ASEAN Engineering Journal

Full Paper

REDUCTION OF PAPR USING ASYMMETRIC NUMERAL SYSTEM QC-LDPC WITH HUFFMAN AND ARITHMETIC CODING FOR F-OFDMA SYSTEM

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Article history
Received
11 November 2021
Received in revised form
25 February 2022
Accepted
22 June 2022
Published online
30 November 2022

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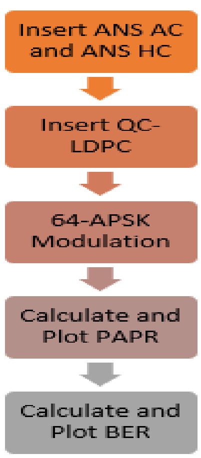
Graphical abstract



Abstract

As modern wireless communication systems move towards 5G implementation, the system must provide sophisticated and ubiquitous service and flexibility. Therefore, Filtered Orthogonal Frequency Division Multiple Access (F-OFDMA) is one of the most suitable modulation techniques used in 5G systems to achieve efficient and reliable wireless communication. Other than that, F-OFDMA also has good quality rather than OFDM since it provides a better result of high side lobes and enlarges the scale of the spectrum analyzer. However, one of the significant problems in the F-OFDMA system is the high peak-to-average power ratio (PAPR), affecting the system's overall performance and causing high transmit power at the transmitter. In this paper, combination of Arithmetic Coding (AC) and Huffman coding (HC) with Asymmetric Numeral Systems (ANS) provide better performance for PAPR as well as bit error rate (BER) in F-OFDMA. Both AC and HC are proposed to combine with ANS and Quasi-Cyclic Low-Density Parity Check (QC-LDPC) since it provides a good result to defeat the high PAPR. BER and PAPR performance were compared for the AC and HC with ANS QC-LDPC. Based on the results, ANS-AC-QCLDPC proved as the best joint method has 35.25% improvement for PAPR while BER has 89.87%. This research also justified that ANS with Arithmetic-QCLDPC and Huffman-QCLDPC give better BER results as well.

Keywords: Arithmetic Coding (AC), Asymmetric Numeral Systems (ANS), Filtered-Orthogonal Frequency Division Multiple Access (F-OFDMA), Huffman Coding (HC), Quasi-Cyclic Low-Density Parity Check (QC-LDPC)

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1.0 INTRODUCTION

Wireless communication has evolved into one of the most significant mediums in modern life. Moving towards 5G, especially during the pandemic, uninterrupted internet connection is essential for people. Many relevant research works has been conducted to make sure new 5G waveform can be implemented in sufficient way. The demands for low latency, low complexity, and low power consumption with exceptional higher data rates are increase rapidly. Unfortunately, like the previous generation, 5G also cannot avoid connection loss, unstable data connection, and high system complexity [1] .

Researchers studied various multicarrier modulation to overcome problem in wireless communication. Orthogonal Frequency Division Multiple Access (OFDMA) is one of the multicarrier modulation techniques that can boost data transmission. As a result of its effectiveness in minimizing interference, OFDMA is widely used in wireless communication [2]. This research advances OFDMA to F-OFDMA by drawing inspiration from the Filtered Orthogonal Frequency Division Multiplexing (F-OFDM) proposed for 5G networks earlier. F-OFDMA has high reliability to overcome multipath propagation and also higher spectral efficiency. However, high value of PAPR still affect performance of the system.

As the volume of data increases, so does the need for greater compression. Asymmetric Numeral Systems (ANS) as mention by [3] designed to function at speeds comparable to Huffman coding (HC), with compression equivalent to Arithmetic coding (AC). This research will introduce an alternative to minimize the problem of PAPR in F-OFDMA by applying the joint method. This system utilizes HC and AC scheme with QC-LDPC as an error-correcting technique. The ANS are added to the block coding techniques in both HC and AC. This proposed method is expected to reduce the value of PAPR in the F-OFDMA system as well as diminish BER for the 5G wireless system. It distinguishes itself from prior works [4][5][6][7] because so far there is no exact literature for joint method of QC-LDPC with ANS-AC and ANS-HC for F-OFDMA.

The scope of this study is organized as follows: In section 2.0, the F-OFDMA system model, ANS, AC, HC, and QC-LDPC were introduced. The process of developing the proposed technique was explained in further detail. Section 3.0 presents and discusses the results obtained from Matlab simulations. Finally, section 4.0 gives the conclusion for this research, and recommendations for future work.

2.0 METHODOLOGY

2.1 F-OFDMA

F-OFDMA is a multiple access extension of F-OFDM. This technique's aim is to allow access of a multi-user system [2]. It cannot be denied that all multicarrier modulation suffers significant negative impact due to high PAPR. However, lower PAPR is the 5th generation's basic waveform design standard, hence PAPR need to be minimized. Figure 1 above shows block diagram of F-OFDMA system. Technically, wireless system divided into three parts which are transmitter, channel and receiver [9]. Firstly, the orthogonality is achieved using FFT. OFDMA is modulated in same bandwidth with N-subchannel. Transmitted signal is obtained through convolution of transmitted data with filter sequence. Filter sequence is process for ideal filter with window function.

Authors in [10] analyze performance of cyclic prefix OFDM (CP-OFDM) and F-OFDM. Although CP is well known method to reduce intersymbol interference, however F-OFDM proved its flexible form with lower PAPR, making it perfect for 5G wireless applications. Performance of OFDMA has been studied by authors in [11] by minimizing value of PAPR and BER using signal recovery algorithm. Comprehensive study regarding multiple access and multi carrier from 1G until 5G has been addressed by authors in [12]. Multiple access and multi-carrier waveforms have the ability to improve the quality of services provided to meet customer demands. Authors also mentioned that joint design has potential to be enhanced for next generation. In this research, F-OFDMA with joint methods has been proposed to satisfy the 5G prerequisites.

2.2 Asymmetric Numeral System

HC and AC are well-known entropy coding methods. Although the previous one is much quicker, typically leads to low compression rates. While AC utilizes practically identical probabilities that almost reach Shannon entropy but AC comes with a higher computational cost. ANS is a method to ensure precise entropy coding that eliminates the compromise between speed and rate. Jarek Duda in [13] introduced a combination of Shannon entropy effectiveness with HC efficiency. A minimal number of states to achieve optimum performance is needed for hardware coders to satisfy simple high throughput. Large alphabets can be grouped into a few symbols with the benefit of speed and simplicity but with the cost of memory due to its proportionality. Later on, the author takes advantage of HC speed and compression rate of AC by combining these two methods for ANS [14]. The authors in [15] proposed a novel approach for parity-check matrix structure. The research proved it can minimize encoding complexity, error rates and outperforms existing IEEE 802.16e code. However, it's only limited to additive white Gaussian noise (AWGN) environment, and it reached until 100 block error.

Encoding utilize a symbol and number of states into new form while decoding occurs when each state is assigned with a particular symbol and number of digits to be processed:

$$\text{Coding} : C(x, s) \rightarrow x\,0$$
$$\text{Decoding} : D(x\,0\,) \rightarrow (x, s)$$

2.3 Arithmetic Coding

Data compression can be classified into two types; lossy and lossless. AC is well known lossless algorithm and utilize compression with the lower number of bits. AC allocates a stream of bits in the form of symbols to a message, which is then transformed into a list or message as a single unit. AC does not implement a discrete number of bits, unlike the HC scheme. Because each symbol in the signal varies according to the probability, the number of bits was used to encode the signals in AC. [16]. The probability is assigned for every symbol to divide them into low and high probability. Many bits will be used for the low probability whereas fewer bits will be used for the high probability. Since the length of the arithmetic coding depends on the statistical frequency, therefore it has the capability of probability equalization to produce lower PAPR values compared to other block coding techniques [17].

The coding range is originally set to 0 as the low end and 1 as the high end during the compression process [18]. AC has a unique technique when assigning codewords to a particular sequence. It means for a length of *m*, AC can be generated directly without the need to generate codewords for all sequences of length *m*. In AC, before encoding the sequence, a unique identifier firstly is generated. For example, all possible inputs will be allocated with cumulative probability intervals (A_y, A_{y+1}) with *y* as a symbol. With probability $B_y = B_{y+1} - A_y$, for each process of encoding, the range will be minimized according to a part assigned for the input symbol. The coding range for new low and high ends can be summarized based on the equations stated below:

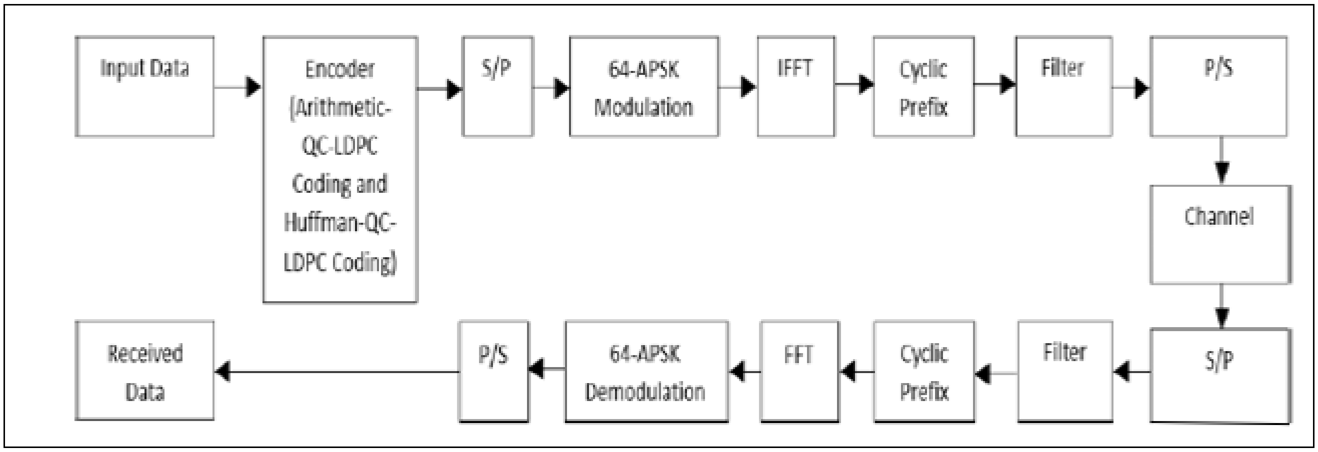

Figure 1 Block diagram of F-OFDMA transceiver system [8]

$$high_{new} = low_{original} + range_{original} \times A_{y+1} \quad (1)$$

$$low_{new} = low_{original} + range_{original} \times A_{y} \quad (2)$$

$$range_{original} = high_{original} - low_{original} \quad (3)$$

$$range_{new} = range_{original} \times B_{y} \quad (4)$$

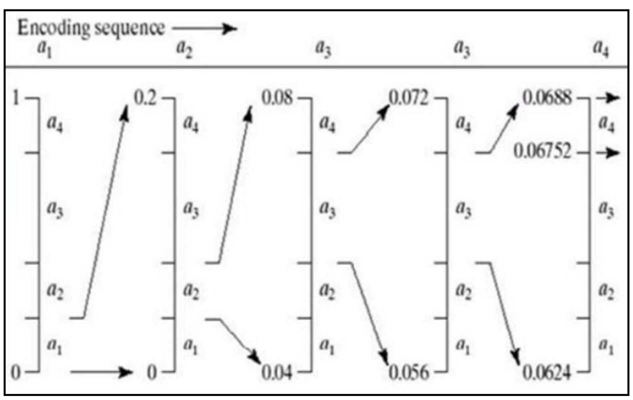

Figure 2 An Example of Arithmetic Encoding Process [18]

Table 1 Probability and Range Distribution of Symbols [19]

Source Symbol	Probability	Initial Subinterval
a_1	0.2	[0.0,0.2)
a_2	0.2	[0.2,0.4)
a_3	0.4	[0.4,0.8)
a_4	0.2	[0.8,1.0)

An example of the AC encoding process is depicted in Figure 2 while Table 1 represents the probability and ranges distribution of symbols. The key idea of AC is assigning each of the symbols into an interval starting from zero to one and each interval will be divided into several sub-intervals with its sizes are proportional to the current probability of the corresponding symbols [19]. The coded symbol's sub-interval will therefore be used as the interval for the next symbol, and the outcome will be the interval of the last symbol. Since the length of AC depends on the statistical frequency, AC is said to have a probability equalization capability that can further reduce the high PAPR compared to HC. Hence, it is expected that AC can outperform HC by providing a much lower PAPR value.

2.4 Huffman Coding

The Huffman code is an iterative algorithm constructed over the associated Huffman tree, in which the two nodes with the lowest weights are combined to form a new node with a weight that is the sum of the weights of its two pairs. Each left-going edge represents a 0, each right-going edge a 1 as shown in Figure 3 below. Authors in [20] proposed enhancement Huffman code for OFDM using index modulation to strengthen accuracy of data transmission. The efficiency of the techniques was determined, and it was discovered that the Huffman tree's depth has a substantial impact on error performance, resulting in more secure data transmission. However, high complexity cannot be avoided and can lead to high value of PAPR. Adaptive Huffman codes implemented by authors in [21] to reduce PAPR in OFDM system. The PAPR reduction of adaptive Huffman codes outperforms the classical Huffman codes according to simulation outcomes. Although adaptive Huffman codes proved its effectiveness but authors only applied small number of modulation mapping schemes during simulation process.

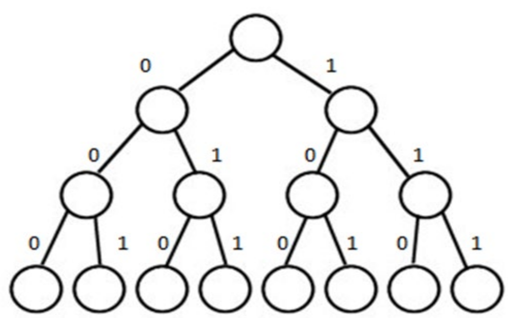

Figure 3 Huffman Tree

2.5 QC-LDPC

QC-LDPC has low complexity in encoding. Moreover, due to. their simple encoding, this technique is a viable contender to random codes in practical applications

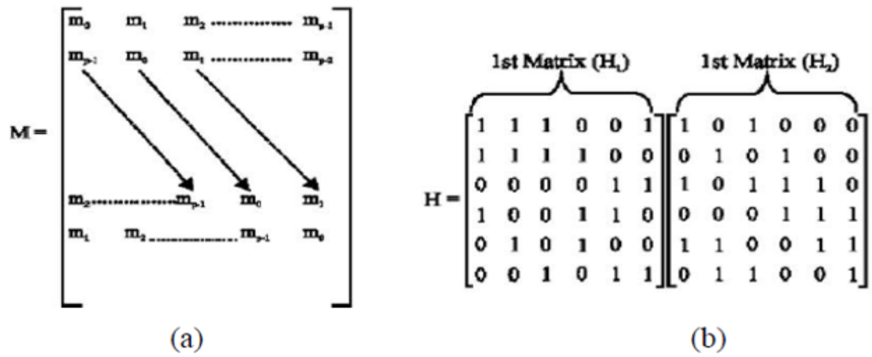

Figure 4 (a) General Circulant Matrix Structure (b) Parity Check Matrix Subdivided Two Matrixes

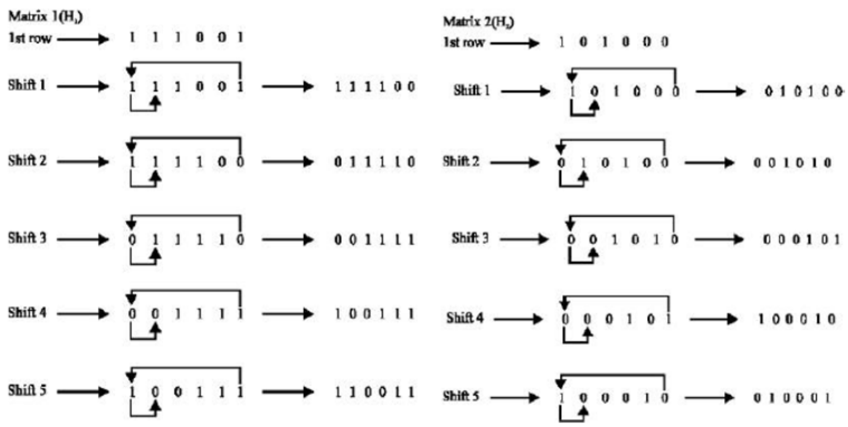

Figure 5 Example of Circulant Shift Operation [15]

In order to acquire a further decrement in the PAPR and BER values, a joint method among AC and HC with an error-correcting code known as Quasi-Cyclic Low-Density Parity Check (QC-LDPC) was introduced in this research. QC-LDPC has the potential to minimize PAPR in an F-OFDMA system and can be used to enhance the system's error-correcting effectiveness. The complexity and speed of encoding can be compromised due to the QC-LDPC structure code [17]. Furthermore, the QC-LDPC code has a linear time encoding capability, which reduces the code's memory requirement significantly, providing a solution to the system's memory problem [17].

The QC-LDPC code is made by applying circulant matrixes based on the parity check matrix, *H* of a Low-Density Parity Check (LDPC) code [17], [22] where *M* is the general circulant matrix structure shown in Figure 4a. The *H* matrix is subdivided into two matrixes *H1* and *H2* which have an equal length of row and column as shown in Figure 4b and each row of the matrixes are shifted to the right in a cyclic manner of the previous one. An example of the shifting process can be seen in Figure 5 for the matrix *H1* and *H2*

Figure 6a represents the obtained weight of the matrix after the shifting operation is done. The weight of the column and row is constant during the shifting process, and the codeword encoded by the generator matrix must abide by the property of $CH^T = 0$, where *C* is a codeword. The parity check matrix will be used to obtain the block structure of QC-LDPC, as shown in Figure 6b.

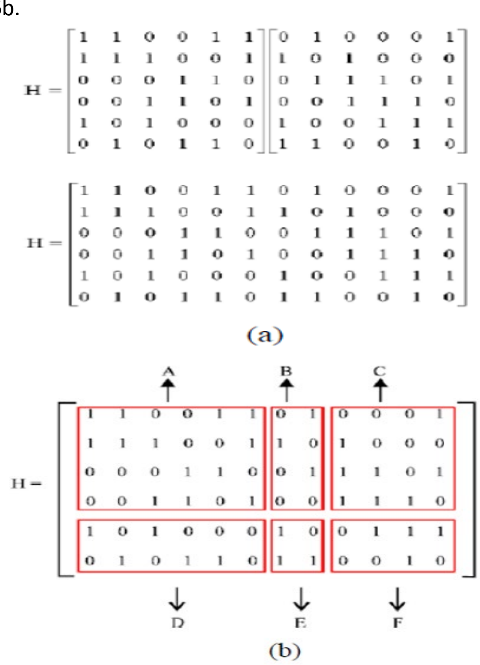

Figure 6 (a) Parity Check Matrix after Circulant Shift (b) Obtained QC-LDPC Block Structure

2.6 Peak to Average Power Ratio (PAPR)

The performance of PAPR was measured at the transmitter of the F-OFDMA system. Since the system has a different value of frequencies, phases, and amplitudes, the output of PAPR in a time-domain signal might be higher than the average of the overall system [17] [23]. Signal clipping and out of band radiation would occur when a high-power amplifier needs to operate in a non-linear region. Therefore, the purpose of this research is to lessen the value of PAPR in the F-OFDMA system by using block coding techniques (Arithmetic and Huffman) and error-correcting codes (QC-LDPC). The average power for the whole system can be calculated as follows [17]:

$$Average\ Power = \frac{Sum\ of\ magnitude\ of\ all\ symbols}{Number\ of\ symbols} \quad (5)$$

Where PAPR can be mathematically derived as below where x(t) is the continuous-time signal [24];

$$PAPR = \frac{max|x(t)|^2}{E[|x(t)^2|]} \quad (6)$$

$$max|x(t)|^2 = peak\ signal\ power$$

$$E[|x(t)^2|] = average\ signal\ power$$

The PAPR can be presented in a Complementary Cumulative Distribution Function (CCDF) plot where the plot is used to analyze the PAPR reduction of the system against the threshold value. The CCDF can be calculated based on the equation below where X is the threshold value [17]:

$$P(PAPR > X) = 1 - P(PAPR < X) \quad (7)$$

The threshold value can be calculated using the equation given below [17];

$$Threshold = \frac{0{:}\,(maximum\ PAPR - minimum\ PAPR)}{maximum\ PAPR : minimum\ PAPR} \quad (8)$$

2.7 Simulation Development

All simulations in this research were carried out using MATLAB software, which is appropriate to analyze the PAPR and BER performance of the F-OFDMA system.

Table 2 System Parameter [25]

Parameter	Specification
Channel model	Rayleigh
Bandwidth	10MHz
Modulation scheme	64 APSK
FFT size	4096
Cyclic prefix modes	(1/4)*4096
Filter Order	256

The system parameter applied for this research is based on Table 2. Rayleigh Fading channel is used in this research since it takes into account the effect of propagation environment through the wireless communication medium [26]. The bandwidth used for multiple access systems can be up to a maximum of 20 MHz [19], where the larger the bandwidth, the higher the system's capacity. However, in this study, the bandwidth size chosen for the F-OFDMA system is 10MHz based on [25]. The entire bandwidth is divided into sub-channels, and data symbols are sent in a parallel form. Moreover, a 64-APSK modulation scheme was chosen over the QAM modulation scheme as it can carry more data as well as able to reduce the PAPR value of the system.

This research used 4096 number of FFT size and applied cyclic prefix at the transmitter. The number of cyclic prefix is ¼ FFT size and removed at the receiver. For all coding technique simulations, AC and HC, were used to compare which block coding method can give better PAPR reduction and BER performance to the system. To further reduce the PAPR values and improve the BER, QC-LDPC codes were implemented to the system.

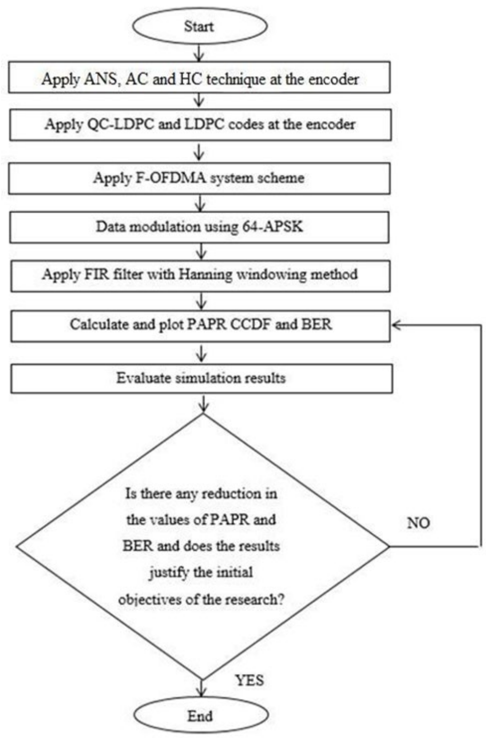

Figure 7 Simulation Process

Figure 7 depicts the flowchart of the simulation development process throughout the implementation of the study. All results obtained from simulations were compared with the theoretical approach for justification.

The initial step in developing the simulation for this study is by setting the F-OFDMA system's parameters based on Table 2. Then, the encoder of the system implements AC and HC and continues with QC-LDPC. The encoding process for the system uses a random data input with the same number of F-OFDMA symbols. Next, the F-OFDMA system is modeled based on the system's block diagram shown in Figure 1. The signal then undergoes modulation process where 64-APSK modulation technique was chosen since it is robust against nonlinear channels and at the same time reduces the PAPR. The filter used for this study is Finite Impulse Response (FIR) filter to give fast, convenient, and robust suboptimal while minimizes the side lobes of F-OFDMA signal with good frequency resolution maintenance and hence further improve the PAPR performance [18]. Finally, the PAPR and BER were plotted to evaluate the system's performance.

3.0 RESULTS AND DISCUSSION

This section presents the results and discussions of the PAPR and BER performances obtained from simulations using MATLAB software. The CCDF plot illustrates the PAPR performance of the system whereas the Signal to Noise Ratio (SNR) plot depicts the BER performance of the system.

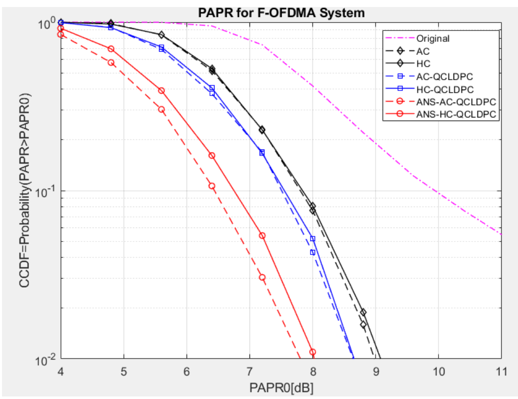

Figure 8 PAPR for F-OFDMA System

Figure 8 illustrates the CCDF plot for the F-OFDMA system without coding technique and with the joint technique of block coding and error-correcting codes. The values of PAPR are read at 10^{-1} and can be seen in Table 3. The purpose of obtaining this result is to compare the PAPR reduction improvements between uncoded and coded scenarios. By analyzing the PAPR values in Table 3, it is clear that when the threshold value is set to the PAPR value of the original F-OFDMA without any coding method used, the PAPR for the F-OFDMA system using ANS-AC-QC-LDPC gives an improvement of 35.25 %. Theoretically ANS is less complicated than AC. In ANS, the state is composed of a single natural integer instead of applying two to describe a range. Development of ANS include adding information at the least relevant location. Different with AC which also known as range coding, is the method of assigning new data in the most important spot. The PAPR reduction is improved by 24.07% when QC-LDPC is used. QC-LDPC is a Low-Density Parity Check (LDPC) improvement that introduces circulant shifts into the design to minimize memory complexity. F-OFDMA has huge enhancement when HC and AC applied to the system. Without error-correcting codes, the system still acquired an improvement of 21.45% and 21.14% respectively.

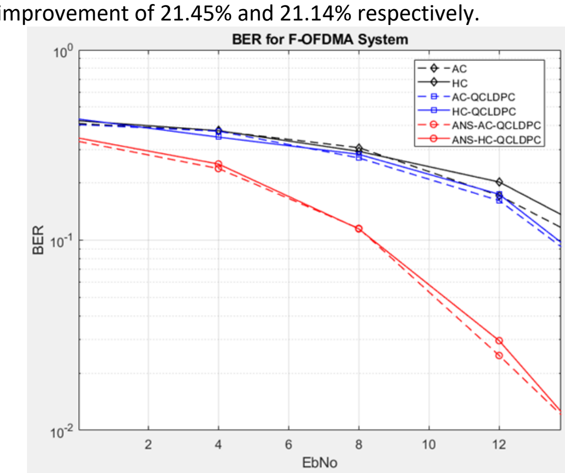

Figure 9 BER for F-OFDMA System

Figure 9 illustrate values of BER for F-OFDMA system. The values were interpreted at EbNo 13dB and tabulated in Table 4. The guideline was set to the BER value of F-OFDMA using the HC technique for comparisons. Although HC has good performance in data compression, however the probability density fluctuates due to the HC. According to the BER value obtained above, it indicates that the BER performance for F-OFDMA with ANS-AC-QCLDPC gives huge improvement of 89.87% whereas ANS-HC-QCLDPC improves the BER value by 87.92%. Same with outcome of PAPR, BER of the system significantly improves when ANS is added to the system. This is due to ANS characteristic that had a significant impact on data compression since they offered the almost same compression rates as AC and sometimes executed faster than HC depending on the scenarios. Low OOB can be reflected by lower BER readings. By selecting the appropriate shaping filters, F-OFDMA can be utilized to reduce OOB emission. Aside from filter design, guard interval also must be considered during simulation. Adding QC-LDPC to the system shows improvement of 27.82% and 24.22% respectively. This is because QC-LDPC can reduce system complexity. The process needs to apply simple shift register to encode QC code. It is well known that QC-LDPC codes offer a higher practical value since the codes lessen hardware needs. Since QC-LDPC error-correcting codes achieved excellent PAPR reduction for F-OFDMA systems, it also contributes to the system's low BER performance. Adding QC-LDPC shows a reduction in BER while ANS proved that it can give the best performance than AC and HC. Hence, the cascaded method of ANS with QC-LDPC is one of the best ways to enhance system performance.

Table 3 Percentage Improvement of PAPR for F-OFDMA System

	Original	HC	AC	HC-QCLDPC	AC- QCLDPC	ANS-HC- QCLDPC	ANS-AC-QCLDPC
PAPR(dB)	9.93	7.83	7.80	7.54	7.50	6.74	6.43
Improvement	-	21.14	21.45	24.07	24.47	32.12	35.25

Table 4 Percentage Improvement of BER for F-OFDMA System

	HC	AC	HC-QCLDPC	AC- QCLDPC	ANS-HC QCLDPC	ANS-AC QCLDPC
BER (10^{-3})	163.5	138	123.9	118	19.75	16.56
Improvement	-	15.60	24.22	27.82	87.92	89.87

4.0 CONCLUSION

In conclusion, the joint technique proved that it can reduce the value of PAPR and BER for the wireless communication system. The improvement might not huge for certain values, but it gives better performance. The two-block coding techniques were combined with the Asymmetric Numerical System and error-correcting code QC-LDPC. The block coding chosen is Huffman and Arithmetic to reduce the high PAPR in F-OFDMA. PAPR and BER value of Arithmetic and Huffman and combination with ANS and QCLDPC were analyzed, evaluate, and compared. The simulation result shows ANS-AC-QCLDPC method shows the better result in PAPR which is decreased by 35.25% while value of BER show 89.87% improvement. For future work, the block coding techniques can combine with other error correcting codes to enhance the better performance of PAPR and BER in F-OFDMA. Other than that, the F-OFDMA system can apply a multiple-input and multiple-output (MIMO) antennas with diversity technique to increase the reliability of wireless communication system.

Acknowledgement

This work was supported by Ministry of Higher Education FRGS/1/2018/TK04/UITM/02/29 with Fundamental Research Grants Scheme 600-IRMI/FRGS 5/3 (016/2019).

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