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Out-of-band power reduction by using computationally efficient cancellation pulses

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ABSTRACT

Cancellation carrier technique is a well-known out-of-band (OOB) power suppressing method in orthogonal frequency-division multiplexing (OFDM) overlay systems. In this technique, OOB power emission reduction is achieved by employing additional carriers, known as cancellation carriers (CCs), and optimizing their amplitude and phase in order to satisfy the desired spectral mask. The more CCs we employ, the deeper spectrum mask we achieve; however, it is shown in this paper that the computational complexity of this optimization algorithm dramatically grows by increasing the number of total employed CCs. In order to reduce the complexity of this method, a class of unique offline-optimized cancellation pulses is introduced which can perform as well as conventional sinc-shaped CC, but with considerably less computational complexity. In fact for a particular set of reserved cancellation tones, we need fewer proposed cancellation pulses to suppress a certain amount of OOB radiations. Therefore, the number of parameters in the optimization algorithm is reduced and consequently the computational complexity is decreased. This complexity reduction has been achieved at no extra side cost in system performances.

1. Introduction

Due to emersion of new wireless standards and plethora of demands to lease empty spectral resources, the telecommunication world has faced an exhaustive challenge. The report of spectrum efficiency working group of Federal Communication Commission in 2002 revealed that a large amount of licensed spectrums, such as TV bands, are underutilized [1,2]. Recently, Cognitive Radios (CRs) are considered as a promising solution to the current inefficiency of the radio spectrum. CRs are intelligent and adaptive transceivers which are able to make opportunistic and dynamic access to unused portions of the spectrum by adapting the radio's operating parameters so that no significant interference threatens adjacent licensed bands [3–5]. Obviously, the type of the employed air interface technique should be such that the delivered service quality to the licensed users are kept unchanged while the spectral efficiency of CR user is being maximized [6].

Orthogonal frequency division multiplexing (OFDM) multicarrier technique is a promising air interface candidate in spectrum pooling overlay systems for its ability to transmit data at high rates on non-contiguous frequency bands. However, OFDM suffers from high side-lobes of its sinc-shaped subcarriers due to rectangular windowing of time domain symbols. Therefore, the spectrum of a baseband OFDM signal does not accomplish a high spectral containment in out-of-band (OOB) regions. In the sequel, unwanted interference is applied to adjacent frequency bands even if an ideal power amplifier has been employed in radio frequency (RF) section [6]. That is why most of the OFDM based communication standards such as IEEE 802.22 and 802.16e, employ some frequency guard bands (null subcarriers) at both side ends of the spectrum along

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with adjusting power amplifier parameters to satisfy the spectral mask constraint. In fact, there is no transmitted energy on these subcarriers to enable the signal naturally to decay and prevent energy into adjacent bands. However, this is achieved by sacrificing considerable bandwidth.

Recently several signaling [7–20] and pre-coding [21–24] approaches for reducing the intrinsic OOB power of an OFDM system have been proposed which outperform the conventional OFDM with guard bands. These techniques can mitigate the OOB radiations considerably without sacrificing much bandwidth. Instead, they come at the costs of small degradation of the system performances such as peak to average power ratio (PAPR) and bit error rate (BER) which often can be ignored due to insignificance. Windowing [9,10,20], cancellation carrier (CC) [7–11], active interference cancellation (AIC) [15,16], partial response signaling [13], orthogonal projection [23], constellation adjustment [12], are some of these important techniques.

Among all these methods, the CC method is more investigated in the literature for practical implementation of the OFDM-based systems due to its ease of use, ability to suppress large enough OOB power, and backward compatibility to the conventional OFDM based systems [7–11,25]. In the CC method, a few reserved subcarriers at both edges of the signal spectrum, known as cancellation carriers (CCs), are dynamically weighted by complex gains under a particular constraint so that the total spectrum leakage of each transmitted symbol in the OOB regions is minimized [7]. The weights of CCs are determined using constrained minimum mean square error (MMSE) optimization algorithm under the constraint that the transmission power of the CCs does not exceed a predefined percentage of the total power budget per each symbol.

The CC technique is the improved version of the AIC method. In the AIC [16], modulations of the subcarriers at the OOB (null tones) and the guard band (auxiliary protection tones) inserted at both sides of the spectrum are tuned by a non-constrained MMSE optimization so that the leakage power at the OOB regions is minimized. Results demonstrated in [16] show that the auxiliary protection tones (they are equivalent to the CCs in the conventional CC method) play a dominant role in side-lobes suppression, and null tones have small magnitudes compared with them. However, since the data carried by tones for OOB suppression are obtained as a solution of the unconstrained optimization algorithm, they may have large magnitudes which overshoot the spectrum mask. Hence, this method is not preferred for practical implementation of the OFDM systems. However, in an OFDM system, the improved version of AIC, known as the CC method in the literature, is considered as a candidate of spectrum shaping.

The performance of the CC has been extensively investigated, recently. A slight improvement in OOB suppression capability of the CC method by using constrained weighted MMSE (WMMSE) algorithm instead of solving the constrained conventional MMSE algorithm has been reported in [8]. Since the data signal spectrum tends to decrease as frequency gets far from the data carriers, its contribution is considerable at the frequencies near the data subcarriers. Thus, the author of [8] proposed the WMMSE criterion instead of the MMSE optimization to find out the CCs weights. In [9], it has been shown that the suppression capability of the CC method is sensitive to the cyclic prefix (CP) length. However, it has been suggested in [24] that using the well known zero prefix (ZP) could simply resolve the difficulty. Moreover, authors in [7,9,11] have shown that OOB suppression using the CC method comes at a few costs including (1) spending a certain amount of extra transmission power for the cancellation in addition to the power assigned to data carriers for transmitting each OFDM symbol. However, increasing the transmission power may not be always possible due to constraints on the total power and the maximum power allowed per carrier. In such cases, the particular percentage of a given transmission power budget is dedicated to the CCs. In the sequel, BER of the target system will be increased slightly. (2) Slight augmentation in PAPR. (3) Increase in computational complexity which depends dramatically on the number of employed CCs. (4) Very slight degradation of spectral efficiency since no effective data are sent via CCs.

Naturally, degree of freedom in suppressing the OOB radiations increases by growing the number of employed CCs in the optimization algorithm. Obviously, by employing more CCs, more OOB suppression can be achieved, and consequently less interference threatens neighboring licensed users [11]. Therefore, to obtain a good protection level for the primary system and to satisfy stringent spectral mask constraints, one may need to employ more CCs. However, this makes the system computationally expensive since complexity of the MMSE (or the WMMSE) algorithm dramatically depends on the number of its parameters, i.e. the employed CCs.

In this paper, the CC method of [7] is improved along the direction of computational complexity reduction. On the complexity reduction, we rely on finding better than sinc-shaped cancellation pulses so as to get the same OOB suppression as with the CC method, fewer proposed pulses can be used in the optimization algorithm. We propose a class of semi-orthogonal offline optimized cancellation pulses which are referred here as improved cancellation pulses (ICPs). We define improved cancellation carrier (ICC) method as the CC method that adopts the ICPs in its optimization algorithm. The ICPs, unlike the conventional sinc-shaped CCs, hold more than one subcarrier, but they exhibit an overlapped arrangement in the frequency domain. It means that while the number of employed CCs in a conventional method is equal to the number of reserved cancellation subcarriers, fewer overlapped ICPs can occupy these spectral resources in our proposed method. We estimate the computational complexity of the optimization algorithms used in the CC and ICC methods and demonstrate that the ICC method performs as well as the CC in OOB suppressing, but with significant less computational complexity.

The rest of the paper is organized as follows. The basic concept of cancellation carrier method is discussed in Section 2. In Section 3, design of the computationally efficient ICPs are presented, and methodology of employment in an OFDM system is fully described. In Section 4, implementation of the optimization algorithms for both the CC and