Experimental Assessment of 5-10Gbps 5G Multicarrier Waveforms with Intensity-Modulation Direct-Detection for PONs

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Abstract—**The sensitivity performance of an IMDD-OFDM/FBMC/UFMC/GFDM system with a PIN based receiver is experimentally evaluated for downstream in broadband passive optical networks. Results show sensitivities better than -14.5(-8.0)dBm over 50km of SSMF at 5(10)Gbps**

Keywords—OFDM, UFMC, FBMC, GFDM, IMDD

I. Introduction

The telecommunication scenario has been rapidly and dramatically changing in the last years. New multimedia and cloud services, the deployment of the "Internet of Things" and the convergence between optical and wireless communications at the 5G paradigm [1, 2] are requiring changes to the access networks in order to enable scalable growth in traffic volume, while supporting a high level of dynamic connectivity, full flexibility and increased energy-efficiency. In this context, orthogonal frequency division multiplexing (OFDM) has been extensively explored as a potential candidate for future next generation of passive optical networks (PONs) ought to the fact that it brings about numerous benefits, such as high spectral efficiency, high resilience to chromatic dispersion, and efficient/flexible resource management [3]. Nevertheless, the main drawback of OFDM in multi-user environments such as PONs is the multiple access interference (MAI) on the performance of the upstream channel due to its high out-of-band radiation. In order to overcome that problem, filter-bank based multi-carrier (FBMC), generalized frequency division multiplexing (GFDM) and universal filtered multicarrier (UFMC), all of them considered as new 5G multicarrier waveforms, have recently been proposed as future candidate technologies for replacing OFDM [4].

In this paper, using intensity-modulation direct detection (IMDD) for being the simplest and, hence, the most cost-effective solution to implement, we assess and compare OFDM, FBMC, GFDM and UFMC system performance in terms of the sensitivity of a PIN-based receiver for different data rates (R_b) and distances. Specifically, 4/16-quadrature amplitude modulation (4/16-QAM) formats combined with OFDM, FBMC, GFDM and UFMC providing transmission data rates of 5Gbps and 10Gbps, respectively, have been evaluated for downstream applications in PONs. As reference cases, on-off keying (OOK) and 4 pulse-amplitude modulation (4-PAM), which could be considered as straightforward modulation formats for IMDD PONs, have been also benchmarked.

II. Experimental setup

The experimental setup is depicted in Fig. 1. The optical line terminal transmitter (OLT-TX) is based on an external cavity, 100kHz linewidth, tunable laser source (TLS), modulated by a Mach-Zehnder modulator (MZM). The MZM is biased at its quadrature point and thermally controlled to ensure its stability. The OLT-TX uses a digital transmitter (DTX) where a total of 2^{18} bits are randomly generated and modulated into OOK, 4-PAM and 4/16-QAM formats. In the case of 4/16-QAM, the obtained symbols are digitally modulated according to OFDM, UFMC, FBMC and GFDM modulation schemes [4] with 256 sub-carriers. The sub-bands number for UFMC is 32 with 8 sub-carriers each one that are filtered using a Dolph-Chebyshev filter with a length of 43. A PHYDYAS filter with an overlapping symbol factor, K, of 4 has been used for FBMC. Finally, a root raised cosine (RRC) filter with a roll-off factor, α, equal to 0.5 has been considered for GFDM, defining a number of overlapping subcarriers of 2. No cyclic prefix is added to OFDM or GFDM. In order to adapt the obtained complex signals to real ones for direct detection in amplitude, juxtaposing technique in time domain of the obtained complex components is used. This technique consists on splitting the complex output into real and imaginary parts and sending one after the other.

The modulated signals are digital-to-analogue converted using a 4GHz-bandwidth arbitrary waveform generator (AWG) at a sample rate of 5GSa/s, obtaining the electrical base-band spectrums shown in Fig. 1(a)-(e). To exhaust the MZM dynamic range, electrical amplification is used. The modulated optical signal is amplified to obtain 0dBm at OLT-TX's output by an erbium-doped fiber optical amplifier (EDFA). The optical signal-to-noise ratio (OSNR) is then of 41dB. So, to reduce the amplified spontaneous emission noise over the optical signal, it is filtered using a 100GHz bandpass optical filter centered at the transmitted wavelength of 1545nm. The optical signal is launched into 25km/50km of standard single-mode fibre (SSMF). The optical network unit receiver (ONU-RX) is based on single PIN photodetector combined with an electrical amplifier. The detected signal is then digitalized with a 25GSa/s real time oscilloscope (MSO-70804C) with 8GHz of bandwidth to be processed off-line. The first step in the digital receiver (DRX) is the low pass filtering of the digitalized signal with a FIR filter so as to reduce the noise. The filtered signal is

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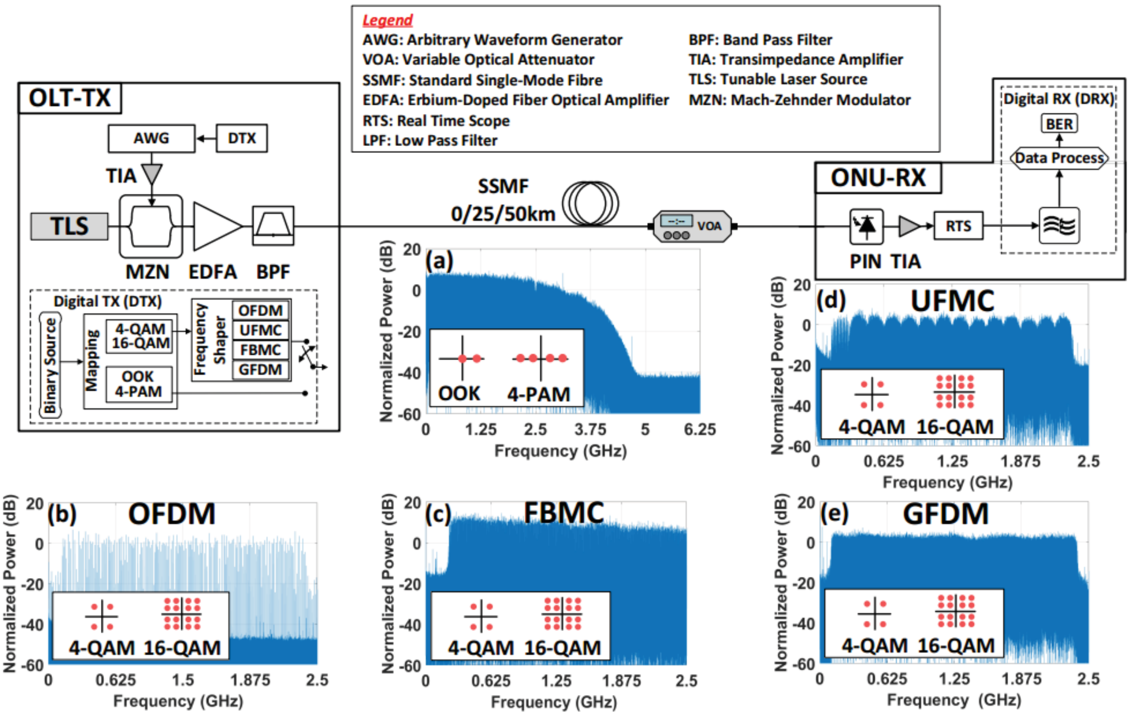

Fig. 1: Experimental setup. Measured electrical base-band spectra at the transmitter using (a) OOK/4-PAM, (b) 4/16-QAM OFDM, (c) 4/16-QAM FBMC, (d) 4/16-QAM UFMC and (e) 4/16-QAM GFDM modulation formats.

now digitally demodulated according to the received signal format [4].

III. Results

We study the IMDD system performance with the PIN-based receiver for 4/16-QAM modulation formats combined with OFDM, FBMC, UFMC and GFDM delivering transmission data rates of 5Gbps and 10Gbps, respectively. As reference cases, 5Gbps OOK and 10Gbps 4-PAM have been considered as well. In particular, the system performance has been measured in terms of the bit error rate (BER) vs. received optical power (P_RX) as shown in Fig. 2 and Fig. 3 for: back-to-back (B2B), 25km and 50km of SSMF. The BER limits of 2.2×10-3 and 1.32×10 2 corresponding to 7% and 25% overhead (OH) for forward error corrections (FEC)4, respectively, have been explored. The sensitivity is then defined as the minimum received power for reaching these BER limits.

Tab. 1 summarizes the B2B 7% and 25% OH FEC sensitivities depicted in Fig. 2 for OOK and 4-QAM-OFDM/FBMC/UFMC/GFDM at 5Gbps as well as the power penalty of the considered multicarrier modulation formats with regard to OOK. From Tab. 1, it can be observed that, for both considered OH FEC limits, the power penalty compared to OOK increases with the different multicarrier modulation formats, being the OFDM penalty the lowest (2-2.5dB) and the GFDM the highest (5-5.5dB). While FBMC and UFMC, provide intermediate values, FBMC penalty (3-3.5dB) being smaller than the UFMC (4.5dB). Negligible transmission penalties are observed on the obtained sensitivities in the Fig. 2 when the optical signal is launched into 50km of SSMF. Taking into account the obtained 7(25)% OH FEC sensitivities at 5Gbps, the maximum splitting ratios available over 50km SSMF are 32(64), 32(32), 16(32), 16(16) and 16(16) for OOK, OFDM, FBMC, UFMC and GFDM, respectively. Hence, for OFDM, UFMC and GFDM, the splitting ratio does not change for 7% and 25% OH FEC limits, while, for OOK and FBMC, the splitting ratio is doubled.

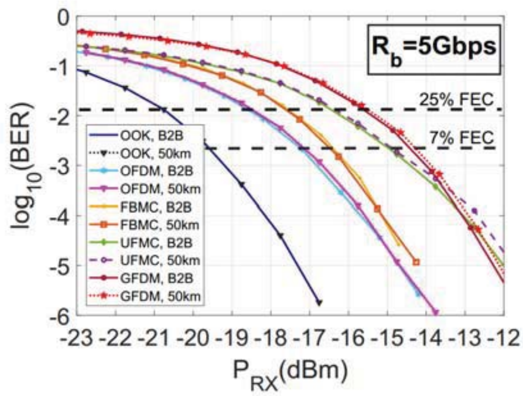

Fig. 2: BER vs. received power (P_{RX}) of OOK, 4-QAM-OFDM/FBMC/GFDM/UFMC for a transmission data rate of 5Gbps with 0km and 50km of SSMF

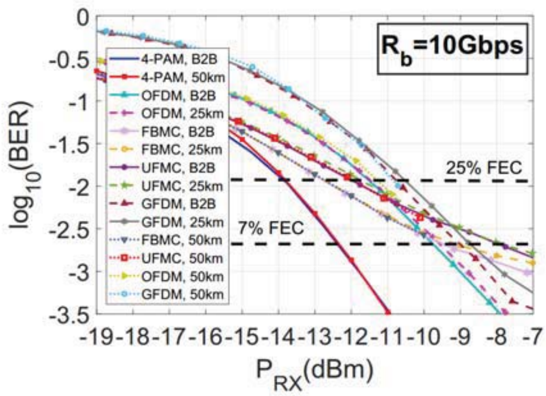

Fig. 3: BER vs. received power (P_{RX}) of 4-PAM, 16-QAM-OFDM/FBMC/GFDM/UFMC for a transmission data rate of 10Gbps with 0km, 25km and 50km of SSMF.

The B2B 7% and 25% OH FEC sensitivities depicted in Fig. 3 for 4-PAM and 16-QAM-OFDM/FBMC/UFMC/GFDM at 10Gbps are outlined in Tab. 2, and also the power penalties of the multicarrier modulation formats compared to 4-PAM. In this case, for the 7% OH FEC limit, the OFDM and FBMC penalty values are the lowest (3dB) while the UFMC is the highest (4.5dB). Different penalty behaviour can be deduced from Tab. 2 for the 25% OH FEC limit. The FBMC penalty is now the lowest (1.5dB) and the GFDM the highest (3.5dB). Between them, OFDM and UFMC show similar penalties (2.5 and 2dB). From Fig. 3, any penalty is observed in the sensitivities over 25km of SSMF. For 50km SSMF case, the 7% OH FEC sensitivity is not defined due to the fact that the power budget is insufficient. Fortunately, the 25% OH FEC sensitivities do not change compared to B2B. So, while the 4-PAM enables splitting ratios up to 8(16) for 7(25)% OH FEC and 25km of SSMF, the splitting ratio of the multicarrier modulation formats at 10Gbps is of 8 for both 7% and 25% OH FEC limits. A splitting ratio of 8 is similarly offered for 50km of SSMF and 25% OH FEC. An improvement up to 10dB in the sensitivity values can be obtained by replacing the PIN photodetector by an avalanche photodetector (APD) [6], providing a splitting ratio increase factor of 8, by raising the system cost.

TABLE 1: SUMMARY OF B2B 7% AND 25% OH FEC SENTITIVITIES (S) OF OOK, 4-QAM-OFDM/FBMC/UFMC/ GFDM MODULATION FORMATS AT 5GBPS AND THIER POWER PENALTY (Δ) COMPARED TO OOK.

Mod. format	**$S_{7\%FEC}$ (dBm)**	**$\Delta_{7\%}$ (dB)**	**$S_{25\%FEC}$ (dBm)**	**$\Delta_{25\%}$ (dB)**
OOK	-19.5		-21.0	
OFDM	-17.5	2.0	-18.5	2.5
FBMC	-16.5	3.0	-17.5	3.5
UFMC	-15.0	4.5	-16.5	4.5
GFDM	-14.5	5.0	-15.5	5.5

TABLE 2: SUMMARY OF B2B 7% AND 25% OH FEC SENTITIVITIES (S) OF 4-PAM, 16-QAM-OFDM/FBMC/UFMC/ GFDM MODULATION FORMATS AT 10GBPS AND THIER POWER PENALTY (Δ) COMPARED TO 4-PAM.

Mod. format	**$S_{7\%FEC}$ (dBm)**	**$\Delta_{7\%}$ (dB)**	**$S_{25\%FEC}$ (dBm)**	**$\Delta_{25\%}$ (dB)**
4-PAM	-12.5		-14.0	
OFDM	-9.5	3.0	-11.5	2.5
FBMC	-9.5	3.0	-12.5	1.5
UFMC	-8.0	4.5	-12.0	2
GFDM	-9.0	3.5	-10.5	3.5

IV. CONCLUSIONS

New 5G multicarrier waveforms (FBMC, UFMC, and GDFM) and OFDM have been assessed over an IMDD system with a PIN-based receiver for downstream at different transmission data rates and distances. Obtained results show sensitivities at 5Gbps (10Gbps) over 50km of SSMF in the range of -18.5 to -14.5dBm (-11.5 to -8dBm) only 2 to 5.5dB (1.5 to 4.5dB) higher than reference OOK (4-PAM) for 7%-25% OH FEC.

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