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On the Evaluation of DWT Incorporated MIMO-RoF system

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Abstract: A robust and spectral-efficient Radio over Fibre (RoF) system needs the signal processing techniques such as MIMO and OFDM to be employed for supporting broadband wireless communication. However, the conventional FFT-OFDM suffers from low spectral-efficiency and high peak-to-average power ratio (PAPR), which makes the overall RoF system more power greedy and susceptible to errors. To ease the high power requirement for accomplishing a certain level of BER performance, the discrete wavelet transform (DWT) is integrated with MIMO-RoF system in this work. The proposed DWT-OFDM system makes use of Space-Time Block Codes (STBC) to achieve diversity and the resultant MIMO-OFDM signal is transmitted over RoF link (≈50Km) under the optical nonlinearity sway. In particular, the power penalty for Daubechies (db) wavelets is evaluated in the reported work with various PSK schemes. The demonstrated system equipped with 1st order db wavelet (db1) using QPSK offers a power saving of ≈6 dB to achieve the target BER in contrast to higher order wavelets.
Keywords Radio over Fibre; OFDM; Wavelet; Space-time Block code.

1. Introduction

The smart portable devices offering broadband multimedia applications with extremely high capacity and reliability are becoming an essential part of life in today's world. To cope with this, the radio coverage needs to be denser; necessitating the installation of micro- and pico-cells [1]. Radio over fibre (RoF) is a capable technology to install the micro- and pico-cells economically by concentrating the intricate RF signal processing tasks at a central station, thereby using inexpensive Radio Access Points (RAPs). The benefits such as larger frequency reuse; greater capacity and smaller power expenses make the RoF technology suitable for many communication based applications [2]. Despite the number of qualities presented by RoF systems, some issues of concern are also there.

A high bit-rate, wireless communication system is subjected to the time dispersive channel causing inter-symbol interference (ISI). The multi-carrier technique such as OFDM, is a proficient method to reduce ISI, which uses narrow sub-carriers for converting and modulating the original high-speed bit stream into parallel low speed bit streams [3-4]. The Discrete Fourier Transform (DFT) based OFDM is a sturdy format against multi-path fading and chromatic dispersion [5-7]. However, the disadvantages such as large side lobes, interference and PAPR make it less sought after as multi-carrier modulation [8]. To deal with the precincts of FFT-OFDM, application of DWT is considered in the multi-carrier modulation scheme [9]. The motivation for considering the wavelets, on the whole, may be accredited to their enhanced characteristics over the Fourier transform. The DWT algorithm can be used to compute the wavelet representation of a discrete signal.

In a DWT-OFDM system, the process of inverse DWT (IDWT) and DWT are executed instead of inverse DFT (IDFT) and DFT. Superior multi-carrier and multi-resolution signals can be produced for modulation by an arrangement of wavelet filters. The IDWT and DWT are basically the synthesis and analysis filter bank respectively. A filter bank is a collection of filters which are connected by sampling operators and delay. A two-channel filter bank usually consists of low-pass and high-pass filter, which divide the input signal into different frequencies. The type of wavelet family characterizes the low and high pass filters. Depending upon the particular wavelet family e.g. Daubechies, Coiflet, Symlet, Meyer etc., the signal is decomposed into shifted and scaled versions and the original signal is recreated through opposite process. The wavelet transform ensure several benefits such as constrained side lobes, higher power spectral density and spectral efficiency, small PAPR and flexibility [10]. However, the computational intricacy is greater in contrast to DFT systems. Although there are many wavelet filters, the current work is restricted to the Daubechies wavelet. For a fixed number of vanishing moments, the Daubechies wavelets possess the support of minimum size. Among all the orthogonal wavelets, the shortest support is provided by Haar (db1) wavelet. Furthermore, the Daubechies wavelets have compact scaling and wavelet functions [11-12].

The signal processing techniques known as spatial multiplexing and spatial diversity are also widely used to improve the wireless system performance in terms of bit rate/BER by installing multiple antennas on the transmitter and/or the receiver. In spatial diversity MIMO, STBCs are used to alleviate fading effects by sending replicas of a symbol from all the transmitting antennas [13]. However, the propagation of MIMO-OFDM signals on the RoF link is highly affected by the optical nonlinearity. The nonlinearity may be attributed to the optical source or the combination of source and fibre [14-16]. The authors of [17] and [18] demonstrated the compensation of optical nonlinearity of the RoF link by using the Orthogonal STBC. The authors of [19], [20] and [21] demonstrated the compensation of wireless channel impairments in OFDM-RoF system using spatial diversity MIMO. The authors of [22] investigated the MIMO-RoF system with conventional OFDM under the influence of phase noise. However, these research studies considered only Conventional OFDM based MIMO-RoF systems. In [23], the authors studied the SISO-RoF system with W-OFDM under the influence of phase jitter and inferred that DWT-OFDM outperform DFT-OFDM with low phase noise, though they achieve the comparable performance with high phase noise. In [24], the authors demonstrated that DWT-OFDM based MIMO-RoF system significantly outperforms the respective FFT-OFDM system under optical nonlinearity sway.

2. Major Contributions

The earlier reported work is focused on the comparative evaluation of C-OFDM and W-OFDM incorporated MIMO-RoF system under the impact of optical nonlinearity and carrier-synchronization phase-ambiguity. The considered wavelet family for evaluation of DWT-OFDM system is Haar (db1) wavelet only. The authors extend this work by considering other OFDM resolutions with higher orders of Daubechies wavelet with a higher level of nonlinearity and fibre length. Initially, the demonstrated system is evaluated with RoF link of 25 km and 50 km for diverse PSK modulation schemes with db1 wavelet only. Later, the comparative analysis of the proposed system is carried for even (db2, db4 and db6) and odd-order (db3, db5 and db7) Daubechies wavelets. The proposed MIMO-OFDM-RoF system with db1 wavelet achieves power saving of 6 dB for accomplishing the threshold BER in contrast to the higher order db wavelet families.

3. System Setup

The MIMO-OFDM signal is generated and transmitted over the RoF link and Rayleigh faded wireless channel as per the MATLAB^{TM} system setup shown in Fig.1. Firstly, the user data bits are mapped on to the constellation of considered PSK modulation scheme i.e. QPSK, 8-PSK and 16-PSK. The process of serial to parallel conversion and 256-point IDWT computation make part of OFDM modulation. The considered wavelet families include odd-order db wavelets i.e db1, db3, db5, db7 and even-order db wavelets i.e db2, db4, db6. The space-time block coding is achieved using the STBC encoder which encodes the symbol according to two transmitting antennas at full rate [25]. The generated MIMO-OFDM signal is propagated over the RoF link, where it is used to intensity modulate laser output at 1550 nm and transmitted on single mode optical fibre. The memory-less nonlinearity is used to model the RoF link, where the nonlinearity is characterized by AM-AM/PM behavioural model [26]. The 3rd Order Input Intercept Point (IIP3) is considered to represent the RoF link nonlinearity in the proposed work [27-28]. The AM-AM distortion of RoF link corresponds to IIP3 taken as 15 dBm [29]. The large IIP3 values represent the RoF link with linear response. The RoF link having IIP3 more than 35 dBm have highly linearized behaviour [30]. On the other end of the fibre link i.e at the RAP, the photo-detector converts the received optical signal into a RF signal and two antennas are employed to radiate the signal over Rayleigh fading channel. On the user equipment, the diversity reception is achieved using two antennas. The OFDM demodulation is accomplished using DWT computation and STBC decoding is achieved in the maximum-likelihood algorithm based space-time block code combiner and the original bit stream is reconstructed by the demodulator.

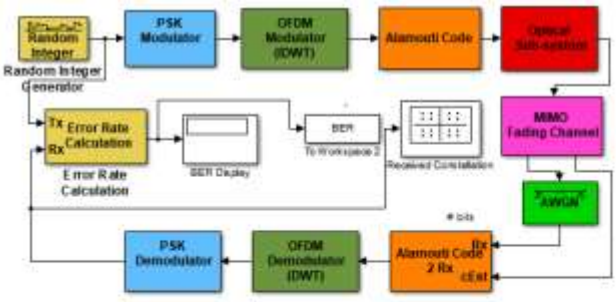

Fig. 1. 2x2-Alamouti Coded DWT-OFDM-RoF System

4. Results and Discussion

To investigate the performance of the reported system for diverse wavelet families and PSK modulation schemes, the target BER is kept at 10-3. The system performance is estimated on the basis of the power penalty imposed in different scenarios. At the outset, the characteristics of the proposed system are evaluated for the fibre length of 25 km and 50 km with db1 wavelet family as depicted in Fig. 2. The observations unveil that the proposed system successfully achieves the error-free transmission of the user data in both cases. The SNR requirement of 5 dB and 9 dB is observed to accomplish the target BER for the case of 25 km fibre length with 8-PSK and 16-PSK modulation formats respectively. An additional power penalty of 5 dB is observed in the proposed system with a fibre length of 50km to achieve the target BER. The power margin of 4 dB is observed between the 8-PSK and 16-PSK modulated system for both considered fibre lengths. The scatter plots for the proposed system in case of 50 km fibre length are shown in Fig.3 and Fig.4., which depict the SNR requirements for attaining the BER of 10^{-3} (target BER) and BER of 10^{-5} in case of 8-PSK and 16-PSK schemes.

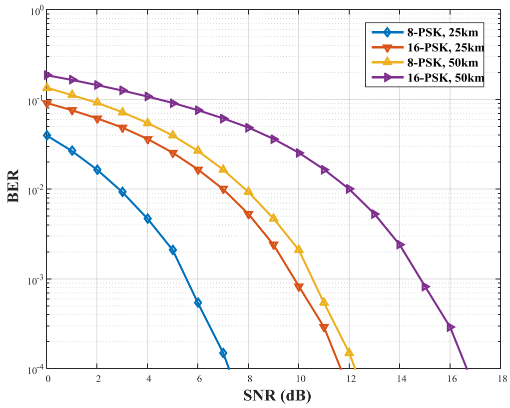

Fig. 2 BER performance of DWT incorporated MIMO-RoF system using diverse PSK schemes

(a) (b)

Fig. 3 Received 8-PSK constellation with db1 wavelet at (a) SNR=10 dB (b) SNR=13 dB

(a) (b)

Fig. 4 Received 16-PSK constellation with db1 wavelet at (a) SNR=14dB (b) SNR=17dB

Further, the impact of employing high-order db wavelet families is evaluated. It is observed in Fig. 5, that the BER curves with odd-order wavelets do not follow the linear behaviour. It is observed that db3 wavelet family has rather inferior BER performance than the db5 wavelet family. On the contrary, the even-order wavelet families show linear behaviour in terms of power penalty imposition and target BER attainment. It is observed that the power penalty increases as the order of wavelet increases. The power margin for achieving the target BER using the various Debauchies wavelets in the proposed system is given in Table 1.

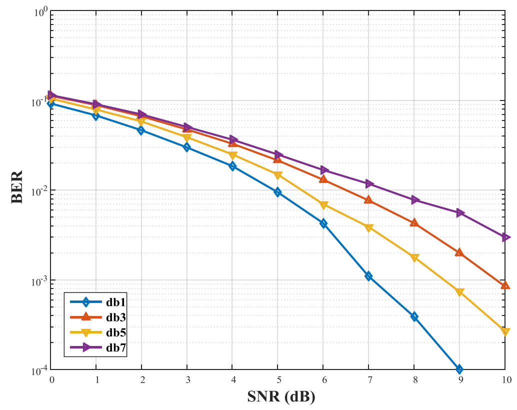

Fig. 5 DWT-OFDM based MIMO-RoF system for odd-order Daubechies wavelets with QPSK modulation

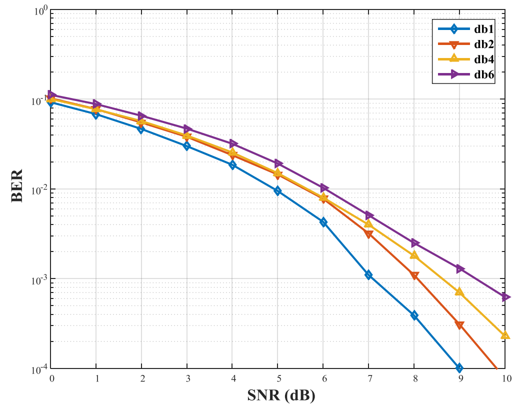

Fig. 6 DWT-OFDM based MIMO-RoF system for even-order Daubechies wavelets with QPSK modulation

Table 1
Power Penalty for Target BER

Odd-order Wavelet Family	SNR (dB)	Even-order Wavelet Family	SNR (dB)
Db1	7	-	-
Db3	9.7	Db2	8
Db5	8.6	Db4	8.5
Db7	13	Db6	9.4

5. Conclusion

A MIMO-OFDM-RoF system utilizing STBC codes is demonstrated and analysed for diverse Daubechies wavelet resolutions in the presence of optical nonlinearity (IIP3). The power margin for RoF link of 25 km extended to 50 km is evaluated for the error-free transmission of 8-PSK and 16-PSK modulated signals. Further, a comprehensive contrast is drawn with odd-order and even-order Daubechies wavelet families to authenticate the potential of the proposed system using the QPSK modulation scheme. The proposed QPSK-modulated system shows a distinct power saving of 6 dB (approx) with db1 wavelet in contrast with high-order Daubechies wavelets. Furthermore, it is observed that the even-order wavelets comparatively with odd-order wavelets exhibit linear augmentation of power penalty.

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