Multi-Mode OFDM Communication System Using the Multiple Constellations

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***Abstract* - We like to propose a multi-mode OFDM (orthogonal frequency division multiplexing) system of the multiple constellations that has a new mapping scheme to improve the OFDM system efficiency. As an example, the multi-mode OFDM system can use different modes of multiple constellations that have different shapes and are not overlapped. Furthermore, by using the additional index bits, modulation types and each mode is identified to determine by the combination method which mode symbol is to be mapped to each subcarrier. In the receiver, the log likelihood ratio (LLR) algorithm can be used to find and demodulate the arrangement of subcarriers. For the performance comparison with the conventional OFDM system, we investigate the bit error rate (BER) performance and peak-to-average power ratio(PAPR) performance using the same constellation form as the overall constellation form of the multi-mode OFDM system using the non-overlapping four-mode constellation diagram. In the high signal-to-noise ratio (SNR) region, the proposed multi-mode OFDM system shows some BER performance improvement than the conventional OFDM system. In addition, the multi-mode OFDM system has more flexible because it forms the overall constellation by combining several types of non-overlapping constellation diagrams, which makes it possible to use a constellation shape suitable for the environment**.

***Keywords* : *OFDM, Multi-mode OFDM, Constellation, Combinadics, LLR, BER*.**

I. INTRODUCTION

Currently, the OFDM system used in 4G LTE (Long Term Evolution) is a high-speed transmission using multi-carrier [1] [2]. There are various factors in order to enable high-speed communication in accordance with an increasing trend of data information amount desired by users. In order to design a system with lower communication error rate when using the same power in terms of power efficiency, we propose a Multi-mode OFDM system that improves the existing OFDM system.

In general, multiple input multiple output(MIMO), which is a technique to increase the communication capacity by using multiple transmit and receive antennas, is a widely used technology. In MIMO systems, multiple transmit and receive antennas can increase system performance in proportion to the number of antennas [2]. Therefore, when a plurality of transmitting and receiving antennas communicate, problems such as inter-channel interference and antenna synchronization interference occur. To reduce the interference, spatial modulation(SM) is used. The SM scheme refers to an antenna that is activated among the antennas transmitted by information bits, and the multiple transmit antennas used in the scheme change and transmit a transmission signal [3]. The receiver uses the algorithm to find the active transmit antenna and finds the information bits through the information of the found transmit antenna. The orthogonal frequency division multiplexing-index modulation (OFDM-IM) system is used for subcarrier mapping in OFDM systems [4] [5]. A sequence of information bits is divided by the index bits used for indexing and the data bits used to form the symbol, and the symbol is mapped to each activated subcarrier according to the index bits. Thereafter, a transmission signal is generated through an IFFT operation in the same manner as a general OFDM system. The signal passed through the channel finds the active subcarrier in the receiver. It also demodulates the index bits and data bits at the receiver by demodulating the symbols mapped to the subcarriers and finding the active subcarriers. In the OFDM-IM system, a subcarrier that is activated using an on-off keying (OOK) scheme and a subcarrier that is deactivated by a power of 0 are divided. In an OFDM-IM system using an index bit without using the OOK scheme This dual mode OFDM system maps symbols to all subcarriers unlike normal OFDM-IM, and uses two types of non-overlapping constellations. The index bit indicates whether the symbol mapped to each subcarrier is a symbol using the first mode constellation or a symbol using the second mode constellation [6].

The proposed multi-mode OFDM system is an improved version of the dual mode OFDM system and transmits more information bits than the existing OFDM-IM and dual mode OFDM systems by increasing the number of information bits based on the multiple constellations. The information bits other than the bits used for modulation and demodulation are increased, thereby improving the overall BER performance of the system.

II. SYSTEM MODEL

A. Dual mode OFDM system model

At first, the dual mode OFDM system maps information symbols into all subcarriers, which is different from the ordinary OFDM-IM system. The index bits for selecting the subcarriers like OOK (on-off keying) scheme in OFDM-IM are used for indexing two types of constellations in the dual mode OFDM systems. Here, the constellation diagrams of the two modes should not overlap each other and should be distinguishable at the receiver. Figure 1 shows the structure of the dual mode OFDM transmitter. A series of bits is divided into an index bit to designate a mode and a bit to constitute a symbol. Thereafter, each frame is composed of sub-carriers mapped using the first mode and sub-carriers mapped using the second mode according to index bits [6]. In the conventional OFDM and dual mode OFDM, symbols are mapped to all sub-carriers. However, the dual mode OFDM system increases the amount of information transmitted by sending more index bits in addition to symbols. In the conventional OFDM and dual mode OFDM, symbols are mapped to all sub-carriers. However, the dual mode OFDM system increases the amount of information transmitted by sending more index bits in addition to symbols.

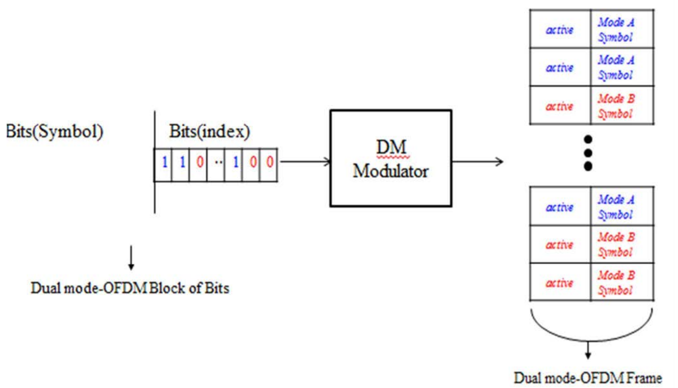


Fig. 1. Transmitter of dual mode OFDM.

B. Multi-mode OFDM system model

Multi-mode OFDM is an extended system of dual mode OFDM. In Dual mode OFDM, which forms symbols using two modes, the system is extended with Multi-mode OFDM using various modes, thereby increasing the number of index bits and increasing the amount of information sent. So, it can improve the efficiency. In this paper, we map subcarriers using four modes of constellation diagrams. The following is the transmitter configuration of the Multi-mode OFDM system.

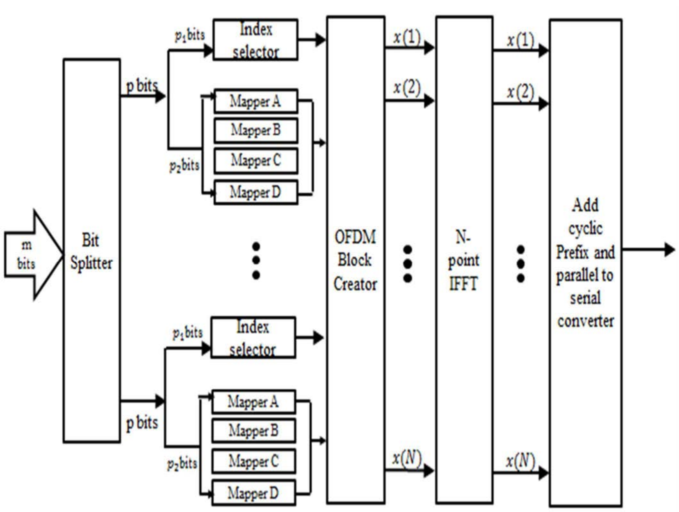


Fig. 2. Transmitter of Multi-mode OFDM.

A series of bits m is divided into groups with a number of bits per group.

$$p = m / g \tag{1}$$

The p bits are again divided into bits used for subcarrier allocation and bits forming a symbol.

$$\mathrm{p} = p_1 + p_2 \tag{2}$$

At this time, the length l of a group is determined by the FFT magnitude.

$$\mathrm{l} = \mathrm{N/g} \tag{3}$$

Therefore, symbols are formed using four different constellation diagrams, and symbols are mapped on each subcarrier according to the index bits to form one frame of the OFDM system [4] [5] [7]

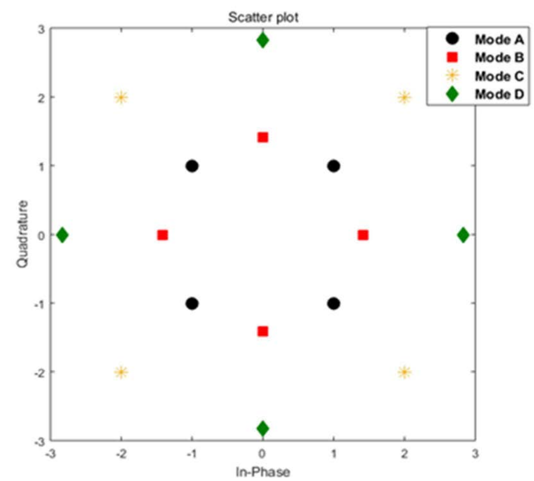


Fig. 3. Four different mode constellations.

Figure 3 shows the constellation diagrams of the four modes. One mode is the same as the QPSK scheme for composing symbols using 2 bits. For multi-mode OFDM systems, we use two types of QPSK and pi / 4QPSK constellation sizes in terms of power efficiency. Each of these constellation modes do not overlap and eventually form a 16 APSK constellation. In the transmitter, each bit is divided to form these symbols using different mappers according to each mode.

The figure 4 illustrates one frame of a Multi-mode OFDM system. The symbols formed by each different mode are mapped to different subcarriers by a series of index bits. In order to construct such a frame, a sub-carrier is arranged using a combination scheme with index bits. The combining method is a one-to-one mapping method using the number of subcarriers used for mapping among the number of subcarriers. In this scheme, subcarriers are selected using a combination of decimal numbers and input values.

S={c_k,⋯,c_1} (4)

$c\_k>\cdots>c\_1\geq 0$ in equation (4). This means that all the numbers Z of $Z\in[0,C(n,k)-1]$ can be represented by a sequence of k lengths.

$$Z=C(c\_k,k)+\cdots+C(c\_2,2)+C(c\_1,1) \qquad (5)$$

Equation (5) explains Z using this sequence S. For example, if Z=50 when n=8 and k=4using equation (5), then 50=C(7,4)+C(5,3)+C(3,2)+C(2,1)and the subcarrier sequence S becomes (7,5,3,2) at this time. Therefore, S refers to the subcarrier to which the symbol is mapped [5]. In this system, to use many index bits, the symbols of the mode are mapped using the case of selecting the arrangement of the subcarriers of half of the total subcarriers when the number of combinations is the greatest.

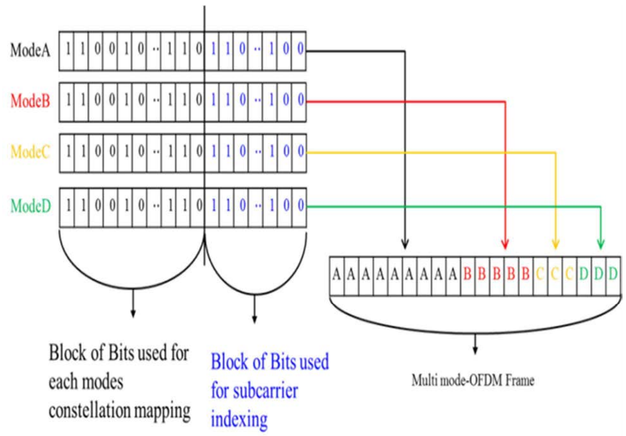


Fig. 4. Frame of Multi-mode OFDM.

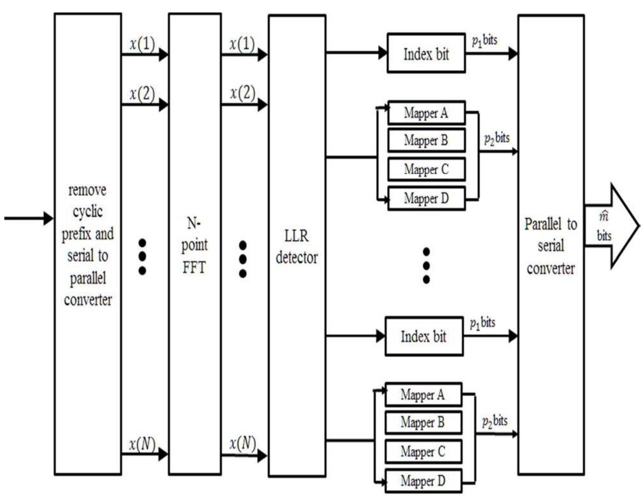


Fig. 5. Receiver of Multi-mode OFDM system.

Figure 5 shows the receiver of a Multi-mode OFDM system. However, since the mode used for symbol mapping is different for each subcarrier using the index bits in the transmitter, and the index bits must be found through the mode, the receiver uses the LLR algorithm. Since the symbols mapped to each subcarrier are modulated using different modes of the constellation maps, the logarithm of the posterior probability ratio is calculated through the LLR algorithm operation to find the constellation used in the subcarrier mapping. In addition, the LLR algorithm has the advantage of reducing the computational complexity in the receiver.

$$\gamma_n = \hbar \left(\frac{\sum_{j=1}^{A}\Pr(X_n=A(j)|Y_n)}{\sum_{q=1}^{B}\Pr(X_n=B(q)|Y_n)}\right) \qquad (6)$$

$$\gamma_n = \ln\left(\frac{N_B k}{N_A(l-k)}\right)+\ln\left(\sum_{j=1}^{N_A}\exp\left(-\frac{1}{N_0}\left|Y_n-H_nA(j)\right|^2\right)\right) - \ln\left(\sum_{q=1}^{N_B}exp\left(-\frac{1}{N_0}\left|Y_n-H_nB(q)\right|^2\right)\right) \qquad (7)$$

Equations (6) and (7) are LLR algorithms for calculating the symbol mapped using some constellation diagrams using two constellation values. Equation (6) A and B denote the mapper using different constellation diagrams, and Y_n denotes the received data. In Equation (7), N_A and N_B denote the number of symbols forming the constellation diagram, and N_0 and H_n denote noise power and frequency domain channel transfer function coefficients (FDCTFCs), respectively [6] [8].

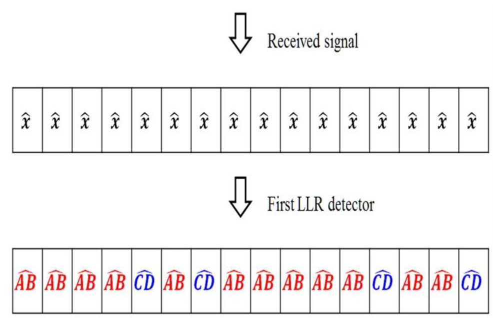


Fig. 6. 1st LLR algorithm in the receiver.

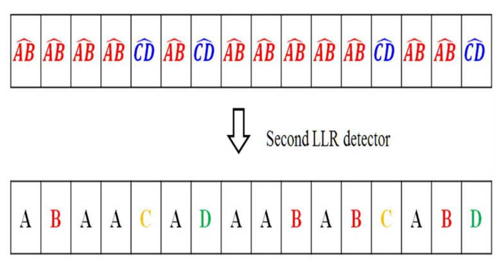


Fig. 7. 2nd LLR algorithm in the receiver.

Figure 6 shows the receiver using the first LLR algorithm. Through the LLR algorithm, the mapped values distinguish between A, B mode and C, D modes. Then, A, B, C, and D modes are found by using the LLR algorithm once again for the values divided into the A and B modes and the values separated by the C and D modes as shown in Figure 7. The demodulation is performed for each of the demultiplexed modes, and the index bits are extracted through the arrangement of the sub-carriers to which the respective modes are mapped on a frame-by-frame basis. Thus, although the index bits are not actually transmitted, the index bits are demodulated together at the receiver.

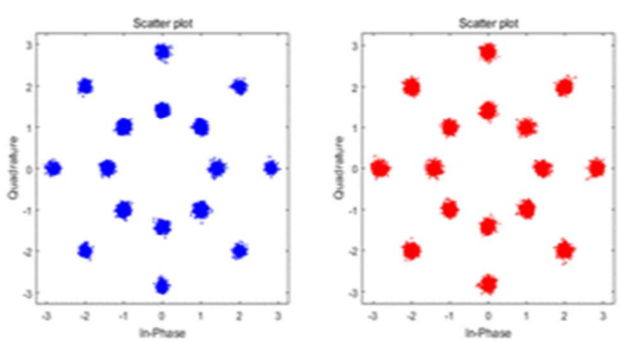
III. Simulation Results and Evaluation

In this paper, we propose a multi-mode OFDM system that simulates the performance analysis and verification using MATLAB program. In a multi-mode OFDM system, four different types of constellations are used without overlap to form the overall constellation. *A* and *B* modes are QPSK and pi / 4 QPSK modulation types, and *C* and *D* modes are the same as *A* and *B* modes, but different modes are distinguished by different average power. The overall constellation of the multi-mode OFDM is shaped like a 16 APSK constellation with two concentric circles in the conventional OFDM system. Therefore, we compare the BER and PAPR performance of the conventional OFDM system using 16 APSK.

TABLE I. Simulation Parameters

Modulation	QPSK+pi/4 QPSK(Multi-mode OFDM) 16APSK(OFDM)
FFT size	1024
Number of subcarrier per subblock	32
Number of subblock	32

Figure 8 shows the overall constellation of the signal received from the receiver. In the case of Multi-mode OFDM, the modulation is performed using the QPSK type and the pi / 4 QPSK type with different average power levels, and thus the overall constellation appearance is the same as that of a general 16APSK system using two concentric circles. Thus, both systems have the same form of constellation, thereby comparing the two systems.



(a) multi-mode OFDM (b) OFDM

Fig. 8. Received signal constellation of each systems.

Figure 9 compares the BER performance of the two systems. Compared with the conventional OFDM system, the Multi-mode OFDM system achieves better performance than the existing OFDM in the SNR of about 14dB or more. Based on the BER 〖10〗^(-5), the multi-mode OFDM system shows a difference of about 2dB from the conventional OFDM system. This is because, in the case of the Multi-mode OFDM system, the receiver demodulates the index bit values in addition to the modulated data values using the LLR algorithm, unlike the conventional method of demodulating the modulated data values in the OFDM system.

Figure 10 compares PAPR performance of Multi-mode OFDM system and conventional OFDM system. When the two systems compare the overall constellation diagrams, the PAPR performance is the same because the same constellation diagrams are used. Therefore, the two systems have the same PAPR performance. In a high SNR environment, the Multi-mode OFDM system exhibits better BER performance than the conventional OFDM system.

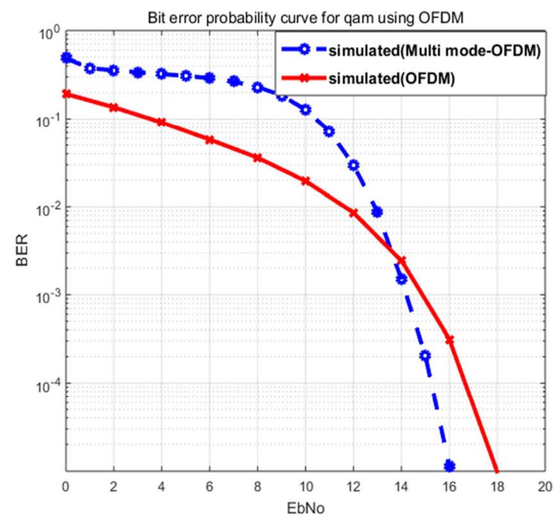


Fig. 9. BER performance comparison of multi-mode OFDM and conventional OFDM system.

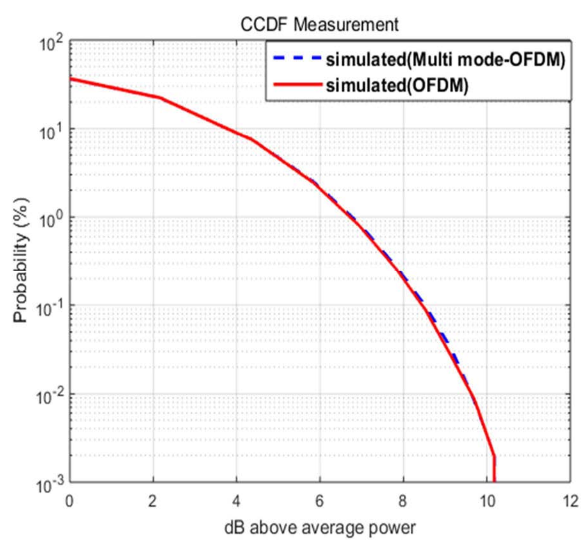


Fig. 10. PAPR comparison of multi-mode OFDM and conventional OFDM system.

IV. CONCLUSIONS

In this paper, we propose a multi-mode OFDM system that improves the existing OFDM system performance. Multi-mode OFDM system is an improved version of the existing OFDM system and possible dual mode OFDM system. As an example, four types of non-overlapping constellation diagrams are used for the modulation of multi-mode OFDM system. Accordingly, the information on the use of a certain constellation diagram is mapped through index bits. The index bits are not actually transmitted bits. The combination mode is used to indicate which mode constellation map is used for mapping in each subcarrier. The overall constellation diagram of the received signal shows the same constellation form as the existing OFDM system, but unlike the existing system, the Multi-mode OFDM system has a floating constellation form. Accordingly, the Multi-mode OFDM system combines and uses various constellation shapes. This makes it easy to create a constellation form suitable for each environment. In addition, as a method of constructing the overall constellation shape, each subcarrier is mapped to each constellation shape according to a combination scheme by using index bits in addition to bits used for modulation. Although not actually transmitting the index bits, the receiver finds out which type of constellation-mapped symbol is mapped to each subcarrier through the LLR algorithm, and thereby demodulates the entire bit. In the high SNR environment, the BER performance of the Multi-mode OFDM system is 2dB better than that of the conventional OFDM system based on BER of 10^{-5}. Therefore, compared to the conventional OFDM system, the multi-mode OFDM system has the form of a global constellation but has a fluidity to form a constellation shape suited to the environment and has better BER performance than the conventional OFDM system. It is considered to be an improved next generation communication method.

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REFERENCES

[1] R Nee, R Prasad, OFDM for wireless multimedia communications, 1st Ed. Artech House, Inc. 2000.

[2] Larsson, E. G., Edfors, O., Tufvesson, F., & Marzetta, T. L. "Massive MIMO for next generation wireless systems. " IEEE communications magazine. vol. 52, no.2, pp.186-195, Proceedings of the IEEE, vol .102, no. 1, pp. 56-103, 2014.

[3] Mesleh, Read Y., et al, "Spatial modulation." IEEE Transctions on Vehicular Technology, vol. 57, no. 4, pp. 2228-2241, 2008.

[4] Abu-Alhiga, Rami, and Harald Haas, "Subcarrier-Index modulation OFDM," in 2009 IEEE 20th International Syposium on Personal, Indoor and Mobile Radio Communications (PIMRC 2009), pp. 177-181, Tokyo, Japan, Sep 2009.

[5] Başar, Ertuğrul, et al. "Orthogonal frequency division multiplexing with index modulation." IEEE Transactions on Signal Processing, vol.61, no.22, pp.5536-5549, 2013.

[6] Mao, Tianqi, et al. "Dual-Mode index modulation aided OFDM," IEEE Access 5, pp. 50-60, 2017.

[7] Başar, Ertuğrul, Ümit Aygölü, and Erdal Panaylrcl. " Orthogonal frequency division multiplexing with index modulation in the presence of high mobility." Communications and Networking (BlackSeaCom), 2013 First International Black Sea Conference on., pp. 147-151, Batumi, Georgia, July, 2013.

[8] Mao, Tianqi, Qi Wang, and Zhaocheng Wang. "Generalized dual-mode index modulation aided OFDM." IEEE Communications Letters, vol.21, no.4, pp.761-764, 2017.