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Transmission of 1.2 Gbit/s Polarization-Multiplexed UWB Signals in PON with 0.76 Bit/s/Hz Spectral Efficiency

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Abstract: The transmission of 1.2 Gbit/s Polarization-Multiplexed OFDM-based UWB signals in PON is proposed and experimentally demonstrated. This technique allows more than 25 km SSMF transmission reach with 0.76 Bit/s/Hz spectral efficiency.

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1. Introduction

The radio-over-fiber (RoF) transport of wireless signals over a shared optical infrastructure is foreseen as an interesting solution for the rapid and cost-effective provision of wireless connectivity in fiber-to-the-home (FTTH) networks. Furthermore, provided the right wireless radio technology is selected, bitrates exceeding Gbit/s are feasible [1]. Ultra-wideband (UWB) is a radio modulation technique defined by the Federal Communications Commission (FCC) which employs signals with a fractional bandwidth larger than 20%, or a bandwidth exceeding 500 MHz. UWB radio is permitted in the band between 3.1 and 10.6 GHz in current regulation in United States [2]. The UWB band is channelized [3], so a large number of users can be served by a single wavelength transporting UWB signals. The maximum power spectrum density (PSD) level is limited to -41.3 dBm/MHz to minimize the potential interference on licensed (e.g. WiMAX) and un-licensed (e.g. WiFi) wireless services overlapping in spectrum [4]. UWB is an attractive technology for indoor short-range communications, as wireless personal area networks (WPAN). UWB is inherently a low cost solution, i.e. UWB extracted channels at user premises can be received by commercial low-cost receivers. The low radiated PSD levels allowed in current regulation in force worldwide, makes UWB one of the potentially lowest energy-consumption technologies in the market, where UWB-enabled devices like laptops, mobile phones or TV sets are already available.

FTTH technology, implemented as a passive optical network (PON) properly conditioned for UWB transmission, is expected to support other RoF wireless technologies also employing OFDM modulation, allowing coexistence with other microwave access techniques (e.g. WiMax) [5]. A PON is a repeater-less network architecture which accesses the user by standard single mode fiber (SSMF). The use of a passive optical power splitting in PON is mostly preferred when large areas must be served with a larger number of users, being more economical than other point-to-point topologies [6]. Also the easy repair of breaks in the PON reduces the network maintenance cost. A straight-forward PON implementation leads to limitations to the optical transmission reach as amplification, regeneration and impairment compensation stages are eliminated.

Two main UWB implementations are being used nowadays: Impulse radio-based UWB (IR-UWB) and OFDM-based UWB (OFDM-UWB) following the ECMA-368 standard [3], also known as WiMedia-defined or Multi-Band OFDM (MB-OFDM UWB). UWB-on-fiber distribution in FTTH was first proposed for IR-UWB and OFDM-UWB in [7]. Reported work indicates that OFDM-UWB exhibits better performance in typical FTTH networks including amplifier sections. Moreover, the OFDM modulation employed in WiMedia-defined UWB is especially well suited for the fiber transmission impairments compensation, i.e. chromatic dispersion, intra-channel nonlinear distortion and nonlinear phase noise [8] expected in PON deployments.

This paper proposes and analyses, for the first time to our knowledge, the distribution of polarization-multiplexed UWB (PM-UWB) signals as a suitable technique for the provision of wireless connectivity to a large number of users. This technique exhibits the following advantages: (i) It is capable of providing Gbit/s connectivity using a full standard UWB low-cost receiver. (ii) As UWB is a low cost technology, there is a reduction the overall network deployment costs. (iii) OFDM-UWB is especially well suited to un-compensated and un-amplified passive optical access networks. (iv) A high spectral efficiency is feasible, and (v) user capacity is doubled compared with UWB on a single wavelength. The maximum transmission reach of the proposed PM-UWB technique is also investigated in this paper. The experimental results indicate that this technique is suitable for PON deployments larger than 25 km reach, which exceeds the maximum range in typical FTTH deployments [9].

2. Experimental set-up

Fig. 1 shows the experimental setup. This setup implements a PM-UWB demonstration to evaluate the performance after L km repeater-less optical transmission in SSMF. The central office (CO) transmitter in Fig. 1(a) generates a single wavelength at 1555 nm external cavity laser (ECL). This single wavelength is intended for a single user. Two full standard ECMA-368 OFDM-UWB signals, each comprising three channels at 200 Mbit/s per channel, are modulated on the orthogonal polarization of this light. Two UWB transmitters (Wisair DV-9110) generate the required signals which are amplified (Picosecond 5865) and modulated by a Mach-Zehnder electro-optical modulator (MZ-EOM) at quadrature bias (QB) point. The UWB-modulated optical signal at points (1) and (2) in Fig. 1(a) are adjusted with a polarization controller to linear-horizontal (LH, named Pol. A in Fig. 1) and linear-vertical states (LV, named Pol. B in Fig. 1) and combined by a polarization beam splitter (PBS) to generate the polarization-multiplexed UWB (PM-UWB) signal. The PM-UWB signal is boosted by an EDFA (Amonics 30-B-FA) at the CO transmitter output and launched through a SSMF spool with different lengths ($L=5, 10, 25$ and 50 km). These lengths correspond to the distances expected in PON access. The EDFA output level remains constant in order to maintain the noise introduced by EDFA. However, the total optical power level in point (3) in Fig. 1(a) (launch power) is adjusted with a variable attenuator from -3 to 7 dBm, to investigate the PM-UWB performance from the customer point-of-view.

The PM-UWB signal is received at point (4) in Fig. 1(a), where the two polarizations are splitted, photo-detected, filtered, amplified and should be radiated to the final user. No demodulation or up-conversion stages are required with this technique. The receiver at customer premises employs a polarization controller, which would be an automatic in an on-the-field deployment, and a PBS providing the polarization splitted to resolve Polarization A and B at points (5) and (6) respectively. Each PM-UWB polarization is detected with a PIN photo-detector (0.7 A/W responsivity), amplified and feed to a digital signal analyzer (Agilent DSA8000B), which includes filtering, to evaluate the error vector magnitude (EVM) in each channel of both polarizations.

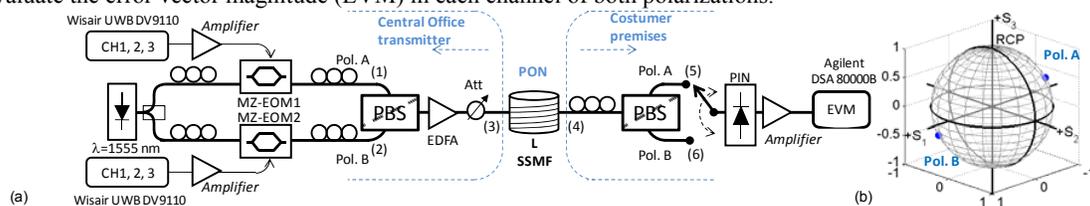


Fig. 1. (a) Evaluation setup for optical polarization multiplexing effect over MB-OFDM UWB signals distribution on PON links. (b) Measured polarization at point (1) and (2) in Fig. 1(a).

A dual-polarization multiplex with three channels of 528 MHz bandwidth each (center frequencies of 3.432 GHz, 3.96 GHz and 4.488 GHz respectively) is demonstrated in the experiment. These channels correspond to the low band group #1 in ECMA-368 MB-OFDM UWB specification. Each channel is configured at 200 Mbit/s bitrate using ECMA time frequency codes (TFC) 5, 6 and 7, giving 0.76 Bit/s/Hz spectral efficiency. Fig. 2(a) shows the corresponding electrical spectrum at point (1) and (2) before PBS combining and fiber launch for each polarization employed. Fig. 2(b) shows the corresponding spectrums at the receiver, points (5) and (6) in Fig. 1 after 10 km SSMF transmission. The cross-polarization residual crosstalk is shown in Fig. 2(c) and it can be observed that 30 dB and 33 dB discrimination for each polarization is achieved in this experiment.

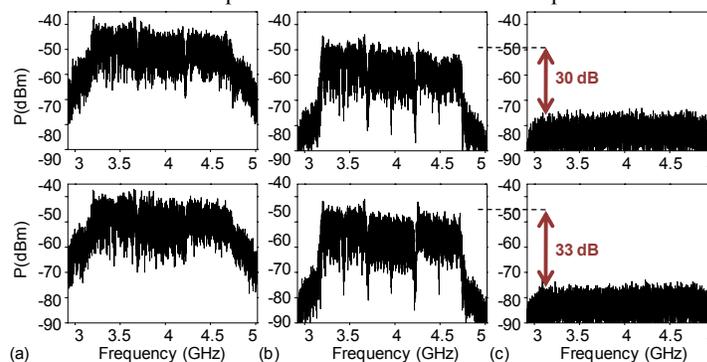


Fig. 2. (a) RF transmitted spectrum measured in points (1) and (2) of Fig. 1(a), (b) RF received spectrum after 10 km SSMF transmission measured in points (5) and (6) of Fig. 1(a), and (c) cross-polarization residual crosstalk, for polarization A and B (top/bottom respectively).

3. PM-UWB performance

Fig. 3(a) shows the EVM performance transmitting 3 MB-OFDM UWB channels using the same setup but with one only polarization (no polarization multiplexing). Fig. 3(b) and 3(c) show the EVM of the received Pol. A and Pol. B at points (5) and (6) in Fig. 1(a) respectively. The results show the combined EVM for all channels after four PON SSMF links of 5, 10, 25 and 50 km respectively. Figure 3(d) show an example of the received constellation over 48 received symbols of the first channel of polarization after 10 km SSMF. The results indicate that both PM-UWB polarizations achieve the successful communication threshold of 18.84% EVM defined in ECMA-368 for distances between 5 and 25 km. PON reach of 50 km can not be achieved, even employing a high launched power of 7 dBm. The reach is then estimated in 25 km for the proposed PM-UWB configuration. This reach is adequate for typical PON networks [9]. Comparing the results using single polarization, with the polarization multiplexed approach, it can be observed that the interference between orthogonal polarizations induces only a 2% EVM penalty, while the spectral efficiency is doubled.

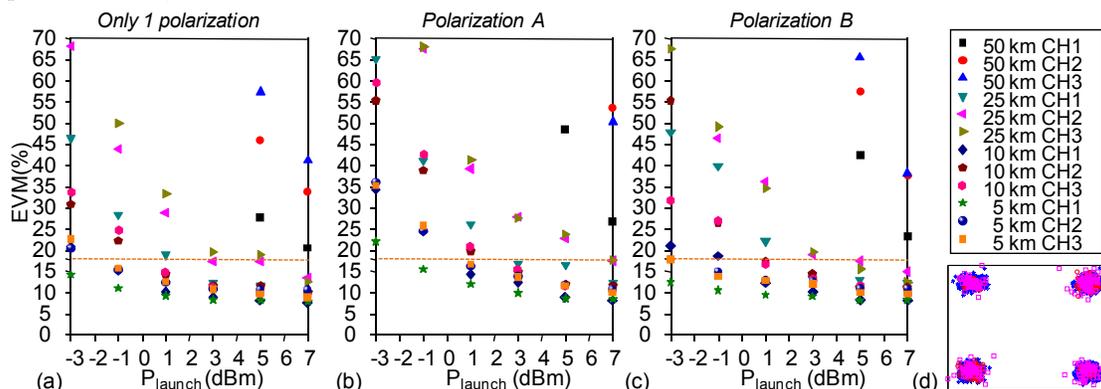


Fig. 3. (a) Single-polarization UWB-on-PON performance. (b) Pol. A in PM-UWB-on-PON performance. (c) Pol. B in PM-UWB-on-PON performance. (d) Received constellation example. Horizontal dashed lines show the 18.84% EVM threshold for successful UWB transmission.

4. Conclusion

The experimental results demonstrate that the Polarization multiplexing can be used for the transmission of fully-standard MB-OFDM UWB signals over PON networks. Successful PM-UWB transmission is feasible with transmission range exceeding 25 km reach ($EVM_{\text{RMS}} < 18.84\%$ threshold). Using the PM-UWB technique, the bitrate provided to a single user on a single wavelength is 1.2 Gbit/s with 0.76 Bit/s/Hz spectral efficiency.

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