Economic Tradeoffs Between SBS and ACTS for Providing Customer Premise Service

Theodore J. Sheskin*
Cleveland State University, Cleveland, Ohio

The objective of this work was to perform two economic tradeoffs for customer premise service (CPS) Earth stations. The first tradeoff is between frequency division multiple access (FDMA) and time division multiple access (TDMA) to determine which is the more economical method for allocating satellite transponder capacity among CPS Earth stations. The second is between separate Earth stations for each user and a shared Earth station on the premises of the larger user. A terrestrial digital link connects the smaller user to the shared Earth station. NASA Lewis Research Center and the Federal Building in Cleveland were selected as potential users of Earth stations. The author conducted a telecommunications traffic survey at each facility. The annual traffic volumes were converted to digital traffic rates during a busy hour. The major contribution of this work is the application of grade of service calculations to specify the digitized transmission capacities of Earth stations. Currently, an FDMA Earth station costs less than a TDMA terminal. In the future a TDMA Earth station may cost less. The annual cost of a shared Earth station was equal to the sum of the costs of two stand-alone terminals.

Nomenclature

BHCS = busy hour call seconds
bps = bits per second
CPS = customer premise service
CPU = central processing unit
EFT = electronic funds transfer
FTS = Federal Telecommunications System
GHz = gigahertz
kbps = kilobits per second
Mbps = megabits per second
pf = peak factor

I. Introduction

THIS paper analyzes economic tradeoffs involved in choosing customer premise service (CPS) Earth stations for satellite communications in Cleveland, Ohio. A customer premise service Earth station is located directly on the premise of a customer and may be shared by other local users by means of dedicated terrestrial links. Two potential users of customer premise service selected as the objects of this study are NASA Lewis Research Center in Cleveland and the Federal Building of Cleveland. These two facilities are 14 miles apart.

Two economic tradeoffs are made. The major comparison is between time division multiple access (TDMA) and frequency division multiple access (FDMA) to determine which is the more economical system configuration for allocating satellite transponder capacity to an Earth station at NASA Lewis. TDMA and FDMA are two fundamentally different approaches to providing multiple access to customers whose Earth stations are geographically dispersed and whose demands for service vary over time.[1] A TDMA system makes available a stream of time slots. Customer channels are multiplexed on a common digital stream and sent to the satellite in bursts using different time slots for each customer. The satellite uses scanning beams and a baseband processor. An FDMA system makes available a pool of frequencies. Customer channels are combined in a single channel per carrier format and sent to the satellite in parallel using different frequency assignments for each customer. The satellite must be able to reallocate satellite capacity among fixed beams.

A second economic comparison is made between separate TDMA Earth stations at NASA Lewis and the Federal Building of Cleveland, and a shared TDMA Earth station located at the Federal Building of Cleveland. In this comparison, a dedicated terrestrial digital link connects NASA Lewis to the shared Earth station at the Federal Building of Cleveland.

In this study, costs for TDMA Earth stations at NASA Lewis and the Federal Building of Cleveland are based on the tariff published by Satellite Business Systems (SBS) for its Customer Network Service. Satellite Business Systems currently offers 14/12 GHz service to corporate and institutional users. Cost estimates for an FDMA Earth station at NASA Lewis are based on contractor reports for NASA's experimental Advanced Communications Technology Satellite (ACTS). ACTS, scheduled to become available to customers in the late 1990's, will offer 30/20 GHz service to alleviate orbit and frequency congestion.

II. Telecommunications Traffic Survey

To begin this study, an estimate of the long-distance telecommunications traffic at both NASA Lewis and the Federal Building of Cleveland is required. The author conducted a brief telecommunications traffic survey by telephone, letter, and visits to selected personnel at NASA Lewis. Average monthly voice, video, and data traffic were requested. Telecommunications users were asked to summarize their monthly or daily data message traffic via teletype and facsimile, and their computer traffic via terminals, magnetic tape, and punched cards. An accurate record of typical monthly Federal Telecommunications System (FTS) telephone traffic for both NASA Lewis and the Federal Building of Cleveland was provided by the General Services Administration telecommunications coordinator in Chicago. No video traffic was reported for either facility. Only a partial summary of data traffic was obtained for the Federal Building of Cleveland because the author was not always able to reach a knowledgeable individual in every agency, and because some military contacts declined to furnish the information requested. The annual voice and data traffic volumes provided by survey respondents for NASA Lewis and the Federal Building of Cleveland have been converted to digital traffic rates during a busy hour.

The telecommunications traffic loads obtained from traffic survey respondents at NASA Lewis and at the Federal Building of Cleveland are used to determine the capacities of poten-

Presented as Paper 86-0685 at the AIAA 11th Communication Satellite Systems Conference, San Diego, CA, March 17–20, 1986; received Sept. 15, 1986; revision received Aug. 21, 1987.

*Associate Professor, Industrial Engineering. Member AIAA.

Table 1 Conversion of periodic telecommunications traffic to busy hour simplex bits per second

Assumptions

120 words/message
6 characters per word
250 days per year
24 hours per day
21,600,000 seconds per year
2 bits per character reserved for control functions

Detailed calculations

1) Voice Traffic

$$\frac{(\times \text{ BHCS})\ (32 \text{ kbps per duplex TDMA circuit})}{3600 \text{ s/h}} = 8.89 \times \text{bps (duplex)}$$

$$\frac{(\times \text{ BHCS})\ (64 \text{ kbps per duplex FDMA circuit})}{3600 \text{ s/h}} = 17.78 \times \text{bps (duplex)}$$

2) Data Traffic
2.1) Message Traffic
2.1.1) Teletype
2.1.1.1) Advanced Record Systems (ARS) Narrative
(× msg/mo) (12 mo/yr) (120 wd/msg) (6 char/wd) (9 bits/char) (4 pf)/ [(0.01 eff) (21,600,000 s/yr)] = 1.44 × bps
2.1.1.2) Telex
1.12 (× msg/mo) bps, 7 bits/char
2.1.2) Facsimile
(× pages/mo) (12 mo/yr) (300,000 bits/page) (4 pf)/ [(0.15 eff) (21,600,000 s/yr)] = 4.44 × bps
2.2) Computer Traffic
2.2.1) Terminal/CPU
2.2.1.1) Library
(× h/search) (3600 s/h) (170 searches/5 mo) (12 mo/yr) (11.35 char/s) (10 bits/char) (4 pf)/ [(0.0015 eff) (21,600,000 s/yr)] = 20,581 × bps
2.2.1.2) IRS inquiries
(× inq/mo) (1.4 lines/inq) (35 char/line) (10 bits/char) (12 mo/yr) (4 pf)/[(0.0015 eff) (21,600,000 s/yr)] = 0.726 × bps
2.2.1.3) IRS responses
(× resp/mo) (1 page/resp) (10 lines/page) (35 char/line) (10 bits/char) (12 mo/yr) (4 pf)/[(0.0015 eff) (21,600,000 s/yr)] = 5.19 × bps
2.2.2) CPU/CPU-Dist. Proc.
2.2.2.1) Mag Tape
(× msg/mo) (12 mo/yr) (120 wd/msg) (6 char/wd) (11 bits/char) (3 pf)/ [(0.007 eff) (21,600,000 s/yr)] = 1.89 × pbs
2.2.2.2) Punched Cards
(× msg/mo) (12 mo/yr) (120 wd/msg) (6 char/wd) (14 bits/char) (3 pf)/ [(0.007 eff) (21,600,000 s/yr)] = 2.4 × bps
2.2.3) CPU/CPU-EFT
(× transactions/mo) (12 mo/yr) (1000 bits/transaction) (2 pf)/[(0.1 eff) (21,600,000 s/yr)] = 0.0111 × bps

Summary of results

	Busy hour bits per second, duplex	
Traffic component	NASA Lewis	Federal Building of Cleveland
Voice		
FTS, TDMA:	812×10^3	$3,806 \times 10^3$
FTS, FDMA:	$1,624 \times 10^3$	$7,612 \times 10^3$
Data		
Narrative	208	63,243
Telex	39	432
Facsimile	5,255	1,016
Library search	950	
Terminal/CPU	2×10^6	953,037
CPU/CPU, magnetic tape	5,546	10,859
CPU/CPU, punched cards	549	22,213
CPU/CPU, electronic funds transfer	63	1,445
Total data traffic	2,012,610	1,052,245

tial CPS Earth stations at these facilities. Since an Earth station transmission capacity must be designed for peak traffic, it is first necessary to convert periodic traffic volumes reported in the survey into busy-hour traffic rates of bits per second (bps). Contractors for CPS predict that all satellite channels will be digital, with voice traffic being carried in digitized form. Data traffic volumes are reported in such diverse formats as messages per month, pages per month, and responses per month. The calculations of busy-hour duplex voice traffic, and sample calculations required to convert each component of data traffic into busy-hour bps are presented in Table 1. The results of these calculations are summarized in Table 1 for both NASA Lewis and the Federal Building of Cleveland. The total data traffic of 2,012,610 bps reported in Table 1 for NASA Lewis is the basis for the 2013 kbps used in Eq. (5). Similarly, the total of 1,052,245 bps reported in Table 1 for the Federal Building of Cleveland is the basis for the 1052 kbps used in Sec. III.C.

III. Grade of Service Calculations to Specify Earth Station Transmission Capacity

A. Grade of Service Applied to Calls Lost

The probability of not obtaining service when it is requested is referred to as the grade of service.[5] It is unnecessarily expensive to design a system so that terminals will always receive service when they request it. On the other hand, too low a system availability may discourage customers from using the system. Figures for grades of service are specified for both voice and data traffic, and Earth station transmission facilities at NASA Lewis and the Federal Building of Cleveland will, in this paper, be designed to achieve these figures. Voice traffic is real-time while much data traffic can be deferred. Therefore, a better grade of service has been specified for voice traffic than for data. On the basis of current practice in telephone engineering,[5] the author has specified a grade of service of 0.02 for voice traffic, and a poorer grade of service of 0.05 for data.

Grade of service calculations are based on a multiserver queuing model that makes the following assumptions:

1) Calls arrive according to a Poisson process.
2) Calls are served on a first-in, first-out basis.
3) Service times follow an exponential distribution.
4) All circuits have identical service time distributions.

If a circuit is available when a subscriber dials a call, the circuit will be assigned to the requesting user. If a call is dialed when all circuits are busy, the grade of service model treats it as lost (blocked calls lost model). No queues form. The probability of losing a call is given by:

$$\text{grade of service} = \frac{\dfrac{(\mathrm{Mr})^M}{M!}}{\displaystyle\sum_{i=0}^{M} \frac{(\mathrm{Mr})^i}{i!}} \tag{1}$$

where

M = number of circuits
r = utilization of each circuit
Mr = traffic volume in Erlangs

An Erlang, a dimensionless unit of traffic intensity, is the

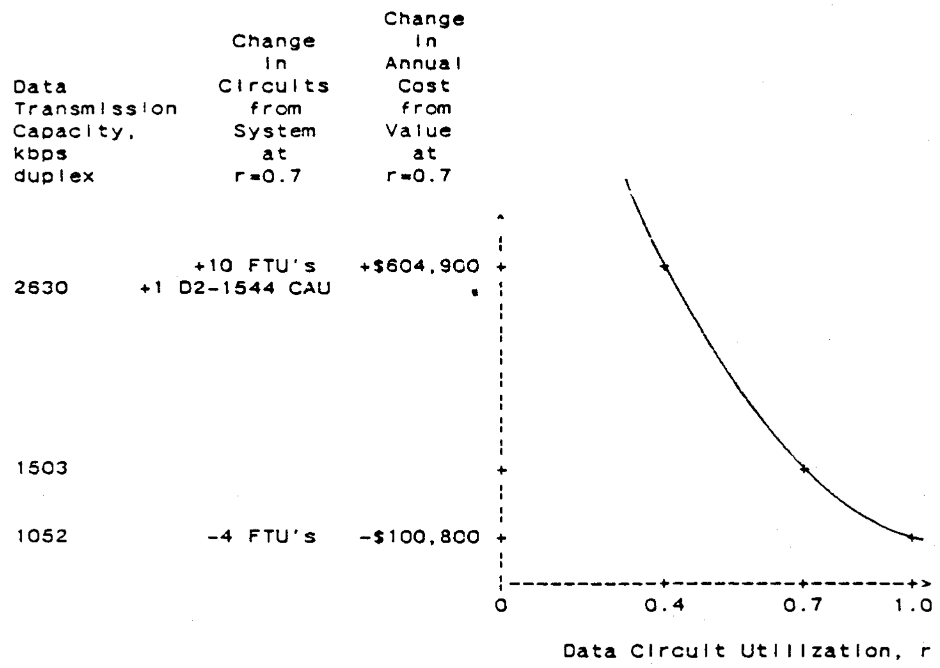

Fig. 1. Inverse relationship between data transmission capacity and data circuit utilization for the Federal Building of Cleveland.

amount of traffic one circuit can handle in one hour if it is continuously occupied. For voice traffic,

$$\text{One Erlang} = \frac{\text{busy hour call second}}{3600} \tag{2}$$

Grade of service values, expressed as a function of Mr and M, are tabulated in Table 11 of Martin.[5]

B. Calculation of the NASA Lewis Earth Station Data Transmission Capacity

Projected communications between terminals at NASA Lewis and remote computers at other NASA centers will form the bulk of NASA Lewis data traffic. NASA Lewis has about 85 terminals, each connected to the NASA Lewis IBM 370 computer for about 30 min during a busy hour. The author has assumed that during a typical busy hour 25%, or 21 of these terminals, will be in use with remote computers at other NASA centers. Therefore, the data traffic volume in Erlangs is:

$$M = \frac{21 \text{ terminals/h} \times 30 \text{ min/terminal}}{60 \text{ min/h}} = 10.5 \text{ Erlangs} \tag{3}$$

Hence,

$$\text{grade of service} = \frac{1.05^M/M!}{\sum_{i=0}^{M} 10.5^i/i!} \tag{4}$$

The number of duplex data circuits needed to provide a grade of service of 0.05 is required. Using Table 11 in Ref. 5, the grade of service = 0.07044 for $M = 14$ circuits, and 0.04699 for $M = 15$ circuits. Therefore, 15 duplex data circuits are needed to give a grade of service of 0.05. Table 1 indicates that NASA Lewis has a data traffic volume of 2013 kbps duplex. To compute the data transmission capacity of a NASA Lewis Earth station which would use 15 data circuits, equate two equivalent definitions of the utilization:

$$r = \text{data circuit utilization} = \frac{\text{Erlangs}}{M} = \frac{10.5}{15} = 0.7$$

$$= \frac{\text{actual number of characters transmitted}}{\text{maximum possible number of characters transmitted}}$$

$$= \frac{\text{2013 kbps of Lewis duplex traffic}}{\text{transmission capacity for Lewis duplex data traffic}}$$

$$= \frac{\text{2013 kbps duplex}}{\text{2876 kbps duplex}} \tag{5}$$

Thus, 2876 kbps duplex is the required data transmission capacity of a NASA Lewis Earth station that would offer a grade of service of 0.05 with a circuit utilization of 0.7.

C. Calculation of the Federal Building of Cleveland Earth Station Data Transmission Capacity

For the reasons indicated in Sec. II, neither the number of terminals nor the mean usage time per terminal is known for the Federal Building of Cleveland. Hence:

1) The data traffic volume in Erlangs cannot be computed.

2) The number of duplex data circuits required to provide a specified grade of service cannot be calculated. To determine the data transmission capacity for an Earth station at the Federal Building of Cleveland, the author has assumed, in the absence of information to the contrary, the same utilization of data circuits at the Federal Building of Cleveland as at NASA Lewis. The affect of this assumption is analyzed graphically in Fig. 1.

Following the previous approach used for Eq. (5), for a data traffic volume of 1052 kbps duplex recorded in Table 1, 1503 kbps duplex is the data transmission capacity of an Earth station at the Federal Building of Cleveland which will achieve a circuit utilization of 0.7.

D. Calculation of the NASA Lewis Earth Station Voice Transmission Capacity

The voice traffic volume at NASA Lewis is 91,333 call seconds during a typical busy hour. Applying Eq. (2), the voice traffic volume at NASA Lewis is 25.4 Erlangs. NASA Lewis has 38 FTS terrestrial telephone circuits, 22 of which carry both incoming and outgoing calls, and 16 of which carry outgoing calls only. Since outgoing calls can be initiated on any one of the 38 FTS duplex circuits, the circuits currently have a utilization of

$$r = \frac{\text{Erlangs}}{M} = \frac{25.4}{38} = 0.67 \tag{6}$$

and provide a grade of service of 0.005. To provide a grade of service of 0.02, specified in Sec. III.A, $M = 34$ duplex voice circuits.

r = utilization of Lewis Earth station voice circuits

$$= \frac{\text{Erlangs}}{M} = \frac{25.4}{34} = 0.75 \tag{7}$$

E. Calculation of the Federal Building of Cleveland Earth Station Voice Transmission Capacity

The voice traffic volume at the Federal Building of Cleveland is 428,200 busy hour call seconds. Applying Eq. (2), the voice traffic volume at the Federal Building of Cleveland is 119 Erlangs. The Federal Building of Cleveland has 134 two-way FTS terrestrial telephone circuits, all of which carry both incoming and outgoing calls. To provide the Federal Building of Cleveland with a grade of service of 0.02, only $M = 133$ duplex voice circuits are required.

r = utilization of Federal Building Earth station voice circuits

$$= \frac{\text{Erlangs}}{M} = \frac{119}{133} = 0.89 \tag{8}$$

IV. Cost of an Earth Station for NASA Lewis

In this report, two Earth stations are specified for NASA Lewis. The first Earth station uses TDMA accessing and is based on the service description and tariff published by Satellite Business Systems (SBS) for its Communications Network Service (CNS-A).[3,4] The second Earth station uses FDMA accessing. The cost of the FDMA Earth station is reported in Ref. 6. Both the TDMA and FDMA Earth stations would provide NASA Lewis with 2876 kbps of duplex data transmission capacity to offer a grade of service of 0.05 for data traffic and would provide 34 duplex voice circuits to offer a grade of service of 0.02 for voice traffic.

A. NASA Lewis TDMA Earth Station

To estimate the cost of a TDMA Earth station at NASA Lewis, the author assumed that NASA Lewis would lease a Network Access Center (NAC), which is an Earth station provided by SBS and located on the premises of NASA Lewis. The capacity of a NAC is 24,550.4 kbps duplex. A transmission unit (TU) is a unit of measure that represents 224 kbps simplex of assigned satellite transponder capacity. A full-time transmission unit (FTU) is one TU assigned to a customer's network 24 hours per day, 7 days per week. A demand transmission unit (DTU) is one TU assigned to a customer's network as needed from a common pool of satellite transponder capacity subject to availability. The minimum CNS-A configuration is three NAC's and six FTU's. Connection arrangement units (CAU) are the pieces of equipment that connect customer-provided facilities to the NAC. Different types of CAU's are provided for voice and for data. The author has assumed that NASA Lewis would select voice and data digital connections on a switched basis for a slightly higher cost than on a nonswitched basis. Switched connections are established on a dial-up basis by the user. Type A2 CAU's, which may be used for switched voice connections, require 32 kbps of TU capacity subject to reduction by voice activity compression and 32 kbps of NAC capacity. Type D2-3088 CAU's are for use with switched synchronous digital connections at a data rate of 3088 kbps duplex. They can operate at the highest data rate of all the digital, switched, synchronous CAU's.

1. NASA Lewis Earth Station Data Traffic

Transmission capacity for the space segment of CNS-A is provided by TU's. To offer a grade of service of 0.05 for data traffic, 2876 kbps of duplex data transmission capacity must be provided. To determine the number of simplex TU's required, the 2876 kbps of duplex data capacity is multiplied by 2 to convert it to simplex capacity, and divided by the 224 kbps capacity of a simplex TU.

$$\frac{(2876 \text{ kbps duplex})\ (2)}{224 \text{ kbps per simplex TU}} = 25.68 \text{ simplex TU's}$$

For the space segment, 26 simplex FTU's are required, with half to send data and the other half to receive data. Transmission capacity for the ground segment of CNS-A is provided by CAU's, which are duplex. Therefore, the data transmission capacity of 2876 kbps duplex should not be multiplied by 2. It is most economical to use the largest capacity digital switched synchronous CAU available, namely the D2-3088 CAU, which supports 3088 kbps.

$$\left(\frac{2876 \text{ kbps duplex}}{3088 \text{ kbps per duplex D2-1544 CAU}}\right)$$
$$= 0.93 \text{ D2-3088 CAU's}$$

For the ground segment, one duplex D2-3088 CAU is required.

2. NASA Lewis Earth Station Voice Traffic

To provide a grade of service of 0.02 for voice traffic, 34 duplex voice circuits digitized at a rate of 32 kbps per duplex voice circuit are required. For the space segment

$$\frac{(34 \text{ duplex voice circuits}) \times (32 \text{ kbps per duplex voice circuit}) \times (2)}{224 \text{ kbps per simplex TU}}$$
$$= 9.7 \text{ simplex TU's}$$

Thus, 10 simplex FTU's would be used. Type A2 voice grade CAU's transmit 32 kbps duplex. Since a duplex voice circuit is digitized at the rate of 32 kbps, 34 duplex A2 CAU's are required for the ground segment of voice traffic.

3. Annual Cost of a NASA Lewis TDMA Earth Station

A summary of the circuits in space and ground segments for the voice and data traffic of the NASA Lewis TDMA Earth station is given in Table 2. Annual costs for an Earth station assume a life of 10 years and a compound interest rate of 8% per year. Annual costs for the NASA Lewis TDMA Earth station are itemized in Table 3.

B. Annual Cost of a NASA Lewis Earth Station

The cost of an FDMA Earth station at NASA Lewis is based on 1980 contractor data reported in a June 1983 evaluation[6] of FDMA and TDMA approaches to 30/20 GHz satellite communications. The cost data of Ref. 6 is briefly compared to the results of two parallel design studies of 30/20 GHz ground terminals conducted in 1983 by contractors.[7,8] Although the three studies postulate somewhat different systems for accommodating CPS traffic, the following general assumptions are shared. The uplink is at 30 GHz and the downlink 20 GHz. An Earth station on a customer's premises requires a high power amplifier of about 20 W and an antenna diameter of about 5 M. Satellite switched TDMA and FDMA are considered.

All three studies conclude that the costs of Earth terminals are not directly proportional to their data rates. For example, one contractor[7] estimates a cost of $290,200 for an installed FDMA terminal with a throughput of 64 kbps, and a cost of $318,300 for an installed FDMA terminal with a capacity of 1.5 Mbps. Although the capacity of the larger terminal is more than 20 times that of the smaller, the cost of the larger is only 10% greater than that of the smaller.

The total FDMA duplex transmission capacity required at NASA Lewis is equal to (2876 kbps duplex data) + (34 duplex voice circuits) × (64 kbps per duplex voice circuit) = 5052 kbps duplex. However, the largest FDMA terminal for which costs are estimated by the contractors has a capcity of only 1.5 Mbps. To use four of these FDMA terminals to satisfy

Table 2 Circuits in space and ground segments of SBS CNS-A TDMA earth station at NASA Lewis

Space Segment:	Simplex FTU's at 224 kbps each
	26 FTU's data
	10 FTU's voice
	36 FTU's total
Ground Segment:	Duplex CAU's
	1 Type D2-3088 CAU, data
	34 Type A2 CAU's voice

Table 3 Annual costs of SBS CNS-A TDMA Earth station at NASA Lewis

36 FTU's	
Annual recurring charge at $2,550 per FTU per month	$1,101,600
1 Type D2-3088 CAU	
Installation charge at $100 per CAU A/P 8%, 10 ($100) (0.149)	15
Annual recurring charge at $3,300 per CAU per month	39,600
34 Type A2 CAU's	
Installation charge at $100 per CAU A/P 8%, 10 34 ($100) (0.149)	507
Annual recurring charge at $275 per CAU per month	112,200
1 NAC	
Minimum installation charge of $12,500 A/P 8%, 10 $12,500 (0.149)	1,863
Annual recurring charge at $17,850 per NAC per month	214,200
TOTAL Annual Cost	$1,469,985

the capacity required at NASA Lewis would not be cost effective. Reference 6 reports an installed cost of $471,000 for an FDMA terminal with a peak data rate of 6.3 Mbps, which is more than sufficient to meet the requirements of NASA Lewis. This cost is only 43% higher than his cost for a 1.5 Mbps terminal with less than one-fourth the capacity. To calibrate the FDMA Earth station costs of Ref. 6 with respect to those of both contractors,[7,8] consider a 1.5 Mbps terminal for which all three studies furnish costs. An installed cost of $329,000 reported by Ref. 6 is only 4% higher than an installed cost of $318,300 given by one contractor[7] but is 167% higher than an installed cost of $123,000 given by the other contractor.[8] The higher cost data of Ref. 6 will be accepted as a conservative estimate. The 6.3 Mbps FDMA Earth station of Ref. 6 is chosen to satisfy the requirements of NASA Lewis at an installed cost of $471,000. Annualized over 10 years using an interest rate of 8%, the cost to NASA Lewis is only $471,000 (A/P 8%, 10) = $70,180 per year.

C. Comparison of NASA Lewis TDMA and FDMA Earth Station Costs

At NASA Lewis, the annual cost of an SBS CNS-A TDMA Earth station is $1,469,985, which is about 21 times the annual cost of $70,180 for a 6.3 Mbps FDMA Earth station. However, the TDMA cost includes the space segment while the FDMA cost excludes the space segment. To compare both forms of accessing on the basis of ground costs alone, the $1,101,600 annual cost of the TDMA space segment consisting of 36 FTU's is subtracted from the total annual cost of $1,469,985 to yield an annual cost of $368,385 for the TDMA ground segment. On this basis the FDMA CPS Earth station at NASA Lewis appears to have a significantly lower cost than the TDMA terminal. This tenative conclusion must be qualified by by the observation that TDMA costs are actual costs based on an SBS 14/12 GHz service currently available to corporate and government satellite users. On the other hand, FDMA costs are only projected costs based on an anticipated 30/20 GHz satellite technology which has not been commercially developed. Both contractors[7,8] indicate that, historically, TDMA terminals have been more expensive than FDMA terminals. This cost difference is due mainly to the modem, which includes a TDMA bit synchronization unit. Baseband processing is the second most costly element in a TDMA system. TDMA costs can be significantly reduced by advances in the technology of large-scale integration for implementing modems and baseband processing. TDMA terminals offer higher routing flexibility. Satellite size and complexity are greater for FDMA. Reference 6 concludes that TDMA will offer a cost advantage in the space segment, requiring about one-third the payload weight and about two-thirds the power of an FDMA system with an equivalent capacity.[7,8] Both contractors anticipate that in the near future a TDMA 30/20 GHz CPS network will be the more cost effective alternative.

Table 4 Circuits in space and ground segments of SBS CNS-A TDMA Earth station at the Federal Building of Cleveland

Space Segment:	Simplex FTU's at 224 kbps each
	14 FTU's data
	38 FTU's voice
	52 FTU's total
Ground Segment:	Duplex CAU's
	1 Type D2-1544 CAU, data
	133 Type A2 CAU's voice

V. Annual Cost of a TDMA Earth Station for the Federal Building of Cleveland

The TDMA Earth station for the Federal Building of Cleveland is specified in the same manner as it is for NASA Lewis in Sec. IV.A. The TDMA Earth station is also based on SBS CNS-A. A summary of the circuits in the space and ground segments for the voice and data traffic of the Earth station for the Federal Building of Cleveland is given in Table 4. Annual costs for the Federal Building of Cleveland Earth station are itemized in Table 5. As indicated in Sec. III.C, the affect of the assumption that the Federal Building of Cleveland has the same utilization of data circuits as NASA Lewis is analyzed graphically in Fig. 1.

VI. Comparison between Two Separate Earth Stations and a Shared Earth Station at the Federal Building of Cleveland

Customer premise service users who are separated by distances of up to several miles may either share one Earth station on the premises of a single user or maintain separate Earth stations on each of their own premises. This issue may be decided on the basis of minimum annual cost. If users choose to share a CPS Earth station on the premises of one of the users, then all the other users must be connected to the shared Earth station by means of terrestrial links. In this report two alternative Earth station networks are considered. In the first alternative, the Federal government maintains separate Earth stations at NASA Lewis and the Federal Building of Cleveland. The total annual cost to the government is the sum of the annual costs of the two separate Earth stations. In the second alternative, a shared Earth station could be located on the roof of the Federal Building of Cleveland because the Federal Building has more CPS voice and data traffic than NASA Lewis. Digital terrestrial links would carry NASA Lewis CPS

Table 5 Annual costs of SBS CNS-A TDMA Earth station at the Federal Building of Cleveland

52 FTU's	
Annual recurring charge at $2,550 per FTU per month	$1,591,200
1 Type D2-1544-CAU	
Installation charge at $100 per CAU A/P 8%, 10	
($100) (0.149)	15
Annual recurring charge at $2,750 per CAU per month	33,000
133 Type A2 CAU's	
Installation charge at $100 per CAU A/P 8%, 10	
133 ($100) (0.149)	1,982
Annual recurring charge at $275 per CAU per month	438,900
1 NAC	
Minimum installation charge of $12,500 A/P 8%, 10	
$12,500 (0.149)	1,863
Annual recurring charge at $17,850 per NAC per month	214,200
TOTAL Annual Cost	$2,281,160

traffic between NASA Lewis and the shared Earth station at the Federal Building of Cleveland. The alternative, which involves sharing an Earth station, must provide the same grades of service to both NASA Lewis and the Federal Building of Cleveland as are provided by separate Earth stations at each facility. Therefore, under the shared Earth station alternative, the circuits used for the space segment and the circuits used for the ground segment of NASA Lewis CPS traffc must be transferred from NASA Lewis to the Federal Building of Cleveland.

A. Comparison between Two Terrestrial Digital Links Connecting NASA Lewis and the Federal Building of Cleveland

Both a one-hop digital microwave link and a digital coaxial cable link were considered as candidates for linking NASA Lewis with a shared Earth station at the Federal Building of Cleveland. Components and costs for the digital microwave link are from a CPS proposal by a contractor. The microwave link operates at 2 GHz and carries up to four duplex 1.544 Mbps T1 channels on a single rf channel. Annual costs are $148,314.

A digital T1 carrier coaxial cable can be leased from Ohio Bell for a one-time installation charge of $994 and an annual recurring charge of $28,560. Each T1 carrier cable has a capacity of 1544 kbps duplex and is capable of carrying both data and digitized voice. For a 10-year life, the total annual cost is $28,708.

B. Costs for Two Separate Earth Stations and a Shared Earth Station

The TDMA Earth station at NASA Lewis has the following digital transmission capacity:

Data: (1 D2-3088 CAU) × (3088 kbps per duplex CAU) = 3088 kbps duplex

Voice: (34 A2 CAU's) × (32 kbps per duplex CAU) = 1088 kbps duplex

Total: 4176 kbps duplex

Three digital T1 carrier coaxial cables at 1544 kbps duplex per carrier cable can be used to link NASA Lewis with a TDMA Earth station at the Federal Building of Cleveland at an annual cost of 3($28,708) = $86,124. For a shared TDMA Earth station the digital coaxial cable link is cheaper than the microwave link. A comparison of annual costs for a shared TDMA Earth station at the Federal Building of Cleveland and separate TDMA Earth stations at NASA Lewis and at the Federal Building of Cleveland is given in Table 6. The two separate TDMA Earth stations cost $3,751,420, slightly higher than the cost of $3,621,205 for a shared Earth station.

Table 6 Annual costs for a shared TDMA Earth station and two separate TDMA Earth stations

Shared TDMA Earth Station at the Federal Building of Cleveland	
Add: Lewis Earth station (transferred to Federal Building)	$1,469,985
Delete: Lewis NAC	(216,063)
Add: 3 digital coaxial cable T1 carriers	86,124
Add: Federal Building Earth station	2,281,160
TOTAL	$3,621,206
Two Separate TDMA Earth Stations	
Lewis	$1,469,985
Federal Building	2,281,435
TOTAL	$3,751,420

VII. Conclusion

The grade of service concept has been applied to calculate Earth station data transmission capacity and voice transmission capacity. At present, FDMA Earth stations cost less than TDMA Earth stations. In an anticipated 30/20 GHz CPS network, TDMA accessing is expected to be more cost effective than FDMA. A digital coaxial cable link consisting of T1 carriers is cheaper than a one-hop microwave link for connecting NASA Lewis with a shared Earth station at the Federal Building of Cleveland. A shared TDMA Earth station is slightly cheaper than two separate Earth stations.

Acknowledgment

The author is grateful to the following individuals in the Advanced Communications Technology Satellite program, NASA Lewis Research Center, Cleveland, Ohio, for helpful discussions: William Poley, Jack Salzman, Grady Stevens, James Hollansworth, and Ronald Schertler. He thanks Grady Stevens, James Hollansworth, and Ronald Schertler for providing updated cost data. He is grateful to the people at NASA Lewis and the Federal Building of Cleveland who provided data for his telecommunications traffic survey.

References

[1]Martin, J., *Communications Satellite Systems*, Prentice-Hall, Englewood Cliffs, NJ, 1987.

[2]*30/20 GHz Fixed Communications Systems Service Demand Assessment*, Vol. 2, U.S. Telephone and Telegraph, ITT, NASA Contract NAS3-21366, CR 159620, Aug. 1979.

[3]"Communications Network Service," Satellite Business Systems, McLean, VA, Tariff FCC 2, Effective Oct. 1983.

[4]Center for Communications Management, Inc., Sec. 11–31, McGraw-Hill, New York, Aug. 1984.

[5]Martin, J., *Systems Analysis for Data Transmission*, Prentice-Hall, Englewood Cliffs, NJ, 1972.

[6]Stevens, Grady, *A Comparison of Frequency Domain Multiple Access (FDMA) and Time Domain Multiple Access (TDMA) Approaches to Satellite Service for Low Data Rate Earth Stations,* NASA Lewis Research Center, Cleveland, OH, NASA TM 83430, June 1983.

[7]*30/20 GHz Ground Terminal Design Study*, Ford Aerospace & Communications Corp., Palo Alto, CA, NASA Contract NAS3-23340, Document 3-7-F-5-F, Oct. 1983.

[8]*30/20 GHz Low Data Rate Ground Terminal Design Study*, TRW Electronic Systems Group, Redondo Beach, CA, NASA Contract NAS3-23341, Document 3-6-T-9-F2, June 1983.