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Demand-Assigned TDMA System for a Digitally Integrated Services Network

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The demand-assigned time division multiple access (DA-TDMA) system has remarkable advantages with regard to effective utilization of satellite traffic channels and network flexibility. The DA-TDMA system is one of key technological developments for application to integrated services satellite digital networks (ISSDN) which transmit digitally integrated information signals between Earth stations. The experimental DA-TDMA system designed for an ISSDN experiment has a 20 Mbps bit rate and operates in a fully variable demand-assignment mode. The ISSDN experiment using the Japanese 30/20 GHz band "CS" satellite, which is planned as the first stage of ISSDN study in Japan, is scheduled to start in 1980. This paper describes the outline of the DA-TDMA system and the ISSDN experimental plan.

Introduction

IN 1973 development was started in Japan on a medium-capacity domestic satellite communications system which uses mainly 30/20 GHz bands. To date two types of preassigned time division multiple access (TDMA) systems, a 64 Mbps system for 30/20 GHz bands and a 107 Mbps system for 6/4 GHz bands, have been developed.[1] These systems have been successfully demonstrated using the "CS" satellite.[2]

Moreover, research has also been conducted on a demand-assigned TDMA system (DA-TDMA). The DA-TDMA system is used for an integrated services satellite digital network (ISSDN) experiment using the "CS" satellite. The DA-TDMA system operates in a fully variable demand-assignment mode for various services information signals, such as voice, data, facsimile, and video, with bit rates of 6.4-6300 kbps.

This paper briefly describes the DA-TDMA system and presents an experimental plan using the "CS" satellite. This experiment is planned as the first stage of ISSDN study in Japan. The objective of this experiment is to confirm that various service networks are possible with satellite communications in which various information signals are digitalized and integrated for communication between Earth stations.

Integrated Services Digital Network via Satellite Communication

In recent years remarkable advances in satellite communications have expanded the service areas of regional and domestic satellite communications systems as well as international systems. As the main satellite communications techniques which have promoted this extension of service areas, the following technological developments can be considered: digital satellite communications techniques such as TDMA; development of communications satellites with higher EIRP (effective isotropic radiated power) and G/T (gain-to-noise temperature ratio); and techniques for new frequency exploitation in frequency bands over 10 GHz.

By using TDMA systems and small Earth stations, high-quality and high-speed digital communications networks have become possible. Furthermore, developments in frequency bands over 10 GHz make it possible to locate these small Earth stations near terrestrial traffic centers. Therefore, high-quality and wide-band signal transmission networks between subscribers are possible via satellite communication.

Recently, there has been a trend toward integrating services networks with digital transmission lines and time-division switching systems in the terrestrial networks. One disadvantage of satellite networks in comparison with these terrestrial integrated services digital networks (ISDN) is propagation delay. On the other hand, satellite networks have the following advantages: quick construction of networks, wide-band signal transmission between subscribers, multiaddress broadcast mode communication, and mesh-type switching networks. In these situations, satellite communications networks which offer integrated services by digital communications systems are called integrated services satellite digital networks in this paper. This viewpoint is very important in satellite communications system research for the purpose of expanding satellite services in the future.

Outline of the DA-TDMA System

The major features of the DA-TDMA system are: fully variable demand assignment; a central network control system; rate-1/2 convolutional encoding and Viterbi decoding with soft decision and coherent phase-shift keying (CPSK), i.e., coherent detection; open-loop initial acquisition; and synchronous interface between customer terminals and DA-TDMA equipment.

Table 1 shows the major features of the DA-TDMA system.

Frame and Burst Structure

Figure 1 shows the frame and burst structure of the DA-TDMA system. Primary frames with a time interval of 2 ms have one synchronization burst and 39 data bursts. The time positions of these bursts are fixed in the primary frame. The first superframe is composed of 40 primary frames. Synchronization bursts in the first superframe, which is arranged at the top of each primary frame, are respectively transmitted from different small Earth stations. The reference station assigned to the network control station (NCS) transmits five synchronization bursts in the first superframe once every eight frames. Therefore, maximum number of Earth stations that can participate in this system is 35 with one network control station.

The second superframe (which consists of the two first superframes) becomes the time interval of traffic channel assignment. When alloting the number of data bursts in

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Table 1 Major features of the experimental DA-TDMA system

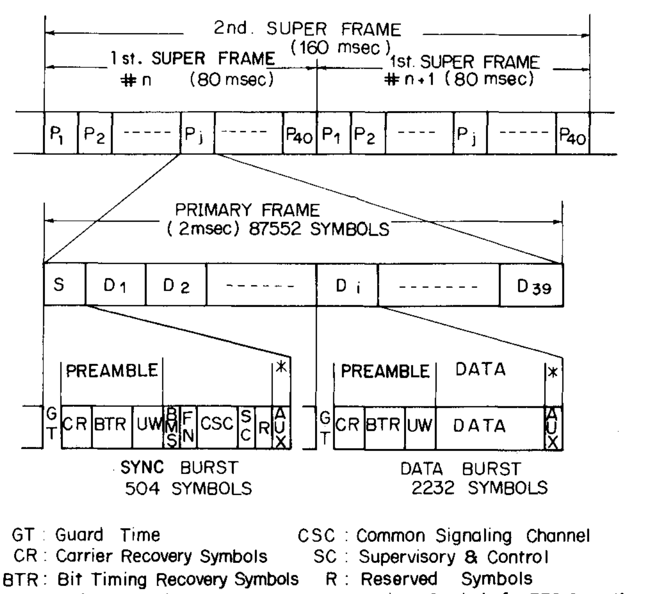
System	
Satellite	Japanese "CS"
Frequency band	30/20 GHz
Bit rate	19.968 Mbps
Clock rate	43.776 MHz
Number of stations	Network control stations: 1 Small Earth stations: 35
Network control	Central control system
CTTE & MODEM subsystem	
Modulation	Two-phase PSK,[a] coherent detection
Burst synchronization	Transmit timing storage counter method
Initial acquisition	Open-loop prediction method
Forward error correction	Rate-1/2 convolutional encoding, Viterbi decoding with three-bit soft quantization
DAMA subsystem	
Traffic channel assignment	Fully variable demand assignment (preassignment available)
Signaling	
Signaling	Common signaling channel control

[a] PSK = phase shift keying.

identical time slots of the primary frame within the second superframe to an information signal, it is possible to assign a traffic channel to the information signal on a single channel per burst basis according to the bit rate of the signal.

In this manner, the DA-TDMA system operates in a fully variable demand-assignment mode on a per-call basis. Each call from the customer terminals is assigned to a traffic channel from the "pool" of the satellite capacity by the allotment of data bursts in the second superframe according to their bit rates. This assignment is maintained for the duration of communication between customer terminals and is released to the "pool" when the call is completed. Table 2 shows the bit rates of information signals that can be assigned in the second superframe.

The third superframe is composed of the four first superframes and has a time interval of 320 ms which covers the round-trip delay time. It is used for the control time interval of burst time position correction.



GT : Guard Time
CR : Carrier Recovery Symbols
BTR : Bit Timing Recovery Symbols
UW : Unique Word
BMS : BER Measurement Symbols
FN : Frame Number
CSC : Common Signaling Channel
SC : Supervisory & Control
R : Reserved Symbols
AUX : Auxiary Symbols for FEC Decoding
DATA : Data Symbols
* : Postamble

Fig. 1 Frame and burst structure.

Table 2 Information signal bit rate

Bit rate, kbps	Number of DATA bursts in second superframe
6.4	1
12.8	2
32	5
64	10
128	20
256	40
512	80
1536	240
6312	1040

Synchronization Burst

The reference and nonreference synchronization bursts are transmitted from the network control station and small Earth stations, respectively. These bursts include a unique word (UW) of 40 symbols. The reference UW represents the fixed position in TDMA systems. Each small Earth station establishes transmitter timing by detecting reference UW and its own nonreference UW.

Preamble and Postamble Words

Preamble and postamble words are arranged at the beginning and end of each burst, respectively. Preamble word includes carrier recovery symbols, bit timing recovery symbols, and an UW. There are 40 all-zero symbols used for carrier recovery. They are also utilized for removing carrier phase ambiguity in order to realize coherent detection of CPSK without differential encoding. A postamble word which comprises 16 symbols is used to complete forward error correction (FEC) decoding within one burst.

Data Burst

Each data burst has 1024 information bits and pre- and postamble words. Information bits are doubled by rate-1/2 FEC coding.

Common Signaling Channel (CSC)

The CSC which is included in each synchronization burst is used as a signaling channel for connection and release of traffic channels. It is transmitted between the NCS and each small Earth station. The bit rate of this channel is 6 kbps from the NCS to the stations and 1.2 kbps in the opposite direction.

The frame utilization efficiency of this frame structure is 91%, as there are 87,552 total symbols and 79,872 data symbols in the primary frame.

Description of the DA-TDMA System

The proposed DA-TDMA system operates in a fully variable demand-assignment mode. This system provides a satellite traffic channel of full-duplex and multiaddress broadcast circuits when requested by customer terminals. The provided traffic channel is created on time slots within a common TDMA frame under the control of the demand-assignment signaling system. Information signals from customer terminals are directly connected to the DA-TDMA equipment in a small Earth station. The NCS controls traffic channel assignments and signaling procedures when assignment requests from small Earth stations are transmitted through a common signaling channel. If a traffic time slot is not available when assignment request is detected, the NCS does not assign a traffic channel and the call is not completed.

This system partially operates in a preassignment mode to meet the requirement for fixed point-to-point or point-to-multipoint communications. In this case traffic channels are assigned to fixed traffic time slots by command inputs at the

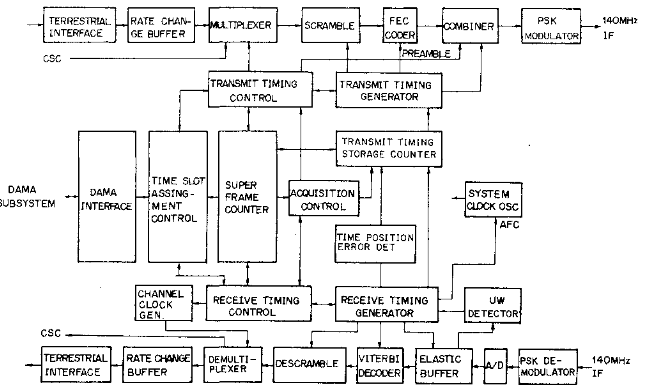


Fig. 2 Block diagram of CTTE & MODEM subsystem.

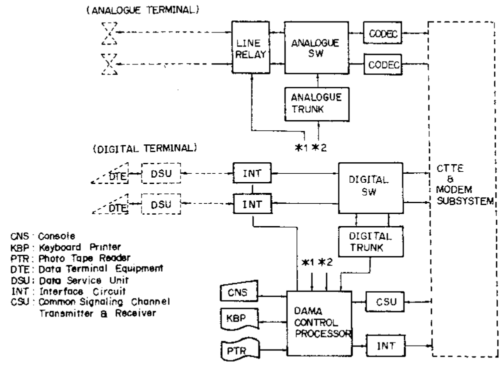


Fig. 3 Block diagram of DAMA subsystem.

NCS, and are maintained until release commands are keyed in the NCS.

Figures 2 and 3 show block diagrams of the DA-TDMA equipment. The equipment is subdivided into common TDMA terminal equipment and modem (CTTE & MODEM) and demand-assignment multiple access (DAMA) subsystems, each having its respective functions. The functions of the CTTE & MODEM subsystem are: CPSK modulation and demodulation, data compression and expansion, multiplexing, FEC coding and decoding, synchronization, preamble word generation and detection, initial acquisition, and data scrambling. Those of the DAMA subsystem are: interface with customer terminals, analog/digital voice-band signal conversion, signaling to/from customer terminals, DAMA assignment control, and initial acquisition control.

Digital voice, data, and video signals of a demand-assignment mode are connected to and processed at a digital trunk interface unit which includes a baseband signal transmission terminating circuit. Analog voice-band signals, such as telephone and voice-band data signals, are processed at an analog trunk interface and converted to digital signals by PCM (pulse code modulation) codecs.

These signals are converted to data bursts by time compression at rate change buffers, and are then connected to a multiplexer. Time slot assignments of data bursts are established by the DAMA control processor at a small Earth station. This assignment control is managed by the DAMA subsystem of the NCS through the common signaling channel via the satellite link.

The multiplexed data bursts are scrambled to disperse transmitting carrier burst energy density and to insure a stable bit timing recovery at the demodulator. They are also convolutionally encoded to provide forward error correction by means of Viterbi decoding at the receiving side.

CPSK-coherent detection is adopted for modulation and demodulation. Soft decision of the demodulator output is provided by a three-bit analog/digital converter. The reference carrier is recovered by reverse modulation of the received PSK signal and by a single-tuned filter and limiter circuit with an automatic frequency control loop. Recovered carrier phase ambiguity is removed at the carrier recovery circuit by detecting the carrier phase of carrier recovery symbols arranged at the top of each burst. By adopting CPSK with soft decision and Viterbi decoding, 4.6 dB of coding gain at a decoded bit error rate of 1×10^{-4} is obtained where the parameters of the Viterbi decoder are K (constraint length) = 7 and rate-1/2.

Frame and burst synchronization are maintained to effect receiving and transmitting frame and burst alignment, respectively. Frame and receive data burst synchronization are achieved by detecting the reference UW of the reference synchronization burst and data UWs of the data bursts. Transmit burst synchronization is realized using the transmit timing storage counter method. In this method, a variable delay which covers range variations due to the movement of the satellite is controlled to correct the burst-transmitting timing by comparing the local synchronization UW receiving time position with a prediction time position.

An open-loop prediction acquisition method is adopted for the initial acquisition. The range of the satellite is predicted by the DAMA subsystem at each small Earth station using range data measured at the NCS. These range data are transmitted through the common signaling channel from the NCS. The NCS monitors the communication states at all small Earth

Table 3 Major characteristics of an experimental small Earth station

Antenna	
Type	Offset Cassegrain
Frequency band	Transmit: 27.45-28.75 GHz Receive: 17.45-18.95 GHz
Size	$4.7 \times 2.9\ m^2$
Gain	Transmit: 58.6 dB Receive: 55.0 dB
Tracking mode	Fixed
High-power amplifier	
Type	Klystron
Output power	1 kW (peak, 30% duty factor)
Bandwidth	80 MHz
Low-noise receiver	
Type	Parametric amplifier
Cooling mode	Uncooled
Noise temperature	200 K
Bandwidth	80 MHz

Table 4 Satellite link parameters

Parameter	Earth station to satellite	Satellite to Earth station
Transmit power, dB·W	30.0	4.4
Transmit antenna gain, dB[a]	58.1	36.3
Transmitter EIRP, dB·W	88.1	40.7
Free space loss, dB[b]	213.2	209.2
Earth station antenna pointing loss, dB	2.2	1.0
Receive antenna gain, dB[a]	34.6	54.5
Receive system temperature, dB/K[c]	37.8	27.1
Receive G/T, dB/K	−3.2	27.4
k, dB·W/Hz/K	−228.6	−228.6
C/N_0, dB·Hz	98.2	86.5
Required C/N_0, dB·Hz	78.8	78.8
Margin, dB	18.6	7.7

[a] Includes feeder loss and satellite antenna pointing loss.
[b] Includes atmospheric loss.
[c] Includes noise temperature increase due to rain attenuation in the satellite to Earth station link.

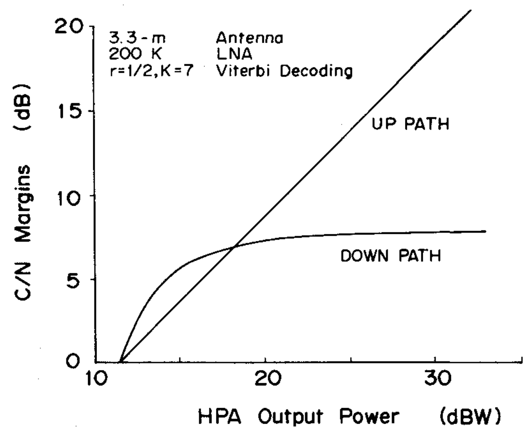


Fig. 4 C/N margins vs HPA output power.

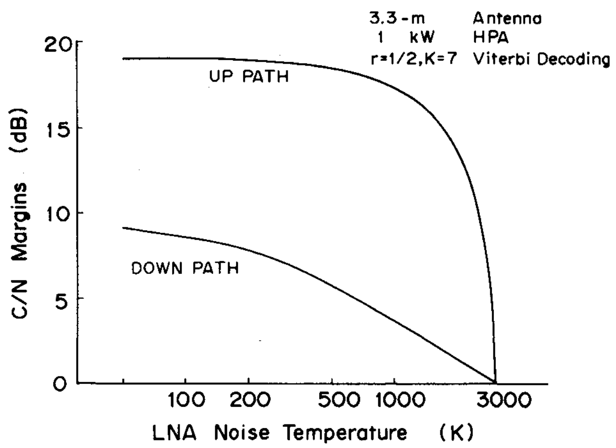


Fig. 5 C/N margins vs LNA noise temperature.

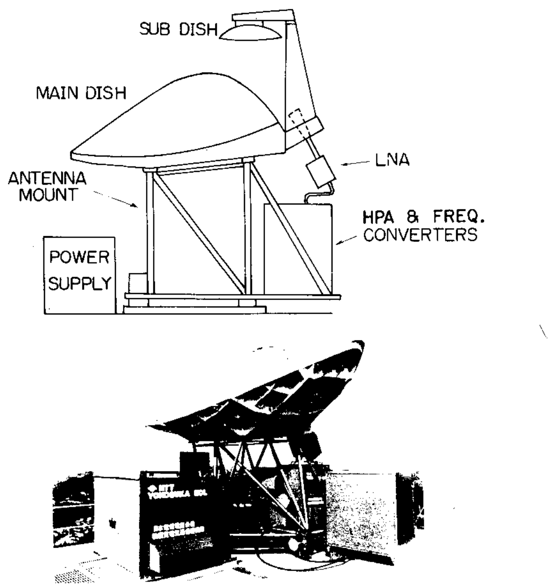


Fig. 6 Configuration and external appearance of small Earth station.

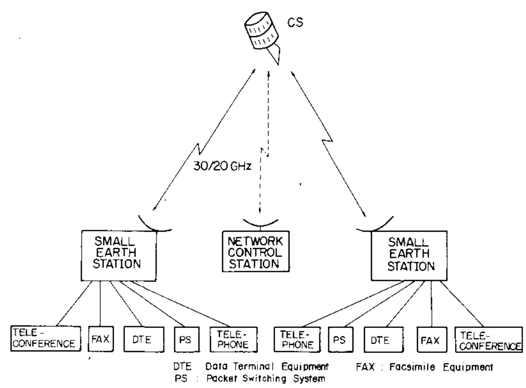


Fig. 7 Configuration of experimental satellite network.

stations by detecting the UW of each synchronization burst. When a loss of UWs is detected, the DAMA subsystem of the NCS assigns one data burst as an initial acquisition time window. The small Earth station performs the initial acquisition at this assigned time slot using the predicted timing.

A highly stable clock oscillator whose frequency is automatically controlled to eliminate frequency differences between the reference and nonreference stations performs the function of system clock timing. Clock timing of the receiving side is recovered from the bit timing recovery symbols of each burst. The recovered clock timing is used to regenerate the symbols of the demodulator output. Because clock timings recovered from individual bursts are noncoherent with one another, retiming of regenerated symbols is accomplished by the system clock timing using an elastic buffer. Variation of burst transmit and receive timing caused by the movement of the satellite are compensated for by providing another kind of elastic buffer which covers the round-trip time variation. Rate change buffers which perform time compression and expansion also perform the function of this elastic buffer.

Clock timing of terrestrial interface is frequency-locked to the channel clock timing which is generated from the system clock timing.

Table 5 Major experimental communication services

Communication services	Terminal equipment	Bit rate, kbps	Mode[a]
Low-speed data communication	Data terminals and computers	6.4 12.8	DA
Voice	Telephone	64	DA
Transport system	Computers	64	DA
Packet switching system	Packet switching system	64	PA
High-speed file access	Computer	256	DA
High-speed facsimile	High-speed facsimile	1536	PA
Video conference			
Moving picture (A)	6.3 Mbps codec	6312	PA
Moving picture (B)	Interframe codec	1536	PA
Still picture	Still picture codec	1536	DA
Voice	Voice codec	256	PA

[a] DA = demand-assignment mode; PA = preassignment mode.

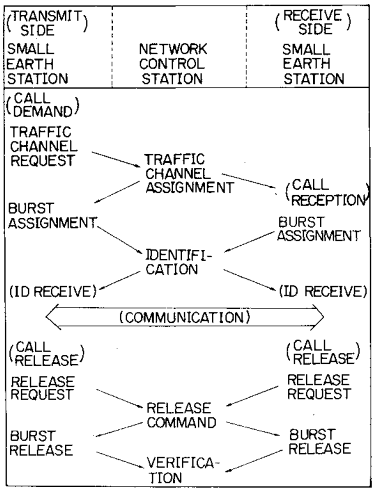


Fig. 8 Digital DA signaling procedure.

Small Earth Station

This experiment uses small Earth stations installed on the roofs of buildings and operated in the 30/20 GHz bands. This arrangement provides direct access of wide-band information signals from customer terminals to small Earth stations without long transmission lines on the ground. Major characteristics of the small Earth stations are shown in Table 3.

This small Earth station has an offset Cassegrain antenna with an equivalent aperture of 3.3 m. This size was chosen by making tradeoffs between off-beam power loss due to the movement of the satellite, high-power amplifier (HPA) output power, and the transportability of the station on the condition that there would be no need for Earth station antenna tracking. Maximum up-link and down-link losses that are caused by nominal satellite station keeping of the "CS" satellite (± 0.1 deg north-south and east-west) are estimated to be 2.2 and 1.0 dB, respectively. A larger antenna aperture would have more off-beam losses and would adversely affect transportability. On the other hand, a smaller antenna aperture would require more output power of the 30 GHz band HPA which is more limited at the present time than the conventional 6 GHz band HPAs.

Table 4 shows the experimental satellite link parameters. Each 30/20 GHz bands transponder of the "CS" satellite has a 200 MHz bandwidth and is automatically gain-controlled against 16 dB input signal power fading due to up-link rainfall attenuation.

Figures 4 and 5 show up-path and down-path C/N (carrier-to-noise power ratio) margins vs HPA output power or low-noise amplifier (LNA) noise temperature. Large HPA output power is required in order to realize sufficient Earth station EIRP. In the case of 1 kW peak power HPA and 200 K noise temperature LNA, an up-link margin of 18.6 dB and a down-link margin of 7.7 dB are estimated at a signal quality of 10^{-4} bit error rate for a 20 Mbps bit rate. From these values and rainfall attenuation statistics in Japan, the link availability is estimated to be 99.5% in the Tokyo region. This estimated value is sufficient for experiments; however, it may have to be improved for future commercial use.

The configuration and external appearance of the small Earth station are shown in Fig. 6. The transmitter and receiver are installed on an antenna mount. Therefore, rotary joints or a beam-guided feed system for connection between the antenna and radio frequency equipments are not necessary. The DA-TDMA equipment can be installed in a 2×4 m shelter. This shelter and small Earth station are easily transferred and installed on the roofs of buildings.

Because this system will operate in the 30/20 GHz bands, it will be feasible to locate the Earth stations in cities. Interfaces to customer terrestrial terminals will be simplified because the small Earth station is easy to install.

Experimental Plan

Figure 7 shows configuration of the experimental network. It has one NCS and two small Earth stations with 30/20 GHz bands. Communications between customer terminals, such as telephones, data terminals, high-speed facsimiles, and packet switching systems, are performed through the two small Earth stations. The NCS, which is a large Earth station with a 11.5 m antenna, operates as a reference station in a TDMA synchronization system and also as the central station of a network control system.

The following communications services are being prepared in conjunction with this ISSDN experiment: low-speed data communication, high-speed data communication, high-speed file access, transport system experiment, high-speed facsimile, voice communication, video conference, and packet switching signal transmission. Table 5 summarizes the major features of these communications services. These services include both demand-assigned and preassigned modes. Supporting signaling procedures for both modes are shown in Table 5 and an example of a digital DA signaling procedure is shown in Fig. 8. In this digital DA signaling procedure, the call setup time between small Earth stations is estimated to be 4 s.

Conclusion

This paper describes the demand-assigned TDMA system which is designed for an integrated services satellite digital network experiment. This DA-TDMA system operates in a fully variable demand-assignment mode for some kinds of services information signals with various bit rates.

The ISSDN experiment uses a 30/20 GHz band satellite network which consists of one network control station and two small Earth stations. The experiment will start using the Japanese "CS" satellite in 1980.

Acknowledgments

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