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Reduction of Bit Error Rate using Guard Interval Measurements for 5G Network

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ABSTRACT

Orthogonal Frequency Division Multiplexing (OFDM) is reliable for improving the wireless performance of the 5G network. This multicarrier modulation is expected to have high speed and efficient signal transmission. However, it still suffers from high error and can cause signal interference, thus affecting the performance of the bit error rate (BER). The error can be minimized by utilizing Guard Interval (GI), which reduces signal interference and increases Spectral Efficiency (SE). Hence, this research focuses on optimizing GI evaluation for BER reduction, which balances multipath mitigation and data rate efficiency in the systems. A simulation was developed in MATLAB software with varying parameter numbers of Fast Fourier Transform (N_{FFT}). It is observed that, the best GI implementation is based on number of N_{FFT}, with 512, ¼ is the best for multiuser environment. Fewer error of the system leads to the better signal transmission efficiency in 5G network.

1. Introduction

Wireless technology for 5G is innovating towards the next generation with tremendously promising services, such as sending data with higher rates, ultra-low latency and responsiveness to provide real-time communications. It is important to have reliable data for secure information. With the advanced wireless system, a transmitter and receiver can send and receive data at minimal error rates as studied by Noorazlina *et al.,* [1].

OFDM system as a multicarrier modulation for 5G networks is popular among researchers as mentioned by Jolania *et al.,* [2] and Kumar *et al.,* [3]. The demand for this system has grown exponentially through the decades with a specific type of transmitter and receiver system used in the

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network as introduced by Kumar *et al.,* [3], Panem *et al.,* [4] and Sulong *et al.,* [5]. In general, wireless technology provides multiple signals that can be transmitted through space with various techniques or processes such as modulations, equalization, error correction and diversity reception. However, these signals suffer from reflections, diffraction and scattering that can degrade system performance that mentioned by Sulong *et al.,* [5].

The Guard Interval (GI) has been proposed for OFDM to enhance system performance. This method introduces a period interval between symbols (data duration) or bits in a transmitted signal. It is implemented to reduce the impact of multipath interference and delay spread in wireless channels. A wireless signal propagates as an electromagnetic wave through the air from a transmitter to a receiver; it takes multiple paths due to reflections and other obstacles [5]. Previously, a system without GI was said to have higher inter-symbol interference (ISI), making it difficult to obtain the real received signal.

There are two types of guard intervals: Cyclic Prefix (CP) and GI as studied by Yli-Kaakinen *et al.,* [6]. In OFDM systems like Wi-Fi and 4G/LTE networks, a CP is added at the beginning of each symbol. This prefix is a copy of the end part of the symbol and is applied to guard against multipath distortion. The receiver uses CP to eliminate the effects of multipath interference and accurately demodulate the received symbols that approached by Jolania *et al.,* [2]. Meanwhile, the GI is deployed in Time Division Multiple Access (TDMA) systems and is added between time slots to prevent signal overlap. TDMA is widely used in cellular networks, including GSM (2G) and LTE (4G). The GI ensures that signals from different time slots do not interfere with each other [5]. Although the processed information has been encoded and decoded, a space channel or GI is required to protect the information and improve the BER values. The chosen method for determining the GI length is discussed in the following section.

GI are reserved frequency ranges that separate various wireless communication channels. They act as barriers to prevent interference between adjacent channels, also mentioned by Idris *et al.,* [7]. This isolation controls the integrity of each channel's signal, reduces signal degradation and allows data to be delivered and received without interference. For instance, GI helps to reduce channel adjacent interference. In wireless communication, adjacent channel interference occurs when signals from nearby channels overlap, causing distortion and data errors that introduced by Wu *et al.,* [8]. GIs provide a buffer zone to minimize the impact of this interference, ensuring that signals in adjacent channels can coexist with minimal disruption. Furthermore, GI can be utilized to adapt to changing communication demands that studied by Ghaith *et al.,* [9]. They provide flexibility in spectrum allocation, allowing new services or technologies without disrupting the existing ones as mentioned by Ali *et al.,* [10] and Lin *et al.,* [11].

This research presents the reduction of BER by determining the measurement length of GI for a 5G network, optimizing the BER and increasing the reliability and quality of the received signal in a challenging multiuser environment with fading and noise.

2. Methodology

2.1 Wireless System with Guard Interval

This section illustrated Figure 1 as a basic block diagram of wireless communication, which includes a transmitter, a channel and a receiver. At the receiver, a diversity combiner integrates multiple versions of the same signal transmitted through different paths or channels. Next, the equalizer is a device that compensates for the distortion obtained through the propagation channel by adjusting the amplitude and phase of the received signal. A demodulator retrieved the original coded message at the receiver as mentioned in Elgam *et al.,* [12]. Meanwhile, the channel decoder corrects the errors in the coded message transmitted by the information source. It uses various techniques to correct the inaccuracies caused by noise and interference. The source decoder performs the opposite role of the source encoder: decompressing the coded message back to its actual format to retrieve the original data. The output finally receives the processed information transmitted by the information source.

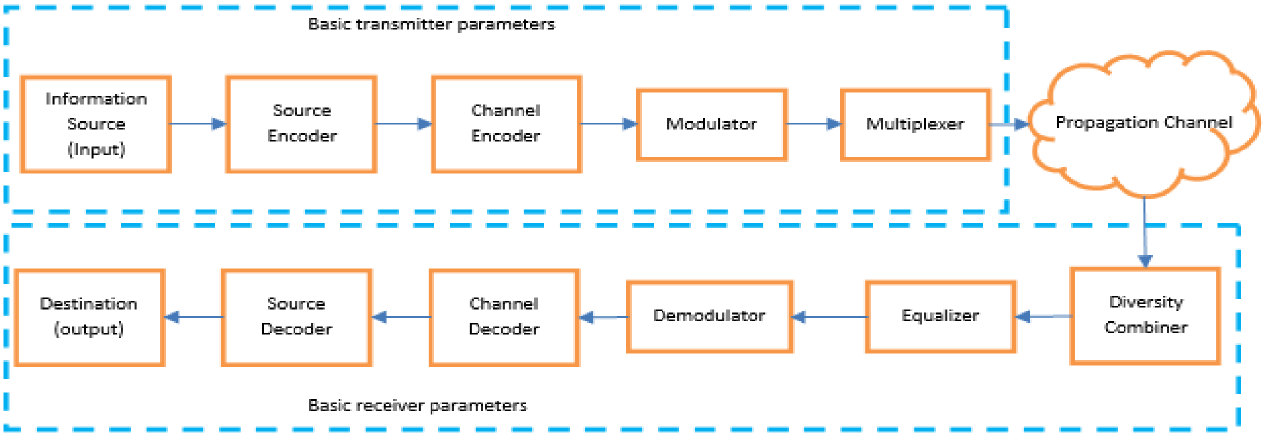

Fig. 1. Block diagram of wireless communication

Figure 2 depicts a flow chart of GI inserted into the 5G network system. It showed that the random data symbol was generated and converted into bits. The conversion process was meant for transmission efficiency that has been studied in Mirahmadi *et al.,* [13]. The data was mapped to symbols, also studied by Din *et al.,* [14]. The choice of modulation scheme was OFDM, which determines how many bits are represented by each symbol. The length of the GI has been determined based on the number of subcarriers. The subcarrier allows the signals to be transmitted simultaneously over the same channel without interference with each other. The BER was calculated at the receiving end.

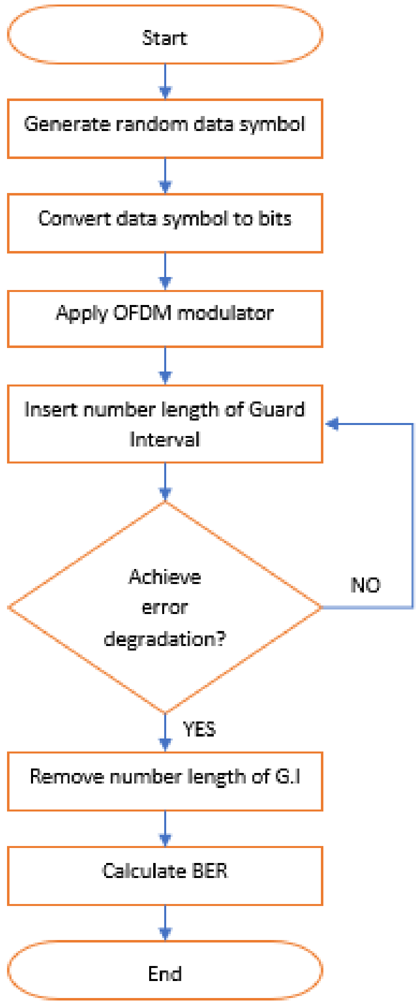

Fig. 2. Flow chart of GI deployment in the system

Meanwhile, the system improvement is shown in Figure 3. It highlights the methodology for the OFDM system, with GI inserted at the transmitter part. In detail, the information source, such as voice, signal and big data went through the process of encoding the codes properly, then a digital modulator was used to modulate the signal, to maintain the signal strength [2]. The signal was converted to the frequency domain after going through the time domain. The GI was added to the data to ensure channels could be assigned and delivered using space. For this research, the GI length was measured with 1/4 of FFT, 1/8 of FFT and 1/16 of FFT. The number of N_{FFT} such as 512, 1024 and 2048 are chosen to determine its capacity to reduce BER of the system.

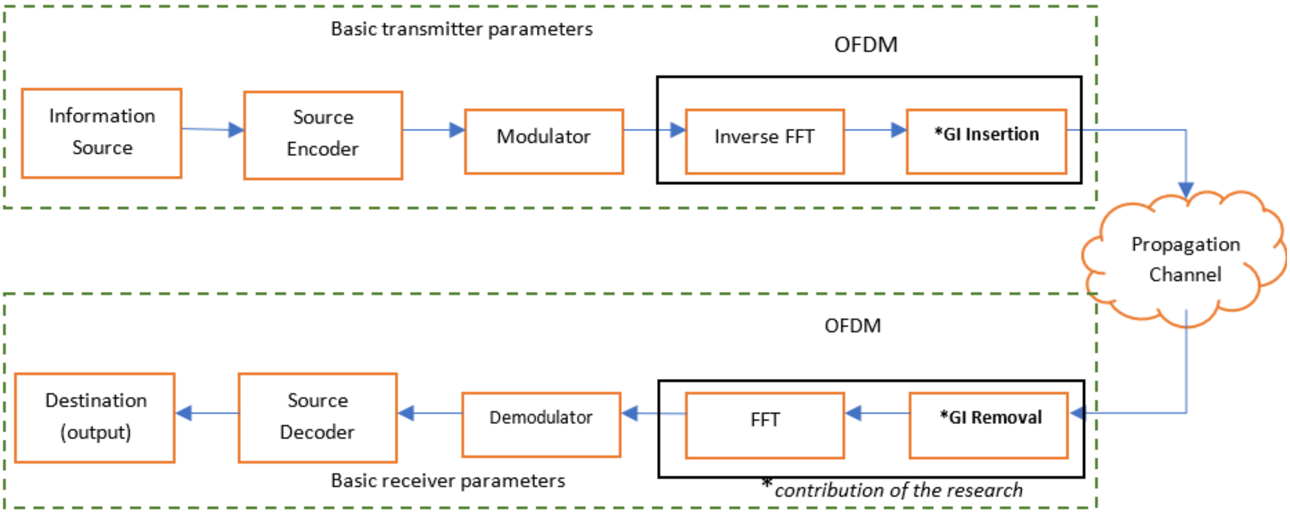

Fig. 3. GI inserted in OFDM System

On the receiving end, the signal will go through the demodulation processes in between after being transmitted through the channel as mentioned by Kenney *et al.,* [15]. By applying these procedures, the output signal will be received with minimum error, due to the insertion of GI during the multiplexing process. The demodulation process will demodulate the signal into suitable data to be received.

2.2 OFDM Frame with GI Extension

The guard interval operating in an OFDM frame is explained in this section. These frames have different structures. Figure 4(a) depicts the OFDM frame without GI comprising the minimum data frame to be transmitted, which would be susceptible to ISI as studied in Firdaus *et al.,* [16]. Figure 4(b) describes the data time (T_D) frame less than the sum of T_{GI} and T_{IFFT}, which contributes to the potential of data aliasing between each other that affects the system performance. Meanwhile, In Figure 4(c), the sum of T_{GI} and T_{IFFT} are greater than T_D, with a short period inserted between subsequence data. To further mitigate the ISI, the best length of GI needs to be considered to improve errors. Finally, Figure 4(d) shows the best frame of T_D by using 1/4, 1/8 and 1/16 of GI to balance the need for spectral efficiency against the reliability and quality of the received signal. Data time (T_D) can be expressed as mentioned in IEEE Wireless Standard, 802.11n [17].

$$T_D = T_{GI} + T_{IFFT} \tag{1}$$

$$T_{GI} = GI \times T_{IFFT} \tag{2}$$

When T_{GI} is the guard interval and T_{IFFT} is the inverse Fast Fourier transform for the OFDM symbol.

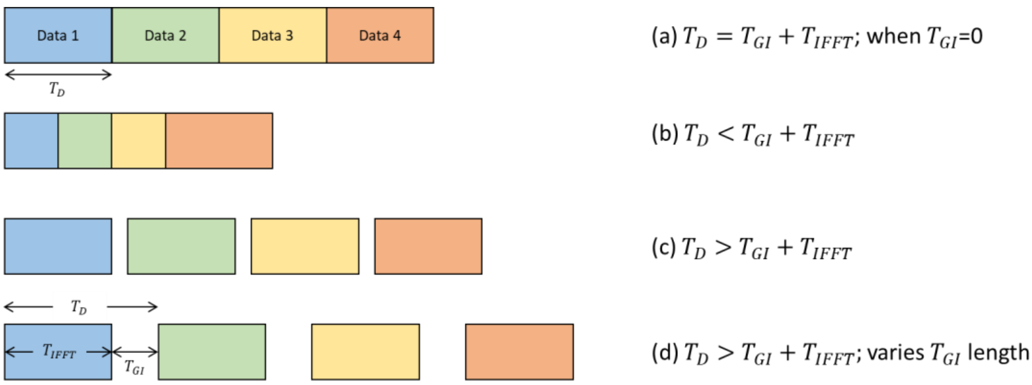

Fig. 4. OFDM frame with GI extension

A shorter guard interval results in a shorter symbol time, which affects the increasing data rates by about 10 percent. Thus, ISI still occurs. In detail, for a typical OFDM symbol $x(n)$ is expressed as Eq. (2).

$$x(n) = \frac{1}{N}\sum_{k=0}^{N-1} X(k)e^{\frac{j2\pi kn}{N}} \qquad n = 1,2 \dots \dots N-1 \tag{3}$$

Where N is the number of subcarriers, $X(k)$ denotes the complex data symbol and $x(n)$ is the OFDM signal using IFFT.

Figure 5 shows the length of useful data duration for 1/4, 1/8 and 1/16 GI. The OFDM system detected GI length and copied a part of the useful data that can be used as a cyclic prefix to prevent symbol interference in the transmission environment [6]. The GI length ensures the consequence of multipath components of a symbol does not interfere with the subsequent symbol.

Fig. 5. Method and circuit for detecting guard intervals in OFDM systems [18]

2.3 System Parameters

Table 1 depicts the system parameters for the OFDM system by referring to 3GPP Standard [19]. A 20 MHz bandwidth offers a good balance between data rate and spectral efficiency (SE). It provides a sufficient spectrum to transmit substantial data while fitting within the available frequency allocations. The GI length deployed in the system is 1/4 of FFT, 1/8 of FFT and 1/16 of FFT [16]. The channel model, COST 207 refers to the typical urban environment. The QAM is used as the modulation technique to achieve a high data rate of SE usage [20]. Meanwhile, the number of symbols in an OFDM system is not fixed. It can vary based on the specific communication environment, bandwidth requirements and the modulation scheme. The number of symbols in an OFDM system is determined by the total duration of the transmission and the symbol duration [21].

In general, the number of subcarriers in an OFDM system is typically determined by standards such as IEEE 802.11 (Wi-Fi) or LTE (4G) [22].

Table 1
System parameters for OFDM [23]

Parameters	Specifications
Bandwidth	20MHz
No. of subcarrier(s)	100
Subcarrier spacing	30kHz – 60kHz
Modulation technique	Quadrature Amplitude Modulation
IFFT/FFT size	512, 1024, 2048
Channel model	COST 207
GI length	1/4, 1/8, 1/16
Type of Antennas	MIMO (2X2)

3. Results

This section discusses the simulated results from comparing the GI length deployed in the OFDM system. The outcome was measured between Bit Error Rate (BER) and SNR (Signal Noise Ratio). It can be calculated as in Eqs. (4) to (6).

$$BER = \left(\frac{number\ of\ bits\ received\ in\ error}{total\ number\ of\ transmitted\ bits}\right) x100\% \tag{4}$$

Where BER is measured in percentage.

$$SNR\ (dB) = 10 \log \frac{signal\ power}{noise\ power} \tag{5}$$

Where SNR is measured in decibels.

$$BER = \frac{1}{2}\sqrt{SNR} \tag{6}$$

Where BER is the root square of the SNR. Figure 6 shows the values of GI taken at 1/4 (0.25), 1/8 (0.125) and 1/16 (0.0625) of N_{FFT}. The measurements taken at SNR 16dB, which is the most common point to be analysed [16].

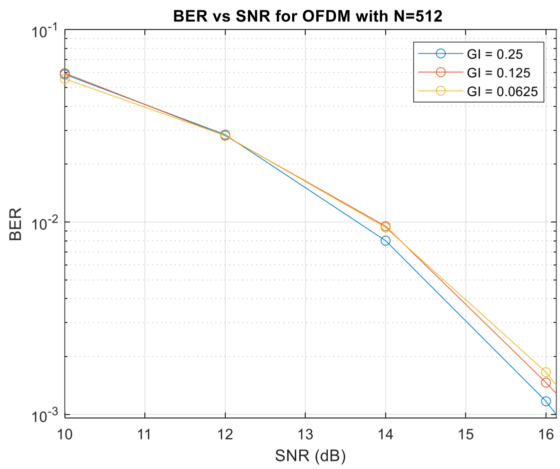

Fig. 6. Simulated with N_{fft} 512

Table 2 describes how the BER value decreases as the GI value increases at N is 512. Thus, at 1/4, it is measured as 1.179 x 10^{-3} compared to 1/8 and 1/16 with 1.465 x 10^{-3} and 1.660 x 10^{-3}, respectively. This indicates better performance and fewer errors.

Table 2
The BER measurements for subcarrier 512 of the system

GI length	SNR(dB)	BER
1/4	16	1.179 x 10^{-3}
1/8	16	1.465 x 10^{-3}
1/16	16	1.660 x 10^{-3}

The system is used to combat the effects of multipath fading and delay spread in wireless communication channels. When the number of IFFT in an OFDM system has increased, the duration of each symbol (including both the data and the guard interval) increases [24]. This is because the total bandwidth available for communication is divided into smaller subcarriers, resulting in each subcarrier having a longer symbol duration. As the symbol duration decreases, the length of the guard interval, which is a fixed duration, becomes a larger proportion of the overall symbol duration [6].

A longer guard interval has better protection against delayed versions of the transmitted signal arriving at the receiver. This is significant because signals might bounce off obstacles and travel in multiple directions before reaching the receiver. If these delayed versions of the signal are not properly handled, they can interfere with the correct reception of the data [3].

Table 3 shows the measurements from the simulations of Figure 7. 1/8 or 0.125 has the best performance compared to 1/4 and 1/16 when utilizing 1024 IFFT with 37% and 54.3% improvement respectively.

Table 3
The BER measurements for N= 1024 of the system

GI length	SNR(dB)	BER
1/4	16	1.953 x 10^{-3}
1/8	16	1.227 x 10^{-3}
1/16	16	2.685 x 10^{-3}

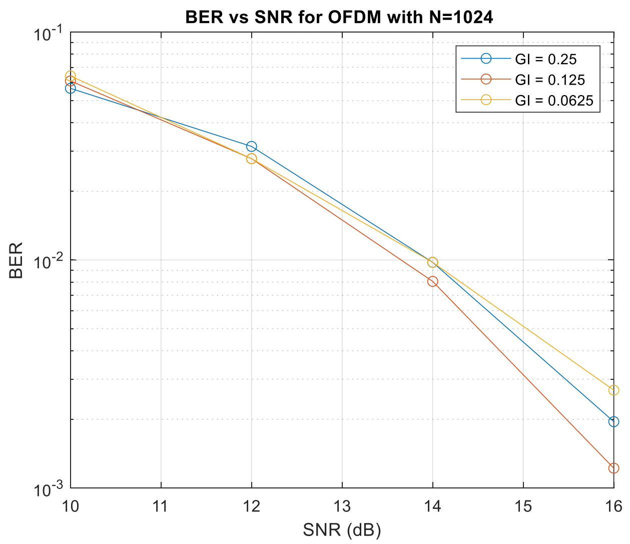

Fig. 7. Simulated with N_{fft} 1024

It is usually noticeable but not extremely destructive. 1/8 is a moderate GI length that provides a good balance between ISI protection and symbol duration. Generally, a longer guard interval is preferable for environments with significant multipath, while a shorter guard interval enhances data throughput but might require a thorough evaluation of channel factors.

Table 4 depicts the readings taken at SNR 16dB. At 1/4 of N_{FFT} the BER measured as 2.3193 x 10^{-3}. For 1/8 of N_{FFT} the BER has 1.7089 x 10^{-3}. As 1/16 of N_{FFT}, the BER is observed at 1.4648 x 10^{-3}. It is stated that 1/16 of N_{FFT} has the lowest BER, thus improving the system performance by 36.8%. However, the system did not exhibit significant improvement compared to other subcarriers.

Table 4
The BER measurements for N = 2048

GI length	SNR(dB)	BER
1/4	16	2.3193 x 10^{-3}
1/8	16	1.7089 x 10^{-3}
1/16	16	1.4648 x 10^{-3}

Figure 8 shows the simulated result for subcarrier 2048. It showed that the GI length of 1/16 with 2048 IFFT deployed in the system has better BER performance, which improves signal transmission. Although higher subcarrier sizes, like 2048, need more ISI prevention, a shorter GI length of 1/16 may be ideal because the longer symbol duration can be applied to transmit data. This is because the system can still provide robust performance against multipath interference.

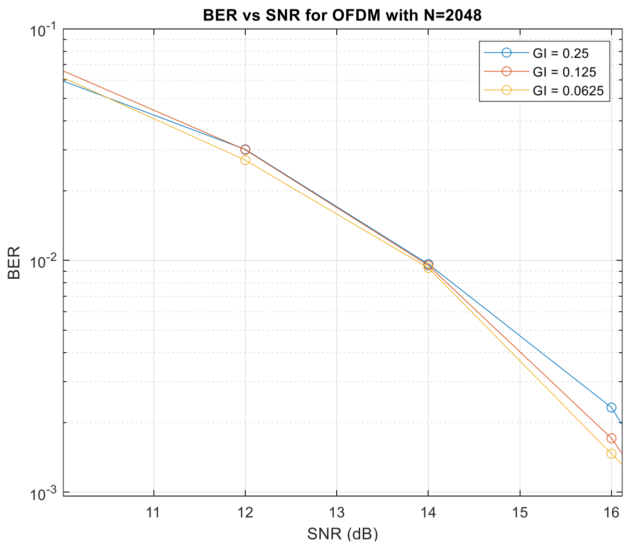

Fig. 8. Simulated with N_{fft} 2048

By configuring the GI with varied sizes, it is preferable to have one that contributes to the flexibility of the received signal waveform that has the lowest BER. The duration becomes suitable for data transmission with frame length when the GI is included before the OFDM signal begins. The most significant finding of this work was the deployment of 2048 subcarriers of the system with GI of 1/16 N_{FFT} showing better BER values when applied to real-world wireless systems, for example, wireless fidelity (Wi-Fi), DVBT2, broadcasting and mobile communications.

4. Conclusions

This paper concludes that the length of GI can mitigate the signal interference or BER in OFDM systems. It corresponds to a specific GI value(s) with N at 512, 1024 and 2048 performs under acceptable noise conditions. The minimization of BER is characterized by varying the number of FFT sizes and GI lengths. It is observed that N_{FFT} for 512, GI of ¼ has the best BER values. Meanwhile, at N_{FFT} for 1024, GI of 1/8 is the best compared to 512 and 2048. Finally, at NFFT for 2048, GI of 1/16 has better BER performance to improve the OFDM system.

This research proves that the GI length affects the BER value and number of FFT sizes in a multicarrier environment to support the 5G network. It has huge potential in supporting new wireless communications technology in multiple transmitting signals. It also helps the users retrieve signals with minimum interference. The future of the research may consider the value of subcarriers and GI length. Moreover, the GI is vital for the sustainability of data in the system. The most prominent aspect of future generation networks is the ability to have great flexibility for multiple signal transmission with minimum error.

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