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Developed PC-GFDM based on interleaver

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Abstract

The significant development in devices based on communication technologies requires the provision of advanced generations of communications to provide these requirements. The current hot topics are moving towards providing that meets the requirement of modern systems for industrial and technical requirements. This paper developed the GFDM system with Polar Code (PC) and interleaver, which presents the BER of GFDM at AWGN and the channel effect. Then GFDM transceiver system is built with the PC and interleaver. At each step, test and compare the BER performance. The performance computed under the effect of multipath frequency selective channel. The BER at 22 SNR of GFDM, PC-GFDM, and PC-GFDM with random interleaver is 0.1096, 0.0970, and 0.0680. The BER at 28 SNR of GFDM, PC-GFDM, and PC-GFDM with random interleaver is 0.1047, 0.0914, and 0.0607. This result presents the enhancement of using PC and interleaver. It also showed a distinct enhancement over the other methods mentioned in the researcher's survey.

Keywords: GFDM, interleave, LS, and PC
2020 MSC: 93-XX

1 Introduction

The development of communication systems requires the provision of specific characteristics such as high data rates, flexibility, and low latency and must be efficient, robust, reliable, and versatile. Multiple access has become the core of the modern generation of cellular networks. It refers to technologies that have the ability of multiple users to share a communication channel under conditions of reliability and efficiency [8].

The 5G presented a distinct set of characteristics compared to the previous generation. Where they were given as the data rate must be at least 10 Gbps (100 times more than in 4G), latency is 1 ms (10 times more than 4G), the connections devices are 1 million per km^2 (100 times more than in 4G), the use of efficient multiple access techniques can meet these requirements [16]. The specifications are summarised in Figure1. There are various technologies through which the requirements of the 5G can be provided. These technologies work with the support of the system to achieve the desired. Several systems are connected in communications systems, such as GFDM, Orthogonal Frequency Division Multiplexing (OFDM), PC, etc.

GFDM is a non-orthogonal and multi-carrier modulation scheme representing a transceiver architecture and a physical layer concept. It is a robust waveform and one of the 5G and current waveform candidate schemes, giving

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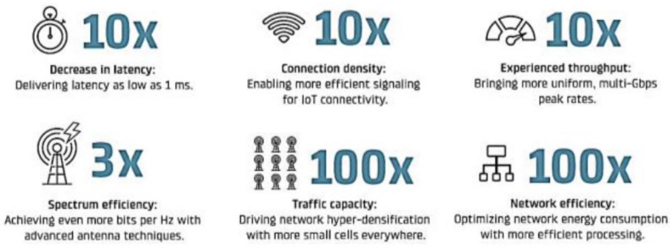

Figure 1: comparison between 4G and 5G [16]

sufficient flexibility to address 5G. Its multi-carrier support scenario with pulse shaping filters, used for different cases, arranged the data symbol as a time-frequency block. The GFDM is considered an optimized step over OFDM [10].

Communication systems use channel coding to protect information from transmission errors caused by poor signals, interference, and noise. The channel encoder uses to encode the signal at the transmitter sides, which might be a handset, base station, or another user device [20]. To recover the transmitted information by mitigating the transmission errors at the receiving side. In the last decades, various channel codes have been presented which allow the transmission of information reliably at a level relatively close to the theoretical limit set by channel capacity. Specifically, Turbo code adopts the 3G and 4G mobile communication standards, while LDPC code is used in satellite and Wi-Fi standards. A modern type of coding called the PC has appeared that provides encryption with high efficiency. The PC is a promising technology in communication systems, adopted in control channel functions for the 5G systems under the channel coding area. PC is a linear block code achieving channel capacity, and it is a simple encoder technique that uses a SIC decoder to detect the transmitted signal [13].

The first appearance of GFDM in 2009 was by a group of researchers from Vodafone Chair Mobile Communications Systems/ Technical University Dresden under Prof. Gerhard Fettweis in Germany, which provided the general structure and mathematical model, then performed several optimizations by integrating with other technologies [4]. Then other researchers continued to use optimized algorithms to enhance the performance of the GFDM transceiver system as follows: Valluri and Mani, in 2018, proposed a new scheme based on the unique word for GFDM, which uses redundant subcarriers to improve performance. This system enhancement the BER performance by 0.00013 at 19 dB [17]. Zhong et al., in 2018, used an iterative frequency domain equalization algorithm to enhance the fidelity and used a new nulling filter design to cancel the residual interference. This present system enhancement of 0.01 at 19 dB [21]. Valluri et al., in 2019, used the block circulant nature of GFDM receiver to reduce the complexity. It used the sum of permutation matrices instead of the inverse to reduce the complexity. It implements its work by National Instruments (NI) 2953R as hardware and LABVIEW as software. This system enhancement the BER performance by 0.019 at 19 dB [18]. Turhan et al., in 2019, used a deep convolutional neural network connected by a fully-connected neural network for GFDM detection and demodulation. This system presents a trade-off between complexity and performance, enhancing the BER performance by 0.0032 at 19 dB [15]. Agrawal and Appaiah, in 2019, used a scattered pilot for the Kalman filter as an estimation to avoid self-interference under time-varying channels. This present system enhancement of 0.055 at 19 dB [1]. Yıldırım et al. in 2020 used convolutional neural network for detection and demodulation of GFDM reciver.It compared the proposed with the classical method regarding the performance and the parameters required for each system. This present system enhancement of 0.0013 at 19 dB [19].

This paper uses the GFDM to simulate the transceiver communication system. Which computes the performance based on BER vs. SNR. The transverse optimization by PC as coding code presents its effect on the performance. Three types of interleavers (random, helical, and matrix) are built into the proposed system, presenting their effect on the performance. The AWGN simulates as a channel with a multipath frequency selective fading channel. The channel degradation was estimated by LS and NLMS estimation. The enhancement in BER of the proposed system compared with other researchers' surveys.

2 Proposed System

The proposed work presents a communication system based mainly on GFDM as a modulation technique and is supported by a coding system based on the PC. The proposed block diagram is presented in Figure 2. The binary source provides the vector encoded by the polar encoder to obtain the coded vector and then permute by interleaver. The mapper maps the interleaved bits of the blocking mapper affected by modulation order.

The data block can modulate and decompose into K subcarriers with M subsymbols according to $d = (d_{0,0}, ..., d_{K-1,0}, d_{0,1}, ..., d_{K-1,m-1})$. The total number of symbols $N = KM$ and the single elements $d_{k,m}$ refer to the data transmitted on the kth subcarrier and in the mth subsymbols. After GFDM modulation, the addition cyclic prefix then transmitted the signal.

The transmitted signal is affected by a multipath frequency selective fading channel. The signal is then processed at the system's receiving stages to obtain the original signal with the minimum error. Which removes the CP and demodulates by the GFDM scheme, then implements estimation and equalizer-based LS in the GFDM demodulation. Finally, perform the de-interleaver and polar decoder and get the generated data by the data sink.

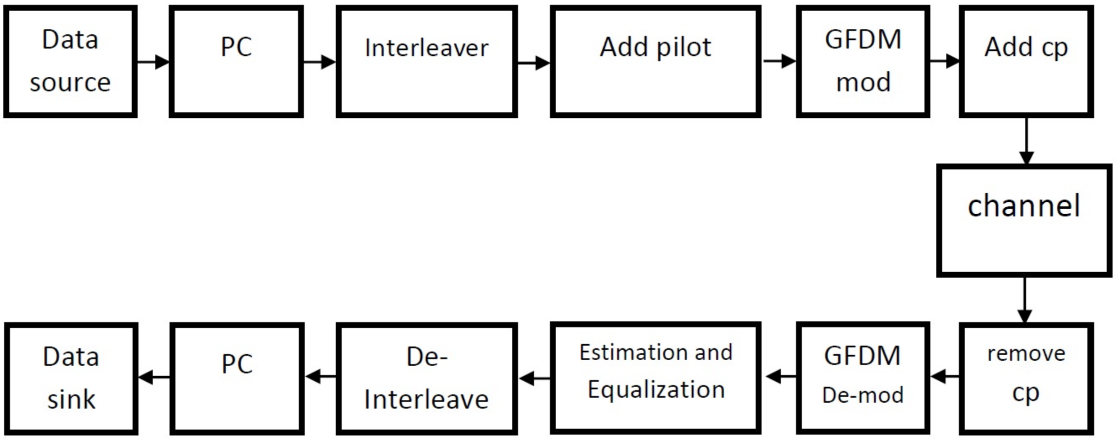

Figure 2: proposed block diagram.

3 Theoretical Background

This section will discuss the theoretical background of the proposed techniques for use.

The principle of working with the basic mathematical model that organizes GFDM, PC, interleaver, channel estimation, and equalization will be presented.

3.1 Generalized Frequency Division Multiplexing

The operation of GFDM is based on filtering each subcarrier with a pulse shaping. Time-frequency structure match with low latency applications. The generalization of GFDM came from time-frequency resources. GFDM modulation structure scheme is based on the independent blocks, which divide into M subsymbols and K subcarriers to match different requirements for all applications [6]. The GFDM transmitter and receiver's block diagram are presented in Figures 3 and 4. In GFDM systems with N total, transmitted data shaped by a filter $g_{k,m}$ circularly shifts by time and frequency domain. Shift version based on raised cosine configuration and the filtering prevents the OOB as expressed in Eq. (3.1) to (3.3) [7].

$$g_m[n] = g[(n - mk)_{mod\ N}]exp\left(j2\pi\frac{kn}{K}\right) \tag{3.1}$$

where $k = 0, 1, ..., K - 1$ and $m = 0, 1, ..., M - 1$.

$$g[n] = \frac{\sin c(n) \times \cos(\pi \times a \times n)}{1 - (4 \times a^2 \times n^2)} \tag{3.2}$$

$$x[n] = \sum_{k=0}^{K-1}\sum_{m=0}^{M-1} g_{k,m}[n]d_{k,m} \tag{3.3}$$

Where $n = 0, ..., N - 1$. Eq. (3.3) as a matrix form can be written by the form $x = Ad$.

Which the modulation matrix $A = (g_{0,0}, ..., dg_{K-1,0}, g_{0,1}, ..., g_{k-1,m-1})$ [11].

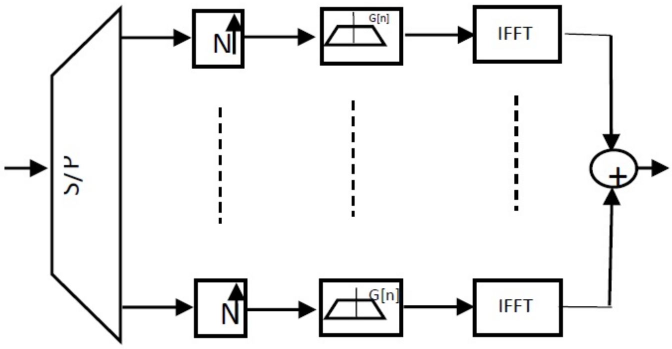

Figure 3: Block diagram of GFDM transmitter

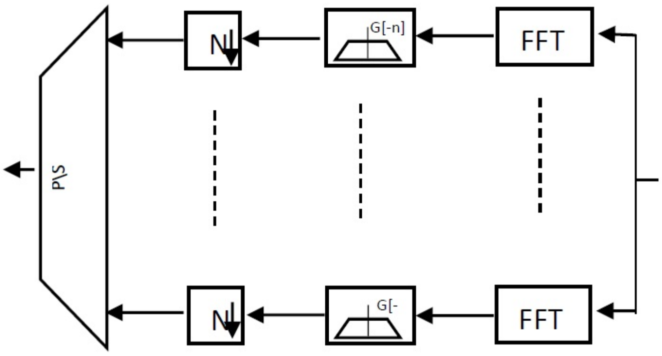

Figure 4: Block diagram of GFDM receiver

3.2 Polar code

PC is a new and immature technique introduced by arikan in 2009. Its simple structure, elegant, and low-complexity binary error correction method for arbitrary symmetric binary-input discrete memoryless channels are considered for the 5G. The performance of PC is more guaranteed than LDPC and turbo codes. Its substructure of parity checks and repletion combined brilliantly and smartly to create its system. The basic idea depends on channel polarization, which takes a noisy channel and, through clever technique, makes an ideal noiseless and extremely noisy channel out of a single noisy channel. The idea of channel polarization is to combine multiple channels cleverly to get either noiseless or very noisy ones more than the original channels by repetition. Its work is foreseen by the 5G standards, which is the easy implementation of 5G-PC. The general mathematical model for the polarization effect of PC depends on the matrix. The mathematical model present in Eq. (3.4)—(3.8) [9].

$$G_{2^n} = \begin{bmatrix} 1 & 0 \\ 1 & 1 \end{bmatrix}^{\bigotimes n} \tag{3.4}$$

$$N = 2^n \tag{3.5}$$

$G_N : N \times N$ matrix, Kronecker product of 2×2 kernel. In binary tree representation at depth n.

$$u^{(N)} = uG_N \tag{3.6}$$

Which N is the polar transform bit, $n = 0, 1, 2, ..., G$ is a kernel, $\bigotimes$ is Kronecker product operation, $u^{(N)}$ is output, u is input at 5G standard $n = 10$.

$$G_2 = \begin{bmatrix} 1 & 0 \\ 1 & 1 \end{bmatrix} \tag{3.7}$$

$$[u_1 \quad u_2]G_2 = u^{(2)} = [u_1 + u_2 \quad u_2] \tag{3.8}$$

Its most basic contract in PC, called polar transform or arikan transform, can also represent the root as in Figure 5. This transform takes 2 bits to 2 bits so that this polar transform G_2 and can get more extended versions of it as G_4, G_8 for any power of 2. The + refers to XOR logic or mode two operations. u_1 u_2 are the input vector and the $u^{(2)}$ is the output vector [3].

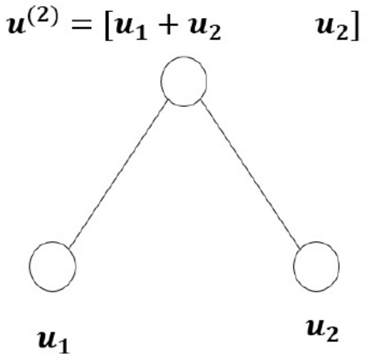

Figure 5: 2-bit polar encoder [3]

The information is recovered to the encoded block in the demodulator at the receiver. In general, the demodulator cannot get absolute confidence about the 5encoded 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) as in Eq (3.9) [3].

$$LLR = \ln \left[\frac{pr(bit = 0)}{pr(bit = 1)} \right] \tag{3.9}$$

The $pr(bit = 0)$ and $pr(bit = 1)$ refer to the probability of the corresponding bit being 0 and 1, respectively. The positive value of LLR indicates that the bit value is zero with higher confidence. In comparison, the negative value of LLR suggests that the bit value is one with higher confidence. The value of LLR refers to confidence, and the infinite magnitude expresses absolute confidence in the value of the bit.

3.3 Interleaver

Interleaver is an essential technique used to make forward error correction based permute sequences of symbols, which is widely used in improving the error correction abilities of coding algorithms through bursty channels. There are many types of interleavers customized according to the permute process, and the most famous types are random, helical, and matrix. In random interleaver, randomize the bits by selecting an address and separating the adjacent error bits by a few bits [12]. In helical interleaver, the data is in row by row. However, it reads diagonally by diagonal. in the matrix, interleaver the bits written in a matrix row by row and read column by column [14].

3.4 Channel estimation

The signal is transmitted through a channel; hence it is affected by a multi-tape frequency selective fading channel. The received signal present in Eq. (3.10) [2].

$$y(n) = x(n) * h(n) + w(n) \tag{3.10}$$

where: y is the received signal. n is the index. x is the transmitted signal. $*$ is the linear convolution. h is the channel effect. w is the AWGN.

Channel estimation is a significant factor in wireless communication, in which the receiver compensates for the degradation of the multi-tape channel effect. The channel estimation is based on the pilot, which inserts the pilot signal at the transmitter and receives it at the receiver after the channel affects them. Hence, LS estimation was applied by applying the received pilot over the transmitted pilot and then recovering the transmitted signal by interpolation as in Eq. (3.11)—(3.13) [5].

$$LS_{es} = \frac{Y_p}{x_p} \tag{3.11}$$

$$H_{LS} = \text{interpolate}(LS_{es}) \tag{3.12}$$

$$Y_{es} = \frac{Y}{H_{LS}} \tag{3.13}$$

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.

4 Simulation Results

This section presents the performance of the GFDM system under different cases, which will present the effect of the channel under two tapes, the PC, and interleaver. The system is built at specific parameters present in Table 1. The SNR in dB vs. BER is present only in the GFDM transceiver under the AWGN effect. Comparison with the system under the effect of the channel and LS estimation and equalization with two tapes for frequency selective channel, the BER degradation under multi-path effect at 10, 22, and 28 SNR are 0.1141,0.1046 and 0.1002, respectively. Effect of PC presents the noisy channel GFDM system, which shows the PC's enhanced performance at 17 dB and more as in Figure 6.

The enhanced in BER at 22 and 28 are 0.0126 and 0.0114. Figure 7 presents interleaver types effect over GFDM-PC under channel effect. In general, all the interleaver types enhance performance by the different types.

At 10 SNR, the random and helical interleaver present enhancements in BER by 0.0042 and 0.0087, while the matrix interleaver gives degradation by 0.0059. At 22 SNR, the random, helical, and matrix interleaver present enhancements in BER by 0.0290, 0.0257, and 0.0081, respectively. At 28 SNR, the random, helical, and matrix interleaver present enhancements in BER by 0.0307, 0.0289, and 0.0126, respectively. The random and helical types are best than the matrix. The performance of random interleaver is helical at SNR of more than 22, but at less, the helical interleaver is the best. The interleaver does not enhance the performance when used without a PC, as in Figure 8. Figure 9 presents the performance of all the states, which compares the effect of AWGN channel, LS as channel estimation, and PC when added to the system as a coding scheme. Finally added, three types of interleavers (random, helical, matrix). The comparison with other works by the difference in BER between conventional and optimized work, which each work gives the reduction in BER vs. SNR as in table 2.

Table 1: System parameters

Symbols	Values	Description
K	20	Number of samples per subsymbols
M	15	Number of subsymbols
CP	0.1	Percentage of cyclic prefix
a	0.1	Roll off factor of the pulse shaping filter
mu	4	Modulation order of the QAM symbol
cp1	4	spacing pilot

Table 2: Performance comparison

References	Improving
[17]	0.00013
[21]	0.01
[18]	0.019
[15]	0.0032
[1]	0.055
[19]	0.0013
Proposed	0.05

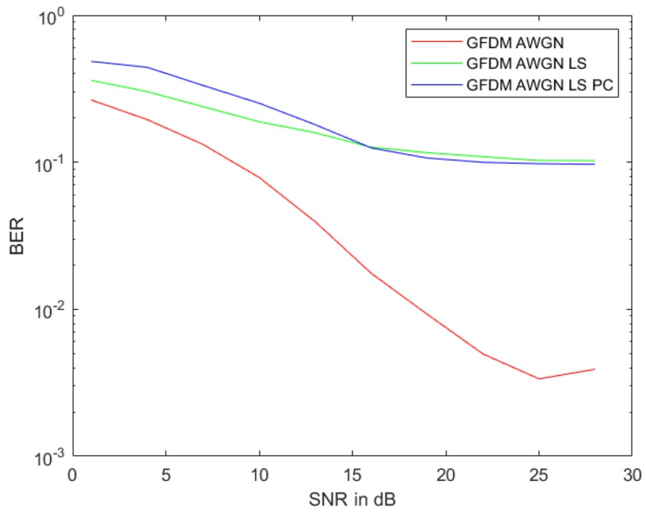

Figure 6: System performance at GFDM AWGN LS and PC

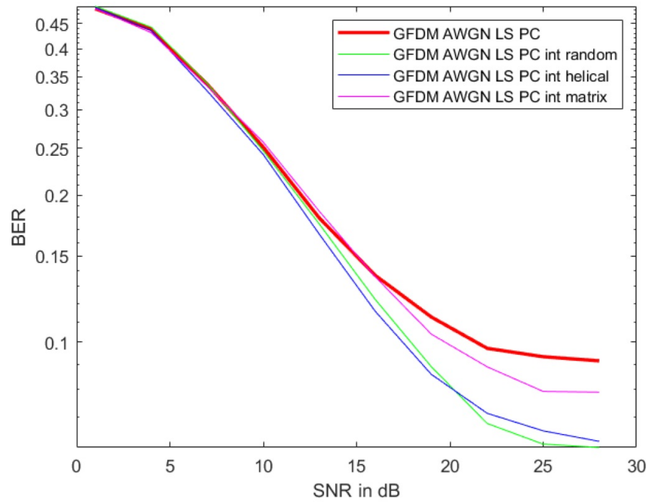

Figure 7: System performance at GFDM AWGN LS PC with interleavers

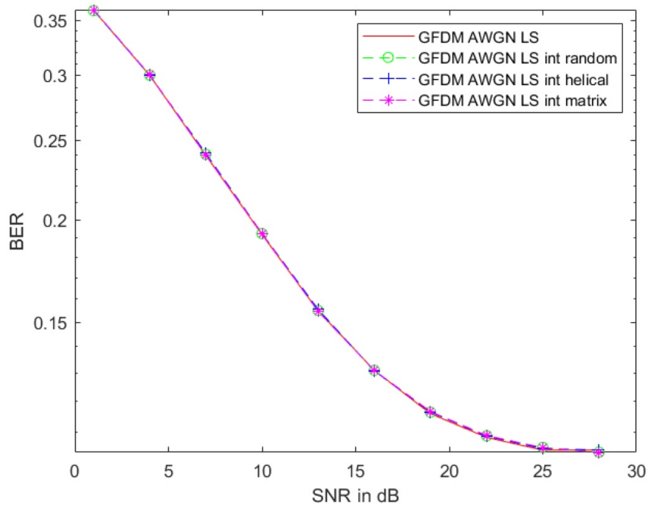

Figure 8: System performance at GFDM AWGN LS with interleavers

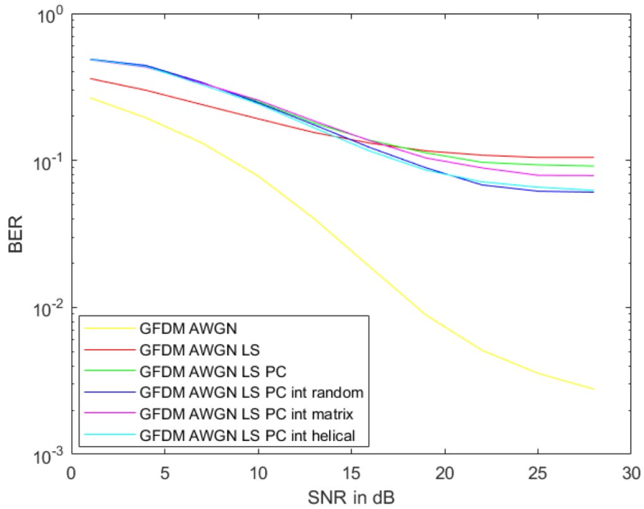

Figure 9: System performance at all the states

5 Conclusion

This paper built a transmitter and receiver communication system based on the GFDM scheme, which used multipath and AWGN as channel effects and was estimated by LS and NLMS. The transceiver used a PC as detect and correct the error at the receiver. The random interleaver gives the best performance, efficiently transforming burst error to random, helping the coding system reduce the error. The comparison table presents the enhancement performance compared with other researchers' surveys.

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