International Journal of Wireless Communications and Mobile Computing
2016; 4(5): 68-75
http://www.sciencepublishinggroup.com/j/wcmc
doi: 10.11648/j.wcmc.20160405.11
ISSN: 2330-1007 (Print); ISSN: 2330-1015 (Online)

SI Free PTS Technique for PAPR Reduction in OFDM Systems Using Concentric Circle Constellation Mapping

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To cite this article:

Md. Moshiur Rahman, Muhammad Ahad Rahman Miah, Farhana Akter Mou. SI Free PTS Technique for PAPR Reduction in OFDM Systems Using Concentric Circle Constellation Mapping. *International Journal of Wireless Communications and Mobile Computing*. Vol. 4, No. 5, 2016, pp. 68-75. doi: 10.11648/j.wcmc.20160405.11

Received: October 19, 2016; **Accepted:** October 31, 2016; **Published:** November 18, 2016

Abstract: The Orthogonal Frequency Division Multiplexing is one of the widely used modulation techniques in the broadband wireless technology. One of the main problems is the high peak-to-average power ratio of transmitted signal due to the superposition of many subcarriers. Partial transmit sequences (PTS) is a popular technique to reduce the peak-to-average power ratio (PAPR) in orthogonal frequency division multiplexing (OFDM) systems. PTS is highly successful in PAPR reduction and efficient redundancy utilization, but the considerable computational complexity for the required search through a high-dimensional vector space and the necessary transmission of side information (SI) to the receiver are potential problems for a practical implementation. Existing SI embedding schemes eliminate the requirement of SI transmission but these suffer from one drawback or the other, whether in terms of computational complexity, poor PAPR reduction capability or incorrect SI detection. In this paper we have considered SI free PTS based method 'Concentric Circle Constellation Mapping (CCCM)', which do not require SI at the receiver with low computational complexity and better PAPR reduction capability with low SER probability.

Keywords: Side Information (SI), Partial Transmit sequence (PTS), Peak-to-Average Power Ratio (PAPR), Orthogonal Frequency Division Multiplexing (OFDM), Concentric Circle Constellation (CCC), Symbol Error Rate (SER)

1. Introduction

PTS is one of the popular non distortion PAPR reduction scheme for OFDM system. In this scheme, a block of modulated data symbols is partitioned into multiple sub-blocks or partitions, using one of the partitioning schemes discussed in [1-3]. The obtained data sub- blocks are multiplied with the phase rotation factor to avoid the peak formation. In this scheme a phase optimization technique can be used to reduce the computational complexity. But, at the receiver, the information about phase rotation factors is required to recover the original data block. Therefore, SI should be transmitted with each OFDM symbol for data recovery. The SI has prime importance for data recovery of original data block because any error in SI detection may cause the corruption of complete data block. Hence, in case of SI corruption the error performance of the OFDM system may degrade severely. The transmission of SI along with each OFDM symbol results in data rate loss in the OFDM system. The subcarriers used for transmitting the SI may be lost in frequency selective fading channel. In order to protect the SI, a good error control mechanism can be employed, but it increases the system complexity and processing delay in the system. Any error control scheme with a code rate less than one further reduces the data rate loss in the OFDM system.

In [4], an SI embedding scheme has been proposed by Cimini and Sollenberger based on a marking algorithm and decision statistic at transmitting and receiving ends, respectively. The scheme in [4] may not be reliable for large constellation size and applicable only for M-ary PSK modulation. Jayalath and Tellambura proposed a maximum-likelihood decoding [5] for eliminating the requirement of side information. In this scheme [5], the modulation symbols of given constellation and multiple signals generated by multiplication of phase factors have sufficient Hamming distance to decode the original signal, but the SI detection capability of this scheme degrades at lower SNR values. The methods proposed in [4], [5] embed SI butsuffer from the problem of peak re-growth [4], increased decoding complexity [4], [5] and incapable of general search algorithm [4].

In [6] Nguyen and Lampe proposed a combinatorial optimization based search algorithm, to find the optimal phase factors and precoding of data stream with small redundancy is used to embed SI, but it [6] requires one bit per sub block and hence transmission of SI is not completely eliminated. In [7], Zhou et al. proposed multi point square mapping scheme for PTS-OFDM signal, which maps quaternary data points over 16-QAM constellation points using (1, j, -1, -j) as a phase rotation factors, to eliminate the requirement of side information. In [8], Yang et al. proposed an SI embedding scheme, in which the candidate signals are obtained by cyclically shifting each of the sub-blocks in time domain and combining them in recursive order, but the receiver design of such a system is complex.

In [4]-[6], [8], the information about the phase factors used at the transmitter for minimizing the PAPR is recovered from the extracted SI. The reciprocal of recovered phase factors are further used to multiply the demodulated signal at the receiver to recover the original data signal, but this operation increases the computational complexity at the receiving end, whereas the scheme proposed in [7] does not require SI and therefore, no such multiplication operation needs to be performed at the receiver, hence the receiver structure of the scheme proposed in [7] is computationally less complex. In many of the SI embedding schemes [4]-[6], [8] the SI detection at low SNR is very poor, and due to which error performance of the OFDM system degrades severely.

In wireless standards like LTE, OFDM is used in downlink, where mobile station acts as receiver. The mobile stations have limited computational resources; therefore, a PAPR reduction scheme with less computational complexity at receiving end will be beneficial. As discussed above, the schemes proposed in [4]-[6], [8] have computationally complex receiver in comparison to the schemes proposed in this paper.

Hence, CCM-PTS scheme is a viable choice for PTS-OFDM system. Theoretical results for SER performance of CCM-PTS-OFDM over AWGN channel is derived using minimum distance decoding algorithm and verified by simulation results. The simulation results for SER performance of CCM-PTS-OFDM over fading channel using minimum distance decoding have been found out and compared with MPSM-PTS OFDM system. The PAPR and SER performances of the CCM-PTS method are compared with the existing MPSM-PTS method of [7]. The advantages of CCM-PTS over MPSM-PTS in terms of SER performance, PAPR reduction capability and computational complexity are shown. Since the methods [7], and our proposed method are SI-free, the drawbacks associated with SI transmission, are automatically removed.

2. Multicarrier Modulation and OFDM

Multicarrier modulation is an advanced form of Frequency Division Multiplexing (FDM), where a number of frequency sub-bands called subcarriers are allocated to a user. Multicarrier modulation, and especially OFDM, is one of the promising candidates [9] that employ a set of subcarriers in order to transmit the information symbols in parallel over the communication channel. It allows the communication system to transmit the data at a lower rate on multiple subcarriers and the throughput of multicarrier system remains equal to the single carrier system. This allows us to design a system supporting high data rates, while maintaining symbol durations much longer than the channel delay spread, thus simplifying the need for complex channel equalization mechanism and can easily combat the effect of ISI[10], [11].

A simplified block diagram of OFDM modulator is shown in Figure 1. The input serial data stream is passed through a serial-to-parallel converter, which splits the input data stream into a number of parallel subchannels. The data in each of the subchannel is applied to a modulator, such that for N subchannels there are N modulators whose carrier frequencies are $f_0, f_1, \ldots\ldots f_k, \ldots\ldots f_{N-1}$. The carrier frequency spacing between two adjacent subchannel is Δf and the overall bandwidth of N modulated subchannels is $N\Delta f$. We may view the serial-to- parallel convertor as applying every N^{th} symbol to a modulator. This has the effect of interleaving the symbols into each modulator, e.g. X_0, $X_N, \ldots\ldots X_{2N} \ldots\ldots X_{kN}$ are applied to the subcarrier, whose carrier frequency is f_0.

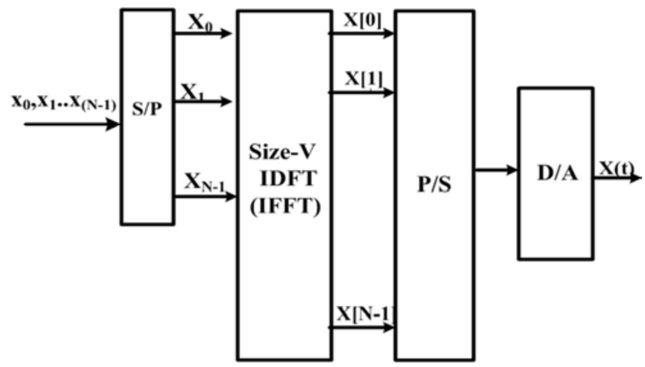

Figure 1. *OFDM modulator.*

Therefore, the discrete time baseband OFDM signal of can be expressed as$x[n] = \sum_{k=0}^{N-1} X_k \exp\left(\frac{j2\pi k_n}{N}\right) = \mathrm{IDFT}\{x_k\}$

Where IDFT denotes the inverse discrete Fourier transform. Therefore, in OFDM system subcarrier modulation can be performed by using the IDFT block.

The inverse fast Fourier transform (IFFT) algorithm provides an efficient way of implementing the IDFT operation. Therefore, when the number of subcarriers is large, then system's computational complexity may be reduced by using IFFT for performing the subcarrier modulation as shown in Figure 1. In order to deal with the delay spread of wireless channels, a cyclic prefix (CP) is usually added at the transmitter to maintain the orthogonality between the subcarriers.

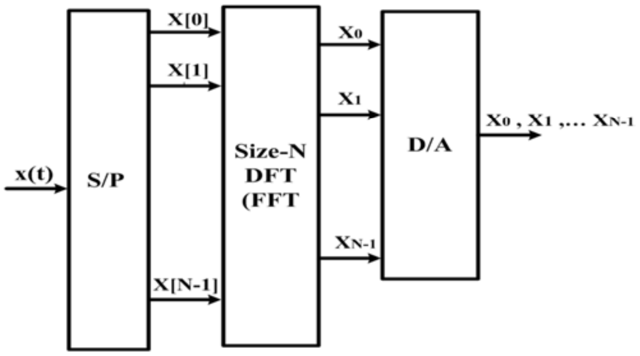

Figure 2. *OFDM demodulator.*

Figure 2 illustrates the basic principle of OFDM demodulation. The continuous time domain OFDM signal received at the receiver is first converted into digital and then applied to serial to parallel converter. After that FFT of thecorrelators operating in parallel to demodulate the multicarriermodulator shown in Figure 2signal obtained from is performed to achieve the subcarrier demodulation. As seen from Figure 2, that FFT operationused in OFDM demodulator eliminates the requirement of Ncorrelators operating in parallel to demodulate the multicarrier modulator shown in Figure 2

3. Peak to Average Power Ratio (PAPR)

The transmit signals in an OFDM system can have high peak values in the time domain since many subcarrier components are added via an IFFT operation. Therefore, OFDM systems are known to have a high PAPR (Peak-to-Average Power Ratio), compared with single-carrier systems. In fact the high PAPR is one of the most detrimental aspects in the OFDM system, as it decreases the SQNR (Signal-to-Quantization Noise Ratio) of ADC (Analog-to-Digital Converter) and DAC (Digital-to-Analog Converter) while degrading the efficiency of the power amplifier in the transmitter. The PAPR problem is more important in the uplink since the efficiency of power amplifier is critical due to the limited battery power in a mobile terminal [12].

In general, the PAPR of a continuous time baseband OFDM signal x(t) is defined as the ratio of the maximum instantaneous power to its average power [13]

$$\mathrm{PAPR}(\mathrm{x(t)}) = \frac{\max_{0\le t\le T_s}[|x|^2]}{\mathrm{p_{av}}}$$

where P_{av} is the average power and can be computed in frequency domain because IFFT is a unitary transformation.

4. Partial Transmit Sequences (PTS)

PTS is one of the most popular distortions-less PAPR reduction scheme [14], [15]. In this scheme a block of N modulated data symbols $\{X_k\}_{k=0}^{N-1}$is partitioned into S disjoint sub- blocks, where S <N. After partitioning, S data sub-blocks are represented by $[X_k^s$, s = 0, 1, 2,……..,S-1, k = 0, 1, ….., N-1], here the length of each data sub-block is N and all of them are disjoint in a sense that the value of $X_k^s$is non-zero only for one particular value of s, s ϵ 0, 1, 2, ……, S-1, therefore we have

$$\{\mathrm{X_k}\}_{\mathrm{k=0}}^{\mathrm{N-1}} = \sum_{\mathrm{s=0}}^{\mathrm{S-1}} \mathrm{X_k^m} \quad \text{, Where k = 0, 1, ……., N-1} \quad (1)$$

After this, IFFT of each of the data sub-block is taken to obtain partial transmit sequences$x_s$is given by

$$\mathrm{x_s(n)} = \frac{1}{\sqrt{\mathrm{N}}}\sum_{\mathrm{k=0}}^{\mathrm{N-1}} \mathrm{X_k^m} \mathrm{e}^{\frac{\mathrm{j2\pi k_n}}{\mathrm{N}}}, \text{ Where s = 0, 1, 2,…,S-1,} \quad (2)$$

n = 0, 1, 2,…,N-1

The partial transmit sequences are multiplied by phase rotation factors b(s) and all of them are combined to obtain a time domain OFDM signal (x’) given by following expression

$$\mathrm{x}' = \sum_{\mathrm{s=0}}^{\mathrm{S-1}} \mathrm{b(s)x_s} \quad (3)$$

Whereb(s) is the phase rotation factor for s^{th} data sub-block. Here, the objective of combining the partial transmits sequences after multiplication with phase factor is to obtain a time domain OFDM signal (x’) with lowest possible PAPR. Therefore, to find the optimal values of phase factors to achieve lowest possible PAPR of OFDM signal x’ following optimization criterion is used

$$\mathrm{b^0(0)b^0(1)\ldots\ldots b^0(S-1)} = \underset{[\mathrm{b(0)\ b(1)\ldots b(S-1)}]}{\arg\min} \left\{ \max_{0\le \mathrm{n}\le \mathrm{N}-1} |\mathrm{x}'| \right\}$$

Where $[\mathrm{b(0)\ b(1)\ldots b(S-1)}]$ are the optimized phase rotation factors for sub-blocks $X_{k,}^0\ X_k^1 \ldots\ldots\ldots X_k^{S-1}$ respectively. The block diagram of the PTS transmitter is shown in Figure 3.

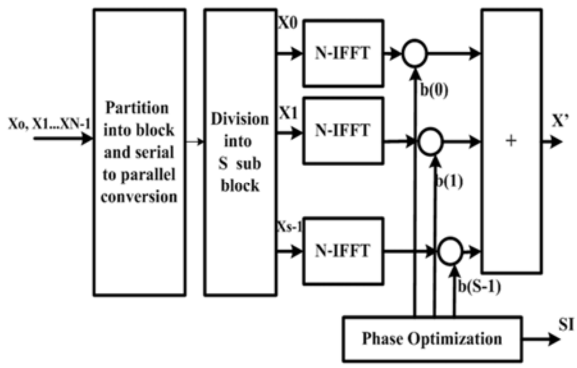

Figure 3. *Block diagram of conventional PTS-OFDM system transmitter.*

The PAPR reduction capability of PTS-OFDM system increases by increasing number of partitions (S). But, in this scheme for S data sub-blocks, S IFFT operations are required to calculate x’, which results in high computational complexity. Therefore, the number of partitions (S) is restricted to 4 [16]-[18].

As observed from (3), the IFFT of x_s has to be multiplied with phase factor b(s),if phase rotation factors have non-zero real and imaginary parts then it requires SN additional complex multiplications, which will further increase the computation complexity of the PTS scheme. In order to reduce the computational complexity incurred in the computation of x'phase factor b(s) should be pure rotational, and therefore chosen from the set, $B = \{1, j, -1, -j\}, here, b(s) \in B$

The optimum search algorithm [14], [15] requires W^{S-1} iterations (searches) to find phase rotation factors, where W is the number of phase factors in phase set B. Many sub-optimal search algorithms [19]-[22] have been proposed for finding $[b^0(0)b^0(1) \dots\dots b^0(S-1)]$. The information about the phase rotation factors $[b^0(0)b^0(1) \dots\dots b^0(S-1)]$ used at the transmitter for PAPR reduction is required to be sent along with each OFDM symbol for data recovery at the receiver. The information used for this purpose is called side information (SI), which reduces the effective data rate of PTS-OFDM system. If straight binary coding scheme is used then $\log_2 (W^{S-1})$ bits per OFDM symbol are required to encode the SI. The loss in data rate will further increase if any error control coding with low code rate is used for encoding the SI.

5. Proposed Concentric Circle Constellation Mapping

In this mapping scheme, the original bit stream is converted into quaternary data and then quaternary data points are mapped to concentric circle constellation (CCC), as shown in Figure 4. The constellation points are located at origin and two concentric circles of radius 2d and 4d. As shown in Figure 4, quaternary data points 0, 1, 2 and 3 are mapped to four different points of CCC, located at 0, j2d,-4d and 2√2 (1-j) d and are denoted by diamond, triangle, circle and square respectively as shown in Figure 4. Concentric circles of radius 2d and 4d ensure a minimum Euclidean distance 2d between any two constellation points. In QPSK constellation (± 1± j), the minimum Euclidean distance between two constellation points is 2. If we take d = 1 then Euclidean distance between any two nearest constellation points of concentric circle constellation can be maintained same. The constellation points 0, j2d, -4d and 2√2(1-j)d after multiplication with phase rotation factors lie on the circle of same radius. As shown in Figure 4, the constellation points0, j2d , -4d and 2√2(1-j)d, after multiplication with phase rotation factors {1, j, -1, -j} are mapped to {0}, {j2d, - 2d, - j2d, 2d }, {- 4d, - j4d, 4d, j4d} , and {2√2(1-j)d, 2√2(1+j)d, 2√2(-1+j)d, 2√2(-1-j)d} respectively, therefore, all 13 points of CCC are occupied. The constellation points of CCC are divided into four different groups, these groups contains the constellation points located at (i) origin, (G1) (ii) on circle of radius 2d , (G2) (iii) on circle of radius 4d with phase angels {0, π/2, π or 3π/2}, (G3) and (iv) on circle of radius 4d with phase angles{π/4, 3π/4, 5π/4 or 7π/4 }, (4G). The constellation points obtained after multiplication with phase factor are unique and can be easily de-mapped to original quaternary data as per Table 2, without requiring any side information. In CCM no data rate loss takes place due to the constellation extension and the only price paid for this advantage is requirement of increased Eb/No.

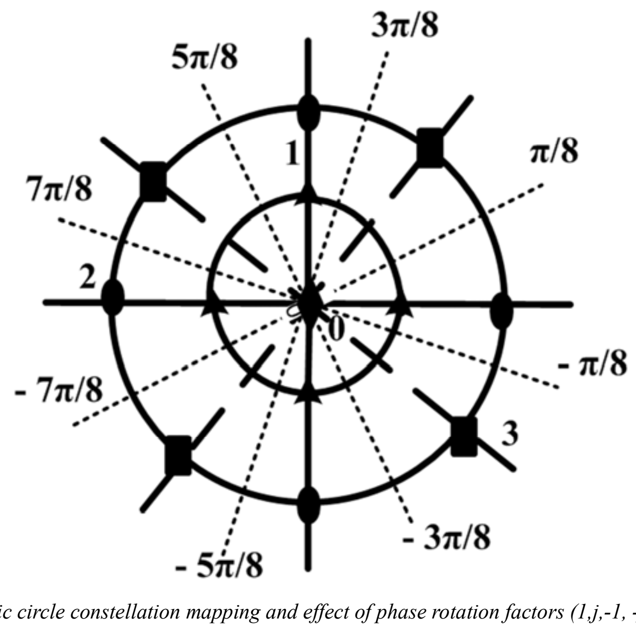

Figure 4. *Concentric circle constellation mapping and effect of phase rotation factors (1,j,-1, -j) on data symbols.*

5.1. System Model

We have considered an OFDM system with PTS based PAPR reduction scheme. The block diagram of PTS based OFDM system utilizing concentric circle constellation is shown in Figure 5. In this system model, an OFDM system with N=256 subcarriers and a PTS based PAPR reduction scheme with S=4 partitions is used. The partitioning of the data block is performed by using adjacent partitioning scheme and W=4 pure rotational phase factors B={1,j,-1,-j} are utilized in PTS-OFDM system. The proposed scheme can be applied for any number of subcarriers in OFDM system.

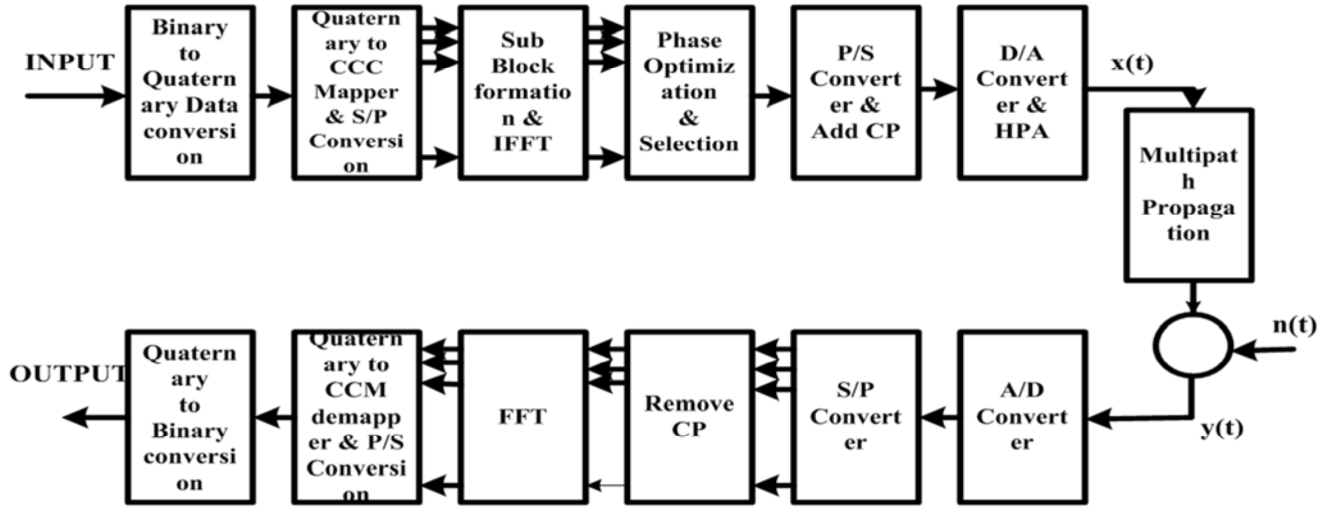

Figure 5. *CCM-PTS OFDM system transceiver.*

As shown in Figure5the binary input signal is first converted to quaternary data signal and then quaternary to concentric circle mapping scheme is performed by using Table 1. After that, these obtained modulated data symbols are converted into N parallel substreams. The obtained data block of N modulated data symbols $\{X_k\}_{k=0}^{N-1}$ is partitioned into S=4 sub-blocks using adjacent partitioning scheme. The IDFT or IFFT of each of the sub-blocks is performed to obtain S partial transmitted sequences. Each of these partial transmit sequences are multiplied by the phase rotation factors and then combined to avoid the peak formation. A phase optimization is required forachieving better PAPR reduction with low computational complexity.

After that thediscrete time domain OFDM signal is converted into serial and cyclic prefix of 1/16th OFDM symbol duration is inserted to eliminate the effect of ISI. The discrete time OFDM signal is passed through digital to analog (D/A) converter to obtain the analog signal. Finally, the analog signal is amplified by HPA to achieve the desired signal power. At the receiver, the received signal is converted into digital by using A/D converter and then cyclic prefix is removed. The obtained serial OFDM signal is converted into parallel using S/P converter. After that, subcarrier demodulation is performed by taking the FFT of OFDM signal obtained from S/P converter. In order to retrieve the original quaternary data signal, quaternary to concentric circle constellation de-mapping is performed, using Table 2. Finally, to obtain binary input, quaternary to binary data conversion is performed.

Table 1. *Quaternary to concentric circle constellation mapping using phase factors (1,j,-1,-j) for d=1.*

Quaternary Symbol	Initially Mapped Quaternary data points to concentric circle constellation	Constellation Points After Multiplication with the Phase Factors in S			
		1	j	-1	-j
0	1 + j0	1 + j0	1 + j0	1 + j0	1 + j0
1	0 + j2	0 + j2	-2 + j0	0 – j2	2 + j0
2	-4 + j0	-4 + j0	0 – j4	4 + j0	0 + j4
3	2√2 (1 - j)	2√2 (1 - j)	2√2 (1 + j)	2√2 (-1 + j)	2√2 (- 1 - j)

Table 2. *De- Mapping of Concentric Circle Constellation Symbols To Quaternary Data Points.*

Demodulated Constellation symbols	De-mapped Constellation Point	Recovered Quaternary data
{0 + j0}	1 + j0	0
{j2, - 2, - j2, 2 }	0 + j2	1
{- 4, - j4, 4, j4}	-4 + j0	2
{2√2(1-j), 2√2(1+j)}, 2√2(-1+j)}, 2√2(-1-j)}}	2√2 (1 - j)	3

5.2. Calculation of Probability of Error for CCC Using Minimum Distance Decoding

Before going into the detail, first we discuss the various notations used in this analysis. Let P_{el}^1denote the conditional probability of making an error when the transmitted point belongs to group Gl. Here, the superscript 1 is used for the case of minimum distance decoding andsubscript l denotes the group number. In concentric circle constellation, all constellation points are divided into four groups G1 to G4. So we need to calculate 4 different error probabilities P_{el}^1toP_{el}^4. The decoding regions for recovering quaternary data points (0, 1, 2 and 3) are shown in figure 6.

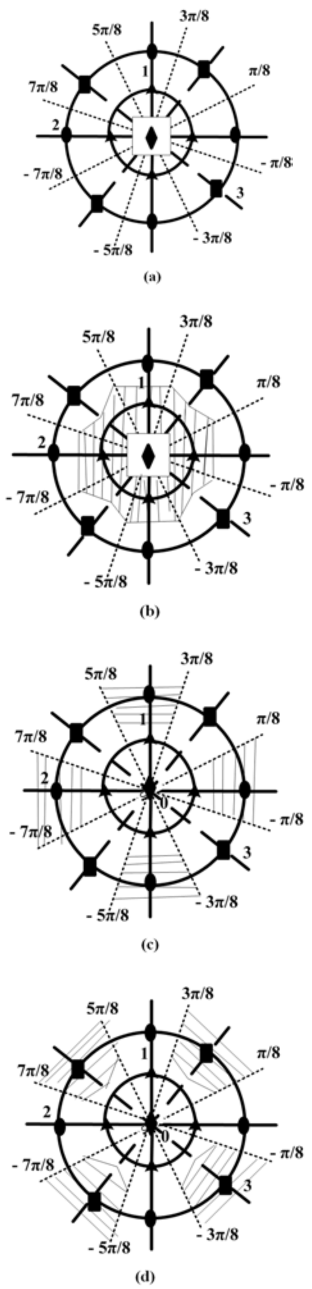

Figure 6. Decoding of quaternary data points (a) '0' (b) '1' (c) '2' and (d) '3' from concentric circle constellation points using minimum distance decoding rule.

The constellation points belonging to group G1 have four nearest neighbours belonging to group G2, and have a Euclidean distance of 2d, as shown in Figure 6. The probability of error P_{el}^{1}can be calculated using union bound approximation [22] as

$$P_{el}^{1} \leq 4 \times \frac{1}{2}\mathrm{erfc}(\sqrt{\frac{d^2}{\eta}})$$

Here η is single sided PSD of complex Gaussian white noise and erfc(.) is complementary error function [23].

Similarly, for the constellation points belonging to group G2, there are four nearest neighbors, one of them belongs to group G1 and has a distance of 2d, one in group G3 at also at a distance of 2d and the remaining two belong to the group G4 and are at a distance of $2d\sqrt{5-\sqrt{2}}$. The probability of error P_{e2}^{1} can be calculated as

$$P_{e2}^{1} \leq 2 \times \frac{1}{2}\mathrm{erfc}\left(\sqrt{\frac{d^2}{\eta}}\right) + 2 \times \frac{1}{2}\mathrm{erfc}(\sqrt{\frac{(5-\sqrt{2})d^2}{\eta}})$$

Similarly, for the constellation points belonging to group G3, there are three nearest neighbors; one of them belongs to group G2 and is at a distance 2d and remaining two belong to group G4 and are at a distance of $8dsin(\frac{\pi}{8})$. The probability of error P_{e3}^{1}can be calculated as follows

$$P_{e3}^{1} = \frac{1}{2}\mathrm{erfc}\left(\sqrt{\frac{d^2}{\eta}}\right) + 2 \times \frac{1}{2}\mathrm{erfc}(\sqrt{\frac{\{8d\sin(\pi/8)\}^2}{4\eta}})$$

Similarly, for constellation points belonging to group G4, there are four nearest neighbors, two of them belong to group G2 and are at a distance of $2d\sqrt{5-\sqrt{2}}$, while remaining two belong to group G3 and are at a distance of $8dsin(\frac{\pi}{8})$. The probability of error P_{e4}^{1} can be calculated using

$$P_{e4}^{1} \leq 2 \times \frac{1}{2}\mathrm{erfc}\left(\sqrt{\frac{(5-\sqrt{2})d^2}{\eta}}\right) + 2 \times \frac{1}{2}\mathrm{erfc}(\sqrt{\frac{\{8d\sin(\pi/8)\}^2}{4\eta}})$$

The overall average probability of symbol error (P_e^1) is calculated as follows

$$P_{e}^{1} \leq \frac{1}{4}(P_{e1}^{1} + P_{e2}^{1} + P_{e3}^{1} + P_{e4}^{1})$$

$$P_{e}^{1} \leq \frac{1}{4}\left(\frac{7}{2}\mathrm{erfc}\left(\sqrt{\frac{d^2}{\eta}}\right) + 2 \times \mathrm{erfc}\left(\sqrt{\frac{(5-\sqrt{2})d^2}{\eta}}\right) + 2 \times \mathrm{erfc}(\sqrt{\frac{\{8d\sin(\pi/8)\}^2}{4\eta}})\right)$$

5.3. Simulation and Results

Here PAPR and error performance of PTS based schemes under consideration are evaluated by computer simulations using MATLAB and verified with their corresponding mathematical results presented in above. In order to check the validity of simulation results, 10,000 OFDM symbols are considered. To compare the SER performance of the proposed CCM-PTS scheme with existing MPSM-PTS, over AWGN channel, we haveconsidered complex AWGN with zero mean. Figure 7 shows the PAPR performance of original

OFDM signal without PAPR reduction, CCM-PTS with four phase factors and MPSM-PTS with four phase factors.It can be observed from Figure 7 the PAPR performance of our proposed scheme isbetter than the MPSM-PTS.

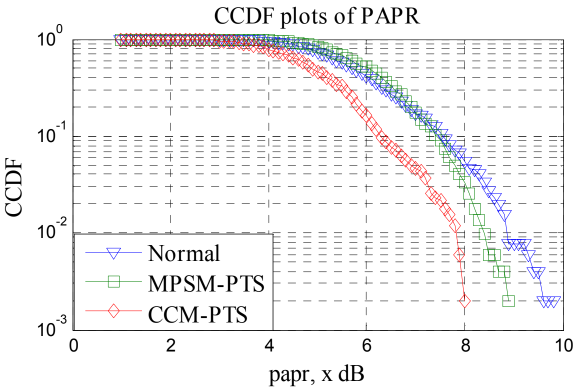

Figure 7. *PAPR performance comparison of CCM-PTS and MPSM-PTS based PAPR reduction schemes.*

The SI detection capability of MPSM-PTS is very poor at lower values of SNR. The main reasons associated with CCM to achieve better PAPR and SER performance in comparison to MPSM is lesser number of constellation points with lesser average power while maintaining same Euclidean distance. In CCM-PTS we have 10 decision regions, one each for decoding the constellation point located at zero and on a circle of radius 2. Further to decode the eight constellation points located on the circle of radius 4 we require 8 decision regions. So, in this scheme we require a total of 10 different decoding regions (D). In MPSM- PTS with four phase factors quaternary data is mapped to a 16-QAM constellation which has 16 distinct points. The SER performance of MPSM-PTS and CCM-PTS are shown in figure 8. It can be seen from Figure 8 that SER performances of CCM-PTS using minimum distance decoding scheme is better than MPSM-PTS.

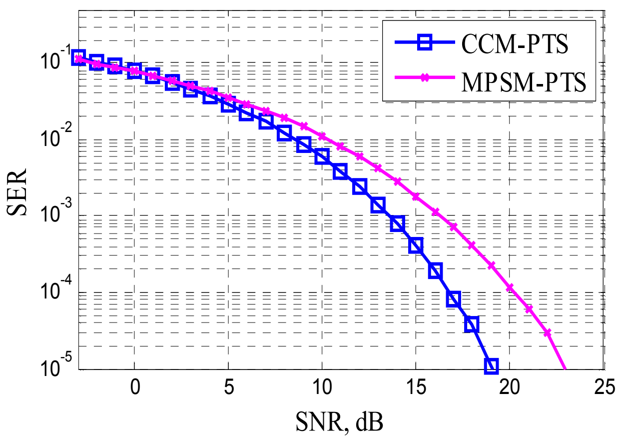

Figure 8. *SER performance comparison of CCM-PTS and MPSM-PTS.*

6. Conclusion

In PTS based methods, SER performance depends on how SI is encoded with the OFDM symbol, and if it gets corrupted, then entire OFDM symbol may be erroneous. Existing SI embedding schemes eliminate the requirement of SI transmission but these suffer from one drawback or the other, whether in terms of computational complexity, poor PAPR reduction capability or incorrect SI detection. In this paper, we have considered SI free PTS based methods (MPSM-PTS, CCM-PTS), which do not require SI at the receiver and therefore found to be the good alternative of SI embedding schemes. The PAPR reduction capabilities of CCM-PTS and MPSM-PTS schemes are compared. The SER performances of such PAPR reduction schemes over AWGN are derived analytically and confirmed by using MATLAB simulations. However, their SER performances over fading channel are evaluated by doing simulations. The SER performances of CCM-PTS using minimum distance decoding scheme over AWGN and fading channels are better than MPSM-PTS. In CCM-PTS, with circular boundary decoding, we require only 10 decoding regions, whereas other requires 13 decoding regions Therefore, the decoding complexity of CCM-PTS is lesser compare to MPSM-PTS. At the same time, it is also seen that, the PAPR reduction capability of CCM-PTS is almost 1dB better than the MPSM-PTS. Two main reasons associated with CCM to achieve better PAPR and SER performances in comparison to MPSM are lesser number of constellation points with lesser average power while maintaining same Euclidean distance.The CCM approach has only 13 constellation points and their average power is 9, whereas MPSM schemes has 16 constellation points and having an average power equal to 10.

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