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# A Multi-mode OFDM System with Coded Direct Index Modulation (MM-OFDM-CDIM)

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## Abstract

Orthogonal frequency division multiplexing (OFDM) has various advantages and is used in many kinds of communication services. However, the next generation mobile communication systems will require higher performance and efficiency. The more advanced OFDM have been actively considered to meet such requirements. In this paper, we like to propose a multi-mode OFDM system with coded direct index modulation (MM-OFDM-CDIM) that can improve both performance and efficiency than the conventional OFDM system. The proposed MM-OFDM-CDIM system maps symbols into subcarriers and transmits the symbols, and it also maps data to indexes of subcarriers directly and transmits the data. At first, transmission and reception processes of the proposed system are described. Then, in order to verify the superiority of the proposed MM-OFDM-CDIM system, the bit error rate (BER) performance of the proposed system is compared with the conventional OFDM system in the additive white Gaussian noise and Rayleigh fading channel. As simulation results, it is confirmed that MM-OFDM-CDIM system can improve both BER performance and efficiency, compared to conventional OFDM system.

**Keywords** OFDM · OFDM-IM · MM-OFDM-CDIM · Multi-mode · Direct index modulation

## 1 Introduction

Recently, 3rd generation partnership project (3GPP) selected orthogonal frequency division multiplexing (OFDM) as the core modulation technology of physical layer in the first step of 5th generation (5G) mobile communication standardization [1]. Since OFDM has various advantages, it is widely used in 4th generation (4G) mobile communication and wireless local area network (WLAN) currently in service [2]. As such, OFDM satisfies the requirements of the current wireless communication system sufficiently. However, in the second stage of 5G mobile communication standardization and next generation wireless

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communication system, it will require more improved performance in various indicators [3]. In order to satisfy these future requirements, researches for the improvement of OFDM are being actively carried out. One of these studies is about index modulation based OFDM (OFDM-IM) [4–9].

OFDM-IM maps data to symbols and subcarrier indexes and transmits it [4]. In this way, OFDM-IM can control a trade-off between performance and transmission efficiency [5]. This trade-off function can be applied to various fields. Particularly, in mobile communication environment, the number of active subcarriers in OFDM-IM can be appropriately selected to reduce transmission efficiency, and effectively improve quality of experience (QoE) of users at cell edge [5]. However, performance degradation can't be avoided in order to improve transmission efficiency due to such trade-off characteristics. In particular, OFDM-IM maps and demaps data through complex combination operations at transmitter and receiver. Such the processing method can increase complexity of the system and decrease processing speed as the number of all subcarriers increases. Currently, many attempts have been made to improve these characteristics to improve both performance and efficiency [9].

In this paper, we propose a new system that can improve characteristics of conventional OFDM. The proposed system is multi-mode OFDM system with coded direct index modulation (MM-OFDM-CDIM). This proposed MM-OFDM-CDIM system transmits additional information by using indexes of subcarriers like the existing OFDM-IM. However, the proposed system directly assigns additional data to the indexes without additional operation. Each index of subcarrier can be mapped from one to a plurality of bits. These mapped bits are used to select a mode. If one bit is assigned to each subcarrier index, this bit will be used to select one of two modes. If two bits are assigned to each subcarrier index, one of four modes will be selected. Each mode has a different constellation. After a mode for each subcarrier is selected, one symbol is selected in the corresponding mode and mapped to each subcarrier. Here, only bit sequence allocated to indexes of subcarriers is coded to minimize reduction of code rate and to improve the performance.

In this paper, we describe the transmission and reception processes of the proposed system and compare characteristics of the proposed system and that of the existing OFDM system in additive white Gaussian noise (AWGN) and Rayleigh channel environment through simulation. For the simulation, we design OFDM-CDIM using two modes and four modes. Particularly, in this comparison, evaluation is performed considering both transmission efficiency and performance. In other words, through the simulation, we confirm that the proposed system can improve both transmission efficiency and performance compared with those of existing OFDM system.

## 2 The Proposed MM-OFDM-CDIM System

In this paper, we propose an MM-OFDM-CDIM system that can improve performance and efficiency compared to those of conventional OFDM system. The proposed system maps symbols to subcarriers and transmits the symbols, and it also maps data to indexes of subcarriers directly and transmits the data. In particular, only the data mapped to indexes is coded to improve performance of the overall system and reduce efficiency decrease due to code rate. The proposed system improves both performance and efficiency compared with conventional OFDM system.

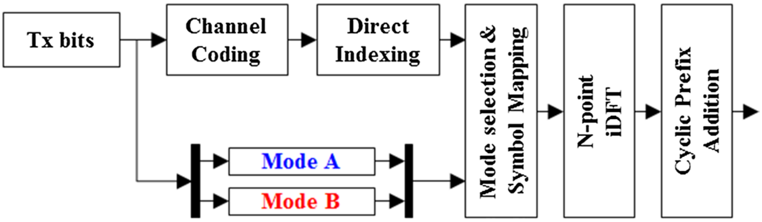


**Fig. 1** Block diagram of transmitter for 2M-OFDM-CDIM system

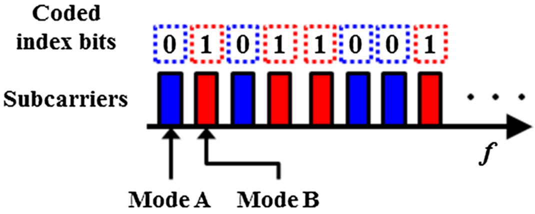


**Fig. 2** Bits allocation method for subcarrier indexes in 2M-OFDM-CDIM system

## 2.1 Transmitter

Figure 1 shows the block diagram of transmitter for OFDM-CDIM using two modes (2M-OFDM-CDIM) system. In the transmission process, data bits are first divided into two streams in order to be encoded and to select a symbol. Figure 2 shows bits allocation method for subcarrier indexes in 2M-OFDM-CDIM system. The encoded bits are assigned to the indices of subcarriers. The A mode is selected when the allocated bit is 0, and the B mode is selected when the allocated bit is 1. Since 2M-OFDM-CDIM system uses two modes, one bit is allocated to index of each subcarrier to distinguish each mode. The bits mapped to subcarriers are used to select a mode.

Figure 3 shows the constellation configuration of two modes for 2M-OFDM-CDIM system. Each mode consists of four symbols. Since performance of the system changes depending on how the constellation diagram of each mode is constructed, it is important to find an effective constellation diagram. In this paper, we evaluate performance of the system according to amplitude ratio, R2/R1, of mode A constellation and mode B constellation, and find a ratio with excellent performance.

After mapping each symbol is completed on the subcarriers, iDFT operation is performed to convert symbols in frequency domain into signals in time domain. Then, CP is inserted to effectively remove the ISI influence on multipath fading. Finally the signal with CP is transmitted.

Figure 4 shows the block diagram of transmitter for OFDM-CDIM using four modes (4M-OFDM-CDIM) system. The transmission process is similar to 2M-OFDM-CDIM system. However, since 4M-OFDM-CDIM system uses four modes, the number of bits allocated to each subcarrier index is different.

Figure 5 shows how to allocate bits to index of subcarrier in 4M-OFDM-CDIM system. Since the system needs to distinguish four modes, two bits are assigned to each subcarrier index. Then, a mode is selected according to the bits. When assigned bits are [0 0], [0 1], [1 0], and [1 1], mode A, B, C, and D are selected respectively. Figure 6 shows the constellation configuration of four modes for 4M-OFDM-CDIM system. Each

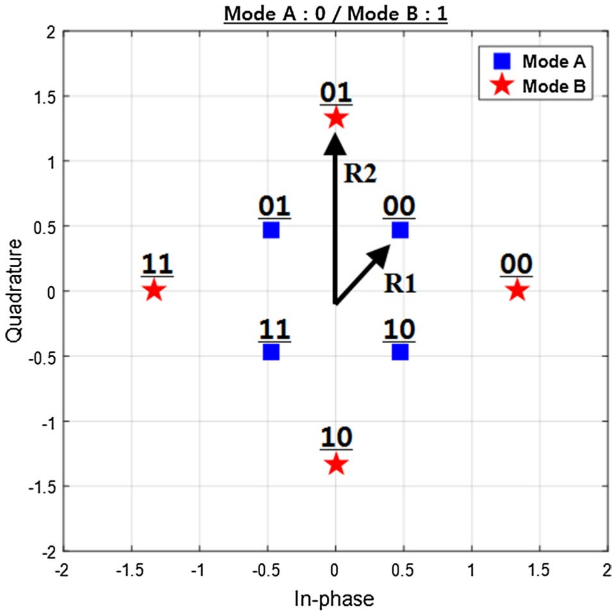


**Fig. 3** Constellsation configuration of two modes for 2M-OFDM-CDIM system

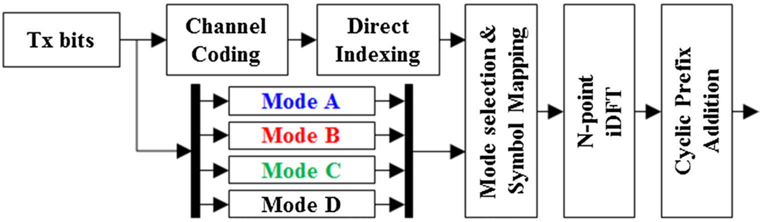
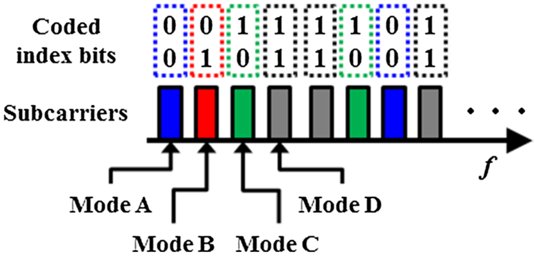


**Fig. 4** Block diagram of transmitter for 4M-OFDM-CDIM system

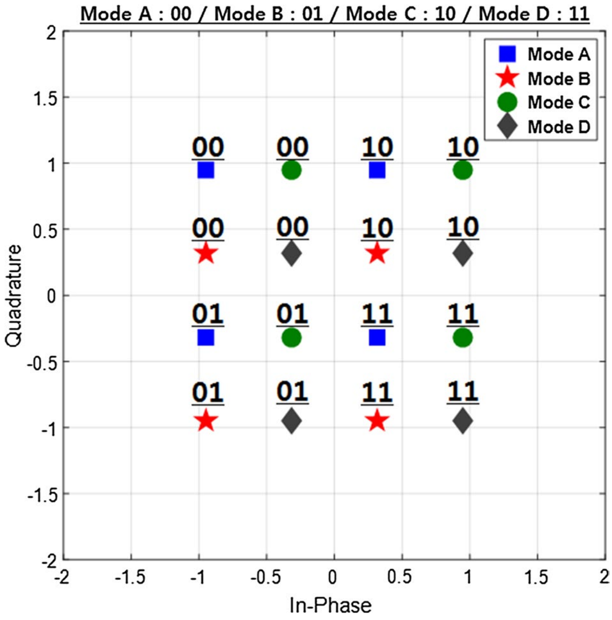
**Fig. 5** Bits allocation method for subcarrier indexes in 4M-OFDM-CDIM system



mode consists of four symbols. After mode is selected, one symbol is selected according to information in two bits in the corresponding mode.

In 4M-OFDM-CDIM system, after mapping each symbol is completed on all subcarriers, iDFT operation is performed to convert frequency domain symbols into time

**Fig. 6** Constellsation configuration of two modes for 4M-OFDM-CDIM system



domain signals. Then, CP is inserted to effectively remove the ISI influence on multipath fading. Finally the signal with CP is transmitted.

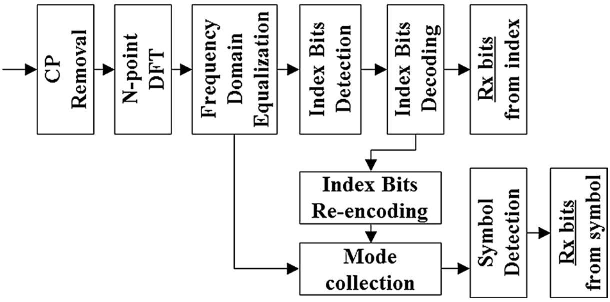
It is possible to configure a system by further increasing the number of modes in the same method as 2M-OFDM-CDIM and 4M-OFDM-CDIM systems.

## 2.2 Receiver

In MM-OFDM-CDIM system, since mode selection information is encoded on the transmitter side, received signal is processed using this characteristic to improve performance of the system.

Figure 7 shows the block diagram of receiver for MM-OFDM-CDIM system. First, CP is removed from received signal. And then time domain signal converts into frequency domain symbol through DFT operation. Then effect of multipath fading is equalized. Information about mode and symbol must be discriminated in received symbol. First,

**Fig. 7** Block diagram of receiver for MM-OFDM-CDIM system



mode discrimination is performed. A mode is determined by obtaining Euclidean distance between the received symbol and each mode, and then decoding is performed using the information. If transmitter uses convolutional coding, receiver can decode it using trellis based Viterbi decoding technique. The decoded information is determined as received bits, and then encoded again. In this way, the mode information is corrected. After the mode is corrected, a symbol is determined in this mode and received bit information is obtained from the symbol.

## 3 Simulation Results and Analysis

In order to verify superiority of the proposed MM-OFDM-CDIM system, we have compared bit error rate (BER) performance of the proposed system and conventional OFDM system. Table 1 shows the simulation parameters for the evaluation. For the performance evaluation of MM-OFDM-CDIM system, 2M-OFDM-CDIM and 4M-OFDM-CDIM systems have been designed. These systems use 1024 subcarriers and CP length of 256. A convolutional coder with code rate of 1/2 is used for the transmitter of each system. Therefore, the 2M-OFDM-CDIM system has an efficiency of 2.5 bits/Hz, and the 4M-OFDM-CDIM system has an efficiency of 3 bits/Hz. Two types of convolutional coders have been considered. One has a constraint length of 3, and the other has a constraint length of 7. AWGN and Rayleigh fading channel which has 256 taps have been considered as channel environment.

Figures 8 and 9 show the BER performance of the 2M-OFDM-DIM system, which does not use encoding in the transmitter evaluated in AWGN and Rayleigh fading channel

**Table 1** Simulation parameters

| Parameter | Value |
|---|---|
| # of symbol for a mode | 4 |
| Modulation | OFDM-CDIM with 2 modes<br>OFDM-CDIM with 4 modes |
| # of subcarriers | 1024 |
| CP length | 256 |
| Magnitude ratio between QPSK modes for 2M-DIM-OFDM | 1–3 |
| Code rate for indexing bits | 1/2 |
| Code rate of total system | 5/6, 3/4 |
| Efficiency | 2M-OFDM-DIM: 3 bits/Hz<br>2M-OFDM-CDIM: 2.5 bits/Hz<br>4M-OFDM-DIM: 4 bits/Hz<br>4M-OFDM-CDIM: 3 bits/Hz |
| Constraint length and Convolutional code polynomials for trellis | Coding method 1<br>Constraint length: 3<br>Code polynomial: [5, 7]<br>Coding method 2<br>Constraint length: 7<br>Code polynomial: [133, 171] |
| Channel | AWGN<br>256-tap random Rayleigh channel |

**Fig. 8** BER performance of 2M-OFDM-DIM system according to ratio of R1 and R2 in AWGN channel

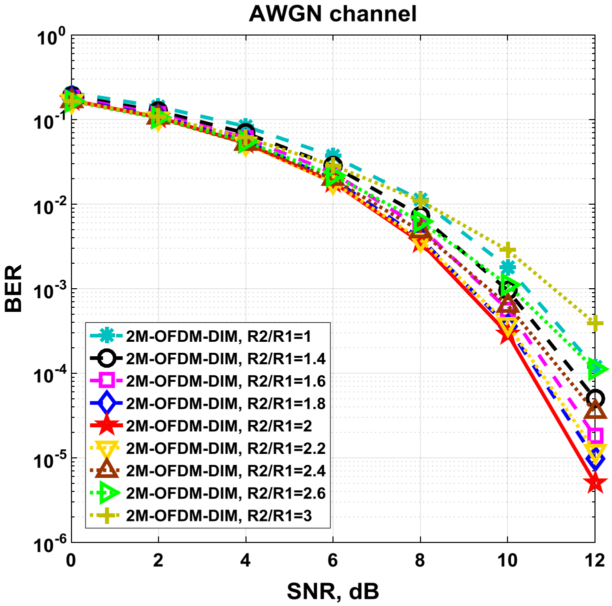
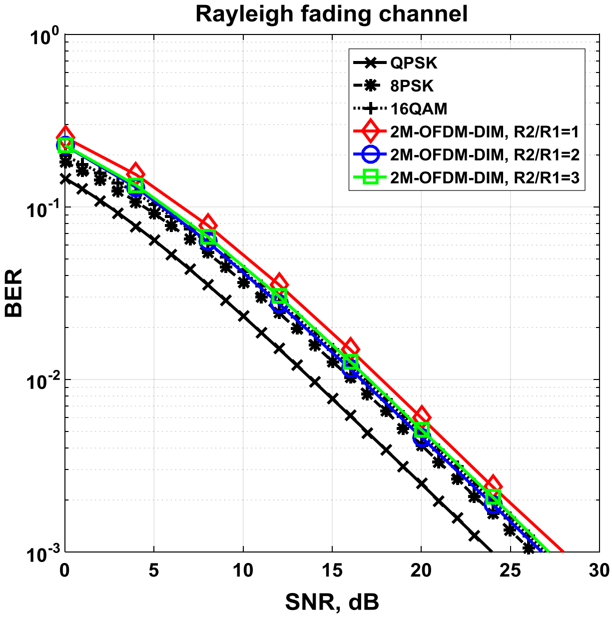


**Fig. 9** BER performance of 2M-OFDM-DIM system according to ratio of R1 and R2 in Rayleigh fading channel



respectively. It can be seen that the BER performance of the system is best when R2/R1 is 2 in AWGN and Rayleigh fading channel. This is because a distance between symbols constituting the constellation diagram used in the 2M-OFDM-DIM system is the farthest when the mode is not distinguished when R2/R1 is 2. However, the performance of the 2M-OFDM-CDIM is worse than the performance of the existing OFDM system using

8PSK. Since the 2M-OFDM-DIM system does not use coding, the transmission efficiency is 3 bits/Hz. This is the same as the OFDM system using 8PSK. Therefore, it is difficult to find superiority in terms of the BER performance and efficiency over conventional OFDM systems if encoding is not performed.

Figures 10 and 11 show the BER performance of the 2M-OFDM-CDIM system evaluated on AWGN and Rayleigh fading channel when R2/R1 is 1, respectively. In AWGN channel, when the constraint length is 7 and the SNR is higher than 6.5 dB, the 2M-OFDM-CDIM system has better BER performance than the quadrature phase shift keying (QPSK) based OFDM system with the transmission efficiency of 2 bits/Hz. In Rayleigh fading channel, the 2M-OFDM-CDIM system has better BER performance than the QPSK-based OFDM system when the constraint length is 7 and the SNR is higher than 8 dB. In particular, even when the constraint length is 3 and the SNR is higher than 14 dB, it can be seen that the 2M-OFDM-CDIM system has better BER performance than the existing system using QPSK. That is, 2M-OFDM-CDIM can improve performance and transmission efficiency compared to conventional OFDM systems in Rayleigh fading channel.

Figures 12 and 13 show the BER performance of the 2M-OFDM-CDIM system on AWGN and Rayleigh fading channel when R2/R1 is 2, respectively. In the case of AWGN channel, when the constraint length of 7 is used, the 2M-OFDM-CDIM system is not superior to that of the OFDM system using the conventional QPSK. However, in Rayleigh fading channel, the BER performance of the 2M-OFDM-CDIM system is slightly better than that of the conventional system when the constraint length is 7.

Figures 14 and 15 show the BER performance of the 2M-OFDM-CDIM system in AWGN and Rayleigh fading channel when R2/R1 is 3, respectively. It can be confirmed that the performance of the system is not better than that of the conventional OFDM system using QPSK even when the constraint length is 7 in both AWGN and Rayleigh fading channels. A summary of the performance evaluation results of the 2M-OFDM-CDIM system shows that when the index information is not encoded and R2/R1 is 2, the

**Fig. 10** BER performance of 2M-OFDM-CDIM in AWGN channel when R2/R1 is 1

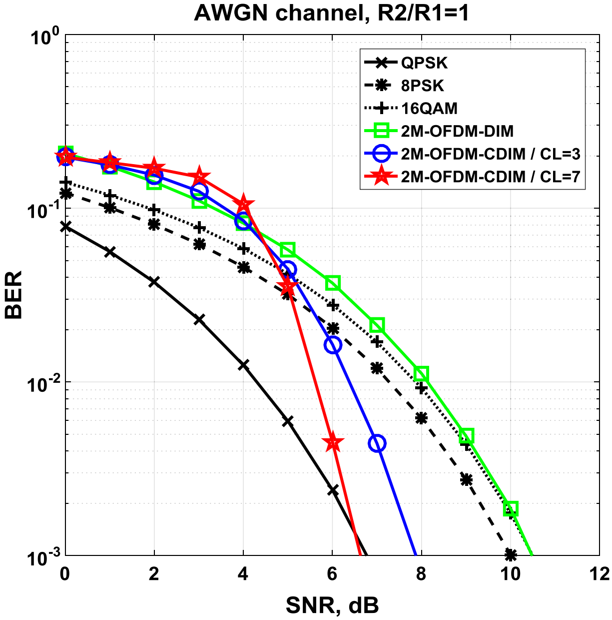


**Fig. 11** BER performance of 2M-OFDM-CDIM in Rayleigh fading channel when R2/R1 is 1

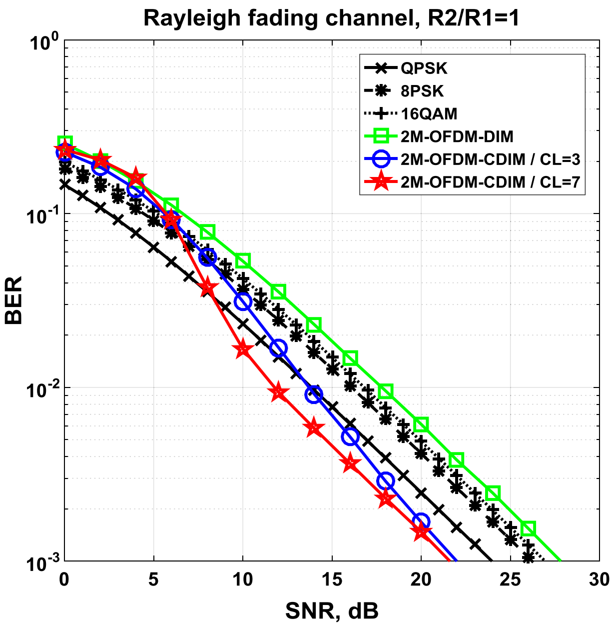
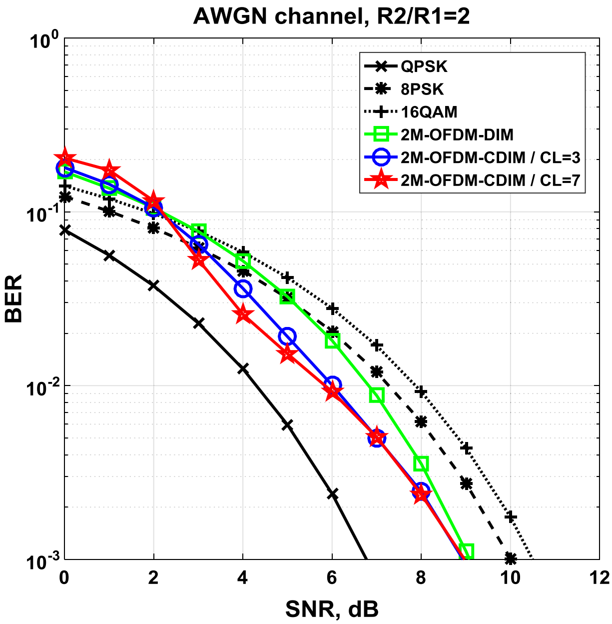


**Fig. 12** BER performance of 2M-OFDM-CDIM in AWGN channel when R2/R1 is 2



best performance is obtained in AWGN and Rayleigh fading channel. However, when the index information is coded, it is confirmed that the best performance is obtained when R2/R1 is 1. This is because the received mode information can be corrected even when the interval between modes is reduced when R2/R1 changes from 2 to 1 when

**Fig. 13** BER performance of 2M-OFDM-CDIM in Rayleigh fading channel when R2/R1 is 2

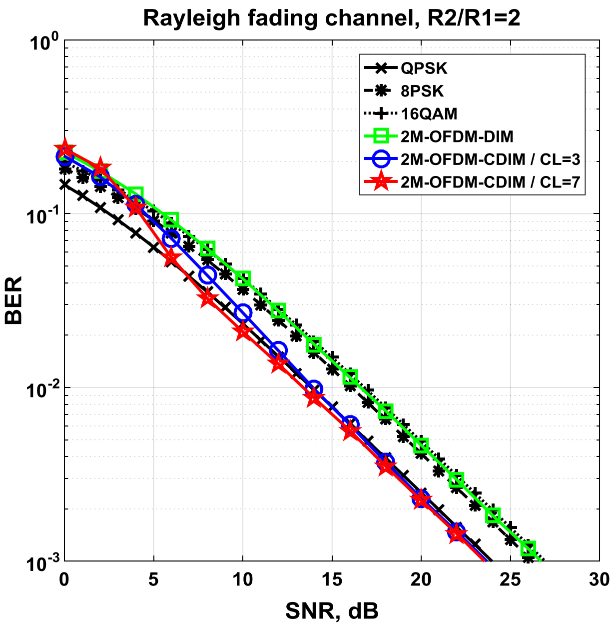
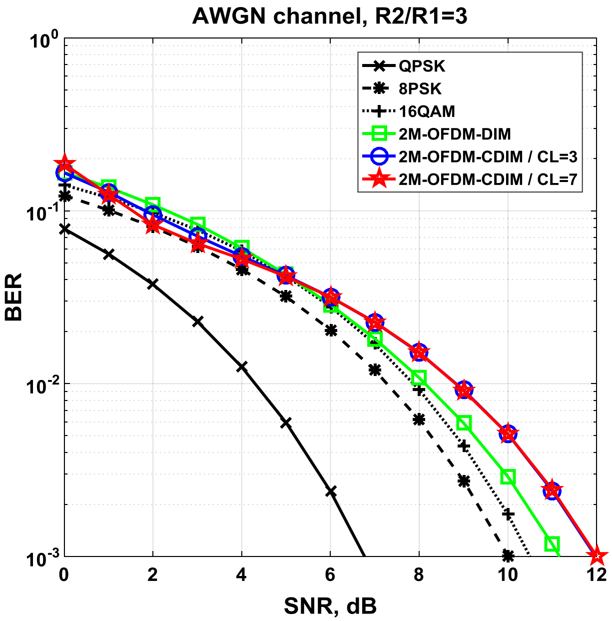


**Fig. 14** BER performance of 2M-OFDM-CDIM in AWGN channel when R2/R1 is 3



encoding is performed. This also is because the average interval between the uncoded symbols in each mode is widened.

Figures 16 and 17 show the performance of the 4M-OFDM-CDIM system on AWGN and Rayleigh fading channel. In AWGN channel, it is confirmed that when the constraint length is 7 and the SNR is higher than 6.9 dB, the 4M-OFDM-CDIM system has better

**Fig. 15** BER performance of 2M-OFDM-CDIM in Rayleigh fading channel when R2/R1 is 3

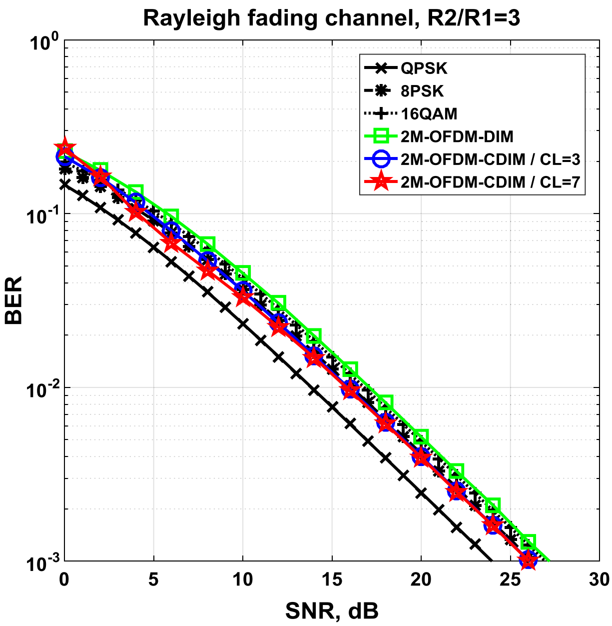
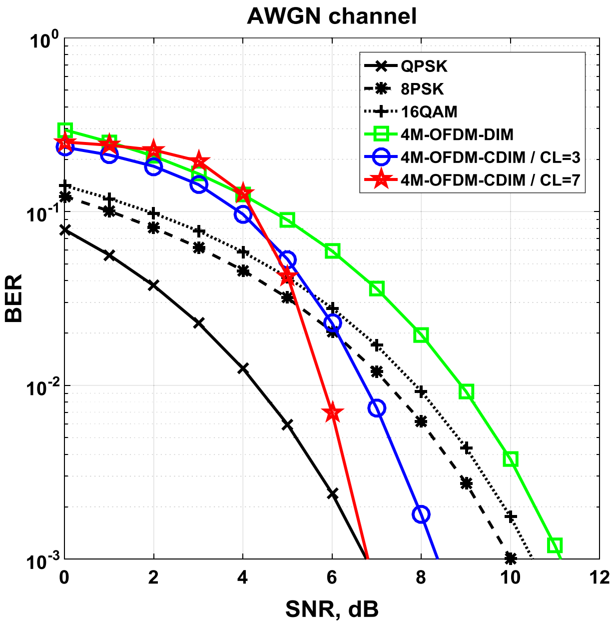
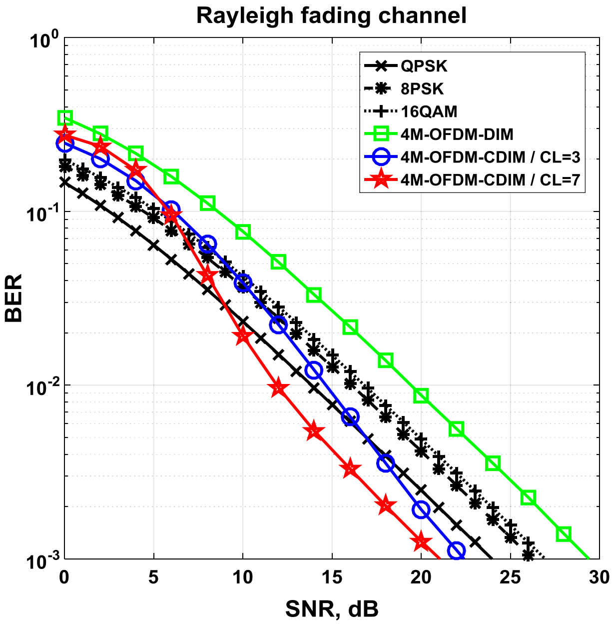


**Fig. 16** BER performance of 4M-OFDM-CDIM in AWGN channel



BER performance than the conventional OFDM system using QPSK. In Rayleigh fading channel, the performance of the system is better than the existing system using QPSK when the constraint length is 7 and the SNR is over 9.2 dB. Even though the constraint length is 3, if the SNR is 17 dB or more, the 4M-OFDM-CDIM system has the better BER performance than this existing system. All the take together, the 4M-OFDM-CDIM system

**Fig. 17** BER performance of 4M-OFDM-CDIM in Rayleigh fading channel



has higher transmission efficiency and superior performance than the conventional OFDM system.

Table 2 summarizes the performance of the MM-OFDM-CDIM systems and the conventional OFDM system evaluated on AWGN channel. The efficiency of the 2M-OFDM-CDIM system is improved by 25% compared with the QPSK-OFDM system, and the SNR required to satisfy the BER of $10^{-3}$ is improved by about 0.2 dB. The efficiency of the 4M-OFDM-CDIM system is improved by 50% compared with the QPSK-OFDM system, and the SNR required to satisfy the BER of $10^{-3}$ is the same. In addition, the 4M-OFDM-CDIM system has the same transmission efficiency as the 8PSK-OFDM system, and the SNR required to satisfy the BER of $10^{-3}$ is improved by about 3.4 dB.

Table 3 summarizes the performance of the MM-OFDM-CDIM systems and the conventional OFDM system evaluated in Rayleigh fading channel. It can be seen that the 2M-OFDM-CDIM system improves the efficiency by 25% as compared with the QPSK-OFDM system and

**Table 2** Efficiency and BER performance of MM-OFDM-CDIM system in AWGN channel

| AW2GN | QPSK-OFDM | 8PSK-OFDM | 16QAM-OFDM | 2M-OFDM-CDIM | 4M-OFDM-CDIM |
|---|---|---|---|---|---|
| Efficiency (Bits/Hz) | 2 | 3 | 4 | 2.5 | 3 |
| SNR for BER of $10^{-3}$ | 6.8 dB | 10 dB | 10.5 dB | 6.6 dB (CL = 7),<br>7.9 dB (CL = 3) | 6.8 dB (CL = 7),<br>8.4 dB (CL = 3) |

**Table 3** Efficiency and BER performance of MM-OFDM-CDIM system in Rayleigh fading channel

| Rayleigh fading | QPSK-OFDM | 8PSK-OFDM | 16QAM-OFDM | 2M-OFDM-CDIM | 4M-OFDM-CDIM |
|---|---|---|---|---|---|
| Efficiency (Bits/Hz) | 2 | 3 | 4 | 2.5 | 3 |
| SNR for BER of $10^{-3}$ | 24 dB | 26.2 dB | 26.9 dB | 21.6 dB (CL = 7),<br>21.9 dB (CL = 3) | 21 dB (CL = 7),<br>22.3 dB (CL = 3) |

the required SNR to satisfy the BER of $10^{-3}$ is improved by about 2.4 dB. It can be seen that the 4M-OFDM-CDIM system has the 50% improvement in efficiency and the 3 dB improvement in the required SNR for satisfying the BER of $10^{-3}$ as compared with the QPSK-OFDM system. In addition, the 4M-OFDM-CDIM system has the same transmission efficiency as the 8PSK-OFDM system, and the SNR required to satisfy the BER of $10^{-3}$ is improved by about 5.2 dB (Table 4).

The 2M-OFDM-CDIM system uses two modes. Here, the BER performance changes according to the amplitude ratio R2/R1 between the modes, and when the ratio of R2/R1 is 1, the best BER performance is obtained. This performance change is determined by the Euclidean distance between the symbols in each mode used in the 2M-OFDM-CDIM system. Mode A and mode B are each composed of four symbols. Here, when averaging is performed using the sum of the distances between adjacent symbols in mode A and the sum of the distances between adjacent symbols in mode B, the average value is largest when the ratio of R2/R1 is 1, small. Therefore, the BER performance is the best since a sufficient distance is secured between adjacent symbols. With this principle, when the ratio of R2/R1 is 2 in the case of 2M-OFDM-DIM system in which coding is not used, the distance between the nearest adjacent symbols is the greatest, and the best BER performance is obtained. In the case of 4M-OFDM-CDIM system, as compared with 2M-OFDM-CDIM system, the coders used therein are the same and the average values of the distances between adjacent symbols in each mode are similar, but the code rate is lower. For this reason, the performance is slightly better than that of the 2M-OFDM-CDIM system (Table 5).

The approximate performance estimate of the proposed system in this paper can be calculated using squared Euclidean distance (SED) value. First, Euclidean distance between symbol $x_1 + y_1 i$ and symbol $x_2 + y_2 i$ is calculated as follows.

$$d = \sqrt{\left(x_1 - x_2\right)^2 + \left(y_1 - y_2\right)^2} \tag{1}$$

**Table 4** Squared Euclidean distance between 000 symbol and each symbol (000, 010, 100, 110)

| Squared Euclidean distance (SED) | 000 | 010 | 100 | 110 |
|---|---|---|---|---|
| R2/R1 = 1 | 0 | 2 | 2 | 4 |
| R2/R1 = 2 | 0 | 0.8 | 0.8 | 1.6 |
| R2/R1 = 3 | 0 | 0.4 | 0.4 | 0.8 |

**Table 5** Squared Euclidean distance between 000 symbol and each symbol (001, 011, 101, 111)

| Squared Euclidean distance (SED) | 001 | 011 | 101 | 111 |
|---|---|---|---|---|
| R2/R1 = 1 | 0.586 | 0.586 | 3.414 | 3.414 |
| R2/R1 = 2 | 0.869 | 0.869 | 3.131 | 3.131 |
| R2/R1 = 3 | 1.152 | 1.152 | 2.849 | 2.849 |

Generally, the coding gain that is roughly expected when a symbol is generated using coded bits and uncoded bits is defined as follows [10].

$$\gamma = \frac{d^2_{trellis/coded}}{d^2_{min/uncoded}} * \frac{E_{s/coded}}{E_{s/uncoded}} \tag{2}$$

where $d^2_{trellis/coded}$ represents SED value of one sequence in Trellis, and the lowest $d^2_{trellis/coded}$ value is used to obtain the coding gain. $d^2_{min/uncoded}$ represents minimum SED between a symbol and an adjacent symbol in uncoded constellation. $E_{s/coded}$ and $E_{s/uncoded}$ indicate the average power of the coded and uncoded constellations, respectively. In this paper, we have normalized these two values to 1.

For the 2M-OFDM-CDIM system used in this paper, we have used the convolutional code with a constraint length of 3 and a code polynomial of [5, 7]. The symbols generated using this code follow the trellis rules as shown in Fig. 18. In the 2M-OFDM-CDIM system, when one index bit is coded, two bits are generated, which affects two symbols, so that two Trellis structures are generated, and these two structures must be considered together. That is, in order to calculate SED value of a trellis sequence, the calculated SED value at each trellis should be added. The difference in the SED values between the trellis paths that can be constructed

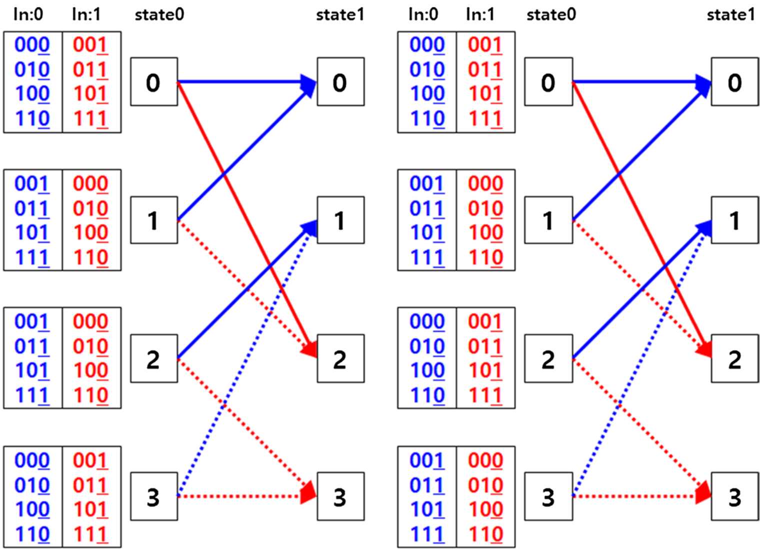


Fig. 18 Trellis information of the proposed 2M-OFDM-CDIM system

by simultaneously considering these two Trellis structures determines the performance. The larger the difference between the SED values is, the better the performance. The smaller the difference, the lower the performance.

When the R2/R1 is 1 in the 2M-OFDM-CDIM system, the state is shifted to 0, 2, 1, 0 when the trellis sequence having the minimum SED value is configured except for the sequence having the SED value of 0. The sequence with the minimum SED depends on the ratio of R2/R1. On the basis of this principle, the coding gain is obtained by comparing the 8PSK symbols that are not coded as follows.

$$\begin{aligned}\gamma_{\frac{R2}{R1}=1,[0210]} &= 10\log10((0.586*2+0.586+0.586*2)/1.172)=3.975\mathrm{dB}\\ \gamma_{\frac{R2}{R1}=1,[00]} &= 10\log10(2*2/1.172)=5.331\mathrm{dB}\\ \gamma_{\frac{R2}{R1}=1} &= \min\left[\gamma_{\frac{R2}{R1}=1,[0210]},\gamma_{\frac{R2}{R1}=1,[00]}\right]=3.975\mathrm{dB}\end{aligned}\tag{3}$$

$$\begin{aligned}\gamma_{\frac{R2}{R1}=2,[0210]} &= 10\log10((0.869*2+0.869+0.869*2)/1.172)=5.691\mathrm{dB}\\ \gamma_{\frac{R2}{R1}=2,[00]} &= 10\log10(0.8*2/1.172)=1.352\mathrm{dB}\\ \gamma_{\frac{R2}{R1}=2} &= \min\left[\gamma_{\frac{R2}{R1}=2,[0210]},\gamma_{\frac{R2}{R1}=2,[00]}\right]=1.352\mathrm{dB}\end{aligned}\tag{4}$$

$$\begin{aligned}\gamma_{\frac{R2}{R1}=3,[0210]} &= 10\log10((1.152*2+1.152+1.152*2)/1.172)=6.915\mathrm{dB}\\ \gamma_{\frac{R2}{R1}=3,[00]} &= 10\log10(0.4*2/1.172)=-1.658\mathrm{dB}\\ \gamma_{\frac{R2}{R1}=3} &= \min\left[\gamma_{\frac{R2}{R1}=3,[0210]},\gamma_{\frac{R2}{R1}=3,[00]}\right]=-1.658\mathrm{dB}\end{aligned}\tag{5}$$

That is, referring to the Eqs. (3), (4) and (5), 2M-OFDM-CDIM system achieves coding gain of 3.975 dB, 1.352 dB, and – 1.658 dB when R2/R1 is 1, 2, and 3, respectively, as compared with the uncoded 8PSK system. That is, the best performance can be obtained when R2/R1 is 1, and the approximate calculation results are similar to the tendencies of Figs. 10, 12, and 14. By using this method, it is possible to calculate the theoretical performance even for the constraint length 7, and furthermore, the performance for the 4M-OFDM-CDIM system can be calculated.

## 4 Conclusions

In this paper, we have proposed a multi-mode OFDM system with coded direct index modulation (MM-OFDM-CDIM) that can improve performance and efficiency than the conventional OFDM system. The proposed system maps symbols to subcarriers and transmits the symbols, and it also maps data to indexes of subcarriers and transmits the data. In particular, only the data mapped to indexes is coded to improve performance of the overall system and reduce efficiency decrease due to code rate. We have described transmission and reception process of the proposed system and compare characteristics of the proposed system and that of the existing OFDM system in AWGN and Rayleigh channel environment through simulation. The simulation results are as follows. On AWGN channel, the efficiency of the 2M-OFDM-CDIM system is improved by 25% compared with the QPSK-OFDM system, and the SNR required to satisfy the BER of $10^{-3}$ is improved by about 0.2 dB. The efficiency of the 4M-OFDM-CDIM system is improved by 50% compared with the QPSK-OFDM system, and the SNR required to satisfy the BER of $10^{-3}$ is the same. On Rayleigh fading channel, it can be seen that the 2M-OFDM-CDIM system improves the efficiency by 25% as compared with the QPSK-OFDM system and the required SNR to satisfy the BER of $10^{-3}$ is improved by about 2.4 dB. It can be seen that the 4M-OFDM-CDIM system has the 50% improvement in efficiency and the 3 dB improvement in the required SNR for satisfying the BER of $10^{-3}$ as compared with the QPSK-OFDM system. As simulation results, it is confirmed that MM-OFDM-CDIM system can improve both BER performance and efficiency compared to conventional OFDM system.

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