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An Improved QPSK based on a Hybrid Genetic Algorithm for Efficient OFDM Transmission

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ABSTRACT Lowering the bit error rate (BER) and signal-to-noise ratio (SNR) in orthogonal frequency division multiplexing (OFDM) channels is computationally challenging due to internal weaknesses within modulation schemes. In this paper, the amplitudes of various data sets in the four quadrants of a quadrature phase shift keying (QPSK) signal are varied. Furthermore, a hybrid genetic algorithm (GA) is used for phase allocations during OFDM transmission. These enhancements are done so that the received data can be recovered by considering two different aspects, i.e., phase and its corresponding amplitude. The hybrid GA is created with two main enhancements. Firstly, the wind-driven optimization is used as its selection function, and secondly, a custom three-point crossover is used as its genetic recombination operator. When compared to the conventional QPSK and 64QAM, the enhanced modulation technique has less than 24%-BER in a Rayleigh channel whereas the conventional QPSK and 64QAM show results that spanned up to 40% and 29% BER respectively. The modified QPSK has an improved OFDM channel BER-SNR performance because there is great coherence between its transmitter and receiver.

KEYWORDS Bit error rate; Crossover; Genetic algorithm; OFDM; QPSK; Selection; Signal envelope; SNR; Wind-driven optimization.

I. INTRODUCTION

ORTHORGONAL frequency division multiplexing (OFDM) is a concurrence of modulation and multiplexing whereby the channel bandwidth is shared in a well-defined manner amongst several modulated data sources [1]. OFDM is the main digital data transmission technique for mobile communication systems. It is also being considered for the forthcoming radio technologies. This is creating more pressure for improvement in its bandwidth usage, data capacity and error rates [2].

Quadrature phase-shift keying (QPSK) is a modulation technique that transmits OFDM subcarriers by varying the phase of the carrier signal. Due to QPSK being based on phase transitions across different constellations, it struggles with carrier offset drift and phase ambiguity. These negative attributes distort the transmitted signal and result in poor data recovery [3]. This creates a need for improving this modulation technique. Besides these QPSK internal weaknesses, noise in the channel distorts the envelope of the transmitted signal and inhibits efficient transmission. To ensure that the envelope is maintained there is a need for ensuring a constant amplitude throughout. Maintaining a constant amplitude remains a challenge because the peak-to-average power ratio (PAPR) of a communication channel cannot be precisely anticipated and curbed. A high PAPR shifts the signal peaks into the non-linear regions of the RF power amplifier [4].

The genetic algorithm (GA) and the wind-driven optimization (WDO) are algorithms that use the concepts of biological evolution. They can address any optimization problem regardless of its complexity. They solve problems stochastically by having numerous solutions and narrowing them down to the best and most optimum one [5]. In this article, these two optimization techniques are combined into a composite algorithm. The GA is used as the base algorithm and the WDO is incorporated to select the best populations during evolution. A custom three-point crossover is also created and used as the recombination genetic operator to ensure optimum gene synthesis for the GA. This composite algorithm is referred to as the GAW3. The GAW3 is used in an analytical modelling technique to determine an optimum phase for a QPSK signal and allocate an amplitude for that particular domain. This results in an amplitude-varied QPSK signal which is referred to as the AVQPSK. When evaluated against the traditional QPSK, the enhanced modulation technique gave significantly better results under both clean and harsh channel conditions. The limitations of the AVQPSK could also be noted.

The rest of the paper is structured as follows: Section II presents the literature assessment conducted on related research work. This section also gives the main contributions of this research. Section III introduces the GAW3 and the AVQPSK. This Section also gives the full details of their integration before OFDM network optimization. Section IV presents the performance evaluation of the developed methodology and Section V gives the results and their analysis. Finally, Section VI proposes the conclusion of the paper.

II. METHODS AND MATERIALS

A. RELATED WORK

This section highlights the ongoing research on spectral optimization and power efficiency for quadrature phase shift keying and orthogonal frequency division multiplexing channels. The execution of Fourier transforms on a QPSK signal including a cyclic prefix (CP) results in an OFDM signal [1]. QPSK can be expanded to higher orders but some distortions will start to occur. The authors in [4] presented a methodology for reducing modulation peaks by using phase rotation factors and Dither signals on the OFDM subcarriers. This technique gives a lower BER compared to the traditional modulation methodologies. Their methodology inspired the advanced QPSK phase assignments that are implemented in this paper using the GAW3. The authors in [6] introduced a differential chaos shift keying MIMO system. This method shows that irregularly assigning phases give a better BER-SNR performance in a communication channel when compared to sequential phase assignment. Their methodology gave good results in clean operating scenarios. However, it was not explored in Rayleigh flat-fading channels with Doppler shifts. Therefore, its robustness in noisy channels which resemble real-world scenarios remains unconfirmed. The authors in [7] proposed a modulation technique based on Golay complementary sequences in OFDM systems. Their theoretical analysis and simulation results show that the proposed new sequences can achieve a higher data rate and a lower peak-to-mean envelope power ratio. The authors showed that the traditional modulation methodologies can be positively modified to give better channel performance and low PAPR. In [8], the authors used an evolutionary algorithm (EA) to combat carrier offset drift in an OFDM system. The introduction of an EA reduced the demodulation deterioration caused by noise. This methodology showed that OFDM network results can be greatly improved if more advanced parameter selection is used. Concise parameter selection reduces synchronization and detection errors. These authors' work motivated and guided the use of EAs implemented in this paper.

In [9], the authors introduced another differential QPSK. Their technique aims at overcoming the consequences of phase ambiguity in fading channels. The methodology showed good results in optical communication channels. The details provided by the authors of modelling, designing, case implementation and limitations of using a modified QPSK guided the phase selection domains used by the GAW3 in this paper. Their methodology could not guarantee a BER below a certain level because it would have instances of low coherence between the modulation and demodulation stages. This was not the case with the developed GAW3 AVQPSK. In [10], the authors used an extended-ranging unified sensor framework to minimize the problems caused by cyclic prefixing in OFDM networks. This methodology gave good results in fading channels. The successful results from this methodology show that full network optimization in an OFDM system can increase data throughput and decrease energy consumption. In [11], the authors emphasized the need for efficient envelope amplification and restoration. Poor envelope transmission increases energy usage requirements and SNR. The authors encourage other researchers to come up with further improvements in OFDM systems and the current modulation techniques. The authors' aim of good envelope transmission helped to further develop the idea of assigning different amplitudes implemented in this paper. The authors in [12] aimed at improving network security. They introduced a communication network with frequency hopping-aided orthogonal frequency division multiplexing with differential chaotic shift keying. Their results are based on evaluating BER after hiding user information in chaotic/noisy sequences. These enhancements increased bandwidth usage because of additional codes. Their system also had a significant amount of inter-symbol interference. The authors noted that these effects can be reduced by optimizing other sub-blocks of the OFDM network. Their work aided in analyzing and evaluating the OFDM sub-blocks used in this research work.

The literature reviewed above gives important guidelines on how to considerably improve OFDM channel transmission. This can mainly be achieved by optimizing the modulation processes. The literature also directs on how to implement and achieve these enhancements whilst conserving bandwidth and maintaining a low BER.

B. MAIN CONTRIBUTIONS OF THIS RESEARCH

Guided by the literature survey provided in Section II, it is found that the basis of efficient OFDM transmission lies in perfecting the modulation processes. Proper modulation directly increases bandwidth efficiency, reduces BER and demodulation deterioration and raises data throughput. This research is conducted to create a robust GAW3 for the use when developing a stable AVQPSK modulation scheme. The current QPSK and other modulation techniques evaluated in the literature assessment above show a deterioration in performance as more noise is introduced in the channel. This is mainly attributed to poor indexing, unconcise phase allocation and a rise in PAPR.

This research comes up with a custom three-point crossover function which is used within the GA to integrate genetics during recombination and ensure maximum gene synthesis [13]. The research also incorporates the WDO within the GA. It is used as an advanced selection function to choose the best individuals during evolution thereby increasing the quality of the mutated and surviving individuals [5, 14]. The hybrid GAW3 is used to determine and assign a different modulation amplitude for the four QPSK domains. This is done so that various parameters can be taken into consideration during demodulation. This is intended to lessen the misappropriation of the transmitted message signal. The current QPSK technique given in [9] has significant inter-symbol interferences (ISI) and inter-carrier interferences when tested in high-Doppler scenarios. This is attributed to internal challenges within the traditional QPSK concerning phase assignments. In this research, on top of being used for varying amplitude assignments, the GAW3 is further utilized to estimate and assign optimum phases for a QPSK signal thereby eliminating phase shifts, carrier offset drifts and inter-symbol interferences [15, 16]. The enhanced AVQPSK modulation technique is used to combat BER and improve the BER – SNR performance in an OFDM network. Full details of the GAW3 structure and AVQPSK are given in Section III.

III. GAW3 FOR OFDM NETWORK OPTIMIZATION

A. THE PROPOSED GAW3

The WDO and GA are optimization algorithms that use evolutionary techniques during problem-solving. They commence with numerous solutions and use the Pareto sense to narrow down the solutions to the most rational settlement [17]. This makes them better than most traditional techniques [18]. Regardless of these superior operational principles, both algorithms have their weaknesses. The GA struggles with trapping into a suboptimal solution. This is caused by the loss of diversity during the evolution processes [19]. Perfect crossover and selection help to avoid the loss of important genetic material. These two important factors ensure and maintain good diversity which leads to proper convergence. The WDO is an algorithm that converges very fast. It is a simple algorithm with very few parameters that need adjustments. It is also an algorithm that can ensure its own internal population diversity throughout optimization henceforth it can easily be merged with other algorithms and improve their performance [5].

In this paper, the WDO is added to the GA as its selection function. A custom three-point crossover is also created and used as the genetic recombination operator. This resulted in a hybrid algorithm referred to as the GAW3 in this article. This algorithm is developed to give results that surpass those of the conventional GA. The WDO and three-point crossover are incorporated into the GA for the following reasons:

- To implement advanced gene concatenation when combining the properties of parents through an advanced crossover. This creates superior genes for children thereby preventing the loss of genetic materials [13].
- To sufficiently replace genes and achieve good population diversity throughout optimization and maintain it. This eliminates degenerate scenarios and ensures maximum population diversity because the likelihood of repeating gene structures across generations will be low [17].
- To select and use the best parents during optimization. This will eliminate stalling and convergence into suboptimal minima. This ensures the exploration of all search spaces. This is important since the GA is a multipath search algorithm [18].
- To influence the quality of individuals that can be created during the search processes by selecting and using a healthy population. This directly controls reproduction and increases the survival rates of individuals with the best attributes [19].

The hybrid GAW3 algorithm is made by amalgamating the GA and the WDO as shown in Fig. 1.

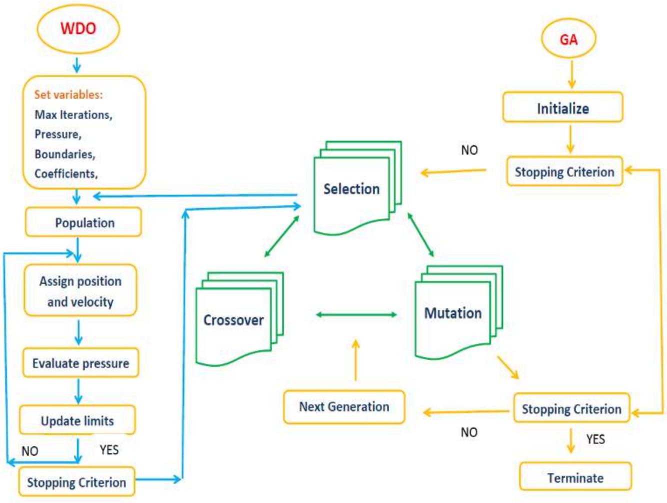

Figure 1. GAW3 Structure.

B. AMPLITUDE VARIED QPSK

A communication signal is made up of three basic attributes, i.e., amplitude, frequency and phase [16]. Manipulation of these attributes results in a change in the waveform of the communication signal. These characteristics are shown in equation (1) whereby $y(t)$ is the communication signal, $A(t)$ is the amplitude component, $f(t)$ is the frequency component and $\varphi(t)$ is the phase component.

$$y(t) = A(t) \times \sin\big(2\pi f(t) + \varphi(t)\big)\,. \tag{1}$$

For QPSK, the message signal is transmitted by altering the phase of the carrier wave. This is done without interfering with the frequency and amplitude aspects of the signal [3]. Amplitude and frequency are kept constant. The carrier wave is incorporated into the message signal with great precision. QPSK uses four anti-phase points when mapped on a constellation plot [6]. QPSK modulation is vulnerable to noise because of its usage of binary data. QPSK also experiences carrier offset drifts and phase ambiguity. Non-linearity within the channels also contributes to the emergence of inter-symbol interferences (ISI) and inter-carrier interferences (ICI). These interferences result in bit errors on the receiver side [9]. These errors have to be kept at a minimum because of the scarce spectrum. Regardless of these weaknesses, QPSK remains prominent over other modulation techniques because of its robustness against noise and a generally low BER when compared to other modulation techniques. Further optimization and reduction of the QPSK weaknesses will increase its robustness against real-world occurrences, for example, multipath fading, narrowband interferences, noise and attenuation at high frequencies [15]. A phase-modulated signal $s(t)$ is given in equation (2).

$$s(t) = A cos\phi_n cos2\pi f_c t - A sin\phi_n sin2\pi f_c t\,, \tag{2}$$

$$\text{for } 0 \le t \le T \;\&\; n = 1,2,3,4\,,$$

whereby f_c is the carrier frequency, n is the number of carriers, and t is the symbol period.

The amplitude part A in equation (2) is determined by the GAW3. For each modulation cycle, the complex envelope, i.e., amplitude of each respective quadrant is multiplied by a rational number between 0 and 1 determined by the GAW3. This alteration only affects the amplitude component which is independent of the phase aspect and constant frequency as elaborated in equation (1). The phase for equation (2) will be given by equation (3).

$$\phi_n = \tau + (2i - 1)\frac{\pi}{4} , \quad (3)$$

where τ is assigned by the GAW3. It is a radian value that shifts the phase into the optimum quadrant depending on the modulation cycle. Since QPSK uses four different phases, the GAW3 samples and assigns a constellation phase value from different sinusoids shown in Fig. 2. All these sinusoids are not in phase therefore phase ambiguity is minimum [5].

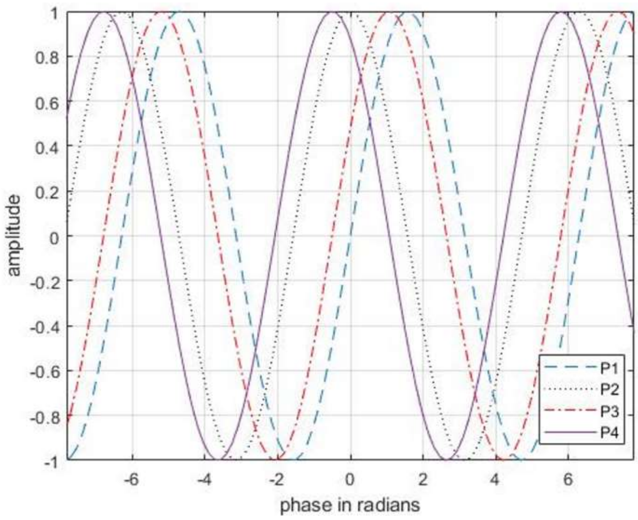

Figure 2. QPSK phase selection domains.

During demodulation, the complex envelope of the modulated message signal is de-rotated. This is done using element-wise array multiplication since the demodulator receives parallel data streams. The value τ is also subtracted to get the original signal. The optimized OFDM channel has the entities shown in the flow chart in Fig. 3. The channel used is a Rayleigh fading channel with additive white Gaussian noise (AWGN).

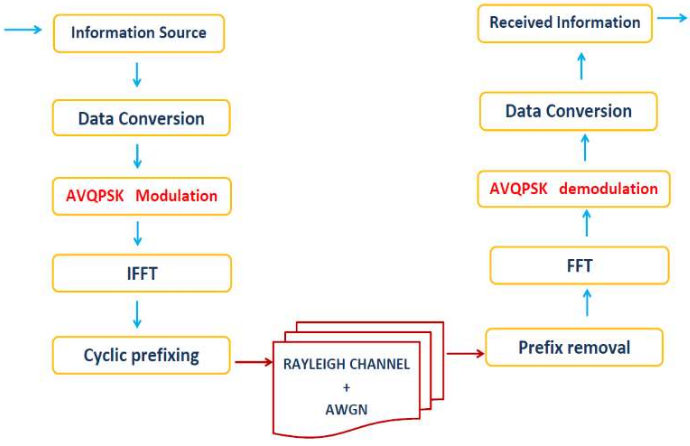

Figure 3. OFDM channel with AVQPSK modulation.

IV. PERFOMANCE EVALUATION

A. SIMULATION SETTINGS

All the algorithms are executed within MATLAB R2022a using an Intel(R) Core i7 (2.2 GHz) CPU with 16GB RAM installed on Microsoft Windows 10 Pro. The properties of the GAW3 are given in Table 1. These properties are implemented based on simulation guidelines from [5, 13, 17]. Trial and error during simulation also helped to get these final parameter values.

Table 1. Parameters of the GAW3

Parameters	Settings
Creation function	Uniform
Crossover function	Custom: three-point crossover
Population type	Double vector
Population size	500
Pareto fraction	0.35
Selection function	Wind-driven algorithm
Penalty factor	75
Migration fraction	0.25
Migration interval	25
Fitness scaling function	Rank
Migration direction	Both
Mutation function	Adaptive feasible

B. TESTING OF THE ALGORITHMS

To check for accuracy and robustness, the GAW3 was first tested on the Matyas, Schaffer and Three-hump camel benchmark functions. The functions are given in equations (4) – (6), respectively

$$g(x, y) = 0.26(x^2 + y^2) - 0.48xy , \quad (4)$$

$$g(x, y) = 0.5 + \frac{\sin^2(x^2 - y^2) - 0.5}{[1 + 0.001(x^2 + y^2)]^2} , \quad (5)$$

$$g(x, y) = 2x^2 - 1.05x^4 + \frac{x^6}{6} + xy + y^2 . \quad (6)$$

For comparison, the GAW3 was tested against the conventional GA. The traditional GA was derived from [13, 19]. The simulation results are presented in Tables 2 to 4.

Table 2. Algorithm results on the Matyas function for -10 ≤ x; y ≤ 10

	1st Run	2nd Run	3rd Run	4th Run	5th Run
	$(X_1; X_2)$	$(X_1; X_2)$	$(X_1; X_2)$	$(X_1; X_2)$	$(X_1; X_2)$
GA	(0; 0)	(0; 0)	(0; 0)	(0; 0)	(0; 0)
GAW3	(0; 0)	(0; 0)	(0; 0)	(0; 0)	(0; 0)

Table 3. Algorithm results on the Schaffer function for -100 ≤ x; y ≤ 100

	1st Run	2nd Run	3rd Run	4th Run	5th Run
	$(X_1; X_2)$	$(X_1; X_2)$	$(X_1; X_2)$	$(X_1; X_2)$	$(X_1; X_2)$
GA	(-6; 0.1)	(0.6; 0)	(-1.05; 2.2)	(0; 0)	(0.1; 0)
GAW3	(0; 0)	(0; 0.4)	(0; 0)	(0; 0)	(0; 0)

Table 4. Algorithm results on the Three-hump camel function for -5 ≤ x; y ≤ 5

	1st Run	2nd Run	3rd Run	4th Run	5th Run
	(X_1; X_2)	(X_1; X_2)	(X_1; X_2)	(X_1; X_2)	(X_1; X_2)
GA	(0; 0)	(0.03; 0)	(0; 0)	(0; 0)	(-1; 2)
GAW3	(0; 0)	(0; 0)	(0; 0)	(0; 0.04)	(0; 0)

All three benchmark functions given above have a global minimum of (0; 0) [5]. From Tables 2, 3 and 4, it can be noted that if no enhancements are made, the GA will struggle to converge at the global minima. This discredits the usage of the GA in its traditional form [20]. The GAW3 remained as the only suitable algorithm for optimizing the AVQPSK.

C. MATERIAL AND METHODS SIMULATION SETTINGS

The optimization prototype used in this paper is formulated using the network properties in [16, 21]. These properties were implemented based on the illustration in Fig. 3. The AVQPSK was using 4 constellations. The binary data sets that were tested were 2^5, 2^6, 2^7, 2^8, 2^9 and 2^{10}. The block sizes that were implemented on the data sets varied from 2^2 to 2^6. The cyclic prefix was limited to 10% of the block size to avoid oversampling. A smaller CP also conserves bandwidth [10]. The Fourier points corresponded to the block size.

If $s_n(t)$ are the symbols mapped to a QPSK chosen constellation and N is the parallel streams of data points at a particular frequency, the OFDM signal $S(t)$ will be given by equation (7) [22]:

$$\mathrm{S(t)} = \sum_{\mathrm{n=0}}^{\mathrm{N-1}} \mathrm{s_n(t)} \times \sin(2\pi \mathrm{f_n t}). \tag{7}$$

The transmitted data is first coded and modulated into AVQPSK symbols. These symbols are loaded into equally spaced frequency bins and an inverse fast Fourier transform (IFFT) is applied to transform the signal into orthogonally overlapping sinusoids in the time domain. Conversion back to the original message signal is done by using a FFT at the receiver end. FFT and IFFT can be used interchangeably on transmitter and receiver stages as long as the opposite transform is used on the opposite end [5, 15]. Jake's model was used to design the Rayleigh fading channel that was used during simulations. The fading of the symbol k over time t is given in equation (8) below [21]:

$$g(t,k) = 2\sqrt{2}\left[\sum_{n-1}^{M}\left((\psi)\times(\delta)+\frac{1}{\sqrt{2}}(\text{ȸ})\times(\varphi)\right)\right], \tag{8}$$

where Ψ is $(\cos\beta_n + \mathrm{j}\sin\beta_n)$, δ is $(\cos 2\pi f_n t + \lambda_{n,k})$, ȸ is $(\cos\alpha + \mathrm{j}\sin\alpha)$, and φ is $(\cos 2\pi f_d t)$. Since the simulations were done using a QPSK with phases coming from the GAW3, α was set to 0. The simulations considered a single-path channel and henceforth, λ_n was also set to 0. β_n was carefully selected to avoid cross-correlation between the real and imaginary parts of $Y(t)$ [4, 8].

The bit error probability of QPSK over an additive white Gaussian noise (AWGN) channel is given by [5]:

$$P_b = \frac{1}{2} erfc\left[\sqrt{\frac{E_b}{N_0}}\right], \tag{9}$$

whereby $\frac{E_b}{N_0}$ is the energy per bit to noise spectral density.

V. RESULTS

A. NOISELESS CHANNEL SIMULATION OUTPUTS

Fig. 4 is the BER plot for a non-fading OFDM network with no noise. In a channel with no noise, after demodulation, the transmitted signal is expected with no distortions or BER. All three modulation techniques that were tested proved to be able to fulfill the minimum transmission requirements because they managed to recover a certain amount of the transmitted bits. The 64QAM that was used for comparison was created with reference to [11] and the QPSK was created based on [5].

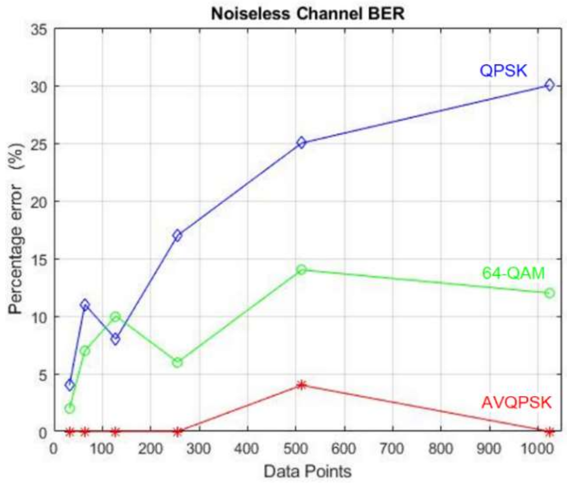

Figure 4. Noiseless channel BER plot.

In practice, any decent modulation technique must be able to transmit and recover all the data with no errors in a clean channel [23]. However, from Fig 4, this was not the case with the conventional QPSK and 64QAM. They showed a rise in BER as the number of transmitted bits increased. This translates to a distortion in the envelope during data detection. This also shows that the QPSK and 64QAM have internal weaknesses which inhibit perfect data transmission regardless of the absence of noise in the OFDM network system. Table 5 gives a clear representation of the percentage errors shown in Fig 4.

Table 5. BER comparison in a noiseless OFDM network

Data Points	AVQPSK % Error	64QAM % Error	QPSK % Error
32	0	2	4
64	0	7	11
128	0	10	8
256	0	6	17
512	4	14	25
1024	0	12	30

Using Table 5, it can be noted that the AVQPSK has the least BER in a noiseless channel. In most instances, the transmitted signal fully matches the received signal. There is no distortion. However, for the QPSK and 64QAM, they present a BER that spans up to 14% and 30%, respectively. This shows that both modulation techniques have internal challenges which inhibit their full data recovery. Regardless of the clean channel conditions, the QPSK and 64QAM could not guarantee a low BER. Due to the traditional QPSK being based on phase variations across the message signal, the poor results show that phase ambiguity and carrier offset drift remain rife during modulation. This also shows that using fixed points on a constellation diagram is not the best way of assigning QPSK phases [6]. Strategic and optimum phase assignments prove to give better results if QPSK is to be used at the base modulation technique. For the 64QAM, the rise in BER is caused by a distortion in the envelope. This emanates from poor indexing which results in the occurrence of additional sidebands thereby causing bit errors [7].

B. NOISY CHANNEL SIMULATION OUTPUTS

The three modulation techniques were further tested using a Rayleigh fading channel. Rayleigh fading gives a concise scenario of real-world propagation when there is no dominant line of sight between the transmitter and the receiver. Additive white Gaussian noise (AWGN) was also introduced in the same channel. A fading noisy channel is expected to cause distortions. The modulation outputs of the three algorithms are presented in Fig. 5.

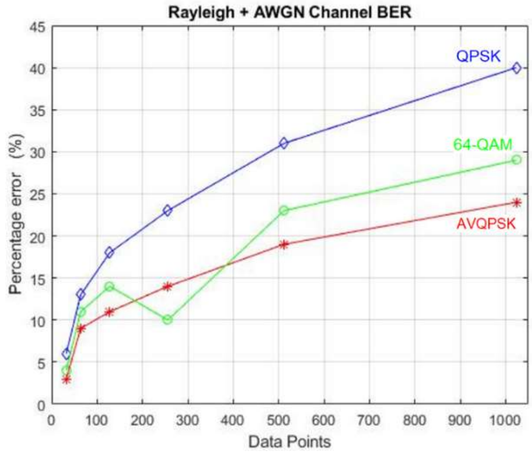

Figure 5. Rayleigh channel with AWGN BER plot.

From Fig. 5, all the modulation techniques experience distortions but the severity differs. The robustness of a modulation technique can aggravate or mitigate the severity of these distortions. If a system is robust enough, then regardless of the channel properties, an envelope with approximate transmitted data properties is supposed to be detected by the receiver [24]. The data from the conventional QPSK has the most bit errors. This means that there are significant discrepancies between the transmitted and received data. There is poor data propagation. This means that the modulation scheme struggles to achieve high data throughput when compared to the developed AVQPSK or 64QAM. Table 6 gives a clearer statistical representation of the data in Fig. 5.

Table 6. BER comparison in a Rayleigh fading OFDM network

Data Points	AVQPSK % Error	64QAM % Error	QPSK % Error
32	3	4	6
64	9	11	13
128	11	14	18
256	14	10	23
512	19	23	31
1024	24	29	40

From Table 6, the GAW3 AVQPSK faces a maximum average BER of 24%. This means it can guarantee the detection of more than 75% of the message signal. In most instances, the percentage error is less than 15%. This is a good data recovery percentage considering the massive fading and noise properties of the channel [21]. For 64QAM, the maximum percentage error was 29% with most instances also less than 15%. This also shows good data recovery and justifies why it is prominently used in modern communication systems. For all the binary data sets, the percentage deviation between the AVQPSK and 64QAM BER does not exceed 5%. This shows great comparability in the quality of output even though the AVQPSK shows much lower BER. The traditional QPSK has errors spanning up to 40%. This is expected since this modulation scheme could not guarantee a low BER in a noiseless network. This high percentage error in a noisy channel means that envelope or coherent detection on the receiver side will not recover a significant portion of the transmitted data. This is a big cause of concern because we are living in a world that has a scarce spectrum but requires a high data throughput. The BER of the traditional QPSK will increase if other real-world conditions are considered, for example, narrowband interferences and attenuation during high-frequency transmission [25, 26]. These performances by the traditional QPSK make it undesirable for usage in most digital networks which are dependent on efficient binary data transmission.

Of the three techniques, the GAW3 AVQPSK shows better robustness to hostile channel conditions as it could recover more than 75% of the transmitted data. The coherence between the transmitter's modulator and the receiver's demodulator is satisfactory. There is low data loss. This means that the developed methodology of using an enhanced modulation technique is more accurate as the transmitted data is recovered based on two independent aspects, i.e., phase and its amplitude.

C. BER-SNR EVALUATION

The BER-SNR plots for the 3 techniques are presented in Figures 6 – 8. Fig. 6 shows a channel that only has AWGN. Fig. 7 is for a Rayleigh fading channel and Fig. 8 is for a Rayleigh fading channel with AWGN.

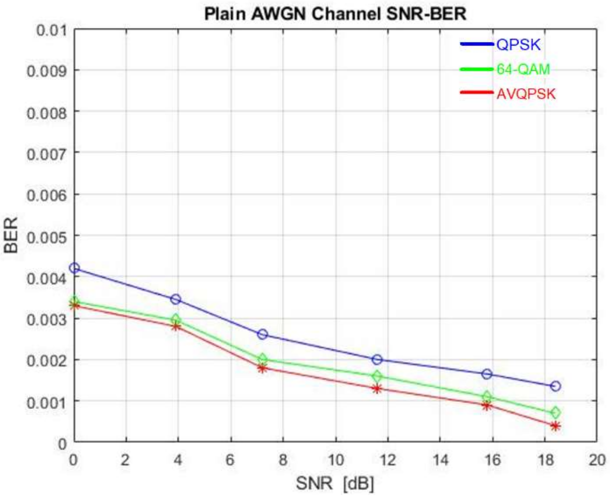

Figure 6. AWGN channel BER-SNR plot.

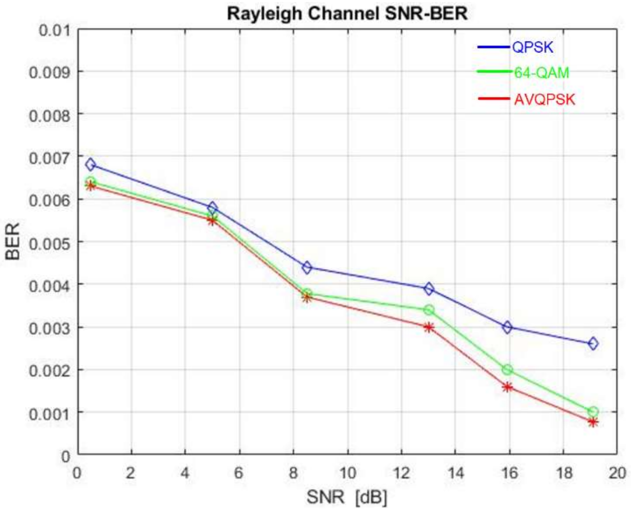

Figure 7. Rayleigh channel BER-SNR plot.

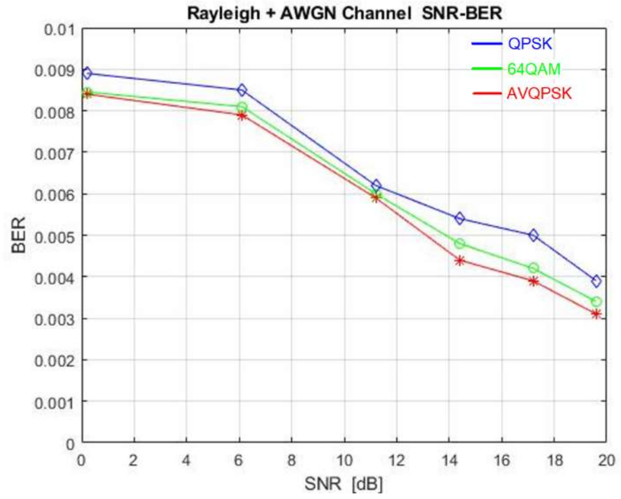

Figure 8. Rayleigh channel with AWGN BER-SNR plot.

The channel with AWGN only, i.e., Fig. 6, gave the least BER-SNR whereas the channel with both Rayleigh fading and AWGN gave the poorest BER-SNR performance, i.e., Fig. 8. Due to the figures above, harsh channel conditions deteriorated the BER-SNR performance. Nonetheless, in all three figures, the AVQPSK gives the lowest BER-SNR line of best fit. This good performance occurs regardless of the tested channel conditions. This shows that it outperforms the QPSK and 64QAM in all regards. Regardless of the low percentage deviation between the 64QAM and AVQPSK line plots, the AVQPSK always gives a better line of best fit.

D. COMPUTATIONAL COMPLEXITY

Fig. 9 gives a performance evaluation of the three schemes that were used during modulation. Fig. 9 shows that the optimization and simulation time of the GAW3 AVQPSK is more than that of the traditional QPSK and 64QAM.

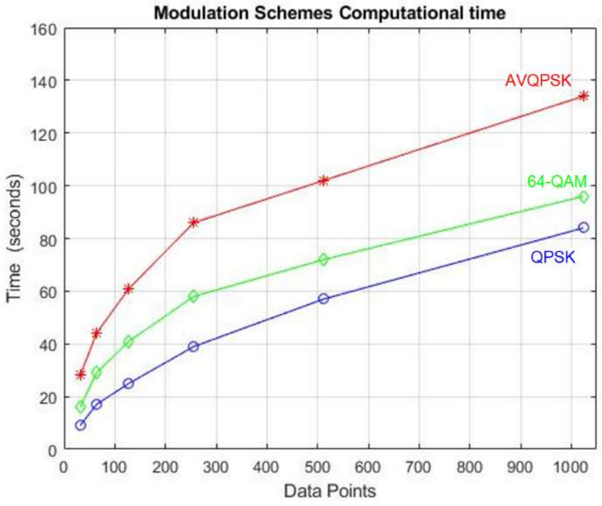

Figure 9. Modulation algorithms' computational time

The line graphs have six points each, which are the average computational times for transmitting the binary data points indicated in Section IV. The GAW3 AVQPSK takes more computational time because it has 2 optimization algorithms that have to determine 2 independent parameters during modulation, i.e., the WDO first runs as a sub-function of the GA and the resulting hybrid algorithm is further used to determine the phase value of a QPSK signal and assign them different amplitudes. These evolutionary processes consume more time than the conventional QPSK or 64QAM processes. However, the observed time differences are not vast. This is seen in Fig. 9 whereby the computational time used by the GAW3 AVQPSK is not more than double the time of either the QPSK or 64QAM. This computational time difference is also negligible when comparing the quality of results from the three modulation schemes. The advantages presented by the developed methodology overshadow these effects of computational complexity.

64QAM and QPSK do not propagate data well. They do not offer efficient transmission because of signal interferences. For 64QAM, as the modulation index increases, the amplitude of the sidebands also increases. Consequently, data recovery becomes difficult and some BER emerges. This internal weakness deteriorates the performance of 64QAM before taking to account noise, changes and uncertainties in channel conditions. For the traditional QPSK, it is overwhelmed by phase ambiguity and as a result, its BER-SNR performance is degraded. However, the developed methodology of assigning optimum QPSK phases using the GAW3 during modulation improved the quality of OFDM transmission because the received signal became more consistent with the transmitted signal. The developed technique has better data detection because two different aspects are considered during demodulation, i.e., phase and its respective amplitude. This made the AVQPSK outperform the traditional QPSK and 64QAM. The developed AVQPSK proved to have more immunity towards harsh channel conditions. Using Fig. 4 and Fig. 5, its data recovery rate was always more than 75% regardless of the noise and fading characteristics of the channel. This means that the proposed methodology gives a much better modulation technique for OFDM transmission. The BER-SNR plots also show that the developed methodology has better noise performance in a variety of channel conditions.

VI. CONCLUSIONS

This paper outlines an optimization technique that offers better digital data transmission in OFDM systems. A custom three-point crossover was created for the GA and used to integrate genes during reproduction and guarantee optimum gene synthesis. The WDO was subsequently incorporated into the GA to select the best parents and improve the quality of mutated individuals. This hybrid algorithm, i.e., GAW3 was used to develop a better-performing modulation scheme. A literature review showed that the conventional modulation techniques, i.e., 64QAM and QPSK suffer from poor indexing and phase distortions respectively. These weaknesses result in poor modulation depth, phase ambiguity, over-modulation and under-modulation. These subsequently result in additionally transmitted sidebands, ICI and ISI. The GAW3 was examined for robustness using the Three-hump camel, Schaffer and Matyas benchmark functions. It had good convergence. It also had high confidence intervals when tested multiple times. The GAW3 was subsequently used to generate a phase and an amplitude for the four domains of a QPSK signal. When implemented on an OFDM network, the GAW3 AVQPSK had no more than 4%-bit errors in a non-fading channel. In a channel with noise and Rayleigh fading characteristics, this developed algorithm had a maximum of 24%-BER. The traditional QPSK and 64QAM had a maximum of 12% and 30%-BER respectively in a non-fading channel and a maximum of 29% and 40%-BER respectively in a noisy fading channel. The proposed methodology proved to be more reliable than the conventional modulation techniques. It could handle harsh channels with more robustness. For future works, we are currently investigating the usage of evolutionary algorithms on communication networks that are fully based on either frequency or amplitude modulation. We are investigating which modulation technique can best be improved by optimization algorithms and subsequently give the lowest BER in OFDM channel systems. This is very crucial because OFDM is the current biggest data transmission methodology. OFDM operational principles are also being used for the conceptualization of more advanced transmission technologies, for example, orthogonal frequency division multiple access, multi-user multiple-input multiple-output transmission and orthogonal time-frequency spacing networks. These technologies aim at offering very high data throughput. Moreover, the GAW3 developed in this research can also be used for other various optimization problems as it supersedes the conventional optimization algorithms, i.e., the GA and the WDO. This has been elaborated on in section IV of this paper.

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Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

C. Shambare carried out the research under the supervision of Prof. Y. Sun and Dr. 'Ayo IMORU. The authors approve the final submitted version.

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