Achieving Reduced PAPR by Residue Number System Model using MIMO OFDM

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Abstract— Multiple-input multiple-output orthogonal frequency division multiplexing (MIMO-OFDM) technology is one of the most attractive candidates for fourth generation (4G) wireless communication. MIMO-OFDM effectively combats the multipath fading channel and improves the bandwidth efficiency. At the same time, it also increases system capacity so as to provide a reliable transmission. The main drawback of MIMO-OFDM is high peak-to-average power ratio (PAPR), which is the main limitation of OFDM-based systems due to multiple subcarriers. In our proposed method, residue number system (RNS) module to effectively limit the output in each residue subchannel after inverse fast Fourier transform, which is smaller than the corresponding modulus. The main contribution of the proposed scheme is to reduce the dynamic range of the transmitted signal without nonlinear distortion so as to reduce the PAPR during the transmission. Compared with the partial transmit sequence (PTS) scheme, the RNS-based PAPR reduction scheme has not only much better PAPR reduction performance without restriction to modulation format, but also low computational complexity without side information.

Key words: RNS, PAPR, PTS, MIMO

I. INTRODUCTION

Multiple input multiple outputs (MIMO) and orthogonal frequency division multiplexing (OFDM) have therefore been adopted due to their superior performance. They promise to become key high-speed wireless communication technologies and combining them can provide wireless industry evolution from 3G to 4G system. In MIMO- OFDM system, the output is the superposition of multiple sub-carriers. In this case, instantaneous power outputs increases and may demand higher powers than the mean power of the system since the phases of these carriers are same. High PAPR is one of the most serious problems in MIMO-OFDM system. To transmit signals with high PAPR, it requires power amplifiers with very high power scope. These kinds of amplifiers are very expensive and have low efficiency-cost factor. This gives rise to non-linear distortion which changes the superposition of the signal spectrum resulting in performance degradation. If there are no measures to reduce the high PAPR, MIMO-OFDM system could face serious restriction for practical applications. To combat increase in PAPR, one intuitive solution is to adopt amplifiers to have larger trade-off range Two sub-type algorithms, selected mapping (SLM) and partial transmit sequence (PTS) are investigated. A comprehensive analysis and comparison are conducted in terms of all possible influencing factors and PAPR reduction performance.

When high PAPR OFDM signal pass through a nonlinear device such high power amplifiers (HPA), it causes the out-of-band radiation that affects signals in adjacent bands, and in-band distortions that result in rotation, attenuation, and offset on the received signal. So a large back-off in input OFDM power is required to force the operation in linear region of HPA. Such HPA with large dynamic range are quite expensive and increase overall cost of the system. By reducing PAPR we reduce the overall cost as well as complexity of various components in the OFDM system. [1]-[10]

The amount of PAPR reduction is proportional to the number of phase weighting factor. If the number of phase weighting factor is large, the number of parallel addition processor and the number of phase weighting factor sequences are searched to find the optimum combination of phase weighting factors will be increased incorporating huge complexity in the system. Then we cannot assume that the candidate signals are independent in PTS. The correlation among candidate signals deteriorates the PAPR reduction performance in PTS. The correlation among candidate signals is governed by two factors-one is the sub-block partition style as described in [6] and the other is the value of phase weighting factor set. So it is possible to alter these two factors to produce candidate signals with diminished correlation, so as to prevent degradation of the PAPR reduction performance.

Residue number system (RNS), a parallel number system, is based on Chinese remainder theorem (CRT), which divides a large integer into several independent and parallel smaller ones with a specific modulus set. Due to the carry-free and parallel properties, RNS further simplifies the computations by decomposing a problem into a set of parallel, independent residue computations. Thus, RNS has received wide attention in very large scale integration applications. The activities of RNS focus on RNS to-binary conversion, RNS parity check, and RNS scaling scheme.

When an RNS-based transmission scheme is employed in OFDM, one of the big advantages is that the dynamic range of the inverse fast Fourier transform (IFFT) output is limited by the corresponding modulus due to the characteristic of RNS modular operation. The main principle of the proposed scheme is to utilize the parallel property of RNS to divide the original frequency band into V equal portions and to convert the input signals into V smaller residues using the corresponding modulus set. Then, these V residue signals are preformed modulations (in particular, OFDM in this paper) in the corresponding V residue sub channels. Signals of each residue subchannel share the original frequency band through frequency division multiplexing (FDM). Specifically, the value of the corresponding modulus determines the dynamic range of the output in each residue subchannel. When the number of subcarriers is large, the proposed scheme is still able to limit the transmitted signals within a small dynamic range and reduce PAPR without nonlinear distortion. It is demonstrated that the PAPR performance has been improved by more than 5 dB compared with conventional OFDM[12]-[18]

II. BACKGROUND

A. Orthogonal Frequency Division Multiplexing (OFDM):

Orthogonal frequency division multiplexing (OFDM) is a widely used modulation and multiplexing technology, which has become the basis of many telecommunications standards including wireless local area networks (LANs), digital terrestrial television (DTT) and digital radio broadcasting in much of the world. In the past, as well as in the present, the OFDM is referred in the literature as Multi-carrier, Multi-tone and Fourier Transform. The OFDM concept is based on spreading the data to be transmitted over a large number of carriers, each being modulated at a low rate. The carriers are made orthogonal to each other by appropriately choosing the frequency spacing between them.

A multicarrier system, such as FDM divides the total available bandwidth in the spectrum into sub-bands for multiple carriers to transmit in parallel. It combines a large number of low data rate carriers to construct a composite high data rate communication system [2]. Orthogonality gives the carriers a valid reason to be closely spaced with overlapping without ICI. With the increase of communications technology, the demand for higher data rate services such as multimedia, voice, and data over both wired and wireless links is also increased. New modulation schemes are required to transfer the large amount of data which existing techniques cannot support. Orthogonal Frequency Division Multiplexing (OFDM) is a digital transmission Method developed to meet the increasing demand for higher data rates in communications which can be used in both wired and wireless environments.

B. PAPR:

The PAPR is the relation between the maximum power of a sample in a given OFDM transmit symbol divided by the average power of that OFDM symbol. PAPR occurs when in a multicarrier system the different sub-carriers are out of phase with each other. At each instant they are different with respect to each other at different phase values. When all the points achieve the maximum value simultaneously; this will cause the output envelope to suddenly shoot up which causes a 'peak' in the output envelope. Due to presence of large number of independently modulated subcarriers in an OFDM system, the peak value of the system can be very high as compared to the average of the whole system. This ratio of the peak to average power value is termed as Peak-to Average Power Ratio.

Many methods have been suggested to reduce PAPR over the year [12]. PAPR reduction techniques vary according to the requirement of the system and are dependent on various factors such as PAPR Spectral efficiency, reduction capacity, increase in transmit signal power, loss in data rate, complexity of computation and increase in the bit-error rate (BER) at the receiver end are various factors which are taken into account before adopting a PAPR reduction technique of the system. Many techniques have been suggested for PAPR reduction, with different levels of success and complexity.

C. Partial transmit sequence (PTS):

The partial transmit sequence (PTS) scheme is an efficient approach and a lossless scheme for PAPR reduction by optimally combining signal sub-blocks. Selective mapping (SLM) is also a good approach, in which some statistically independent sequences are generated from the same information and the sequence with the lowest PAPR is transmitted. Partial Transmit Sequence (PTS) algorithm is a technique for improving the statistics of a multi-carrier signal. The basic idea of partial transmit sequences algorithm is to divide the original OFDM sequence into several sub-sequences, and for each sub-sequence, multiplied by different weights until an optimum value is chosen. Both schemes provide improved PAPR statistic at the cost of additional complexity and loss of the data rate, because they need to implement some extra IFFT and iterations of phase optimization and transmit the side information. In addition, SLM scheme leads to a higher computational complexity at the same level of PAPR reduction, because it operates on all carriers.

D. Proposed Method:

E. RNS-based PAPR reduction:

An RNS is defined by the relative prime modulus set$m_v (v = 1,2, \dots .V)$. Any integer R can be represented in RNS by residue sequence $\{r_1, r_2, \dots . r_v\}$

$$r_v = R(mod m_v) \quad (8)$$

The number r_v is said to be the residue of R with respect tom_v , and we shall usually denote this by $r_v = \langle R \rangle_{m_v}$. In this sense, a big integer can be converted into the small residues in RNS, and these residues are always smaller than the corresponding modulus. The integers in the range of $[0, M_I)$ can be represented in this RNS uniquely and unambiguously, where $M_I = \prod_{i=1}^{V} m_v$ is referred to as the information dynamic range, i.e., the legitimate range of the information symbol.

The information symbols can be uniquely recovered by residue sequence through CRT, which is one of the fundamental theorems of RNS. The relationship between the information symbols R and its residues is as follows

$$R = \left(\sum_{v}^{V} S_v \langle 1/S_v \rangle_{m_v} r_v \right) mod M_1 \qquad (9)$$

where$\langle 1/S_v \rangle_{m_v}$ called as multiplicative inverse of S_v , $S_v = M_I / m_v$ and $\left(S_v \langle 1/S_v \rangle_{m_v} \right) mod M_v = 1$

The basic diagram of RNS-based PAPR reduction scheme in MIMO-OFDM is given in Fig.2. The number of modulus $\{m_1, m_2, \ldots . m_V\}$is , and the input are converted into V residues by the corresponding modulus set, and the number of transmit antennas equals the number of residue sub-channels. These residue signals are preformed OFDM modulation in the corresponding residue channels. In the each of the V parallel residue sub-channels one IFFT of length N is employed.

The function of mapping module, if the input is positive, it can be sent into B/R (binary to residue) module directly; otherwise the input adds the legitimate MI before B/R.Through B/R conversion, according to (8), the serial data streams are divided into parallel residue sub-channels transmitting signals.

$$S_{m_v,k} = s(KT/N) = \sum_{i=0}^{N-1} r_{m_v,i} \exp\left(j\frac{2\pi ik}{N}\right), (0 \le k \le N-1, 0 \le i \le N-1) \qquad (10)$$

F. PAPR of RNS-based scheme:

The real and imaginary parts of OFDM signals have asymptotically Gaussian distributions for a large number of subcarriers by the central limit theorem. Then the amplitude of the OFDM signals follows a Rayleigh distribution. The PAPR of RNS-based scheme in each sub-channel can be written as

$$PAPR_{n_t} = 10log\frac{max\left\{\left|\sum_{i=0}^{N-1} r_{m_v,i}\exp\left(j\frac{2\pi ik}{N}\right)\right|^2\right\}}{E\left\{\left|\sum_{i=0}^{N-1} r_{m_v,i}\exp\left(j\frac{2\pi ik}{N}\right)\right|^2\right\}} \quad (11)$$

$$= 10\log\frac{max\left\{\left|\sum_{i=0}^{N-1} r_{m_v,i}\exp\left(j\frac{2\pi ik}{N}\right)\right|^2\right\}}{2\sigma^2}(dB)$$

where σ is the variance of OFDM signals. In the MIMOOFDM sceneries, the PAPR performance is governed by the worst-case PAPR, it can be presented as

$$PAPR_{rns-mimo} = \max_{n_t=1,2,\ldots.n_r} PAPR_{n_t}$$

$$= 10\log\frac{max\left\{\left|\sum_{i=0}^{N-1} r_{m_v,i}\exp\left(j\frac{2\pi ik}{N}\right)\right|^2\right\}}{2\sigma^2}(dB) \qquad (12)$$

According to (8), the residue is always smaller than the corresponding modulus, which may be chosen smaller than the original number. Then the residue is smaller than the original number. After multiplying a rotation factor and summing up all the N elements, it is still smaller than the sum of original one. It can be seen that the proposed scheme has the potential to improve the PAPR reduction performance.

G. Complexity:

In RNS, the addition and multiplication are modular operations. In theoretical analysis, they can be designed for flexibility in which case the methodology allows the design of adders for any modulus. The basic adder for any modulo-m is defined as (13)

$$\langle A+B\rangle_m = \begin{cases} A+B if A+B<m \\ A+B-m otherwise \end{cases} \qquad (13)$$

In the most straightforward implementation, the most complex way, a basic modular requires 3 adders: one for the addition, one for the subtraction, and one for the comparison [13].

A modular multiplication of complex signals can be expressed as (14)

$$\langle A\times B\rangle_m = \langle\langle a_1a_2\rangle_m - \langle b_1b_2\rangle_m\rangle_m + i\langle\langle b_1a_2\rangle_m + \langle a_1b_2\rangle_m\rangle_m \qquad (14)$$

The modular multiplication of complex signals needs more 6 modular operations than complex multiplier. In each modular operation, it needs 2 adders (one for addition and one for comparison), which is similar to the case of the modular adder. Based on the definition of RNS, the residue is smaller than its corresponding modulus. Regardless of the number of addition and multiplication, the sum of residue signals in each residue sub-channel is still smaller than its corresponding modulus. It can be seen that this scheme effectively controls the dynamic range of the transmitted signals to improve the PAPR reduction performance.

III. SIMULATION RESULTS

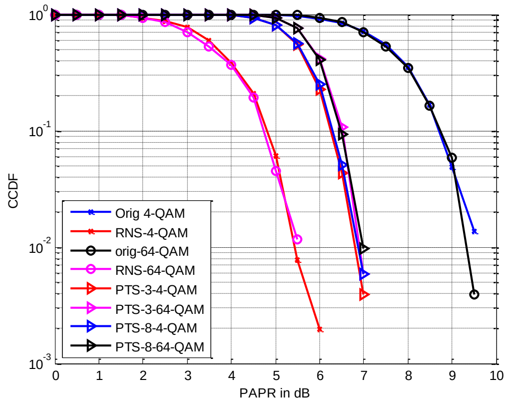

Fig. 1: PAPR reduction performance of the proposed scheme, PTS scheme and the conventional MIMO-OFDM

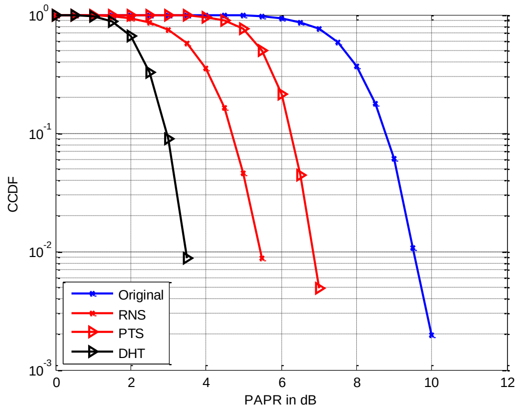

Fig. 2: PAPR reduction performance of extension scheme (DHT), RNS, PTS scheme of MIMO-OFDM.

IV. CONCLUSION

The demand for high data rate wireless communication has been increasing drastically over the last decade. One way to transmit this high data rate information is to employ well known conventional single carrier systems. In this paper, an RNS based PAPR scheme in MIMO-OFDM is proposed, which utilizes the properties and characteristics of RNS module to efficiently reduce the PAPR without any side information. Compared to the partial transmit sequence, RNS technique provides reduced PAPR and computational complexity is less. Theoretical analysis and simulation results demonstrate the performance of RNS scheme.

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