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Mitigating the impact of pointing errors in a 1 Tbps OWC link through PCS and AGC-amplification

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Introduction

The exponential increase in the demand for capacity in future wireless networks, has led the scientific community to search for alternatives to typical radio frequency (RF) wireless networks. In that sense, optical wireless communications (OWC) appear as a promising solution for next-generation wireless networks, with this technology already being proposed for a wide variety of applications [1]. OWC networks bring to wireless the advantage of an unlicensed spectrum with virtually no bandwidth limitations, thus enabling the capability of high-capacity wireless links. Moreover, OWC provides advantages such as high-security, immunity to electromagnetic interference (EMI), and the capability of quick recovery in disaster scenarios [2].

With the ever-increasing capacity demand, we start to see the proliferation of coherent optical transceivers, emerging from long-haul fiber links to different markets [3]. In fact, after the OIF 400G standardization, we observe the appearance of commercial-off-the-shelf (COTS) coherent optical transceivers. Furthermore, we already see the initial steps into 800G standardization, leading this type of technology to be proposed for shorter-reach scenarios [3].

The compliance between OWC and high-capacity coherent optical links, arises with the utilization of seamless air-to-fiber collimation. In these types of links, the interface between fiber and free-space is done by a lens, namely a collimator. In these scenarios, the OWC receiver collects the free-space signal and directly focus it into a fiber-core. This architecture removes all optical-to-electrical (O/E) conversion, thus keeping all the bandwidth inherent to optical fibers [4]. However, these advantages come at an expense of increased sensibility to pointing-error and angle-of-arrival (AoA) fluctuations. These problems can be addressed by deploying and active acquisition tracking and pointing (ATP) mechanism; however the power-consumption of this mechanism can be unbearable for most scenarios. The impact of these impairments in the link will result in a power loss at the receiver which, if known, can be properly compensated. A method to compensate this power loss can be by introducing a pre-amplifier before the optical receiver; the gain of this amplifier can be managed employing an automatic gain control (AGC) loop, which if proper set, adjusts the amplifier gain to account for the power losses induced by link misalignment.

In this work, we make use of coherent optics and seamless fiber-to-air collimation, to demonstrate an indoor 3 m OWC link, transmitting 1 Tbps in a single-wavelength. We improve the link resiliency to pointing-errors, employing a pre-amplifier erbium-doped fiber amplifier (EDFA) at the receiver, and probabilistic constellation shaping (PCS) to create a dynamic bitrate channel, while maintaining the same performance.

Experimental Setup and Results

The experimental setup used is depicted on Fig. 1. At the transmitter offline digital-signal processing (DSP), we generate a PCS shaped signal following a 64QAM template, with a symbol-rate of 100 Gbaud. A root-raised cosine (RRC) pulse shaping filter with a roll-off of 0.1 is applied to the digital signal, and finally pre-emphasis is applied to compensate for the bandwidth limitations of the system. The digital signal is then uploaded to an arbitrary waveform generator (AWG) with a sample rate of 120 GSaps and 45 GHz bandwidth (Keysight M8194A) and is then optical modulated over an external cavity laser (ECL) by a dual-polarization IQ modulator (35 GHz bandwidth). After travelling through 13 km of standard single-mode fiber (SMF), the optical signal is sent to free-space by a collimator (Thorlabs F810APC-1550) that has a lens diameter of 24 mm, a numerical aperture of 0.24, and a divergence angle of 0.0017º. After travelling through 3 m of free-space channel, the optical signal is directly focused into the fiber core by an equal collimator. To compensate for any misalignment-induced power losses, we amplify the optical signal using an EDFA with AGC. The automatic mechanism of adjusting the amplifier gain can be used to maintain a constant power after amplification. Finally, the optical signal is received by a coherent receiver with a bandwidth of 70 GHz. The electrical signal is then sampled and quantized by a real-time oscilloscope (RTO), with 70 GHz bandwidth and 256 GSaps. Typical DSP techniques are applied to the digital signal, and finally the performance is evaluated by the signal normalized generalized mutual information.

The effect of pointing errors is introduced in the system by two high-precision stepper motors (Thorlabs ZST206) attached to the Tx collimator, these motors control the tip/tilt of the collimator, thus controlling the free-space beam position in the *x*- and *y*- axis. Most of the pointing errors effects are compensated by the AGC of the pre-amplifier EDFA, however, in order to account for persistent small fluctuations, we employ a control loop that adjusts the system bitrate. This control loop starts with the normalized generalized mutual information (NGMI) [5] evaluation, then we convert this value to signal-to-noise ratio (SNR), we estimate the next SNR, and adjust the signal bitrate accordingly.

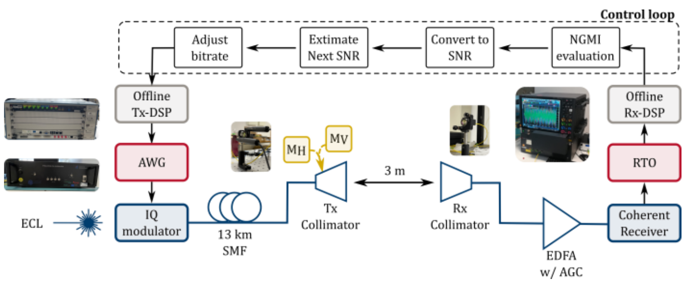

Fig. 1 - Experimental setup of a coherent fiber-OWC link capable of transmitting 1 Tbps.

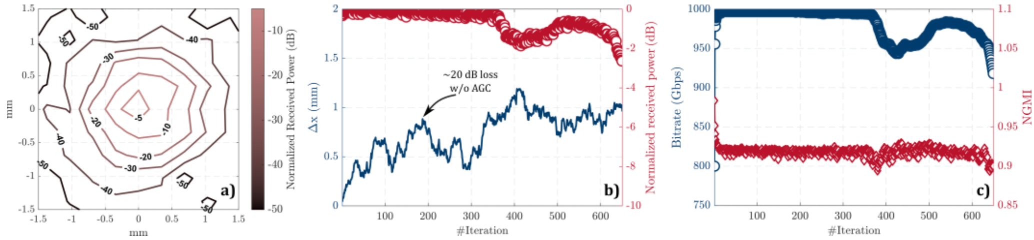

Fig. 2 - Experimental results: a) calibration of the received power in function of beam deviation; b) received power with the AGC-EDFA for a random positional noise; c) transmitted bitrate and NGMI depending on the beam misalignment.

The experimental results obtained are depicted in Fig. 2. In Fig. 2a) we depict the impact of beam deviations in the received power. From the figure analysis we observe that a beam deviation of 0.5 mm leads to a power loss of roughly 10 dB. After a deviation of 1 mm the attenuation is higher than 30 dB. This type of attenuation will considerably impact the transmission system if not compensated. If we consider the system with the pre-amplifier with automatic gain control, we can partially compensate for this loss. Fig. 2b) shows the normalized received power (after amplification) while applying a random noise dithering in the Tx collimator motors. From the results we observe that the AGC-EDFA is compensating for this power losses, for instance for a misalignment of 0.8 mm we have a loss below that 1 dB, when without the amplifier we should have more than 20 dB. If we increase the deviation too much, the amplifier is not able to provide enough gain, and we see higher power losses (after roughly 350 iterations), in this scenario, adapting the system bitrate can be beneficial to make sure that we minimize the possibility of link failure. Fig. 2c) shows the bitrate transmitted in function of the link deviation, it is also shown the measured NGMI. We observe that when the losses are majorly compensated by AGC-EDFA, the link bitrate is kept around 1 Tbps, however, when the losses are too high, the PCS adaptation is used to adjust the bitrate between 1 Tbps and 900 Gbps. This adaptation is performed in order to maintain a fixed NGMI, that we can see that is almost constant throughout all the experiment.

Conclusion

In this work we demonstrated a 1 Tbps optical wireless link with pointing error compensation through a pre-amplifier with automatic gain control and bitrate adaptation through probabilistic constellation shaping. These mechanisms allow to maintain a constant performance through a scenario with random pointing errors that can ascend to values higher than 1 mm.

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