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Wavelet Packet Assisted Genetic Algorithm Based ISI-ICI Suppression for OFDM Systems

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Abstract

In this paper, the behavior of Wavelet Packet-Orthogonal Frequency Division Multiplexing (WP-OFDM) system based on Genetic Algorithm (GA) to mitigate both the Inter-Symbol Interference (ISI) created by a channel with longer impulse response duration than that of the Cyclic Prefix (CP)as well as the Inter-Carrier Interference (ICI) resulting from high Doppler spreads is investigated. This is realized by simulation environment to utilize the advantages of modeling programs. In this simulation, Wavelet Transforms (WT) have been considered as alternative platforms for replacing Inverse Forrier Transform (IFFT) and FFT; all are programmed using MATLAB package. The simulation result shows that the ICI (ISI) power is significantly reduced. In this investigation,the effectof delay spread with 16-QAM and QPSK modulation schemes was studied. Results also show that our model, genetic based WP-OFDM, is superior as compared to WP-OFDM.

Key Words:OFDM, GA, WP, WT,ISI, ICI.

1 Introduction

Orthogonal Frequency Division Multiplexing (OFDM),which is considered as a key technology of the next generation mobile communication, has been proposed or adapted for digital audio and video broadcastings, wireless Local Area Network (LAN), and high definition television [1].In OFDM transmission system, channel variations within an OFDM symbol destroy orthogonality between subcarriers, resulting in inter-Carrier Interference (ICI), which increases the error floor in proportional to normalized Doppler frequency [2].On the other hand OFDM provides an efficient means to handle high-speed data streams on a multipath fading environment that causes serious Inter-Symbol Interference (ISI). Adding a Cyclic Prefix (CP) is the main way for Fourier-based OFDM to eliminate the ISI. But this can decrease the bandwidth (BW) efficiency greatly, which means that we have a long way to go to improve the BW efficiency. To decrease the BW waste brought by adding CP, wavelet-basedhas been proposed due to its excellent orthogonality between subcarriers and wonderful spectral containment [3].

Wavelet transforms have been considered as alternative platforms for replacing Inverse Forrier Transform (IFFT) and FFT [3,4]. By using the transform, the spectral containment of the channels is better since it does not use CP. One type of wavelet transform is the Discrete Wavelet Transform (DWT). It employs Low Pass Filter (LPF) and High Pass Filter(HPF) operating as Quadrature Mirror Filters (QMF) satisfying perfect reconstruction and orthonormal bases properties. The transform uses filter coefficients as approximate and detail in LPF and HPF respectively. The approximated coefficients is sometimes referred to as scaling coefficients, whereas, the detailed is referred to wavelet coefficients.Sometimes these two filters are called subband codingsince the signals are dividedinto sub-signals of low and highfrequencies respectively[4]. Generally, there are several advantages of using wavelets and wavelet packets, for wireless communicationsystems [5]: semi arbitrary division of the signal space and multirate systems, flexibility with time frequency tiling, signal or waveform diversity, sensitivity to channel effects, flexibility with sub carriers, power conservation …etc. While the latest advancements and developments in the use of wavelets for wireless communications are: channel characterization (modeling wireless channels with wavelets as bases, antenna design and electromagnetic computations and speed estimation in wireless systems), interference mitigation and denoising (signal denoising, mitigation of interference and mitigation of ISI and ICI), wavelets for modulation and multiplexing (wavelets for single carrier modulation, wavelets for multicarrier modulation WOFDM, fractal modulation and multiplexing), wavelets for multiple access communication (Scale Code Division Multiple Access SCDMA and Multi Carrier (MC)-CDMA), UWB Communication (Impulse Radio IR and Multi Band OFDM MB-OFDM), cognitive radio-intelligent wireless communication system and wavelet for networking (wavelet-based adaptive and energy efficient data processing for mobile services, wavelets for traffic analysis, wavelet based data reconstruction scheme, wavelets for modeling network traffic and wavelets for adaptive distributed data processing in wireless sensor networks) [5].

Now, since these effects (ISI-ICI) degrade the OFDM signal, it is a severe challenge to increase the system performance and the accuracy of channel estimation. As well known, an OFDM system is very sensitive to the quality of channel estimation, and apart from the WT, which is the most complex unit of the receiver.

The purpose of this paper is to perform simulation studyon the wavelet (Haar family) based OFDM particularly in WP-OFDM using a genetic algorithm (GA) innovation to ameliorate the effects of narrowband interference and isinherently more robust with respect to ISI, ICI than traditionalFourier-based OFDM.

GAs have been employed for solving many complex optimization problems in numerous fields. While GAs are not perfect, i.e., they do not always find the optimal point, they are very efficient in attaining near-optimal solutions significantly faster than conventional point-by-point exhaustive search techniques, especially in large solution spaces [6]. The evolution process of genetic algorithms is based on the natural selection. Genetic algorithms employ chromosomes through three operations, reproduction, crossover, and mutations to generate offspring for next iterations. The advantages of genetic algorithms are derivative-free stochastic optimization, parallel-search procedure and applicable to both continuous and discrete problems.

The paper is organized as follows. In the next section wepresent the system model used in this paper. We consider a WP-OFDM over a multipath channel. Section (3) describes the GAs used to implementour proposed WP-OFDM. Our simulation results are presented in Section (4). Section (5)concludes the paper.

2 System Description
A. DWT and WPT

The Digital Wavelet Transform (DWT) analyzes the signal at different frequency bands with different resolutions by decomposing the signal into an approximation containing coarse and detailed information [5]. DWT employs two sets of functions, known as scaling and wavelet functions, which are associated with low pass and high pass filters. The decomposition of the signal into different frequency bands is simply obtained by successive high pass and low pass filtering of the time domain signal. The original signal $x[n]$ is first passed through a half-band high pass filter $g[n]$ and a half-band low pass filter $h[n]$. A half-band low pass filter removes all frequencies that are above half of the highest frequency, while a half-band high pass filter removes all frequencies that are below half of the highest frequency of the signal. The low pass filtering halves the resolution time, but leaves the scale unchanged (figure (1)). The signal is then subsampled by two since half of the number of samples is redundant, according to the Nyquist's rule. This decomposition can mathematically be expressed as follows:

$$y_{\text{high}}[k] = \sum_n x[n]g[2k - n]$$
$$y_{\text{low}}[k] = \sum_n x[n]g[2k - n]\ldots \qquad (1)$$

where $y_{\text{high}}[k]$ and $y_{\text{low}}[k]$ are the outputs of the high pass and lowpass filters, after subsamplingby a factor of two.

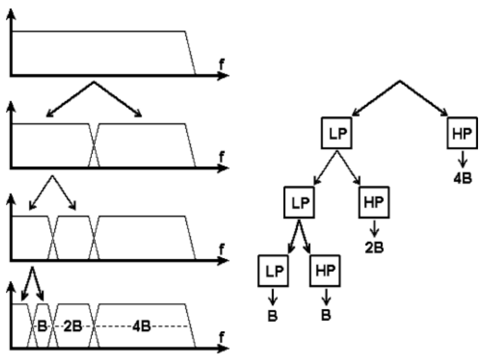


Figure (1).Subband Coding; (Left): Frequency domain representation,(Right): Tree-structure [7]

This decomposition halves the time resolution since only half the number of samples then comes to characterize the entire signal. Conversely it doubles the frequency resolution,since the frequency band of the signal spans only half the previous frequency band effectivelyreducing the uncertainty by half. The above procedure, which is also known as subbandcoding, can be repeated for further decomposition. At every level, the filtering andsub-sampling will result in half the number of samples (and hence half the time resolution)and half the frequency bands being spanned (and hence doubles the frequency resolution) [5].

The Wavelet Packet Transform (WPT) is just like the wavelet transform except that it decomposes eventhe high frequency bands which are kept intact in the wavelet transform. Figure (2) [5] illustrates thewavelet packet based OFDM transceiver.

In this figure, at the transmitter the data stream X= (x[1], x[2], x[3], …, x[N]) is first converted from serialto parallel sequences S_k and then modulated with M-ary Inverse WPT (IWPT) [5,8].

The transmitted signal Y,is composed of successive K symbols, as the sum of M amplitude modulated waveforms byϕ_k. It can be expressed using matrix notations as:

$$Y=\sum_k S_k \cdot \phi_k \quad (2)$$

whereY= (y[1], y[2], y[3], …, y[N]) is transmitted signal,
S_k= ($s_0[k]$, $s_1[k]$, $s_2[k]$, …, $s_m[k]$, …, $s_M[k]$),is constellation encoded k-thdata symbol,and

$$\phi_k = \begin{pmatrix} \emptyset_0[1-kM] & \cdots & \emptyset_0[N-kM] \\ \vdots & \emptyset_m[n-kM] & \vdots \\ \emptyset_{M-1}[1-kM] & \cdots & \emptyset_{M-1}[N-kM] \end{pmatrix} \quad (10)$$

is the waveforms matrix which $\emptyset_m[n]$ are mutually orthogonal to reduce the interference errors, i.e.

$$\emptyset_i[n] * \emptyset_j[n] = \delta[i-j]\ldots\ldots \quad (4)$$

Where * indicates a convolution operation and, δrepresents the Dirac function.
The relationship [8] between the number of iterations $j$and the number of carrier waveforms M isgiven by $M=2^j$.
In orthogonal wavelet systems, quadrature mirror filter pair (QMF) consists of the scaling filter $h_{lo}^{rec}$and dilatation filter h_{hi}^{rec}, and knowledge of the scaling filter and wavelet tree depth is sufficient to design the wavelet transform. The scaling filterh_{lo}^{rec} and dilatation filterh_{hi}^{rec}, and the corresponding reversed filters h_{lo}^{dec} and h_{hi}^{dec}, are used to form a wavelet packet tree.

These filters satisfy the following conditions:

$$\sum_{n=-\infty}^{n=\infty} h_{lo}^{rec}[n] = 2 \quad (5)$$

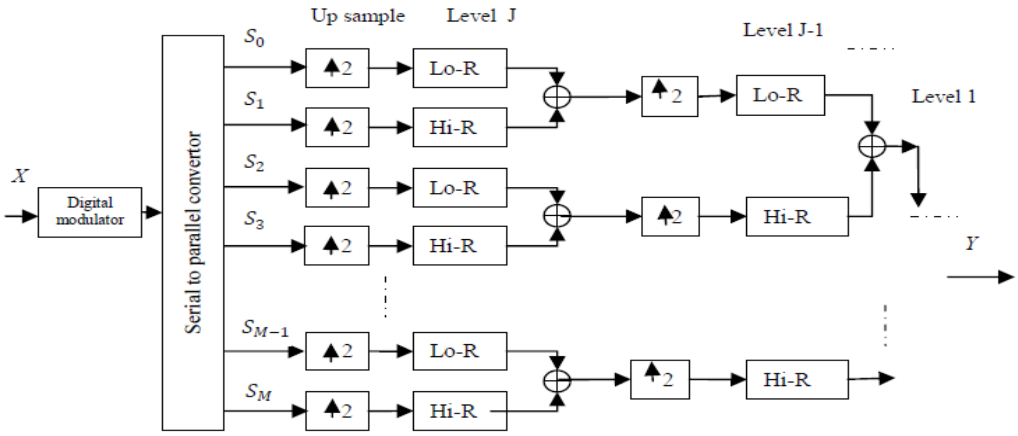
$$\sum_{n=-\infty}^{n=\infty} h_{lo}^{rec}[n] h_{lo}^{rec}[n-2q] = 2\delta(q) \quad (6)$$

$$h_{hi}^{rec}[n] = (-1)^n h_{lo}^{rec}[\lambda - n - 1] \quad (7)$$

whereλ is the span of the filters.
The carrier waveforms are obtained by iteratively filtering the signal into high and low frequencycomponents. The waveforms $\emptyset_m[n]$ are derived by $j$successive iterations as the followingrecursive equations [8]:

$$\begin{cases} \emptyset_{j,2m}[n] = h_{lo}^{rec}[n] * \emptyset_{j-1,m}[\frac{n}{2}] \\ \emptyset_{j,2m+1}[n] = h_{hi}^{rec}[n] * \emptyset_{j-1,m}[\frac{n}{2}]\ldots \\ \emptyset_{0,m}[n] = \begin{cases} 1, & n=1 \\ 0, & else \end{cases} \end{cases} \quad (8)$$

where$j$ is the iteration index, $1 \le j \le J$, and m the waveform index $0 \le m \le M-1$. Using usual notation in discrete signal processing $\emptyset_{j,m}[\frac{n}{2}]$ denotes two version upsampling of $\emptyset_{j,m}[\frac{n}{2}]$.
The type of WPT algorithm depends on the choice of mother wavelet, the number of levels ofexpansion, and signal specifications such asperiodic, nonperiodic, extended and finite WPT. Time and frequency domain localizations are notindependent and a waveform with higherfrequencydomain localization can be obtained with longertime support



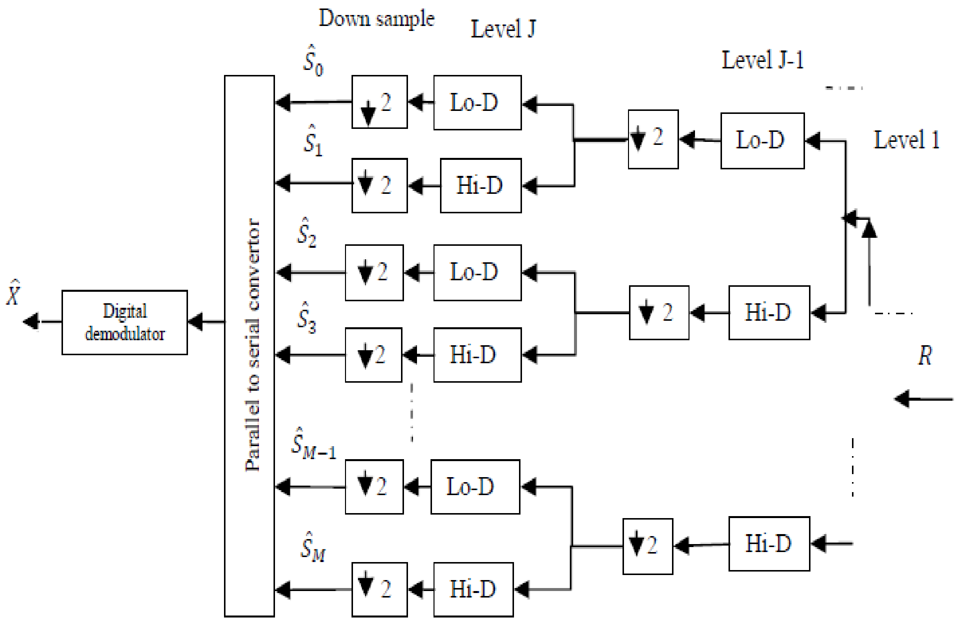


Figure (2b). Wavelet packet based OFDMreceiver part, including decomposition filters

Furthermore, shortduration waveforms have shorter symbol duration than the channel coherence time, limit themodulation-demodulation delay, and require less memory and less computation [8].
For the evaluation of a channel, we assume a channel H, with L multipaths,

$H = (h[0], h[1], \dots, h[l], \dots, h[L-1])$……(9)

and received signal at the output of the channel can be written as:

$R = H.Y + V$,……(10)

where$R = (r[1], r[2], \dots, r[n], \dots, r[N])$ is the received signal, and

$V = (v[1], v[2], \dots, v[n], \dots, v[N])$is Additive White Gaussian Noise (AWGN).

We consider [9] a two-path wireless channel with $r[n] = h[n]\{y[n] + y[n-d]e^{j\theta}\} + v[n]$,where $d$is a positive integer denoting the excess delay ofthe channel, normalized to the symbol period ofincoming M-ary modulated serial data, and θ,is therandom phase of the second path with uniform distribution over $[0, 2\pi)$.

B. ISI and ICI Power Calculations

We focus on the power of interference which can becalculated using the definitions of IS1and IC1 in [9]. That is, IS1 for a particular subchannel joccurs when delayedwaves oftransmitted symbols of the subchannelj, affectthe reception of the currently transmitted symbol of thesame subchannel and IC1 occurs when delayed waves oftransmitted symbols of all other channels affect thedetection of the currently transmitted symbol of thesubchannel j. Therefore, the IS1and IC1 for the subchannel j are:

$$\sum_{i=-\infty}^{i=\infty} S_j[i]\emptyset_{jjp}[n_j[n-i]] = ISI_j(n)$$

$$\sum_{i=-\infty}^{i=\infty}\sum_{\substack{k=0\\k\neq j}}^{M-1} S_k[i]\emptyset_{jkp}\left[nn_j - in_k\right] = ICI_j(n) \qquad (11)$$

where,

$$\emptyset_{jkp}[n] = \emptyset_k[n-p] * \emptyset_j{}^*[-n] =$$

$\sum_{i=-\infty}^{i=\infty}\emptyset_k[i-p]\emptyset_j{}^*[i-n]]$, and

.

$$\emptyset_{jjp}[n] = \emptyset_j[n-p] * \emptyset_j{}^*[-n] =$$

$$\sum_{i=-\infty}^{i=\infty}\emptyset_j[i-p]\emptyset_j{}^*[i-n]]$$

The power of ISI and ICI [9], $\sigma^2_{ISI_j}$ and $\sigma^2_{ICI_j}$are determined, respectively, as:

$\sigma^2_{ISI_j} = \sum_{m=-\infty}^{m=\infty}|\emptyset_{jjp}\left[mn_j\right]|^2$, and

$$\sigma^2_{ICI_j} = \sum_{m=-\infty}^{m=\infty}\sum_{\substack{k=0\\k\neq j}}^{M-1}|\emptyset_{jkp}[mn_k]|^2 \qquad (12)$$

3 GA Assisted ISI-ICI Suppression for OFDM Systems

The simplest form of genetic algorithm involves three typesof operators: selection, crossover, and mutation [10].

A. Selection

This operator selects chromosomes in the population forreproduction. The fitter the chromosome, the more times it islikely to be selected to reproduce. Selection is based on fitnessfunction (eq. (14)):

B. Crossover

This operator randomly chooses a locus and exchanges the subsequences before and after that locus between two chromosomes to create two offspring. For example, the strings 10000100 and 11111111 could be crossed over after the third locus in each to produce the two offspring 100-11111 and 111-00100. The crossover operator roughly mimics biological recombination between two single chromosome organisms.

C. Mutation

This operator randomly flips some of the bits in achromosome. For example, the string 00000100 might bemutated in its second position to yield 01000100. Mutation can occur at each bit position in a string with someprobability, usually very small (e.g., 0.01).

Figure (3) below shows the schematic of the GA employedin an OFDM system. The output of this figure is an estimated signal ($\hat{X}$) in serial form.

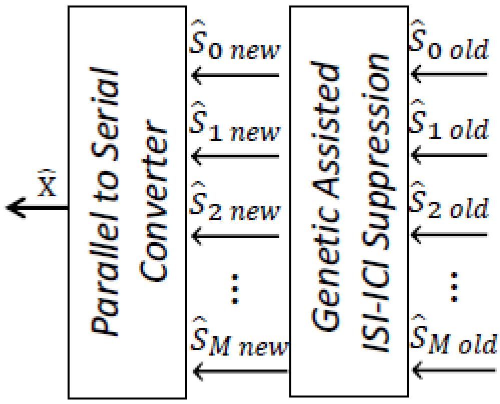


Figure (3). Schematic of the GA assistedISI-ICI suppression aided WP-OFDM base station receiver

Now, the decision rule for optimum OFDMISI-ICI suppression scheme based on the maximum likelihood criterion is tochoose the specific *M*-carriers bit combination *S*. Hence, wehave tofind:

$\hat{s}_{m\ old} = arg\{max[R(Y^{-1})]\}$, and

$\hat{S}_{old} = \left[\hat{s}_{0\ old,}\hat{s}_{1\ old,}\dots,\hat{s}_{Mold}\right]$ ......(13)

The maximization of $R(Y^{-1})$ is a combinatorial optimization problem [11], which requires anexhaustive search for each of the 2^Mcombinations of *S*in order to find the one that maximizes this relation. Explicitly, since in case of binary transmissions thereare 2^Mpossible combinations of *S*, the optimum interference suppressorhas acomplexity that increases exponentially with the numberof carriers$M$.

The flowchart depicting the structureof the genetic algorithmadopted for ourGAassisted ISI-ICI technique is shown in figure (4) [11-14].

Firstly, an initial population consisting of Pnumber of so-called individualsis created in the initializationblock, where P is known as the population size. Each individualrepresents a legitimate M-dimensional vector of QPSK (and 16-QAM) symbolsconstituting the solution of the given optimization problem. Inother words, an individual canbe considered asan$M$-dimensionalvector consisting of the QPSK (16-QAM) decision variables to be optimized.

A different randomly mutated version [12] of the harddecision vector $\hat{S}_{old}$ was assignedto each of theindividuals in the initial population, where the same probabilityof mutation, namely $p_m$was adopted for allindividual. Notethat we cannot assignthe same hard decision vector $\hat{S}_{old}$toall the individuals, since the process of incest prevention isinvoked, which will not allow identical individuals to mate.

The so-called fitness value [12] associated with each individualin the population is evaluated by substituting the candidate solution represented by the individual under consideration into the objective function (or Fitness Function, FF), as indicated by the evaluation blockof figure (4):

$$FF_m = e^{-(\hat{s}_{m\ old})} \ldots\ldots(14)$$

Individuals having the T number of highest fitness values are then placed in a so-called mating pool.

Our fitness value is defined by the correlation metric [12]of $R(Y^{-1})$. Our goal is to find the specific individualthat corresponds to the highest fitness value in the sense of$R(Y^{-1})$ then converted this binary string to its equivalent weighted value.Again, the legitimatesolutions are the 2^M possible combinations of the M symbolvector S.Hence, each individual will take the form of an$M$symbolvector corresponding to the Mcarriers QPSK (16-QAM) symbolsduring a single-symbol interval.

Using a kind of natural selection scheme together with the genetically-inspired operators of crossover and mutation, the individuals in the mating pool are then evolved to a new population. We will denote the pth individual here as:

$$\hat{S}_{p\ new}(x) = \left[\hat{s}_{p,0\ new}(x), \hat{s}_{p,1\ new}(x), \ldots, \hat{s}_{p,M\ new}(x)\right],$$

where $x$denotes the yth generation. Once a pair of parents is selected, the crossover and mutation operations are then applied to this pair of parents.

As before, the crossover [12] operation is a process in which arbitrary decision variables are exchanged between a pair of selected parents, "mimicking the biological recombination process between two single-chromosome organisms". Hence, the crossover operation creates two new individuals, known as offspring in GA parlance, which have a high probability of having better fitness values than their parents. In order to generate P number of near offspring, P/2 number of crossover operations is required.

A new pair of parents is selected from the mating pool for each crossover operation. The newly created offspring will form the basis of the new population.

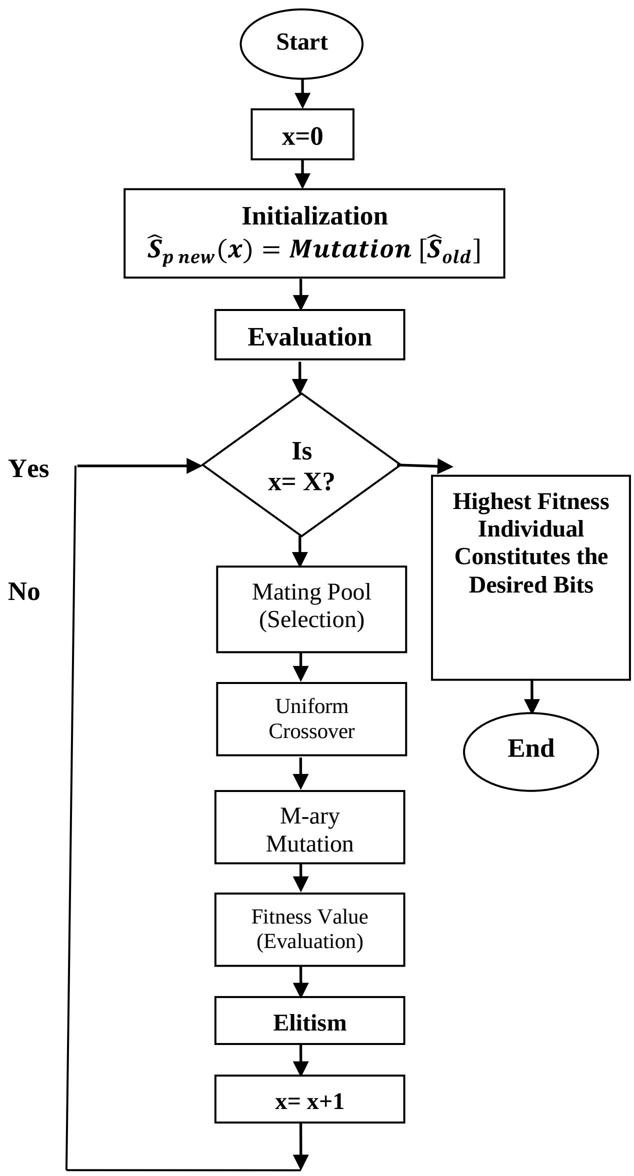


Figure (4).A flowchart depicting the structure of thegenetic algorithm adopted for our GA-assisted OFDM system.

During the mutationoperation[12], each decision variable in the offspring is perturbed, i.e.corrupted, with a probability of p_m, by either a predeterminedor a random value. This allows new areas in the search spaceto be explored. The mutation probability of a decision variableis usually low, in the region of 0.1-0.01 [12]. This value is oftenreduced throughout the search, when the optimization is likelyto approach the finalsolution. In this contribution, single-point crossover and binary mutation were employed.

In order to ensure that high-merit individuals are not lost from one generation to the next, the best or a few of the best individuals are copied into the forthcoming generation, replacing the worst offspring of the new population. This technique is known as elitism [12, 14]. In our application, we will terminate the GA-assisted search at the Xth generation and the individualassociated with the highest fitness value at this point will bethe suitable solution. The configuration of the GA employedin our system is characterized in table (1) below.

Table (1). GA parameters

GA Type	Nonoverlapping
Population Size	25
Number of Generations	25
Mutation Type	Binary Mutator
Probability of Mutation	0.01
Crossover Type	Single-Point Crossover
Scaling	Sigma Truncation
Initialization	Uniform
Genome Type	Binary String
Comparison	Bit Comparator
Encoding/Decoding	Binary Encoding/Decoding
Selection	Roulette Wheel
Elitism	On

4Simulation Results

In this section simulation results are presented based on evaluating the power performance of the ISI and ICI based GA technique. After computationof the IS1 and IC1 for each of subchannels, the mean valueof interference is calculated. Figures(5&6) show the average power performance againstthe increasing in carrier number (table (2)). Simulation results have shown that theperformance of genetic assisting wavelet packet in OFDM systems is better for the ISI and much better for the ICI thanthe ordinary wavelet transformer. It is seen thatcomparing with the conventional WP-OFDM; the average IS1 (ICI) power in the case of intelligent modelishighly reduced.

Table (2). Average power of interference for OFDM system

		Number of Carriers			
		4	**8**	**16**	**32**
WP-OFDM	**ISI (dB)**	-4.19	-2.38	-1.32	-0.22
	ICI (dB)	-3.1	-7.42	-18.41	-42.10
Genetic WP-OFDM	**ISI (dB)**	-4.43	-2.53	-1.39	-0.30
	ICI (dB)	-4.96	-11.88	-19.93	-53.29

On the other hand, the BER performance of genetic WP- and WP-OFDM systems as a function of delay of second path is shown in figure (7). Two types of modulation QPSK and 16-QAM are taken. From the figure, as shown, the BER will increase with increasing the delay.

5.Conclusions

In conclusion, it has been developed aninterference suppressor based on GAin a multipath channel in order to circumvent the complexity problem faced by the Multi-Carrier (MC)suppressor. To mitigate the effects of interference, wavelet packet transform (with Haar family) was used. It was shown that the GA-WP is capable of significantly reducing the computational power of the MC suppressor (table (2)), also exhibited a lower BER compared to this employing the former strategy.

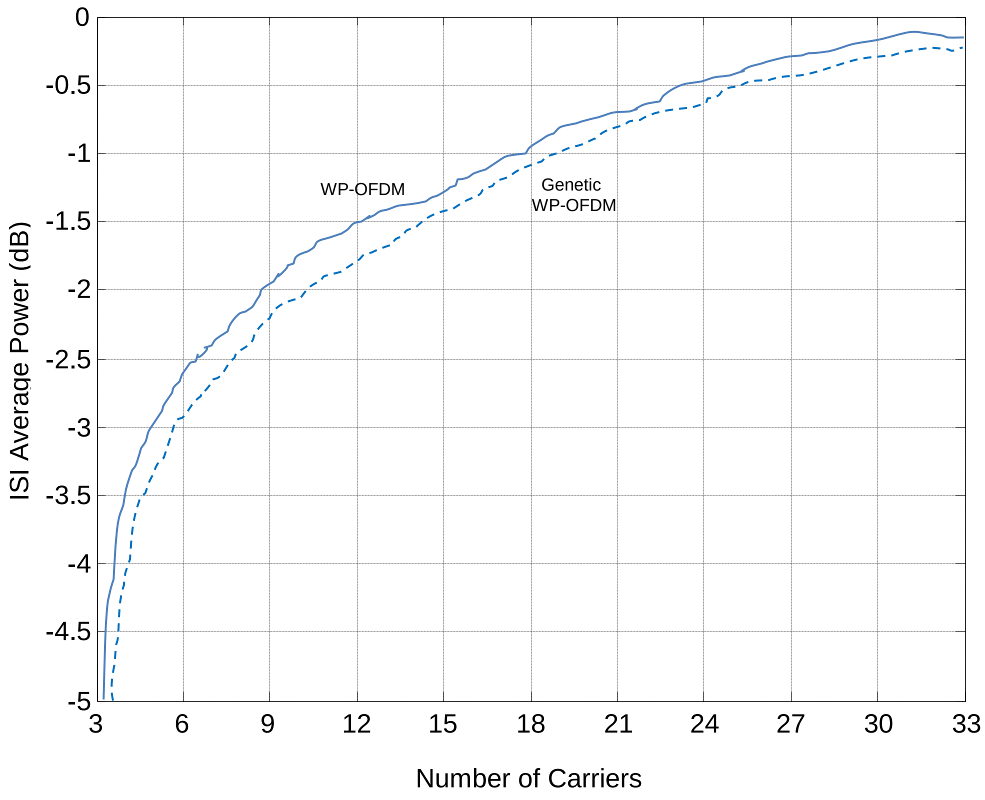


Figure (5).ISI average power for both conventional wavelet packet and genetic assisted wavelet packet based OFDM systems

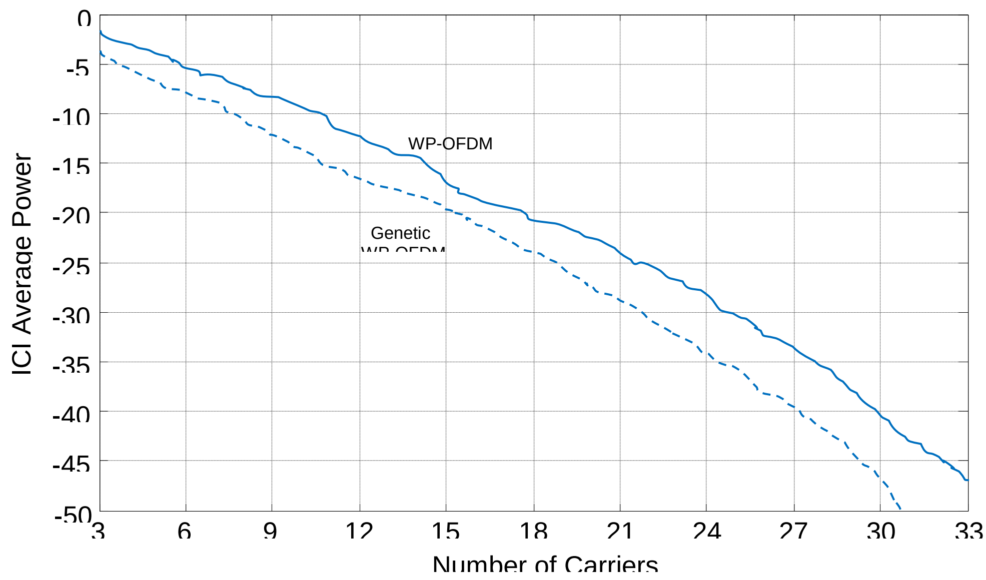


Figure (6). ICI average power for both conventional wavelet packet and genetic assisted wavelet packet based OFDM systems

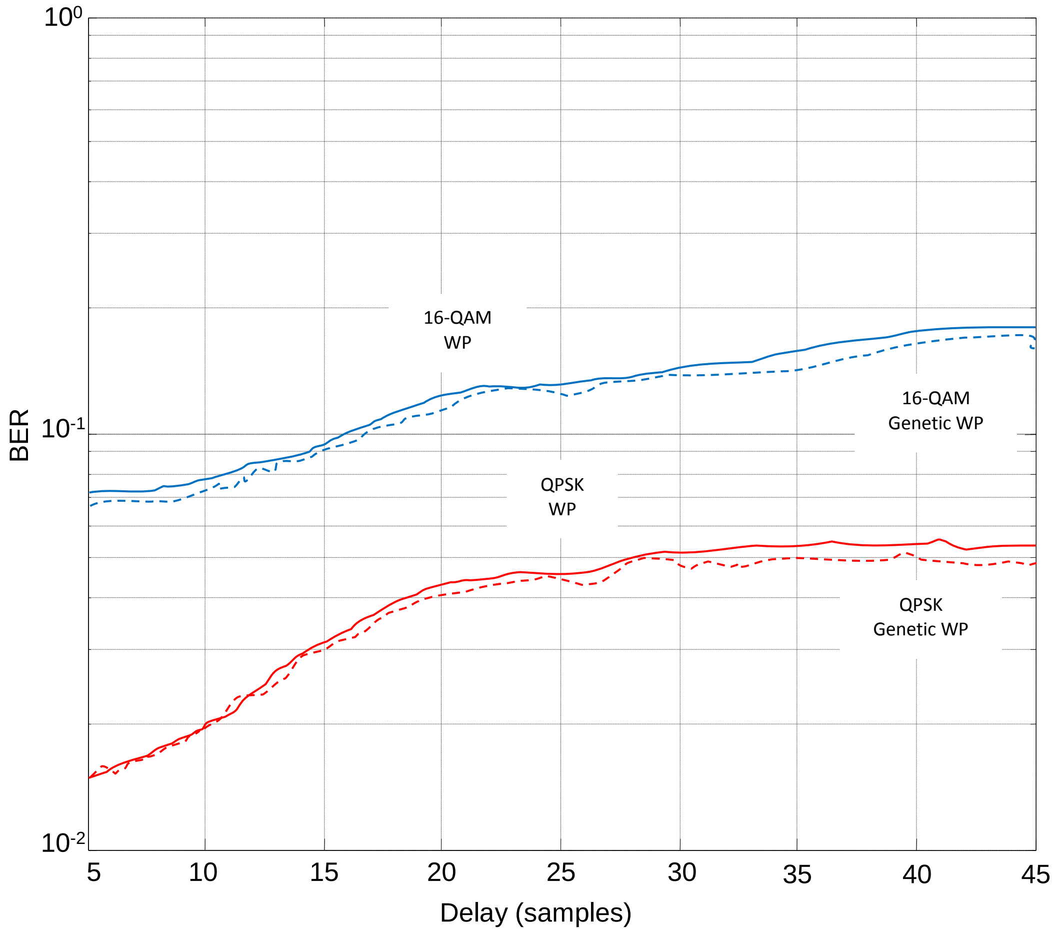


Figure (7).BER performance of OFDM based second path delay

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الخلاصة:

تم أقتراح وتنفيذ منظومة لتحسين أداء أنظمة مزج تقسيمات التردد المتعامدة في هذا البحث وذلكمن خلال تخفيف تداخل الرموز (ISI والمتولد بسبب طول فترة الأستجابة للنبضة في القناة على حساب البادئة الحلقية) وتداخل القنوات (ICI والناتج كذلك بسبب ظاهرة دوبلر في انتشار الموجات)باستعمال الخوارزمية الجينية. كذلك تم استبدال تحويل الفورييرِ بتحويل المويجات المتعامدة (WT) لجعل عمل المنظومة أكفأوتمثيل العمل في بيئة MATLAB. أن نتائج التمثيل أظهرت تحسن ملحوظ في اخماد التداخل من خلال انخفاض قدرة التداخل بالنسبة لعدد الحاملات. أيضا" تم دراسة بعض تأثيرات القناة على الأشارة المرسلة (تأثير تأخير الأشارة)بأستعمال التضمين (QPSK , 16-QAM) لأشارة الأرسال.وجد أن النظام المقترح اكفأ أذا ما قورن بالنظام التقليدي غير الذكي (أي بدون أستخدام الخوارزمية الجينيـة).