VOLUME I

EXECUTIVE SUMMARY

NASA REPORT NO. CR 165231

MARKET CAPTURE BY 30/20 GHz SATELLITE SYSTEMS

by: R. B. GAMBLE,
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L. SAPORTA,
DATA INDUSTRIES

prepared for:

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EXECUTIVE SUMMARY

This report summarizes the results of a study of telecommunications demand performed under NASA Contract NAS3-21366. The work described is a continuation of a previous study performed under the same contract.*

The earlier study presented demand forecasts for communications services which indicate the emergence over the next two decades of a greatly expanded need for communications capacity. 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. SCOPE

This study estimates demand for 30/20 GHz satellite communications systems, and forecasts the expected build-up of traffic on these systems, as a function of time, for each of several operational scenarios. The subjects covered include the following:

1.1 DEMAND FORECASTS

Previous forecasts of demand for communications services are updated and provide a starting point for further analysis.

1.2 PROFILE OF THE COMMUNICATIONS MARKET

The ability of the major terrestrial and satellite long haul transmission media to support the communications applications expected to be of importance over the next two decades is discussed.

1.3 NETWORK OPERATING MODES

The suitability of switched, dedicated, and packet network operating modes are explored 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.

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*"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)

1.4 REAL-TIME AND DEFERRED TRAFFIC DEMAND

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

1.5 QUALITY AND RELIABILITY

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

1.6 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.

1.7 ECONOMIC COMPARISONS

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

1.8 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.

2. 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 requiring high volume transmissions. 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.

3. DEMAND FORECASTS

Since large traffic volumes are the prime target for Ka satellites, the ranking by size of the various communications applications is of importance. Table 1 updates and summarizes the results of a prior study and presents estimates of the demand for long haul communications services expected for the years 1980, 1990 and 2000. The demand forecasts shown in the table represent average annual traffic volumes for all telecommunications media measured in bits per year. Over the two decade period traffic demand is projected to grow by a factor of 5.3.

Analysis of the applications represented in Table 1 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. As will be discussed later in Section 5.1, the large volumes associated with private or leased line traffic are, in part, due to the reservation of communications capacity for this traffic whether or not the lines are actively employed by the user.

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 appropriate to the wide bandwidths possible with 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 which together account for most of the demand anticipated over the next two decades.

TABLE 1. LONG DISTANCE TRAFFIC DEMAND BY COMMUNICATION CATEGORY

CATE-GORY	COMMUNICATIONS SUBCATEGORY	TRAFFIC DEMAND (BITS PER YEAR x 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

4. PROFILE OF THE COMMUNICATIONS MARKET

Each type of transmission medium has special characteristics which influence its competitive position and potential for use in particular applications.

At present the long haul transmission plant is implemented primarily by microwave line-of-sight radio systems and by coaxial cable systems. Satellite systems, and fiber optics systems, play a relatively minor role, but are expected to have high growth rates over the next two decades.

4.1 CAPACITY FOR EXPANSION

All of the long haul transmission media referred to above are capable of high capacity transmissions and can be expanded considerably beyond their existing capacities. However, when scenarios implying growth of the existing telecommunications plant to more than five times its present size are considered, certain media are likely to prove more cost effective than others.

Coaxial cable systems are highly right-of-way dependent and are likely to be confined to backbone routes, with lateral extensions 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 high 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 high capacity links to widely separated points without encountering right-of-way difficulties. 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 links extending the communications to local users.

4.2 DIGITAL AND ANALOG TRANSMISSION FACILITIES

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 a form appropriate for transmission over the facility. However, 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 co-existing 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.

4.3 TIME DELAY AND ECHO PROBLEMS

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 evolutionary sequences are likely:

(a) VOICE

Present: A preference for terrestrial paths predominates. Satellites are used in single direction with the return path established through the terrestrial network.

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

Future: The 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: The use of satellite delay compensation units permits present 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.

4.4 LOCAL ACCESS

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 cost of local access are avoided.

5. NETWORK OPERATING MODES

The ability of Ka satellite systems to address various sectors of the communications market depends, in part, on the network operating mode used. Forecasts for the traffic volumes expected for each mode are presented below.

5.1 DEDICATED, CIRCUIT SWITCHED, AND PACKET MODES

The most commonly encountered network operating modes are:

(a) DEDICATED MODE - Dedicated circuits, chiefly in the form of private, or leased, lines are generally preferred when communications volume between two points is high. For voicegrade leased lines, an aggregate use for two to four hours a day is usually sufficient to cost justify the installation of full-time dedicated lines. Dedicated operation is also indicated when special line characteristics are required, a situation which frequently arises in data communications.

(b) CIRCUIT SWITCHED MODE - Circuit switched operation, as exemplified by the common user switched telephone network, is preferred when calls must be placed to a wide range of destinations, and where communications volumes to any particular destination is not high enough to justify the use of a leased line to that point.

(c) PACKET MODE - Packet operation provides high efficiency for many data communications applications. It offers fewer advantages for voice communications and has not been seriously proposed for video applications.

Table 2 provides estimates for the percentages of voice, video, data and total traffic expected to use each network operating mode in the year 2000.

TABLE 2. PERCENT OF ANNUAL TRAFFIC USING EACH OPERATING MODE (YEAR 2000)

	VOICE	VIDEO	DATA	TOTAL TRAFFIC
TRAFFIC VOLUME* (BITS/YEARx10^{15})	4894	419	434	5747
PERCENT USING DEDICATED MODES	66.8%	87.1%	80.0%	69.3%
PERCENT USING CIRCUIT SWITCHED MODES	28.2%	12.9%	19.0%	26.4%
PERCENT USING PACKET MODES	5.0%	0%	1.0%	4.3%
	100.0%	100.0%	100.0%	100.0%

*FROM TABLE 1

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 is highly efficient and a small amount of packet capacity can handle a large amount of traffic. The small fraction of capacity ascribed to packet modes in Table 2 actually represents the net effect of approximately sixty percent of all data transfer activity projected for the year 2000.

5.2 TRUNKING MODE AND CUSTOMER PREMISES

While terrestrial communications is almost exclusively via trunking, satellite communications permits an additional option in the form of Customer Premises Service (CPS). One of the major advantages of CPS is that the problems and costs of local distribution to the user are avoided. This is particularly important when wideband or specialized services are desired.

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. Furthermore, in order to involve CPS operation at both ends of the link, the destination establishment must also have high volume requirements. Thus, communications applications suitable for CPS must originate at a high volume establishment, and be directed to another high volume establishment within the CPS community. Applications such as switched voice, which require wide distribution to both high and low volume recipients are, therefore, not well adapted to CPS. In addition, CPS at Ka band is expected to provide a lower reliability than other competing transmission methods. This introduces a further limitation on the communications applications suitable for CPS where Ka band transmissions are employed. Other definitions of CPS which allow for trunking at one end of the link, or shared earth station usage, are also possible and lead to a broadening of the addressable traffic. Unless otherwise noted, however, the more restrictive definition, implying dedicated earth terminals on the customer's premises at both ends of the link applies in this report.

Table 3 provides estimates for the percentages of the various communications applications addressable by CPS in view of the limitations imposed by (a) traffic volume requirements, (b) the need for widespread distribution, and (c) the reliability considerations applicable to Ka band CPS transmissions. The weighted averages are derived by weighing each traffic component according to the year 2000 traffic projected in Table 1. Overall, only four percent of the total traffic is estimated to be addressable by CPS, but it should be noted that in absolute terms this is a large volume of traffic and may therefore represent an attractive target for many common carriers. The basis for the estimates in Table 3 is further discussed in the following paragraphs.

TABLE 3. ADDRESSABLE TRAFFIC PERCENTAGES FOR
Ka BAND SATELLITE CPS*(YEAR 2000)

	COMMUNICATIONS SUBCATEGORY	PERCENT ADDRESSABLE BY CPS AFTER LIMITATIONS DUE TO:			
		(a) TRAFFIC VOLUME	(b) WIDE DISTRIB.	(c) RELIAB. CONSID.	(d) OVERALL PERCENT
VOICE	RESIDENTIAL	0	-	-	0
	BUSINESS (SW.SVC.)	30	0	-	0
	BUSINESS(PVT.LINE)	30	50	20	3
	WEIGHTED AVG.				2
VIDEO	NETWORK TV	100	95	40	38
	CATV	100	95	50	48
	EDUCA. VIDEO	80	95	45	34
	VIDEOCONFERENCING	80	95	40	30
	WEIGHTED AVG.				32
DATA	FACSIMILE	30	50	50	8
	ELECT. MAIL	85	90	90	69
	COMPUTER	30	50	20	3
	WEIGHTED AVG.				4
	TOTAL TRAFFIC WEIGHTED AVG.				4

* CPS TO CPS TRANSMISSIONS ONLY

VOICE

Residential voice traffic, emanating from homes, clearly cannot pass the test of adequate traffic volume and, as indicated in the table, is therefore immediately disqualified as a potential candidate for CPS. For switched business voice traffic an appreciable portion (estimated at 30 percent) is expected to originate at large establishments, but this type of traffic requires wide distribution to small as well as large users. Switched business voice traffic therefore requires some trunking capability and is not well suited to communications systems employing CPS without the capability of accessing the switched network.

Business private line voice traffic also originates in part (30 percent) from establishments of suitable size, and in this case wide distribution is not a requirement. Fifty percent of the private line voice traffic originating from CPS sources is estimated to be destined for a recipient also large enough for CPS and, as a result, an appreciable portion of this traffic qualifies for CPS in general. When Ka band CPS is considered, however, only 20 percent of this qualified traffic is expected to find the lowered reliability levels acceptable. The net result is that only three percent (.3x.5x.2x100%) of the private line voice subcategory remains addressable by CPS when all of the limitations cited are accounted for.

When all three voice subcategories are weighted according to the traffic volumes of Table 1, the resulting Ka band CPS addressable component is found to be 2 percent.

VIDEO

A similar analysis applies to video and is reflected in Table 3. The broadcast TV subcategories (Network TV, CATV and Educational Video) usually account for enough traffic to justify a dedicated earth station. Furthermore, reception is in the broadcast mode simultaneously to many low cost receive-only earth stations. As a result, wide distribution needs are not a significant limitation. Reliability limitations do, however, play an important role and limit the traffic to only that portion involving the transmission of programs which can be tape recorded for later local broadcast.

Unlike the deferred broadcast mode video subcategories just discussed, video conferencing is generally point-to-point, and real-time. Nevertheless, in view of the high cost of the wideband transmissions involved, a willingness on the part of users to adapt to reliability limitations in order to achieve the benefits of this service at lower cost, has been assumed. Executives and other users of video conferencing are expected to show some degree of tolerance to rain induced outages, just as occasional disruption of air travel, as a result of bad weather, is accepted as a necessity of travel to a conference.

Overall, a weighted average of 32 percent of video traffic is expected to be addressable by Ka band CPS.

DATA

In the data category, facsimile traffic tends to have distribution patterns primarily to pre-established locations. CPS requirements, therefore, are similar to those estimated for private line business traffic, except for an additional degree of tolerance to reliability limitations.

Most electronic mail is unaffected by reliability limitations. The high percentages of traffic estimated to originate at large CPS equipped establishments and to be distributed to similar establishments is the result of a postulated large component of post office to post office traffic.

Computer traffic, primarily consisting of traffic generated by real-time terminal to computer access, has requirements similar to those of private line business traffic. Because the computer traffic is much larger than the other two data traffic subcategories, the overall weighted average for data is close to that for computer traffic, and is estimated to be about 4 percent.

When all traffic subcategories are considered, and weighted in accordance with the traffic volumes presented in Table 1, the net traffic addressable by Ka band CPS, with CPS operation at each end of the link, is found to be approximately 4 percent of the total traffic demand. It should be noted, however, that 4 percent of the total traffic referred to represents a substantial volume of traffic and may be an attractive target for some common carriers. It should also be noted that the definition adopted for CPS operation is a restrictive one. If the definition used for CPS operation is broadened to allow transmission from a CPS station at one end of a link to trunking stations at the other, the limitations in Table 3 due to wide distribution needs are eliminated and this percentage would approximately double. Other configurations which lessen the distinctions between CPS operation and trunking, such as shared earth station operation, are under study and may result in a further broadening of the role of CPS.

6. 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 percentages of traffic capable of utilizing deferred transmission must be high.

Table 4 presents estimates for the percentages of real-time and deferred traffic expected for the years 1980, 1990 and 2000. These estimates are briefly discussed in the following paragraphs.

TABLE 4. 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 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 and therefore while such traffic is desirable, the small quantity involved will not have an important effect on the efficiency of Ka band satellite communications.

7. QUALITY AND RELIABILITY

The signal quality of Ka band satellite systems is expected to be excellent. The only exception to this results from the long time delay inherent in synchronous orbit satellites. Time delay can be a disadvantage in many voice and data applications, but, as discussed in Section 4.4, technical solutions are at hand which largely dispose of this difficulty.

Ka band satellite communications, however, are subject to outages caused by rain and unless special provisions are made offer 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 application of Ka band satellite communications in certain 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 higher (99.99 percent) at a cost premium of 20 percent.

(c) Ka reliability performance 5 times lower (99.5 percent) at a 30 percent cost reduction.

(d) Ka reliability performance 10 times lower (99.0 percent) at a 35 percent cost reduction.

The percentages of each of the traffic subcategories defined in Table 1, preferring each of the four categories listed above, were estimated. These estimates, weighted according to the relative traffic volumes of each subcategory, were aggregated to arrive at overall estimates for voice, video, data and total traffic. The results, as presented in Table 5, are only slightly dependent on time.

TABLE 5. 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

Roughly 70 percent of the total traffic requires reliability levels equal to those typical of competing media (99.9 percent nominal) and only 6 to 8 percent of this 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.

Thus, 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, as discussed in Section 5.2, that consequent reductions in the traffic otherwise preferring CPS modes will occur.

8.0 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 (including the newer transmission media such as fiber optics), 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 presented in Table 6, and discussed below, are based on reasonable projections, but large deviations from these projections are possible.

TABLE 6 - ESTIMATED CAPACITY OF TELECOMMUNICATIONS SYSTEMS CIRCA 2000

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

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

Most traffic today is served by terrestrial facilities. The annual long haul traffic level of 1083 x 10^{15} bits per year estimated in Table 1 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, could carry about 47 percent of the traffic projected for this year.

The estimated capacities of C and Ku band systems are based on dense packing of the orbital arc and a number of other assumptions related to spectrum allocation, frequency reuse, 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 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. 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 initial costs of the long haul transmission plant.* 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 expanding demand than on the possible cost arguments.

*One benefit of CPS transmission is that it reduces cost dependence on some of these items, particularly the costs of local distribution.

10. 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. A carrier entering the market for the first time, without existing terrestrial or C or Ku band satellite facilities, might choose stand-alone Ka configurations of this type, circa 1990 to 2000. The second and third scenarios postulate close integration between the Ka satellite system and terrestrial long haul facilities. AT&T is the preeminent carrier having the terrestrial facilities needed for fullest exploitation of these configurations, but carriers such as ITT can also implement such systems on a reduced scale. The last three scenarios assume that the Ka band satellite system is associated with C or Ku band satellite facilities. Scenarios of this type would apply to carriers such as Western Union, or SBS, with existing C or Ku band capabilities, and a need for expansion of capacity.

The scenarios selected emphasize those high volume applications which take best advantage of the large capacity possible with Ka satellite systems. This implies the existence of a Ka band trunking component in each scenario, since Ka band CPS is expected to address a more limited segment of the market. Each scenario, therefore, includes a primary Ka satellite trunking component, and, as a variation, explores the effects of adding a Ka band CPS capability to the trunking.

To fully address the communications applications that account for the largest portions of demand, it is necessary that the Ka satellite system provide trunking capabilities at a level of reliability comparable to those of competing transmission media. In some scenarios this is accomplished by designing the Ka band trunking link to a satisfactory level of reliability. In other scenarios the Ka band trunking links are designed to lower levels of reliability, but overall reliability is assured by providing back-up capability through terrestrial facilities, or through C or Ku band satellite facilities. It is assumed in all scenarios that Ka band CPS will be designed to lower reliability levels than competing transmission media. More reliable CPS operation is assumed possible only under those scenarios in which Ka band CPS can be backed up by C or Ku band CPS.

Table 7 summarizes the configurations assumed for each of the six scenarios that were analyzed. The table shows the Ka band satellite configuration assumed, and, where applicable, the configuration of the terrestrial, or C or Ku band, system which provides back-up.

For each of the configurations summarized in Table 7, estimates were formed of the traffic volumes addressable by Ka band satellite systems for the years 1990 and 2000. Values for 1995 were obtained from the year 1990 and 2000 values by interpolation assuming constant compound growth rates.

Estimates were also developed for the percentage of traffic expected to be captured by Ka satellite systems (a) in the long term, and (b) at the inception of Ka band service assumed to be initiated circa 1990. The number of years needed for traffic to build from the initial value in 1990 to 90 percent of the long term value was also estimated.

These parameters were used in a traffic growth model* to arrive at estimates for the growth of Ka satellite traffic as a function of time. Results are presented in Tables 8 through 13. For each scenario and its variations, the traffic estimated to be addressable, and capturable, by Ka satellite systems is shown for the years 1990, 1995 and 2000.

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*Based on the Gompertz curve, a frequently used econometric growth model.

TABLE 7. SUMMARY OF Ka BAND SATELLITE AND BACK-UP SYSTEM CONFIGURATIONS

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

TABLE 8. SUMMARY OF TRAFFIC UNDER SCENARIO 1 (BITS/YEARx10^{15})
(Ka SATELLITES IN STAND-ALONE CONFIGURATIONS)

SCENARIO 1a - HIGH RELIABILITY Ka TRUNKING

	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 - HIGH RELIABILITY Ka TRUNKING WITH CPS

	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

Scenarios 1a and 1b are well suited to new carriers entering the marketplace. The stand-alone high reliability trunking provided in Scenario 1a results in the capture of 23.3 percent of the year 2000 traffic demand. The addition of a lower reliability CPS capability in Scenario 1b increases capture to 24.3 percent.

TABLE 9. SUMMARY OF TRAFFIC UNDER SCENARIO 2 (BITS/YEARx10^{15})
(Ka SATELLITES IN COMBINATION WITH TERRESTRIAL FACILITIES)

SCENARIO 2a - LOW RELIABILITY Ka TRUNKING

	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 - LOW RELIABILITY Ka TRUNKING WITH CPS

	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

Back-up through the terrestrial network in Scenarios 2a and 2b permits reliable trunking service to be offered, even though the Ka links themselves are provided without diversity or other reliability enhancements. Under these scenarios access to the existing terrestrial facilities and customer base of a dominant terrestrial carrier greatly enhances the addressable and capturable traffic percentages for Ka satellites. Scenario 2a results in the capture of 39.5 percent of the year 2000 traffic demand, while the addition of a lower reliability CPS capability in Scenario 2b results in 40.6 percent capture.

TABLE 10. SUMMARY OF TRAFFIC UNDER SCENARIO 3 (BITS/YEARx10^{15})
(Ka SATELLITES IN COMBINATION WITH TERRESTRIAL FACILITIES)

SCENARIO 3a - HIGH RELIABILITY Ka TRUNKING

	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 - HIGH RELIABILITY Ka TRUNKING WITH CPS

	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

Scenarios 3a and 3b are similar in concept to the previous Scenarios 2a and 2b except that the Ka trunking links are designed with intrinsically high reliability rather than relying on back-up through the terrestrial network. This allows the common carrier some additional flexibility in network configuration and operating procedures. Access to the existing terrestrial facilities and customer base of a dominant terrestrial carrier remains available with beneficial results on Ka band satellite traffic. Scenario 3a results in the capture of 39.7 percent of the year 2000 traffic demand. The addition of a lower reliability CPS capability in Scenario 3b increases this to 40.8 percent.

TABLE 11. SUMMARY OF TRAFFIC UNDER SCENARIO 4 (BITS/YEARx10^{15})
(Ka SATELLITES IN COMBINATION WITH C OR Ku SATELLITE TRUNKING FACILITIES)

SCENARIO 4a - LOW RELIABILITY Ka TRUNKING

	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 - LOW RELIABILITY Ka TRUNKING WITH CPS

	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

Back-up for trunking under Scenarios 4a and 4b is provided by lower frequency satellite systems operating at C or Ku band. These scenarios are therefore suitable for carriers with existing Domsat capabilities. Scenario 4a results in the capture of 19.1 percent of the year 2000 traffic demand. The addition of lower reliability Ka band CPS capability in Scenario 4b results in the capture of 20.3 percent.

TABLE 12. SUMMARY OF TRAFFIC UNDER SCENARIO 5 (BITS/YEARx10^{15})
(Ka SATELLITES IN COMBINATION WITH C OR Ku TRUNKING AND CPS FACILITIES)

SCENARIO 5a - LOW RELIABILITY Ka TRUNKING

	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 - LOW RELIABILITY Ka CPS

	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 - LOW RELIABILITY Ka TRUNKING WITH CPS

	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

In Scenarios 5a, 5b and 5c both Ka trunking and CPS are backed-up by lower frequency satellite systems. Scenario 5a considers Ka trunking only with results identical to those of Scenario 4a. Scenario 5b considers the provision of backed-up Ka band CPS alone. Combined trunking and CPS capabilities with back-up are considered in Scenario 5c. Scenarios 5a, 5b and 5c capture 19.1, 9.1 and 24.8 percent, respectively, of the year 2000 traffic demand.

In Scenario 6 Ka band trunking is designed to provide intrinsically high reliability. This service is offered in conjunction with Ka band CPS backed-up by lower frequency satellite CPS systems. Scenario 6 captures 28.5 percent of the year 2000 traffic demand.

TABLE 13. SUMMARY OF TRAFFIC UNDER SCENARIO 6 (BITS/YEAR$\times 10^{15}$)
(HIGH RELIABILITY Ka TRUNKING WITH LOWER RELIABILITY Ka CPS BACKED-UP BY C OR Ku BAND CPS)

	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

Results are further summarized and interpreted in Table 14. The first column in Table 14 presents addressable traffic, for the year 2000, expressed as a percentage of the total demand (5747 x 10^{15} bits per year) shown in Table 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.

TABLE 14 - 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. IN PRACTICE ADVANCED SATELLITES WILL USE MUCH WIDER BANDWIDTH TRANSPONDERS, MORE TRANSPONDERS IN EACH SATELLITE, AND A NUMBER OF ADVANCED TECHNOLOGY APPROACHES TO REDUCE THE ACTUAL NUMBER OF SATELLITES IN ORBIT.

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 Scenario 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 14 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 (31.5×10^6). The effects of traffic peaking are then taken into account by multiplying by a factor of 2. The values listed 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.

11. 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.

In order to make optimum use of the capability of 30/20 GHz systems to support high transmission volumes, the marketing of these systems should emphasize high volume applications. More than 90 percent of this volume will exist in the voice and computer areas. New video applications, chiefly videoconferencing and educational and social uses of video, increase this to 99 percent of total demand.

Dedicated modes (private and leased line service) account for about 69 percent of projected long haul demand, in part because dedicated modes occupy reserved communications facilities even when not in active use. Circuit switched modes will account for 26 percent of demand. The high efficiency of packet modes causes demand for capacity to be disproportionately low. Packet modes, as a result, account for only four percent of projected transmission capacity.

The major portion of demand for Ka band services involves trunking. If it is assumed that CPS operation implies CPS at each end of the link, traffic volume will be limited by establishment traffic volume requirements, needs for widespread distribution, and reliability considerations to only 4 percent of the total. Other configurations combining CPS and trunking or allowing for shared use of CPS stations can result in substantial increases in this percentage.

Deferrable traffic exists in applications such as electronic mail, taped video transmissions, data base updating, etc. Such traffic can improve the efficiency of facility usage, and can lessen concern over reliability limitations. However, the volume of deferrable traffic projected for the year 2000 is only 4 percent of the total and is not, therefore, expected to have a very significant impact on operations.

About 70 percent of communications demand is projected to require reliability levels equal to those of competing transmission media. Only 6 to 8 percent would be attracted to a higher cost, more reliable offering. About 23 percent of demand would find lower reliability, lower cost, transmissions preferable.

Six scenarios involving the use of Ka band satellite communications with, or without, back-up by terrestrial, or C or Ku band satellite facilities were explored. 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 Ka satellites become one of several transmission media interchangeably used to provide capacity between network modes, while the alternative routing capabilities of the terrestrial 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 associated 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.

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.