Bidirectional transmission of WiMedia-compliant UWB over 100m perfluorinated graded-index plastic optical fiber

Citation for published version (APA):

Okonkwo, C. M., Yang, H., Shi, Y., Alemany, R., Sambaraju, R., Herrera, J., Koonen, A. M. J., & Tangdiongga, E. (2011). Bidirectional transmission of WiMedia-compliant UWB over 100m perfluorinated graded-index plastic optical fiber. *IEEE Photonics Technology Letters*, 23(14), 995-997. <https://doi.org/10.1109/LPT.2011.2144966>

DOI:

[10.1109/LPT.2011.2144966](https://doi.org/10.1109/LPT.2011.2144966)

Document status and date:

Published: 01/01/2011

Document Version:

Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
- The final author version and the galley proof are versions of the publication after peer review.
- The final published version features the final layout of the paper including the volume, issue and page numbers.

[Link to publication](#)

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license above, please follow below link for the End User Agreement:

www.tue.nl/taverne

Take down policy

If you believe that this document breaches copyright please contact us at:

openaccess@tue.nl

providing details and we will investigate your claim.

Bidirectional Transmission of WiMedia-Compliant UWB Over 100-m Perfluorinated Graded-Index Plastic Optical Fiber

C. M. Okonkwo, *Member, IEEE*, H. Yang, *Student Member, IEEE*, Y. Shi, *Student Member, IEEE*, R. Alemany, R. Sambaraju, *Student Member, IEEE*, Jaherllo Herrera Llorente, *Member, IEEE*, A. M. J. Koonen, *Fellow, IEEE*, and E. Tangdionga, *Member, IEEE*

Abstract—We present the first experimental demonstration of full-duplex, bidirectional transmission of WiMedia-compliant ultra-wideband (UWB) signals at 200 Mb/s over 100-m perfluorinated graded-index plastic optical fiber (POF) with 50- μm core diameter. Error vector magnitude penalties of 1.2 dB and 2.1 dB are achieved for up- and downlink transmission, respectively.

Index Terms—Access networks, in-home communication, optical fiber communications, ultra-wideband (UWB) communication.

I. INTRODUCTION

THE growth of ultra-wideband (UWB) radio for personal area networks (PAN) is mainly attributed to its robustness and spectrum efficiency allowing coexistence with other radio signals whilst providing high data-rates up to 480 Mb/s. However, a significant shortcoming of UWB is the federal communications commission (FCC) regulated power spectral density (PSD), which restricts the transmission range typically to 10 m or less [1]. Therefore, for the purpose of extending the range of UWB radio signals whilst reducing the complexity of the architecture required for distributed antenna systems, the benefits of radio-over-fiber (RoF) techniques for in-building/home networks are gaining momentum.

Recently, several scenarios have been presented for UWB-over-fiber transmission including a half-duplex, bidirectional transmission system over single-mode fiber [2].

However, for short-range in-building infrastructures, plastic optical fibers are more attractive than silica single/multi-mode fibers due to ease of installation and maintenance, less stringent alignment tolerances and smaller bending radius (< 5 mm). Hence, further developments in this direction have led to the

demonstration of multiband orthogonal frequency division multiplex (MB-OFDM) UWB signals transmission over 62- μm core diameter perfluorinated (PF) graded-index plastic optical fiber (GI-POF) [3].

Full duplex and bidirectional transmission of UWB signals have not been realized using plastic optical fibers. Therefore, an in-building/home network architecture using directly modulated lasers and direct detection transmission system over a single fiber is an attractive solution for easy implementation. The in-home installer does not require knowledge of uplink/downlink fiber as in the case of dual fiber installations.

This letter presents the first demonstration of bidirectional transmission of WiMedia-compliant MB-OFDM UWB signals over a single 100 m PF GI-POF with 50 μm core diameter. An error vector magnitude (EVM) penalty of 1.2 and 2.1 dB is achieved for the downlink and uplink respectively. This letter is organized as follows: the format for MB-OFDM format is discussed in Section II and the experimental setup to represent the in-building network architecture is presented. The experimental results obtained are discussed in Section III. Finally, the letter is concluded in Section IV.

II. EXPERIMENTAL SETUP

Fig. 1 illustrates the experimental setup for the in-building network scenario. The residential gateway transmits the UWB signal via the POF link to the UWB transceiver at the remote site. At the remote site, UWB signals can be transmitted and received wirelessly from the mobile ONU, which is not shown. The UWB signal generated at the residential gateway (RG) uses an off-the-shelf UWB transceiver (UWB module from Wisair). The format for the UWB signal is based on OFDM employed to combat the effects of multipath fading in the wireless channel. Each OFDM symbol is composed of 128 orthogonal subcarriers spaced by 4.125 MHz. Although the FCC UWB spectral mask ranges between 3.1 and 10.6 GHz, in this work we use UWB bands centered at 3.432 and 4.488 GHz. Each UWB band occupies 528 MHz. The PSD is limited to -41.3 dBm/MHz in order to comply with the FCC spectral mask for air transmission.

For the downlink, the MB-OFDM data is at the time-frequency code 5 (TFC 5), meaning that the transmitter only sends one subband data at the centre frequency of 3.432 GHz corresponding to band group 1, subband 1. After an electrical power amplifier, the signal is used to directly intensity-modulate a distributed feedback (DFB) laser at 1302.56 nm with a bias current

Manuscript received July 23, 2010; revised March 03, 2011; accepted April 02, 2011. Date of publication April 21, 2011; date of current version July 01, 2011. This work was supported by the EU program FP7 ICT 224402 EURO-FOS and ICT-212352 ALPHA.

C. M. Okonkwo, H. Yang, Y. Shi, A. M. J. Koonen, and E. Tangdionga are with the COBRA Research Institute, Eindhoven University of Technology, Electro-Optical Communications, 5600MB Eindhoven, The Netherlands (e-mail: c.m.okonkwo@tue.nl; h.yang1@tue.nl; y.shi@tue.nl; a.m.j.koonen@tue.nl; e.tangdionga@tue.nl).

R. Alemany, R. Sambaraju, and J. Herrera Llorente are with Universidad Politécnica de Valencia, Camino de Vera 46020, Valencia, Spain (e-mail: jaherllo@nte.upv.es).

Color versions of one or more of the figures in this letter are available online at <http://ieeexplore.ieee.org>.

Digital Object Identifier 10.1109/LPT.2011.2144966

Fig. 1. Concept and experimental diagram (Downlink: MB-OFDM UWB TFC5, Uplink: TFC7).

in the linear regime at 50 mA. This results in 70 mA peak-to-peak modulations wing of the DFB laser. The laser bandwidth is large enough for the transmission of MB-OFDM UWB signals over PF GI-POF.

The transmitted signal is launched via a multimode optical circulator (OC₁) into the POF with an optical power of -2 dBm. After transmitting the signal over $\varnothing 50 \mu\text{m}$ POF of 100 m, a $25 \mu\text{m}^2$ active area multimode photo-detector with a responsivity of 0.8 A/W was used to directly detect the signal. The received signal is electrically amplified with a gain of 19 dB before being sent via two electrical circulators (loss = 0.4 dB and isolation = 18 dB) to a real-time oscilloscope (DPO) running at a sampling rate of 25 GSamples/s for accurate WiMedia compliance evaluation.

For bidirectional transmission, the electrical circulator (EC₁) enables the simultaneous transmission of the uplink (and downlink) UWB signal at TFC-7 with centre frequency of 4.488 GHz chosen to minimize interference at the receiver for measurement. Note that for full implementation, the use of only one TFC is recommended for both upstream and downstream to simplify the UWB signal receivers. The uplink signal is injected at port 1 of the second electrical circulator (EC₂), and propagates through port 2 to electrical circulator 1 (EC₁). At port 3 of EC₁, the signal is electrically amplified and used to modulate the uplink DFB laser running at the same wavelength of 1302.56 nm . Note that a fixed transmission rate of 200 Mb/s is used for both directions. After transmission over the same 100 m POF link, the signal is received at the RG for evaluation. Unfortunately, it was not possible to operate at the full UWB rate of 480 Mb/s using the current UWB transceiver prototype. We believe that the proposed scheme is scalable to accommodate the full UWB transmission rate.

III. RESULTS AND DISCUSSION

The compliance of the received signals for both directions with the FCC spectral mask was measured. Figs. 2 and 3 shows the power spectral density and spectrograms obtained using a real-time oscilloscope (Tektronix DPO72004). In Fig. 2, the crosstalk in the downlink appears to be more severe due to the interference between uplink and downlink signals at the electrical circulator (EC₂) near the UWB transceiver at the remote site. Due to the isolation of the circulator, this crosstalk appears because of leakage at port 1 to port 3 of EC₂ which is used

Fig. 2. (top) Downlink power spectral density; (bottom) downlink measurements spectrogram.

Fig. 3. Uplink Measurements: Power spectral density (top) and spectrogram (bottom).

only for monitoring purposes. The crosstalk does not impair the transmission in the system.

Fig. 4. EVM performance measurement for upstream and downstream links back-to-back and after 100-m POF.

The coexistence of the two bands centered at 3.432 and 4.488 GHz at the same time indicates crosstalk. Despite the detected crosstalk, the downlink signal passes the FCC spectral mask requirements for air transmission with a power of -47.7 dBm.

With both uplink and downlink signals transmitted simultaneously, Fig. 4 shows the measured EVM values of the received UWB-OFDM subband.

In the best case, the EVM value for downlink back-to-back is 7.3% (-22.7 dB) for a received optical power of -3 dBm. After 100 m POF transmission, the penalty is negligible indicating excellent performance. For the worst case (i.e., at receiver optical power of -8 dBm), the EVM for the back-to-back case is 9.4% (-20.9 dB).

After 100 m transmission with the same received optical power, the measured EVM is 10.4% (-19.7 dB), indicating a penalty of 1.2 dB. For the worst-case in the uplink direction, the minimum received optical power is -7 dBm with the EVM of 11.8% (-18.6 dB). Note that compared to the back-to-back EVM of 9.2% (-20.7 dB), the uplink direction experienced a penalty of 2.1 dB. The crosstalk does not impair the transmission in the system.

The higher penalty obtained for the uplink is attributed to the lower modulation swing for the directly modulated laser due to the losses at the electrical circulators. Note that the standard EVM requirement for WiMedia compliance is 15% (-16 dB), and all measurement results obtained are well below this requirement. The demodulated signals for downlink and uplink are shown in Figs. 5 and 6. The benefits of MB-OFDM are such that although some subcarrier indices have higher than the average EVM, the overall system performance still meets the required standards. The constellation diagrams of Fig. 5 (lower) and Fig. 6 (lower) show clear separation between the points of the demodulated QPSK signals. Both figures indicate good performance for either direction during simultaneous transmission.

IV. CONCLUSION

For the first time, bidirectional transmission of WiMedia-compliant MB-OFDM UWB over a single PF GI-POF link is

Fig. 5. EVM (dB) of demodulated MB-OFDM UWB subcarriers with corresponding constellation diagrams for downlink transmission over 100-m POF.

Fig. 6. EVM (dB) of demodulated MB-OFDM UWB subcarriers with corresponding constellation diagrams for uplink transmission over 100-m POF.

reported. This scheme enables ease of installation without prior knowledge of the transmission direction. Using off-the shelf UWB modules, good performance across all subcarriers allows simultaneous transmission of uplink and downlink signals with low EVM penalties. Overall system penalties of 1.2 dB and 2.1 dB have been measured for downlink and uplink 100 m POF transmission respectively, indicating that with adequate margin, extending the reach of UWB wireless signals in a low-cost in-building/home infrastructure employing PF GI-POF is feasible.

REFERENCES

- [1] G. Heidari, *WiMedia UWB: Technology of Choice for Wireless UWB and Bluetooth*. Hoboken, NJ: Wiley, 2008, ISBN: 0470518340.
- [2] M. P. Thakur, T. Quinlan, S. Dundley, M. Toyman, C. Bock, S. D. Walker, D. W. Smith, A. Borghesani, D. Moodie, R. Lorente, M. Ran, and Y. Ben-Ezra, "Bi-directional, 480 Mbps, ultra-wideband, radio-over-fibre transmission using a 1310/1564 nm reflective electro-absorption transducer and commercially-available components," in *Proc. ECOC'08*, 2008, pp. 1–2, Paper Tu.4.F.4.
- [3] C. Lethien, C. Loyez, J.-P. Vilcot, L. Clavier, M. Bocquet, and P. A. Rolland, "Indoor coverage improvement of MB-OFDM UWB signals with radio over POF system," *Opt. Commun.*, vol. 282, no. 24, pp. 4706–4715, 2009.