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Published: 26/07/2021

Dyfyniad o'r fersiwn a gyhoeddwyd / Citation for published version (APA):
Gonem, O., Giddings, R., & Tang, J. (2021). *DSP-based Reduction of the Impact of White ADC Timing Jitter on Hybrid OFDM-DFMA PONs*. Paper presented at OSA Advanced Photonics Congress 2021.

Advanced Photonics Congress (IPR, Networks, NOMA, PVLED,
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DSP-based Reduction of the Impact of White ADC Timing Jitter on Hybrid OFDM-DFMA PONs

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Abstract: We show that in hybrid OFDM-DFMA PONs, simple receiver-based sideband processing reduces jitter effects, increasing signal to noise ratio by 3dB, thus increasing robustness against white ADC timing jitter and reducing jitter-induced optical power penalty. © 2021 The Author(s)

OCIS codes: (060.0060) Fiber optics and optical communications; (060.4250) Networks

1. Introduction

Recent years have witnessed growing research into different digital signal processing (DSP)-based passive optical networks (PONs) to meet the rigorous requirements imposed by next-generation optical access networks and 5G networks. Recently, hybrid orthogonal frequency division multiplexing (OFDM) digital filter multiple access (DFMA) PONs have been proposed [1], where each individual optical network unit (ONU) utilizes reconfigurable Hilbert pair-based digital shaping filters to flexibly locate its OFDM signal at the desired sub-wavelength (SW) spectral region, whilst a single fast Fourier transform (FFT) operation followed by simple parallel data recovery processes is employed to achieve a matching filter-free optical line terminal (OLT) architecture, thus achieving reduced OLT DSP complexity with greatly enhanced upstream performance [1]. However, as multi-GS/s analogue-to-digital converters (ADCs) are employed in these PONs, it is critical to understand their tolerance to white (uncorrelated) ADC sample timing jitter.

White timing jitter is often modelled as a wide sense stationary (WSS) Gaussian process with a zero mean and characterized by its normalized root-mean-square (RMS) value σ_j/T_s, in reference to the sampling unit interval T_s. The work in [2, 3] shows that white ADC timing jitter-induced inter-carrier interference (ICI) in OFDM-based systems can be reduced by oversampling the signal at the receiver's ADC, however, this requires an ADC with a higher sampling rate which leads to increased component costs. In this paper, we explore the effects of white ADC timing jitter on hybrid OFDM-DFMA PONs and show that jointly processing two sidebands increases robustness against white ADC timing jitter and reduces the timing jitter-induced optical power penalty. Thus, we present a simple, highly effective DSP-based technique which has the same efficiency as oversampling method in reducing jitter-induced ICI.

2. System setup and joint sideband processing DSP operation

Fig.1 shows the system setup where signal generation and detection are simulated using Matlab and the optical fibre transmission is simulated using VPI Transmission Maker [1]. The key system parameters are listed in Table 1. In each ONU, a real-valued OFDM signal containing 15 data-bearing subcarriers is produced at the output of the IFFT by adopting Hermitian symmetry. The resultant signal is M× up-sampled and filtered with in-phase digital shaping filters. The signal is then individually clipped and quantized with a jitter-free digital-to-analogue converter (DAC). Similar to [1], each ONU employs an ideal optical intensity modulator for the E-O conversion, different ONUs' optical signals are then passively coupled and transmitted through the fibre transmission link. In the OLT, a PIN detector performs the O-E conversion. To emulate the jitter effect, L parallel Lagrange fractional delay filters are used to intentionally fractionally delay each of L signal samples at the ADC, and a single FFT operation is then employed for subcarrier recovery. As two sidebands conveying identical data are transmitted in each SW spectral region, the sideband processing is used to either choose a single subcarrier in one sideband or to perform joint sideband processing where the corresponding subcarriers from both sidebands undergo a simple sideband coherent sum operation after arranging the conjugates of the upper sideband subcarriers in a reverse order, as these two sidebands are conjugate symmetric.

Table 1. List of parameters

Parameter	Value	Parameter	Value	Parameter	Value
DAC/ADC sampling speed	12.5GS/s	Cyclic prefix	25%	Fibre Kerr coefficient	2.6e-20m^2/W
Data-carrying subcarriers	15 per ONU	Clipping ratio	13dB	Fibre dispersion	16ps/nm/km
OFDM IFFT/FFT size	32/256	DAC/ADC resolution	8 bits	Fibre loss	0.2dB/km
Modulation format	16QAM	Digital filter length	64	PIN detector bandwidth	12.5GHz
Digital filter roll-off factor	0	Up-sampling factor (M)	8	PIN detector sensitivity*	-19dBm
PIN detector quantum efficiency	0.8	Transmission distance	30km	Fibre dispersion slope	0.08ps/nm^2/km

*Corresponding to 10 Gb/s non-return-to-zero data at a BER of 1.0 × 10^{-9}

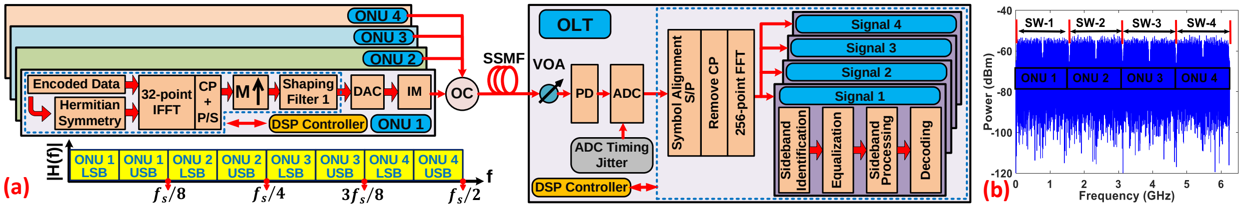

Fig. 1. (a) System setup for the hybrid OFDM-DFMA PON. (b) spectrum after PD. CP: cyclic prefix, S/P: serial-to-parallel conversion, P/S: parallel-to-serial conversion, LSB: lower sideband, USB: upper sideband, IM: intensity modulator, OC: optical coupler, f_s: sampling frequency.

3. Results

Figs. 2(a) - 2(c) show the performance robustness against white ADC timing jitter where electrical back-to-back systems are considered to effectively observe the effect of the jitter in isolation. White timing jitter-induced ICI has a flat power spectral density, therefore all low and high-frequency ONU channels and their sidebands show identical bit error ratio (BER) performances as in Figs. 2(a) and 2(b), where all ONU channels have BER performances lower than the adopted forward error correction (FEC) limit up to 8% unit interval root-mean-square (UI$_{\mathrm{rms}}$) jitter. In general, if an ideal baseband OFDM system with white jitter, transmits the same data on R subcarriers, then by joint subcarrier coherent addition at the receiver, the jitter ICI power increases by a factor of R, whereas the resultant subcarrier power increases by a factor of R^2, thus the signal to ICI power ratio (σ_s^2/P_{ICI}) increases by a factor of R as shown in Fig. 2(d). Compared with oversampling [2,3], our technique demonstrates the same ability in reducing ICI. Therefore, joint sideband processing improves the signal to noise ratio (SNR) and increases the signal to ICI power ratio by 3dB, this increases the robustness against white ADC jitter to 12.5% UI$_{\mathrm{rms}}$, as shown in Fig. 2(c).

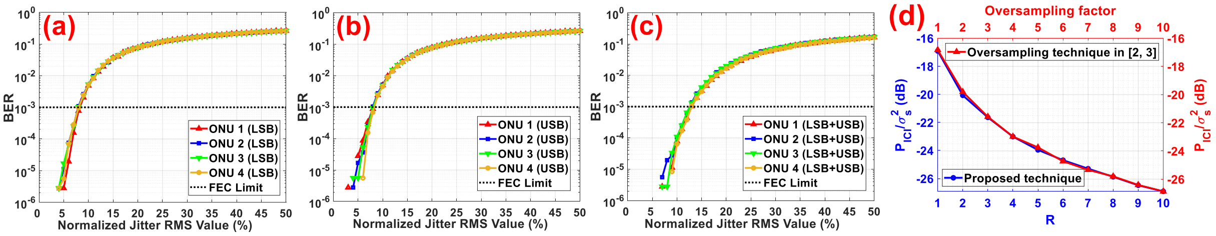

Fig. 2. BER vs. normalized jitter RMS value of white ADC timing jitter for (a) LSB, (b) USB, (c) joint sideband processing, (d) ICI to signal power ratio (dB) for 16QAM 256 subcarrier OFDM system with white ADC timing jitter $(\sigma_j/T_s) = 8\%$ UI$_{\mathrm{rms}}$: proposed technique vs. oversampling.

Figs. 3(a) and 3(b) show the effect of white ADC timing jitter and received optical power (ROP) on error vector magnitude (EVM) in hybrid OFDM-DFMA PON upstream transmissions as presented in Fig.1. The results confirm the ability of the joint sideband processing to increase the robustness against white timing jitter in the presence of optical channel-induced impairments. Increasing jitter levels increase optical power penalty, however for a fixed level of jitter, the joint sideband processing achieves a reduction in the minimum required ROP, for example comparing Fig. 3(b) with Fig. 3(a), at a fixed BER of 1×10^{-3} (equivalent to an EVM of -17dB for 16QAM), shows improvements of ~1.5dB (~5dB) at 0% (8%) UI$_{\mathrm{rms}}$ jitter. Fig. 3(c) shows the optical power penalty due to white ADC jitter at a fixed EVM of -17dB, the joint sideband processing is shown to significantly reduce the jitter-induced optical power penalty.

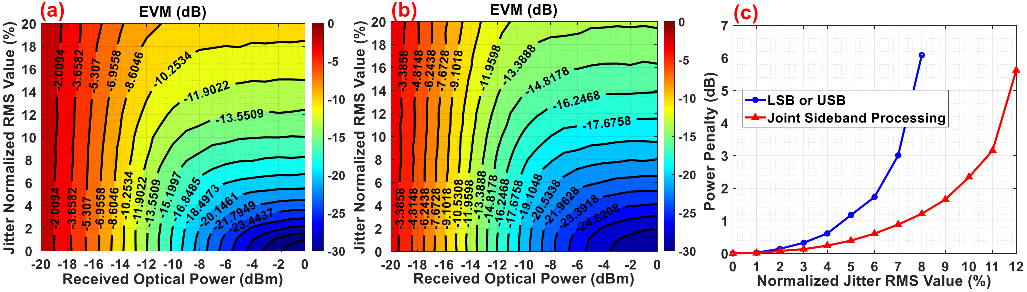

Fig. 3. EVM (dB) of the ONU occupying the 2$^{\mathrm{nd}}$ sub-wavelength spectral region of hybrid OFDM-DFMA PON with white ADC jitter (a) LSB/USB, (b) joint sideband processing, (c) power penalty (dB) of hybrid OFDM-DFMA PON due to white ADC timing jitter at a fixed EVM of -17dB.

4. References

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