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Space Administration
Office of Management
Scientific and Technical
Information Program

Summary

This report concentrates on a destination-directed, packet-switching architecture for a 30/20-GHz frequency-division multiple-access/time-division-multiplexed (FDMA/TDM) geostationary satellite communications network. Critical subsystems and problem areas are identified and addressed. Efforts have concentrated heavily on the space segment, but the ground segment has been considered concurrently to ensure cost efficiency and realistic operational constraints.

Introduction

In the mid-1980's NASA began the Advanced Communications Technology Satellite (ACTS) Program to develop a 30/20-GHz geostationary communications satellite. The satellite is to be launched in 1993. This satellite will open up the Ka-band frequency for commercial communications, develop multibeam and hopping-beam antennas, and demonstrate onboard processing technology. The ACTS system utilizes time-division-multiple access (TDMA) uplinks and time-division-multiplexed (TDM) downlinks. One drawback of TDMA uplinks is that the Earth terminals are forced to transmit at a much higher data rate than their actual throughput rate. For example, in the ACTS system an Earth terminal wishing to transmit a single voice channel at 64 kbps would have to transmit at a burst rate of 27.5, 110, or 220 Mbps (ref. 1). This, in effect, drives the cost of the Earth terminals up dramatically by requiring either substantially higher power transmitters or larger antennas, both which are major cost drivers in a low-cost Earth terminal. Realizing this, recent emphasis has been placed on driving the cost of the Earth terminals down. One way to accomplish this is to eliminate the need for high-power transmitters on the ground by allowing the user to transmit at a lower data rate by using a frequency-division multiple access (FDMA) uplink architecture. TDM was chosen for the downlink architecture because the high-power amplifier (HPA) can then beoperated at maximum power, thereby increasing the downlink signal strength and enabling the use of very small-aperture terminals, or VSAT's (ref. 2).

Currently, NASA envisions the need for meshed VSAT satellite communications systems for direct distribution of data to experimenters and direct control of space experiments. In the commercial arena NASA envisions a need for low-data-rate, direct-to-the-user communications services for data, voice, fax, and video conferencing. Such a system would enhance current communications services and enable new services. For this type of satellite system to exist, it must be cost competitive with terrestrial systems at the user level while enhancing the existing quality of service. The key to making this system cost competitive is to drive the cost of the Earth terminals down and spread the cost of the satellite among tens of thousands of users. NASA has completed and is continuing to perform a number of studies on such communications systems (refs. 3 to 6).

Meshed VSAT satellite networks can be implemented by using either a circuit-switched architecture, a packet-switched architecture, or a combination of the two. Intuitively, it appears that a circuit-switched network would be far simpler to implement, but a packet switch has many potential advantages over circuit switching. Therefore, NASA Lewis is currently investigating a packet-switched satellite network in order to identify the common subsystems of circuit- and packet-switched networks and to quantify the complexity of a packet- switched network versus a circuit switch. This report is a direct result of those studies. It describes the overall network requirements, the network architecture, the protocols and congestion control, and the individual subsystems of a destination-directed, packet-switched geostationary satellite network for commercial communications.

Network Requirements

In order to begin designing the conceptual satellite architecture, a list of salient requirements has to be created: First, the system has to be economically viable and cost competitive with existing terrestrial telecommunications systems while enhancing existing services and adding new ones. Second, the system must provide voice, data, fax, datagram, teleconferencing, and video communications services. In order to provide these services, the Earth terminals will either transmit fixed-length packets at 64 kbps or transmit continuously at 2.048 Mbps. It is envisioned that at 2.048 Mbps the required service will be trunked continuous-transmission circuits analogous to the present practice of leasing dedicated T1 circuits. Third, the system will be capable of point-to-point, multicast, and broadcast transmission. Multicast capability is a necessity in order to provide teleconferencing and video conferencing services. Broadcast transmission may not be necessary but is desirable. The requirement to communicate to every user in the system simultaneously (broadcast) rather than only a select number of users within the system (multicast) is not readily apparent. Fourth, the satellite has to accommodate destination-directed packets on a packet-by-packet basis. There does not appear to be any advantage to using packets rather than a simple circuit switch through a satellite system unless they are destination directed (i.e., the packet destination is contained in each header). For example, the use of packets to set up a virtual circuit simply adds the complexity of packet synchronization and processing to what is actually a circuit switch. Fifth, the satellite will not drop packets. Because of the long round-trip delay times to geostationary satellites (250 ms), if packets are dropped, the size of the window for requesting a retransmission and the data buffering involved become quite undesirable.

Network Architecture Description

The network consists of meshed VSAT's operating at 30/20 GHz and transmitting through a processing satellite. Transmission is FDMA up and TDM down. There are eight uplink beams and eight downlink hopping beams covering the continental United States. Each downlink beam has eight dwell locations. Associated with each uplink beam is a MCDD capable of demultiplexing and demodulating 1024 64-kbps channels, a packet synchronizer, a decoder, and an MCDD-to-switch formatting buffer. Associated with each downlink is a switch-to-TDMA formatting buffer, an encoder, and a 150-Mbps burst modulator. The $N \times N$ switch performs the spacial switching functions, and the formatting buffers perform the temporal switching functions. The switching, the routing, and the congestion control are the responsibility of the autonomous network controller onboard the satellite (figs. 1 and 2).

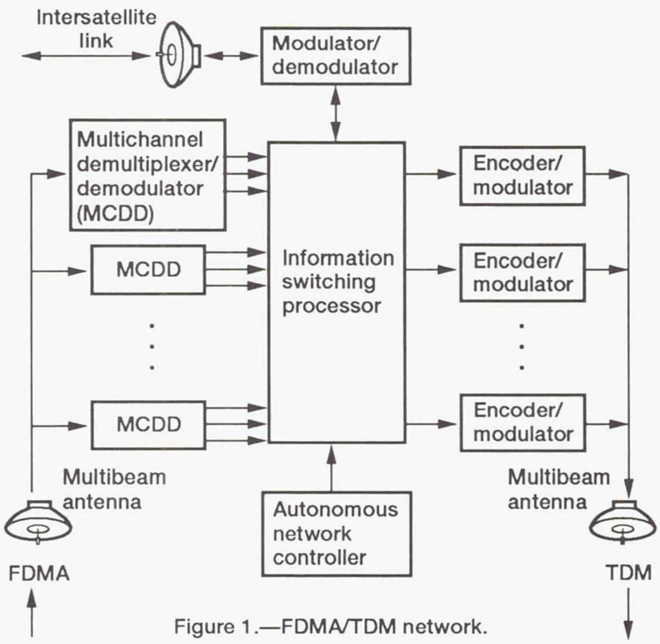

Figure 1.—FDMA/TDM network.

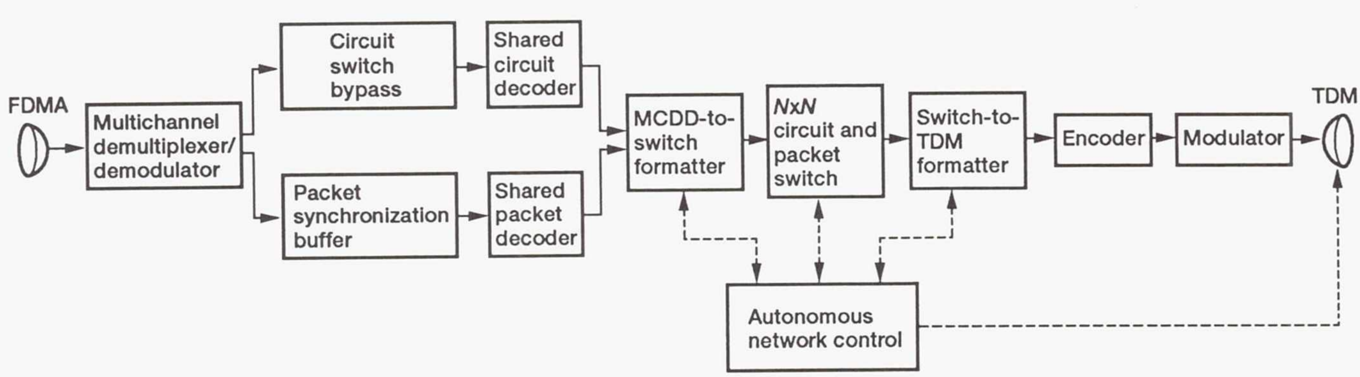

Figure 2.—ISP detailed architecture.

Many of the relative numbers used to establish the network size and data rates are taken from an architecture study performed by TRW. This report includes a complete link budget and hardware analysis in sufficient detail to estimate size, weight, and power requirements for the satellite and the Earth terminals (ref. 7).

Protocols

Initial Access

Initial access into the system would be by a reserved signaling channel. One channel for each multichannel demultiplexer would be reserved for requesting entry into the system. This channel would be set up in a slotted ALOHA format (ref. 8) and accept 64-kbps packets that contain a request for a data transmission rate corresponding to either 64-kbps packet data transmission or 2.048-Mbps circuit transmission. Additional information that may be conveyed during initial access would be related to the type of data being transmitted (voice, video, fax, datagram, etc.) and the effective data throughput rate. This information may be useful to the autonomous network controller in anticipating and correcting for congestion problems. Also, during initial access the Earth terminal will have to specifically request multicast or broadcast services. A request is necessary in order to verify that the downlink capacity can handle the request and to properly bill the user for these services. For broadcasts and multicasts the satellite must be capable of duplicating the received message up to 64 times onboard and of placing that information into the correct downlink beam and dwell.

Upon reception of the initial access request the satellite will respond with a downlink inband orderwire message as to whether the request is granted or denied and a corresponding frequency allocation.

Packet Formats

For 64-kbps packet transmission the Earth terminal will translate incoming data (be it packets, voice, continuous data, etc.) into packets that are specific to the satellite network. The data packets are of fixed length in order to simplify the onboard processing. All flow control, acknowledgments, and buffering are performed at the Earth terminal. Six fields are specific to the packet: synchronization header, destination address, source address, control, information, and parity (fig. 3).

The synchronization field is used to determine the start of the packet. This field is only necessary in an asynchronous packet network where no timing structure is overlaid on the transmitting portion of the Earth terminals. The synchronization header field has to be long enough to reduce the probability of a false detection without being so long as to dramatically increase the packet overhead. Presently, this field is 32 bits long.

The destination address field specifies the downlink destination, which consists of the downlink beam and the dwell location within that beam. Sixteen bits are reserved for this field; they correspond to the 8 downlink beams, 8 dwell locations within each beam, and the 1024 possible Earth terminals.

The source address field specifies the uplink source. Sixteen bits are reserved for this field: 3 specify the uplink beam, 10 specify the uplink frequency corresponding to the transmitting Earth terminal, and 3 specify one of 8 multiplexer input ports where up to 8 active users may share one Earth terminal simultaneously.

A 1-bit control field indicates whether the packet contains useful information or is a dummy packet. Dummy packets are not passed on to the switch but are simply used by the demodulator to maintain lock.

The information field contains communications data that are being passed from Earth terminal to Earth terminal. These can be continuous-transmission data, such as voice, or standard packets that have the satellite network packet structure overlaid. The length of the packet has not been determined at this time. The tradeoff on packet length is between improved packet efficiency and increased onboard storage. The longer the packet, the greater the packet efficiency due to a reduction in the overhead-to-information ratio, but the longer the packet, the greater the onboard storage requirements.

The address, control, and information fields are error correction encoded, and that information is placed in the parity field. The length of the parity field has yet to be determined but is directly related to the length of the information field and the bit error rate (BER) required for the address field. The BER for the address and control fields

Synchronization header	Destination address	Source address	Control	Information	Parity
1 – 32	33 – 48	49 – 64	65	66	
32 Bits	16 Bits	16 Bits	1 Bit	Bits to be determined	Bits to be determined

Figure 3.—Packet format.

should be at least two orders of magnitude higher than the overall network BER of 10^{-7} in order to guard against misrouted or dropped packets. Thus, an overall BER performance of approximately 10^{-9} is required for the address and control fields. The information field will receive this link quality by default.

The idea of increasing the data content in the address and control fields and using two-for-three majority voting to guarantee 10^{-9} BER performance in those fields was contemplated, discarded, and replaced with the concept of using added parity. This was done to reduce the complexity of the onboard processing. It is assumed that the information data field will have to be encoded in order to maintain an overall end-to-end BER performance of 10^{-7} regardless of how the address and control fields are treated. Therefore, it appears to be more efficient to combine the address, control, and information fields before encoding on the ground. Although a formal analysis has not been done, it appears that fewer parity bits are required to encode all three fields than to triple the address and control fields for use in majority voting and still require parity bits for encoding the information field—albeit not as heavily as the combined encoding requires. In addition, when the combined address, control, and information fields are heavily encoded, no two-for-three majority voting circuits need to be implemented.

TDM Frame Structure

The TDM frame structure has yet to be defined in detail. The TDM frame will be between 1 and 32 ms long. The frame efficiency increases with frame length, but a longer frame requires greater onboard storage capability. Also, the packet length will directly affect the frame length. Because the downlink location capacity is limited by the packet size and the dwell time, if the packet is large, the dwell time and the frame length must also be large in order to handle a reasonable number of packets per downlink dwell location. In addition, if the dwell time and the frame length are made as large as possible, the hopping-beam antenna system will not be required to switch as often, and system efficiency will be improved.

A superframe structure will be placed over the TDM frame structure. Various orderwire messages will be reserved for particular frames within a superframe.

Downlink Orderwire Message Format

Orderwires will be used to convey satellite switch status, system timing information, initial access granted and denied messages, etcetera. The downlink orderwire message will be the first message of each dwell.

Contention and Congestion Control

In a destination-directed, packet-switched satellite network, contention and congestion control are major concerns. Contention problems appear in the $N \times N$ beam-to-beam switch. The beam-to-beam switch along with the MCDD-to-switch buffer must be designed so that contention is avoided within this portion of the switching system (i.e., two or more inputs may not attempt to route to the same output at the same time).

Congestion occurs when more information is destined for a specific downlink or dwell than is available. This situation occurs because the data packets are self-routing and the routing information is not available until the packet arrives at the satellite. Because of the long propagation delay from the satellite to Earth (125 ms), “handshaking” and requests for retransmission are impractical. In addition, because there is limited storage capability on the spacecraft, buffering numerous packets for thousands of users is also impractical. Therefore, a users congestion control method has to be developed that is specific to this destination-directed, packet-switched satellite system.

Presently, two methods have been identified to deal with this problem. The first method simply denies access into the network after an analysis of the current state of the switching system and a statistical prediction of the additional capacity that would be required by the new user. In this scenario, during initial access the user would inform the network control of the message destination and the anticipated mean, mode, and peak data throughput requirements and would request point-to-point, multicast, or broadcast service. The network control would then take this information and determine whether or not there was enough capacity available to support the request. According to this method, the packets would be destination directed, but each packet would have to be sent to the same destination. Whenever the destination changes, a new request for access must be performed. This congestion control method has two major drawbacks: It would be extremely computation intensive to keep track of the statistical nature of each user’s data, and the method precludes multiplexing users at the Earth terminal.

A second method relies on distributive flow control at the Earth terminals. In this scenario the network control will continually monitor the downlink burst buffers to determine the current capacity of each downlink and dwell location. The network control will periodically transmit information regarding the current state of the downlink buffers to the Earth terminals. This information will indicate the relative capacity of each downlink and dwell. For instance, downlink beam 1, dwell location 3, may be at 70 percent capacity while downlink beam 7, dwell location 6, is at 90 percent capacity. The network control will set a capacity threshold at perhaps 85 percent. Once that threshold is exceeded, no new transmissions are permitted to that downlink and dwell location. Communications that were already in progress to downlink beam 7, dwell location 6, are allowed to continue, but no new transmissions may be sent to this location until the capacity falls below 85 percent. Meanwhile, any user may transmit to downlink beam 1, dwell location 3, because its capacity is already under the 85-percent threshold. It is up to the Earth terminals to institute the flow control. The threshold is set by the network control in order to allow the Earth terminals adequate time to institute flow control before a congestion problem occurs in the downlink burst buffer. One advantage that this method has over the previous one is that only the downlink burst buffers need to be monitored in order to determine the state of the switch rather than compiling statistics for every user in the system. A second advantage is that this method allows individual packets to be routed to different destinations, and thus multiplexing of users can be done at the Earth terminal. One potential disadvantage may be that the threshold would have to be set to such a conservative number that the satellite capacity may be severely underutilized.

Network Hardware

Earth Terminals

The Earth terminal is composed of indoor and outdoor units (fig. 4). The indoor unit consists of a terrestrial interface, a protocol converter, a packet formatter, a continuous modulator, a burst demodulator, a decoder, a message assembler, an orderwire processor, and timing and control circuity.

The Earth terminals will interface to the terrestrial telecommunications network at the DS–0 rate (64 kbps); the integrated services digital network (ISDN) basic service rate, 2B+D (144 kbps); and T1 rates (1.544 or 2.048 Mbps). In addition, the Earth terminal will be capable of interfacing to commercial communications equipment and will be compatible with commercial standards.

The protocol converter provides an interface between the commercial communications packet-switching standards and the internal packet-switching protocol. All "handshaking," acknowledgments, and flow control with the terrestrial networks will occur here.

The packet formatter breaks or appends commercial packets into packets of constant length. The source and destination address and the control fields are appended to the fixed-length packets, and this total package is encoded. At this point the synchronization bits are appended to the front of the packet, and the information is passed on to the modulator.

The modulator and demodulator are two completely separate units. Presently, it is envisioned that the uplink modulator will produce an offset quaternary-phase-shift-keying (QPSK) signal and transmit continuously at either 64 kbps or 2.048 Mbps. Filtered offset QPSK is used on the uplink in order to obtain a bandwidth efficiency of approximately 1.45 to 1.6 bps/Hz. A burst demodulator is required on the downlink. The modulation format has yet to be determined, but the data rates will be in the range 150 to 180 Mbps.

The message assembler reads the demodulated data, strips off the source address fields, and reassembles the orderwire messages and any messages destined for that Earth terminal. The reassembled messages are then passed on to either the orderwire processor or the protocol converter for entry into the terrestrial communications network.

Because this communications network utilizes time-division multiplexing on the downlink with bursted data transmission in the 150-Mbps region, the timing and control of the communication are critical. The timing and control

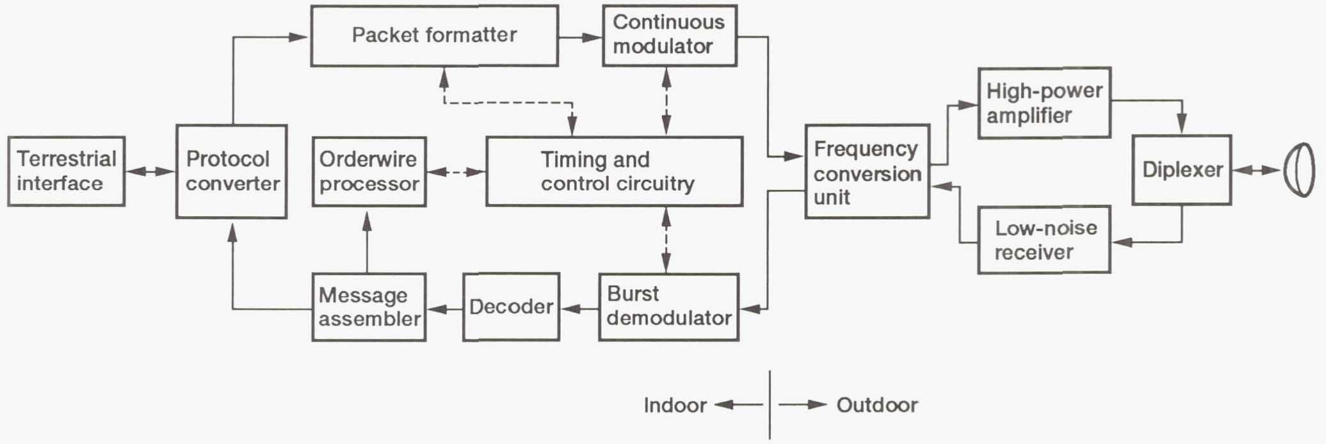

Figure 4.—Earth terminal.

system (T&CS) is responsible for obtaining and maintaining synchronization with the satellite. The T&CS informs the burst demodulator of the approximate time of burst arrival and receives a signal indicating actual burst arrival times. The T&CS uses the information obtained from the demodulator to adjust the Earth terminal receiver-side timing in order to synchronize the Earth terminal to the network. The T&CS also receives network control information from the orderwire processor and uses this information to determine what type of information is entered into the control fields of the transmitted packets. In addition, the T&CS will turn off the transmitter and the modulator during periods when the Earth terminal has relinquished access to the satellite uplink channel.

The outdoor unit contains the radiofrequency (RF) equipment, which consists of a frequency conversion unit, a high-power amplifier, a diplexer, an antenna system, and a low-noise-receiver (LNR). The HPA is required to produce approximately 2 W of transmitted power. The required noise figure for the LNR is approximately 2.6 dB. The outdoor unit accounts for the majority of the Earth terminal cost.

Multichannel Demultiplexers/Demodulators

Onboard demultiplexing and demodulation of narrowband traffic will be provided by multichannel demultiplexers/demodulators. In general, the MCDD can be viewed as a multifrequency channelizer and a demodulator system. The channelizer operates relatively independent of the modulation scheme although some channelizer optimization may be performed if the modulation format has been identified early on. The demodulator system is either a time-shared demodulator, a bank of individual demodulators, or a combination of the two.

The MCDD has been identified as a critical subsystem that must be developed for an FDMA/TDM architecture. Acousto-optical, optical, and digital signal-processing technologies have all been identified as candidates for implementing an MCDD. NASA is investigating each of these approaches through contracts, grants, and in-house activity.

Amerasia Technology Incorporated is in the second phase of a Small Business Innovative Research contract (NAS3–25862) to develop a proof-of-concept (POC) multichannel demultiplexer (MCD). The MCD uses a convolve-multiply-convolve technique to perform the demultiplexing function. It is implemented by using a surface acoustic wave (SAW) herringbone-shaped reflective array compressor with hyperbolically shaped transducers (fig. 5).

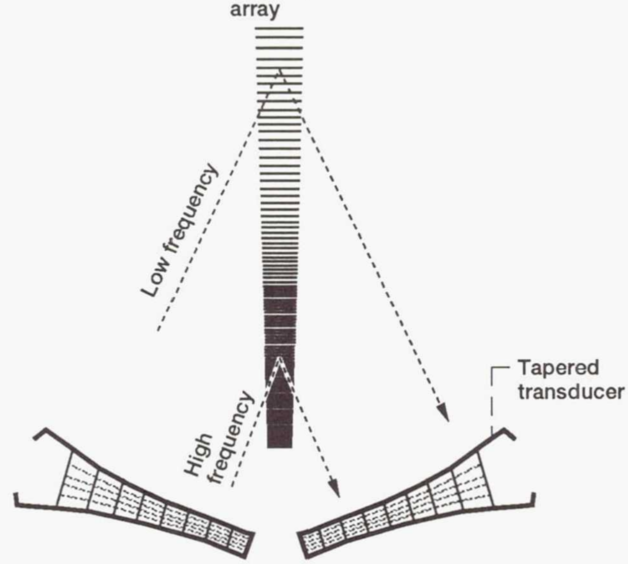

Figure 5.—Hyperbolic reflective array compressor.

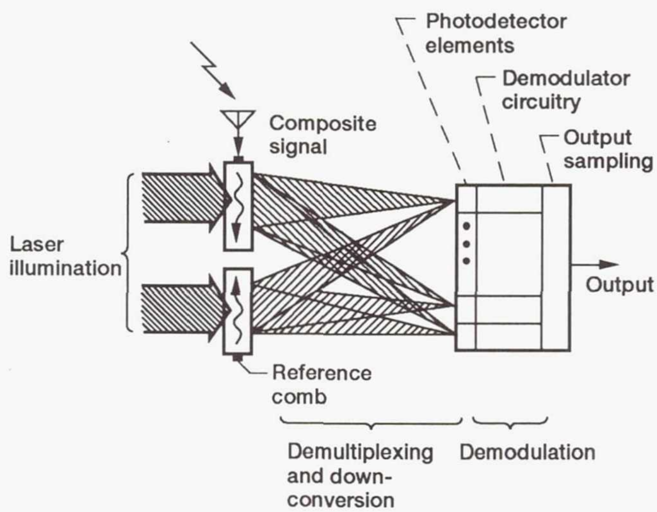

Figure 6.—Optical multichannel demultiplexer/demodulator.

Westinghouse Electric Corporation's Communications Division is under contract to NASA Lewis (NAS3–25865) to develop a POC MCD that demonstrates the capability of demultiplexing 1000 low-data-rate FDMA uplinks. The multichannel demultiplexer is implemented as a coherent acousto-optic RF spectrum analyzer that uses heterodyne detection with a modulated reference (fig. 6). The optical MCD, which is similar to the reflective array compressor SAW implementation, is expected to have lower size, weight, and power requirements than a fully digital MCD and does not require a high-speed analog-to-digital (A/D) converter at the front end. The POC model will have a dynamic range of approximately 80 dB and will be capable of demultiplexing 1000 64-kbps channels at 1.6 bps/Hz. Because most components are passive acousto-optic devices, this implementation of the MCD is highly reliable and radiation hard. Demodulation would be performed either serially, by using a time-shared demodulator, or in parallel, by using an individual demodulator for each channel. One drawback to this implementation, however, is that a separate MCD is required for each separate data rate.

TRW is under contract to NASA Lewis (NAS3–25866) to

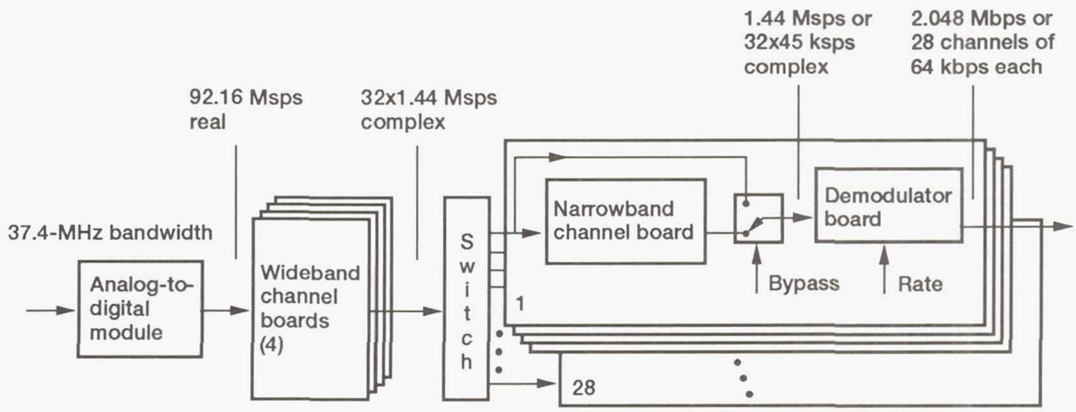

Figure 7.—Digital multichannel demultiplexer/demodulator.

develop a POC MCDD that uses advanced digital technologies. The composite frequency-division-multiplexed (FDM) signal is A/D converted and is channelized into wideband channels of 2.048-MHz bandwidth. The wideband channel is then either further channelized into 32 narrowband 64-kbps channels or passed directly on to the multirate demodulator as a 2.048-MHz channel. The modulation format used is differentially encoded offset QPSK, and the overall bandwidth efficiency of this system is 1.42 bps/Hz. The multirate demodulator can demodulate either one 2.084-MHz channel or thirty-two 64-kbps channels. This demodulator is designed as a continuous demodulator (fig. 7).

The University of Toledo is in the third year of a grant (NAG3–799) to develop a programmable architecture for multicarrier demodulation based on parallel and pipeline digital design techniques for increased throughput. The hardware architecture and designs have been optimized for variable channel rates and variable numbers of channels. A POC model to demonstrate small-scale operation is under development.

Lewis has begun an in-house effort to develop an MCDD that uses commercial digital signal processors. The multichannel demultiplexer will be implemented as a combination of software executing on a general-purpose digital signal processor (DSP) and a state-of-the-art application-specific DSP.

Demodulator

Once the demultiplexing function has been completed, the individual channels have to be demodulated. The present approach is to time share a bank of demodulators, each of which can handle 24 to 32 channels.

The demodulators are presently designed to operate on continuous transmissions. The mode of operation relates well to circuit-switched operations. However, for packet switching the transmission is bursty. Therefore, either the demodulators must be capable of receiving burst transmissions, or the Earth terminals must transmit at regular intervals so that the continuous demodulators do not lose lock. For continuous demodulators the Earth terminals will have to send dummy packets. If the demodulators are capable of receiving burst transmissions, no dummy packets will be required. In addition, a TDM overlay could be placed on the FDMA uplinks whereby any uplink channel could be shared by several Earth terminals.

Packet-Synchronizing Buffer

The packet-synchronizing buffer is responsible for receiving data from the MCDD and assembling and aligning the packets for use by the shared decoder. Assuming that the MCDD uses a time-shared demodulator, the information from the MCDD will be presented to the packet synchronizer in a bit-interleaved TDM format. Each bit in the TDM frame will correspond to a particular uplink frequency channel. The packet synchronizer will buffer each user data stream to a length of $2N-1$, where N is the number of bits in a packet. The packet synchronizer will examine each user data buffer to determine the beginning of a packet and pass the individual packets—minus the synchronization header portion of the packet—on to the shared decoder.

The memory requirements of this subsystem are quite large, $(2N-1)KL$, where, K is the number of channels in each MCDD and L is the number of MCDD's in the system. If packets from individual Earth terminals could be sent to the satellite so that the packets reached the satellite synchronously, the memory requirements could be reduced by approximately 50 percent. Most of this improvement would be due to an additional $N-1$ bits per channel no longer being required in order to be certain a full packet is captured. A second savings would be achieved because synchronization bits would no longer be needed in the packet, and thus the overall packet length would be reduced.

One possible method for synchronizing the uplink channels would be to synchronize them to the Global Positioning

System (GPS). Many commercial GPS receivers are presently available, but the cost per Earth terminal is approximately $500 to $1000. By adding this additional complexity on the ground, the packet-synchronizing buffer could be dramatically simplified.

Shared Decoder

The decoder subsystem decodes each packet on a packet-by-packet basis. Most likely, a bank of decoders will be time shared, particularly if the demodulator is time shared. Both trellis and block decoders have been considered. If a trellis decoder were used, one could either throw away a predetermined amount of bits at the beginning of each packet in order to allow the decoder to initialize, or one could save the previous state of the codec and jam this state into the decoder at the beginning of the next time slot for that particular source channel. For either of these methods trellis decoding appears to be overly complex when the number or independent channels sharing the decoder is considered. If a block decoder were used, the packet length would have to be an integer multiple of the block length. Because we have already determined that the packet will be a fixed length, the block code and the packet length can readily be optimized.

Switching and Routing Elements

The switching and routing circuitry is composed of three major subsystems, the MCDD-to-switch formatter, the 8×8 switch, and the switch-to-TDM formatter. These three subsystems combine to effectively act as a 8192×64 packet switch and a 256×64 circuit switch assuming eight MCDD's with either 1024 64-kbps users or thirty-two 2.048-Mbps users. The MCDD-to-switch and switch-to-TDM formatters perform the temporal routing, and the 8×8 switch performs the spacial routing.

MCDD-to-Switch Formatter

The main function of the MCDD-to-switch formatter is to take parallel messages and convert them into a TDM message stream (fig. 8). It receives decoded packets, examines the destination address, multiplies multicast and broadcast packets, sorts the messages, and stores the messages in a buffer for transmission through the *N*×*N* switch. In effect, the MCDD-to-switch formatter acts as a 1024-to-64 switch, with each message residing in the transmitter buffer so that the messages can be transferred to the switch-to-TDM circuitry in sequential order.

The circuitry for duplicating multicast and broadcast messages must reside in either the MCDD-to-switch or the switch-to-TDM formatter. Because the downlink beam address must be examined in the MCDD-to-switch formatter, it appears advantageous to put the packet duplication function here rather than in the switch-to-TDM formatter. Therefore, the switch-to-TDM formatter will only have to examine the dwell address and the downlink beam address can be discarded.

N×*N* Switch

The *N*×*N* switch consists of two separate switches: the 2.048-Mbps circuit switch and the 64-kbps packet switch.

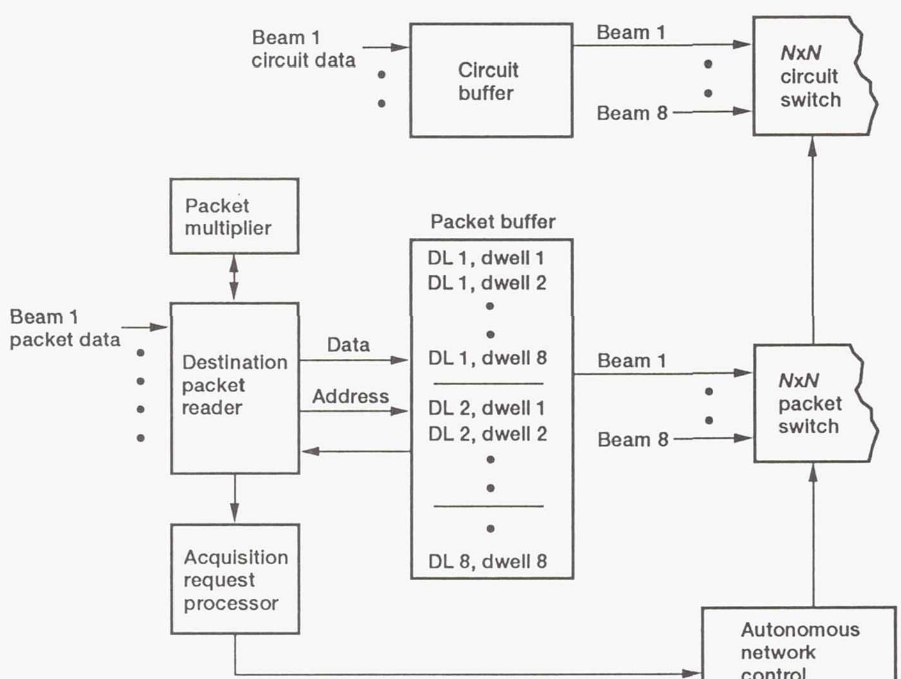

Figure 8.—MCDD-to-switch formatter.

This portion of the overall switching system is responsible for beam-to-beam interconnects. Because this is the sole function of the $N \times N$ switch, both the circuit and packet data can use the same type of switching architecture—although this is not necessary. Regardless, both switches must be capable of handling contention problems relative to the downlink beams. Information from two separate inputs cannot reach the same output port at the same time. This problem must either be addressed within the $N \times N$ switch or be excluded from occurring by the MCDD-to-switch formatter.

Of the overall switching and routing system the $N \times N$ switch may be the most straightforward portion to implement. Numerous studies and papers have been published in this area (refs. 9 to 15). Optical switching and neural networks have also been recently investigated to solve this type of switching problem. One promising implementation is to use a high-speed TDM fiber-optic bus to perform the $N \times N$ switching.

Switch-to-TDM Formatter

The switch-to-TDM formatter must receive data from the eight ports of the spacial circuit switch and the spacial packet switch and write that information into the proper locations of the burst transmitter memory (fig. 9). This must occur without losing any packets or circuits. Therefore, the switch-to-TDM formatter must be capable of resolving contention problems relative to the downlink dwell locations.

The burst transmitter buffer is arranged so that each section corresponds to a particular downlink dwell location for the hopping beams. Time slots must be reserved within each dwell array for orderwires and for each 2.048-Mbps circuit destined for that particular downlink dwell. Additional memory space for each dwell is allocated by the autonomous network controller according to the "near-real-time" traffic demands of the packet network. After filling the appropriate dwell memory locations with circuit data, the switch-to-TDM formatter reads each packet and writes the packet to the corresponding memory location.

Encoder

The encoder is required to provide coding gain on the downlink. This encoder may be either a convolutional encoder or a block encoder capable of operating at 150 to 200 Mbps. A corresponding decoder is required at the Earth terminal. Presently, block decoders that handle these rates are available as commercial products; convolutional decoders are much more difficult to implement. Therefore, the initial assumption is that a block encoder will be used.

Modulator

A burst modulator capable of a bandwidth-efficient modulation scheme is required. A continuous phase modulation format is desired in order to run the satellite's high-power amplifiers at saturation and thus improve the downlink efficiency. NASA Lewis has an ongoing program in modulation and coding directed at such requirements. Two completed contracts have been awarded for 200-Mbps burst modems for satellite-to-ground applications: a 16–CPFSK (continuous phase frequency shift keying) modem and an 8–PSK modem (refs. 16 and 17). Additional

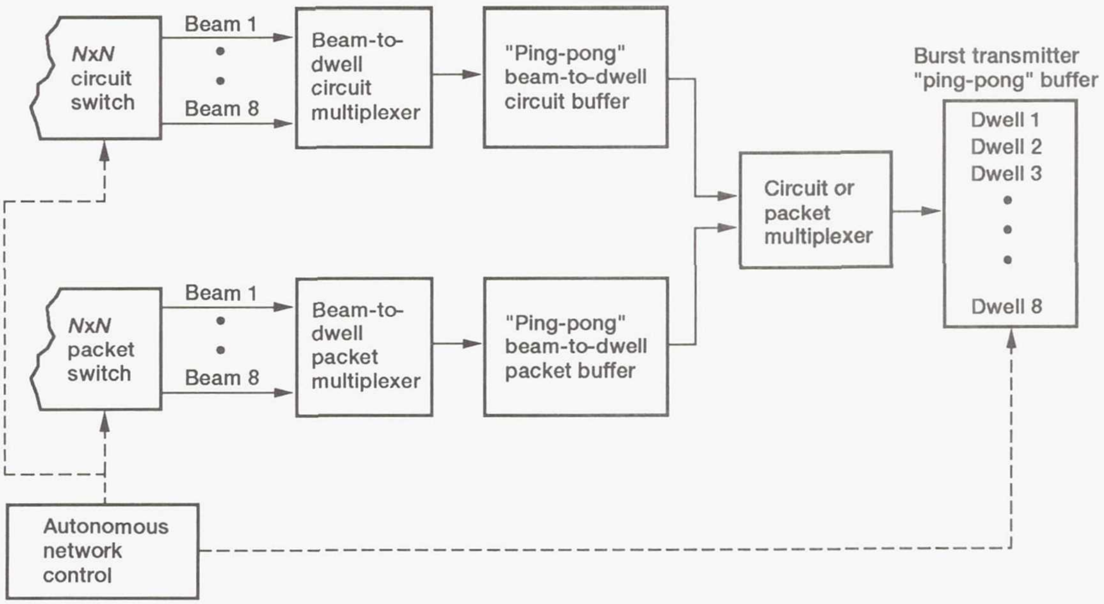

Figure 9.—Switch-to-TDM formatter.

work is being performed by Comsat Laboratories under contract NAS3–319317 for a programmable digital modem capable of binary, QPSK, 8–PSK, and 16–QAM (quadrature amplitude modulation) modulation with up to 300 Mbps of data throughput.

Autonomous Network Controller

Onboard the satellite the autonomous network controller (ANC) is responsible for allocating space and ground resources and for real-time health monitoring and fault recovery of the onboard communications systems. The ANC may not perform all of the required network control functions, but a favorable distribution of these functions will be realized between the onboard ANC and a ground-based network controller. In particular, traffic allocation and routing functions will be placed onboard to shorten call setup and disconnect times. The ANC responds to narrowband user connection requests by allocating an uplink frequency to the requesting terminal. The ANC also allocates downlink time slots for 2.048-Mbps circuit-switched data. The ANC monitors the downlink burst buffer capacity, forwards the burst buffer status to the Earth terminals by downlink orderwires, and varies the length of the downlink dwells to accommodate changing traffic patterns. In addition, the ANC controls the burst transmissions and the hopping-beam antenna system.

Concluding Remarks

From an overall systems view the problem of getting tens of thousands of low-data-rate users to communicate with each other through a processing satellite is of equal complexity whether it is accomplished by using TDMA/TDM, FDMA/TDM, code-division multiple access (CDMA)/TDM, or another type of architecture. FDMA and more recently CDMA techniques have been touted as being superior to TDMA because they require less uplink transmitter power and thus may reduce Earth terminal costs. These techniques, however, mandate that extremely complicated functions be performed onboard. In fact, all the functions from the MCDD to the transmitter buffer of the MCDD-to-switch formatter are necessary to get to a point that looks very similar to a TDMA uplink.

Any onboard processing system requires fault-tolerant implementation. With size, weight, and power at a premium, traditional fault-tolerant methods, such as simple two-for-one redundancy of components and systems or majority voting, will not suffice. NASA Lewis plans to address these issues in all aspects of the information switching processor (ISP) design and is pursuing innovative fault-tolerant approaches that optimize redundancy requirements. Presently, the issue of fault tolerance in the digital multichannel demultiplexer is being addressed through a grant with the University of California, Davis (NAG3–1166).

The present data rates of 64-kbps and 2.048 Mbps were chosen as a starting point and to be compatible with terrestrial ISDN's. It is understood that these data rates may not be optimum. In particular, the uplink transmission rates will most certainly be slightly higher in order to accommodate the increased overhead inherent in a packet-switched network.

Status and Future Directions

NASA plans to develop a POC information-switching processor. The POC model will be constructed at NASA Lewis. In-house-developed POC hardware will be supplemented by advanced fault-tolerant components developed under contracts. The ISP architecture will ultimately be demonstrated in a satellite network simulation by integrating the ISP with high-speed codecs, programmable digital modems, and MCDD's currently being developed under industry contracts and university grants (ref. 18) and with compatible Earth terminals and onboard and ground-based network control.

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13. ABSTRACT *(Maximum 200 words)*
This report concentrates on a destination-directed packet-switching architecture for a 30/20-GHz frequency-division multiple-access/time-division-multiplexed (FDMA/TDM) geostationary satellite communications network. Critical subsystems and problem areas are identified and addressed. Efforts have concentrated heavily on the space segment; however, the ground segment has been considered concurrently to ensure cost efficiency and realistic operational constraints.

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