A blind SLM receiver for PAR-reduced OFDM

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Abstract— **Selected mapping (SLM) generates a set of independent signals from an information sequence and transmits the signal with minimum peak-to-average power ratio (PAR). To recover data, the receiver is sent critical side information (SI) about the generation process. In this paper, a novel blind detection algorithm is developed for coded orthogonal frequency division multiplexing (OFDM) and SLM. The blind SLM algorithm performs well in both AWGN and fading channels in the presence of amplifier non-linearities.**

Key words - Maximum likelihood decoding, OFDM, pairwise error probability, peak-to-average power ratio, selected mapping, side information, trellis codes.

I. Introduction

OFDM is used for wireless communications due to its robustness against severe multipath fading [1]. Moreover, OFDM transceiver can be implemented efficiently using the fast Fourier transform algorithm. However, OFDM signals can have high PAR values [2]. Due to the non-linearities of transmitter power amplifiers, high PAR values of the OFDM signal generate out-of-band noise and cause inband distortion. Many solutions to the PAR problem have recently been proposed [3–8].

The SLM approach [9, 10] uses multiple signal representation to reduce PAR. In SLM one favorable signal is selected from a set of different signals all of which represent the same information. The complex baseband OFDM signal may be represented as

$$s(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} c_n e^{j2\pi n \Delta f t}, 0 \le t \le T_s \qquad (1)$$

where Δf is the subcarrier separation and $T_s = 1/\Delta f$. The subcarrier vector $c \in \mathcal{C}$, $c = (c_0, c_1, \ldots, c_{N-1})$ is a vector of N constellation symbols from a constellation $\mathcal{Q}$. $\mathcal{C}$ is an optional channel code such as a convolutional code or trellis code. Note that $\mathcal{C}$ is not related to SLM.

Let pseudo noise vectors

$$P_u = \left[e^{j\phi_0^u}, e^{j\phi_1^u}, \ldots, e^{j\phi_{N-1}^u}\right],$$

$\phi_n^u \in (0, 2\pi]$, $u \in \{0, 1, \ldots, U-1\}$. Also let $a \otimes b$ represent the vector product of a and b. For a given input frame c, the lowest PAR sequence $c \otimes P_{\tilde{u}}$, $\tilde{u} \in \{0, 1, \ldots, U-1\}$ is selected for transmission. It appears that the SLM receiver needs to know $\tilde{u}$. Clearly, $\log_2(U)$ bits are required to represent this information, which is of critical importance to the receiver. One solution is to reserve several subcarriers (i.e. pilot tones) for side information. In a frequency selective fading channel, such pilot tones may be lost and an irrevocable decoding error can occur. Extra protection bits may need to be sent and the total redundancy can thus exceed $\log_2(U)$ bits. A scheme without explicit side information is reported in [11]. Labels representing the side information are inserted as a prefix of the binary input data and passed through a scrambler. However, this scheme needs to send the labels together with the data for the descrambling operations although they are not explicitly used at the receiver.

In this paper, we present a novel blind decoding algorithm (ie. without the knowledge of the generation process at the transmitter) to recover SLM-OFDM. The blind SLM receiver utilizes (1)c_n's are restricted to a given signal constellation, (2) The set of P_u's is fixed and known a prior, (3) $c \otimes P_u$ and $c \otimes P_v$ are sufficiently different for $u \ne v$. The Hamming distance is N between any two P_u and P_v. The necessary condition for this method to work is $c_n e^{j\phi_n^u} \notin \mathcal{Q}$ for all n and u. The set of P_u can be chosen readily

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to ensure this.

More generally, let $f_j(c), j = 1, 2, \ldots, U$ are a set of U mappings of vector c. For a given c, let $f_{\tilde{u}}(c)$ have the minimum PAR. A blind receiver does not need to know $\tilde{u}$. For simplicity, let us assume a distortionless and noiseless channel. Now the receiver gets $f_{\tilde{u}}(c)$ and computes $f_j^{-1}(f_{\tilde{u}}(c))$ for $j = 1, 2, \ldots, U$. Note that $f_j^{-1}(f_{\tilde{u}}(c))$ will not be a vector of symbols from the constellation $\mathcal{Q}$ unless $j = \tilde{u}$. This is the basis of the blind receiver.

For coded OFDM, the blind algorithm can use minimum-distance decoding via the Viterbi algorithm. As linear block codes, convolutional codes and trellis codes have well-defined trellises our blind algorithm can be integrated into the channel decoder itself. For uncoded OFDM it is prohibitive to search all possible sequences and we thus derive a suboptimal metric. We compare our blind algorithm against an idealized receiver which has perfect side information. We show that the performance degradation is negligible for two particularly important cases (1) A non-linear amplifier is applied to OFDM signals with SLM (2) Subcarriers experience Rayleigh fading.

II. Blind SLM demodulation

Consider the received signal r_n after the FFT demodulation at the receiver

$$r_n = H_n c_n e^{j\phi_n^u} + \eta_n \tag{2}$$

where $j = \sqrt{-1}$, H_n is the frequency response of the fading channel at the n-th subcarrier and η_n is a complex additive white Gaussian noise (AWGN) sample. Let $r = [r_0, r_1, \ldots, r_{N-1}]$ and $H = [H_0, H_1, \ldots, H_{N-1}]$. The optimal blind SLM receiver uses the decision metric:

$$\mathcal{D} = \min_{\substack{[\hat{c}_0, \hat{c}_1, \ldots, \hat{c}_{N-1}] \in \mathcal{C} \\ P_{\hat{u}}, \hat{u} \in \{0,1,\ldots,U-1\}}} \sum_{n=0}^{N-1} \left| r_n e^{-j\phi_n^{\hat{u}}} - H_n \hat{c}_n \right|^2 . \tag{3}$$

This minimization can be performed as follows. The minimum-distance $H \otimes \hat{c}$ to $r \otimes P_0^*$ is determined, where P_0^* is the conjugate of P_0. This can be done by the Viterbi algorithm for coded systems or by searching all q^N data sequences for uncoded q-ary modulation. This process is repeated for $P_1, P_2, \ldots, P_{U-1}$. The global minimum-distance solution yields the best estimates for c and $\tilde{u}$. The overall complexity is U times that of COFDM without SLM.

Consider the QPSK constellation given by,

$$\mathcal{Q}_{\text{QPSK}} = \left\{ e^{j\pi m/2}, m = 0, 1, \ldots, 3 \right\}. \tag{4}$$

For the uncoded case, there are $UN4^N$, $|.|^2$ operations to solve (3). This is of very high complexity and can be performed only for small N. We next propose a suboptimal decoding metric with low complexity.

Suboptimal metric

Now $H_n^{-1} r_n e^{-j\phi_n^{\hat{u}}}$ is detected (ie. hard decision) into its nearest constellation point. That is, a hard decision is made for each subcarrier. This whole process is repeated for $0 \leq \hat{u} \leq U-1$. The minimum Euclidean distance solution yields the data sequence. The suboptimal metric can thus be written as

$$\mathcal{D}_{\text{so}} = \min_{P_{\hat{u}}, \hat{u} \in \{0,1,\ldots,U-1\}} \sum_{n=0}^{N-1} \min_{\hat{c}_n \in \mathcal{Q}_{\text{QPSK}}} \left| H_n^{-1} r_n e^{-j\phi_n^{\hat{u}}} - \hat{c}_n \right|^2 . \tag{5}$$

Now there are only $4UN$, $|.|^2$ operations to be performed.

III. Simulation results

An OFDM system with 256 quadrature amplitude modulation (QPSK) modulated subcarriers is used in all the simulations. For uncoded OFDM the suboptimal decoding algorithm (5) is used at the receiver. Performance of the blind detection algorithm (BSLM) is compared with a SLM scheme with perfect side information (PSI-SLM). Fig. 1 compares the performance in an AWGN channel. As expected, received data can be perfectly decoded using the blind detection algorithm. Fig. 2 compares the bit error rate (BER) of BSLM receiver and PSI-SLM in an AWGN channel and a soft-limiter (non-linearity) with back-off values 2 dB, 5 dB and 7 dB. BER is not degraded when using BSLM for these levels of back-offs at the soft-limiter.

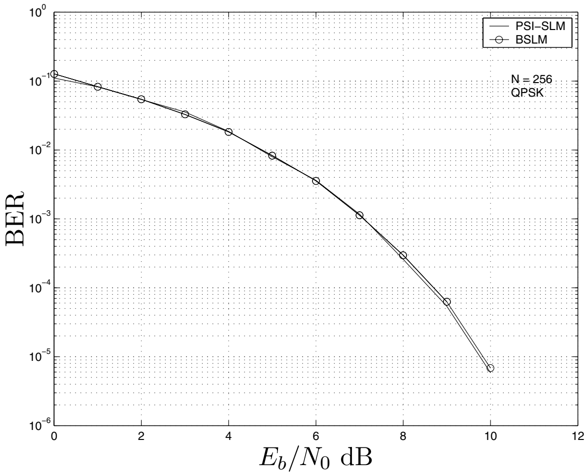

Fig. 1. BER performance in an AWGN channel

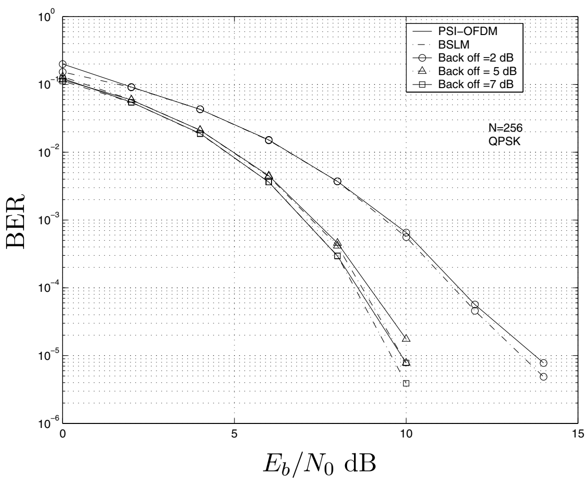

Fig. 2. BER performance in a soft-limiter and an AWGN channel.

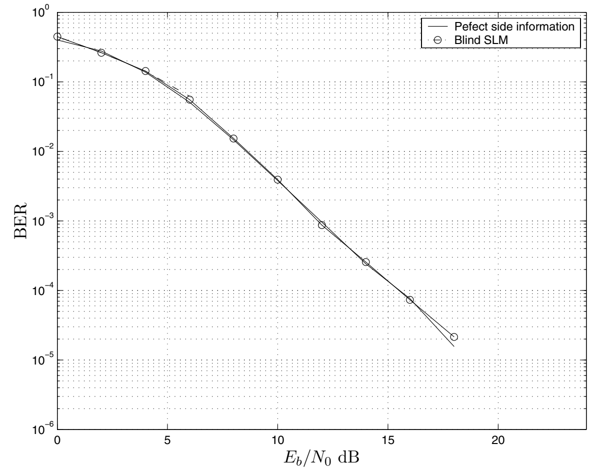

Fig. 3. BER performance in a Rayleigh fading channel with perfect CSI (8 states- 8PSK TCM coded OFDM).

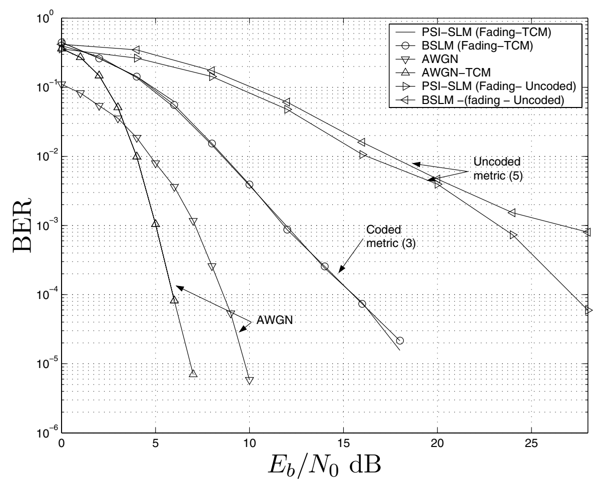

Fig. 4. Comparison of BER of PSI-SLM and BSLM in different channels with and without coding.

Having established the validity of our blind algorithm for an AWGN channel and non-linear channels, we next investigate its performance in fading channels. Trellis coded modulation (TCM) and Rayleigh fading are considered. TCM schemes employ redundant non-binary modulation and a finite-state encoder, which governs the selection of modulation signals to generate coded signals [12]. In the receiver, a soft-decision Viterbi decoder recovers the noisy signals. Non systematic, eight-state encoder with 8-PSK (phase shift keying) mapping is used in the simulations. Note that 8-PSK COFDM has the same spectral efficiency as uncoded QPSK-OFDM. Fig. 3 shows the BER of TCM coded OFDM signals in a Rayleigh fading channel. Perfect channel estimation (CSI) and ideal interleaving are assumed. Once again BER does not degrade for COFDM with our blind algorithm. However, BER is slightly degraded for BSLM if channel coding is not used as shown in Fig. 4.

Fig. 4 compares the BER of coded and uncoded OFDM signals in AWGN and Rayleigh fading channels. TCM-OFDM has about 13 dB gain in a Rayleigh fading channel and a 3 dB gain in an AWGN channel at a BER of 10^{-4}. The proposed BSLM algorithm can decode coded OFDM symbols completely in both AWGN and fading channels even in the presence of a non-linear amplifier.

IV. Conclusion

A novel blind detection algorithm is proposed to decode SLM-OFDM signals without side information. This algorithm performs equally well in both AWGN and fading channels without any BER degradation. It offers reliable performance in conjunction with trellis based forward error correction codes such as TCM. The proposed BSLM algorithm can decode coded OFDM symbols completely in both AWGN and fading channels even in the presence of a non-linear amplifier. The proposed suboptimal metric can be used to decode uncoded SLM-OFDM signals completely in AWGN channels and with a slight BER degradation in fading channels.

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