Preprint
UCRL-JC-151555

Characterization of Fibre Channel Over Highly Turbulent Optical Wireless Links

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This article was submitted to the *"Society of Photo-Instrumentation Engineers (SPIE)" International Symposium on Optical Science and Technology, San Diego, CA, August 3-8, 2003*

U.S. Department of Energy

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July 28, 2003

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Characterization of Fibre Channel over highly turbulent optical wireless links

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ABSTRACT

We report on the performance characterization and issues associated with using Fibre Channel (FC) over a highly turbulent free-space optical (FSO) link. Fibre Channel is a storage area network standard that provides high throughput with low overhead. Extending FC to FSO links would simplify data transfer from existing high-bandwidth sensors such as synthetic aperture radars and hyperspectral imagers. We measured the behavior of FC protocol at 1 Gbps in the presence of synthetic link dropouts that are typical of turbulent FSO links. Results show that an average bit error rate of less than $2X10^{-8}$ is mandatory for adequate throughput. More importantly, 10 ns dropouts at a 2 Hz rate were sufficient to cause long (25 s) timeouts in the data transfer. Although no data was lost, this behavior is likely to be objectionable for most applications. Prospects for improvements in hardware and software will be discussed.

Keywords: Fibre Channel, free-space optical communications, FSO, SATRN

1. INTRODUCTION

Military applications for free-space optical (FSO) links call for deployments in extremely challenging environments. Establishing a link between ground, air, or sea-based mobile platforms in a wide variety of weather conditions leads to severe dynamic fading and pointing errors in addition to the usual propagation losses. To address these difficult situations, we began a project called SATRN--Secure Air-optic Transport and Routing Network. Under the SATRN project we are currently demonstrating a suite of new techniques including adaptive optics, optical signal processing, high-power fiber amplifiers, and forward error correction. Our intent is to improve link availability on long-range (>10 km) links aboard mobile platforms by focusing on optical solutions, thus maintaining protocol transparency.

Fibre Channel (FC) is a storage area network ANSI standard that provides high bandwidth with low overhead and very low CPU burden on the host computers. This standard has multiple layout topologies; point-to-point, loop, and mesh. It supports multiple bit rates, the standard speeds being 1.0625, 2.125 and 4.250 Gbps, with backwards compatibility for faster speeds to operate with slower speeds. The typical transport medium is fiber optic cable, but the standard does have the capability to operate short distances on copper wire. The SATRN project chose to investigate the use of FC over its FSO link for several reasons. Several existing high-bandwidth sensors such as synthetic aperture radars and hyperspectral imagers already use FC for moving their data to storage. It would be advantageous if live, high-fidelity, raw data could stream via FC to some distant node for real-time analysis. This would simplify the payload aboard remote-sensing platforms and permit more sophisticated analysis after the fact. Fibre Channel's performance combination of high bandwidth with low overhead is particularly appealing for a FSO system where maximal data throughput is an objective. The work described here is an initial laboratory test to evaluate the robustness of Fibre Channel protocol and its future applicability to FSO links.

2. SYSTEM OVERVIEW

The equipment used to test the Fibre Channel (FC) link consisted of a Dell 530 workstation running Redhat Linux version 8 (Fig.1). The workstation contained a Qlogic QLA8310F FC host bus adapter that can operate at either 1 or 2 Gbps rates. The target for the tests was a Ciprico Rimfire 7010, 140-gigabyte RAID disk. The driver was configured to run iSCSI protocol which effectively embeds SCSI interface commands in FC packets. Atmospheric fading and noise was artificially introduced by converting the FC optical signal to an electrical signal with a Finisar GBIC evaluation board. The electric signal was leveled with a Maxim MAX3264 limiting amplifier evaluation board. A GaAs FET microwave switch driven by a programmable pulse generator created short dropouts in the electrical signal. Only one side of the duplex link was interrupted; we selected the path to the disk which carries the highest traffic loading. The electrical signal was converted back into an optical signal with a second GBIC. A Finisar Gigabit Traffic Check diagnostic monitored gross link performance. A Linux script using a disk performance diagnostic, lmdd, from Lmbench was used to test the FC data throughput. It is also a simple matter to connect this test setup to our FSO transceiver equipment once the bench testing and development phase is completed.

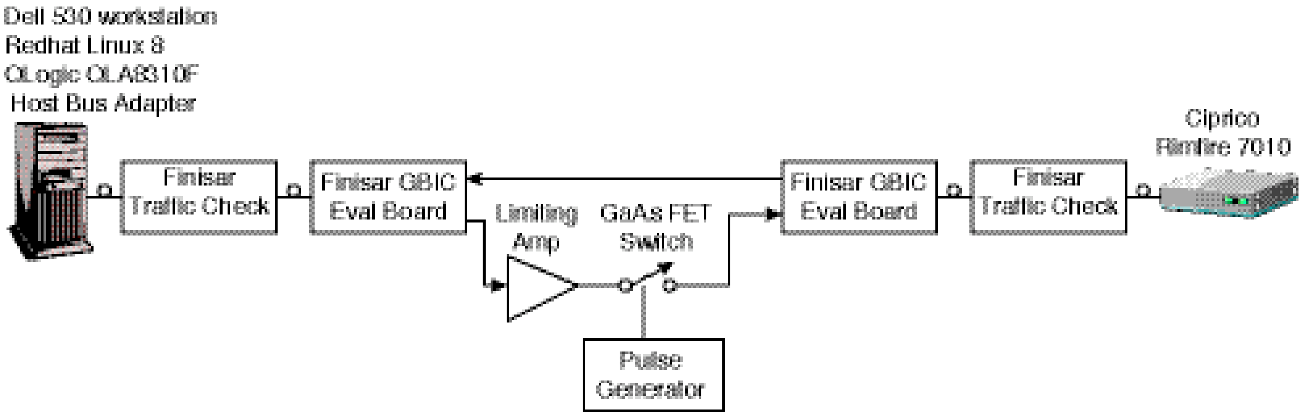

Figure 1. Block diagram of the Fibre Channel test setup with an interrupting switch in one electrical leg.

Two test procedures were used. The first involved a fixed-duration interrupt with adjustable frequency. The second test involved single event interruptions of different length. Before any testing, baselines were recorded that (a) involved only the optical components and (b) that involved all the electronic components except the switch.
The first test involved interruptions that were 10 ns in length at 0.1, 1, 2, and 5 Hz. One hundred tests were run at each interruption frequency and each test consisted of a 491 MB file transfer. The second test involved starting a data transmission and then sending a single interruption 0.1, 0.5, 1, 10, 100, or 999 ms in length for each 491 MB file. Each test was run 10 times for each interruption length.

3. EXPERIMENTAL RESULTS

Results for the first test with 10 ns interruptions are shown in Table 1. This table also includes baseline data with no interruptions. Beginning at one interruption per second, we observed occasional FC timeouts that lasted 1 to 25 seconds. Once the timeout had passed, data transfer would resume at the nominal full speed of 48 MB/s without data loss. A 2 Hz, 10 ns interruption equates to a $2X10^{-8}$ average BER. Timeouts occurred more often as the interruption frequency increased.

Table 1. Transfer Rates with 10 ns Interruptions.

Rep Rate (Hz)	0 (a)	0 (b)	0.1	1	2	5
Max MB/s	48.56	48.93	48.70	49.38	47.43	42.26
Mean MB/s	48.00	48.08	47.86	46.00	38.04	28.63
Min MB/s	47.37	47.28	46.86	42.50	3.52	5.54

(a) Initial condition with fiber-only connection.
(b) Electronics in the loop, coax coupled, no switch present.

In the second test with variable-width interruptions (Table 2), sporadic timeouts were more likely with longer interruptions. As a benchmark, we have previously reported 10 ms deep fades at a frequency of about 1 Hz on a highly-turbulent 1.2 km horizontal FSO link[1]. In this simulated data, mean throughput dropped to about 47% under similar circumstances.

Table 2. Transfer Rates with One Variable-Width Interruption Per Test Iteration.

Interruption width (ms)	0.1	0.5	1	10	100	500	1000
Max MB/s	50.04	50.39	49.46	14.00	49.49	13.99	13.99
Mean MB/s	34.01	35.24	23.32	12.78	15.87	11.18	13.30
Min MB/s	5.83	13.79	8.64	8.57	8.76	8.16	8.40

Efforts were made to reduce the frequency and duration of timeouts. Reconnection time was shortened from about 30 s by forcing all interfaces into 1 Gbps in point-to-point mode. Also, the target's address and information was stored in the Qlogic host bus adapter's onboard memory. No additional improvement was observed though "tweaking" of user parameters in the host bus adapters.

4. DISCUSSION

Fibre Channel specifies a 10^{-12} Bit Error Rate (BER) and this seems to be a realistic requirement. We found that even short interruptions (10 ns) could create timeouts in the link that would last 1 to 25 seconds. This is not a useful recovery speed for a high bandwidth link unless a high-capacity buffer is available. These dropouts were sporadic and may depend upon where in the data packet or header the dropout occurs. For specific data sets where dropouts did not induce a timeout, the data rates seemed to be reasonable, slowly declining when the dropout frequency was increased. It is important to note that no data loss was ever reported by the test software thanks to the retransmission-based error recovery in FC protocol.

We received no additional advice from the vendors since we were operating outside the standard configuration and BER norms. A suitable FC analyzer was not available during these tests. Such an instrument would help to determine the origin of the long timeouts and lead to a possible hardware or software solution. For instance, it may be that certain synchronization packets are particularly critical and are the direct cause of network failures. Our only other recommendation is that standard FC should only be used over FSO links when exceptionally good BER performance is guaranteed, perhaps by incorporating advanced forward error correction hardware.

It is useful to contrast these results with the performance of gigabit ethernet (GigE) operating on an actual turbulent link. GigE did not exhibit long timeouts and demonstrated adequate throughput (50%) for an average BER around $1X10^{-6}$. However, GigE never reached the high througput of FC, achieving only 15 MB/s on the same computers. Also, the CPU utilization of TCP/IP is very high. Fibre Channel uses exceptionally small amounts of CPU time.

5. CONCLUSION

Fibre Channel protocol at 1 Gbps was tested over a simulated turbulent FSO link. Dropouts of 10 ns at a 2 Hz rate were shown to cause long (25 s) timeouts in the data transfer. Thus, off-the-shelf FC hardware and software has been shown to be somewhat unstable for realistic link conditions where noise and fading result in bit error rates in excess of about $2X10^{-8}$ with random burst errors. Additional experiments with protocol analysis could lead to a possible solution that requires custom hardware or driver software development.

6. ACKNOWLEDGEMENTS

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract W-7405-ENG-48.

7. REFERENCES

1. Gary W. Johnson, John P. Cornish, Jeffrey W. Wilburn, Richard A. Young, and Anthony J. Ruggiero, "Characterization of Gigabit Ethernet over highly turbulent optical wireless links," *Proceedings of SPIE* **4821**, Seattle, July, 2002.