Free-space system for metropolitan optical network transparent link

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ABSTRACT

An optical wireless system useful for short metropolitan distance connections is proposed. Differently from other apparata described in literature or commercially available, our solution is completely transparent to third window telecommunication channel thanks to standard single mode optical fiber interfaces, without any electro-optic conversion. Such a system guarantees the high performances required to optical communication networks (BER, SNR and so on) without link fault and bit broadening penalties. System characterization and BER performances at 10Gbit/s, also in presence of 1.55µm multi-wavelength signal, are presented for connections up to 200m building-to-building roof distance. The implemented transmitter and receiver devices are compact in dimensions, very low cost and can find application not only in metropolitan network links in case of digging impediments due to time, license and cost constraint, but also in disaster recovery and local extraordinary high-bandwidth demand.

Keywords: Optical Wireless Communications, All-Optical Wireless, Free-Space Optical Communications

1. INTRODUCTION

Nowadays, thanks to the development and diffusion of optical networks, the bandwidth demand in metropolitan areas is going to increase more and more. The installed copper lines, also with new modulation techniques, cannot be able to follow this trend. For this reason optical communications are coming to be employed not only in usual long distance connections but in metropolitan networks too.

On the other hand the capillary diffusion of fiber optic networks has to overcome some economical, technical and temporal problems. Fiber installation in high-density infrastructures environment is still limited by high costs and times of installation, physical or legal impediments and regulatory restrictions[1]. Free-space optical communication systems are an interesting solution to achieve optical bandwidth in economical and fast way in metropolitan short links. Other promising applications of optical wireless communications are in disaster recovery and special events temporary high-bandwidth demand.

In the last few years several optical wireless systems were proposed and now commercially available[2][3][4][5][6]. Their short time of installation, costs and available bandwidth are key factor for their success.

In this work we present a new free-space optical system for short metropolitan links. In order to maintain the complete protocol and bandwidth transparency of fiber optic links, we developed an all-optical wireless link with standard telecom fiber optic interfaces without any electro-optic conversion. The aim of our work is to realize a “free-space virtual fiber” with all the great advantages that optical fibers connections allow in communication networks.

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2. THE OPTICAL WIRELESS APPARATA

The system project and experimentation activity was focused on some critical system performances.

In case of application in a metropolitan environment the typical building-to-building distance (up to 200m) allows to project simple and small optical interfaces able to overcome the impairments on the optical beam propagation due to atmospheric effects\(^7\)\(^,\)\(^8\). In case of 200m metropolitan network connections the main atmospheric constraints are attenuation by fog, beam steering and scintillation by turbulence and wave-front distortion by scattering. These negative effects can be solved by means of suitable optical amplification, active alignment systems and dedicated coupling optics.

The two opto-mechanical interfaces have to perform two different operations: the transmitter should be able to irradiate optical intensity from a standard single-mode telecom fiber into air, the receiver to collect the propagated optical intensity from atmosphere into another standard optical fiber. Due to atmospheric effects the well-controlled optical beam out coming from the transmitter degrades during atmospheric propagation in shape, phase and direction. In order to couple maximum and stable optical intensity, the receiver device requires a more complex layout than the transmitter one. Fig.1 shows a schematic draw of the main system block.

For simplicity and costs we realized the optical transmitter as a single lens Newtonian telescope. We choose a focal length of 120mm and a diameter of 80mm in order to maintain small device dimensions an a propagating beam diameter (30mm large) enough to maintain a good collimation (divergence of 37\(\mu\)rad) during 200m propagation. The device (fig.2) is realized with two aluminum tubes with a lens case at one side and a tilting holder for FC connector of the fiber on the other side. The two tubes can slide each other in order to tune the fiber-lens distance and the output beam properties.

The realized receiver device (fig.3) presents the same Newtonian scheme, but with two lenses and a collimating system. In order to maximize the coupling ratio of the system and minimize its sensitivity to wave-front aberrations and link instabilities we realized the receiver with the same external lens of the transmitter, but with a second diverging lens. So it is possible to reduce the numerical aperture and match the one of a final pigtailed collimating system. In this case the
converging lens is of ~5mm focal length. The increasing complexity of the receiver is a trade-off between a large and simple device and a small but multi-lens one. Also for the receiver device we used three sliding aluminum tubes. All these focal controls are for experimental purposes only; in case of commercial implementation no tunable parameter will be present in order to make the system simpler and cheaper.

In order to compensate beam deviation effects in the atmosphere we implemented an active track control on the receiver device. Part of the received signal is splitted by a pellicle beam-splitter (90/10) and a four-quadrant photo-diode reveals the received beam position inside the telescope. This information, suitably processed and amplified, drives two step-motors controlling the receiver tilts in order to maximize the coupled optical intensity and compensate small beam deviation on the link. To realize this active tracking control we realized a gimbal mount for the receiver device and a hole for the 4-quad photodiode on one side of the receiver. This kind of system cannot compensate large wave-front distortions and deviations (the tilt controls should be also present for the transmitter). However for short link applications this simple solution appears efficient enough.

3. EXPERIMENTATION

3.1. EXPERIMENTAL IMPLEMENTATION

Each part of the two optical interfaces has been accurately aligned in the lab with the help of visible light and micro-positioning systems. Great alignment precision is necessary between the receiver optical fiber and the position sensitive 4-quadrant photodiode, in order to get equal electric signal on each quadrant when the input beam is perfectly aligned with the fiber. The tracking system on the gimbal mount of the receiver (two piezo-driven screws) has been connected and calibrated with electronic control produced by the 4-quad photodiode. The two devices were mounted on a tripod and placed on CoreCom’s building roof (4 floors high). A standard aluminum mirror (50x50cm) was placed on the other side of the roof in case of 50m link measurements, and on the roof of an adjacent building in case of 200m. This testing configuration is not the ideal one owing to mirror penalties and tripod instabilities introduced during measurement; in case of a real installation better experimental results are expected. Fig.5 shows a picture of the experimental prototypes and 200m field of measurements.

Two main transmission setup have been implemented in our experimentation in order to check the long-term stability of the virtual free-space link and BER performances on a real optical communication signal. In the first case a CW telecom pigtailed laser was used in transmission together with a photo-receiver with PC acquiring board and Lab-View routine in reception. For BER measurements the standard telecom fibers employed in the transmitter and in the receiver were connected to a 10Gbit/s transmission system. Fig.6 shows the transmission setup for BER measurements. In order to test the system performances in presence of WDM (Wavelength Division Multiplexing) transmissions two telecom laser diodes at wavelengths spaced 100GHz (0.8nm) have been coupled in the input fiber.
3.2. PERFORMANCES CHARACTERIZATION

In absence of AR coating in all the optical system elements CW measurements show about -7dB of total insertion losses for 200m link and clean air (-2dB losses are due to glass-air interfaces). In presence of medium intensity fog (about 70m visibility) the losses grows of about 3dB on the same link. Long-term link stability measurements have been performed, in almost every visibility condition (no high intensity fog happened). Received intensity fluctuations up to 18dB have been measured. Fig.7a and 7b show two 40 hours link stability measurements for 50 and 200m links. The short-time fluctuations are due to atmospheric turbulence, the long-term drift are instead due to thermal excursions from day to night. An additional thermal control can easily solve this kind of instability.
BER performances at a transmission bit-rate of 10Gbit/s have been tested in the case of 25-50m roof link (fig.8a) and 200m building-to-building link (fig.8b). The experimental eye diagrams are well open in both cases. BER measurements show system penalties for 25-50 and 200m links, respectively 0.5-1.5 and 5dB at BER 10^{-11} with respect to back-to-back characterization. No WMD impairments have been noticed during experimentation.
Fig. 8a. 25 and 50m link 10Gbit/s transmission measurements: BER (left) and eye diagram (right).

Fig. 8b. 200m link 10Gbit/s transmission measurements: BER (left) and eye diagram (right).
4. CONCLUSIONS

An all-optical short-link wireless communication system has been realized and experimented. Thanks to its optical fiber telecom interfaces and low complexity and cost it is well suited for metropolitan last-mile connections. The system is able to realize in a simple and low-cost way a “virtual fiber” through the air, with all the powerful capabilities of optical fibers: protocol transparency, high bandwidth, WDM transmissions, standard telecom devices compatibility.

The experimental results confirm 10Gbit/s transmission rate availability, WDM scalability and good link stability (improvable with additional thermal control). The use of such a system for fast disaster recovery and local extraordinary high-bandwidth demand is also very promising. A bi-directional configuration is also possible and experiments of such a system will be done in future.

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6. REFERENCES