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Performance Analysis of FBMC O-QAM System Using Varied Modulation Level

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Abstract — Communication channels that are affected by various disturbances will cause a high Bit Error Rate (BER). To maximize the performance of the channel in the future, Filter Bank Multicarrier (FBMC) technique is used as a renewal of Orthogonal Frequency Division Multiplexing (OFDM). FBMC has better spectrum efficiency properties due to the nature of orthogonality, which only divides bandwidth for sub-channels. The purpose of the research was to know the performance of FBMC Offset QAM (FBMC O-QAM), which has a variety of modulation levels of 4-QAM, 16-QAM, and 64-QAM. The Zero Forcing (ZF) method is used to detect the original signal sent by the transmitting antenna. System performance in this study was measured by parameter BER and channel capacity. The results showed that the FBMC O-QAM system with ZF had decreased BER value on each modulation. At the time of modulation, 4-QAM has a BER value of 0.0008945 with a Signal-to-Noise Ratio (SNR) value of 20 dB. Modulation 16-QAM also experienced the same thing when the SNR value of 20 dB has a BER value of 0.001856, and at modulation 64 QAM has BER value of 0.01766 at a SNR of 20 dB. Besides decreasing the BER parameters, the FBMC O-QAM ZF system has own characterize in channel capacity. For the 4-QAM has 4.808 b/s/Hz, 16-QAM has 4.627 b/s/Hz, and 64-QAM has 3.903 b/s/Hz at SNR 20 dB. It concludes that 4-QAM has a best channel capacity enhancement. The value of channel capacity generated based on simulations using ZF shows an increase in value along with an increase in SNR, but has a smaller value compared to channel capacity in theory.

Keywords – FBMC, Offset QAM, BER, Zero Forcing, Modulation Level

I. INTRODUCTION

Communication channels are affected by various kinds of interference, such as inter-symbol interference, which caused a high Bit Error Rate (BER). In this case, Multicarrier Modulation (MCM) can be used as a solution to maintain optimal channel performance. Orthogonal Frequency Division Multiplexing (OFDM) is a special form of MCM which divides high-speed data streams into a number of low-speed data streams and sends them simultaneously through several subcarriers [1].

With its orthogonality, intercarrier can be overlapped without causing the Intercarrier Interference (ICI) effect. Overlay multiplexing subcarriers will save channel bandwidth and increase channel capacity. However, OFDM has several weaknesses in the form of systems such as sensitive to carrier frequency offset, high Peak Average Power Ratio (PAPR) values, and the difficulty of operating Fast Fourier Transform (FFT). The presence of Carrier Frequency Offset in OFDM makes it difficult for the receiver to detect OFDM signals and causes frequency shifting, which will make a loss of orthogonality of OFDM signals [2]. OFDM technology has been widely used, but OFDM also has certain disadvantages, such as the use of Cyclic Prefix (CP), large side lobes that limit spectrum utilization [3]-[5].

A new method of Filter Bank Multi-Carrier with Offset Quadrature Amplitude Modulation (FBMC O-QAM) is needed for maximizing the OFDM performance [6]. FBMC is the most promising wave pattern for wireless networking in the future, especially 5G communication [7], [8]. FBMC consists of two processes, namely pre-processing and post-processing.

The pre-processing at FBMC is called Synthesis Filter Bank, while the post-processing is called Analysis Filter Bank. The synthesis filter bank is placed in the process of transmitting data precisely after the O-QAM pre-processing. In contrast, on the receiver, the analysis process is carried out before the post-processing.

Digital modulation is used to help the transmission technique usually using Quadrature Amplitude Modulation (QAM). However, QAM has some susceptibilities, the complexity of high implementation, and ICI included. One of the opportunities to overcome the susceptibilities is by applying the Offset QAM (O-QAM) modulation. The O-QAM scheme overlaps adjacent channels spectrum without causing crosstalk between subcarriers due to a delay of half-time symbol between the in-phase component and the quadrature signal on each subcarrier [9].

This study compares the performance of FBMC O-QAM with different modulation levels of 4-QAM, 16-QAM, and 64-QAM. The Zero Forcing (ZF) symbol detection algorithm is chosen as the equalization method to detect the original signal sent by the sending antenna. Performance parameters to be analyzed are BER and channel capacity for each modulation level.

II. RESEARCH METHOD

This section discusses the research method, including the discussion of the System Model of FBMC O-QAM with and without ZF. The discussion in this section also includes an explanation of each process in the block diagram, from the input process to the output process.

A. System Model

This simulation modeling is based on predetermined parameters such as input type, use of mapper types, filter type selection, channel and noise usage, equalization type, and modulation level variations used. System testing is done by analyzing and comparing simulation results with theoretical results at each modulation level variation used. The parameters tested in this simulation including BER and channel capacity. In modeling system of FBMC O-QAM, it can be seen that the filter banks on the transmitter and receiver consist of an array of N filters that process the N input signal to produce output N. If the input of the N filter is connected together, then the system in an analog way is measured as an analyzer of the input signal based on each filter's characteristics. In Fig. 1, the input signal is converted from series to parallel, then passes through the synthesis filter bank. FBMC works on the trans-multiplexer configuration with a set of synthesis filters and analysis filters together with FFT and Inverse Fast Fourier Transform (IFFT) blocks. Synthesis filters are used on the transmitter, while the analysis filter is used on the receiver [10]. Fig. 2 shows the FBMC O-QAM system using ZF equalization.

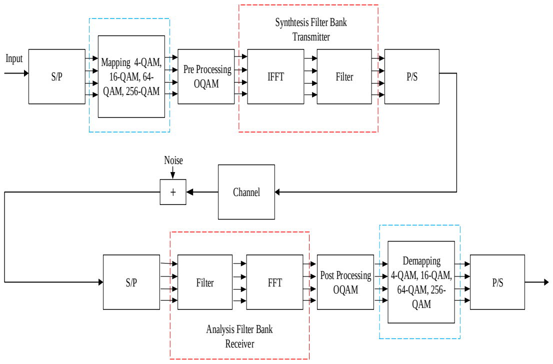


Fig. 1. System Model of FBMC O-QAM

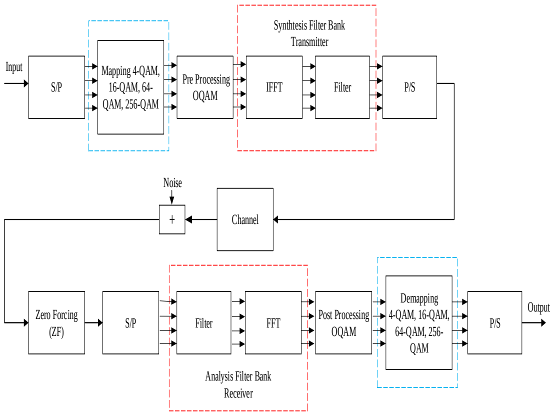


Fig. 2. System Model of FBMC O-QAM with ZF

B. Input Data

In this simulation, the input data is in the form of audio files *.wav. The audio signal has a normalized amplitude from -1 Volt to 1 Volt. Changing the signal into binary digit with the aims to transmit the signal. The equation to convert the signal into a binary is,

$$V_1 = V_0 + 1 \quad (1)$$

$$V_t = V_1 * 2^{nbit-1} \quad (2)$$

$$B = \text{binary}\ (V_t) \quad (3)$$

where V_0 is the original audio signal, V_1 is the audio signal that has been added with a value of 1, so that it is positive. V_t is an audio signal that is converted into decimal format where *nbit* is the signal quantization level (*nbit* = 8 binary bits), and variable B is the conversion decimal numbers into binary numbers. The processed binary signal is then sent to the receiver. At the receiver side, the signal is returned to the initial position that is equal to -1 Volt to 1 Volt. This change is the opposite of the previous process; that is, binary numbers are converted into decimal numbers using decimal operations to obtain a signal of -1 Volt to 1 Volt [11].

C. Serial-to-Parallel Data Conversion (S/P)

The serial-to-parallel function is to change the shape of serial data bits into parallel form by grouping the data with the modulation level used. The result of serial to parallel conversion is a matrix of bits with the number of rows indicating the number of subcarriers to be used. The process of converting parallel data into series is shown in Fig. 3. The purpose of this process is to group binaries from the serial form into parallel forms. The binary digits form a symbol. These symbols can be ordered by multiplying the sampling frequency (f_s) with time (t_{At}) as follows,

$n = fs \times t_{At}$
$n = 22050 \times 0{,}00004535$
$n = 0{,}9999675$
$n = 1$

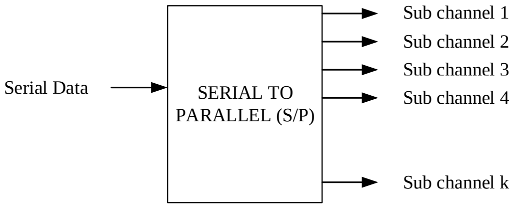


Fig. 3. Serial to Parallel Data Conversion

D. Varied Mapper

The output of the serial to parallel data converter is then mapped with modulation level variations, including 4-QAM, 16-QAM, and 64-QAM. Mapping is done by converting binary input data into complex numbers $S_k = I_k + jQ_k$, where k is a symbol variable, I is an in-phase or real number, and Q is a quadrature or imaginary number. The modulation used in this simulation is varied, causing each symbol received in this mapping is grouped according to the type of modulation. In 4-QAM mapping consists of two bits/symbol, a 16-QAM mapping consists of four bits/symbol, and 64-QAM mapping consists of six bits/symbol.

E. Pre-processing O-QAM

Pre-processing blocks utilize changes between QAM and O-QAM symbols. As shown in Fig. 4, the first operation is the conversion of complex numbers into real numbers. The real and imaginary parts of complex-valued symbols are separated again to form two new symbols (this operation can be called staggering). The order of these new symbols depends on the number of the sub channel. For example, conversions differ for sub-channels with even and odd numbers. The second operation is doubling by sequence, as in Fig. 4 [12].

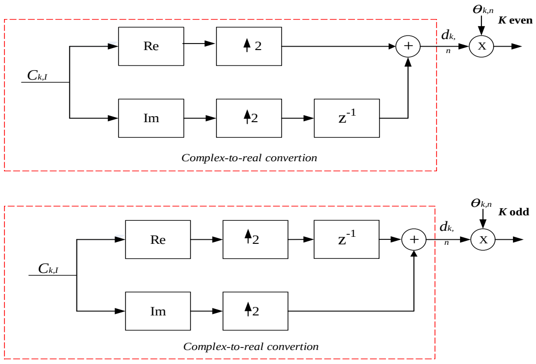


Fig. 4. Post-processing O-QAM

F. Synthesis Filter Bank

Based on Fig. 5, the synthesis filter bank need two processes, the IFFT process and the filter process. The synthesis filter bank consists of a set of parallel band pass filters that merge multiple input narrowband signals into a single broadband signal. The input narrowband signals are in the baseband. Each narrowband signal is interpolated to a higher sampling rate by using the up-sampler, and then filtered by the low pass filter. A direct form SFB consists of M up samplers and M synthesis filters.

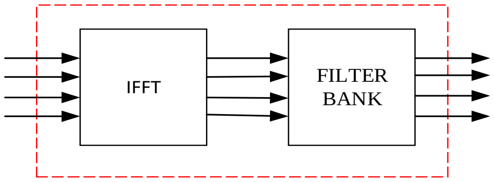


Fig. 5. Synthesis Filter Bank

G. Parallel-to-Serial Data Conversion

In the process of converting parallel to serial, each data is received at a different time. This process on the transmitter side functions to convert data from parallel to serial at the output of the bank filter synthesis so that it can be transmitted.

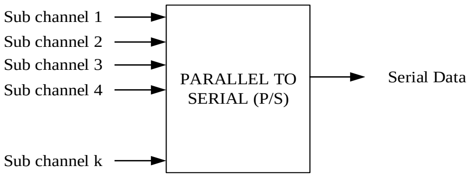


Fig. 6. Parallel-to-Serial Data Conversion

H. Channel Model

Channel modeling in this simulation uses AWGN channels. The AWGN channel is assumed to have a normally distributed (Gaussian) noise. The average value of normalized distributed AWGN noise is zero. AWGN noise has random properties and adds the original signal. Noise is a disturbance in the form of unwanted signals that can cause damage to the information signal during the transmission process from the transmitter to the receiver. AWGN is a noise which adds to the signal in all frequency spectral and is distributed Gaussian,

$$\varphi(f) = \frac{1}{2}N_0 \quad (W/Hz) \tag{4}$$

with No is constant, and is also called Noise Power Density. AWGN has additive properties, which means that this noise will be added to the information signal, white here means noise has a constant power density, while the Gaussian means the noise voltage value is normalized distributed Gaussian [13].

I. ZF Equalization

The signal processing in symbol detection aims to get the original signal value digitally. In this simulation, we are using the ZF algorithm because of its simplicity [14]. ZF is the simplest type of equalizer or symbol detection algorithm. The use of this algorithm is quite easy namely H is a channel matrix, and W is a matrix that represents a linear process at the receiver so that the ZF must meet the requirements [15],

$$WH = 1 \tag{5}$$

In order for the data symbol to be detected, an interferer is needed to be zero. The W matrix is the inverse or pseudo-inverse (PI) matrix of the H channel matrix, as shown in the following equation [15],

$$W_{ZF} = H^{-1} \quad untuk\ N_{Tx} = N_{Rx} \tag{6}$$

$$W_{ZF} = (H^H H)^{-1} H^H \quad untuk\ N_{Tx} \neq N_{Rx} \tag{7}$$

with H^H a conjugate transpose matrix H. Pseudo Inverse (PI) exists if the number of sending antennas (N_{Tx}) is smaller or equal to the number of receiving antennas (N_{Rx}), whereas for N_{Tx} which is greater than N_{Rx}, then $H^H H$ is singular so the inverse is undefined.

J. *Analysis Filter Bank*

Based on Fig. 7, the analysis filter bank consists of two processes, namely the FFT process and the filter process. Filters in the analysis filter bank are used to combine signals based on their frequency. The type of filter used in the filter bank analysis must match the type of filter used in the filter bank synthesis process.

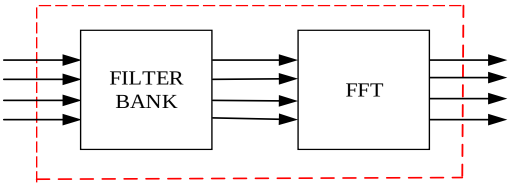


Fig. 7. Analysis Filter Bank

K. *Post-processing O-QAM*

The O-QAM post-processing block is the opposite of the O-QAM pre-processing block. Post-processing O-QAM as shown in Fig. 8, has two slightly different structures depending on sub-channel numbers as below [16].

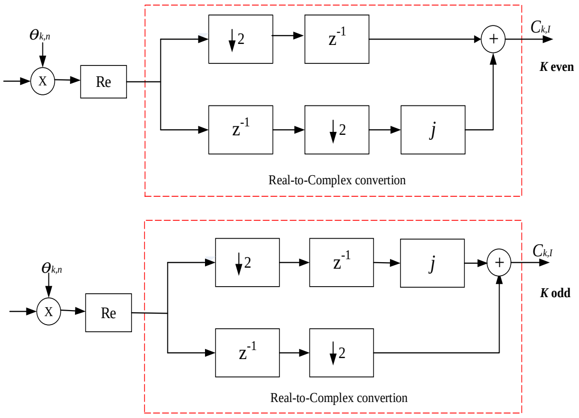


Fig. 8. Post-processing O-QAM

The first operation is the multiplication with the conjugate of *θk*, n the sequence followed by the operation taking the actual part. The second operation is real-to-complex conversion, where two consecutive real-valued symbols (with one multiplied by j) form complex-valued symbols (this operation is also called de-staggering). The real conversion to complex decreases the sample rate by a factor of 2. The first operation is converting the complex to real form. Where the real and imaginary parts of the symbol $C_{k,l}$ complex values are separated to form two new symbols $d_{k,2l}$ and $d_{k,2l+1}$. The order of these new symbols depends on the serial number of sub-channels. This change is different for even and odd-numbered sub-channels. The function of converting complex numbers into real numbers is used to increase the sample rate by two times. The second operation is multiplication with $\theta_{k,n}$.

L. *Output Data*

The output signal results can be analyzed by comparing the output bit with the input bit to get the value of the signal to noise ratio (SNR) to BER. The next process is converting the binary bit back to its original form, the audio signal.

III. RESULTS

In the FBMC O-QAM simulation, the analysis is done by comparing the performance of SNR, BER parameters, and channel capacity with the modulation level variations using ZF equalization at the receiver.

A. *Transmitted Data*

In this simulation, the input data is in the form of audio files, as shown in Fig. 9, with file format *.wav, which has a sampling frequency of 22050 Hz or around 5.6 seconds. The audio signal has a normalized amplitude between the values of -1 Volt to 1 Volt. The binary format of transmitted data shown in Fig. 10.

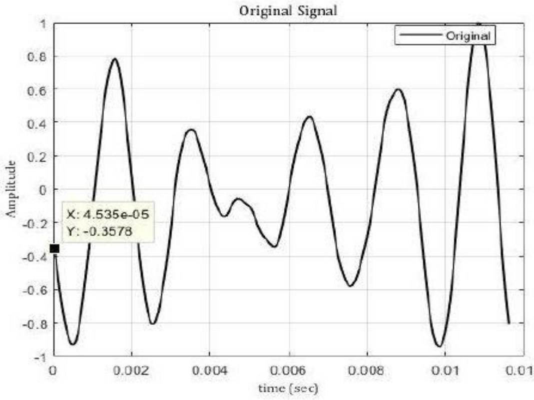
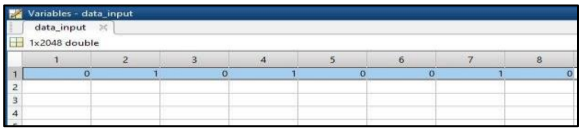


Fig. 9. Input Signal



1x2048 double

	1	2	3	4	5	6	7	8
1	0	1	0	1	0	0	1	0
2								
3								
4								

Fig. 10. Transmitted Data in Binary Form

B. Received Data

In the results of this simulation, signal measurements are carried out based on various SNR parameters, from 0 dB to 20 dB. It aims to determine the effect of SNR on the received signal results.

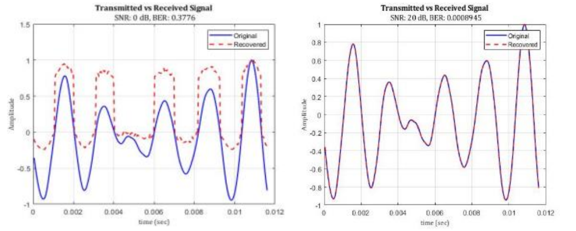


Fig. 11. Output Data for 4 QAM: (a) SNR=0 dB, (b) SNR=20 dB

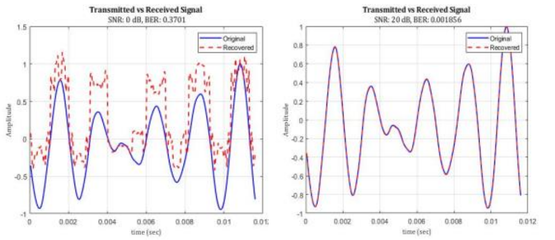


Fig. 12. Output Data for 16 QAM: (a) SNR=0 dB, (b) SNR=20 dB

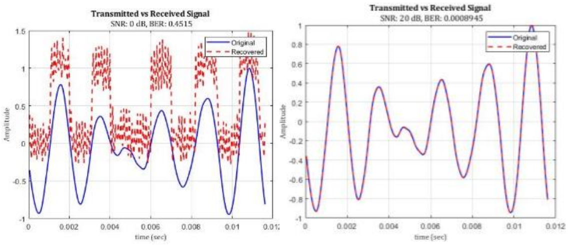


Fig. 13. Output Data for 64 QAM: (a) SNR=0 dB, (b) SNR=20 dB

C. BER Performance Using ZF

In this FBMC O-QAM system simulation, the data received at the receiver side is the result of multiplying the send signal to the channel and then adding noise, with the addition of a ZF equalizer. A comparison of BER performances from simulation results is shown in Fig. 14 to Fig. 16.

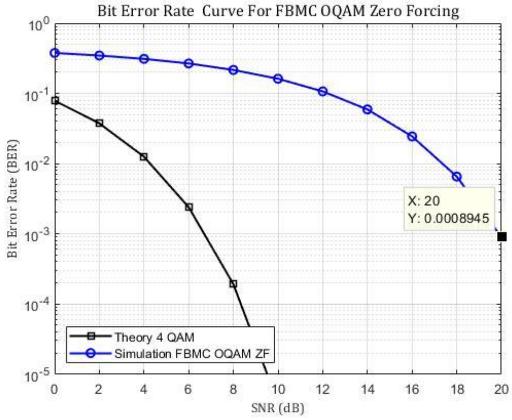


Fig. 14. BER Performance Using ZF for 4-QAM

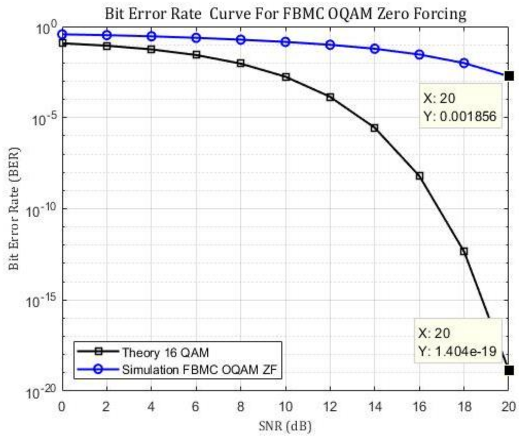


Fig. 15. BER Performance Using ZF for 16-QAM

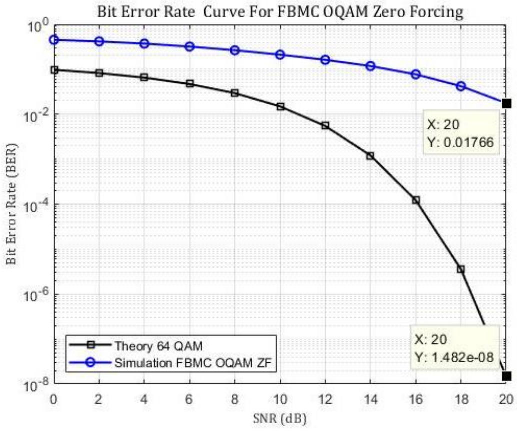


Fig. 16. BER Performance Using ZF for 64-QAM

D. Shannon's Channel Capacity of FBMC O-QAM

Comparison of channel capacity in the FBMC O-QAM system that uses ZF can be seen in Fig. 17 to Fig.19.

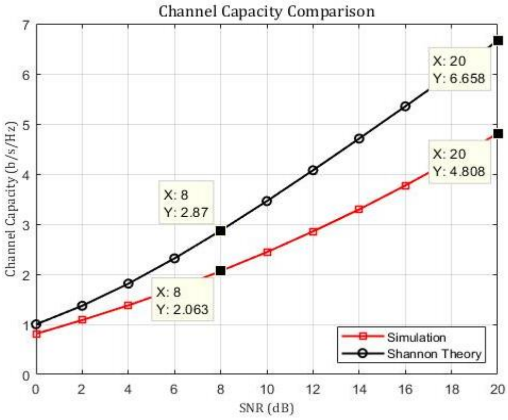


Fig. 17. Shannon's Channel Capacity for 4-QAM

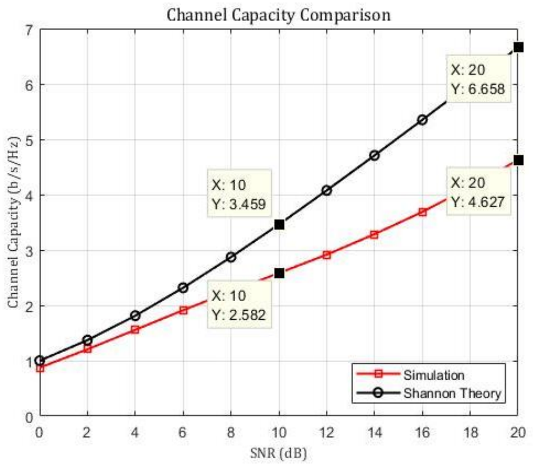


Fig. 18. Shannon's Channel Capacity for 16-QAM

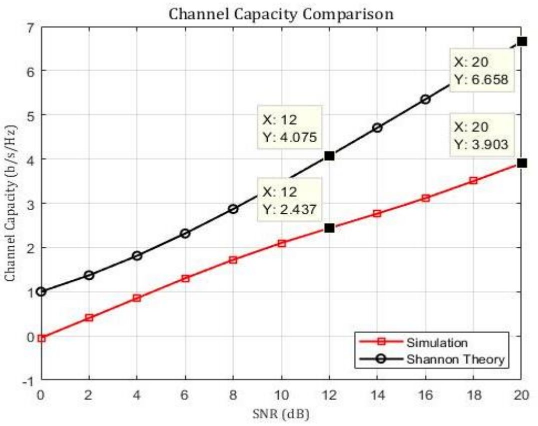


Fig. 19. Shannon's Channel Capacity for 64-QAM

IV. DISCUSSIONS

This paragraph discusses the analysis of simulation results obtained in chapter III. The analysis includes analysis of input data, output data, and FBMC O-QAM system performance based on BER parameters and Shannon's channel capacity.

A. *Transmitted Data*

The process of converting points into binary numbers needs to add an amplitude of 1, so it is positive. Thus the audio signal can be transmitted to the receiver. The following is an example of the process of converting these signals into decimal numbers,

A_t = (A+1) x 2n-1
A_t = (-0.3578+1) x 28-1
A_t = 0.6422 x 27
A_t = 0.6422 x 128
A_t = 82.2016
A_t = 82_{10}

where A_t is the amplitude. The result of converting the signal into decimal numbers is then converted to binary numbers. With this conversion process, binary 01010010_2 will be transmitted.

B. *Received Data*

In Fig. 11, 12, and 13 show output data with different SNR values. When the SNR value of 0 dB, the received signal is very different from the input data transmitted, while at the SNR value of 20 dB, it is similar to the data transmitted. This result happens because, at SNR 20 dB, the AWGN noise power is smaller than the transmitted signal power. In the FBMC O-QAM system simulation, the data received at the receiver side is the result of the multiplication of the signal transmitted by the channel then the noise is added.

C. *BER Performance using ZF*

At SNR 20 dB, for the 4-QAM, the BER value produced is 0.0008945, and for the 16-QAM modulation, the resulting BER value is 0.001856, while for the 64-QAM the BER value is 0.0166. Simulation results show that BER has decreased according to BER theory, but not significantly. The BER simulation results have also demonstrated that the performance of the FBMC O-QAM system using ZF has a fairly good decrease in BER values. The drop occurs because ZF returns the original signal that has been sent to the receiving antenna even though the signal has been added to the noise coming from the AWGN channel. So, in the FBMC O-QAM system, using ZF proves that increasing the SNR value can affect the resulting BER value. The higher the SNR value, the smaller the BER value.

D. *Shannon's Channel Capacity of FBMC O-QAM*

Fig. 17 shows that the channel capacity in the 4-QAM has a value of 2.063 b/s/Hz when the SNR is 8 dB and when the SNR value is 20 dB, the channel capacity value is 4.808 b/s/Hz. This shows that the channel capacity value has increased from SNR 8 dB to 20 dB of 2.745 b/s/Hz. This shows that the value SNR of channel capacity has increased along with the increase in SNR.

Based on Fig. 18 shows the simulation results of 16-QAM modulation when the SNR value of 10 dB has a channel capacity value of 2.582 b/s/Hz while on SNR value of 20 dB, the resulting channel capacity value is 4.627 b/s/Hz. This shows that the value of channel capacity has increased from SNR 8 dB to SNR 20 dB of 2.045 b/s/Hz.

Simulation results of 64-QAM modulation, as shown in Fig. 19, at the SNR 12 dB, it has a channel capacity value of 2.437 b/s/Hz while at the SNR 20 dB, the channel capacity value is 3.903 b/s/Hz. This shows that the value of channel capacity has increased along with the increase in SNR, as shown in the results from SNR 8 dB to SNR 20 dB there is an increase in channel capacity of 1.466 b/s/Hz.

Based on the all simulation results of the Shannon channel capacity show that channel efficiency for 4-QAM modulation is the best result because this system has the reliability of the BER value.

V. CONCLUSSION

The simulation results show that the modulation levels variations of 4-QAM, 16-QAM, and 64-QAM affect the performance of the FBMC O-QAM system. The performance of the FBMC O-QAM system using ZF equalization in the parameter BER and channel capacity shows that the 4-QAM modulation has the best BER performance. In general, the greater the SNR value used, the smaller the BER value generated. The value of channel capacity generated based on simulations using Zero Forcing shows an increase in value along with an increase in SNR. Still, it has a smaller value compared to channel capacity in theory.

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