DOWNLINK SIGNAL LEVEL AND ERROR MEASUREMENTS FOR PACSAT-1

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Abstract

The PACSAT-1 store-and-forward amateur radio satellite was placed into low earth orbit (LEO on January 22, 1990 using the Ariane Structure for Auxiliary Payloads (ASAP). Most of the first year of operation was spent on application software development with full time operation of file server and file broadcast services beginning in late 1990. During 1991, both ground station and satellite-based software matured and stabilized such that the satellite sees a high volume of daily use both by individual amateur radio station operators and stations acting as gateways for terrestrial packet radio networks operating in the Amateur Radio Service. The purpose of this paper is to characterize system operation from the viewpoint of a PACSAT-1 user. The results should be useful to system designers who would like to know what performance can be expected from similar systems. Among the topics addressed are: (1) the equipment configuration used during testing; (2) a comparison of expected and observed downlink signal strength; (3) an estimate of the downlink bit error probability; (4) a determination of the downlink efficiency, on a per-user basis, during typical file downloading operations; and (5) a brief characterization of downlink traffic according to type: file server, file broadcasting, and telemetry.

I. Introduction

The PACSAT-1 store-and-forward amateur radio satellite was placed into low earth orbit (LEO) on January 22, 1990 using the Ariane Structure for Auxiliary Payloads (ASAP). In addition to the primary payload, five other satellites were launched with PACSAT-1: DOVE-1, LUSAT-1, WEBERSAT-1, UoSAT-3, and UoSAT-E. PACSAT-1, DOVE-1, LUSAT-1, and WEBERSAT-1 have been given the designation "micro-satellites or microsats" due to their small size and weight. Complete technical details of the microsats have been published in [6]. More information about UoSAT-3 can be found in [8], [9], and [10]. UoSAT-E failed shortly after launch and the exact nature of the failure remains unknown.

The primary mission of the PACSAT-1 and LUSAT-1 microsats is that of providing store-and-forward message relay service to radio amateurs worldwide. Most of the first year of operation was spent on application software development with full time operation of file server and file broadcast services beginning in late 1990. During 1991, both ground station and satellite-based software matured and stabilized such that these satellites see a high volume of daily use by individual amateur radio station operators and stations acting as gateways for terrestrial packet radio networks operating in the Amateur Radio Service.

Providing store-and-forward message relay to radio amateurs constitutes a distinct type of personal communications service. While there are significant differences between the systems discussed here and those which propose to provide communications services via LEO multiple satellite systems (MSS), PACSAT-1 and the other satellites mentioned represent on orbit systems which are available for immediate study. This paper will concentrate on PACSAT-1 which is owned and operated by the Radio Amateur Satellite Corporation of North America (AMSAT-NA).

The purpose of this paper is to characterize system operation from the viewpoint of a PACSAT-1 user. The results should be useful to system designers who would like to know what performance can be expected from similar systems. Among the topics addressed are: (1) the equipment configuration used during testing; (2) a comparison of expected and observed downlink signal strength; (3) an estimate of the downlink bit error probability; (4) a determination of the downlink efficiency, on a per-user basis, during typical file downloading operations; and (5) a brief characterization of downlink traffic according to type: file server, file broadcasting, and telemetry.

II. Hardware and Software Configuration

Figure 1 shows the equipment configuration used during the tests reported here. Two computer/radio systems were employed--one for two-way communication or monitoring (System No. 1) and one for monitoring only (System No. 2). Each radio system has its own antenna system and a single computer controls the antenna position for both systems. Equipment specifications shown in Figure 1 are those published by the manufacturers.

During the tests the equipment was operated in one of two modes. For some of the downlink bit error rate determination tests, both computer/radio systems were operated in monitor mode. This allowed two independently captured data samples to be obtained during the same satellite visibility period. At other times during the downlink bit error rate tests, the audio from the System No. 1 receiver was connected to both modems. The same procedure was used during the file downloading tests. This allowed one computer system to be engaged in the downloading

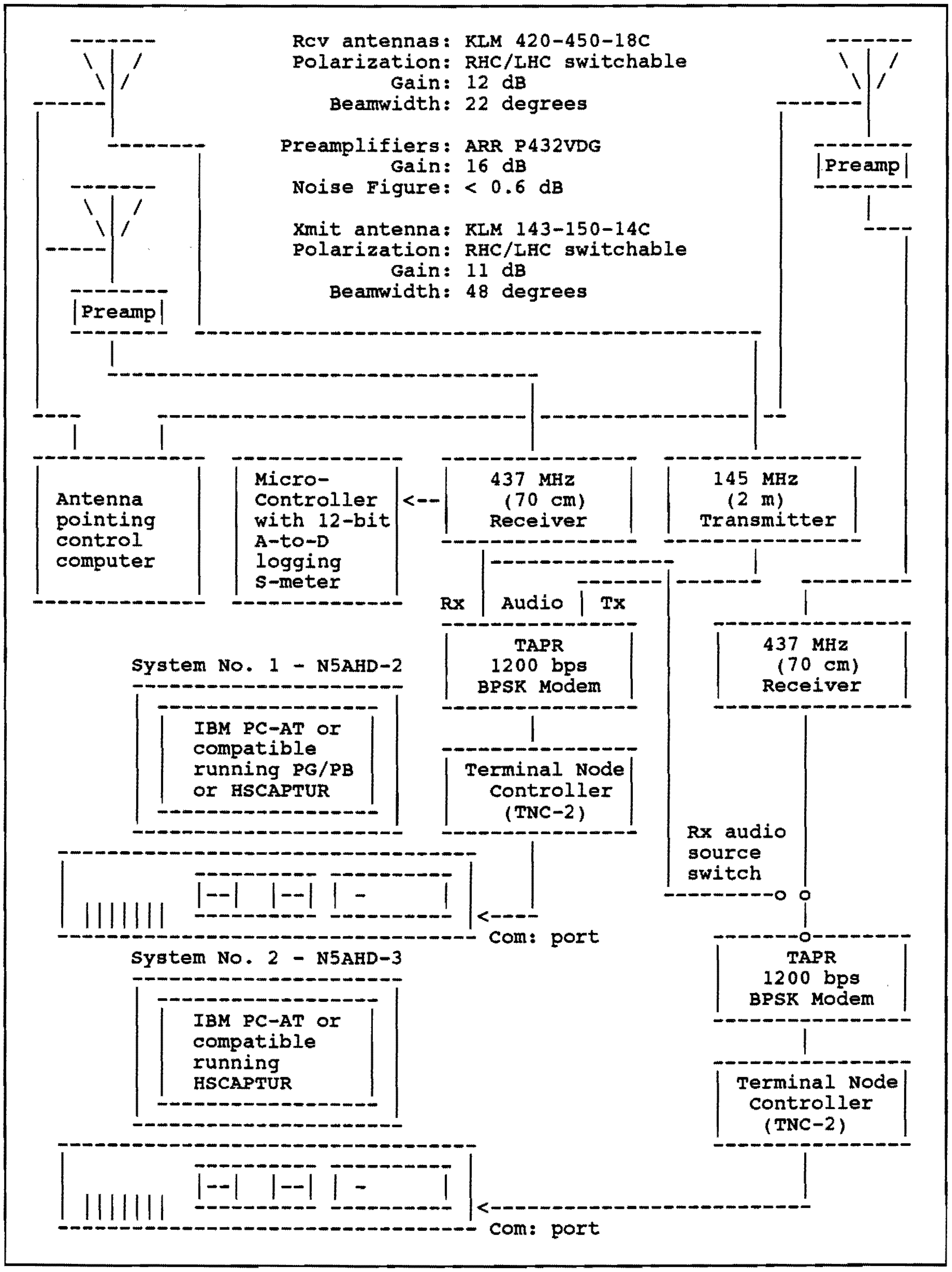

Figure 1. Equipment configuration for PACSAT-1 downlink signal strength and error measurements.

process while the other system captured all the data on the downlink.

The received signal S-meter voltage on system no. 1 can be recorded using a single-board microcontroller unit (MCU) and its associated analog-to-digital (A-to-D) converter. The MCU records the voltage fed to the receiver S-Meter from the last IF stage at one second intervals. The raw A-to-D counts can be stored and conversion to engineering units is done after retrieval of the data from the MCU. Each recorded value has a date and time stamp for correlation with the separately-recorded downlink data stream.

The two receivers were calibrated using a Cushman Electronics Model CE-4B service monitor. The instrument used had been factory calibrated in March, 1991. A signal was fed into the receiver starting at -127 dBm and increased in 3 dB steps until the receiver was saturated. The S-Meter voltage was recorded at each step. The transfer functions for the two calibrated receivers are shown in Figure 2. Table 1 shows the results of a regression analysis done for the data obtained during the calibration procedure. A regression equation is used during the processing of the raw A-to-D data to compute a receiver input power value in dBm from a corresponding S-meter voltage value in mV. Receiver No. 1 was used for the measurements which were analyzed and reported in the next section.

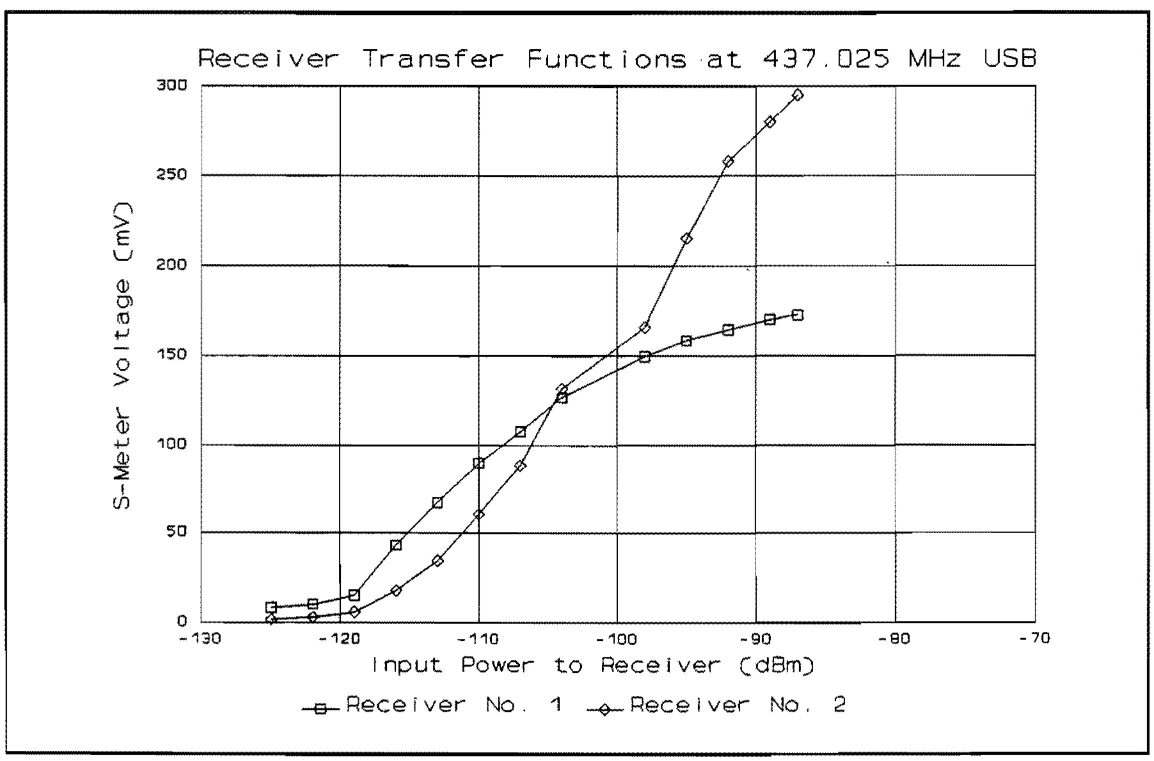

Figure 2. Transfer functions for ICOM IC-451A receivers on 437.025 MHz USB.

Table 1
Receiver Calibration Regression Analysis

Receiver	Frequency/Mode	X Coeff	Constant	Std Err Y Estimate
Rx No. 1	437.025 MHz USB	0.196978	-125.362	2.616515
Rx No. 2	437.025 MHz USB	0.101823	-119.191	2.784316

III. Downlink Signal Level Measurements

Table 2 gives a downlink margin computation for PACSAT-1. The link margin computation is based on a preliminary estimate made by Duncan and King [2] and has been modified to match the conditions under which the measurements reported were made. The system noise temperature calculation includes all components of the receiving system up to the receiver antenna terminal [3]. Assuming the E_b/N_0 value of 9.4 dB is required for a BER of 1E-4, there is a link margin of 25.7 dB under the conditions of maximum

Table 2
PACSAT-1 Downlink Margin Computation
for 1200 BPS PSK and Directional Antenna

1.	Spacecraft transmitter power	+3.0 dBW
2.	Spacecraft transmission losses	-0.7 dB
3.	Spacecraft antenna gain	+2.0 dB
4.	Downlink EIRP	+4.3 dBW
5.	Downlink path loss @ 3340 km	-155.7 dB
6.	Polarization loss	0.0 dB
7.	Atmospheric & ionospheric losses	-2.0 dB
8.	Isotropic signal level @ antenna	-153.4 dBW
9.	User station antenna gain	12.0 dB
10.	Cable loss, antenna to preamp	-0.5 dB
11.	Signal level at preamp (RSL)	-141.9 dBW
12.	Preamplifier (LNA) gain	+16.0 dB
13.	Cable loss, preamp to receiver	-1.1 dB
14.	Signal level at receiver	-127.0 dBW
15.	User system noise temperature	120.7 K
16.	User G/T	-9.3 dB/K
17.	User C/N_0	65.9 dB-Hz
18.	User E_b/N_0	35.1 dB
19.	Required E_b/N_0 for 1E-4 BER	9.4 dB
20.	Link margin	25.7 dB

slant range to the satellite. The minimum possible slant range would occur when the satellite passed directly over the ground station at the time of closest approach (TCA). For this case the path loss would be about 12 dB less.

Downlink signal level measurements for PACSAT-1 have been made on a number of occasions. Most of the signal level measurements were made using a directional antenna system that tracks the satellite under computer control. The antenna pointing error is estimated to be +/- five degrees in both the vertical and horizontal planes (azimuth and elevation). The antenna beamwidth is 22°. The signal level measurements were made from a ground station location of 27.8N, 97.4W (on the lower Texas Gulf Coast).

Figures 3 and 4 show typical downlink signal level measurements. Figure 3 shows plot of raw measurements taken at one-second intervals. The upper plot in Figure 4 was made from 30-second averages of the once-per-second measurements. When comparing the values in Figures 3 and 4 to the estimated signal level at the receiver given in Table 2, it should be noted that the values in the figures are given in dBm and the values in the link margin table are given in dBW. Consequently, a 30 dB conversion factor must be applied to one value or the other.

In spite of the existence of a link margin of over 20 dB, there are many physical phenomena that can affect a LEO satellite radio link carrying digital data. The existence of some of these factors are obvious such as the effect of Doppler shift and tracking errors. Moreover, since PACSAT-1 employs a passive magnetic stabilization system, polarization and antenna pointing changes will result from differing spacecraft orientations. Local meteorological conditions will also become a factor in downlink performance at low elevation angles.

In addition to the potential sources of signal degradation already mentioned, one observer [7] has reported that the PACSAT-1 standard PSK transmitter typically exhibits +/- 10° rms random phase noise and that there are occasional peaks as high as +/- 27°. The existence of the random phase noise has also been observed by others [11] and at the time this paper was being prepared, testing was in progress to characterize the carrier suppression and phase noise exhibited by both PACSAT-1 70 cm downlink transmitters. In [4] Gagliardi points out, phase-reference errors (in the demodulator) can produce bit-error probabilities several orders of magnitude higher than that predicted by the ideal case. Furthermore, as a rule of thumb, if PE performance (for BPSK) is to be maintained at about 10^{-5}, rms phase-reference errors must be limited to about 12° or less.

The performance of a PACSAT-1 ground station will depend on how well the system performs in the presence of all the possible impairments to the received signal. The downlink bit-error performance will depend, in part, on the ability of the demodulator to cope with any random phase noise being generated. The

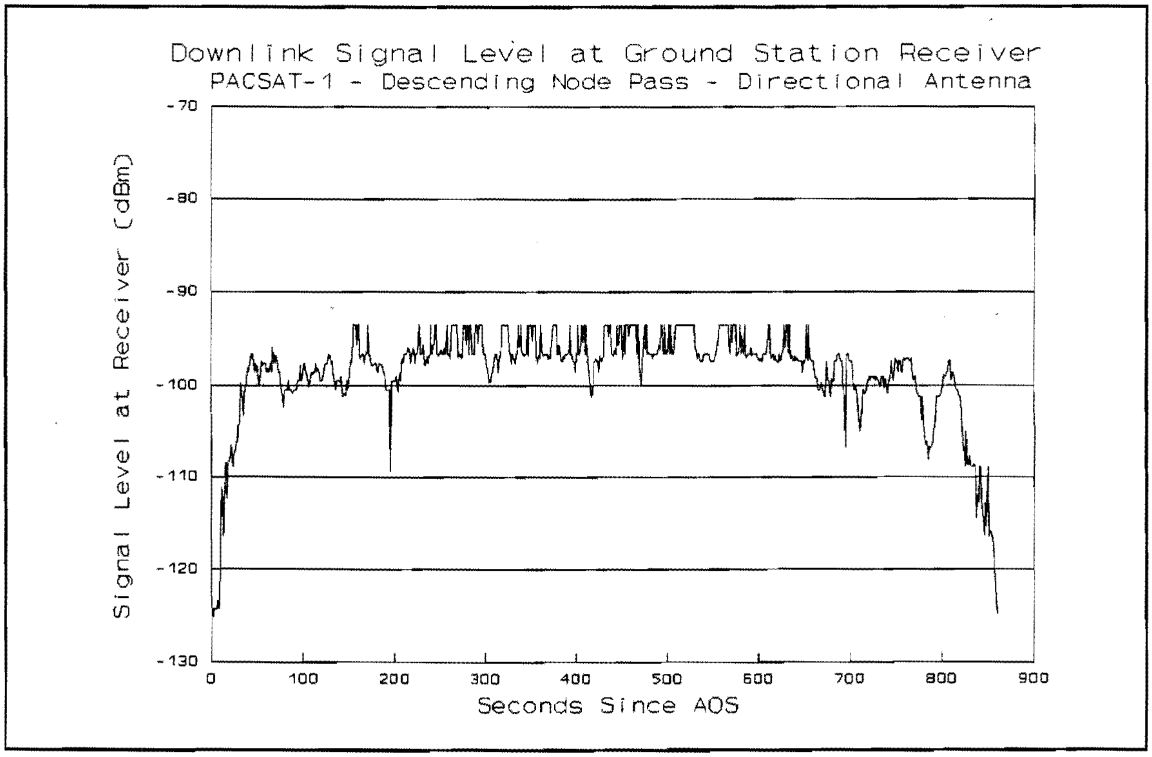

Figure 3. Downlink signal level as recorded for orbit no. 6608 at 18:23 UTC on 04/29/91 using a directional antenna.

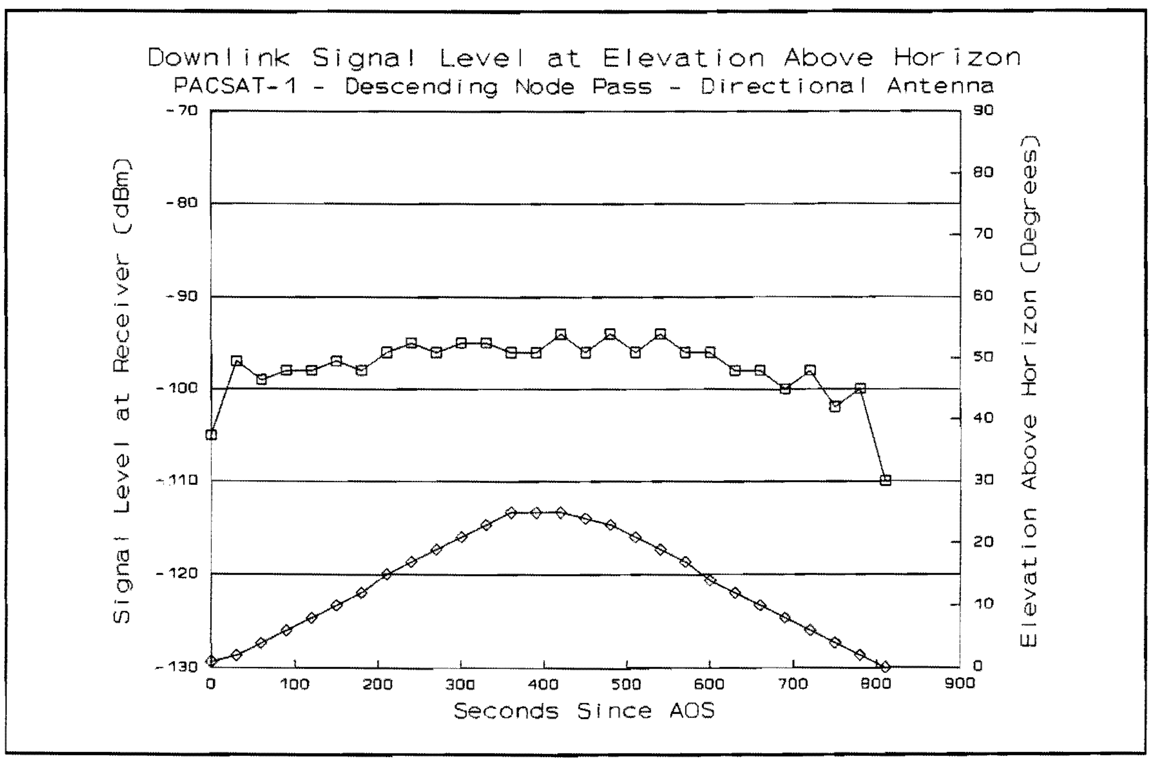

Figure 4. Downlink signal level averaged in 30-second intervals as recorded on orbit no. 6608 at 18:23 UTC on 04/29/91 using a directional antenna.

following two sections detail experiments that have been performed to characterize performance attainable by a typical PACSAT-1 ground station.

IV. Estimate of Downlink Bit Error Probability

Since the performance of any digital communications system is affected by the block error rate, and since an LEO satellite system is subject to additional factors which can introduce errors, several error rate observations have been carried out.

There are times when the satellite telemetry system is transmitting a fixed and recurring sequence of frames with no other traffic on the downlink. This situation usually occurs between the time the housekeeping and telemetry system software is loaded and the loading of the file server system. Since the number and type of frames that should appear can be determined, it is only necessary to compare what should have been received with what was actually received and then compute a block error probability.

During the past year, downlink data has been collected under the conditions described above on three occasions and estimates have been made of the downlink bit error probabilities. The first data set was collected during the time period from July 21 through July 26, 1991 while the standard PSK transmitter was in use. The second data set was collected between July 28 and August 7, 1992. This period coincides with the reloading of the housekeeping and telemetry system after the onboard computer crash of July 26, 1992 and the switch to the raised cosine PSK transmitter. All observations in this sample were recorded while the standard PSK transmitter was in use. The third sample was taken beginning August 10, 1992. All observations in this sample are from the raised cosine PSK transmitter.

During all three collection periods, data from many more orbits were captured than appear in the summary tables. This is because only those visibility periods free of uplink traffic were used in the final analyses. (There are times in the software reloading process where the digipeater service is available to ground station users. If the digipeater is used, the telemetry rate is reduced from 10-second intervals to 60-second intervals. Rather than trying to compute what the rate should have been in any given interval, visibility periods with any user activity at all were discarded.) Data from passes that caused the azimuth rotator to pass through 180 degrees were also discarded because tracking of the satellite is interrupted during the nearly 360 degree travel of the azimuth rotator. Other than discarding observations in which uplink activity caused a varying downlink frame transmission rate and those where the satellite could not be tracked continuously throughout the visibility period, there were no other alterations to the collected data. Data from low-elevation passes has been retained as has data collected during unusual local meteorological and noise conditions.

Figure 5 shows an example of the types of frames that are always transmitted by the satellite. Some of the frames have an information field containing printable ASCII characters and others have information fields containing binary data. Typical

```
1.  PACSAT-1>TLM [12/09/90  04:02:28] <UI>:

2.  PACSAT-1>STATUS [12/09/90  04:02:28] <UI>:

3.  PACSAT-1>LSTAT [12/09/90  04:02:29] <UI>:
    I P:0x3000 o:0 l:13627 f:13627, d:1 st:0

4.  PACSAT-1>TIME-1 [12/09/90  04:02:35] <UI>:
    PHT: uptime is 002/00:41:51.
    Time is Sun Dec 09 04:01:36 1990

5.  PACSAT-1>BCRXMT [12/09/90  04:03:09] <UI>:
    vmax=744283 battop=753664 temp=436389
```

Figure 5. Frame types transmitted by the PACSAT-1 telemetry system.

information field contents are shown for those frames containing ASCII data. For other types, only the frame header is shown. While the data analyzed here was being collected, the satellite file server was closed to users so the time between frames was 10 seconds for all types except BCRXMT which was 60 seconds.

A computer program was used to read the captured downlink data, determine how many of each frame type should have been received, and then compute the block error probability based on how many frames were actually received. Figure 6 shows an

```
Data from file: ao167808.p22
Frame = TLM
Start = 203.77520833 = 18:36:18 on 07/22/91
  End = 203.78436342 = 18:49:29, Duration =  791 Seconds
Frames possible =   79 @ Standard rate ( 10)

Interval  Occurs  Received  Possible   Errors   Users  Ovhd  Info
    10      75       75        75         0       0    1425  9150
    20       2        2         4         2       0      38   244
Frames possible =  79
Frames received =  77                     Frame size (bits) 1128
Frames in error =   2                Perror (block) = 0.02531645
```

Figure 6. Computation of block error probability for frame type TLM for orbit no. 7808.

example of the program output for one frame type and orbit. A total of 75 TLM frames were received in 10-second intervals and there were two twenty-second intervals which means that two TLM frames were not received.

The same general procedure has been employed in the analysis of data from each of the three samples. First, the block error probability for each telemetry frame type is computed for each orbit in the sample. Next, the average block error probability for each frame type for the entire sample is computed. From the average block error probability a bit error probability is computed by solving Eq. 1 for Pe_{block}, giving Eq. 2, where n is the block (frame) size in bits (control bits plus information bits). The result is a bit error probability that would have produced the observed average block error probability for the block length of interest. Finally, an overall average bit error probability is computed by weighting the bit error probability for each frame type by the frame length. It should be noted that Eq. 1 and 2 assume that bit errors are independent. For a discussion of why the independence assumption does not always apply to real world systems, see [5].

$$Pe_{block} = 1 - (1 - Pe_{bit})^{n} \qquad (1)$$

$$Pe_{bit} = 1 - (1 - Pe_{block})^{\frac{1}{n}} \qquad (2)$$

Table 3 shows the block error probabilities by frame type for each visibility period contained in the July 1991 data sample. Applying the procedure described above results in the bit error probabilities by frame type and the weighted average bit error probability given in Table 4. Similar data and computations are given in Tables 5 and 6 for the July 1992 data from the standard PSK transmitter and in Tables 7 and 8 for the July/August 1992 data from the raised cosine PSK transmitter.

In Tables 3, 5, and 7, the -1 and -2 suffix on the orbit numbers refers to the receiving system used to capture the data (See Figure 1). For the data in Table 3, the two receiving systems were operating completely independently. For the data in Tables 5 and 7, the audio from receiver no. 1 was fed to both modems. Thus, for these two samples, differences in block error probabilities are caused by differences in the demodulation capabilities of the two modems.

Table 9 shows the block and bit error probabilities that result from combining all data into a single sample. All three data sets have been reproduced in the tables so the reader can see the range of possible block error probabilities encountered. Since many aspects of the data collection process and monitoring environment cannot be controlled, the bit error probabilities

Table 3
Block Error Probabilities by Frame Type
Sample No. 1 ---- July 21 to July 26, 1991
Standard PSK Transmitter

Orbit Number	STATUS Blk Err	LSTAT Blk Err	TIME Blk Err	TLM Blk Err	Max Elev	Pass Duration
7794-2	0.0392	0.0588	0.0196	0.0980	9	08:34
7799-1	0.0267	0.0263	0.0263	0.0400	53	12:47
7799-2	0.0233	0.0230	0.0230	0.0233	53	12:47
7807-1	0.0115	0.0115	0.0345	0.0920	36	14:38
7807-2	0.0115	0.0115	0.0341	0.0833	36	14:38
7808-1	0.0127	0.0595	0.0380	0.0253	20	13:18
7808-2	0.0127	0.0000	0.0256	0.0385	20	13:18
7836-1	0.0353	0.0471	0.0471	0.0357	79	14:14
7836-2	0.0471	0.0588	0.0471	0.0476	79	14:14
7850-1	0.0122	0.0000	0.0247	0.0617	51	13:43
7850-2	0.0122	0.0000	0.0244	0.0617	51	13:43
7865-1	0.0448	0.0294	0.0000	0.0303	27	11:19
7865-2	0.0256	0.0127	0.0000	0.0385	27	11:19
Total						02:48:32
Mean	0.0242	0.0260	0.0264	0.0520		
Std Dev	0.0130	0.0221	0.0140	0.0243		
Blk Size	344	424	664	1128		

Table 4
Bit Error Probabilities Corresponding to
Observed Block Error Probabilities
Sample No. 1 --- July 21 to July 26, 1991

Frame Type	Block Error Prob Pe_{block}	Bit Error Prob Pe_{bit}	Length L_{frame}	Weighted $L_{frame} * Pe_{bit}$
STATUS	0.0242	0.71E-4	344	0.0245
LSTAT	0.0260	0.62E-4	424	0.0264
TIME	0.0264	0.40E-4	664	0.0268
TLM	0.0520	0.47E-4	1128	0.0534
Total			2560	0.1311
Average		0.51E-4		

Table 5
Block Error Probabilities by Frame Type
Sample No. 2 --- July 28 to August 7, 1992
Standard PSK Transmitter

Orbit Number	STATUS Blk Err	LSTAT Blk Err	TIME Blk Err	TLM Blk Err	Max Elev	Time Visible
13137-1	0.0380	0.0127	0.0385	0.0253	33	13:14
13137-2	0.0370	0.0123	0.0253	0.0247	33	13:14
13143-1	0.0353	0.0345	0.0345	0.0353	45	14:33
13143-2	0.0244	0.0357	0.0581	0.0595	45	14:33
13150-1	0.0000	0.0484	0.0323	0.0328	8	10:39
13150-2	0.0156	0.0645	0.0645	0.0678	8	10:39
13193-2	0.0833	0.0882	0.0746	0.0758	13	12:01
13194-2	0.0114	0.0115	0.0682	0.0345	49	14:43
13199-1	0.0000	0.0159	0.0769	0.1129	9	10:50
13199-2	0.0159	0.0476	0.0923	0.0968	9	10:50
13265-1	0.0000	0.0000	0.0222	0.0217	4	13:11
13265-2	0.0127	0.0253	0.0385	0.0759	4	13:11
Totals						02:31:38
Mean	0.0228	0.0330	0.0522	0.0553		
Std Dev	0.0226	0.0246	0.0221	0.0294		
Blk Size	344	424	664	1128		

Table 6
Bit Error Probabilities Corresponding to
Observed Block Error Probabilities
Sample No. 2 --- July 28 to August 7, 1992

Frame Type	Block Error Prob Pe_{block}	Bit Error Prob Pe_{bit}	Length L_{frame}	Weighted $L_{frame} * Pe_{bit}$
STATUS	0.0228	0.67E-4	344	0.0231
LSTAT	0.0330	0.79E-4	424	0.0336
TIME	0.0522	0.81E-4	664	0.0536
TLM	0.0553	0.50E-4	1128	0.0568
Total			2560	0.1671
Average		0.65E-4		

Table 7
Block Error Probabilities by Frame Type
Sample No. 3 --- August 10 to August 31, 1992
Raised Cosine PSK Transmitter

Orbit Number	STATUS Blk Err	LSTAT Blk Err	TIME Blk Err	TLM Blk Err	Max Elev	Time Visible
13322-1	0.0238	0.0000	0.0119	0.0361	36	14:04
13322-2	0.0238	0.0000	0.0119	0.0361	36	14:04
13323-1	0.0779	0.1013	0.1154	0.0789	19	13:09
13323-2	0.0779	0.1013	0.1154	0.0921	19	13:09
13328-1	0.0000	0.0732	0.0732	0.0617	26	13:44
13328-2	0.0000	0.0732	0.0732	0.0617	26	13:44
13336-1	0.0260	0.0132	0.0779	0.0789	17	12:58
13336-2	0.0260	0.0132	0.0779	0.0789	17	12:58
13337-1	0.0588	0.0824	0.0930	0.1928	38	14:20
13337-2	0.0588	0.0824	0.0930	0.1807	38	14:20
13351-1	0.0220	0.0112	0.0778	0.1556	78	15:10
13351-2	0.0220	0.0112	0.0778	0.1556	78	15:10
13379-1	0.0000	0.0122	0.0617	0.0741	24	13:42
13379-2	0.0000	0.0122	0.0494	0.0617	24	13:42
13393-1	0.0152	0.0000	0.0156	0.0152	11	11:01
13393-2	0.0152	0.0000	0.0156	0.0152	11	11:01
13408-1	0.0000	0.0000	0.0462	0.0308	70	10:54
13408-2	0.0000	0.0000	0.0469	0.0154	70	10:54
13414-1	0.0000	0.0000	0.0000	0.0000	1	04:36
13414-2	0.0000	0.0000	0.0000	0.0000	1	04:36
13443-1	0.0345	0.0351	0.0169	0.0526	12	09:56
13443-2	0.0182	0.0182	0.0000	0.0364	12	09:56
13457-1	0.0000	0.0227	0.0000	0.0000	4	07:21
13457-2	0.0000	0.0000	0.0000	0.0000	4	07:21
13465-1	0.0114	0.0227	0.0000	0.0455	47	14:41
13465-2	0.0227	0.0341	0.0000	0.0455	47	14:41
13466-1	0.0533	0.0267	0.0667	0.0946	15	12:38
13466-2	0.0400	0.0267	0.0667	0.0946	15	12:38
13487-1	0.0290	0.0290	0.0143	0.0145	39	11:40
13487-2	0.0294	0.0294	0.0145	0.0147	39	11:40
13522-1	0.0488	0.0122	0.1098	0.1098	32	13:48
13522-2	0.0488	0.0122	0.1098	0.0976	32	13:48
13529-1	0.0127	0.0253	0.0375	0.0253	23	13:20
13529-2	0.0000	0.0864	0.0263	0.0133	23	13:20
13557-1	0.0000	0.0000	0.0222	0.0000	3	07:33
13557-2	0.0000	0.0000	0.0222	0.0000	3	07:33
13565-1	0.0227	0.0682	0.0227	0.0455	44	14:51
13565-2	0.0227	0.0682	0.0225	0.0455	44	14:51
13566-1	0.0541	0.0274	0.0405	0.0676	16	12:24
13566-2	0.0541	0.0411	0.0405	0.0676	16	12:24
Total						08:03:40
Mean	0.0237	0.0293	0.0442	0.0573		
Std Dev	0.0227	0.0310	0.0365	0.0494		

Table 8
Bit Error Probabilities Corresponding to
Observed Block Error Probabilities
Sample No. 3 --- August 10 to August 31, 1992

Frame Type	Block Error Prob Pe_{block}	Bit Error Prob Pe_{bit}	Length L_{frame}	Weighted $L_{frame} * Pe_{bit}$
STATUS	0.0237	0.70E-4	344	0.0240
LSTAT	0.0293	0.70E-4	424	0.0297
TIME	0.0442	0.68E-4	664	0.0452
TLM	0.0573	0.52E-4	1128	0.0590
Total			2560	0.1579
Average		0.62E-4		

Table 9
Bit Error Probabilities Corresponding to
Observed Block Error Probabilities
All Samples Combined

Frame Type	Block Error Prob Pe_{block}	Bit Error Prob Pe_{bit}	Length L_{frame}	Weighted $L_{frame} * Pe_{bit}$
STATUS	0.0237	0.70E-4	344	0.0240
LSTAT	0.0293	0.70E-4	424	0.0298
TIME	0.0421	0.65E-4	664	0.0430
TLM	0.0559	0.51E-4	1128	0.0575
Total			2560	0.1542
Average		0.60E-4		

given should be considered estimates of what might be encountered by a similar ground station using an LEO satellite like PACSAT-1. It is possible that, taken as a whole, the operating environment imposes an irreducible bit error probability near the estimated value.

V. Estimate of the Downlink Efficiency Factor

In most circumstances, there are three types of data that can be transmitted on the PACSAT-1 downlink: (1) spacecraft telemetry; (2) files for which broadcast requests have been received; and (3) file server directory, download, and upload requests. Telemetry transmission and file broadcasting are handled in unconnected mode via the AX.25 unnumbered information (UI) frame. File server transactions are accomplished in connected mode using the AX.25 data link layer protocol. PACSAT-1 has four uplinks and a single downlink.

A maximum of four simultaneous file server connections are allowed. However, it is not required that each file server connection be on a separate uplink. All four connections could be using a single uplink or two could be using one and two another with two uplinks idle. Stations requesting file broadcasts can use any uplink. In the following discussion of the downlink efficiency factor for connected-mode file server transactions, it is important to realize that access to the uplinks is completely uncoordinated. Uplink collisions are one cause of repeated downlink data. The downlink efficiency is the ratio of correctly-received bytes or frames to total bytes or frames transmitted for a given user.

Some of the data shown in the section on user traffic statistics had to be downloaded in the form of activity log files. While these logs were being downloaded, all traffic on the downlink was recorded separately and repeated frames were counted. Retransmissions can occur for one of two reasons: (1) the ground station received the frame and the acknowledgement sent to the satellite was lost; or (2) the ground station didn't receive the frame at all. Although there has been no attempt to identify the cause of the retransmissions, most of the retransmissions counted are probably the result of lost acknowledgements. The measurements described in this section show what performance might be expected from the system as a whole in the presence of multiple user traffic on the uplinks.

A summary of retransmissions observed during file downloading operations at the author's station is shown in Table 10. Since PACSAT-1 has only one outstanding frame per connected mode user (Maxframe=1), a retransmission can be identified by comparing the sequence number in consecutive information frames. If the same sequence number appears twice (or more) in succession, the second through n frames are retransmissions. Table 10 gives an efficiency factor computed on the basis of both frames and bytes retried. There is very little difference in the two figures because the bulk of the retried frames are full-length information frames. No attempts were made to artificially optimize the downloading tests, for example, by choosing only high elevation passes or times when user activity was light. Consequently, the data reported should represent what a user could expect over a period of time when using properly operating ground station equipment.

In contrast to the tabulation of retransmissions for a single station described above, a much larger data set was also analyzed for retransmissions. This larger data set spans the time period from April 1 through July 26, 1992 and contains data collected from 95 passes. From the 95 passes, 47 with a downlink

Table 10
Frames and Bytes Retried While Downloading Activity Log Files

Orbit Number	Total Bytes	Total Frames	Retried Bytes	Retried Frames	Eff Fact Bytes	Eff Fact Frames
10763	28812	109	8392	32	0.71	0.71
10764	21019	96	7301	28	0.65	0.71
10770	23667	92	1955	7	0.92	0.92
10771	37223	144	2165	14	0.94	0.90
10777	23136	96	3937	16	0.83	0.83
10778	5773	29	337	3	0.94	0.90
10779	18741	94	2154	11	0.89	0.88
10785	8196	44	280	1	0.97	0.98
10792	21660	90	6138	22	0.72	0.76
10793	14909	60	2501	9	0.83	0.85
10799	15768	77	1844	12	0.88	0.84
10807	27355	111	5010	18	0.82	0.84
10813	28848	116	5060	20	0.82	0.83
10828	24847	100	2788	10	0.89	0.90
10856	18177	102	5141	25	0.72	0.75

	Bytes	Frames		Bytes	Frames
Total	318131	1360	Mean	0.83	0.84
Retried	55003	228	Std Dev	0.09	0.08
Eff	0.8271	0.8324			

utilization greater than 60 percent were chosen for further analysis. For these 47 passes, a count of retried frames and bytes was extracted for each connected-mode user. For this tabulation, all activity for a given station during the same pass was counted as a single transaction. The data from the large sample analysis is summarized in Table 11.

The transaction records contained in the large sample summarized in Table 11 were examined to find the stations with the largest byte counts and fewest number of retries. These records are presented in Table 12 to show the operating conditions that are possible with the PACSAT-1 file server and a properly operating station and moderate loading conditions. The data presented in Table 12 results from 10 different stations. The total byte and frame counts include the retransmitted bytes and frames. The downlink utilization and total user columns are included to give some idea of the level of activity at the time the transaction was completed.

VI. Downlink Usage Statistics

There are two methods which may be used to collect satellite usage statistics. First, a ground station can monitor the downlink while the satellite is visible and record all traffic

Table 11
Summary of Frame Retransmission Analysis for Large Sample

Number of stations:	70		
Number of transactions:	262		
Total bytes:	1,476,340	% retransmitted bytes:	33.8
Total frames:	12,320	% retransmitted frames:	28.9
Retransmitted bytes:	499,110	Efficiency factor (bytes):	0.662
Retransmitted frames:	3,553	Efficiency factor (frames):	0.712

for later analysis. Second, an analysis of the activity log files stored on the spacecraft can be done. The activity log files (AL files) can be downloaded just as any other file kept by the file server. Monitoring the downlink provides a view of the traffic from a particular location. Analysis of the AL files

Table 12
File Server Transactions with More Than 10,000 Bytes of Downlink Data and Retransmission Rate Below the Mean

Orbit Number	D/L Util	Total Users	Total Bytes	Total Frames	Retried Bytes	Retried Frames	% Retry Bytes	% Retry Frames
11664	64	3	11903	61	19	1	0.2	1.6
11665	67	7	10005	62	554	2	5.5	3.2
11978	69	12	13647	64	831	3	6.1	4.7
12199	65	3	17125	68	1674	6	9.8	8.8
12808	65	6	20627	88	2238	8	10.8	9.1
12865	61	6	12206	51	1393	5	11.4	9.8
11814	89	5	11784	61	902	6	7.7	9.8
12728	65	2	13474	63	1950	7	14.5	11.1
12185	64	7	24433	101	3081	12	12.6	11.9
12193	87	8	21349	133	3699	17	17.3	12.8
12292	95	5	10432	78	1530	11	14.7	14.1
12042	76	9	14310	82	2019	16	14.1	19.5
12193	87	8	16174	71	3137	14	19.4	19.7
12192	79	9	15339	81	4623	18	30.1	22.2
12865	61	6	19374	76	4736	17	24.4	22.4
12328	89	5	14436	66	2431	15	16.8	22.7
13022	79	2	22922	85	5564	20	24.3	23.5
12342	79	4	13736	63	3443	15	25.1	23.8
12793	75	5	25637	101	6960	25	27.1	24.8
13028	65	4	11000	60	3403	15	30.9	25.0
11664	64	3	27002	107	7257	27	26.9	25.2
12542	72	5	17551	63	4449	16	25.3	25.4
12850	81	2	11619	86	4075	22	35.1	25.6
11714	72	5	11805	66	3970	18	33.6	27.3
12850	81	2	21387	95	6219	26	29.1	27.4

Table 13
Summary of Downlink Traffic Samples

	Sample No. 1 03/17/91-05/29/91	Sample No. 2 06/16/91-08/27/91	Sample No. 3 09/02/91-11/28/91
Total Bytes	3,168,924	2,107,941	5,878,189
File Server	1,353,752-42.7%	897,444-42.6%	2,376,650-40.4%
Broadcasting	1,630,643-51.4%	1,089,510-51.7%	3,123,095-53.1%
Telemetry	184,259- 5.8%	120,987- 5.7%	378,444- 6.5%

Table 14
Downlink Traffic Sample No. 3 by
Time of Day and Day of Week

	Weekdays Daytime	Weekdays Nighttime
Total Bytes	513,660	1,576,803
File Server	214,418-41.7%	680,316-43.1%
Broadcasting	268,366-52.2%	786,245-49.9%
Telemetry	30,876- 6.1%	110,242- 7.0%
Downlink Time	01:05:40	03:27:24

	Weekends Daytime	Weekends Nighttime
Total Bytes	2,177,564	1,610,162
File Server	834,598-38.3%	647.318-40.2%
Broadcasting	1,206,108-55.4%	862,376-53.6%
Telemetry	136,858- 6.3%	100,468- 6.2%
Downlink Time	05:00:20	03:50:49

provides an observation of the traffic from the viewpoint of the satellite. Both methods were employed during collection of data reported in this section.

The data shown in Table 13 was collected during a nearly year-long time period and shows little variation in the mix of file server, file broadcast, and telemetry traffic observed on the downlink. Analyses of data comprising Sample Nos. 1 and 2 have been used during the construction of a downlink traffic simulator [1]. During the previous analyses it was thought that further breakdown of a sample into weekday versus weekend and daytime versus nighttime traffic might yield additional useful

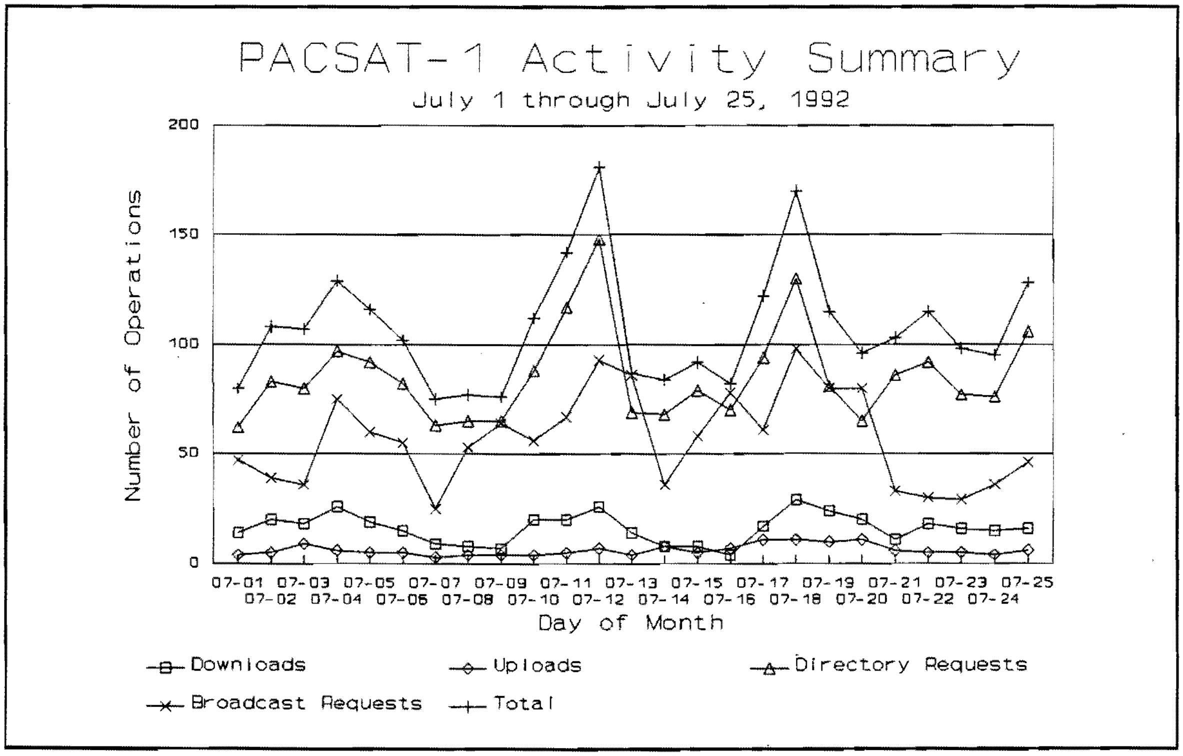

Figure 7. **PACSAT-1 activity summary in transactions for 07-01-92 thru 07-25-92.**

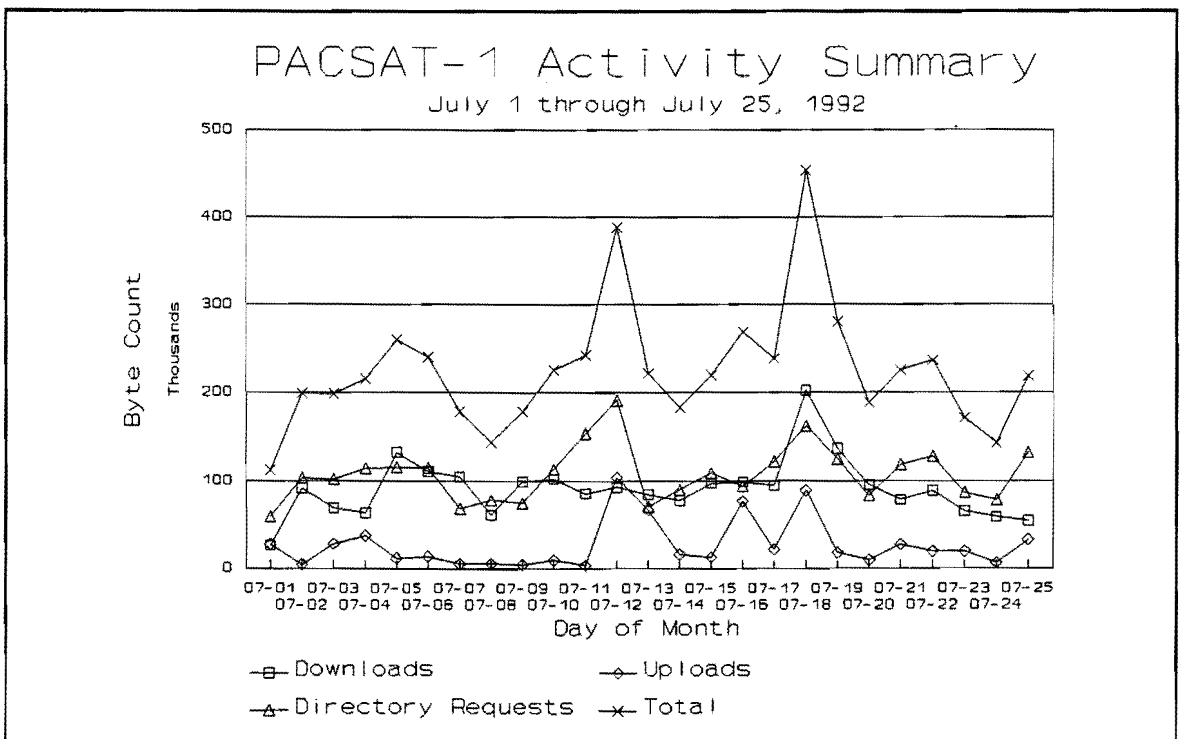

Figure 8. **PACSAT-1 activity summary in bytes transmitted for 07-01-92 thru 07-25-92.**

parameters for the simulator. Such a breakdown for Sample No. 3 is shown in Table 14.

For the data presented in Table 14, daytime refers to the local (CST/CDT) daytime visibility periods which occur between roughly 16:00 and 19:00 UTC. Nighttime refers to visibility periods which occur between 03:00 and 06:00 UTC. The later is due to the fact that local CST/CDT evening is the next day UTC. There are considerably fewer observations in the daytime weekday category because, for the most part, work schedules did not allow monitoring during that time period. Even so, there is still very little variation in the traffic mix for the three traffic types. It should be remembered that downlink monitoring will not record file uploading traffic from ground stations since uplink traffic is not repeated on the downlink.

In contrast to the data in Tables 13 and 14 being observed at a single ground station location, the data used to produce the plots in Figures 7 and 8 is taken from the daily activity log files kept on the spacecraft. For PACSAT-1, these figures represent complete file server activity summaries for the period July 1 through July 25, 1992. Figure 7 shows a transaction count and Figure 8 shows a byte count for the 25-day time period. These charts show that directory requests and broadcast requests follow each other fairly closely and that they outnumber uploads and downloads by a considerable amount. Apparently, stations connect and get a recent directory listing and from that listing issue broadcast requests.

VII. Summary

Several aspects of PACSAT-1 operation have been examined in this paper. An estimate of the downlink bit error probability has been made based on block errors encountered during telemetry frame reception in the absence of any uplink traffic. An average bit error probability of 6.0E-5 was computed by combining observations from three downlink data samples made under different conditions. The bit error probabilities for the three individual samples ranged from 5.1E-5 to 6.5E-5. Data collection and analysis to further refine these values is still in progress.

Average downlink efficiency computations were made for the case of a single station downloading files and for a large sample of connected-mode users. The downlink efficiency is the ratio of correctly-received bytes or frames to total bytes or frames transmitted for a given user. For the single-user case, the author's station downloaded a total of 318,131 bytes in 15 sessions. Of the total bytes downloaded, 55,003 were retransmissions resulting in an efficiency factor of 0.83. In the large sample, 1,476,340 bytes destined for 70 users in 262 sessions was monitored. Of this total 499,110 were retransmissions resulting in an efficiency factor of 0.67.

Additional data has been presented which shows that the mixture of traffic types heard on the downlink did not change appreciably during much of 1991 nor did the mixture change much with time of day or day of week. As this paper is being prepared, software supporting enhanced directory and file broadcasting features already available on UO-22 is being readied for installation. Another traffic study will be done once the new software is placed in operation.

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