY CPS
IN COMBINATION WITH C OR Ku CPS.

	COMMUNICATIONS SUBCATEGORY	YEAR 2000* ADDRESSABLE TRAFFIC BITS/YR$\times 10^{15}$	LONG TERM Ka CAPTURABLE PERCENTAGE	% OF LONG TERM TRAFFIC CAPTURED BY 1990	YEARS AFTER 1990 TO REACH 90%
VOICE	RESIDENTIAL	37.8	38	5	12
	BUSINESS (SWITCHED SVC.)	107.6	38	5	12
	BUS. (PVT. OR LEASED LINE)	3440.0	43	10	12
VIDEO	NETWORK TV	11.0	20	15	10
	CATV	27.0	20	15	10
	EDUCATIONAL VIDEO	113.1	50	5	10
	VIDEOCONFERENCING	268.0	78	5	15
DATA	FACSIMILE	2.0	55	10	10
	ELECTRONIC MAIL	6.3	80	10	15
	COMPUTER	346.9	44	10	10

*YEAR 2000 TRUNKING PLUS CPS ADDRESSABLE TRAFFIC FROM TABLE 8-32

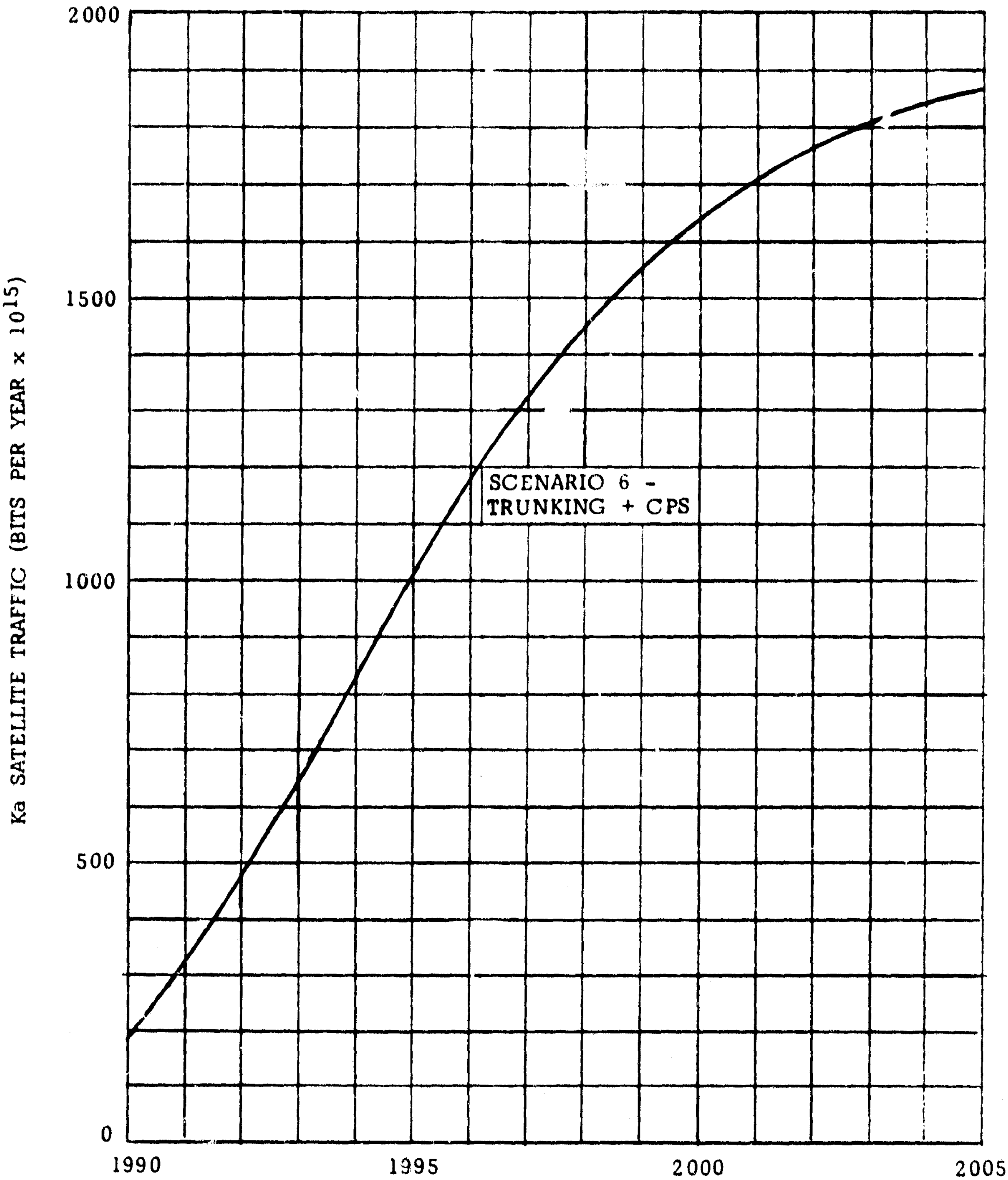


FIGURE 8-9 DEVELOPMENT OF Ka SATELLITE TRAFFIC FOR SCENARIO 6

TABLE 8-35 SUMMARY OF TRAFFIC CAPTURED BY Ka SATELLITES UNDER SCENARIO 6 (BITS PER YEAR$\times 10^{15}$)

SCENARIO 6

	ADDRESSABLE TRAFFIC			CAPTURED TRAFFIC		
	1990	1995	2000	1990	1995	2000
VOICE	1533	2344	3585	151	809	1286
VIDEO	171	268	419	15	116	209
DATA	229	285	355	16	96	142
TOTAL	1933	2897	4360	182	1021	1638

8.9 SUMMARY OF SCENARIO RESULTS

The previous sections discussed the market performance of Ka satellite systems under six scenarios. For each scenario estimates of the annual traffic, addressable and capturable, by Ka satellites were presented in terms of bits per year.

This section summarizes these results for the year 2000. Table 8-36 presents the Ka satellite traffic, addressable and capturable, in the year 2000 for each scenario. The first column presents addressable traffic expressed as a percentage of the total demand (5747 x 10^{15} bits per year) shown in Table 1-1. The second column does the same for the capturable traffic.

Addressable and capturable traffic are largest in Scenarios 2 and 3 in which Ka satellites are integrated with terrestrial facilities. Addressable traffic ranges from 95 to 98 percent of total demand, and 40 to 41 percent of total demand can be captured by Ka systems.

The scenarios involving stand-alone Ka facilities (Scenario 1) and those in which C or Ku band satellites provide back-up (Scenarios 4, 5 and 6) are expected to address and capture smaller fractions of the total demand. Except for Scenario 5b, which offers Ka band CPS alone, these scenarios are expected to address 70 to 76 percent of the traffic demand, and to capture 19 to 29 percent.

In general, the addition of a CPS component increases the traffic captured by trunking alone by only a few percent. The largest impact of the CPS offering is in Scenarios 5 and 6, in which a reliable Ka band CPS capability is obtained by means of C or Ku back-up. In Scenario 5b, where the Ka band CPS capability is offered without trunking, an addressable market of 16 percent of total demand is predicted, with capture estimated at 9 percent.

The last column of Table 8-36 presents the captured traffic estimates in terms of the number of conventional satellites that would be needed. To arrive at this, the captured traffic for the year 2000, in bits per year, is first translated to bits per second by dividing by the number of seconds in a year (31.5 x 10^6). The effects of traffic peaking are then taken into account by multiplying by a factor

TABLE 8-36 - SUMMARY OF SCENARIO RESULTS

SCENARIO	ADDRESSABLE TRAFFIC % OR YR. 2000 DEMAND	CAPTURED TRAFFIC % OF YR. 2000 DEMAND	PEAK TRAFFIC MBPS x 10^3*	NO. OF CONVENTIONAL SATELLITES NEEDED**
STANDALONE Ka SYSTEM:				
1a HIGH REL. KA. TRUNKING	71	23	84.9	71
1b HIGH REL. PLUS CPS	73	24	88.9	74
Ka WITH TERRESTRIAL:				
2a LOW REL. Ka TRUNKING	95	40	144.0	120
2b LOW REL. PLUS CPS	97	41	148.1	123
3a HIGH REL. Ka TRUNKING	95	40	144.7	121
3b HIGH REL. PLUS CPS	98	41	148.8	124
Ka WITH C OR Ku TRUNKING:				
4a LOW REL. Ka TRUNKING	71	19	69.9	58
4b LOW REL. PLUS CPS	73	20	74.0	62
Ka WITH C OR Ku TRUNK. & CPS:				
5a LOW REL. Ka TRUNKING	70	19	69.9	58
5b LOW REL. Ka CPS	16	9	33.1	28
5c BOTH	75	25	90.7	76
Ka WITH C OR Ku CPS:				
6 HIGH REL. Ka TRUNK. & CPS	76	29	104.0	87

*BASED ON PEAK-TO-AVERAGE RATIO OF 2.
**BASED ON 50 MBPS TRANSPONDERS, 24 TRANSPONDERS PER SATELLITE.

of 2. As discussed in Chapter 6, the throughput of future satellite designs is highly dependent on technical and regulatory developments. The values listed in the last column of Table 8-36 are based on the assumption that the digital equivalent of a conventional 36 MHz transponder has a peak throughput capacity of about 50 megabits per second, and that a typical satellite contains 24 such transponders. Future satellite designs, particularly for Ka band systems, may have many times the capacity of the conventional satellites postulated here. Translation from the values presented in the table to those appropriate to satellites with higher capacities can be accomplished by linearly scaling the results.

REFERENCES

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9.0 CONCLUSIONS

Traffic projections developed in previous studies point to a large growth in the demand for communications capacity over the next two decades. The broad, uncongested, spectrum available in the 30/20 GHz fixed satellite service bands offers an important means of providing the large expansion in communications capacity that will be required to satisfy this demand.

9.1 ROLE OF Ka SATELLITES

Satellite transmissions at Ka band are not without some important limitations. In common with all synchronous orbit satellite communications, Ka band satellite systems introduce a round-trip time delay of about six-tenths of a second. This is a source of some inconvenience for many voice and data communications applications. Signal attenuation due to heavy rain is another limitation. It requires that special provisions be made to obtain the reliability levels desired by most users. Lastly, advanced, and possibly complex, technology will be needed to achieve the fullest benefits of this medium.

The major factor offsetting these limitations is the availability of the very large capacities needed to satisfy emerging demand. To make optimum use of this advantage, scenarios for the development of Ka satellite communications must emphasize those applications involving high volumes of transmission. Lower volume specialty applications may also be addressed, but only as an increment to those major traffic components whose volumes are consistent with the primary role of Ka satellites as a high volume communications medium.

9.2 COMMUNICATIONS APPLICATIONS

Since large traffic volumes are the prime target for Ka satellites, the ranking by size of the various communications applications is of importance. Analysis of these applications shows that about 85 percent of the long distance traffic projected for the year 2000 is in the voice category. Business voice applications account for the greatest part of this, but residential voice traffic is also sizable.

In the data category, real-time terminal-to-computer applications are the most important. When these are added to the business and residential voice traffic, more than 90 percent of communications demand is accounted for. Electronic mail, facsimile and other data sources are of relatively minor significance.

In the video category, videoconferencing and other new uses in education, health and related activities will grow to exceed by many times the more conventional Network and CATV applications. When these newer video applications are added to the voice and computer categories, more than 99 percent of demand is included.

To be consistent with the high volume transmission role most appropriate to Ka satellite communications, market emphasis should therefore be on voice, computer, and advanced video applications. Other applications are of less significance and should be addressed only as a supplement to these prime high volume traffic categories.

9.3 COMMUNICATIONS MODE

The ability of Ka satellite systems to address various communications sectors depends in part on the communications mode employed. The basic communications modes are (a) dedicated; (b) circuit switched; and (c) packet. Dedicated service, chiefly in the form of private or leased voicegrade lines, is expected to account for about 69 percent of the annual long haul traffic projected for the year 2000. Circuit switched traffic, most often used for dial-up voice or data transmissions, accounts for 26 percent of demand. The more recent packet switched mode, which has its primary application in data transmission, accounts for only 4 percent of projected annual traffic.

The high percentage of annual traffic projected for dedicated modes deserves some comment. Dedicated traffic requires the reservation of capacity on a full time basis, whether in active employ by the user or not. In terms of occupied capacity over the year, therefore, the role of dedicated traffic is magnified. However, in the design of communications facilities, concern is often with peak-hour traffic as well as with average annual traffic. On a peak-hour basis, circuit switched traffic, with its tendency to concentrate during peak business hours, assumes an increased level of importance.

In a somewhat similar manner, the relatively low percentage of annual traffic volume projected for packet mode traffic may not fully reflect the significance of this traffic mode relative to the others. Packet mode transmission of data traffic tends to be highly efficient. A small fraction of annual traffic in the packet mode may, therefore, represent a large amount of ongoing data transfer activity.

9.4 TRUNKING VS. CUSTOMER PREMISES SERVICE

While terrestrial communications is almost exclusively via trunking, satellite communications permits an additional option in the form of Customer Premises Service (CPS). In order to justify the use of CPS, an establishment must generate a sufficient volume of traffic to make the dedicated use of an earth station cost effective. The definition adopted for CPS communications in this report requires CPS operation at both ends of the link. Under this definition, the destination establishment must have a high traffic volume. Thus, communications applications suitable for CPS must originate at a large volume establishment, and be directed to another large volume establishment within the CPS community. Applications such as switched voice, which require wide distribution to both large and small volume recipients are, therefore, not well adapted to CPS.

In addition, CPS at Ka band is expected to provide lower reliability than other competing transmission methods. This introduces a further limitation on the communications applications suitable for CPS. Overall, only 3 percent of voice traffic and 4 percent of data traffic is expected to use CPS. For video traffic a larger percentage, 32 percent, is expected to find CPS an attractive mode, predicated on a substantial component of pre-recorded traffic transmitted for later broadcast to avoid reliability problems. When all traffic components are weighted according to projected traffic volumes, the portion of long haul annual traffic using CPS is expected to be approximately 4 percent.

The traffic percentages for CPS presented above, however, are predicated on a definition of CPS requiring CPS installations at both ends of the link. If the definition adopted for CPS is broadened to allow transmission from a CPS station at one end of a link to trunking stations at the other, a wider range of applications is addressable and these values approximately double.

9.5 REAL-TIME AND DEFERRED TRAFFIC DEMAND

Deferred traffic allows communication facilities to be used more efficiently by filling in the gaps between traffic peaks. It also is tolerant of the lower reliability levels associated with some Ka satellite configurations.

In order to introduce significant benefits in the operation of a communications system, however, the percentage of traffic capable of utilizing deferred transmission must be high. Small amounts of deferred traffic, or deferred traffic components able to accept only short delays, do not significantly affect the operating performance of a communications facility.

It does not appear that the percentage of deferred traffic will be very significant. In the high volume voice category, despite some recent interest in deferred mode call answering services, virtually all traffic is expected to be real-time.

In the video category, videoconferencing, the largest component projected for the year 2000, is also real-time traffic. The use of pre-recorded video, taped for later broadcast, however, introduces the possibility of deferred modes for some broadcast video components. Overall, a weighted average of 18 percent of video traffic is expected to use deferred modes by the year 2000.

In the data category, applications such as electronic mail, facsimile, and electronic funds transfer have large components of deferred traffic. In addition some portion of the data base access applications can tolerate moderate delays. A relatively high 41 percent of data traffic in the year 2000 is, therefore, likely to be a candidate for deferred transmission.

When all traffic components are weighted according to their expected volumes, however, the portion of traffic using deferred modes of transmission remains a modest 4 percent. While such traffic is desirable, the small quantity involved precludes significant impact on the efficiency or reliability parameters applicable to Ka band satellite communications. The greatest portion of traffic is, and will remain, real-time.

9.6 RELIABILITY CONSIDERATIONS

Ka band satellite communication is subject to outages caused by rain, and consequently offers a less reliable service than that obtainable with other competing transmission media. Special provisions in the design of Ka links can be made to bring the reliability level up to, or beyond, that of other media, but this can be costly, and in general applies to trunking but not to CPS. Reliability can also be obtained by associating Ka band links with terrestrial or lower frequency satellite links. When the Ka link is rained out, alternative routes are obtained via the associated transmission facility. In either case the problem of rain outages limits the usefulness of Ka band satellite communications in certain applications and scenarios.

To explore the impact of reliability on the traffic addressable by Ka satellites several service offerings, at different levels of reliability, were postulated, and the probable degree of acceptability of each was estimated. The offerings included:

(a) Ka reliability performance and cost levels equal to those of typical competing media (nominal reliability 99.9 percent).

(b) Ka reliability performance 10 times better (99.99 percent) at a cost premium of 20 percent.

(c) Ka reliability performance 5 to 10 times poorer (99.5 to 99.0 percent) at a 30 to 35 percent cost reduction.

With each traffic component weighted according to expected volume in the year 2000 the overall results indicate that 71 percent of the total traffic requires reliability levels equal to those of typical competing media (99.9 percent nominal) and that only 6 percent of the traffic would be attracted to the higher cost, higher reliability (99.99 percent) offering. Those offerings providing substantially poorer reliability (99.5 to 99.0 percent), at lower cost, would be adequate for approximately 23 percent of the traffic.

The implication of the above is that to attract the greatest portion of traffic, Ka band satellite systems should be designed to levels of reliability about equal to those of typical competing media. For trunking the design should, therefore, include diversity reception and/or other technical reliability enhancements, or provision for alternative routing through other transmission media. For CPS it is likely that the desired level of reliability will be difficult to achieve and that consequent reductions in the traffic otherwise preferring CPS modes will occur.

9.7 CAPACITY OF COMPETING SYSTEMS

The most important impetus to the development of Ka band satellite communications systems is the rapid growth of demand for communications capacity projected for the next two decades. Terrestrial systems, and C and Ku band satellite systems, will accommodate much of this growth. Ka satellite systems, at a minimum, however, should acquire the excess over that accommodated by the other long haul systems. It is therefore of interest to evaluate the potential capacity of these competing systems as a guide to the amount of projected traffic that is likely to be available for Ka band satellite systems.

Capacity estimates for major long haul communications systems are subject to wide variations depending on the assumptions made for future technical, economic, and regulatory developments. The estimates discussed below, are based on reasonable projections, but large deviations from these projections are possible.

Most traffic today is served by terrestrial facilities. The traffic estimated for 1980, therefore, serves as a rough measure of the capacity, under normal loading, of present terrestrial networks. Growth of these terrestrial networks over the next two decades by a factor of 2.5 has been assumed. At this level of growth terrestrial networks, by the year 2000, would carry about 47 percent of the traffic projected for this year.

The estimated capacities of C and Ku band satellite systems are based on dense packing of the orbital arc, and a number of other assumptions related to spectrum allocation, frequency re-use, and efficiency of spectrum utilization. With reasonable assumptions for these and other parameters it appears that C band satellites could accommodate about 5 percent of the demand projected for the year 2000, and that Ku band satellites could accommodate 17 percent of this demand. Again it should be noted that changes in assumptions can lead to significant variation in these estimates.

Terrestrial, C band and Ku band systems combined, under the above capacity estimates, could accommodate about 69 percent of projected demand. Ka band satellites, on an overflow basis alone, would therefore expect to receive 31 percent of the year 2000 traffic. For those traffic applications in which terrestrial, C or Ku band facilities are preferred, this overflow basis can be expected to apply. For other traffic components, in which no preference among the various media applies, Ka satellites can compete on a parity rather than on an overflow basis and therefore would be expected to capture a larger share of the market.

9.8 ECONOMIC COMPARISONS

The prime concern with economic comparisons between transmission media in this market research study is the degree to which economic factors may influence the viability and traffic capture potential of Ka systems.

Only broad cost comparisons are possible at the level of system definition appropriate to this study. It appears from some estimates of probable Ka system costs that there will be significant cost savings associated with Ka systems. However, it is not clear whether these cost savings are fundamental to Ka technology, or are the result of the high capacity assumed for the Ka systems. Communications costs are highly volume sensitive and similar high volume assumptions for Ku systems, for example, might result in comparable cost estimates.

In addition, the costs of communications to the end users are only partially related to the cost of the long haul transmission plant. The costs of local distribution, operating personnel, maintenance, switching, etc. reduce overall cost dependence on the long haul transmission portion. Furthermore, the long haul transmission plant is often made up of a combination of long haul media of various types. In these circumstances costs are a composite of those of the various media involved. Lastly, at the tariff level, regulatory issues and the need to preserve investment in established equipment have much to do with setting the rates.

Thus, Ka satellite costs may turn out to be lower than those of other media, but the net result is not likely to have significant impact on overall costs, or on demand. The scenarios developed in this report, therefore assume that Ka satellites provide service comparable to that of other media, at a comparable cost. The need for Ka band service may depend more on the availability of capacity to satisfy demand than on the possible cost arguments.

9.9 SCENARIOS FOR THE DEVELOPMENT OF Ka SATELLITE SYSTEMS

Six scenarios were explored for the development of Ka satellite systems. The first of these considers the use of Ka satellites in stand-alone configurations. The second and third scenarios postulate close integration between the Ka satellite system and terrestrial long haul facilities. The last three scenarios assume that the Ka band satellite system is associated with C or Ku band satellite facilites.

In each scenario the Ka satellite system provides high volume transmission capacity, and addresses, to the extent feasible, high volume traffic applications. For those scenarios in which the Ka satellite links are designed to lower levels of reliability, terrestrial facilities, or C or Ku band satellite facilities are used to provide back-up.

In terms of the traffic projected for the year 2000, Ka satellites play a significant role in all scenarios. Integration with terrestrial facilities results in the highest capture volume for Ka satellites. In those scenarios involving integration with terrestrial facilities, Ka satellites become one of several transmission media interchangeably used to provide capacity between network nodes. The alternative routing capabilities of the network largely compensate for the possibility of outage of the Ka links. Additionally, the issues of maintaining orderly growth, customer back-log, and efficient levels of satellite fill are well accommodated by the existence of the large customer base served by terrestrial facilities. With Ka satellites fully integrated with terrestrial facilities, it is estimated that as much as 41 percent of the year 2000 traffic will travel via Ka satellite systems.

Ka satellites in stand-alone configurations are also expected to capture substantial portions of traffic. In this case, however, those components of traffic requiring the wide distribution typical of circuit switched voice are not likely to be successfully addressed. Competition from the terrestrial network, in which integration of long haul and local distribution facilities are under the control of a single carrier, is expected to prove difficult to surmount. In stand-alone configurations, Ka satellites are projected to capture about 24 percent of the traffic anticipated for the year 2000, most of this deriving from traffic applications for which dedicated transmission modes are appropriate.

Those scenarios in which Ka satellites are associated with C or Ku band facilities have characteristics and market performance not much different from those of the scenario in which Ka satellites are used in stand-alone configurations. Depending on the configuration assumed, Ka satellites used with lower frequency satellite systems are expected to carry from 19 to 28 percent of the traffic projected for the year 2000. Back-up of Ka capacity through the lower frequency satellite systems, however, requires that an appreciable portion of the lower frequency capacity be reserved for this purpose.

In general the main traffic associate with Ka systems, in the six scenarios considered, results from trunking. The addition of a CPS component increases captured traffic by only a few percent, but even a few percent of the high volume of total traffic amounts to a sizeable traffic volume. It should also be noted that a broadened definition of CPS operation to permit shared earth station operation and the use of trunking at one end of the link would increase the amount of traffic projected for CPS.

The traffic projected for Ka satellites in all scenarios is high, consistent with the recommended role of Ka systems as a means of supplying high volume capacity. Traffic volumes in the range of 20 to 40 percent of projected demand for the year 2000 are put in perspective when it is noted that reasonable estimates for the combined total capacities of C and Ku band satellite systems amount to 22 percent of demand. Thus, the Ka scenarios examined project Ka band traffic for the year 2000 to be roughly equal to, and in some cases double, the full capacity of C and Ku bands combined.