On the evaluation of an Optical OFDM Radio over FSO system with IM-DD for high-speed indoor communications

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ABSTRACT

A novel radio over fiber (RoF) and free space optics (FSO) hybrid system based on optical OFDM (OOFDM) signal transmission is proposed in this paper to provide high capacity optical wireless indoor communication links. A low cost transmission scheme based on IM-DD is proposed to simplify and reuse existing infrastructure to deploy a high bandwidth FSO link. This paper shows the experimental results based on the implementation of the proposed scheme under a 16-QAM OOFDM digital transmission over 10 km Single Mode Fiber (SMF) and 300 mm FSO link. The results show the feasibility to deploy a 20 Gbit/s communication system over a 5 GHz RF bandwidth OFDM signal by using IM-DD scheme for the optical transmission without any optical multiplexing technique.

Keywords: OFDM, FSO, OWC; IM-DD, indoor, radio over fiber.

1. INTRODUCTION

In recent years, the increasing demand for wireless services which require high-speed, high capacity and ubiquitous connections has become essential to the development of the access networks. In this area, fiber technologies to the home (FTTH) are becoming a usual asset in residential areas to address those requirements. However, due to the implementation of 5G technologies and the need for ubiquitous access demand free-space optical (FSO) links as part of optical wireless communications (OWC) for mostly outdoor applications [1]–[3]. Among providing reliable high data rate optical wireless links [4] FSO links are recognized as fundamental part for the development of future 5G and beyond technologies [5]. The FSO technology will help to improve the capacity of such 5G wireless systems at their mobile fronthaul and backhaul [6][7].

This paper focused on the evaluation of a proposed OOFDM system for its application over a free space link to provide high-speed indoor communications. For example, dual polarization phase state modulation in combination with wavelength multiplexing techniques has been demonstrated over FSO for 16 x 100 Gbit/s high capacity optical metro and access networks [4], [8]. In this paper, we focus on the demonstration of high-speed radio over FSO system with a low cost solution based on IM-DD for indoor communications environments.

2. SYSTEM DESCRIPTION

The proposed experimental set-up is depicted in Fig. 1. Generation and reception of the OFDM signal is processed offline in Matlab. The transmitted signal is loaded into an Arbitrary Waveform Generator (AWG7122C, Tektronix), sampling at 24 GS/s. An FFT size of 4096 with 854 16-QAM data-bearing subcarriers is used, satisfying Hermitian symmetry. The resulting OFDM signal is centered at 3.25 GHz with a raw data rate of 20 Gbit/s. A 6.25% cyclic prefix of the symbol is applied and channel estimation and equalization areperformed in detection by the inclusion of a block-type equispaced pilot pattern of 10%. A pre-emphasis filter is also applied to overcome the non-flat response of the electrical transmitter.

Table 1. System parameters

OFDM BW	3.25 GHz
Modulation format	16-QAM
EDFA	15 dBm
Laser CW wavelength	1550 nm
Optical laser power output	8 dBm
MZM - Intensity modulator- BW	10 GHz
MZM V_{BIAS}	5.3 V_{DC}
FSO link length L_{FSO}	300 mm

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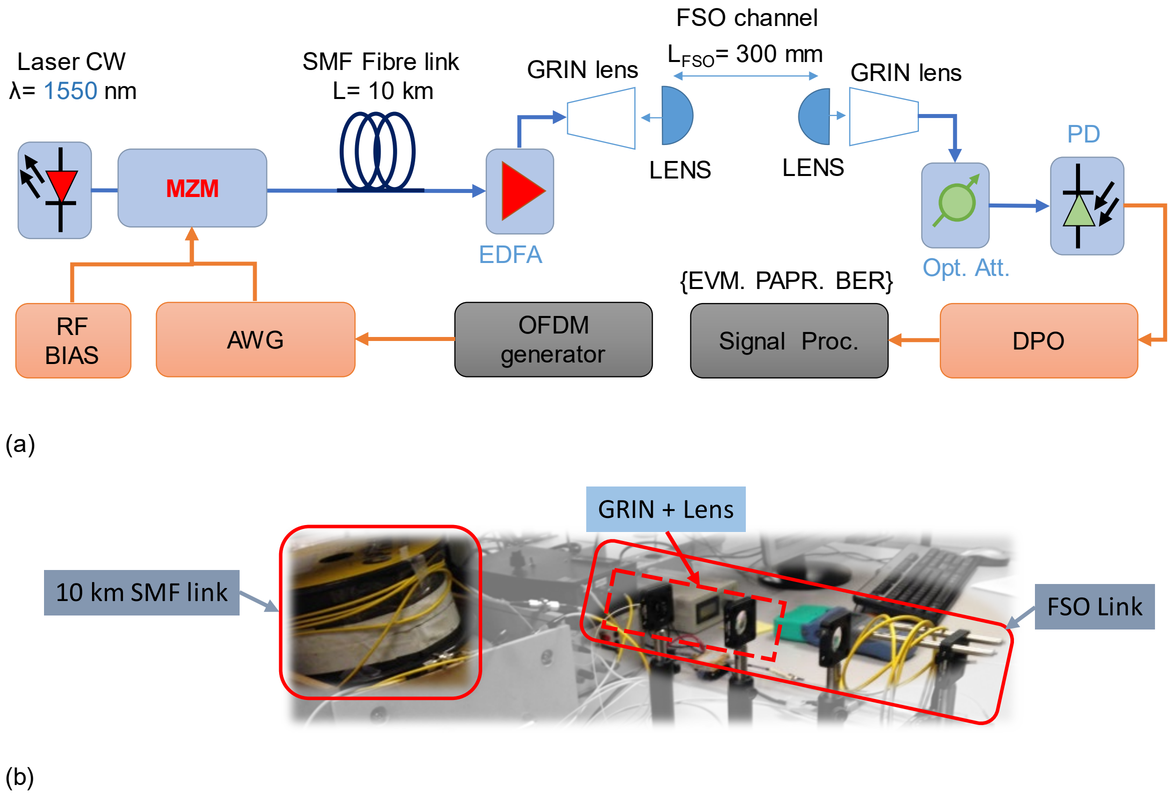

Fig. 1. System set-up (a) description and (b) snapshot of the FSO link and SMF link laboratory implementation.

Then, the RF signal is double-sideband modulated onto a Mach-Zehnder modulator fed by a CW laser source at 1550 nm. The signal is transmitted over an optical channel formed by a SMF spool of 10 km. The output signal from SMF is amplified by Erbium doped fiber amplifier (EDFA) to compensate loss and gain sufficient power budget. Afterwards, the optical signal launch into the FSO link - both FSO transceivers composed of graded-index lenses (GRIN) (Thorlabs 50-1550A-APC) with an aperture of 1.8 mm and plano-convex lenses with a diameter of 25.4 mm. The optical signal is collimated at the receiver part and passed through an optical attenuator to emulate optical losses on the system.

The received optical signal is photodetected (U2T BPDV2020R-VF-FP) and captured electrically by a Real-Time Digital Phosphor Oscilloscope (DPO72004C, Tektronix), sampled at 50 GS/s, in order to process it offline. The captured samples are synchronized following a cross correlation scheme, and parallelized for processing in the regular OFDM receiver blocks. The cyclic prefix is removed before the application of the 4096-FFT. The channel estimation and equalization is performed with the information carried by the pilot symbols, and 16-QAM data are detected, recovering the transmitted bit stream after serialization. The main parameters of the overall system are summarized in Table 1.

3. EXPERIMENTAL RESULTS

The electrical signal generated and received is centered at 3.25 GHz, as depicted in Fig. 2. The main results obtained are shown in Fig 3. Once the modulator is biased at the quadrature point of 5.3 V the signal is either detected as a back-to-back (B2B) configuration or passed through the RoF 10 Km SMF link or over the overall hybrid system, i.e. the RoF 10 Km SMF+FSO link. The optical attenuator allows evaluating the impact of the attenuation losses in the system performance. The optical power received at the photoreceiver is 3 dBm without the optical attenuator. The FSO link losses are in the range of 2 dB due the short range of the link and a precise process of alignment. However, it is worth to mention that the small misalignments on this experimental set-up address to accumulate losses of around 8 dB. This evaluation procedure provided results depicted in Fig.3 in terms of EVM and BER measured results. The FSO link range is 300 mm in order to emulate a high-capacity short-range optical wireless communication channel typical for indoor environments, e.g. data centers.

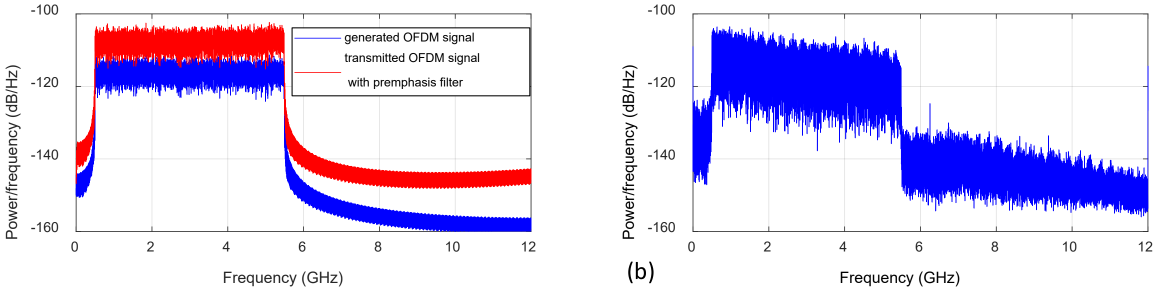

Fig. 2.(a) Generated and transmitted OFDM signal. (b) Received electrical OFDM signal.

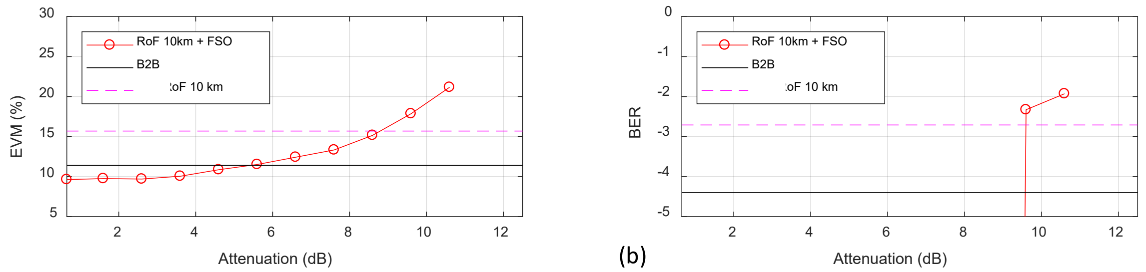

Fig. 3. Impact of the optical losses, due to optical attenuation, at the proposed 16 QAM OOFDM 10 km SMF radio-over-FSO system in terms of measured (a) EVM and (b) BER.

The measured EVM shown in Fig. 3(a) indicates that the inclusion of the 10 km SMF RoF link decreases, as expected, the quality of the system about 5% from the initial B2B configuration. However, the combination of the RoF and FSO link leads to obtaining similar values as the B2B system up to 6 dB of optical attenuation. Then the system starts to degrade quickly for optical attenuation values beyond 9-10 dB. On the other hand, evaluating the measured BER results, in the Fig. 3(b), shows no degradation until the aforementioned value 9-10 dB optical attenuation. The experimental EVM results indicated that no errors were detected until the optical receiver power decreases below 10 dB of optical attenuation,

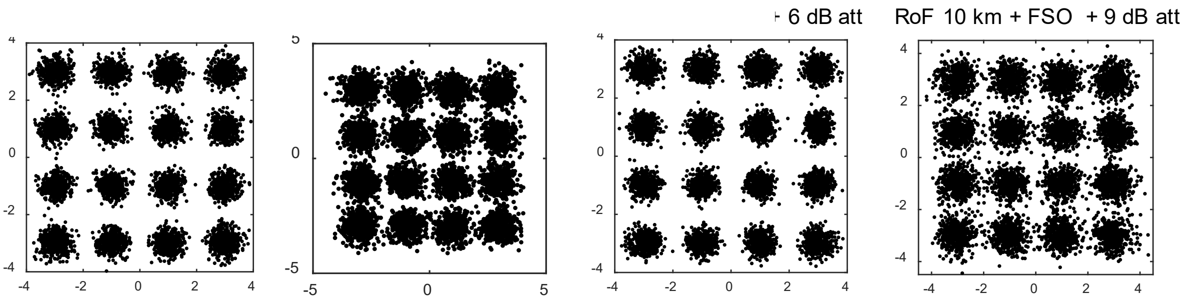

Fig. 4. 16 QAM-OOFDM signal constellations (a) B2B configuration, (b) with 10 Km radio over fiber, (c) adding the FSO channel with optical power reduced 6 dB and (d) reducing the optical power 9 dB.

The 16 QAM-OOFDM signal constellations at Fig. 4 show the corresponding degradation to different experimental parameters. It is very interesting to point out how the degradation of the performance for RoF + FSO system is comparable to the B2B and RoF system after detection and signal processing. Moreover, it is well known that the FEC limit defines the 3.8×10^{-3} BER threshold level for a 16-QAM communication digital systems, and our proposed system accomplish such requirement when optical attenuation is less than 10 dB [9].

4. CONCLUSIONS

In this paper, we address the feasibility to build ultra-broadband high-speed radio over FSO links for short-range links indoor scenarios. The innovative introduction of IM-DD scheme allows proposing a moderate cost approach compared to previous ones which are based on balanced detection schemes, advanced modulation formats and optical multiplexing techniques. Moreover, this proposal improves the feasibility of reuse, easy deployment and management as one of the main characteristics of the aforementioned OWC systems as they use moderate cost optical components to deploy the final FSO link. The evaluated 16-QAM OOFDM transmission system shows the feasibility to support 20 Gbit/s over an ultra-broadband RF signal of 5 GHz over 10 km fiber and 300 mm free space link. These results will help to pave future studies on the feasibility of high capacity optical wireless communication systems for IoTs environments.

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