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Side Information Transmission Using Pilot Tones for PAPR Reduction of OFDM Signal

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ABSTRACT

One of the maindisadvantages of Orthogonal Frequency Division Multiplexing (OFDM) is the Peak to Average Power Ratio (PAPR) problem. To reduce PAPR and improve the error performance of the OFDM signal over a fading channel, an OFDM system combining an Adaptive Symbol Selection Scheme (ASSS) and channel estimation can be used. Because of the side information of ASSS, however, the data rate decreases in the conventional ASSS OFDM system. In this letter, to overcome this impairment, we propose a technique to transmit side information by using pilot tones, and demonstrate that the proposed technique can give reasonable bit error rate (BER) performance.

Key Words : Adaptive symbol selection scheme, Clipping, Rayleigh fading, Side information, OFDM

Ⅰ. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) is considered to be a promising technique for wireless communications. However, OFDM has a serious Peak to Average Power Ratio (PAPR) problem. There are many PAPR reduction techniques which are currently used to solve the PAPR problem[1]. These techniques can be divided into distortion techniques and distortionless techniques. For example, clipping technique[1] is the typical distortion technique, while the selected mapping (SLM) technique and the interleaving technique[1] are the typical distortionless techniques. Both SLM and interleaving technique use an adaptive symbol selection scheme (ASSS) in which one OFDM symbol with the smallest PAPR is selected from a number of statistically independent reference OFDM symbols[2]. ASSS can reduce the PAPR without signal distortion and need side information transmission. When the side information is transmitted with the data information, the transmitted data rate will decrease in some extent.

This paper does not provide a new PAPR reduction technique, but focuses on the transmission of side information for an adaptively selected OFDM signal over a Rayleigh fading channel. In the Rayleigh fading channel, the pilot tones are usually used for channel estimation. We propose a transmission technique in which the side information is inserted into the positions of the pilot tones and transmitted to a proposed receiver. In the receiver, side information is decided and used as the pilot tones for channel estimation. The numerical analysis and simulation result show that the proposed transmission technique and the receiver can increase the transmitted data rate, and will not obviously affect the channel estimation result.

Ⅱ. Background

An OFDM symbol can be expressed as the sum of many independent symbols modulated onto sub-channels of equal bandwidth. Let $X_k (k=0,1,..,N-1)$ de-

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note the input data symbol with period T. Then the complex representation of an OFDM symbol is given as

$$x(t) = \sum_{k=0}^{N-1} X_k \cdot e^{j2\pi k \triangle f t}, 0 \le t < NT \qquad (1)$$

where N is the number of subcarriers, and $\triangle f = 1/NT$ is the subcarrier spacing. The samples are denoted by $x_n (n = 0,1,...,FN-1)$ for the OFDM symbols with the sampling rate L. By the use of Nyquist rate sampling, which corresponds to the case of $F=1$, we have N samples for one OFDM symbol. In the following, we considered the sampling rate to be the Nyquist rate. The PAPR of the OFDM symbol is defined as the ratio of the peak power and the average power:

$$PAPR \equiv \frac{\max\left[|x_n|^2\right]}{E\left[|x_n|^2\right]}, n \in [0, N-1] \qquad (2)$$

where $E[.]$ denotes the statistical expectation function and $\max[.]$ gives the highest value among the samples.

2.1 Adaptive Symbol Selection Scheme

As a distortionless technique, ASSS can be used to reduce PAPR in which one OFDM symbol with the smallest PAPR is selected from a number of statistically independent OFDM symbols. The probability distribution of the samples'amplitude of the adaptively selected OFDM signal is related with the number of reference OFDM symbols[3]. As the number of reference OFDM symbols increases, the PAPR of the selected OFDM signal decreases. For U reference OFDM symbols, ASSS needs U IDFT operations and the number of bits for the required side information is at least $\log_2 U$. Usually, the side information is coded by a channel coding that will further increasethe length of side information.

2.2 Fading Channel and Channel Estimation

If the OFDM signal is transmitted through a frequency selective fading channel, in the frequency domain, the received OFDM signal is given as

$$Y_k = H_k X_k + V_k \qquad (3)$$

where V_k is AWGN and H_k is the channel gain on the kth subcarrier. The fading channel can severely degrade the error performance of the transmitted signal therefore, the channel estimation is necessary for a signal over a fading channel. For channel estimation, a simple least square (LS) method can be used by inserting the pilot tones in the subcarriers[4]. Assume the W pilot tones are equally spaced in the subcarriers with spacing of $J = N/W$ subcarriers. The estimated channel gain in the pilot tones can be given as

$$\widehat{H}_p = \left[\widehat{H}_{p_1}, \widehat{H}_{p_2}, ..., \widehat{H}_{p_w}\right] \qquad (4)$$

where $\widehat{H}_{p_z} = \frac{Y_{p_z}}{X_{p_z}} = H_{p_z} + \frac{V_{p_z}}{X_{p_z}}$, and p_z denotes the zth pilot tone placed in the p_z th OFDM subcarrier. Assuming the fading channel has L time delay paths, from equation (4), the channel response on the kth subcarrier can be calculated using LS as in[4]

$$\widehat{H}_k = Q_L (Q_p^* Q_p)^{-1} Q_p^* \widehat{H}_p \qquad (5)$$

where Q_p is a $W \times L$ matrix with the (z,l) element $e^{-j2\pi p_z l/N}$, $z = 1,2,..., W$, and $l = 1,2,...,L$, and Q_L is a $1 \times L$ vector with the lth element $e^{-j2\pi kl/N}$. By using the simple LS method, for a given channel, the expectation of the estimated channel is given as

$$E\left\{\widehat{H}_k | H_k\right\} = H_k, \qquad (6)$$

and the mean square error (MSE) of the estimated channel is given as

$$MSE_{H_k} = E\left\{\left|\frac{V_k}{X_k}\right|^2\right\}. \qquad (7)$$

Ⅲ. Proposed Method

In the conventional ASSS OFDM system, the side information is inserted into data information and separated from the pilot system. The OFDM symbol in the frequency domain can be presented in Fig.1 (a).The transmitted symbol over fading channel is given as

$$X_k = \{X_0, X_1, \dots, X_{N-1}\}, \tag{8}$$

where $X_0, X_J, \dots, X_{N-J}$ are the pilot tones.

In the presented method, the side information is inserted into pilot tones. Assuming half pilot tones are used for transmission of side information, the OFDM symbol in the frequency domain can be shown in Fig.1 (b). Comparing with Fig.1 (a), half pilot tones are replaced by side information. The pilot tones and the side information are expressed as

$$X_p = \{X_0, X_{2J}, \dots, X_{N-2J}\} \tag{9}$$

and

$$X_S = \{X_J, X_{3J}, \dots, X_{N-J}\}, \tag{10}$$

respectively.

Comparing with the conventional channel estimation, it seems that transmitting the side information in the pilot tones will seriously degrade the channel estimation result because few pilot tones are used for channel estimation. To improve the result of channel estimation for proposed transmission technique, a special receiver which uses iterative channel estimation is proposed in Fig. 2.

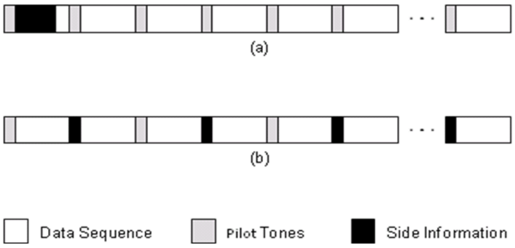

Fig. 1. OFDM symbols of (a) the conventional ASSS OFDM system and (b) the ASSS OFDM system using proposed transmission technique

The followingare the operational steps of the proposed receiver:

1) Transfer received signal y_n into the frequency domain to obtain Y_k and pick up Y_p, where Y_p is the received value of X_p over a fading channel.
2) Perform 1st channel estimation using Y_p to obtain the channel information $\widehat{H_k^{(0)}}$ as[4].
3) Divide Y_k by $\widehat{H_k^{(0)}}$ to obtain $\widehat{Y_k}$ and pick up $\widehat{Y_J}, \widehat{Y_{3J}}, \dots, \widehat{Y_{N-J}}$.
4) Decide side information using $\widehat{Y_J}, \widehat{Y_{3J}}, \dots, \widehat{Y_{N-J}}$, then the side information is considered as the additional pilot tones for 2nd channel estimation.
5) Perform channel estimation one more time to obtain channel information $\widehat{H_k^{(1)}}$ by using $\widehat{Y_0}, \widehat{Y_J}, \widehat{Y_{2J}}, \dots, \widehat{Y_{N-J}}$ with information of pilot tones and decided side information.
6) Divide Y_k by $\widehat{H_k^{(1)}}$ and use a hard decision to get $\widehat{X_k}$ as the estimated value of the kth subcarrier.

Using the special receiver, the degradation of channel estimation caused by side information can be reduced. The increased complexity of using the proposed receiver is the pre-channel estimation in step 2 and the division in step 3, where $N+N/2J$ vector divisions and a vector matrix calculation using equation (5) are needed.

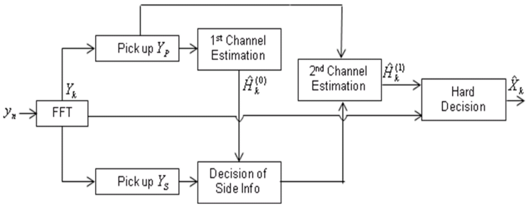

Fig. 2. The speical receiver for the ASSS OFDM system using proposed transmission technique

Ⅳ. Numerical Analysis

By transmitting the side information in the pilot tones, the additional subcarriers for the side information are not required. Table 1 shows the improvement in the transmitted data rate by using the proposed method to transmit the side information, where N is the number of subcarriers, W is the number of subcarriers for pilot and side information, U is the number of reference symbols for ASSS, S is the symbol rate (symbols/s) and $\lceil x \rceil$ is the ceiling function which gives the smallest integer $\geq x$.

The side information is normally coded before transmission. Assuming the coded side information is the ranks of the $U \times U$ Hadamard matrix, the hamming distance of any two pieces of side information is $U/2$. According to coding theory, we can correct $(U/2-2)/2$ errors. Therefore, in the proposed method, the error performance of the side information should have

$$\begin{aligned} P_e &= \Pr\{>(U/2-2)/2\, bits\, are \in correct\} \\ &= 1-\Pr\{\geq [U-(U/2-2)/2]\, bits\, are\, correct\} \\ &= 1-[C_U^{[U-(U/2-2)/2]}(1-P_b^{(0)})^{[U-(U/2-2)/2]} \\ &\quad (P_b^{(0)})^{(U/2-2)/2}+\ldots+C_U^{U-1}(1-P_b^{(0)})^{U-1}P_b^{(0)} \\ &\quad +C_U^U(1-P_b^{(0)})^U] \end{aligned} \tag{11}$$

where $C_a^b = \dfrac{a(a-1)\ldots(a-b+1)}{b(b-1)\ldots1}$, and $P_b^{(0)}$ is the bit error rate (BER) of the modulated symbol after the first channel estimation. Computer calculation has shown P_e approaches 0 for $P_b^{(0)} \ll 1$ and large values of U . P_e equals 0 means there is no symbol error in the side information. Therefore, when decided value of side information are used as the pilot tones for 2nd channel estimation, we can think the numbersof pilot tones are the same as that in the conventional ASSS system. So, the channel estimation result will not be degraded when $P_b^{(0)} \ll 1$ and U is a relatively large number.

Table 1. M-ary Modulation System

Metho.ds of transmitting side information	Number of subcarriers for side information	Symbol rate (symbols/s)
Transmitting in data information	$\geq \lceil \log_2 U / \log_2 M \rceil$	$\leq S/N \times (N-W- \lceil \log_2 U / \log_2 M \rceil)$
Transmitting in pilot system	0	$\leq S \times (N-W)/N$

Ⅴ. Simulation Result

We examined the performance of the proposed ASSS OFDM system by the computer simulation. For the computer simulation, QPSK and 16-QAM systems with 256 subcarriers were used. The interleaving technique was used as the adaptively symbol selection scheme, and there are 16 and 32 reference OFDM symbols for each OFDM symbol for QPSK system and 16 QAM system, respectively. The duration of guard interval is 1/4 of the duration of ASSS OFDM symbol.

ASSS OFDM symbols were transmitted over a frequency selective Rayleigh fading channel with four multi-paths including one direct path and three time delay paths. The first delay path was -10 dB less than the first direct path, and the second delay path was -20dB less than the first direct path, and the third path was -25dB less than the first direct path. The delays spread of 3 delay paths were two, three, and four samples period, respectively. The data rate is 25Mbps and the maximum Doppler frequency was 200Hz.

For each OFDM symbol, 16 subcarriers were used for pilot tones and coded side information. The coded side information for the ith reference OFDM symbols was the ith rank of 16×16 and 32×32 Hadamard matrices for QPSK and 16-QAM systems, respectively. The first pilot tone is in the first subcarrier and the total pilot tones were equally spaced with 32 subcarriers. The first subcarrier for coded side information is the 8th subcarrier and total subcarriers for coded side information were equally spaced with 32 subcarriers. The pilot tones and side information were transmitted at same power as the information signal, and the simple LS method was used for channel estimation.

In Fig. 3~Fig. 5, we compare the performance of the proposed ASSS system with the performance of a conventional ASSS system which transmit side information in the data information sequence. Fig. 3 shows the complementary cumulative distribution of PAPR of the adaptively selected OFDM signal and that of the non-selected OFDM signal. Because the proposed technique only concerns the transmitted data rate and channel estimation, the PAPR reduction ability of the ASSS is not affected by proposed technique. Therefore, the figure shows that the ASSS OFDM system using proposed technique has the same PAPR reduction ability as the conventional ASSS system.

Fig. 4 compares the MSE of the estimated channels obtained by proposed receiver and simple LS channel estimation. We can see, after the second channel estimation using the proposed receiver, the MSE of the estimated channels of the proposed ASSS system is almost the same as that of the conventional ASSS system. Therefore, the channel estimation performance is not degraded by transmitting side information in the pilot system.

Fig. 5 shows the error performances of the proposed ASSS OFDM system and the conventional ASSS OFDM system. We can see the BER performance of the proposed ASSS system gradually approaches to that of the conventional ASSS system as the E_b/N_0 increases. When E_b/N_0 is larger than 15dB for QPSK systems and larger than 10dB for 16 QAM systems, the ASSS systems using proposed transmission methods give nearly the same BER performance as the conventional ASSS system.

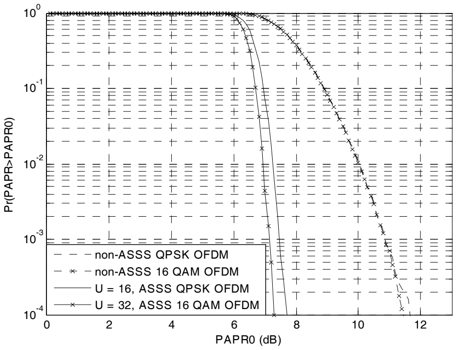

Fig. 3. Complementary cumulative distribution of PAPR of adaptively selected OFDM signal and that of non-selected OFDM signal

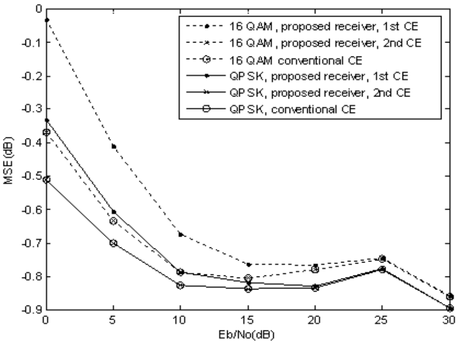

Fig. 4. MSE of the estimated channels obtained by proposed receiver and simple LS channel estimation

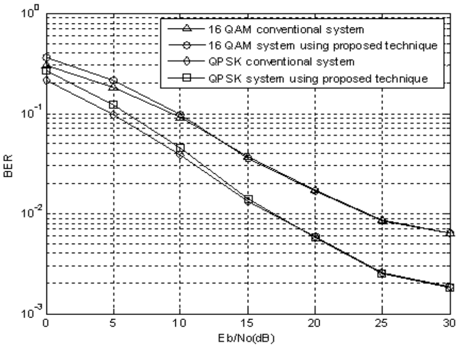

Fig. 5. BER performance of the ASSS OFDM systems in a frequency selective Rayleigh fading channel

Ⅳ. Conclusions

In this paper, we have presented a transmission technique for side information transmission of ASSS OFDMsystem over a fading channel. To reduce the degradation of channel estimation caused by the proposed transmission technique, a special receiver using iterative channel estimation method is proposed. The numerical analysis and simulation result demonstrate the ASSS OFDM system using proposed transmission technique has the same PAPR reduction ability as the conventional ASSS OFDM system but relatively higher transmitted data rate.

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