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PAPR reduction for LDPC coded OFDM systems using binary masks and optimal LLR estimation

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ABSTRACT

A probabilistic PAPR reduction method using binary masks is proposed for OFDM systems. The binary masks are used to generate multiple signal candidates containing the same information. The candidate with the lowest PAPR is selected for transmission. In the presence of a non-linear amplifier (soft limiter), as the number of candidates increases, the PAPR is reduced, resulting in the reduction of clipping distortion power. Taking into account both distortion and channel noise, we derive the analytical total noise power to estimate the log-likelihood ratio (LLR), which is then used to enhance the decoding performance. We derive a minimum achievable E_b/N_0 and a decoding threshold for LDPC codes in the presence of the soft limiter. Simulation results show that our LLR estimation improves the error performance, and multiple candidate system lowers the error rate.

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1. Introduction

Orthogonal frequency division multiplexing (OFDM) is a multi-carrier multiplexing technique, where data is transmitted through several parallel frequency sub-channels at a lower rate. It has been popularly standardized in many wireless applications such as Digital Video Broadcasting (DVB), Digital Audio Broadcasting (DAB), High Performance Wireless Local Area Network (HIPERLAN), IEEE 802.11 (WiFi), and IEEE 802.16 (WiMAX).

A significant drawback of the OFDM-based system is its high peak-to-average power ratio (PAPR) at the transmitter, requiring the use of a highly linear amplifier which leads to low power efficiency [1,2]. For reasonable power efficiency, OFDM signal level should be close to the non-linear area of the amplifier, going through non-linear distortions and degrading the error performance.

The classical approaches to alleviate this problem in OFDM-based systems can be classified into five categories: clipping and filtering [3–5], coding [6–8], frame superposition using reserved tones (TR) [9–11], expandable constellation points: tone injection (TI) [11] and active constellation extension (ACE) [12,13], and probabilistic solutions [14–23].

The clipping and filtering method [3–5] deliberately clips the OFDM symbols. Therefore, this method may cause significant in-band distortion which degrades the error rates, and out-of-band noise which reduces the spectral efficiency.

TR methods reserve several subcarriers or pilot tones for minimizing the PAPR at the expense of spectral efficiency [9–11], and both TI and ACE methods require more power due to extended constellation points [11–13].

Probabilistic methods are distortionless without additional power increase. The principle of probabilistic methods is to reduce the probability of high PAPR by generating several OFDM symbols carrying the same information and by selecting the one having the lowest PAPR. Partial transmit sequence (PTS) [14–17], selected

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mapping (SLM) [17–20] and interleaving [21–23] are well-known probabilistic methods.

In probabilistic methods, the receiver has to recover the information from the received candidate. There are two solutions to solve this problem: blind detection [19,20,24,25] which implements maximum likelihood processing, and side information transmission, where the side information indicates which candidate has been sent at the transmitter. The first one is quite complex for handheld devices. The second one requires the side information to be sent on an error free channel.

One way to send the side information is to concatenate it with the information stream [21–23]. This side information is so important that it should be protected by a channel code. For that, channel coded side information can be embedded into the original data. The loss of spectral efficiency is not so important since the number of bits dedicated to side information is usually negligible compared to the redundancy of the error correcting code.

Channel coding has also been proposed to generate multiple candidates in [26–30]. In this technique, multiple uncoded-candidates are generated by inserting different labels into the original data frame. These labels may consist of several bits. Each uncoded-candidate is encoded, modulated, and IFFTed to finally generate multiple time domain OFDM candidates. Then, the one with the lowest PAPR is selected and transmitted.

At the receiver, the error correcting code decoder is performed, and then, the original data bits are recovered by truncating the label bits. However, the performance in PAPR reduction depends on the channel coding scheme: this comes from the high correlation between the candidates. For example, a systematic code needs an interleaver to improve the PAPR reduction [27]. Also, when a convolutional code is used, non-recursive codes should be avoided [29,30].

To improve the benefit of error correcting codes in PAPR reduction, soft decoding should be implemented. However, when a non-linear amplifier is considered, coded OFDM symbols go through two kinds of noise: distortion due to the non-linear amplifier and channel noise. In this case, the distortion depends both on the non-linearity of the amplifier and on the PAPR reduction capability.

In this paper, we present a binary mask framework to generate multiple signal candidates using error correcting codes. High PAPR reduction is achieved regardless of the coding method. In addition, we derive the log-likelihood ratio (LLR) in the presence of a non-linear amplifier from the complementary cumulative distribution function (CCDF) of the PAPR, so as to improve the decoding performance.

2. Binary mask framework

2.1. Notations and definitions

An OFDM signal is the sum of N independent signals over sub-channels of equal bandwidth and regularly spaced with frequency. At the transmitter, N modulated data symbols $\mathbf{F}=[F_0,F_1,\ldots,F_{N-1}]$ in the frequency domain are transformed via an N-point inverse discrete Fourier transform (IDFT) to the discrete time domain OFDM symbol $\mathbf{T}=\{T_0,T_1,\ldots,T_{N-1}\}$:

$$T_m=\frac{1}{\sqrt{N}}\sum_{k=0}^{N-1}F_k\cdot e^{j2\pi km/N},\quad m\in\{0,1,\ldots,N-1\}. \tag{1}$$

Then, the PAPR λ for the N OFDM samples with the Nyquist rate is given by

$$\lambda=\frac{\max_{m\in[0,\ldots,N-1]}|T_m|^2}{\frac{1}{N}\sum_{m=0}^{N-1}|T_m|^2}. \tag{2}$$

A binary mask $\mathbf{m}^{(u)}$ is a binary vector which is added to the binary information vector $\mathbf{d}$ to generate the uth candidate $\mathbf{d}\oplus\mathbf{m}^{(u)}$, where $u\in\{1,\ldots,U\}$.

As illustrated in Fig. 1 for $U=4$ candidates, the original data vector $\mathbf{d}$ is the concatenation of the all zero vector of length $L_I \geqq \lceil\log_2(U)\rceil$ with the binary data vector of length L_D. The binary mask $\mathbf{m}^{(u)}$ is also the concatenation of two binary subvectors: the index bits $\mathbf{m}_I^{(u)}$ of length L_I and the data mask $\mathbf{m}_D^{(u)}$ of length L_D.

We will distinguish two families of binary masks: the first one is the identical data mask family, denoted IDM (L_I, U), where all the data masks $\mathbf{m}_D^{(u)}$ are equal and can be set to all zeros for example; the second one is the random data mask family, denoted RDM(L_I, U), where all the data masks $\mathbf{m}_D^{(u)}$ are different and are randomly chosen once for all.

The IDM(L_I, U) family is a particular case of RDM(L_I, U), and it corresponds to the label insertion method as described in [26–30].

Fig. 2 illustrates the binary mask based transmission system for PAPR reduction. A binary data $\mathbf{d}$ is channel encoded and modulo-2 added by $\mathbf{m}_\mathbf{c}^{(u)}$ to generate U candidates (codewords), where $\mathbf{m}_\mathbf{c}^{(u)}$ is the channel encoded version of the binary mask: $\mathbf{m}_\mathbf{c}^{(u)}=\mathrm{EnC}(\mathbf{m}^{(u)})$. Note that we consider linear channel codes in this paper. So the encoding process can be indifferently placed before or after the mask addition. We may introduce interleavers before the modulation processing to avoid high correlation between candidates, especially when systematic

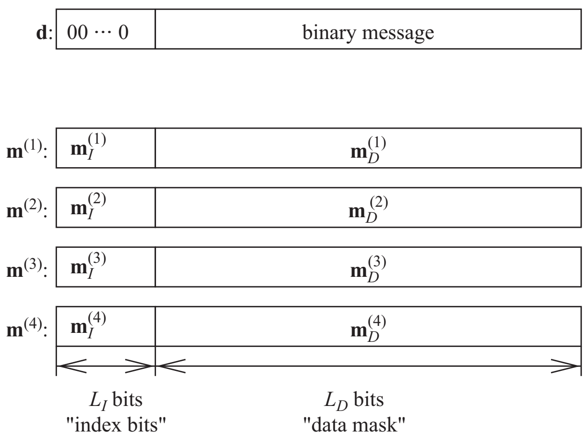

Fig. 1. Binary mask definition for $U=4$ candidate case, where $\mathbf{d},\mathbf{m}^{(1)},\mathbf{m}^{(2)},\mathbf{m}^{(3)},\mathbf{m}^{(4)}\in\{0,1\}$.

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