Available *online* at : http://jnte.ft.unand.ac.id/

Jurnal Nasional Teknik Elektro

| ISSN (Print) 2302-2949 | ISSN (Online) 2407-7267 |

Performance Comparison of FBMC-OQAM and CP-OFDM Using AWGN Channel

Anggun Fitrian Isnawati, Dhia Fikri Zam Zami, M. Lukman Leksono

Institut Teknologi Telkom Purwokerto, Jl. D.I Panjaitan No.128, Purwokerto, 53147, Indonesia

ARTICLE INFORMATION

Received: July 06, 2022
Revised: November 22, 2022
Available online: March 31, 2023

KEYWORDS

AWGN Channel, Cyclic Prefix, FBMC, OFDM, OQAM

CORRESPONDENCE

Phone: +62 (281) 641629

E-mail: anggun@ittelkom-pwt.ac.id

A B S T R A C T

The 5G NR network planning covers the types of use scenarios and applications that include Enhanced Mobile Broadband (eMBB), Ultra-Reliable and Low Latency Communications (URLLC), and Massive Machine Type Communications (MTC). Regarding multicarrier modulation schemes, Orthogonal Frequency Division Multiplexing (OFDM) has become the most popular choice in previous technology, so OFDM is a strong candidate for its 5G NR technology application. However, OFDM has disadvantages such as higher PAPR and decreased bandwidth efficiency due to the addition of CP. These weaknesses can be overcome by the FBMC modulation scheme with Offset Quadrature Amplitude Modulation (OQAM) as a more efficient CP replacement for its implementation in 5G NR. This study analyzed the development of OQAM in Filter Bank multicarrier (FBMC) and compared it with using Cyclic Prefix (CP) based on OFDM using the AWGN channel. The first step of this research is to present an overview of the modulation scheme used. Next, compare the performance of FBMC-OQAM and CP-OFDM by analyzing several Bit Error Rate (BER) simulation results against the SNR value when both systems use the same simulation parameters. Based on the test results of each BER, both methods have different values, almost 2 dB for the same BER results. It indicates that the FBMC-OQAM system reached the BER value of 10-4 at SNR 15 dB. The CP-OFDM system, meanwhile, was able to achieve a BER value of 10-4 at SNR 17 dB. These results indicate that the FBMC-OQAM system is superior to CP-OFDM based on the BER values.

INTRODUCTION

The implementation of International Mobile Telecommunication in 2020 (IMT-2020) makes 5G technology also develop rapidly. 5G services that require speed, coverage and reliability require different network solutions, both in the form of evolution of existing and potential new networks, new deployment models including small cell, appropriate network infrastructure including optical fiber and wireless connectivity, and access to different frequency spectrum [1]. Due to the increase in cellular network data traffic every year, this indicates that telecommunication services are an important need for humans today to support all their activities and encourage progress from various sectors including the industrial sector due to the need for speed of accessing information.

The need for completion in the establishment of 5G New Radio (NR) technology standards makes the roadmap for the development of 5G NR technology an important discussion at national and international levels. The 5G NR services have requirements such as speed, coverage, and reliability for the creation of different network solutions, both in the form of network evolution from existing ones and the potential for new networks to emerge, the network infrastructure used in the form of wireless connectivity, as well as access to different frequency spectrums. There is a requirement of 5G communication which aim to provide a high capacity, data-rate at the speed of 1 Tbps. By selecting a better modulation technology, the required capacity and data rate can be achieved [2]. The frequency of millimeter Wave (mmWave) as the frequency used in 5G NR cellular technology as a form of spectrum addition and can achieve multi Gigabit-per-second (Gbps) data rates to users, and it is predicted that this technology will use frequencies between 1 GHz - 100 GHz [3]. This is a challenge for telecommunications service providers due to the very dense use of frequencies. Therefore, telecommunications service providers must be ready to prepare the right design by serving their customers and providing the best network. Proper network design cannot be separated from the use of a Multi Carrier Modulation (MCM) system [4].

OFDM is a well-known MCM scheme and also the most widely used in today's wireless communication standards [5]. However, OFDM has several disadvantages, such as sensitive to carrier frequency offset, easily disturbed by linear distortion, and its complexity for implementing Fast Fourier Transform (FFT) on the receiving side. Therefore, a new method to improve OFDM performance has been developed, namely Filter Bank Multi Carrier Offset Quadrature Amplitude Modulation (FBMC-OQAM), which can also save communication bandwidth. FBMC

https://doi.org/10.25077/jnte.v12n1.1034.2023

is also recommended as the most promising modulation scheme for 5G cellular communication systems since it does not require CP, so it can save the bandwidth and have better efficiency than OFDM [6]. In some aspects the use of QAM modulation is replaced with Offset QAM (OQAM) modulation because the performance of OQAM is able to exceed conventional QAM at the time of implementation. The advantages of OQAM include a high level of dispersion, improve the performance of the decision-making process and have a higher bit rate. The use of OQAM in OFDM has also been widely implemented, with results that can reduce inter carrier interference (ICI) and inter symbol interference (ISI) [7]. The use of OQAM is not only used in OFDM multicarrier but also used in Generalized Frequency Division Multiplexing (GFDM) technology [8], [9]. As well as diversity techniques that can improve system performance [10], application of OQAM in the FBMC technique aims to increase the received SINR [11]–[13]. Based on the background, this study focuses on the comparison of system performance between CP-OFDM and FBMC-OQAM in terms of Bit Error Rate (BER) and Signal to Noise Ratio (SNR) parameters.

This paper is organized as follows: The research background is explained in the Introduction, then followed by an explanation of the method/system model and research flowchart. The next discussion is related works that are in line with this research, then followed by a presentation of the results and discussion/analysis. The final section presents the conclusions of this research.

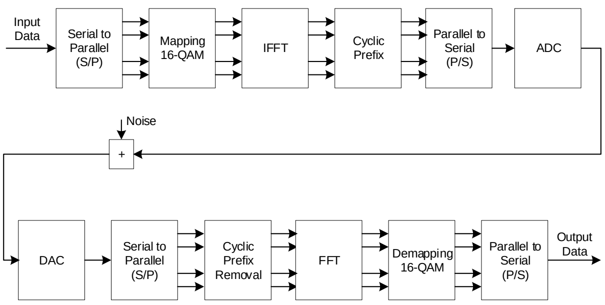

Figure 1. Block Diagram of Transceiver CP-OFDM

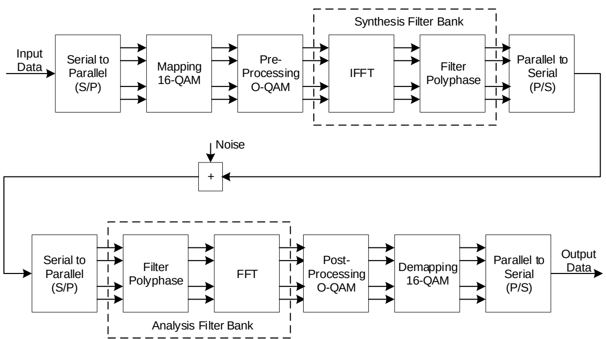

Figure 2. Block Diagram of Transceiver FBMC-OQAM

METHOD

Based on the two block diagrams in Figs. 1 and 2, each part can be explained as follows.

1. Input Data

At this stage, a random input signal will be given as input from the system as much as 52,000 bits. The n frames variable has a value that can be changed according to needs, the subcarrier variable has a certain value according to the number of predefined subcarriers, and the bit per symbol variable has a value of 4 for 16 QAM modulation types. Variable bits per symbol can change according to the desired modulation level.

2. Serial to Parallel (S/P)

In serial to parallel, the modulated stream will be converted into N subcarriers, so that the stream with high data rate will become N subcarrier with low data stream.

3. Mapping 16-QAM (Modulation)

In this process the stream of OFDM signal is modulated separately with the choice of 16-QAM modulation technique. In the 16-QAM modulation technique, there are mapping processes for 4 bits of information into 1 symbol, as shown in Table 1.

Table 1. Mapping Process of 16-QAM

No	4-Bit Group				Complex Number (χ)
	Bit-4	Bit-3	Bit-2	Bit-1	
1	0	0	0	0	0.3162 + 0.3162*i*
2	0	0	0	1	-0.3162 + 0.3162*i*
3	0	0	1	0	0.3162 – 0.3162*i*
4	0	0	1	1	-0.3162 – 0.3162*i*
5	0	1	0	0	0.9486 + 0.3162*i*
6	0	1	0	1	-0.9486 + 0.3162*i*
7	0	1	1	0	0.9486 – 0.3162*i*
8	0	1	1	1	-0.9486 – 0.3162*i*
9	1	0	0	0	0.3162 + 0.9486*i*
10	1	0	0	1	-0.3162 + 0.9486*i*
11	1	0	1	0	0.3162 – 0.9486*i*
12	1	0	1	1	-0.3162 – 0.9486*i*
13	1	1	0	0	0.9486 + 0.9486*i*
14	1	1	0	1	-0.9486 + 0.9486*i*
15	1	1	1	0	0.9486 – 0.9486*i*
16	1	1	1	1	-0.9486 – 0.9486*i*

4. Inverse Fast Fourier Transform (IFFT)

This block serves to convert data from the frequency domain to the time domain by using the Inverse Fast Fourier Transform (IFFT) technique. The purpose of this process is to create orthogonality between the subcarriers, so that their spectra in the frequency domain can be overlapped. Each subcarrier will be modulated with IFFT so that the subcarrier that was previously a frequency domain will turn into a time domain. Modulation with IFFT will also cause superposition of the transmitted signals.

5. Cyclic Prefix (CP)

Adding a guard interval in the time domain by using a cyclic prefix. The purpose of the cyclic prefix is to combat inter symbol interference (ISI) when an OFDM signal is transmitted in a dispersive channel. This CP preserves the orthogonality of the subcarriers as well. The cyclic prefix is a guard time made up of a replica of the time-domain OFDM waveform. The basic premise is to replicate part of the back of the OFDM signal to the front to create the guard period, as shown in Fig. 3.

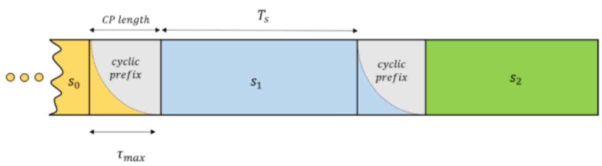

Figure 3. Cyclic-prefix and OFDM symbol [14]

6. Parallel to Serial (P/S)

In parallel to serial, N subcarriers, each of which has been converted into a frequency domain, will be converted into a stream, so that N subcarriers with low data streams will become streams with high data rates. The parallel to series converter block has a function to convert the original form of parallel bits into serial bits, by grouping 4 bits of output from the 16-QAM mapping controller, into one line as the output of the 16-QAM mapping process to serial data bits.

7. Digital to Analog Converter (DAC)

DAC is used to convert a digital input which is generally in binary form into an analog input/ signal which is generally in the form of current, voltage or electric charge. In addition, DAC is also a liaison between digital circuits and analog circuits.

8. Analog to Digital Converter (ADC)

Down Converter device that translates a signal from a radio frequency at a frequency of 4 GHz or 12 GHz into an intermediate frequency signal.

9. Cyclic Prefix Removal

At the receiver side, the signal is first converted to parallel blocks, and then CP is removed from each block.

10. Fast Fourier Transform (FFT)

The FFT block serves to convert from a row of OFDM symbols into complex numbers according to the M-ary QAM mapping constellation on the transmitter.

Table 2. Demapping Process of 16-QAM

No	Re (x)	Im (y)	Output
1	0.6324>x>0	0<y<0.6324	0 0 0 0
2	-0.6324<x<0	0<y<0.6324	0 0 0 1
3	0.6324>x>0	0>y>-0.6324	0 0 1 0
4	-0.6324<x<0	0>y>-0.6324	0 0 1 1
5	x>0.6324	0<y<0.6324	0 1 0 0
6	x<-0.6324	0<y<0.6324	0 1 0 1
7	x>0.6324	0>y>-0.6324	0 1 1 0
8	x<-0.6324	-0.6324<y<0	0 1 1 1
9	0.6324>x>0	y>0.6324	1 0 0 0
10	-0.6324<x<0	y>0.6324	1 0 0 1
11	0.6324>x>0	y<-0.6324	1 0 1 0
12	-0.6324<x<0	y<-0.6324	1 0 1 1
13	x>0.6324	y>0.6324	1 1 0 0
14	x<-0.6324	y>0.6324	1 1 0 1
15	x>0.6324	y<-0.6324	1 1 1 0
16	x<-0.6324	y<-0.6324	1 1 1 1

11. Demapping 16-QAM (Demodulation)

In this process, each carrier of the OFDM signal is demodulated separately with a choice of 16-QAM demodulation technique. At the receiving end, the reverse process occurs, namely from the 16-QAM mapper, namely the 16-QAM map guard process. In this process, each symbol will be remapped to form four data bits again. The decision-making process on the 16-QAM carrier, is used to determine which symbol is actually sent by the sending antenna. Decision making is needed because of the influence of channels and noise which causes the QAM symbol at the receiver to be not original compared to the 16-QAM mapper output at the sender. The results of this decision, in the form of real and imaginary components which are then returned back into data bits. The decision-making rules is shown in Table 2.

12. OQAM Pre-Processing

In this section the symbols will be separated into odd symbols and even symbols. It is known for the odd and even symbols seen from the order. Then the symbol is processed using two operations, namely:

a. The process of converting complex numbers into real numbers.
b. Multiplication process with k, n.

In the first operation, the odd-even symbols consisting of real and imaginary numbers will be separated, respectively. Then each real and imaginary number increased in number (two times up-sampling) followed by a half-phase shift of 90^o.

13. Synthesis Filter Bank (SFB)

The Synthesis Bank Filter process as shown in Fig. 6, consists of two processes, namely the inverse fast Fourier transform (IFFT) process and bank filter process. The bank filter process in SFB is carried out using a polyphase filter [15].

14. Transmission Channel

The transmission channel used in this simulation is the AWGN channel. The AWGN channel is assumed to have normally distributed (Gaussian) noise. AWGN noise is normally distributed with an average value of zero. This noise is random and adds to the original signal.

15. Analysis Filter Bank (AFB)

The filter bank analysis process is the opposite of the filter bank synthesis process. The filter bank analysis consists of two processes, namely the fast Fourier transform (FFT) process and the bank filter process, and it can be shown in Fig. 7. The bank filter process in AFB is carried out using a polyphase filter as well [15].

16. OQAM Post-Processing

OQAM post-processing is the opposite process of OQAM pre-processing chart.

17. Output Data

The results of the output binary bits of the signal can be used to compare the output bits with the input bits to get the SNR value against the BER

https://doi.org/10.25077/jnte.v12n1.1034.2023

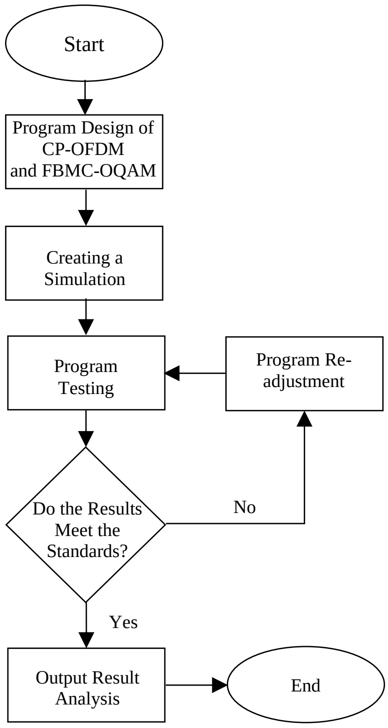

Figure 4. Flowchart of The Program Simulation Design

Figure 4 shows the flowchart of the program simulation design. Designing program simulations using MATLAB software by comparing the performance of CP-OFDM and FBMC-OQAM using BER and SNR parameters.

RELATED WORKS

Research conducted by Leonardo G. Baltar and Josef A. Nossek discusses the review of FBMC and makes a comparison with OFDM based on Cyclic Prefix (CP) then performs spectral measurements and Peak to Average Power Ratio (PAPR). This study discusses the subcarrier model used in the derivation of the channel-per-subcarrier equalizer found in the recent literature and presents a new method of per-subcarrier channel estimation based on the same model [16]. The research method is carried out by comparing the performance of FBMC and CP-OFDM by showing several BER simulation results, when both systems occupy the same bandwidth and the results are the same. Furthermore, by estimating the FBMC channel, it is able to achieve an advantage of more than 1 dB at E_b/N_0 compared to CP-OFDM. This research can be developed on the parameter E_b/N_0 because it is proven that the gain value is better than OFDM when the receiver has determined the impulse response subcarriers and each subcarrier has used the MMSE equalizer. This study also presents a new scheme for channel estimation of impulse response subcarriers. Based on the simulation results, it can be seen that the FBMC system can still achieve a gain of more than 1 dB for the value of E_b/N_0 exceeding CP-OFDM.

In 5G communication, more data rates are needed that are supported by machine to machine (M2M) communication, and currently OFDM has weaknesses such as high PAPR, spectrum wastage due to CP and out of band emissions (OBE). The solution to overcome this problem, this research is looking for another multicarrier waveform, namely FBMC. This research will implement the Poly-phase network filter bank multicarrier (PPN-FBMC) which can reduce complexity and high computation [6]. The research method used is a prototype filter for FBMC with a high overlapping factor (K=6 and K=8). Then compared with OFDM performance such as Error Vector Magnitude (EVM), Peak to Average Power Ratio (PAPR) and Power Spectral Density (PSD). This research can be developed to analyze the performance of the FBMC system under various fading conditions in real time. In this study, the results are displayed from several test parameters, namely waveform filter, EVM analysis, PSD analysis and Complementary Cumulative Distribution Function (CCDF) analysis. The results show that OFDM has a higher probability of carrying a signal with a higher PAPR than FBMC. After further observation, it was found that with increasing spread factor k, the performance of FBMC related to PAPR parameters was much better than OFDM.

Filter Bank can overcome the shortcomings that arise due to the use of FFT, but this is a trade-off due to complexity to the system namely Poly-Phase Networks (PPN). This study measures the Out of Band (OOB) emission, PSD, and Bit Error Probability (BEP) parameters [7]. The research method was carried out by comparing OFDM and FBMC filters which were simulated in the time domain and the frequency domain. This study proposes FBMC as a 5G waveform due to its much lower OOB radiation. FBMC is one of the best schemes to consider due to its local frequency coefficient and high spectrum efficiency. In the same study, the error probability of Vehicle Channel Model A, which is one of the vehicles used, shows that FBMC performs better than OFDM on cellular channels. CP-OFDM shows a better error probability than FBMC at lower speeds, but at high speeds FBMC is superior. CP-OFDM shows a low error probability at low speeds because CP is very suitable for multipath fading. It shows that when the channel is dominated by Doppler shift, FBMC has better performance than CP-OFDM due to the PHYDYAS filter factor [17]. It can be seen that the OFDM performance without using CP is considered very bad on the fading channel.

CP-OFDM

Cyclic Prefix (CP) is an important element in OFDM on multipath fading channels. When CP is added at the transmitter side (before it is eliminated at the receiver side), the $\boldsymbol{H_c}$ channel matrix becomes circulant [8]. The concept of CP can be explained simply if the PDP has $h = [h_0, h_1]$ and the transmitted data x is added length CP (Q) = 3 which is $x_{cp} = [d\ e\ \mid a\ b\ c\ d\ e\ ]$, then the receiver signal (y) with additional noise (n) is determined as teoplitz matrix equation below [18]:

$$y = Hx + n \qquad (1)$$

$$\begin{bmatrix} h_0 & 0 & 0 & 0 & 0 & 0 & 0 \\ h_1 & h_0 & 0 & 0 & 0 & 0 & 0 \\ 0 & h_1 & h_0 & 0 & 0 & 0 & 0 \\ 0 & 0 & h_1 & h_0 & 0 & 0 & 0 \\ 0 & 0 & 0 & h_1 & h_0 & 0 & 0 \\ 0 & 0 & 0 & 0 & h_1 & h_0 & 0 \\ 0 & 0 & 0 & 0 & 0 & h_1 & h_0 \\ 0 & 0 & 0 & 0 & 0 & 0 & h_1 \end{bmatrix} \begin{bmatrix} d \\ e \\ a \\ b \\ c \\ d \\ e \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ n_3 \\ n_4 \\ n_5 \\ n_6 \\ n_7 \\ n_8 \end{bmatrix} \qquad (2)$$

After CP removal process at the receiver, we get the following circulant matrix equation below:

$$y = \begin{bmatrix} h_{1e} + h_{0a} \\ h_{1a} + h_{0b} \\ h_{1b} + h_{0c} \\ h_{1c} + h_{0d} \\ h_{1d} + h_{0e} \end{bmatrix} + \begin{bmatrix} n_3 \\ n_4 \\ n_5 \\ n_6 \\ n_7 \end{bmatrix} \quad (3)$$

Or y can be obtained by multiplying the circulant matrix ***Hc*** with x because the circulant matrix has the same value as the matrix resulting from transmission using CP as follows:

$$\begin{bmatrix} h_0 & 0 & 0 & 0 & 0 \\ h_1 & h_0 & 0 & 0 & 0 \\ 0 & h_1 & h_0 & 0 & 0 \\ 0 & 0 & h_1 & h_0 & 0 \\ 0 & 0 & 0 & h_1 & h_0 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \\ d \\ e \end{bmatrix} + \begin{bmatrix} n_3 \\ n_4 \\ n_5 \\ n_6 \\ n_7 \end{bmatrix} \quad (4)$$

FBMC-OQAM

The modulation system uses a lot of QAM with guard intervals and OQAM with pulse shaping. Figure 5 shows the difference between QAM and OQAM modulation. The bits in the inphase position remain in their original position while there is an offset or bit shift on the Quadrature side.

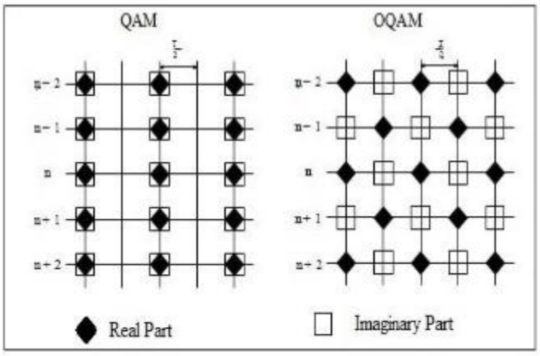

Figure 5. The Difference of QAM and OQAM

With the OQAM scheme, the spectrum of adjacent channels will overlap but without causing crosstalk between subcarriers due to the half symbol time delay between the inphase and quadrature components of the signal on each subcarrier. Crosstalk is moved or shifted to even samples when complex symbols are transmitted from odd samples. This will reduce the effect of ICI because there is a reduction in the distance of adjacent channels on the subcarrier.

In Offset QAM, the phase shift is limited from 0º to and ± 90º every T second. This is not like in QAM where there is a phase jump of up to 180º. In contrast to QAM, the I and Q channels in OQAM do not experience a transition at the same time. This shows that the transition never exceeds 90º [19].

FBMC consists of 2 processes, namely pre-processing and post-processing. Pre-processing at FBMC is often referred to as Synthesis Filter Bank (SFB), while post-processing is referred to as Analysis Filter Bank (AFB). The Synthesis Filter Bank is placed in the data transmission process, precisely after the O-QAM pre-processing. While on the receiving side, the analysis process is before the OQAM post-processing. The processes for the two filter banks are shown in Figs. 6 and 7. Based on Fig. 6, the Synthesis Filter Bank consists of 2 processes, namely the IFFT process and the filter process. The filter in the synthesis filter bank is used to separate signals based on their frequencies. The concept of an ideal filter is that the existing frequency will be directly forwarded or passed without any attenuation. Based on Fig. 7, AFB consists of 2 processes, namely the FFT process and the filter process. Filters in filter bank analysis are used to combine signals based on their frequencies. The type of filter used in the AFB must match the type of filter used in the SFB process [20].

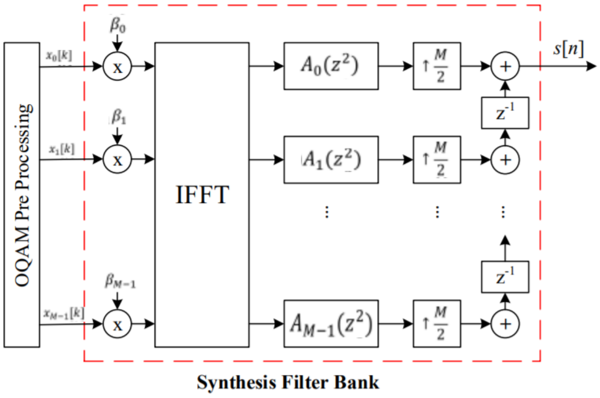

Figure 6. Syntesis Filter Bank [20]

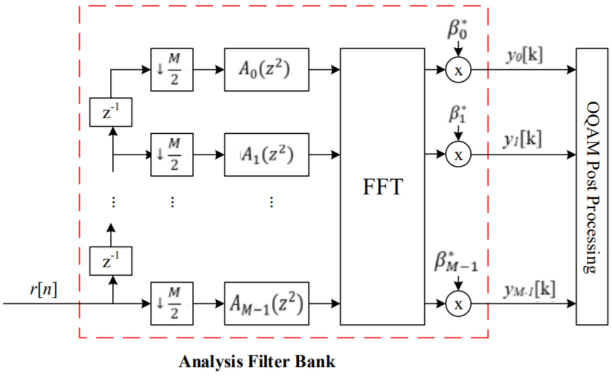

Figure 7. Analysis Filter Bank [20]

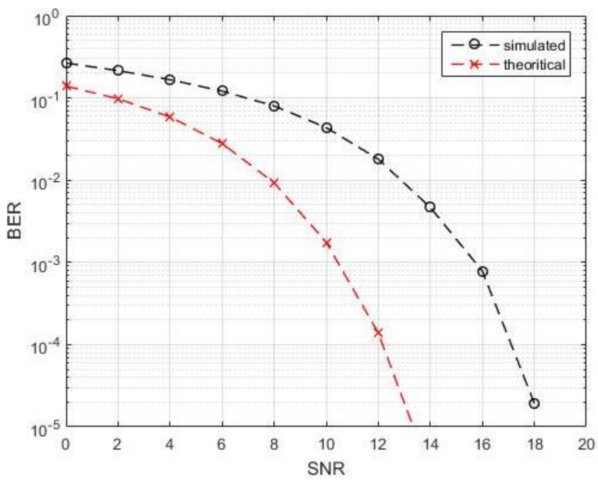

Figure 8. BER Performance of CP-OFDM

https://doi.org/10.25077/jnte.v12n1.1034.2023

RESULTS AND DISCUSSION

Analysis of CP-OFDM

The simulation process for the CP-OFDM system is carried out following the system modeling in Figs. 8 and 9. This simulation aims to determine the performance of the OFDM system by adding a cyclic prefix to the AWGN transmission channel based on the BER parameter to the SNR. The graph of the performance of the CP-OFDM system can be seen in Fig. 8.

Based on Fig. 8, it can be seen that the simulation value of BER is quite good. The BER value shows a significant decrease. The simulation results show that when the SNR is 0 dB, the average BER value is 0.264. Based on Fig. 8 the CP-OFDM system can reach a BER value of 10^{-4} requiring an SNR value of 17 dB. The resulting BER value is inversely proportional to the SNR value, the greater the SNR value, the smaller the resulting BER value.

Analysis of FBMC-OQAM

The simulation process for the FBMC-OQAM system is carried out following the system modeling in Fig. 9. This simulation aims to determine the performance of the FBMC system using the type of OQAM modulation on the AWGN transmission channel based on the BER to SNR parameters. The graph of the performance of the FBMC-OQAM system can be seen in Fig. 9. Based on the graph, the resulting performance of the FBMC-OQAM system has a good reduction in the simulated BER value. The decrease in BER that occurs in the FBMC-OQAM system proves that an increase in the SNR value can affect the resulting BER value.

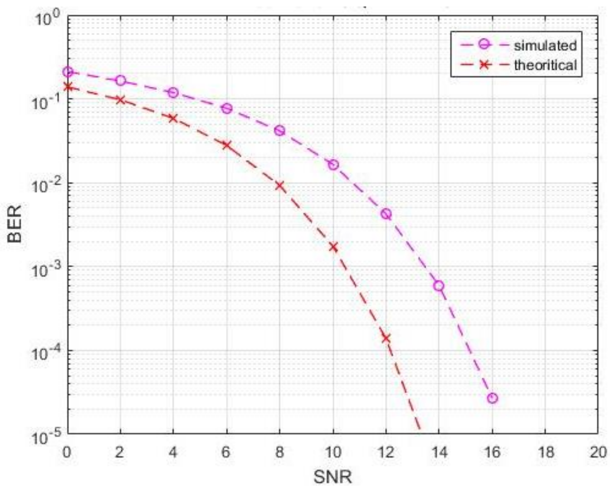

Figure 9. BER Performance of FBMC-OQAM

The simulation results show that at SNR 0 dB, the BER value is 0.2121. In the FBMC-OQAM system to reach a BER value of 10^{-4} requires an SNR value of 15 dB. The resulting BER value is inversely proportional to the SNR value, the greater the SNR value, the smaller the resulting BER value. This is because the value of the noise contained in the channel is getting smaller if the SNR value used is large. Meanwhile, if the SNR value used is small, the noise value in the AWGN channel will be greater and will produce a large BER.

Comparison of CP-OFDM and OQAM-FBMC Systems

In this study, we will compare the results of testing the BER against SNR, between the OFDM system BER using cyclic prefix and FBMC system using OQAM modulation as shown in Fig. 10. It can be seen based on the previous discussion, in Fig. 8 and 9, the BER obtained are quite good because as the SNR value increases, the resulting BER value decreases. Even at the value of SNR 20 dB, both systems can reach a value of BER ≈ 0. These results indicate that the FBMC-OQAM system is superior to CP-OFDM as seen from the comparison of the BER values.

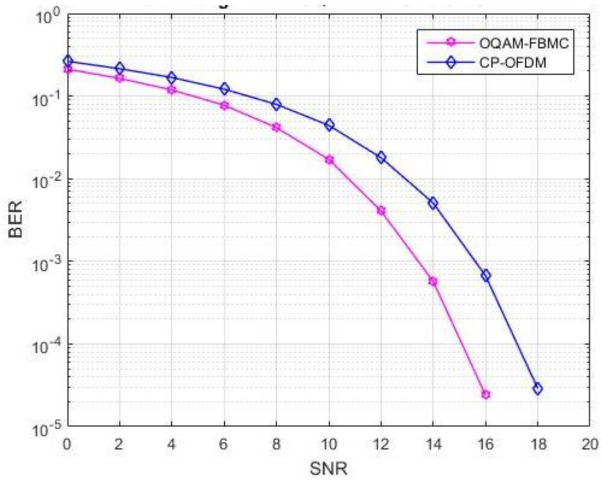

Figure 10. BER Comparison of CP-OFDM and FBMC-OQAM

CONCLUSIONS

Comparison of performance trials between the CP-OFDM and FBMC-OQAM systems using the BER value against the SNR, it was found that the FBMC-OQAM system succeeded in achieving a BER 10^{-4} at SNR 15 dB. Meanwhile, the CP-OFDM system only managed to achieve a BER 10^{-4} when SNR value of 17 dB. These results indicate that the FBMC-OQAM system is superior to CP-OFDM in terms of the comparison of the BER values.

REFERENCES

[1] "5G Vertical Use Cases," White Paper, Oct. 2021.

[2] A. Kumar and M. Gupta, "A Novel Modulation Technique for 5G Mobile Communication System," American Journal of Applied Sciences, vol. 12, no. 9, Art. no. 9, Sep. 2015.

[3] M. T. Moayyed, F. Restuccia, and S. Basagni, "Comparative Performance Evaluation of mmWave 5G NR and LTE in a Campus Scenario," in 2020 IEEE 92nd Vehicular Technology Conference (VTC2020-Fall), Victoria, BC, Canada, Nov. 2020, pp. 1–5.

[4] P. Rani, S. Baghla, and H. Monga, "Performance Evaluation of Multi-carrier Modulation Techniques for Next Generation Wireless Systems.," International Journal of Advanced Research in Computer Science, vol. 8, no. 5, Art. no. 5, 2017.

[5] J. A. C. Bingham, "Multicarrier modulation for data transmission: an idea whose time has come," IEEE Commun. Mag., vol. 28, no. 5, pp. 5–14, May 1990.

[6] A. F. Isnawati and J. Hendry, “Implementasi Filter Pre-Emphasis untuk Transmisi Sinyal Audio pada Sistem Komunikasi FBMC-OQAM,” Jurnal Nasional Teknik Elektro dan Teknologi Informasi, vol. 8, no. 4, p. 340, Nov. 2019.

[7] P. Siohan, C. Siclet, and N. Lacaille, “Analysis and design of OFDM/OQAM systems based on filterbank theory,” IEEE transactions on signal processing, vol. 50, no. 5, Art. no. 5, 2002.

[8] E. N. O. Herawati, A. F. Isnawati, and K. Ni’amah, “Analysis of GFDM-OQAM Performance Using Zero Forcing Equalization,” in 2021 IEEE International Conference on Communication, Networks and Satellite (COMNETSAT), Purwokerto, Indonesia, Jul. 2021, pp. 135–140.

[9] A. Lizeaga, M. Mendicute, P. M. Rodriguez, and I. Val, “Evaluation of WCP-COQAM, GFDM-OQAM and FBMC-OQAM for industrial wireless communications with Cognitive Radio,” in 2017 IEEE International Workshop of Electronics, Control, Measurement, Signals and their Application to Mechatronics (ECMSM), Donostia, San Sebastian, Spain, May 2017, pp. 1–6.

[10] B. Abbas, “Analisa Unjuk Kerja Peningkatan Transmisi Citra pada Kanal Wireless Menggunakan Teknik Diversity Selection Combining,” JNTE, vol. 6, no. 1, Mar. 2017.

[11] M. Yusuf, A. F. Isnawati, and S. Larasati, “Analisis Kinerja FBMC OQAM menggunakan Kode Konvolusi,” ELKOMIKA, vol. 9, no. 4, p. 775, Oct. 2021.

[12] B. Raynaldi, A. F. Isnawati, and M. A. Afandi, “Analisis Unjuk Kerja FBMC-OQAM Pada Transmisi Citra QR Code Menggunakan Ekualisasi Zero Forcing,” JNTE, vol. 10, no. 1, p. 32, Mar. 2021.

[13] H. Lin, M. Gharba, and P. Siohan, “Impact of time and carrier frequency offsets on the FBMC/OQAM modulation scheme,” Signal Processing, vol. 102, pp. 151–162, Sep. 2014.

[14] Jiamin Xie, “A constant envelope variation of OFDM waveform,” 2017.

[15] I. A. Shaheen and A. Zekry, “Complexity Analysis of FBMC/OQAM Transceiver using SRRC Polyphase Filter,” in 2019 International Conference on Promising Electronic Technologies (ICPET), Gaza City, Palestine, Oct. 2019, pp. 67–72.

[16] L. G. Baltar and J. A. Nossek, “Multicarrier systems: a comparison between filter bank based and cyclic prefix based OFDM,” in OFDM 2012; 17th International OFDM Workshop 2012 (InOWo’12), 2012, pp. 1–5.

[17] A. J. Ramadhan, “Implementation of 5G FBMC PHYDYAS Prototype Filter,” vol. 12, no. 23, Art. no. 23, 2017.

[18] E. M. Alfaroby, N. M. Adriansyah, and K. Anwar, “Study on channel model for Indonesia 5G networks,” in 2018 International Conference on Signals and Systems (ICSigSys), Bali, May 2018, pp. 125–130.

[19] V. Selvakumar, S. S. Nemalladinne, and P. Arumugam, “Analysis of LTE Radio Frame by eliminating Cyclic Prefix in OFDM and comparison of QAM and Offset-QAM,” Linnaeus University, Sweden, 2012.

[20] A. F. Isnawati, M. A. Afandi, and J. Hendry, “Performance Analysis of FBMC-OQAM System for Barcode and QR Code Image Transmission,” in 2020 IEEE International Conference on Industry 4.0, Artificial Intelligence, and Communications Technology (IAICT), Bali, Indonesia, Jul. 2020, pp. 162–166.

AUTHOR BIOGRAPHY

Anggun Fitrian Isnawati was born in Cilacap, Indonesia, in 1978. She received Doctoral Degree in Telecommunication Engineering from Universitas Gadjah Mada, Yogyakarta, Indonesia in 2018. She joined as a Lecturer at the Institut Teknologi Telkom Purwokerto since 2002. Her research interests including wireless communication, cellular network, optical communication, visible light communication, waveform technology (OFDM, FBMC, GFDM), channel estimation, game theory and cognitive radio.

Dhia Fikri Zam Zami was born in Banyumas, Indonesia, in 1998. He received Bachelor Degree in Telecommunication Engineering Study Program of Institut Teknologi Telkom Purwokerto (ITTP) in 2021. His research interest including wireless communication especially in multi-carrier modulation (MCM) such as OFDM and FBMC.

M. Lukman Leksono was born in Brebes, Indonesia, in 1987. He obtained his Masters in Indonesian Language Education from Semarang State University, Indonesia in 2017. Joined as a Lecturer at the Institut Teknologi Telkom Purwokerto since 2019. His research interests include classroom action research (PTK), development of learning tools (R&D) for Indonesian language and literature, pragmatics, linguistics, semantic critical discourse analysis (AWK), BIPA (Indonesian for Foreign Speakers).

https://doi.org/10.25077/jnte.v12n1.1034.2023