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Comparison of Channel State Information Estimation Using SLM and Clipping-based PAPR Reduction Methods

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Abstract

Channel estimation is a crucial issue in orthogonal frequency-division multiplexing (OFDM) as well as in all multicarrier systems. However, OFDM suffers from a major setback, the peak-to-average power ratio (PAPR). PAPR can be solved using a number of available techniques in literature, such as coding, active constellation extension, amplitude clipping, and selected mapping. The coding approach presents a disadvantage, represented by redundant data that significantly reduce the bit rate. The active constellation extension is an effective method; however, it requires higher transmission power. The clipping method is the simplest, but it produces high bit error rate (BER) degradation. Selected mapping (SLM) is the best among the available methods; however, it sends several bits as side information. In this study, we compare the clipping and SLM methods and show how the channel state information (CSI) estimation is affected in both techniques. Simulation results show that the SLM method is more effective than the clipping technique. The BER significantly increases when the clipping method is used because of the inaccurate estimation of CSI when the high peaks are clipped, such as in the case of the inserted pilots.

Keywords: Channel state information; channel estimation; clipping; SLM; PAPR reduction.

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1. Introduction

Orthogonal frequency-division multiplexing (OFDM) has become important in many applications during the last decade because of its advantages. OFDM can provide high data rates as well as handle multipath channels without requiring complicated equalizers. Given the importance of such a system, the channel state information (CSI) is estimated to provide good quality for the delivered data. Two main methods are used to estimate the CSI: blind and non-blind. The blind method does not send pilots (at least explicitly), whereas the non-blind sends the inserted pilots to estimate the CSI. The pilot insertion-based channel estimation is subdivided into two approaches: the block type and the comb type [1-5]. The comb type is the most applicable for multipath channel estimation purposes [1].

However, one of the crucial problems in the OFDM system is the peak-to-average power ratio (PAPR). A number of techniques can be used to reduce the PAPR values, such as the block-coding technique [6], active constellation extension [7], amplitude clipping (AC) [8-9], and the selected mapping (SLM) [10-11]. Several other methods have been reported in literature [12]. However, this study focuses only on the AC and the SLM-based methods. A new problem that arises when the PAPR reduction methods are applied is the distortion of the pilot tones before these are sent to the multipath channel. This problem is addressed in this study using the AC-technique, wherein the high peaks are cut off to reduce the PAPR. In a normal case, the pilot tones are inserted at high power (high peaks). All data are then subjected to the PAPR reduction block to remove the high peaks, which results in the inaccurate estimation of CSI by the receiver.

If the SLM-based PAPR reduction method is used instead of the AC approach, some phases of the inserted pilots would change. However, this change would not affect the CSI estimation at the receiver. These phenomena are discussed in the subsequent sections of the paper.

2. OFDM principles and PAPR formulation

An OFDM symbol consists of N-subcarriers that can be formulated as [9],

$$x(k) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X(n) e^{j2\pi \frac{kn}{N}} \tag{1}$$

where k and n = 0, 1 … N-1 are the time and frequency indices, respectively, and $X(k)$ is the modulating data drawn from a randomly generated multiple quadrature amplitude modulation (M-QAM) or multiple phase-shift keying (M-PSK) bit mapping. Eq. (1) shows a total of N sinusoidal subchannels. That is, Eq. (1) is the inverse discrete Fourier transform (IDFT) of the input sequence $X(k)$. Thus, the utilization of the IDFT will make the OFDM system make high efficiency for the available spectrum (or the total bandwidth). Practically, an efficient fast version of the IDFT/DFT will be used (fast Fourier transform (FFT)/ inverse FFT (IFFT)).

Thus, in-phase sinusoids may be added coherently (constructive summation). Hence, high peaks are produced compared with the average power. This phenomenon is called PAPR, which can be mathematically formulated as

$$PAPR = \frac{\max\left(|x(n)|^2\right)}{P_{avg}} \tag{2}$$

where P_{avg} is the average power. Fig. 1 shows a block diagram of the OFDM system. It is shown that the OFDM will be first do mapping for the input data (constellation mapping such as M-QAM/PSK), parallelize the output of the map-er, then the pilots will be inserted. Then after, the PAPR reduction scheme to pass the output to the IFFT process, then serialize the output to insert the cyclic prefix. At the receiver, the reverse of the aforementioned sequence of operations will be used to recover the original data. The pilots are inserted prior to PAPR reduction. Hence, the pilot tones are affected differently during each PAPR reduction method.

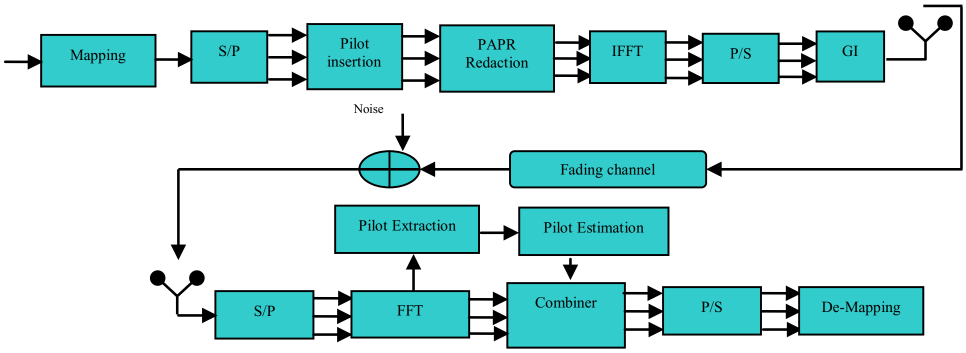

Fig. 1. Block diagram of an orthogonal frequency-division multiplexing (OFDM) system, which includes a peak-to-average power ratio (PAPR) reduction block.

3. Channel estimation using the least-squares-errors (LSE)

Fig. 2 shows the pilot insertion in each OFDM symbol. In this study, this comb-type arrangement is used with the multipath channel estimation methods. To understand the LSE method, the multipath channel must first be understood. The multipath channel can be mathematically formulated as [1]

$$h(t,\tau)=\sum_{k=0}^{N-1} a_k(t)\cdot\delta(t-\tau_k) \tag{3}$$

where a is the amplitude of each path and τ is the time delay. In Eq. (3), a is normally distributed and statistically independent. The signal at the receiver side is [1]

$$\hat{X}=\tilde{X}W_P\hat{h}+G \tag{4}$$

where $\tilde{X}$ is the pilot, P is the number of pilots, $\hat{h}$ is the CSI, G is the additive white Gaussian noise, and W_P is the discrete Fourier transform (DFT) matrix. LSE can then be expressed as

$$B=\left|\hat{X}-\tilde{X}W_P\hat{h}\right|^2 \tag{5}$$

By ignoring the noise, the CSI can be obtained using the LS method, as follows:

$$\tilde{h}=W_P^{-1}\tilde{X}^{-1}\hat{X} \tag{6}$$

If Eq. (9) undergoes DFT, we obtain,

$$\tilde{H}=\tilde{X}^{-1}\hat{X} \tag{7}$$

The LSE-based estimation method is the simplest technique to obtain the CSI because it assumes that the noise is zero. At the least, this technique gives the initial channel parameters, which is sufficient for our study. Therefore, the LSE-based method was employed in this paper.

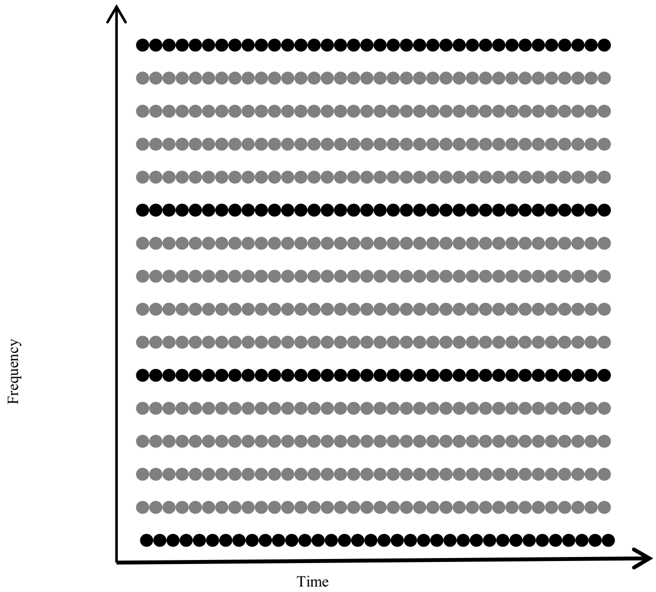

Fig. 2. Comb-type pilot distribution; the filled squares represent pilots.

4. AC- and SLM-based PAPR reduction techniques

PAPR reduction has become a highly popular topic for many researchers. As stated in the introduction, a number of methods can be used to reduce the PAPR at varying costs. The simplest method is amplitude clipping. This method can be stated as follows: the high power peaks produced after the inverse fast Fourier transform (IFFT) processes must be cut off, as follows:

$$B(x)=\begin{cases} x, & |x|\le A \\ Ae^{j\varphi(x)}, & |x|>A \end{cases} \tag{8}$$

where $\varphi(x)$ is the phase of x. Hence, a threshold A determines the subchannel that should be reduced. As previously stated, the pilots are inserted prior to PAPR operation, which results in their corruption when the AC method is used; that is, the amplitudes of the pilot tones will be cut-off according to the threshold value (A), thus, the receiver will not be able to recognize the pilot tones among the whole OFDM symbol, where the pilot's amplitudes will be similar to that of the data that suffers cutting.

The second method used to reduce PAPR is SLM [10-11]. The SLM approach is sometimes called the multiple signal representation. In this method, the signal is copied U times before it is fed to the IFFT block, such that the IFFT processes have U similar blocks. All copies are multiplied component-wise using their corresponding phase rotation vector, followed by the checking of the PAPR at the output of each IFFT block. The block that produces the lower PAPR is adopted for signal transmission, along with its corresponding phase rotation vector index u (u=1, 2…U) as side information. These procedures show that the pilot magnitudes are not corrupted, and that the CSI can be properly estimated at the receiver. However, the phase rotation sequences are unity-power, that is, no change in the constellation mapping will be noticed, thus, no BER degradation will be produced at the receiver or even no need for extra transmitting power.

The above two approaches based PAPR reduction will be simulated numerically in the next section. It will be shown that the AC-scheme will deeply affect the channel estimation process, while the SLM-approach will produce better channel estimation behavior but at the expense of the computational complexity.

5. Results and discussion

The simulation results for the two PAPR reduction techniques are discussed in this section. The exact effects of the clipping method on the inserted pilots (i.e., distortion) are also presented. Fig 3 shows the estimated CSI for an OFDM system of 256 subcarriers, a comb-type pilot arrangement of period 8, and a random multipath channel with a length of 30 taps has been employed. As explained previously, AC-scheme is a non-linear operation and therefore it needs a filtering operation after the clipping function. However; the results is that the amplitudes of the pilot subcarriers have been cut, that is, some of the subcarriers that also have been cut-off, now have the same amplitudes of the cut-off pilots which is equal to A. in other words, the estimation operation will not be successful.

On the other hand and as a comparison, the CSI is correctly estimated without the use of any PAPR reduction method as shown in Fig. 3, and the CSI estimation is accepted. However, when employing the SLM-scheme, the CSI was also highly accurate (i.e., no errors) because only the phases of the pilots are modified by SLM, and the channel estimation solely depends on the magnitude. Therefore, the benefit of using the SLM is that the channel estimation process will performs correctly. However, the clipping method destroys the amplitudes of the pilots, thereby resulting in the inaccurate estimation of the CSI, as shown in Fig 3. The cost for correct channel estimation that should be paid is the increased complex computations due to the multiple copies of the IFFT operations at the transmitter.

On the other hand, the BER is degraded when the CSI is incorrectly estimated as depicted in Fig 4. The BER is degraded when the clipping and filtering method was employed, whereas the SLM method does not degrade the BER performance. The reason was explained above which is that the amplitude of the subcarriers will not be affected during the SLM approach, while during the amplitude clipping, it will be distorted by the amplitude threshold.

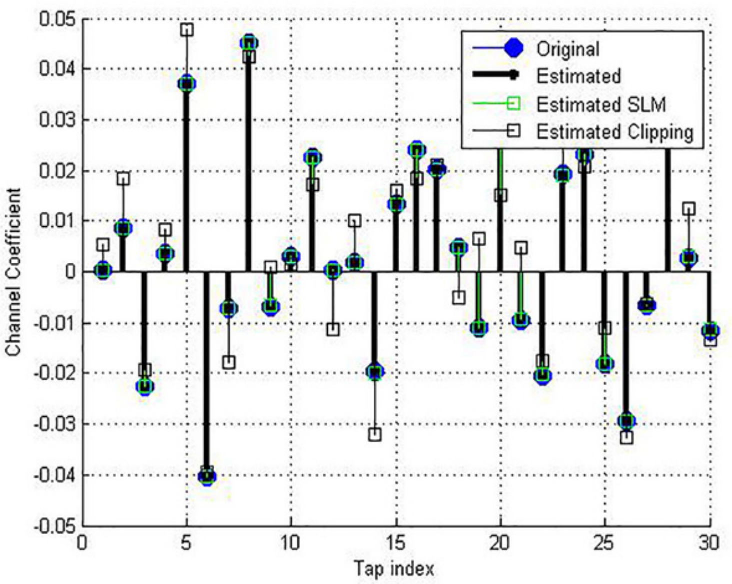

Fig. 3. State information (CSI) estimation using the PAPR reduction methods for a comb-type pilot distribution.

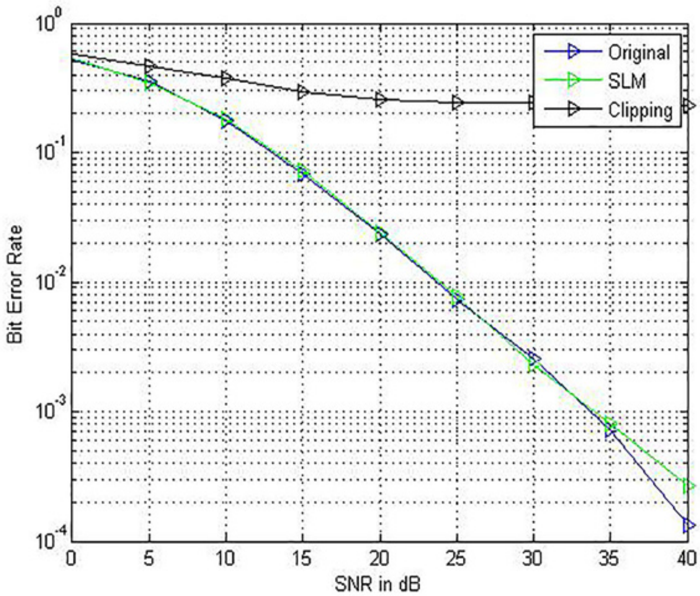

Fig. 4. Bit error rate (BER) performance using the selected mapping (SLM) method as well as the clipping and filtering technique as compared to the original system.

6. Conclusions

The PAPR problem inherent to OFDM is addressed in this study. The reduction of the PAPR values is vital to a properly working system. A number of methods, such as amplitude clipping and filtering as well as selected mapping, are available in literature. However, not all PAPR-based reduction methods can be used, because some techniques, such as the amplitude clipping method, can corrupt the pilot channels. Therefore, PAPR-based reduction methods that change the absolute values of the pilot channels should not be used, or at least, some improvements to such PAPR based reduction approach should be introduced. However, methods such as the SLM, which affects only the phases are recommended since the channel estimation operation, do not considers the phase of the subcarrier in some situations.

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