A hybrid of the selected mapping and partial transmit sequence approaches for reducing the high peak average to power ratio based on multi-carrier systems – review

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Article Info

ABSTRACT

The orthogonal frequency division multiplexing (OFDM)-4G and 5G filter technology suffer a drawback that represents the direction of the peak average to power ratio (PAPR) in orthogonal frequency division multiplexing due to the nonlinear nature of the transmitter. There are a lot of traditional and hybrid methods of these traditional methods to reduce the harmful high PAPR value. Newly, several new hybrid methods have been adopted to reduce PAPR but it faces an increasing level of computational complexity in the system. In this paper, two important and effective conventional methods for reducing PAPR are studied, analyzed, and investigated for the hybrid pathway which is the incorporation of selective mapping (SLM) method and partial transport sequencing (PTS) method, which achieve increased efficiency of PAPR reduction while computing the computational complexity of each method. The method depends and balances with computational complexity. The search is based on multi-carrier connections such as multi carrier-code division multiple access (MC-CDMA) and OFDM.

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1. INTRODUCTION

The Orthogonal frequency division multiplexing (OFDM) and multi carrier-code division multiple access (MC-CDMA) system has been widely spread in modern high-speed wireless protocols. MC transmission systems suffer from a high peak-to-average power ratio (PAPR), a critical disadvantage resulting in in-band distortion and out-of-banded radiation in the power amplifier nonlinear region [1]. Consequently, new candidates of the multicarrier waveform schemes have recently drawn increasing interest in 5G waveform architecture such as filtered-OFDM [2], [3], universal filter multicarrier (UFMC) [4], and filtered bank multi-carrier (FBMC) [5]. Although the latest waveform candidates were designed to resolve the shortcomings of the OFDM system and meet the requirements of the (5G) scenarios, the high PAPR pattern remains the challenge of these waveform candidates [6]. Furthermore, MC-CDMA is deemed as a promising waveform contender for (5G) based on filtering the bandwidth by a pair of spectral shaping filters in transmitter and receiver. OFDM has several benefits, such as eliminating out-of-banded emissions (OOBE), asynchronous transmission, increasing spectral efficiency, and low latency [7]. But this candidate's major drawback is the high PAPR pattern because it promotes orthogonal transmission [3]. Coding techniques [8], techniques of clipping and filtering [9], techniques for expanding the constellation [10], nonlinear compounding transform schemes [11], and techniques, multiple signal representation (MSR) Like

interleaving [12], selective level mapping (SLM) [13], partial transmit scheme (PTS) [14]. Due to their high performance, the multi-point signal resonator (MSR) techniques are an attractive choice and are implementable without signal distortion [15]. Between the mentioned techniques, the conventional PTS (C-PTS) scheme is a very well-known deterministic non-signal distortion method that provides excellent PAPR reduction performance but is set to increase the calculation complexity and require side information. SLM and Interleaving are considered other schemes of the MSR technique, which provide a lower computational complexity, on the degradation expense in the PAPR reduction performance [16]. In recent years, several studies have been proposed to combine two types of MSR methods to employ the inherent features of each method in one hybrid scheme. These hybrid methods aim to enhance the gain in PAPR reduction with low computational complexity.

In the last works, several approaches have been introduced to combine PTS and SLM to minimize the PAPR-value. Pushkarev et al. [17] introduced a hybrid algorithm based on the combination of SLM and PTS by applying the input data sequence to the SLM technique and then passing each modified sequence to the PTS technique. Pushkarev algorithm can give better PAPR reduction performance than the C-PTS and SLM techniques, whereas the computational complexity is higher than that of the C-PTS scheme. Similarly, Satyavathi and Rao [18] applied the inverse discrete Hartley transform (IDHT) instead of inverse fast Fourier transform (IFFT) units to a Pushkarev's algorithm, where IDHT has the asymmetrical clipping property which achieves a further PAPR reduction level compared with IFFT. Singh et al. [19] and Mohammad et al. [20] combined the SLM and PTS techniques with a new approach by applying SLM as the sequence input data and the resulting OFDM signal is selected to be the input of the PTS technique. Since the degree of similarity between the sub-carriers inside the sunblock is reduced, Singh's method can achieve better PAPR reduction efficiency than C-PTS and SLM schemes but likened with the C-PTS process, the degree of computational complexity and side information is degraded. Just the same way, Wang in [21] combined the SLM and PTS techniques based on filter bank multicarrier (FBMC) like Singh's method to minimize the PAPR value in a new candidate of the next generation. Another tactic has been proposed by Tiwari et al. [22] by combining the SLM and PTS schemes. Tiwari's method depended on applying the SLM technique firstly, and then the resulting OFDM signal is transmitted to the block fast Fourier transform (FFT) before the implementation of the C-PTS technique. The Tiwari's algorithm is superior to the C-PTS method for PAPR reduction, at the detriment of increasing the complexity of computing and side-information.

Likewise, Duanmu and Chen [23] and Singh and Singh [24] proposed a new method for combining the SLM technique and PTS technique in parallel. Dynamos algorithm is based on passing some of the data to PTS, and the remaining data are processed by SLM. The PAPR efficiency and the level of the computational complexity of the Duanmu algorithm are superior to the C-PTS process, whereas the amount of side information bits is increasing. In comparison to the C-PTS approach, several algorithms that combine the interleaving technique and the PTS technique have been proposed to minimize the PAPR reduction potential and/or the degree of computational complexity. Wang et al. [25] suggested a system to combine the interleaving and (PTS) techniques, sequentially. In Wang's algorithm, first, apply the interleaving method to process the input data sequence and then the modified-PTS method that has been proposed in [26] is performed to resulting signal by the interleaving technique. The PAPR reduction capacity of Wang's algorithm is better than C-PTS with slightly increasing computational complexity, while the side information level is increased. Also, Xiaoqiang in [27] introduced an algorithm dependant on the combination of interleaving and PTS techniques in which the permutation data sequence corresponding to the optimum time-domain sequence is transferred to the C-PTS technique to further improve the efficiency of the peak-to-average power ratio (PAP). However, mathematical calculations and bits of side information are much higher than the C-PTS process. The study reveals that there is a trade-off between the PAPR reduction efficiency and the hybrid methods' computational complexity level.

In previous research, we concentrated on improving PAPR reduction efficiency and lowering computational complexity in the frequency domain portion of the PTS technique. In this paper, we combine two types of the MSR techniques in parallel, the SLM technique and the modified-PTS technique named the cyclic shift sequences PTS technique [28] to be a hybrid scheme. The hybrid scheme (SLM-PTS) aims to increase PAPR efficiency and level of computational complexity better than the traditional PTS technique. In the SLM-PTS method, the input data sequence is divided into two equal parts, where one of them undergoes the SLM technique and the other undergoes the PTS technique, in the time domain, the two parts are again combined to produce the transmitter signal. This method ensures excellent gain PAPR reductions and low level of computational complexity.

2. PAPR BASED ON OFDM AND MC-CDMA

PAPR can be defined as the ratio of the maximum transmitted signal peak power divided by the mean signal power [29]. Figure 1 shows a simplified OFDM system diagram in which the input data

sequence is mapped first by one of the modulation families and then parallel transferred into the IFFT block. IFFT modulates the baseband input sequence by the sub-carriers ' orthogonality and converts the data sequence from the frequency domain to the time domain. Before transmission, the cyclic prefix (CP) is added to the signal, so that the OFDM signal could be represented as (1).

$$x(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X(k) e^{j2\pi k \frac{n}{N}} \quad , \quad 0 \le n \le N-1 \tag{1}$$

where *X (k) is* the input data sequence, and *(N)* is the sub-carrier numbers. On the receiver side, all the operations that have been done in the transmitter are reversed. At the OFDM system, the signal output is composed of summing several different modulated subcarriers as a sinusoidal form. Due to the nature of the IFFT unit, the instantaneous peak power of some subcarriers of the sinusoid signal may be added together to become much larger than the average power of the signal [30]. Exactly, PAPR in decibel (dB) can be formulated as [31] as (2).

$$\text{PAPR (dB)} = 10 \, log_{10} \frac{max \, |x(n)|^2}{E\{|x(n)|^2\}} \tag{2}$$

where $E\{.\}$ represents the mean value for the signal. Also, the complementary cumulative distribution function (CCDF) is one of the popular methods for determining PAPR output [32]. The PAPR-based CCDF denotes the probability that the PAPR value exceeds a certain threshold for OFDM symbols *(PAPR₀)*.

$$Pr(\text{PAPR} > PAPR_0) = 1 - (1 - exp(-PAPR_0))^{NL} \tag{3}$$

where, the oversampling factor is (L). The continuous time of the OFDM baseband signal (nearly) can be obtained through applying L-time over-sampling of the discrete OFDM signal to capture certain signal peaks which do not appear when calculating the PAPR value. Oversampling is accomplished by adding (L-1) N zeros between the subcarriers. To improve the accuracy of the PAPR value, it is necessary to sample the discrete baseband signal with L equal to 4 samples.
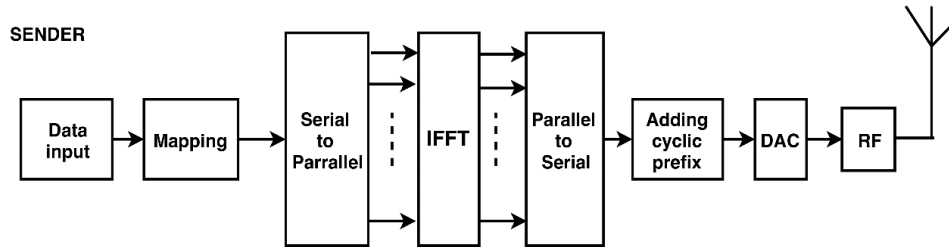

Figure 1. Block diagram of transmitted OFDM

While, MC-CDMA, on the other hand, is one of the (5G) waveform candidates that applies a pair of transmitter and receiver filters across the frequency entire bandwidth. Figure 2 shows in the transmitting side of a complex data symbol, an MC-CDMA signal is produced and assigned to user h. The user-specific spread code is multiplied by ah in the data symbol transmitter $bh = [b_1^h, b_2^h, \ldots, b_{M-1}^h]^T$ of spread factor *M*. The spread code c^h obtained after spreading can be given in vector scheme as [33].

$$c^h = a^h \, b^h = [C_1^h, C_2^h, \ldots, C_{M-1}^h]^T \tag{4}$$

The c^h is converted to parallel C_m^h, where $m = 0, 1, \ldots, M-1$, and modulated onto *M* subcarriers followed by IDFT of size $N = 1 \times M$ to obtain a multi-carrier spread spectrum signal. A time-domain baseband transmission signal $x^h(t)$, after IDFT, for one MC-CDMA symbol, $0 \le t \le T_s$, is

$$x^h(t) = \sum_{m=1}^{M} \sum_{h=1}^{H} a^h b_m^h \, e^{j2\pi(m-1)t/T_s} \tag{5}$$

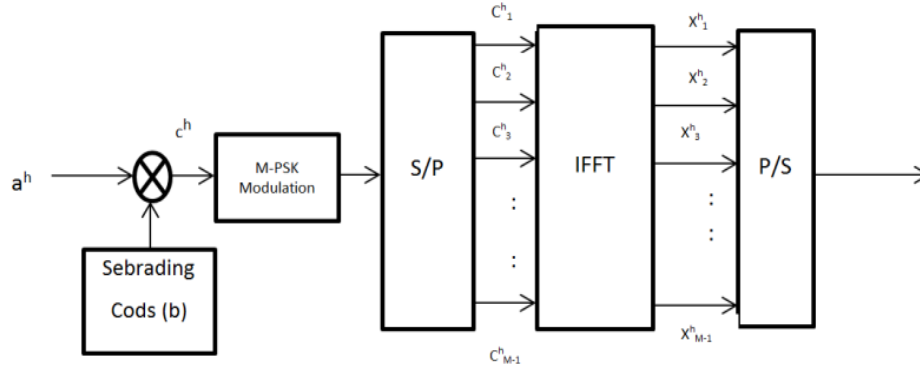The MC-CDMA symbol period T_s, is and the total number of users is H.

Figure 2. Transmitted side of MC-CDMA [33]

3. MULTIPLE SIGNALS REPRESENTATION TECHNIQUES (MSR)

Multiple signal representation techniques can be classified as partial transmit sequences, selective mapping, and interleaving processes, in which the input data block is divided into several groups, and these groups are combined to select the best transmission signal [34].

3.1. PTS technique

Muller introduced the partial transmission sequence technique in 1997 to improve the OFDM system's PAPR reduction efficiency. The PTS technique, on the other hand, has a high computational complexity for determining the best step factor. In addition, as side information (SI), PTS must provide the index of optimum phase rotation factors needed to recover the original receiver data [7]. Breaking the data block into disjunct sub-blocks is the core concept of modern PTS. The data is then transformed from the frequency domain to the time-domain by feeding each sub-block into the IFFT. To minimize the PAPR value, phase weighting factors are used to multiply the transformed sub-blocks by the phase factor's vectors, which are then combined to produce the candidate signals. For transmission, the candidate signal with the lowest PAPR value is chosen. The optimum phase factor that achieves the lowest PAPR value must transmit the phase factor to recover the original data phase factor index to the receiver. Figure 3 depicts the C-PTS block diagram, in which the X block of data is partitioned into non-overlapping Xv sub-blocks [35].
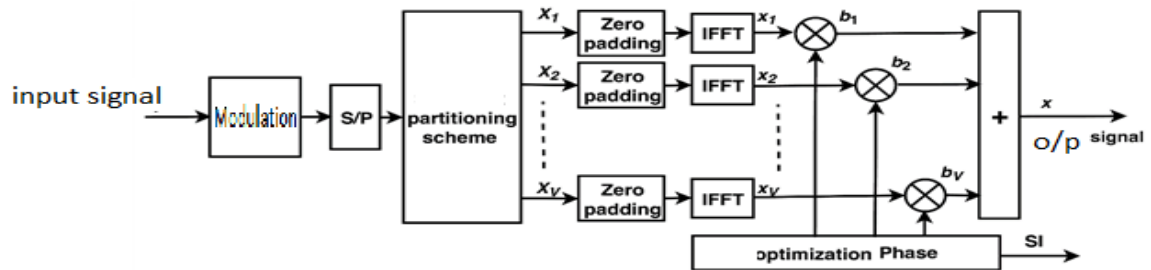

Figure 3. Transmitted of PTS block diagram [35]

$$X_v = [X_{v,0}, X_{v,1}, \ldots, X_{v,NL-1}]^T, v = \{1,2,\ldots,V\} \tag{6}$$

thus,

$$X = \sum_{v=1}^{V} X_v \tag{7}$$

where V is the number of the sub-block, and subscription $v = 1, 2, \ldots, V$. The phase factors must have an amplitude of unity and the phase factors (bv) components are usually set to $\{\pm 1\}$ or $\{\pm 1, \pm j\}$ to prevent complex multiplication operations. Therefore, the phase factors can be obtained as (8).

$$b_v = e^{j2\pi v/W} | v = \{0,1,\ldots,W-1\} \tag{8}$$

where W is the number of phase factors allowed. In addition, the vector for phase rotation may be expressed as (9).

$$b_v = [b_1, b_2, \ldots, b_V]^T \tag{9}$$

In general, phase factors are translated into the time domain using a linear property of the inverse discrete Fourier transform (IDFT), Wu *et al.* [36] give the OFDM time domain signal after the sub-locks have been combined.

$$x = \text{IFFT}\{\textstyle\sum_{v=1}^{V} b_v X_v\} = \sum_{v=1}^{V} b_v \ \text{IFFT}\{X_v\} \ = \sum_{v=1}^{V} b_v x_v \tag{10}$$

The goal is to find a collection of phase factors that reduce the OFDM signal's PAPR value. The optimal phase factor is thus obtained as (11).

$$\{b_1, b_2, \ldots, b_v\} = \begin{array}{c} \arg\min \\ 1 \le w \le W \end{array} \left(\begin{array}{c} max \\ 0 \le n \le NL - 1 \end{array} \left| \textstyle\sum_{v-1}^{v} b_v x_v \right| \right) \tag{11}$$

3.2. Selective mapping technique (SLM)

Bauml proposed the selective mapping technique in 1995 to reduce the PAPR value in the OFDM scheme. The SLM technique is a subset of the MSR techniques. The SLM method procedure begins with the generation of some phase rotation vectors (PRVs), after which the original data sequence is copied in proportion to the number of PRVs [37]. The PRVs multiply the data sequences to produce new independent sequences that are transferred to the IFFT bank to generate a collection of OFDM candidate signals. For transmission, the candidate signal with the lowest PAPR value is chosen. Figure 4 displays the block diagram of the SLM method, in which the input data sequence is copied and then multiplied by specific step sequences U. Afterwards, the changed data sequences are transferred to the IFFT U-point to produce OFDM signals U-candidates. The transmitter must send the selected phase sequence index to the receiver as SI to recover the original data. thus, the quantity of side information bits is given as [14].

$$SI^{SLM} = log_2 U \tag{12}$$

actually [38], the computational complexity of SLM lies in the number of multiplication operations (C_{mult}^{SLM}), which are given as $C_{add}^{SLM} = U[N \ log_2 N]$.
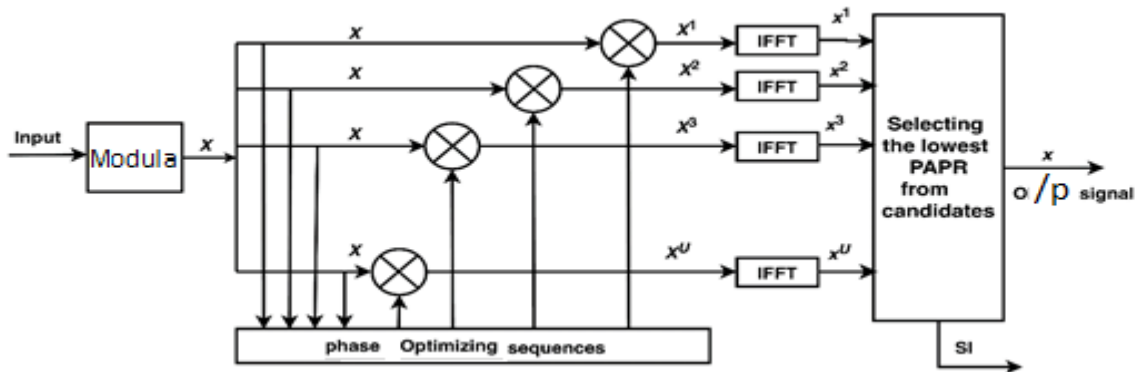

Figure 4. Transmitted of SLM block diagram

3.3. Interleaving technique

Jayalath implemented the interleaving technique in 2000 as a way to reduce the high similarity between input data sequence samples and increase the PAPR reduction benefit. The interleaving technique is similar to the SLM technique in terms of working form. Rather than using step sequences, the interleaving technique employs a set of interleavers. The interleaver is a device which reorders or makes the data symbol in a certain way [37]. The interleavers produce (K-1) the permuted data sequences from the original data

sequence and transfer these permuted data sequences and the original data sequence to the K-IFFT bank for an assortment of OFDM signals candidates. The deepest PAPR signal between the candidate signals is then chosen for transmission, as illustrated in Figure 5. Also, the computational complexity [39] of the interleaving technique can be written as (13).

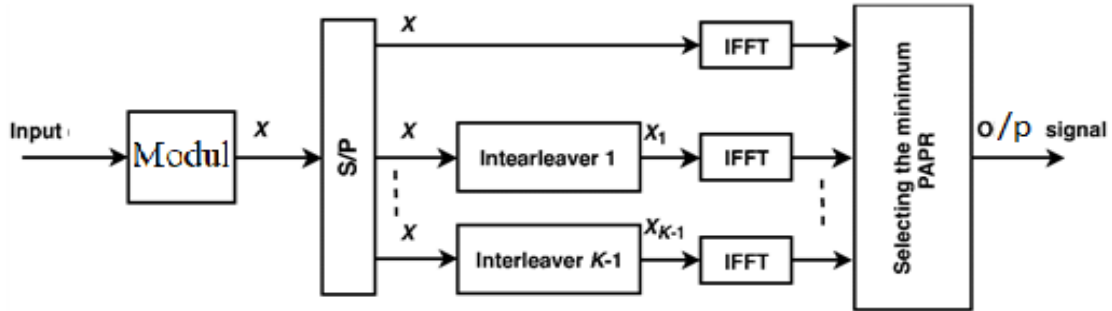$$SI^{Interleaving} = log_2 K; \; C_{add}^{Interleaving} = KN \, log_2 N \tag{13}$$

Figure 5. Block diagram of interleaving [32]

4. METHOD OF COMBINING SLM AND PTS

As previously said, SLM and PTS are two forms of MSR techniques. With a moderate level of computational complexity, SLM can provide good PAPR reduction efficiency, while PTS can provide superior PAPR reduction performance at the expense of a high level of computational complexity. Also, since both SLM and PTS require sending bits of side information to the receiver to retrieve the original data, a new approach combining the SLM and the cyclic shift sequence (CSS-PTS) methods is proposed, which is dubbed the SLM-CSS-PTS process. This approach aims to reduce the PAPR value and computation complexity more effectively than the C-PTS method. The SLM method is a procedure for lowering the PAPR value to generate (U) phase rotation vectors (PRV), $P^u = [P_{u,0}, P_{u,1}, \cdots, P_{u,N-1}]$, where $(u) = [1, 2, \dots, U]$, and (N) is the length of the data sequence [40]. Moreover, the original data sequence, $X = [X_0, X_1, \cdots, X_{N-1}]$, is copied according to a combined number of PRVs [37]. Next, U-PRVs multiply the data sequences component-wise to generate the new independent sequences [38].

$$X^u = [X_0 P_{u,0}, X_1 P_{u,1}, \cdots, X_{N-1} P_{u,N-1}] \tag{14}$$

After that, the independent sequences are transferred to the IFFT bank to generate a collection of candidate signals, and the candidate signal with the lowest PAPR value is chosen for transmission with the best PRV index [15]. In the CSS-PTS method, the procedure for reducing the PAPR value starts after obtaining the time-domain subblock sequences {x_v | v=1, 2, …, V}, in which the gth candidate sequence, $1 \leq g \leq G$, is generated by cyclically shifting some subblock sequences and combined them [41]. The OFDM signal is as (15).

$$x = \sum_{v=1}^{V} x_v^g \; , \; 1 \leq g \leq G \tag{15}$$

where x_v^g is the cyclically shifting version of x_v by some of the integer shift numbers. This is [42],

$$x_v^g = circular(x_v, q_v^g) = [x_v(q_v^g), x_v(q_v^g + 1), \dots, x_v(N + 1), x_v(0), \dots, x_v(q_v^g - 1)] \tag{16}$$

where q_v^g,$1 \leq v \leq V$, is the shift number. Also, the set of shift numbers for the gth candidate sequence is denoted by $H^g = [q_1^g, q_2^g, \dots, q_V^g]$. Hence, the CSS-PTS method needs to construct G-shift number sets, $H = [H^1, H^2, \dots, H^G]$, to generate the OFDM signals needed for the candidate [35]. The candidate sequence with the lowest PAPR is chosen for transmission to the receiver, along with the right optimum shift number. The reduction protocol for PAPR in the (SLM- PTS) process is to combine the SLM and PTS methods in parallel, where each method is used to process half the input data sequences and both halves are again combined before transmitting to the receiver. The SLM- PTS system is depicted in Figure 6, in which the

sequence of input data is divided into two equal sections A and B as $X = [XA, XB]$. In addition, $XA = [X_0, X_1, X_2, \ldots, X_{(N/2)-1}]$, and $XB = [X_{N/2}, X_{(N/2)+1}, X_{(N/2)+2}, \ldots, X_{N-1}]$. After that, the data of part A undergoes the PTS technique, while the data of part B undergoes the SLM technique. Next, the first part employs the CSS-PTS procedure to reduce its PAPR, where, instead of phase rotation variables, the cyclic shift technique is used to optimize the transformed sub-blocks to produce the optimal signal of part A.

$$xA = \sum_{v=1}^{V}\{\text{circular}(xA_v^g)|\ g = 1,2,\ldots,G\} \tag{17}$$

where V is the candidate's sub-block number and G is the total number of signals. Part B also employs the SLM method to reduce its PAPR, with the SLM technique producing part B's best signal: $xB = \text{IFFT}(XB^u)$, $u = 1,2,\cdots,U$. Lastly, the optimal signals of both parts A and B are combined to produce the entire transmitting signal transmitted to the receiver with each part's side information, $x = [xA, xB]$.
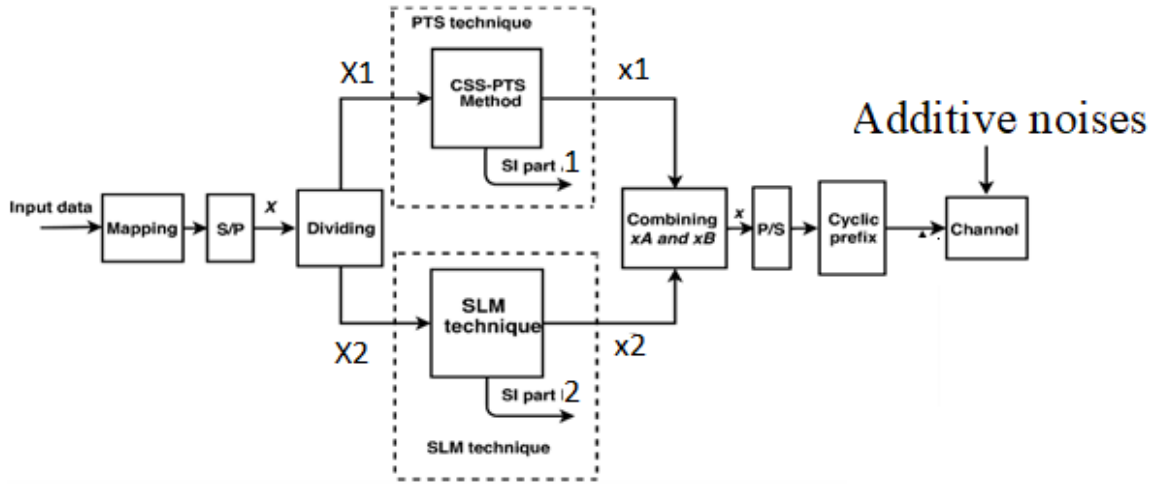

Figure 6. SLM-PTS process system structure

The PAPR reduction efficiency of the SLM- PTS system will be increased, and the subcarriers will be more autonomous since both SLM and PTS techniques are used to minimize the PAPR value. Furthermore, the numerical complexity of the SLM-SC-PTS method is equal to the number of the SLM and PTS methods. Also, PTS mathematical calculations in the time domain are a complex multiplication operation (CSLM-PTS) using H shift number sets.

$$C_{mult}^{SLM-PTS} = [UN] + \left[(U + V)\left(\frac{N}{4}log_2 \frac{N}{2}\right)\right] + \left[\frac{N}{2}\left(H + (H - 1) \times (V - 1)\right)\right] \tag{18}$$

Besides, the SLM-PTS side information bits number is the sum of the SLM side information and the CSS-PTS side information.

$$SI^{SLM-PTS} = log_2 U + log_2 H \tag{19}$$

The SLM-PTS method can be utilized to reduce the computational complexity and improve the PAPR reduction gain. The combined method is applied to the transmitter of the OFDM or MC-CDMA system in the time and frequency domain. Also, the optimum phase factor indexes for each part of the combined method are transmitted to the recipient as *(SI)* for recovery of the original data. Figure 7 demonstrates the baseband of transmitting the OFDM or F-OFDM signal using the proposed combined method. On the transmitter side, the number of complex (SLM-PTS) additions to the MC-CDMA system can be defined in (34). However, the number of complicated multiplications includes the complexity of the OFDM signal and the complexity of the added filter. So, the number of (SLM-PTS) multiplication operations in MC-CDMA (C) can be given as [40].

$$C_{MC-CDMA}^{SLM-PTS} = [UN] + \left[(U+V)\left(\frac{N}{V}log_2\frac{N}{2}\right)\right] + \left[\frac{N}{2}\big(H + (H-1)\times(V-1)\big)\right] + [N\times(O-1)] \quad (20)$$

In the receiver's case, the OFDM or MC-CDMA signal received is reversed in the receiver compared to the transmitter side, in which the received OFDM signal is split into two parts and the received side information of each component is used to re-rotate its phases. Before the de-mapping operation, the two parts are thus combined again to produce the output data, as shown in Figure 8.
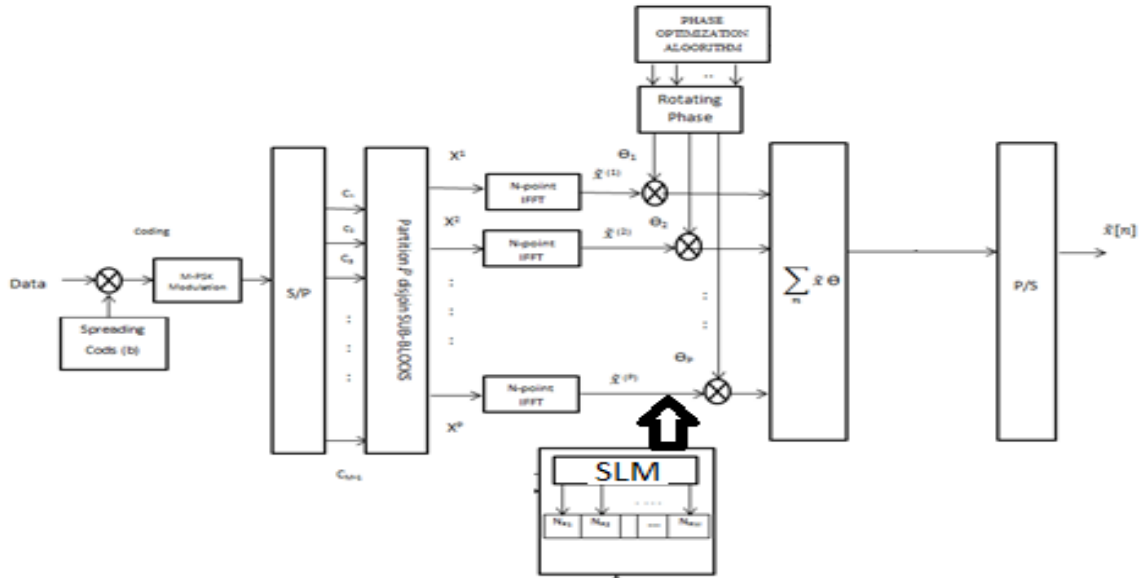
Figure 7. Baseband of transmitting the MC-CDMA method signal using the combined based PTS-SLM PAPR reduction
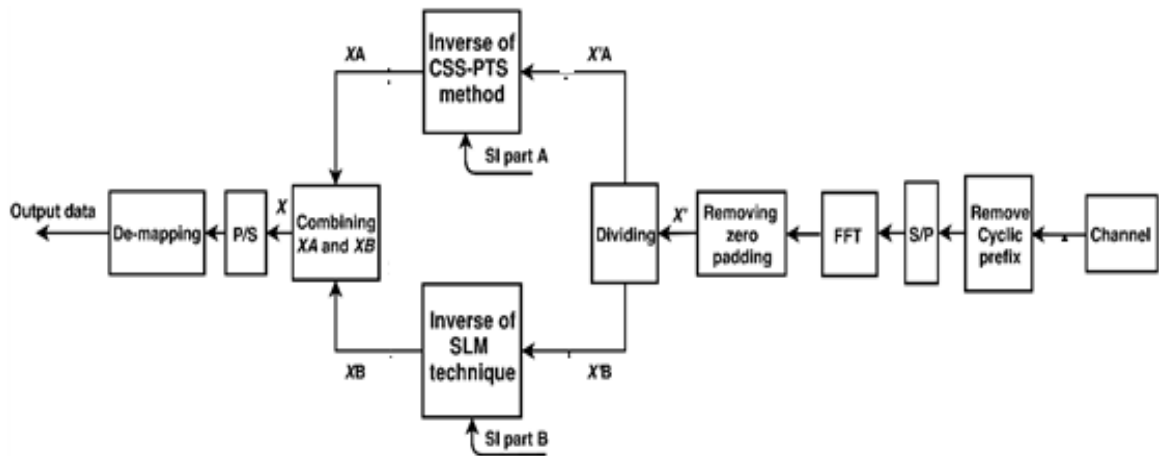
Figure 8. Baseband of OFDM receiving a signal using the combined method

5.   CALCULATION OF COMPLEXITY AND DISCUSSION

The SLM-PTS system is introduced to combine the SLM technique's low computational complexity and the PTS method's superior PAPR reduction efficiency into a single scheme. In this section, the PAPR and BER, PSD, side information, and computational complexity performances of SLM–PTS in the OFDM and MC-CDMA systems are evaluated. Table 1 lists the simulation parameters for evaluating the SLM-CSS-PTS system compared with the other OFDM and MC-CDMA methods in the works.

The model is performed in the OFDM system when the subcarrier number is 1024 and the constellation order M=265. In this work, the method compared and simulated by PTS, SLM, interleaving, Pushkarev's method [17], Singh's method [24], Tiwari's method [22], Duanmu's method [30], Wang's method [37], and Xiaoqiang's method [27] when $V=4$, $U=24$, $K=11$, $W=4$. The SLM-CSS-PTS method outperforms other methods in terms of PAPR performance reductions. This is because the process SLM-CSS-PTS is a class of MSR techniques, where no signal distortion using the SLM-CSS-PTS method. Table 3 lists the number of complex addition and multiplication operations in Table 2 for the different methods. The results offer that SLM-CSS-PTS is the lowest computational complexity among the combined methods.

Table 1. Parameters of SLM-CSS-PTS in OFDM and MC-CDMA

Parameters	Values
The number of sub-carriers	1024, 2048
The number of constellation order	256
Number of transmitting bits	10000
No. of users H	8, 16
Number of permitted phase factors W	$\{\pm 1\}$, or $\{\pm 1, \pm j\})$
Modulation	M-PSK
Additive noises	20dB
Number of sub-blocks	4
Number of oversampling	4
Slm method–number of phase rotation vectors	24
Interleaving method–number of interleaves (K)	11
Pts method–number of shift sets (H)	64

Table 2. Complexity equations of the literature's methods previously combined

Method	Complexity
PR-PTS	$\left[\frac{VN}{2} log_2 N\right] + [W^{V-1} \times N \times (V+1)]$
SLM	$[2UN] + \left[\frac{UN}{2} log_2 N\right]$
Interleaving	$[KN] + \left[\frac{KN}{2} log_2 N\right]$
SLM- PTS [43]	$[UN] + \left[(U+V)\left(\frac{N}{4} log_2 \frac{N}{2}\right)\right] + \left[\frac{N}{2}(H + (H-1) \times (V-1))\right]$
Pushkarev [17]	$[UN] + \left[U \times \left(\frac{VN}{2} log_2 N\right)\right] + [U \times (W^{V-1} \times N \times (V+1))]$
K. Singh [26]	$[2UN] + \left[(U+V)\left(\frac{N}{2} log_2 N\right)\right] + [W^{V-1} \times N \times (V+1)]$
Tiwari [22]	$[2UN] + \left[(U+V+1)\left(\frac{N}{2} log_2 N\right)\right] + [W^{V-1} \times N \times (V+1)]$
Duanmu [30]	$[UN] + \left[(U+V)\left(\frac{N}{4} log_2 \frac{N}{2}\right)\right] + \left[W^{V-1} \times \frac{N}{2} \times (V+1)\right]$
Z. Wang [33]	$[KN] + \left[(K+V)\left(\frac{N}{2} log_2 N\right)\right] + [W^{V-1} \times N \times (V+1)]$
Xiaoqiang [27]	$[KN] + \left[(K+V)\left(\frac{N}{2} log_2 N\right)\right] + [W^{V-1} \times N \times (V+1)]$

Table 3. The computational complexity of the different combined methods in literature, V=4, U=24, K=11

sub-carriers	SLM [38]	PTS [35]	Interleaving [41]	K. Singh [26]	Pushkarev [17] (U=2)	Tiwari [22]	Duanmu [30]	SLM-CSS-PTS [43]	Xiaoqiang [7]
256	35864	87016	14080	51072	123904	172544	122880	58948	95176
512	78872	169056	30976	105728	255232	347136	252880	122880	195584
1024	172032	348160	67584	218624	525312	698368	520192	252928	403456
2048	368640	700416	146432	451584	1080320	1404928	1069056	520192	833536
4096	786432	1409024	315392	931840	2220032	2826240	2195456	1069056	1724416

The number of complex additions and multiplications in the frequency and time domains is represented by the computation's complexity. The mathematical estimation of the SLM- PTS system is performed in this section, and it is compared to PR-PTS and other related methods discussed in the literature. Table 2 registers the complex addition and multiplication equations for PR-PTS, SLM- PTS, and some of the combined methods in the references. The parameters relating to the calculation of computational complexity are computational complexity reduction ratio (CCRR):

$$CCRR = \frac{\text{Complexity} - Proposed\ Method\ Complexity}{\text{Complexity of other ways}} * 100\% \qquad (21)$$

Then, the SLM-CSS-PTS [43] approach is considered to be an effective method for enhancing PAPR reduction efficiency at low computational complexity compared to other combined approaches. Table 4 compares the efficiency of the SLM-CSS-PTS approach with that of other similar methods in terms of computational complexity reduction ratio (CCRR). The level of the computational complexity of the SLM-CSS-PTS process is better than other combined methods. For example, when N=1024, the complex addition operations of SLM-CSS-PTS have been reduced by 40.61%, 52.15%, 50.96%, 53.74%, 50%, 32.05%, and 31.85% compared with PR-PTS, Pushkarev, Singh, Tiwari, Duanmu, Wang, and Xiaoqiang, respectively. As well, the complex multiplication operations of SLM-CSS-PTS have been reduced by 39.2%, 66.69%, 56.97%, 55.38%, 15.34%, 45. 18% and 46.22% compared with the PR-PTS.

In this part, information bits are needed for the different methods, where the SI bits of the SLM-CSS-PTS system can be measured with 26. The SLM-CSS-PTS method required 11 bits as side information for Z. Wang's method, 10 bits for Xiaoqiang's method, 12 bits for K. Singh's method, Tiwari's method, and Duanmu's method. Therefore, The SLM-CSS-PTS has more side-information bits than the PTS method, considering that the method proposed is better than PR-PTS as regards PAPR performance reduction and level of computational complexity. Moreover, the method proposed has the lower or the same number of side information bits compared with the other combined methods, except Xiaoqiang's method which has 10 bits, as side details at the expense of PAPR performance degradation.

Table 4. CCRR combined between of the different approaches

No. of sub-carriers	SLM-CSS-PTS & Pushkarev [24] CCRR %	SLM-CSS-PTS & PR-PTS [43] CCRR %	SLM-CSS-PTS & Tiwari [22] CCRR %	SLM-CSS-PTS & Duanmu [23] CCRR %	SLM-CSS-PTS & Z. Wang [44] CCRR %	SLM-CSS-PTS & Xiaoqiang [27] (CCRR$^×$)%	SLM-CSS-PTS & k. Singh [24] CCRR %
256	71.42	40.62	58.78	14.37	45.92	46.22	30.71
512	69.54	38.9	58.57	13.95	45.94	45.94	30.66
1024	68.69	37.2	57.38	13.56	45.81	45.81	31.05
2048	67.85	35.52	59.19	13.18	45.82	45.82	31.79
4096	67.02	33.86	58.82	12.83	45.96	45.96	32.79

6. CONCLUSION

This study is an extrapolation and survey of a hybrid approach to MSR to reduce the high PAPR pattern with low transmitter signal complexity in OFDM and MC-CDMA. The proposed hybrid method combines SLM method and PTS method in parallel, SLM system has good complexity low efficiency PAPR, PTS approach has distinct medium complexity, low performance PAPR. Simulations and numerical computations were performed to test better hybrid approaches to reduce PAPR and PSD capacity and computational complexity. It has been proven that the hybrid method can improve the performance of PAPR reduction better than the conventional PTS method. The current hybrid methods are present but need more development. Meanwhile, the hybrid approach has been computationally less complex than the PTS method and the current hybrid methods. Moreover, the number of bits of side information for the investigated methods of the mixed methods are currently used. As a result, the SLM-PTS method is found to be suitable for reducing high PAPR patterns in OFDM and MC-CDMA systems with low computational complexity.

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