Reduction of Peak-to-Average Power Ratio of Multicarrier Modulation Signals with Adaptive Companding Scheme

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Abstract

High peak-to-average power ratio (PAPR) of transmitted signals is a major drawback in Multicarrier modulation (MCM) systems. Companding transform is a well-known method to reduce the PAPR without restrictions on system parameters such as the number of subcarriers, frame format and constellation type. In this paper, a novel adaptive companding scheme, mainly focuses on compressing the large signals into the desirable distribution, is proposed to reduce the PAPR with low implementation complexity. In addition, formulas to calculate its PAPR and bit error rate (BER) performance are also derived. Simulation results confirm that the proposed scheme can achieve an effective tradeoff between PAPR reduction and BER performance by carefully choosing the companding parameter.

Keywords: Multicarrier modulation (MCM), companding, peak-to-average power ratio (PAPR), high power amplifier (HPA)

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1. Introduction

Multicarrier modulation (MCM), such as orthogonal frequency division multiplexing (OFDM) [1], has drawn explosive attention in a number of wireless applications owing to the advantages of high spectral efficiency, robustness to frequency selective fading channel and easy implementation.
However, some drawbacks are still unresolved in the MCM systems. One of the major problems is the high peak-to-average power ratio (PAPR) [2], [3] of the transmitted signals. In MCM system, the peak power of the signal can be up to N times the average power (where N denotes the number of subcarriers), which requires the transmit power amplifier to have an extremely large dynamic range and significantly reduces the efficiency of the amplifier. Therefore, PAPR reduction schemes have attracted extensive research, and many methods have been presented, which can be divided in two groups. One group intends to reduce the occurrence of large signals before multicarrier modulation, among this group, PAPR can be reduced if the independence of MCM signals on different sub-channels is demolished by coding [4], selective mapping (SLM) [5], or the number of independent sub-channels is decreased by partial transmit sequence (PTS) [6], [7], or by using a peak-canceling signal (PCS) that satisfies the tone reservation (TR) [8], [9] and tone injection (TI) [9]-0 constraints. Nevertheless, these schemes achieve PAPR reduction at the expense of signal power increase, data rate loss, computational complexity increase and etc. The other group processes the MCM signals directly, such as clipping [12]-[14] and companding transform [15]-[19]. In [15], [16], it has been proved that the μ-law companding transform can reduce the PAPR more effectively than the clipping method. But its average power increases and the bit error rate (BER) performance remains high. Later, Jiang presented two nonlinear companding techniques, namely exponential companding (EC) [16] and error companding (ErC) [18], to overcome the problem of increasing average power and to have efficient PAPR reduction. These two schemes utilize a nonlinear operation to transform the original Gaussian distributed MCM signals into the uniform distribution and significantly outperform the μ-law companding scheme. However, the referred uniformly- distributed companding schemes result in large companding distortion noise. It follows that the BER performance is degraded when the transmitters employ a power amplifier with heavy nonlinearity.

In order to obtain more effective reduction in PAPR, we proposed a simple method in our previous work [19]. And yet, it cannot achieve an effective tradeoff between PAPR reduction and BER performance, which restricts the flexibility of the system. In this paper, further motivated by tradeoffs among BER performance, PAPR reduction, distortion noise, and transmit power of MCM systems, we propose an adaptive nonlinear companding scheme with low companding distortion noise. In addition, an inflexion point is derived to maintain the average power constant. Formulas for calculating its PAPR and BER are also presented. Simulation results indicate that the proposed scheme offers a better BER performance, PAPR reduction, and power spectrum than the EC and ErC schemes.

The outline of this paper is as follows. Section II describes the MCM system model and formulates the problem of high PAPR. Section III puts forth the proposed scheme and analyzes its PAPR, distortion noise and BER performance. In Section IV, the performance of the proposed scheme is evaluated through simulations and it is followed by conclusions in Section V.

2. MCM description system

In a typical MCM system, data symbols typically modulated by phase shift keying (PSK) or quadrature amplitude modulation (QAM) are transmitted independently on the subcarriers. The task of modulation is performed by an inverse discrete Fourier transform (IDFT) unit. The output samples produced are passed through a digital-to-analog (D/A) converter before being launched into the wireless channel. Here, in order to reduce the PAPR of MCM signals, we introduce a transform-based unit before the D/A conversion, as shown in Fig. 1. This unit is called companding transform (CT), which will be addressed in the next section in detail.

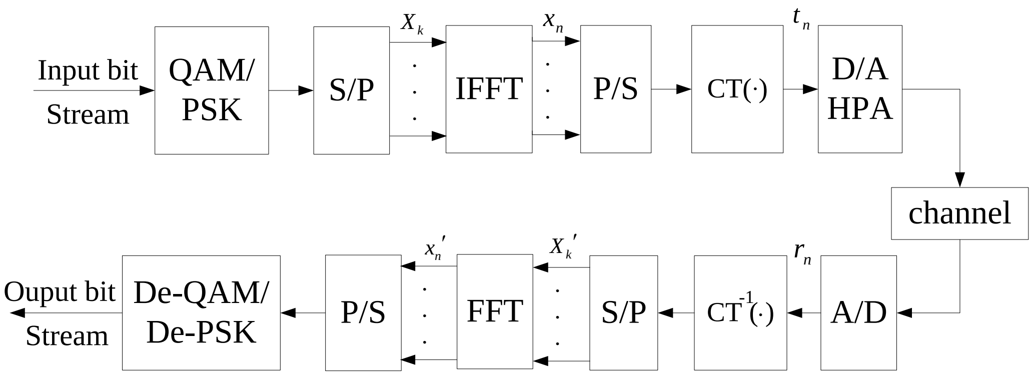

Fig. 1. Block diagram of an MCM system with the companding transform.

Let vector $\boldsymbol{X}=[X_0,\ldots X_k \ldots X_{N-1}]^T$ denote the input data block, where N is the number of subcarriers in the MCM system. Hence, the complex representation of an MCM signal consisting of N subcarriers is given by

$$x_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j2\pi nk\Delta f T/L}, \quad n=0,1,\cdots,NL-1, \tag{1}$$

where $j=\sqrt{-1}$, Δf is the subcarrier spacing, T is the sampling period, and L denotes the oversampling factor. Thus, each x_n can be seen as the sum of a large number of complex exponentials whose amplitudes, $|x_n|$, can be treated as Rayleigh distribution according to the central limit theorem, provided N is large. Thus, the probability distribution function (PDF) of $|x_n|$ can be written as

$$f_x(x) = \frac{2x}{\sigma^2} \exp\left(-\frac{x^2}{\sigma^2}\right), x \geq 0, \tag{2}$$

where $\sigma^2=E[|X_k|^2]/2$ is the variance of the original MCM signals. The cumulative distribution function (CDF) of $|x_n|$ can be expressed as

$$\begin{aligned} F_x(x) &= Prob\{|x_n| \leq x\} \\ &= \int_0^x \frac{2y}{\sigma^2} \exp\left(-\frac{y^2}{\sigma^2}\right) dy = 1-\exp\left(-\frac{x^2}{\sigma^2}\right), x \geq 0. \end{aligned} \tag{3}$$

The PAPR of the transmit signal is defined as

$$PAPR = 10 \cdot \log_{10} \frac{\max\limits_{0 \le n < NL-1} \left\{ |x_n|^2 \right\}}{E\left[|x_n|^2 \right]} (dB) \ , \tag{4}$$

where $E[\cdot]$ denotes the expectation operation.

By using the proposed companding transform in Section 3, the MCM signals are companded before they are converted into analog waveforms and amplified by the high power amplifier (HPA). The proposed companded signal t_n is given by

$$t_n = C(x_n), \quad (0 \le k \le N-1) \tag{5}$$

where $C(\cdot)$ is the proposed companding function that changes only the amplitudes of input signals. Then MCM signals are transmitted into the radio channel.

Consider an additive white Gaussian noise (AWGN) channel, the received signal r_n after the analog-to-digital (A/D) conversion can be expressed as

$$r_n = t_n + w_n = C(x_n) + w_n, \tag{6}$$

where w_n is the AWGN noise and t_n is the companded signal.

3. Proposed Companding Scheme and Analysis

In this section, we will firstly derive the general formulas for the MCM signal with the proposed distribution, and then analyze the PAPR, distortion noise and BER of the proposed companding scheme.

3.1 Previous Work and Original Adaptive Companding

In order to obtain more effective reduction in PAPR, we proposed a simple method in our previous work [19]. However, it cannot achieve an effective tradeoff between PAPR reduction and BER performance, which limits the design flexibility of the system. For this purpose, we propose a novel adaptive nonlinear companding scheme, which can effectively improve system performance of transmitted MCM signals. Therefore, the efficiency of the amplifier can be improved.

From the Section III of [19], it is straightforward to obtain the adaptive companding function (without considering the variation of the average power): Let the companded signal follow Rayleigh distribution in the interval [0, A] and uniform distribution in the interval [A, G], where A and G are the companding transition point and cutoff point, respectively. Then, the CDF of the amplitude of the companded signal can be calculated as

$$F_t(x) = \begin{cases} 1-\exp\left(-x^2/\sigma^2\right) & 0 \le x < A \\ 1-\exp\left(-\gamma^2\right)+\dfrac{2\gamma}{\sigma}\exp\left(-\gamma^2\right)(x-\gamma\sigma) & A \le x < G \\ 1 & x \ge G \end{cases}, \tag{7}$$

where γ is the adaptive parameter.

On the other hand, given that the original adaptive companding function $C_a(x)$ is a strictly monotonic increasing function, that is

$$F_X(x) = Prob\left\{|x_n| \le x\right\} = Prob\left\{C_a(|x_n|) \le C_a(x)\right\} = F_t\left(C_a(x)\right), \tag{8}$$

Obviously, $F_t(x)$ is also strict monotone increasing function. It follows that the companding function $C_a(x)$ can be given by

$$C_a(x) = sgn(x) \cdot F_t^{-1}(F_X(x)) , \tag{9}$$

where $sgn(x)$ denotes the sign function. Substituting (3) and (7) into (9), the adaptive companding function $C_a(x)$ can be expressed as

$$C_a(x) = \begin{cases} x & |x| \le \gamma\sigma \\ sgn(x) \cdot \dfrac{\sigma}{2\gamma}\left[1+2\gamma^2-\exp\left(\gamma^2-\dfrac{|x|^2}{\sigma^2}\right)\right] & |x| > \gamma\sigma \end{cases}. \tag{10}$$

However, this derivation does not take signal power into account and thereby causes the variation of the average power. To solve this problem, we introduce a new inflexion parameter and then obtain the proposed companding scheme.

3.2 Proposed Adaptive Companding Scheme

In order to matain a strictly constant average power level in the companding operation, we put forward the proposed scheme. Similarly, we can obtain the proposed nonlinear companding transform function.

Let the new proposed companded signal also follow Rayleigh distribution in the interval $[0, \gamma'\sigma]$ and uniform distribution in the interval $[\gamma'\sigma, G']$, where the parameter γ' is defined as the ratio between the companding threshold and the root mean square level of the MCM signal,

$$\gamma' = \frac{A}{\sigma}. \tag{11}$$

Note that the definition of γ' is similar to that of clipping ratio (the ratio between the clipping threshold and the root mean square level of the MCM signal), so this parameter is named as companding ratio for the purpose of simplicity and direct-perception.

Considering the constant average power level, we assume that the companding transition point is discontinuous and its coordinate is $(\gamma'\sigma, p)$. In the following derivation, we will show that with the help of this parameter, the proposed scheme can maintain the average power strictly constant. Correspondingly, the PDF of the amplitude of the companded signal is given by

$$f_{t'}(x) = \begin{cases} \dfrac{2x}{\sigma^2}\exp\left(-\dfrac{x^2}{\sigma^2}\right) & x < \gamma'\sigma \\ p & \gamma'\sigma < x \le G' \end{cases}. \tag{12}$$

The CDF of the amplitude of the companded signal can be then represented as

$$F_{t'}(x) = \begin{cases} 1-\exp\left(-\dfrac{x^2}{\sigma^2}\right) & 0 \le x < \gamma'\sigma \\ px+1-\exp\left(-\gamma'^2\right)-\gamma' p\sigma & \gamma'\sigma \le x < G'. \\ 1 & x \ge G' \end{cases} \tag{13}$$

Because $F_t'(x)$ is a strictly monotonically increasing function, it has a homologous inverse function. Then, similar to (8), the relationship between $F_x(x)$ and $F_t'(x)$ can be written as

$$\begin{aligned} F_X(x) &= Prob\{|x_n| \le x\} \\ &= Prob\{C(|x_n|) \le C(x)\} \\ &= F_{t'}(C(x)), \end{aligned} \tag{14}$$

Finally, substituting (3) and (12) into (9), the companding function of the proposed scheme can be expressed as

$$C(x) = \begin{cases} x & |x| \le \gamma'\sigma \\ sgn(x) \cdot \frac{1}{p}\left[\exp\left(-\gamma'^2\right) - \exp\left(-|x|^2/\sigma^2\right) + \gamma' p\sigma\right] & |x| > \gamma'\sigma \end{cases}. \tag{15}$$

This companding function is restricted to being a strictly monotonically increasing function and has an inverse transform function, which is the de-companding function. Therefore, the de-companding function of the proposed scheme can be represented as

$$C^{-1}(x) = \begin{cases} x & |x| \le \gamma'\sigma \\ sgn(x) \cdot \sigma\sqrt{-\ln\left[\exp\left(-\gamma'^2\right) - p \cdot \left(|x| - \gamma'\sigma\right)\right]} & |x| > \gamma'\sigma \end{cases}. \tag{16}$$

In order to make the input and output signals at the same average power level during the companding transform, companding function should satisfy $E[|x_n|^2]=E[|C(x_n)|^2]$.
On one hand, the power of original MCM signal x_n can be calculated as

$$\int_0^\infty x^2 f_X(x)\,dx = \int_0^\infty \frac{x^2 \cdot 2x}{\sigma^2} \exp\left(-\frac{x^2}{\sigma^2}\right) dx. \tag{17}$$

On the other hand, the power of companded signal can be expressed as

$$\int_0^\infty x^2 f_{t'}(x)\,dx = \int_0^{\gamma'\sigma} \frac{x^2 \cdot 2x}{\sigma^2} \exp\left(-\frac{x^2}{\sigma^2}\right) dx + \int_{\gamma'\sigma}^{G'} x^2 \cdot p\; dx. \tag{18}$$

Simultaneously, by combining (17) and (18) yields p.

$$p = \frac{1}{6\sigma} \exp\left(-\gamma'^2\right) \cdot \left(3\gamma' + \sqrt{9\gamma'^2 + 12}\right). \tag{19}$$

Based on above derivation, we can clearly find that the nonlinear companding transform is also an especial clipping scheme. Clipping deliberately clips the original MCM signals larger than the given threshold, and thereby the clipped signals cannot be recovered at the receiver. However, companding transform compresses large signals by using a strict monotone increasing function. Accordingly, the companded signals can be recovered correctly through the corresponding inversion function. It follows that the system performance degradation due to the clipping may not be optimistic, whereas companding transform can operate well with good BER performance while keeping good PAPR reduction.

3.3 PAPR Analysis

The complementary cumulative distribution function (CCDF) of the PAPR is one of the most frequently used performance measures for PAPR reduction techniques. We can also determine a proper output back-off of HPA to minimize the total degradation according to CCDF. The CCDF of the PAPR of MCM signals is defined as the probability of PAPR larger than given $PAPR_0$, which is

$$CCDF_c\left(PAPR_0\right) = Prob\left(PAPR_c > PAPR_0\right), \tag{20}$$

where $PAPR_C$ is the PAPR of the companded signal. For the theoretical analysis of the CCDF of the PAPR, it must be computed the largest and average power of the companded signals.

From the definition of the PDF $\int_{-\infty}^{\infty} f(x)dx = 1$, it can be obtained that the companding cutoff point G' (the largest signal of the companded signals) as follows,

$$G' = \exp\left(-\gamma'^2\right)\Big/ p + \gamma'\sigma. \tag{21}$$

Besides, the average power of the companded signals by the proposed scheme is designed to be the same as that of the original MCM signal, i.e., $E[|x_n|^2]=E[|C(x_n)|^2]=\sigma^2$.

Correspondingly, according to (20) and (21), the CCDF expression of proposed companded signals is given by

$$\begin{aligned} CCDF_{p'}\left(PAPR_{p'}\right) &= CCDF_{p'}\left(\frac{G'^2}{\sigma^2}\right) \\ &= CCDF_{p'}\left[\left(\exp\left(-\gamma'^2\right)\Big/ p+\gamma'\sigma\right)^2 \Big/ \sigma^2\right] \\ &= CCDF_{p'}\left[\left(\gamma'+\left[6\Big/\left(3\gamma'+\sqrt{9\gamma'^2+12}\right)\right]\right)^2\right] \end{aligned} \tag{22}$$

With reference to (4), the PAPR of the proposed scheme can be shown as follows,

$$\begin{aligned} PAPR &= 10\cdot\log_{10}\frac{Max\left(\left|C(x_n)\right|^2\right)}{E\left[\left|x_n\right|^2\right]} \\ &= 20\cdot\log_{10}\left(\gamma'+\left[6\Big/\left(3\gamma'+\sqrt{9\gamma'^2+12}\right)\right]\right)\ (dB). \end{aligned} \tag{23}$$

According to (23), it follows that the different PAPR reduction can be obtained by adjusting the companding parameter γ'.

3.4 Distortion Noise Analysis

Based on the extension of the Bussgang theorem [20], a complex or real Gaussian inputs can be written as the sum of a useful attenuated input replica and an uncorrelated nonlinear distortion noise. For this reason, the companded signal t_n can be modeled as the aggregate of an attenuated signal component and companding noise b_n, as expressed by

$$t_n = \mu x_n + b_n, \tag{24}$$

where μ is the attenuation factor. Though the MCM signal x_n is not stationary, it has been shown in [20], [21] that an MCM signal guarantees μ to be time invariant. In [21], μ has been given as

$$\mu = \frac{E\left\{t_n \bar{x}_n\right\}}{E\left\{x_n \bar{x}_n\right\}} = \frac{1}{\sigma^2}\int_0^{\infty} xC(x) f_{|x_n|}(x)dx. \tag{25}$$

Consider a constant average power level in the companding operation, we have

$$P_{x_n} = P_{t_n} = P_{\mu x_n} + P_{b_n} = \mu^2 P_{x_n} + P_{b_n}, \qquad \Rightarrow\ P_{b_n} = (1-\mu^2) P_{x_n}. \tag{26}$$

This formula indicates that $\mu<1$ and the closer μ to 1, the smaller P_{bn} will be. Let μ_p denote the attenuation factor of the proposed scheme, and it can be calculated as

$$\mu_p = \frac{1}{\sigma^2}\int_0^{\infty} xC(x) f_{|x_n|}(x)dx = \int_0^{\gamma'\sigma} x\cdot x\cdot \frac{2x}{\sigma^4}\exp\left(-\frac{x^2}{\sigma^2}\right)dx + \int_{\gamma'\sigma}^{\infty} x\cdot x\frac{1}{p}\left[\exp\left(-\gamma'^2\right)-\exp\left(-|x|^2/\sigma^2\right)+\gamma' p\sigma\right]\cdot\frac{2x}{\sigma^4}\exp\left(-\frac{x^2}{\sigma^2}\right)dx \tag{27}$$

According to (27), different μ can be obtained to generate the noise by setting γ'. Thus, the proposed scheme can achieve a good tradeoff between the PAPR reduction and BER performance. Take γ'=1.6 as an example: when γ'=1.6, it can be calculated from (27) tha μ_p =0.999 and μ_{EC}=0.992 (where μ_{EC} denotes the attenuation factor of the EC scheme). THerefore, the distortion noise power of the proposed scheme and the EC scheme are 0.0012P_{xn}, and 0.0082P_{xn}, respectively. Based on this, it follows that compared with the EC scheme, the distortion noise power caused by the proposed scheme (γ'=1.6) is reduced by 98%. Therefore, we obtain that the proposed scheme with γ'=1.6 results in only a little companding noise.

3.5 BER Analysis

Let h_n denotes the impulse response of the fading channel. Follow the analysis in the end of Section 2, the received signal is a distorted version of the companded signal, i.e.,

$$r_n = h * C(x_n) + w_n, \tag{28}$$

where * denotes the convolution operation. After the de-companding, the signal can be obtained as

$$\hat{x}_n = C^{-1}\left[h^{-1} * \left(h * C(x_n) + w_n\right)\right]. \tag{29}$$

Thus, the noise signal between the transmitted and received signals can be calculated as

$$e_n = \hat{x}_n - x_n = C^{-1}\left[h^{-1} * \left(h * C(x_n) + w_n\right)\right] - x_n = C^{-1}\left[C(x_n) + h^{-1} * w_n\right] - x_n. \tag{30}$$

In order to obtain the close form of the expectation of the noise signal in (30), the first order Taylor series expansion of the function $C^{-1}[C(x_n)+h^{-1}*w_n]$ at the point of $C(x_n)$ is used [3],

$$C^{-1}\left[C(x_n)+h^{-1}*w_n\right] \approx C^{-1}\left[C(x_n)\right] + h^{-1}*w_n\cdot\left\{C^{-1}\left[C(x_n)\right]\right\}' = x_n + h^{-1}*w_n\cdot\left\{C^{-1}\left[C(x_n)\right]\right\}', \tag{31}$$

where $\{\cdot\}'$ denotes the differential operation. Here, note that

$$\left\{C^{-1}\left[C(x_n)\right]\right\}' = \frac{1}{C'(x_n)}, \tag{32}$$

Therefore, the expected absolute error E_n can be expressed as

$$\begin{aligned} E_n &= E(e_n) = E\left\{C^{-1}\left[C(x_n) + h^{-1} * w_n\right] - x_n\right\} \\ &\approx E\left\{x_n + h^{-1} * w_n \cdot \left\{C^{-1}\left[C(x_n)\right]\right\}' - x_n\right\} \\ &= E\left[\frac{h^{-1} * w_n}{C'(x_n)}\right]. \end{aligned} \tag{33}$$

Since x_n and w_n are uncorrelated, Eq. (33) can be rewritten as

$$E_n = \left[\frac{h^{-1} * w_n}{C'(x_n)}\right] = \frac{E\left(h^{-1} * w_n\right)}{C'\left[E(x_n)\right]} = \frac{E\left(h^{-1} * w_n\right)}{C'\left[\sigma\sqrt{\pi/2}\right]}. \tag{34}$$

4. Performance Evaluation

In this section, we evaluate the performance of the proposed scheme with the EC [16] and ErC [18] schemes based on an 802.11a/g WLAN MCM system. The system parameters are given in **Table 1**.

Table 1. Simulation Environment

System Parameter	Simulation Environment
Modulation Scheme	QPSK
Number subcarriers	64
Number of data subcarriers	48
Number of pilot subcarriers	4
Channel Model	AWGN and Rayleigh fading

Furthermore, most radio systems often employ HPA in the transmitter to obtain sufficient transmit power [21]-[23]. For this reason, one WLAN HPA with model number AP 1093 produced by RF Integrated Corporation is employed so that the sufficient transmit power can be achieved. Consider that the odd order nonlinearity causes maximum in-band distortion and 3 order is a good approximation of the intermodulation (IM) power [22], therefore, the PA output can be approximated as

$$y_{out} = v_1 \cdot y_{in} + v_3 \cdot \left|y_{in}{}^2\right| \cdot y_{in}, \tag{35}$$

where the value of the PA model parameter v_1 and v_3 are 1 and -0.14, respectively.

Due to the high PAPR, original MCM signals have a very sharp, rectangular-like power spectrum. This good property will be affected by the PAPR reduction schemes, such as more spectrum side-lobes, slower spectrum roll-off, and higher adjacent channel interference. Many PAPR reduction schemes cause spectrum side-lobes generation, but the proposed scheme causes less spectrum side-lobes. As shown in **Fig. 2**, the proposed scheme (γ'=1) has much less impact on the original power spectrum compared to the EC scheme. Moreover, the companded signals have almost no spectral regrowth caused by the PAPR reduction, which can increase the immunity of MCM signals from out-of-band noise. The power spectrums of the proposed scheme with other parameter values (i.e., γ'=1.2 or 1.6) are found similar to that of γ'=1.

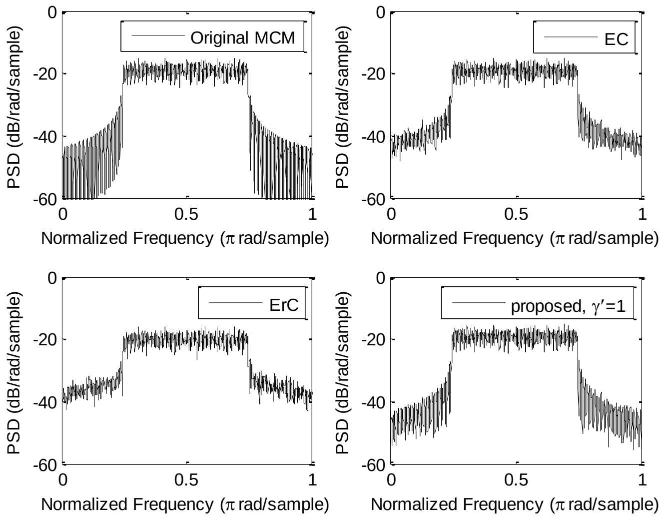

Fig. 2. Power spectrums of various companded signals.

Fig. 3 shows the CCDF of the PAPR of original MCM signals, EC companded signals, ErC companded signals and the proposed companded signals, respectively. The CCDF of the PAPR is defined in (20). Correspondingly, according to the analysis in Section 3.4, it can be concluded that compared with EC scheme, the distortion noise power caused by the proposed scheme (γ'=1.6) decreases to 2%, with only about 1.7 dB PAPR increase, which can be clearly seen in Fig. 3. From this figure, it also can be observed that the proposed scheme effectively improves the PAPR distribution by properly choosing the companding parameter.

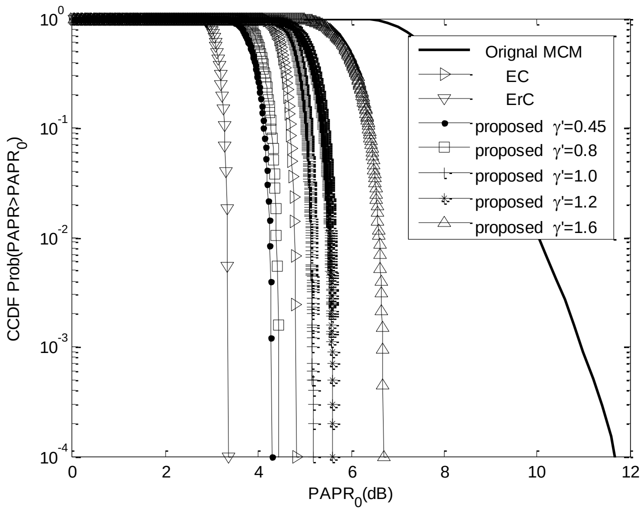

Fig. 3. The CCDF's of original MCM signal and various companded signals.

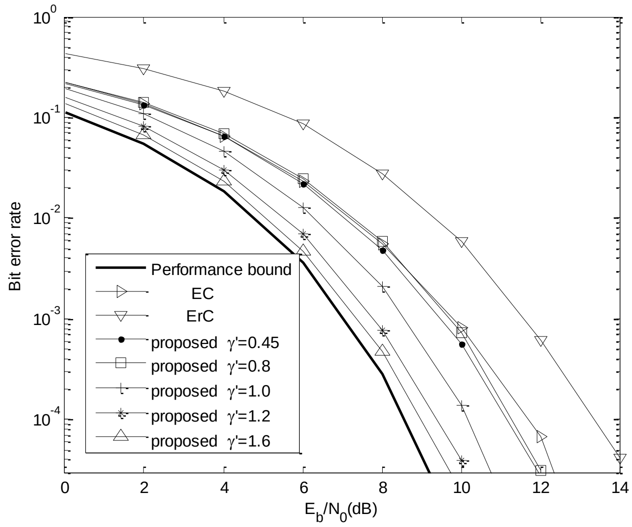

Fig. 4. BER performance of various companding schemes over AWGN channel.

The wireless channel is modeled as the Rayleigh fading channel corrupted by an additive white Gaussian noise (AWGN). For simplicity of analysis, we first use an AWGN model and then to extend the analysis to a more complex channel model. **Fig. 4** shows the BER performance of the MCM systems over AWGN channel. Note that, the performance bound is obtained by ignoring the effect of HPA and directly transmitting the original MCM signals through the channel. Specifically, compared with the performance bound, the BER of proposed scheme (γ'=1.6) only results in 0.5 dB performance degradation. To achieve a BER of 10^{-4}, the minimum required E_b/N_0 is 8.57 dB ("Performance bound"), whlie the required E_b/N_0s under the proposed γ'=0.45, γ'=1.2, EC and ErC schemes are 11.2 dB, 9.37 dB, 11.7 dB, and 13.35 dB, respectively.

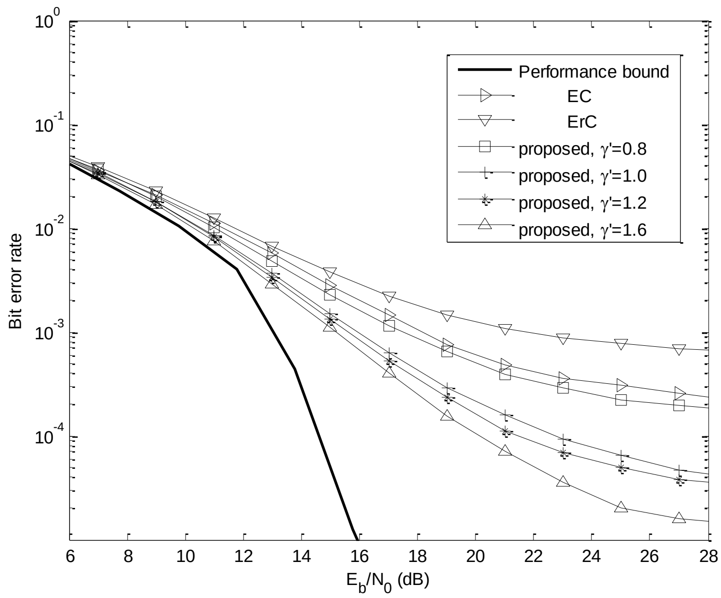

Fig. 5. BER performance of various companding schemes with HPA over fading channel.

Fig. 5 depicts the performance of BER versus E_b/N_0 under various companding schemes with HPA over Rayleigh fading channel, with comparison to that of the original MCM scheme. Due to the nonlinear effect of the SSPA, the BER for all schemes suffer from error floors at the high SNRs.As shown in Fig. 5, it is remarkable that most of the proposed scheme (γ'=0.8 to 1.6) offer a better BER performance than the EC and Erc schemes. When all comes to all (from Figs. 2, 3, 4 and 5), it can be concluded that with a proper inflexion point, the proposed scheme can achieve an excellent tradeoff between PAPR reduction and BER performance. Therefore, the proposed scheme is a suitable scheme and propitious to the application.

5. Conclusion

In this paper, we have presented and evaluated a novel nonlinear companding scheme that can effectively improve the MCM system performance with low companding distortion noise. In addition, properly choosing the companding transition point of the proposed scheme, it can achieve an effective tradeoff between PAPR reduction and BER performance. Simulation results have demonstrated that the proposed companding scheme could offer better system performance in terms of PAPR reduction, power spectrum and BER performance than the EC and ErC schemes.

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