Transmission of Multi-Band OFDM-UWB Signals along NG-FTTH Networks using Directly Modulated Lasers

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Abstract: Transmission of multi-band OFDM-UWB signals along FTTH networks using directly modulated lasers is experimentally evaluated. Reach of 100 km of standard SMF is achieved with a BER below 10^{-4} and an OSNR of 25 dB.

OCIS codes: 060.4080 Modulation, 060.4510 Optical communications

1. Introduction

With the increase demand of bandwidth capacity by access services, either in the optical-fixed or radio-access networks, telecommunication operators face the challenge of consolidating networks in order to optimize resources and maximize the data throughput while maintaining flexibility in the provided services. Next generation fiber-to-the-home (NG-FTTH) networks present the advantage of enabling multi-protocol services and transmission distances above 100 km, permitting consolidating the transmission network from the backbone to the last mile (or closest to the final subscriber) [1]. Additionally, broadband wireless networks distributing high definition (HD) audio/video streams can be consolidated considering transmission of ultra-wideband (UWB) signals modulated with orthogonal-frequency-division-multiplexing (OFDM) over NG-FTTH [2]. More importantly, multi-band OFDM-UWB signals allows feeding more than one HD stream without expending more than one wavelength.

Recently, directly modulated lasers (DML) transmitting OFDM signals have been proposed to be used with passive optical networks [3]-[4]. Such application presents lower cost, compact size, high output power characteristics and lower power consumption when compared to externally modulation techniques. Additionally, inherent limitations of DML like chirp and reduced intensity-modulation bandwidth restrict the application of DMLs to relative low-speed systems. However, previous works have focused on the transmission of OFDM signals using DMLs without investigating distances of the order of 100 km of standard single mode fiber (SSMF), typical of NG-FTTH. Furthermore, the degradation due to transmission of several UWB sub-bands in the same wavelength using DMLs for such distances is still to be assessed as previous works considered non-UWB OFDM signals and non-SSMF [3] or very short reach systems (~1 km) [4].

In this work, we present an experimental investigation on the transmission of multi-band OFDM-UWB signals using low-cost DMLs focusing on distances typical of NG-FTTH networks. Three UWB sub-bands are considered. Optimization of the modulation index of the OFDM signal is performed considering single-band UWB and multi-band UWB signals allowing the assessment of the degradation induced by multi-band transmission. Considering optimized modulation index, a distance of 100 km along SSMF is achieved with a bit error ratio (BER) below 10^{-4} for the worst UWB sub-band and an optical signal-to-noise ratio (OSNR) of 25 dB.

2. Experimental setup

The experimental setup is depicted in Fig. 1. The setup is divided into three parts: generator of the optical OFDM-UWB signal, optical transmission and receiver of the OFDM-UWB signal. In the generator, the OFDM-UWB signal is generated offline where each UWB sub-band is modulated according to the standard ECMA 368 (640 Mb/s, bandwidth of 528 MHz, 128 sub-carriers modulated with quadrature phase shift keying, where 12 sub-carriers are used as pilot for adaptive electrical equalization, 10 sub-carriers are used as guard sub-carriers and 6 sub-carriers are null sub-carriers to relax the electrical filtering requirements) [5]. Only the UWB sub-bands centered at 3.43 GHz, 3.96 GHz and 4.49 GHz are considered due to the limited bandwidth of the DML. The signal is then converted to an electrical signal by an Arbitrary Waveform Generator (AWG) Tektronix 7052 with 20 Gsamples/s, amplified by an electrical driver and filtered by an electrical filter to remove high frequency components before being injected in the DML. The DML is a commercially available multi-quantum well distributed feedback laser with threshold current

I_{th} of 8.1 mA, chirp parameter of 2.6, biased with I_b of 30 mA in order to guarantee an output power around 6 dBm, centered at 1553.33 nm and an intensity modulation response with 3 dB bandwidth of 4 GHz. The optical transmission path is composed by spoils of SSMF (with dispersion parameter of 17 ps/nm/km), an erbium doped fiber amplifier (EDFA), a noise loader and a 2nd order super-Gaussian optical filter to limit the noise bandwidth. The receiver of the OFDM-UWB signal is composed by a Digital Sampling Oscilloscope (DSO) Agilent 81204A with 20 Gsamples/s and an offline demodulator which demodulates and evaluates the performance of each OFDM-UWB sub-band. Along this work, performance is assessed measuring the BER according to the method described in [6] which allows reaching low BERs values without resorting to long measurement times. All BERs are obtained for an OSNR at the input of the photodetector of 25 dB, measured in a bandwidth of 0.1 nm.

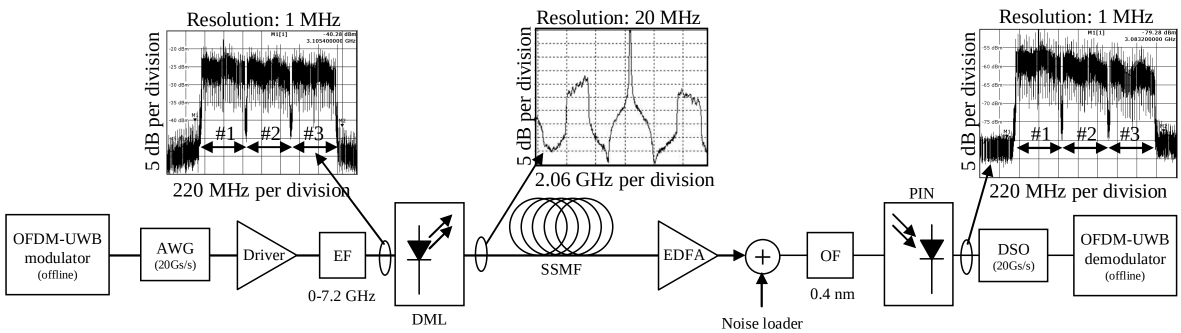

Fig. 1 – Experimental setup. Inset: electrical and optical spectra in different points of the setup. EF: electrical filter; OF: optical filter.

3. Experimental results

In order to maximize the performance obtained by DMLs when transmitting an OFDM-UWB signal, the modulation index of the electrical signal driving the DML is optimized against BER. The modulation index, *m*, is given by:

$$m = \frac{1}{I_b - I_{th}} \cdot \sqrt{\frac{1}{T}\int_0^T \left[i_{DML}(t) - I_b \right]^2 dt} \qquad (1)$$

where T is the duration of the overall OFDM-UWB signal and $i_{DML}(t)$ is the electrical current injected into the DML. In case of multi-band OFDM-UWB signals, the effective modulation index of the signal transmitted in each UWB sub-band is obtained from expression (1) divided by $N^{-1/2}$, where N is the number of transmitted UWB sub-bands. This means that, when a multi-band OFDM-UWB signal has a high modulation index, each of the UWB sub-bands has a reduced modulation index which limits the performance. Such fact can be seen in Fig. 2, which depicts the BER as a function of the modulation index for OFDM-UWB signals considering one single UWB sub-band and the three UWB sub-bands simultaneously in a back-to-back situation and after 100 km of SSMF.

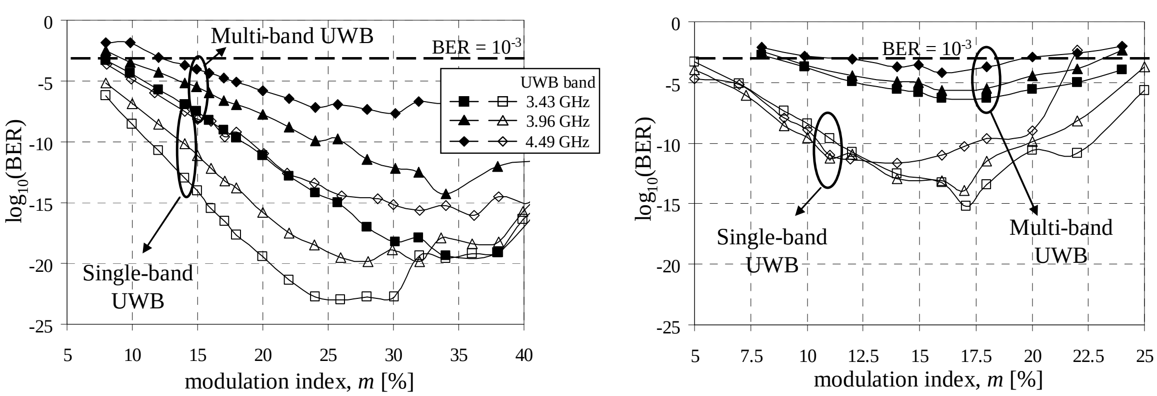

Fig. 2 – BER as a function of the modulation index for an OSNR of 25 dB. Left – back-to-back; right – after 100 km of SSMF.

Fig. 2 shows a similar behavior for all dependences of BER on the modulation index: 1) for low modulation index, an increase of the modulation index leads to BER improvement as the limiting effect is noise; 2) above an optimum modulation index, an increase of the modulation index leads to BER degradation as the limiting effect is signal distortion. In case of back-to-back, the optimum modulation is in the range of 25%-35% for all tested cases whereas, after 100 km of SSMF, the optimum modulation index is in the range of 12.5%-17.5%. Such fact indicates that the modulation index for which distortion becomes the limiting effect can be considered approximately independent of the number of UWB sub-bands and depends mainly on the transmission distance. Considering optimum modulation indexes and back-to-back condition, BERs lower than 10^{-15} are obtained for single-band UWB and lower than 10^{-7} for multi-band UWB, for all tested bands. In case of transmission over 100 km of SSMF, BERs lower than 10^{-11} are obtained for single-band UWB and lower than 10^{-4} (appropriate for forward error correction usage) for multi-band UWB, for all tested bands. The significant BER degradation is explained by the fact that the optimum modulation index is almost the same for the multi-band UWB and single-band UWB cases, but the effective modulation index of each UWB band is reduced by the term $N^{-1/2}$. Observing in detail the case of 100 km of SSMF, the optimum modulation index of 16% observed for the multi-band UWB leads to a BER between 10^{-4} and 10^{-7} for the different UWB sub-bands and gives an effective modulation index of 9% for each one of the UWB sub-bands. Considering such modulation index and single-band UWB, the different UWB sub-bands present a BER between 10^{-7} and 10^{-8}. Such observation allows concluding that most of the degradation is not specific of DMLs (when compared to external modulators) but instead is due to the reduction of modulation index of each UWB sub-band when multi-band is considered, caused by the nonlinear transfer characteristic of the electro-optic conversion.

In order to evaluate the system performance and the importance of the conditions used for modulation index optimization, Fig. 3 presents the BER as a function of the SSMF distance for a multi-band OFDM-UWB signal with a fixed modulation index optimized considering back-to-back (optimum m=30%) and a fixed modulation index optimized for 100 km of SSMF (optimum m=16%). As can be seen, considering m=30% leads to a significant BER degradation after 25 km and to almost undetectable signals at 100 km. On the other hand, considering m=16% leads to high BER degradation in back-to-back (when compared to m=30%) but to a much smaller BER degradation with SSMF transmission.

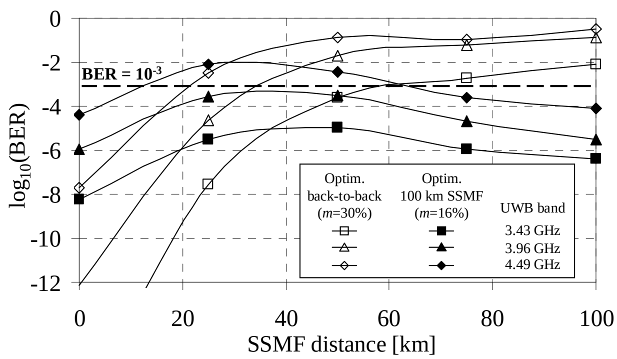

Fig. 3 – BER of multi-band OFDM-UWB signals as a function of the SSMF distance, for different modulation index optimization conditions.

4. Conclusion

The performance of low-cost DML in NG-FTTH networks using multi-band OFDM-UWB signals has been experimentally evaluated. SSMF transmission distances up to 100 km have been achieved with a BER below 10^{-4} (appropriate for forward error correction usage) for an OSNR of 25 dB only after optimization of the modulation index used in the DML. Such achievement proves that DMLs can be a competitive solution for cost-efficient consolidation of broadband wireless signal distribution along NG-FTTH networks.

Acknowledgments

This work was supported by the European Union FP7-ICT-2009-4-249142 FIVER project and by the PTDC/EEA-TEL/104358/2008 TURBO project from Fundação para a Ciência e a Tecnologia of Portugal.

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