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# Performance Analysis of ANN-Based Improved Modulation Classification for GFDM System

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**ABSTRACT**

With the introduction of new multicarrier modulation technologies, multicarrier waveform detection has grown more challenging and has become an open topic for current and future 5G/6G surveillance and signal interception. For multicarrier modulation, waveforms need to be recognized practically; for this, a practical recognition technique is required. Generalized Frequency Division Multiplexing (GFDM) results in the superimposition of multiple sub-symbols in the time domain, which leads to high non-linearity. One of the popular non-linearity reduction methods used in GFDM, ANN-NFFE (Artificial Neural Network-Nonlinear Feed Forward Equalizer), creates a variety of signal representation modulation matrices. The findings from the study show that GFDM behaves well in distinguishing several modulation approaches tested with various valid wireless channel deficiencies, including AWGN, multipath fading, and clock offset. The recommended ANN-NFFE design significantly enhances classification accuracy at low SNR values, which is suitable for practical cases. It achieves 86.1 % accuracy at −2 dB SNR, 96.5 % at 0 dB SNR, and 99.8 % at 10 dB SNR. The GFDM-based improved Proportional Fairness (PF) scheme achieved a throughput performance of 97.66 %, enhancing the overall efficacy of the GFDM system. Finally, the dispersion in the optical communication GFDM system is decreased using ANN-NFFE.

**Keywords:** Wireless communications; GFDM; ANN-NFFE; SNR; Non-linearity

## NOMENCLATURE

| | |
|---|---|
| GFDM | : Generalized frequency division multiplexing |
| ANN | : Artificial neural network |
| NFFE | : Nonlinear feed forward equalizer |
| SNR | : Signal-to-noise ratio |
| PF | : Proportional fairness |
| CP | : Cyclic prefix. |

## 1. INTRODUCTION

The capacity of wireless systems is expanding quickly due to the creation of applications like voice over internet protocol, video streaming, and wireless gaming, as well as the widespread use of wireless devices such as tablets, laptops, and smartphones. These gadgets and applications consume a significant amount of the spectrum[3] as a result of their usage. Spectrum is a naturally scarce resource, so future wireless networks will face limited bandwidth availability. Consequently, wireless networks heavily depend on the effective use of spectrum. Long-Term Evolution (LTE) and other recent wireless technologies like Wi-Fi cannot ensure effective spectrum utilization. To address these challenges in wireless technology, Cognitive Radio (CR) technology has been developed. GFDM systems relying on CR have become increasingly popular lately. They offer flexibility in allocating dynamic radio resources and can achieve high data rates[7]. Because GFDM leaves several subcarriers empty, it can be used in a system for renting out the spectrum. As a result, significant effort has been devoted to implementing CR-based GFDM systems. The main objective is to investigate the various challenges encountered by CR-based GFDM systems. GFDM refers to a communication technology that improves on traditional frequency division multiplexing by providing better adaptability and efficient utilization of the available bandwidth.

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## 2. LITERATURE REVIEW

The flexible and straightforward nature of OFDM is combined with the interference reduction mechanism[1]. The goal is to evaluate the effects of the non-orthogonal carriers of GFDM, which are governed by the digital filters used for transmission and reception selectivity. Because GFDM has a lower PAPR than OFDM, its implementation is less expensive. Additionally, the amount of power used decreases. The OOB (out-of-band) radiation is reduced by the programmable transmitter filtering.

The equalization is based on FFT and is block-based, using CP (cyclic prefix) insertion during transmission. Each block of information contains several subcarriers, and each subcarrier contains several sub-symbols. The information is organized into blocks. Pulse shaping is applied to each symbol[2]. Compared to the useful data, it reduces the CP amount. However, the need for single-tap FDE remains. The tail-biting technique is used to eliminate the periods required in a traditional system. By using interference cancellation techniques, pulse shaping filters eliminate ISI (inter-symbol interference) and ICI (inter-carrier interference). This paper employs the interference cancellation scheme to significantly enhance BER performance[5]. A less complicated transmitter model is created, which lowers the expense of installing new hardware. Individual subcarriers are subjected to pulse shaping, reducing transmitted signal OOB radiation.

The GFDM scheme can be implemented with fewer calculations by leveraging the FFT/IFFT algorithms. An article [4] examined GFDM, a modulation technique capable of supporting the requirements of 5G networks. Various methods for reducing OOB radiation are presented. Additionally, a synchronization technique that reduces spectral emissions is discussed[6-7]. The author explores MIMO-GFDM for diversity-related purposes. A variety of channel models and iterative linear GFDM demodulators yield diverse configurations[8]. The signal is initially transmitted using the IDGT (Inverse Discrete Gabor Transform) and is then converted to the DGT (Discrete Gabor Transform) at the receiver to recover the original GFDM signal when using the GFDM modulation technique. Because it reduces the complexity caused by channel equalization, frequency-domain IDGT is preferred over time-domain IDGT[9].

The BER performance of GFDM when using frequency-domain DGT is very comparable to that of OFDM at low roll-off factor values. LDGT (Low-Density Group Testing) reduces system complexity, but there is BER loss that can be mitigated by enlarging the window. By truncating the frequency-domain DGT, it is possible to achieve LDGT-like complexity. Comparatively speaking, this receiver reduces complexity more effectively than other receivers. A technique for using GFDM to achieve transmit diversity was presented by D. Zhang[10], *et al.* Transmit diversity is achieved with STC when used within a GFDM block, as opposed to transmission through a single antenna, without increasing physical layer latency. At the receiver, a broadly linear assessor is employed to decode a block of GFDM. The performance of different multi-carrier waveforms that could replace OFDM in 5G networks is also evaluated.

To achieve lower OOB emissions than OFDM, this method requires a longer latency time. Multipath fading channels cause significant degradation in the frame error rate (FER). Furthermore, research is being conducted on GFDM and FBMC [11,12]. A comparison between GFDM and OFDM shows that reduced PAPR (Peak-to-Average Power Ratio) and better FER (Frame Error Rate) are achieved. Performance metrics use a formula to determine the SNR value, and the SER value of the degraded signal is also calculated[13]. A combination of GFDM and STC schemes allows for full diversity gain with reasonably low computational overhead. Reed-Solomon coding was chosen because it has short code words that fit entirely within one frame and is resilient to error bursts. As frame-by-frame decoding is performed, the system's overall latency is reduced[14]. Comparing non-iterative Reed-Solomon decoding to iterative Reed-Solomon decoding, the non-iterative Reed-Solomon decoding offers a lower level of receiver complexity.

### 2.1 Contribution of the Work

A novel generalized frequency division multiplexing (GFDM) method based on ANN-NFFE (Artificial Neural Network-Nonlinear Feed Forward Equalizer), is proposed and demonstrated.

The proposed neural network model includes a layer of Gaussian noise to capture the uncertainty and enhance modulation classification.

Using an artificial neural network, a novel feed-forward equalizer has been developed to increase classification efficiency.

The subsequent part of the article is as follows: The previous works are described in Segment 2, the suggested work is explained in Part 3, chapter 4 describes the results and discussion, and the proposed conclusion and subsequent work are outlined in Part 5.

## 3. PRINCIPLES OF PROPOSED GFDM ANN-FFE SYSTEM

### 3.1 Motivation

The proposed architecture leverages convolution neural networks and equalizers to address non-linearity and dispersion, enhancing signal quality. Incorporating Gaussian noise further improves noise resilience and modulation classification, driving advancements in communication systems. A single carrier is used for sequential data transmission in a single-carrier modulation scheme. To effectively combat the time dispersive effects of a multipath fading channel without the use of complicated time domain equalization techniques, the signalling period of a multicarrier scheme is significantly bigger than usual for a single carrier system. Initially, conventional frequency division multiplexing technology was used in multicarrier modulation schemes to transmit data across multiple carriers.

The receiver used filters to retrieve the individual sub-channels while the transmitter assigned the spectra of various subcarriers to non-overlapping frequency slots[15,17]. In a later section, orthogonal multicarrier modulation schemes, also known as OFDM schemes, are discussed. In these schemes, the spectra of various subcarriers are allocated to overlaid frequency slits, and distinct sub-channels are extracted using the orthogonal features, which eliminate crosstalk among the distinct sub-channels. Compared to traditional multicarrier methods, orthogonal multicarrier techniques produced a more effective use of the accessible bandwidth[18-19]. The following sections explain the guiding principles of GFDM. The advantage of GFDM systems over OFDM systems is that they reduce neighbouring subcarrier overlapping, allowing for the simultaneous operation of multiuser applications. To effectively multitask and reduce subcarrier overlapping, GFDM uses circular filtering at each subcarrier[20]. With this approach, ISI is avoided, and system performance is improved by using GFDM system.

$$d_K^N[n] = \sum_{(M=0)}^{(m-1)} d_K[M]\delta[n - MN], n = 0, \ldots, N_{(m-1)} \quad (1)$$

The GFDM Modulator modulates the input binary data into QAM style (Tian*, et al.*, 2018). Then, it is separated into KM symbols. Each d K [M] symbol is divided into 'M' time

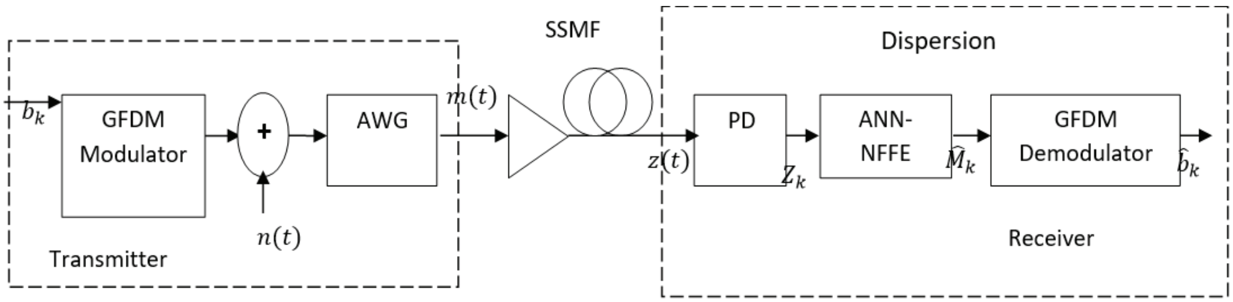


**Figure 1. Schematic illustration of proposed ANN-NFFE scheme.**

slots and 'K' subcarriers for transmission, where 'K' is defined as 0 to k-1 and 'M' as 0 to m-1. Equation (1) is produced by up-sampling the data symbols, d K [M], with the factor N. Where δ[n-MN] – Dirac Function and N – Up-sampling factor.

### 3.2 Block Representation of the Suggested System

This section discusses the system architecture. Diagram 1 depicts the design of the recommended structure. The GFDM modulator begins by modifying the input signal before moving on to the signal in this block. Before being transmitted to the receiver, this modulated signal is transformed using a RoF into an optical signal. The optical signals are de-multiplexed using an Arbitrary Waveform Generator (AWG), which serves as a channel. In order to increase the received signal levels so they can be launched into the fiber link, Standard Single Mode Fiber (SSMF) is installed after the channel. A photodetector converts optical signals into electrical signals in a matter of seconds. PD's Millimeter Wave (MMW) signal is then amplified and filtered before being fed into the antennas. Through MMW links, these antennas send the signals to the necessary receivers. A Low Noise Amplifier is employed to boost the MMW signals at the receiver's end (LNA). A GFDM demodulator is then used to rebuild the signal. Equation (2) is used to express the GFDM signal, which undergoes digital pulse shaping and up-conversion after being up-sampled by N.

$$X_1[n]=\sum_{(M=0)}^{(m-1)}\sum_{(K=0)}^{(k-1)} d_K^N[n]g_T[n], g_T[n]=g[(n-MN)[mN]]e^{(i2\Pi,N^{Kn})} \quad (2)$$

The optical communication GFDM system uses ANN-NFFE to lessen the dispersion.

Here, the input signal bk is amplified by noise n (t) before being sent to the channel. The optical signals are multiplexed using an Arbitrary Waveform Generator (AWG) before transmission. m(t), is given in Eqn. 3.

$$m(t)=\sum_{(K=-N/2)}^{(N/2)} b_k X(t-kT)+n(t) \quad (3)$$

Given in equation 4, where N is the number of symbols being transmitted, x(t) is the pulse shape, and $b_k$ is the input data symbols.

$$x(t)=\sqrt{P(t)}\exp(-i\varnothing(t)) \quad (4)$$

In this case, i=, and P(t) is the output power distribution (-1). The frequency chirping causes the phase (t) to be introduced. Which is represented as follows:

$$\varnothing(t)=\frac{\alpha}{2}\int_0^t\left(\frac{1}{P(t)}\frac{dp(t)}{dt}+K_v P(t)\right)dt \quad (5)$$

The signals are amplified using Standard Single Mode Fiber (SSMF) to the levels necessary for launching them into the fiber link. SMF is used instead of MMF due to its lower attenuation and higher bandwidth-distance product, making it more suitable for long-distance and high-capacity applications despite real-time constraints. The SSMF's output is defined as z(t), which is given in Formula 6.

$$z(t)=m(t)*h(t) \quad (6)$$

Where * indicates convolution, and h (t) is the impulse response of the fiber. Direct electrical signal to optical signal conversion occurs in the photodetector (PD). As $Z_k$ defines the output. To prevent system dispersion, an ANN-NFF equalizer is employed. This equalizer compensates for dispersion because it is necessary to effectively reconstruct the transmitted data. An extensive training routine parameter for the equalizer is proposed, and it is discovered using ANN. Finally, the decision circuit uses a specific decision function to assign the balanced values Mk to the closest symbol k.

#### *3.2.1 ANN Equalizer*

Dispersion and nonlinear distortion are both compensated for using an ANN equalizer[21]. It conveys the nonlinear transformation of the input parameters ZRn to the output parameters $M_R$. The distorted signal output from the channels is contained in the equalizer's input vector Z, and the equalizer taps are represented here by the number n. They are the output layers of a 1-node and the hidden layer of an r-node. Weight is appended to the input vector Z for each invisible layer node. If $f_h$ (.) is an invisible layer scalar function that operates on the entire amount of every concealed layer node, Eqn. 7 provides the layer's reaction.

$$y_j=f_h\left(\sum_{l=1}^{n} w_{jl}^h z_l\right), j=1,2,\ldots,m \quad (7)$$

where, $w_{jl}^h$ is the weight filed among input $z_1$ of $1^{th}$ and $j^{th}$ hidden layer node.

$$\widehat{M}=f_o\left(\sum_{j=1}^{m} w_j^o y_j\right) \quad (8)$$

where, $w_j^o$ is the weighted node of the ANN system? Two modes of ANN process 1. Training mode 2. Transmission mode.

#### *3.2.2 Training Model*

A known symbol set is sent via the channel, and the equalizer weights are adjusted so that the equalizer k=Mk for all the training symbols transmitted in the training mode models the inverse response of the channel. A finite set of $N_{tr}$ training pairs $\{Z_k, M_k\}$, k=1, 2…$N_{tr}$ is used in the training mode. $Z_k$ is the $k^{th}$ equalizer input, which is stated as $Z_k = \left[Z_{-\frac{N_{tr}}{2}+k-1} Z_{-\frac{N_{tr}}{2}+k} \dots\dots Z_{-\frac{N_{tr}}{2}+k+n-1}\right]^T$ and $M_k$ is the delayed version employing the time shift function ττ, which is given by $M_k = m(kT - \tau)$. The optimum weight is achieved using the Eqn. 9.

$$f(W) = \sum_{k=1}^{N_{tr}} \left\| \widehat{M}_k(W.Z_k) - M_k \right\|^2 \quad (9)$$

The optimized weight is achieved, and W represents the ANN weights.

$$E_k = \widehat{M}_k(W.Z_k) - M_k \quad (10)$$

The revised Eqn. of the Levenberg–Marquardt algorithm is given as follows:

$$W^{(i+1)} = W^{(i)} - \left(H^{(i)} + \mu I\right)^{-1} \nabla f^{(i)}, \qquad i = 0, 1, 2.., \quad (11)$$

here, f(((i)) and H((i)) are, respectively, the objective function's gradient vector and Hessian matrix at the current weights W((i)). I is the identity matrix, and is a positive scalar. Eqn. 12 and Eqn. 13 represent f and H, respectively.

$$\nabla f^{(i)} = \frac{\partial f}{\partial W} = 2 \sum_{K=1}^{N} \nabla \widehat{M}_k(W, Z_K) E_K \quad (12)$$

$$H = J^T J \quad (13)$$

where the Jacobian matrix j is given in Eqn 14.

$$J = \left[\nabla \widehat{M}_1 \nabla \widehat{M}_2 \nabla \widehat{M}_3 \dots \nabla \widehat{M}_N\right]^T \quad (14)$$

Once the weights have been optimized and the ANN-NFFE has shifted into transmission mode, the real data are transmitted. Eqn. 15 defines the ANN-NFFE vector's input as follows:

$$V_q = \left[v, v_{-q+q+1} \dots . v_q \dots . v_{q+q\_1}, v_{q+q}\right]^1, q = 0, 1, 2, .., \quad (15)$$

where, q is the expected number of conflicting symbols and v q is the transmitted signal. The ANN-NFFE generates a signal for each input vector q that corrects for system dispersion.

$$E_q = \widehat{M}_q\left(W.Z_q\right) - \hat{b}_q \quad (16)$$

## 4. RESULTS

The simulation results of the hybrid RoF-based GFDM model are presented in the result and discussion section. It concentrated mainly on reducing network problems. There were issues with non-linear effects, dispersion, and coverage area when sending information signals. With the least amount of signal transmission expense and without signal loss, it focuses on achieving the greatest distance or coverage area. Performances of the various equalizers are compared based on the BER, SER, path loss, and channel capacity. The simulation results are produced using the MATLAB 2018a program. Because it combines optical (wired) and microwave (wireless) networks, Radio over Fiber (RoF) technology are used in 5G wireless communication. This network supports various wireless applications and is designed to simplify signal transmission over optical fiber links. The suggested method uses microcells to move the furthest without straying. With minimal path loss to the receiver, these microcells are used to transmit data over an area of about 2 km. GFDM Improved Proportional Fair (PF) performs better on the path loss and throughput performance curves than the other methods. Once all channel gains are saved in matrix H, the bit and subcarrier allocation procedure starts by allocating 2 bits (lowest modulation scheme, 16-QAM) for every subcarrier to the user with the higher channel gain (with dimensions 5x512). When all subcarriers have been assigned, the total data rate from each user is added. This step typically does not assign a subcarrier to a user whose channel conditions are poor across all available bands, which prevents them from transmitting data.

### 4.1 Input Signal

The RoF-based GFDM models proposed hybrid architecture takes the optical signal as its input. It is produced by figuring out the binary message's length in the system's employed subcarriers. The input signal's allocated time range is 0 to 1200 seconds, and its magnitude ranges from 0 to 1.

### 4.2 GFDM Signal

The input signal is received by the GFDM modulator, which modifies it to create the GFDM signal. The input signal is modulated using a method called QAM modulation. The input is given as binary data, which the GFDM Modulator modulates into QAM format. In GFDM modulation, the data at the $i^{th}$ sub-carrier is up-sampled using the sampling element N to create the impulse sequence. The non-orthogonal multi-carrier is flexible in pulse shaping.

### 4.3 Channel Output

Additive white Gaussian noise (AWGN), which is included in the channel of the suggested GFDM model system, is a common model for noise. It simulates a wide range of noises, including thermal noise and shot noise sources. White because it is uncorrelated or has a flat power spectral density, and additive because it is additive in nature. The signals are de-multiplexed and transformed into electrical waveforms using this channel. The simulation results are presented in Table 1.

**Table 1. Simulation parameters used in GFDM**

| Parameter | Value |
|---|---|
| Sub-symbols (M) | 5 |
| Sub-carriers (K) | 512 |
| Mapping | 16-QAM |
| Roll-off factor (α) | 0.1 |
| Cyclic Prefix (CP) length | 32 |
| Channel | AWGN |

The attenuation of a signal emitted from a transmitter due to the distance traveled and properties of the propagation channel are known as path loss. The proposed system's coverage area necessitates the ability to model path loss as realistically as possible. There are three distances for which the path loss is calculated: 500 m, 1 km, and 2 km. According to the analysis, for short-range coverage, the path loss is high. The path loss is minimal due to the 2 km length of this work. With the aid of an improved proportion fair algorithm, the propagation loss is reduced. Figure 2 displays the comparison curve between frequency and path loss in decibels (dB). Utilizing Improved

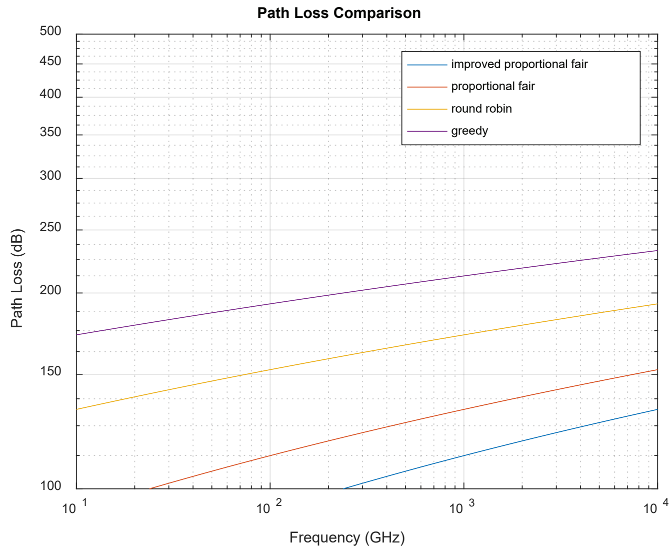


**Figure 2. Path loss comparisons.**

Proportional Fairness, the proposed method allows resources with less path loss (PF). When the frequency rises, path loss also rises with the aid of Improved PF.

When compared to PF, Round Robin, and Greedy algorithms, using Improved PF yields better results. The scheduling algorithm known as improved PF maintains maximum throughput while allocating resources at regular intervals. Here, the resource consumption is inversely correlated with the data rates computed at each interval.

### 4.4 Performance Comparison Based on Different Scheduling Algorithms

Scheduling is a technique for balancing computer property in the difficult flow of data. This is accomplished by classifying the packets from each flow and allocating time for them. Scheduling is a crucial part of networking systems because it helps share the bandwidth while ensuring the quality of services (QoS). The effectiveness and integrity of well-planned scheduling techniques can be improved while requiring less complexity. Here, four scheduling algorithms that use GFDM and do not use OFDM are compared.

Figure 3 displays the base station graph plotted against the total logarithmic throughput. According to this graph, GFDM Improved PF performs better resource allocation and scheduling as the number of base stations increases. By combining the proposed technique's total capacity and actual throughput, the sums of logarithmic values are obtained. Using an improved proportional fairness algorithm, the proposed method offers a throughput of 29 dB in 20 base stations.

Only 7 dB are provided by the OFDM algorithm in 20 base stations. As seen in Figure 4, the SNR values for different tx-rx antennas are plotted against varying capacities. SNR changes by their capacity in b/s/Hz when the tx and rx are both 1. Generally speaking, when a system's capacity increases, its SNR also increases. The SNR is displayed versus the capacity based on the number of transmitter and receiver antennas. If there are four transmit antennas, the maximum SNR (30dB) and the maximum capacity of 35 bits per second are achieved.

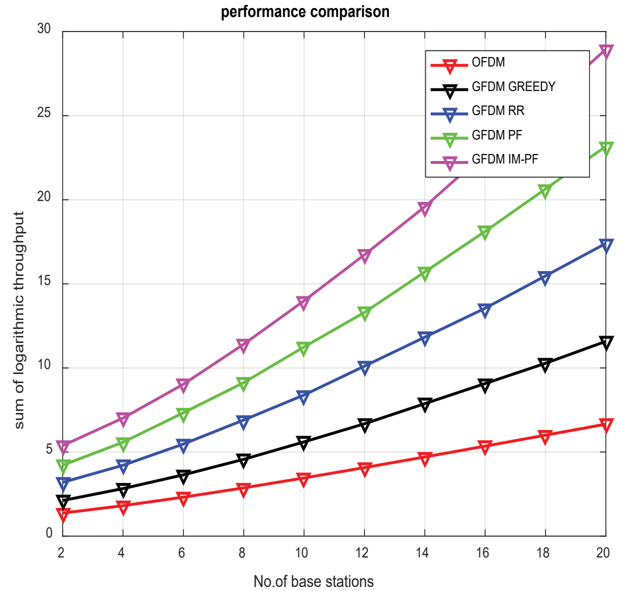


**Figure 3. Compares the performance of various GFDM and OFDM scheduling algorithms.**

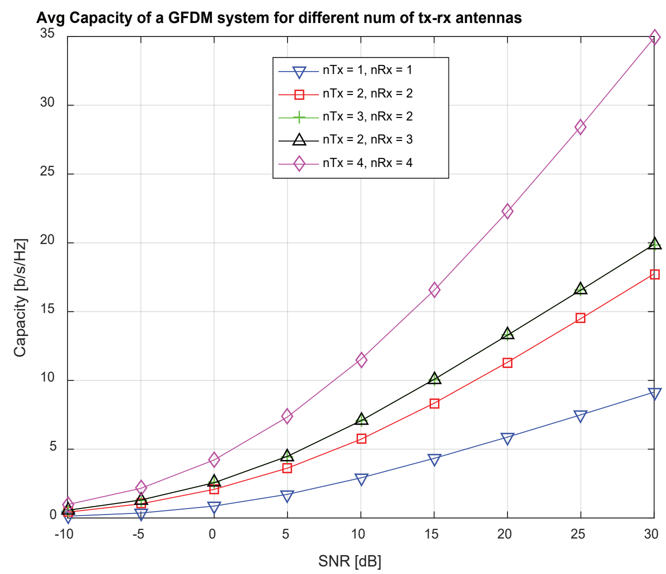


**Figure 4. Shows the average GFDM system capacity for various tx-rx antenna counts.**

### 4.5 Throughput of the System

Transceivers at nodes have the greatest impact on wireless throughput with their ability to transmit and receive. Figure 5 displays the GFDM system's throughput performance bar chart. Figure 6 displays the performance comparison for non-linearity. The throughput is calculated over a 2 km distance. When the throughput scale is changed, the GFDM Greedy percent, GFDM RR percent, GFDM PF percent, and GFDM Improved PF percent all equal 81.6. The proposed work is compared with existing work, as shown in Table 2 and Fig. 5.

The suggested GFDM Improved PF has been demonstrated to increase system performance and be a more effective way to distribute resources among users. An artificial neural network nonlinear feed-forward equalizer (ANN-NFFE) is used in the GFDM optical communication system

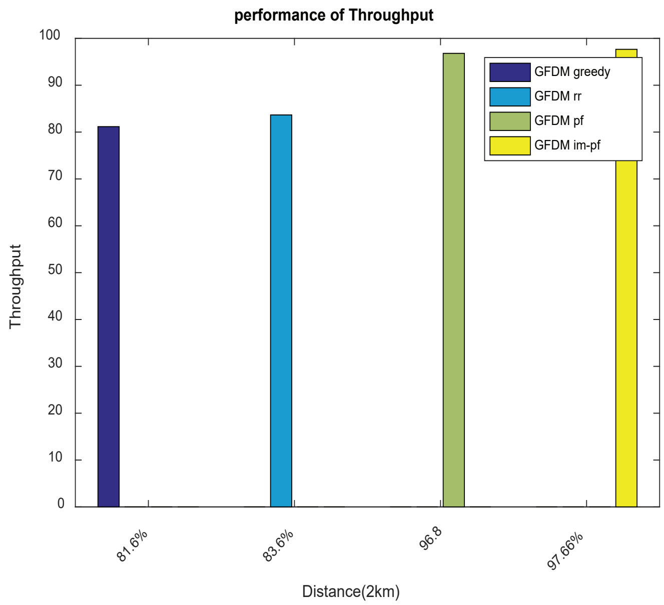


**Figure 5. Performance chart –throughput.**

**Table 2. Performance comparison with existing works**

| Parameter | Ref(12) | Ref(13) | Ref(19) | This work |
|---|---|---|---|---|
| Sub-symbols (M | 7 | 9 | 7 | 5 |
| Sub-carriers (K) | 256 | 64 | 256 | 512 |
| Channel | Multipath | AWGN | AWGN | AWGN |
| Mapping | QPSK | 16-QAM | QPSK | 16-QAM |

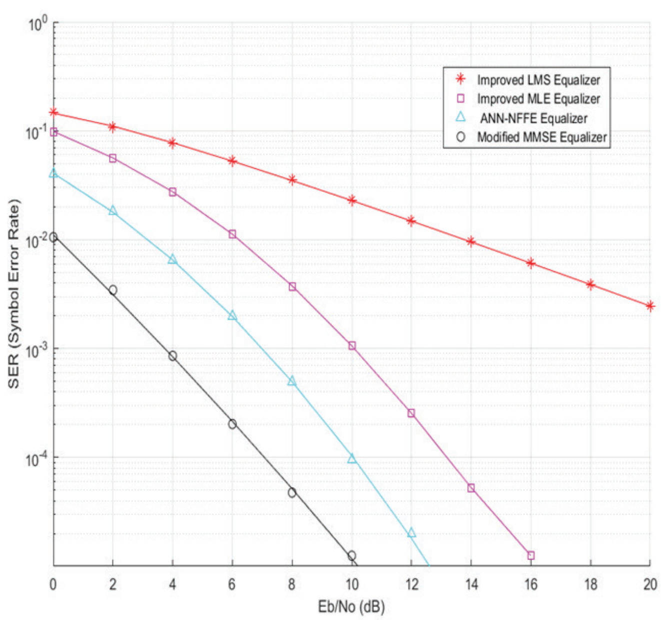


**Figure 6. Performance of nonlinearity.**

to reduce dispersion. This equalizer contains a trained hidden ANN layer that behaves like a nonlinear filter. This results in the impulse response in the absence of dispersion. Optimize the ANN parameters before starting the training process to take into account all potential data collections that might later be transmitted through the communication channel. It offers a higher transmission system response in terms of BER and a lower computational cost compared to other equalizers. In-depth descriptions are provided of the GFDM system's non-linearity and dispersion, which are balanced by the ANN-NFFE equalizers.

SNR increases and BER decreases for AWGN channels when compared to Rayleigh channels. The ANN-NFFE achieves the required minimum BER by raising Eb/No values. The BER value is 10-1 at an Eb/No value of 20 dB. Equation (17) indicates the symbol error rate.

$$SER_{ANN-NFFE} = Q\left(\sqrt{\frac{2\gamma E_b}{N_0}}\right) \quad (17)$$

## 5. CONCLUSION

According to the results, the proposed hybrid GFDM system demonstrates significant advancements over traditional modulation methodologies, particularly in optical communication scenarios. The suggested method utilizes architectures; the system achieves superior path maintenance and data transmission over a 2 km range with minimal signal degradation. The innovative integration of ANN-NFFE significantly reduces dispersion, while the enhanced PF scheduling algorithm achieves an impressive throughput of 97.66 %, establishing a new benchmark for GFDM systems. Additionally, comprehensive evaluation metrics, including throughput, capacity, path loss, and scheduling, underline the system's robust performance. With the aid of this work, future researchers can explore the advanced MMSE and neural network equalizers to mitigate dispersion and improve modulation efficiency. Further, it optimizes channel estimation techniques and enhances the performance of GFDM systems for next-generation communication networks.

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