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Performance comparison of wavelet packet transform based and conventional coherent optical OFDM transmission system

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ABSTRACT

In this work, the performance of WPT-COOFDM system is investigated and compared to that of FFT-COOFDM system over a fiber link. Simulation results show that the longer length of wavelet filters achieve a better performance, whereas the complexity is higher. For different wavelet mother functions employed in WPT-COOFDM systems, the chromatic dispersion robust of John64E wavelet outperforms that of other wavelets, and which could be a viable alternative for coherent optical OFDM to be considered in short distance transmissions. The simulation results also show that most of the developed wavelet mother functions mainly for image processing are not suitable for COOFDM transmission for its sensitivity to chromatic dispersion.

1. Introduction

Optical orthogonal frequency division multiplexing (OOFDM) is very attractive for modern optical fiber communications due to its high spectral efficiency and capability to combat fiber dispersion. One advantage of the conventional OFDM is to employ the efficient Fast Fourier Transform (FFT) for OFDM modulation and demodulation. On the other hand, the major concerns in OFDM systems include inter-symbol-interference (ISI) and inter-carrier-interference (ICI) for a large number of subcarriers and the channel dispersion. One solution is to use guard interval (GI) to eliminate ISI which results in the cyclic extension of the OFDM waveform, known as cyclic prefix (CP). The addition of CP reduces the effective data rate of the system. Instead of sinusoids used for FFT, wavelet packet transform (WPT) based on wavelet packet basis has been considered as an alternate to replace FFT [1]. WPT is one of the overlapped transforms, which has longer symbol duration and hence, yields a better spectral containment. Further, the wavelet has many varieties and therefore, it can provide more freedom for system design to suit different applications. OFDM based wavelet transform (WT) has been widely studied in wireless communications as an alternate to FFT-OFDM, and more information can be found in literatures [2–7]. Recently, it has been studied in optical fiber communications. Literature [8] introduces the WT to OOFDM system for the first time, and [9] has proved that WPT based COOFDM system (WPT-COOFDM) is very sensitivity to polarization-mode dispersion (PMD). Some more literatures about WT based OOFDM could be found in [10,11].

In this work, we investigate the transmission performance of WPT-COOFDM based several kinds of wavelet mother functions in coherent optical transmission systems. The chromatic dispersion robust in different transmission distance with different wavelet mother function selections is also investigated. John64E wavelet mother function selected for the WPT-COOFDM system is superior as compare to other wavelets for its high level of spectral containment, with which the transmission performance of WPT-COOFDM is comparable to FFT-COOFDM. Whereas the other wavelets based WPT-COOFDM systems cannot achieve a good BER performance for the fiber chromatic dispersion, and could be considered to introduce into short reach transmission systems as a viable alternative to intensity modulation/direct detection OOFDM (IM/DD-OOFDM). We also present that the WPT-COOFDM systems with same spectral containment have the same chromatic dispersion robust. This paper is organized as follows: Conventional COOFDM based FFT and WPT-COOFDM system model are developed in Section 2. In Section 3, simulations with different wavelet mother function selections

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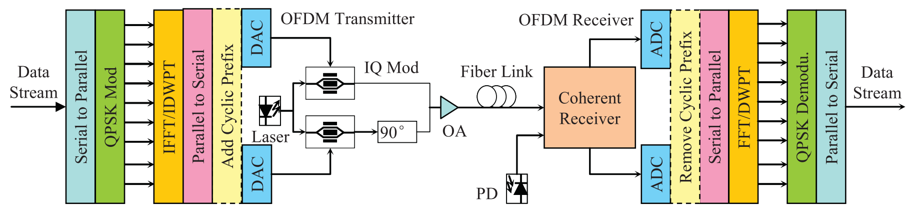

Fig. 1. The conceptual diagram of WPT-OOFDM transmission system; OA, optical amplifier; ADC/DAC, analog-to-digital and digital-to-analog converter; PD, photodiodes.

for different transmission distance are conducted and the results are presented. The BER performance comparison between FFT-COOFDM and WPT-COOFDM are also examined. The last section summarized the conclusions.

2. Principle WPT-COOFDM

As one of the alternative of OOFDM transmission systems, WPT-COOFDM transmission system is similar to the conventional COOFDM transmission system, in which the IFFT/FFT is replaced by the inverse discrete WPT (IDWPT)/DWPT. On the contrary of FFT which only has frequency localization and its waveforms are infinitely long in time domain, the DWPT is another form of time-frequency representation called by wavelets. The key factor of OFDM signal is to maintain the orthogonality between the sub-carriers. We will first explain the definition of DWPT and follows with the proposed coherent optical WPT-OFDM transmission system model, namely WPT-COOFDM system.

The fundamentals of the DWPT starts by defining it as recursively of the mother wavelet function $\psi(t)$ and its scale function $\phi(t)$, which decomposes the signal into details and approximations, i.e., given a signal, a pair of low pass filters (LPF) and high pass filters (HPF) corresponding the mother wavelet function and its scale function respectively is employed to yield two sequences to occupy different frequency sub-band features of the original signal. A full recursive binary tree structure of 2-level inverse DWPT (IDWPT) and forward DWPT are depicted in Fig. 2(a) and (b), respectively. IDWPT/DWPT uses quadrature mirror filter (QMF) pairs of the filters $g(n)$ and $h(n)$ that are used to recursively define the sequence of mother wavelet function $\psi(t)$ and its scaling function $\phi(t)$ [12]

$$\begin{cases} \phi(t) = \sqrt{2}\sum_{n\in Z} h(n)\phi(2t-n) \\ \psi(t) = \sqrt{2}\sum_{n\in Z} g(n)\phi(2t-n) \end{cases} \tag{1}$$

where $g(n) = (-1)^n h(1-n)$, i.e., $g(n)$ and $h(n)$ are quadrature mirror and correspond to the HPF and LPF coefficients, respectively. If $h(n)$ has a finite and even length L, $g(n) = (-1)^n h(L-1-n)$, $(n = 1, 2, \ldots, L-1)$, where L is length of the filter coefficients.

In order to obtain the mathematical expression of wavelet packet analysis function, we define the first two wavelet packet functions as

$$W^0(t) = \phi(t), \quad W^1(t) = \psi(t) \tag{2}$$

Wavelet packet functions $W^n(t)$ are recursively defined by

$$W^{2n}(t) = \sqrt{2}\sum_{k\in Z} h(k)W^n(2t-k) \tag{3}$$

$$W^{2n+1}(t) = \sqrt{2}\sum_{k\in Z} g(k)W^n(2t-k) \tag{4}$$

An appropriate subset of wavelet packet base is all orthonormal bases chosen among the functions [13]

$$\{W_{j,k}^n(t) = 2^{j/2}W^n(2^j t - k), \quad (j,k)\in(Z,Z), \quad n\in N\} \tag{5}$$

Therefore, any signal $s(t)$ can be decomposed on the base $\{W_{j,k}^n(t), \quad (j,k,n)\in Z\}$ as the sum of weighted wavelet packets, which gives the idea of wavelet packet modulation and employs it to OFDM systems. We can decompose any OFDM signal $s(t)$ with N_{sc} subcarriers on the base $\{W_{j,k}^n(t), \quad (j,k)\in(Z,Z)\}$ by

$$s(t) = \sum_{i=-\infty}^{+\infty}\sum_{k=1}^{N_{sc}}\sum_{(n,j)} c_{j,k,i}^n W_{j,k,i}^n(t) \tag{6}$$

where j is the iteration index, $1 \le j \le J$, $J = \log 2(N)$, and $c_{j,k,i}^n$ is the i-th information symbol at the k-th subcarrier. The process that transforms the symbols from the wavelet domain to time domain is called IDWPT, namely wavelet packet synthesize, whereas its "mirror image" process with a similar tree structure, as depicted in Fig. 2(b), that transforms the received signal from time-domain to the wavelet domain is called DWPT, namely wavelet packet analysis [9].

For the conventional COOFDM system based FFT, its equivalent baseband with i-th information symbol is given by $s(t) = \sum_{i=-\infty}^{+\infty}\sum_{k=1}^{N_{sc}} c_{ki}s_k(t-iT_s)$. While in the COOFDM system based IDWPT/DWPT, a set of wavelet packet functions $W^n(t)$, which satisfy certain mathematical conditions as defined in Eqs. (3) and (4), is used to replace the sinusoidal functions. The transmitted signal is constructed as the sum of N_{sc} wavelet packet functions $W^n(t)$ individually modulated with the constellation encoded data symbols. On the other hand, in conventional COOFDM systems, the Fourier Transform analyzes signal by means of sinusoids of high and low frequency, whereas wavelet packet transform by means of wavelet packet functions which can be implemented by a set of HPF $g(n)$ and LPF $h(n)$ corresponding the wavelet mother function $\psi(t)$ and its scaling function $\phi(t)$. The proposed conceptual diagram of WPT-COOFDM transmission system is depicted in Fig. 1, which has the same architecture with FFT-COOFDM that takes the IDWPT/DWPT instead of IFFT/FFT.

3. Simulation setup and results

An efficient implementation of OFDM transmitter and receiver can be built with the IFFT and FFT. In a FFT-OOFDM system with coherent detection, the high bit rate serial input data stream is first sent to the modulator and mapped onto the complex domain by quadrature phase shift keying (QPSK) modulation or quadrature amplitude modulation (QAM). Pilot bits are added to the modulated output and the resultant is spited into parallel to transform into time domain signal by IFFT. CP which consists of a part of the original transmitted data and whose length is proportional to the channel delay spread is wrapped on the output serial data. This constitutes an OFDM symbol which is then transmitted through the fiber channel. Then the time domain signal is up-converted to optical domain by an optical IQ modulator for fiber transmission. At the receiver, the coherent optical signal is down-converted to electrical domain and sampled. In the digital signal processing (DSP), the CP is removed first and the data is fed into FFT to transform it back to frequency domain. Pilots at the receiver are used to