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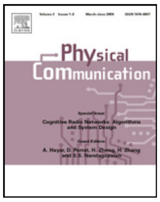

Full length article

A new hybrid multicarrier transmission technique with iterative frequency domain detection

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ABSTRACT

The growing progress in wireless communication services led to a demand in high data rates, spectral efficiency and flexibility requirements. The Block-Windowed Burst Orthogonal Frequency Division Multiplexing (BWB-OFDM) technique has been recently proposed to face these demands. This technique employs smoother, non-rectangular windows, allowing a power spectral density similar to the filtered OFDM approach, thus achieving high spectral efficiency; also, it packs together several OFDM symbols, with the addition of a sole zero-padding to accommodate the multipath channel's propagation delay, thereby improving power efficiency. However, BWB-OFDM has the same drawbacks of OFDM when transmitting over hostile channel conditions, namely the performance degradation due to deep fades associated to severe frequency-selective channels.

This paper proposes a new Time Interleaved BWB-OFDM (TIBWB-OFDM) technique that performs interleaving on the time-samples of each BWB-OFDM block, creating a kind of diversity effect at the frequency domain, granting a much better resilience against deep inband fades, while keeping all the mentioned advantages of BWB-OFDM at the cost of no added complexity. Also, by regarding TIBWB-OFDM as a hybrid technique combining single-carrier and multicarrier characteristics, this paper also proposes the use of non-linear frequency domain equalizers based on the Iterative Block Frequency Domain Equalization (IB-DFE) concept for TIBWB-OFDM detection. It is shown that noteworthy improvements can be achieved in bit error rate (BER) performance compared to conventional OFDM schemes when employing typical zero-forcing (ZF) and minimum mean-square error (MMSE) linear equalizers.

1. Introduction

The future of wireless communications, with 5G on the horizon, stands on higher data rates, spectral efficiency and flexibility requirements as the evolution and expansion of mobile communications brought the need to transmit efficiently over hostile channel conditions at changing rates [1,2]. Orthogonal Frequency Division Multiplexing (OFDM) [3] has been for a long time the preferred transmission technique for wireless communications, due to its robustness against multipath propagation effects, and, also, to its simplicity brought by an efficient implementation based on the Fast Fourier Transform (FFT). These advantages are usually leveraged through the use of a cyclic prefix (CP) longer than the duration of the overall channel impulse response that enables a simplified frequency domain equalization (FDE) with only a single tap equalizer per carrier. However, the use of a CP per OFDM symbol, with a typical required duration of 10%–25% of the OFDM symbol period, reduces the effective throughput and the spectral efficiency of CP-OFDM systems. In addition, due to the power wasted on CP transmission, it can also decrease considerably the power efficiency of OFDM transceivers. In fact, the OFDM power efficiency is already conditioned by the high peak-to-average power ratio (PAPR) (which grows with the number of carriers) [4,5], that requires a considerable back-off at the front-end power amplification stage to ensure a distortion-free linear signal amplification, leading to a poor amplification efficiency. These power efficiency issues are of particular concern at the uplink transmission, due to the fact that mobile terminals are battery driven, which prompts for new transceiver architectures.

Recently, a new block-windowed burst OFDM (BWB-OFDM) transceiver scheme has been proposed [6] allowing a considerable improvement on spectral-efficiency compared to typical OFDM systems, while keeping the low complexity of those. This is achieved by either improving spectral confinement compared to a CP-OFDM system operating at the same transmission rate, and for

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the same number of carriers, or by achieving higher transmission rates for the same spectrum characteristics of a conventional CP-OFDM. The superior spectrum confinement is assured by using windowing techniques [7] in which each OFDM symbol is cyclic extended and windowed at the time-domain with a square-root raised cosine (SRRC) shape at the transmitter; at the receiver, after the equalization step, each one of those windowed symbols has applied the same window (matched filtering) in order to reject any inter-carrier interference (ICI). In addition, instead of using a CP between symbols systematically (as in CP-OFDM), the BWB-OFDM system applies a sole zero padding (ZP) [8,9] to a set of consecutive N_s windowed-OFDM symbols, sharing similarities with combined OFDM time division multiplexing (OFDM/TDM) systems [5]. At reception, emphasis is put at the frequency domain equalization (FDE) that treats the overall received signal (i.e. set of N_s OFDM consecutive symbols) as a block-based single carrier (SC) transmission type [10].

The new BWB-OFDM transceiver scheme allows as so a commitment between better signal spectrum confinement and a higher transmission rate, while keeping the main advantage of OFDM systems, which is the orthogonality between sub-carriers that allows a simple FDE, presenting a different alternative to the recent proposed generalized frequency division multiplexing (GFDM) [11] technique, that also provides better power and spectral efficiency, but where orthogonality between carriers is lost. In fact, since it does not use a CP per transmitted OFDM symbol, BWB-OFDM has higher transmission rates than typical OFDM schemes when keeping its rectangular symbol configuration. As an alternative, it can keep the same transmission rate as OFDM but with much more compact spectrum [6]. Another important aspect of this transmission technique is that it increases the energy efficiency compared to typical CP-OFDM systems, since a single ZP guard interval is used per N_s OFDM symbols.

Nevertheless, the system has the same drawbacks of OFDM when transmitting over hostile channel conditions, namely the performance degradation due to deep fades associated with severe frequency selective channels. Although the overall bit error rate (BER) performance of BWB-ODFM is superior to CP-OFDM when using the minimum-mean-squared error equalizer (MMSE), this performance is still far from the theoretical matched filter bound (MFB) limit [12] and the BWB-OFDM receiver lacks an equalizer capable of approaching it.

As previously referred, the BWB-OFDM received signal is equalized as a block-based SC transmission type [6,10]. In fact, BWB-OFDM can be regarded as a hybrid technique combining single-carrier and multicarrier characteristics. The SC characteristics of the received block prompts for the use of non-linear FDE, based on the Iterative-Block Decision Feedback Equalization (IB-DFE) concept, because, as it has been recently shown that Single Carrier Frequency Domain Equalization (SC-FDE) schemes have an overall performance advantage over OFDM when employing the (IB-DFE) [13,14]. However, experiments conducted by the authors have shown no added gains compared to the MMSE equalizer. The reason was due to the poor symbol estimation performed by the feedforward (FF) path at the end of the first IB-DFE iteration, essential to a fair canceling of inter-symbol or inter-block interference (ISI or IBI) through the feedback path in the following iteration, making IB-DFE to converge; in fact, the FF path at the first iteration of the IB-DFE corresponds to a linear equalizer, usually the MMSE [14] that, as already referred, fails to present a desirable performance against deep fadings of severe frequency selective channels.

This paper proposes a new Time Interleaved BWB-OFDM (TIBWB-OFDM) technique that performs interleaving on the time-samples of each BWB-OFDM block, creating a kind of diversity effect at the frequency domain, granting a much better resilience against deep inband fades, while keeping all the mentioned advantages of BWB-OFDM at the cost of no added complexity. It is also shown that the new TIBWB-OFDM technique leverages the use of non-linear iterative FDE, due to the much better performance of linear equalizers for TIBWB-OFDM employed at the initial iteration. In this regard, this paper also presents a non-linear iterative FDE for the TIBWB-OFDM, based on the IB-DFE concept, capable of effectively approaching the MFB limit with a very small number of iterations.

The concept of using diversity in the frequency domain in order to improve detection has already been used in the past in different contexts, such as multi-user scenarios employing Code Division Multiple Access (CDMA) [15] and Interleaved Frequency Division Multiplexing (IFDM) [16]. However, the proposed approach considerably differs from previous ones. The TIBWB-OFDM comb-shape type spectrum produced by the proposed time-interleaving procedure, despite mimicking some of the characteristics of the spectra of [15,16], is achieved within the contiguous bandwidth of a single-user and not along the bandwidth shared by different users. Therefore, regarding to a single-user the contiguous occupied bandwidth of TIBWB-OFDM is the same as for conventional CP-OFDM and previous proposed BWB-OFDM techniques. Regarding the achievable diversity gain, while the spread of the replicas associated with each user along a large bandwidth as in [15,16], may help to decrease the correlation between these replicas (when compared to the TIBWB-OFDM) for the case of channels with low frequency selectivity, this is not the case for severe frequency selective scenarios (such as the ones considered in this paper) where the low correlation between the spectrum replicas of a user is also easily guaranteed for TIBWB-OFDM, with all the mentioned methods experiencing as so similar diversity gains.

This paper is organized as follows. To understand how the deep fading occurrences can be dealt with, the transmitted BWB-OFDM signal is presented in Section 2, and analyzed in order to provide a suitable solution to increase its robustness in hostile environments. The new TIBWB-OFDM scheme is presented in Section 3, where it is shown that it provides the same advantages as the BWB-OFDM scheme, since it is built on it, ensuring, at the same time, a considerable gain in BER performance. An IB-DFE receiver for the new TIBWB-OFDM scheme is proposed in Section 4. Main performance results on BER and power efficiency are presented and discussed in Section 5. Final conclusions are drawn in Section 6.

Throughout this paper the following notation will be employed: capital bold lettering (e.g., $\mathbf{S}_k$) is used to refer a block/vector of samples at the frequency domain, and lower-case bold lettering (e.g., $\mathbf{s}_n$) to denote a block/vector of samples at the time domain, while non-bold capital (e.g., S_k) or lower-case lettering (e.g., s_n) are used to denoted the symbols/samples of each of those block/vectors, respectively.

2. Inband deep fading effects

2.1. OFDM vs. BWB-OFDM

A BWB-OFDM symbol is a set of packed blocks resulting from cyclic extension and windowing of the baseband conventional OFDM symbols [6]; conventional OFDM symbols are assumed to have length N, and duration $N_{sym} > N$ after adding the cyclic extension and performing windowing. The procedure is illustrated in Fig. 1, where a set of N_s windowed OFDM symbols, $\mathbf{s}_{w,i}$ (with $i = 1, \dots, N_s$ and where subscript w stands for windowed) are packed together to form a BWB-OFDM symbol, $\mathbf{s}_B$. Analytically, a BWB-OFDM symbol can be expressed as a packed sum of juxtaposed OFDM symbols, delayed by multiples of the windowed OFDM's symbol duration, N_{sym}, and so, can be written as

$$s_B[n] = \sum_{m=0}^{N_s-1} s_{w,m}[n - mN_{sym}] \,, \qquad (1)$$