PAPR Reduction Techniques with Hybrid SLM Partial Transmit Sequence Algorithm for OFDM System

Aisha Siddiqui, PratyushTripathi

Abstract—**In recent time, the demand for multimedia data services has grown up rapidly. One of the most promising multi-carrier system, Orthogonal Frequency Division Multiplexing (OFDM) forms basis for all 4G wireless communication systems due to its large capacity to allow the number of subcarriers, high data rate and ubiquitous coverage with high mobility. OFDM is significantly affected by peak-to-average-power ratio (PAPR).In general; the high peak-to-average power ratio (PAPR) of transmitted signals for OFDM systems reduces the system efficiency and hence increases the cost of the radio frequency (RF) power amplifier. This thesis emphasis mainly on the PAPR reduction of OFDM system using partial transmits sequence (PTS) and pre-coding techniques. Some other techniques such as amplitude clipping have low-complexity; on the other hand, they suffer from various problems such as in-band distortion and out-of-band expansion. Signal companying methods have low-complexity, good distortion and spectral properties; however, they have limited PAPR reduction capabilities.**

A modified hybrid algorithm is developed to obtain better PAPR reduction performance and reduce computational complexity compared with the conventional hybrid scheme. This proposed algorithm combines selected mapping (SLM) with partial transmit sequence (PTS) strategies, and further employs linear addition and exchange of various PTS sub-blocks to create more alternative OFDM signal sequences. As a result, with the same numbers of IFFT and phase rotation sequences, our proposed algorithm has the potentials to provide better PAPR reduction performance with lower computational complexity.

Index Terms—**Orthogonal Frequency Division Multiplexing (OFDM), Peak-to-Average Power Ratio (PAPR), Partial Transmit Sequence (PTS), SLM.**

I. Introduction

The modern day phenomenon of increased thirst for more information and the explosive growth of new multimedia wireless applications have resulted in an increased demand for technologies that support very high speed transmissionrates, mobility and efficiently utilize the available spectrum and network resources. Orthogonal Frequency DivisionMultiplexing (OFDM) is one of the best solutions to achieve this goal and it offers a promising choice for future highspeed data rate systems [1].The modulators and demodulators of OFDM systems can be simply implemented by employing inverse fast Fourier transform (IFFT) and FFT to make the overall system efficient and effective. Nowadays, it has been adopted as a powerfully potential candidate for next-generation mobile communications systems.

For OFDM-based systems, one of the main disadvantages is high PAPR problem. This phenomenon results from that in the time domain, an OFDM signal is the superposition of many narrowband subcarriers. At certain time instances, the peak amplitude of the signal is large and at the other times is small, that is, the peak power of the signal is substantially larger than the average power of the signal. The influence of high PAPR reduces system efficiency and then increases the cost of the RF power amplifier. Therefore, how to find a solution to reduce high PAPR effectively is one of the most important implementation issues in OFDM communications. The multiple signal representation is one of well-known PAPR reduction techniques for OFDM systems [2]. Several helpful schemes related to SLM-based and PTS-based techniques have been proposed for improving PAPR reduction performance or reducing the computational complexity. Those techniques included the conventional hybrid method [3] and the modified SLM scheme [4]. Based on the preceding survey results, a novel modified hybrid algorithm combining the additional hybrid with switching hybrid schemes is proposed to reduce the number of IFFT and obtain a significant PAPR reduction performance in OFDM systems.

II. Generation of OFDM Symbol

OFDM is simply defined as a form of multi-carrier modulation where the carrier spacing is carefully selected so that each sub carrier is orthogonal to the other sub carriers. Two signals are orthogonal if their dot product is zero. That is, if you take two signals multiply them together and if their integral over an interval is zero, then two signals are orthogonal in that interval. Orthogonality can be achieved by carefully selecting carrier spacing, such as letting the carrier spacing be equal to the reciprocal of the useful symbol period.

As the sub carriers are orthogonal, the spectrum of each carrier has a null at the center frequency of each of the other carriers in the system. This results in no interference between the carriers, allowing them to be spaced as close as theoretically possible. Mathematically, suppose we have a set of signals φ then

$$\int_0^T \varphi_p(t)\,\varphi_q(t) = k \text{ for } p=q \qquad (1)$$
$$= \text{ for } p\neq q$$

Where φ_p and φ_q are pth and qth elements in the set. The signals are orthogonal if the integral value is zero. Where, T is a symbol period. Since the carriers are orthogonal to each other the nulls of one carrier coincides with the peak of another sub carrier. As a result it is possible to extract the sub

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carrier of interest OFDM transmits a large number of narrowband sub channels. The frequency range between carriers is carefully chosen in order to make them orthogonal one another. In fact, the carriers are separated by an interval of 1/T, where T represents the duration of an OFDM symbol. A baseband OFDM symbol can be generated in the digital domain before, modulating on a carrier for transmission. To generate a baseband OFDM symbol, a serial digitized data stream is first modulated using common modulation schemes such as he phase shift keying (PSK) or quadrature amplitude modulation (QAM). These data symbols are then converted to parallel streams before modulating subcarriers. Subcarriers are sampled with sampling rate N /T, where N is the number of subcarriers and T is the OFDM symbol duration. The frequency separation between two adjacent subcarriers is 2π / N. Finally, samples on each subcarrier are summed together to form an OFDM sample. An OFDM symbol generated by an N-subcarrier OFDM system consists of N samples and the mth sample of an OFDM symbol is given by

$$x_m = \sum_{n=1}^{N} X_n e^{j\frac{2\pi mn}{N}} \qquad 0 \le m \le N-1 \tag{2}$$

Where, Xn is the transmitted data symbol on the nth carrier. Equation (1.2) is equivalent to the N-point inverse discrete Fourier transform (IDFT) operation on the data sequence with the omission of a scaling factor. It is well known that IDFT can be implemented efficiently using inverse fast Fourier transform (IFFT). Therefore, in practice, the IFFT is performed on the data sequence at an OFDM transmitter for baseband modulation and the FFT is performed at an OFDM receiver for baseband demodulation. Size of FFT and IFFT is N, which is equal to the number of sub channels available for transmission, but all of the channels needs to be active. The sub-channel bandwidth is given by

$$f_{sc} = \frac{1}{T} = \frac{f_{samp}}{N} \tag{3}$$

Where, fsamp the sample rate and Ts is the symbol time. Finally, a baseband OFDM symbol is modulated by a carrier to become a band pass signal and transmitted to the receiver. In the frequency domain, this corresponds to translating all the subcarriers from baseband to the carrier frequency simultaneously.

III. Literature Review

Many PAPR reduction techniques have been proposed in the literature.

In 2013, Komal Gupta, Monika Kushwaha, AbhayPratap Sharma &Arvind Singh Panwar et.al [5] proposed Peak – to – Average Power Ratio (PAPR). Due to high PAPR there is inefficient use of high power amplifier and this could limit transmission efficiency. OFDM consist of large number of independent subcarriers, as a result of which the amplitude of such a signal can have high peak values. In this paper, we introduce a modified SLM technique to reduce PAPR. The simulation results show PAPR can be reduced by applying the proposed scheme. The complexity is also reduced in proposed scheme. The PAPR of original OFDM is near about 10.4dB. By using SLM technique with original OFDM PAPR is reduced nearly about 3.5dB. And by using the modified SLM technique PAPR is reduced nearly about 3.8dB in comparison to original OFDM.

In 2014,PoonamKundu, Prabhjot Kauret.al [6] suggested OFDM (Orthogonal Frequency Division Multiplexing) is generally preferred for high data rate transmission in digital communication.OFDM system has a major shortcoming of high peak to average power ratio (PAPR) value. This paper explains different PAPR reduction techniques and presents a comparison of the various techniques based on theoretical and simulated results. It also presents a survey of the various PAPR reduction techniques and the state of the art in this area.

In 2007, Tao Jiang, Weidong Xiang, Paul C. Richardson,JinhuaGuo, and Guangxi Zhu [7] proposed a Simulated Annealing (SA) method to search the optimal combination of phase factors for PTS to obtain almost same PAPR as that of optimal PTS with low complexity. PTS scheme utilizes SA basic properties of global optimization technique for huge combination problems. Global optimization technique accepts increases trail to shun early convergence to local optimum solutions.

In 2009, Jung Chien Chen [8] proposed Cross Entropy (CE) algorithm for PTS method to reduce PAPR and computational complexity. The objective of CE algorithm is to find phase factor optimally. According to this method, first score function is defined as the amount of the PAPR, then after that this score function is overset into a stochastic approximation problem. Now, this problem can be solved effectively. The CE algorithm PTS method achieves almost same PAPR as to conventional PTS method with low complexity as shown by simulation results.

In 2010, Sheng.Ju. Ku et al., [9] proposed a new reduced complexity PTS scheme. In this scheme, a new cost function is created which can be defined as the sum of the power samples after taking IFFT in each subblock. The samples with cost function that are greater than or equal to a fixed threshold are selected. As a consequence, the signal with lowest PAPR for transmission is chosen from the selected candidates. The proposed scheme can achieve approximately the same PAPR as of the CPTS scheme with less computational complexity.

In 2010, Yajun Wang et al., [10] proposed a Artificial Bee Colony (ABC) algorithm for reducing the phase complexity. For high number of subblocks ABC algorithm reduces computational complexity effectively. The searching capacity of combination of phase factor is high. As it has only three control parameters, it is easy to adjust.

In 2010, Jung Chien Chen [11] proposed Quantum-inspired Evolutionary Algorithm (QEA) which reduces the searching process for finding the optimal phase factors. Like in the evolutionary algorithms, the evolution function and the population dynamics parameters are used to characterize the QEA. Also, QEA follows the concept of generational population based search scheme same as genetic algorithm.

In 2011, Jun Hou et al., 2011 [12] proposed a novel scheme for PTS method to reduce the computational complexity. This scheme utilizes the correlation among the weighting phase factors. In this scheme, instead of decreasing the number of candidate signals, it focused simplifying the computation for each candidate signal. Since the number of candidates is not decreased, the proposed scheme can achieve similar reduction in PAPR as compared to the PTS scheme with lower computational complexity.

In 2011, Lingyin Wang and Ju Liu [13] proposed a method which reduces the complexity by combining Grouping Phase Weighting (GPW) and Recursive Phase Weighting (RPW) methods. The combination of these two methods has low complexity for searching the phase factors than CPW and

RPW individually. Also, it achieves same PAPR as conventional PTS.

IV. PAPR Reduction Techniques

PAPR reduction methods can be mainly divided into two domain methods: frequency domain method and time domain method [14]. The basic notion of frequency domain method is to increase the cross correlation of the input signal before IDFT and decrease the output of the IDFT peak value or average value. Selective Mapping (SLM), Partial Transmit Sequence (PTS), Pre-coding etc. schemes are example of frequency domain method. However, in time domain method PAPR is reduced by distorting the signal before amplification and added of extra signals which increase the average power. Clipping and filtering, Peak widowing etc. are examples of time domain method. It is very simple method because it requires very less computational time but introduces the distortion, increases out of band radiation and also degrades BER performance. On comparing between these two domain methods, frequency domain PAPR reduction technique is the most efficient one because of its ability to compress the PAPR without distorting the transmitted signal, no production of in band distortion and out of band radiation in OFDM signals.
Broadly PAPR reduction techniques are classified into four sections [15].

a) *Signal scrambling (Probabilistic) technique*

Signal Scrambling technique scramble each OFDM symbol with different scrambling techniques and select the sequence that gives the smallest PAPR value. It includes methods like Selective Mapping (SLM) and Partial Transmit Sequence (PTS).

b) *Signal distortion technique*

This technique reduces the PAPR by distorting the OFDM signal non-linearly. The methods like clipping and filtering, peak windowing, and non-linear companding are the example of this technique. These methods are applied after the generation of OFDM signal (after the IFFT).

c) *Coding technique*

The coding technique employed some error correcting codes for the PAPR reduction. These methods are applied before the generation of OFDM signal (before IFFT). When N signals are added with the same phase, they produce a peak power, which N is times the average power. The basic idea of all coding schemes for the reduction of PAPR is to reduce the occurrence probability of the same phase of many signals. The coding methods select such code words that minimize or reduce the PAPR. It causes no distortion and creates no out of band radiation, but it suffers from bandwidth efficiency as the code rate is reduced. It also suffered from the complexity to find the best codes and to store large lookup tables for encoding and decoding, especially for a large number of subcarriers. The error correcting codes like block codes, cyclic codes, Golay complementary sequence, Reed-Solomon (RS) code, Reed-Muller (RM) code, Hadamard code and Low Density Parity Check (LDPC) code can be used.

d) *Pre-distortion technique*

The pre-distortion technique is based on the reorientation or spreading the energy of data symbol before taking IFFT. The pre-distortion scheme includes DFT spreading, pulse shaping or pre-coding and constellation shaping.

V. Proposed Hybrid Schemes

a) *Conventional hybrid scheme*

The conventional hybrid (CH) method combining the SLM with PTS schemes is investigated. The strategy was first explicitly proposed [6]; the block diagram of the CH method is shown in Figure 1. The original OFDM symbol is multiplied with the U phase rotation sequences, and then each of the new OFDM symbols is partitioned into V pairwise disjoint sub-blocks. Those OFDM sub-block values are calculated by each optimization of PTS blocks. For simplicity and without loss of generality, V = 2 is always considered in this paper. Each signal x(u),
Where u = 1. . . U, with the lowest PAPR is selected by each optimization block. They can be written as

$$\{b_1{}^{(u)}, b_2{}^{(u)}\} = argmin\{\sum_{v=1}^{2} b_v{}^{(u)}, X_v{}^{(u)}\} \quad (4)$$

$$X(u) = \sum_{v=1}^{2} b_v{}^{(u)}, X_v{}^{(u)} \quad (5)$$

Where, $1 \ll u \ll U$
By the selection block, the relatively lower PAPR can be obtained from those lowest PAPR values of each PTS block. Because those lowest PAPR values of each PTS block are statistically independent to each other, the CCDF of CH scheme can be written as

$$CCDF_{CH} = (\Pr(PAPR_{PTS} > PAPR_0))^U \quad (6)$$

In order to recover transmitted data information, the receiver must have the knowledge of side information. Because the CH signal must include the side information of SLM and the side information of PTS, the number of required side information bits can be written as

$$N_{CH} = log_2 U + (V-1)log_2 (7)$$

Where W is the number of allowed phase rotation factors. In the first term expresses the SLM required side information bits and the second term is the additional bits from the PTS algorithm

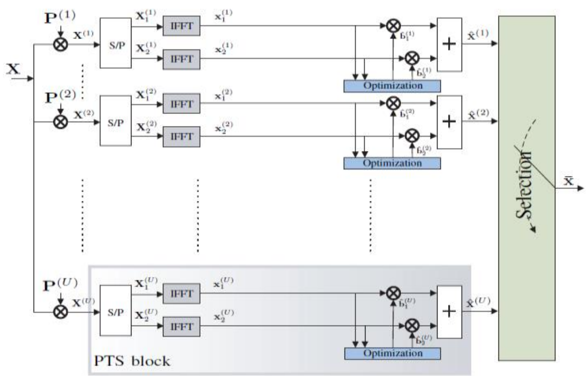

Figure 1: Block diagram of conventional hybrid scheme[16]

b) *Additional Hybrid Scheme*

In order to improve the PAPR reduction performance in CH scheme, we have to generate a large number of alternative OFDM signal sequences without increasing the number of IFFT to avoid high computational complexity. Here, a new additional hybrid (AH) scheme by combining the modified SLM scheme with CH scheme. The system performance is desirable that the number of IFFT is reduced but the PAPR reduction performance is not compromised. The block diagram of AH scheme is shown in Figure 2.

Clearly, the first U signals x(u), where u = 1, . . . , U, are the same as the signals in the CH scheme. Furthermore, the alternative OFDM signal sequences are generated by the linear combination of the sub-block signals from different PTS blocks after IFFT operation. Using the linear property of Fourier transform, the linear combination of these sequences can be obtained by

$$X_v^{(u)} = c^{(i)} X_v^{(i)} + c^{(k)} X_v^{(k)} \quad (8)$$

OFDM signal of lowest PAPR in AH scheme can be written as

$$\{b_1^{(u)}, b_2^{(u)}\} = argmin\left\{b_1^{(u)} X_1^{(u)} + b_2^{(u)} X_2^{(u)}\right\} (9)$$

$$X(u) = b_1^{(u)} X_1^{(u)} + b_2^{(u)} X_2^{(u)} \quad (10)$$

Where, U+1≤ u ≤ U^2 ,We have to select and transmit the resulting OFDM signal sequence x, which has the minimum PAPR among the whole OFDM signal sequences of overall lowest PAPR x(u) sequences, which are composed by $\{X_1^{(u)}$, ..., $X_V^{(u)}$ } after each optimization operation. The number of required side information bits for transmitter can be written as

$$N_{AH} = log_2 U^2 + (V-1) log_2 W (11)$$

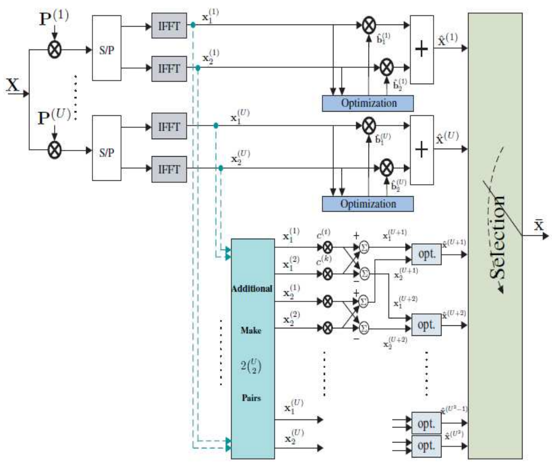

Figure 2: Block diagram of additional hybrid scheme[16]

c) Switching Hybrid Scheme

Instead of generating alternative OFDM sequences with linear combination, a new switching hybrid (SH) scheme by combining the switching technique with the CH scheme. The system performance is desirable that the number of IFFT is reduced but the PAPR reduction performance is not compromised. The block diagram of SH scheme is shown in Figure 3.By the switching block, we can use original U pairs $\{X_1^{(u)} + X_2^{(u)}\}$ to generate excessive $2\binom{U}{2}$ pairs of OFDM sequences without increasing the number of IFFT units. Thus, there are total U2 pairs $\{X_1^{(u)} X_2^{(u)}$, ..., $X_1^{(u^2)} X_2^{(u^2)}$ } are operated by each optimization unit. Obviously, the first U signals$X^{(u)}$, where u = 1, . . . , U, are the same as the signals in the CH scheme.

After the optimization blocks, the other alternative OFDM sequences with lowest PAPR$X^{(u)}$ can be written as

$$\{b_1^{(u)}, b_2^{(u)}\} = argmin\left\{b_1^{(u)} X_1^{(i)} + b_2^{(u)} X_2^{(k)}\right\} (12)$$

$$X(u) = b_1^{(u)} X_1^{(i)} + b_2^{(u)} X_2^{(k)} (13)$$

Where, U+1≤ u ≤ U2, 1 ≤i, k ≤u and i ≠ k In (4.10),$x_v^{(i)}$ and $x_v^{(k)}$, i ≠ k come from different PTS blocks, which are generated by different phase rotation sequences, so that $P^{(i)}$ and $P^{(k)}$, where 1 ≤i, k ≤u and i ≠ k, can obtain differently alternative OFDM sequences with the minimum PAPR. Noteworthy, the number of required side information bits can be written as

$$N_{SH} = log_2 U^2 + (V-1) log_2 W \quad (14)$$

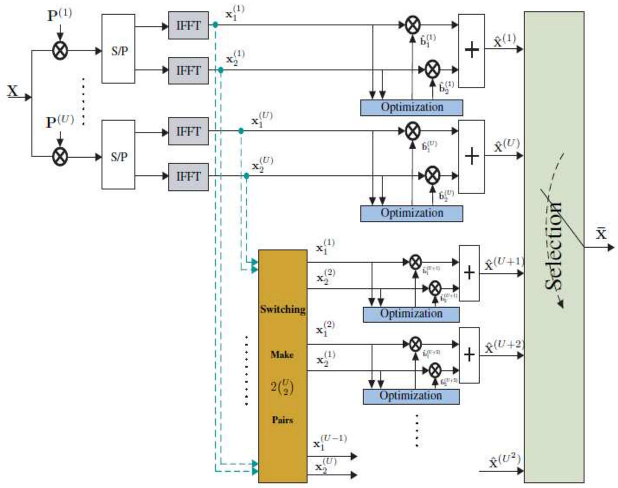

Figure 3: Block diagram of switching hybrid scheme[16]

d) Modified Hybrid Scheme

In order to further improve the PAPR reduction performance without increasing the number of IFFT, the modified hybrid (MH) algorithm is proposed by combining AH and SH schemes to generate more and more alternative OFDM sequences. Those $\{x_1^{(u)} x_2^{(u)}\}$ pairs,

where 1≪ u ≪U,are the signal inputs of the additional block and switching block respectively and simultaneously. The block diagram of MH scheme is shown in Figure 4.

Using the linear property of Fourier transform, the linear combination of U phase rotation sequences can obtain excessive $2\binom{U}{2}$ alternative OFDM sequences. After optimization blocks, those overall lowest PAPR$x^{(u)}$ can be written as the same as (10). Using the switching technique among PTS blocks, the signals of U phase rotation sequences can obtain excessive $2\binom{U}{2}$ alternative OFDM sequences. After optimization blocks, those overall lowest PAPR $x^{(u)}$can be written as the same as (13).

In the MH scheme, if V = 2 and U phase rotation sequences are considered, the original signals $x_v^{(u)}$ can generate excessive $2\binom{U}{2}$ pairs of sequences respectively and simultaneously by either additional block or switching block. Therefore, there are total $2U^2 - U$ OFDM sequences with the lowest PAPR in the MH scheme. In order to recover the transmitted data information, the number of required side information bits can be obtained by

$$N_{MH} = log_2(2U^2 - U) + (V-1) log_2 W \quad (15)$$

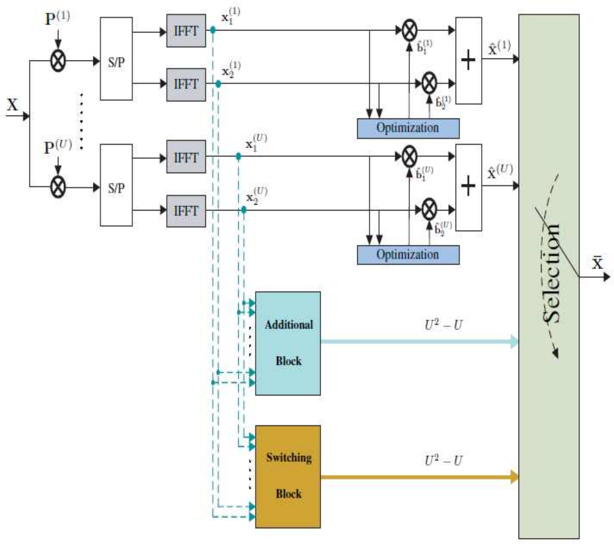

Figure 4: Block diagram of Modified hybrid scheme[16]

VI. SIMULATION RESULTS

The PAPR reduction performance with the CH scheme for various values of U is shown in Figure 5. It shows that the PAPR reduction performance becomes better as the number of U increases.

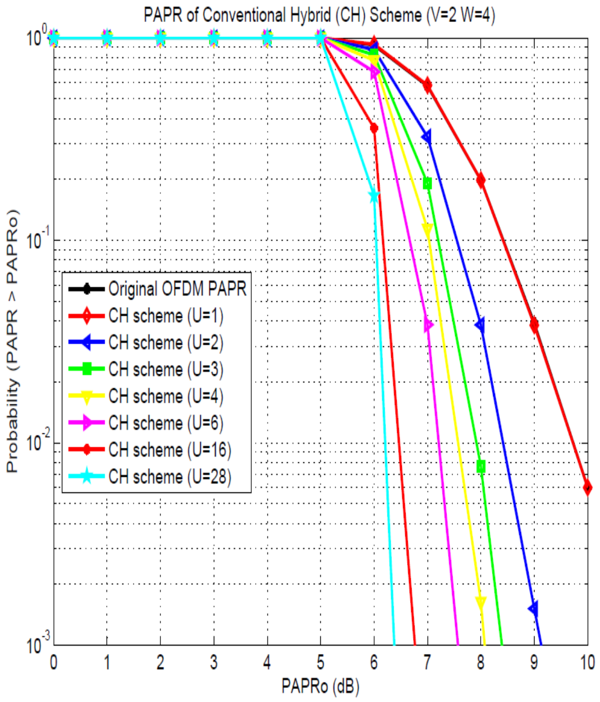

Figure 5:PAPR reduction performance of conventional hybrid scheme for OFDM systems

In Figure 5.2 and Figure 5.3, the performance of AH scheme is similar to that of SH scheme. The AH and SH schemes with $U = 2$ and $U = 4$ have almost the same performance compared with the CH scheme with $U = 4$ and $U = 16$, respectively. In Figure 5.4, the MH method with $U = 2$ and $U = 4$ has almost the same performance compared with the CH scheme with $U = 6$ and $U = 28$, respectively.

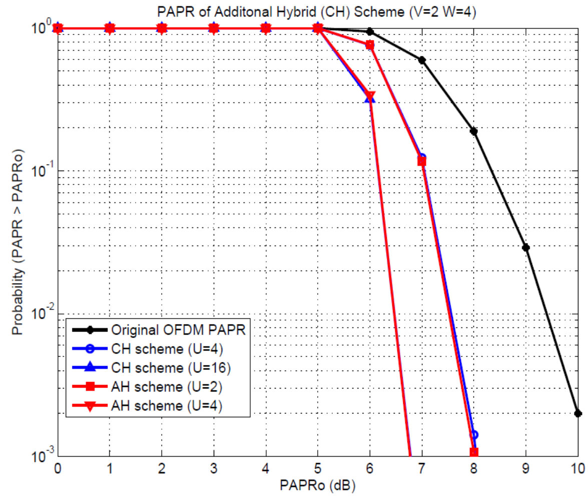

Figure 6:PAPR reduction performance of additional hybrid scheme for OFDM systems

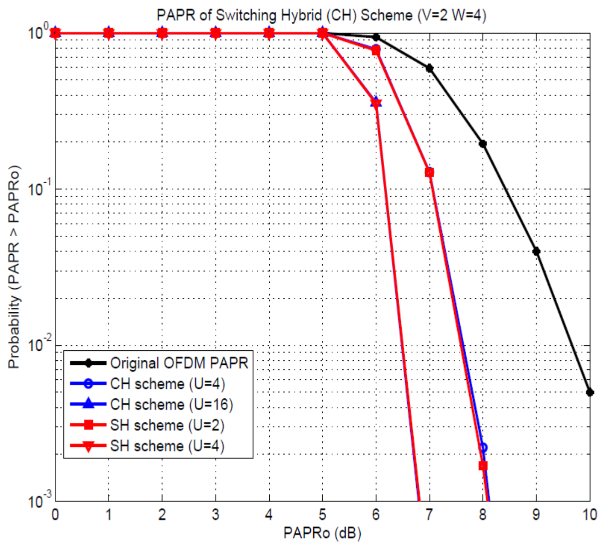

Figure 7:PAPR reduction performance of switching hybrid scheme for OFDM systems

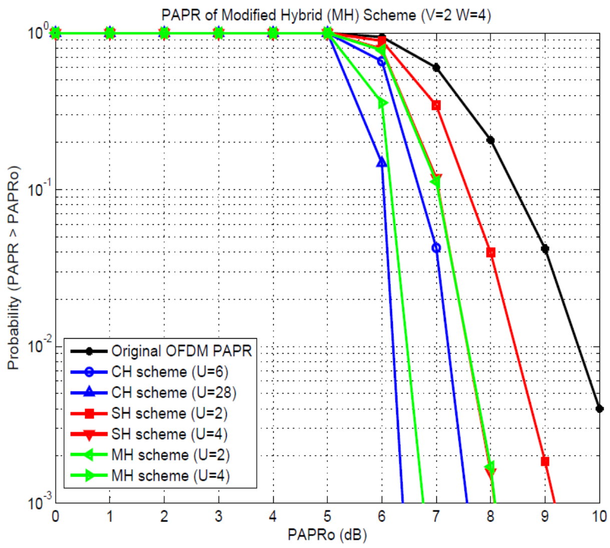

Figure 8:PAPR reduction performance of switching hybrid scheme for OFDM systems

VII. Conclusion

In general, the PAPR reduction performance becomes better as the number of U increases in CH scheme, but the CH scheme has high computational complexity because of the increase of the number of IFFT. Therefore, based on original signals of CH scheme, several powerful algorithms have been proposed to improve high PAPR reduction performance without increasing the number of IFFT, including AH, SH and MH schemes. The MH scheme can obtain the best PAPR reduction performance by combining the AH with SH schemes. After a number of comparative simulations, the MH scheme has shown that the excellent PAPR reduction performance can be achieved without increasing the number of IFFT. The proposed MH scheme has obtained a superior PAPR reduction performance for OFDM systems. The technique has a better PAPR reduction performance by increasing the number of alternative OFDM sequences. In particular, when the number of IFFT is the same, the MH scheme has the best PAPR reduction compared with CH, AH and SH schemes. Therefore, for the MH scheme, it can expend less IFFT units to obtain similar PAPR reduction performance without the dramatic increase of side information bits.

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