Ultra-Wideband Radio Signals Distribution in FTTH Networks

R. Llorente, T. Alves, M. Morant, M. Beltran, J. Perez, A. Cartaxo, and J. Marti

Abstract—The use of an ultra-wideband (UWB) radio technique is proposed as a viable solution for the distribution of high-definition audio/video content in fiber-to-the-home (FTTH) networks. The approach suitability is demonstrated by the transmission of standards-based UWB signals at 1.25 Gb/s along different FTTH fiber links with 25 km up to 60 km of standard single-mode fiber length in a laboratory experiment. Experimental results suggest that orthogonal frequency-division-multiplexed UWB signals exhibit better transmission performance in FFTH networks than impulse radio UWB signals.

Index Terms—Fiber-to-the-home (FTTH), radio-over-fiber, ultra-wideband (UWB).

I. INTRODUCTION

ULTRA-WIDEBAND (UWB) has been indicated as one of the most promising techniques to be used in wireless communication networks. The growing interest in this technique is due to its low self-interference, tolerance to multipath fading, low probability of interception, and capability of passing through walls while maintaining the communication [1]. Today, UWB is appointed for high bit-rate wireless communications at picocell range, namely as a replacement of high-definition (HD) video/audio cabling [2].

This letter proposes to extend this application to the distribution of HD audio/video content by the optical modulation and transmission of UWB signals in their native format through fiber-to-the-home (FTTH) access networks. This approach exhibits several advantages: 1) FTTH networks provide bandwidth (BW) enough to distribute a large number of UWB signals, as each one of them can occupy up to 7 GHz in current UWB regulation [3]. 2) No transmodulation is required at user premises. HD audio/video content is transmitted through the fibers in UWB native format. 3) No frequency up-conversion is required at customer premises. The UWB signals are photodetected, filtered, amplified, and radiated directly to establish the wireless connection. 4) FTTH networks are transparent to the specific UWB implementation employed. This flexibility

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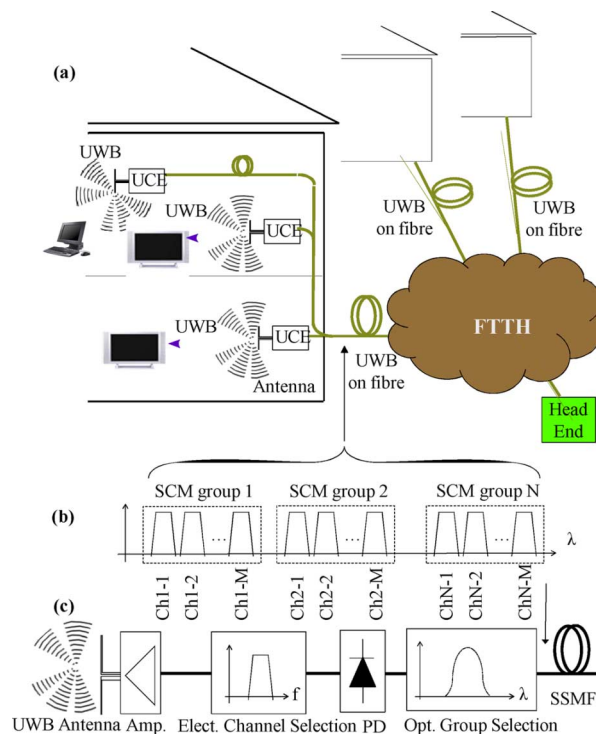
Fig. 1. (a) Concept of UWB on FTTH for distribution of HD audio/video. (b) Proposed SCM channelization. (c) Proposed UCE architecture.

is of special interest for operators as UWB regulation is still evolving.

II. FTTH DISTRIBUTION OF UWB SIGNALS

The proposed technique is depicted in Fig. 1(a). This figure shows a central node (head-end) which generates UWB signals transporting HD content. These signals are distributed through the FTTH network to a number of subscribers. At the subscriber premises, the received UWB signals are photodetected, filtered, amplified, and radiated to broadcast the HD content to a UWB-enabled television set or computer. This technique benefits from the high bit-rate capabilities of UWB, supporting bit rates up to 1 Gb/s at a few meters range [4], which can be extended to 30 m by multiple-input multiple-output processing techniques [5] covering a whole home.

UWB is defined as a radio modulation technique with 500 MHz of minimum BW or at least 20% greater than the center frequency of operation. The modulated signal must meet stringent equivalent isotropic radiated power (EIRP) limits [3] shown by the dashed line of Fig. 2, inset (b).
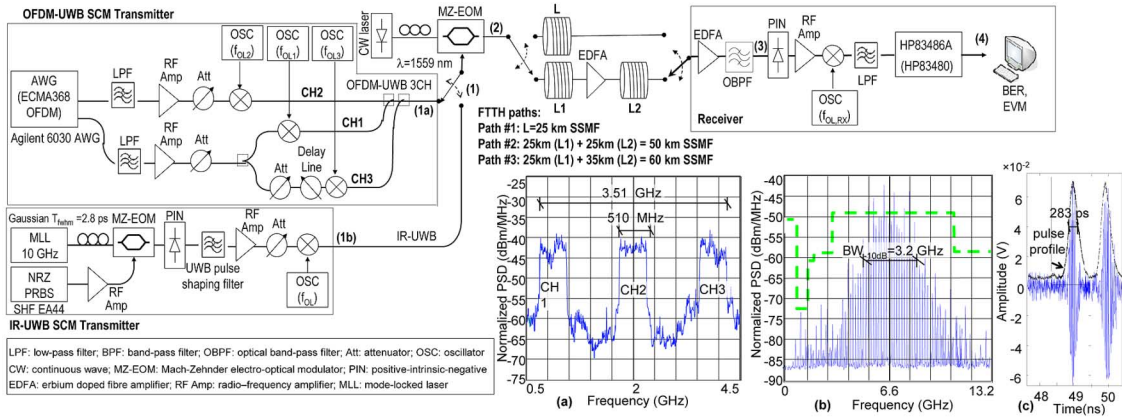
Fig. 2. UWB on FTTH demonstration setup. Both IR-UWB and OFDM-UWB signals have a total bit rate of 1.25 Gb/s. Both UWB signals are transmitted through three different FTTH paths with reach from 25 to 60 km. The receiver emulates the UCE, including down-converting and filtering. (a) OFDM-UWB electrical spectrum at point (1a) of transmitter; (b) IR-UWB RF spectrum; and (c) electrical IR-UWB signal and pulse profile at point (1b).

Two specific UWB implementations are mainstream today: impulse-radio (IR-UWB), which transmits data by short impulses (monopulses), and orthogonal frequency-division multiplexing (OFDM-UWB), which divides the UWB spectrum into 14 channels of 528-MHz BW. Each channel contains an OFDM signal comprising 128 carriers binary or quaternary phase-shift keying (QPSK) modulated.

Fig. 1(b) shows the subcarrier-multiplexing (SCM) channelization proposed for the FTTH transmission. The channelization consists of several 528-MHz-wide channels (each one in accordance with [3]) forming an SCM group which modulates an optical carrier. Different optical carriers can be wavelength-division multiplexed to increase the number of UWB channels delivered by each fiber of the FTTH network. Each UWB channel bears one HD audio/video stream, which is extracted at the customer premises by a UWB channel extractor (UCE). Fig. 1(c) shows the proposed architecture for the UCE. Operation is as follows. A given SCM group is first selected by optical filtering, and then the group is photodetected and filtered in the electrical domain to select the specific UWB channel transporting the desired HD contents. The selected UWB channel is then amplified and radiated. The proposed UCE architecture does not require demodulation or frequency translation of the UWB signal, and is transparent to the specific modulation employed. Other UCE architectures can be used, but their analysis is out of the scope of this letter.

III. EXPERIMENTAL SETUP AND RESULTS

In this section, the suitability of the proposed UWB-on-FTTH technique for HD content distribution is evaluated. We analyze the signal degradation due to the fiber transmission impairments experienced in the FTTH link.

Fig. 2 shows the experimental setup to evaluate the UWB signal degradation due to fiber transmission. The two UWB versions are implemented for performance comparison: IR-UWB and OFDM-UWB as in current regulation [6]. The UWB signal bit rate is 1.25 Gb/s in both cases, adequate for the transmission of $1920 \times 1080\,\mathrm{i} \times 18\,\mathrm{bpp} \times 60$ Hz uncompressed video [7]. The UWB signals are transmitted along different standard single-mode fiber (SSMF) links, ranging from 25 to 60 km corresponding to conventional FTTH transmission paths. The OFDM-UWB transmitter consists in three OFDM

channels with an aggregated bit rate of 1.25 Gb/s, forming an SCM group. Each OFDM channel has 128 carriers, each QPSK-modulated, including pilots. Separation between carriers is 4.11 MHz. The channel under study (labeled CH2 in Fig. 2) is located at $f_{OL2} = 2.5$ GHz and is surrounded by two adjacent channels centered at frequencies $f_{OL1} = 1$ GHz and $f_{OL3} = 4$ GHz. The BW at −10 dB of the OFDM-UWB SCM group is 3.51 GHz [see Fig. 2, inset (a)]. The average optical power after modulation and before transmission (point (2) in Fig. 2) is −2 dBm. The three OFDM channels are generated by an AWG6030 arbitrary waveform generator at 1.25 Gsamples/s. The IR-UWB signal is generated as shown in Fig. 2, in accordance with the FCC UWB spectral mask between 3.1 and 10.6 GHz. The IR-UWB monopulses are obtained from a 10-GHz Gaussian pulse ($T_{fwhm} = 2.8$ ps) train generated by a mode-locked laser. The pulse train is gated by a Mach–Zehnder electrooptical modulator (MZ-EOM) with 1.25-Gb/s pseudorandom binary sequence data. The gated optical pulses are photodetected, shaped to monopulses with $T_{fwhm} = 283$ ps by a pulse-shaping filter and up-converted to $f_{OL} = 6.6$ GHz for fiber transmission. The overall −10-dB BW of IR-UWB signal is 3.2 GHz [see Fig. 2, inset (b)] and occupies the band from 5 to 8.2 GHz, following actual UWB regulation [3]. The average optical power at point (2) in Fig. 2 is adjusted to −2 dBm.

The two UWB versions modulate a 20-GHz BW MZ-EOM at quadrature-bias point and are transmitted through the three FTTH paths shown in Fig. 2. After transmission, the signals are filtered by a 0.8 nm at −0.5-dB optical filter (SCM group selection) and photodetected by a PIN photodiode (0.65 A/W, 50-GHz BW) as in the UCE architecture proposed in Fig. 1(c). In order to evaluate the performance of the UWB channel under study, the photodetected signal is converted to baseband and sampled by an HP83486A module (20-GHz BW). Performance is evaluated with received optical power ranging 0–10 dBm at the photodiode. These levels translate to −51.8 to −31 dBm/MHz (50 Ω) power spectral density over the 3.2-GHz BW. These values would meet the wireless EIRP limits [3] employing a 0-dBi antenna. In the OFDM-UWB case, after sampling the received channel, the channel under study is equalized from pilot information, demodulated and the error vector magnitude (EVM) is measured. Bit-error ratio (BER) is calculated as BER $= Q(1/\text{EVM})$
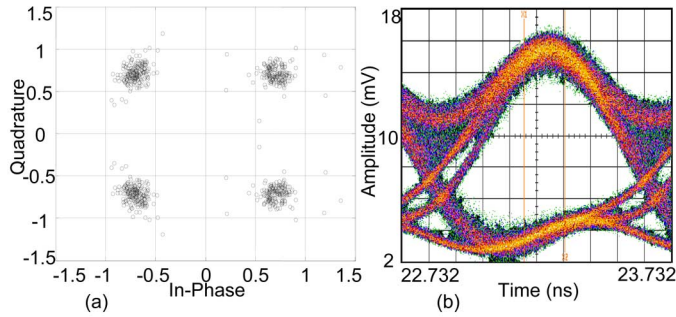
Fig. 3. (a) Received OFDM-UWB (QPSK carriers) constellation (784 symbols shown) after pilot compensation, at point (4) of Fig. 2. Aggregated bit rate 1.25 Gb/s. (b) IR-UWB received eye diagram, at point (4) in Fig. 2.
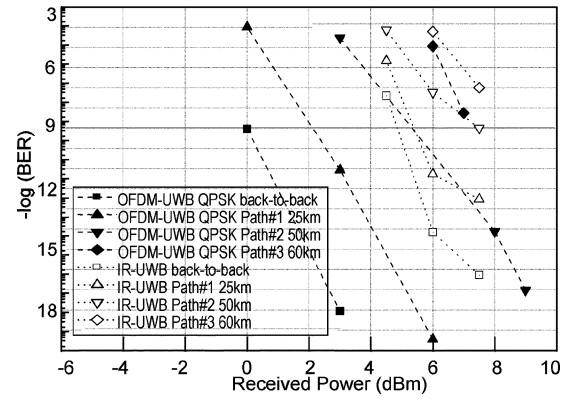

Fig. 4. Comparison of UWB implementations at 1.25 Gb/s for the three FTTH SSMF paths. Dotted lines: OFDM-UWB three channels SCM group (QPSK per carrier); dashed lines: IR-UWB signal. OFDM-UWB signal achieves better performance at same received power for all FTTH paths.

[8]. In the IR-UWB cases, the monopulses are demodulated, low-pass filtered, and the Q-factor is measured by the HP83480 instrument in Fig. 2. Under Gaussian noise assumption, BER is given by BER $= 0.5 \times \mathrm{erfc}(Q/\sqrt{2})$. The measurements have been done in back-to-back and for three FTTH transmission paths: Path#1 $=$ 25 km SSMF, Path#2 $=$ 25 km SSMF $+$ amplification $+$ 25 km SSMF (50-km reach), and Path#3 $=$ 25 km SSMF $+$ amplification $+$ 35 km SSMF (60-km reach). These paths are depicted in Fig. 2. Inline amplification is realized by a 23-dB gain, 4-dB noise figure erbium-doped fiber amplifier (EDFA) (Keopsys BT2C-13). The receiver includes a 4.5-dB noise figure, 19-dBm saturation power EDFA (Exelite SFA-19).

Fig. 3(a) shows the OFDM-UWB received constellation after equalization employing pilot tones information, at point (4) of Fig. 2. Fig. 3(b) shows the IR-UWB received eye diagram, at point (4) of Fig. 2. The constellation and eye diagram shown in Fig. 3 are obtained at point (3), at 9-dBm received power and after 50-km transmission on SSMF. Fig. 3 shows that the received signal presents good quality for both IR-UWB and OFDM-UWB signals; therefore, good performance is expected for both UWB implementations.

The BER achieved by OFDM-UWB and IR-UWB are shown in Fig. 4 for all the FTTH paths between 25 and 60 km and back-to-back versus the received power, measured at point (3) in Fig. 2. These experimental results demonstrate the feasible distribution of 1.25-Gb/s UWB signals achieving BER $< 10^{-9}$ operation at 50 km with both IR-UWB and OFDM-UWB implementations. Fig. 4 shows that the IR-UWB technique exhibits a performance degradation compared to the OFDM-UWB. This is due to the different modulation schemes. OFDM-UWB channels are generated independently and up-converted to generate an SCM group. The IR-UWB signal does not follow this channelization, and to provide a bit rate of 1.25 Gb/s, a single IR-UWB signal with 3.2-GHz BW at -10 dB was generated. IR-UWB suffers from the nonperfect operation of up- and down-converting mixers over such wide BW. Fig. 4 also shows that OFDM-UWB degrades quickly with fiber length. We believe this is due to the carrier suppression effect originated from the SSMF chromatic dispersion [9].

The BW occupied by the three channels in OFDM-UWB (3.51 GHz), that ensures the accumulated bit rate of 1.25 Gb/s, leads to an equivalent spectral efficiency of 0.36 b/s/Hz. The IR-UWB BW (3.2 GHz) for the same bit rate gives a spectral efficiency of 0.39 b/s/Hz. This similar spectral efficiency combined with the improved performance obtained for OFDM-UWB suggests that the UWB-over-fiber implementation should be accomplished with OFDM signals.

IV. CONCLUSION

The distribution of IR-UWB and OFDM-UWB signals in FTTH networks for HD audio/video broadcasting has been proposed and experimentally demonstrated. Experimental results suggest that OFDM-UWB signals show better transmission performance than IR-UWB signals, although other detection techniques could lead to different results. Optimization of the generation schemes of each one of UWB flavors will provide a thorough conclusion. An improved spectral efficiency can still be achieved in IR-UWB and OFDM-UWB through generating monopulses with a narrower BW and reducing of the channel spacing, respectively.

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