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ISINT Performance Validation Test Report

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ABSTRACT

The Satellite Networks and Architectures branch is researching the application of standard Internet technologies over satellite communication links to LEO spacecraft. The In-Space Internet Testbed (ISINT) simulates this communications path through the use of two experimental subnets of workstation communicating over the Advanced Communications Technology Satellite (ACTS) proof-of-concept radio frequency testbed. In order to validate the end-to-end performance of ISINT, similar file transfers were sent over the RF testbed and over an actual ACTS T1 link. Comparison of the results shows that the ISINT facility has very similar performance to communications over ACTS. This test was only for a stationary point-to-point, bent pipe communications link. ISINT will be configured for more complex links now that point-to-point performance has been validated.

PURPOSE

The purpose of this test set is to validate and characterize the performance of the In-Space Internet Testbed (ISINT), comparing the use of a real GEO space link to the ISINT radio frequency (RF) tabletop transponder and simulated antennas. The Advanced Communications Technology Satellite (ACTS) was used for the GEO space link. Once an accurate stationary point-to-point simulation configuration is achieved, then the testbed will be upgraded to include dynamic signal variation and dynamic range delay. Those two elements will simulate the characteristics of a LEO spacecraft moving through a communications beam of a GEO transfer node.

CONFIGURATION

A functional block diagram of the ISINT system is provided in Figure 1. For file transfers over an ACTS satellite link, the ISINT routers were disconnected from the testbed modems and reconnected to CSU/DSUs (Command Service Unit/Data Service Unit). The CSU/DSUs were connected to two twisted pair lines to the ACTS Ground Station number 1. The resulting configuration linked the ISINT simulated space Intranet to the ISINT terrestrial Intranet via the ACTS satellite.

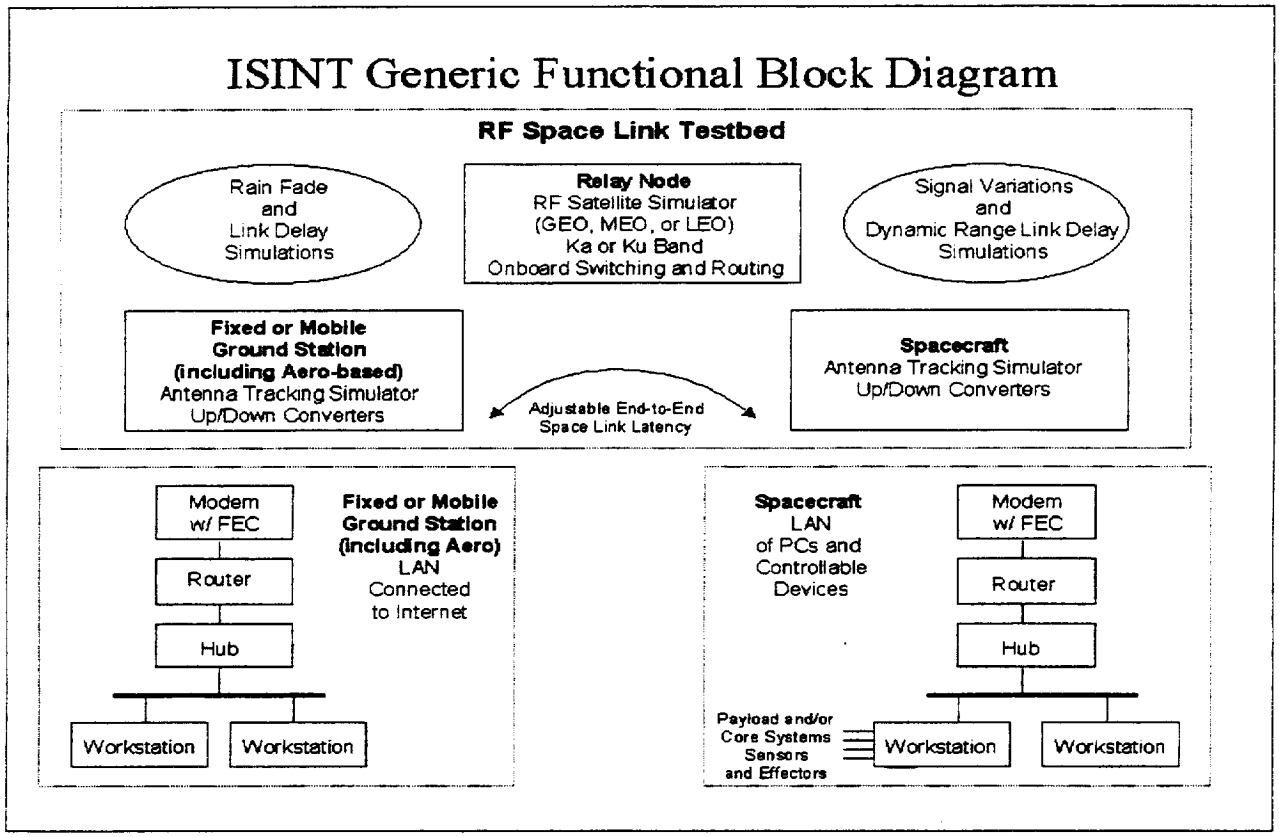

Figure 1. ISINT Functional Block Diagram

The file transfers were between two PC workstations running Linux 2.2.0. The Linux kernels were configured to incorporates the standard TCP features for transport layer control, specifically RFC 1323, TCP Extensions for High Performance [JBB92], RFC 2001, TCP Slow Start [Ste97], Congestion Avoidance, Fast Retransmit, and Fast Recovery Algorithms, and RFC 2018, Selective Acknowledgment (SACK) [MMFR96]. Although RFC 1191, Path MTU Discovery, is an important feature, it has not been implemented in the ISINT topology. The Linux kernels used a TCP window size of 655,350 bytes, a factor of 10 greater than the default Linux window size. Equation 1 shows the calculation of the theoretical window required to load a given link [Pos81].

RTT Delay (sec) * bandwidth (bytes/sec) = Window Size (bytes)

Equation 1. Delay-Bandwidth Product

Using Equation 1, the T1 Window Size for ACTS is 112,318 bytes.

0.555 sec * 1.544 Mbits/sec = **112,318 bytes**

The ISINT window size of 655,350 bytes is sufficiently large enough to allow TCP to self-congest for large files (> 6 MB) transferred over a T1 link with about a half second round trip time delay.

After completing the file transfers using ACTS, the system was reconfigured to use the ISINT RF tabletop transponder, modems, and simulated antennas. The same set of file transfers was then repeated over this configuration. The results of transferring the same set of files over each link are presented below. A comparison of the performance over each link is then given.

RESULTS USING ACTS

Round Trip Time Ping Results

The average of 682 ping round trip times was 555 ms. between a "terrestrial" workstation and a "space" workstation over the ACTS link. The standard deviation for those pings was 0.05718384. During one 30 MB FTP transfer, ping RTTs were recorded. The RTT during a transfer increased to between 561 and 580 ms. The average of 237 RTTs was 570 ms, with a standard deviation of 4.933657. Pings were not continued during other file transfers in order to not add any extraneous effects to the FTP results.

File Transfer Results

Thirty files were transferred for each of the following file sizes: 50KB, 750KB, 30MB, and 50MB. The sizes of these files are multiples of 10, not binary, therefore 1 KB = 1,000 bytes and 1 MB = 1,000,000 bytes. Throughput is the main metric used in evaluating file transfer performance, and results are expressed in the exact number of data bits transferred per second. Table 1 shows the reported FTP average throughputs for each file size.

File Size:	**50,000 Bytes**	**750,000 Bytes**	**30,000,000 Bytes**	**50,000,000 Bytes**
Average Throughput Kbits/second (Kbps)	460,000	1,040	1,435	1,435

Table 1. Average Throughput Over ACTS T1 As Reported by FTP Application

A transfer of 30 files of 50KBs was sent from an ISINT space node workstation to an ISINT terrestrial node workstation via ACTS. Since the file size was small, one can see via time sequence plot [She90], in Figure 2 below, that TCP never got out of slow start [Ste97].

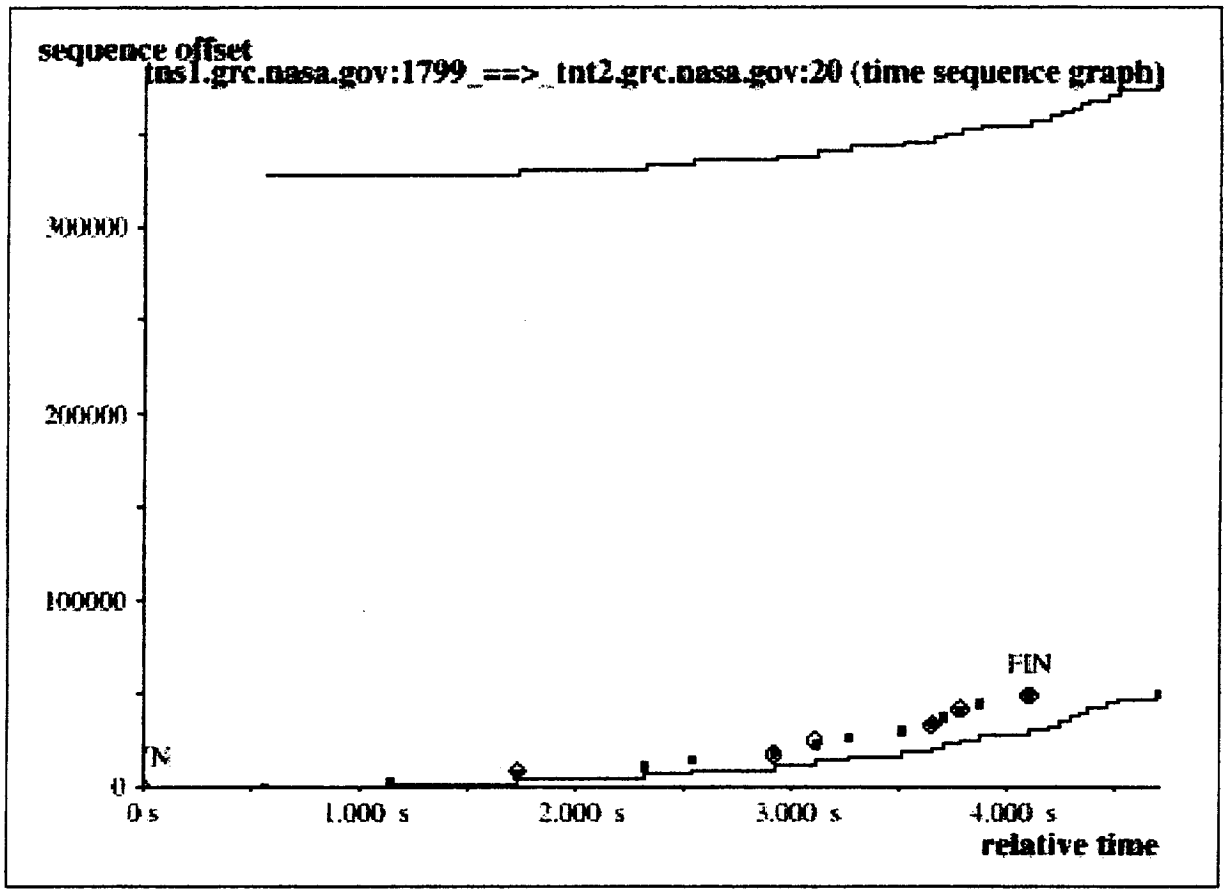

Figure 2. Time Sequence Plot for a 50 KB File

The FTP application's throughput numbers are misleading, stating that each transfer finished on average in 0.000856 seconds, which FTP equated to 460 Mbps. That is impossible since the topology utilized a single T1 circuit through ACTS (i.e., a link capable of 1.544 Mbps, with actual performance being slightly less than that). FTP uses TCP in transferring files. For small files, such as these 50 KB and 750 KB files, FTP places the data segments into the TCP queue faster than TCP can retrieve them from the queue and/or faster than TCP can send the segments and receive acknowledgment to/from the receiving host. The net result is that FTP assumes the files have been transmitted after handing off the data to TCP, while in reality the data is still in the sending machine's memory buffer or is in transit. This queueing effect is not noticeable when larger files are transferred because of the time required for FTP to access the file segments from the mass storage device and subsequently write them into the TCP queue.

Thirty 750 KB files were transferred with a reported average throughput of 1.040 Mbps. Near T1 bandwidth capacity was achieved for the 30 MB and 50 MB file transfers. The average throughput for those file sizes was 1.435 Mbps. Appendix A lists the transfer time for each file as reported by the FTP application program.

Tcptrace provides a more accurate throughput calculation for the transfer of small files than does the FTP application. Using tcpdump data, tcptrace reports the actual TCP performance,

analyzing the actual TCP packets being transferred over the link. Unfortunately, only two transfers per file size were captured by tcpdump. The average of two data points is not statistically significant, but does provide a better indication of the actual transfer throughput rate. For the 750 KB files, the average throughput of 574 Kbps is almost half of that reported by the FTP application, 1.040 Mbps. This supports the proposed explanation above of the FTP application reporting erroneous results for transfers of smaller files. See Table 2 for a summary of the average of two Tcptrace throughputs per file size.

File Size:	50,000 Bytes	750,000 Bytes	30,000,000 Bytes	50,000,000 Bytes
Average Throughput Kbits/second	88	574	1,383	1,407

Table 2. Average Throughput Over ACTS T1 As Reported by Tcptrace

RESULTS USING RF TESTBED

Round Trip Time Ping Results

The average of hundreds of ping RTTs over the RF tabletop transponder was 514 ms.

File Transfer Results

Table 3 summarizes the average throughputs achieved over the ISINT RF Testbed as reported by the FTP application program. The throughput for the 50 KB file is obviously erroneous, as was noted in the ACTS File Transfer Results section. The 750 KB throughput average of 1,200 Kbps, though within the T1 bandwidth, is also suspect when compared with the tcptrace calculated value of 640 Kbps, shown in Table 4. The Appendix B lists the FTP reported transfer time for each file.

File Size:	50,000 Bytes	750,000 Bytes	30,000,000 Bytes	50,000,000 Bytes
Average Throughput Kbits/second (Kbps)	436,427	1,200	1,440	1,429

Table 3. Average Throughput Over ISINT RF Testbed T1 As Reported by FTP Application

Table 4 provides the average throughputs calculated by Tcptrace for the same set of transfers. As stated before in the ACTS section, only two file transfers per file size were captured by tcpdump. The average of two samples is not statistically significant, but provides a better picture of the actual transfer rates for smaller files.

File Size:	50,000 Bytes	750,000 Bytes	30,000,000 Bytes	50,000,000 Bytes
Average Throughput Kbits/second	102	640	1,394	1,413

Table 4. Average Throughput Over ISINT RF Testbed T1 As Reported by Tcptrace

Throughput Comparisons

Tcptrace averages, shown in Table 5, reveal the percentage of throughput improvement when using the RF Testbed versus ACTS. Throughput for large files is similar for ACTS and the RF Testbed, having less than 1 % difference. For smaller files, there is a greater difference in throughputs. Although they do not appear significant when viewed in Figure 3, they do need to be explained in future tests. As stated before, the tcptrace results are only based on two tcpdump files generated for two transfers in each set of 30, and therefore are not statistically significant. A follow on test set will examine transfer times for each file based on the SYNs and FINs captured by tcpdump. That method will avoid the creation of enormous tcpdump files and will provide a better calculation of average transfer times.

	File Size				
Link	50KB	750KB	30MB	50MB	
ACTS	88	574	1383	1407	Kbps
RF TB	102	640	1394	1413	Kbps
% Diff from ACTS	15.51%	11.62%	0.81%	0.42%	

Table 5. Percent Difference Between ACTS and ISINT RF Testbed Throughput Based on Tcptrace Output

FTP application averages, shown in Table 6, also substantiate that for large file transfers, the ISINT RF testbed link demonstrates very similar throughput performance to ACTS throughput performance for a T1 line. As mentioned earlier, for small files, the FTP application produces erroneous throughput numbers. When TCP reached a steady-state transfer rate, there was less than 1 % different between ACTS and the ISINT RF testbed. Since the round trip time for ACTS is 555 ms and is 514 ms for ISINT, the performance over ISINT is expected to be slightly better than over ACTS. This data supports that theory. Based on the data presented in this paper, one can see that the performance of the ISINT Testbed configuration is a very close approximation to that of an actual satellite link.

	File Size				
Link	**50KB**	**750KB**	**30MB**	**50MB**	
ACTS	460000	1040	1435	1435	Kbps
RF TB	436427	1200	1440	1429	Kbps
% Diff from ACTS	-5.12%	15.38%	0.37%	-0.37%	

Table 6. Percent Difference Between ACTS and ISINT RF Testbed

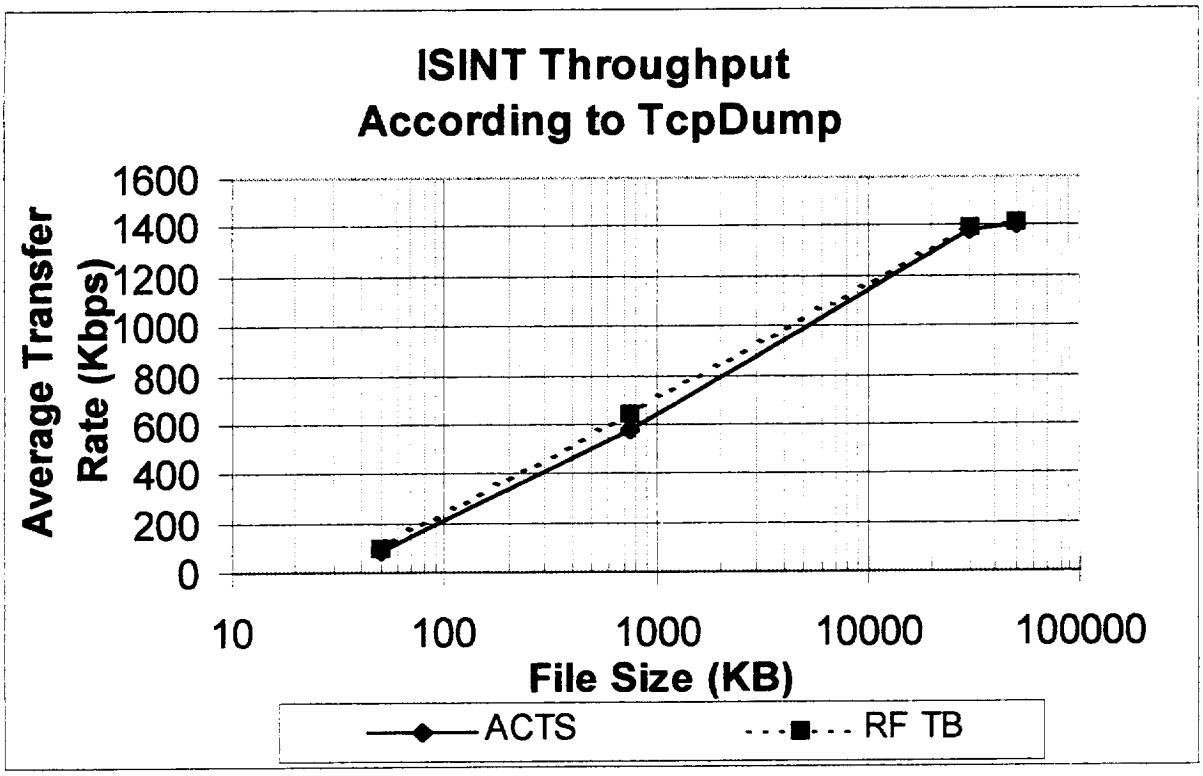

Figure 3. ACTS and ISINT RF Testbed Comparison of Throughput Calculated by Tcptrace

Appendix A

File Transfer Times Over ACTS Reported by FTP Application

ISINT ACTS Test 50KB File		
Seq No.	Seconds to Transfer	KB/sec
1	0.001260	3.90E+04
2	0.000818	6.00E+04
3	0.000837	5.80E+04
4	0.000820	6.00E+04
5	0.000817	6.00E+04
6	0.000823	5.90E+04
7	0.000822	5.90E+04
8	0.000827	5.90E+04
9	0.000818	6.00E+04
10	0.000820	6.00E+04
11	0.000817	6.00E+04
12	0.000826	5.90E+04
13	0.000869	5.60E+04
14	0.000819	6.00E+04
15	0.000827	5.90E+04
16	0.000823	5.90E+04
17	0.000847	5.80E+04
18	0.000902	5.40E+04
19	0.000844	5.80E+04
20	0.000844	5.80E+04
21	0.000830	5.90E+04
22	0.000933	5.20E+04
23	0.000847	5.80E+04
24	0.000833	5.90E+04
25	0.000922	5.30E+04
26	0.000875	5.60E+04
27	0.000838	5.80E+04
28	0.000849	5.80E+04
29	0.000836	5.80E+04
30	0.000832	5.90E+04
Min	0.000817	3.90E+04
Avg	0.000856	57500
Max	0.001260	6.00E+04
KB/sec	* 8 bits/B	= Kbps
57500	8	460000

ISINT ACTS Test 750KB File		
Seq No.	Seconds to Transfer	KB/sec
1	5.53	1.30E+02
2	5.53	1.30E+02
3	5.53	1.30E+02
4	5.53	1.30E+02
5	5.53	1.30E+02
6	5.53	1.30E+02
7	5.53	1.30E+02
8	5.53	1.30E+02
9	5.53	1.30E+02
10	5.53	1.30E+02
11	5.53	1.30E+02
12	5.52	1.30E+02
13	5.54	1.30E+02
14	5.52	1.30E+02
15	5.53	1.30E+02
16	5.54	1.30E+02
17	5.52	1.30E+02
18	5.53	1.30E+02
19	5.53	1.30E+02
20	5.53	1.30E+02
21	5.53	1.30E+02
22	5.53	1.30E+02
23	5.53	1.30E+02
24	5.53	1.30E+02
25	5.53	1.30E+02
26	5.53	1.30E+02
27	5.53	1.30E+02
28	5.53	1.30E+02
29	5.53	1.30E+02
30	5.53	1.30E+02
Min	5.52	1.30E+02
Avg	5.53	130
Max	5.54	1.30E+02
KB/sec	* 8 bits/B	= Kbps
130	8	1040

ISINT ACTS Test 30MB File		
Seq No.	Seconds to Transfer	KB/sec
1	165	1.80E+02
2	165	1.80E+02
3	165	1.80E+02
4	165	1.80E+02
5	165	1.80E+02
6	165	1.80E+02
7	165	1.80E+02
8	165	1.80E+02
9	165	1.80E+02
10	182	1.60E+02
11	165	1.80E+02
12	165	1.80E+02
13	165	1.80E+02
14	165	1.80E+02
15	165	1.80E+02
16	165	1.80E+02
17	165	1.80E+02
18	165	1.80E+02
19	165	1.80E+02
20	165	1.80E+02
21	165	1.80E+02
22	166	1.80E+02
23	165	1.80E+02
24	165	1.80E+02
25	165	1.80E+02
26	165	1.80E+02
27	165	1.80E+02
28	165	1.80E+02
29	165	1.80E+02
30	165	1.80E+02
Min	165.00	1.60E+02
Avg	165.60	1.79E+02
Max	182.00	1.80E+02
KB/sec	* 8 bits/B	= Kbps
179	8	1435

ISINT ACTS Test 50MB File		
Seq No.	Seconds to Transfer	KB/sec
1	273	1.80E+02
2	273	1.80E+02
3	273	1.80E+02
4	273	1.80E+02
5	273	1.80E+02
6	273	1.80E+02
7	276	1.80E+02
8	281	1.70E+02
9	273	1.80E+02
10	273	1.80E+02
11	273	1.80E+02
12	273	1.80E+02
13	273	1.80E+02
14	273	1.80E+02
15	273	1.80E+02
16	273	1.80E+02
17	273	1.80E+02
18	273	1.80E+02
19	273	1.80E+02
20	274	1.80E+02
21	273	1.80E+02
22	273	1.80E+02
23	273	1.80E+02
24	279	1.70E+02
25	273	1.80E+02
26	273	1.80E+02
27	273	1.80E+02
28	273	1.80E+02
29	273	1.80E+02
30	273	1.80E+02
Min	273.00	1.70E+02
Avg	273.60	1.79E+02
Max	281.00	1.80E+02
KB/sec	* 8 bits/B	= Kbps
179	8	1435

Appendix B

File Transfer Times Over ISINT RF Testbed Reported by FTP Application

ISINT RF Testbed Test 50KB File		
Seq No.	Seconds to Transfer	KB/sec
1	0.019100	2.60E+03
2	0.000821	5.90E+04
3	0.000823	5.90E+04
4	0.000821	5.90E+04
5	0.000817	6.00E+04
6	0.000879	5.60E+04
7	0.000894	5.50E+04
8	0.000858	5.70E+04
9	0.000824	5.90E+04
10	0.000866	5.60E+04
11	0.001050	4.70E+04
12	0.000860	5.70E+04
13	0.000885	5.50E+04
14	0.000847	5.80E+04
15	0.000834	5.90E+04
16	0.000813	6.00E+04
17	0.000830	5.90E+04
18	0.000823	5.90E+04
19	0.000822	5.90E+04
20	0.000833	5.90E+04
21	0.001040	4.70E+04
22	0.000900	5.40E+04
23	0.000874	5.60E+04
24	0.000878	5.60E+04
25	0.000998	4.90E+04
26	0.001060	4.60E+04
27	0.000856	5.70E+04
28	0.000823	5.90E+04
29	0.000827	5.90E+04
30	0.000827	5.90E+04
Min	0.000813	2.60E+03
Avg	0.001479	5.46E+04
Max	0.019100	6.00E+04
KB/sec	* 8 bits/B	= Kbps
54553	8	436427

ISINT RF Testbed Test 750KB File		
Seq No.	Seconds to Transfer	KB/sec
1	5.05	1.50E+02
2	5.04	1.50E+02
3	5.04	1.50E+02
4	5.03	1.50E+02
5	5.03	1.50E+02
6	5.03	1.50E+02
7	5.03	1.50E+02
8	5.03	1.50E+02
9	5.03	1.50E+02
10	5.03	1.50E+02
11	5.03	1.50E+02
12	5.03	1.50E+02
13	5.04	1.50E+02
14	5.04	1.50E+02
15	5.04	1.50E+02
16	5.04	1.50E+02
17	5.04	1.50E+02
18	5.04	1.50E+02
19	5.04	1.50E+02
20	5.03	1.50E+02
21	5.03	1.50E+02
22	5.03	1.50E+02
23	5.03	1.50E+02
24	5.04	1.50E+02
25	5.03	1.50E+02
26	5.03	1.50E+02
27	5.02	1.50E+02
28	5.03	1.50E+02
29	5.03	1.50E+02
30	5.03	1.50E+02
Min	5.02	1.50E+02
Avg	5.03	1.50E+02
Max	5.05	1.50E+02
KB/sec	* 8 bits/B	= Kbps
150	8	1200

ISINT RF Testbed Test 30MB File		
Seq No.	Seconds to Transfer	KB/sec
1	164	1.80E+02
2	164	1.80E+02
3	164	1.80E+02
4	164	1.80E+02
5	164	1.80E+02
6	164	1.80E+02
7	164	1.80E+02
8	164	1.80E+02
9	164	1.80E+02
10	164	1.80E+02
11	164	1.80E+02
12	164	1.80E+02
13	164	1.80E+02
14	164	1.80E+02
15	164	1.80E+02
16	164	1.80E+02
17	164	1.80E+02
18	164	1.80E+02
19	164	1.80E+02
20	164	1.80E+02
21	164	1.80E+02
22	164	1.80E+02
23	164	1.80E+02
24	164	1.80E+02
25	164	1.80E+02
26	164	1.80E+02
27	164	1.80E+02
28	164	1.80E+02
29	164	1.80E+02
30	164	1.80E+02
Min	164.00	1.80E+02
Avg	164.00	1.80E+02
Max	164.00	1.80E+02
KB/sec	* 8 bits/B	= Kbps
180	8	1440

ISINT RF Testbed Test 50MB File		
Seq No.	Seconds to Transfer	KB/sec
1	272	1.80E+02
2	272	1.80E+02
3	272	1.80E+02
4	272	1.80E+02
5	272	1.80E+02
6	283	1.70E+02
7	281	1.70E+02
8	272	1.80E+02
9	272	1.80E+02
10	272	1.80E+02
11	272	1.80E+02
12	272	1.80E+02
13	280	1.70E+02
14	272	1.80E+02
15	280	1.70E+02
16	272	1.80E+02
17	272	1.80E+02
18	272	1.80E+02
19	272	1.80E+02
20	272	1.80E+02
21	272	1.80E+02
22	272	1.80E+02
23	272	1.80E+02
24	272	1.80E+02
25	272	1.80E+02
26	272	1.80E+02
27	272	1.80E+02
28	272	1.80E+02
29	272	1.80E+02
30	272	1.80E+02
Min	272.00	1.70E+02
Avg	273.20	1.79E+02
Max	283.00	1.80E+02
KB/sec	* 8 bits/B	= Kbps
179	8	1429

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13. ABSTRACT ***(Maximum 200 words)***

The Satellite Networks and Architectures branch is researching the application of standard Internet technologies over satellite communication links to LEO spacecraft. The In-Space Internet Testbed (ISINT) simulates this communications path through the use of two experimental subnets of workstation communicating over the Advanced Communications Technology Satellite (ACTS) proof-of-concept radio frequency testbed. In order to validate the end-to-end performance of ISINT, similar file transfers were sent over the RF testbed and over an actual ACTS T1 link. Comparison of the results shows that the ISINT facility has very similar performance to communications over ACTS. This test was only for a stationary point-to-point, bent pipe communications link. ISINT will be configured for more complex links now that point-to-point performance has been validated.

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