New Hybrid Schemes for PAPR Reduction in OFDM Systems

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Abstract:

The 3rd Generation Partnership Project (3GPP) introduced LTE to meet increasingly demands for communication services with high speed and quality. LTE uses OFDM in the form of OFDMA in the downlink and SCFDMA in the uplink combined with MIMO offering high data rate, high capacity and immunity against multipath channels. However, still the high PAPR of the LTE transmitted signal is the major problem affecting overall system performance degradation and power efficiency. A plenty of research has been devoted to reduce the performance degradation due to the PAPR problem inherent to LTE OFDM systems. A portion of the current techniques such companding methods have low-complexity, no constraint on modulation format and subcarrier size, good distortion and spectral properties; however, they have limited PAPR reduction capabilities. This paper proposes seven new hybrid schemes including Zaddoff Chu Matrix Transform (ZCT) precoding and six modern companding methods; Rooting Companding (RCT), New Error Function Companding (NERF), Absolute Exponential Companding (AEXP), Logarithmic Rooting Companding (LogR), Cosine Companding (COS) and Tangent Rooting Companding (TanhR). Furthermore, the seventh proposed hybrid scheme has been added incorporating ZCT precoding with new proposed companding called Advanced AEXP (AAEXP) companding. The developed methods are combining properties of both ZCT & Compandings, and achieving superior PAPR performance and optimal BER. Simulations results illustrate that the new seven proposed hybrid schemes achieve better PAPR reduction, and BER performance and the best achievement has been achieved by ZCT+AAEXP scheme.

Keywords: Advanced Absolute Exponential Companding (AAEXP), Zaddoff Chu Matrix Transform (ZCT) Precoding, Orthogonal Frequency Division Multiplexing (OFDM), Peak to Average Power Ratio (PAPR).

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طرق هجينة جديدة لتخفيض نسبة القدرة القصوى إلى المتوسط في أنظمة تقنية مضاعفة تقسيم التردد المتعامد

الملخص:

الـ 3GPP قدمت مشروع LTE لتلبية الطلبات المتزايدة لخدمات الاتصالات ذات السرعة العالية والجودة العالية. يستخدم نظام الـ LTE تقنية مضاعفة تقسيم التردد المتعامد (OFDM) في شكل (OFDMA) في الوصلة الهابطة (Downlink) وشكل الـ (SCFDMA) في الوصلة الصاعدة (Uplink) مجتمعة مع تقنية الـ MIMO لتقديم معدل بيانات عالي، قدرة عالية، وحصانة ضد القنوات متعددة المسارات. ومع ذلك لا يزال ارتفاع نسبة القدرة العظمة إلى المتوسط (PAPR) لإشارة الـ LTE المرسلة هي المشكلة الرئيسية التي تعمل على تدهور كفاءة النظام بشك عام وإمكانية استهلاك الطاقة. لذلك كرست الكثير من البحوث للحد من تدهور الأداء بسبب مشكلة الـ PAPR في أنظمة LTE-OFDM. تعتبر طرق ضغط الإشارة (Companding Methods) جزءاً من الطرق المعروفة والتي تعتبر سهلة ومنخفضة التعقيد، وبلا قيود على شكل التضمين وحجم عدد الحوامل (Subcarrier Size)، ولها خصائص طيفية جيدة، ومع ذلك فإن هذه الطرق تقلل الـ PAPR بمقدار ضئيل. وقد اقترح هذا البحث سبعة طرق هجينة جديدة على أساس مزيج من Zaddoff Chu Matrix Transform (ZCT) مع ست أساليب مختلفة من طرق ضغط الإشارة وهي Rooting Companding (RCT)، New Error Function Companding (NERF)، Absolute Exponential Companding (AEXP)، Logarithmic Rooting Companding (LogR)، Cosine Companding (COS)، وTangent Rooting Companding (TanhR). بالإضافة إلى ذلك تم تطوير الطريقة الهجينة السابعة وتجمع الـ Zaddoff Chu Matrix Transform (ZCT) مع طريقة جديدة مقترحة تسمى Advanced AEXP (AAEXP). أظهرت النتائج أن هذه الطرق المتطورة تجمع بين خصائص طريقة الـ ZCT مع خصائص طرق ضغط الإشارة، وتحقق أداء أمثل وانخفاضاً أفضل من حيث PAPR وBER. كما حققت طريقة الـ ZCT+AAEXP أفضل النتائج مقارنة بالطرق الأخرى.

1. Introduction:

The prerequisites for the next-generation applications with high transmission rates and high-speed broadband wireless strategies have been expanding over the last few years. Third Generation Partnership Project (3GPP) has enhanced Long Term Evolution (LTE) system to present a data rate system with high-speed and high communication capacity. 3GPP LTE uses a method for uplink called Single Carrier-Frequency Division Multiple Access (SC-FDMA) but it utilizes a technique for downlink called Orthogonal Frequency Division Multiple Access (OFDMA). The significant preferred standpoint of the SC-FDMA method is to hold the low peak-to-average power ratio (PAPR), so the energy consumption will be minimized and higher power efficiency than in OFDMA systems. SC-FDMA has the same complexity and throughput as OFDMA.

Recently, a considerable measure of consideration has been centered around OFDMA because of extensive transmission information rate, successful spectrum usage, frequency diversity, throughput boost, and resistance against channel distortion and multipath fading channel. It has difficult issue, for example, high PAPR. Up to now, PAPR issue kept OFDMA from being wireless standards in the uplink of communication systems. If the OFDMA signal sends by means of a not adequately wide nonlinear power amplifier, resulting is out-band radiation, in-band distortion and spectrum expanding will be produced and leading to increase(distortion) in BER performance [1-5].

In literatures, there are distinctive PAPR reduction methods in OFDM based systems have been assumed and portrayed into two sorts: signal scrambling methods and signal distortion techniques. Signal scrambling techniques do not twist the structure of the OFDM signal and no spectral regrowth occur. These schemes involve coding schemes [6-8] which offer no distortion, but experience from bandwidth efficiency, complexity to find the optimum codes for an expansive number of subcarriers, and data rate loss (side information). Both PTS [9-12] and SLM [13-16] schemes accomplish significant PAPR lessening at the expense of high computational complexity and transmission rate loss (side information).

In addition, the precoding schemes [17-20] considered as distortion less techniques which improve PAPR performance without BER distortion, but they perform limit PAPR enhancement. Baig and Jeoti [1] displayed a Zadoff-

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Chu precoding based PAPR reduction technique. This technique is proficient; signal independent, distortion-less and it does not require any optimization algorithm. Moreover, this precoding based PAPR reduction technique does not require power increase and side information to be sent for receiver.

Signal distortion methods introduce spectral regrowth or distort the spectrum of the signal and transmit a PAPR signal with no additional information. These techniques comprising clipping and filtering scheme [21-23] and compandings methods [2, 24-32] which acquire consideration because of its flexibility and simplicity. The idea of companding technique was introduced in [32], which utilizes the μ-law companding technique, which going for lessening PAPR by expanding the average power of the signal while keeping the peak power stays unchanged. Later on, exponential companding (EC) was produced in [24], which can enhance lessening of OFDM's PAPR by modifying the dispersion (distribution) of OFDM signals while keeping average power stays consistent.

Different companding techniques are presented in [27] and it is clear that Log companding is better than erf companding and tanh companding. A new nonlinear companding technique is assumed by [28] which alters the Gaussian distributed signal into distribution form by utilizing a linear function format. This nonlinear companding technique lessens the PAPR of OFDM signal at an expense of high computational complexity. Absolute Exponential Companding (AEXP), Rooting Companding (RCT), New Error Function Companding (NERF), Logarithmic Rooting Companding (LogR), Cosine Companding (COS) and Tangent Rooting Companding (TanhR) are proposed by [2] which exhibit better performance than Mu-law companding, and the best performance in terms of PAPR & BER achieved by AEXP companding. Generally, the compandings are a non-straight process and cause genuine in band distortion which may cause incredible BER loss. Concerning BER performance improvement, some specialists have proposed hybrid methods which consolidate precoding and companding [33-37], where Wang [33] assumed Discrete Cosine Transform(DCT) precoding combined with companding accomplishing upgraded PAPR decrease compared to those of compandings. Rao et al. [37] proposed Piecewise Linear Companding(PLC) combined with three precoder schemes; Discrete Hartly Transform (DHT), Wash Hadmard Transform (WHT) and Discrete Cosine Transform (DCT) and the PLC with DHT method performs the best BER&PAPR performance among others. However, the improvements in BER&PAPR are not much high.

In this paper, we propose new hybrid techniques consolidating Zaddoff Chu Matrix Transform(ZCT) precoding with seven compandings techniques which gather highlights of ZCT precoding and attributes of compandings to accomplish great lessening in PAPR and better improvement in BER performance with no power increase, very much flexibility and no side information against those alone compandings.

In this paper, section 2 explains the PAPR for LTE OFDM system model. Section 3 demonstrates the proposed PAPR reduction hybrid schemes in LTE SISO-OFDM system. In Section 4, simulation results are presented and discussed. Section 5 concludes the paper.

2. PAPR of LTE OFDM System

A block diagram for LTE SISO-OFDM system model is shown in Fig. 1, where the source generates 2.4 Mbps stream of bits that have equal probability. This data modulated with QPSK modulation scheme producing frequency domain symbols $X = [X0, X1, \dots, XN-1]^T$ reordered into parallel by S/P block making them compatible for transmission via OFDM modulator. And then X passes through the OFDM modulator to make IFFT transform, add cyclic prefix and guards constructing OFDM symbol consisting of N subcarriers. The complex baseband OFDM signal can be written as equation (1).

$$X_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k \, e^{\frac{j2\pi kn}{N}}, 0 \leq n < N \qquad (1)$$

In time domain, the signal X_n is actually the mixed signal of N independent subcarriers. Thus the OFDM signal X_n occasionally exhibits very high peaks which can be measured by PAPR. The PAPR is defined as the ratio of maximum signal power to average signal power.

$$PAPR = 10log \frac{\max\{|X_n|\}^2}{E[\{|X_n|\}^2]} \qquad (2)$$

In general, the performance of PAPR reduction is measured by the Complimentary Cumulative Distribution Function (CCDF) which is defined as the probability that the PAPR of signal exceeds an assigned threshold. Assuming PAPR0 is the threshold value, CCDF can be expressed as follows,

$$CCDF = Pr(PAPR > PAPR0) \qquad (3)$$

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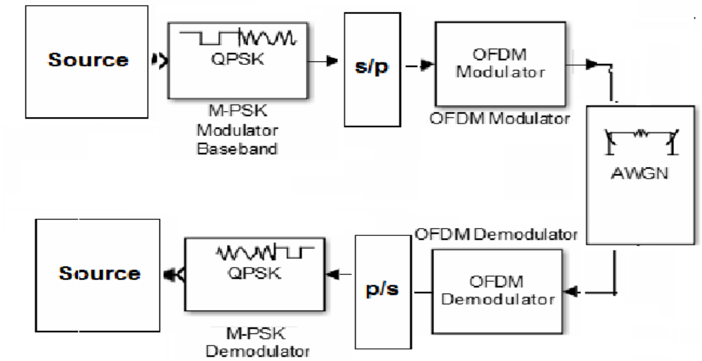

Figure (1): Block diagram for LTE SISO-OFDM system model

3. Proposed PAPR reduction method

The proposed LTE SISO-OFDM system with hybrid PAPR reduction is shown in Fig. 2. We denote the modulated signal vector as X=[X0 ,X1 ,X2,...XN-1]^T. It is processed by ZCT precoding block, and z can be written as

$$z = (Z \times X) \qquad (4)$$

where Z is the N × N ZCT-transform precoding matrix and the following subsection will describe this with more details, the output of the signal $z=[z_0, z_1, z_2, \dots z_{N-1}]^T$ passing through OFDM Modulator performing inverse fast Fourier transform IFFT after adding guard bands and cyclic prefix and can be written as

$$x = IFFT(z) \qquad (5)$$

The output of the signal $x=[x_0, x_1, x_2, \dots x_{N-1}]^T$ passing through one of the seven companding methods and Its output can be written as

$$y = A(x) \qquad (6)$$

where A (•) denotes the compandings function and y is the signal to be sent into wireless channels. Assuming h is the channel impulse response and w is the additive white Gaussian noise, the received signal can be expressed as

$$Rx = y * h + w \qquad (7)$$

with the de-companding operation, the recovered signal can be expressed as

$$De = A^{-1}(Rx) \qquad (8)$$

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Then De is fed into the OFDM demodulator block performing FFT transformation after removing guard bands and cyclic prefix and the signal after this transform is

$$Y = FFT(De) \qquad (9)$$

The output signal of OFDM Demodulator Y enters into inverse ZCT block and the output signal of this block is

$$Zout = Z^{-1} \times Y \qquad (10)$$

Where Z^{-1} is N x N inverse of ZCT matrix precoding. Then the signal Zout is demodulated producing the oringinal data.

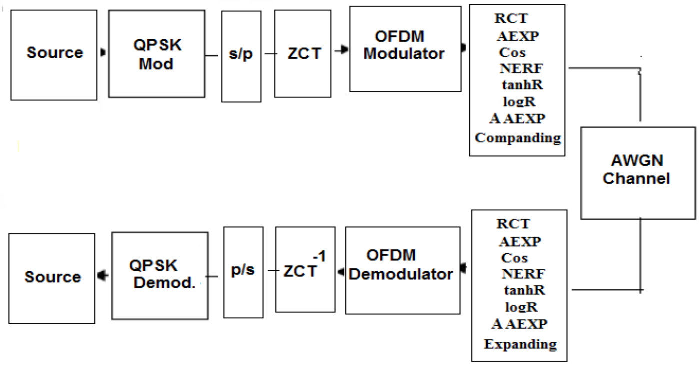

Figure (2): Hybrid proposed PAPR reduction method for LTE SISO-OFDM

The proposed scheme includes two stages for PAPR reduction. One is ZCT precoding and the other is one of the new seven compandings and they can be explained with the following paragraphs.

A. Zadoff ChuMatrix Transform Precoding(ZCT):

ZCT precoding based OFDM system is obtained from Zadoff-Chu sequences which are a class of poly phase sequences having optimum correlation properties [1]. Zadoff-Chu sequences have an ideal periodic autocorrelation and constant magnitude. The Zadoff-Chu sequences of length L can be defined:

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$$z(k) = \begin{bmatrix} e^{(\frac{j2\pi r(k^2+2qk)}{2L})}, & for\ L\ even \\ e^{(\frac{j2\pi r(k(k+1)+2qk)}{2L})} & for\ L\ odd \end{bmatrix} \quad (11)$$

where k = 0, 1, 2 . . . L-1, q is any integer, r is any integer relatively prime to L. With the use of reordering and letting, q = 1 and r = 1 and substitute k = mN +l in equation (11) for L. Even we get R matrix which is a ZCT based row-wiseprecoding matrix of size L = (N X N) and can be written as:

$$R = \begin{bmatrix} r_{00} & r_{01} & \cdots & r_{0(N-1)} \\ r_{10} & r_{11} & \cdots & r_{1(N-1)} \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ r_{(N-1)0} & r_{(N-1)1} & \cdots & r_{(N-1)(N-1)} \end{bmatrix} \quad (12)$$

In the ZCT precoding based OFDM system baseband modulated data is passed through S/P convertor which generates a complex vector of size N that can be written as X=[X0, X1, X2, ... XN -1]^T. Then ZCT precoding is applied to this complex vector which transforms this complex vector into new vector of length N that can be written as Y=RX=[Y0, Y1, Y2 ...YN-1]^T.

B. Companding Techniques

1) Advanced Absolute Exponential Companding (AAEXP):

This part offers our new companding method that is called Advanced AEXP (AAEXP) which is used in a hybrid scheme with ZCT precoding to provide excellent PAPR reduction with slight SNR loss compared to original LTE SISO-OFDM signal and excellent PAPR reduction with high BER improvement compared to alone AAEXP. It has the following equation:

$$h(x) = sgn(x)\sqrt[d]{\alpha[1 - Exp^{(-\frac{|x|^2}{\sigma^2})}]} \quad (13)$$

Where sgn(x) is sign function, Exp represents constant which change from 2.7 to 1000,σ^2 is the variance of the input signal, and the positive constant α determines the average power output signals in order to keep the input and output signals at the same average power level.

$$\alpha = \left[\frac{E[|x|^2]}{E[\sqrt[d]{\left[1 - Exp^{\left(-\frac{|x|^2}{\sigma^2}\right)}\right]^2}]}\right]^{\frac{d}{2}} \quad (14)$$

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At the receiver side, the inverse function h(x) is used in the decompanding operation:

$$h^{-1}(x) = \left| \sqrt{-\sigma^2 \frac{log_e\left(1 - \frac{|x|^{\frac{2}{d}}}{\alpha}\right)}{log_e(Exp)}} \right|. \quad (15)$$

2). Rooting Companding Technique(RCT):

The RCT of the signal is:

$$f(x) = |x|^R * sgn(x) \quad (16)$$

Where R ranges from 0.1 to 0.9 and sgn(x) is sign(x) which maintains the phases of OFDM signal. The phases of OFDM signal Ø_nremains constant whereas the amplitude varies [2]. Therefore, the amount of change in amplitude depends on the value of R. As the value of R decreases the PAPR reduces. The de-companding of RCT is:

$$f(x)^{-1} = |x|^{\frac{1}{R}} * sgn(x) \quad (17)$$

3) New Error Function Companding(NERF):

This new companding method[2] is proposed to reduce PAPR which depends on erf function

$$h(x) = 2\sigma \operatorname{erf}\left(\frac{|x|}{\sqrt{2\sigma}}\right) * sgn(x) \quad (18)$$

NERF de-companding:

$$h(x)^{-1} = \left| \sqrt{2\sigma} \operatorname{erfc}\left(\frac{|x|}{\sqrt{2\sigma}}\right) * sgn(x) \right| \quad (19)$$

4) Cosine Companding:

The proposed COS companding [2] and de-companding equations are:

$$h(x) = \sqrt[y]{\alpha\left[1 - cos\left(-\frac{|x|}{\sigma}\right)\right]} * sgn(x) \quad (20)$$

$$h(x)^{-1} = \left| -\sigma \operatorname{acos}\left(1 - \frac{|x|^{\frac{2}{y}}}{\alpha}\right) \right| * sgn(x) \quad (21)$$

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The value of α determines the average power of output signal and y = 0.1 to 1. In order to maintain the same average power level at input and output signals, α is:

$$\alpha = \left[\frac{E[|x|^2]}{E\left[\sqrt[d]{\left[1 - exp\left(-\frac{|x|}{\sigma}\right)\right]^2} \right]} \right]^{\frac{y}{2}} \quad (22)$$

5) Absolute Exponential Companding(AEXP):

AEXP expression is derived from the exponential companding [2] and Trapezoidal power capacity:

$$h(x) = sgn(x) \sqrt[d]{\alpha \left[1 - exp(-\frac{|x|^2}{\sigma^2})\right]} \quad (23)$$

The exponential function of a signal is distorted as the square root part may be imaginary or complex numbers. Absolute value of square root is taken to avoid phase distortion. The value d is 2≤d≤0.2. The α determines the average power of the output signals. In order to maintain the same average power level at input and output signals, α is:

$$\alpha = \left[\frac{E[|x|^2]}{E[\sqrt[d]{\left[1 - exp\left(-\frac{|x|^2}{\sigma^2}\right)\right]^2}]} \right]^{\frac{d}{2}} \quad (24)$$

The de-companding AEXP is:

$$h^{-1}(x) = sgn(x) \left| \sqrt{-\sigma^2 log_e \left(1 - \frac{|x|^{\frac{2}{d}}}{\alpha}\right)} \right| \quad (25)$$

6) Tangent Rooting companding(tanhR):

This proposed companding depends on tanh [2] and the equation is:

$$f(x) = tanh((|x| * k)^y) * sgn(x) \quad (26)$$

Where k is the positive number for controlling the companding level for the amplitude of x and |x|. The de companding is:

$$f(x)^{-1} = \left| \left(atanh\left(\frac{|x|}{k}\right) \right)^{\frac{1}{y}} \right| * sgn(x) \qquad (27)$$

7) Logarithmic Rooting Companding(logR):

The equation at transmitter is [2]:

$$f(x) = log((|x| * k)^{y} + 1) * sgn(x) \qquad (28)$$

And the de-companding is:

$$f(x)^{-1} = \left| \left(exp\left(\frac{|x|}{k}\right) - 1 \right)^{\frac{1}{y}} \right| * sgn(x) \qquad (29)$$

4. Simulation Results:

To evaluate the performance of the proposed hybrid scheme, simulation results are presented in this section. In all simulations, QPSK modulation is adopted, 1200 data subcarrier, 2048 FFT size, 2.4 Mbps data rate, 848 number of guard bands are used. The length of cyclic prefix is 512. AWGN channel is applied in simulations.

In simulations, we compare the proposed hybrid schemes; (ZCT+AAEXP), (ZCT+RCT), (ZCT+NERF), (ZCT+COS), (ZCT+AEXP), (ZCT+TanhR), (ZCT+LogR) with the new proposed AAEXP companding, (RCT, NERF, COS, AEXP, TanhR, and LogR) existing compandings, and traditional LTE SISO-OFDM signal.

A. ZCT+AAEXP Hybrid Scheme:

In this proposed hybrid scheme, we set d parameter to 1.6 and Fig. 3. shows the PAPR performance for both our proposed AAEXP companding method and our proposed hybrid scheme (ZCT+AAEXP). AAEXP achieves 7.4, 10, 10.5 dB improvements (gains) while hybrid (ZCT+AAEXP) scheme offers larger improvements of 8.15, 10.55, and 11 dB compared to traditional LTE SISO-OFDM signal of 11.4 dB at Exp=3, 50, and 1000 respectively. Also their corresponding BER performance in Fig. 4. shows how proposed (ZCT+AAEXP) scheme highly improves SNR to 7.85, 9, and 10 dB at 10^-3 BER against SNR of AAEXP companding scheme at Exp=3, 50, and 1000 respectively.

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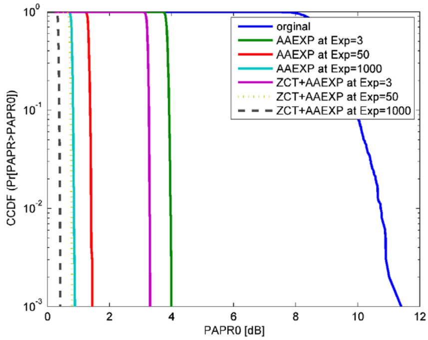

Figure (3): PARP performance for proposed hybrid (ZCT+AAEXP) scheme compared to AAEXP companding for LTE SISO-OFDM system

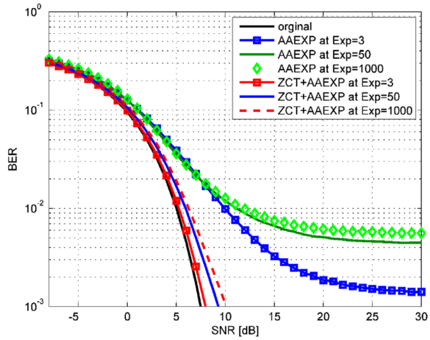

Figure (4): BER performance for proposed hybrid (ZCT+AAEXP) scheme compared to AAEXP companding for LTE SISO-OFDM system

B. ZCT+RCT Hybrid Scheme:

Fig. 5. shows the PAPR performance for existing Rooting Companding (RCT) and our proposed hybrid scheme (ZCT+RCT), where RCT provides 10.02, and 1 dB improvements (gains) while proposed (ZCT+RCT) scheme offers higher improvenents of 10.5, and 4.55 dB compared to traditional LTE SISO-OFDM signal of 11.4 dB at R=0.1, and 0.9 respectively. Also, their corresponding BER performance in Fig. 6. shows how proposed (ZCT+RCT) scheme enhances SNR to 22.9, and 7.5 dB at 10^-3 BER. This means that the proposed (ZCT+RCT) scheme enhances PAPR signal without affecting BER performance when R=0.1 and enhances PAPR signal with more BER performance improvement of 1.1 dB when R=0.9 with respect to current RCT companding.

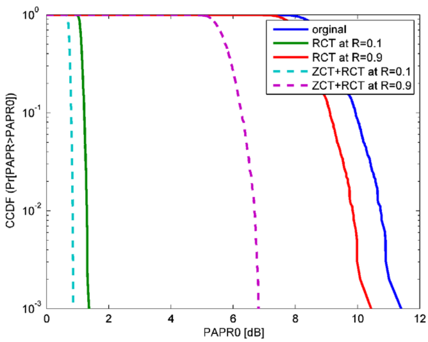

Figure (5): PAPR performance for proposed hybrid (ZCT+RCT) scheme compared to RCT companding for LTE SISO-OFDM system

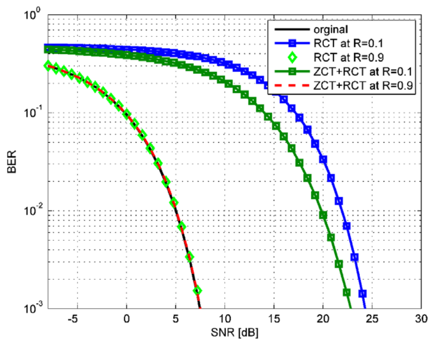

Figure (6): BER performance for proposed hybrid (ZCT+RCT) scheme compared to RCT companding for LTE SISO-OFDM system

C. ZCT+NERF Hybrid Scheme:

Fig. 7. illustrates PAPR performance for current NERF Companding and our proposed hybrid scheme (ZCT+ NERF), where NERF achieves 7.05 dB improvement (gain) while proposed (ZCT+NERF) scheme offers greater improvenent of 7.65 dB compared to traditional LTE SISO-OFDM signal of 11.4 dB, but their corresponding BER performance in Fig. 8. shows how proposed (ZCT+NERF) scheme enhances SNR to 7.9 dB at 10^-3 BER against existing NERF companding scheme.

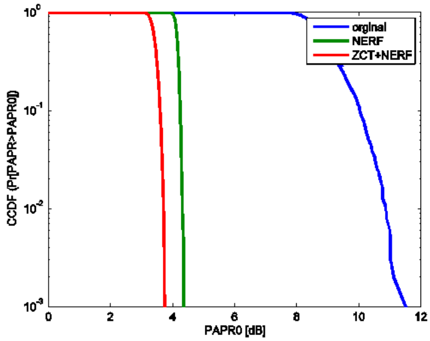

Figure (7): PAPR performance for proposed hybrid (ZCT+NERF) scheme compared to existing NERF companding for LTE SISO-OFDM system

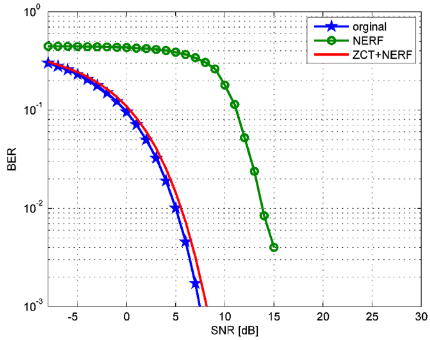

Figure (8): BER performance for proposed hybrid (ZCT+NERF) scheme compared to existing NERF companding for LTE SISO-OFDM system

D. ZCT+COS Hybrid Scheme:

Fig. 9. demonstrates PAPR performance for existing Cosine Companding (COS) and our proposed hybrid (ZCT+ COS) scheme, where COS achieves 10.6, and 4.52 dB improvements (gains) while proposed (ZCT+COS) scheme offers greater improvements of 10.8, and 5.54 dB compared to traditional LTE SISO-OFDM signal of 11.4dB at y=0.1, and 1 respectively. Also their corresponding BER performance in Fig. 10. illustrates how proposed (ZCT+COS) scheme improves SNR to 23.75 dB at 10^-3 BER when y=0.1 and not affected (deteriorated) when y=1. This means that (ZCT+COS) scheme improves PAPR signal highly without BER performance degradation when y =1 while It improves PAPR signal slightly with significant BER performance improvement when y =0.1 with respect to COS companding.

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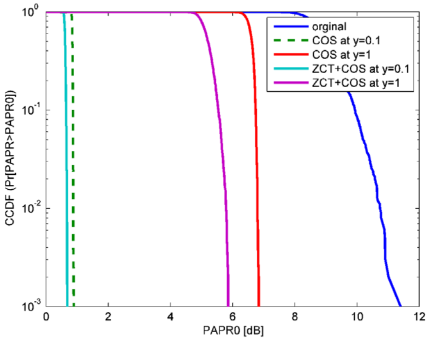

Figure (9): PAPR performance for proposed hybrid (ZCT+COS) scheme compared to existing COS companding for LTE SISO-OFDM system

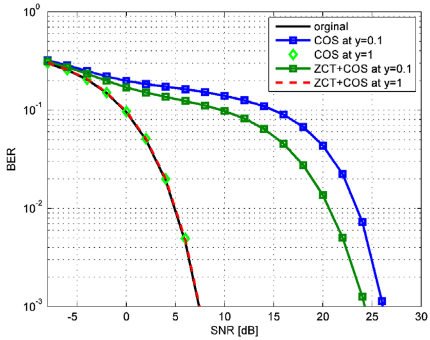

Figure (10): BER performance for proposed hybrid (ZCT+COS) scheme compared to existing COS companding for LTE SISO-OFDM system

E. ZCT+AEXP Hybrid Scheme:

Fig. 11. demonstrates PAPR performance for current AEXP Companding and our proposed hybrid (ZCT+ AEXP) scheme, where AEXP achieves 10.6, 7.65, and 6.4 dB improvements (gains) while proposed (ZCT+ AEXP) scheme offers greater improvements of 10.8, 8.3, and 7.05 dB compared to traditional LTE SISO-OFDM signal of 11.4 dB at d=0.2, 1.3, and 2 respectively. Also, their corresponding BER performance in Fig. 12. shows how proposed (ZCT+ AEXP) scheme improves SNR by 2.6, 0.2, and high dB at 10^-3 BER when d=0.2, 1.3, and 2 respectively against AEXP companding and the best improvement takes place when d=2.

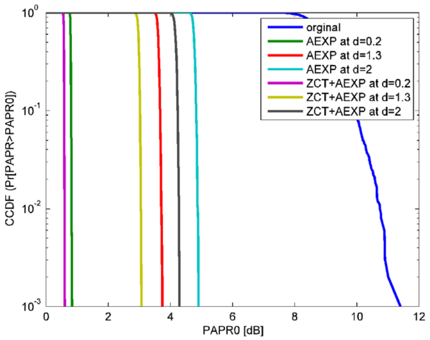

Figure (11): PAPR performance for proposed hybrid (ZCT+AEXP) scheme compared to existing AEXP companding for LTE SISO-OFDM system

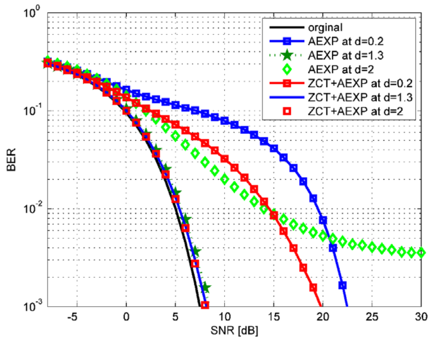

Figure (12): BER performance for proposed hybrid (ZCT+AEXP) scheme compared to existing AEXP companding for LTE SISO-OFDM system

F. ZCT+ TanhR Hybrid Scheme:

Fig. 13. demonstrates PAPR performance for existing TanhR companding and our proposed hybrid (ZCT+ TanhR) scheme, where TanhR achieves 10.4,

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and zero dB improvements (gains) while proposed (ZCT+ TanhR) scheme offers greater improvement of 10.92, and 7.31 dB compared to traditional LTE SISO-OFDM signal of 11.4 dB with y=0.1, and 1 respectively. Also, their corresponding BER performance in Fig. 14. appears how proposed (ZCT+ TanhR) scheme improves SNR by 1 dB and zero dB at 10^-3 BER when y=0.1, and 1 respectively against TanhR companding. This means that the proposed hybrid scheme (ZCT+ TanhR) provides high PAPR reduction while keeping the same BER performance (no degradation) against TanhR companding when y=1. It significantly enhances both PAPR and BER performances against TanhR companding when y=0.1.

Fig. 15. demonstrates PAPR performance for existing TanhR companding and our proposed hybrid (ZCT+ TanhR) scheme, where TanhR achieves 0.1, and 9.65 dB improvements (gains) at k=3, and 100 respectively, while proposed (ZCT+ TanhR) scheme offers greater improvement of 10.4 dB compared to traditional LTE SISO-OFDM signal of 11.4 dB at k=3. In addition, to make excellent comparison for BER performance between the proposed hybrid scheme (ZCT+ TanhR) and existing TanhR companding, we set the k value of TanhR companding to 100 to achieve PAPR level which is close to PAPR level of the proposed hybrid scheme(ZCT+ TanhR) at k=3 as shown in Fig. 15. From Fig. 15 and Fig. 16, we observe that the proposed hybrid scheme(ZCT+ TanhR) at k=3 improves both PAPR and BER performances by 0.75 and 3 dB respectively with respect to what TanhR companding scheme does at k=100.

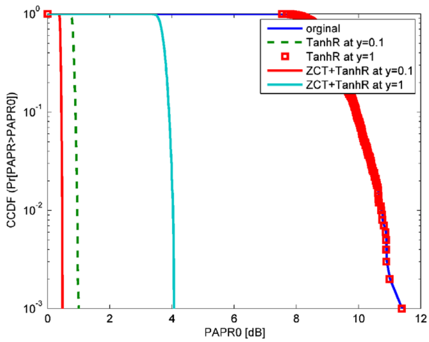

Figure (13): PAPR performance for proposed hybrid (ZCT+TanhR) scheme compared to TanhR companding for LTE SISO-OFDM system

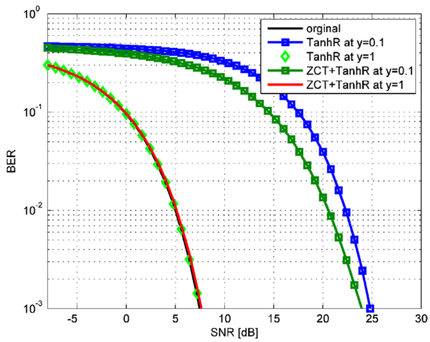

Figure (14): BER performance for proposed hybrid (ZCT+TanhR) scheme compared to existing TanhR companding with different y values for LTE SISO-OFDM system

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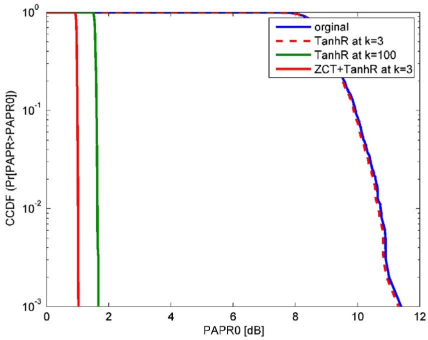

Figure (15): PAPR performance for proposed hybrid (ZCT+TanhR) scheme compared to existing TanhR companding with different k values for LTE SISO-OFDM system

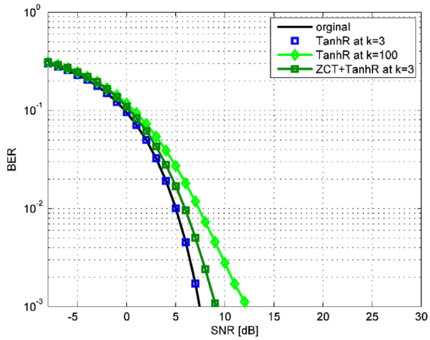

Figure (16): BER performance for proposed hybrid (ZCT+TanhR) scheme compared to existing TanhR companding with different k values for LTE SISO-OFDM system

G. ZCT+ LogR Hybrid Scheme:

Fig. 17. demonstrates PAPR performance for LogR companding and our proposed hybrid (ZCT+ LogR) scheme, where LogR achieves 10.4, and 1.4 dB improvements (gains), while proposed (ZCT+ LogR) scheme offers greater improvements of 10.8, and 8.15 dB compared to traditional LTE SISO-OFDM signal of 11.4dB at y=0.1, and 1 respectively. On the other side, BER performance in Fig. 18. shows how our proposed (ZCT+LogR) scheme improves SNR by 1.2 dB when y=0.1and distorts SNR by 0.7 dB when y=1 against LogR scheme. This means that the proposed hybrid scheme (ZCT+ LogR) when y=0.1 presents significant PAPR and BER improvements against LogR scheme but when y=1, we can observe that the proposed hybrid scheme(ZCT+ LogR) offers great PAPR improvement with slight BER deterioration against LogR scheme. Also, we note if we adjust y parameter of LogR scheme to achieve similar level of PAPR reduction of proposed hybrid scheme(ZCT+ LogR), we observe that the proposed hybrid scheme(ZCT+ LogR) exhibits enhancements for both PAPR and BER performance with respect to LogR scheme.

Fig. 19. demonstrates PAPR performance for LogR companding and proposed hybrid (ZCT+ LogR) scheme, where LogR achieves 1.4, and 4.8 dB improvements (gains), while proposed (ZCT+ LogR) scheme offers greater improvement of 8.2, and 9.5 dB compared to traditional LTE SISO-OFDM signal of 11.4 dB at k=10, and 100 respectively. However, their corresponding BER performance in Fig. 20. shows how proposed hybrid scheme (ZCT+

LogR) slightly degrades SNR by 0.7 dB and 1.1 dB with respect to LogR scheme when k=10 and 100 respectively. This means that the proposed hybrid scheme (ZCT + LogR) provides high PAPR improvements of 6.8 dB and 5.5 dB with slight SNR loss of 0.7 and 1.1 dB against LogR scheme when k=10 and 100 respectively. To make fair comparison for BER performance between the proposed hybrid scheme (ZCT+ LogR) and existing LogR scheme, the k parameter of LogR scheme has been adjusted to achieve similar level of PAPR reduction of the proposed hybrid scheme (ZCT+ LogR). As shown in Fig. 19 and Fig. 20, the proposed hybrid scheme (ZCT+ LogR) with k= 10 provides 3.4 dB PAPR improvement(gain) while keeping the same level of BER performance against LogR scheme with k=100. Moreover, if k parameter of LogR scheme is increased more than 100, the level of PAPR reduction of LogR scheme will close toward the PAPR level of the proposed hybrid scheme (ZCT + LogR) and the BER of LogR scheme will increase away from BER level of (ZCT + LogR) scheme. This means that the proposed hybrid scheme (ZCT + LogR) offers better PAPR and BER improvements than LogR scheme.

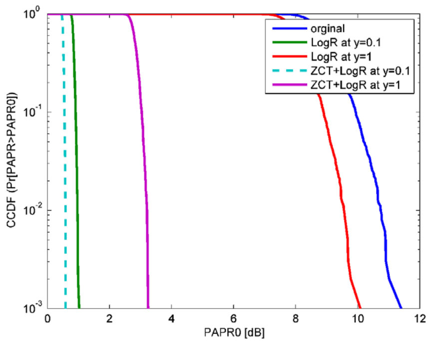

Figure (17): PAPR performance for proposed hybrid (ZCT+ LogR) scheme compared to existing LogR companding with different y values for LTE SISO-OFDM system

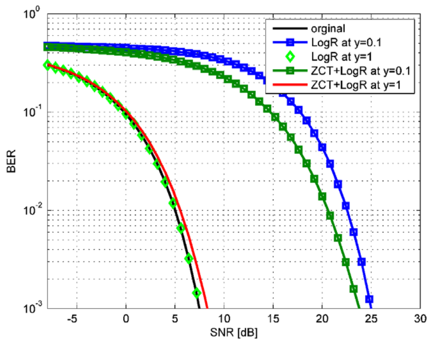

Figure (18): BER performance for proposed hybrid (ZCT+ LogR) scheme compared to existing LogR companding with different y values for LTE SISO-OFDM system

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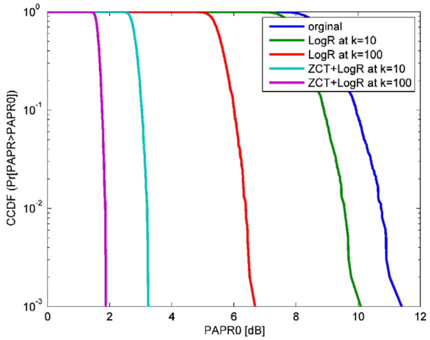

Figure (19): PARP performance for proposed hybrid (ZCT+LogR) scheme compared to existing LogR companding with different k values for LTE SISO-OFDM system

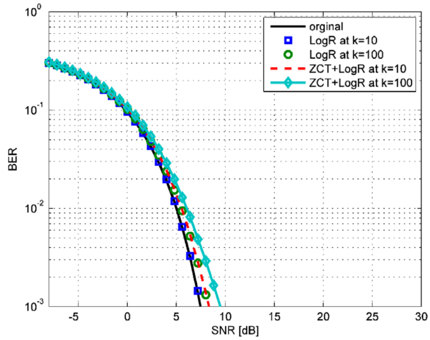

Figure (20): BER performance for proposed hybrid (ZCT+LogR) scheme compared to existing LogR companding with different k values for LTE SISO-OFDM system

5. Conclusion:

In this paper, seven new hybrid PAPR reduction techniques have been developed. They are utilizing ZCT precoding with the new compandings; Rooting Companding (RCT), New Error Function Companding (NERF), Absolute Exponential Companding (AEXP), Advanced Absolute Exponential Companding (AAEXP), Logarithmic Rooting Companding (LogR), Cosine Companding (COS) and Tangent Rooting Companding (TanhR). The proposed hybrid methods with LTE SISO-OFDM system achieve more reduction in PAPR and great improvement in BER with much more design flexibility in the PAPR reduction & BER performance against these compandings alone. Moreover, it is known that the best scheme is the scheme that achieves high PAPR improvement with very small BER degradation against traditional LTE SISO-OFDM signal. From simulation results of proposed hybrid schemes, when comparing them with conventional LTE SISO-OFDM signal, the best result is when PAPR improvement ≥10 dB in the ZCT+AAEXP proposed hybrid scheme which provides 10.55 and 11 dB PAPR improvements (gains) with 1.5 and 2.5dB SNR loss at Exp=50 and 100 respectively. It is followed by ZCT+TanhR proposed hybrid scheme which provides 10.4 dB PAPR improvement (gains) with 1.5 dB SNR loss at k=3.

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