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Data Communication Performance Testing of ACTS

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PREFACE

Certain commercial equipment, instruments, services, protocols, and materials are identified in this report to adequately specify the engineering issues. In no case does such identification imply recommendation or endorsement by the National Telecommunications and Information Administration, nor does it imply that the material, equipment, or service identified is necessarily the best available for this application.

CONTENTS

FIGURES

TABLES

TABLES (Cont'd)

Page

DATA COMMUNICATION PERFORMANCE TESTING OF ACTS

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The results of a series of data communication tests, which define the digital end-to-end performance of the Advanced Communication Technology Satellite (ACTS), are presented. The experiment consisted of a test set characterization to determine the effect of the test set on the results, a preliminary characterization to define the failure/nonperformance outcome thresholds, and a full characterization. The experiments' design, execution, and analysis comply with the American National Standards X3.102 and X3.141. The tests showed that ACTS has a very clean data channel (only one lost byte was recorded during all the tests), the X.25 packet mode did not perform as well as expected, and the parameter estimates did not vary substantially over time or destination location.

Key words: ACTS; ANSI X3.102; ANSI X3.141; Advanced Communication Technology Satellite; satellite communications

1. BACKGROUND

Spurred by emerging technologies such as personal communications services (PCS), asynchronous transfer mode (ATM), and the government's vision of a high-speed network accessible by all citizens (evident in the National Information Infrastructure), speculation of future communications has become headline news in even the most nontechnical magazines, newspapers, and journals. In the new communications environment, everyone wants to be connected to everyone (or everything) else at anytime. They ideally would like to transmit voice, video, and data at various data rates using the same physical equipment and protocols. One envisioned application, supervisory control and data acquisition (SCADA), operates by polling the status of geographically disperse systems such as oil pipelines at rates up to once per second. At the other end of the spectrum, remote supercomputers perform parallel processing at data rates up to 1 Gbps. In between these extremes are desktop conferencing (from 64 kbps to 384 kbps), video conferencing, and video on demand.

Most applications can be implemented using either wireless systems or wire/fiber systems. This is, in part, a result of the new emerging satellite and ground segment technologies, in which "more and

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more satellite equipment will meet terrestrial standards, leading to convergence of ground- and sky-based technologies into one seamless system." [1] The choice of a transmission medium is often based on parameters such as the cost or time of implementation. Given these parameters, satellites may be the preferred choice in the following situations: (1) for areas that do not offer terrestrial service at the data rates a user requires (e.g., in Colorado, there are many areas that still only offer service from analog switches); (2) for connecting remote networks using specialized protocols (e.g., Integrated Services Digital Networks (ISDN) and ATM) and/or operating at high-speeds (e.g., OC-12); (3) for emergency situations when the terrestrial network has been destroyed; (4) for geographically disperse SCADA-type applications; (5) for worldwide wireless consumer applications (e.g., PCS and paging); and (6) as a backup switch for load leveling of a terrestrial network.

The tests described in this paper were performed on an advanced communication satellite system that showcases several new space- and ground-based technologies. Specifically, the tests were performed on NASA’s Advanced Communication Technology Satellite (ACTS) which was launched in September 1993. The system is experimental with enough fuel for four years of operation. Throughout its operational life, more than 80 organizations [2] will test ACTS technical capabilities and demonstrate new applications that ACTS can support. Examples of new technical capabilities and applications include transmission data rates up to 622 Mbps (OC-12), remote medical and educational services, and T1 (1.544 Mbps) video transmissions to aircraft.

NASA initially developed ACTS to reduce industry’s risk in incorporating advanced technologies in future satellite systems. Several commercial systems in the design stage plan on using ACTS-developed technologies. These systems include Motorala’s Iridium, Hughes’ Spaceway, and Norris’ Norstar. These systems are incorporating technologies developed on ACTS such as on-board switching, spot beams, and Ka-band operation.

1.1 ACTS System Description

ACTS uses several newly developed technologies such as on-board baseband switching, scanning and hopping spot beams, high data rate communications between users (OC-12), and Ka-band operation (30/20 GHz). In addition, ACTS applies technologies available 30 years ago, like Demand Assigned Multiple Access (DAMA), that opens the two-way video, data, and voice markets and makes the system act more like a terrestrial switched circuit than a leased line like conventional VSAT (very small aperture terminal) networks [1]. These technologies provide network flexibility, on-demand digital services, and as much as three times the communications capacity for the same weight as today's operational satellites. All in all, the use of these technologies results in a more cost effective system when compared to today's satellites [3].

An ISDN interface, developed specifically for ACTS, translates the ISDN protocols into ACTS orderwires.[2] In a future satellite system that uses ISDN, the orderwires could be designed from the very beginning to accommodate the ISDN call setup messages so no translations would be necessary. Besides ISDN, frame relay and ATM interfaces are being developed to evaluate the satellite transmission medium for these systems. The Institute for Telecommunication Sciences (ITS) is also involved with a study of low data rate ATM (1.544 Mbps) over ACTS in a related project.

The ground segment, or Earth Station (ES), used in this experiment is called a T1-VSAT. The T1-VSAT can communicate at a data rate of 1.792 Mbps (one T1 + four 64-kbps channels) with an antenna size of 1.2 m in diameter. The T1-VSAT has an outdoor unit and an indoor unit. Figure 1 shows the outdoor unit which consists of the antenna (a parabolic dish), the radio frequency (RF) feed, an intermediate power amplifier, and an intermediate frequency (IF) interface unit that mixes the signal down to IF. The IF signals are transmitted over 100 feet of heliax cable to the indoor unit. Figure 2 shows the indoor unit which consists of a controlling computer, a two-shelf, small central office (CO), a frequency standard (rubidium oscillator), a modem, a DC power supply, and a man-machine interface. Due to the switching that occurs on-board the satellite, the electronics of the T1-VSAT are simplified compared to other ES systems and thus are more cost effective. Although an experimental program and manufactured in small quantities, the T1-VSAT's cost was only $260,000. In mass production, the cost would be expected to decrease significantly and has been developed to be comparable on a cost-per-unit-of-data-bandwidth basis to existing Ku-band terminals [5]. In addition, due to the T1-VSAT's small size, it can easily be installed by two people (as was the unit pictured in Figure 1). This also affects the total cost because no equipment (e.g., a crane) is needed for installation.

[2] Orderwires are dedicated two-way control channels through which the Earth Stations maintain communications (for acquisition, synchronization, circuit request, and circuit assignment) with the ACTS master control station (MCS). More detailed information can be found in [4].

Figure 1. T1-VSAT outdoor unit.

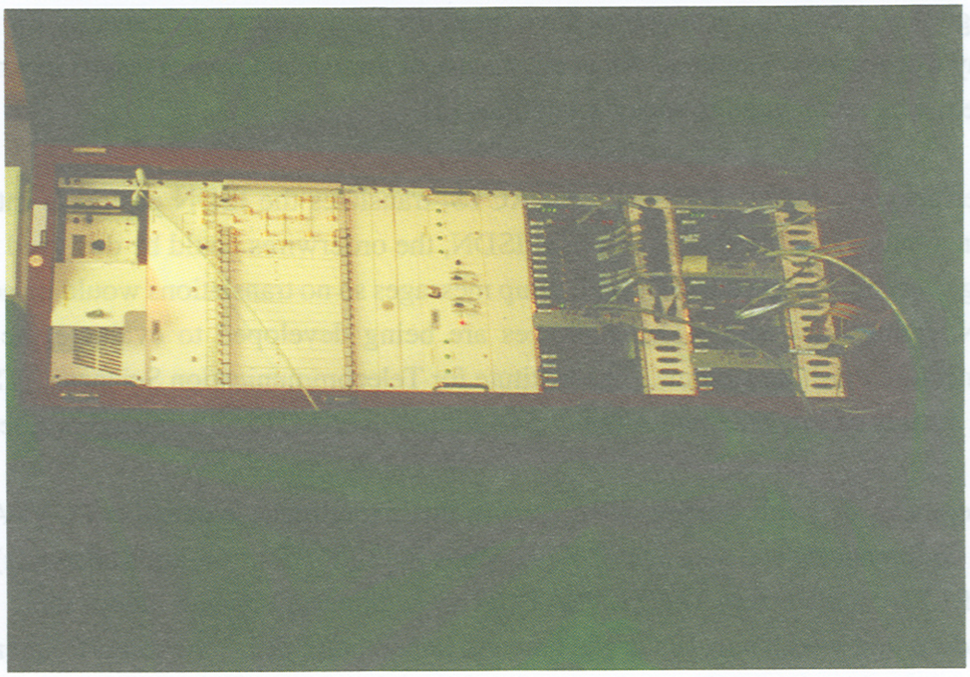


Figure 2. T1-VSAT indoor unit.

1.2 Purpose of ACTS Experiment

For systems such as ACTS, users require different and additional information than was necessary with repeater satellite systems.[3] For example, with the use of DAMA, users will now have the ability to request satellite circuit capacity dynamically. This is called an access request and may be done in a similar way to an access request in the terrestrial network (e.g., lifting a voice handset and dialing a phone number). Depending on the system loading or the existing weather conditions, access may occur within a specified amount of time, or it may be denied or ignored. For a user that requires short access times or a reliable access session, this may be intolerable. However, other users may not have such usage restrictions. Therefore, in this example, a user would need to know the access time and access probabilities in order to make an informed decision.

With this need in mind, the objective of this ACTS experiment was to define the data communication performance provided to a pair of users who use an advanced communication satellite as the transmission medium. Results from this experiment provide users with the information they need to determine the suitability of a system such as ACTS for meeting their needs.

1.3 ACTS Unbiased Measurement System

Measurements were made using a workstation-based system that transfers, collects, and processes data to produce estimated values of the American National Standard (ANS) X3.102 performance parameters [6], listed in Table 1. The measurement software conforms to the standard ANS X3.141 [7], which defines proper methods to estimate the ANS X3.102 parameters. The measurement system treats the data communication system, ACTS and associated equipment, as a black box. The measurements are made between two predefined users (the test software is the user) shown in Figure 3. As shown in the figure, the user interface resides in the workstations and is between the test software and a stream head to the X.25 application programming interface (API) or the operating system (UNIX[4]) for the ISDN and modem tests. In order to more accurately determine the contribution of the ACTS system to the performance parameters and deduct the contribution due to the test sets, the test software was run on the test sets in a back-to-back mode

[3] For a repeater-type satellite, the system's signal-to-noise ratio provides an idea of how reliably the data will be received, and the bandwidth provides an idea of how fast data will be transmitted.

[4] Trademark of AT&T.

Table 1. American National Standard X3.102 Performance Parameters

FUNCTION	PERFORMANCE CRITERION: SPEED	PERFORMANCE CRITERION: ACCURACY	PERFORMANCE CRITERION: RELIABILITY	PERFORMANCE TIME ALLOCATION
ACCESS	ACCESS TIME	INCORRECT ACCESS PROBABILITY	ACCESS DENIAL PROBABILITY ACCESS OUTAGE PROBABILITY	USER FRACTION (UF) OF ACCESS TIME
USER INFORMATION TRANSFER	BLOCK TRANSFER TIME USER INFORMATION BIT TRANSFER RATE	BIT ERROR PROBABILITY BIT MISDELIVERY PROBABILITY EXTRA BIT PROBABILITY BLOCK ERROR PROBABILITY BLOCK MISDELIVERY PROBABILITY EXTRA BLOCK PROBABILITY	BIT LOSS PROBABILITY BLOCK LOSS PROBABILITY	UF OF BLOCK TRANSFER TIME
		TRANSFER DENIAL PROBABILITY		UF OF INPUT/OUTPUT TIME
DISENGAGEMENT	DISENGAGEMENT TIME	DISENGAGEMENT DENIAL PROBABILITY		UF OF DISENGAGE-MENT TIME

Legend:
- (white) Primary Parameters
- (shaded) Ancillary Parameters

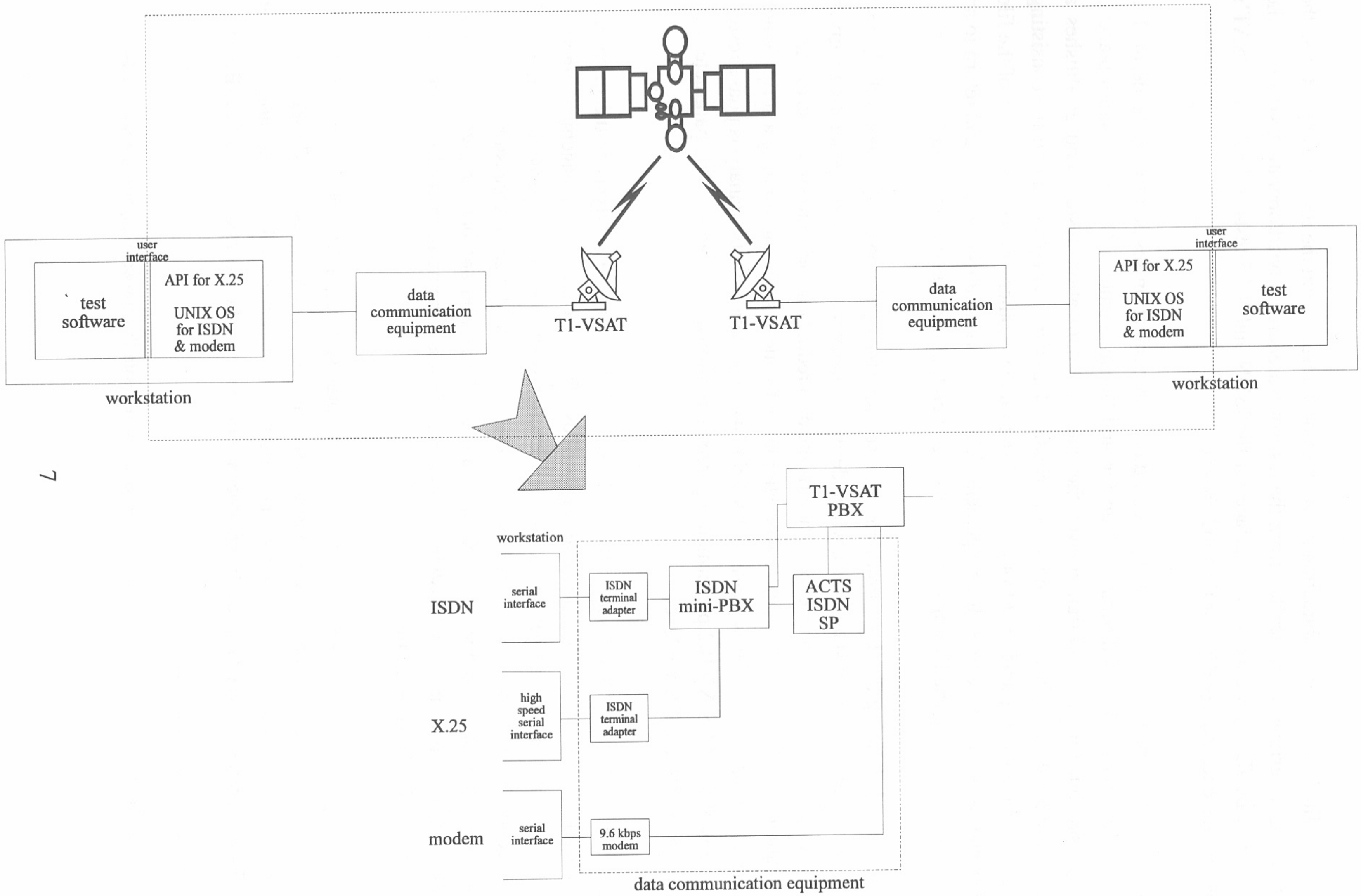


Figure 3. Contents of black box between predefined users.

(i.e., no satellite is used). By subtracting the back-to-back results from the results using ACTS, the effective user interface can be shifted from the test software/stream head/operating system to the ISDN mini-PBX/Earth Station (ES) interface for the ISDN and X.25 tests or to the T1-VSAT's private branch exchange (PBX) for the modem tests.

The test software implements the three generic data communication session functions defined in ANS X3.102: Access, User Information Transfer, and Disengagement. One workstation places a call to a second, remote workstation over the data communication system and establishes a connection in the Access phase. In the User Information Transfer (UIT) phase, a user file consisting of pseudorandom data is transferred from one workstation to the other. At the conclusion of the file transfer, one workstation requests disengagement. The two workstations disengage and return to an idle state, thus finishing the Disengagement phase and ending the data communication session.

The data recorded during the data communication session (the extracted data) is reduced off-line. The extracted data consists of state codes, which define the party responsible for generating a given reference event, and times of occurrence. The off-line data reduction and analysis are performed by consolidating the data files of the remote workstations onto one system and running a script which implements the reduction/analysis phase of ANS X3.141. The data reduction/analysis phase results in estimates of the ANS X3.102 performance parameters shown in Table 1.[5] The parameters are estimated at a 95% confidence level.

As implemented in the ITS version of the ANS X3.141 test software, analysis of the three data communication functions is split into two testing periods. The Access and Disengagement functions are analyzed during one testing period and the UIT function is analyzed in a separate testing period. For the Access/Disengagement tests, one block of data is transferred for each Access/Disengagement trial. For the UIT tests, a number of blocks are transferred one after another (i.e., without a delay between the blocks) in a single Access/Disengagement attempt. The number of blocks transferred is the number of UIT trials for the test.

The number of necessary trials are determined by the precision required. Due to the number of parameters to be estimated, a single parameter was selected for each of the Access/Disengagement tests and the UIT tests to be measured with the specified confidence level and precision. For the Access/Disengagement and UIT tests, the parameters chosen were the Access Time and the Bit Error

[5] Bit and Block Misdelivery Probabilities are not measured with this software implementation of ANS X3.141.

Probability, respectively. The goal was to measure the Bit Error Probability with a relative precision of 50%. Additionally, the goal was to measure the Access Time with an absolute precision of 0.5 seconds for the modem service tests and 0.1 seconds for the remainder of the services. The modem service requires a different precision than other service tests because of testing time. The modem Access/Disengagement tests take approximately 10 times longer to run than the other service's tests. Therefore, to keep the testing time reasonable, the precision required was reduced.

The number of trials necessary to meet the given confidence level and precision were as follows:

modem tests:	Access/Disengagement tests: 20 trials UIT tests: 50 trials with 4000 bytes/block
X.25 service tests:	Access/Disengagement tests: 100 trials UIT tests: 50 trials with 4000 bytes/block
ISDN service tests[6]:	Access/Disengagement tests: 40 trials

Each test was repeated five times. Since the parameters' standard deviations were similar, the data from the multiple tests was pooled. Pooling the test data results in a larger sample which should provide more precise parameter estimates [8].

[6] For the ISDN service tests, no UIT tests were run. The hardware used could not accommodate a full 64-kbps data rate. Section 2 describes how the User Information Bit Transfer Rate is calculated for the ISDN service from the X.25 service results.

2. TEST SET CHARACTERIZATION TESTS

To subtract out the contributions of the test set from the results of the ACTS characterization tests, X3.141 tests must be run over the test sets with the smallest possible intervening network. The "intervening network" consists of a single switch under laboratory conditions. Figure 4 shows the configuration for the ISDN case. The other cases have a similar configuration.

Test set characterization tests were performed for each of the following services:

- modem at 9.6 kbps over a plain analog telephone line (modem service)
- X.25 over a 64-kbps circuit-switched channel (X.25 via circuit service)
- ISDN over a 64-kbps circuit-switched channel (ISDN service)

The only service that was not tested in this configuration but was tested over the satellite system was the X.25 over a packet-switched channel (called X.25 via packet service). This is because, from the test set's point of view, there is only a circuit -switched channel for this case (i.e., in both cases there is a circuit-switched channel between the test set and the ISDN signal processor). For the X.25 via packet service, the packet-switched channel exists between the packet handler in the local ISDN Signal Processor (SP) attached to the local ES and the packet handler in the remote ISDN SP. This is discussed in more detail in Section 3.

The results of the test set characterization are shown in Table 2. Each test was run five times and the results from the five tests were analyzed together to obtain more accurate results. The results from the individual tests appear in Appendix A. Table 2a shows the results for the modem service, Table 2b shows the results for the X.25 via circuit service, and Table 2c shows the results for the ISDN service. Since the tests were run under laboratory conditions, with a single switch acting as

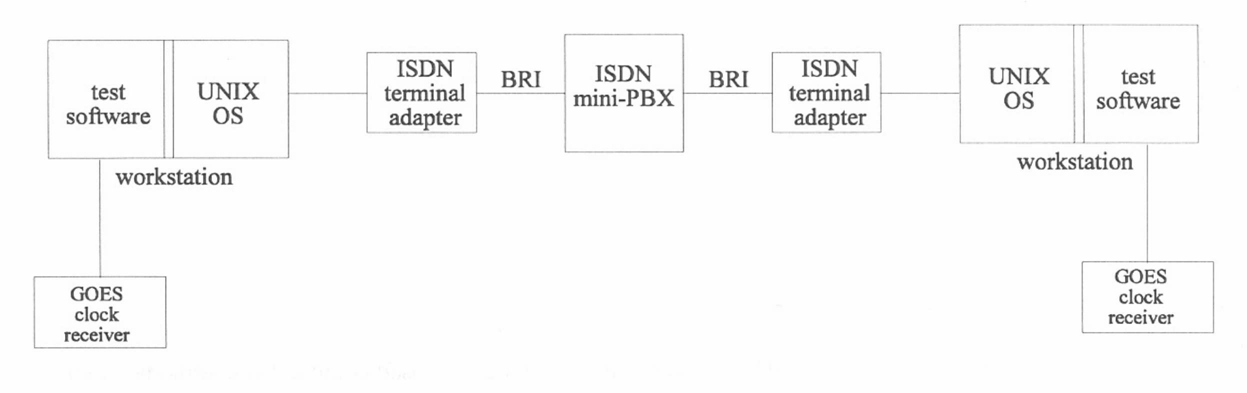


Figure 4. Test set characterization configuration for ISDN tests.

Table 2a. X3.102 Parameter Values for Modem Service at 9.6 kbps - Test Set Characterization

Parameter	Sample Mean	User Fraction	Precision	# Trials	# Correct Trials
Access Time	33.46 s	0.36 %	0.52 s	100	100
Source Disengagement Time	8.00 s	1.13 %	0.14 s	100	100
Destination Disengagement Time	2.16 s	3.40 %	0.001 s	100	100
Block Transfer Time	12.35 s	1. 04 %	0.25 s	250	250
User Information Bit Transfer Rate	7676 bps	--	2.5 bps	5	N/A
User Fraction of Input/Output Time	1.07 %	--	0.078 %	5	N/A

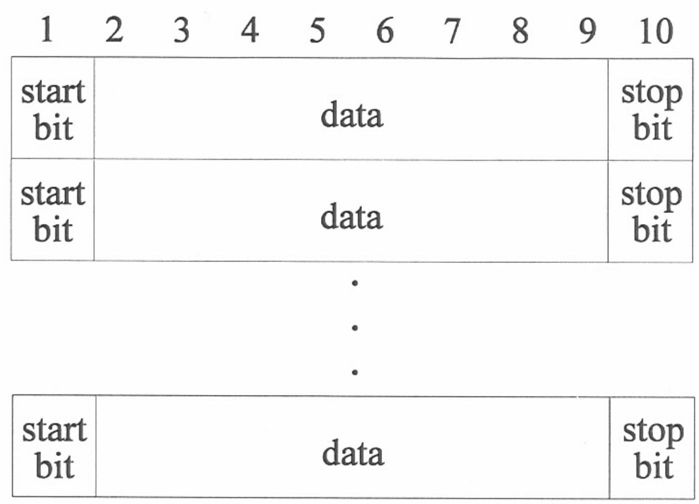
* Precision is the absolute precision based on the 95% confidence level. The absolute precision is given by $\frac{m_u - m_l}{2}$ where m_u and m_l are the upper and lower limits of the 95% confidence interval respectively.

the network, the channel was extremely clean and no Access/Disengagement or UIT failures occurred. Therefore, only the delay, rate, and ancillary parameters are shown in Table 2.

Modem Service Results

As shown in Table 2a, the modem service resulted in a User Information Bit Transfer Rate of 7676 bps. The modem's timing is asynchronous; it requires one start bit and one stop bit for each eight user data bits, as shown in Figure 5. This is an overhead rate of 20%. Thus, in the ideal case, the use of start and stop bits would result in a throughput reduction of 1920 bps for a 9600-bps modem. This results in an ideal User Information Bit Transfer Rate of 7680 bps which was within 4 bps of the measured value. Due to the clear channel between the test sets, (i.e., the test sets have an essentially error free channel between them) no bit or block errors occurred.

The Access Time took approximately 33.5 seconds. This Access Time was approximately split into 10 seconds for the call to be dialed and connected, 13 seconds for the handshaking, 6 seconds to



$$\text{overhead} = \frac{\text{start bit} + \text{stop bit}}{\text{start bit} + \text{stop bit} + \text{data bits}} \times 100\,\% = 20\,\%$$

Figure 5. Frame structure and overhead for asynchronous communication.

receive the login prompt, and 4.5 seconds for the login/password/program initiation. Figure 6 shows the timeline graphically. For disengagement, the source initiates the procedure and takes 8.0 seconds. The 8.0 seconds is split approximately between a few seconds waiting for the destination to disconnect and 5 seconds to receive a "NO CONNECT" after exiting. The destination takes approximately 2.2 seconds to disengage.

X.25 via Circuit Service Results

As shown in Table 2b, X.25 via circuit service resulted in a User Information Bit Transfer Rate of approximately 63 kbps. There are three OSI layers that contribute to the overhead that results in a User Information Bit Transfer Rate less than 64 kbps. The X.25 Packet Layer resides at layer 3, the LAP-B protocol resides at layer 2, and the Sunlink X.25 WAN connection resides at layer 1. The relationship between the three layers is shown in Figure 7.

- The Sunlink X.25 physical layer, layer 1, runs on top of a clear ISDN 64-kbps channel (i.e., no overhead is added). Therefore, there is no drop in data rate due to this layer.

- The layer 2 protocol, LAP-B, adds seven bytes of overhead to every information field. The information field size was 1028 bytes (the packet size of the X.25 Packet Layer). Therefore, the LAP-B frame size was 1035 bytes. The drop in data rate due to LAP-B is 0.676% or 433 bps.

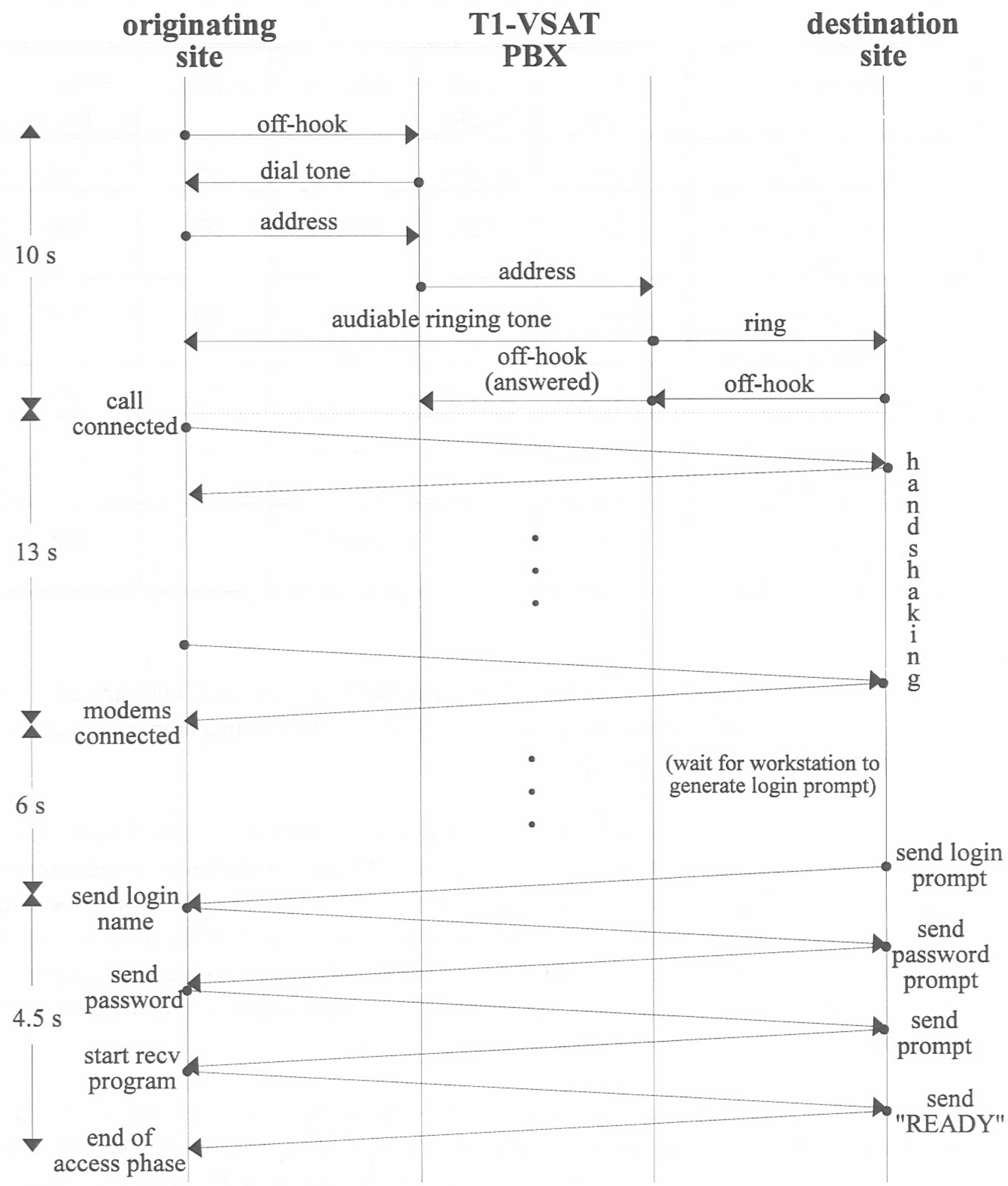


Figure 6. Detailed timing diagram for the modem's Access Time parameter.

Table 2b. X3.102 Parameter Values for X.25 via Circuit Service - Test Set Characterization

Parameter	Sample Mean	User Fraction	Precision	# Trials	# Correct Trials
Access Time	0.27 s	41.25 %	0.03 s	500	500
Source Disengagement Time	0.28 s	0.22%	0.001 s	500	500
Destination Disengagement Time	0.31 s	28.91 %	0.001 s	500	500
Block Transfer Time	9.56 s	6.73 %	0.01 s	250	250
User Information Bit Transfer Rate	63040 bps	--	35 bps	5	N/A
User Fraction of Input/Output Time	6.74%	--	0.09%	5	N/A

- X.25 adds four overhead bytes to every user data field. The user data field size used was 1024 bytes. Therefore, the packet size was 1028 bytes. The resulting drop in data rate due to X.25 was 0.389% or 247 bps.

Adding all the overhead contributions results in a total data rate drop of 680 bps. Therefore, the theoretical User Information Bit Transfer Rate would be 63320 bps. The highest User Information Bit Transfer Rate throughput measured in the five tests was 63101 bps, which is close to the ideal value. The lowest rate measured in the five tests was 62964 bps. The UNIX operating system, which must also perform some housekeeping functions while running the tests, causes the variance in the User Information Bit Transfer rates. The issuing of these housekeeping functions during a test could conceivably reduce the rate by a few hundred bits per second.

The measured Access Time was 0.27 seconds with 41% of this time attributed to the user. Therefore, approximately 0.16 seconds of the Access Time was due solely to the system. The majority of this time was due to the issuance of system calls to make the X.25 connection. Similar Disengagement Times were also measured.

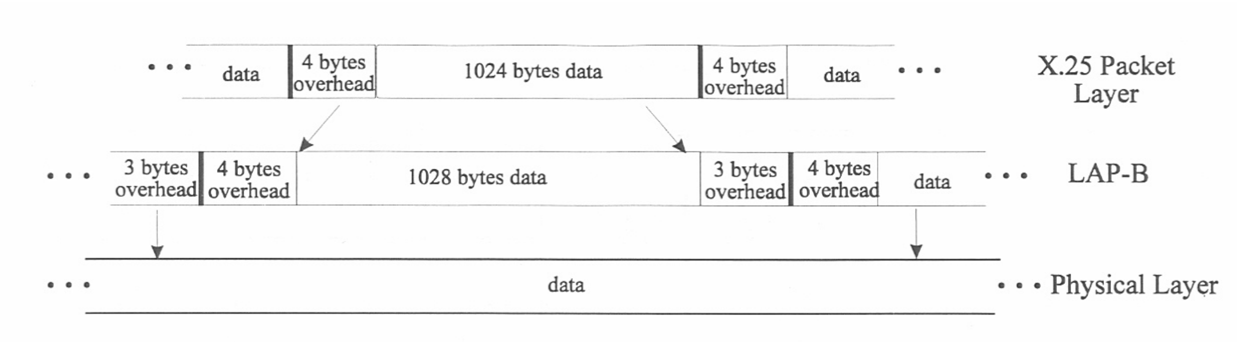


Figure 7. Frame composition for the X.25 over ISDN tests.

<u>ISDN Service Results</u>

In the previous case, X.25 via circuit service, the channel is established prior to establishing the X.25 connections. Therefore, the Access Time is solely the time required to issue and respond to the X.25 CONNECT REQUEST message. For the ISDN service, the Access Time includes the time to setup the satellite channel. In addition, the ISDN service uses a serial port that needs a login process to connect to a remote machine. The workstations used in the test set delay the issuance of the login to prevent unauthorized access (this is part of the operating system and cannot be changed). The login prompt is delayed approximately 6 seconds. The time for the call to be completed (i.e., for the workstations to be connected) took approximately 2 seconds and the login/password/program initiation took approximately 6-7 seconds. All these times together resulted in a measured Access Time of 15.1 seconds (as shown in Table 2c). The disengagement times measured were each approximately a couple of seconds.

Due to the hardware used, there was no way to run the ISDN UIT tests at a full 64 kbps. This is due to the lack of 64-kbps serial ports that can be written to directly. It was determined that the data rate obtained on a straight ISDN channel could be calculated from the X.25 results since

(1) the X.25 tests were run on clean channels (i.e., no errors and thus no retransmissions for the X.25 via circuit service), and

(2) the only difference between the straight ISDN and the X.25 piggybacked on top of the ISDN service is that X.25 adds some overhead packets.

As calculated previously, the X.25 Packet Layer and LAP-B added 680 bps of overhead. Therefore, the estimated User Information Bit Transfer Rate for an ISDN service was approximately 63.7 kbps.

Table 2c. X3.102 Parameter Values for ISDN Service - Test Set Characterization

Parameter	Sample Mean	User Fraction	Precision	# Trials	# Correct Trials
Access Time	15.12 s	0.71%	0.03 s	200	200
Source Disengagement Time	2.68 s	3.42%	0.02 s	200	200
Destination Disengagement Time	1.52 s	4.90%	0.003 s	200	200
Estimated User Information Bit Transfer Rate*	63720 bps	--	--	--	--

* User Information Bit Transfer Rate determined from results of the X.25 via circuit service tests. Subtracted overhead due to X.25 and LAP-B.

3. PRELIMINARY CHARACTERIZATION TESTS

The ACTS characterization tests were split into two testing periods. The first testing period, the Preliminary Experiment Period (PEP), determines an estimate of the performance parameters. The parameter values must be estimated prior to the second testing period, the Full Experiment Period (FEP), in order to set the thresholds for poor or nondelivered service. The thresholds are defined proportional to a "specified value" of a performance parameter. For example, access denial occurs when the duration of an individual access attempt exceeds three times the specified value of the parameter Access Time. The specified value of the Access Time, used in the FEP, equals the sample mean of the Access Time measured in the PEP.

The tests run in the PEP are similar to the tests run in the FEP with the exception that the preliminary experiment is done for nonstressed link conditions and in a loop-back configuration. The nonstressed conditions include clear weather and low traffic. Therefore, referring to the Access Time example again, in times of extreme stress (heavy rain and/or heavy traffic), the system may take an unacceptable amount of time to form a communication session between two points. This trial results in an access denial outcome.

The preliminary characterization tests were run in May, July, October, and November of 1994. The energy per bit per spectral noise density (Eb/No) of the ES and the bit error rate (BER) on other channels than the one under test were measured to obtain a good understanding of how the link was operating at the time of the tests.

3.1 Tests Performed

Four types of services were tested. The first was an ISDN connection over a circuit-switched channel (ISDN service). The configuration of the equipment is shown in Figure 3. The data communication equipment for the ISDN tests is shown at the bottom of the figure. This test began with setting up the ISDN call and ended at the conclusion of the ISDN call.

The second service tested was X.25 over a packet-switched channel (X.25 via packet service). The packet-switched channel is between the ISDN SP on the local and remote ends as shown in Figure 8.[7]

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[7] The data is sent from the originating Earth Station (ES) to the NASA Ground Station's (NGS) packet router. The packet router puts the data on one outgoing broadcast channel to all the X.25-ready ESs. Each X.25-ready ES determines if any of the data is addressed to itself. Therefore, the X.25 packet network uses a double hop to get data from one ES to another ES.

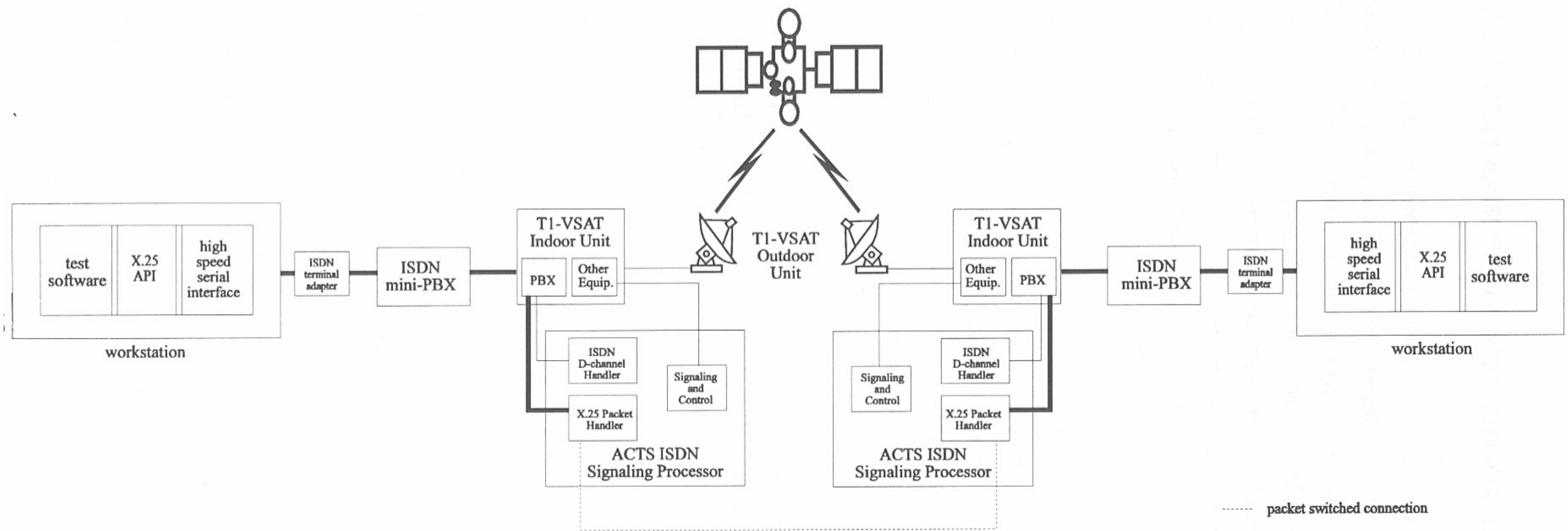

Figure 8. X.25 packet-switched channel over ACTS.

Between the workstation and the ISDN SP, the channel is circuit switched. In addition, due to the design of the ISDN SP, the X.25 is required to piggyback on top of the ISDN. Therefore, as seen in Figure 8, the workstation outputs the X.25 formatted data into an ISDN terminal adapter (TA). The data is then routed through an ISDN mini-PBX to the ES/ISDN SP.

To implement an efficient X.25 packet network, the SP immediately acknowledges the packets. In the case of an errored packet, only the errored packet is retransmitted by the packet handler in the ISDN SP (i.e., selective repeat automatic repeat request (ARQ)). Due to this design of immediate acknowledgment and retransmission only of errored packets, the window and packet sizes used for this service are small. The X.25 via packet service used a window size of 2 and a packet size of 128 bytes.

The way this test was originally conceived, the physical X.25 connection would be setup and torn down for each Access/Disengagement test. However, the packet router was designed so that when the "last" X.25 call is closed, the whole X.25 channel is closed. This includes an ISDN call that is made to the local ISDN SP. Attempting to open the X.25 channel again results in failure. The only way to form another X.25 connection is to restart the X.25 packet handler and packet router (which means powering down the ES to restart the local ISDN SP and having the NASA Ground Station (NGS) restart the packet router). Therefore, in order to run the test as intended by forming and ending several connections in a row, the experiment was changed so that the logical connection, rather than the physical connection, is setup and torn down. So, to prepare for an X.25 packet-switched test, an ISDN call is made to the local SP and then a packet call is made between the local and remote ISDN SPs. This call remains active during all the X.25 packet-switched tests.

Once these preparatory calls have been made, the data extraction software places an X.25 call from the packet handler of the local SP through the packet router at the NGS to the packet handler of the remote unit's SP. For this service, the Access Time is the time required to establish the X.25 connection through the NGS's packet router.

The third service tested was X.25 over a circuit-switched channel (X.25 via circuit service). Figure 9 shows the configuration of this test. The configuration is identical to the X.25 via packet service except the ISDN call is made between the local terminal adapter and the remote terminal adapter instead of between the local terminal adapter and the local ISDN SP. In addition, the window and packet sizes for the X.25 via circuit service were different from those for the X.25 via packet service. The packet size was 1024 bytes and the window size was 127.

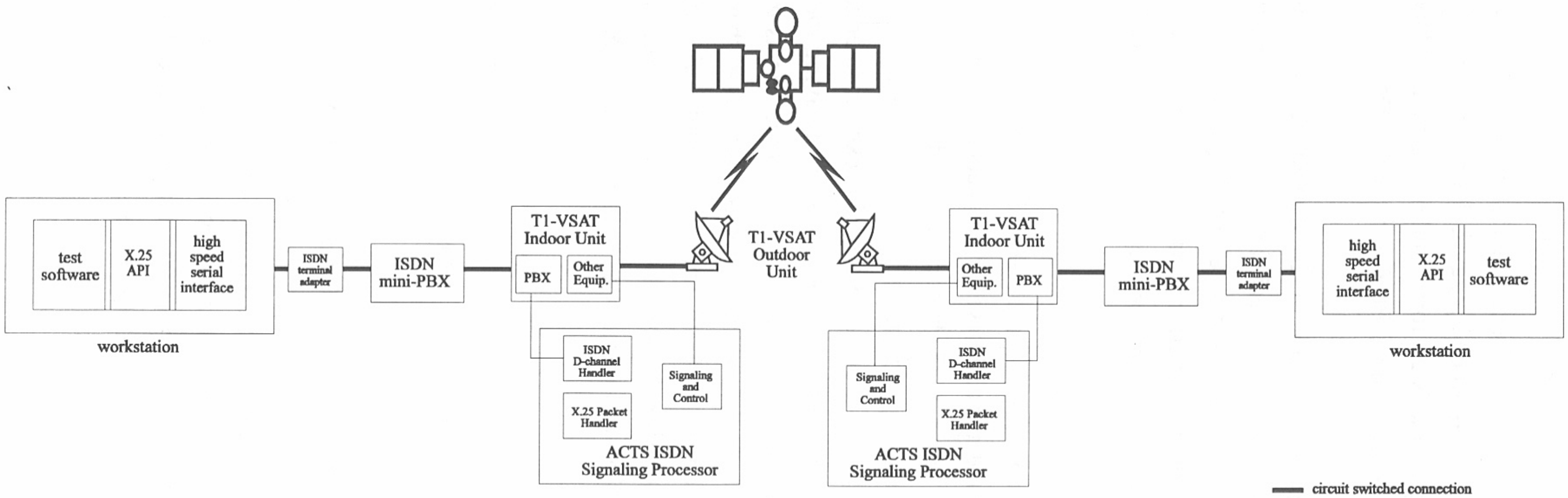

Figure 9. Equipment configuration for the X.25 via circuit service over ACTS.

Prior to the start of the test, an ISDN channel was established between the local and remote SPs. Then the test was started with X.25 "CONNECT REQUEST." Since the satellite circuit was already established in this case, the Access Time consisted solely of the amount of time to make the X.25 connection over the already existing satellite circuit. This connection does not take any additional satellite resources, so the set up time was basically the satellite transmission delay to and from the remote location (or about 0.5 seconds). The main interest in this test was to see the effects of the channel's BER on the UIT data rate. Since X.25 retransmits errored packets and since the X.25 portion of the ISDN SP that immediately acknowledges the packets and only retransmits errored packets was not used, all the data in the channel after an errored packet is received must be retransmitted. This may severely impact the user-perceived data rate. This will show up in the full characterization test when the system is operated in "degraded" situations (e.g., rain).

The fourth service tested was a modem call over a circuit-switched channel (modem service). The modem was operated at 9.6 kbps. This test does not fully stress the satellite's 64-kbps channels as does the X.25 service tests. However, it does provide some valuable information since this type of configuration may be used. The test equipment configuration is shown in Figure 3 with the data communication equipment shown at the bottom of the figure. For this test, the modem's error correction was disabled in order to determine the channel's characteristics (rather than the error correction protocol performance of a given modem).

3.2 Test Results

Table 3 shows the results of the PEP. The tests were run in a loopback mode, from the ITS ES to ACTS and back to the ITS ES. Due to the clear weather conditions, no Access/Disengagement or UIT errors were observed. Therefore, the failure probability parameters are not presented in Table 3.

Each test was run five times and the results of the five tests were analyzed together to obtain a more representative result. The results from the individual tests can be seen in Appendix B.

Modem Service Results

Table 3a shows the results from the modem service test over ACTS. The Access Time increased 16.6 seconds over the test set characterization Access Time. This amount was expected since the observed time to establish a voice call, using ACTS, is approximately 14 seconds. It also approximately takes an additional 2.5 seconds for the login process' prompts and responses to go

Table 3a. X3.102 Parameter Values for Modem Service over ACTS

Parameter	Sample Mean	User Fraction	Precision	# Trials	# Correct Trials
Access Time	50.04 s	0.24%	0.16 s	100	100
Source Disengagement Time	6.59 s	1.37 %	0.27 s	100	100
Destination Disengagement Time	2.44 s	3.00%	0.001 s	100	100
Block Transfer Time	12.54 s	0.94%	0.25 s	250	250
User Information Bit Transfer Rate	7677 bps	--	0.5 bps	5	N/A
User Fraction of Input/Output Time	0.98 %	--	0.02 %	5	N/A

over the satellite. Since the modem line is connected to the same type of card used for a voice call (line circuit card in the T1-VSAT's PBX), a similar amount of time for call setup (i.e., 14 seconds) was expected for the modem service test.

Surprisingly, the Source Disengagement Time decreased by 1.4 seconds from the test set characterization Source Disengagement Time. The reason for the decrease is not known. The Destination Disengagement Time increased by 0.28 seconds over the test set characterization value; this is due to the one-way satellite delay from the destination test set to the originating test set (about an eighth of a second delay from destination test set to satellite + an additional eighth of a second delay from the satellite to the originating test set).

The Block Transfer Time increased by 0.19 seconds when going over ACTS. The User Information Bit Transfer Rate was essentially the same as for the test set characterization. As before, the start and stop overhead bits caused the reduction in bit rate from the modem data rate of 9.6 kbps.

Table 3b. X3.102 Parameter Values for X.25 via Circuit Service over ACTS

Parameter	Sample Mean	User Fraction	Precision	# Trials	# Correct Trials
Access Time	0.85 s	47.19%	0.02 s	500	500
Source Disengagement Time	0.86 s	3.67%	0.002 s	500	500
Destination Disengagement Time	1.18 s	80.03%	0.002 s	500	500
Block Transfer Time	9.67 s	7.31%	0.05 s	250	250
User Information Bit Transfer Rate	63020 bps	--	11 0 bps	5	N/A
User Fraction of Input/Output Time	6.83%	--	0.14%	5	N/A

X.25 via Circuit Service Results

Table 3b shows the results of the PEP for the X.25 via circuit service tests. The Access Time increased by 0.58 seconds over the test set characterization value. For this service, data is sent immediately after the X.25 connection is made (i.e., there is no login session). Since the start of data transfer signals the end of the Access function, Access requires two hops to the satellite and back, as shown in Figure 10.[8] Therefore, the theoretical Access Time increase would be approximately a half of a second (an eighth of a second from the originating user to the satellite + an eighth of a second from the satellite to the destination + a quarter of a second back to the originating user). The observed increase in Access Time is close to the expected increase.

The Source Disengagement Time also increased by 0.58 seconds. The reason for the increase is the same as for the increase in the Access Time. The Destination Disengagement Time increased by

[8] Figure 10 also illustrates that the ISDN channel is already established prior to the X.25 connection. This was described previously in Section 3.1.

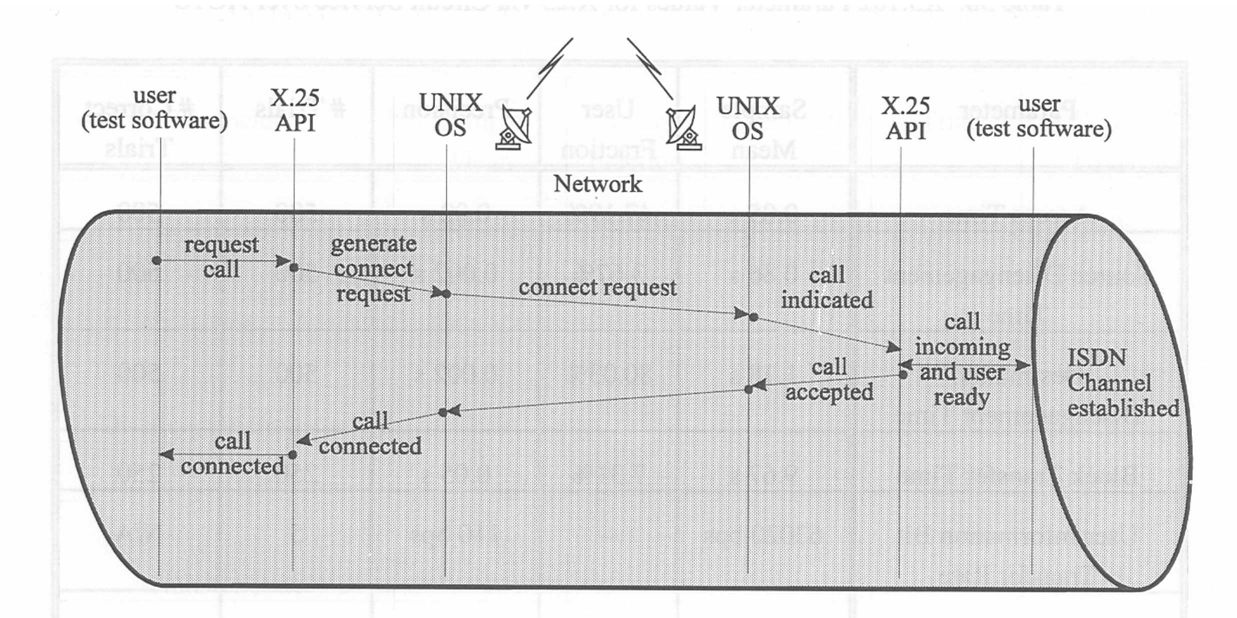

Figure 10. Timeline for X.25 over a circuit-switched channel

0.87 seconds over the test set characterization value. In addition, the User Fraction (UF) of Destination Disengagement Time increased by more than 50 percentage points compared to the test set characterization value. The reason for such a substantial increase is unknown. However, it is interesting to note that the system portion of the Destination Disengagement Time stayed approximately the same for the test set characterization and the PEP (0.22 seconds and 0.24 seconds, respectively). It would seem that the system portion should have increased by approximately a quarter of a second like for the modem service.

The User Information Bit Transfer Rate stayed approximately the same as the Rate for the test set characterization (within the precision value). This was expected since the packet and window sizes were large enough so that the channel was always full of data (i.e., the test set systems did not have to wait for an acknowledgement). In addition, the Block Transfer Time increased by 0.11 seconds over the test set characterization value. Some increase was expected since Block Transfer Time is defined as the average value of the elapsed time between the start of block transfer (on the originating end) and the end of block transfer (on the receiving end) and it takes a finite amount of time for the data to be sent to and from the satellite. However, an increase of approximately a quarter of a second was expected.

X.25 via Packet Service Results

Table 3c shows the PEP results for the X.25 via packet service tests. Since the connection between the workstation and the ISDN SP is a circuit-switched channel, the results obtained in this PEP test were compared to the X.25 via circuit service test set characterization results. The Access Time increased by 1.2 seconds, the Source Disengagement Time increased by 1.4 seconds and the Destination Disengagement Time increased by 2.0 seconds. These increases are the amount of time it takes to set up or tear down the satellite X.25 packet-switched call through the packet router at the NGS.

The User Information Bit Transfer Rate fell to 10.4 kbps. This performance reduction is due to a hardware limitation in the ISDN SP. Contributing factors include the processing power and buffer size in the ISDN SP and the latency in the NGS packet router.[9] However, it is anticipated that the performance will improve when the tests are run between two separate locations (i.e., two different SPs handle the call versus only one SP handling the call). The performance is expected to increase because in the loopback case (where only one SP is used), both packet ports in the ISDN SP are used and the "data between the two [ISDN] SP cards are routed through the MAC [Macintosh computer] host CPU."[9] The limitation is on the outside vendor plugin card which cannot become a bus master. For more information on the design and operation of the ISDN SP see [9].

ISDN Service Results

Table 3d shows the results of the PEP for the ISDN service. For this service, the Access Time increased 8.4 seconds. Approximately 2.5 seconds of this increase was due to the transmission time of a login session over the satellite. The remaining increase was due to the ISDN call setup time. The Source Disengagement Time increased by 1.3 seconds and the Destination Disengagement Time increased by 0.29 seconds. The reason the Source Disengagement Time increased by 1.3 seconds is not known. The Destination Disengagement Time increase is approximately the one-way transmission from the originating site to the receiving site, via the satellite.

[9] E-mail communication, Moorthy Hariharan, COMSAT Laboratories, November 1994.

Table 3c. X3.102 Parameter Values for X.25 via Packet Service over ACTS

Parameter	Sample Mean	User Fraction	Precision	# Trials	# Correct Trials
Access Time	1.47 s	47.25%	0.03 s	500	500
Source Disengagement Time	1.72 s	1.97%	0.03 s	500	500
Destination Disengagement Time	2.34 s	79.29%	0.04 s	500	500
Block Transfer Time	12.03 s	1.45%	0.005 s	250	250
User Information Bit Transfer Rate	10390 bps	--	0 bps	5	N/A
User Fraction of Input/Output Time	1.11%	--	0.008%	5	N/A

Table 3d. X3.102 Parameter Values for ISDN Service over ACTS

Parameter	Sample Mean	User Fraction	Precision	# trials	# correct trials
Access Time	23.48 sec	0.46%	0.10 sec	200	200
Source Disengagement Time	3.95 sec	0.32%	0.08 sec	200	200
Destination Disengagement Time	1.81 sec	4.11%	0.003 sec	200	200
Estimated User Information Bit Transfer Rate *	63700 bps	--	--	--	--

* User Information Bit Transfer Rate determined from results of the X.25 via circuit service tests. Subtracted overhead due to X.25 and LAP-B.

3.3 Specified Values Used in the FEP

The parameter values presented in Table 3 are used to define the specified values for use in the FEP tests. The specified values used are equal to the measured mean parameter values and are used to determine the failure thresholds.

According to the ANS X3.102 standard, an access timeout occurs whenever the duration of an individual access attempt exceeds three times the specified value of the Access Time. Similar definitions, where the timeout threshold is three times the specified value, are used to define Block Transfer, Source Disengagement, and Destination Disengagement timeouts.

A set of thresholds determines the value of the Transfer Denial Probability. The Transfer Denial Probability depends on the measured values of the Bit Error Probability, Bit Loss Probability, Extra Bit Probability and User Information Bit Transfer Rate. The standard defines the threshold for each bit transfer failure probability as the square root of the specified value; the threshold for the User Information Bit Transfer Rate is defined as one-third of the specified value. A Transfer denial outcome is said to have been observed if the performance of a transfer availability trial is worse than the threshold for any of the four parameters and the degradation is attributed to system nonperformance. The ANS X3.102 standard [6] describes how to determine if the user or the system should be attributed with nonperformance.

The data reduction software looks for the specified values in the files *spi.acd,* for the Access/Disengagement tests and *spi.xfr,* for the User Information Transfer tests. Table 4 shows the content of each line in *spi.acd* and Table 5 shows the equivalent information in *spi.xfr*. The first line contains the words SPECIFICATIONS INPUT. The second line contains an identifier that specifies the type of test the *spi* file is used to evaluate. This identifier can be blank or contain any set of words. The identifier is not used by the program. It is for the benefit of the user. The third line contains an assessment option code. The first number is for Access, the second number is for User Information Transfer, and the third number is for Disengagement. The option code is 1 if the option is to be evaluated and 0 if the option is not to be evaluated. Since the measurement software expects the Access and Disengagement parameters to be evaluated in one run and the User Information Transfer parameters to be evaluated in a separate run, the codes used should be

1 0 1

for Access/Disengagement tests and

0 1 0

for User Information Transfer tests. The remaining lines are explained sufficiently in the tables.

Figures 11 through 14 show the *spi* files used in the FEP tests; they contain the specified performance parameter values. The User Information Transfer tests require specified performance parameter values for the failure probability parameters. However, as stated earlier, no bit errors occurred in the PEP. Therefore, the Bit Error Probability was specified at the designed performance level of the T1-VSAT (i.e., BER $\leq 10^{-6}$) and the Bit Loss and Extra Bit Probabilities were specified to be two orders of magnitudes better than the Bit Error Probability. The remaining specified values came from the measured mean parameter values.

Table 4. File Description for *spi.acd* for Access/Disengagement Tests

Line #	Character Field	Contents
1	1 - 32	SPECIFICATIONS INPUT
2	1 - 64	Test Type Identifier
3	1 - 4 5 - 8 9 - 12	Access Assessment Option: 1 User Information Transfer Assessment Option: 0 Disengagement Assessment Option: 1
4	1 - 16 17 - 32	Access Time User Fraction of Access Time
5	1 - 16 17 - 32 33 - 48 49 - 64	Source Disengagement Time User Fraction of Source Disengagement Time Destination Disengagement Time User Fraction of Destination Disengagement Time

Table 5. File Description for *spi.xfr* for User Information Transfer Tests

Line #	Character Field	Contents
1	1 - 32	SPECIFICATIONS INPUT
2	1 - 64	Test Type Identifier
3	1 - 4 5 - 8 9 - 12	Access Assessment Option: 0 User Information Transfer Assessment Option: 1 Disengagement Assessment Option: 0
4	1 - 16 17 - 32 33 - 48 49 - 64	Block Transfer Time User Fraction of Block Transfer Time User Information Bit Transfer Rate User Fraction of Input/Output Time
5	1 - 16 17 - 32 33 - 48 49 - 64	Bit Error Probability for Transfer Sample Bit Loss Probability for Transfer Sample Extra Bit Probability for Transfer Sample Min. # of Bit Transfer Attempts for Transfer Sample
6	1 - 8 9 - 16 17 - 24 25 - 32	User Information Window Size (bits) Maximum Bit Shift in Bit Error Identification Algorithm (bits) Maximum Shift in Undelivered Bit Identification Algorithm (bits) Maximum Shift in Extra Bit Identification Algorithm (bits)

```
SPECIFICATIONS INPUT
ACTS modem tests
 1  0  1
  50.04E+00     0.01E+00
   6.59E+00     0.05E+00     2.44E+00     0.05E+00


SPECIFICATIONS INPUT
ACTS modem tests
 0  1  0
  12.54E+00      0.03E+00      7.677E+03      0.03E+00
    1.0E-06         1.0E-08         1.0E-08         320000.
  16  64000.  96000.  96000.
```

Figure 11. *spi.acd* and *spi.xfr*, respectively for FEP modem service tests.

```
SPECIFICATIONS INPUT
ACTS X.25 CKT tests
 1  0  1
   0.85E+00     0.50E+00
   0.86E+00     0.05E+00     1.18E+00     0.80E+00


SPECIFICATIONS INPUT
ACTS X.25 CKT tests
 0  1  0
   9.67E+00       0.08E+00      63.020E+03      0.07E+00
    1.0E-06          1.0E-08          1.0E-08          320000.
  16  64000.  96000.  96000.
```

Figure 12. *spi.acd* and *spi.xfr*, respectively for FEP X.25 via circuit service tests.

```
SPECIFICATIONS INPUT
ACTS X.25 PKT tests
 1  0  1
   1.47E+00      0.50E+00
   1.72E+00      0.05E+00      2.34E+00      0.80E+00


SPECIFICATIONS INPUT
ACTS X.25 PKT tests
 0  1  0
   12.03E+00        0.05E+00      10.390E+03      0.05E+00
      1.0E-06          1.0E-08          1.0E-08          320000.
   16   64000.  96000.  96000.
```

Figure 13. *spi.acd* and *spi.xfr*, respectively for FEP X.25 via packet service tests.

```
SPECIFICATIONS INPUT
ACTS ISDN tests
 1  0  1
  23.48E+00      0.01E+00
    3.95E+00      0.01E+00      1.81E+00      0.05E+00
```

Figure 14. *spi.acd* for FEP ISDN service tests.

4. FULL CHARACTERIZATION TESTS

The FEP tests were performed from the ITS site in Boulder, CO to the NASA Lewis Research Center in Cleveland, OH over a two-month period from late December to late February, 1995. The results were analyzed using the evaluation thresholds determined by the PEP tests.

Originally, the FEP tests were to be conducted over a six-month period, split between two different destination locations. However, because the mean PEP and FEP parameter estimates were so similar, they were considered to come from the same population, and thus the FEP tests were cut short.

4.1 FEP Results

Tables 6a through 9a show the results of the FEP. The tests were run under the prevailing weather and traffic conditions. For all of the FEP tests, the ITS ES's Eb/No varied by only 3.0 dB. This value is within the ES design specification and therefore did not result in the generation of bit errors. For the NASA ES, the Eb/No varied by 6.4 dB over all the tests. However, two different antenna sizes were used on the NASA ES – a 2.4-m antenna for a majority of the tests and a 1.2-m antenna for the remaining tests. When the signal level was evaluated with respect to the antenna size, the Eb/No varied by only 4.1 dB when the 2.4-m antenna was used and by only 1.5 dB when the 1.2-m antenna was used. The 4.1-dB signal level variation is not within the design specification of 3.0 dB (without invoking the Forward Error Correction); however, due to the use of the 2.4-m antenna, no bit errors were generated. Therefore, even though the tests were not solely run under clear weather conditions, the ES performance did not change substantially for any of the tests. There were no Access/Disengagement errors during the FEP and only one UIT error occurred (for the modem service tests).

Each test was run a number of times and the results from the tests were analyzed together to obtain a more representative result. The results from the individual tests are included in Appendix C.

Table 6a. X3.l 02 Parameter Values for Modem Service - FEP Results

Parameter	Sample Mean	User Fraction	Precision	# Trials	# Correct Trials
Access Time	50.25	0.26%	0.17 s	80	80
Source Disengagement Time	6.54 s	1.39 %	0.36 s	80	80
Destination Disengagement Time	2.46 s	3.00 %	0.004 s	80	80
Block Transfer Time	12.63 s	1.02 %	0.26 s	250	249
User Information Bit Transfer Rate	7678 bps	--	2 bps	5	N/A
User Fraction of Input/Output Time	1.07 %	--	0.06%	5	N/A

Modem Service Results

Table 6a shows the time and rate parameter estimates for the modem service tests. Comparing this table to Table 3a shows a striking similarity in the estimates of the performance parameters. To prove the similarity of the estimated parameters, the data was analyzed to determine if the FEP and the PEP data could be pooled. The results of the pooling are shown in Table 6b, as are the rest of the performance parameter estimates.

Table 6b specifies different levels of pooling – pooling all of the trial estimates (trials), pooling the test means (tests), and pooling the level means (levels).[10] The first type of pooling examines the null hypothesis that all test means are equal. The parameter test mean for test number j, a_j, is calculated by

[10] Tests are made up of a number of trials. For example, for the Access/Disengagement modem tests, each test was made up of 20 trials.

Table 6b. Summary of Performance Parameter Estimates for Modem Service

Performance Parameters	95% Lower Limit	Sample Mean	95% Upper Limit	Pooling* Ability	Number of Tests	Total Number of Trials
Access Time (s)	50.02	50.14	50.25	trail	9	180
User Fraction of Access Time (%)	0.22	0.25	0.28	trial	9	180
Incorrect Access Probability	0	0	7.5×10^{-2}**	trial	9	180
Access Denial Probability	0	0	7.5×10^{-2}**	trial	9	180
Access Outage Probability	0	0	7.5×10^{-2}**	trial	9	180
Block Transfer Time (s)	12.53	12.59	12.64	trial	10	499
User Fraction of Block Transfer Time	0.94	0.98	1.02	trial	10	499
User Fraction of Input/Output Time	0.98	1.03	1.07	test	10	10
User Information Bit Transfer Rate (bps)	7677	7678	7679	test	10	10
Bit Error Probability	0	0	8.9×10^{-7}**	trial	10	15999992
Bit Loss Probability	2.4×10^{-8}	5.0×10^{-7}	3.8×10^{-6}	trial	10	16000000
Extra Bit Probability	0	0	8.9×10^{-7}**	trial	10	15999992
Block Error Probability	0	2.0×10^{-3}	3.4×10^{-2}	trial	10	500
Block Loss Probability	0	0	2.9×10^{-2}**	trial	10	500
Extra Block Probability	0	0	2.9×10^{-2}**	trial	10	500
Transfer Denial Probability	0	0	5.2×10^{-2}**	trial	10	265
Source Disengagement Time (s)	6.41	6.57	6.73	test	9	180
User Fraction of Source Disengagement Time (%)	1.35	1.38	1.41	test	9	180
Source Disengagement Denial Probability	0	0	7.5×10^{-2}**	trial	9	180
Destination Disengagement Time	2.44	2.45	2.46	level	9	180
User Fraction of Destination Disengagement Time	2.98	3.00	3.02	level	9	180
Destination Disengagement Denial Probability	0	0	7.5×10^{-2}**	trial	9	180

* Pooled by destination city.

** Assumed that the conditional probability (an error occurred given that an error just occurred) is 0.8.

$$a_j = \frac{1}{N}\sum_{i=1}^{N} a_i$$

where a_i is the estimated parameter value for trial number i and the number of trials per test is N. If the hypothesis is accepted, the trials from all the tests are considered to come from the same population and the results can be pooled. The second type of pooling examines the hypothesis that the all level means of a variable condition (in this case the destination city) are equal. The level mean, a_L, is calculated by

$$a_L = \frac{1}{M}\sum_{j=1}^{M} a_j$$

where M is the number of tests with a given level value. If the hypothesis is accepted, means from all tests are considered to come from the same population and can be pooled. If neither hypothesis can be accepted, there is a significant difference among the parameter estimates obtained from the different destination locations. The means of each level of the selected variable condition (destination location in this case) are pooled. This pooling provides the least precision of the three.

For the modem tests, all the parameters can be considered to come from the same population with the exception of the Destination Disengagement (and user fraction) Time. The mean Destination Disengagement Time for the two set of tests were only 0.002 seconds apart. They are not considered to come from the same population however, due to the very small precision window obtained for the tests (0.001 s for the PEP and 0.004 s for the FEP). However, due to the small numerical difference between the parameter estimates, it was determined that additional testing would not provide any more information.

In one of the last modem tests performed, 8 consecutive bits were lost (test number 5711). This was the only time the received data differed from the transmitted data.

Table 7a. X3.102 Parameter Values for X.25 via Circuit Service - FEP Results

Parameter	Sample Mean	User Fraction	Precision	# Trials	# Correct Trials
Access Time	0.85	47.38 %	0.02 s	600	600
Source Disengagement Time	0.86 s	3.60 %	0.003 s	600	600
Destination Disengagement Time	1.18 s	80.17 %	0.005 s	600	600
Block Transfer Time	9.66 s	7.26 %	0.02 s	400	400
User Information Bit Transfer Rate	62980 bps	--	60 bps	8	N/A
User Fraction of Input/Output Time	6.79 %	--	0.06 %	8	N/A

X.25 via Circuit Service Results

Table 7a shows the time and rate parameter estimates for the X.25 via circuit service tests. Comparing this table to Table 3b shows the performance parameter estimates varied little from the PEP values. To prove the similarity of the estimated parameters, the data was analyzed to determine if the PEP and the PEP data could be pooled. The results of the pooling are shown in Table 7b, as are the rest of the performance parameter estimates.

All the parameters can be considered to come from the same population with the exception of the Source Disengagement (and user fraction) Time. The mean Source Disengagement Time for the two set of tests is only 0.006 seconds apart. They are not considered to come from the same population however, due to the very small precision window obtained for the tests (0.002 s for the PEP and 0.003 s for the FEP). However, due to the small numerical difference between the parameter estimates, it was determined that additional testing would not provide any more information.

Table 7b. Summary of Performance Parameter Estimates for X.25 via Circuit Service

Performance Parameters	95% Lower Limit	Sample Mean	95% Upper Limit	Pooling* Ability	Number of Tests	Total Number of Trials
Access Time (s)	0.83	0.85	0.86	test	11	1100
User Fraction of Access Time (%)	46.67	47.29	47.91	test	11	1100
Incorrect Access Probability	0	0	1.3×10^{-2}**	trial	11	1100
Access Denial Probability	0	0	1.3×10^{-2}**	trial	11	1100
Access Outage Probability	0	0	1.3×10^{-2}**	trial	11	1100
Block Transfer Time (s)	9.64	9.66	9.68	trial	13	650
User Fraction of Block Transfer Time	7.11	7.28	7.45	trial	13	650
User Fraction of Input/Output Time	6.75	6.80	6.86	test	13	13
User Information Bit Transfer Rate (bps)	62950	63000	63040	test	13	13
Bit Error Probability	0	0	6.0×10^{-7}**	trial	13	20800000
Bit Loss Probability	0	0	6.0×10^{-7}**	trial	13	20800000
Extra Bit Probability	0	0	6.0×10^{-7}**	trial	13	20800000
Block Error Probability	0	0	2.2×10^{-2}**	trial	13	650
Block Loss Probability	0	0	2.2×10^{-2}**	trial	13	650
Extra Block Probability	0	0	2.2×10^{-2}**	trial	13	650
Transfer Denial Probability	0	0	5.0×10^{-2}**	trial	13	277
Source Disengagement Time (s)	0.85	0.86	0.87	level	11	1100
User Fraction of Source Disengagement Time (%)	3.50	3.63	3.77	level	11	1100
Source Disengagement Denial Probability	0	0	1.3×10^{-2}**	trial	11	1100
Destination Disengagement Time	1.17	1.18	1.18	test	11	1100
User Fraction of Destination Disengagement Time	8.00	8.01	8.02	test	11	1100
Destination Disengagement Denial Probability	0	0	1.3×10^{-2}**	trial	11	1100

* Pooled by destination city.

** Assumed that the conditional probability (an error occurs given that an error just occurred) is 0.8.

Table 8a. X3.102 Parameter Values for X.25 via Packet Service - FEP Results

Parameter	Sample Mean	User Fraction	Precision	# Trials	# Correct Trials
Access Time	1.48 s	47.36 %	0.01 s	700	700
Source Disengagement Time	1.67 s	2.17 %	0.006 s	700	700
Destination Disengagement Time	2.29 s	81.49 %	0.009 s	700	700
Block Transfer Time	12.01 s	1.40 %	0.005 s	350	350
User Information Bit Transfer Rate	10400 bps	--	5 bps	7	N/A
User Fraction of Input/Output Time	1.12 %	--	0.02 %	7	N/A

X.25 via Packet Service Results

Table 8a shows the FEP time and rate parameter estimates for the X.25 via packet service tests. Comparing this table to Table 3c shows a close similarity in the estimates of the performance parameters. To prove the similarity of the estimated parameters, the data was analyzed to determine if the FEP and PEP data could be pooled. The results of the pooling are shown in Table 8b, as are the rest of the performance parameter estimates.

All the parameters can be considered to come from the same population with the exception of the User Information Bit Transfer Rate (and the User Fraction of Input/Output Time from which the User Information Bit Transfer Rate was calculated). The mean User Information Bit Transfer Rate was 10390 bps for the PEP tests and 10400 bps for the FEP tests. The difference between the two means is 10 bps which is less than 0.1 % of the Transfer Rate. The Rates are not considered to come from the same population due to the small precision window obtained for the tests. Table 3c shows

Table 8b. Summary of Performance Parameter Estimates for X.25 via Packet Service

Performance Parameters	95% Lower Limit	Sample Mean	95% Upper Limit	Pooling* Ability	Number of Tests	Total Number of Trials
Access Time (s)	1.47	1.48	1.50	test	12	1200
User Fraction of Access Time (%)	46.98	47.31	47.64	test	12	1200
Incorrect Access Probability	0	0	1.2×10^{-2}**	trial	12	1200
Access Denial Probability	0	0	1.2×10^{-2}**	trial	12	1200
Access Outage Probability	0	0	1.2×10^{-2}**	trial	12	1200
Block Transfer Time (s)	11.81	12.02	12.23	trial	12	600
User Fraction of Block Transfer Time	1.08	1.42	1.76	trial	12	600
User Fraction of Input/Output Time	1.10	1.12	1.14	level	12	12
User Information Bit Transfer Rate (bps)	10390	10400	10400	level	12	12
Bit Error Probability	0	0	8.9×10^{-7}**	trial	12	19200000
Bit Loss Probability	0	0	8.9×10^{-7}**	trial	12	19200000
Extra Bit Probability	0	0	8.9×10^{-7}**	trial	12	19200000
Block Error Probability	0	0	2.4×10^{-2}**	trial	12	600
Block Loss Probability	0	0	2.4×10^{-2}**	trial	12	600
Extra Block Probability	0	0	2.4×10^{-2}**	trial	12	600
Transfer Denial Probability	0	0	5.1×10^{-2}**	trial	12	273
Source Disengagement Time (s)	1.67	1.69	1.70	trial	12	1200
User Fraction of Source Disengagement Time (%)	2.05	2.08	2.11	trial	12	1200
Source Disengagement Denial Probability	0	0	1.2×10^{-2}**	trial	12	1200
Destination Disengagement Time	2.29	2.31	2.32	trial	12	1200
User Fraction of Destination Disengagement Time	80.0	80.6	81.1	trial	12	1200
Destination Disengagement Denial Probability	0	0	1.2×10^{-2}**	trial	12	1200

* Pooled by destination city.

** Assumed that the conditional probability (an error occurs given that an error just occurred) is 0.8.

Table 9a. X3.1 02 Parameter Values for ISDN Service - FEP Results

Parameter	Sample Mean	User Fraction	Precision	# trials	# correct trials
Access Time (with packet router ON)	24.62 s	0.43 %	0.135 s	200	200
Access Time (with packet router OFF)	27.03 s	0.40 %	0.345 s	160	160
Source Disengagement Time	4.10 s	2.24%	0.141 s	360	360
Destination Disengagement Time	1.86 s	4.03 %	0.017 s	360	360
Estimated User Information Bit Transfer Rate*	63660 bps	--	--	--	--

* User Information Bit Transfer Rate determined from the results of the X.25 via circuit service tests. Subtracted overhead due to X.25 and LAP-B.

that the precision for the PEP tests was 0 bps. The analysis software only prints out the four most significant digits (i.e., the PEP User Information Bit Transfer Rate's 95th lower confidence limit, the mean and the 95th upper confidence limit all equal 0.1039E+5). If more digits were listed, the absolute precision would be between 0 and 5 bps. The precision for the FEP test is also 5 bps. Therefore, due to the small numerical difference between the parameter estimates, it was determined that additional testing would not provide any more information.

<u>ISDN Service Results</u>

Table 9a shows the FEP time and rate parameter estimates and Table 9b shows the pooled PEP/FEP parameter estimates. The Disengagement and Rate parameter estimates of Table 9a are similar to the values shown in Table 3d. Table 9b shows the results of pooling the FEP and PEP data. As for the other services, one parameter fails the pooling test due to a very small precision window. For the ISDN service, the parameter is the Destination Disengagement Time. The absolute precision for

Table 9b. Summary of Performance Parameter Estimates for ISDN Service (with the packet router OFF)

Performance Parameters	95% Lower Limit	Sample Mean	95% Upper Limit	Pooling* Ability	Number of Tests	Total Number of Trials
Access Time (s)	17.61	25.25**	32.89	level	9	360
User Fraction of Access Time (%)	0.29	0.43	0.57	level	9	360
Incorrect Access Probability	0	0	3.9×10^{-2}***	trial	9	360
Access Denial Probability	0	0	3.9×10^{-2}***	trial	9	360
Access Outage Probability	0	0	3.9×10^{-2}***	trial	9	360
User Information Bit Transfer Rate (bps)****	--	63660	--	--	--	--
Source Disengagement Time (s)	3.84	3.98	4.11	test	9	360
User Fraction of Source Disengagement Time (%)	2.24	2.31	2.38	test	9	360
Source Disengagement Denial Probability	0	0	3.9×10^{-2}***	trial	9	360
Destination Disengagement Time	1.76	1.831	1.90	level	9	360
User Fraction of Destination Disengagement Time	4.00	4.09	4.18	level	9	360
Destination Disengagement Denial Probability	0	0	3.9×10^{-2}***	trial	9	360

* Pooled by destination city.

** The FEP ISDN service tests were run with the ISDN terminal adapter set to answer on the second ring. Due to the error, the PEP and the FEP Access Times could not be pooled. The PEP Access Time (which correctly answered the ISDN terminal adapter on the first ring) should be used as shown in Table 3d (23.48 ± 0.10 s).

*** Assumed that the conditional probability (an error occurs given that an error just occurred) is 0.8.

**** User Information Bit Transfer Rate determined from the results of the X.25 via circuit service tests. Subtracted overhead due to X.25 and LAP-B.

Table 10. Comparison of ISDN Service Access Times

Set Description	# of Tests in Set	Access Time Test Means	Mean of Test Means
PEP tests	5	23.490 s 23.400 s 23.367 s 23.407 s 23.712 s	23.48 s
FEP tests with the Packet Router OFF	4	26.866 s 27.346 s 26.962 s 26.932 s	27.03 s
FEP tests with the Packet Router ON	5	24.511 s 24.530 s 24.776 s 24.613 s 24.677 s	24.62 s

the PEP tests was 0.003 seconds and the precision for the FEP tests was 0.017 seconds. The mean for the two test series were just 0.05 seconds apart. Due to the small numerical difference between the parameter estimates, it was determined that additional testing would not provide any more information.

The Access Time was also unable to be pooled. For this parameter, it was not due to a small precision window. For the ISDN service, the Access Times can be grouped into three sets as shown in Table 10. The first set is for the PEP tests. The mean Access Times for the PEP tests range from 23.367 seconds to 23.712 seconds. The mean of the five test means was 23.48 seconds. The second set is for the FEP tests when the packet router is turned OFF. The mean Access Times for the FEP, with the packet router OFF, ranged from 26.866 seconds to 27.346 seconds. The mean of the four test means was 27.03 seconds. The third set is for the FEP tests when the packet router is turned ON. The mean Access Times for the FEP, with the packet router ON, ranged from 24.511 seconds to 24.776 seconds. The mean of the five test means was 24.62 seconds.

The packet router is normally only used in X.25 communications. However, for ISDN communications, the D-channel uses the packet router, when available (i.e., when it is turned ON), for call setup. When the packet router is not available, call setup is performed using the ACTS orderwires. Original estimates were that the packet router would reduce the call setup time by 1.5 to 3 seconds. Comparing the Access Time mean for the FEP with the packet router OFF, 27.03 seconds, and the mean for the PEP with the packet router ON, 24.62 seconds, results in a call setup improvement of 2.41 seconds. The observed improvement agrees with what was anticipated.

As stated previously, Table 9b shows that the Access Time measured in the PEP and FEP (with the packet router OFF) tests came from two separate populations. The packet router remained OFF during the PEP tests though.[11] However, comparing the Access Times of the PEP tests to the FEP with the packet router OFF shows a difference of 3.5 seconds. After the conclusion of the tests, it was discovered that the ISDN terminal adapter was set to answer on the second ring for the FEP. The terminal adapter was set to answer after the first ring for the PEP tests. The change occurred during the shipment/setup of the equipment in Cleveland. Therefore, for ISDN service with the packet router OFF, the mean Access Time and precision that should be used is 23.48 ± 0.10 seconds as shown in Table 3d.

4.2 Discussion of Results and Tests

The major result from the PEP and FEP tests was that even though the tests were performed between different cities, at different times of the year (PEP tests mainly performed in the spring/summer and FEP tests mainly performed in the fall/winter), and under the prevailing traffic conditions (which were dependent on the number of other experimenters using the satellite), much of the data could still be pooled. This implies that the data came from the same population. Therefore, even though the tests were only performed between two city sets, the results can be considered valid for other locations operating under similar conditions.

A surprising result was that the X.25 via packet service throughput performance did not improve as expected in Section 3.2 when the tests were run between two separate locations. Designers of the ISDN SP thought the performance would improve when the remote packet handler was implemented in a different computer from the local packet handler. This was not observed in these tests. The PEP

[11] The packet router was not functional until mid-November, 1994 and the ISDN service PEP tests were performed in mid- to late-October of that year.

tests, performed in a loopback mode in Boulder, and the FEP tests, performed between Boulder and Cleveland, resulted in the same throughput value of 10.4 kbps.

In addition, the throughput was much less than the originally expected 64 kbps. The ISDN SP designers mentioned that they measured the throughput at approximately 20 kbps (still less than the originally anticipated 64 kbps) with a block size of 128 bytes. Several tests were run at ITS to understand this difference in measured throughput. Our tests found that when the total data block transferred was smaller than 4096 bytes, the measured throughput was approximately 20 kbps. However, when the data block size exceeds 4096 bytes, as in our tests, the measured throughput dropped to approximately 10 kbps. This finding suggests the existence of a 4096-byte buffer somewhere in the system. This is currently being investigated to determine the location of this buffer.

A final observation was that the BER performance of the system was extremely good. All the tests except for one resulted in clean data transfer; eight consecutive bits were lost in one test. These results are consistent with BER measurements NASA has taken for the ITS ES. NASA runs BER tests for each T1-VSAT in the network when the satellite is operating in baseband processor mode (the necessary mode for T1-VSAT operation). For the ITS ES, the BER tests have demonstrated longterm error-free operation.

4.3 Problems and Recommendations for Test Set Improvement

One of the main problems experienced during the testing period was that tests would sometimes fail halfway through a test due to the computer system and not be able to recover. This occurred most often during an Access/Disengagement test; the serial port would lock up and could only be corrected by rebooting the system. It would not have been correct to count all the remaining tests as Access Denials or Access Outages since the problem had nothing to do with the network or user; it had to do with the test set itself.

Another problem experienced was the limit on the amount of data that could be transferred for each test. Data had to be limited for two reasons. First, an increase in the amount of data taken increases the amount of time needed to reduce/analyze the data. Due to the algorithms used to detect lost, errored, or extra bits, a relatively small increase in the transmitted data size results in a larger increase in data reduction time. Second, the data had to be stored. The collection of 1.6 Mb of data for each of 60 tests (five tests per service for 4 services for the test set characterization, the PEP tests, and the FEP tests) adds up to 96 Mb of stored data. If the amount of data per test is increased much beyond this level, the amount of data to control becomes unruly.

Since the amount of data to be transferred was on the order of megabits, and not tens or hundreds of megabits, it was impossible to measure the ACTS Bit Error/Loss/Extra Probability with the desired accuracy. NASA took BER measurements consistently on two channels for each ES. They restarted the BER measurement every 10 minutes and recorded the measured BER at the end of the 10 minutes. In 10 minutes, 76.8 Mb get transferred in two channels. Therefore, assuming a half of an errored bit (so the error is not seen) during the 10 minute test, the measured BER would be 6.5×10^{-9}. A typical example of a 24-hour plot for ES #9 (the ITS site), on both the uplink and downlink, is shown in Figure 15. As this plot shows, no errors were received during the testing period.[12] Therefore, the actual BER of the ACTS system under normal conditions is very low and performing tests using 1.6 Mb of data, even for 50 trials, does not suffice to determine the system's performance.

A solution to both of these problems would be to operate the tests in real time and to calculate the results cumulatively rather than just at the end of the test. With such a system, the tests could be kept running the whole time the system under test is active so that an access denial (which may be days or weeks between occurrences) or bit error outcomes (which may be hours or days between occurrences) could be "caught."

One last problem identified was that the software was originally designed to only work with serial ports. In order to use the X3.141 testing system with the X.25 protocol, the software had to be changed to accommodate the X.25 API. This required extensive changes and should not have been required – especially if the goal is for any user, even one that does not know the test software intimately, to be able to use the system to test their data communication network. Ideally, the system should be flexible enough to accommodate an unlimited number of software (e.g., APIs) and hardware interfaces. If such a system were built, the interfaces that are available today would not limit the system at some future time when different interfaces are then available. In summary, at some point, an effort needs to be undertaken to start from scratch and make the system interface-independent.

[12] During the period from 1400 to 2330 hours, NASA was not taking BER measurements for this T1-VSAT. The symbols at 2010 and 2250 hours show that the T1-VSAT requested to be shut down and then reacquired at those times.

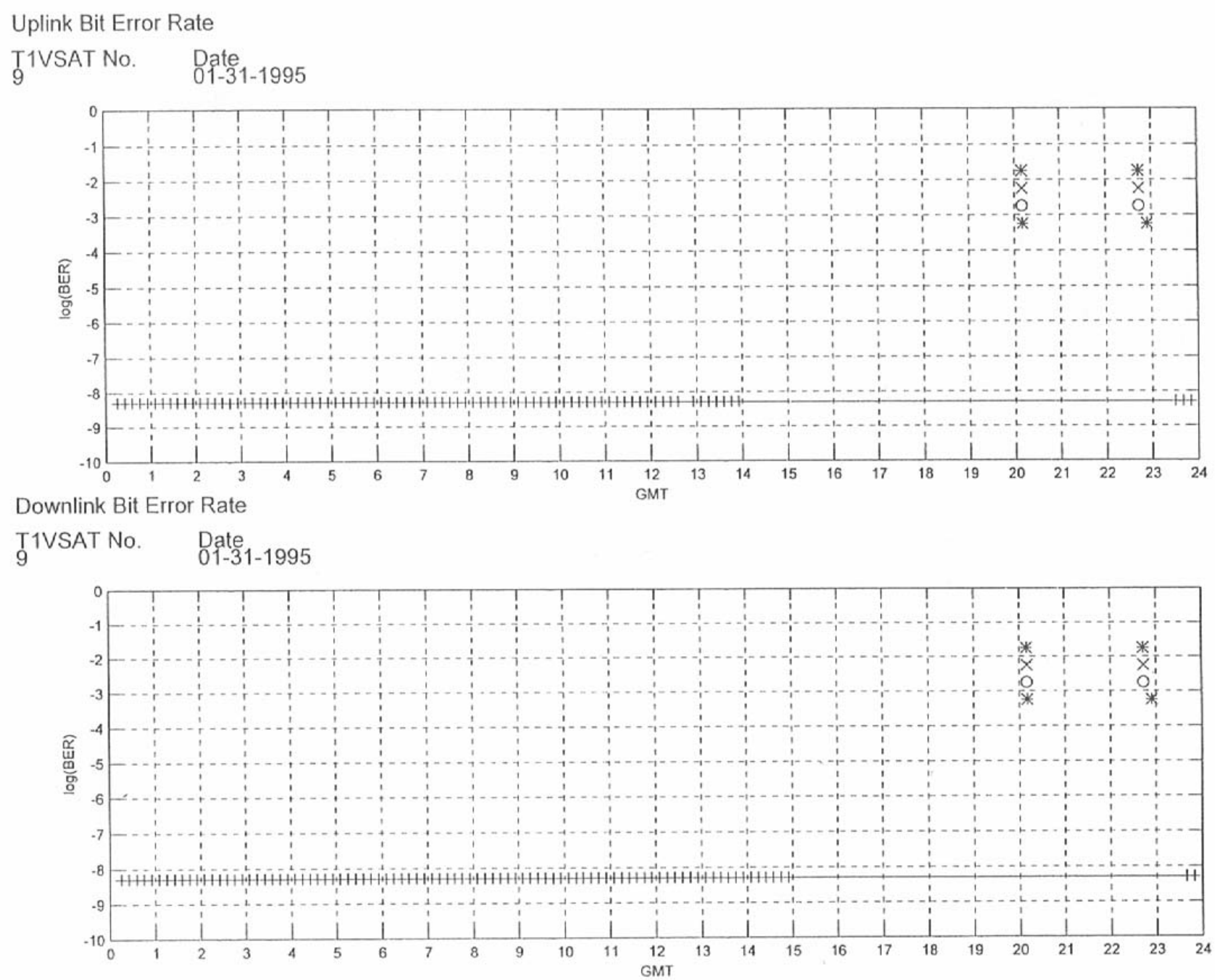

Figure 15. BER data for ES #9.

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