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# Performance of MB-OFDM UWB and WiMAX IEEE 802.16e Converged Radio-over-Fiber in PON

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**Abstract**— Experimental results about the performance of converged radio-over-fiber transmission including multiband-OFDM UWB and WiMAX 802.16e wireless over a passive optical network are reported in this paper. The experimental study indicates that UWB and WiMAX converged transmission is feasible over the proposed distribution set-up employing a single wavelength. However, the results indicate that there is an EVM penalty of 3.2 dB for a UWB 10 km SSMF transmission in presence of WiMAX wireless.

## I. INTRODUCTION

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. FTTH technology, implemented as a passive optical network (PON) access the customer premises employing repeater-less optical power splitting and standard single-mode fiber (SSMF) [1]. PON technology is preferred when large areas with a larger number of users must be served [2]. A straightforward PON implementation leads to limitations in the optical transmission reach distances since amplification, regeneration and impairment compensation stages are eliminated. Typical PON reach distances have been reported to be around 20 km [3].

Ultra-wideband (UWB) wireless technology is a candidate for the future beyond third generation (B3G) wireless systems due to its unique characteristics, such as very low power transmission and consumption, high tolerance to multi path fading, low probability of interception and low cost devices [4]. In current regulation, UWB is an unlicensed wireless service allocated in the 3.1 to 10.6 GHz band [5-7], with 20% fractional bandwidth or, at least, 500 MHz [5] or bandwidth significantly wider than 50 MHz at ETSI regulation [8]. WiMedia-defined UWB signals are based on multi-band orthogonal frequency division multiplexing (MB-OFDM) modulation [9]. This specification has been adopted as UWB standard on ECMA-368 specification. Regarding current wireless standards, UWB radio transmission technology has been proved to be adequate for the distribution of

uncompressed high definition audio/video in hybrid fiber radio networks [10]. Due to the unlicensed nature of UWB signals, UWB spectrum band overlaps the spectrum of already existing narrowband and wideband systems, such as WiMAX, and hence, coexistence issues are of primary concern. WiMAX, worldwide interoperability for microwave access, is a wireless transmission technology targeting a medium- to long- range data communications at bit rates up to 12 Mb/s [11]. WiMAX is expected to replace large wireless local area networks installations [12], e.g., commercial areas, airports lounges, etc. Comparing the bit rate and expected range, WiMAX and UWB can be seen as complementary radio technologies, which may coexist in a near future.

PON is an access technology properly conditioned for UWB transmission, and is expected to support other RoF wireless technologies also employing OFDM modulation, allowing coexistence with WiMAX and other wireless access techniques. The distribution of different wireless standards in PON, known as hybrid fiber-radio access, exhibits several advantages. For example, no frequency upconversion is required at customer premises, optical access networks are transparent to the specific modulation employed, and no trans-modulation is required at the customer premises since the wireless signal is transmitted through the optical path in its native format. UWB and WiMAX coexistence on low-cost multi-mode fiber has been reported in [13] for indoor applications.

This paper proposes a joint distribution of UWB and WiMAX radio over SSMF in a PON optical link. The experimental results indicate a converged successful transmission of UWB and WiMAX up to 25 km SSMF employing a single wavelength.

The paper is structured as follows. Section II describes the UWB and WiMAX wireless converged distribution RoF in PON concept evaluated in this work. The experimental set-up implemented for the simultaneous distribution over PON is described in Section III. Section IV discusses experimental results for joint UWB and WiMAX PON distribution.

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Finally, the main conclusions are drawn in Section V.

## II. CONVERGED UWB AND WiMAX RADIO-OVER-FIBER TRANSMISSION OVER PON CONCEPT

The concept of converged wireless services distribution over PON for different scenarios and users is depicted in Fig 1.



Figure 1. Converged wireless services transmission and distribution over PON concept.

Fig. 1 shows a central node (central office, CO), which can generate standard UWB and WiMAX wireless signals according to the operator and user premises. These wireless radio signals are typically converted to the optical domain by external modulation. Both optical signals are combined and distributed through an SSMF-based PON access network to a given number of subscribers. At the subscriber premises, the optical signal is photodetected, filtered, amplified and each wireless service is directly radiated to the users present at the customer premises. This approach benefits from the high bitrate capabilities of UWB, supporting bitrates up to 1 Gbit/s at a few meters range [14], which can be extended to 30 m by multiple-input multiple-output (MIMO) processing [15]. Furthermore, the WiMAX radio complements UWB providing coverage to the whole home/building at a lower bitrate of 2 Mbit/s [11],[16].

Multi-user operation can be implemented by wavelength-division multiplexing (WDM) and/or sub-carrier multiplexing (SCM) techniques [17]. Both transmitted UWB and WiMAX signals are based on OFDM modulation with a spectral efficiency of 0.3788 bit/s/Hz and 0.634 bit/s/Hz, respectively.

## III. EXPERIMENTAL SET-UP

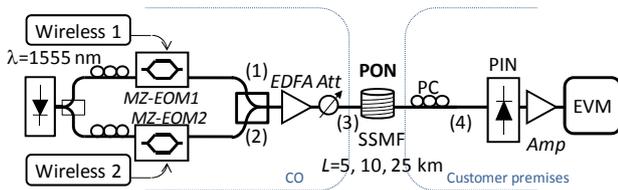


Figure 2. Experimental set-up for converged MB-OFDM UWB and WiMAX IEEE 802.16e transmission performance analysis over PON.

In order to implement the MB-OFDM UWB and WiMAX IEEE 802.16e wireless convergence transmission over PON, the setup depicted in Fig. 2 has been implemented. In this setup the central office (CO) transmitter provides a single wavelength at 1555 nm generated by an ECL. In this figure wireless service 1 comprises UWB MB-OFDM signal generation by Wisair DV-9110 modules. The UWB signal is generated following the WiMedia-defined UWB specification

described in the ECMA-368 standard [14] on the first UWB band group, which comprises three bands of 528 MHz. UWB link parameters are summarized on Table I.

TABLE I. WiMEDIA-DEFINED UWB LINK PARAMETERS

Time frequency coding	TFC1	TFC5 – TFC6
Band frequency	Band group #1 {3.168 – 4.752 GHz}	Band #1, #2 {3.168 – 3.696 GHz} {3.696 – 4.224 GHz}
Center frequency	3.960 GHz	3.432 GHz 3.960 GHz
Bit rate	200 Mb/s	
EIRP	-41.3 dBm/MHz	

The wireless service 2 is a WiMAX signal that corresponds to a broadband wireless access (BWA) indoor terminal following IEEE 802.16e standard [14]. WiMAX utilizes a scalable orthogonal frequency division multiple access (SOFDMA) QPSK modulation. The signal is centered at 3.5 GHz following the European regulation [18]. The main WiMAX signal parameters are summarized in Table II.

TABLE II. WiMAX SIGNAL PARAMETERS

Center frequency	3.5 GHz		
Bandwidth	5 MHz	10 MHz	20 MHz
FFT-points	1024		
Subchannel spacing	5.46875 kHz	10.9375 kHz	21.875 kHz
Oversampling rate	24/28		
Guard period	1/8		
Symbol duration	182.86 $\mu$ s	102.85 $\mu$ s	57.14 $\mu$ s
Modulation	QPSK (1/2 CTC)		
Downlink Data rate	3.17 Mbit/s	6.34 Mbit/s	12.68 Mbit/s

The WiMAX signal is synthesized by software (Agilent N7615B signal studio) and generated by a vector signal generator (Agilent ESG 4483C). Three possible bandwidths (5, 10, and 20 MHz) are considered in the transmission performance measurements.

The two generated wireless signals, UWB and WiMAX, are modulated by a MZ-EOM at quadrature bias (QB) point. Then, the joint optical signal is boosted by a EDFA (Amonics 30-B-FA) at the CO output and launched through different lengths of SSMF ( $L=5, 10, \text{ and } 25 \text{ km}$ ). Notice that these lengths correspond to the expected distances in PON access. The PMD effect associated to these SSMF lengths is negligible since the SSMF fiber used in this experiment shows a very-low PMD factor (first-order approximation) of  $0.08 \text{ ps/km}^{1/2}$ . The EDFA output level remains constant to not improve the noise introduced by EDFA. However, the total optical power level in point (3) in Fig. 2 (optical launch power over PON) is adjusted with a variable attenuator from -3 to 7 dBm to investigate the optical link performance from the customer point-of-view.

The joint signal is received at point (4) in Fig. 2. At the receiver, the state of polarization is manually adjusted by a polarization controller (PC), in order to maximize photoreceiver performance. A PIN photodetector (0.7 A/W responsivity) is used, and then the detected signal is amplified and analyzed in order to evaluate the error vector magnitude (EVM) of each wireless service. No demodulation or up-conversion stages are required with this technique. The EVM is a figure of merit for assessing the quality of digitally modulated communication signals. EVM measurements have

been performed on a digital signal analyzer (Agilent DAS 80000B) to evaluate the link degradation experienced by simultaneous wireless services distribution over the system.

#### IV. EXPERIMENTAL RESULTS

A single UWB transmission is used in order to evaluate the performance of UWB radio distribution in PON over different SSMF path distances. The implemented set-up is described in Fig. 2. In this case, only wireless service 1 is active. The UWB signal comprises two channels (generated by a Wisair DV9110 module), each channel corresponds to TFC5 and TFC6 configuration, as described in Table I. The channel bitrate is 200 Mbit/s, which is the maximum bitrate for QPSK modulation according to [6], providing an aggregated bitrate of 400 Mbit/s per user. Each channel is centered at 3.432 GHz (Ch 1) and 3.960 GHz (Ch 2), respectively.

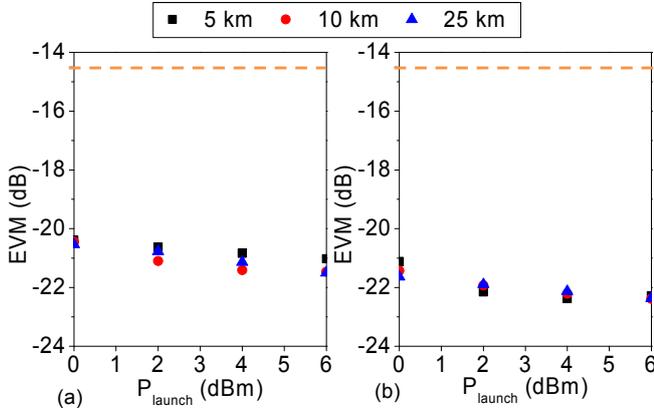


Figure 3. UWB EVM for (a) UWB Ch 1 and (b) UWB Ch 2 single transmission over PON.

The EVM results for UWB Ch 1 and Ch 2 at different optical launched power are shown at Fig. 3. The EVM threshold of -14.5 dB for successful UWB transmission is depicted with a dashed line in Fig. 3. It should be noticed that for different optical launched power the UEB EVM results indicate a soft EVM variation for the SSMF path lengths under study. These EVM results indicate that UWB single transmission over PON is feasible up to a 25 km SSMF path length.

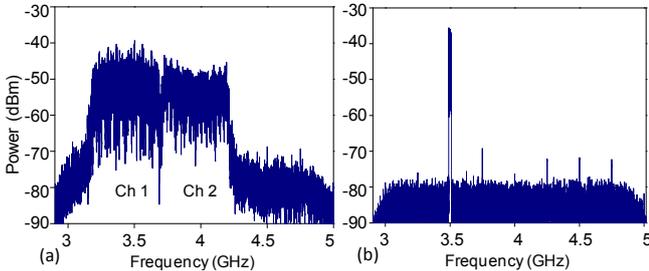


Figure 4. RF received spectrum of (a) UWB Ch 1 and Ch 2 and (b) WiMAX 20 MHz BW wireless signals distributed, measured at point (1) and (2) of Fig. 2. RBW = 1 MHz.

The simultaneous transmission has been performed in the set-up described in Fig. 2. In this case, the wireless service 1 comprises a MB-OFDM UWB signal following ECMA-368

for TFC1, TFC5 and TFC6 configuration as described in the previous section. The wireless service 2 is a IEEE 802.16e WiMAX signal, configured as described in Table II, with three different WiMAX BW in order to analyze the BW impact over the complete simultaneous optical link distribution. Two different joint distribution wireless services configurations have been implemented in order to evaluate the performance of the optical link, one comprises UWB TFC5 and TFC6, (Ch 1 and Ch 2), with WiMAX signals and the other UWB TFC1 with WiMAX signals. The RF spectrum generated by each wireless service, measured at point (1) and (2), is shown at Fig. 4.

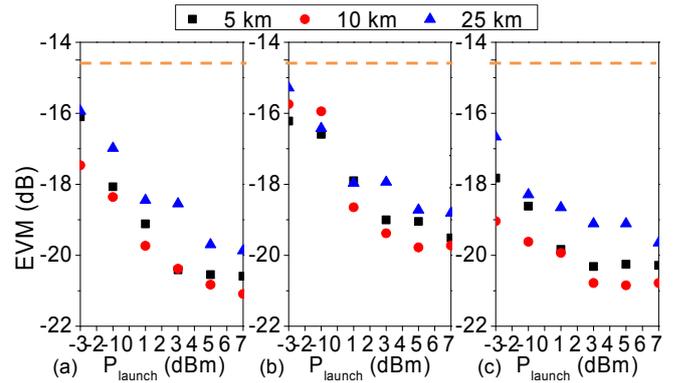


Figure 5. UWB EVM results for a WiMAX 10 MHz BW simultaneous transmission with joint UWB (a) Ch 1 and (b) Ch 2 configuration, and for single UWB (c) TFC 1 configuration.

The EVM measured in presence of WiMAX 10 MHz for UWB Ch 1 and Ch 2 configuration is shown in Fig. 5(a)(b), and for UWB TFC1 configuration in Fig. 5(c). The UWB EVM results fulfill the UWB threshold of -14.5 dB. The presence of WiMAX 10 MHz introduces an EVM penalty of 3.2 dB for a 25 km PON SSMF path distribution at 1 dBm optical launched power for double UWB channels, and 2.7 dB for TFC1 UWB configuration. The EVM results for different WiMAX BW indicates a soft EVM variation, for example UWB TFC1 EVM for 10 km SSMF at 1 dBm  $P_{\text{launch}}$  is -19.82, -19.93, -20.14 dB for 5, 10 and 20 MHz WiMAX BW, respectively.

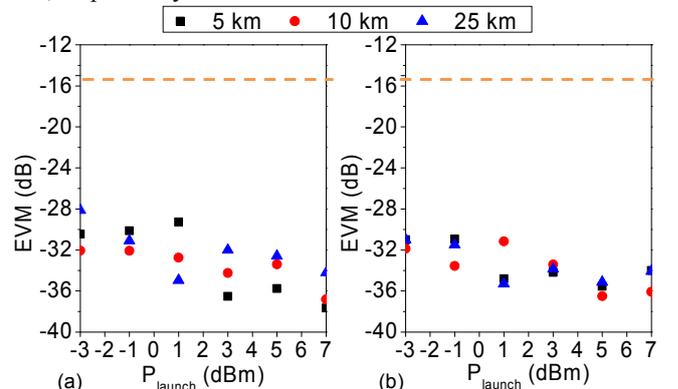


Figure 6. WiMAX EVM results for a WiMAX 10 MHz BW simultaneous transmission with (a) UWB Ch 1 and Ch 2 configuration and (b) TFC1 UWB configuration.

Fig. 6 (a) shows the EVM results for a WiMAX 10 MHz

simultaneous distribution over PON in presence of UWB Ch 1 and Ch 2 and Fig. 6 (b) in presence of UWB TFC1. The EVM threshold of -15 dB for successful WiMAX communication according to [11] is depicted in Fig. 6 as a dashed line. The WiMAX EVM threshold is accomplished up to 25 km SSMF paths, for any WiMAX BW configuration. The presence of the UWB wireless service introduces an EVM penalty of 1 or 2 dB. For example, WiMAX 20 MHz 25 km SSMF path at 1 dBm  $P_{\text{launch}}$  EVM in presence of UWB double channel is -33.45 dB, -35.22 dB without UWB.

## V. CONCLUSIONS

The experimental performance of a MB-OFDM UWB and WiMAX IEEE 802.16e converged RoF in PON distribution has been reported in this paper. The joint distribution over PON of WiMAX and UWB wireless services has been reported to be feasible up to 25 km SSMF paths. The EVM penalty for joint distribution is around 3 dB for UWB and 2 dB for WiMAX wireless service. For higher optical launched power, more than 1 dBm, the EVM measured values remain constant, which may be caused by fiber impairments related to higher optical power effects.

For future work, the spectral efficiency should be improved considering a UWB 480 Mbit/s bitrate configuration. However, this configuration follows a dual carrier modulation (DCM) scheme which requires higher linearity on the RoF distribution system than QPSK modulation [19]. Furthermore, polarization division multiplexing techniques should be considered in further research to improve the overall wireless converged RoF in PON distribution performance.

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