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# The Impact of Modulation Adaptation and Power Control on Peak to Average Power Ratio Clipping Technique in Orthogonal Frequency Division Multiplexing of Fourth Generation Systems

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**Abstract:** This research tries to study the impact of modulation adaptation and power control on PAPR clipping technique by combining all these techniques together to produce a new algorithm not only to reduce the PAPR, but to improve the performance of the SER and enhance the data rate of OFDM signals for 4G systems. This algorithm is called MPC (modulation adaptation, power control and clipping) and it presents a new issue which is the ability of using the high order modulation schemes such as 256-QAM at low SNR values without degrading the SER performance.

**Key words:** Modulation adaptation, power control, clipping, PAPR, MPC, CCDF

## INTRODUCTION

The emerging of 4G has led to the necessity of looking for an attractive technique for wireless communication system that can promise high data rate and high spectral efficiency. The 4G systems are expected to provide bandwidth higher than 20 Mbps and to accommodate a significantly increased amount of traffic, so sufficient frequency resources will be required (Mishra, 2007). Orthogonal Frequency Division Multiplexing (OFDM) is proving to be a possible multiple access technology to be used in 4G. It is a very attractive technique for the transmission of high bit rate data in a radio environment. But OFDM comes with its own challenges like high Peak to Average Power Ratio (PAPR), linearity concerns and phase noise. OFDM is becoming the chosen multiplexing technique for wireless communications. OFDM is actually a combination of both modulation and multiplexing (Mishra, 2007). A particularly, attractive feature of OFDM systems is that they are capable of operating without a classic channel equalizer, when communicating over dispersive transmission media, such as wireless channels, while conveniently accommodating the time and frequency domain channel quality fluctuations of the wireless channel (Hanzo and Keller, 2006). A major disadvantage of an OFDM system is the large dynamic range signal (also referred as PAPR) due to the summation of a large number of subcarriers coherently. As the number of sub-carriers N increases, the maximum possible peak power becomes N times the average power (Li and Cimini, 1998). To reduce the PAPR, several techniques have been proposed. Examples of distortion techniques are clipping, peak windowing and peak cancellation (Van Nee and Prasad, 2000). There is a trade off between power control and modulation adaptation. If the value of SER is small, so the transmitted power can be maintained and a high order modulation scheme is used, or the power can be increased and the order of modulation scheme reduced accordingly.

## MATERIALS AND METHODS

In Matlab simulation, OFDM symbol would be assumed with subcarriers of length 128 and a guard interval with duration of 1/4 of the symbol duration. Four modes of algorithm MPC were tested. Five, four and three modulation levels were proposed apnd adopted to be used in these modes. The modulation or mapping schemes that would be used in this simulation were BPSK, 4-QAM, 16-QAM, 64-QAM and 256-QAM. Input data could be mapped onto symbols using anyone of the above mentioned constellations, in this simulation the high order modulation schemes could be used to map the input data stream at low SNR values to enhance the data rate and improve the performance of SER. If the digital OFDM signals were clipped directly, the resulting clipping noise would all fall in-band and could not be reduced by filtering. To address this aliasing problem, in this simulation, OFDM signal could be oversampled by a factor of 4. In addition, to reduce the implementation complexity, the complex valued baseband OFDM signal was modulated up to a carrier frequency equal to 1/4 of the sampling frequency. Then, the real valued bandpass samples, x, were clipped at amplitude A as follows:

Table 1: Simulation parameters

| Parameters | Values |
|---|---|
| Modulation scheme (Mapping scheme) | BPSK, 4QAM, 16QAM, 64QAM, 128QAM, 256QAM, |
| FFT size (NFFT) | 512 |
| No. of subcarriers | 128 |
| Useful symbol duration $T_U$ | 1.02 μsec |
| Carrier frequency $f_c$ | 2.50 GHz |
| Guard time ( $T_g = (1/4)^* T_U$ ) | 255 nsec |
| No. of symbols/Frame | 48 |

$$y = \begin{cases} -A, & \text{if } x < -A \\ x, & \text{if } -A \le x \le A \\ A, & \text{if } x > A \end{cases} \tag{1}$$

Table 1 shows the values of parameters were used in this simulation model. A simple AWGN channel is used as channel model, the channel bandwidth provided in this simulation can support two data rates vary from 125 Mbps (when using BPSK as a mapping scheme), to 1 Gbps (when using 256-QAM as a mapping scheme), which meet the bandwidth requirement of 4G systems.

The variation of the envelope of a multi-carrier signal can be defined by the Peak to Average Power Ratio (PAPR) which is given by:

$$PAPR = \frac{Max\left\{ |x(t)|^2 \right\}}{E\left\{ |x(t)^2| \right\}} \tag{2}$$

The large peaks occur with low probability because the signal amplitude is approximately Rayleigh distributed when the number of subcarriers is large. To evaluate the performance, the Complementary Cumulative Distribution Function (CCDF) of PAPR for OFDM signal x, that is:

$$CCDF\big(PAPR(x)\big) = Prob\big(PAPR(x) > PAPR0\big) \tag{3}$$

is calculated. CCDF can be interpreted as the probability that the PAPR of an OFDM signal exceeds some clip level PAPR0. The goal of the modulation adaptation algorithm used in this simulation is to improve the performance of SER and enhance the data rate through enabling the high order modulation schemes to be used to map the input data onto symbols at low SNR values.

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, or based on SNR value which is allocated for each modulation scheme to maintain the SER value less than $10^{-4}$. The power control algorithm used in this simulation is very simple and used for power adjustment after each symbol transmission.

## RESULTS AND DISCUSSION

Four modes of MPC were tested with five, four and three modulation levels. The simulation results will be presented as the (CCDF) of the PAPR of the OFDM signals.

**Case 1: The modulation adaptation is based on SER:** If the value of SER is small, the high order modulation scheme will be selected, but if there is increasing in the value of the SER, the decision will be made to select the low order modulation scheme. The expected result is reduction in PAPR, enhancing the data rate and all modulation levels can be applied at all SNR values depend on the value of SER, without degrade the performance of SER. Figure 1 shows the simulation results of all above mentioned modes.

The best reduction in PAPR was noticed with the mode MPC (BPSK, 4-QAM, 16-QAM, 64-QAM and 256-QAM) as shown in Table 2.

It is easy to note that the data rate is enhanced dramatically at low SNR values as shown in Table 3.

At SNR equals to 8 dB which is the threshold of BPSK, 13% of the transmitted symbols were mapped with the high order modulation scheme 256-QAM, 20% with 64-QAM, 18% with 16-QAM and 20% of them with 4-QAM. This means 71% 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, 63% of the transmitted symbols were mapped with modulation schemes have order higher than 4-QAM. At 18 dB, 55% of the transmitted symbols were mapped with modulation schemes have order higher than 16-QAM. So it was clear how the proposed algorithm can decrease the PAPR and enhance the data rate at low SNR values without degrading the target SER. As shown in Fig. 2, the SER performance of the tested MPC modes with five and four modulation schemes is improved. It is easy to note this improvement in SER performance especially at low SNR values compared to SER performance in the normal and clipped OFDM with 256-QAM.

As in Table 3 and 4 show how the proposed algorithm MPC (BPSK+4+16+128-+256-QAM) mode allows the high order modulation schemes to be applied to map the input data onto symbols at low SNR values in order to enhance the data rate without degrade the SER as shown in Fig. 2 and reduce the PAPR.

In Fig. 3, the reduction in PAPR using the mode MPC (4+16+64-QAM) was 4.9 dB compared to normal OFDM with 64-QAM and 3.5 dB compared to normal OFDM with 4-QAM. It was found at SNR equal to 8 dB, 58% of the

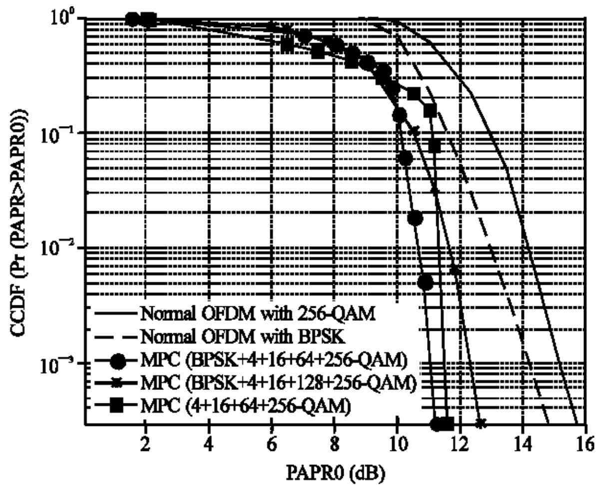


Fig. 1: CCDF of PAPR for normal OFDM with 256-QAM and the proposed modes: MPC (BPSK+4+16+64-+256-QAM),MPC(BPSK+4+16+128-+256-QAM) and MPC (4+16+64-+256-QAM)

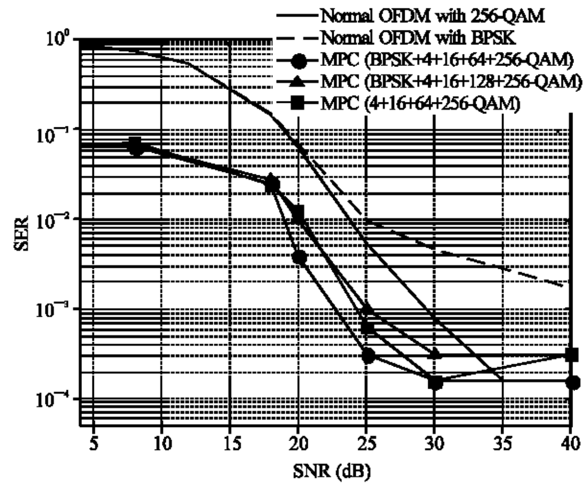


Fig. 2: SER performance of the normal OFDM with 256-QAM and the proposed modes: MPC (BPSK+4+16+64-+256-QAM), MPC (BPSK+4+16+128-+256-QAM)andMPC(4+16+64-+256-QAM)

Table 2: The obtained PAPR reduction

| MPC mode | PAPR reduction compared to the normal OFDM with: BPSK (dB) | 256-QAM (dB) |
|---|---|---|
| BPSK+4+16+64+256-QAM | 3.6 | 4.5 |
| BPSK+4+16+128+256-QAM | 2.2 | 3.1 |
| 4+16+64+256-QAM | 3.2 | 4.1 |

Table 3: The percentage of transmitted symbols of MPC (BPSK+4+16+64+256-QAM) that were mapped using various orders of modulation schemes at different SNR values

| Mod. scheme | SNR(dB) 2 | 5 | 8 | 12 | 18 | 20 | 30 | 40 |
|---|---|---|---|---|---|---|---|---|
| **Symbol (%)** | | | | | | | | |
| 256-QAM | 2 | 5 | 13 | 23 | 32 | 79 | 91 | 93 |
| 64-QAM | 7 | 13 | 20 | 21 | 23 | 16 | 7 | 6 |
| 16-QAM | 13 | 15 | 18 | 19 | 20 | 2 | 1 | 1 |
| 4-QAM | 28 | 28 | 20 | 19 | 18 | 2 | 1 | 0 |
| BPSK | 50 | 39 | 29 | 18 | 7 | 1 | 0 | 0 |

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

| Mod. scheme | SNR(dB) 2 | 5 | 8 | 12 | 18 | 20 | 30 | 40 |
|---|---|---|---|---|---|---|---|---|
| **Symbol (%)** | | | | | | | | |
| 256-QAM | 2 | 7 | 12 | 24 | 28 | 78 | 90 | 95 |
| 128-QAM | 9 | 9 | 15 | 19 | 17 | 11 | 6 | 4 |
| 16-QAM | 11 | 16 | 19 | 18 | 19 | 6 | 2 | 1 |
| 4-QAM | 26 | 26 | 25 | 20 | 22 | 4 | 2 | 0 |
| BPSK | 52 | 42 | 29 | 19 | 14 | 1 | 0 | 0 |

transmitted symbols were mapped using modulation schemes with order higher than 4-QAM. But at 18 dB, 82% of the transmitted symbols were mapped using 64-QAM.

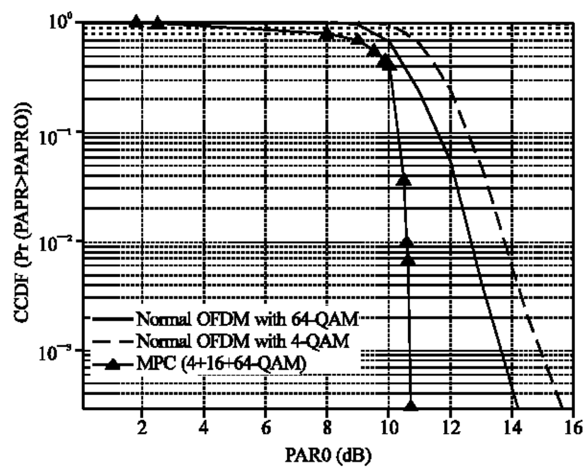


Fig. 3: CCDF of PAPR for normal OFDM with 64-QAM and the proposed mode MPC (4+16+64-QAM)

The SER performance of the mode MPC (4+16+64-QAM), normal and clipped OFDM with 64-QAM are illustrated in Fig. 4. Although the OFDM signals are clipped, it is easy to note the improvement in SER performance especially at low SNR values with increment in the data rate.

**Case 2: The modulation adaptation is based on SNR:** The same decision technique used in earlier will be made here, but the modulation adaptation here is based on SNR.

Figure 5 shows the obtained reduction in PAPR is 2.7 dB when applying the mode MPC with 256-QAM and 8.8 dB when the mode MPC with 4-QAM was used.

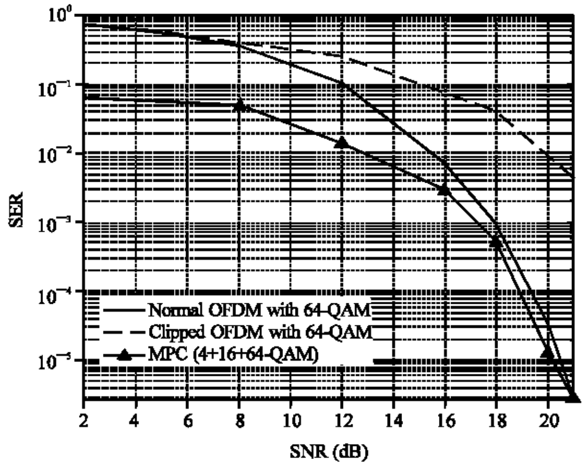


Fig. 4: SER performance of the normal OFDM with 64-QAM and the mode MPC (4+16+64-QAM)

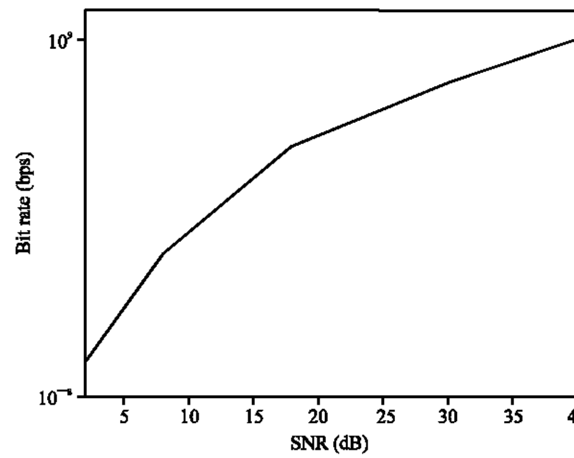


Fig. 6: Bit rate per second of MPC OFDM system (2+4+16+64+256-QAM)

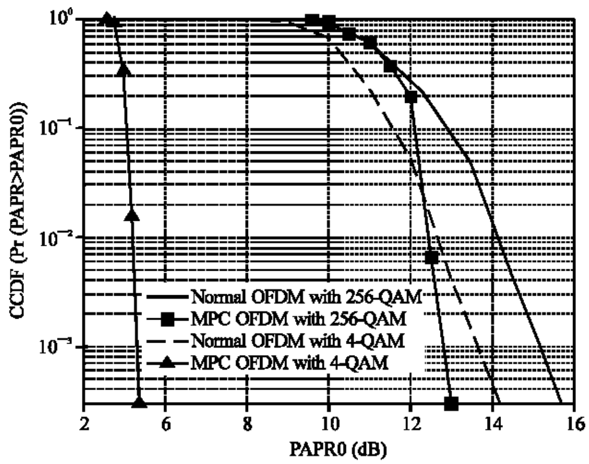


Fig. 5: CCDF of PAPR for normal and MPC OFDM system with 64-QAM and 256-QAM based on SNR value

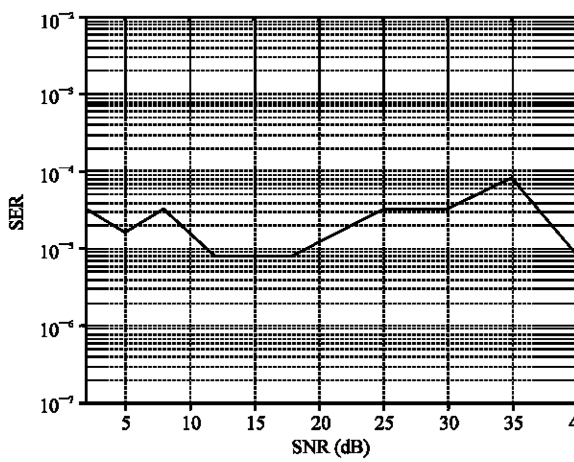


Fig. 7: SER performance of the mode MPC (4+16+64+256-QAM) based on SNR value

Table 5: Comparison between the required transmission time of the normal OFDM and the proposed algorithm MPC at different SNR values

| | Transmission time when using: | | |
|---|---|---|---|
| Data size | MPC (BPSK+4+16+64+256-QAM) (sec) | Normal OFDM (sec) | SNR value (dB) |
| 5 Gbps | 23.82 | 40.0 | 5 |
| | 15.45 | 20.0 | 12 |
| | 6.02 | 10.0 | 20 |
| | 5.52 | 6.67 | 30 |
| | 5.15 | 5.0 | 40 |

It was obvious the bit rate is increasing as the value of SNR is increasing, but the cost of keeping the symbol error rate under $10^{-4}$, is low bit rate at low SNR as shown in Fig. 6.

The symbol error rate as shown in Fig. 7 was kept under certain value, which is $10^{-4}$ by applying the proposed algorithm MPC OFDM with (2+4+16+64+256-QAM) modulation schemes.

Table 5 shows the time required to transmit the data (5 Gbps as an example) using the proposed mode MPC with five modulation schemes is less than the time required using the normal OFDM at different SNR values.

By carrying out comparison between the proposed algorithm in case 1 and case 2, it is easy to note the two proposed algorithms introduce a good reduction in PAPR, but the advantage of the proposed algorithm in case 1 over what was proposed in case 2 is the possibility of using the high modulation levels at the low SNR values and this will reflect in enhancing the bit rate at low SNR values, but the disadvantage is increasing the SER also at low SNR values. But the proposed algorithm in case 2 can decrease the SER at low SNR values and keep it under certain threshold, but it can not promise high data rate at low SNR values.

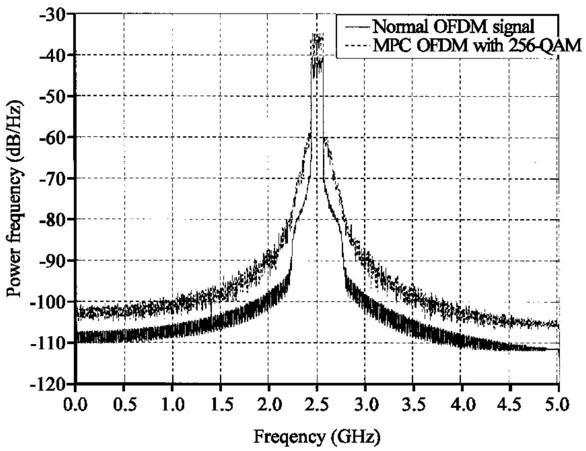


Fig. 8: The power spectral density of the normal OFDM and MPC OFDM signal with 256-QAM

It was clear how the proposed algorithm MPC in this simulation can attenuate the out-of-band noise as shown in Fig. 8.

## CONCLUSION

A new algorithm is proposed in this study which is in fact a hybrid of different techniques. This algorithm employs the modulation adaptation and power control techniques together with clipping technique which called MPC. The modulation adaptation in this algorithm was classified into two cases. The first one was based on SER and the other was based on SNR. Both of two cases introduced a good PAPR reduction, but the algorithm used in first case could increase the bit rate at low SNR by using the high order modulation schemes at the low SNR values. The second case showed the ability to reduce the SER at low SNR values. In both cases the result was OFDM system has small PAPR and high data rate with a good SER performance.

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