USER-ORIENTED PERFORMANCE MEASUREMENTS OF THE AMSAT-NA MICROSAT

by
Robert J. Diersing
Conrad Blucher Institute for Surveying and Science
Corpus Christi State University

ABSTRACT

A preliminary set of user-oriented performance measurements has been conducted using the AMSAT-NA PACSAT-1, and to a lesser degree, the AMSAT-LU LUSAT-1 Microsats. These preliminary measurements have been carried out by exchanging files and commands between two separate ground stations. During some of the tests a third station was used to monitor the satellite downlink independent of the stations engaged in the communications exchange. The monitored frames were captured and examined as an aid in determining the effective data rate and response time as observed by the end user. The tests have been an attempt to determine approximately what performance users can expect given certain ground station equipment. This paper provides a description and summary of the tests as well as a discussion of planned future experiments to be based on the experience gained from the tests described here.

INTRODUCTION

Since shortly after its launch in late January, 1990, the AMSAT-NA Microsat called Pacsat-1 has provided radio amateurs digital repeater service using the AX.25 [1] data link layer protocol. Consequently, two properly equipped amateur radio stations can connect to each other using the satellite as a relay as long as both stations are within the footprint of the spacecraft. In most cases, the stations use terminal node controllers (TNC) based on Tucson Amateur Packet Radio Corp. designs [2]. The mode of operation of Pacsat-1 will soon change with the installation of the broadcast protocol and bulletin board system proposed and implemented by Price and Ward [3].

During the the past several months a number of tests have been run in an attempt to learn how a communications system which includes a path through Pacsat-1 might perform. Most of the testing has involved determination of the effective data rate and response time as seen by the end user.

Along with the response time measurement, an attempt has been made to characterize the downlink traffic present during the testing. The data and results presented should be considered preliminary since the testbed configuration and testing methodology will be refined as experience dictates.

The test environment will be described completely later, but the general idea has been to establish a communications link through Pacsat-1 or Lusat-1 between two completely independent but co-located stations. In most cases, one station (called the originating station) would connect to the other station (called the destination station) resulting in the operator of the originating station becoming the console operator of a computer system at the destination station. The originating station would then execute certain operating system commands on the remote computer system. In some cases a file transfer would be initiated. During the response time tests the satellite downlink was monitored and recorded during the connection. Of course, the monitored downlink included all traffic resulting from the tests as well as spacecraft telemetry and other users on the satellite. The downlink was not monitored during the effective data rate tests because the equipment was not yet available.

In actual practice a LEO satellite would probably seldom be used to access a general purpose computer system in real time. However, there may be applications where some type of remotely located system could be accessed in real time via a Microsat-type satellite. For example, for the past several years this author has been involved in the development and installation of a remote water level measurement network on the Texas Gulf Coast. Some of these stations generate a fairly small amount of data per day, typically around 10 Kbytes. It should be possible to develop a LEO satellite system to retrieve such small amounts of data either automatically or on command.

METHODOLOGY

It has already been mentioned that the communications system used during the tests allowed an operator at the originating station to become the remote user of a computer system at the destination station. Commands for execution by the remote system were then entered at the originating station. During the effective data rate tests, file transfers were initiated and during the response time tests, selected operating system commands were executed.

Effective Data Rate Determination

The effective data rate from the end-user perspective is the amount of user data transmitted divided by the time required for the transfer. In order to make an estimate of the user observed data rate, a file of 5,888 bytes was transferred from the destination system to the originating system upon the command of the originating system operator. This was done a total of twelve times. Most of the transfers were done using Pacsat-1, but three tests were done using Lusat-1. Since the third-party monitoring system had not yet been established, the primary sources of information about the transfer were the internal counters maintained by the TNC. In particular, the TNC clock/calendar was used to determine the elapsed time and the RCVDIFRA counter was used to find out how many I-frames had been received from the system sending the file.

Response Time Determination

Experience gained during the file transfer tests dictated that it would be better to minimize the amount of information transferred bewteen the two systems. As a result, it was decided to execute operating system commands such as DIR and measure the elapsed time bewteen the origination of the command and the echo of the command by the remote computer system. During the tests a complete log of downlink traffic was captured and stored on a third computer system. Later, the captured downlink log was processed by a computer program.

The computer program processing the captured downlink data would first search for a specified command in the I-field of a frame from the originating station and note the time of its appearance. The search would then continue until the same command appeared in a frame from the destination station and the time would again be noted. Times were obtained from TNC monitor message time stamps.

The appearance of the command in a frame from the destination station indicated that the remote computer system had received the command and its operating system had echoed the command back to the originator. The time between the appearance of the command of interest in a frame from the originator and the time of appearance of the command in a frame from the destination is the response time referenced in this paper.

The search algorithm also allowed for the cases where the command might appear again from the originator before it appeared in a frame from the destination. This would happen in the case of a retry due to no ACK from the destination. Similarly, the command might appear again from the destination station if there was no ACK from the originator for the echo. In these cases the response time is the time between the first appearance of the command from the originating station and the last appearance of the command from the destination station.

It should be noted that while the method outlined above is probably a reasonable approximation of response time, it does not include all of the components of what the end-user would observe as response time. For example, by virtue of starting the response time clock at the first appearance of the command of interest in a downlink I-frame from the originator, two potential components of response time are being ignored. First, the time between the origination of the frame on the uplink and its appearance on the downlink is being ignored. Under light loading conditions this is probably not important but as the demand on the spacecraft's communications processors increases the delay through the satellite could be an important consideration.

Second, due to uplink contention, a command from the originating station might never appear on the downlink because it was never received by the satellite. Consequently, from the end user's perspective the response timer started when he/she entered the command but the response timer implementation used here would not have started until the first time the frame made it through the satellite to the downlink. Future work will involve logging the time when the command first leaves on the originating user's uplink.

In order to provide some measure of total downlink utilization during the tests, all traffic was logged and categorized. The downlink capacity was assumed to be the time between the first correctly received frame after AOS and the last correctly received frame before LOS times the downlink data rate. The total bytes in all received frames divided by the total downlink capacity is called the downlink utilization. Although care was taken to use the best performing equipment in the downlink logging activity, the reader is cautioned that it is very easy to lose some data. For example, signal fades due changes in received signal polarization or antenna off pointing during rapid Doppler shift on high elevation passes can cause loss of data by the monitor system.

EQUIPMENT CONFIGURATION

This section contains the details of the equipment configuration used during the tests. The originating station was used to initiate and terminate connections with the destination system. The destination station computer was running special software which would recognize when a station connected to its associated TNC. After the connection was established data sent to the local terminal screen would also be sent to the TNC for transmission on the satellite link. Similarly, data arriving via the satellite was sent from the TNC to the computer just as if it had been typed at the local keyboard.

During the response time tests, audio from the destination station receiver was sent to a separate modem/TNC combination so that all downlink activity could be logged independently of the other systems. No performace measurement of the system components was done other than to make "eye pattern" checks of the PSK demodulators to see that equalization and group delay were satisfactory. Antenna position updating was done every 1/2 minute on both the originating and destination system antennas by the control system. The antenna control system runs user-written software which is driven by files of spacecraft position information previously computed for one week intervals.

Originating Station

Transmitter: ICOM IC-255A
TX power amp: AMCOMM 2M15R
TX power out: 60 W
TX anetnna: KLM 143-150-14C
TX antenna gain: 11 dBdC
TX feedline: 30 ft. 1/2 inch Heliax + 16 ft. RG-8 Foam
Receiver: Yaesu FRG-9600
RX amplifier: ARR SP-432-VDA at antenna
RX antenna: KLM 420-450-18C
RX antenna gain: 12 dBdC
RX feedline: 31 ft. 1/2 inch Heliax + 13 ft. RG-8 Foam
TNC: TAPR Beta SN 150 with TNC-2 upgrade
TAPR 1.1.6 software
Modem: TAPR PSK
Computer: IBM-XT clone
Procomm

Destination Station

Transmitter: ICOM IC-251A
TX power amp: Heath VL-2280
TX power out: 80 W
TX antenna: KLM 143-150-14C
TX antenna gain: 11 dBdC
TX feedline: 58 ft. 1/2 inch Heliax + 40 ft. RG-8 Foam
Receiver: ICOM IC-451A
RX amplifier: ARR SP-432-VDG at receiver
RX antenna: KLM 420-450-18C
RX antenna gain: 12 dBdC
RX feedline: 80 ft. 1/2 inch Heliax + 14 ft. RG-8 Foam
TNC: TAPR TNC-1 SN 270 with TNC-2 upgrade
TAPR 1.1.6 software
Modem: TAPR PSK
Computer: Cromemco Z-2D
User-written remote console interface to TNC.

Logging Station

TNC: TAPR TNC-1 SN 269 with TNC-2 upgrade
TAPR 1.1.7 software
Modem: TAPR PSK with audio input from
destination station receiver.
Computer: IBM PC
Procomm

Control Station

Computer: Cromemco Z-2D
User-written antenna position control
software for two antenna systems.

RESULTS

Effective Data Rate Tests

Table 1 shows the effective data rate realized during twelve separate transmissions of a 5,888 byte ASCII file. The duration of the transfer was determined by recording the time with the TNC DAYTIME command at the start and end of the transfer. The number of I-frames received from the station sending the file was recorded via the TNC RCVDIFRA counter and the total I-frames received was obtained from the TNC RXCOUNT counter.

TABLE 1
SUMMARY OF EFFECTIVE DATA RATE TESTS

S/C Name	Orbit Number	Duration of Xfer	I-Frames Connectee	I-Frames Total	Effective Data Rate
AO-16	2,186	375	84	272	125.6
AO-16	2,194	248	87	313	189.9
AO-16	2,223	208	79	184	226.5
AO-16	2,280	229	89	211	205.7
AO-16	2,294	208	91	216	226.5
AO-16	2,295	242	93	203	194.6
AO-16	2,309	270	100	310	174.5
AO-16	2,315	264	99	658	178.4
AO-16	2,337	299	106	369	157.5
LO-19	2,194	413	87	314	114.1
LO-19	2,315	277	87	208	170.1
LO-19	2,329	279	87	217	168.8
Avg		276	91	289	177.7

When examining the effective data rates observed, one naturally wonders if they seem reasonable. It turns out that if all of the parameters affecting data transmission are considered, the values do appear reasonable. Consider, for example, the third line in Table 1 where the duration of the transfer is 208 seconds and the number of connectee I-frames is 79.

Since the file size was 5,888 bytes and TNC parameter PACLEN was set to 80, 5,888 / 80 = 74 frames were required to transmit the file. Each frame has 27 bytes of overhead associated with it--19 bytes minimum AX.25 overhead, 1 byte I-frame PID overhead, and 7 bytes digipeater callsign. The number of outstanding frames was set to 3 via the TNC MAXFRAME parameter so the 74 frames were transmitted in 25 separate transmissions if no errors were encountered. The transmission of each window of frames would begin after the time set by the TNC parameter TXDELAY. The value of TXDELAY for both sending and receiving stations was 30 which corresponds to 300 ms. Each window of frames from the sending station would have to be acknowledged by an RR frame from the receiver resulting in a minimum of 25 RR frames with a length of 26 bytes being transmitted. These 25 frames would also be subject to the TXDELAY value before actual data was transmitted.

47,104	Data bits in I-frames (5,888 x 8)
15,984	Overhead bits in I-frames ((152 + 8 + 56) * 74)
5,200	Overhead bits in RR frames ((152 + 56) * 25)

68,288	Total data and overhead bits

68,288 / 1200 = 56.9 seconds transmission time @ 1200 bps

56.9	Frame transmission time in seconds
7.5	Total TXDELAY at sender (0.3 sec x 25 windows)
7.5	Total TXDELAY at receiver (0.3 sec x 25 RR frames)

71.9	Seconds elapsed time

So far, less than half of the 208 seconds elapsed time has been explained. The constituents of the remaining file transfer time are not precisely known. Had the third-party downlink monitoring used during the response time tests been available, at least some of the remaining elapsed time could be explained. Nevertheless, some of the potential sources for further delays can be given.

The elapsed time includes the time it took for the operator to initiate the command and time for the system at the destination to locate the file to be transmitted on the disk. Since the system transmitting the file uses floppy disks, this could take 5-6 seconds. There is also some delay from the time the spacecraft receives a frame on the uplink until it is transmitted on the downlink. The largest remaining component of the transfer time duration results from errors caused by collisions and timeouts.

Suppose an entire window's worth of frames is sent by the transmitter but none are ever received. The transmitter will time out in the amount of time specified by TNC parameter FRACK. FRACK was set to 4 during the tests which caused the timeout value to be 12 seconds since there is a digipeater in the path. Now, in addition to the timeout time itself, there is the time to retransmit the frame(s) missing or in error. It is easy to see that a few error recovery actions by the system can lengthen the elapsed time significantly.

Response Time Tests

As was mentioned in the methodology section, the response time tests were done by initiating certain operating system commands at the destination system from the originating system via the Microsat satellite link. For example, if the originating station enters the "DIR" command, the idea is to measure the elapsed time between the time of command entry and the time the command text appears on the originator's screen. This means that the command has traversed the satellite link to the remote computer and back again. Note that the time of actual command execution and the time to transmit any resulting output text back to the originator is not being considered. Note also that the time for the remote system to echo the command is negligible since it is a single-user system.

The data in Table 2 indicates that as long as there are no data link level errors and under similar downlink loading, a response time of 2 seconds or better should be realizable. Since there is only one case of a command being retried, it is not clear how retries would affect end-user response time. The downlink utilization shown in Table 2 assumes that data could be transmitted on the downlink during the entire logging period. The utilization shown is the fraction of the maximum value represented by the logged data. It should be remembered that the spacecraft will reduce the rate at which telemetry and other spacecraft information frames are generated on the downlink when user activity is detected on the uplinks. Thus, as long as users are accessing the spacecraft, high utilization values will not be observed.

Table 3 provides some additional information about the downlink traffic. Columns labelled "S/C Ovhd" and "User Ovhd" represent the number of bytes of AX.25 protocol overhead for spacecraft and user frames respectively. The columns "S/C % of Traffic" and "User % of Traffic" show the spacecraft and user percentages of the total monitored downlink traffic. The column "No. Users" shows the total number of users heard during a logging period. They are not necessarily concurrent users, although it is likely that they were concurrent at some point when a significant portion of the continental U.S. was within the satellite's footprint. It should be remembered that the count of user stations includes the two stations conducting the response time checks.

TABLE 2
SUMMARY OF LOG FILES MADE DURING RESPONSE TIME TESTS

Orbit Number	Log Duration	Total Frames	Total Bytes	Downlink Utilization	Commands Executed	Command Retries	Average Resp Time
2,615	13:52	337	21,234	0.17	3	0	5.6
2,629	13:37	399	25,846	0.21	3	0	1.3
2,671	10:25	310	15,510	0.16	3	0	2.0
2,679	07:32	132	7,298	0.10	1	0	2.0
2,694	13:42	393	24,008	0.19	2	0	2.0
2,700	13:45	356	21,282	0.17	2	0	1.0
2,714	11:23	240	13,175	0.12	2	0	2.0
2,715	13:20	374	22,640	0.18	3	0	2.0
2,723	15:00	316	20,279	0.15	2	0	2.0
2,728	08:07	219	10,920	0.14	2	1	9.0
2,757	12:26	336	33,714	0.30	2	0	1.0
2,765	11:03	362	36,570	0.36	2	0	2.0
2,779	07:43	304	21,896	0.31	1	0	2.0
2,794	14:20	564	43,027	0.33	3	0	1.6
Avg	11:52	331	22,671	0.21	2	0	2.5

TABLE 3
SUMMARY OF DOWNLINK USAGE DURING RESPONSE TIME TESTS

Orbit Number	S/C Ovhd Bytes	S/C Info Bytes	S/C % of Traffic	User Ovhd Bytes	User Info Bytes	User % of Traffic	No. Users
2,615	4,180	10,954	52	3,387	2,713	29	5
2,629	4,460	12,526	66	4,657	4,203	34	5
2,671	2,260	6,022	53	5,191	2,037	47	5
2,679	1,340	3,774	70	1,724	460	30	4
2,694	4,420	12,887	72	4,524	2,177	28	5
2,700	4,500	12,270	79	3,438	1,074	21	7
2,714	2,760	7,023	74	2,679	713	26	4
2,715	4,260	11,634	70	4,253	2,493	30	4
2,723	3,940	11,175	75	3,141	2,023	25	4
2,728	1,400	4,047	50	3,912	1,561	50	6
2,757	5,420	25,807	93	1,706	781	7	5
2,765	5,420	27,541	90	2,410	1,199	10	3
2,779	2,680	12,979	72	4,471	1,766	28	6
2,794	5,560	27,191	76	7,553	2,723	24	9
Avg	3,757	13,274	72	3,789	1,852	28	5

FUTURE TESTS

There are many improvements which can be made to the testing process described in the preceding sections. If one wishes to determine the response time of the satellite's digipeater mode, then it will be necessary to know when a command is generated on an uplink by the user. This would be easily done by monitoring the user's local transmitter and timestamping the captured frame. The need for capturing the user's command on the uplink as opposed to the satellite downlink has already been discussed.

The downlink file processing program could be improved such that it could provide a measure of satellite system response time by examining the AX.25 data link layer frame control information on a user-by-user basis. For example, it could measure the time between the origination of an I or RR frame with poll set to the time of the arrival of an RR frame with final set from the corresponding user. Improved measurement techniques will require a high-resolution clock for time stamping monitored frames.

The effective data rate tests should be repeated now that it is possible to monitor the downlink during the tests. Careful analysis of the monitor log might reveal which TNC parameters could be optimized to increase throughput. Furthermore, the ability of a third-party station to monitor the downlink will provide a measure of downlink utilization and characterization of downlink traffic which was not previously available.

Finally, once a baseline performance standard has been established, all tests should be repeated with reduced transmitter powers and omni-directional antennas. The spirit of the Amateur Radio Service is to use the minimum amount of power necessary to maintain communications. Many potential Microsat applications will require simple low-power ground stations. Thus, testing must be done to establish performance levels for low powered transmitters and omni-directional antennas. The only reason higher power levels were used in the tests described here was to try to eliminate one of the many factors impacting performance while the testing procedure was developed.

CONCLUSION

The preceding sections have presented descriptions of tests conducted using the AMSAT-NA Pacsat-1, and to a lesser extent, the AMSAT-LU Lusat-1 Microsats. The tests were conducted using equipment available to radio amateurs. The response time tests showed that an average end-user response time of 2 seconds could be realized. The effective data rate tests resulted in an average data rate of 177 bits per second.

Both of these values can be determined more accurately by investigating some of the ideas given in the future tests section.

REFERENCES

1. Fox, Terry L., AX.25 Amateur Packet-Radio Link Layer Protocol Version 2.0, Newington, CT: American Radio Relay League, Inc., October, 1984.

2. TAPR Terminal Node Controller Firmware Release 1.1.7, Tucson, AZ: Tucson Amateur Packet Radio Corp., March, 1990.

3. Price, H.E. and J.W. Ward, PACSAT Broadcast Protocol, Unpublished manuscript, May, 1990.

GLOSSARY

AX.25 --- A slightly modified version of CCITT X.25 level 2 LAPB protocol used in distributed amateur packet radio networks.

DAYTIME --- Used to set and read the internal TNC clock/calendar. The internal clock/calendar is used to time-stamp received and monitored messages.

FRACK --- After transmitting a packet requiring acknowledgement, the TNC will wait for a frame acknowledgement timeout before incrementing the retry counter and sending the frame again. If the packet address includes relay requests, the time bewteen retries is adjusted to: Retry interval = FRACK * (2 * m + 1) seconds where m is the number of intermediate relay stations.

MAXFRAME --- Sets an upper limit on the number of unacknowledged packets which the TNC can have outstanding at any one time. This is also the maximum number of contiguous packets which can be sent during any given transmission. If some but not all of the outstanding packets are acknowledged, a smaller number may be transmitted the next time, or new frames may be included in the retransmission so that the total unacknowledged does not exceed MAXFRAME.

PACLEN --- Specifies the maximum length of the data portion of a packet.

RCVDIFRA --- A counter in the TNC which increases by 1 for each I-frame received from a connectee.

RXCOUNT --- A counter in the TNC which increases by 1 for each correctly received I-frame.

TNC --- Terminal Node Controller. A packet assembler/ disassembler which executes the AX.25 protocol.

TXDELAY --- This value tells the TNC how long to wait after keying up the transmitter before sending data. The delay will be TXDELAY * 10 ms.