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A Developed Polar Coded Generalized Frequency Division Multiplexing Based on Bit-Interleaved Coded Modulation

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Abstract. *Due to the tremendous development in the wireless communication field and the wide requirements of current generations, such as high data rates, extremely low power consumption, and high performance, it is necessary to think about techniques and methods that present improvement to meet the growing requirements. The introduction of the Generalized Frequency Division Multiplexing (GFDM) technique was one of the proposed methods; it is one of the candidate schemes for the current generations and beyond. GFDM was presented as an improved method over other multiplexing techniques, as it provided an improvement in the field of Out Of Band (OOB) and Peak Average Power Ratio (PAPR). At the same time, it provided a lower performance in BER with respect to SNR. In this paper, methods of enhancement were presented based on Matlab to improve the performance of the GFDM system, which was improved by adding a coding system based on Polar Coding (PC). The proposed method is presented to improve the performance of GFDM by using the Genetic Algorithm (GA) to improve the performance of the Pulse shaping Filter (PSF) in GFDM. The channel estimation is accomplished by means of the LS method, and the Artificial Neural Network (ANN) based on feed-forward backpropagation is used to enhance the estimation process. The proposed Genetic Algorithm Artificial Neural Network Polar Code Interleaver GFDM (GNPI-GFDM) presents an enhancement over the traditional GFDM of more than 3.5dB at BER=10^{-4} over the Rayleigh fading channel.*

Keywords: *ANN, Channel estimation, GA, GFDM, Interleaver, PC.*

1. INTRODUCTION

Generalized Frequency Division Multiplexing (GFDM) is a technique used in modern communication systems such as wireless systems. It is a generalization of the traditional Frequency Division Multiplexing technique, which is used to share a communication channel among users by dividing the frequency spectrum into separate sub-carriers. It can achieve high spectral efficiency, transmitting more data in a given frequency band than other multiplexing techniques. Its structure is based on the block of multicarrier containing several sub-carriers (K), sub-symbols (M), and prototype Pulse Shaping Filter (PSF). The GFDM block is created by time and frequency shifting of prototype PSF with the multiplication of finite time windows. The GFDM presents preference motivation based on efficient multicarrier filter bank utilization [1]. Wireless communication systems face various challenges, such as interference, noise, fading, and limited bandwidth. These challenges can be mitigated using multiple techniques, such as channel estimation and equlization, error correction codes, and multiplexing techniques [2].
Channel estimation is estimating the characteristics of the communication channel in a wireless communication system to the compensation in the receiver. In the mobile strategy, stations move and the

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received signal strength and phase change rapidly. Moreover, the signal transmitted over the channel is reflected by buildings and other obstacles in the ground, which leads to different paths to the receiver, which leads to different time delays, phases, amplitudes, and additional noise. It will cause severe fading. The estimated perform based known signal for the transmitter and receiver signal called pilot insert in each data frame with various forms depending on practical cases. It is an essential aspect of wireless communication, as the channel's characteristics can affect the system's performance, such as the Signal-To-Noise Ratio (SNR) and the error-correction capabilities. A transmission signal's channel characteristics show how the environment in which it is being sent affects it. This includes signal-weakening factors including fading, interference, and noise when transformed between the transmitter and receiver [3]. The channel performance estimation process is based on traditional methods such as Least Squares (LS) and Normalized Least Mean Squares (NLMS) or by innovative approaches such as Artificial Neural Network (ANN). Channel estimation-based LS is one method for estimating the channel response. It is a low-complexity method because it does not require prior knowledge of environmental statistics. It involves an estimate based on a divided pilot of the received over the transmitter to find the channel response estimate. NLMS channel estimation differs from LS channel estimation, designed based on the adaptive filter, reducing errors iteratively [4].

The human biological neural network simulation is called ANN. It is a computational network used to perform a wide range of tasks and controls based on the working of nerve cells of the central nervous system, which contains neurons that are simple and highly interconnected units. The neurons are the processing unit of the network that work in parallel and distributed form and belong with weighted links to adjacent neurons, and this weight is the memory unit of ANN. The weight can be changed according to the application by the training process [5].

A Genetic Algorithm (GA) is a heuristic optimization search algorithm inspired by natural selection and evolution principles. It involves generating a population of possible solutions to a problem, evaluating their fitness, and selecting the best solutions for the next generation. This procedure is iterative until a solution or a predetermined number of iterations has been reached. GA is often used to solve complex optimization problems that are difficult to solve using traditional algorithms. GA is an evolutionary operation combining the random search containing the crossover and mutation and goal-oriented searches-based fitness functions. Its investigations are simultaneously in parallel form because it includes several chromosomes. The basic principle of the work is to find the definition of all the variables and find the optimal value. GA is an efficient method to solve the problem optimally based on natural selection. It continuously modified the population solutions values. The procedure of GA is based on randomly choosing individuals of the existing population to act as parents and bear the next generation's offspring. Over consecutive generations, the population develops across the best solution. GA is appropriate for specific optimization problems that standard optimization cannot solve when the issue is random, discontinuous, and indistinguishable [6].

The coding system corrects the error caused by interference, noise, or poor signal strength; the digital system encodes the transmitter device's information and decodes the receiver's signal, reducing the error and recovering the transmitted data. Various recent channel codes presented in the communication system are to be reliably sent in the 5th Generation, PC was chosen in the channel coding of the control signal. PC is the constructive code representing the possibility of repair on memoryless channels, which Arıkan delivered in 2009. It used the channel capacity technique in signal processing scenarios. PC is an error-correcting code designed to be highly efficient regarding its error-correction capabilities and computational complexity. They are based on channel polarization, separating the channel into several "good" and "bad" channels based on their reliability. The good channels transmit the data, while the bad channels are used for error correction. Polar codes are widely used in modern communication systems, including cellular and satellite communication systems [7]. The optical environment is considered one of the hot topics in developing the communication system and still, the researchers present its solutions and innovations[8-14].

IOT also takes up a wide space, especially in terms of connectivity with other technologies such as wireless communications and other fields [15-17].

2. RELATED WORK

GFDM was first demonstrated by Gerhard Fettweis and his research team in 2009 with the Vodafone Chair in Mobile Communication Systems at the Dresden University of Technology, which presents some attractive features such as high degrees of spectrum fragmentation based on the efficient use of the cyclic prefix and the efficiency in the PAPR and OOB [18]. This research team continued to develop communication systems, especially those related to GFDM, in which Datta et al. 2011 presented the simple estimation method called Serial Inter-Carrier interference cancellation (SIC). This method is applied under the effect of Additive White Gaussian Noise (AWGN) channel and gives an enhanced Bit Error Rate (BER) performance equal to 0.0009 at 16 dB and 0.00649 at 20dB [19]. Valluri and Mani 2018[20] used a Unique Word GFDM (UW-GFDM) to enhance the performance, which the BER reduced by using redundant sub-carriers that perform correlation in the frequency domain. The receiver used Weiner noise interpolation and sphere decoding. They use LABVIEW to simulate the GFDM transceiver with AWGN and multipath channels. And they have approved the National Instruments (NI) over other traditional receivers by 20×10^{-6} at 20dB. Agrawal and Appaiah 2019[21] used a scattered pilot based then derived the Kalman filter as channel estimation for Multiple Input Multiple Output-GFDM (MIMO-GFDM) hence handling time-varying channels. The estimation-based Kalman filter gives enhancement in BER performance by 0.038 at 30 dB. LI et al. in 2019 [22] present efficient GFDM system-based PC, turbo code, Multi-Level Coding (MLC), and Bit-Interleaved Coded Modulation (BICM). The enhancement is 0.0048 at 5dB. Valluri et al., 2020[23] invested in the block circulant GFDM nature to reduce the error and complexity on the receiver side. The sum of permutation matrices represents the modulation matrix, which uses the Discrete Fourier Transform with the theory of circular arrays. To reduce the complexity, it computes the inverse sum of permutation matrices. The transceiver system was built by LABVIEW as software and the hardware by using Universal Software Radio Peripheral 2953R, which presents enhancement in BER by 8×10-6 at 30 dB. Kumar et al. in 2021[24] present an enhancement of GFDM system-based Sub-carrier Index Modulation and Constellation Precoding (SIM-CP). The enhancement is 0.00099 at 12dB. Kumar et al. in 2022 [25] present an efficient method of reducing the PAPR and BER-based Chaotic Biogeography Optimization-Selective Level Mapping (CBBO-SLM) at lower computational complexity. The enhancement in BER is 0.0049 at 20dB. Bouslam et al. in 2023[26] proposed an efficient reduction method for PAPR and BER-based intelligent swarm algorithm called JAYA and combined it with a Selective Mapping (SLM) scheme. The enhancement is 14×10^{-6} at 15 dB and 1 dB at BER $=10^{-6}$.

3. THEORETICAL BACKGROUND

In his section presents the Theoretical Background of GFDM, Wireless Channel, Channel Estimation, LS, NLMS, PC, Interleaver, ANN, and GA.

3.1 GENERALIZED FREQUENCY DIVISION MULTIPLEXING

Generalized Frequency Division Multiplexing (GFDM) is a flexible multicarrier scheme proposed for the next-generation networks. GFDM is a new optimization idea. It is a non-orthogonal frequency division multiplexing operating on Inverse Fast Fourier Transforms (IFFT)/Fast Fourier Transform (FFT), which perform tasks of reasonable complexity. The waveform of GFDM is a Multicarrier, which divides the data stream over multiple lower data rate carriers. Each one is modulated individually. Present a suitable arrangement of boundaries over the requirements of the last generations. It does not require orthogonal verification between the sub-carriers and thus reduces the power loss to the lowest amount. The structure is based on blocks built by sub-carriers (K) and sub-symbols (M) and modulated separately. Prototype Pulse

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Shaping Filter (PSF) designed in time and frequency shifting is applied for each K to reduce the out-of-band (OOB) emission effect. The applied filtering on the K caused a loss of orthogonality [27].
Figure (1) presents the blocks of data transmitted by each block divided by the spectrum into K in the frequency domain and M in the time domain. dk,m represents data sent in GFDM blocks with kth sub-carrier and mth sub-symbol. Each symbol is filtered with a PSF. The behavior of PSF is present in Figure (2). Each block N=K×M that required to transmit. The spectral efficiency of GFDM is more efficient due to the single Cyclic Prefix (CP) of each block [28].

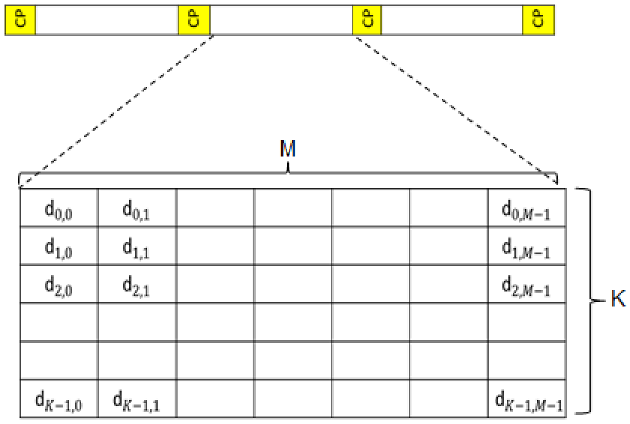

Figure (1): The structure of GFDM data block [28]

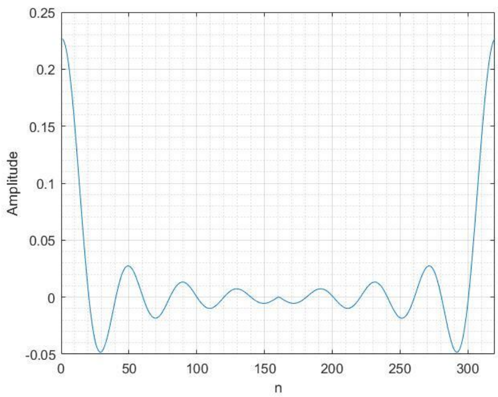

Figure (2): The impulse response of PSF [28].

The GFDM transmitted signal is presented in Equation (1), the filter circularly shifted in Equation (2), and the equation of PSF is given in Equation (3). The block diagram of the modulation of GFDM is present in Figure (3) [29].

$$x[n] = \sum_{m=0}^{M-1}\sum_{k=0}^{K-1} d_{m,k} g_{m,}[n] \quad (1)$$

$$g_m[n] = g[(n-mk)_{mod\ N}] \exp\left(j2\pi\ \frac{kn}{K}\right) \quad (2)$$

$$g[n] = \frac{sinc(n)\times\cos(\pi\times r\times n)}{1-(4\times r^2\times n^2)} \quad (3)$$

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Where $x[n]$ is the transmitted signal. $[n]$ is the sampling index $n = 0, \ldots, N-1$. $d_{m,k}$ is the complex data. $g_{m,}[n]$ is prototype PSF, r is Roll off factor of the pulse shaping filter, N is K×M. k is constant value from 1 to K. m is constant value from 1 to M. where K is sub-carriers and M is sub-symbols.

The main advantage of GFDM is summarized below [30]:

1- Presents lower OOB and PAPR due to the PSF.
2- Shows an efficient spectrum using one CP for each block.
3- present high flexibility in terms of setting up GFDM blocks.

Meanwhile, the disadvantages of GFDM are the complexity and the performance of Bit Error Rate (BER) [31].

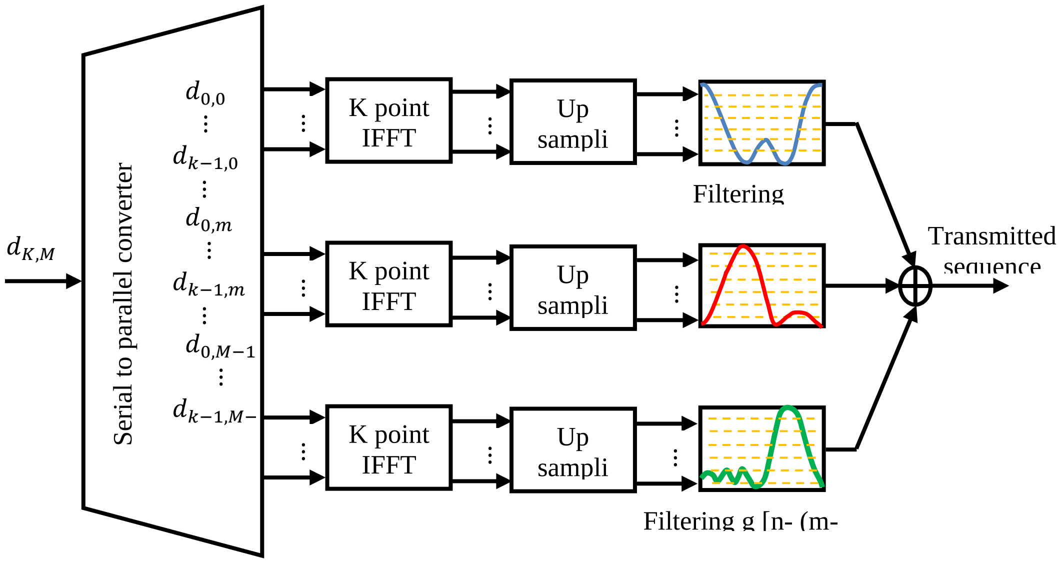

Figure (3): GFDM modulation [7].

3.2 WIRELESS CHANNEL

Typical mobile radio systems need the information transferred from a stationary base station to a mobile device in motion. The communication data is modulated and transmitted across a wireless channel as waveforms. As signals travel across the wireless channel to the receiver, objects such as automobiles, buildings, trees, mountains, and hills collide. Block the line-of-sight propagation route, causing unwanted effects on the propagating symbols. Due to the detrimental effects of these obstructions, the signals undergo reflection, diffraction, and scattering, causing them to arrive at the receiver via multiple reflective paths with varying time delays, amplitudes, and phases, a phenomenon known as multipath propagation [32,33]. When propagating, waves suffer from reflection, diffraction, and scattering. Reflection occurs when radio waves experience reflection caused by an obstacle with dimensions larger than the wavelength of the transmitted signal. Diffraction occurs when a sharp object's surface blocks a wave, resulting in an apparent wave propagating toward the receiver. Meanwhile, signal scattering occurs when objects with dimensions smaller than the wavelength of the transmitted signal block the signal. This signal scattering will then cause the signal to be reflected in all directions. For example, the signal is scattered by rainwater. The transmitted data is generally corrupted by noise through the channel propagation, which suffers from fading and multipath, the received signal present as Equation (2.4). This fading and multipath made detecting the transmitted data challenging, which required pinpoint methods for channel estimation [34 35].

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$$y(n)=x(n)*h(n)+w(n) \quad (2.4)$$

Where: y(n) is the received signal. x(n) is the transmitted signal. * is the convolution operation. h(n)is the channel effect. w(n) is the AWGN.

Rayleigh fading channel is one of the wireless channel simulations based on a Gaussian or normal distribution with more tapes, multiple indirect paths between transmitter and receiver, and no distinct dominant path. It means there is no line of sight. Rician fading channel differs from the applied direct line of sight in addition to the number of indirect multipath [36].

3.3 CHANNEL ESTIMATION

The channel estimation process determines the characteristics of a communication channel in a wireless system, which helps the receiver to predict the approximation of the channel impulse response and understand the effects of the channel on the transmitted data, hence performing optimum reconstruction of the transmitted information. The precision of the channel estimate is essential to a wireless communication system's success since it directly impacts the quality of the recovered signal. The communication systems parameters, such as the modulation scheme, channel type, and available resources, determine the channel estimate technique. There are various estimation types, one of which is the pilot-based channel estimation schemes. The pilot-based channel estimate is a technique for assessing the parameters of a communication channel in a wireless communication system by introducing pilot symbols into the sent signal. The receiver then applies this information to estimate the channel response. In pilot-based channel estimation, the transmitter regularly broadcasts a known sequence of symbols throughout the data transmission. Adding a pilot means adding symbols to the transmitted stream for identifying the sender and the user to the total sent frames. These symbols, known to the receiver, aim to offer a reference for the receiver to estimate the channel response. The receiver can estimate the channel response by comparing the known pilots to the received pilots. Pilot-based channel estimation is a straightforward and efficient technique, although it has limits. For example, it needs many pilot symbols in the transmission, limiting its capacity. Additionally, the channel response varies across pilot symbols. In addition, a high-resolution channel assessment is necessary for the receiver to adjust correctly for channel-induced distortion. Pilot-based channel estimation is a simple and effective approach for channel estimate in wireless communication systems. However, it has significant drawbacks, mainly when dealing with high-resolution estimation is necessary [37]. The general block diagram related to channel estimation is presented in Figure (4).

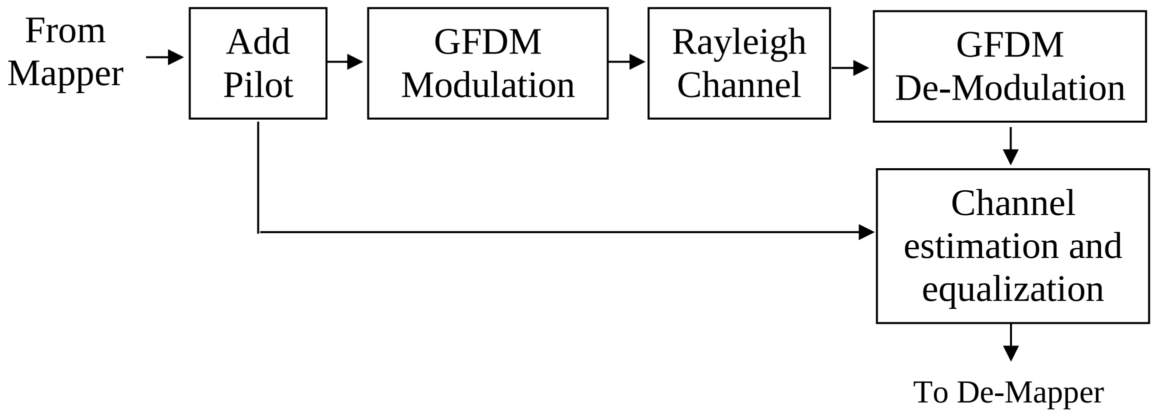

Figure (4): General channel estimation block diagram [38].

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3.4 LEAST SQUARE

The estimation-based LS is one of the channel estimation methods for wireless communication, which presents how the channel affects the signal by the environment. This effect includes interference and noise, which always weaken the signal between sending and receiving. The LS estimation contains the training pilot signal inserted in the transmitted signal and used to estimate the signal in the receiver. LS reduces the sum square error between the transmitter and receiver pilot to find the best channel response estimate, the theoretical block diagram of LS is present in Figure (5) [39].

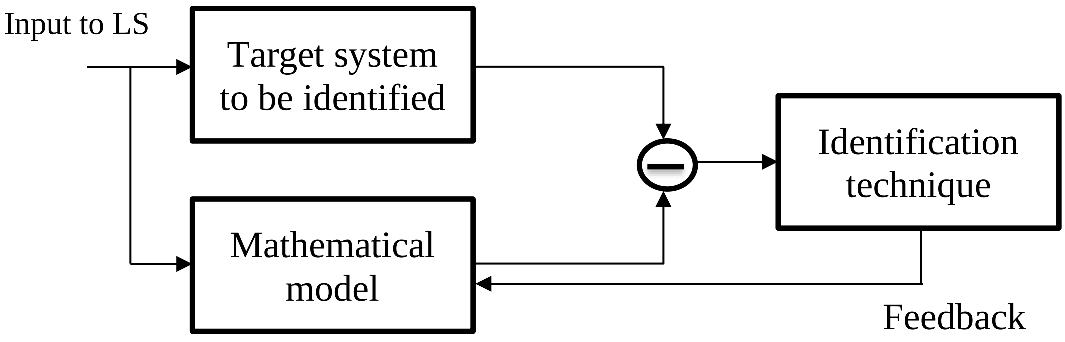

Figure (5): General block diagram of LS identification system [39].

After performing GFDM demodulation, LS steps were applied for each K. The received pilot extracted from the received signal (demodulated signal). Then the estimated LS is computed as Equation (4). Interpolation is applied to get the channel estimation HLS as Equation (5). Finally, the transmitted signal was recovered by dividing the receiving signal over HLS as Equation (6) [39].

$$LS_{es} = \frac{Y_p}{x_p} \quad (4)$$

$$H_{LS} = \text{interpolate}\,(LS_{es}) \quad (5)$$

$$Y_{es} = \frac{\text{Y}}{H_{LS}} \quad (6)$$

Where: LS_{es}: is the LS estimation. Y_p: is the received pilot. x_p : is the transmitted pilot. H_{LS}:is the channel estimation. Y_{es} :is the estimation of received signal.

3.5 NORMALIZED LEAST MEAN SQUARE

One of the methods for channel estimation in wireless communication systems is the NLMS algorithm. The NLMS algorithm is a type of adaptive filter that is used to estimate the response of a wireless channel. The algorithm uses the adjustment of the filter coefficients to minimize the error between the desired signal and the filtered version of the received signal. In the NLMS algorithm, the filter coefficients are updated at each time step based on the current error, the current input signal, and a step size parameter. It is relatively simple to implement. However, it can be sensitive to the choice of step size, and the algorithm can sometimes converge to a suboptimal solution. It can join slowly when the channel is highly correlated. The general block diagram of NLMS presented in Figure (6). Equation (7) to Equation (11) present the procedure

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of NLMS which w_{NLMS} is the output of NLMS, h_{NLMS} is the NLMS estimation for channel. e_{NLMS} is the error. H_{NLMS} is the channel estimation. Y_{NLMS} is the received estimation [40].

$$w_{NLMS} = h_{NLMS} * x_p \quad (7)$$

$$e_{NLMS} = Y_p - w_{NLMS} \quad (8)$$

$$h_{NLMS} = h_{NLMS} + \frac{2 * e_{NLMS} * x_p}{{x_p}^T * x_p} \quad (9)$$

$$H_{NLMS} = \text{interpolate}\ (h_{NLMS}) \quad (10)$$

$$Y_{NLMS} = \frac{\text{Y}}{H_{NLMS}} \quad (11)$$

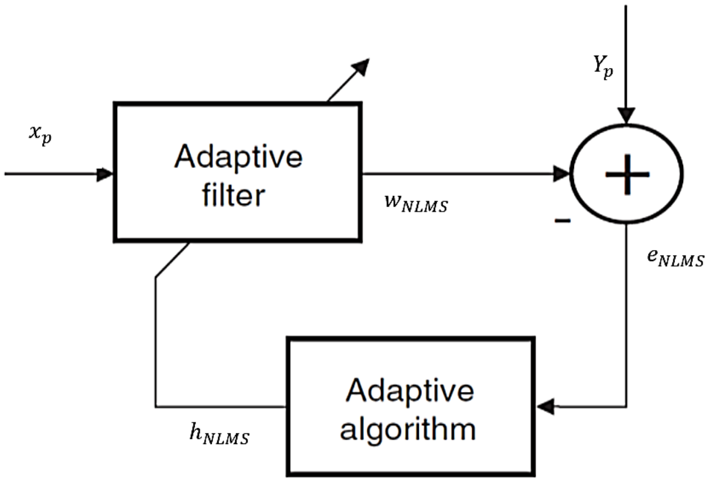

Figure (6): General block diagram of NLMS [40].

3.6 POLAR CODING

Channel coding is used in mobile communication to protect the transmitted data from errors through the transmission, such as interference, noise, and drop strength of the signal, which encodes the data at the transmitter and decodes it at the receiver. Communication systems are continuously in development hence required to improve their performance and apply new services and applications. PCs are one of the modern types of coding systems. It is one kind of forward error correction; however, they have been used in 5G communication systems as channel coding of the control channel. PC performs well compared to Low-Density Parity-Check Code (LDPC) and turbo codes which give the lowest complexity [41].

PC generates virtual channels, which assign as proper channels and useless channels. The PC's encoding process is performed by kernel matrix or generator matrix (F) shown in Equation (12) and performs Kronecker product as in Equation (13). The Kronecker product contains the + character, which refers to the XOR operation. u refer to input bit data that length of P. The kernel matrix can expand to large number of bits as Equation (14). ⊗ is Kronecker product operation. The polar encoder of 2-bit present in Figure (7). Which the stage compute based on $q = \log_2 P$. The input data to encoder is V bit and the output is P, P-V is the frozen bit often adjusts a value of 0 [42].

$$F_2 = \begin{bmatrix} 1 & 0 \\ 1 & 1 \end{bmatrix} \quad (12)$$

$$[u_1 \ \ u_2]F_2 = u^{(2)} = [u_1 + u_2 \ \ \ u_2] \quad (13)$$

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$$G_{2^n} = \begin{bmatrix} 1 & 0 \\ 1 & 1 \end{bmatrix}^{\otimes q} \quad (14)$$

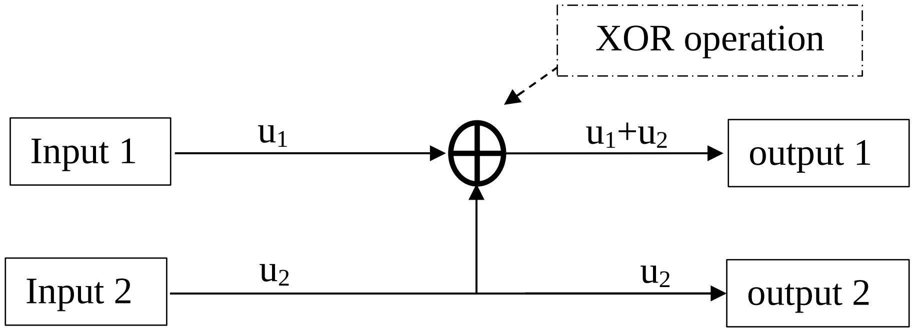

Figure (7): 2-bit PC encoder [38]

The information is recovered to the encoded data in the demodulator at the receiver-based successive-cancellation list decoder method. In general, the demodulator cannot get absolute confidence about the encoded block because of the unstable behavior of the noise in the communication channel. At the demodulator, give the confidence about of bit in the encoded by applying Logarithmic Likelihood Ratio (LLR)[42].

3.7 INTERLEAVER

The procedure of interleaving plays a crucial role in a modern communication system. Its present de-correlation is through the neighboring bits in the coding and decoding steps. Its method of arranging the data stream to become in nonadjacent locations without adding or losing anything. Different types depend on the behavior of change locations of a bit stream. The interleaved system is easy to build at the transmitter and receiver side and sometimes requires bit storage. It converts burst errors to random errors and helps the error correction process by enhancing the coding algorithm, such as PC. On the transmitter side, it is used after the encoding of the PC, while the receiver is used before the PC decoding [38].

3.8 ARTIFICIAL NEURAL NETWORK

ANN is a method for processing information created to generalize a mathematical representation of people's brains[43]. Inspired by the biological nervous system study. Understanding the biological nervous is restricted to medical details. The neuron is the brain's fundamental unit. Through input routes called dendrites, it is a complex metabolic and electrical signal processing unit that ingests and combines data from many other neurons. Figure (8) illustrates a neuron from the human brain [44].

ANN is a grid of linked neurons. In other words, the neural network resembles the human brain in its operation. It aims to generate an output decision or pattern in response to the input [45]. The ANN process-based collecting data and prepared for training and testing to give its decision based on the error function. The general flowchart of ANN is shown in Figure (8).

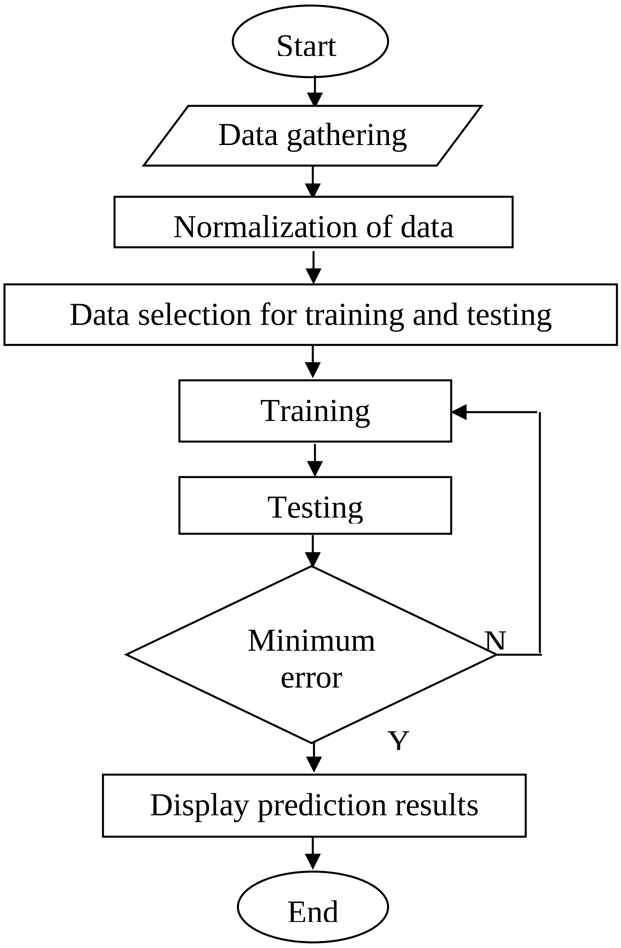

Figure (8): General flowchart of ANN [38].

3.9 GENETIC ALGORITHM

Optimization is the primary purpose of using GA and any other evolutionary algorithm in all fields. Since optimization is the goal, it is also used in broad areas such as control, simulation, modeling, and others. The conventional optimization methods start with a single factor of search performed iteratively to arrive at the optimal solution based on static heuristics. GAs represent the most representative, well-known, characterized, and widespread evolutionary computation; this was done by using the essential principles of biological evolution without the need to overcomplicate the biological mechanisms at the cell level. GA can be applied without restrictions related to the type of problem or method of optimization and requires a long time for execution which presents a high number of iterations and hence has been categorized as an offline optimization algorithm [46].

GAs incorporate all the essential natural evolution items, making them exceptionally effective. It is kept simple and is hence easy to use for many problems. Generally, GA is used to search for an optimal solution or solution under challenging issues. Their use is beneficial in nonsmoothed optimization environments, while other algorithms present weak performance. GA used a group of candidates (population) to seek several paths or spaces together. GA operates based on the population of individuals; each can have a solution encoded as binary with a fixed length string, similar to an actual chromosome. After generating the first population randomly, the algorithm develops the process through iterative and sequential selection,

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crossover, and mutation. New generations appear after the termination of each iteration. The population can merge previous knowledge with solutions. This process should not limit population variety; otherwise, convergence is accelerating. Selection is applied over the current population to generate an intermediate population, then crossover and mutation to develop the next generation's possible solutions. The block diagram of GA is present in Figure (9) [47].

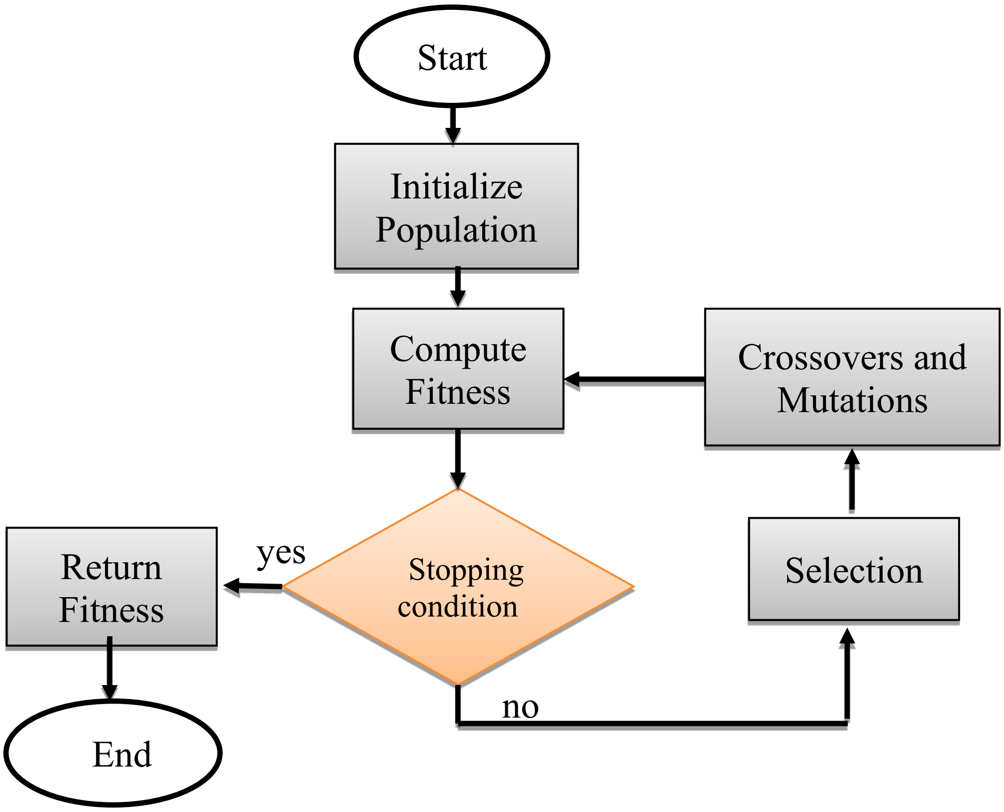

Figure (9): Block diagram of GA [38].

4.THE PROPOSED GFDM SYSTEM

This section presents the proposed system's modeling details with GFDM, PC, interleaver, ANN, and GA. The wireless communication system generally contains several steps. Each one belongs to the overall system and performs its function. The general block diagram of the transmitter and receiver system is shown in Figure (10).

The first step is to generate data that would be sent over the channel and then received. This data is used to compute the performance by calculating the BER between the transmitted data and the received.

The second step is the coding system used to detect and correct the error through the channel based on added redundancy bit, without the need to data re-transmit, which is considered a type of forward error correction.

The third step is the interleaver, which almost belongs to the coding system to convert burst error to random error, enhancing the coding system's ability to detect and correct the error.

The fourth step is the mapper, which gets a modulated signal.

The fifth step is adding a pilot. It is considered bits of identifier for sending and receiving that can be used for channel estimation. It is used to know the channel effect on the transmitted signal and perform the estimation and equalization process.

The sixth is the GFDM modulation step.

The seventh step is adding CP, which cancels the effect of inter-symbol interference, which the three tapes (multipath) generate it through the channel.

The eighth step is the channel that transmits the signal through it. It is crucial due to its effect on the system's performance and various scenarios used to estimate its effect and equalize it to get the transmitted signal.

At the receiver, the signal entered the same transmitted step in reverse order with an additional step called the estimation and equalizer. In this step, estimate the channel effect over the transmitted signal, then equalize it to remove its effect.

Table (1) presents the parameters of the proposed system. Table (2) presents the enhancement on BER when using the GA-GFDM (G-GFDM), added ANN to estimate the channel as in GA-ANN-GFDM (GN-GFDM), added the PC as GA-ANN-PC-GFDM (GNP-GFDM), and added interleaver to GNP-GFDM as GA-ANN-PC-interleaver (GNPI-GFDM). Figure (11) shows the performance enhancement for the GFDM scenarios based on BER vs SNR.

Table (1): GNPI-GFDM scenario system parameters.

Symbols	**value**	**Description**
K	20	Number of sub-carriers
M	16	Number of sub-symbols
CP	0.1	Percentage of cyclic prefix
r	0.1	Roll off factor of the pulse shaping filter
pilot	20%	
mu	4	Modulation order of the QAM symbol = 16QAM
SNR	1:3:31	SNR range
Channel	random	AWGN
Ne	10-35	Number of neurons in hidden layer

Table (2): proposes a scenario comparison with standard GFDM-LS.

Scenario	BER Enhancement comparison with GFDM-LS at 13 dB	BER Enhancement comparison with GFDM-LS at 19 dB
G-GFDM	0.0191	0.0153
GN-GFDM	0.0214	0.0167
GNP-GFDM	0.0331	0.0201
GNPI-GFDM	**0.0332**	**0.0201**

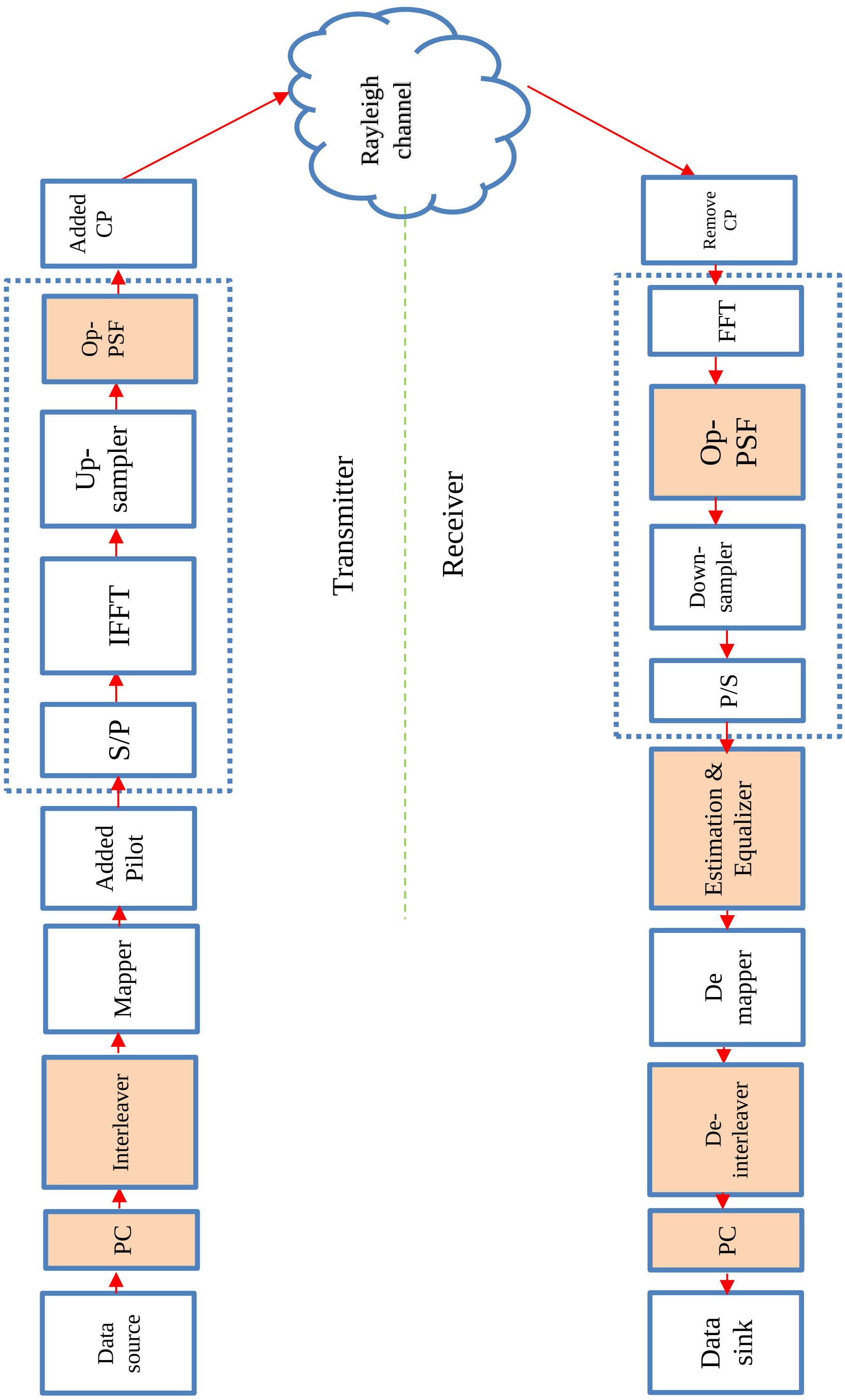

Figure (10) Proposed scenarios enhancement based on K20 M16.

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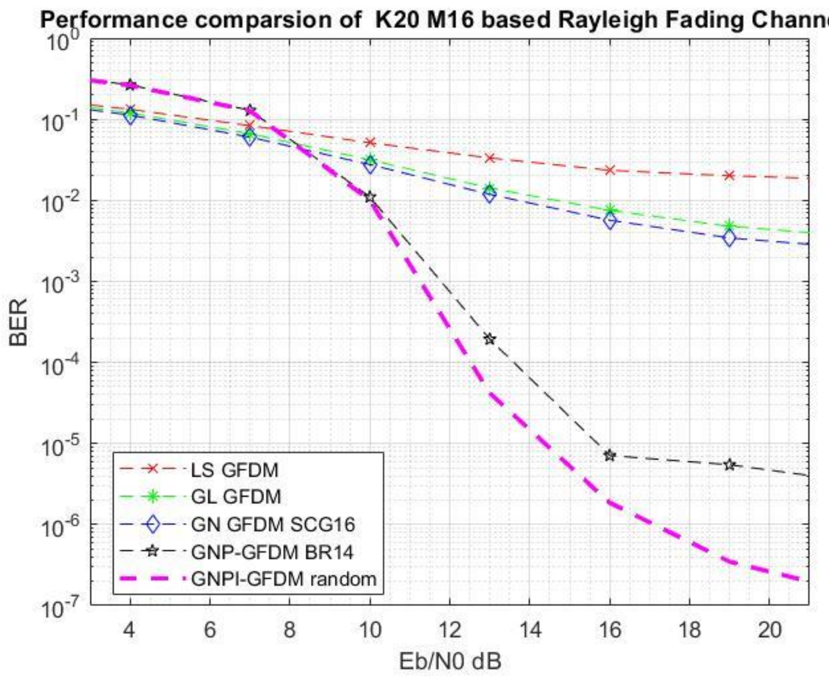

Figure (11) Proposed scenarios enhancement.

The comparison with the Least Square-GFDM (LS-GFDM). The GL-GFDM presents enhancement-based GA in PSF. The 16 neurons of ANN-based GA-Scaled Conjugate Gradient GN-GFDM SCG 16. The 14 neurons in ANN-based Bayesian Regularization GNP-GFDM BR 14. The comparison between the proposed scenario and other related work is presented in Table (3). It presents the comparison with PI-GFDM under the AWGN channel. The comparison is based on the BER to SNR. The structure of PI-GFDM is built with different values based on the related work. In comparison, similar points were adopted structure (value of K and M), channel (AWGN), and SNR. The comparison is based on the BER value of traditional GFDM with the proposed GFDM of the scenario or related work based on the same SNR. In some cases, an approximation value of SNR was adopted because some of the researchers used the Energy Per Bit To Noise Power Spectral Density Ratio (Eb/No), and they did not mention the amount of the rate.

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Table (3) Performance comparison with a literature survey

Structure	K		64	128	16	256	128	128
	M		48	5	8	5	24	5
SNR (dB)			20	30	19	12	21	15
Proposed system	BER	Traditional GFDM	0.032	7.8×10^{-6}	0.156	0.145	0.0057	0.043
		PI GFDM	0	0	0	0	0	0
literature survey	Ref.		[19]	[121]	[22]	[24]	[25]	[26]
	Type		SIC	Kalman	BIC-PC	SIM- CP	CBBO -SLM	JAYA-SLM
	BER	Traditional GFDM	6.5×10^{-4}	2×10^{-1}	10^{-1}	10^{-4}	10^{-2}	9×10^{-5}
		Proposed GFDM	1.5×10^{-5}	2×10^{-2}	10^{-3}	0.5×10^{-6}	10^{-5}	10^{-6}

5. CONCLUSION

The GFDM is considered a new communication system and has yet to be officially adopted in the generations of wireless communications. Thus, it is within the stage of development and improvement. Traditional GFDM is studied with AWGN and Rayleigh fading channels. This paper presents scenarios for developing the BER of the GFDM system.

6.CONFLICTS OF INTEREST

"The authors affirm that they have no financial or other conflicts of interest to disclose about the current work".

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