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# Comparative study of SLM and PTS techniques for PAPR Reduction of an MC-CDMA system

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## ABSTRACT

**Multicarrier Code Division Multiple Access (MC-CDMA) is the most promising technique for high speed data transmission. However, the MC-CDMA signals are characterized by large peak-to-average power ratios (PAPR), which can reduce the system efficiency. In this paper, SLM and PTS techniques are investigated and their performances are compared. The performance metric utilized in evaluating PAPR reduction scheme is CCDF of the PAPR of transmitted continuous time signal. With the help of MATLAB simulation it has been found that PTS has better PAPR reduction capability than SLM scheme.**

***Keywords:*** Complementary Cumulative Distribution Function, MC-CDMA, Partial Transmit Sequence, Peak-to-Average Power Ratio, Selected Mapping.

## 1. INTRODUCTION

Multicarrier systems like CDMA and OFDM are now days being implemented commonly. MC-CDMA multiple access has become a most likely technique for future generation broadband wireless communication system such as 4G. This scheme is a combination of both OFDM and CDMA that can provide protection against frequency selective fading and time dispersion. The CDMA part of this scheme provides multiple access ability as well as spread each user signal over the frequency domain to reduce the impact of frequency selective fading. On the other hand OFDM provides spreading across time domain of each spreading code's chip which reduces the impact of inter-symbol interference. This achieves in fulfillment of high data rate transmission.[1],[2]

Although MC-CDMA is a powerful multiple access technique but it is not problem free. MC-CDMA signal has large peak to average ratio (PAPR) which severely limits its applications. High PAPR values causes a serious problem to the power amplifier (PA) used at transmitter. The power efficiency performance at such amplifiers decreases as PAPR increases. Therefore signal suffers from non-linear distortion at transmitter and degrades BER performance at receiver. This forces the use of power amplifier with large linear range which translates into higher cost.

Therefore it is desirable to reduce PAPR by means of PAPR reduction schemes. There are number of schemes to deal with the issue of PAPR, such as, Signal Distortion and Symbol Scrambling techniques. Signal distortion schemes include techniques like clipping, peak windowing and companding. Scrambling scheme includes techniques such as Selected Mapping (SLM), Partial Transmit Sequence (PTS), Interleaving, coding based and discrete transform techniques. Among these SLM and PTS are promising probabilistic distortionless techniques.

In this paper, SLM and PTS techniques are investigated and their performances are compared. The performance metric utilized in evaluating PAPR reduction scheme is CCDF of the PAPR of transmitted continuous time signal.

## 2. SYSTEM DESCRIPTION

### 2.1 MC-CDMA system

The transmitter structure of an MC-CDMA system is shown in fig. 1. It is assumed that there are $K$ active users and each user transmits $M$ parallel modulated symbols. $d^{(k)}=[d_1^{(k)},d_2^{(k)},...,d_M^{(k)}]^T$ denotes the $M$ modulated data symbols of $kth$ user, $k$=1, 2,…, $K$. Modulated data symbols of $k$th user $d_m^{(k)}$ are converted from serial to $M$ parallel data streams. After this serial to parallel conversion each complex symbol is spread by the user specific code $c^{(k)}=[c_1^{(k)},c_2^{(k)},...,c_L^{(k)}]$ where $L$ denotes the spreading factor (SF). As the spreading sequences orthogonal sets of sequences are preferred for reducing low multiuser interference. Walsh-Hadamard (WH) sequences are used as spreading sequences in this procedure. Then the input of $K$ users is summed up, and is interleaved in frequency domain as $X=\sum_{k=1}^{K} X^{(k)}=[X_0,X_1,...,X_{N-1}]^T$ to achieve frequency diversity. After interleaving the symbol element are then input to the IFFT block of size $N=M\times L$.

The resultant baseband signal for one MC-CDMA $0\le t\le T_s$ symbol is represented as

$$s(t)=\frac{1}{\sqrt{N}}\sum_{k=1}^{K}\sum_{m=1}^{M}\sum_{l=1}^{L} d_m^{(k)} c_l^{(k)} e^{j2\pi(M(l-1)+(m-1))t/NT} \qquad (1)$$

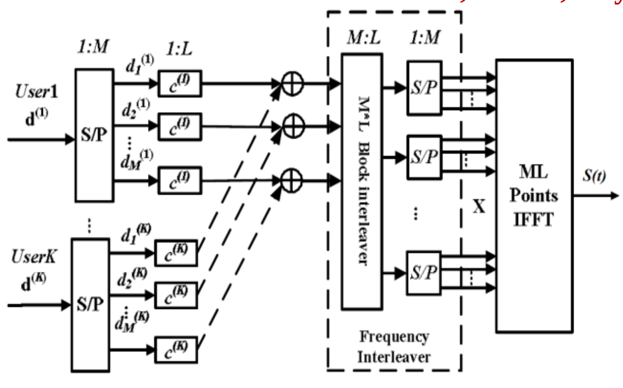


Figure 1: MC-CDMA transmitter model

## 2.2 PAPR

MC-CDMA signals have a higher peak-to-average power ratio (PAPR) than single-carrier signals do. The reason is that in time domain, multicarrier signal is the sum of many narrowband signals. At some instances, this sum is large and other time it is small, which means that the peak value of the signal is substantially larger than the average value. This high PAPR is one of most important implementation challenges that face MC-CDMA, because it reduces the efficiency and hence increases the cost of the RF power amplifier, which is one of the most expensive components in radio.

The PAPR of the MC-CDMA symbol is defined as ratio of the peak power and the average power:

$$PAPR = \frac{p_{peak}}{p_{average}} = 10\log_{10}\frac{\max\left[\left|s(t)\right|^2\right]}{E\left[\left|s(t)\right|^2\right]} \quad (2)$$

where $p_{peak}$ represents output peak power, $p_{average}$ means output average power. $[\cdot]$ denotes the expected value.

## 2.3 Cumulative Distribution Function

The cumulative distribution function (CDF) is one of the most regularly used parameters, which is used to measure the efficiency on any PAPR technique. Normally, the Complementary CDF (CCDF) is used instead of CDF, which helps us to measure the probability that the PAPR of a certain data block exceeds the given threshold [4].

The CDF of the amplitude of a sample signal is given by

$$F(PAPR0) = 1 - \exp(PAPR0) \quad (3)$$

The CCDF of the PAPR of the data block is desired is our case to compare various reduction techniques. This is given by [3]:

$$P(PAPR > PAPR0) = 1 - P(PAPR \le PAPR0)$$

$$= 1 - F(PAPR0)^N$$

$$= 1 - (1 - \exp(-PAPR0))^N \quad (4)$$

When calculating the PAPR, we have to consider the actual time domain signal that is in analog form. The IFFT outputs, which are symbol spaced sampling values, will miss some of the signal peaks. Therefore, if we calculate PAPR by using these sample values, then the calculated PAPR is less than the actual PAPR [6]. This is an optimistic result and will not illustrate the real situation. However, they are enough for signal reconstruction. To account for this issue, oversampling is performed by low pass filtering the IFFT signal and then sampled at higher rate. Now, the increased samples are close to the real analog signal and calculation of PAPR based on these samples will give a better estimated PAPR.

# 3. SELECTED MAPPING (SLM) METHOD

The block diagram of MC-CDMA system is with SLM technique shown in fig.2. The input data sequences of each user $d^{(k)} = [d_1^{(k)}, d_2^{(k)}, ..., d_M^{(k)}]$ with length $M$ are first converted into $M$ parallel data sequences $c^{(k)} = [c_1^{(k)}, c_2^{(k)}, ..., c_L^{(k)}]$ and then each S/P converted output is multiplied with the spreading code with length $L$. Multiplexed symbol sequences $X = \sum_{k=1}^{K} X^{(k)} = [X_0, X_1, ..., X_{N-1}]^T$ are multiplied by $U$-1 different phase sequences $b^u = [b_0^u, b_1^u, ..., b_{N-1}^u]$ whose length is equal to the number of carriers before IFFT process resulting in $U$-1 modified data blocks $S = \sum_{u=0}^{U-1} X_n b_n^u = [X_0 b_0^{(u)}, X_1 b_1^{(u)}, ..., X_{N-1} b_{N-1}^{(u)}]^T$. After the IFFT process, the PAPR is calculated for $U$-1 phase rotated symbols sequences $s(t) = \sum_{u=0}^{U-1} x_n b_n^u = [x_0 b_0^{(u)}, x_1 b_1^{(u)}, ..., x_{N-1} b_{N-1}^{(u)}]^T$ and one original sequence and then the symbol sequence with lowest PAPR is selected for transmission and the corresponding selected phase sequence $\left\{\tilde{b}^{(0)}, \tilde{b}^{(2)}, ..., \tilde{b}^{(U-1)}\right\} = \underset{\left\{\tilde{b}(1), \tilde{b}(2), ..., \tilde{b}(U-1)\right\}}{\arg\min} \left( \max_{0 \le n \le N-1} \left| \sum_{u=0}^{U-1} b^{(u)} x_n^{(v)} \right| \right)$ is also transmitted to the receiver side for transmission [8-14].

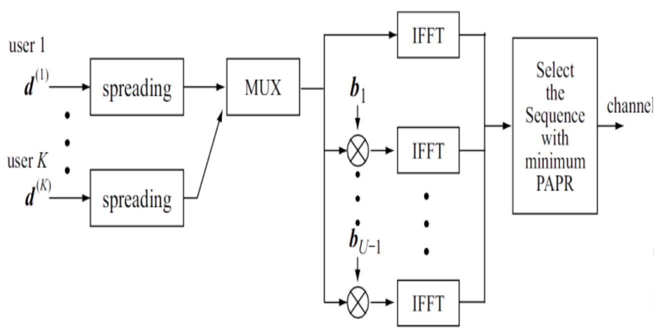


Figure 2: MC-CDMA system using SLM

## 4. PARTIAL TRANSMIT SEQUENCE (PTS)

This method is based on phase shifting of sub-blocks of data and multiplication of data structure by random vectors. In the PTS technique, an input data block of $N$ symbols is partitioned into disjoint sub-bocks. The subcarriers in each sub-block are weighted by phase factor for that sub-block. The phase factors are selected such that the PAPR of the combined signal is minimized. [15-17]

In the conventional PTS scheme in MC-CDMA, before applied to IFFT operation, $X$, i.e., the sum of all active user sequences after spreading and frequency interleaving is input to PTS model as shown in figure 3 [17]. The data block, $X_n$, $n=0,1,...,N-1$ is defined as vector, $X=[X_0, X_1,...., X_{N-1}]^T$. Then partition $X$ into $V$ disjoint sets, represented by vectors $X^{(v)}$, $v=1,2,...,V$ such that

$$X=\sum_{v=1}^{V} X^{(v)} \tag{5}$$

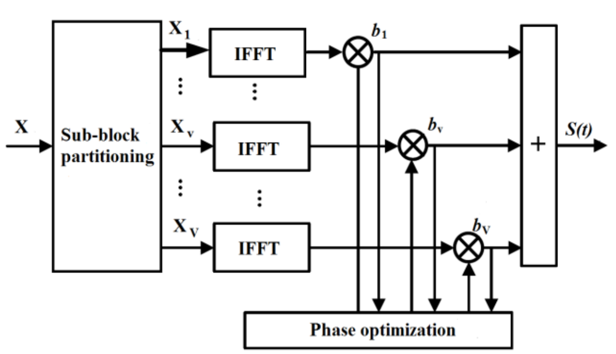


Figure 3: Block diagram of conventional PTS scheme

The objective of PTS approach is to form weighted combination of $V$ clusters, each of equal size.

$$S=\sum_{v=1}^{V} b^{(v)} X^{(V)} \tag{6}$$

where $b^{(v)}$ , $v=1,2,...,V$ are weighting factors or phase factors and are assumed to be pure rotations.

After transferring in time domain equation (6) becomes

$$s(t)=\sum_{v=1}^{V} b^{(v)} x^{(V)} \tag{7}$$

The vector $x^{(v)}$ called partial transmit sequence is the IFFT of $X^{(V)}$. The weighting factors are chosen to minimize the PAPR by searching for the appropriate combination of each cluster and by corresponding weighting clusters.

$$\left\{\tilde{b}^{(1)},\tilde{b}^{(2)},...,\tilde{b}^{(V)}\right\}=\underset{\left\{\tilde{b}(1),\tilde{b}(2),...,\tilde{b}(V)\right\}}{\arg\min}\left(\max_{0\le m\le N-1}\left|\sum_{v=1}^{V} b^{(v)} x_n^{(v)}\right|\right) \tag{8}$$

The combination with weighting factors is called rotation factor or combining sequence. Optimized transmit sequence is

$$\tilde{s}(t)=\sum_{v=1}^{V} \tilde{b}^{(v)} x_m^{(v)} \tag{9}$$

## 5. COMPARISON BETWEEN SLM AND PTS TECHNIQUES

Although SLM and PTS are important probabilistic schemes for PAPR reduction. SLM can produce independent multiple frequency domain MC-CDMA signals, whereas the alternative MC-CDMA signals generated by PTS are independent. PTS divides the frequency vector into some sub-blocks before applying the phase transformation. Therefore some of the complexity of several full IFFT operations can be avoided in PTS, so it is more advantageous than SLM if amount of computational complexity is limited.

Moreover, in PTS scheme, all the entries in $x_v$ are multiplied by the same rotation $b_v$. It is clear that PTS method is special case of SLM method. For PTS method, the number of rotation factors $b_v$ may be limited in certain range. $W^{V-1}$ accessorial information sequences are required in PTS, where $W$ denotes the number of phase factors. And the redundant bits of side information are as follows:

$$R_{ap}=(V-1)\log_2 W \tag{10}$$

In SLM, $U$ accessorial information sequences are required in MC-CDMA with $U$ vectors $b^u$. And the redundant bits of side information are as follows:

$$R_{ap}=(V-1)\log_2 (U-1) \tag{11}$$

Thus the required bits of side information in PTS are larger than that of SLM.

## 6. SIMULATIONS

TABLE I
SIMULATION PARAMETERS

| | |
|---|---|
| Spreading codes | Walsh Hadamard |
| Modulation process | BPSK |
| Processing Gain (*L*) | 8 |
| Number of data symbols per an MC-CDMA symbol (*M*) | 16 |
| Number of sub-carriers (*N*) | 128 |
| Number of active users (*K*) | 8 |
| Number of phase sequences (*U*), Number of sub-blocks (*V*) | 4,8,16 |
| Oversampling factor (*O*) | 4 |

In this section we evaluate the performance of MC-CDMA system using SLM and PTS techniques using MATLAB. Table I above shows the simulation parameters. The performance comparison of SLM scheme and PTS scheme is also shown. The performance metric utilized in evaluating PAPR reduction scheme is CCDF of the PAPR of transmitted continuous time signal. The resulting CCDF curves are presented for 1000 input symbol sequences when considered the number of active users to be equal to 8. For all the simulations, a BPSK modulated MC-CDMA system with 128 subcarriers is assumed. If we oversample a transmitted signal by a factor of four, the discrete PAPR is almost the same as continuous PAPR [18]. Thus we oversample the transmitted signal by a factor of four in IFFT process.

### 6.1 Oversampling effect

Fig.4 shows the CCDFs of the original PAPR of the un-modified MC-CDMA data block, non-oversampling (*O*=1) and 4-times oversampling (*O*=4) are examined.

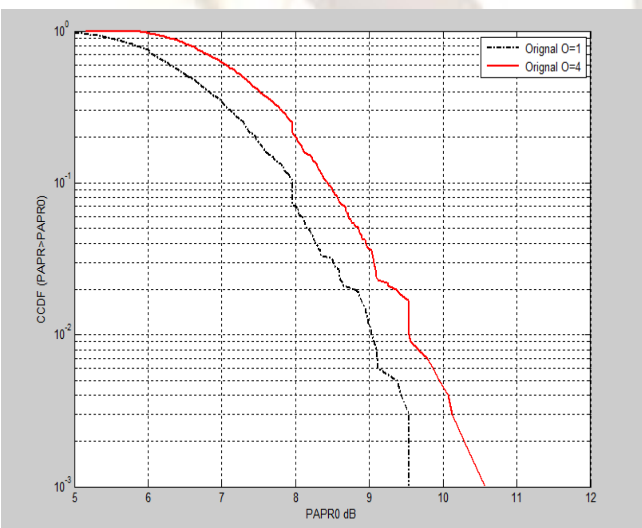


Figure 4: CCDF of MC-CDMA system showing oversampling effect

From the right to left the CCDF curves are original PAPR with *O*=4, the original PAPR with *O*=1.It is shown in figure 4 that the PAPR of 4-times oversampled signal is 1dB higher than the PAPR of Nyquist-rate sampled signal. This justifies the discussion, that we miss some peaks and get optimistic values for the PAPR with Nyquist-rate sampling.

### 6.2 Comparison of SLM approach with different values of *U*

In this section we evaluate the performance of MC-CDMA system using SLM technique by simulations.

Fig.5 shows a comparison of PAPR performance as the number of phase sequences, *U* varies. Here *U* takes the value of 4, 8 and 16. The phase sequences used in SLM are binary phase sequences i.e., $b^u$ = {+1,-1}. The rows of hadamard matrix are used in phase factor generation. The PAPR reduction performance is evaluated by the CCDFs computed by an oversampling factor of *O*=4. *O* times oversampling is realized by inserting *N* (*O*-1) zeros in the middle of MC-CDMA block.

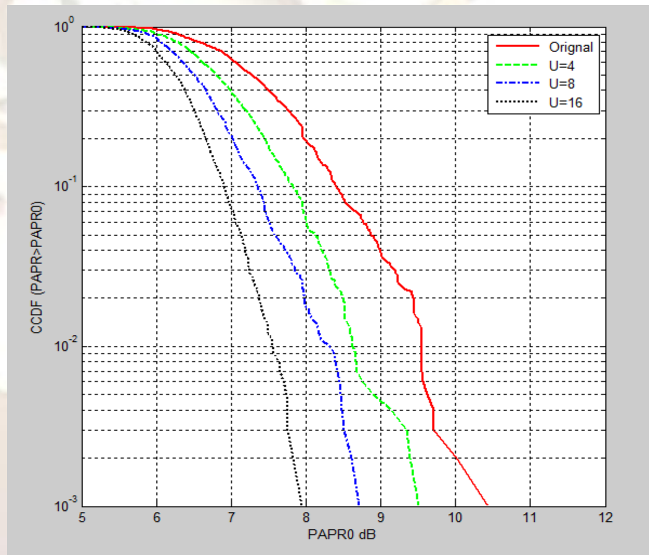


Figure 5: CCDF of PAPR of MC-CDMA using SLM for various *U*

Fig.5 shows a comparison of PAPR performance as the number of phase sequences, *U* varies. Here *U* takes the value of 4, 8 and 16. It is seen in fig.5 that with increase in number of *U*, the probability of high PAPR decreases compared to the original MC-CDMA signal. If the probability is set to $10^{-3}$ and then the CCDF curves with different *U* values are compared. The PAPR value of case *U*=4 is about 0.9dB is smaller than the original MC-CDMA. For the case, *U*=8, the PAPR is reduced 1.6dB at the probability of $10^{-3}$. For the case of *U*=16, the PAPR values can be reduced more than the original MC-CDMA signal with maximum of 2.5dB.

### 6.3 Comparison of PTS approach with different values of *V*

In this section we evaluate the performance of MC-CDMA system using PTS technique by simulations. The phase sequences used in PTS are binary phase sequences i.e., $b^v$ = {+1,-1}. Suboptimal combination algorithm is used to generate the binary phase sequences. This algorithm can be summarized as:

1. Partition the input data block into *V* subsets as in equation (5).
2. Set all the phase factors $b^v$ for v=1:*V*, find PAPR of equation (7), and set it as PAPR_min.
3. Set the *v*=2.
4. Find PAPR of equation (7) with $b^v$ = -1.
5. If PAPR>PAPR_min, switch $b^v$ back to 1. Otherwise, update PAPR_min=PAPR.
6. If *v*<*V*, increment v by 1 and go back to step 4. Otherwise, exit this process with the set of optimal phase factors, $\tilde{b}$ .

The PAPR reduction performance is evaluated by the CCDFs computed by an oversampling factor of *O*=4. *O* times oversampling is realized by inserting *N* (*O*-1) zeros in the middle of MC-CDMA block.

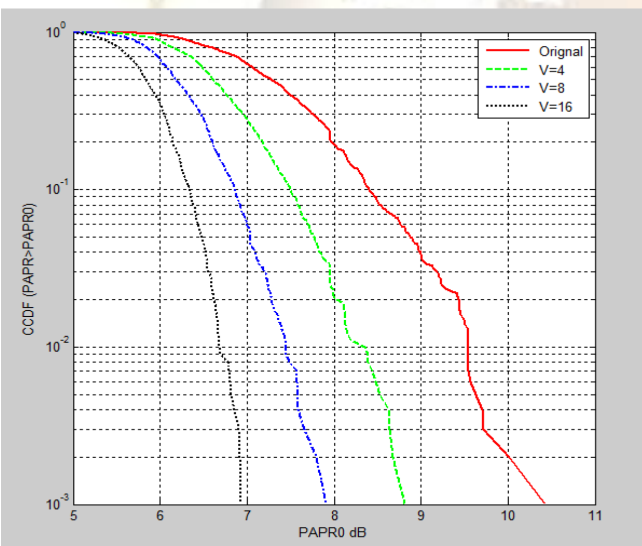


Figure 6: CCDF of PAPR of MC-CDMA using PTS for various *V*

Fig.6 shows the CCDF of BPSK modulated MC-CDMA system using PTS technique as the number of sub-block *V* varies. It can be noted that PAPR performance improves as the number sub-blocks increases with *V*=4, 8 and 16. From the fig.6 we can see that at probability of $10^{-3}$, PAPR of the original signal is 10.4dB, while at *V*=4 and *V*=8 it reduces to 8.85dB and 7.9dB, respectively. From the figure, we noticed that at probability of $10^{-3}$, the PAPR value for *V*=8 have 2.5dB improvement than the original MC-CDMA signal. For the case *V*=16, the value of PAPR at probability $10^{-3}$ is 6.95dB which shows 3.45dB improvement from the original MC-CDMA signal.

### 6.4 Comparison Between SLM and PTS

Fig.7 shows the comparison of PAPR CCDF curves for both SLM and PTS schemes. Phase sequences for both the schemes are chosen from the set of binary phase sequence set, {+1,-1}. For this case, the number of sub-blocks, *V*, and the number of phase vectors, *U*, is taken as 4. Based on the theory, we know that the IFFT calculation amount of these two methods is same when *V*=*U*. From the fig.7 it can be noticed that, PTS scheme has better performance of PAPR reduction as that of the SLM scheme. For the same CCDF probability $10^{-3}$, the PAPR value equals to 9.5dB when SLM is employed, while the PAPR value reduces to 8.5dB under the same circumstances.

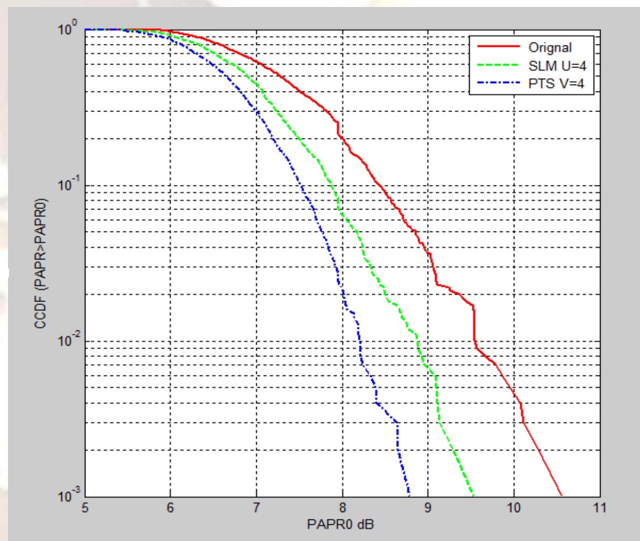


Figure 7: Comparison of PAPR reduction performances for SLM and PTS method

## 7. CONCLUSION

In this paper, the two distortionless PAPR reduction schemes, SLM and PTS are investigated and their performance is compared. Performance analysis of SLM with varying phase factors (*U*) is carried out, which shows that with increase in number of *U* PAPR decrease. Also, performance analysis of PTS with varying number of sub-blocks (*V*) is carried out that shows PAPR reduction with increase in number of sub-blocks (*V*). A series of detailed comparison results shows that SLM and PTS are similar techniques with similar characteristics. Both techniques scramble an input data block of MC-CDMA symbols and transmit one of them with minimum PAPR so that probability of incurring high PAPR can be reduced. The performance comparison between SLM and PTS shows that PTS is better than SLM in terms of PAPR reduction capability.

Thus, we can conclude that, the main difference between SLM and PTS is that, SLM is better than PTS in terms reduction capability vs. redundancy, but PTS is considerably better than SLM with respect to reduction capability vs. additional complexity in the system as it is capable of providing more reduction. Obviously, complexity is the main factor if practical MC-CDMA systems are considered and so PTS could be a strong candidate.

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