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Improved Papr Reduction in Ofdm Systems Adopting Genetic Algorithms for Slm

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ABSTRACT

Orthogonal Frequency Division Multiplexing (OFDM) technique has been widely adopted in many wireless communication systems due to its high data-rate transmission ability and robustness to the multipath fading channel. One of the major disadvantages of OFDM technique is the high PAPR in the time domain signal. The larger peak-to-average power ratio (PAPR) would cause the fatal degradation of BER performance and undesirable spectrum regrowth. One of the promising PAPR reduction methods is the Selective Mapping method (SLM) which can achieve better PAPR performance without signal distortion. In this paper, a new effective PAPR reduction technique using SLM based on Genetic Algorithm (GA) is proposed. GA is applied to SLM-OFDM system for searching the optimum phase rotation factors and reducing computational burden. The simulation results show that the proposed GA based SLM-OFDM system provides better PAPR reduction compared to conventional SLMOFDM system.

Keywords—Orthogonal Frequency Division Multiplexing (OFDM), Peak-to-Average Power Ratio (PAPR), Selected mapping (SLM), Genetic Algorithm (GA).

I.INTRODUCTION

Initial proposals for OFDM were made in the 60s and the 70s. It has taken more than a quarter of a century for this technology to move from the research domain to the industry.The concept of OFDM is quite simple but the practicality of implementing it has many complexities.So, it is a fully software project. OFDM depends on Orthogonality principle. Orthogonality means, it allows the sub carriers, which are orthogonal to each other, meaning that cross talk between co-channels is eliminated and inter-carrier guard bands are not required. This greatly simplifies the design of both the transmitter and receiver, unlike conventional FDM; a separate filter for each sub channel is not required. Orthogonal Frequency Division Multiplexing (OFDM) is a digital multi carrier modulation scheme, which uses a large number of closely spaced orthogonal sub-carriers.

A single stream of data is split into parallel streams each of which is coded and modulated on to a subcarrier, a term commonly used in OFDM systems. Each sub-carrier is modulated with a conventional modulation scheme (such as quadrature amplitude modulation) at a low symbol rate, maintaining data rates similar to conventional single carrier modulation schemes in the same bandwidth. Thus the high bit rates seen before on a single carrier is reduced to lower bit rates on the subcarrier. In practice, OFDM signals are generated and detected using the Fast Fourier Transform algorithm. OFDM has developed into a popular scheme for wideband digital communication, wireless as well as copper wires.Actually, FDM systems have been common for many decades. However, in FDM, the carriers are all independent of each other. There is a guard period in between them and no overlap whatsoever. This works well because in FDM system each carrier carries data meant for a different user or application.

FM radio is an FDM system. FDM systems are not ideal for what we want for wideband systems. Using FDM would waste too much bandwidth. This is where OFDM makes sense. In OFDM, subcarriers overlap. They are orthogonal because the peak of one subcarrier occurs when other subcarriers are at zero. This is achieved by realizing all the subcarriers together using Inverse Fast Fourier Transform (IFFT). The demodulator at the receiver is parallel channels from an FFT block. Note that each subcarrier can still be modulated independently. Since orthogonality is important for OFDM systems, synchronization in frequency and time must be extremely good. Once orthogonality is lost we experience **inter-carrier interference** (ICI). This is the interference from one subcarrier to another. There is another reason for ICI. Adding the guard time with no transmission causes problems for IFFT and FFT, which results in ICI.

A delayed version of one subcarrier can interfere with another subcarrier in the next symbol period. This is avoided by extending the symbol into the guard period that precedes it. This is known as a **cyclic prefix**. It ensures that delayed symbols will have integer number of cycles within the FFT integration interval. This removes ICI so long as the delay spread is less than the guard period. Orthogonal frequency division multiplexing (OFDM) technology is one of the most attractive candidates for fourth generation (4G) wireless communication. It effectively combats the multipath fading channel and improves the bandwidth efficiency.

At the same time, it also increases system capacity so as to provide a reliable transmission. OFDM uses the principles of Frequency Division Multiplexing (FDM) but in much more controlled manner, allowing an improved spectral efficiency . The basic principle of OFDM is to split a high-rate data stream into a number of lower rate streams that are transmitted simultaneously over a number of subcarriers. These subcarriers are overlapped with each other. Because the symbol duration increases for lower rate parallel subcarriers, the relative amount of dispersion in time caused by multipath delay spread is decreased. Inter-symbol interference (ISI) is eliminated almost completely by introducing a guard time in every OFDM symbol.

II.BACKGROUND

Most first generations systems were introduced in the mid 1980's, and can be characterized by the use of analog transmission techniques and the use of simple multiple access techniques such as Frequency Division Multiple Access (FDMA). First generation telecommunications systems such as Advanced Mobile Phone Service (AMPS) only provided voice communications. They also suffered from a low user capacity, and security problems due to the simple radio interface used. Second generation systems were introduced in the early 1990's, and all use digital technology. This provided an increase in the user capacity of around three times. This was achieved by compressing the voice waveforms before transmission.

Third generation systems are an extension on the complexity of second-generation systems and are expected to be introduced after the year 2000. The system capacity is expected to be increased to over ten times original first generation systems. This is going to be achieved by using complex multiple access techniques such as Code Division Multiple Access (CDMA), or an extension of TDMA, and by improving flexibility of services available.

The telecommunications industry faces the problem of providing telephone services to rural areas, where the customer base is small, but the cost of installing a wired phone network is very high. One method of reducing the high infrastructure cost of a wired system is to use a fixed wireless radio network.

Many currently separate systems and services such as radio paging, cordless telephony, satellite phones and private radio systems for companies etc, will be combined so that all these services will be provided by third generation telecommunications systems.

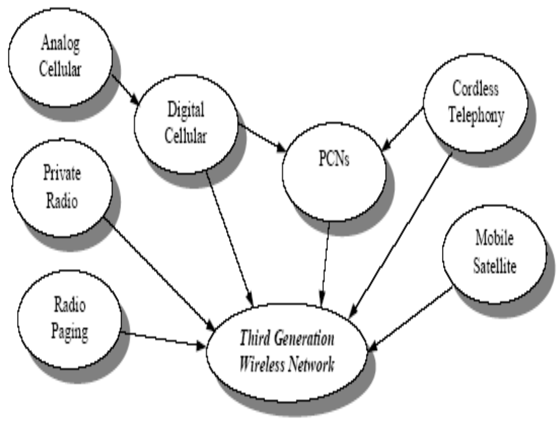

Figure 2.1 Evolution of current networks to the next generation of wireless networks

Currently Global System for Mobile telecommunications (GSM) technology is being applied to fixed wireless phone systems in rural areas. However, GSM uses time division multiple access (TDMA), which has a high symbol rate leading to problems with multipath causing inter-symbol interference. Several techniques are under consideration for the next generation of digital phone systems, with the aim of improving cell capacity, multipath immunity, and flexibility. These include CDMA and OFDM. Both these techniques could be applied to providing a fixed wireless system for rural areas. However, each technique as different properties, making it more suited for specific applications.

OFDM is currently being used in several new radio broadcast systems including the proposal for high definition digital television (HDTV) and digital audio broadcasting (DAB). However, little research has been done into the use of OFDM as a transmission method for mobile telecommunications systems. In CDMA, all users transmit in the same broad frequency band using specialized codes as a basis of channelization. Both the base station and the mobile station know these codes, which are used to modulate the data sent. OFDM/COFDM allows many users to transmit in an allocated band, by subdividing the available bandwidth into many narrow bandwidth carriers. Each user is allocated several carriers in which to transmit their data.

The transmission is generated in such a way that the carriers used are orthogonal to one another, thus allowing them to be packed together much closer than standard frequency division multiplexing (FDM). This leads to OFDM/COFDM providing a high spectral efficiency. Orthogonal Frequency Division Multiplexing is a scheme used in the area of high-data-rate mobile wireless communications such as cellular phones, satellite communications and digital audio broadcasting. This technique is mainly utilized to combat inter-symbol interference.

III. PEAK – TO – AVERAGE POWER RATIO

OFDM is one of the many multicarrier modulation techniques, which provides high spectral efficiency, low implementation complexity, less vulnerability to echoes and non – linear distortion. Due to these advantages of the OFDM system, it is vastly used in various communication systems. But the major problem one faces while implementing this system is the high peak – to – average power ratio of this system. A large PAPR increases the complexity of the analog – to – digital and digital – to – analog converter and reduces the efficiency of the radio – frequency (RF) power amplifier.

Regulatory and application constraints can be implemented to reduce the peak transmitted power which in turn reduces the range of multi carrier transmission. This leads to the prevention of spectral growth and the transmitter power amplifier is no longer confined to linear region in which it should operate. This has a harmful effect on the battery lifetime. Thus in communication system, it is observed that all the potential benefits of multi carrier transmission can be out - weighed by a high PAPR value.

There are a number of techniques to deal with the problem of PAPR. Some of them are amplitude clipping, clipping and filtering, coding, partial transmit sequence (PTS), selected mapping (SLM) and interleaving. These techniques achieve PAPR reduction at the expense of transmit signal power increase, bit error rate (BER) increase, data rate loss, computational complexity increase.

3.1 Peak – to – Average Power Ratio

Presence of large number of independently modulated sub-carriers in an OFDM system the peak value of the system can be very high as compared to the average of the whole system. This ratio of the peak to average power value is termed as Peak-to-Average Power Ratio. Coherent addition of N signals of same phase produces a peak which is N times the average signal.

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.

3.2 PAPR of a Multicarrier Signal

Let the data block of length N be represented by a vector $X = [X_0, X_1, \ldots., X_{N-1}]^T$. Duration of any symbol X_k in the set X is T and represents one of the sub-carriers chosen to transmit the signal are orthogonal to each other, so we can have $\{f_n, n = 0,1,\ldots, N-1\}$set. As the N sub carriers chosen to transmit the signal are orthogonal to each other, so we have $f_n = n\Delta f$, where $n\Delta f = \frac{1}{NT}$ and NT is the duration of the OFDM data block X. The Complex data block X. The complex data block for the OFDM signal to be transmitted is given by.

$$x(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n . e^{j2\pi n \Delta f t}, \quad 0 \leq t \leq NT$$

The PAPR of the transmitted signal is defined as

$$PAPR = \frac{\max_{0<t<NT} |x(t)|^2}{1/NT \int_0^{NT} |x(t)|^2 dt}$$

Reducing the $max|x(t)|$ is the principle goal od PAPR reduction techniques. Since discrete-time signal are dealt with in most system, many PAPR technique 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 by some factor to give the true PAPR value.

3.3 Cumulative Distribution Function

The Cumulative Distribution Function (CDF) is one of the most regularly used parameters, which is used to measure the efficiency of any PAPR technique. Normally, the Complementary CDF (CCDF) is used instead of CDF, which helps us to measure the probability that the PAPR of a certain data block exceeds the given threshold.

By implementing the Central Limit Theorem for a multi – carrier signal with a large number of sub-carriers, the real and imaginary part of the time – domain signals have a mean of zero and a variance of 0.5 and follow a Gaussian distribution. So Rayleigh distribution is followed for the amplitude of the multi – carrier signal, where as a central chi-square distribution with two degrees of freedom is followed for the power distribution of the system.

The CDF of the amplitude of a signal sample is given by

$$F(z) = 1 - \exp(Z)$$

The CCDF of the PAPR of the data block is desired is our case to compare outputs of various reduction techniques. This is given by

$$\begin{aligned} P(PAPR > Z) &= 1 - P(PAPR \leq Z) \\ &= 1 - F(Z)^N \\ &= 1 - (1 - \exp(-Z))^N \end{aligned}$$

3.4 PAPR REDUCTION TECHNIQUES

PAPR reduction techniques vary according to the needs of the system and are dependent on various factors. PAPR reduction capacity, increase in power in transmit signal, loss in data rate, complexity of computation and increase in the bit-error rate at the receiver end are various factors which are taken into account before adopting a PAPR reduction technique of the system.

The PAPR reduction techniques on which we would work upon and compare in our later stages are as follows:

3.4.1 Amplitude Clipping and Filtering

A threshold value of the amplitude is set in this process and any sub-carrier having amplitude more than that value is clipped or that sub-carrier is filtered to bring out a lower PAPR value.

3.4.2 Selected Mapping

In this a set of sufficiently different data blocks representing the information same as the original data blocks are selected. Selection of data blocks with low PAPR value makes it suitable for transmission.

3.4.3 Partial Transmit Sequence

Transmitting only part of data of varying sub-carrier which covers all the information to be sent in the signal as a whole is called Partial Transmit Sequence Technique.

3.4.5 Amplitude Clipping And Filtering

Amplitude clipping is considered as the simplest technique which may be under taken for PAPR reduction in an OFDM system. A threshold value of the amplitude is set in this case to limit the peak envelope of the input signal. Signal having values higher than this pre-determined value are clipped and the rest allowed passing through un-disturbed

$$B(x) = \begin{cases} x & |x| \leq A \\ Ae^{j\phi(x)}, & |x| > A \end{cases}$$

Where

$B(x) =$ the amplitude value after clipping.

x = the initial signal value.

A = The threshold set by the user for clipping the signal

The problem in this case is that due to amplitude clipping distortion is observed in the system which can be viewed as another source of noise. This distortion falls in both in – band and out – of – band. Filtering cannot be implemented to reduce the in – band distortion and an error performance degradation is observed here. On the other hand spectral efficiency is hampered by out – of – band radiation. Out – of – band radiation can be reduced by filtering after clipping but this may result in some peak re – growth. A repeated filtering and clipping operation can be implemented to solve this problem. The desired amplitude level is only achieved after several iteration of this process

3.4.6 Selected Mapping

The main objective of this technique is to generate a set of data blocks at the transmitter end which represent the original information and then to chosen the most favorable block among them for transmission. Let us consider an OFDM system with N orthogonal sub-carriers. A data block is a vector $X = (x_n)N$ composed of N complex number$b_{u,n}$. $u \in \{0,1,\ldots,U-1\}$. Defined so that $|b_{u,n}| = 1$ where $|.|$ denoted the modulus operator each resulting vector $X_u - (X_{u,n})_N$, where $x_{u,n} = b_{u,n}.x_n$, produce after IDFT, a corresponding OFDM signal $s_u(t)$ given by

$$s_u(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N=1} x_{u,n} e^{j2\pi n \Delta f t}, \quad 0 \leq t \leq T$$

Where T is the OFDM signal duration and $\Delta f = 1/T$ is the sub-carrier spacing.

Among the modified data blocks, the one with the lowest PAPR is selected for transmission. The amount of PAPR reduction for SLM depend on the number of phase sequence U and the design of the phase sequences.

3.4.7 Partial Transmit Sequence

In PTS technique, input data block X is partitioned in M disjoint sub-blocks $X_m = [X_{m,0}, X_{m,1}, \ldots, X_{m,N-1}]^T, m = 1,2,\ldots,M,$ is obtained by taking the IDFT of length NL on X_m concentrated with $(L-1)N$ zeros. These are called the partial transmit sequences. Complex phase factors is denoted a vector $b = [b_1, b_2, \ldots, b_M]^T$. The time domain signal after combining is given by

$$x'(b) = \sum_{m=1}^{M} b_m . x_m$$

Where $x'(b) = [x'_0(b), x'_1(b), \ldots, x'_{NL-1}(b)]^T$. The objective is to find the set of phase factors that minimizes the PAPR. Minimization of PAPR is related to the the minimization of $max_{0 \leq k \leq \leq NL-1} |x'_k(b)|$.

3.4.8 Tone Reservation (TR)

The main idea of this method is to keep a small set of tones for PAPR reduction. This can be originated as a convex problem and this problem can be solved accurately Tone reservation method is based on adding a data block and time domain signal. A data block is dependent time domain signal to the original multicarrier signal to minimize the high peak. This time domain signal can be calculated simply at the

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transmitter of system and stripped off at the receiver. The amount of PAPR reduction depends on some factors such as number of reserved tones, location of the reserved tones, amount of complexity and allowed power on reserved tones This method explains an additive scheme for minimizing PAPR in the multicarrier communication system.

It shows that reserving a small fraction of tones leads to large minimization in PAPR ever using with simple algorithm at the transmitter of the system without any additional complexity at the receiver end. Here, N is the small number of tones, reserving tones for PAPR reduction may present a non–negligible fraction of the available bandwidth and resulting in a reduction in data rate. The advantage of TR method is that it is less complex, no side information and also no additional operation is required at the receiver of the system.

3.4.9 Tone Injection (TI) Method

This technique is based on general additive method for PAPR reduction. Using an additive method achieves PAPR reduction of multicarrier signal without any data rate loss. TI uses a set of equivalent constellation points for an original constellation points to reduce PAPR. The main idea behind this method is to increase the constellation size. Then, each point in the original basic constellation can be mapped into several equivalent points in the extended constellation, since all information elements can be mapped into several equivalent constellation points. These additional amounts of freedom can be utilized for PAPR reduction. The drawbacks of this method are; need to side information for decoding signal at the receiver side, and cause extra IFFT operation which is more complex.

3.4.10 Selective Mapping Technique (SLM)

The block diagram of SLM technique is shown in Figure 2.

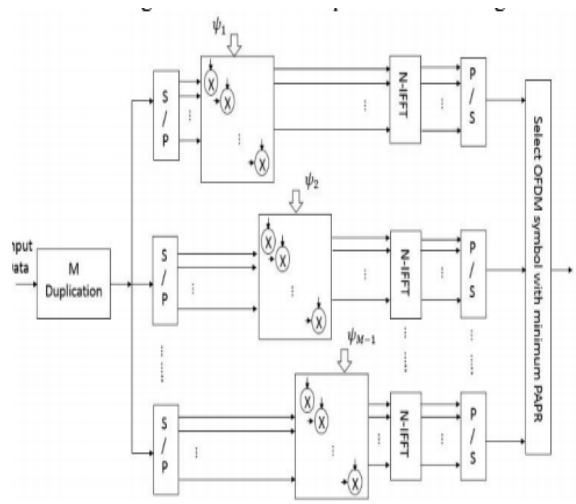

Fig 3.4.10: Functional block diagram of the SLM technique.

In this approach, firstly M statistically independent input data sequences Xm which represent the same information are generated, and then each sequence are processed by M parallel N-point complex IFFT to generate M different time-domain OFDM symbols . The OFDM symbol with the smallest PAPR is selected for transmission [13], [14].
The key point of SLM method lies in how to generate multiple distinct time-domain OFDM symbols when the input data for transmission is the same. For this purpose, M pseudo-random phase rotation sequences ψm are generated.

$\psi m = [\psi m,0\ \psi m,1\ \dots\ \psi m,N-1]\ T$ (4)

With $m = 1,2, \dots , M$,
$\psi m, = ej\varphi m,$ and $\varphi m,$
k is uniformly distributed in $[0, 2\pi]$ and $0 \leq k \leq N - 1$.
This process can be seen as performing a dot product operation on the input tones
$X = [(0), (1), \dots , X(N-1)]$

with rotation factors
$\psi m. Xm = X. \psi m, m = 1,2, \dots , M$ (5)

Then, the time-domain OFDM symbols xm can be written as
$:x\ m = IFFT\{Xm\} = IFFT\{X. \psi m\}$ (6)

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In practice, all the elements of the phase sequence $\psi 1$ are set to 1 to make this branch sequence as the original OFDM symbol. This approach is applicable with all types of modulation and any number of subcarriers. The amount of PAPR reduction for SLM depends on the number of phase sequences M and the design of the phase sequences.

IV.PROPOSED GA BASED SLM-OFDM SYSTEM

This section investigates how GA can be used for phase optimization of SLM-OFDM system. In order to solve the optimization problem of this system and acquiring more PAPR reduction, the proposed technique uses GA as the selection mechanism of phase rotation factors for SLMOFDM system. GA, which is a search heuristic algorithm based on the the process of natural evolution, can find a good solution for optimization problems by evolving the population of solutions with genetic operators such as selection, mutation and crossover [15].

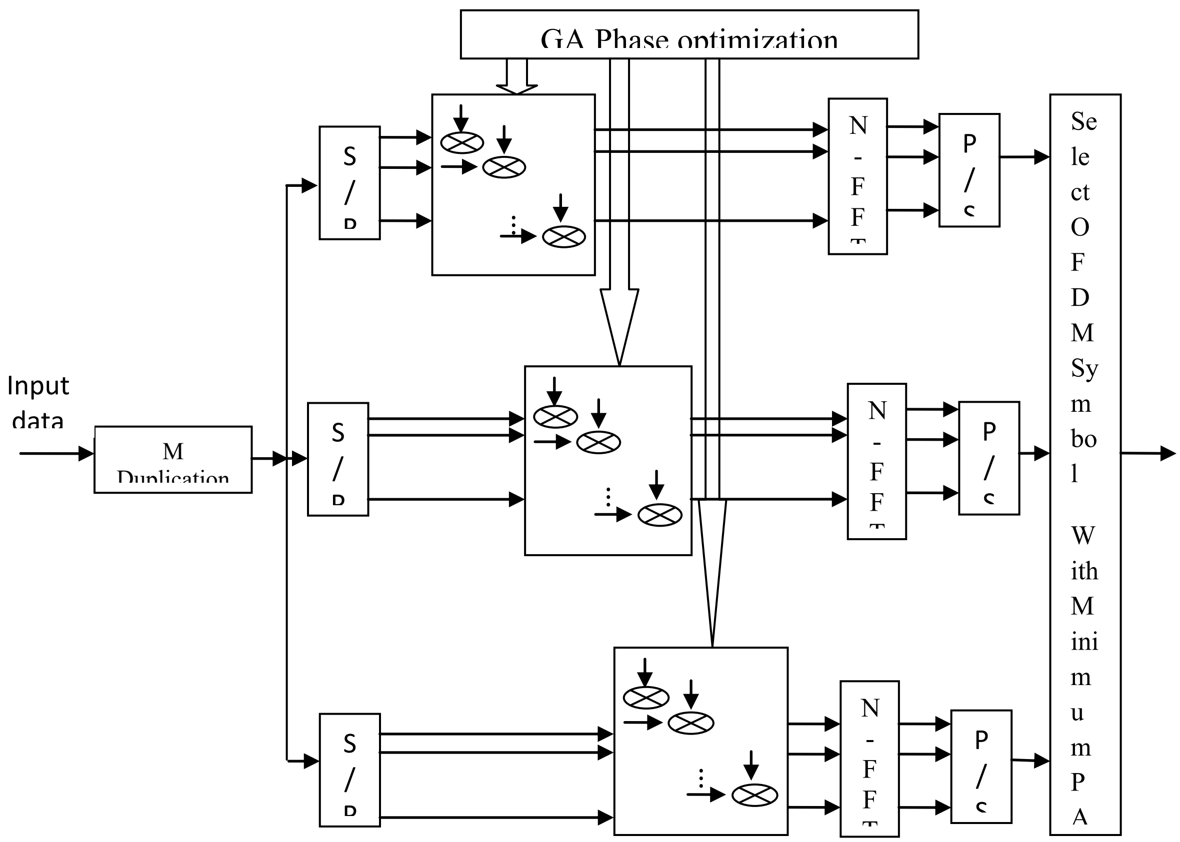

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Fig 3: Functional block diagram of the proposed GA based SLMOFDM technique.

The block diagram of the proposed GA based SLM-OFDM system is shown in Figure 3.
In order to employ the GA method to find the optimum phase factors that minimize the PAPR in the SLM-OFDM system, the following optimization problem is required to be solved:

$$\psi_{opt} = argmin_{\psi}\left\{\frac{max_{0\leq n\leq N-1}|x_m(n)|^2}{E\{|x_m(n)|^2\}}\right\} \quad (7)$$

Where $m = 1,2, \ldots, M$ and ψopt is the optimum phase rotation factors.
The selection mechanism of GA based SLM-OFDM is described as follows:

Proposed Algorithm: GA-SLM-OFDM method

1. Select the first population size, the mutation probability, crossover probability, and initial population randomly. Each gene represents a vector of phase factor candidate.
2. Calculate the PAPR value for each gene by multiplying X with the set of phase rotation factors as given by (6).
3. Select genes with smallest PAPR value (called set of parents).
4. Crossover and mutate all genes to generate a new genes (offspring's).
5. Go back to step 2 using the new generated population. The processing is repeatedly executed until termination (maximum number of generation). The vector of phase rotation factors with the lowest PAPR are used for the transmitted data and sent to the receiver.
6. End

V. SIMULATION RESULTS

Using MATLAB software simulation analysis of PAPR reduction is performed by averaging over 104 randomly OFDM symbols with QPSK modulation. The analysis of PAPR performance for original OFDM, the conventional SLM-OFDM and GA based SLM-OFDM systems is presented in terms of CCDF. The simulation parameters used through the comparative study are stated in Table I. Table I: Simulation parameters.

System parameters	Value
Number of subcarriers	128
Modulation type	QPSK
Phase rotations	-1, 1, j, -j
Size of initial population	150
Number of iteration	10
Mutation probability	0.3
Crossover probability	0.7

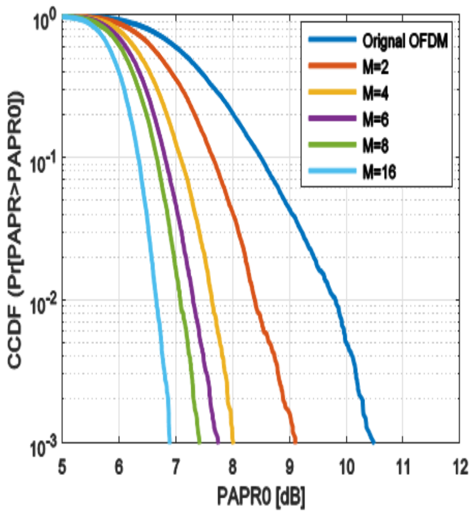

Fig 5.1: CCDF of the OFDM for SLM technique with different number of phase sequences M and N = 128 subcarrier.

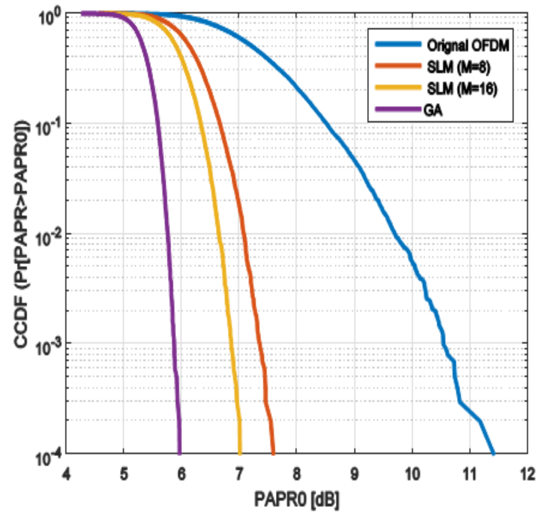

Fig 5.2: CCDF of the original OFDM, GA based OFDM-SLM and OFDM-SLM techniques with (M = 8,16).

As shown in Figure 4, it can be observed that the conventional 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 the number of phase sequences M leads to the improvement of PAPR reduction performance. If the probability is set to 10-2 and then the CCDF curves with different M values are compared.

The PAPR value of case M = 2 is about 1.5 dB smaller than the unmodified one M = 1. Under the same condition, the PAPR value of case M = 16 is about 3.2 dB 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 about 0.5 dB. 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 $M \geq 8$), the PAPR reduction performance of OFDM signal will not be considerably improved and it will also add more computational complexity.

The PAPR Reduction performance of proposed GA based SLM-OFDM system is compared with conventional SLMOFDM system in Fig 5 . The simulation depicts that GA based SLM-OFDM is more effective in reducing the PAPR than SLM-OFDM. At CCDF probability of 10-2, GA based SLM-OFDM attains 5.8 dB PAPR, while the SLM-OFDM with (= 16) attains 6.7 dB with reduction gain of 0.9 dB. We can notice also that the PAPR reduction gain of the GA based SLM-OFDM compared with original OFDM is about 4 dB. From Figure 6, it can be seen that the proposed GA based OFDM-SLM algorithm undeniably improves the performance of OFDM system, moreover, with the increasing of population size P, the improvement of PAPR reduction performance becomes better and better. Assume that we fix the probability of PAPR at 10-2, and compare the CCDF curve with different P values. Form the Figure 6, we notice that the CCDF curve has nearly 0.2 dB improvement when P = 300 compared to P = 150. When P = 600, the 10-2 PAPR is about 5.4 dB, so an optimization of more than 0.35 dB is achieved compared to P = 150.

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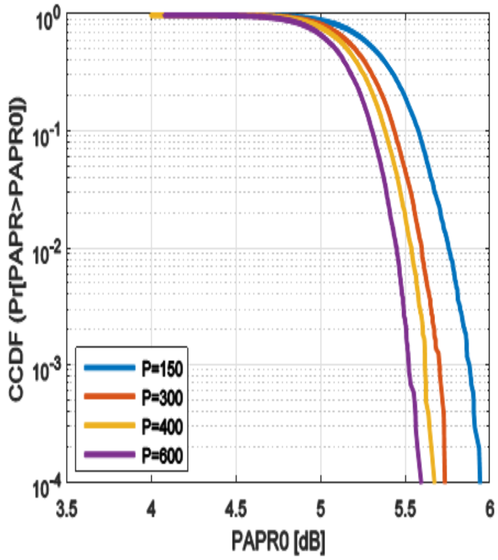

Fig 5.3 : CCDF of the GA based OFDM-SLM technique with different population size *P*.

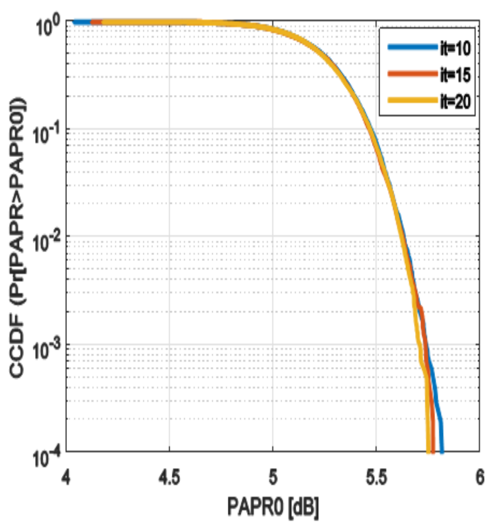

Fig 5.4: CCDF of the GA based OFDM-SLM technique with different iteration values .

Figure 7 shows the effect of the iterations on the PAPR performance. It can be seen that the PAPR is reduced clearly by increasing the number of iterations.

VI.CONCLUSION

In this paper, an efficient technique based on GA is proposed to achieve PAPR reduction. The PAPR reduction performance of the proposed SLM-OFDM system using GA for optimum phase rotation factors searching was compared with the original OFDM and conventional SLM-OFDM systems. According to the simulation results, the proposed GA based SLM-OFDM outperforms the compared systems with low computational complexity.

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