TCP PERFORMANCE ENHANCEMENT OVER IRIDIUM

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ABSTRACT

In support of iNET maturation, NASA-JPL has collaborated with NASA-Dryden to develop, test and demonstrate an over-the-horizon vehicle-to-ground networking capability, using Iridium as the vehicle-to-ground communications link for relaying critical vehicle telemetry. To ensure reliability concerns are met, the Space Communications Protocol Standards (SCPS) transport protocol was investigated for its performance characteristics in this environment. In particular, the SCPS-TP software performance was compared to that of the standard Transmission Control Protocol (TCP) over the Internet Protocol (IP). This paper will report on the results of this work.

KEYWORDS

Network telemetry, distributed systems, disruption tolerant networking, airborne science

INTRODUCTION

The value of broadcast telemetry technology will be enhanced when integrated as a component of a future network communication architecture. The integrated Network-Enhanced Telemetry (iNET) program is a unique effort that will redefine the basic test and evaluation telemetry infrastructure used at every Department of Defense (DoD) major range and test facility. Sponsored by the Office of the Secretary of Defense, Operational Test and Evaluation Directorate (OSD/DOTE&E), the iNET technology vision is to establish and iterate an experimental architecture toward mature and stable standards that accommodate the needs of the broadest possible user base.

The architecture and technology in use today for traditional telemetering of data from suborbital vehicles has been essentially unchanged for the last 50 years. Broadcast communications are used in point-to-point (typically air-to-ground) configurations using reserved electromagnetic spectrum. The time criticality (perceived or otherwise) of safety-related data as part of the data stream has been the dominant justification for this approach. A broadcast architecture with inefficient and cumbersome spectrum management is now recognized to be a limiting factor in the growth of new capabilities for test and measurement industry niches. The solution path necessarily includes enhancement of broadcast technology with network technology.

In support of iNET maturation, NASA-JPL has collaborated with NASA-Dryden to develop, test and demonstrate an over-the-horizon vehicle-to-ground networking capability, using Iridium as the vehicle-to-ground communications link for relaying critical vehicle telemetry. To ensure reliability concerns are met, the Space Communications Protocol Standards (SCPS) transport protocol was investigated for its performance characteristics in this environment. In particular, the SCPS-TP software performance was compared to that of the standard Transmission Control Protocol (TCP) over the Internet Protocol (IP). The normal TCP protocol considers loss of data to be due to congestion, whereas in radio links data loss is normally due to poor link conditions. The TCP response to data loss is to lower the transmission rate to ease potential congestion problems. Among other features designed to improve radio link performance, the SCPS-TP is a TCP performance-enhancing proxy protocol which handles data loss without unnecessarily lowering the transmission rate, thus providing for greater throughput under conditions of noisy or intermittent links.

EXPERIMENT DESIGN

The primary objective of the multi-channel Iridium/SCPS experiment was to measure the performance differences between standard TCP and the Space Communications Protocol Standard Transport Protocol (SCPS-TP) when used in an arrangement that striped data over several IRIDIUM channels for increased total channel capacity. This experiment was focused on reliable stream-oriented protocol operation in an unstable, R/F communication environment.
In the experiment, two test applications establish a TCP connection and exchange data over a transparent communication network consisting of one, two or three independent Iridium satellite communication links. Network transparency is achieved by using teql, the ‘trivial equalizer’, as a single network interface through which IP traffic can be routed from one workstation to another over multiple PPP links. The teql approach was used for the TCP specific tests. SCPS-TP provides a similar network interface, where IP traffic is routed through SCPS, which in turn used teql for multiplexing and de-multiplexing IP traffic to/from multiple PPP sessions. PPP was used to establish network identification between workstations over the Iridium modems.

A series of tests were conducted, varying the size, rate and direction of traffic flow between test applications, and using both TCP and SCPS-TP for reliable transport. The number of Iridium links used was varied as well.

TEST BED CONFIGURATION

The JPL iNET test bed consists of four PC workstations running Linux Fedora residing on the same Ethernet subnet. Two workstations are tagged as clients and two as gateways. The client workstations were given the names ‘romeo’ and ‘juliet’. All four are commodity PCs. The gateways have four serial ports installed (two original, and two additional). The test bed is shown in Figure 1.

To support both IP and SCPS communication, the gateway workstations use PPP to establish network connectivity across the Iridium modem connections. The Linux component teql, the ‘trivial equalizer’, presents a single network interface to either the IP layer or to SCPS and performs a simple round-robin multiplexing of network traffic across the (up to three) different PPP links. When receiving information from different PPP links, teql simply forwards the IP packets on to either the IP layer or SCPS, in the order the packets were received. The teql itself does not perform any retransmission of missed packets or enforce packet ordering when de-multiplexing.

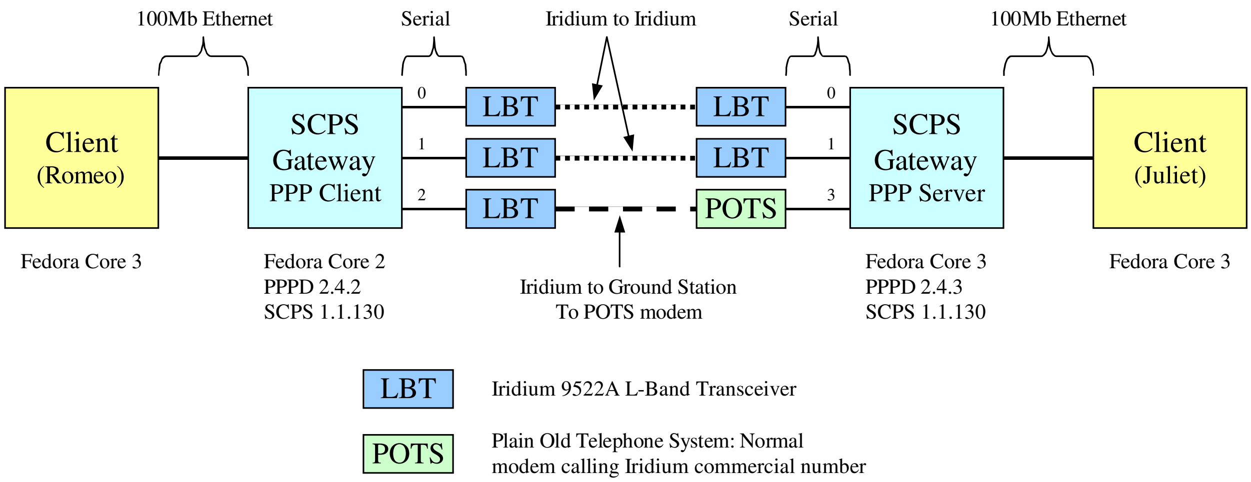

Figure 1 iNET Test Bed SCPS-TP Configuration

One gateway workstation, the PPP client, is connected via three of the serial ports to three Iridium 9522A L-Band Transceivers, or LBTs. The LBTs appear to the computer as modems connected to phone lines. The other gateway, the PPP server, is connected via two of the serial ports to two more Iridium LBTs. The third serial port is connected to a 56K external modem.
The LBTs are connected to external antennae via a cable system to the roof, giving them a fairly clear view of the Iridium satellites. Two different lab locations were used during the course of testing, building 126 and building 301. The antenna and cabling assemblies for building 126 are shown in Figure 2. Standard fixed-mast antennas were used. Note that there are a total of five antenna and cabling assemblies. In place of a sixth assembly, the 56K external modem to an Iridium commercial number is used. The building 301 antenna assemblies differed in that it used AD510-10 active Iridium antennae. The main cable run is 130 feet of RG-213 cable. Note that the same testbed configuration (5 Iridium transceivers with one POTS modem was used in both locations).

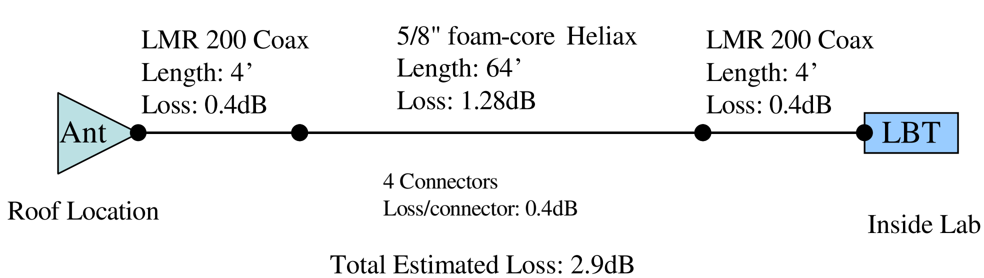

Figure 2 Antenna Assemblies, Building 126

The LBTs receive power through an external 5V DC power supply. This setup allows three simultaneous phone calls to be made from the client gateway to the server gateway, each running PPP.

The advertised data rate for an Iridium connection is up to 2.4Kbps. This data rate is without compression. An add-on capability, the Iridium Direct Connect, advertises a potential data rate of up to 10Kbps, depending on content. This add-on compression capability was not used for this experiment as it was not suitable for Linux-based Iridium-to-Iridium connections.

SCPS GATEWAY MODIFICATIONS

We use SCPS in the “gateway” mode, allowing SCPS to be used transparently. Essentially, this means that the testing software is unaware of the existence of SCPS. When the gateway is brought up, it intercepts data on the configured interfaces and processes it through the SCPS protocols. Using the gateway with teql and multiple PPP interfaces posed several problems for SCPS. For technical reasons, teql cannot be intercepted directly by SCPS. Instead, SCPS intercepts ppp0, and then uses Linux iptables rules to allow ppp1 and ppp2 to be intercepted as well. This special initialization is performed in the script we use to launch the SCPS gateway. Also, SCPS needs the queue length of the PPP interfaces in order to perform intelligent buffering. That requires a minor modification to the PPP Linux kernel module, and the running of a special application, “ppp_current_tx_len” to request the queue lengths and to pass them to the gateway. ppp_current_tx_len must be running before starting the gateway.

TESTING SOFTWARE

The test software consisted of two applications that would establish a TCP connection with each other and send data at a prescribed rate. The data was sent in the form of a message, which included a unique timestamp, length field and an array of random bytes up to the overall specified length of the message. The overall message size and number of messages sent per second were both varied to simulate a variety of loads on the communication network. Throughput was calculated by the number of messages received by a test application within the time specified for the test, and adjusted for the size of the messages. Latency was calculated by taking the difference between the time the message was received and the time at which it was sent.

BASELINE SYSTEM PERFORMANCE

System Time Synchronization

All workstations used the Network Time Protocol (NTP) service for synchronizing system clock times. System times are kept to within 100-200ms of each other.

Ping Latency

The ‘ping’ system utility included with the Linux operating system provided a baseline performance metric for the Iridium connections. The ping utility uses the ICMP protocol to send an ‘echo request’ to a target workstation and expects to receive an ‘echo response’ in return. These tests used the default size of 64 ICMP data bytes and sent a series of requests every second for approximately one minute. The ping tests were used over each of the Iridium channels independently, and in both directions. For the two Iridium-to-Iridium channels, ping times were 3.1sec on average with a standard deviation of 1.8sec. For the Iridium-to-POTS channel, ping times were 1.2sec on average with a standard deviation of 0.4 seconds.

TEST CASES

The total set of test cases performed spanned one, two and three channel configurations. The test application could be configured to vary the message size and the rate at which messages were sent over the system as well as the ability to send data one-way or two-way. Tests were also performed to investigate the effects of forced call drops on both SCPS and TCP. Tests were designed to cover the entire performance range for one, two and three channel configurations. Iridium is advertised as supporting a 2400 bps data rate over a single link. Accordingly, the theoretical maximum for a 3-channel link would be 7200 bps. Only the results of the 3-channel tests are presented in this paper. The bulk of tests were performed in the building 126 lab in which fixed antennas were used with the Iridium transceivers. Follow-up tests in which the data size was kept fixed and only the data rates were performed in the building 301 lab, using the active antennas and longer cable runs. These follow up tests sent 64 byte messages at rates that were multiples of 1024 bps, up to 8192 bps.

SCPS-TP AND TCP COMPARISON

The first set of multichannel throughput results for SCPS and TCP over a 3-channel configuration are plotted in Figure 3. The 'ideal' curve represents perfect throughput with no loss. The term "offered rate" in the figures represents the rate at which the test application was sending data to the system, and the actual rate was a measure of how much data arrived at the endpoint during the span of the test. Past an offered rate of 3000 bps SCPS provides greater throughput in all cases, and more than double the throughput of TCP in some. The general trend for the TCP throughput is to reach a maximum rate of approximately 3200 bps whereas the SCPS trend is closer to 5000 bps. The average performance advantage of SCPS over TCP is 53%. These tests were performed in building 126.

A series of follow-on tests were performed using a 3-channel configuration in which the message size was held constant at 64bytes and the rate varied. The tests were performed in building 301 with the active antennas and longer cable runs. The tests were duplicated for SCPS and TCP. During this series of tests the maximum actual rate achieved by SCPS was only about 4Kbps and 3.5Kbps for TCP. In analyzing the data, one of the Iridium-to-Iridium channels was essentially non-functional due to a large number of call drops, approximately 1 drop every two minutes. The other Iridium-to-Iridium channel also had a high level of call drops, approximately 1 drop every4 minutes. We switched the worst offending Iridium-to-Iridium channel to using a POTS modem

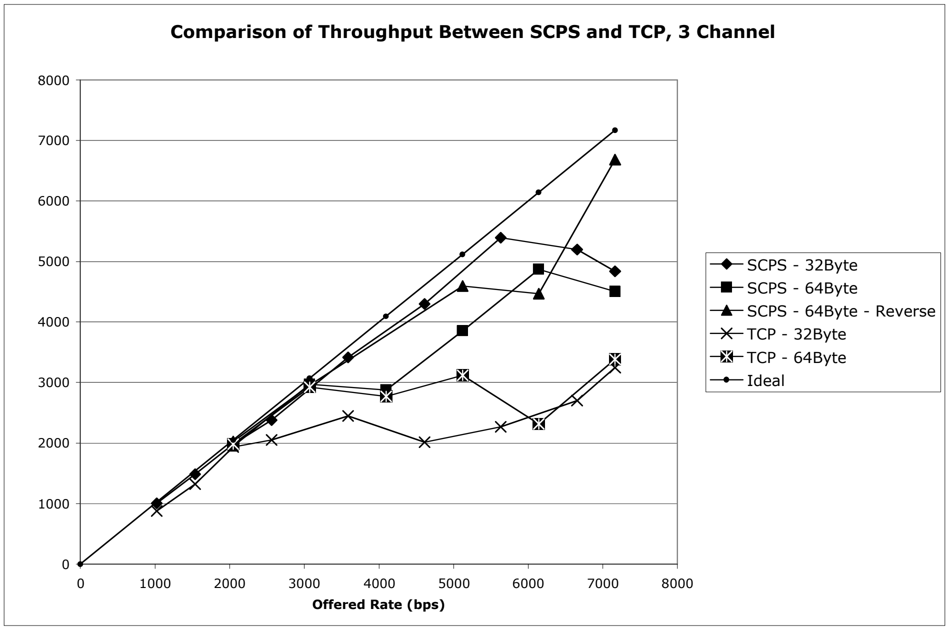

Figure 3 - SCPS-TP and TCP Throughput with Three Channels

at the PPP server. The resulting data is shown in Figure 4. From this data, SCPS-TP provides an almost 1.9Kbps, or 64%, improvement over TCP for offered rates higher than 5Kbps.

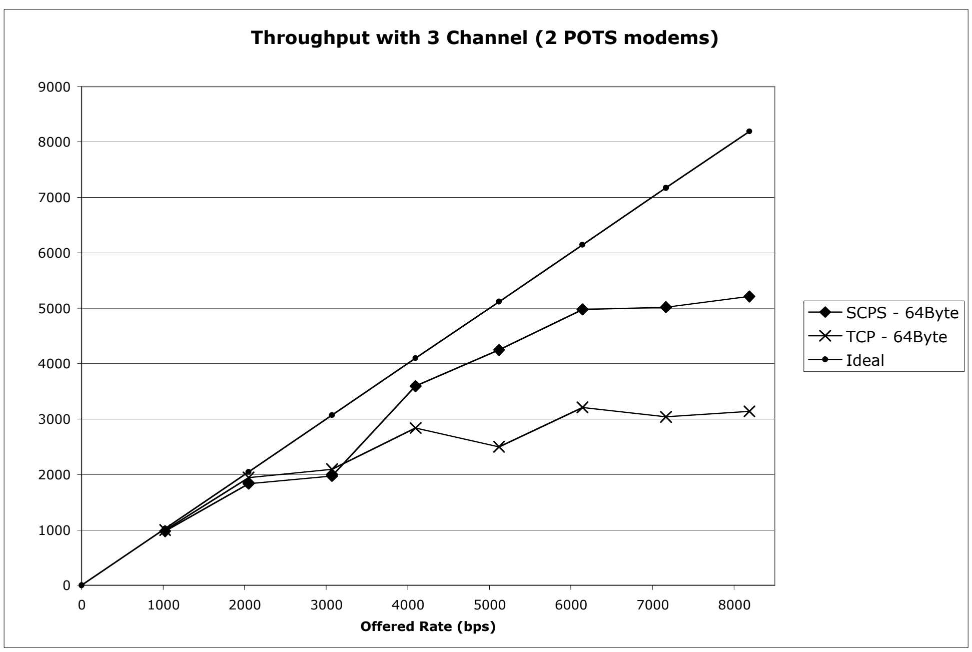

Figure 4 - 3-Channel Throughput with 2 POTS Terminals

SCPS Performance

Throughput

The results for testing SCPS-TP in building 126 across all data size, range and channel combinations are shown in Figure 5. An expected trend, as visible in the figure, is that the actual throughput falls into bands according to the number of channels in use. Of note is that almost ideal throughput is achieved with three channels at offered rates up to about 4500 bps. Latency within this operating regime is under 60 seconds for smaller messages sizes.

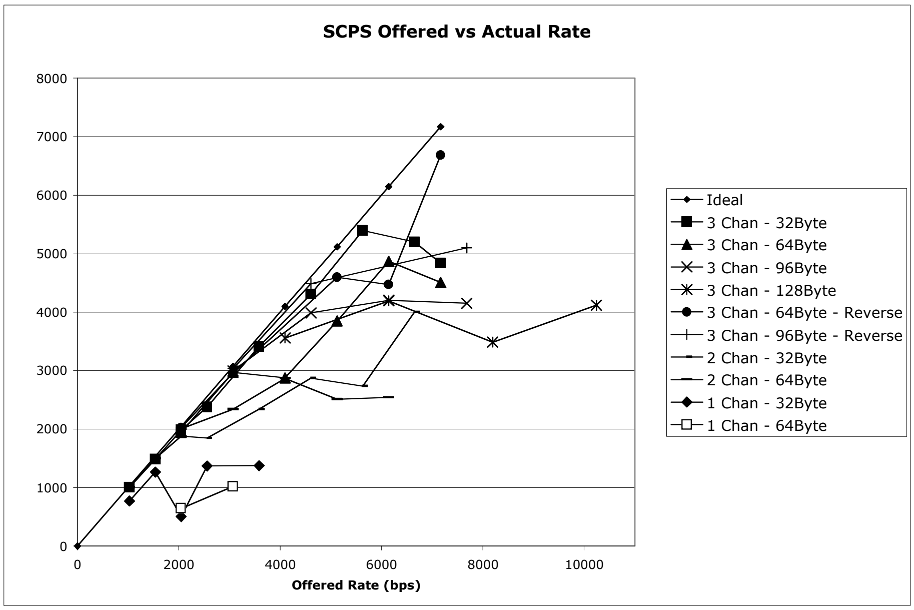

Figure 5 - SCPS Throughput

Latency

Transmission latency for SCPS-TP in the building 301 tests indicated a linear increase as the offered rate increased, starting at 11.3 sec at 1024 bps to 83.3 sec at 8192 bps. TCP transmission latency ranged from 6.9 sec at 1024 bps to 60.0 sec at 8192 bps. The latency from the tests performed in building 126 did not show such a discrepancy between the two protocols.

Two-Way Communication

A limited set of two-way communication tests were performed, in which both the Romeo and Juliet nodes sent data simultaneously over a 3-channel configuration. In the first test case, each client sent 64 byte messages at an offered rate of 2048 bps. The actual rate of data was 1580 bps for the Romeo node and 1987 bps for the Juliet node. In the second test case each client sent 96 byte messages at an offered rate of 3072 bps. The actual rate of data was 1847 bps for the Romeo node and 2513 bps for the Juliet node. In the third test case, the Romeo node sent 96 byte messages at an offered rate of 4608 bps and the Juliet node sent 32 byte messages at an offered rate of 1024 bps. The actual rate of data was 2361 bps for the Romeo node and 630 bps for the Juliet node. The combined actual rates for the first two tests are consistent with the rates for the one-way SCPS three-channel tests, whereas the third test throughput performance is more comparable with the 2-channel one-way tests results. Communication latency for the two way tests averaged 10.5 sec for the 2048 bps (combined) case and 26.0 sec for the 6144 bps (combined) case. Latency for the third test case varied from 59.0 sec for data sent from the Romeo node and 8.4 sec for data sent from the Juliet node.

Iridium Connection Statistics

For those follow-up tests performed in building 301, the number of times the PPP connection needed to be restored on each of the channels was recorded for each test run. This metric is taken when the gateway server workstation receives an Iridium call and attempts to establish a PPP connection with the client. It does not indicate the duration of a connection, nor does it indicate the duration of an outage (i.e. the client gateway could not place an Iridium call). While not a true indicator of connection uptime, this metric does indicate an overall quality of the connection during a test. Including a 10-second wait before retrying to establish a connection after a call drop, each connection attempt requires an approximately 45-50 second period of time in which the Iridium call is established, the mgetty process spawns PPP and the PPP connection is established, before the connection available to teql. The channel 0 Iridium-Iridium connection averaged 15 drops per test run, the channel 1 Iridium-Iridium connection averaged 8.7 drops per test run and the channel 3 Iridium-POTS connection averaged 0.3 drops. Each test was roughly 47 minutes in duration, so on average the channel 0 connection reset every 3 minutes.

CONCLUSIONS

Impact of Increasing Number of Iridium Channels - Increasing the number of Iridium connections has four primary effects:

a) Increased available bandwidth (and hence a higher total data rate)
b) Better performance during call drops (as mitigated by the presence of other connections)
c) Increased possibility of antenna interference
d) Potential for loss of performance due to out-of-order packets

Most of the time, call drops are related to individual connections, i.e., they are random and uncorrelated. That is, rarely did we lose connectivity across all links simultaneously. So, adding channels will increase the average bandwidth and make it more likely that there will always be some bandwidth available.

In our test facilities, the antenna spacing met the stated minimum requirements for the antenna types. However, our testbed is unusual in that calls are both initiated and received from the same location. As noted above, this could result in increased interference between antennae, both at the ground location as well as at the satellite. In most cases, due to Iridium satellite coverage, the likelihood of all Iridium transceivers in the testbed being serviced by the same cell within the same beam of a single satellite is high.

In general, TCP does not expect packets to arrive out of order. When they do arrive out of order, some IP stacks will trigger unnecessary requests for lost packets – packets that will actually arrive soon. Unfortunately, the nature of running multiple bonded PPP connections means that there will definitely be many out-of-order packets; it can't be helped. We were able to tailor SCPS to minimize the problem, by adjusting its parameters. The Linux IP stack is considered relatively immune to the problem.

SCPS Performance Compared to TCP – In both testing locations SCPS-TP showed superior throughput performance than TCP, providing an 18% to 64% average increase in data rate. SCPS-TP did, however, have slightly higher latencies than TCP in general. The difference in latencies was greater in the building 301 tests compared to the building 126 tests. In general, the throughput and latency results from the building 301 tests using a single POTS modem on the PPP server correspond more closely to the results of the 2-channel tests performed in building 126, indicating that the Iridium-to-Iridium channel with the highest call drop rate was essentially non-functional. Using two POTS modems in building 301 provided much greater connection stability and from that, achieved the performance levels we witnessed in the building 126 configuration. In addition, we could clearly see the performance improvement of SCPS-TP over TCP.

Effects of Data Size and Rate on Performance – Examining Figure 3 we conclude that data size has a minimal, if any impact on throughput. The primary effect of data rate on performance was the almost linear increase in latency as rate was increased. In terms of throughput, data rate approached an asymptotic limit below the theoretical maximum rate supported by the number of Iridium channels in use. For the building 126 tests, this limit was approximately 5500 bps and in building 301 this limit was approximately 4000 bps (3000 bps for TCP), compared to the 3-channel limit of 7200 bps. SCPS-TP was also tuned for bulk data transfer, with best performance when the MTU of 1500 bytes is full. Since many of the test cases would not completely fill an MTU, if SCPS performs a re-transmission of a missed segment, it would need to resend an MSS of approximately 1448 bytes, the end result of which would be that more data is retransmitted than necessary.

Variability of Iridium Performance - Iridium connections live in a world of constant change; they hop from satellite to satellite, and from beam to beam within the purview of a single satellite. The calls are affected by the weather, the view of the sky, reflections from buildings and the local geography, and the ever-changing position of the satellite relative to the antennae. Given all this, it is simply a given that connections will drop periodically, and that some connections will be marginal. Marginal connections are actually a worse problem than dropped calls; when a connection drops, it is detected and a new connection attempted. A connection with a high error-rate that manages to stay up will simply deliver poor performance as it will be chosen round-robin by teql. The call-drop statistics reinforce how variable the Iridium performance can be, particularly on the channel 0 connection. IN contrast, the (comparatively) good call-drop performance of the Iridium-POTS channel 3 connection suggests that by simply removing a satellite link from one-half of the connection there is an almost 50-fold improvement in connection stability.

RECOMMENDATIONS

Antenna Placement – Antenna placement and geometry on an airborne platform should be designed such that all antennae are not occluded at the same time during turns and other maneuvers.

Future Testing – Many questions regarding the variability in Iridium performance have been raised as a result of the tests performed. Future testing is being planned to help further understand the interaction of Iridium antennae, satellite capability for the number of calls and connection quality:

- Increase the geographic distance between the gateways to a more realistic distance. Ideally this distance will be sufficiently far to guarantee that the endpoints of Iridium calls are handled by separate satellite beams.
- Increase use of POTS modems on the server gateway, such that all channels are Iridium-POTS. Although this would potentially restrict locations for the receiver of telemetry from an airborne platform, a (possibly) resulting increase in bandwidth may be a worthwhile trade-off.
- Perform additional longer-term tests to reduce the effects of call drops on overall bandwidth. Test durations will be on the order of hours to help determine a more accurate performance baseline.
- Provide additional instrumentation in the test suite to correlate the number of call drops, connection up-time and connection performance on tests.
- Flight testing at NASA Dryden with a multiple-channel airborne system is anticipated during the summer of 2007.

Update to Latest Versions – Newer versions of PPP and Linux used on the gateway workstations are available. Some of the dropped calls may be attributable to a known problem in the version of PPP used during these tests.

Monitor Link Performance - The PPP links are automatically restarted when they die (a frequent occurrence, as noted above.) However, they are not restarted when they perform poorly. It would be a good idea to investigate a way to monitor the link performance and drop and reestablish the links when necessary.

ACKNOWLEDGEMENTS

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SCPS software available from http://www.openchannelfoundation.org

SCPS Website: **http://www.scps.org**