TCP/IP Performance over Satellite Links - Summary Report

Technology Development Group, Loral CyberStar, Inc.

INTRODUCTION

WorldCast℠ is Loral CyberStar's satellite-based Internet access product. TCP/IP is the protocol used as the transport mechanism for most file transfers in the Internet. This memo presents the results of a study which compares TCP/IP performance using WorldCast, with terrestrial service of equivalent - and usually more expensive - bandwidth. Future studies will compare WorldCast with equal cost terrestrial solutions. These studies will show that WorldCast will many times outperform the terrestrial solution.

SUMMARY RESULTS

The study analyzed two performance measures: effective throughput for a large file transfer, and response time for a web page retrieval. Three reference cases are covered: terrestrial circuit, hybrid satellite/terrestrial circuit, and two-way satellite circuit. In each case the server is located at an ISP location in the US, the client in Europe. The study models performance for a single session in an error-free, non-congested channel. Real world results will differ depending upon channel characteristics, TCP/IP implementation and degree of congestion. However, the study provides an insight into the relative performance of equivalent terrestrial and satellite circuits. The effective throughput is based on long - i.e. 10 megabyte transfers. Results are summarized in Tables 1 and 2.

TABLE 1 - Relative Performance for a 2048 Kbps Channel

Case with a 2048 Kbps Channel in Direction of File Transfer and 512 byte segment size	Representative Round Trip Delay for a Non-Congested Channel	Effective Throughput for Window size = 32,768 bytes	Effective Throughput for Window size = 8,192 bytes	Response Time for a 5 Kbyte Web Page; Window size = 32,768 bytes
Full Duplex Terrestrial Circuit	150 milliseconds	~1600 Kbps	~450 Kbps	~.6 seconds
WorldCast℠ Services/512 Kbps Terrestrial Return	370 milliseconds (satellite, terrestrial)	~650 Kbps	~190 Kbps	~1.6 seconds
WorldCast Services/ 512 Kbps Satellite Return	590 milliseconds (2 way satellite)	~400 Kbps	~100 Kbps	~2.5 seconds

TABLE 2 - Relative Performance for a 256 Kbps Channel.

256 Kbps Channel in Direction of File Transfer: 512 byte segment size	Representative Round Trip Delay for a Non-Congested Channel	Effective Throughput for Window size = 32,768 bytes	Effective Throughput for Window size = 8,192 bytes	Response Time for a 5 Kbyte Web Page; Window size = 32,768 bytes
Full Duplex Terrestrial Circuit	150 milliseconds	248 Kbps	~248 Kbps	~.6 seconds
WorldCast Services/ 64 Kbps Terrestrial Return	370 milliseconds (satellite, terrestrial)	247 Kbps	~150 Kbps	~1.7 seconds
WorldCast Services/ 64 Kbps Satellite Return	590 milliseconds (2 way satellite)	245 Kbps	~100 Kbps	~2.6 seconds

Effective throughput is determined by dividing the number of bits in the file by the time it takes to transmit the file. This measure is of interest to users who initiate long file transfers. *Response time* is defined as the time it takes to transmit a file, once the file transfer is initiated. This measure is of interest to users who initiate short file transfers, such as needed to retrieve Web pages.

From Tables 1 and 2, we see that performance very much depends upon channel speed, TCP/IP *window size* and *round trip delay*. Window size is a TCP/IP parameter used for flow and congestion control in file transfers. Round trip delay is measured from the time the first bit of a segment is transmitted by the sender, until the time the last bit of the acknowledgment of that segment is received by the sender. Round trip delay depends upon propagation time for the links, implementation of the TCP/IP protocol, and the degree of congestion in the network.

Table 3 depicts the delay factors for each of the three cases presented in Tables 1 and 2. In Table 3, we assume three router hops for the terrestrial link, and two router hops for the satellite link. Each hop adds a five millisecond delay. One-way terrestrial circuit propagation delay is assumed to be 35 ms. One-way satellite propagation delay is assumed to be 260 ms. Processing delays in the sender and receiver are assumed to be 50 ms. Serialization delay, resulting from transmitting a TCP/IP segment down the channel, is not shown in Table 3. This delay depends upon channel speed and is automatically accounted for in the model. Queuing delay is assumed to be 0, in accordance with our earlier assumption that the link is non-congested.

In real-world situations queuing delay could become the dominant factor in determining throughput. If so, satellite links will, in many cases, provide better performance than terrestrial links.

TABLE 3 - Calculation of Round Trip Delay (in milliseconds)

CASE	Forward link router delay	Forward link prop. delay	Client Server processing delay	Return link prop. delay	Return link router delay	Queue delay	Total delay
Full Duplex Terrestrial Circuit	15	35	50	35	15	0	150
WorldCast Services/ 64 Kbps Terrestrial Return	10	260	50	35	15	0	370
WorldCast Services/ 64 Kbps Satellite Return	10	260	50	260	10	0	590

From Table 1 we see that all cases are window-limited. That is, none of the reference cases will support a file transfer at the full channel rate. With a 32,768 byte window, the terrestrial circuit is limited to 1600 Kbps, the WorldCast satellite/terrestrial solution is limited to 650 Kbps, the WorldCast satellite-only solution is limited to 400 Kbps.

We see from Table 1 that performance diminishes as window size decreases. With a 8,192 byte window, the terrestrial circuit is limited to 450 Kbps, the WorldCast satellite/terrestrial solution is limited to 190 Kbps, the WorldCast satellite-only solution is limited to 100 Kbps.

It should be noted that a window-limited channel can be fully utilized, because a channel can support multiple simultaneous transfers. Hence, large scale users - such as Internet Service Providers (ISP) and corporate enterprises - can fully and cost-effectively use the full channel for all cases, even at the lower window size.

We see from Table 2, that the 256 Kbps channel is <u>not</u> window-limited, if the window size is 32,768 bytes. However, the satellite-based cases are window-limited if the window size is 8,192 bytes. Again, the channel can be fully utilized if there are sufficient simultaneous file transfers in progress.

From Tables 1 and 2 we see that average response times are approximately the same for the 256 and 2048 Kbps channels. In both instances, Web page response time increases with increasing round trip delay. However, even in the two-way satellite case, the average response time is less than 2.6 seconds, which should satisfy most users.

THROUGHPUT ANALYSIS

Figure 1 provides a more complete representation of effective throughput as a function of round trip delay. This figure was used to determine the results presented in Table 1. The figure depicts the effective throughput of a 10 megabyte file transfer over an error-free, non-congested, 2048 Kbps channel.

A TCP/IP *segment* size of 512 bytes is used in the calculation. A segment is the unit of transmission used by TCP/IP. Each segment contains a checksum that is used to determine if a transmission has been transmitted without error. Segment sizes can vary from 0 to 1500 bytes. 512 bytes is a representative number.

Figure 1 presents throughput as a function of round trip delay, with window size (in bytes) as a parameter. The TCP/IP standard allows a maximum window size of 65,535 bytes. It is unusual to see an implementation larger than 32,768 bytes. Future versions of the standard will support larger windows, but it is unlikely that we will encounter implementations of the larger windows for several years. Figure 1 shows the impact of window sizes down to 4096 bytes

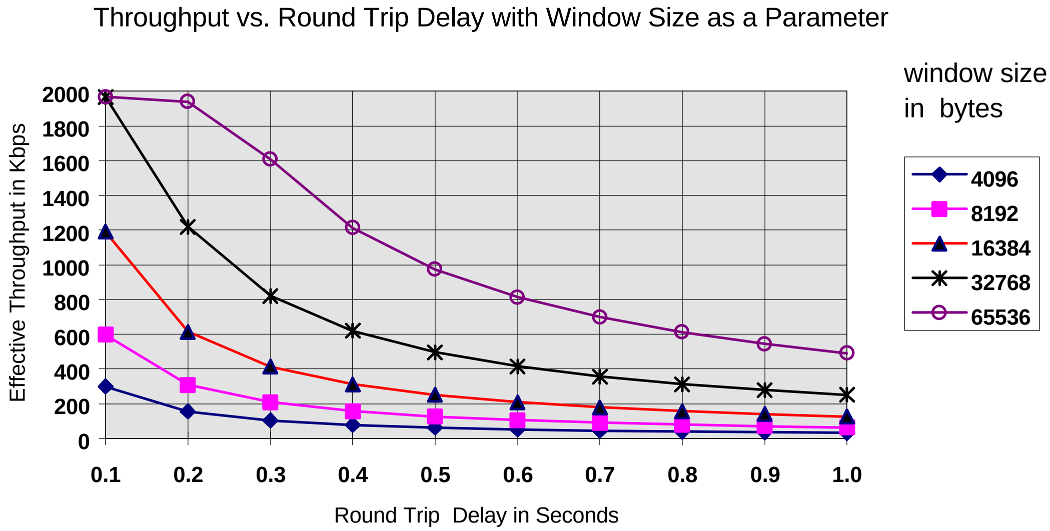

Figure 1 - Effective Throughput in a Non-Congested, Error-Free Link with Channel Speed of 2048 Kbps

Figure 2 shows the impact of round-trip delay and window size for the 256 Kbps channel, using the same parameters described for Figure 1. Figure 2 was used as the basis for tabulating the results in Table 2.

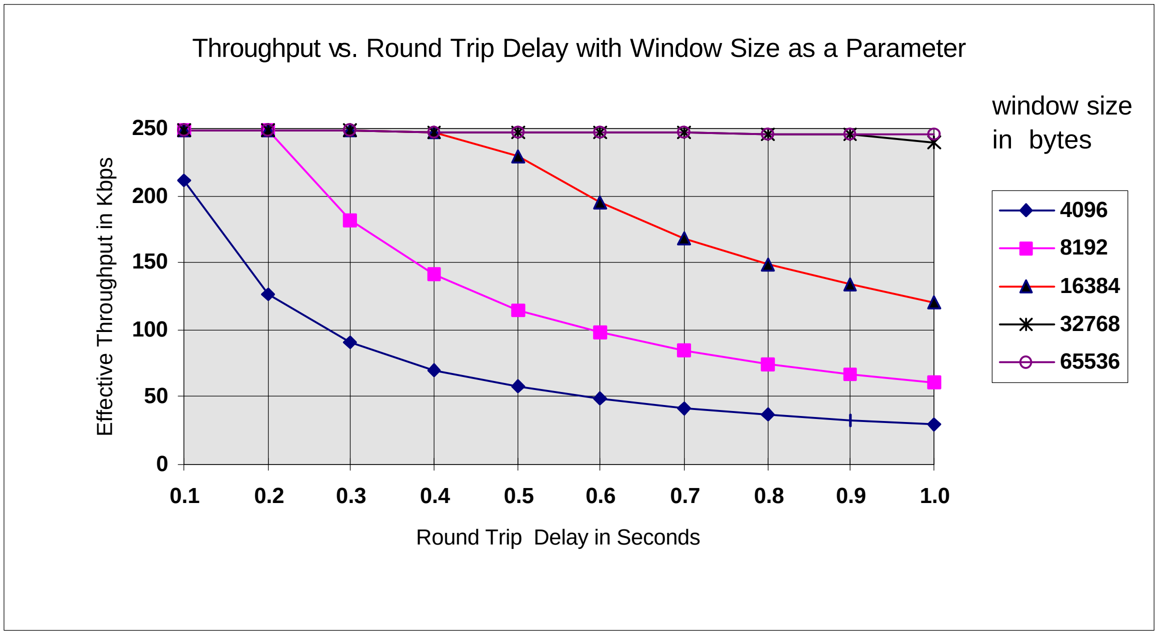

Figure 2 – Effective Throughput for 256 Kbps Link

IMPACT OF SHORT FILES AND BIT ERRORS

The performance measures cited above assume long file transfers, and error-free channels. This will be the case for many file transfers. However, there will be cases where short files are transmitted and cases where the satellite channel will have errors. Effective throughput will decrease in these situations.

Figure 3 shows the impact of file size on throughput, with window size as a parameter, assuming an error-free 2048 Kbps channel. The figure depicts the case where the round trip delay is 590 milliseconds, which represents a two-way satellite transfer.

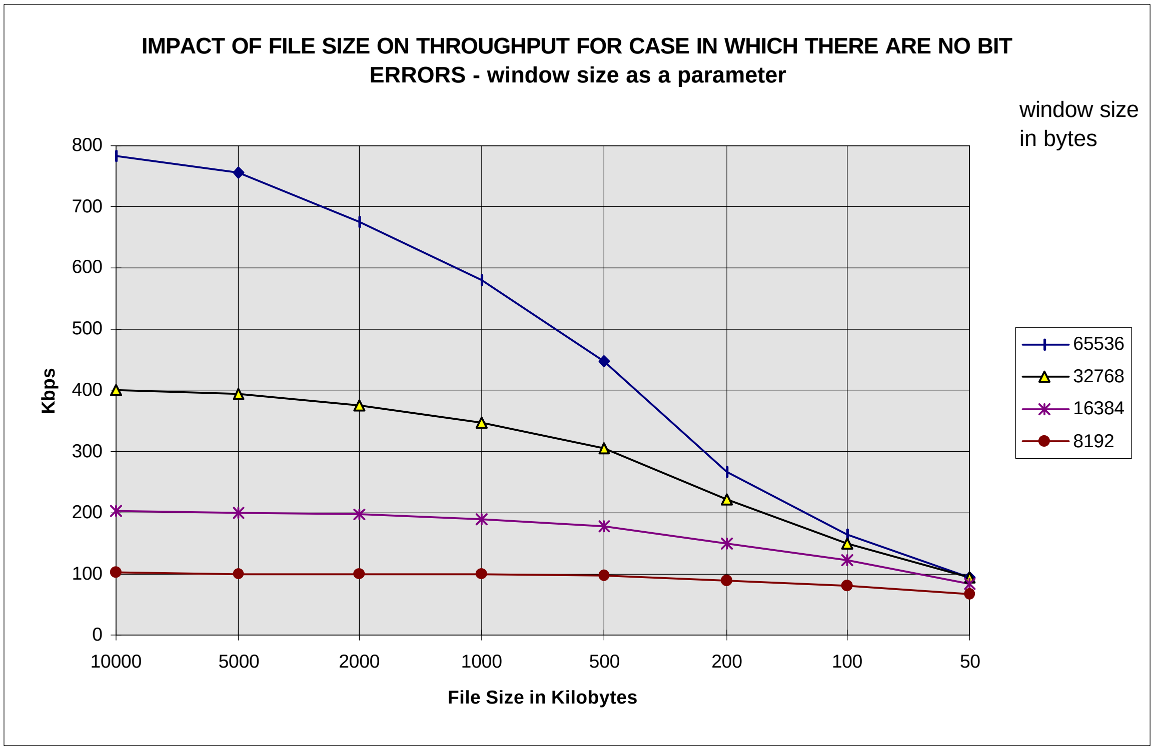

Figure 3 - Impact of File Size on a 2048 Kbps Channel with 590 Millisecond Round Trip Delay.

Throughput drops off as file size decreases because of TCP/IP's congestion control features. TCP/IP will not allow a file transfer to start at the speed allowed by the window size. It must build up over a period of time. This technique is called *slow start*. For a window size of 32,768 bytes the impact of slow start shows up for files that contain less than one megabyte of data.

Effective throughput will also drop as bit error rate increases. Figure 4 shows this impact with window size as a parameter. This calculation is approximate and is subject to a 30% error at those points where the curves start to fall off.

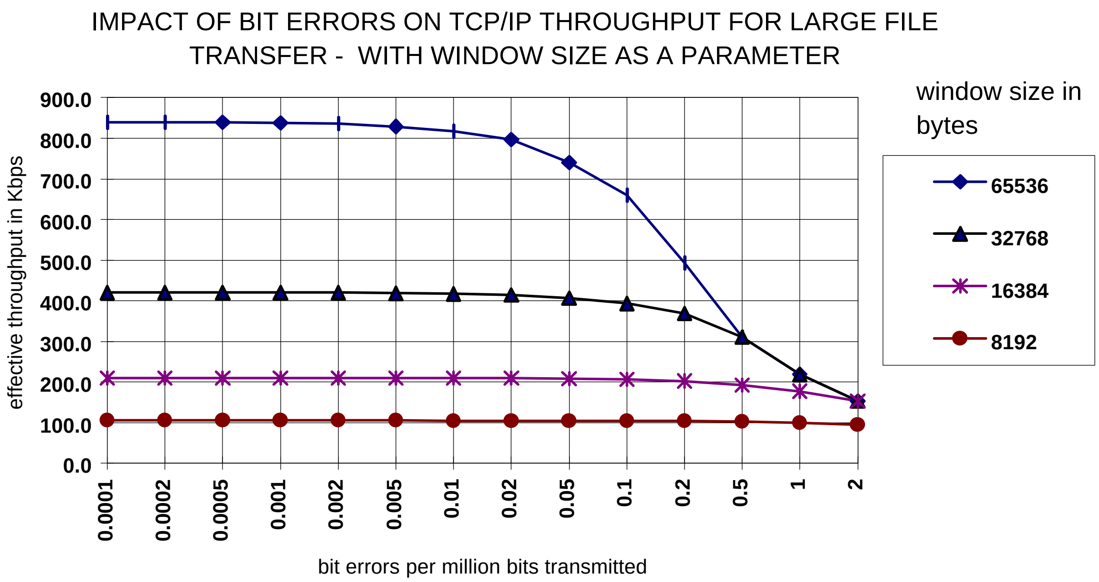

Figure 4 - Approximate Impact of Bit Errors on Long File Transfers for a 2048 Kbps Channel with 590 Millisecond Round Trip Delay.

Figure 4 shows that, with a 32,768 byte window, bit errors do not significantly decrease throughput until the bit error rate becomes greater than 1 error per 10^7 bits (i.e. 0.1 bit error per million bits transmitted). At that point effective throughput begins to drop. If we wish to maintain throughput commensurate with a 65,635 byte window, we must keep the bit error rate less than one error per 10^8 bits.

RESPONSE TIME RESULTS

Response time is defined as the time it takes to complete a file transfer. This measurement is of most interest to users who retrieve Web pages, an application that comprises as much as 50% of the activity in the Internet. Some studies have indicated that the median size Web page is in the order of 5 to 7 kilobytes. Figure 5 shows the response time for retrieving a Web page in a non-congested, error-free 2048 Kbps link, with a window size of 32,768 bytes, as a function of round trip delay. Figure 6 shows the response under the same conditions for a 256 Kbps per link.

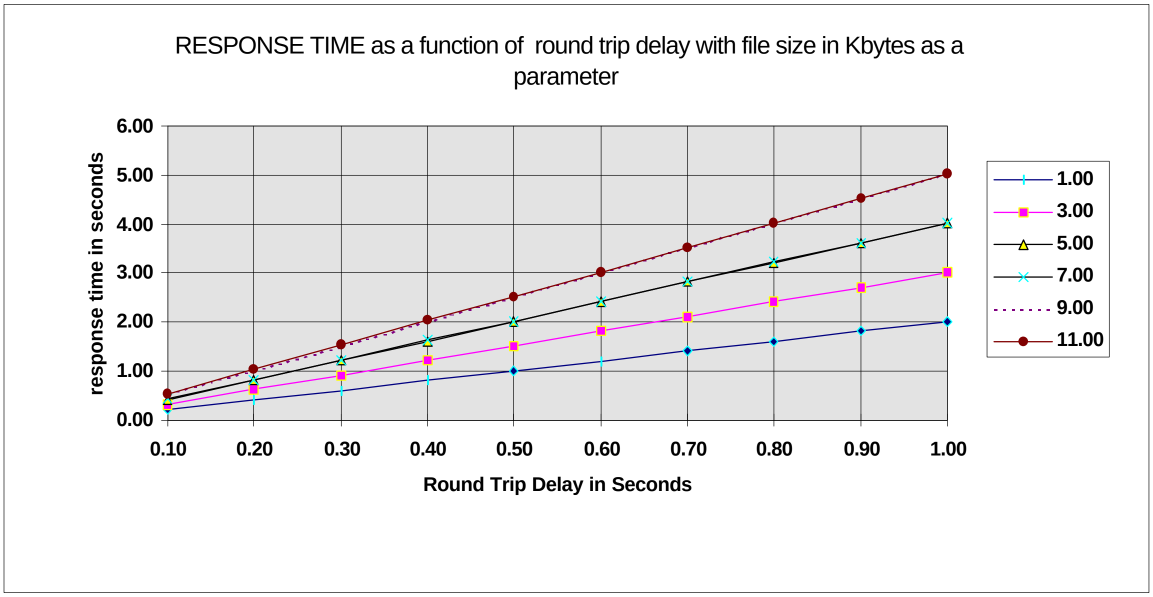

Figure 5 - Response Time for Web Page Transfers as a Function of Round Trip Delay - 2048 Kbps Channel

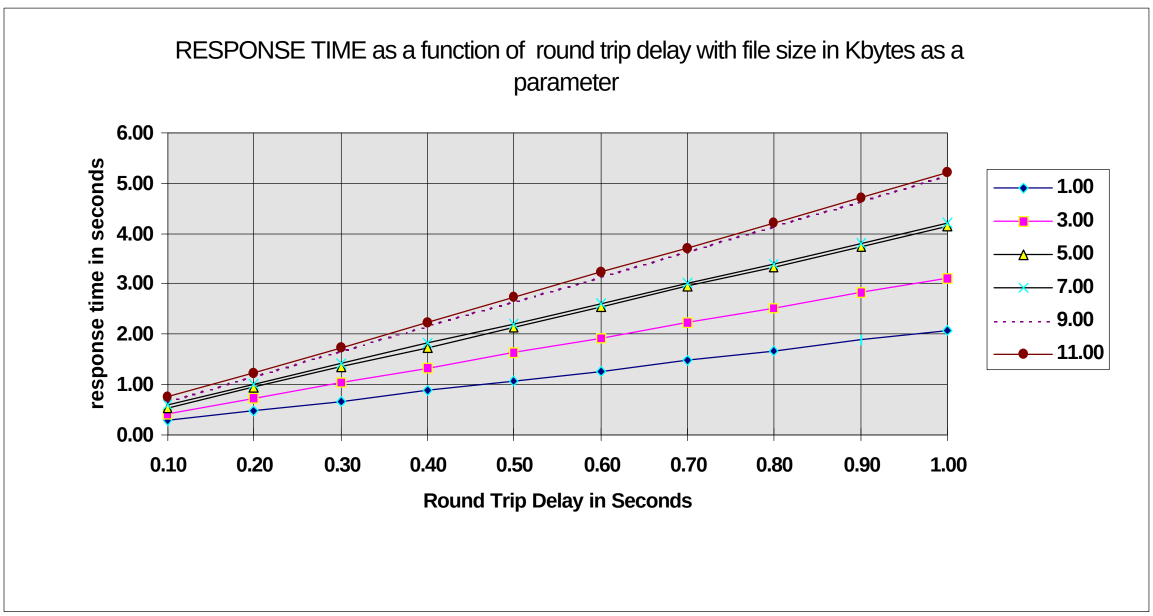

Figure 6 - Response Time for Web Page Transfers as a Function of Round Trip Delay - 256 Kbps Channel

As expected, response time increases with the size of the Web page, and the round trip delay. The response times are only slightly affected by the channel speed. For a 5 kilobyte page, the response time on a 2048 Kbps channel will be ~ 2.5 seconds for a two- way satellite circuit, compared to ~1.6 seconds for the hybrid WorldCast network and ~.6 seconds for a terrestrial circuit.

CONCLUDING REMARKS

For a 2048 Kbps channel, a 32,768 byte window and the reference case conditions assumed in this study, we will be able to achieve effective throughputs of ~ 650 Kbps for the hybrid satellite/terrestrial system, and ~400 Kbps for a two-way satellite solution. To achieve these rates the bit error rate must be better than one error in 10^7 bits, and file sizes must be greater than one megabyte. For a 256 Kbps channel the satellite link can support full file transfers with effective throughput approaching the channel capacity if the window size is 32,768 bytes. Some vendor implementations might provide smaller windows. In such cases, effective throughput will diminish; i.e. the transfer will be window-limited.

Even where we are window-limited and cannot achieve full channel speeds, satellite links can be fully utilized, because the links can support multiple file transfers.

The response time for typical Web page transfers will be less than 2.6 seconds for the satellite solutions. Response time is not as sensitive to channel speed and window size as is the case for effective throughput.

The study compared terrestrial and satellite circuits with the same bandwidth. **In most cases the satellite solution will be less costly.** Future studies will compare terrestrial and satellite solutions of comparable cost. **We strongly believe that - with cost as a factor - the satellite solutions will in most cases outperform the terrestrial approach.**

The calculations provided in this report are derived from a set of Excel models. These models can be used to determine effective throughput and response time for a wide range of parameters. Future work will extend the accuracy of the bit error models, and will document the details of the models. We will also consider the case of congested links. In addition we plan to validate and improve the models by running controlled experiments on actual TCP/IP implementations for file transfers under a wide variety of bit error rates, file sizes and channel speeds.