320 Gbit/s (8x40 Gbit/s) double-pass terrestrial free-space optical link transparently connected to optical fibre lines

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Abstract

World first demonstration of WDM 8x40 Gbit/s free-space transmission is presented in a terrestrial double-pass link, by using compact terminals, which allow direct optical connection to fibre links.

Introduction

Wherever short fibre deployment is not possible or convenient, free space optical (FSO) communications can allow flexible and high-speed point-to-point links. However, FSO is not a very suitable and practical solution to carry out current high capacity WDM signals, as many equipment ask for OEO conversion at the terminals. Additionally, limited power budget due to difficult collimation and/or beam tracking issues limit the system performance. Therefore, FSO systems up to now were mostly reported having much lower capacity than in current fibre systems. The highest presented results are indeed an FSO transmission 4x10 Gbit/s demonstrated in a terrestrial link [1], and 2x40 Gb/s system working over an aerial link [2]. Both systems were one-way and suffered from time-drift of performance, i.e. system outage.

We present here a system demonstration of a pair of novel FSO terminals that feature special fine tracking optics and can be transparently connected to single-mode fibre lines, i.e., they are fully compatible with the terrestrial fibre communication systems. We thus transmit the record capacity of 8x40 Gbit/s over a transparently looped-back double-pass FSO link (2x210 m). To the best of our knowledge, this is the highest FSO system capacity ever reported.

Experiment

The experimental scheme is reported in Fig. 1. We located a pair of identical FSO terminals on the roof of two buildings (distance around 210 m) in the CNR campus in Pisa, Italy (right inset in Fig. 1).

The two FSO terminals produce an optimised collimated beam (close to gaussian profile) with around 24 mm beam waist. Each terminal encompasses a special optics with diffraction limited performance (a collimator and a custom beam expander) to efficiently focus the free-space laser beam and couple it into a single mode fibre. Both FSO terminals have a single connection fibre, so that for bi-directional operation each fiber is combined with an optical circulator (OC). The fine tracking system (3.5 kHz bandwidth) is based on a miniature Galvano mirror actuator, a dedicated fine tracking sensor and an analogue-based PID controller. Once the terminals are initially aligned, a stable continuous optical link is automatically maintained by the pair of tracking circuits: these are optimised to react at the frequency values at which the scintillation impairments (temporal intensity variations in light intensity due to the atmospheric turbulence) is most detrimental. The design details and the results of the performance evaluation of the tracking system were reported in [3].

The WDM signal are produced and detected in the lab. We use eight CW DFB lasers, with 200 GHz spacing (wavelengths from 1545.93 nm to 1557.36 nm), aligned in polarization, combined by an AWG, and modulated at 40 Gbit/s by a $LiNbO_3$ intensity modulator (PRBS length: 2^{31}-1). All channels are then amplified by an Erbium doped fibre amplifier (EDFA, output power: 20 dBm). The signals are passed

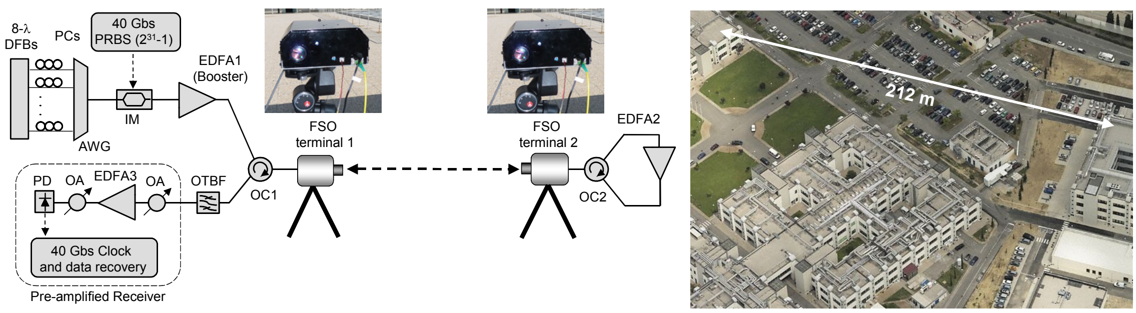

Fig. 1: Experimental setup. 8 CW DFB lasers are modulated at 40 Gb/s, amplified by an EDFA, transmitted over the FSO link, amplified again and sent back again over the free space (dashed line) .

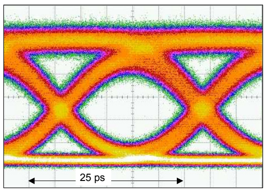

Fig. 2 Received 40 Gbit/s eye diagram (ch. 5; λ=1552.35 nm), taken at 10-min. long persistence.

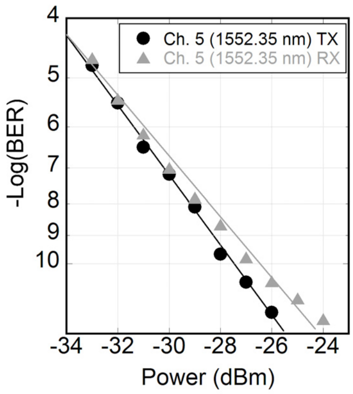

Fig. 3 BER curve taken for Ch.5 in back-to-back (squares) and after transmission (triangles).

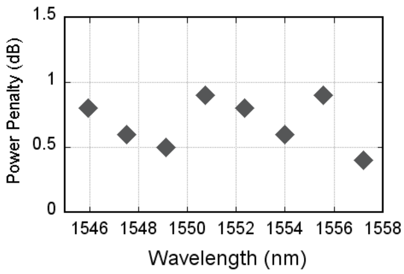

Fig. 4 Power penalty (at BER=10^{-9}) at the various wavelengths (5 hours measurement).

through a optical circulator (OC1) and then moved from the lab to the roof of the first building using a single mode fibre patch cord (around 20 m), which is directly plugged in the fibre connector of the first FSO terminal.

On the second building roof (210 m distance), the signal is received by a similar FSO terminal. The FSO link has around 7.6 dB one-way loss (including losses within the two terminals). At the second terminal, the received signal is coupled into a singlemode fibre, passes a second OC (OC2) and is injected into a EDFA. The EDFA increases system margin and, mostly, allows to strongly reduce the effects of scintillation [4]: indeed, as the operating region is close to saturation, the EDFA, combined with the tracking system, further reduces the power fluctuations due the atmospheric turbulence. The signal is then re-injected into the second terminal and transmitted back in free space to first terminal. Here, it is separated from the counter-propagating light by OC1, then optically filtered (by a 0.8 nm FWHM tunable filter) pre-amplified by an EDFA, and detected by a pin photodiode. The electrical 40 Gbit/s signal drives a clock recovery (needed because of the jitter introduced by the FSO-link) and is then sent to an error detector. As the received optical power is 5 dBm, high margins (>20 dB) exist to increase substantially the number of channels or the FSO link length.

Stable and smooth operation was obtained on all channels, over more than 5 hours time, with no evidence of error bursts. As an example Fig.2 reports a long-term 40 Gb/s eye diagram at the receiver (λ=1552.35 nm), recorded over 10 minutes.

Bit error ratio (BER) measurements confirm the validity of the solution. Fig. 3 reports a typical BER curve (λ=1552.35 nm) as a function of input power at the pre-amplified receiver. As can be seen, transparent transmission over the bi-directional link comes with just 0.8 dB penalty. Finally Fig.4 summarizes the final penalty values (at BER=10^{-9}) observed on all the WDM channels. Here, the average penalty is around 0.7 dB and all values are lower than 1 dB.

All BER measurements took more than 4 hours, during which no error burst was observed. Yet, they started in the late evening, to avoid spurious reflections by the close white buildings during the Italian summertime. Fog and rain effects as well as long term (daytime) measurements are still to be investigated at the time of writing.

Conclusions

We achieved the highest ever transmission capacity of 320 Gbit/s (8x40 Gbit/s) over a free-space optical link (2x210 m), in a common environment (between two building roofs): this demonstrates transparent connection of high-speed fibre links through FSO links. We employed novel FSO terminals, which feature special optics, optimised tracking algorithms and are transparently connected to the fibre lines. Scintillation effects are further reduced by saturated EDFAs. Long-time measurements never showed the error bursts typical of other previous FSO demonstrations. Investigation of day-long BER as well as fog/rain effects is still in progress. These results indicate that, besides other applications, FSO technology can be used even to bridge high capacity WDM links.

References

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