EXPERIMENTAL PERFORMANCE EVALUATION OF A GBPS FSO LINK
A Case Study

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Abstract: Wireless communications have been increasingly important. Besides Wi-Fi, FSO plays a very relevant technological role in this context. Performance is essential, resulting in more reliable and efficient communications. A FSO medium range link has been successfully implemented for high requirement applications at Gbps. An experimental performance evaluation of this link has been carried out at OSI layers 1, 4 and 7, through a specifically planned field test arrangement. Several results are presented and discussed, as obtained from simultaneous measurements of powers received by the laser heads, TCP, UDP and FTP experiments, resulting in determinations of TCP throughput, jitter, percentage datagram loss and FTP transfer rate. Conclusions are drawn about link performance.

1 INTRODUCTION

Wi-Fi and FSO are wireless communications technologies whose importance and utilization have been growing.

Wi-Fi uses microwaves in the 2.4 and 5 GHz frequency bands and IEEE 802, 11a, b, g standards. Nominal transfer rates up to 11 (802.11b) and 54 Mbps (802.11a, g) are specified (IEEE Std 802.11-2007). It has ben used in ad hoc and infrastructure modes. Point-to-point and point-to-multipoint configurations are used both indoors and outdoors, requiring specific directional and omnidirectional antennas. FSO uses laser technology to provide point-to-point communications e.g. to interconnect LANs of two buildings having line-of-site. FSO was developed in the 1960's for military and other purposes, including high requirement applications. At present, speeds typically up to 2.5 Gbps are possible and ranges up to a few km, depending on technology and atmospheric conditions. Interfaces such as fast Ethernet and Gigabit Ethernet are used to communicate with LAN's. Typical laser wavelengths of 785 nm, 850 nm and 1550 nm are used. In a FSO link the transmitters deliver high power light which, after travelling through atmosphere, appears as low power light at the receiver. The link margin of the connection represents the amount of light received by a terminal over the minimum value required to keep the link active: (link margin) $_{dB}$= 10 $\log_{10}$ (P/P_{min}), where P and P_{min} are the corresponding power values, respectively.

There are several factors related to performance degradation in the design of a FSO link: distance between optical emitters; line of sight; alignment of optical emitters; stability of the mounting points; atmospheric conditions; water vapour or hot air; strong electromagnetic interference; wavelength of the laser light (Rockwell & Mecherle, 2001). A redundant microwave link is always essential, as the laser link can fail under adverse conditions. Several studies and implementations of FSO have been reported (D'Amico, Leva & Micheli, 2003). FSO has been used in hybrid systems for temporary multimedia applications (Mandl et al., 2007).

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Performance has been a very important issue, resulting in more reliable and efficient communications. Telematic applications have specific performance requirements, depending on application. New telematic applications present special sensitivities to performances, when compared to traditional applications. E.g. requirements have been quoted as: for video on demand/moving images, 1-10 ms jitter and 1-10 Mbps throughput; for Hi Fi stereo audio, jitter less than 1 ms and 0.1-1 Mbps throughputs (Monteiro e Boavida, 2002).

Several performance measurements have been made for 2.4 and 5 GHz Wi-Fi (Pacheco de Carvalho et al., 2008a, 2009). FSO and fiber optics have been applied at the University Campus to improve communications quality (Pacheco de Carvalho et al., 2007, 2008b, 2008c). In the present work we have further investigated that FSO link for performance evaluation at OSI layers 1, 4 and 7.

The rest of the paper is structured as follows: Chapter 2 presents the experimental details i.e. the measurement setup and procedure. Results and discussion are presented in Chapter 3. Conclusions are drawn in Chapter 4.

2 EXPERIMENTAL DETAILS

The main experimental details, for testing the quality of the FSO link, are as follows.

A 1 Gbps full-duplex link was planned and implemented, to interconnect the LAN at the Faculty of Medicine building and the main University network, to support medical imaging, VoIP, audio and video traffics (Pacheco de Carvalho et al., 2007, 2008b). Then, a FSO laser link at 1 Gbps full-duplex, over a distance of 1.14 km, was created to interconnect the Faculty of Medicine (FM) building at Pole III and the Sports (SB) building at Pole II of the University (Figure 1).

We have chosen laser heads from FSONA (Figure 2) to implement the laser link at a laser wavelength of λ= 1550 nm for eye safety, where allowable laser power is about fifty times higher at 1550 nm than at 800 nm (Rockwell & Mecherle, 2001). Each laser head comprised two independent transmitters, for redundancy, and one wide aperture receiver. Each laser had 140 mW of power, resulting in an output power of 280 mW (24.5 dBm). 1000-Base-LX links over OM3 50/125 µm fiber were used to connect the laser heads to the LANs.

For a matter of redundancy a 802.16d WiMAX point-to-point link at 5.4 GHz (IEEE Std 802.16-2004) was available, where data rates up to either 75 Mbps or 108 Mbps were possible in normal mode or in turbo mode, respectively (Alvarion, 2007). This link was used as a backup link for FM-SB communications, through configuration of two static routing entries in the switching/routing equipment (Pacheco de Carvalho et al., 2007).

Performance tests of the FSO link were made under favourable weather conditions. During the tests we used a data rate mode for the laser heads which was compatible with Gigabit Ethernet. At OSI layer 1 (physical layer), received powers were simultaneously measured for both laser heads. Data were collected from the internal logs of the laser heads, using STC (SONAbeam Terminal Controller) management software (FSONA, 2006). At OSI layer 4 (transport layer), measurements were made for TCP connections and UDP communications using Iperf software (NLANR, 2005), permitting network performance results to be recorded. . Both TCP and UDP are transport protocols. TCP is connection-oriented. UDP is connectionless, as it sends data without ever establishing a connection. For a TCP connection over a link, TCP throughput was obtained. For a UDP communication, we obtained UDP throughput, jitter and percentage loss of datagrams. TCP packets and UDP datagrams of 1470 bytes size were used. A window size of 8 kbytes and a buffer size of the same value were used for TCP and UDP, respectively.

A specific field test arrangement was planned and implemented for the measurements (Figure 3). Two PC's having IP addresses 192.168.0.2 and 192.168.0.1 were setup as the Iperf server and client, respectively. The PCs were HP computers, with 3.0 GHz Pentium IV CPUs, running Windows XP. The server had a better RAM configuration than the client. They were both equipped with 1000Base-T network adapters. Each PC was connected via 1000Base-T to a C2 Enterasys switch (Enterasys, 2008). Each switch had a 1000Base-LX interface. Each interface was intended to establish a FSO link through two laser heads, as represented in Figure 3. The laser heads were located at Pole II and Pole III, at the SB and FM buildings, respectively. The experimental arrangement could be remotely accessed through the FM LAN. In the UDP tests a bandwidth parameter of 300 Mbps was used in the Iperf client. Jitter, which represents the smooth mean of differences between consecutive transit times, was continuously computed by the server, as specified by RTP in RFC 1889. RTP provides end-to-end network transport functions appropriate for applications transmitting real-time data, e.g. audio, video, over multicast or unicast network services. At OSI layer 7 (application layer) the setup given in Figure 3 was also used for measurements of FTP transfer rates through FTP server and client applications installed in the PCs. Each measurement corresponded to a single FTP transfer, using a 2.71 Gbyte file. Whenever a measurement was made at either OSI layer 4 or 7, data were simultaneously collected at OSI layer 1. Batch command files were written to enable the TCP, UDP and FTP tests. The results, obtained in batch mode, were recorded as data files in the client PC disk.

3 RESULTS AND DISCUSSION

Large amounts of data were collected and processed by averaging over several time intervals. The corresponding results are shown for TCP in Figure 4, for UDP in Figure 6 and FTP in Figure 8. The average received powers for the SB and FM laser heads, mostly ranged high values in the 25-35 μW interval which corresponds to link margins of 4.9-6.4 dB (considering P_{min}=8 μW). From Figure 4 it follows that TCP average throughput (313.6 Mbps) is reasonably steady, although some small peaks arise for throughput deviation. Figure 5 illustrates details of TCP results over a small interval. Figure 6 shows that UDP average throughput (125.5 Mbps) is fairly steady, having a small steady throughput deviation. The jitter is small, usually less than 1 ms, while percentage datagram loss is practically negligible. Figure 7 illustrates details of UDP-jitter results over a small interval. Figure 8 shows that average FTP throughput (344.5 Mbps) is very steady, having low throughput deviation. Figure 9 illustrates details of FTP results over a small interval. Transfer rates of the PC's disks are always a limitation in this type of FTP experiments. In all cases, having high values of average received powers, the quantities under analysis did not show on average significant variations even when the received powers varied. The results here obtained complement previous work by the authors (Pacheco de Carvalho et al., 2007, 2008b, 2008c). Generally, for our experimental conditions, the FSO link has exhibited very good performances at OSI layers 4 and 7.

Besides the present results, it must be mentioned that we have implemented a VoIP solution based on Cisco Call Manager (Cisco, 2004). VoIP, with G.711 and G729A coding algorithms, has been working over the laser link without any performance problems. Tools such as Cisco IP Communicator have been used. Video and sound have also been tested through the laser link, by using eyeBeam Softphone CounterPath software (CounterPath, 2007). Applications using the link have been well-behaved.

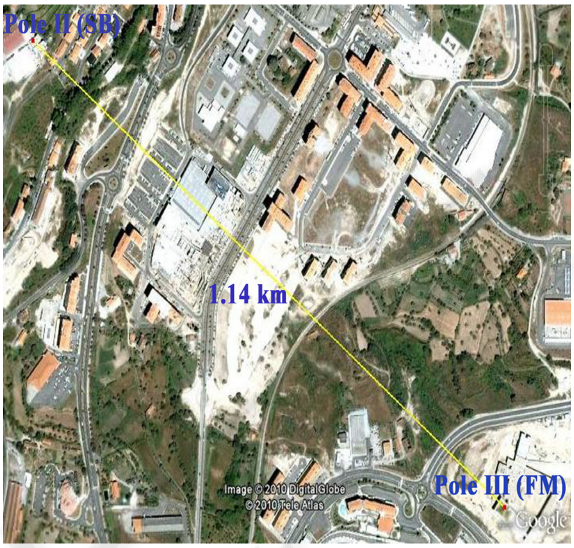

Figure 1: View of the 1.14 km laser link between Pole II (SB) and Pole III (FM).

Figure 2: View of the laser heads at FM (Pole III) and SB (Pole II).

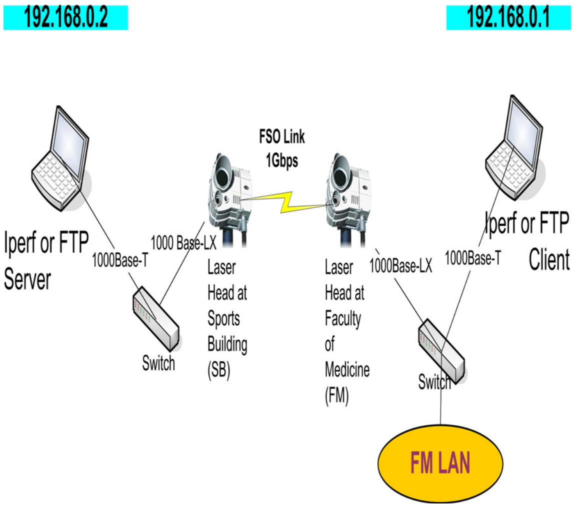

Figure 3: Field tests setup scheme for the FSO link.

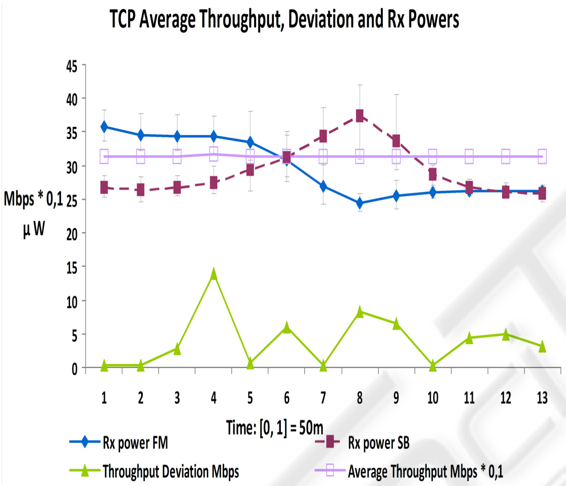

Figure 4: TCP results.

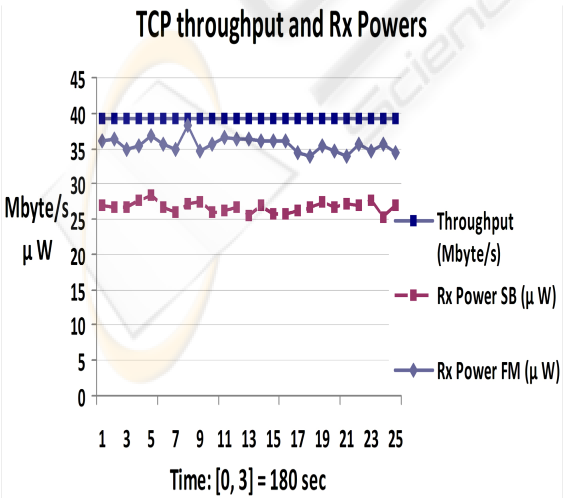

Figure 5: Details of TCP results.

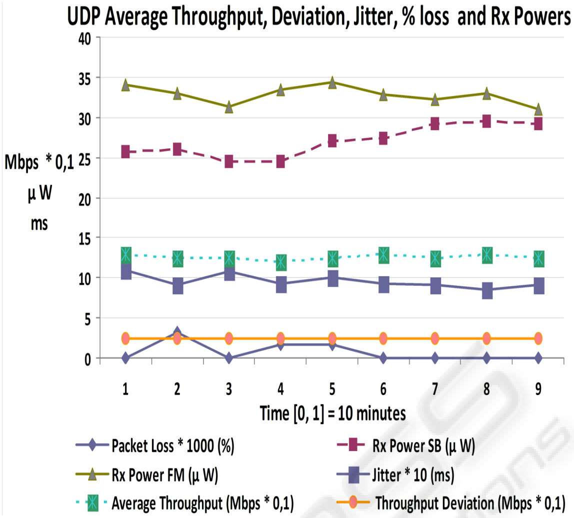

Figure 6: UDP results; 300 Mbps bandwidth parameter.

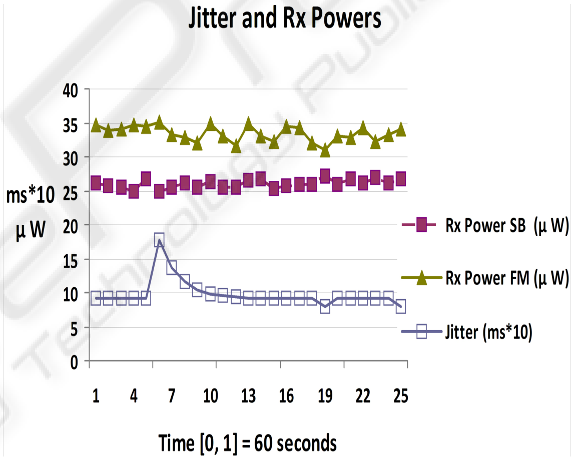

Figure 7: Details of UDP-jitter results; 300 Mbps bandwidth parameter.

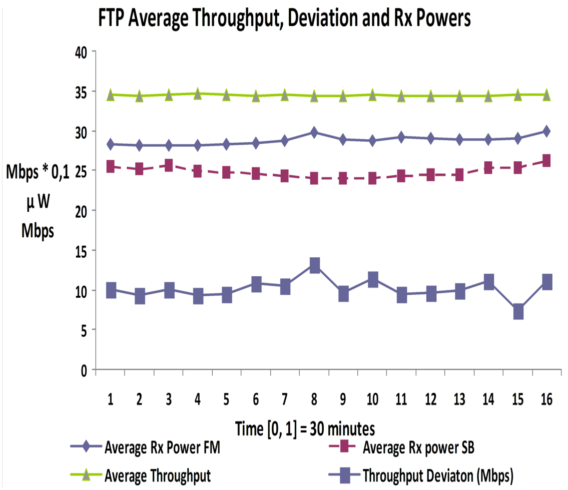

Figure 8: FTP results.

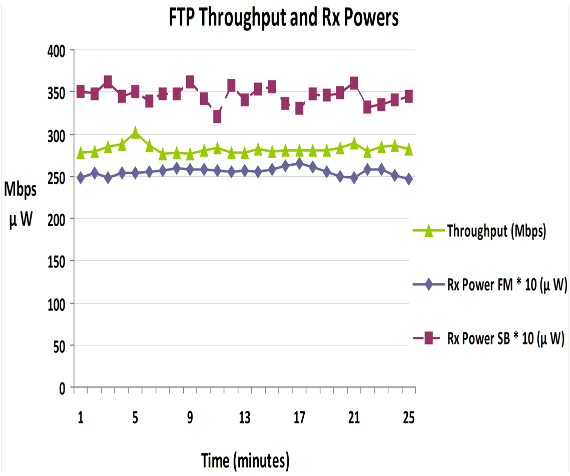

Figure 9: Details of FTP results.

4 CONCLUSIONS

An FSO laser link at 1 Gbps has been successfully implemented over 1.14 km along the city, for interconnecting Poles of the University and support high requirement applications.

A field test arrangement was planned and implemented for FSO performance measurements at OSI layers 1, 4 and 7. At OSI layer 1, received powers were simultaneously measured in both laser heads. At OSI layer 4, TCP throughput, jitter and percentage datagram loss were measured. Through OSI layer 7, FTP transfer rate data were acquired. Under favourable experimental weather conditions, when the measurements were carried out, the link has shown to be very well behaved, presenting very good performances. Applications such as VoIP, video and sound, have been well-behaved. Further measurements are planned under several experimental conditions, such as environmental and multimedia traffic.

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