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*Published in:*

35th European Conference on Optical Communication, 2009. ECOC '09.

*Publication date:*

2009

*Document Version*

Publisher's PDF, also known as Version of record

[Link back to DTU Orbit](#)

*Citation (APA):*

Prince, K., Osadchiy, A. V., & Tafur Monroy, I. (2009). WiMAX radio-on-fibre in 118-km long-reach PON with deployed fibre. In *35th European Conference on Optical Communication, 2009. ECOC '09.* (pp. 1-2). IEEE.

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# WiMAX Radio-on-Fibre in 118-km Long-Reach PON with Deployed Fibre

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**Abstract** We demonstrate a radio over fibre link supporting 256-QAM / 12 Mbaud WiMAX signalling over 118-km long-reach PON with deployed fibre. Our colourless implementation uses commercially-available, low-complexity devices typically used in TDM-PON or WDM-PON.

## Introduction

Long-reach optical access networks are being developed as a means of providing increased user access speeds while simultaneously reducing the number of operator network points of presence. Such so-called “Super-PON” access networks are anticipated to provide current access speeds at link lengths exceeding 100-km<sup>1,2</sup>. Continued development of converged access networks must therefore integrate long-reach access, while preserving all the other advantages currently being exploited in shorter-reach radio-over-fibre (RoF) implementations<sup>3</sup>.

We demonstrate transmission of single-carrier WiMAX-compliant<sup>4</sup> 64-QAM and 256-QAM signals over a long-reach PON with 118 km optical transmission length. This link integrated 78 km of deployed optical fibre (DF), installed within metropolitan Copenhagen. We also included 500 m of bend-insensitive fibre, used for in-home signal distribution and an air transmission link. This is the first known demonstration of WiMAX signalling over a long-reach PON, and marks significant progress towards converged fixed and wireless access over a common optical infrastructure.

## Experiment Description

System layout and sample constellations are presented in Fig. 1. Dispersion was pre-compensated at the central office (CO); we implemented optical pre-amplification at remote node (RN) for low customer premises equipment (CPE) complexity.

The CW laser at the CO provided +8 dBm optical power at 1549.3 nm: with the EAM biased for linear operation, 20 dB of optical amplification was implemented after the EAM to maintain 0 dBm average optical launch power into the deployed fibre. The DCF was optimised for 80 km SMF: we implemented 78 km of deployed standard SMF between CO and RN. A 35 dB gain low-noise WDM preamp EDFA at the RN was cascaded with a 15 dB single-channel EDFA preamp to maintain -5 dBm average power into the 10 GHz PIN photodiode (PD) at the CPE. Additional access fibre was used between the RN and CPE: this was implemented with, 40 km SMF (17 ps/nm.km) and an additional 500 m of bend-insensitive single-mode optical fibre (BIF). Colourless optical transceivers (40 GHz EAM and 10 GHz PIN PD were used) and the AWG allow operation of this system in a long-reach WDM-PON

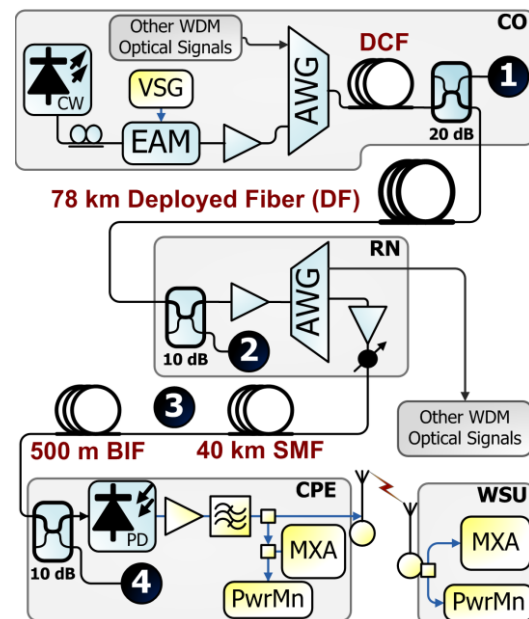


Fig. 1: WiMAX RoF on 118-km PON with wireless link between CPE and wireless subscriber unit (WSU).

A 5.8 GHz WiMAX radiofrequency (RF) signal from an Agilent E4438C vector signal generator (VSG) allowed operation in the unlicensed ISM band. A pseudo-noise PN11 data sequence modulated the RF carrier at 64-QAM (at 15 Mbaud, for 90 Mbps) and 256-QAM (at 12 Mbaud). Air transmission (at 40 cm) was implemented with omni-directional 12 dBi antennas. Signal quality at CPE and WSU was evaluated with an Agilent N9020A MXA signal analyzer (MXA) using the RMS error vector magnitude (EVM) metric evaluated over 4096 transmitted symbols. A 35 dB gain low-noise amplifier was implemented between PD and antenna to overcome the attenuation of the optical link and provide adequate signal for air transmission. RF power meters (PwrMn) and ISM band RF filters were used to ensure compliance of the 5.8 GHz ISM band link between CPE and WSU. Test points indicated in Fig. 1 allowed monitoring of signal quality; we report results obtained at points 1, 3 and 4 and at the WSU.

## Results

Optical signal quality at the CO and CPE was assessed as a function of the source RF power. The results for 64-QAM/15 Mbaud are presented in Fig. 2. The inset indicates a sample of the constellation

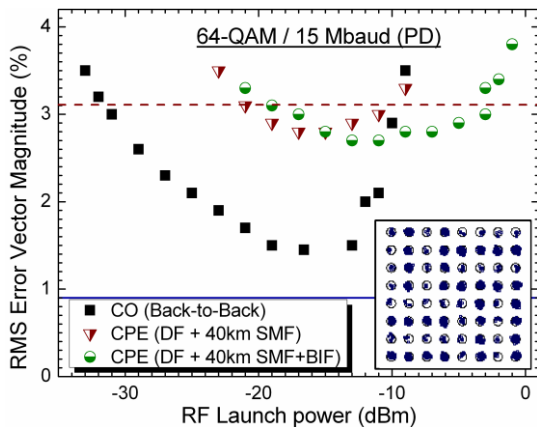


Fig. 2: 64-QAM EVM vs. RF launch power: at CO and CPE (Point3 and Point 4). Sample constellation (inset)

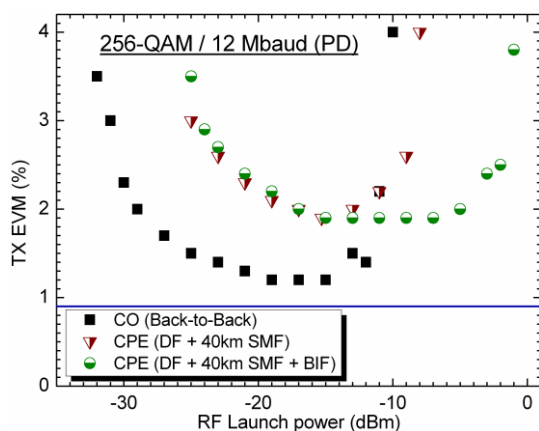


Fig. 3: 256-QAM EVM vs. RF launch power at CO, and CPE (at Point 3 and Point 4).

obtained at the CO after optical transmission through the SMF and BIF (point 4). We observed a clear constellation, and also clear open eye diagram results (not shown). The EVM threshold<sup>4</sup> for 64-QAM WiMAX signal is 3.1%; this is indicated by the dashed (red) horizontal line: our configuration satisfied this target with input power in the range [-19,-11] dBm. We measured 0.9% EVM at the EAM input, indicated by the solid (blue) horizontal line. Optical back-to-back performance had 0.6% EVM degradation; the optical transmission EVM penalty was below 1.9%.

We assessed system performance with 256-QAM/12 Mbaud and present the results in Fig. 3; the solid (blue) line indicates the 0.9% EVM floor obtained at the EAM input. The WiMAX spec<sup>4</sup> does not mandate EVM limits for 256-QAM, we noted EVM below 3.1 % in the source power range [-24, -11] dBm. Total EVM penalty through the system (point 4) is 1%.

Both Fig. 2 and Fig. 3 indicate that higher RF power is required with BIF than for either the Back-to-Back (point 1) or after the 40 km SMF (point 3); this is consistent across the modulation formats assessed.

The optical access link between RN and CPE was not dispersion-compensated, residual dispersion could perhaps account for the 1.8% and 0.8% EVM penalty observed after the link for 64-QAM and 256-

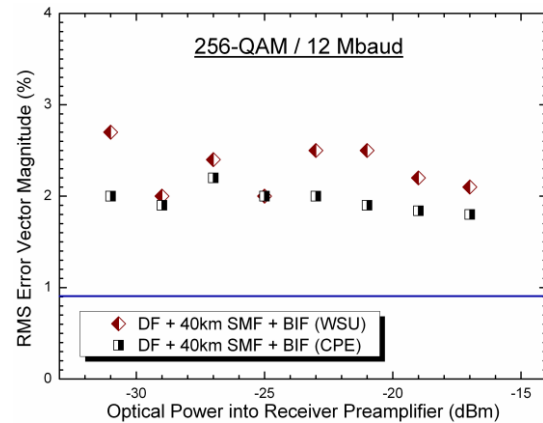


Fig. 4: 256-QAM EVM sensitivity to preamplifier optical power, at CPE and WSU. Constellation at CPE (inset)

QAM transmission, respectively. Future work is planned to investigate the potential for improved performance with optimised dispersion management, as well as the performance with an active WDM PON.

System sensitivity to optical power into the receiver preamplifier was assessed directly at the PD output, and after a 40 cm air link. These results are presented in Fig. 4. We observed that the EVM at the CPE varies by less than 0.5% within the optical input power range assessed, i.e. [-31,-16] dBm. Further reduction of the optical input power below this level caused the preamp output to fall below -5 dBm. Sample results after air transmission indicated typical wireless transmission phenomena; our system may directly replace traditional RF distribution schemes, using a simple low-complexity CPE.

**Conclusions**

We have demonstrated a radio-over-fibre system for long-reach access with a 118 km long optical link incorporating 78 km of deployed SMF, 40 km of additional SMF and 500 m of BIF. Commonly-available 10 GHz PD allowed single-channel WiMAX-compliant transmission of QAM modulated RF: results indicate 7 dB dynamic range for 64-QAM signals at 15 Mbaud and 13 dB range for 256-QAM signals at 12 Mbaud. Less than 0.5 % EVM variation was observed within a 15 dBm optical power variation into the preamplifier at the RN, indicating that this system may also tolerate longer-length PON spans.

**Acknowledgements**

Thanks to Agilent Technologies Denmark, and GlobalConnect Denmark for equipment and deployed fibre used. K. Prince acknowledges a scholarship from the Danish Ministry of Science, Technology & Innovation. Work was partly funded by ICT GigaWaM.

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