Mobile WiMAX Performance Improvement Using a Novel Algorithm with a New Form of Adaptive Modulation

Ibrahim Ismail Al-kebsi[1], Mahamod Ismail[1], Kasmiran Jumari[1] and T. A. Rahman[2]

[1]Dept. of Electrical, Electronic & Systems Engineering, Faculty of Engineering, Universiti Kebangsaan Malaysia, 43600 UKM, Bangi, Selangor, Malaysia
[2]Wireless communication centre, Faculty of Electrical, Universiti Technologi Malaysia, Skudai, Johor, 81310 UTM, Johor, Malaysia

Summary
Worldwide Interoperability for Microwave Access (WiMAX) is an emerging broadband wireless technology that promises high-speed data services. Mobile WiMAX is a broadband wireless solution that enables convergence of mobile and fixed broadband networks through a common wide area broadband radio access technology and flexible network architecture. Mobile WiMAX is based on orthogonal frequency division multiplexing/ orthogonal frequency division multiplexing Access (OFDM/OFDMA) technology [1, 2, 3]. It supports Adaptive Modulation and Coding in both downlink and uplink with variable packet size. This paper presents a new form of Adaptive Modulation (AM), which has the ability to enhance the data rate of Mobile WiMAX OFDMA system especially at low SNR values, this new form of AM will combine together with the simplest Peak to Average Power ratio (PAPR) reduction technique, which is the clipping to produce a novel algorithm called Modulation adaptation and Clipping algorithm (MC) has the ability to improve the performance of Mobile WiMAX system through reducing the PAPR, improving the SER performance, and increasing the data rate.
Key words:
Mobile WiMAX OFDMA, adaptive modulation, clipping, PAPR, MC.

1. Introduction

In December, 2005 the IEEE completed the 802.16e-2005 [2] amendment, which added new features to support mobile applications. The resulting standard is commonly referred to as Mobile WiMAX. Mobile WiMAX integrates a rich set of features that offer considerable flexibility in terms of deployment options, as well as potential applications. Mobile WiMAX can provide tens of megabits per second of capacity per channel from each base station with a baseline configuration.

The high data throughput enables efficient data multiplexing and low data latency [4]. The original WiMAX physical layer (PHY) used OFDM. This provides strong performance in multipath and non-line-of-sight (NLOS) environments [5]. Mobile WiMAX extends the OFDM PHY layer to support efficient multiple-access.
The resulting technology is known as scalable OFDMA. Data streams to and from individual users are multiplexed to groups of subchannels on the downlink and uplink. By adopting a scalable PHY architecture, Mobile WiMAX is able to support a wide range of bandwidths. The scalability is implemented by varying the FFT size from 128 to 512, 1024, and 2048 to support channel bandwidths of 1.25 MHz, 5 MHz, 10 MHz, and 20 MHz respectively. The Mobile WiMAX Air Interface adopts Orthogonal Frequency Division Multiple Access (OFDMA) for improved multi-path performance in non-line-of-sight environments. Scalable OFDMA (SOFDMA) is introduced in the IEEE 802.16e Amendment to support scalable channel bandwidths from 1.25 to 20 MHz [3]. In wireless communication systems, random fluctuations prevent the continuous use of highly bandwidth-efficient modulation, and therefore Adaptive Modulation and Coding (AMC) has become a standard approach in recently developed wireless standards, including WiMAX. The idea behind AMC is to dynamically adapt the modulation and coding scheme to the channel conditions so as to achieve the highest spectral efficiency at all times [6]. The performance of OFDM can be improved dramatically if adaptive modulation is used [7], [8]. The basic premise of adaptive transmission is a real-time balancing of the link budget through adaptive variation of the transmitted power level, symbol transmission rate, constellation size, coding rate/scheme, or any combination of these parameters [9, 10, 11, 12]. There have been many methods tested to reduce the PAPR. Clipping is a simple method that can reduce the power peaks. The simple concept behind this is to clip the power peaks that go beyond a predetermined level. Clipping has been thought to introduce error. But it actually depends on careful selection of clipping level. Clipping the OFDM signal

Manuscript received February 5, 2009
Manuscript revised February 20, 2009

before amplification is a simple and typical method for the PAPR reduction [13]. For a brief overview of various PAPR reduction techniques including clipping, see [14].

The paper is organized as follows: The section II describes the simulation model, including the clipping, and adaptive modulation. Next, numerical results, plots of Complementary Cumulative Distribution Function (CCDF), PSD, throughput, and plots of SER, are presented in section III. Finally, draw the conclusion.

2. Simulation Model

The proposed Adaptive modulation (AM) in this paper as shown in figure 1 has the ability of using the high order modulation scheme such as 256-QAM and 64-QAM to map the data onto the carriers at low SNR values such as 2, 5, and 8 dB.

The modulation or mapping schemes used in this simulation are BPSK, 4-QAM, 16-QAM, 64-QAM, 128-QAM, and 256-QAM. The clipping technique was combined together with the new form of AM to produce a novel algorithm has the ability to reduce the PAPR, enhance the data rate, and improve the performance of the SER at low SNR values compared to the SER performance of the Mobile WiMAX system when applying the normal OFDMA with high order modulation schemes such as 16QAM, 64QAM, 128QAM, and 256QAM. If the digital OFDM signals are clipped directly, the resulting clipping noise would all fall in-band and could not be reduced by filtering.

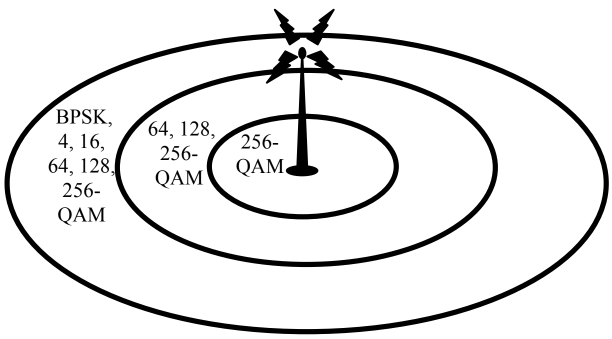

Fig.1. The proposed Adaptive Modulation

To address this aliasing problem, in this simulation, OFDMA signal could be oversampled by a factor of 4. In Matlab simulation, OFDMA symbol would be assumed with subcarriers of length 1024 and a guard interval with duration of 1/8 of the symbol duration. Each frame in the Mobile WiMAX configuration contains 48 OFDM symbols, 37 data symbols and 11 overhead symbols. In OFDM, a block of N symbols, $\{y_n, n=0,1,\ldots,N-1\}$is formed with each symbol modulating one set of N subcarriers,$\{f_n=0,1,\ldots,N-1\}$. The N subcarriers spacing is chosen to be orthogonal, that is $f_n = n\Delta f$, where $\Delta f = 1/NT$ and T is the symbol period. Thus the complex envelope of the transmitted OFDM signal is represented by

$$x(t) = \sum_{n=0}^{N-1} y_n e^{j2\pi f_n t} \quad 0 \le t \le NT \tag{1}$$

The instantaneous envelope power of the signal is the real valued function of $P(t)$ where $P(t)=|x(t)|^2$. the PAPR of the transmitted OFDM signal $x(t)$ can be defined as

$$PAPR = \frac{\max|x(t)|^2}{\mathrm{E}\left[|x(t)|^2\right]} \tag{2}$$

A simple AWGN channel is used as channel model, the channel bandwidth provided in this simulation can support data rate vary from 8 Mbps (when using BPSK as a mapping scheme), to 63 Mbps (when using 256-QAM as a mapping scheme).

Table 1: Simulation parameters

Parameters	Values
Channel Bandwidth	10 MHz
Modulation scheme (Mapping scheme)	BPSK, 4QAM, 16QAM, 64QAM, and 256QAM
FFT Size (NFFT)	1024
Number of data subcarriers	720
Useful symbol duration (T_U)	91.43 µs
Cyclic prefix or guard time	1/8
Carrier spacing (1/ T_U)	10.94 KHz
Guard Time (T_g =(1/4)* T_U)	11.43 µs
OFDM symbol duration	102.86 µs
Number of OFDM symbols in 5 ms frame	48

Then, the real valued bandpass samples, x, were clipped at amplitude A as follows:

$$y = \begin{cases} -A, & \text{if } x < -A \\ x, & \text{if } -A \le x \le A \\ A, & \text{if } x > A \end{cases} \tag{3}$$

In the literature, it is customary to use the Complementary Cumulative Distribution Function (CCDF) of the PAPR as a performance criterion. The CCDF of the PAPR is defined as the probability that the PAPR per OFDM symbol exceeds a certain clipping level PAPR0.

$$CCDF(PAPR(x)) = \text{Prob}(PAPR(x) > PAPR0) \qquad (4)$$

The clipping process is characterized by the clipping ratio (CR), defined as the ratio between the clipping threshold and the root-mean square (rms) level of the OFDM signal. However, Clipping is a nonlinear process that leads to distortion. Without filtering, clipping causes out-of-band radiation. Digital filtering is present to control out-of-band radiation.

$$\text{CR} = \frac{\text{Clipping level}}{\text{rms level}} \qquad (5)$$

The goal of the modulation adaptation algorithm used in this simulation is to improve the performance of SER and enhance the data rate. In this simulation, all modulation levels can be adopted for each symbols based on the SER value which is specified for each modulation scheme at any value of SNR values after the transmission of each OFDMA symbol. The function of clipping technique in the proposed MC algorithm is not only to reduce the PAPR, but it is acting as a controller of the switching between the modulation schemes by using hard clipping ratio values with the low order modulation schemes to force the high order modulation schemes to be used to map the data onto the carriers at low SNR values.

3. Results and Discussion

Simulation results were obtained in a Mobile WiMAX OFDMA system with a total of 1024 subcarriers which employs five modulation schemes as shown in table 1. This simulation was implemented in MATLAB. Figure 2 shows the ability of clipping technique only to reduce the PAPR for different modulation schemes. The obtained reduction in PAPR at the probability of 10^{-3} is 10 dB, 9.6 dB, 7.8 dB, 6.3 dB, and 4.4 dB in the clipped Mobile WiMAX OFDMA signal with BPSK, 4-QAM, 16-QAM, 64-QAM, and 256-QAM respectively. Figure 3 shows the SER performance as a function of the received signal-to-noise ratio (SNR), averaged across all the subchannels, with clipping and filtering over a channel of additive white Gaussian noise. In OFDMA with 64-QAM, for (CR= 0.9), the degradation is more than 1 dB at the 10^{-2} SER level. But At 10^{-4} SER level, less than a 5 dB penalty is encountered. This hard clipping ratio reduced the PAPR but caused degradation in the performance of the SER. So this paper introduces a new form of adaptive modulation to be combined together with the clipping technique to produce a new algorithm which called MC. This algorithm should achieve two goals, the first one is to reduce the PAPR, and the second one is to enhance the data rate especially at low SNR values without degrade the SER performance.

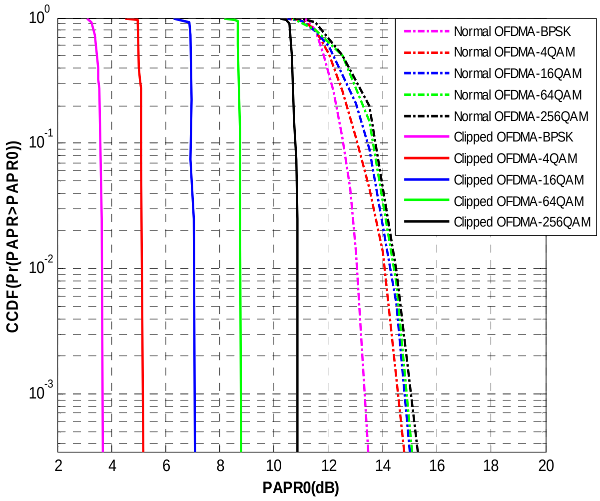

Fig. 2. CCDF of PAPR for normal and clipped Mobile WiMAX OFDMA signal with different modulation schemes

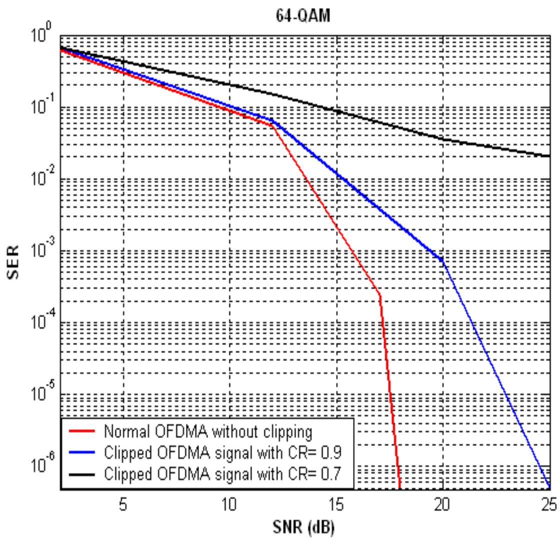

Fig. 3. SER of the clipped-and-filtered 64QAM-Mobile WiMAX OFDMA signal for different clipping ratios

The proposed new form of adaptive modulation proved its ability to enhance the data rate by using the high order modulation schemes such as 256QAM and 128-QAM to map the input data onto carriers at low SNR values as shown in table 2 and table 3. At SNR equals to 8 dB which is the threshold of BPSK, 45% of the transmitted symbols were mapped with the high order modulation scheme 256-QAM, 15% with 64-QAM, 25% with 16-QAM and 15% of them with 4-QAM. This means 100% of the transmitted symbols were mapped at 8 dB with modulation schemes have order higher than the BPSK. Also at 12 dB which is the threshold of 4-QAM, 100% of the transmitted symbols were mapped with modulation schemes have order higher than 4-QAM. At 18 dB, which is the threshold of 16-QAM, also all of the transmitted symbols were mapped with modulation schemes have order higher than 16-QAM.

Table 2: The percentage of transmitted symbols of MC (BPSK+4+16+64+256-QAM) that were mapped using various orders of modulation schemes at different SNR values

SNR(dB) / Mod. scheme	2	5	8	12	18	20	22	
256-QAM	17	30	45	52	97	99	100	Symbols Percentage %
64-QAM	35	25	15	38	3	1	0	
16-QAM	4	5	25	10	0	0	0	
4-QAM	30	34	15	0	0	0	0	
BPSK	14	6	0	0	0	0	0	

Table 3: The percentage of transmitted symbols of MC (BPSK+4+16+128+256-QAM) that were mapped using various orders of modulation schemes at different SNR values

SNR(dB) / Mod. Scheme	2	5	8	12	18	20	22	
256-QAM	8	23	37	50	95	99	100	Symbols Percentage %
128-QAM	45	33	26	29	5	1	0	
16-QAM	13	9	19	21	0	0	0	
4-QAM	1	25	18	0	0	0	0	
BPSK	33	10	0	0	0	0	0	

In this new form of Adaptive Modulation the order of the modulation scheme is chosen based on the value of the SER measured at the receiver side after each symbol transmission. As shown in Figure 4, the SER performance of the tested mode MC-OFDMA-(BPSK+4+16+64+256QAM) with five modulation schemes is improved. It is easy to note this improvement in SER performance especially at low SNR values compared to SER performance of the normal and clipped OFDM with 256-QAM. The performance of the SER with proposed mode in figure 4 is better than the performance of SER with the proposed mode in figure 5. But both proposed modes proved their ability to improve or at least enhance the throughput of the Mobile WiMAX system without degrade the ser performance.

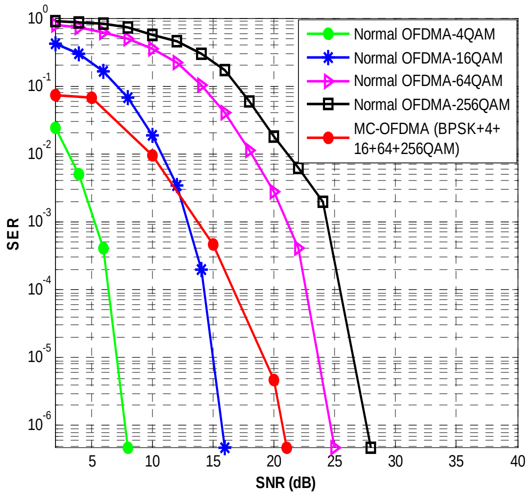

Fig. 4. SER performance of the normal OFDMA with 4, 16, 64, and 256-QAM and the proposed mode MC (BPSK+4+16+64+256-QAM)

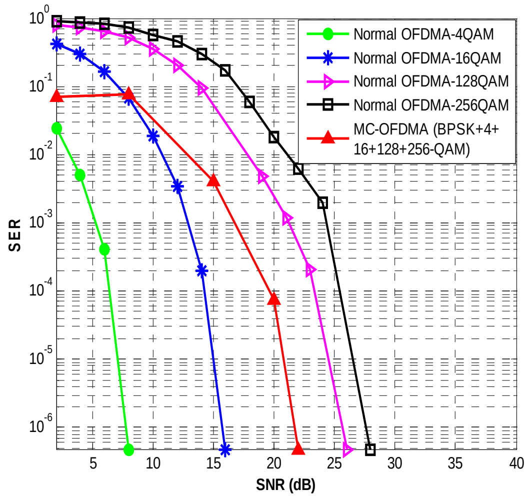

Fig. 5. SER performance of the normal OFDMA with 4, 16, 128, and 256-QAM and the proposed mode MC (BPSK+4+16+128+256-QAM)

The performance of the SER of the Mobile WiMAX OFDMA system after applying the proposed algorithm is better the performance of the normal OFDMA with 64QAM, and 256QAM and 16QAM especially below 14 dB. Figure 6 shows PAPR as a function of the clipping ratio. The PAPR of the unclipped Mobile WiMAX OFDMA signal is 15.6 dB. This means that for large CR the OFDMA signal *x(t)* is unclipped, but as CR→0, the peak and average power converge, thus PAPR→0 dB. For the region 0.5 dB< CR <2 dB, the OFDMA signal *x(t)* is clipped. In this region it is easy to note the effectiveness of the clipping technique. To prove the effectiveness of the new form of adaptive modulation which used in the proposed algorithm MC to enhance the data rate especially at low SNR values, table 4 shows an example of transmission a data with a total size of 1 Gbps.

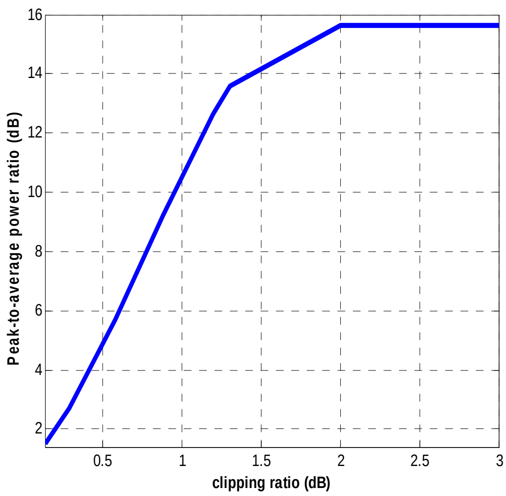

Fig.6. PAPR of Mobile WiMAX-MC-OFDMA-256QAM signal as a function of Clipping Ratio (CR)

Table 4: Comparison between the required transmission times of the normal OFDMA and the proposed algorithm MC (BPSK+4+16+64+256-QAM) at different SNR values

Data size	Transmission time when using:		SNR value (dB)
	OFDMA with proposed MC (BPSK+4+16+64+256 -QAM) (sec)	OFDMA with Conventional AM (sec)	
1Gbps	29.13	127.07	2
	26.24	127.07	5
	18.57	63.49	12
	16.00	31.76	18
	15.92	21.16	20
	15.88	15.88	23

The time required to send 1 Gbps using the proposed mode MC-OFDMA (BPSK+4+16+64+256-QAM) is less than the time required to send the data using the OFDMA with the conventional Adaptive Modulation (AM). By make a comparison between table 4 and Table 5, it is obvious to conclude that the proposed mode MC-OFDMA (BPSK+4+16+128+256-QAM) can achieve better saving in the time required to transfer 1 Gbps than the proposed mode MC (BPSK+4+16+64+256-QAM).

Table 5: Comparison between the required transmission times of the normal OFDMA and the proposed algorithm MC (BPSK+4+16+128+256-QAM) at different SNR values

Data size	Transmission time when using:		SNR value (dB)
	OFDMA with proposed MC (BPSK+4+16+128+256-QAM) (sec)	OFDMA with Conventional AM (sec)	
1Gbps	27.26	127.07	2
	24.85	127.07	5
	18.49	63.49	12
	15.97	31.76	18
	15.90	18.14	20
	15.88	15.88	23

Figure 7 shows the CCDF of the normal OFDMA signal with different modulation schemes, the proposed mode MC-OFDMA-(BPSK+4+16+64+256QAM) and the proposed mode MC-OFDMA-(BPSK+4+16+128+256QAM).

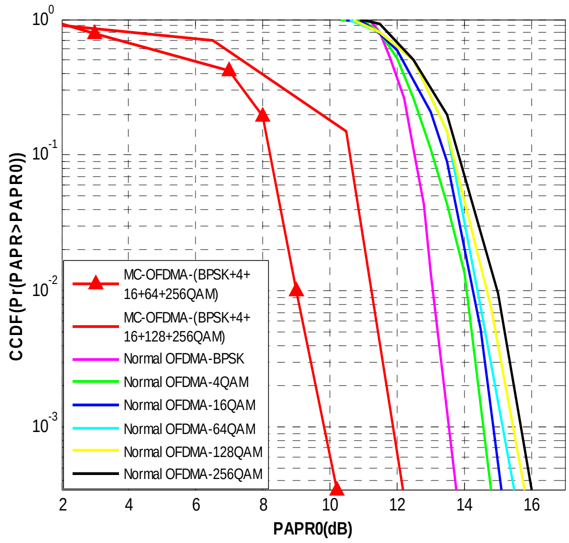

Fig. 7. CCDF of PAPR for normal OFDMA with BPSK, 16, 64, 128, 256-QAM and the two proposed modes MC-OFDMA (BPSK+4+16+64-+256-QAM), MC-OFDMA (BPSK+4+16+128+256-QAM)

The best improvement in the PAPR was achieved with the proposed mode MC-OFDMA-(BPSK+4+16+64+256QAM), which was on the order of 3.9 dB at the probability of 10^{-3}compared to the normal OFDMA with BPSK and of 6 dB compared to the normal OFDMA with 256-QAM as also shown in Table 6.

Table 6: The obtained reduction in PAPR

MC mode	Reduction in the PAPR at the probability of 10^{-3} compared to the normal OFDMA with:	
	BPSK (dB)	256-QAM (dB)
BPSK+4+16+64+256-QAM	3.9	6
BPSK+4+16+128+256-QAM	1.7	3.8

Figure 8 presents the throughput versus SNR graphs for the OFDMA with the conventional (AM), the proposed mode MC-OFDMA (BPSK+4+16+64+256QAM), the proposed mode MC-OFDMA-(BPSK+4+16+128+256QAM). As expected, the conventional (AM) does not improve the data throughput, but the proposed modes with the new form of (AM) can provide a significant increase in throughput through using the high order modulation scheme at low SNR value. Figure 9 shows the power spectral density (PSD) of the Mobile WiMAX MC-OFDMA-256-QAM clipped signal.

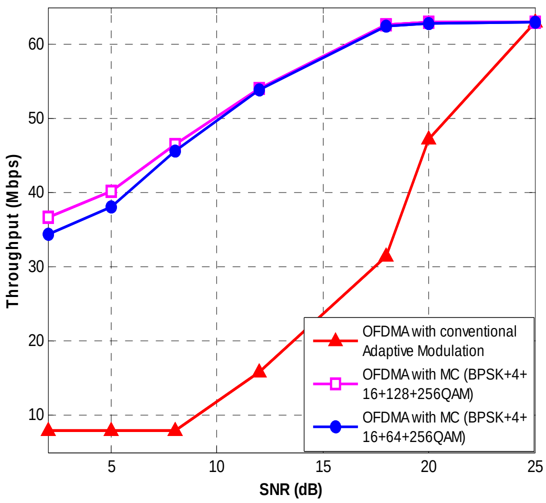

Fig. 8. Throughput of the Normal Mobile WiMAX OFDMA system and the two proposed modes MC-OFDMA of the novel algorithm MC

The in-band signal attenuation as well as the out-of-band caused by clipping is evident. In Normal OFDMA the out-of-band noise emission power is only 30 dB lower than the signal power. But With hard clipping ratio CR= 0.5 and after applying the filtering, it is easy to note that the spectral sidelobes after filtering are now at least 25 dB lower than the signal mainlobe. It was clear as shown in figure 9 how the proposed algorithm MC in this simulation can attenuate the out-of-band noise even the clipping ratio (CR) was equal to 0.5.

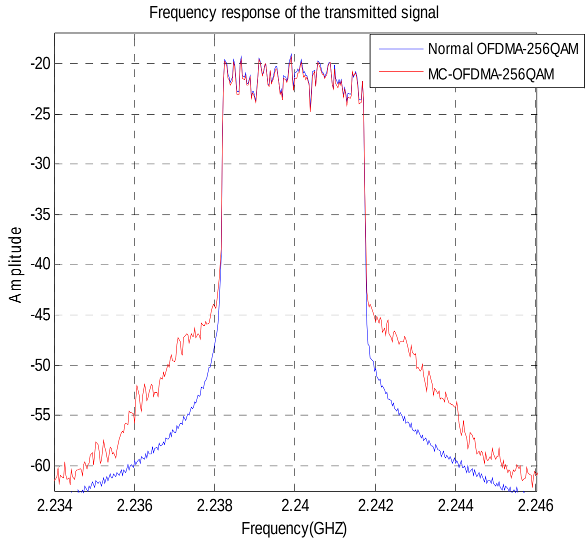

Fig. 9. The PSD of the signals of normal Mobile WiMAX-OFDMA-256-QAM and Mobile WiMAX MC-OFDMA-256-QAM

4. Conclusion

Mobile WiMAX aims to provide wireless data over long distances, and provides up to 70 Mbps symmetric broadband speed over 31 miles, therefore this paper tries to present a novel algorithm with a new form of adaptive modulation (AM). This algorithm called MC which is a combination of two techniques, the clipping and a new form of AM which is based on the SER value after transmission of each symbol. The results proved the ability of this algorithm to reduce the PAPR, and enhance the data rate of the Mobile WiMAX OFDMA system without degrade the SER performance especially at low SNR values. It was clear how this algorithm can improve the total throughput of the system better than the conventional AM. Also the proposed algorithm proved his effectiveness to attenuate the out-of-band noise emission power even the OFDMA signal is clipped at hard CR value.

Acknowledgment

This research work was partially supported by SKMM/RPD/SRPD(2)/SRCP/TC/03/07(7) research grant. The authors would like to thank the project leader and appreciate his kindness, valuable assistance, and financial support.

References

[1] IEEE Std 802.16TM-2004, "Part 16: Air interface for fixed broadband wireless access systems," Oct 2004.
[2] IEEE Std 802.16Etm-2005, "Part 16: Air interface for fixed and mobile broadband wireless access systems," Feb. 2006

[3] Hassan Yagoobi, "Scalable OFDMA Physical Layer in IEEE 802.16 WirelessMAN", *Intel Technology Journal*, vol. 08, Aug. 2004.
[4] "Mobile WiMAX – Part I: A Technical Overview and Performance Evaluation", WiMAX Forum, 2006.
[5] J. G. Andrews, A. Ghosh and R. Muhamed, "Fundamentals of WiMAX, Understanding Broadband Wireless Networks," Prentice Hall, Feb 2007.
[6] S. G. Chua and A. Goldsmith. Adaptive coded modulation for fading channels. IEEE Transactions on Communications, 46(5):595602, May 1998.
[7] Tainer Grunheid and Hermann Tohling, "Adaptive Modulation and Multiple Access for the OFDM Transmission Techniques" Wireless Personal Communications, 2000, pp. 5-13.
[8] Thomas Keller and Lajos Hanzo, "Adaptive Multicarrier Modulation: A Convenient Framework for Time-Frequency Processing in Wireless Communication," *IEEE Proceedings of the IEEE,* vol. 88, no. 5, pp. 5-13, May 2000.
[9] A. J. Goldsmith and L. Greenstein, "variable-rate variable-power MQAM for fading channels," IEEE *Trans. Commun.*, vol. 45, pp. 1218-1230, Oct 1997.
[10] W. T. Webb and R. Steele, "Variable rate QAM for mobile radio," IEEE Trans. on Commun., pp. 2223{2230, July 1995.
[11] H. Matsuoka and S. Sampei and N. Morinaga and Y. Kamio, "Adaptive modulation system with variable coding rate concatenated code for high quality multi-media communication systems," *IEICE Trans. Commun.*, vol. E79-B, pp. 328-334, March 1996.
[12] A. J. Goldsmith and P. Varaiya, "Capacity of Fading Channels with Channel Side Information," *IEEE Trans. on Inform*. Theory, Vol. 43, pp. 1986{1992, Nov. 1997.
[13] H. Ochiai and H. Imai, "Performance Analysis of Deliberately Clipped OFDM Signals," *IEEE Trans. On commun.*, vol. 50, pp. 99-101, Jan. 2002.
[14] S.H. Han and J.H. Lee, "An overview of peak-to-average power ratio reduction techniques for multicarrier transmission," *IEEE wireless commun,* vol. 12, no. 2, pp. 56-65, April 2005.

Ibrahim Ismail Al-kebsi received the B.Sc. degree in electronic and communication engineering from University of Technology, Baghdad, IRAQ, in 2000. He received the M.Sc. degree in computer and communication engineering from University Kebangsaan Malaysia, Bangi, Malaysia, in 2005. He is currently a PhD student at university Kebangsaan Malaysia (UKM). His research interests are signal processing in communications especially in multicarrier systems (OFDM), wireless communication systems, and radio transmission techniques for 4G systems.

Mahamod Ismail received the B.Sc. degree in Electrical and Electronics from University of Strathclyde, U.K. in 1985, the M.Sc. degree in Communication Engineering and Digital Electronics from UMIST, Manchester U.K. in 1987, and the Ph.D. from University of Bradford, U.K. He is currently a Professor with the Department of Electrical, Electronics and System Engineering, and attach to the Center for Information Technology as the Deputy Director (Research and Education), Universiti Kebangsaan Malaysia. His research interests include mobile communication and wireless networking. He published more than 200 technical papers in journal and proceeding at local and international level. He is the past chapter chair of IEEE Communication Society, Malaysia and Educational Activities chairman, IEEE Malaysia Section and currently the committee member for the Joint chapter Communication and Vehicular Technology Society, IEEE Malaysia. He is also actively involved in conference and became the Technical Program Chairman, technical committee and paper reviewer.

Kasmiran Jumari received the B.Sc. degree from Universiti Kebangsaan Malaysia in 1976. He received the M.Sc. degree from University of Aberdeen in 1977. He received the PhD degree from University of Kent, UK, in 1985. He is now a professor at the Department of Electrical, Electronic and System Engineering, Universiti Kebangsaan Malaysia, Bangi, Malaysia. . His main research interests include network security, and image processing.

Tharek Abd. Rahman received the B.Sc. degree from University of Strathclyde, UK, in 1979. He received the M.Sc. degree from UMIST, Manchester, UK, in 1982. He received the PhD degree from University of Bristol, UK (1988), in 1985. He is now a professor at the Department of Radio Communication Engineering, Faculty of Electrical Engineering, Universiti Teknologi Malaysia. His research interests include mobile communication and wireless networking.