ESD-TR-83-225

(12)

Semiannual Technical Summary

AD A139924

Wideband Integrated Voice/Data Technology

30 September 1983

Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LEXINGTON, MASSACHUSETTS

Prepared for the Defense Advanced Research Projects Agency
under Electronic Systems Division Contract F19628-80-C-0002.

The work reported in this document was performed at Lincoln Laboratory, a center for research operated by Massachusetts Institute of Technology. This work was sponsored by the Defense Advanced Research Projects Agency under Air Force Contract F19628-80-C-0002 (ARPA Order 3673).

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

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WIDEBAND INTEGRATED VOICE/DATA TECHNOLOGY

SEMIANNUAL TECHNICAL SUMMARY REPORT
TO THE
DEFENSE ADVANCED RESEARCH PROJECTS AGENCY

1 APRIL 1983 — 30 SEPTEMBER 1983

ISSUED 15 FEBRUARY 1984

LEXINGTON MASSACHUSETTS

ABSTRACT

This report describes work performed on the Wideband Integrated Voice/Data Technology Program sponsored by the Information Processing Techniques Office of the Defense Advanced Research Projects Agency during the period 1 April through 30 September 1983.

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INTRODUCTION AND SUMMARY

An important challenge in the design of future military communications networks is to achieve system economy and adaptability through efficient and flexible allocation of common network resources to voice and data users. The major objective of the Wideband Integrated Voice/Data Technology Program is to address this challenge through the development of techniques for integrated voice and data communications in digital packet networks which include wideband common user satellite links. A major focus of activity in the program has been the establishment of an experimental wideband packet satellite network for realistic testing of a variety of strategies for efficient multiplexing of voice and data users. The program also serves as a focus for the development and testing of techniques for local area packet voice distribution, for speech traffic concentration, and for efficient real-time voice communication in an internetwork environment including local networks of various types connected through a wideband demand-assigned satellite network.

This report covers work in the following areas: development and technology transfer of a generalized compact LPC vocoder, development and experimental application of Packet Voice Terminals (PVTs) and internet stream gateways for packet voice and data experiments, and coordination and execution of multi-user internetwork packet speech experiments using the experimental wideband satellite network (WB SATNET).

Lincoln prototypes of the generalized LPC (Linear Predictive Coding) Speech Processing Peripheral (SPP) have been installed and successfully tested at Carnegie-Mellon University (CMU) and Information Sciences Institute (ISI). Lincoln is executing a two-phase procurement for production and replication of the SPP, with Adams-Russell (AR) Company as the selected contractor. The AR prototype phase currently in progress will be followed by a production phase scheduled for completion in the fourth quarter of FY 84.

PVT hardware and software have remained a stable experimental facility during this period. A bubble memory has been added to one PVT on a test basis, to provide capability for loading of alternate programs without connection to a host computer. A Technical Report on "Protocol Software for a Packet Voice Terminal" has been completed.

The miniconcentrator gateways have continued to operate reliably. A number of evolutionary extensions have been added to support system experiments. These include: stream (ST) packet replication, capabilities to transmit Internet Protocol (IP) packets in streams, support of the CAP8 packet radio net protocol, and IP fragmentation. Gateway capabilities to monitor WB SATNET operations have also been extended and utilized.

Lincoln has coordinated a Task Force effort focused on achieving regular WB SATNET operation at 3 Mbps. Two-site operation at 3-Mbps operation has been achieved, and the Task Force is currently working on extending this capability to multiple sites [including the three new WB SATNET (Wideband Satellite Network) sites at RADC, Fort Monmouth, and Fort Huachuca] on a regular basis.

A successful internet speech exercise including a variety of point-to-point and conference calls has been conducted involving participants at SRI (SRI International), Lincoln, and the Norwegian Telecommunications Authority (NTA). Six networks were involved. Long-haul transport was provided by WB SATNET, ARPANET, and the Atlantic SATNET. Local nets were a LEXNET (Lincoln Experimental Packet Voice Network) (Lincoln), a PRNET (Packet Radio Network) (SRI), and a ring network (NTA).

A number of successful host-level voice tests using the PVTs and gateways have been conducted at the 3-Mbps channel rate established by the Task Force, including a test involving eight PCM (Pulse Code Modulation) talkers on three local nets. A four-participant conference was established over WB SATNET using a combination of the voice-controlled operator with the capability to dial to a new participant during an ongoing conference.

WIDEBAND INTEGRATED VOICE/DATA TECHNOLOGY

I. COMPACT STAND-ALONE VOCODER DEVELOPMENT

A. FIELD INSTALLATIONS AND TESTING

Two prototypes of the Speech Processing Peripheral (SPP) have been installed at remote sites, one at ISI and the other at Carnegie-Mellon University (CMU). Troubleshooting of the installation at CMU was successfully conducted via consultation over the telephone. A problem in the Z80 interface between the PERQ workstation at CMU and the SPP was discovered and corrected. At Lincoln a third SPP is being used in the voice-controlled operator experiments, and a fourth is providing LPC (Linear Predictive Coding) parameters to aid in the experimental emulation of a Dynamic Time Warping (DTW) wafer for connected word recognition. The DTW wafer is being developed in the DARPA-sponsored Restructurable VLSI Program.

A set of diagnostics has been implemented which will be incorporated in the 8085 program to test the production SPP hardware. Upon power-up, the 8085 interface will run in a user selectable slow or fast test mode. Normal operation will be initiated after the tests are successfully completed. Light-emitting diodes (LEDs) will be provided to indicate the nature of any failure encountered while in test mode.

B. TECHNOLOGY TRANSFER

Lincoln Laboratory is executing a two-phase procurement for production and replication of the Speech Processing Peripheral. The goal of phase 1 is for Lincoln to transfer the SPP technology to an appropriate commercial firm who in turn will redesign and repackage the Lincoln Laboratory prototype in a manner resulting in increased economy, reliability and producibility. Phase 1 deliverable items include one functional and qualified preproduction SPP prototype and a master technical documentation package. The second phase of the procurement is to replicate the prototype of phase 1 in quantities of 50 to 100 units. Both phases of the procurement have been awarded to Adams-Russell (AR) Company of Waltham, Massachusetts (see below). Adams-Russell is currently three months into the six-month phase 1 contract. Phase 2 is a six-month contract beginning at the completion of phase 1.

The previously reported RFI (Request for Information) package detailing specifications for the procurement was distributed in March to 23 prospective bidders. Four responses were received, one of which was effectively a no bid. Of the three remaining, only one was judged technically qualified to perform the replication task. That vendor, Adams-Russell Company of Waltham, Massachusetts, was awarded phase 1 of the procurement. Adams-Russell is presently three months into a six-month prototyping phase at the end of which (approximately February 1984), the redesigned SPP prototype will be completed. Currently, the detailed SPP electrical redesign is nearly completed by AR. Although detailed mechanical drawings have not yet been produced, the critical issues of the design (cost, heat dissipation, power supply, chassis, etc.) have been solved. An intermediate design review took place in September at Lincoln Laboratory where the AR SPP Project Manager and design engineers presented a detailed review on the current design status.

The key features of the prototype as described at that design review are summarized below: The AR SPP will be housed in a standard telephone industry type call-director unit (approximately 7 × 8 × 4 inches). An external cradle on the left holds the standard telephone handset. A jack is included on the front for the use of a boom-mounted, noise-cancelling microphone/earphone set for high-quality input. A speaker output jack is available at the rear to drive a small 4- or 8-ohm speaker. The top of the unit will contain the LEDs displaying input volume level and system status. A self diagnostic is run at power-up and any failures are indicated on the status LEDs. The rear of the unit includes a standard 25-pin RS-232C connector for the digital interface.

Internally, only one multilayer PC board (ground and power planes, two signal planes) will be used on which are mounted all ICs and LEDs. Four cable harnesses are required for connection of the PC board to the call-director chassis. A small switching power supply is being used and is mounted inside the chassis at the rear. Maximum power dissipation has been estimated at approximately 11 W AC. Actual dissipation should be considerably less.

Originally, phase 2 of the procurement was to be awarded upon satisfactory completion of the phase 1 prototype. Currently, the semiconductor industry is suffering extreme parts shortages resulting in estimated delivery times of ICs of up to 30 weeks. Given the favorable status of the phase 1 effort and our concerns over total time to produce the phase 2 units, it was judged appropriate to proceed with awarding the phase 2 contract to Adams-Russell. The phase 2 contract calls for delivery of 50 units within six months after completion and acceptance of the prototype SPP unit. Lincoln Laboratory will supply the handset microphone cartridges and the preprogrammed NEC μPD7720 microcomputers for each unit.

II. PACKET VOICE TERMINAL AND LEXNET

A. PVT HARDWARE AND SOFTWARE STATUS

In order to provide ISI with the PVT hardware and software upgrades described in the last report, the two PVTs sent to ISI in February 1981 have been exchanged for newer models. This was judged to be the simplest way to incorporate the improvements. The terminals which were returned are being upgraded locally. Other than the bubble memory experiments described below, there have been no changes in PVT hardware during this period.

PVT software has also remained stable during this period. A Technical Report has been published.*

B. BUBBLE MEMORY SYSTEM

1. System Description

A one-megabit bubble memory system has been added to one of the LEXNET PVTs. The purpose of this experiment was to explore another method of storing and loading the Network Voice Protocol (NVP) program for the protocol processor. As new applications of the PVT have been developed, new versions of the protocol processor code have been generated. At least four versions are now in regular use. Two versions are used in the speech applications, one supporting regular PVT operation and one supporting operation with the Switched Telephone Network Interface (STNI). Two other versions are used to support our network measurements efforts.

In our work to date, two different Protocol Processor program loading techniques have been used. The Protocol Processor subsystem in the PVT consists of two cards. One card contains the CPU, data memory, DMA control, various I/O parts and a bootstrap ROM (Read Only Memory) memory. The second card, the memory extension card, contains 32K bytes of program memory. Two versions of this memory card have been developed, each corresponding to a different program loading technique. The first version is a RAM (Random Access Memory) card. In the RAM configuration, the program is downloaded from a host computer (typically a PDP-11) over an RS-232 data line. The downloading requires about two minutes per terminal and also requires the use of a Trap Control Box, an auxiliary debugging system developed to aid in system checkout. Since there are fewer Trap Control Boxes than PVTs, this method usually requires reconnecting the box for each load. The storage is volatile and the program is lost when the PVT is powered off. The second method uses an EPROM version of the memory extension card. The EPROMs are programmed on a separate system and loaded onto the board which is then inserted into the PVT. This provides nonvolatile storage. However, each card holds only one version of a

*C.K. McElwain, "Protocol Software for a Packet Voice Terminal," Technical Report 663, Lincoln Laboratory, M.I.T. (16 November 1983) AD-A136938.

program, and each change to the program requires changing the memory contents of 16 EPROM chips. The entire process of programming the chips and reinserting them in the Protocol Processor board takes about an hour.

The bubble memory experiment is an attempt to combine the best features of these two methods. The bubble memory is used in conjunction with the RAM memory extension card. It is nonvolatile so that no information is lost if power is shut down. At power-up, the bootstrap ROM automatically loads RAM from the bubble memory. Storing a new program in the bubble memory is also convenient and fast. The program is first downloaded to the RAM memory as before. A utility program in the bootstrap ROM is then used to transfer the contents of the RAM to the bubble memory. The time required to transfer a program into or out of the bubble memory is about five seconds.

2. System Design and PVT Connection

The bubble memory system consists of the bubble memory itself and its peripheral chips on a 4- × 4-inch printed circuit card. The entire unit was purchased as a kit from Intel. It connects to the 8085 bus of the protocol processor via the PVT backplane. Logically, the memory consists of 256 tracks of 4096 bits each which are being continuously shifted around a loop. Eight selected tracks may be read or written in parallel. The maximum data transfer rate is 100 kbps. The printed circuit card contains all the logic necessary to interface the bubble memory to the 8085 CPU bus.

The installation of the bubble memory in the PVT is straightforward. The memory is installed in an unused cardslot in the PVT backplane. Since the bubble memory is on a PC card, a connector change is required. About 20 wires need to be added to extend the 8085 data and control signals from the protocol processor to the bubble memory cardslot. Three wires must be added to the protocol processor card itself to bring out a clock, a system reset, and a decoded address line. The basic circuitry of the protocol processor is unaffected.

Since each of the versions of protocol processor code which were of interest contained between 28K and 31K bytes, the bubble memory was partitioned into four segments of 32K bytes. By default, the system currently loads the program from the first segment of the memory on either a power-up or a system reset. If the bubble memory is used more widely, a feature will be added to the start-up ROM to allow any of the four pages to be loaded.

III. MINICONCENTRATOR GATEWAY

The miniconcentrator gateways have continued to operate reliably and to undergo a number of evolutionary extensions to their scope. Development of the extensions was motivated by the need to support a combined DARPA/NAVELEX exercise (see Section IV-B) to carry out data transmission experiments, to enhance the IP protocol capabilities of the gateway, and to make operation of the software more convenient.

A. ST PACKET REPLICATION

Packet replication in the gateway is required to allow incoming packets to be delivered to two or more nets (e.g., a LEXNET and packet radio net at one site), and/or to two or more terminals on a net without broadcast capability. Replication was implemented during this period, and used to support the DARPA/NAVELEX exercise involving multiple nets and terminals.

In the usual dispatching of speech and data packets, a UMC processor attached to the gateway PDP-11 computer reads in the packet, places header material in a circular buffer and the data in a string of blocks (referred to as extension blocks). The PDP-11 portion of the gateway uses the header material and other information to make decisions about dispatching and eventually hands off new header material and the string of extension blocks to a UMC for output. Since the contents of the extension blocks are of no concern to the PDP-11, the operation of copying over the data from an input buffer to an output buffer in the PDP-11 is avoided.

At any time, a UMC owns a set of extension blocks. It relinquishes ownership of the blocks that it passes to the PDP-11 and gains ownership of the blocks that it obtains from the PDP-11 for subsequent output. This scheme is inadequate for incoming packets that need to be delivered to two or more networks and/or to two or more terminals on a network which does not provide a broadcast capability. For such replication situations, it is unclear which of the UMCs should claim ownership of the blocks especially since output by the UMCs is asynchronous.

Replication of packets was implemented in the gateway through a reporting mechanism by means of which the UMCs report to the PDP-11 when they have completed the output of such a packet. Additionally, in such situations the UMCs do not claim ownership of the string of extension blocks. When all the replications have been completed (as evidenced through the reports from the UMCs), the PDP-11 then hands off the string of extension blocks to a UMC for ownership.

B. CHANGES TO DISPATCH OF DATA PACKETS AND INSTRUMENTATION

WB SATNET streams provide transmission of messages at fixed predetermined intervals, and thereby provide more responsive service than datagram transmission. The latter requires the PSATs (Packet Satellite Interface Message Processors) to make reservations before sending the messages. Such reservations add about 400 milliseconds of delay to the transmission of the message.

To date, streams have been used primarily for speech messages in order to provide results which are more conversational than would be the case if datagrams were used. To support voice/data integration experiments, the gateway software was extended to allow for the optional transmission of Internet datagram Protocol (IP) packets in streams, whenever possible. After the gateway has exhausted the output of speech packets from the queues intended for the WB SATNET, it continues with the queue of data packets if all the following conditions hold:

(1) transmission of IP packets in streams has been user-enabled,

(2) the number of messages that the stream can handle has not been exhausted,

(3) the number of words available in the stream slot has not been exhausted.

For instrumentation purposes, the gateway produces histograms of words of stream capacity that remain before and after the IP packets are transmitted to the Packet Satellite demand assignment processor (PSAT). These histograms are then sent to a specialized post-processing program which processes the data and produces bargraphs showing the percentages of time that various capacities remained. The results have shown that substantially better utilization of stream capacity can be achieved by filling the leftover space with IP messages.

A squelching mechanism was introduced to prevent the long-term accumulation of IP packets faster than they can be disposed of through transmission. This mechanism places a limit on the number of packets that can be placed on the output queue; packets that would cause the queue to overflow are discarded. This scheme favors packets that arrived earlier rather than later and is intended to mesh well with the windowing strategies used by the Transmission Control Protocol (TCP).

The gateway now collects histograms of the following additional instrumentation variables:

(1) number of ST messages actually aggregated into an ST envelope,

(2) number of message blocks available,

(3) the reasons for discarding messages.

C. EXTENSIONS TO IP PROTOCOL CAPABILITIES

The IP protocol provides for fragmentation of IP messages that are too large for transmission on an output network. In the case of our gateway, such fragmentation may also be needed when the IP messages are not too big for the network but exceed the currently available capacity. This may occur on the WB SATNET when most of the capacity is used for streams leaving a small capacity for IP datagrams, or when IP messages are being sent in streams and a limited capacity remains in the streams. We have implemented IP message fragmentation to cover all of these situations.

Major portions of the Internet Control Message Protocol (ICMP) were implemented in the gateway. These include destination unreachable and parameter problem error complaints, echo reply, source quench, and information reply. Error situations which do not lend themselves to ICMP error complaints are tabulated by the gateway internally for later examination.

An IP message generator was implemented in the gateway to provide a convenient means to test program behavior.

D. GATEWAY START-UP AND CONTROL

Up until now, we have used the UMC debugger, MZDB, to download and start the UMC programs when invoking the gateway program. Because of addressing needs and the organization of MZDB, a slightly different version of the program is needed for each UMC that must be downloaded. Such handling of several programs slows down the start-up of the gateway and can be confusing to people in the field who are unfamiliar with the details of bringing up the gateway.

We have therefore extracted relevant portions from MZDB (written in assembly language) into a new EPOS program (written in C) which downloads and starts UMCs. This program is run automatically when the gateway is invoked, thereby speeding up and simplifying the process of bringing up the gateway.

The flexibility of external control of the gateway program via typed commands has been increased with the installation of the following capabilities:

(1) Convenient and optional clearing of gateway and UMC variables at user-defined intervals. For example, this has been used to obtain counts of errors from the PSAT at fixed intervals in order to determine whether errors were uniformly distributed or whether there were peak periods.

(2) Transmission of the internally generated IP messages described above.

(3) Selection of the WB SATNET stream reliability.

(4) Printout of an up/down log showing when the network, as seen from the gateway's point of view, came up and went down; this log has been used primarily in monitoring availability of the WB SATNET.

E. OTHER GATEWAY DEVELOPMENTS

The UMC programs were extended to provide a mechanism for generating and measuring network traffic while serving the usual gateway functions simultaneously. This enables specific traffic patterns to be generated in support of the activities of the WB SATNET Task Force.

The size of the gateway has grown to the point where exploitation of the separate I and D space capabilities of the PDP-11 computers are suggested. Toward this end, the ATOLDA program (which converts a UNIX A.OUT file into an EPOS-compatible file) was extended to handle separate I/D space programs, as per specifications generated by ISI personnel. Once ISI completes extensions to the EPOS system, such I/D space separation will be achieved in the gateway.

Changes were made to the PDP-11 and UMC portions of the gateway to enable communication using the CAP8 (Channel Access Protocol — version 8) packet radio protocol, replacing the previous CAP5 protocol.

IV. WIDEBAND NETWORK EXPERIMENTS AND EXPERIMENT COORDINATION

A. WIDEBAND NETWORK SYSTEM COORDINATION

It was noted in the previous Semiannual Technical Summary that a WB SATNET Task Force was established at the March 1983 Wideband Meeting, with the objectives of resolving current system problems, and achieving reliable operation first at 1.544 Mbps and then at 3.088 Mbps. The Task Force is coordinated by Lincoln, and includes representatives from BBN (Bolt, Beranek and Newman), ISI, and LINKABIT. Some of the major results and observations with respect to the Task Force activity are:

(1) Two sites (Lincoln and ISI) are now operating at 3.088 Mbps with different coding rates for control and speech packets.

(2) The most significant progress has been made during site visits where the Task Force members convened at one site for intensive measurement and debugging efforts.

(3) The problems corrected by the Task Force were not concentrated in a single WB SATNET subsystem, and often involved detailed interactions between subsystems.

(4) The Task Force has extended its efforts to deal with integration of the new WB SATNET sites at RADC, Fort Monmouth, and Fort Huachuca.

These points are covered in more detail in the description of Task Force activities below.

When the Task Force was initiated in March 1983, an initial action was to set up coordinated site visits for intensive system-level debugging. In pursuing the Task Force activity over the ensuing weeks, it was found that the most significant progress was in fact made during the organized site visits, when the Task Force members convened at one of the sites and devoted their efforts exclusively to measurement and debugging for several days. Between these site visits, it was generally more difficult to make progress toward Task Force objectives (except for diagnosis and correction of specific bugs discovered during the preceding visit). The main reason for this was that the problems tended to transcend the diagnostic tools available to any one hardware/software subsystem supplier, so that they would yield only to simultaneous scrutiny by experts in several areas.

It was also found that each round of problem solving tended to disclose another layer of problems below it, so the achievement of stable higher-rate operation was found to be a substantially greater effort than originally estimated. A total of four site visits have taken place to date, and at least one more is planned. The network status at this time is that two sites (Lincoln and ISI) are fully outfitted with the upgrades and fixes developed during the Task Force work, and are operating with reasonable stability at 3.088 Mbps with mixed coding rates (headers and control at rate 1/2, voice coded at rate 3/4). Work is in progress to upgrade the remaining sites, and to pursue the remaining causes of unsatisfactory performance. Below we will describe some of the Task Force efforts in chronological order, beginning with a summary of the first three site visits.

The first visit was at Lincoln Laboratory on 25-28 April, and it focused primarily on correction of several problems in the Earth Station Interface (ESI) and in the ESI/PSAT interface. A major output of this effort was identification of an ESI firmware bug which caused the system to crash under certain conditions when the PSAT attempted to aggregate packets for transmission. The second site visit was at ISI on 16-18 May, again focusing primarily on ESI/PSAT interface issues. At the third site visit (at ISI on 27-29 June), all the modifications and corrections had been incorporated in the ESI and it was possible to attack broader system problems. One such problem was in fact identified: the PSAT was found to be occasionally commanding a very low channel bit rate for certain bursts, with the result that the ESI's uplink buffers would overflow before the transmission of the burst was completed, and the system would crash.

The Western Union earth station antennas were measured and corrected at both Lincoln and ISI, in conjunction with Task Force activities, in a manner similar to that carried out by Western Union last winter at DCEC. In all three cases, it was found that the subreflector had been incorrectly installed at the factory, and that readjustment of the assembly yielded a receive gain improvement of about 1 dB. This translates to a channel bit error rate improvement by about a factor of 2 at 3.088 Mbps, or an order of magnitude at quarter-rate.

An additional accomplishment associated with the Task Force was installation of an RF bandpass filter at ISI, in accordance with the recommendations of the Probe Systems investigation, to correct the problem with interference from radar altimeters on aircraft near LAX. The filter was borrowed from COMSAT Laboratories, and will later be replaced with an optimized unit procured by Western Union. Western Union has made plans to install similar filters at the other sites.

The Wideband Network Task Force delivered a status and progress report to DARPA and the DCA on 1 August in Washington. This report detailed the objectives and accomplishments of the Task Force, focusing particularly on the three site visits that had been carried out at that time. Details of debugging efforts were outlined, showing steady progress toward stable operation at 1.544 Mbps. It was pointed out that this goal appeared to be within reach, but that so far only two sites (ISI and Lincoln) had all the upgrades installed. It was recommended that the Task Force effort be continued. It was also recommended that an order for four additional ESI-As be added to the existing order for six units, so that all ten WB SATNET sites expected to be active by next year would be outfitted with them. This would avoid stability and reliability problems that have been experienced with the original four ESI advanced development models. Additional discussions at the Task Force meeting focused on longer-term issues related to controlling, verifying, and measuring subsystem availability for experimental use. These issues were network and subsystem configuration control, standardized network test procedures, methods for measuring and reporting network quality factors, and host-level testing procedures. The Task Force is currently addressing these longer-term issues as well as the specific efforts involved in system debugging and integration.

The fourth Task Force site visit took place at ISI on 22-24 August, with objectives including pursuit of reliable 1.544-Mbps operation, review and verification of the T and M mechanisms, investigation of ESI burst spacing constraints, and two-site testing at 3.088 Mbps. Significant accomplishments included checkout and satisfactory operation of the new Version 3 PSAT software in a two-site network at 1.544 Mbps with mixed code rates, resolution of Test and Monitoring problems and discrepancies, and reduction of the default inter-burst padding. The two-site net was brought up and thoroughly checked out at 3.088 Mbps with mixed code rates, with satisfactory results; it was therefore decided to leave the channel bit rate at 3.088 Mbps. Operation at that rate has remained satisfactory through the rest of the reporting period, although only two upgraded sites were on the net at the time this report was written.

On 21-22 September, acceptance testing of the new Western Union earth stations at Fort Monmouth and Fort Huachuca was used as a focus for implementing new power and frequency calibration procedures that will become standard in the WB SATNET. The basic issue is that the automatic gain and frequency control (AGC and AFC) mechanisms in the ESI have finite limits on their acquisition apertures, and TDMA communications among multiple sites will fail if the site-to-site differences in these parameters exceed the limits. If local Western Union personnel use locally owned power meters and frequency counters (with possible differences in calibration) to set the parameters, it is very likely that the limits will be exceeded. Accordingly, it has been proposed that all stations be adjusted relative to a reference station, and that this reference station should be Lincoln Laboratory. A highly accurate HP8566A spectrum analyzer has been purchased and installed at Lincoln to support this function. In calibration of the Army sites, Lincoln's transmitted amplitude and frequency were first carefully measured in satellite loopback, and then each station in turn was adjusted so that its parameters (as measured with the spectrum analyzer) matched Lincoln's.

B. INTERNET SPEECH EXPERIMENTS

During the week of 13-17 June, a three-site internet packet speech exercise was carried out involving point-to-point and conference calls among participants at SRI in California, NTA in Norway, and Lincoln Laboratory. The exercise was jointly supported by DARPA and NAVELEX. SRI provided packet voice hosts called Speech Interface Units (SIUs) and CHI-V LPC vocoders for the California and Norway sites. Lincoln provided Packet Voice Terminals (PVTs) and compact LPC vocoders for use at Lincoln Laboratory. The SIU at SRI was connected to a Packet Radio Network (PRNET) running the new CAP8 control protocol. The SIU in Norway was interfaced to a PRONET (a commercially available ringnet). The PVTs at Lincoln were connected via a LEXNET. Long-haul transport was provided by the WB SATNET, ARPANET, and the Atlantic SATNET. Altogether six different networks were used.

Figure 1 shows the exercise configuration. The square boxes labeled G are IP/ST gateways supported by Lincoln. The circles labeled G are standard internet gateways supported by BBN that understand only the IP protocol. The exercise made use of ST protocol packets to carry the point-to-point and conference calls. In order to get the

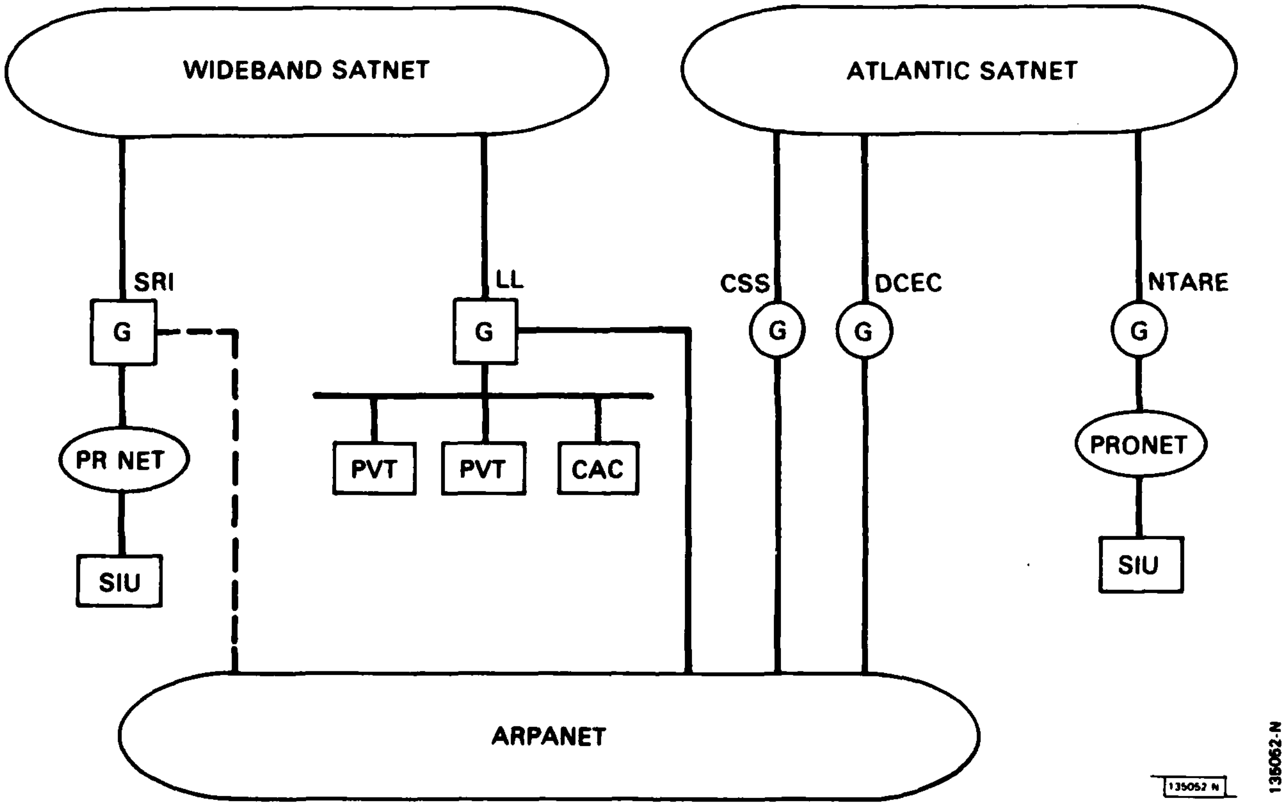

Figure 1. Internet packet voice exercise configuration.

ST packets through the IP-only gateways to the Atlantic SATNET, it was necessary to encapsulate the ST packets in IP datagrams. During the exercise, encapsulation took place in the gateway at Lincoln Laboratory and in the SIU in Norway. The figure shows a dashed line connecting the SRI gateway to ARPANET. That line represents an alternate path that was available for use in the event that difficulties arose in the WB SATNET. Similarly, there were alternate gateways available between ARPANET and the Atlantic SATNET. The alternative routes were not used during the exercise but were explored during the tests that preceded the exercise.

In order to support the exercise, Lincoln extended the IP/ST gateway software to handle encapsulation and to provide replication of conference packets. The replication mechanism was described in Section III. Lincoln also modified the gateway program to handle the new CAP8 PRNET protocol. Support of the exercise also required new software by SRI to handle encapsulation in the SIU in Norway (the SIU at SRI used ST directly).

Prior to the week of the exercise there was no packet speech capability in Norway; therefore, in order to test the path from Lincoln to Norway, we made a series of loop experiments using the measurement host capability of the PVTs at Lincoln Laboratory. Figure 2 shows a delay histogram from one of those experiments. The delays are round-trip

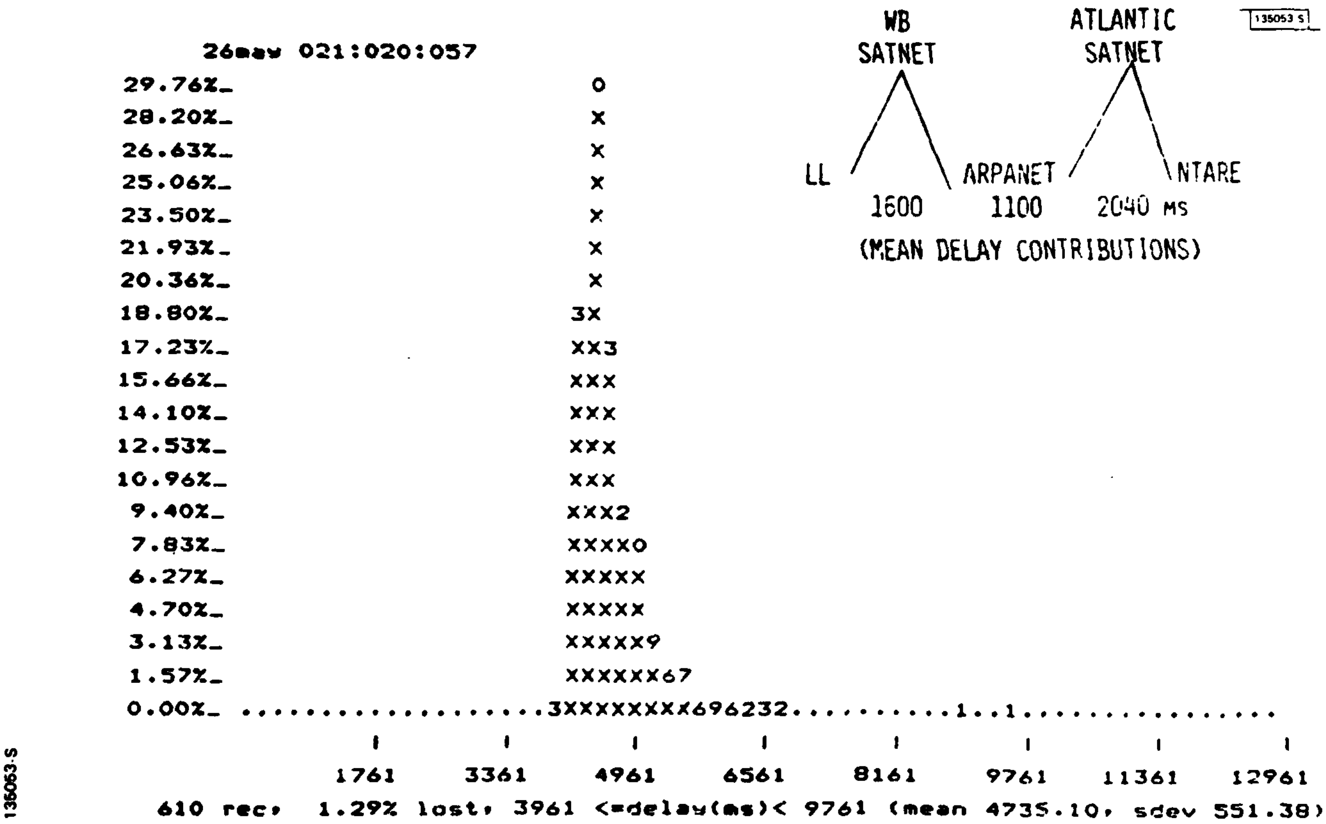

Figure 2. Delay histogram for preliminary test of LL to NTARE gateway loop.

values for the path indicated schematically in the figure. The figure also shows the components of the mean delay attributable to each network traversed. These values were obtained by combining delay data from other experiments with those for this path. The packets traveled from a PVT at Lincoln Laboratory to the NTARE gateway and back. The packet rate was two per second, and the packets were sized to correspond to LPC speech being transmitted at that rate with the anticipated encapsulation (1568 bits per packet, overall).

The digit printed atop each column of the histogram provides fine grain information on the height of the column. The digit represents the fractional part of the ordinate unit that should be added to the scale value at the left. For example, the 3 at the top of the left-most tall column indicates that the actual reading was greater than 18.8% by at least 0.3 times the unit of 1.57% but not by as much as 0.4 times 1.57%.

In the test for which the delays of Figure 2 were measured, datagram service was used for the packets on the WB SATNET. During the exercise itself, stream service was used with a consequent reduction in mean round-trip delay of about 800 ms. The Atlantic SATNET delay contribution shown as 2040 ms is consistent with an assumption of datagram service in that net together with transmission time for the packets in both directions on the 9.6-kbps line between the Atlantic SATNET (TANUM SIMP) and the NTARE gateway. The ARPANET component of 1100 ms is consistent with other measurements for multipacket messages of this size.

We had hoped that a packet rate of four to five packets per second could be sustained by the internet configuration since those rates would allow the messages to be small enough to qualify for raw (type 3) packet service in the ARPANET with a consequent improvement in delay characteristics. The series of preliminary tests showed that the 9.6-kbps line between the NTARE gateway and the TANUM SIMP could not handle the traffic at those rates and that it would be necessary to use a rate below three packets per second to avoid congestion on that link. The lower rate resulted in larger packets and longer delays, but the tests showed that adequate performance could be achieved.

The measurements also showed that the delay dispersion to be expected would be larger than the PVTs were prepared to accommodate. Accordingly, the PVT software was changed to allow a larger buffer for LPC speech and to provide keypad control of packet size and reconstitution delay parameters.

The exercise itself was marred by a problem with the vocoder in Norway that caused rather severe degradation of the speech received from that site making it very difficult to carry on a conversation. Aside from this problem and a failure of equipment at SRI on the last day that prevented a mobile PRNET test from being carried out, all combinations of point-to-point and conference calls were successful at one time or another. There were periods when communication across the Atlantic SATNET was not possible, and times when moderate packet loss rates were observed, but there were other periods when the communication was essentially perfect as measured by comparing counts of packets sent and received. The round-trip speech delay from California to Norway was about 5.5 seconds using the WB SATNET and a little longer using the ARPANET for the segment between LL and SRI. The observed values were consistent with the preliminary measurements, taking into account the use of stream service in the WB SATNET and the addition of reconstitution delays in the receivers to put the playout time toward the end of the tail of the delay histogram.

C. HOST-LEVEL NETWORK MEASUREMENTS

Toward the end of the reporting period, the efforts of the Task Force have resulted in stable operation of the WB SATNET at 3.088 Mbps with control information coded at rate 1/2 and with two sites (Lincoln and ISI) on the network. During lulls in the work of the Task Force, opportunities have been available for host-level tests of the network capabilities. Tests during such periods have included 64-kbps conversations between ISI and Lincoln and calls between two gateways at Lincoln looped through the satellite. In some tests, the voice parcels and internet headers were sent uncoded (3.088 Mbps) and in others the same information was sent coded at rate 3/4 (2.316 Mbps). In the uncoded case, between a third and a half of the packets had bit errors detected by the PSAT checksumming mechanisms. These errors caused the 64-kbps speech to sound a little noisy and a few packets to be lost when the errors occurred in the packet headers, but the overall quality was generally acceptable. For the 3/4-rate case, both the detected errors and packet losses were too low to measure in our tests. Since efficient voice/data multiplexing requires filling out stream reservations with data packets and the error rate at 3.088 Mbps without coding is too high for data use, we have done most of our host-level testing at the 3/4 coding rate which seems quite adequate for data communications.

In tests successfully carried out at the end of September, we looped four 64-kbps conversations (total of eight talkers) through the satellite channel using two gateways connected to the PSAT at Lincoln. Figure 3 shows the test configuration. Four of the telephones were on packet voice terminals (PVTs) on two LEXNETs connected to one of the gateways. The other four were connected through a packet/circuit interface (PCI) on the second gateway. Two of the latter were ordinary extension telephones connected through the Lincoln PBX via trunk lines to the PCI by way of a telephone office emulator that supported the other two phones directly. The eight 64-kbps voice streams carried in these tests were the highest voice traffic loads yet handled by the WB SATNET, and could not have been carried with the channel operating at 772 kbps. As the reporting period ended, efforts were focused on increasing the number of calls by including the ISI site.

D. VOICE-CONTROLLED OPERATOR

A four-participant conference was established using a combination of voice control with the capability to dial to a new participant during an ongoing conference. A talker at Lincoln first trained the VCOP (Voice-Controlled Operator) by dialing the VCOP's number from a PVT and repeating the 20 participant names and command words needed to set up a conference five times each. The talker then hung up, redialed the VCOP, and answered prompting phrases provided by the VCOP to provide a list of conference participants, and the type of speech processing to use. This information was then passed to the conference access controller PVT which rang two PVTs at Lincoln. The participants at these PVTs joined the conference as soon as they picked up their PVT telephone handsets. A fourth participant at ISI was invited to join the conference by dialing this participant's PVT from a Lincoln PVT already in the conference.

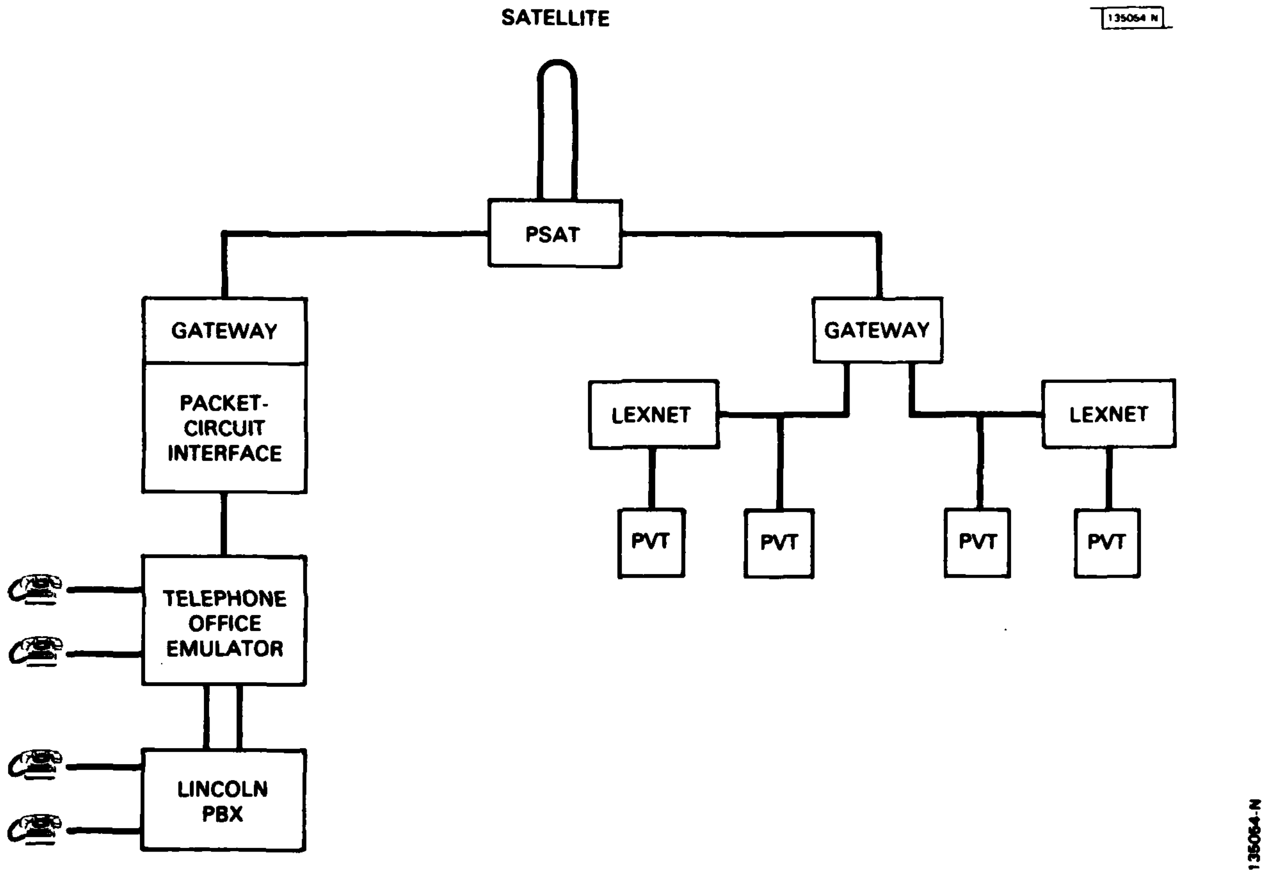

Figure 3. Four-conversation loop test configuration.

GLOSSARY

AFC	Automatic Frequency Control
AGC	Automatic Gain Control
AR	Adams-Russell Company
ARPANET	ARPA Network
BBN	Bolt, Beranek and Newman
CMU	Carnegie-Mellon University
DTW	Dynamic Time Warping
ESI	Earth Station Interface
ICMP	Internet Control Message Protocol
IP	Internet Protocol
ISI	Information Sciences Institute
LEXNET	Lincoln Experimental Packet Voice Network
LEDs	Light-Emitting Diodes
LPC	Linear Predictive Coding
NTA	Norwegian Telecommunications Authority
NVP	Network Voice Protocol
PCI	Packet/Circuit Interface
PCM	Pulse Code Modulation
PRNET	Packet Radio Network
PSAT	Packet Satellite Interface Message Processor
PVT	Packet Voice Terminal
RAM	Random Access Memory
RFI	Request for Information
ROM	Read Only Memory
SIUs	Speech Interface Units
STNI	Switched Telephone Network Interface
SPP	Speech-Processing Peripheral
SRI	SRI International
ST	Stream Protocol
TCP	Transmission Control Protocol
VCOP	Voice-Controlled Operator
WB SATNET	Wideband Satellite Network

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ESD-TR-83-225	2. GOVT ACCESSION NO. A139924	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Wideband Integrated Voice/Data Technology		5. TYPE OF REPORT & PERIOD COVERED Semiannual Technical Summary 1 April 1983 — 30 September 1983
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Clifford J. Weinstein		8. CONTRACT OR GRANT NUMBER(s) F19628-80-C-0002
9. PERFORMING ORGANIZATION NAME AND ADDRESS Lincoln Laboratory, M.I.T. P.O. Box 73 Lexington, MA 02173-0073		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Program Element No. 62708E Project No. 3T10 ARPA Order 3673
11. CONTROLLING OFFICE NAME AND ADDRESS Defense Advanced Research Projects Agency 1400 Wilson Boulevard Arlington, VA 22209		12. REPORT DATE 30 September 1983
		13. NUMBER OF PAGES 30
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Electronic Systems Division Hanscom AFB, MA 01731		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

None

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

packet speech	internetwork	SATNET
Linear Predictive Coding	protocol	voice conferencing
LEXNET	gateway	packet voice terminal
Wideband SATNET	ARPANET	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes work performed on the Wideband Integrated Voice/Data Technology Program sponsored by the Information Processing Techniques Office of the Defense Advanced Research Projects Agency during the period 1 April 1983 through 30 September 1983.