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18 and 30 GHz Fixed Service Communication Satellite System Study

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EXECUTIVE SUMMARY

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SPACE AND COMMUNICATIONS GROUP

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EXECUTIVE SUMMARY

OBJECTIVES AND STATEMENT OF WORK

The detailed statement of work (SOW) for this study, including a discussion of the reasons for the study, appears in Appendix C of Volume I. The study tasks are summarized below. The primary objective of the study was to determine what technology development was most critical for use of the 18 and 30 GHz bands for satellite communications. To this end a number of point to point communication concepts were defined in the SOW. These concepts were to be evaluated, selected baselines optimized, and the system and service costs computed.

Task 1 was to assess the expected 1990's performance and cost of the hardware components of an 18 and 30 GHz satellite system.

Task 2 was the study of a number of potential trunk concepts defined in the SOW. The task was to study the concepts, optimize selected baselines, compute the system cost and the service cost associated with the selected baselines, and compare the variation in service cost influenced by such variables as propagation reliability, data quality, and system size.

Task 3 was a study of direct to user concepts similar to that of the trunk concepts in Task 2.

Task 4 was the comparison of the cost effectiveness of satellite systems at 18 and 30 GHz with existing systems at C and Ku band. The SOW also included a comparison with terrestrial links, but it was agreed among the NASA and the contractors that no effort would be devoted to this comparison in the system studies.

Task 5 was the identification of critical technology developments required to properly use the 18 and 30 GHz bands.

In conjunction with this study, Western Union and IT&T U.S. Telephone and Telegraph Corporation performed studies to assess the potential market for 18/30 GHz satellite communications in the last two decades of this century. Task 6 was to interface with the contractors performing the market demand studies.

SATELLITE COMMUNICATIONS AT 18 AND 30 GHz

The World Administrative Radio Council (WARC) has allocated the portion of the spectrum between 17.7 and 20.2 GHz to the downlink, and the portion between 27.5 and 30.0 GHz to the uplink of satellite communications systems which serve fixed earth stations. These bands differ in some respects from C band and Ku band, as indicated below.

1) The 18 and 30 GHz spectrum is 2.5 GHz wide, compared to 500 MHz at C and Ku band.

2) Very narrow spot beams can be generated by satellite antennas which can fit conveniently on a Shuttle launched spacecraft. This allows extensive reuse of the 2.5 GHz wide band.

3) Orbit slot spacing can be reduced below the 3° minimum spacing currently used at Ku band because of the narrow beams achievable with modest earth station antennas; however, the orbital arc is restricted by the requirement to maintain a higher satellite elevation angle at the earth stations than is required at C or Ku band to prevent excessive propagation losses. Nine or ten slots are available to serve the contiguous United States with elevation angles greater than 30°.

4) Rain attenuation of both up and downlink signals is considerably greater at 18/30 GHz than at C and Ku bands. Also, earth station antenna temperatures increase drastically when rain is in the beam.

5) The downlink flux density allowed by WARC at 20 GHz is 33 dB greater than at Ku band and 37 dB greater than at C band. This allows implementation of a very large rain margin relative to the power required for good digital data transmission in clear weather if it is technically and economically advantageous to provide such a margin.

6) A given performance level is more difficult and expensive to achieve at 18/30 GHz than at the lower frequency bands. Performance tends to degrade as the inverse square of the frequency for some important parameters. Also, the maturity of the state of the art in most devices is several years behind that of devices used for C and Ku band.

A major objective of this study was to determine how the favorable characteristics of the 18/30 GHz frequency band can be exploited and how the unfavorable characteristics can be overcome.

RAIN ATTENUATION

The most critical characteristic of the 18/30 GHz frequency band is the rain degradation. At this time there is considerable uncertainty in the statistics of rain attenuation, particularly for terminals using site diversity. Analysis of the data taken from the COMSTAR satellite may provide better

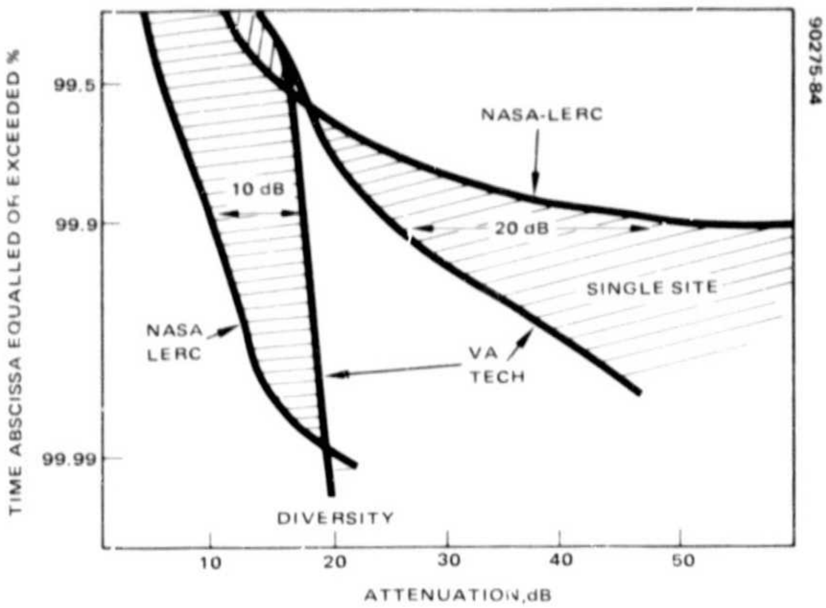

FIGURE 1. ATTENUATION STATISTICS COMPARISON-
ATLANTA, f = 30 GHZ

definition of the rain statistics for single site terminals in the future; however, little data has been acquired for an analysis of the effect of site diversity.

Rain attenuation statistics at 30 GHz from two predictive models are shown in Figure 1. The curves labeled NASA-LeRC are plots of data provided by NASA-Lewis Research Center. The single site NASA-LeRC data is calculated from the model being considered by the International Radio Consultative Committee (CCIR). The diversity curve was obtained by NASA-LeRC by applying a diversity gain factor to the single site data. The other curves are based on a model developed at Virginia Polytechnic Institute. A different approach to diversity gain was taken to generate the diversity curve for this model. Although there is a 20 dB difference between the two single site predictions at a propagation reliability of 99.9 percent, this may not be significant, since even for the more optimistic prediction the rain margin required for 99.9 percent propagation reliability is impractical. The models and their relation to available data are discussed in Appendix B of Volume I.

The curves of Figure 1 are for the 30 GHz uplink band. The curves for the 20 GHz downlink are very similar except that the attenuations expressed in decibels are approximately one-half of those at 30 GHz.

SYSTEM CONCEPTS

The statement of work (SOW) defines two basic types of satellite communication concepts to be studied: trunk and direct to user.

Trunk Concept

The trunk concept is illustrated in Figure 2. In this concept the satellite serves a relatively small number (10 to 40) of heavy traffic centers with individual beams. In each beam there is one terminal which is capable of transmitting and receiving at two sites which are separated by about 15 km, so that the rain degradation of at least one site will be within the rain margin for a very high percentage of the time. Each traffic center has continuous connectivity with each of the other centers. The interconnectivity in the satellite is obtained either through frequency division multiple access

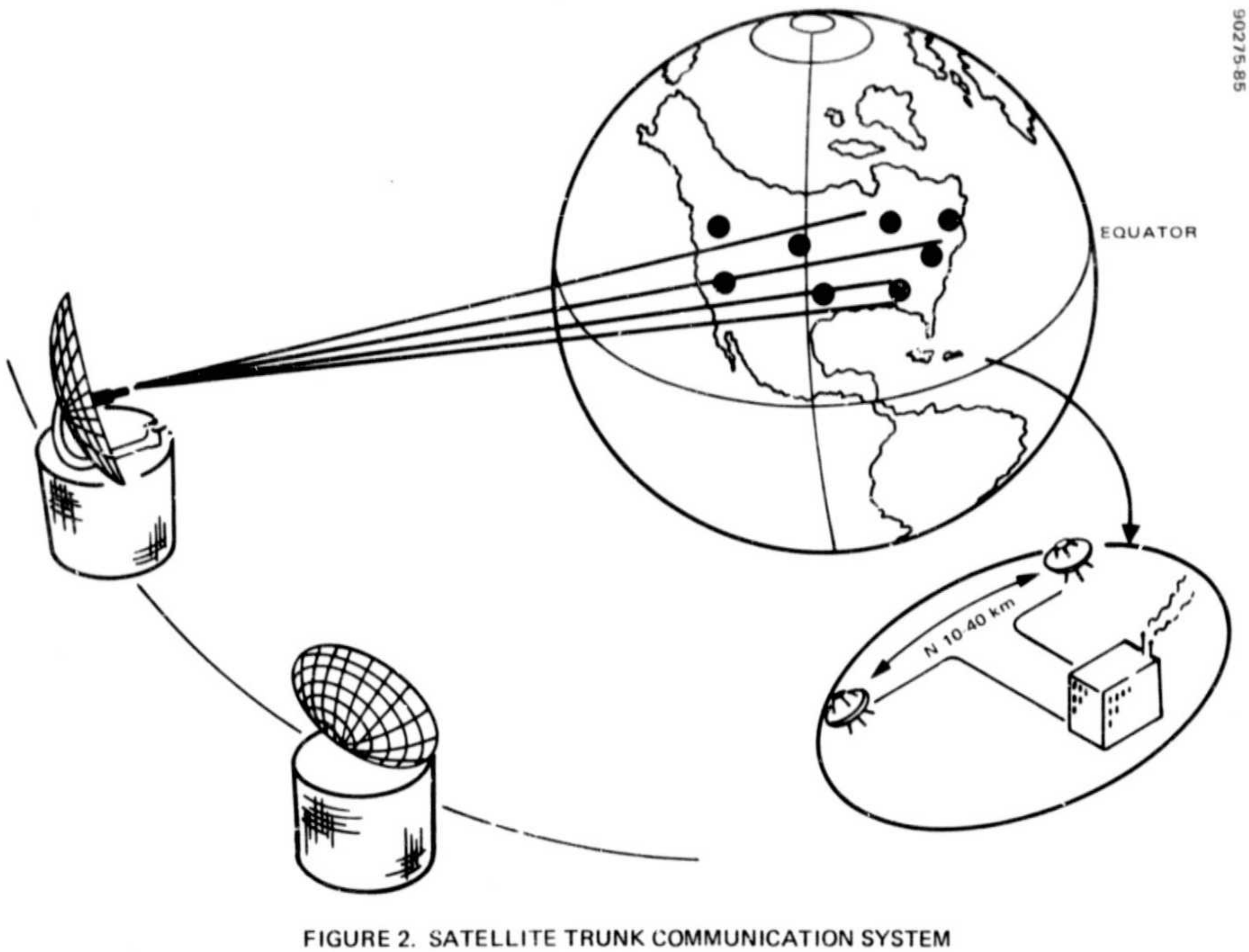

FIGURE 2. SATELLITE TRUNK COMMUNICATION SYSTEM

(FDMA) or time division multiple access (TDMA). In an FDMA system the transmitting earth station modulates the data intended for each of the other centers at different carrier frequencies (Figure 3). In the TDMA concept the earth station transmits the data for each of the other stations during different time intervals. In both cases the SOW prescribes uniform data rate on all links. Concepts with and without satellite switching were considered. The baseline FDMA concept does not include switching. The addition of switching would allow redistribution of the satellite resources as the traffic demand shifted from link to link during the course of the day. This would eliminate the need to size all links for peak demand, and possibly reduce the cost of the satellite. Because of a lack of data on the variation of damand during the day, it was not possible to determine the value of switching by FDMA systems. The baseline TDMA concept includes satellite switching. A TDMA concept without satellite switching becomes a point to multipoint system. That is, all downlink beams carry the same signal. Then, only one uplink beam can be used at a time, and the frequency spectrum cannot be reused in each beam. Since the traffice is point to point, a TDMA concept without satellite switching does not conserve the spectrum. In addition, it is wasteful of the satellite because all downlink beams radiate continuously, even though only one beam is useful at any time. This would reduce the cost effectiveness of the system. For these reasons, TDMA without satellite switching was not considered. In a TDMA system with satellite switching (SS-TDMA) (Figure 4), each station communicates with one and only one other station during a subframe. At the end of the subframe the satellite switch reconfigures so that each station communicates with a different station than it did in the previous subframe. Thus, over a complete frame, each station communicates with each other station. Because the frame duration is a small fraction of a second, it appears to the users that there are continuous links between all stations.

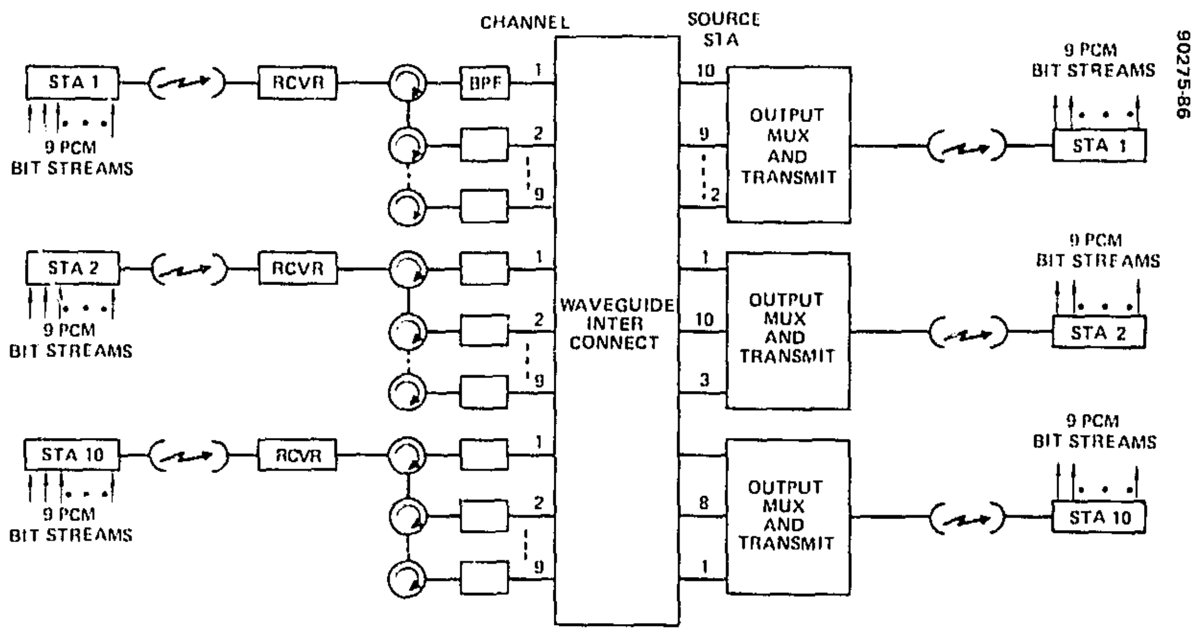

FIGURE 3. TEN STATION FDMA TRUNK

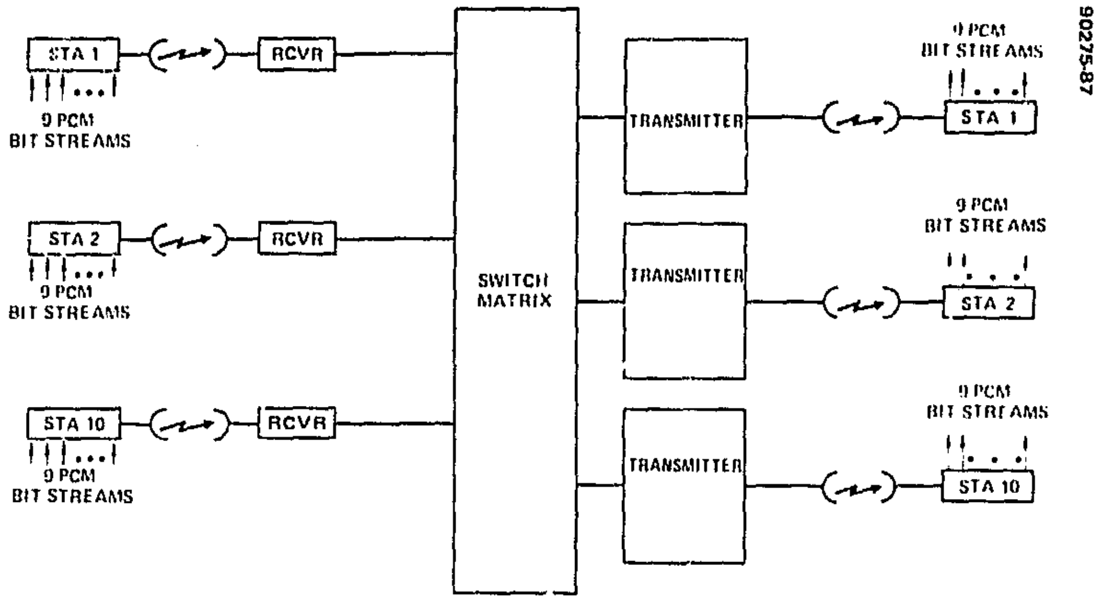

FIGURE 4. TEN STATION TDMA TRUNK

The baseline trunk systems are ten-beam systems. Optimization studies were performed to find the combination of transmitter power, antenna diameter, and receiver type for both the satellite and earth station which minimized the system cost. The satellite carried nearly 25 Gbps of data. The details of the satellite and earth stations for the FDMA and TDMA concepts are described in Section 4 of Volume I.

The cost of the concepts in terms of total investment and investment apportioned to an equivalent 40 MHz transponder and a 64 kbps voice circuit are shown in Table 1. These costs include three satellites, three launches, ten dual site terminals (land cost not included) and the diversity links and switches for the terminals, but do not include the terrestrial tails or the central switching offices. Also, it is difficult to translate the investment per transponder or per voice circuit into a tariff because of the uncertainty in the system utilization factor. The very large system capacity is achieved by assuming that each earth terminal used the entire 2.5 GHz spectrum. This is a very unlikely assumption, given the wide disparity in current communications demand between the ten baseline cities.

TABLE 1. FDMA-TDMA TRUNK INVESTMENT COST

Item	FDMA		TDMA	
Propagation reliability	99.9%	99.9%	99.99%	99.99%
Total investment, $M	251	273	231	245
Capacity, Gbps	19.4	19.4	22.2**	22.2**
Investment				
$K/40 Mbps channel	518*	562*	374*	397*
$/64 kbps VX circuit	1636*	1801*	1197*	1270*

*Multiply by utilization factor.

**At 90 percent synchronization efficiency.

Direct to User Concept

In the direct to user concept, the satellite serves a large number of stations distributed over the contiguous United States (CONUS), as shown in Figure 5. Both multibeam and CONUS beam satellites were defined by the SOW. The advantage of the multibeam satellite antenna is the increased gain associated with the small spot beams. This high gain is critical for the direct to user configuration because the severe rain attenuation associated with single site operation places a great burden on the satellite and earth station resources. In fact, even the 25 beam case studied as a baseline required a very high powered satellite (~10 kW of solar power) to achieve a propagation reliability of 99.5 percent, which was considered minimal by the market study contractors. The use of a low gain CONUS beam antenna made the direct to user concept impractical.

The use of multibeam antennas raises the problem of beam interconnectivity. As in the trunk concepts, interconnectivity can be provided either by FDMA or TDMA; however, the SOW specified that no direct interconnectivity between beams be provided in the FDMA satellite, but is to be provided through master earth stations in each beam. This results in multihop links, as described in Section 5 of Volume I. In the TDMA concept, interconnectivity of the beams in the satellite is required by the SOW. The baseline TDMA system includes satellite switching as described for the TDMA trunk concept.

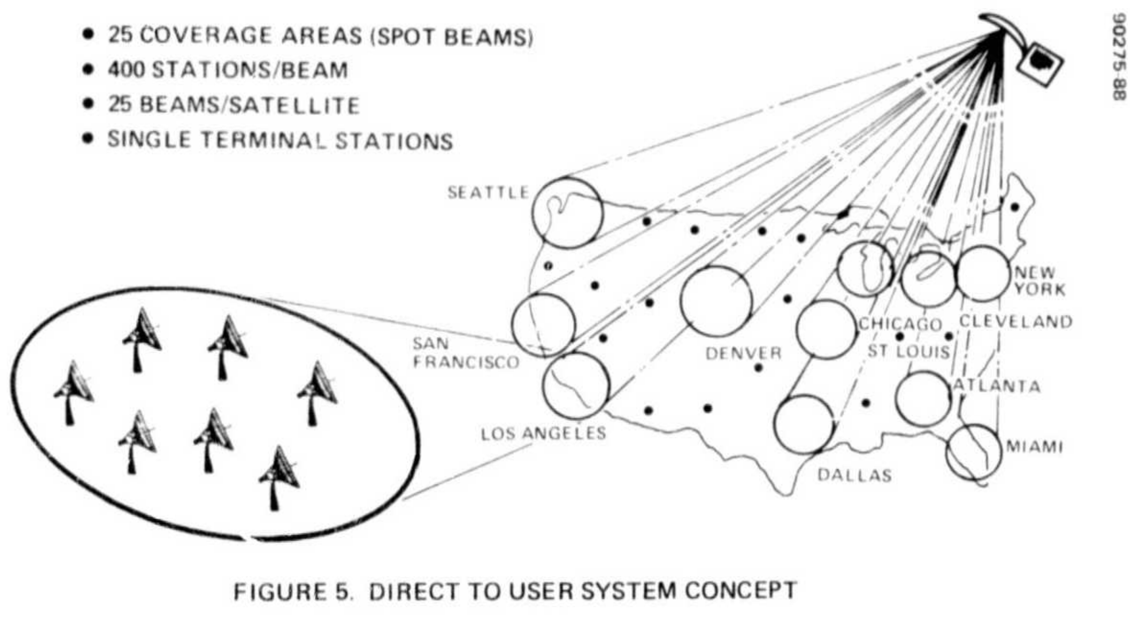

FIGURE 5. DIRECT TO USER SYSTEM CONCEPT

TABLE 2. DIRECT TO USER ANNUAL SERVICE COSTS, $K

Item	Station					
	FDMA			TDMA		
	Small	Medium	Large	Small	Medium	Large
Earth station investment (per station)	277	611	2167	460	580	882
Net earth station revenue (per station)	94	208	736	156	197	300
Revenue required per						
• 64 kbps circuit ($3K)*	16	7.8	6.5	25	7.4	4.4
• 1.5 Mbps circuit ($74K)*	–	134	156	–	180	107
• 6.3 Mbps circuit ($326K)*	–	–	669	–	–	466
	• Not tarrif or lease					
	• Does not account for utilization					

*Share of $398M investment inspace segment, TT&C, and master control.

The cost of 25 beam direct to user concepts is shown in Table 2. The cost shown is for the complete system, since there are no terrestrial tails.

CRITICAL TECHNOLOGIES

The critical technologies which must be developed to take advantage of the 18 and 30 GHz bands are discussed in Section 7 of Volume I. A major item is the multispot beam antenna, since this element provides the capability for extensive frequency reuse. Also in need of development are the low noise and high power amplifiers. The development of these devices in the 18/30 GHz band is several years behind that of the devices for the lower frequencies. Also, for equivalent levels of development, the performance of these devices at 18 and 30 GHz will be inferior to that of the devices used at the lower frequencies.

Although the satellite switch matrices required for SS-TDMA operation do not operate at the carrier frequency, they are more critical to the success of 18 and 30 GHz concepts because of the large number of independent beams which can be generated at these frequencies by a reasonably sized antenna. Although a switch matrix adequate for a 25 beam satellite using the matrix approach can be built with near term technology, the weight and cost of such a matrix becomes impractical as the number of beams increases beyond 25.