COMPARISON OF PAPR REDUCTION TECHNIQUES IN MIMO-OFDM SYSTEM

S. Sushma[1] and S. Srinivas[2]

1. Assistant Professor, SSCE, Etcherla, Srikakulam, Andhra Pradesh, India
2. Assistant Engineer, A.P.E.P.D.C.L, Andhra Pradesh, India

Abstract: This paper enhances two types of PAPR reduction methods namely selected mapping (SLM) and partial transmit sequence (PTS) for OFDM. And comparison of both PTS and SLM technique discussed. Multicarrier systems suffer from a high peak-to-average power ratio (PAR) of their transmit signal as large signal peaks lead to power inefficiency of the amplifiers. This issue becomes even more serious in a multi-antenna transmitter. To increase power efficiency, a PAPR reduction scheme must be applied at the transmitter. Many methods have been proposed to solve this problem, but the most of them decrease high Peak-to-Average Power Ratio (PAPR) as well as the data rate. Recently, generalizations of two popular PAPR reduction techniques, partial transmit sequences (PTS) and selected mapping (SLM), to multi-antenna systems have been proposed. Partial transmit sequence (PTS) can improve the PAPR statistics of an OFDM signal. In the PTS technique, the data block to be transmitted is partitioned into disjoint sub-blocks and the sub blocks are combined using phase factors to minimize PAPR. And selective mapping (SLM) technique is the actual transmit signal lowest PAPR is selected from a set of sufficiently different signals which all represents the same information. SLM Technique are very flexible as they do not impose any restriction on modulation applied in the subcarriers or on their number. In this paper, a comparison of these two schemes is accomplished. Simulation results show that PTS offers significant gains compared to SLM.

Keywords*:* MIMO-OFDM, PAPR, PTS, SLM, CCDF.

I. INTRODUCTION

Wireless communication which was initially implemented analog domain for transfer has is now-a-days mostly done in digital domain. Instead of a single carrier in the system multiple sub-carriers are implemented to make the process easier.

For future communication systems a combination of *orthogonal frequency-division multiplexing (OFDM)[13]* with *multiple input/multiple-output (MIMO)* systems [10]is envisaged. The demand for high-speed mobile wireless communication is rapidly growing. Since bandwidth resource in 4G mobile communications is still scarce, in order to improve spectrum efficiency and achieve as high as 100Mbps wireless transmission rate, it requires more advanced techniques to be employed. Hence, next generation mobile communication systems need more sophisticated modulation scheme and information transmission structure. The multiple-input multiple–output orthogonal frequency division multiplexing (MIMO-OFDM) technology promises to be a key technique for achieving the high data capacity and spectral efficiency requirements for wireless communication systems of the near future .With its natural resistance to multipath fading and its capability to support extremely high data rates, MIMO-OFDM is a major candidate for a fourth generation (4G) system [1]. In MIMO-OFDM system, the output is the superposition of multiple sub-carriers. Due to the OFDM technique such systems exhibit a large *peak-to average power ratio (PAPR)*. Non-linear power amplification of signals with high peak power leads to clipping which causes signal distortion and, even worse, out-of-band radiation. To transmit signals with high PAPR, it requires power amplifiers with very high power scope. These kinds of amplifiers are very expensive and have low efficiency-cost. If the peak power is too high, it could be out of the scope of the linear power amplifier. This gives rise to non-linear distortion which changes the superposition of the signal spectrum resulting in performance degradation. To avoid out-of-band radiation, these amplifiers have to be operated with large input power back-off, which decreases power efficiency. In order to increase the power efficiency, an algorithmic control of the PAPR at the transmitter is indispensable. Over the last years numerous PAPR reduction techniques were published. Two of the most popular PAR reduction techniques are *partial transmit sequences (PTS)* [2] and *selected mapping (SLM)* [3]. Both schemes generate multiple representations of the information carrying signal and choose that one, exhibiting the best PAPR for transmission. Recently, a generalization of both schemes to MIMO systems has been introduced [4, 5, 6]. Subsequently, a comparison of the MIMO extensions of PTS and SLM in a MIMO point-to-point scenario is accomplished. In addition, the situation in broadcast scenarios is considered.The paper is organized as follows .Section II gives short review of MIMO-OFDM system. An overview of the PAPR in OFDM System in section III. Brief description of PTS & SLM PAPR reduction techniques in section IV. Simulation results of both PTS &SLM technique, comparison of both observed in section V. Finally conclusion is in section VI.

II. BASICS OF MIMO-OFDM SYSTEMS

The main challenge of the new generation of wireless cellular systems is the reliability of providing data rate of around 100 Mbps and 30 Mbps for the downlink and uplink physical layer transmission, respectively. In high-speed wireless communication, combining MIMO and OFDM technology, OFDM can be applied to transform frequency-selective MIMO channel into parallel flat MIMO channel, reducing the complexity of the receiver, through multipath fading environment can also achieve high data rate robust transmission. Therefore, MIMO-OFDM [7] systems obtain diversity gain and coding gain by space-time coding, at the same time, the OFDM system can be realized with simple structure. Therefore, MIMO-OFDM system has become a welcome proposal for 4G [8] mobile communication systems.

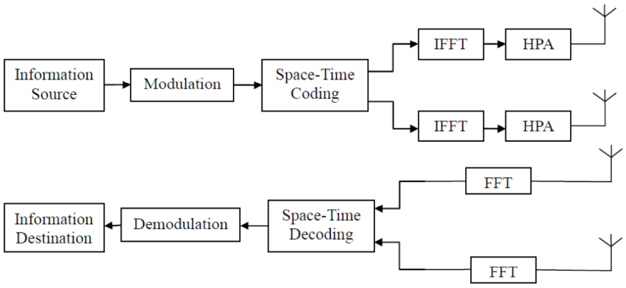

Figure 1. MIMO OFDM System

At the transmitting end, a number of transmission antennas are used. An input data bit stream is supplied into space-time coding, then modulated by OFDM and finally fed to antennas for sending out (radiation). At the receiving end, in-coming signals are fed into a signal detector and processed before recovery of the original signal is made. Fig. 1 shows the basic structure of a MIMO-OFDM system.

2.1 MIMO System

MIMO [9] signaling is a groundbreaking development pioneered by Jack Winters of Bell Laboratories in his 1984 article .Several different antenna configurations are used in defining space-time systems.

Basic Structure of MIMO system: There exist several communication transmission models as follows (see Fig. 2):

1. Single-input-and-single-output (SISO) system: It uses only one antenna both at the transmitter and receiver.

2. Single-input-and-multiple-output (SIMO) system: It uses a single transmitting antenna and multiple receiving antennas [3].

3. Multiple-input-and-single-output (MISO) system: It has multiple transmitting antennas and one receiving antenna.

4. Multiple-input-multiple-output (MIMO) system: It uses multiple antennas both for transmission and reception. Multiple transmitting and receiving antennas will achieve antenna diversity without reducing the spectral efficiency.

In MIMO system [10], a number of antennas are placed at the transmitting and receiving ends, their distances are separated far enough. The distance between different base station antennas can be set as 10 times the carrier wavelength and mobile station antennas can be separated by half carrier wavelength. In this way, independent channels between the transmitting and receiving ends are formed so as to achieve spatial diversity or space division multiplexing.

The idea is to realize spatial multiplexing and data pipes by developing space dimensions which are created by multi-transmitting and receiving antennas. The block diagram in Fig. 2. Illustrates the antenna configuration is space-time systems.

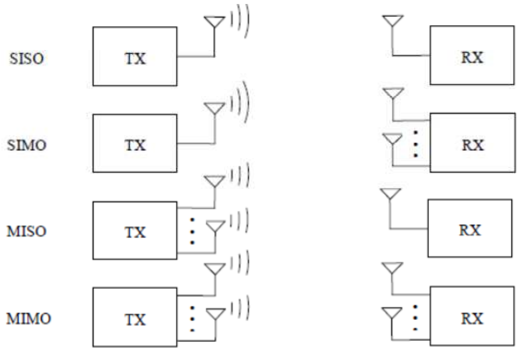

Figure 2. Basic MIMO-STRUCTURE

2.2. OFDM

A typical OFDM [11] transmission system is shown in Fig. 3 the transmitting end, first of all, input binary serial data stream is first processed by channel encoder, constellation mapping and serial to parallel (S/P) conversion. A single signal is divided into *N* parallel routes after *N*-point inverse fast Fourier transform (IFFT). Each orthogonal sub-carrier is modulated by one of the *N* data routes independently. By definition the *N* processed points constitute one OFDM symbol. Next, convert modulated parallel data to serial sequence and then copy the last L samples of one symbol to the front as cyclic prefix (CP). At last, arrive at transmitter after process of digital to analog (D/A) conversion and radio frequency (RF) modulation. To recover the information in OFDM system, reception process is converse and self-explanatory. At the receiving end, digital down conversion is carried out, demodulate receiving signals. At last, demodulated signals are fed into an analog to digital (A/D) converter, sample output and take timing estimation to find initial position of OFDM symbol. The CP added in transmission process is removed and *N*-Points fast Fourier transform (FFT) transformation will be conducted on the left sample points to recover the data in frequency domain. The output of baseband demodulation is passed to a channel decoder, which eventually recover the original data.

$$X[n] = \frac{1}{N}\sum_{k=0}^{N-1} X[k].e^{\frac{j2\pi kn}{N}} \qquad (1)$$

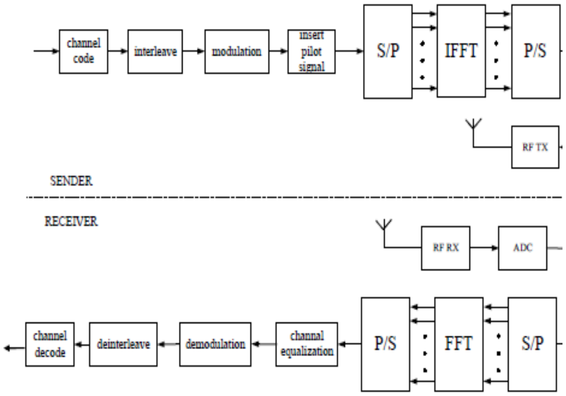

Figure 3: Block diagram of OFDM system

An OFDM receiver consists of a group of decoders, which move different carrier frequencies to zero frequency and perform integration over one symbol period. Since sub-carriers are orthogonal to one another, only specified carrier can be demodulated, the rest irrelevant carriers do not have any impact on the results of the integration.

OFDM has several significant advantages over traditional serial communications; such as the ability to support high data rates for wide area coverage, robustness to multipath fading and a greater Simplification of channel equalization. However, the main drawback of OFDM is its high PAPR, which distorts the signal if the transmitter contains nonlinear components such as power amplifiers and causes some deficiencies such as intermediation, spectral spreading and changing in signal constellation. One of the major drawbacks in implementing OFDM is its high peak-to-average power ratio (PAPR) [12]. Due to high PAPR, the transmit power amplifier must operate in a region where the power conversion is inefficient. In the low-cost application, the potential benefits of the OFDM are overshadowed by the drawbacks of high PAPR. To overcome the low power efficiency requires not only large back off and large dynamic range digital-to-analog converter (DAC) but also highly efficient high power amplifiers (HPA) and linear converters. These demands result in costly hardware and complex systems. Therefore to lessen the difficulty of complex hardware design it has become imperative to employ efficient PAPR reduction techniques.

III. COMPUTATION OF PAPR IN OFDM

Let X(0), X(1), ⋯ , X(N −1) represent the data sequence to be transmitted in an OFDM symbol with N subcarriers. The baseband representation of the OFDM symbol is given by**:**

$$x[t] = \frac{1}{\sqrt{N}}\sum_{n=0}^{N-1} X[n].e^{\frac{j2\pi nt}{N}} \quad 0 \leq t \leq T \qquad (2)$$

Where T is the duration of the OFDM symbol. According to the central limit theorem, when N is large, both the real and imaginary parts of x(t) become Gaussian distributed, each with zero mean and a variance of [E[$|x(t)^2|$]and the amplitude of the OFDM symbol follows a Rayleigh distribution.

Consequently it is possible that the maximum amplitude of OFDM signal may well exceed its average amplitude. Practical hardware (e.g. A/D and D/A converters, power amplifiers) has finite dynamic range; therefore the peak amplitude of OFDM signal must be limited.

PAPR is mathematically defined as:

$$\text{PAPR} = 10\log_{10}\frac{\max[|x(t)^2|]}{\frac{1}{T}\int_0^T |x(t)^2|dt}(\text{dB}) \qquad (3)$$

It is easy to see from (3) that PAPR reduction may be achieved by decreasing the numerator max[$|x(t)^2|$] increasing the denominator $\frac{1}{T}\int_0^T |x(t)^2|$dt or both.

CCDF is a method used to characterize the peak power statistics of a digitally modulated signal. CCDF object measures the probability of a signal's instantaneous power to be a specified level above its average power. The effectiveness of a PAPR reduction technique is measured by the complementary cumulative distribution function (CCDF), which is the probability that PAPR exceeds some threshold, i.e.:

$$\text{CCDF} = \text{Probability}\ (\text{PAPR} > p0), \qquad (4)$$

Where p0 is the threshold

3.1. Peak-to-Mean Envelope Power Ratio (PMEPR)

PMEPR is the ratio between the maximum power and the average power for the envelope of a baseband complex signal Ŝ that is,

$$\text{PMEPR}\ \{\hat{s}(\mathrm{t})\} = \frac{\max|\hat{s}(\mathrm{t})^2}{\mathrm{E}\{|\hat{s}(\mathrm{t})^2|\}} \qquad (5)$$

3.2. Peak Envelope Power (PEP)

PEP represents the maximum power of a complex baseband Signal Ŝ, that is,

$$\text{PEP}\ \{\hat{s}(\mathrm{t})\} = \max|\hat{s}(\mathrm{t})^2| \qquad (6)$$

In the case that the average signal power is normalized (i.e.,$\mathrm{E}\{|\hat{s}(\mathrm{t})^2|\} = 1$), PMEPR is equivalent to PEP.

3.3. Peak-to-Average Power Ratio (PAPR)

PAPR is the ratio between the maximum power and the average power of the complex pass-band Signal s(t) , that is,

$$\text{PAPR}\ \{\hat{s}(\mathrm{t})\} = \frac{\max|\mathrm{Re}(\hat{s}(\mathrm{t})\ e^{j2\pi f c t})|^2}{|\mathrm{Re}(\hat{s}(\mathrm{t})\ e^{j2\pi f c t})|^2\}} = \frac{\max|\hat{s}(\mathrm{t})^2}{\mathrm{E}\{|\hat{s}(\mathrm{t})^2|\}} \qquad (7)$$

The crest factor or peak-to-average ratio (PAPR) or peak-to-average power ratio (PAPR) is a measurement of a waveform, calculated from the peak amplitude of the waveform divided by the RMS value of the waveform.

$$C = \frac{|X|_{peak}}{X_{rms}} \qquad (8)$$

Reducing the *max*|*x(t)*| is the principle goal of PARP reduction techniques. Since, discrete- time signals are dealt with in most systems, many PAPR techniques[13][14] are implemented to deal with amplitudes of various samples of *x(t)*. Due to symbol spaced output in the first equation we find some of the peaks missing which can be compensated by oversampling the equation

The major disadvantages of a high PAPR are-

1. Increased complexity in the analog to digital and digital to analog converter.

2. Reduction is efficiency of RF amplifiers

These disadvantages overcome by using PAPR reduction techniques.

IV. PAPR REDUCTION TECHNIQUES

4.1.Partial Transmit Sequence

The partial transmit sequence (PTS)[15] technique partitions an input data block of N symbols into V disjointsubblocksas follows:

$$X = [x^0, x^1, x^2, \dots\dots\ x^{v-}]^T \qquad (9)$$

Where are X^i the subblocks that are consecutively located and also are of equal size. Unlike the SLM technique in which scrambling is applied to all subcarriers, scrambling (rotating its phase independently) is applied to each subblock [3] in the PTS technique (see Figure 4). Then each partitioned subblock is multiplied by a corresponding complex phase factor $\boldsymbol{b^v}=\boldsymbol{e^{j\emptyset v}}$ v = 1, 2, . . . , V, subsequently taking its IFFT to yield

X= IFFT $\{\sum_{v=1}^{v} b^{v}\, X^{v}\}$ $=\sum_{v-1}^{v} b^{v}$.IFFT $\{X^{v}\}=\sum_{v-1}^{v} b^{v}\, X^{v}$ (10)

where $\{x^{v}\ \}$is referred to as a partial transmit sequence (PTS)

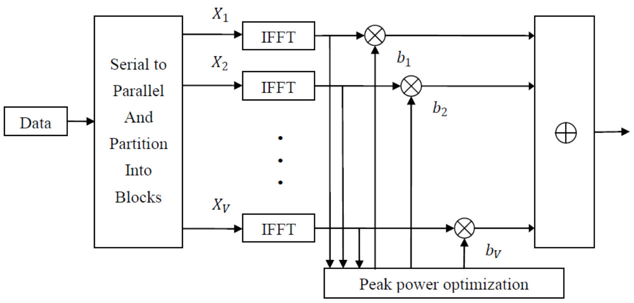

Figure 4: Block diagram of PTS Technique

The phase vector is chosen so that the PAPR can minimized , which is shown as

$$[b^{\sim 1},\ldots\ldots b^{\sim v}] = {}^{argmin}_{b^{1}\ldots b^{v}}\Big({}^{\quad max}_{n=0,1,\ldots N-1} \Big|\sum_{v=1}^{v} b^{v}\, X^{v}[\mathrm{n}]\Big|\Big) \qquad (11)$$

Then, the corresponding time-domain signal with the low

PAPR vector can be expressed as

$$\check{x} = \sum_{v=1}^{V} b^{\sim v}\, x^{v} \qquad (12)$$

In general, the selection of the phase factors $x^{v}\{b^{v}\}_{v-1}^{v}=1$ is limited to a set of elements to reduce the search complexity.

As the set of allowed phase factors is

$$\mathrm{b}=\{e^{\frac{j2\pi i}{W}}|\mathrm{i}=0,1,2,\ldots\mathrm{W}-1\} \qquad (13)$$

W^{v-1} Sets of phase factors should be searched to find the optimum set of phase vectors. Therefore, the search complexity increases exponentially with the number of sub blocks. The PTS technique [16] requires V IFFT operations for each data block and [log2 W^{v}] bits of side information. The PAPR Performance of the PTS technique is affected by not only the number of sub blocks, V, and the number of the allowed phase factors, W, but also the sub block partitioning. In fact, there are three different kinds of the sub block partitioning schemes: adjacent, interleaved, and pseudo-random. Among these, the pseudo-random one has been known to provide the best Performance.

As discussed above, the PTS technique suffers from the complexity of searching for the optimum set of phase vector, especially when the number of sub block[17] increases. In the literature various schemes have been proposed to reduce this complexity. One particular example is a suboptimal combination algorithm, which uses the binary phase factors of {1,-1}.

It is summarized as follows:

1. Partition the input data block into V sub blocks as in (9).

2. Set all the phase factors b^{v}= 1 for v = 1: V, find PAPR of (10), and set it as PAPR_min.

3. Set v = 2.

4. Find PAPR of (9) with b^{v}= -1.

5. If PAPR > PAPR_min, switch bv back to 1. Otherwise,update PAPR_min = PAPR.

6. If v < V, increment v by one and go back to Step 4.

Otherwise, exit this process with the set of optimal phase factors, $\tilde{b}$.

4.2. Selected Mapping

Selected mapping (SLM) [4] is a promising PAPR reduction technique. Although SLM is also a scrambling technique, the main idea of SLM is quite different from PTS. It selects the most favorable signal from a set of phase rotated candidate data blocks generated by transmitter, which all represent the same information as the original data block. A block diagram of SLM scheme is shown in fig. 5.we get U different time domain candidate signals with different PAPR values. Among them, the one with the lowest PAPR is selected for transmission. This selecting can be mathematically expressed as

$$x = \arg\min \{\mathrm{PAPR}\ (X^{(u)})\}$$

SLM techniques generate several OFDM symbols as candidates and then select the one with the lowest PAPR for the actual transmission. Conventionally, the transmission of side information is needed so that the receiver can use the side information to determine which candidate is selected in the transmission and then recover the information. SLM technique do introduced some additional complexity, but with loss in efficiency

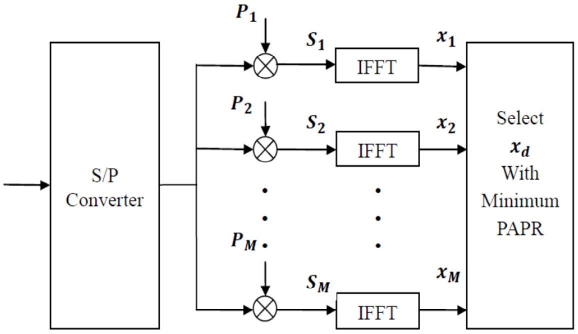

Figure 5: Block diagram of SLM technique

The technique of selected mapping (SLM) for PAPR reduction was proposed in 1996. In SLM from a set of candidate signals which are generated to represent the same information, the signal with lowest PAPR is selected and transmitted. The information about this selection also needs to be explicitly transmitted along with the selected signal as side information.

Selected mapping algorithm is as follows:

1) The sequence of data bits are mapped to constellation points QPSK to produce sequence symbols X0, X1, X2…

2) These symbol sequences are divided into blocks of length N. N is the number of subcarriers.

3) Each block X=[X0, X1, X2….XN-1] is multiplied (point wise multiplication) by U different phase sequence vectors

$$B^{(u)} = [B_0^{(u)}, B_1^{(u)}, \dots\dots\dots\dots\ B_{N-1}^{(u)}]^T \qquad (14)$$

where each row of the normalized Riemann matrix B is taken as B(u), u=1,2,...U.

4) A set of U different OFDM data blocks

$$X^{(u)} = [X_0^{(u)}, X_1^{(u)}, \dots\dots\dots..\ X_{N-1}^{(u)}]^T \qquad (15)$$

Are formed, where

$$X_n^{(u)} = X_n \,.\, B_n^{(u)} \quad n = 0,1, \dots\dots\dots.N-1, \qquad (16)$$

$$u = 1,2,..N$$

5) Transform into time domain to get

$$X^{(u)} = IDFT\{X^u\} \qquad (17)$$

6) Select the one from $X^{(u)}$ $u = 1,2, \dots..U$ which has the minimum PAPR and transmit.

Block diagram of SLM technique is given in figure5 We use MATLAB simulations to evaluate the performance of the different phase sequences for SLM technique. As a performance measure, complementary cumulative density function (CCDF) of PAPR is used. Mean and Variance of PAPR of the whole data blocks is taken as second criteria for performance measure among different phase sequence sets.

V. RESULTS

5.1. PTS Simulation Result

The simulation result in Fig. 6 shows the varying PAPR reduction performance with different *W* (collection range of weighting factor bv) when using

PTS reduction scheme. Simulation specific parameters are: the number of sub-carriers $N = 128$, QPSK 45 constellation modulation, oversampling factor takes $L = 8$, the number of sub-block $V = 4$. From the figure we notice that the CCDF curve has nearly 1dB improvement when $W = 4$, compared to $W = 2$, the 1% PAPR is about 7.5 dB. We conclude that in a PTS MIMO-OFDM system, the larger W value takes, the better PAPR performance will be obtained when the number of sub-block V is fixed.

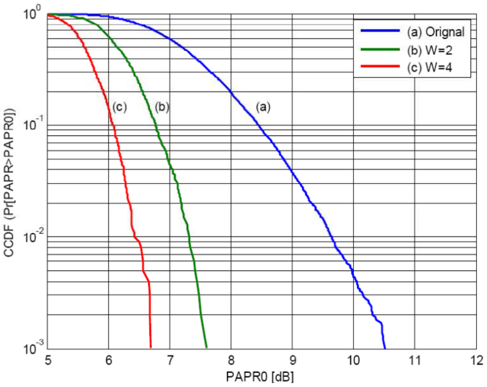

Figure 6: CCDF plot for PTS algorithm technique

5.2. SLM Simulation result

From Fig. 7, it can be observed that the proposed SLM method displays a better PAPR reduction performance than the original OFDM signal which is free of any PAPR reduction scheme. The probability of high PAPR is significantly decreased. Increasing M leads to the improvement of PAPR reduction performance. If the probability is set to 1% and then the CCDF curves with different M values are compared. The PAPR value of case M=2 is about 1dB smaller than the unmodified one M=1. Under the same condition, the PAPR value of case M=16 is about 3dB smaller than the original one M=1. However, from the comparison of the curve M=8 and M=16, we learned that the performance difference between these two cases is less than 0.5dB. This proves that we will not be able to achieve a linear growth of PAPR reduction performance with further increase the value of M (like M>=8), the PAPR reduction performance of OFDM signal will not be considerably improved.

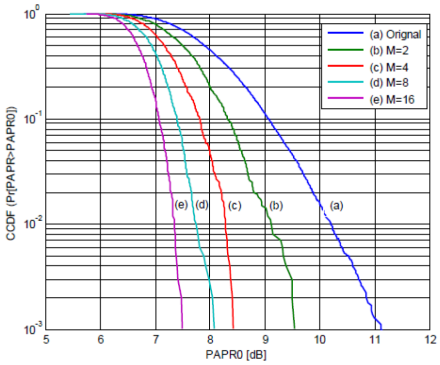

Fig 7: CCDF plot for SLM algorithm technique

5.3. Comparison of PTS and SLM

Fig.8 shows the simulation result of using SLM and PTS method to an MIMO-OFDM system, separately. In PTS method, we set the number of sub-carriers $N = 128$ and applying pseudo-random partition scheme, for each carrier, adopting QPSK constellation mapping, 49 weighting factor $bv \in \pm 1, \pm j$; In SLM method, rotation factor $Pm,n \in \pm 1, \pm j$. Based on the theory, we know that the IFFT calculation amount of these two methods is same when $V = M$, but for PTS method, it can provide more signal manifestations, thus, PTS method should provide a superior performance on PAPR reduction. In fact, this deduction is confirmed by simulation result. From the Figure 8, we learned that with the same CCDF probability 1%, the PAPR value equals to 7dB when PTS is employed, while the PAPR rise up to 8.2dB when SLM is employed under the same circumstance.

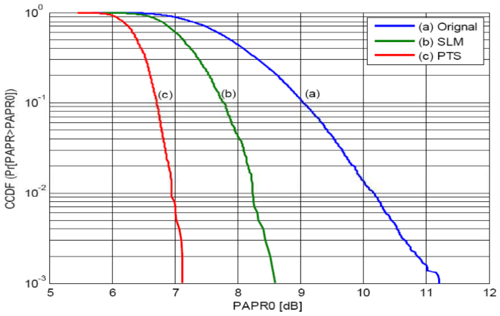

Fig 8: CCDF plot for comparison of PTS algorithm and SLM algorithm technique

VI. CONCLUSION

This paper gives a comparison of the popular PAPR reduction techniques PTS and SLM for multi-antenna OFDM systems. We study the method of selected mapping and partial transmit sequence. A series of detailed comparison results were obtained of these two schemes from the angle of PAPR reduction performance, redundancy of auxiliary information, as well as complexity of system. At last, we also compare these two schemes under the same conditions in general. From the Figure 8, we learned that with the same CCDF probability 1%, the PAPR value equals to 7dB when PTS is employed, while the PAPR rise up to 8.2dB when SLM is employed under the same circumstance. So PTS is the most efficient PAPR reduction technique compared to SLM. Due to the characteristics of multi-antenna of MIMO-OFDM system itself, we can fully explore the advantages of combination between proposed PAPR reduction schemes and outstanding properties of MIMO-OFDM system, such as studying the PAPR reduction technology of MIMO-OFDM system, combine with space-time codes.

REFERENCES

[1] Ramjee Prasad, *OFDM for Wireless Communication Systems*. London: Artech House Universal Personal Communications, 2004.

[2] S.H. M¨uller, R.W. B¨auml, R.F.H. Fischer, and J.B. Huber, *"OFDM with Reduced Peak-to-Average Power Ratio by Multiple Signal Representation,"* Annals of Telecommunications, pp. 58-67, Feb. 1997.

[3] R. B¨auml, R.F.H. Fischer, and J.B. Huber, *"Reducing the Peak-to-Average Power Ratio of Multicarrier Modulation by Selected Mapping,"*IEE Electronics Letters, pp. 2056–2057, Nov. 1996.

[4] R.F.H. Fischer and M. Hoch, *"Directed Selected Mapping for Peak-to-Average Power Ratio Reduction in MIMO OFDM,"* IEE ElectronicsLetters, pp. 1289–1290, Oct. 2006.

[5] R.F.H. Fischer and M. Hoch, *"Peak-to-Average Power Ratio Reduction in MIMO OFDM,"* in Proceedings of IEEE International Conference on Communications (ICC), Glasgow, Scotland, June 2007.

[6] C. Siegl and R.F.H. Fischer, *"Partial Transmit Sequences for Peak-to-Average Power Ratio Reduction in Multi-Antenna OFDM,"* EURASIPJ. on Wireless Com. and Netw., Jan. 2008, Article ID 325829.

[7] H. Sampath, et al., *"A fouth-generation MIMO-OFDM broadband wireless system: design, performance and field trial results,"* IEEE Communication Magazine, Sep 2002, vol. 40, no 9, pp. 143-149.

[8] Young Kyun Kim, Ramjee Prasad, *"What is 4G," in 4G Roadmap and Emerging Communication Technologies*, Artech House, 2006, pp. 12–13.

[9] Mohinder Jankiraman, *"Multicarrier techniques," in Space-time codes and MIMO systems,* Artech House, 2004, pp. 15.

[10] Mohinder Jankiraman, *"MIMO system capacity," in Space-time codes and MIMO systems,* Artech House, 2004, pp. 23.

[11] Shinsuke Hara, Ramjee, *"Principle and history of MCM/OFDM," in Multicarrier techniqu-es for 4G mobile communication,* Artech House, 2003, pp. 39.

[12] Christopher Gerald Santos, *"Peak-to-Average power ratio reduction solutions for OFDM,"* Philippine Journal of ICT and Microelectronics, vol.1, no. 2, July 2002.

[13] V. Vijayarangan, DR. (MRS) R. Sukanesh, *" Overview of the Techniques for Reducing Peak to Average Power Ratio and its Selection Criteria for Orthogonal Frequency Division Multiplexing Radio Systems,"* Journal of Theoretical and Applied

Information Technology,vol. 5, no. 1, pp. 25- 35 2009.

[14] Seung Hee Han, Jae Hong Lee, *"An Overview of Peak-to-Average Power Reduction Techniques for Multicarrier Transmission,"* IEEE Wireless Communication Magazine, Vol. 12, No. 2, pp. 56-65, April 2005.

[15] L. Wang and Y. Cao, *"Sub-optimum PTS for PAPR reduction of OFDM signals,"* IEEE Electronics Letters, July 2008, vol. 44, no. 15, pp.921-922.