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PAPR Reduction using Genetic Algorithm in OFDM System

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Abstract: Orthogonal frequency division multiplexing (OFDM) is a multicarrier modulation technique that relies on orthogonality feature to increase transmission data rate while enhancing spectral efficiency at the same time. OFDM's major issue is the high peaks or peak-to-average power ratio (PAPR) that introduced due to summation of subcarriers' signal. Many methods have been proposed to alleviate this issue, however, some may increase signal average power. In this paper, genetic algorithm (GA) technique is proposed for optimal solution in reducing PAPR of OFDM system. GA is a type of optimisation algorithm which is natural-based selection and is used to find the optimal solution to the computational problem that maximises or minimises a particular function. The PAPR performance is compared and analysed based on the number of subcarriers and modulation size using complementary cumulative distribution function plots between the original OFDM and the proposed OFDM-GA method. By comparing with the original OFDM, simulation result demonstrates that the proposed method is able to reduce the PAPR around 50%.

Keywords: Genetic algorithm; OFDM; Peak-to-average ratio; Simulation.

1. INTRODUCTION

In the earlier time of wireless communication, single carrier modulation (SCM) was a revolutionary by itself in which the data pulses are carried using a single carrier. The SCM was able to increase the speed of data transmission by reducing the symbol duration, thus increasing the symbol rate. However, as the symbol duration decreases, the transmitted symbols start to drastically overlap each other at the receiver. This is due to the multipath effect, which introduces the issue of the inter-symbol interference (ISI). To alleviate the ISI issue, SCM requires the implementation of a very complex equalizer. In order to solve the speed limitation of SCM, a parallel transmission concept was adopted using multi-tone multiplexing techniques such as frequency division multiplexing (FDM) and orthogonal frequency division multiplexing (OFDM) [1-2].

However, unlike FDM where channels are non-overlapping on each other, OFDM, with the help of the orthogonality feature, uses densely packed and overlapping/noninterfering channels to efficiently utilise the bandwidth. In fact, OFDM divides its channel into multiple narrow band sub-channels to gain robustness over the frequency selective fading channel and eliminate the adjacent subcarrier crosstalk. The carrier of each sub-channel is called subcarrier and the subcarriers are orthogonal to each other [3]. OFDM does not only increase the data transmission rate through multiplexing techniques, but it also eradicates the ISI effect easily using a cyclic prefix (CP), of length exceeds the maximum spread delay of the multipath channel, and a very simple equalizer. In facts, the CP with the appropriate length makes channel estimation and equalisation simpler in OFDM. Although OFDM sounds an interesting modulation technique, it was not until the advances in the digital signal processing (DSP) technology that OFDM received an immense interest in application design [4]. Using the discrete Fourier transform (DFT) and its fast implementation algorithm, fast Fourier transform (FFT), an orthogonality feature is maintained and all subcarriers are modulated/demodulated at once using a single FFT function at both transmitter and receiver. Nowadays, OFDM is a very popular technique that forms the basis of many famous applications and standards such as WLAN, ADSL, DVB-T, LTE and 5G.

Although OFDM increases the data transmission rate efficiently and it is robust to channel impairments, its signal suffers from the high peak-to-average power ratio (PAPR). The summation of multiple orthogonal subcarriers constructs some very high peaks. The problem related to the high peaks of the OFDM signal cannot be amplified linearly using a simple high power amplifier (HPA) as the peaks fall down in the saturation/non-linear region of the amplifier, thus distorting the amplified signal and causing in-band and out-band radiations. To prevent such signal distortion, a very complex power amplifier design with back-off is required. However, this solution is power inefficient and complex [5-6]. There are many techniques that have been proposed in the literature to alleviate the PAPR issue. These can be categorised into distortion and distortion-less techniques. The distortion PAPR reduction techniques such as clipping are simple, but with inefficient solution which degrade the bit error rate (BER) performance of the system. On the other hand, the distortion-less PAPR reduction techniques maintain the BER performance of the system under certain criteria. Examples of distortion-less techniques are partial transmit sequence (PTS), selective mapping (SLM), tone injection (TI), tone reservation (TR), active constellation extension (ACE) and coding [7].

This paper proposes reduction of PAPR in OFDM system using the genetic algorithm (GA). By using the GA, an optimal solution can be obtained which results in PAPR reduction of the OFDM system. The proposed solution is evaluated for OFDM with 16QAM and 64QAM, and with four subcarriers. The level of PAPR is examined for both the original OFDM and the proposed technique. Besides, simulation results of complimentary cumulative distributive function (CCCF) are also studied.

2. OFDM

OFDM technique is an interesting multi-tone modulation technique that found its way to broad line of standards and applications that seeks for high data rate, spectral efficiency, robustness against ISI and fading, and design simplicity. The adoption of OFDM as a transmission technique is rapidly growing, and some examples of OFDM based transmission standards includes digital video broadcasting (DVB), digital audio broadcasting (DAB), digital subscriber line (DSL), IEEE 802.11a/g, WiMax and LTE [4]. As the full name implies, the two main basis concept of OFDM are orthogonality feature and parallel transmission through multiplexing technique. Both OFDM and FDM techniques are capable of achieving higher data rate, compared to a single carrier technique, through parallel transmission of data using multiple carriers. However, unlike FDM, OFDM can achieve the same high data transmission rate as FDM with almost half the bandwidth. In other words, with the help of orthogonality, OFDM can achieve almost double the data rate of what can be achieved in FDM using the same bandwidth. Therefore, OFDM is regarded as a bandwidth or spectral efficient modulation technique.

It is interesting to see how the subcarriers in OFDM are so densely packed to the point where they overlap each other but with no interference due to orthogonality feature. If for any reason orthogonality between subcarriers is broken, the subcarriers will interfere with each other and the receiver will not be able to recognise the transmitted data. It is only due to the advances in DSP techniques and manufacturing processes that OFDM is a very popular nowadays despite the fact that this technique was introduced in the mid of 1960s. In fact, the introducing of DFT-based OFDM and the FFT-based OFDM later led to significant complexity reduction of OFDM implementation [6].

In OFDM systems, the baseband operations at the transmitter include mapping the information data bit stream to symbols according to a certain modulation scheme, such as M-Phase Shift Keying (PSK) or M-Quadrature Amplitude Modulation (QAM), a fixed number of successive input data samples are modulated first. The data streams were transmitted simultaneously by number of subcarriers. Each of the sub-carriers is independently modulated and multiplexed. Then it is combined together using inverse FFT (IFFT) at the transmitter side. IFFT is used to produce orthogonal data subcarriers. Let data block of length N be represented by a vector.

$$X = [X_0, X_1, \dots, X_{N-1}]^T \tag{1}$$

Duration of any symbol X_k in the set X is T and represents one of the sub-carriers set. The complex data block for the OFDM signal to be transmitted is given by [3] as

$$x(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_N \, e^{j2\pi n\Delta f t} \qquad 0 \le t \le NT \tag{2}$$

3. PEAK-TO-AVERAGE POWER RATIO (PAPR)

The PAPR is a related measure that is defined as the peak amplitude squared (peak power) divided by the RMS value squared (average power). The PAPR is mostly used in signal processing applications. As it is a power ratio, it is normally expressed in decibels (dB).

$$PAPR(x(t)) = \frac{\overline{\underset{0 \le t \le T}{max}} |x(t)|^2}{P_{av}} \tag{3}$$

where

$$P_{av} = \frac{1}{N} \sum_{k=0}^{N-1} E[|X_k|^2] \tag{4}$$

The performance of a PAPR reduction scheme is usually demonstrated by three main factors: the CCDF, BER and spectral spreading [4].

3.1 Complementary Cumulative Distributive Function (CCDF)

The CCDF is the most informative metric used for evaluating of the PAPR, where the PAPR reduction is measured by the amount of CCDF reduction. CCDF provides an indication of the probability of the OFDM signal's envelope exceeding a specified PAPR threshold [4]. Therefore, the CCDF of PAPR provides information about the percentage of OFDM signals that have PAPR above a particular level. It denotes the probability that the PAPR of an OFDM symbol exceeds the given threshold $PAPR_0$, which can be expressed as:

$$CCDF = 1 - P_r\{PAPR > PAPR_0\} \quad (5)$$

3.2 Bit Error Rate (BER)

The performance of a modulation technique can be quantified in terms of the required signal-to-noise ratio (SNR) to achieve a specific BER. Although the main focus of PAPR reduction techniques is to reduce the CCDF, this is usually achieved at the expense of increasing the BER. Clipping the high peaks of the OFDM signal by the power amplifier (PA) causes a substantial in-band distortion that leads to a higher BER. Other techniques may require that side information be transmitted as well. If the side information is received incorrectly at the receiver, the whole OFDM symbol is recovered in error and the BER performance degrades [4-5].

3.3 Spectral Spreading

Due to the limit imposed on the maximum peak of the OFDM signal by the PA, an increase is encountered in both the in-band and out-of-band distortions. The second causes undesirable increase in the power of the side lobes of the power spectral density (PSD) of the OFDM signal. This effect is referred to as spectral spreading or spectral regrowth. When the nonlinearity of the PA is higher, input back-off (IBO) is smaller, and the spectral spreading is higher. Spectral spreading leads to higher interference between the sub-bands of the OFDM signal, unless the frequency separation between adjacent subcarriers is also increased to maintain orthogonality. However, this solution has the disadvantage of lowering the spectral efficiency [4].

4. GENETIC ALGORITHM (GA)

Optimisation is the process of modifying the inputs or characteristics of a device, and mathematical process to obtain minimum or maximum of the output. GA is one of the most popular techniques in the Evolutionary Algorithms. In addition, GA-based methods offer favourable optimisation strategies as they are easy to implement. In this work, by employing the GA method with a selected fitness function, an optimum candidate signal is obtained which produce better approximation to the optimal solution.

The fitness function equation is:

$$F_i(x(t)) = \frac{1}{10\log PAPR\ (x(t))} \quad (6)$$

where F_i is a fitness function and $x(t)$ is OFMD signal. With an optimal solution, a better PAPR performance is obtained as proved through [8] and [9]. GA use binary vector consisting of 0's and 1's as chromosomes, so that the string of binary bits provides the genetic information. Figure 1 shows the process flow of GA at each stage and Figure 2 illustrates the GA process.

4.1 Initialisation

The genetic algorithm starts with an elementary population comprised of random chromosomes which includes genes with a sequence of 0 s or 1 s. Afterward, the algorithm leads individuals to achieve an optimum solution by the way of repetitive processes including crossover and selection operators. There are two ways to develop a new population [7], which are steady-state GA and generational GA. In the case of the former, one or two members in the population are replaced, whereas the generational GA replaces all the generated individuals of a generation at the same time.

4.2 Selection

At every successive generation, a new generation is developed through adopting members of the current generation to mate on the bases of their fitness. The individuals with higher fitness score have higher chance for being selected, the process which results in preferential adoption of the best solution. Majority of the functions include a stochastically designed element for adopting small number of less fit individuals for sake of keeping diversity in the population [6]. Among the many selection methods, Roulette-Wheel is adopted in this work to differentiate proper individuals with the probability of:

$$P_i = \frac{C_i}{\sum_{i=1}^{n} C_i} \quad (10)$$

where C_i is a fitness chromosome and n is a population size. According to the Roulette-Wheel, each individual is assigned a value between 0 and 1.

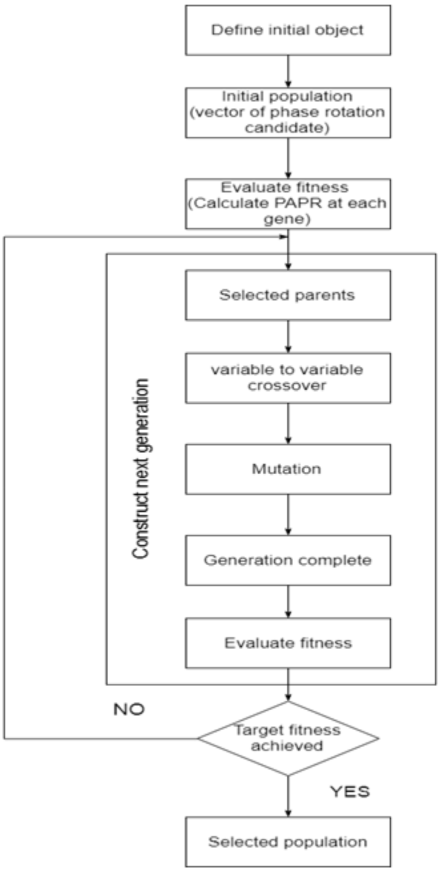

Figure 1. GA flow in OFDM system

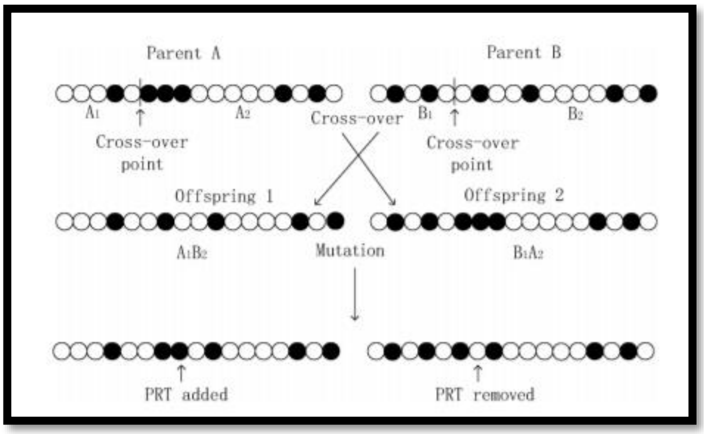

Figure 2. Illustration of GA procedure [7]

4.3 Crossover

The crossover or reproduction process create the major step toward production. Certainly, reproductive process, which inherited characteristics are transferred from one generation to the next generation, is simulated. In the reproduction process, crossover process adopts a couple of individuals as the parents through breeding selection process. The process continues to reach the desired size in the new population.

4.4 Mutation

Crossover operation of GA cannot generate quite different offsprings from their parents because the acquired information is used to crossover the chromosomes. An alternate operator, mutation, can search new areas in contrast to the crossover. Crossover is referred as exploitation operator whereas the mutation is exploration one. With a mutation probability, it mutate a new offspring at each data.

5. RESULTS AND DISCUSSION

Figure 3 shows the flow of the proposed method (OFDM-GA) in a block diagram. Firstly, the input data is transmitted, and converted from series to parallel using a series-to-parallel converter. Next, QAM is implemented into the data. IFFT is used to transform the multiple frequency domain samples to time domain samples [6]. The time domain samples will then be used in GA as a data to reduce the PAPR, and the OFDM signal is transmitted. Simulations were conducted using the original OFDM and the proposed method with 16QAM and 64QAM modulation, and with four different subcarriers.

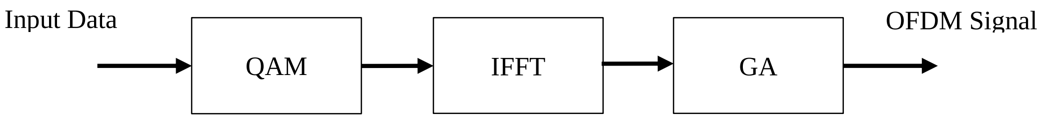

Figure 3. Block diagram of OFDM-GA

Table 1 shows PAPR results for the original OFDM, with subcarriers of 64, 128, 256 and 512. It can be shown that the PAPR values increase when the number of subcarrier increases for both 16QAM and 64QAM modulation.

Table 1. PARR for original OFDM

N/ Modulation	**PAPR (dB)**			
	64	**128**	**256**	**512**
16QAM	22.2	23.8	24.5	26.0
64QAM	23.0	24.0	25.5	27.0

On the other hand, Table 2 shows the improvement of PAPR values when the GA method is applied to the OFDM system for all subcarriers. For example, about 13 dB PAPR reduction was achieved for a case with 512 number of subcarriers and 16QAM.

Table 2. PARR for OFDM-GA

N/ Modulation	**PAPR (dB)**			
	64	**128**	**256**	**512**
16QAM	14.2	12.8	13.0	12.5
64QAM	14.2	13.5	13.0	12.5

5.1 Results of CCDF

The simulation performance for the original OFDM and the GA-OFDM algorithms using different numbers of subcarriers is presented in Figures 4 and 5. It can be noted from the CCDF plots, that the PAPR is gradually promoted by increasing the numbers of sub-carriers. As the number of sub-carrier increases, the PAPR also improves. It can also been seen that when N = 64 and 16QAM, the PAPR of OFDM scheme was approximately 24 dB, whereas with GA-OFDM, PAPR reduced to approximately 14 dB with CCDF of 10^{-3}. In addition, when N = 128, N = 256 and N = 512, after applying GA-OFDM, PAPR was observed to be 12.8 dB, 13.0 dB and 12.5 dB respectively with CCDF of 10^{-3}. It was observed that the quantity improvement in PAPR was dependent on the number of sub-carriers used for OFDM generation, and the optimisation algorithms provided improvement in the PAPR performance in each case. The results showed that GA-OFDM is an effective technique for reducing the PAPR of OFDM system, even with the large number of sub-carriers.

6. CONCLUSION

In this paper, GA has been used to reduce PAPR of an OFDM signal. The proposed method OFDM-GA has been simulated with different number of subcarriers and QAM modulations. The performance of PAPR has been evaluated based on the level of PAPR and the CCDF plots as compared to the original OFDM. Simulation results demonstrate that the GA method outperformed the original PAPR, with significant reductions.

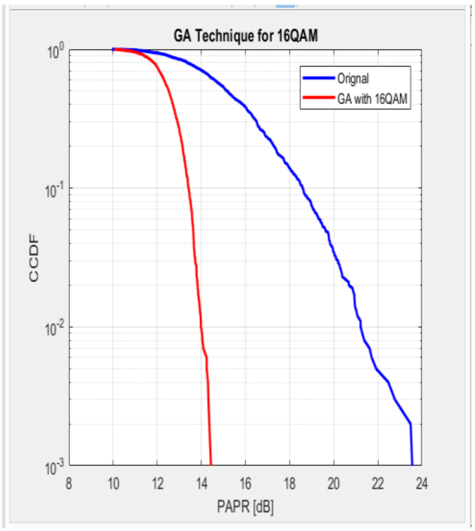

Figure 4. CCDF of 16QAM and 64 subcarrier of OFDM and OFDM-GA

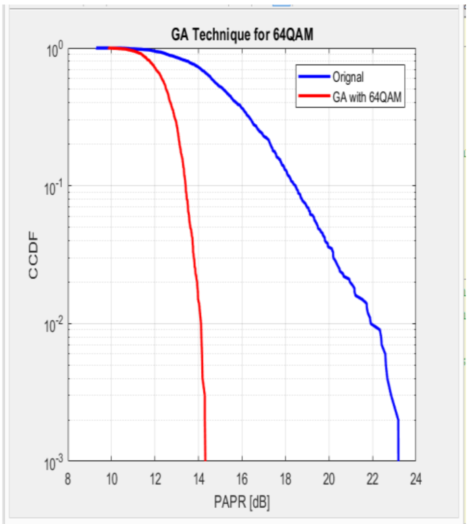

Figure 5. CCDF of 64QAM and 64 subcarrier of OFDM and OFDM-GA

REFERENCES

[1] J. Jang and K. B. Lee, Transmit power adaptation for multiuser OFDM systems, *IEEE Journal on Selected Areas in Communications*, 21(2), 171–178, 2003.

[2] S.-K. Deng and M.-C. Lin, OFDM PAPR reduction using clipping with distortion control, *IEEE International Conference on Communications*, Seoul, South Korea, 2005, pp. 2563–2567.

[3] P. P. Ann and R. Jose, Comparison of PAPR reduction techniques in OFDM systems, *International Conference on Communication and Electronics Systems*, Coimbatore, India, 2016, pp. 1–5.

[4] Y. Rahmatallah and S. Mohan, Peak-to-average power ratio reduction in OFDM systems: A survey and taxonomy, *IEEE Communications Surveys and Tutorials*, 15(4), 1567–1592, 2013.

[5] A. Chadha, N. Satam and B. Ballal, Orthogonal frequency division multiplexing and its applications, *International Journal of Science and Research*, 2(1), 325–328, 2013.

[6] M. S. R. Saheb and K. K. Murthy, PAPR reduction in OFDM systems by a modified genetic algorithm PTS technique, *International Journal of Current Trends in Science and Technology*, 7(12), 20549–20555, 2017.

[7] S.-S. Kim, M.-J. Kim and T. A. Gulliver, PAPR reduction of OFDM signals using genetic algorithm PTS technique, *IEICE Transactions on Communications*, 91(4), 1194–1197, 2008.

[8] I. Sohn, New SLM scheme to reduce the PAPR of OFDM signals using a genetic algorithm, *ICT Express*, 2(2), 63–66, 2016.

[9] W. C. Lee, J. P. Choi and C. K. Huynh, A modified tone injection scheme for PAPR reduction using genetic algorithm, *ICT Express*, 1(2), 76–81, 2015.