International Journal of Electronics, Electrical and Computational System
IJEECS
ISSN 2348-117X
Volume 6, Issue 7
July 2017

# Performance Comparison of a Fixed and Adaptive Piecewise Linear Companding Transform in WiMAX

**Beena A O[1], Sakuntala S Pillai[2], N. Vijayakumar**

[1] Department of Electronics & Communication Engineering, SAINTGITS College of Engineering, Kottayam

[2] Department of Electronics & Communication Engineering, Mar Baselios College of Engg. & Tech., Thiruvananthapuram

[3] Department of Electronics & Communication Engineering, Govt. College of Engineering, Bartonhill, Thiruvananthapuram

***Abstract:*** *One of the challenging issues in multiple-input multiple-output (MIMO) communication systems using orthogonal frequency division multiplexing (OFDM) modulation is the high peak to average power ratio (PAPR). In 4G wireless mobile communication systems MIMO-OFDM is the most popular technique used for high data rate services. To attain full diversity orthogonal space-time block codes (OSTBC) have been suggested for MIMO communication systems. Companding is a promising and well known technique for the PAPR reduction. This paper compares the performance of a piecewise linear companding transform at its fixed and adaptive strategies in the 4G mobile WiMAX (IEEE 802.16e/IEEE 802.16m) system. Analysis has been done by observing the performance of OSTBC with rate ½ for two different transmitting and receiving antennas under Rayleigh fading MIMO channel conditions. Simulation results shows that the adaptive version of the piecewise linear companding transform performs better for the given PAPR preset value.*

***Keywords: OSTBC, MIMO-OFDM, PAPR, companding transform, WiMAX, QAM, BER***

## I. Introduction

The explosive expansion of new wireless multimedia applications and the thirst for more information has been resulted the increase in demand for technologies that support high data rates even in mobility and efficient utilization of the available spectrum and resources. Multi-Input Multi-Output technology with Orthogonal Frequency Division Multiplexing technique (MIMO-OFDM) is one of the best promising solutions to attain this goal [1]-[2]. For channels with large delay spread the overall MIMO-OFDM system performance can be improved by using Orthogonal Space Time Block Codes (OSTBC) for MIMO to achieve full diversity [3]-[5]. MIMO-OFDM has been standardised as part of IEEE standards for high data rate wireless transmissions such as IEEE 802.11a and IEEE 802.11g. Nowadays it is deployed in applications such as digital audio broadcasting (DAB), European HYPERLAN/2, digital video broadcasting (DVB), digital subscriber line (DSL), digital video broadcast-handheld (DVB-H), in the physical layer of the word wide inter operability for microwave access (WiMAX) and long term evolution (LTE) standards.

Even with the invaluable numerous benefits of MIMO-OFDM the inherent drawback of large envelop fluctuations with large number of subcarriers may produce severe performance degradation with the non-linear high power amplifier (HPA) at the frontend of the transmitter. The HPA should operate in linear region with high power back-off to keep the out-of-band power radiations below the specified limits. Otherwise it will leads to inefficient amplification and expensive transmitters with low battery life time. Hence the high peak to average power ratio (PAPR) is one of the major challenges of MIMO-OFDM systems and the research on the distribution and reduction of PAPR is very important for the efficient utilization of the technical features of MIMO-OFDM.

In the field of next generation wireless communication research the PAPR reduction techniques has very important role. Various approaches already have been proposed [6]-[7] such as clipping and filtering [8], Coding [9], Partial Transmit Sequence (PTS) [10], Selective Mapping (SLM) [11], Tone Reservation and Injection [12]-[13], combinational approaches [14], linear and non linear companding transforms [15]-[20]. Among these linear companding technique shows better performance in PAPR reduction [20]. The performance of adaptive piecewise linear companding transform for a single input single output (SISO)

system with OFDM modulation was explained in [21]. In this paper the PAPR reduction performance of a piecewise linear companding transform as fixed and adaptive companders is analysed for OSTBC MIMO-OFDM system which supports 4G WiMAX application under multipath Rayleigh fading channel conditions.

The paper is organized as follows: OSTBC MIMO-OFDM system model and the PAPR reduction scheme applied is described in section II. The philosophy and the practical implementation of the proposed system are discussed in Section III. The simulation results of proposed method are analyzed in Section IV and finally conclusions are drawn in Section V.

## II. System Model

MIMO-OFDM system which supports 4G WiMAX environment with $N_t$ number of transmit antennas and $N_r$ number of receiving antennas is considered. The input bit stream is mapped into symbol vector, $X_k = [X(0), X(1), X(2), ..., X(N-1)]$ is the symbol vector obtained from the data symbol mapped by QAM. $N$ is the number of subcarriers used for OFDM modulation. Orthogonal Space Time Block Coding (OSTBC) is applied for MIMO to improve the overall performance system. Appropriate code matrix, ***C*** is used for the space time coding of the signal. The code matrix, ***C*** is orthogonal and the two rows and columns of the matrix are also orthogonal.

For a system with $N_t = 2$ and $N_r = 2$, the mapped symbols are encoded into two vectors $X_1(k)$ and $X_2(k)$, where, $k = 0,1,\ldots,N-1$ by using a code matrix, ***C*** as follows:

$$C = \begin{bmatrix} c_1 & c_2 \\ -c_2^* & c_1^* \end{bmatrix} \quad (1)$$

$$X_1(k) = [X(0), -X^*(1), ..., X(N-2), -X^*(N-1)] \quad (2)$$

$$X_2(k) = [X(1), X^*(0), ..., X(N-1), X^*(N-2)] \quad (3)$$

The time domain signal for each OSTBC encoded signal is obtained from Orthogonal Frequency Division Multiplexing by the IFFT. Now the oversampled, complex base band of the transmitted discrete-time MIMO-OFDM signal can be written as:

$$x_i(n) = \frac{1}{\sqrt{lN}} \sum_{k=0}^{Nl-1} X_i(k) e^{\frac{j2\pi nk}{Nl}} \quad ; \quad 0 \le n \le Nl-1 \quad (4)$$

where i = 1,…, $N_t$ and $l$ is the oversampling factor. The OFDM signal is transmitted through $N_t$ number of transmit antennas and received by $N_r$ number of receiving antennas.

Generally the PAPR of a system is defined as the ratio of the maximum to the average power during a MIMO-OFDM symbol period and can be expressed as:

$$PAPR\ (dB) = 10 \log_{10} \left( \frac{\max_{0 \le n \le Nl-1} |x_i(n)|^2}{E[|x_i(n)|^2]} \right) \quad (5)$$

where *E[.]* represents the expectation. The metric to analyse the PAPR is Complementary Cumulative Distribution Function (CCDF). It is the probability of the transmitted signal exceeding a given PAPR threshold γ and can be obtained as:

$$CCDF = 1 - \Pr\{PAPR \le \gamma\} = 1 - (1 - e^{\gamma})^N \quad (6)$$

### *A) PAPR Reduction Scheme*

From the taxonomy of available solutions to avoid the PAPR problem companding schemes under the class of signal distortion methods shows better performance with comparatively less computational complexity. Since companding is an extra operation after the OFDM modulation it generates distortion called companding distortion and this may affect the bit error rate (BER) performance of the overall system. Hence the key designing feature of a companding transform is the impact of companding distortion on the BER performance.

The general design criteria for a linear companding transform with reduced companding distortion based on the theoretical analysis of the BER performance was described in [20].

*(i) Fixed Compander*:

The companded signal $t_n$ can be expressed as

$$t_n = x_n + c_n \tag{7}$$

where $x_n$ is the original MIMO-OFDM signal and $c_n$ is the additive companding distortion signal which is having same phase as $x_n$. now the power of the transformed signal will be :

$$\pm_t^{\,2} = E\{t_n^{\,*} t_n\} = \pm_x^{\,2} + 2E\{c_n^{\,*} x_n\} + \pm_c^{\,2} \tag{8}$$

where $\pm_c^{\,2} = E\{c_n c_n^{\,*}\}$ is the power of $c_n$. For a companding operation the average signal power is assumed as constant. Then

$$\pm_c^{\,2} = -2E\{c_n^{\,*} x_n\} \tag{9}$$

Also by considering Bussgang Theorem and AWGN channel the signal to noise ratio (SNR) at the receiver was obtained as [20]:

$$SNR = \left(1 - \frac{\pm_c^{\,2}}{2\pm_c^{\,2}}\right)\frac{\pm_x^{\,2}}{\pm_w^{\,2}} \tag{10}$$

where $\pm_w^{\,2}$ is the variance of AWGN variable. From equation (10) it is clear that the BER performance can be effectively improved by reducing the companding distortion $\pm_c^{\,2}$. Meixia Hu et.al proposed a piecewise linear companding transform (PLCT) with reduced companding distortion in [20]. The piecewise linear companding transform and its inverse are based on three parameters. They are: the clipping level $A_c$, the inflexion point denoted as $A_i$ and the slope, $k$. Mathematical form of the transform can be expressed as:

$$T(x) = \begin{cases} x, & |x| \le A_i \\ kx + (1-k)A_c, & A_i < |x| \le A_c \\ \operatorname{sgn}(x)A_c, & |x| > A_c \end{cases} \tag{11}$$

The peak amplitude level, $A_c$ is determined as, $A_c = \pm_x 10^{PAPR_{preset}/20}$, where $\pm_x^{\,2}$ is the average power of the signal. With the determined $A_c$ the other parameters, inflexion point, $A_i$ and the slope, $k$ can be obtained by solving the equation (12) under the constraints of the compander such as the average power should remain constant and the companding distortion should be minimized.

$$\int_{A_i}^{A_c} (kx + (1-k)A_c)^2 f_{|x_n|}(x)dx + \int_{A_c}^{\infty} A_c^{\,2} f(x)dx = \int_{A_i}^{\infty} x^2 f_{|x_n|}(x)dx \tag{12}$$

The companding distortion is used as the measure of distortion with the application of companding transform. Mathematically the companding distortion can be expressed as $D = [T(x) - x]^2$. The mean companding distortion $\pm_c^{\,2} = E\{D\}$ is related with SNR at receiver as equation (10). The inverse transform used for decompanding at the receiver can be expressed as:

$$T^{-1}(r) = \begin{cases} r, & |r| \le A_i \\ \dfrac{r-(1-k)A_c}{k}, & kA_i + (1-k)A_c < |r| \le A_c \\ \operatorname{sgn}(r)A_c, & |r| > A_c \end{cases} \tag{13}$$

where 'r' is the received OFDM symbol.

The mapped input signal *X(k)* in equation (4) can have any value from a given constellation independently and with equal probability. Hence the complex base band MIMO-OFDM signal, $x_i(n)$ can be considered weighted addition of independent and identically distributed (IID) random variables. According to the central limit theorem, $x_i(n)$ can be approximated as a complex Gaussian random process with Rayleigh amplitude distribution for large number of subcarriers. Hence the cumulative distributive function (CDF) and the probability density function (PDF) of the complex base band OFDM signal, $x_i(n)$ can be written as in equations (14) and (15):

$$F_A(x) = 1 - e^{-\frac{x^2}{\pm_x^2}}, \qquad x \geq 0 \tag{14}$$

$$f_A(x) = \frac{d}{dx}\left(F_A(x)\right) = \frac{2x}{\pm_x^2} e^{-\frac{x^2}{\pm_x^2}}, \quad x \geq 0 \tag{15}$$

where $A$ is the symbol used for the random variable related with $|x_i(n)|$. Since MIMO-OFDM signal amplitude is a Rayleigh random process Rayleigh PDF is used to design deterministic companding functions to modify the signal amplitude.

*(ii) Adaptive Companding*:

For fixed compander the companding functions are designed for an average symbol power. For mapping schemes like 4-QAM and PSK the average power of all MIMO-OFDM symbols will be same at a given number of subcarriers. But for larger QAM constellations, at a given set of subcarriers the distribution of the MIMO-OFDM signal amplitude may vary considerably from symbol to symbol. Hence the fixed companders designed to preserve average power may move away from its expected performance when larger M-ary QAM scheme is used for modulation. An adaptive companding method was proposed in [21] to optimize the compander performance by incorporating the variation in amplitude distribution. Since M-ary QAM with large constellation size is used for baseband modulation in uplink and downlink of the present and next generation wireless mobile communications the adaptive companding techniques are significant.

The adaptive compander described in [21] exploit the statistical features of the MIMO-OFDM signal to make the compander adaptive. The statistical feature denoted as ***S***, used to determine compander parameter should be a measure on signal amplitude. For large constellations the average power, $\pm_x^2$ is not equal in all individual symbols and hence the average power is considered as the statistical measure to make the compander as adaptive.

$$S = \pm_x^2 = \frac{1}{Nl}\sum_{n=0}^{Nl-1}\left|x_n\right|^2 \tag{16}$$

Now to make the compander as adaptive define M successive intervals of S such as the variance of S is equal within all intervals: $[s_0, s_1],(s_1, s_2], (s_2, s_3], \ldots ,(s_{M-1}, s_M]$, where $s_0 < s_1 < s_2 < s_3 < \ldots < s_{M-1} < s_M$ and $s_0 = \min(S)$, $s_M = \max(S)$. The modified cumulative distributive function (CDF) and the probability density function (PDF) of signal amplitude can be obtained by modifying the original distribution as:

$$F_A\left(x \setminus s_{M-1} < S \leq s_M\right) = \Pr\left[A \leq x \setminus s_{M-1} < S \leq s_M\right] \tag{17}$$

$$f_A\left(x \setminus s_{M-1} < S \leq s_M\right) = \frac{d}{dx} F_A\left(x \setminus s_{M-1} < S \leq s_M\right) \tag{18}$$

The compander parameters for symbols in each subset can be calculated with respect to the value of '***S***'. Hence there is $M$ set of compander parameter values. The set of companding parameters, clipping level $A_c$, inflexion point $A_i$ and the slope, $k$ can be expressed as:

$$(A_c, A_i, k) = \begin{cases} (A_{c1}, A_{i1}, k_1), & s_0 < S \le s_1 \\ (A_{c2}, A_{i2}, k_2), & s_1 < S \le s_2 \\ \vdots \\ (A_{cM}, A_{iM}, k_M), & s_{M-1} < S \le s_M \end{cases} \quad (19)$$

For $m^{th}$ interval of S, $(A_{cm}, A_{im}, k_m)$ are calculated using the modified form of design equations defined for symbols in each subset separately. The clipping level $A_{cm}$ can be expressed as:

$$A_{cm} = \pm_{xm} 10^{PAPR_{\Pr eset}/20} \quad (20)$$

The modified companding transform on the signal amplitudes in an OFDM symbol can be written as:

$$T(|x_n|) = \begin{cases} T_1(|x_n|), & S \ of \ |x_n| \in [s_0, s_1] \\ T_2(|x_n|), & S \ of \ |x_n| \in (s_1, s_2] \\ \vdots \\ T_M(|x_n|), & S \ of \ |x_n| \in (s_{M-1}, s_M] \end{cases} \quad (21)$$

If $D_m$ is the measure of companding distortion for $m^{th}$ subset, then the companding distortion for the $m^{th}$ subset can be expressed as:

$$\pm^2_{cm} = E\{D_m\} = E\{(T_m(x) - x)^2\} \quad (22)$$

Since all the $M$ companders have similar mathematical form and constraints the overall mean companding distortion is expected to be same as that of the fixed compander. The over-all mean companding distortion can be expressed as:

$$E\{D\} = \sum_{m=1}^{M} E\{D \setminus s_{m-1} < S < s_m\}.\Pr(s_{m-1} < S < s_m) \quad (23)$$

Since $D$ is considered as the parameter to determine the spectral characteristics and the error performance, the BER performance and the out-of-band radiation of adaptive compander will be similar as that in the case of fixed compander.

## III. Simulation Model

Figure 1 shows a block schematic of the OSTBC MIMO-OFDM (Nt x Nr) system which supports the 4G wireless mobile communication. The system model was simulated with 4G WiMAX environment. WiMAX is categorized as fixed WiMAX (IEEE 802.16d) and mobile WiMAX (IEEE 802.16e). Fixed WiMAX is based on OFDM Physical layer and MAC layer defined in the standard and Mobile WiMAX is based on OFDM Access PHY/MAC. In physical layer, IEEE 802.16e is supporting channel bandwidths of between 1.25 MHz and 20 MHz, with up to 2048 subcarriers. Generally 512 and 1024 FFTs are adopted by most of the manufacturers of mobile WiMAX equipment. It supports adaptive modulation and coding. In good signal conditions, a highly efficient 64-QAM mapping scheme is used, whereas when the signal strength is poor, a more robust BPSK method is used for mapping. In intermediate conditions, 16-QAM and QPSK can also be used for mapping. Other PHY features include support for multiple-input multiple-output (MIMO) antennas in order to provide good non-line of sight propagation (NLOS) characteristics. Both the AWGN and multipath Rayleigh fading channels are applied for simulations. Perfect synchronization and channel estimation was assumed in simulation.

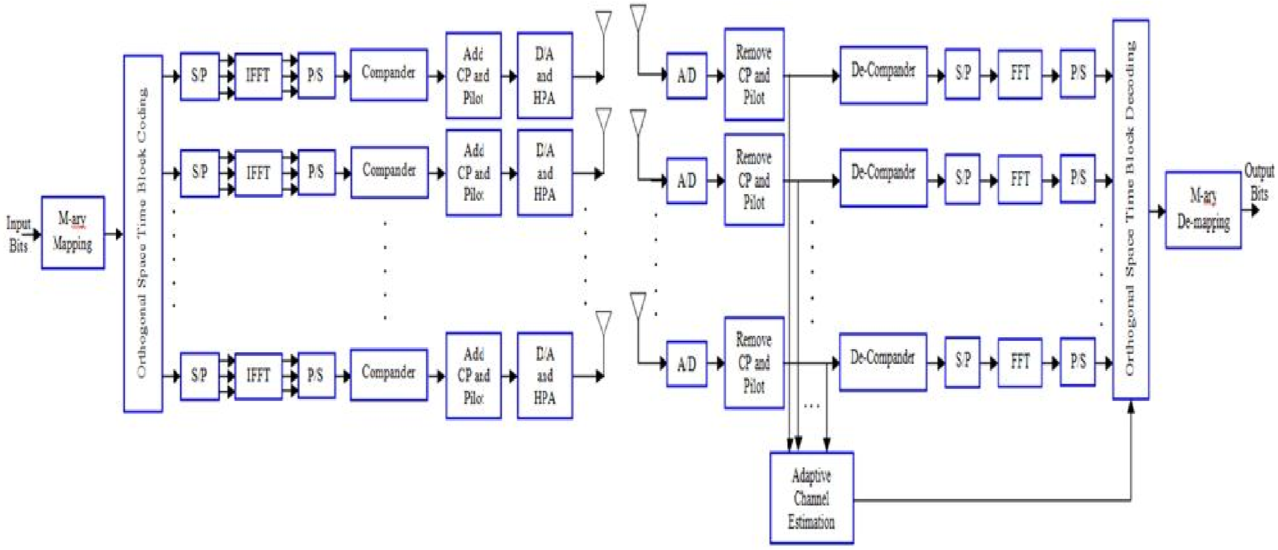


Fig. 1. Block diagram of proposed scheme for OSTBC MIMO-OFDM (Nt x Nr)

The performance analysis of the system under consideration involves the following procedures:

1. The input bit stream is mapped as $X_k = [X(0), X(1), X(2),..., X(N-1)]$ using QAM constellation. The data symbols are generated through 64-QAM constellations.
2. The mapped symbols are encoded for MIMO transmission by the OSTBC encoder to improve the performance against large delay spread.
3. Each output of OSTBC encoder is converted into parallel streams to apply an IFFT with number of subcarriers, *N=1024* and with the oversampling factor, *l=4*.
4. The OFDM modulated signals are companded by the fixed/adaptive piecewise linear companding transform compander. The calculated companding parameter values are transmitted to the receiver end as side information. The null carriers in the OFDM signal can be used for this purpose. The number of subsets, M determined the possible parameter values. Hence the minimum number of bits needed to encode the parameter values will be $\lceil \log_2 M \rceil$.
5. The cyclic prefix and the pilot tones for channel estimation are added to the compressed signal before transmission. The OFDM signal with reduced PAPR is transmitted to the receiver end through $N_t = 2$ number of transmit antennas and $N_r = 2$ number of receiving antennas.
6. At the receiver end after the removal of cyclic prefix and pilot the received signal is expanded by the decompander.
7. The decompanding parameters are detected from the side information and the channel estimation was performed from the extracted pilot carriers.
8. The decompanded signals are demodulated by the FFT block followed by the serial to parallel converter.
9. The OSTBC combiner at the receiver end combines the signal with help of channel information extracted from pilot signals.
10. The Demapping of the combined signal gives the original data stream.

## IV. Results and Discussion

The IEEE 802.16e (Mobile WiMAX) standards used in 4G wireless mobile communications are chosen for validation of the proposed scheme. Simulations have been carried out for 100000 MIMO-OFDM frames with randomly generated 64-QAM mapped symbols in MATLAB (R2013a) environment. For analysis the proposed system is simulated with the specifications described in Table 1:

| Parameters | Specifications |
|---|---|
| Number of transmit antennas, $N_t$ | 2 |
| Number of receive antennas, $N_r$ | 2 |
| Number of subcarriers, N | 1024 |
| Oversampling factor, *l* | 4 |
| Mapping schemes | 64-QAM |
| Companding Scheme | Fixed and Adaptive PLCT |
| Number of subsets *M* for APLCT | 2, 4 and 8 |
| Transmission media | Multipath Rayleigh fading wireless MIMO channel |

Table 1. Performance parameters and specifications

**Case 1: Performance of Fixed Compander**

Figure 2 demonstrated the PAPR reduction performance via CCDF plots of the fixed PLCT along with OSTBC MIMO-OFDM 2x2 system with 4-QAM, 16-QAM and 64-QAM modulation schemes and for number of subcarriers, N = 1024. The performance is evaluated for $PAPR_{preset}$ = 4 dB.

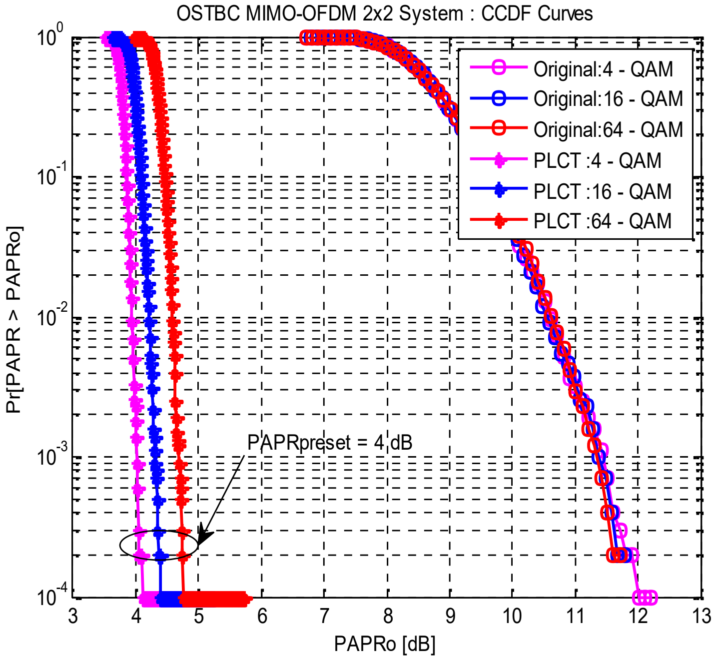


Fig.2. CCDF Curves of PAPR of OSTBC MIMO-OFDM signals with N = 1024

From the curves it can be observed that an improvement of 7.9 dB, 7 dB and 6.7 dB is achieved for 4-QAM, 16-QAM and 64-QAM respectively at CCDF = $10^{-4}$ for the number of subcarriers N = 1024. But there was degradation in performance from PAPRpreset value as the increase in constellation size. It can also be observed from Table 1. The degradation in performance was due to the deviation in amplitude distribution for large constellations. Simulation results show that 4-QAM performs better than the other two. This is due to the variation in amplitude distribution of the OFDM signal from symbol to symbol for large constellations.

| Mapping Method | $PAPR_{preset}$ = 4 dB and PAPR at CCDF $=10^{-4}$, N = 1024 (in dB) | | |
|---|---|---|---|
| | Original | Fixed PLCT | Degradation from preset value (in dB) |
| 4-QAM | 12 | 4.1 | 0.1 |
| 16-QAM | 12 | 4.5 | 0.5 |
| 64-QAM | 12 | 4.8 | 0.7 |

Table 2. Summary of CCDF performance for the fixed companding scheme

**Case 2: Performance of Adaptive Compander**

Figure 3 compares the performance of the fixed and adaptive PLCTs for the OSTBC MIMO-OFDM 2x2 system with 64-QAM modulation and N = 1024. Companders were simulated for $PAPR_{preset}$ = 4 dB. The number of subsets used to make the compander as adaptive was *M=2, 4 and 8*. From the CCDF performance curves obtained, the PAPR values become closer to the preset value as *M* increases. 0.6 dB enhancement was observed for adaptive compander with *M* = 8 over fixed compander at CCDF = $10^{-4}$.

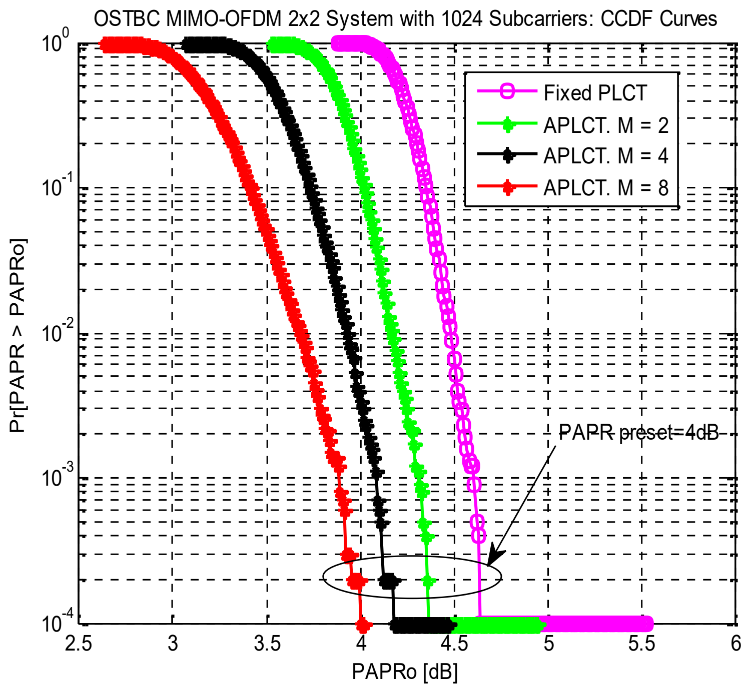


Fig.3. CCDF Curves of PAPR of OSTBC MIMO- OFDM signals with 64-QAM and N = 1024

Figure 4 shows the simulated BER performance of the given OSTBC MIMO-OFDM 2x2 system. From the performance obtained it is clear that for a given value of $PAPR_{preset}$, the error performance is approximately similar for both fixed and adaptive PLCT. The performance evaluation was summarised in Table 3.

Academic Science

International Journal of Electronics, Electrical and Computational System
IJEECS
ISSN 2348-117X
Volume 6, Issue 7
July 2017

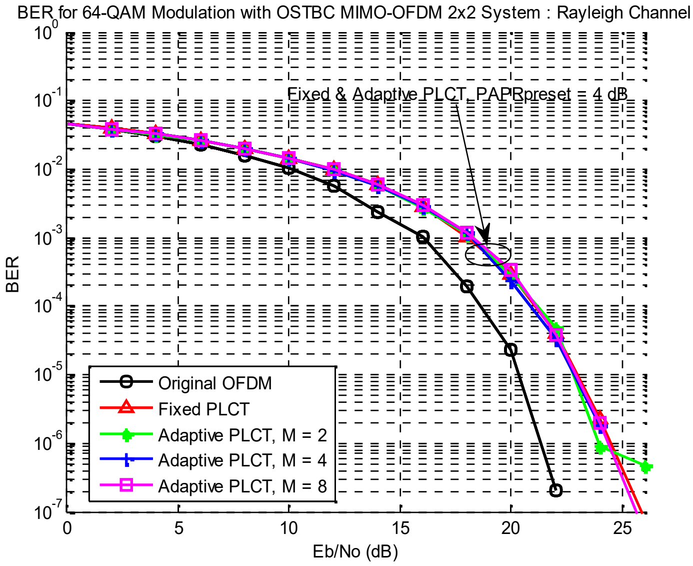


Fig.4. BER performance of OSTBC MIMO-OFDM system with 64-QAM and N = 1024

| Specifications | 64 – QAM, N = 1024 and $PAPR_{preset}$ = 4 dB | | | |
|---|---|---|---|---|
| Number of subsets | Fixed | $M = 2$ | $M = 4$ | $M = 8$ |
| Best PAPR at CCDF $=10^{-4}$ (in dB) | 4.6 | 4.4 | 4.2 | 4 |
| Improvement (in dB) | - | 0.2 | 0.4 | 0.6 |
| BER at $10^{-6}$ (in dB) | 24 | 23 | 24 | 24 |
| Bits for side information | - | $\lceil \log_2 2 \rceil$ | $\lceil \log_2 4 \rceil$ | $\lceil \log_2 8 \rceil$ |

Table 3. Summary of Performance for 64 QAM, N = 1024

## V. Conclusion

The performance comparison for a fixed and adaptive technique of a piecewise linear companding transform for the OSTBC MIMO-OFDM systems for 4G wireless mobile communication under the mobile WiMAX environment was presented in this paper. The technique used in the companding transform applied the statistical features of the input signals were used to set the value of its parameters. In the applied PLCT technique the average power is used as the statistical feature to fix the companding parameters. Using this method the degradation in performance of the fixed compander due to the deviation of amplitude statistics, which is significant for larger QAM constellations, can be reduced significantly. Simulation results show that the adaptive method improves the overall performance of the given OSTBC MIMO-OFDM system by bringing the compander output signal attributes nearer to the $PAPR_{preset}$ value. Since for a given value of $PAPR_{preset}$ error performance remains similar for fixed and adaptive companders, the average companding distortion will remain the same in both fixed and adaptive companders.

In both methods there is an amount of side information is required to share the parameter values to the receiver side. That is to accommodate the details of adaptive companding, $\lceil \log_2 M \rceil$ bits of side information has to be transmitted with each symbol. The decompander will resolve the corresponding parameter for each subset from the side information. Also in fixed compander there is a trade-off between the amount of PAPR reduction and signal distortion. ie. reduction in PAPR can be improved at a cost of signal distortion. By using

adaptive compander, it is possible to realize different levels of reduced PAPR at the same distortion level. Also the adaptive companding will improve the system performance in terms of flexibility, efficiency and adaptability to input and channel conditions.

## References

1. Adachi, F. and Kudoh, E., "New direction of broadband wireless technology", Wireless Communications and Mobile Computing, Vol. 7, No.8, pp.969-983, 2007.
2. Raychaudhuri, D. and Mandayam, N.B., "Frontiers of wireless and mobile communications", Proceedings of the IEEE, Vol. 100, No.4, pp.824-840, 2012.
3. V. Tarokh, N. Seshadri, and A. R. Calderbank, "Space-time block codes for high data wireless communication: performance criterion and code construction", IEEE Trans. Inf. Theory, vol. 44, no. 2, pp. 744–765, Mar.1998.
4. Y. Shang and X.-G. Xia, "Space-time block codes achieving full diversity with linear receivers," IEEE Trans. Inf. Theory, vol. 54, no. 10, pp. 4528–4547, Oct. 2008.
5. J. Liu, J.-K. Zhang, and K. M. Wong, "Full-diversity codes for MISO systems equipped with linear or ML detectors," IEEE Trans. Inf. Theory, vol. 54, no. 10, pp. 4511–4527, Oct. 2008.
6. T. Jiang and Y. Wu, "An overview: Peak-to-average power ratio reduction techniques for OFDM signals," IEEE Transactions on Broadcasting, vol. 54, no. 2, pp. 257–268, Jun. 2008.
7. Y. Rahmatallah and S. Mohan, "Peak-to-average power ratio reduction in OFDM systems: A survey and taxonomy," IEEE Communications Surveys & Tutorials, vol. 15, no. 4, pp. 1567-1592, Nov. 2013.
8. Wang, L. and Tellambura, C., "A simplified clipping and filtering technique for PAR reduction in OFDM systems", IEEE signal processing letters, Vol. 12, No. 6, pp.453-456, 2005.
9. Jiang, T. and Zhu, G., "Complement block coding for reduction in peak-to-average power ratio of OFDM signals", IEEE Communications Magazine, Vol. 43, No. 9, pp.S17-S22, 2005.
10. Han, S.H. and Lee, J.H., "PAPR reduction of OFDM signals using a reduced complexity PTS technique", IEEE Signal Processing Letters, Vol. 11, No. 11, pp.887-890, 2004.
11. Li, C.P., Wang, S.H. and Wang, C.L., "Novel low-complexity SLM schemes for PAPR reduction in OFDM systems", IEEE Transactions on Signal Processing, Vol. 58, No. 5, pp.2916-2921, 2010.
12. Wattanasuwakull, T. and Benjapolakul, W., "PAPR Reduction for OFDM Transmission by using a method of Tone Reservation and Tone Injection", Fifth International Conference on Information, Communications and Signal Processing, pp. 273-277, IEEE, 2005
13. Li, H., Jiang, T. and Zhou, Y., "An improved tone reservation scheme with fast convergence for PAPR reduction in OFDM systems", IEEE Transactions on Broadcasting, Vol. 57, No.4, pp.902-906, 2011.
14. Khushboo Pachori and Amit Mishra, "An Efficient Combinational approach for PAPR Reduction in MIMO-OFDM System", Wireless Networks, vol. 22, no. 2, pp. 417--425, Feb. 2016, Springer.
15. T. Jiang, Y. Yang, and Y.H. Song, "Exponential companding technique for PAPR reduction in OFDM systems," IEEE Transactions on Broadcasting, vol. 51, no. 2, pp. 244–248, Jun. 2005.
16. S.-S. Jeng and J.-M. Chen, "Efficient PAPR reduction in OFDM systems based on a companding technique with trapezium distribution," IEEE Transactions on Broadcasting, vol. 57, no. 2, pp. 291–298, Jun. 2011.
17. Y. Wang, L.-H. Wang, J.-H. Ge, and B. Ai, "An efficient nonlinear companding transform for reducing PAPR of OFDM signals," IEEE Transactions on Broadcasting, vol. 58, no. 4, pp. 677–684, Dec. 2012.
18. J. Hou, J. Ge, D. Zhai, and J. Li, "Peak-to-average power ratio reduction of OFDM signals with nonlinear companding scheme," IEEE Transactions on Broadcasting, vol. 56, no. 2, pp. 258–262, Jun. 2010.
19. P. Yang and A. Hu, "Two-piecewise companding transform for PAPR reduction of OFDM signals," in Proc. of Wireless Communication and Mobile Computing Conference (IWCMC), Istanbul, Turkey, pp. 619–623, Jul. 2011.
20. M. Hu, Y. Li, W. Wang, and H. Zhang, "A piecewise linear companding transform for PAPR reduction of OFDM signals with companding distortion mitigation," IEEE Transactions on Broadcasting, vol. 60, no. 3, pp. 532–539, Sep. 2014.
21. Mazahir, S. and Sheikh, S.A., "An Adaptive Companding Scheme for Peak-to-average Power Ratio Reduction in OFDM Systems", KSII Transactions on Internet & Information Systems, Vol. 9, No.12, 2015.