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GFDM Pulse Shaping Optimization Based Genetic Algorithm

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Abstract

Generalized Frequency Division Multiplexing (GFDM) is one of the candidate schemes for the 5G and beyond. Its multicarrier modulation scheme and structure are independent blocks, and each block contains sub-carriers and sub-symbols. Sub-carriers are filtered with a prototype pulse shaping that shifts by time and frequency domain. This work uses Genetic Algorithm (GA) to assign the best parameters of the pulse shaping filter, which uses the error as a cost function. The algorithm assigns its parameters based on a minimum error by iteratively processing until reaching the pulse values that give the minor error. This method gave the advantage of reducing the error generated due to orthogonality and thus gave improved performance. This method initially depends on searching for filter values that provide the lowest error value and then adopting these values in building the GFDM transmitter and receiver. This method reduced the BER to 0.0107 at 10 SNR and 0.0033 at 25 SNR compared with the traditional method. Thus, this is a new method for building a GFDM transceiver system.

keyword: Genetic algorithm, GFDM, Optimization, Pulse shaping.

1. Introduction

GFDM is multicarrier modulation transmission [1]. Due to its attractive properties, it is proposed beyond 5G [2]. It presents a generalized form of the OFDM scheme. It is used on cyclic prefixes for each block as efficiently as at OFDM [3]. Generally, the coefficient of the pulsed shaping filter is computed by a straightforward method. Besides, it belongs to the structure of GFDM that is arranged in a matrix. The Bit Error Rate (BER) is used to evaluate the system models. The BER is affected by the coefficient quantity of the prototype filter [4]. GFDM at first proposed by Fettweis et al. in 2009. Its multicarrier scheme is flexible in spreading the data into time and frequency slots. Each subcarrier is localized in the frequency domain to present more robustness [5].

A GA is a search algorithm that artificially simulates and imitates a natural genetic process, first presented by John Holland in 1970 [6]. GA is an evolutionary algorithm that can perform artificial intelligence tasks for solving optimization problems such as classification, learning, and identification [7]. The GA simulates the natural development process by adapting different procedures to the number of organisms acclimate to their circumference [8]. The search for the best solution to address the presented problem is by moving from the previous individuals (parents) to the later individuals (children) using factors similar to genetic factors due to their diverse and general nature. It presented the idea of the population [9]. The basic principle of optimization is processing the fit population to generate better offspring for the next generation. The working principle is based on Darwin's "survival-of-the-fittest" present [10-12]. The GA algorithm deduces the most appropriate solutions and then chooses the one that will repeat and send their genetic code to subsequent generations. GA is a reiteration process to enhance the population. The algorithm is used in many applications in the field of wireless communications [13]. Many researchers have presented workers to improve the performance of communications systems, especially GFDM, and some of them will be mentioned in the following:

Jinkyo Jeong et al., in 2019, used tabu search to mitigate the effects of interference in GFDM. It used a new low-cost solution based on maximum likelihood costs [14]. Archana Kumari and Neetu Sood 2020 present GFDM waveguide optimization based on Hilbert envelope and pulse shaping filter in terms of inter-symbol interference and PAPR performance [15]. ZEE ANG SIM et al. in 2020 minimized the OOB radiations and improved power spectral density. They reduced the BER of the GFDM system by using a pulse shaping filter, which was designed by computationally efficient quadratic programming [16]. Sumina Sidiq et al. 2022 used different windowing to optimize the spectral efficiency by using GA. this work applied to UFMC and GFDM under 5G standards [17].

While reviewing the research published on the GFDM transceiver system, no way to improve performance was found for GFDM by using the GA to optimize the filter pulse shaping. The new way of this paper is that it used GA to find the best filter coefficient that presents minimum BER and compare it with standard filter pulse shaping.

2. Theoretical background

The data structure in GFDM is shown in Figure (1). 16 QAM modulators modulate the transmitted data to complex symbols, then add cyclic prefixes entered into GFDM. GFDM modulation is based on independent blocks, each block built by K subcarriers and M subsymbols as a form of two-dimensional (time and frequency domain). The subcarriers are prototype filters that circularly filter at a time and frequency domains, GFDM modulation shown in Figure (2) [18].

Each symbol $d_{k,m}$ represents data send in GFDM blocks with k^{th} subcarrier and m^{th} sub-symbol. Each symbol is filtered with a pule shape filter as in (1-3)[19].

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

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

$$g[n] = \frac{sinc(n)*cos(\pi*a*n)}{1-(4*a^2*n^2)} \qquad (3)$$

Where, $x[n]$ is the transmitted signal. $[n]$ is the sampling index. $d_{m,k}$ is the complex data belonging to the k[th] subcarrier and m[th] sub-symbol. $g_{m,}[n]$ is prototype pulse filter. N is equal to MK. a is roll-off-factor. The transmitted signal suffers from AWGN noise. The block diagram of the received signal is present in Figure (3).

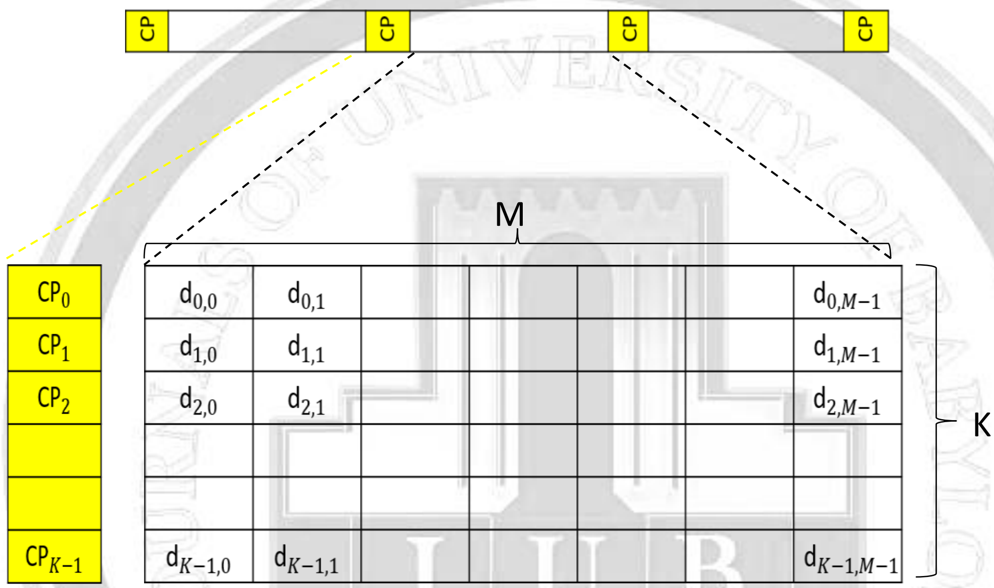

Fig. 1. The structure of GFDM data block [20]

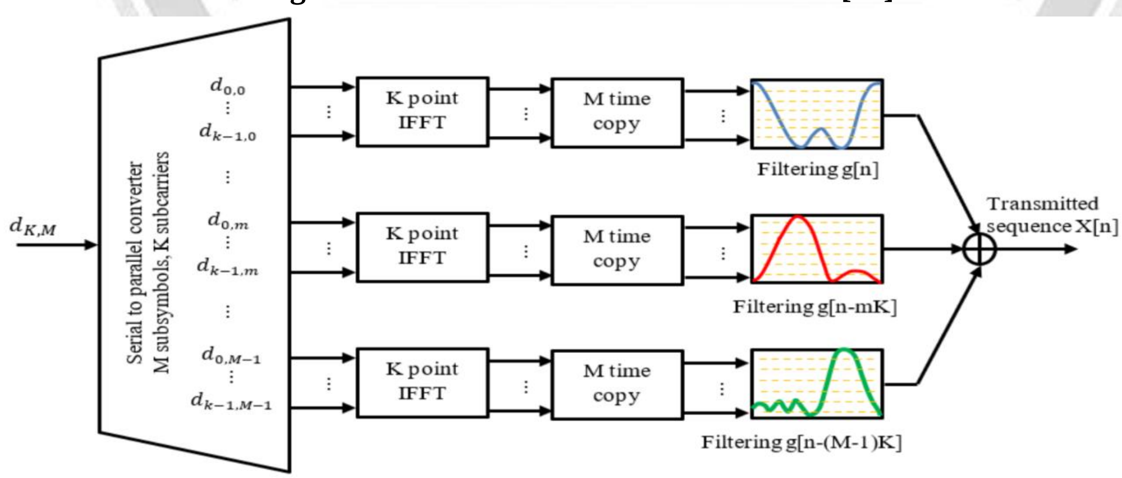

Fig. 2. GFDM Modulator [21]

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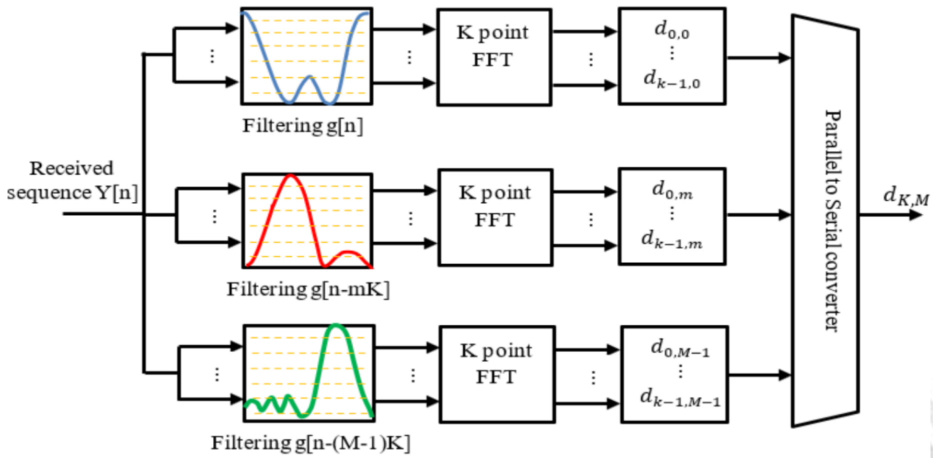

Fig. 3. GFDM Demodulator [21]

3. Genetic algorithm

GA is an active algorithm for achieving the best solutions with fast convergence from the many selections that are hard to solve. Due to these features, it has been used in many applications. The operation procedure of GA is based on generating the population. The group of individuals is a sample of search space through arbitrary search instances. These individuals act as possible solutions to objective functions under the optimization problem. Each individual belongs to its fitness value under the fitness function. The general block diagram present in Figure (4) contains the main step present below [22][23]:

3.1 Population

The population size affects the optimization problem significantly, and the large size leads to a better solution for the optimization but gives a slower convergence speed.

3.2 Fitness function

The fitness function is the objective function that will not be optimized and based on the individuals of a population are to be evaluated, thus, allowing them to survive. It supplies a fitness value for the individuals, providing the direction to the optimal solution. Thus, it is responsible for the quality of the solution and the converging speed. One of the crucial features is the speed of the calculation, which is applied extensively in optimization problems hence improving the quality of the final decision.

3.3 Initialization

At first, the population generates randomly based on candidate individuals with whom they compete against each other, and only a few survive. After that, the surviving individuals suffer from mutations and crossovers (evolutionary transformations) to generate individuals representing the new population. When the initial population is good enough can give better and

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faster convergence, and widened search space can lead to Improving the quality of the obtained solution.

3.4 Selection

It refers to selecting offspring at each stage of evolution, where the strongest are chosen as parents to the next generation. At the same time, the weak perish, and different methods carry out the selection process.

3.5 Crossover

It is the operation to choose an optimal solution between two parent vectors, considered the most significant operation in evaluation. The Random crossover point is selected to exchange their bits (genes).

3.6 Mutation

It is the evolutionary conversion due to tiny random perturbance in individual offspring. This perturbance performed flip in a random position and provides broad diversity in the search space.

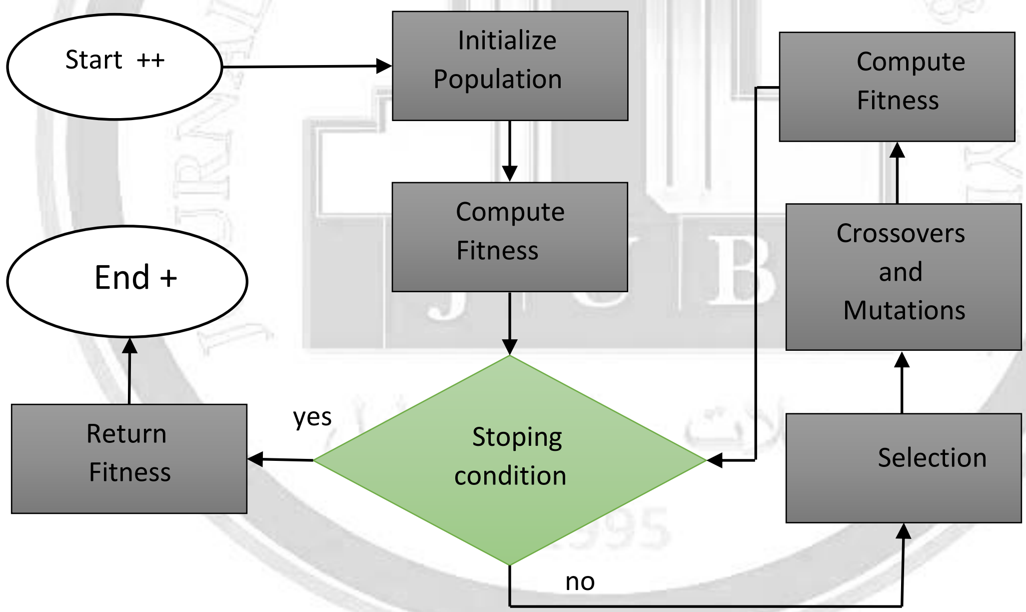

Fig. 4. block diagram of GA [24]

4. Simulation result

The GA is the general usage in computing coefficient factors to get optimum solutions. In this paper, the GA is used to compute the coefficient of the pulse shaping filter to get minimum BER. Used GA to find the lower value of the fitness function (bit error), which gives the GFDM pulse shape coefficient depending on a local unconstrained minimum of the error function. This process must assign the length of the coefficient, lower and upper bounds values

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for the coefficient (which are the values of the coefficients among them), population size, and the initial value of the coefficient. The simulation parameters are presented in Table (1). A GA in MATLAB 2021 Toolbox was used to find pulse shape filter parameters. The constraints of GA are bounded by the general shape of the filter which the search so that the search path is in this form, the standard pulse shape filter given in (3) presented in Figure (5). The lower and upper bounds of the coefficient filter that entered the GA are present in Figure (6). Through the replication of genetic operators, generation by generation, an optimized population is created, hence the optimum coefficient of the pulse shape filter. The optimum coefficient of the filter that optimizes by a GA is presented in Figure (7). The performance comparison between the standard g and the proposed g as a relationship between the BER and the SNR is presented in Figure (8).

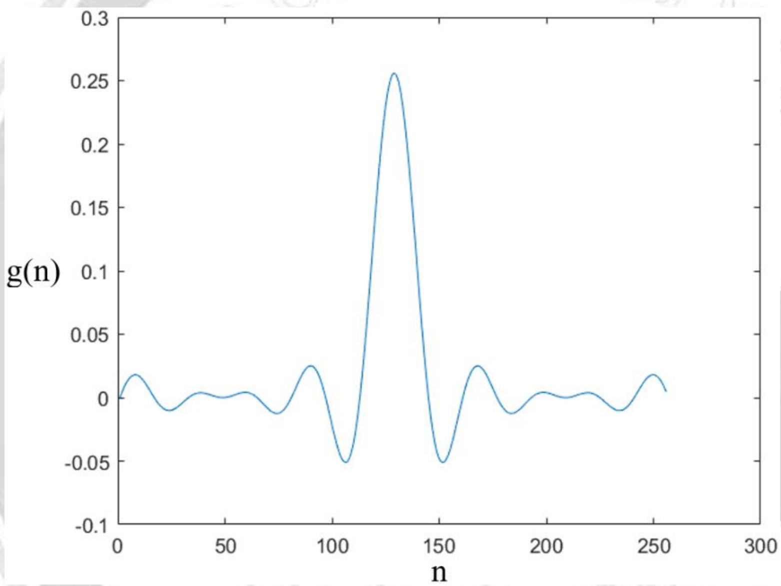

Fig.5. The standard pulse shape filter.

Table 1: System Parameters

Description	***symbol***	***Value***
Number of samples per sub-symbol	*K*	*16*
Number of sub-symbols	*M*	*16*
Block Length	*M*K*	*256*
Roll off factor of the pulse shaping filter	*A*	*0.1*
Modulation order of the QAM symbol	*mu*	*4*
Number of blocks	*N*	*1000*
length of the coefficient	*128*	
population size	*100*	

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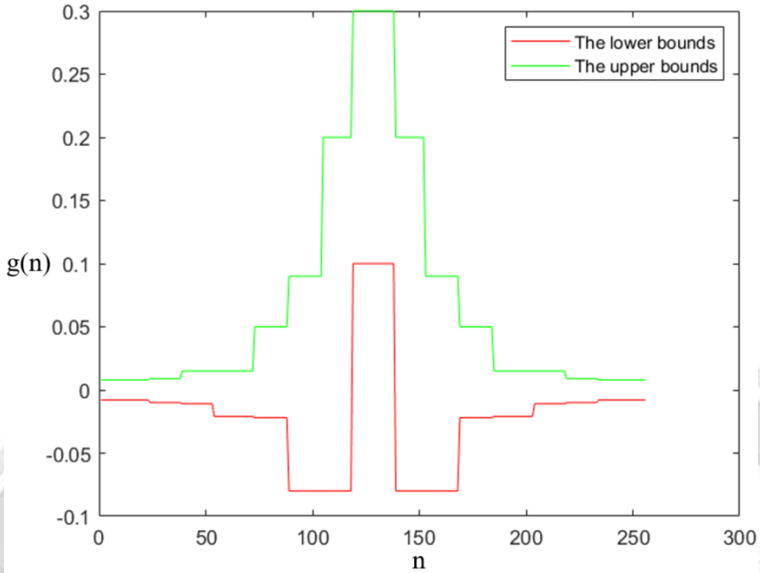

Fig.6. The lower and upper bounds of the coefficient filter.

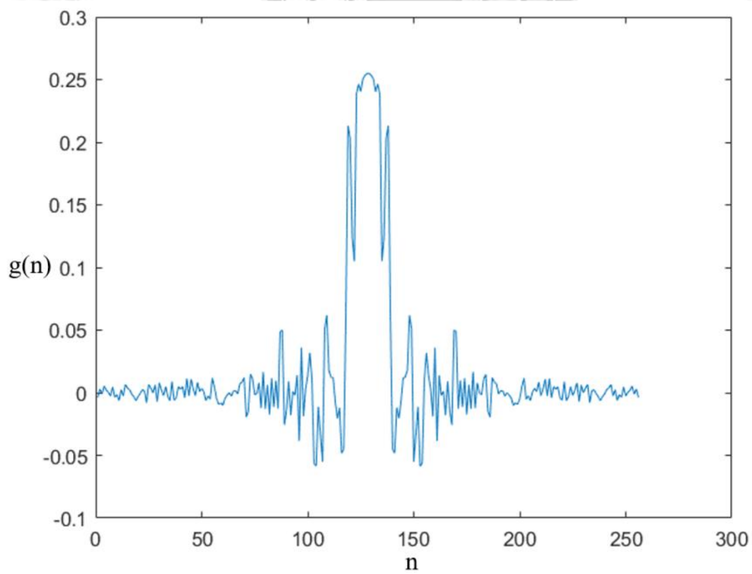

Fig.7. The optimized coefficient of the filter.

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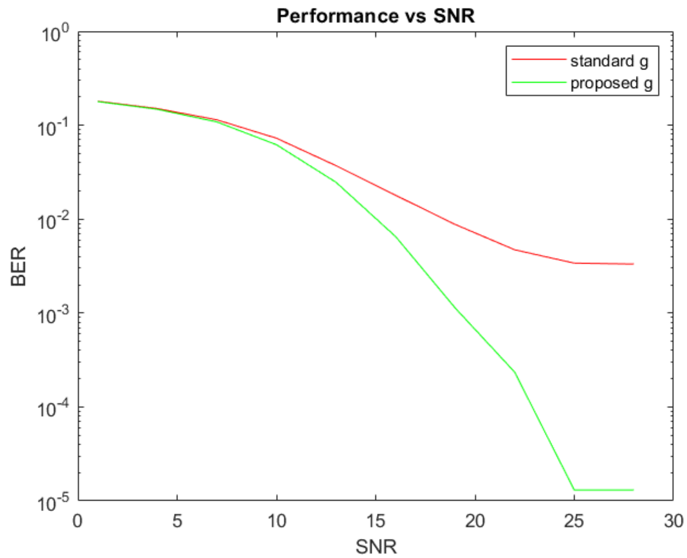

Fig.8. The performance comparison between the standard g and the proposed g.

Fig. (8) present the enhacment of opG over stG which at 16dB and 25 dB the enhancment 0.0106 and 0.0028 respectively.

5. Conclusion

GA successfully built a pulse shape filter by assigning its coefficient. It assigns the fitness function as a bit error for each block. It constrains it by a bounded value to save the general behavior of the standard pulse shaping filter. The high flexibility in choosing the filter pulse values gave it outstanding performance, and the g coefficient performed better. This new method is compatible with the GFDM transceiver based AWGN channel and suitable to applied with other channels environment.

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تحسين شكل النبضة لنظام تعدد الإرسال بتقسيم التردد العمومي بالاستناد الى الخوارزمية الجينية

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الخلاصة

يعد تعدد الإرسال بتقسيم التردد العمومي (GFDM) أحد المخططات المرشحة للجيل الخامس وما بعده. إن مخطط وهيكله لتشكيل الموجات الحاملة المتعددة عبارة عن بلوكات مستقلة، ويحتوي كل بلوك على موجات حاملة فرعية ورموز فرعية. يتم ترشيح الموجات الحاملة الفرعية بنموذج أولي لتشكيل النبضة يتحول حسب الوقت ومجال التردد. يستخدم هذا العمل الخوارزمية الجينية (GA) لتعيين أفضل المعلمات لمرشح تشكيل النبض، والذي يستخدم الخطأ كدالة تكلفة. تقوم الخوارزمية بتعيين معلماتها بناءً على حد أدنى من الخطأ من خلال المعالجة التكرارية حتى الوصول إلى قيم النبض التي تعطي الخطأ الطفيف. أعطت هذه الطريقة ميزة تقليل الخطأ الناتج عن التعامد وبالتالي أعطت أداءً محسنًا. تعتمد هذه الطريقة في البداية على البحث عن قيم المرشحات التي توفر أقل قيمة للخطأ ثم اعتماد هذه القيم في بناء مرسل ومستقبل .GFDM خفضت هذه الطريقة معدل الخطأ في البتات إلى ٠.٠١٠٧ عند ١٠ SNR و٠.٠٠٣٣ عند ٢٥ SNR مقارنة بالطريقة التقليدية. وبالتالي، هذه طريقة جديدة لبناء نظام الإرسال والاستقبالGFDM.

الكلمات الدالة: الخوارزمية الجينية، تعدد الإرسال بتقسيم التردد العمومي، التحسين، تشكيل النبض.

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