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***Abstract*—With the aim of improving the quality and expanding the functions of digital terrestrial television broadcasting services, we have been developing an advanced transmission system that inherits key features of the current Integrated Services Digital Broadcasting-Terrestrial (ISDB-T) system, which employs hierarchical transmission based on frequency division multiplexing (FDM) and a segment structure. The advanced ISDB-T system has a new signal frame structure that enables bandwidth to be flexibly allocated to multiple services for different reception scenarios, such as fixed reception and mobile reception, compared with ISDB-T. By introducing transmission technologies such as the latest forward error correction and modulation scheme, this specification has high spectral efficiency and transmission robustness, i.e., the transmission capacity increases by about 10 Mbps for the same required carrier to noise ratio (CNR) in comparison with the current ISDB-T system, or the required CNR can be reduced by about 7 dB for the same transmission capacity. We describe the channel coding scheme and evaluated the performance of bit-interleaved coded modulation (BICM) in simulations. This paper provides a BICM selection guideline based on the simulation results for fixed reception scenarios toward the practical application of advanced ISDB-T.**

***Index Terms*—digital terrestrial television broadcasting, advanced ISDB-T, bit-interleaved coded modulation**

I. Introduction

THE current transmission scheme for digital terrestrial television broadcasting (DTTB) in Japan was first reported by the Telecommunications Technology Council in May 1999, and it was established as an Association of Radio Industries and Businesses (ARIB) standard in May 2001. In the spirit of terrestrial integrated digital broadcasting, this scheme is called "Integrated Services Digital Broadcasting-Terrestrial" (ISDB-T) [1].

A feature of the ISDB-T scheme, which handles different receiving modes (such as fixed reception and mobile reception), is that it can provide multiple services with different transmission capacities and levels of transmission robustness within one channel (6 MHz) used for terrestrial television broadcasting. Currently, many broadcasting stations simultaneously provide high-definition broadcasts for fixed reception and one-segment broadcasts for mobile reception in Japan. By utilizing orthogonal frequency division multiplexing (OFDM) [2] as the modulation scheme with time/frequency interleaving, we can make ISDB-T robust against (i) multipath echoes reflected off buildings, mountains, etc. in the propagation path and (ii) fluctuation in the electric field strength in the case of mobile reception. Furthermore, ISDB-T is compatible with the Moving Picture Experts Group 2 (MPEG-2) systems adopted for multiplexing video, audio, data, etc., constituting broadcasting satellite (BS) and communication satellite (CS) digital broadcast programs, so it has high interoperability.

At NHK, aiming to improve the functionality of digital terrestrial television broadcasting and attain higher-quality video and audio, we have been developing a frequency division multiplexing (FDM)-based transmission system inheriting the above-described features of the ISDB-T scheme while considering the specification of the next-generation terrestrial-broadcasting transmission scheme (hereafter referred to as "advanced ISDB-T") [3][4]. When we formulated the specification, we stipulated a service requirement that Super Hi-Vision broadcasting for fixed reception and high-definition broadcasting for mobile reception be simultaneously provided on one channel because the radio frequency spectrum is tight in Japan. To satisfy this requirement mentioned above, we introduced a new signal structure and the latest technologies for improving transmission characteristics. Additionally, we kept in mind that the advanced ISDB-T scheme must achieve the increased spectral efficiency, i.e., the transmission capacity per unit frequency, and excellent transmission robustness. Supposing that the MPEG Media Transport (MMT) and type-length-value (TLV) adopted for the multiplexing schemes for 4K/8K satellite broadcasting [5], which started in December 2018, are used, we investigated the physical layer scheme, such as the configuration of the forward error correction (FEC) block and the OFDM frame structure.

Advanced ISDB-T adopts bit-interleaved coded modulation (BICM) [6] and has a wide-ranging transmission capacity and robustness using six types of carrier modulation and thirteen types of low-density parity check (LDPC) code

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rates. To formulate a link budget for advanced ISDB-T, it is necessary to develop BICM that achieves the desired transmission capacity and robustness. In this paper, we report the results of a computer simulation on the transmission performance of all combinations (78 options) of BICM in the additive white Gaussian noise (AWGN) and multipath environments assumed for the fixed reception of DTTB. The evaluation and selection of BICM for practical use have not been researched thus far for advanced ISDB-T, and a method of selecting BICM toward the practical application of advanced ISDB-T is provided.

This paper is structured as follows. Section II reviews the basic configuration of FDM-based advanced ISDB-T. Section III describes the channel coding scheme in the physical layer specification. The methodologies and the simulation setup are presented in Section IV. Section V presents the simulation results and a discussion on the fixed reception performance. The paper is concluded in Section VI.

II. Overview of FDM-based advanced ISDB-T

A. Inherited Features of ISDB-T

The current ISDB-T utilizes OFDM, which has excellent transmission performance against multipath echoes, as a modulation scheme and adopts a segment structure in which a signal block is formed by dividing the band of an OFDM signal into signal blocks, and the block, called an "OFDM segment," is used as a unit for data transmission. This segment structure enables OFDM signals to be partially received, i.e., only part of the spectrum can be demodulated and decodable with a narrowband receiver. By concatenating multiple OFDM segments, a transmission signal bandwidth suitable for the target service can be flexibly configured on a segment basis, and television services for fixed reception and mobile reception can be transmitted simultaneously on one channel.

In the case of ISDB-T, one OFDM segment occupies 1/14 of the channel bandwidth, i.e., 6 MHz, and the transmission signal of ISDB-T is composed of 13 OFDM segments. In addition, it is possible to perform hierarchical transmission that simultaneously transmits up to three layers (layers A, B, and C) with different transmission parameters, such as the carrier modulation, code rate of the FEC, and time-interleaving length. Among the 13 segments, the segment (with a bandwidth of 0.43 MHz, i.e., 1/14×6 MHz) in the center is set as a partial-reception band.

In regard to advanced ISDB-T, functions such as hierarchical transmission and partial reception are inherited. That is, the segment structure is adopted so that hierarchical transmission up to three layers with different transmission capacities and levels of transmission robustness is possible allowing partial reception. Hierarchical transmission and partial reception in advanced ISDB-T are illustrated in Fig. 1. For advanced ISDB-T, the number of divisions of the channel bandwidth is increased from 14 to 36, and the transmission signal is composed of up to 35 OFDM segments. A narrowband receiver that carries out partial reception is supposed to receive 9 OFDM segments (with a bandwidth of 1.50 MHz) in the center from among 35 OFDM segments, and the number of segments in layer A can be set in the range

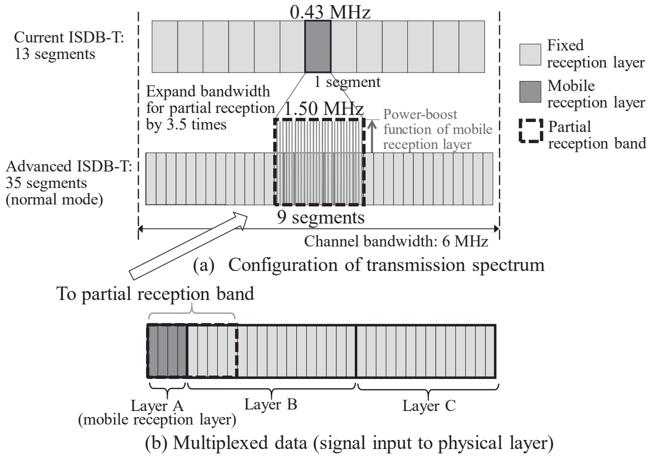

Fig. 1. Hierarchical transmission and partial reception in advanced ISDB-T (in case of 4 segments in layer A).

from 1 to 9 to increase the flexibility of the transmission capacity for partial reception. Moreover, by increasing the partial-reception bandwidth to 3.5 times that of ISDB-T, the effect of frequency interleaving for partial reception is enhanced. The example configuration in Fig. 1 shows hierarchical transmission in which four segments are allocated to a service for mobile reception and transmitted by layer A, and the other segments are allocated to a service for fixed reception and transmitted by layers B and C with different transmission parameters. Figure 1 (b) illustrates multiplexed data that is input to the physical layer and configured to the transmission spectrum as shown in Figure 1 (a). Here, layer A accounts for the transmission capacity of four out of the nine segments of the partial-reception band, and the carriers of layer A are dispersed throughout the partial-reception band in the physical layer processing. The carriers of layer A have a power boost function that sets the transmission power higher than that of the other carriers, thereby improving the robustness of layer A.

In addition to this function, a low-delay transmission path called "LLch" (low-latency channel) is provided in such a way that critical information, such as emergency earthquake warnings, can be transmitted with short delay.

B. Enhanced Signal Structure

Comparing advanced ISDB-T (which uses 35 of 36 segments of the 6-MHz channel) with ISDB-T (which uses 13 of 14 segments) reveals that, together with improving the flexibility in allocating bandwidth for fixed or mobile reception, the increase in the number of divisions of the channel bandwidth reduces the guard band, resulting in an increase in capacity by about 5%.

In the case of advanced ISDB-T, spectral efficiency is improved by reducing the ratio of the guard interval (GI), which does not contribute to information transmission. Although the current ISDB-T can be operated with a fast Fourier transform (FFT) size of 8,192 (2^{13}) points, advanced ISDB-T adopts an FFT size of up to 32,768 (2^{15}) points. Increasing the FFT size reduces the carrier frequency spacing. Also, as the effective symbol length increases, even when the GI duration is set to be the same, the ratio of the GI to the effective symbol length (hereafter referred to as "GI ratio") becomes small, and the transmission capacity can be

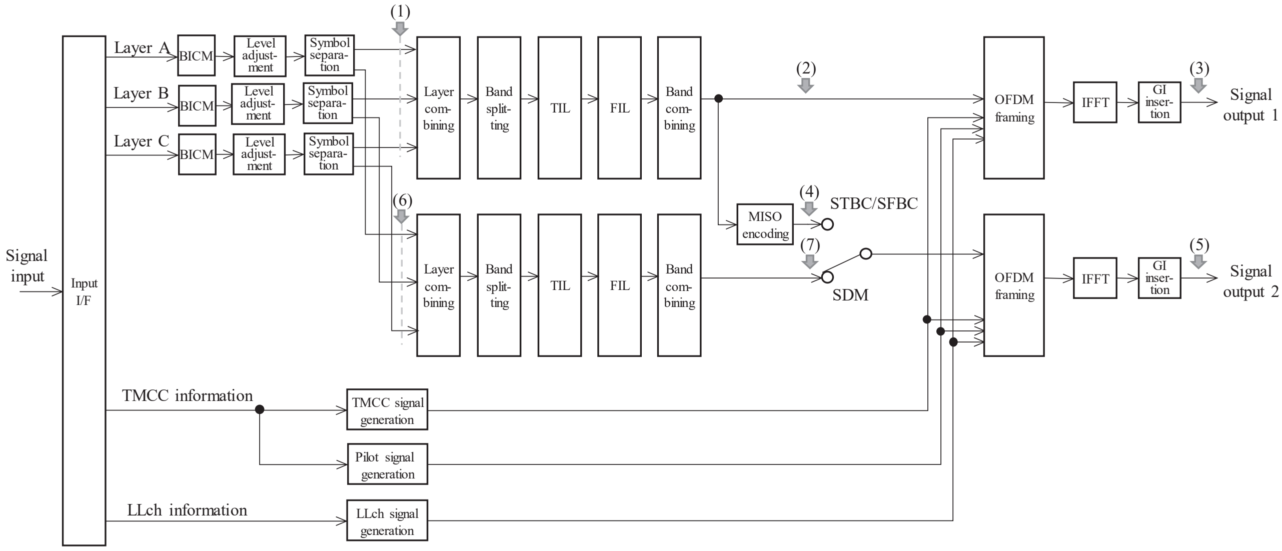

Fig. 2. Block diagram of channel coding in advanced ISDB-T.

increased. However, it should be noted that increasing the FFT size requires higher computational complexity. Compared with ISDB-T, the maximum FFT size is quadrupled from 8,192 to 32,768 in advanced ISDB-T, so the complexity is increased. In addition, considering the compatibility of the advanced ISDB-T with the current ISDB-T, parameters whose bandwidth and GI duration match those of ISDB-T are included in the advanced ISDB-T.

Moreover, in the case of ISDB-T, the pilot signal pattern used for channel estimation is the same in all layers; in contrast, in the case of advanced ISDB-T, optimal patterns can be separately selected for fixed reception and for mobile reception. Additionally, on the premise that the broadcasting coverages are equivalent in all layers, the arrangement interval in the frequency direction (Dx) is set to the same value for all layers, and that in the time direction (Dy) can be set to a different value for each layer.

C. Improved Transmission Performance and Capacity

In the case of ISDB-T, a concatenated code composed of a convolutional code and a Reed-Solomon (RS) code is adopted as an FEC. By correcting errors that cannot be corrected by the convolutional code with the RS code, robustness to noise, interference, etc., is improved. In the case of advanced ISDB-T, to further reduce the required carrier to noise ratio (CNR), an LDPC code that has a higher error-correction capability than a convolutional code is adopted, and transmission performance is improved by using it concatenated with a Bose-Chaudhuri-Hocquenghem (BCH) code.

Regarding the carrier modulation scheme in the case of ISDB-T, three options are available: QPSK (quadrature phase shift keying), 16QAM (quadrature amplitude modulation), and 64QAM, and the signal points are arranged in a uniform constellation (UC). In the case of advanced ISDB-T, by increasing the modulation order ranging from QPSK to 4096QAM, a higher transmission capacity is achieved. In addition to UC, robustness against noise is improved by introducing a non-uniform constellation (NUC), especially in high order modulation, which makes the arrangement of

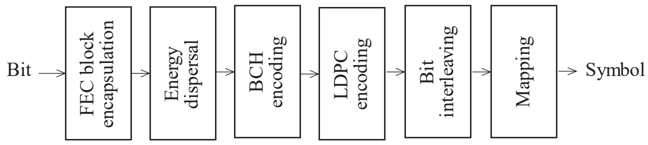

Fig. 3. Configuration of BICM block.

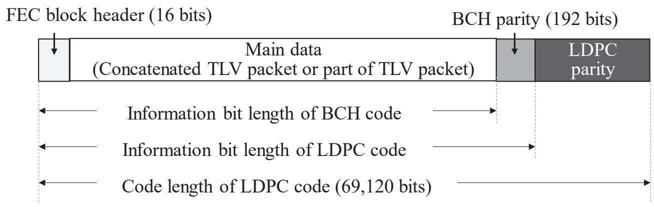

Fig. 4. Configuration of FEC block.

signal points non-uniform [7].

ISDB-T is a single-input single-output (SISO) transmission scheme in which one transmitting antenna and one receiving antenna are configured. It is assumed that a signal stream is transmitted by either a horizontally polarized wave or a vertically polarized wave. In contrast, in the case of the advanced ISDB-T, it is possible to improve transmission robustness by using the 2×1 multiple-input single-output (MISO) scheme—using two transmitting antennas and one receiving antenna—in addition to the SISO scheme and to increase the transmission capacity and/or transmission robustness by using the 2×2 multiple-input multiple-output (MIMO) scheme—using two transmitting antennas and two receiving antennas.

III. Channel Coding

A. Basic Configuration of Channel Coding

The basic configuration of the channel coding of advanced ISDB-T is shown in Fig. 2. Three hierarchical-frame signals (on layers A, B, and C), transmission and multiplexing configuration control (TMCC) information, and LLch information are output from the input interface (Input I/F). The former signals are input into BICM blocks and are

TABLE I
BIT LENGTH OF FEC BLOCK FOR EACH CODE RATE

LDPC code				BCH code		FEC block header	Main data
Code rate	Code length	Parity bit length	Information bit length	Parity bit length	Information bit length		
2/16	69,120	60,480	8,640	192	8,448	16	8,432
3/16	69,120	56,160	12,960	192	12,768	16	12,752
4/16	69,120	51,840	17,280	192	17,088	16	17,072
5/16	69,120	47,520	21,600	192	21,408	16	21,392
6/16	69,120	43,200	25,920	192	25,728	16	25,712
7/16	69,120	38,880	30,240	192	30,048	16	30,032
8/16	69,120	34,560	34,560	192	34,368	16	34,352
9/16	69,120	30,240	38,880	192	38,688	16	38,672
10/16	69,120	25,920	43,200	192	43,008	16	42,992
11/16	69,120	21,600	47,520	192	47,328	16	47,312
12/16	69,120	17,280	51,840	192	51,648	16	51,632
13/16	69,120	12,960	56,160	192	55,968	16	55,952
14/16	69,120	8,640	60,480	192	60,288	16	60,272

subjected to error-correction coding and mapping to carrier symbols. Furthermore, the power for each layer is adjusted, e.g., the power of layer A can be boosted, at the level-adjustment blocks. After that, the layer combining blocks combine the carrier symbols for hierarchical layers A, B, and C. Then, band splitting, time interleaving (TIL), frequency interleaving (FIL), and band combining are performed to form data segments.

To achieve low-latency transmission, processing that differs from the hierarchical frame of the three layers is applied to LLch information, and differential binary phase-shift keying (DBPSK) modulation is performed after the differential reference bit is added to the beginning of the LLch. Some predetermined carriers are assigned to LLch for each OFDM segment, and these carriers can be used for various purposes according to service requirements. At the OFDM framing blocks, a pilot signal, LLch signal, and TMCC signal are added to the data segments to construct an OFDM frame. OFDM modulation is then applied to the frame by using an inverse fast Fourier transform (IFFT), a GI is added, and the output OFDM signal is generated. The signal for SISO transmission is generated via path (1)-(2)-(3) in Fig. 2.

In the case of MISO transmission, the MISO encoding unit applies space time block code (STBC) or space time frequency code (SFBC) to the carrier symbols for data after band combining [8]. The OFDM frame is then formed and subjected to OFDM modulation. Signal output 1 for MISO transmission is generated by the same path (1)-(2)-(3) as for SISO transmission, and signal output 2 is generated by path (1)-(4)-(5). MISO encoding aims to improve the transmission robustness by exploiting the transmission-diversity in a poor reception environment, and the transmission capacity is equivalent to that in the case of SISO.

Moreover, in the case of advanced ISDB-T, it is possible to configure space-division multiplexing (SDM) MIMO [9], which transmits different information from signal outputs 1 and 2, to expand the transmission capacity. For MIMO transmission, it is advantageous that the transmission capacity can be doubled compared with that possible with SISO; however, to achieve satisfactory transmission characteristics by reducing the correlation between propagation paths 1 and 2 in a line-of-sight reception environment, it is necessary to install transmitting and receiving antennas that support orthogonal polarization (horizontal and vertical polarization), which requires an initial cost for broadcasters and viewers. In MIMO transmission, the level-adjusted carrier symbols are separated by symbol-separation blocks into two streams, OFDM frames are formed and subjected to OFDM modulation, and the two signals are output. Signal outputs 1 and 2 of the MIMO transmission are generated via paths (1)-(2)-(3) and (6)-(7)-(5), respectively. For the FIL in MIMO transmission, different interleaving processes are applied for signal outputs 1 and 2 to improve the interleaving effect.

Although SISO, 2×1 MISO, and 2×2 MIMO are introduced in advanced ISDB-T, in the case of using one transmitting antenna, it is supposed that all layers are transmitted via SISO. In the case where two transmitting antennas are available, MISO or MIMO can be selected for each layer. For example, it is possible to improve the reception robustness with layer A (for mobile reception) using MISO and to expand the transmission capacity with layer B (for fixed reception) using MIMO.

B. Bit-Interleaved Coded Modulation

A detailed configuration of the BICM block is shown in Fig. 3. For FEC, a combination of concatenated codes (with the LDPC code as the inner code and BCH code as the outer code) is adopted. Transmission capacity close to the Shannon limit [10] can be obtained by optimizing LDPC codes in combination with bit interleaving and NUCs. For high code rates of 8/16 or higher, the irregular repeat accumulate (IRA) type parity check matrix is used [11]. For low coding rates of 7/16 or less, the multi edge type (MET) parity check matrix characterized by a structure in which two parity check matrices are combined is used [12].

In the block for FEC block encapsulation shown in Fig. 3, the variable-length TLV packet [13], which is the input data, is encapsulated in a fixed-length FEC block. The configuration of the FEC block is shown in Fig. 4. In the case of advanced ISDB-T, to increase the error-correction capability, codes were designed with an FEC block length of 69,120 bits. This block length is longer than that of ISDB-S3 [4], DVB-T2 [14], and ATSC3.0 [15]. The parity length of the LDPC code is determined according to the code rate of the LDPC code. The information bits of the LDPC code include the parity of the BCH code, and the length of the BCH parity is 192 bits regardless of the code rate of the LDPC code.

TABLE II
TRANSMISSION PARAMETERS

	Advanced ISDB-T		ISDB-T
Channel bandwidth	6 MHz		
Number of segment divisions	36		14
Bandwidth of segment	166.7 kHz		428.6 kHz
Number of segments	35	33 + adjusting band	13
Signal bandwidth	5.83 MHz	5.57 MHz	5.57 MHz
Number of layers	Up to 3 layers		
Number of segments in partial reception band	9		1
FFT size (N_{FFT})	8,192, 16,384, 32,768		2,048, 4,096, 8,192
FFT sampling frequency	6.321 MHz (=512/81)		8.127 MHz (=512/63)
Guard interval ratio (GI ratio)	1/4, 1/8, 1/16, 1/32, 1/256, 800/N_{FFT}		1/4, 1/8, 1/16, 1/32
Carrier modulation	QPSK, 16QAM, 64QAM, 256QAM, 1024QAM, 4096QAM (Uniform, Non-uniform)		DQPSK, QPSK, 16QAM, 64QAM (Uniform)
FEC: Inner code	LDPC code		Convolutional code
FEC: Outer code	BCH code		RS code
System configuration	SISO, 2×1 MISO, 2×2 MIMO		SISO

The variable-length TLV packets are stored in the main data area shown in Fig. 4. When a TLV packet cannot fit in this area, it is divided and partly stored there, while the rest is stored in the main data area of the next FEC block. At that time, the start position of the TLV packets in each FEC block is designated by the TLV packet pointer in the FEC block header shown in Fig. 4. The bit length of each part of the FEC block of advanced ISDB-T is listed in Table I.

In general, as the number of decoding iterations and the block length of the LDPC code increase, a larger amount of calculation is required at the receiver. Although it depends on the decoding algorithm, the computational complexity of LDPC code decoding in advanced ISDB-T is considered larger than that of Viterbi decoding in ISDB-T.

C. *Transmission Parameters*

The transmission parameters of advanced ISDB-T are listed in Table II. Although the new scheme attempts to expand the transmission capacity compared with that of ISDB-T by enhancing the frame structure (by increasing the FFT size and reducing the GI ratio while inheriting the functions of hierarchical transmission), considering the migration from the current terrestrial broadcasting to the next-generation system, a GI ratio of 800/N_{FFT} was included for setting the GI length to 126 µs (which is the same as the operational parameter used in Japan for the current ISDB-T). Here, N_{FFT} indicates the FFT size, which is 8,192 (8k), 16,384 (16k), or 32,768 (32k).

Regarding the signal bandwidth, it is possible to choose either the normal mode (bandwidth: 5.83 MHz, where the guard band is reduced compared with that for ISDB-T) using 35/36 of the channel bandwidth or a compatible mode (5.57 MHz: the same bandwidth as for ISDB-T).

TABLE III
BICM SPECTRAL EFFICIENCY (BIT/SYMBOL)

Carrier modulation (bit/symbol)	Code rate of LDPC code (x/16): 2	3	4	5	6	7	8	9	10	11	12	13	14
QPSK(2)	0.25	0.38	0.50	0.63	0.75	0.88	1.00	1.13	1.25	1.38	1.50	1.63	1.75
16QAM (4)	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50
64QAM (6)	0.75	1.13	1.50	1.88	2.25	2.63	3.00	3.38	3.75	4.13	4.50	4.88	5.25
256QAM (8)	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.00
1024QAM (10)	1.25	1.88	2.50	3.13	3.75	4.38	5.00	5.63	6.25	6.88	7.50	8.13	8.75
4096QAM (12)	1.50	2.25	3.00	3.75	4.50	5.25	6.00	6.75	7.50	8.25	9.00	9.75	10.50

TABLE IV
TRANSMISSION PARAMETERS FOR PERFORMANCE EVALUATION

Number of segments (allocated for layer A: layer B)	35 (4:31)
Signal bandwidth	5.83 MHz
Number of layers	2 layers
FFT size (N_{FFT})	16,384
Sub-carrier spacing	385.8 Hz
Guard interval ratio	800/16,384
Effective symbol length	2592 µs
Guard interval length	126.56 µs
Scattered pilot ratio (Dx,Dy)	1/12 (6,2)
Scattered pilot boost (amplitude)	1.29
System configuration	SISO

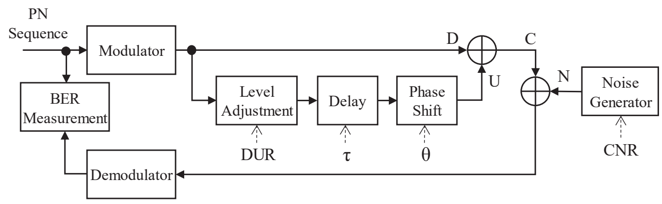

Fig. 5. Block diagram of simulation.

IV. METHODOLOGY AND SIMULATION SETUP

A. *Methodology and Transmission Parameters*

As shown in Table II, there are six options for carrier modulation {QPSK, 16QAM, 64QAM, 256QAM, 1024QAM, 4096QAM} corresponding to the number of transmission bits per symbol V= {2, 4, 6, 8, 10, 12}. There are thirteen types of LDPC code rates R= {2/16, 3/16, …, 14/16}. In this paper, the spectral efficiency of BICM is defined as $V \times R$ [bit/symbol]. Table III shows the spectral efficiency, and combinations having the same spectral efficiency are shown in the same color. As shown, there are multiple combinations with the same spectral efficiency. Fixed reception characteristics were evaluated for the AWGN channel and echo channels for all combinations of BICM with actual channel estimation. The transmission parameters used in the simulations are listed in Table IV. For LDPC code decoding, the layered belief propagation [16] was applied with 25 iterations. For comparison with the current DTTB system, the transmission performance was extensively evaluated with the SISO system. Since MISO is introduced to improve the robustness for mobile reception, this paper focuses on the performance evaluation on SISO in fixed reception. In this paper, we evaluated the fixed reception characteristics of BICM using NUCs and UCs.

B. *Simulation Setup for Fixed Reception Evaluation*

Figure 5 shows a block diagram of the simulation for evaluating the fixed reception performance. The bit error rate (BER) of layer B (for fixed reception) and corresponding

TABLE V
CRITERIA OF BICM SELECTION METHODS FOR FIXED RECEPTION

Method 1-1	Required CNR for AWGN
Method 1-2	Average required CNR for AWGN and 10-dB echo channels
Method 1-3	Average required CNR for AWGN and 3-dB echo channels
Method 1-4	Average required CNR for AWGN, 10-dB echo, and 3-dB echo channels
Method 2	Step 1: required CNR for AWGN Step 2: spectral efficiency and required CNR for 3-dB echo

CNR were evaluated. We defined the signal power "C" as the total power of main wave "D" and the echo wave "U". The CNR was calculated with the total signal power of layers A and B, and the power boost function of layer A was deactivated. The minimum CNR that achieves quasi error free (QEF) data transmission was defined as the required CNR, and the QEF condition was defined as the BER after LDPC code decoding being lower than 10^{-7}. The power ratio between the main wave and the echo in the multipath environment was defined as the desired-to-undesired ratio (DUR), and the phase θ of the echo signal was set to π/2. The delay time between the main wave and the echo was set to a delay time τ = 63 μsec, which is half the GI duration and the value used in the verification of current ISDB-T as a typical value for a practical reception [1]. To confirm the effect of the delay time, the degradation of the required CNR was verified with a short delay time τ = 1 μsec.

C. BICM Selection

Methods for selecting BICM were verified on the basis of the evaluated transmission performance of all BICM combinations (78 options). For all BICMs, the required CNRs for the AWGN and echo channels were compared, and recommended BICM combinations that had the lowest required CNRs were selected. The following two methods were compared.

1) Method 1: One-step selection

Method 1 is a straightforward selection procedure based on the required CNRs for a specific transmission channel. If there are BICM combinations that have the same spectral efficiency, the one that achieves the lowest required CNR should be selected. We considered four typical criteria that are considered reasonable for the fixed reception environment. They are summarized in Table V. Method 1-1 considers only the required CNR for the AWGN channel. Method 1-2 is based on the average required CNR for the AWGN and 10-dB echo channels. Method 1-3 uses the average required CNR for the AWGN and 3-dB echo channels. Method 1-4 is based on the three required CNRs for the AWGN, 3-dB echo, and 10-dB echo channels. The channels of 3-dB echo and 10-dB echo were used in the verification of current ISDB-T as typical values for a practical reception [1].

2) Method 2: Two-step selection

Method 2 is a two-step selection procedure. First, BICM is selected for the AWGN channel in the same manner as Method 1-1. For the surviving BICM combinations in step 1, which have unique spectral efficiency, the final selection is conducted in consideration of the spectral efficiency and the required CNR for the 3-dB echo channel. Specifically, we compared the required CNRs for the 3-dB echo channel of the surviving BICM combinations and when there is a BICM that outperforms others in terms of both the required CNR and spectral efficiency, the inferior one is excluded.

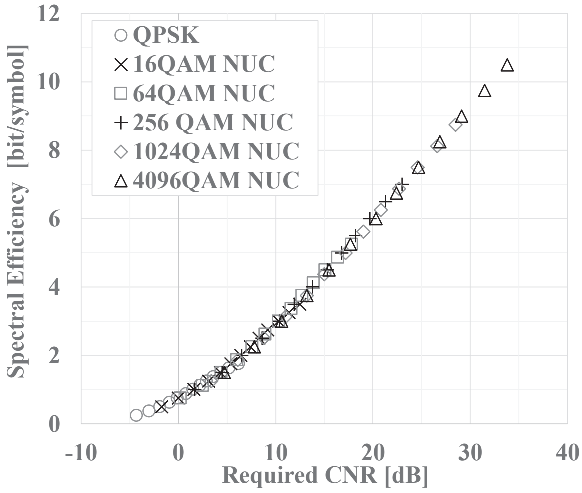

Fig. 6. Required CNR of NUCs for AWGN channel.

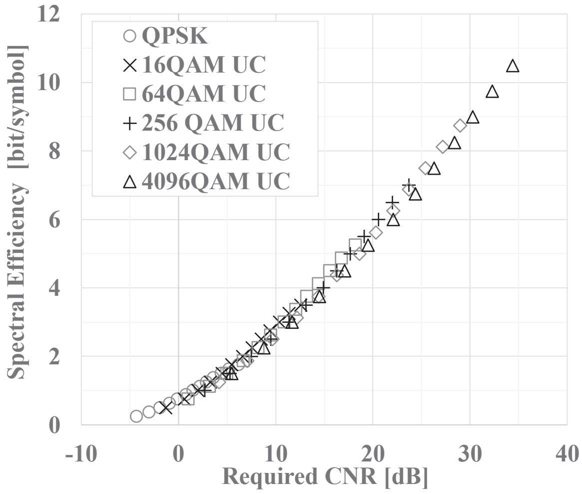

Fig. 7. Required CNR of UCs for AWGN channel.

V. SIMULATION RESULTS

A. Transmission Performance for AWGN Channel

Figure 6 shows the results for the required CNR calculated in simulation for the AWGN channel for all BICM combinations with NUCs. From Fig. 6, each BICM was distributed linearly, and the required CNR corresponding to a spectral efficiency of 0.25 to 10.5 [bps/symbol] was from -5 dB to 35 dB. Figure 7 shows the required CNR for the UCs. It can be seen that the required CNR slightly increased (degraded) for the combination of high-order modulation and low code rate of LDPC codes.

The relationship between the transmission capacity per channel of advanced ISDB-T and the required CNR is plotted in Fig. 8. The results were calculated with the parameters in Table IV with the exception that all 35 segments were allocated for one layer. The capacity of the MIMO system is also shown in Fig. 8. When the advanced ISDB-T SISO (circles) and ISDB-T scheme (diamond) are compared, it can be seen that, for the former scheme, (i) the transmission capacity increased by about 10 Mbps with the same required CNR, and (ii) the required CNR was reduced by about 7 dB

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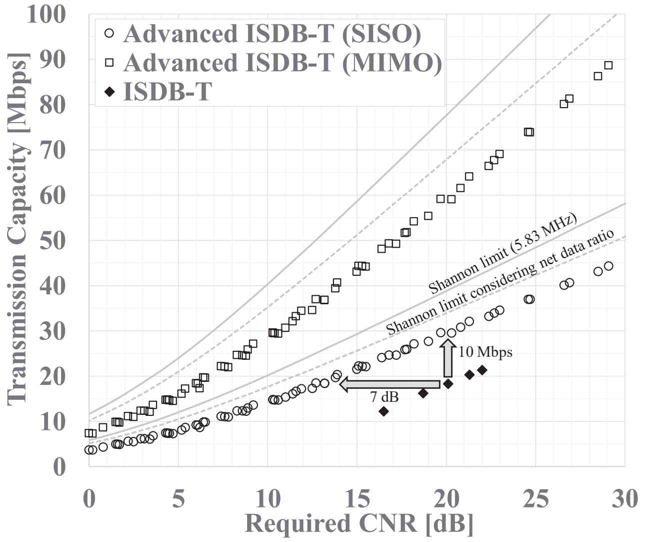

Fig. 8. Transmission capacity for SISO and MIMO systems with NUCs for AWGN channel. Advanced ISDB-T with 35 segments (5.83 MHz) and ISDB-T with 13 segments (5.57 MHz).

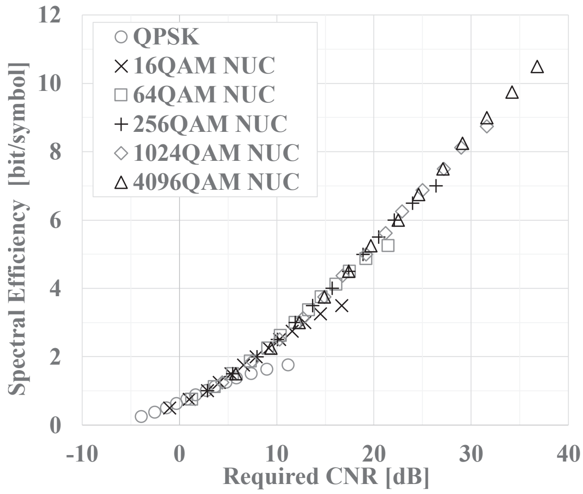

Fig. 9. Required CNR of NUCs for 3-dB echo channel.

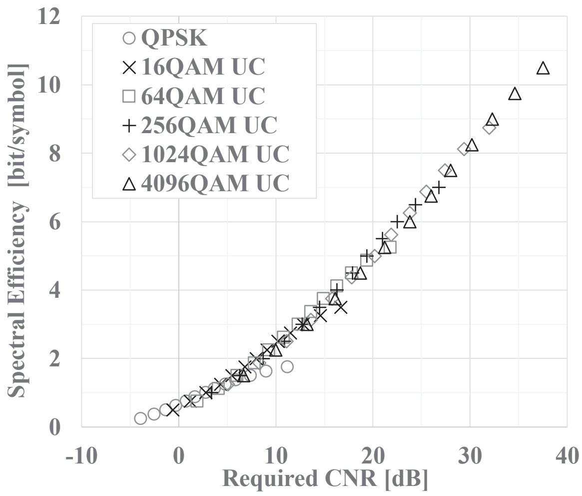

Fig. 10. Required CNR of UCs for 3-dB echo channel.

while keeping the same transmission capacity. As to MIMO configuration, the transmission capacity was doubled compared with SISO configuration, when the overhead signal ratio is the same as SISO.

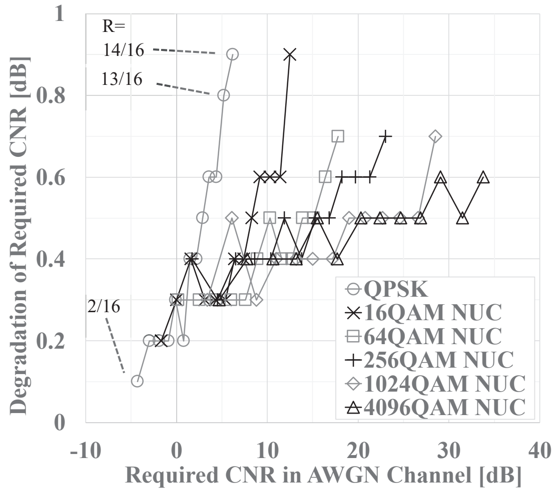

Fig. 11. Degradation of required CNR with NUCs for 10-dB echo channel.

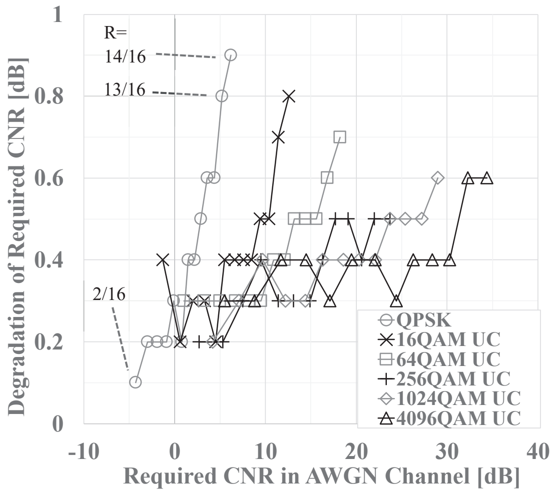

Fig. 12. Degradation of required CNR with UCs for 10-dB echo channel.

B. Transmission Performance in Echo Channel

Figures 9 and 10 show the results for the required CNR for the 3-dB echo channel for NUCs and UCs, respectively. Almost all the BICMs were distributed on a straight line; however, some with high code rates diverged slightly to the right. Table VI shows a summary of the required CNR for the AWGN and echo channels when NUCs were configured. In addition to the 3-dB echo channel, the required CNRs for the 10-dB echo channel were also evaluated. The deterioration in the required CNR from that for the AWGN channel was calculated, and the degradation values are plotted in Figs. 11 and 12, which show the degradation of NUCs and UCs, respectively. Regardless of the carrier modulation whether NUC or UC was used, the degradation of the required CNR for the 10-dB echo channel became within 1 dB. These results indicate that the multipath margin integrated with the required electric field strength used for the link budget of advanced ISDB-T can be 1 dB or less assuming the same 10-dB echo channel used in the current ISDB-T planning used in Japan [1].

TABLE VI
SUMMARY OF REQUIRED CNR FOR NUCS IN AWGN CHANNEL AND ECHO CHANNELS

Channel	Carrier modulation	Code rate of LDPC code (x/16)												
		2	3	4	5	6	7	8	9	10	11	12	13	14
AWGN	QPSK	-4.3	-3	-1.9	-0.9	-0.1	0.8	1.5	2.2	2.9	3.6	4.4	5.2	6.2
	16QAM	-1.7	0	1.6	3.1	4.3	5.4	6.4	7.4	8.3	9.2	10.3	11.4	12.5
	64QAM	0.2	2.5	4.4	6	7.6	8.9	10.3	11.6	12.7	13.9	15.1	16.4	17.8
	256QAM	1.7	4.5	6.5	8.6	10.4	11.9	13.8	15.3	16.8	18.2	19.7	21.3	23
	1024QAM	3.4	6.1	8.8	11	13.2	15	17.2	19	20.8	22.7	24.6	26.6	28.5
	4096QAM	4.7	7.8	10.6	13.2	15.5	17.7	20.3	22.4	24.7	26.9	29.1	31.5	33.8
3-dB echo	QPSK	-3.9	-2.5	-1.3	-0.3	0.8	1.7	2.8	3.7	4.8	5.9	7.4	9	11.2
	16QAM	-1	1	2.9	4.1	5.3	6.6	7.9	9.2	10.3	11.6	12.9	14.5	16.7
	64QAM	1.3	3.6	5.5	7.3	9.1	10.4	11.9	13.3	14.6	16.1	17.5	19.2	21.5
	256QAM	2.9	5.5	8	10.1	11.9	13.7	15.7	17.4	18.9	20.5	22.1	24	26.4
	1024QAM	4.4	7.5	10.3	12.7	14.9	16.8	19.2	21.2	22.9	25	27.2	29	31.6
	4096QAM	5.8	9.4	12.3	14.9	17.4	19.7	22.5	24.6	27.1	29.1	31.6	34.2	36.8
10-dB echo	QPSK	-4.2	-2.8	-1.7	-0.7	0.2	1	1.9	2.6	3.4	4.2	5	6	7.1
	16QAM	-1.5	0.3	2	3.4	4.6	5.7	6.8	7.8	8.8	9.8	10.9	12	13.4
	64QAM	0.5	2.8	4.7	6.3	7.9	9.3	10.8	12	13.1	14.4	15.6	17	18.5
	256QAM	2.1	4.8	6.9	9	10.8	12.4	14.2	15.8	17.3	18.8	20.3	21.9	23.7
	1024QAM	3.7	6.6	9.1	11.4	13.6	15.4	17.6	19.5	21.3	23.2	25.1	27.1	29.2
	4096QAM	5	8.2	11	13.6	16	18.1	20.8	22.9	25.2	27.4	29.7	32	34.4

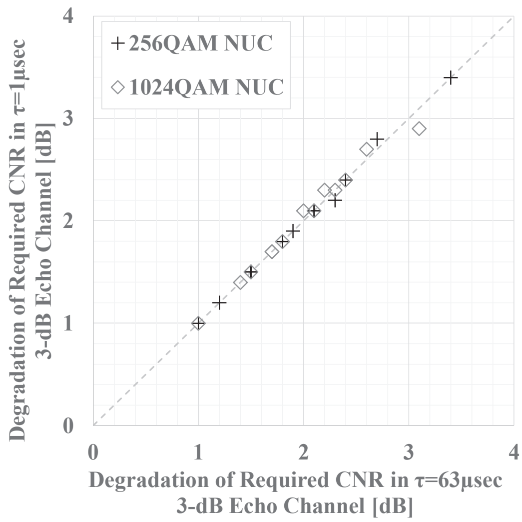

Fig. 13. Comparison of degradation of required CNR with NUCs in short and long delay 3-dB echo channels.

Figure 13 shows the degradation of the required CNR for the 3-dB echo channel with NUCs for delay time τ = 1 μsec and 63 μsec. It was observed that even when the delay time was very short, the degradation amount was almost the same as that observed for the τ = 63 μsec echo channel.

C. BICM Selection

1) Method 1: One-step selection

For NUCs, the BICM selection results with Methods 1-1, 1-2, 1-3, and 1-4 are shown in Tables VII, VIII, IX, and X. The excluded combinations are shown in gray. As an example of a spectral efficiency of 1.00 bps/Hz, the BICMs are shown in brown in Table III, i.e., (QPSK, 8/16), (16QAM, 4/16), (256QAM, 2/16). From Table V, the required CNRs for AWGN were 1.5, 1.6, and 1.7 dB, respectively. In this case, (QPSK, 8/16) was selected with Method 1-1, and the remaining two combinations were excluded. It was confirmed that the difference between the BICMs selected by Methods 1-1 and 1-2 was (16QAM, 12/16). With Method 1-3, two combinations, (QPSK, 10/16) and (16QAM, 12/16), were excluded, and two combinations, (16QAM, 5/16) and (4096QAM, 10/16), survived when compared with the results of Method 1-1. In the results for Method 1-4, (QPSK, 10/16)

TABLE VII
METHOD 1-1: NUC BICM SELECTION RESULTS AND REQUIRED CNR FOR AWGN CHANNEL

Carrier modulation (bit/symbol)	Code rate of LDPC code (x/16)												
	2	3	4	5	6	7	8	9	10	11	12	13	14
QPSK(2)	-4.3	-3.0	-1.9	-0.9	-0.1	0.8	1.5	2.2	2.9	3.6	4.4	5.2	6.2
16QAM (4)	-1.7	0.0	1.6	3.1	4.3	5.4	6.4	7.4	8.3	9.2	10.3	11.4	12.5
64QAM (6)	0.2	2.5	4.4	6.0	7.6	8.9	10.3	11.6	12.7	13.9	15.1	16.4	17.8
256QAM (8)	1.7	4.5	6.5	8.6	10.4	11.9	13.8	15.3	16.8	18.2	19.7	21.3	23.0
1024QAM (10)	3.4	6.1	8.8	11.0	13.2	15.0	17.2	19.0	20.8	22.7	24.6	26.6	28.5
4096QAM (12)	4.7	7.8	10.6	13.2	15.5	17.7	20.3	22.4	24.7	26.9	29.1	31.5	33.8

TABLE VIII
METHOD 1-2: NUCS BICM SELECTION RESULTS AND AVERAGE REQUIRED CNR FOR AWGN AND 10-DB ECHO CHANNELS

Carrier modulation (bit/symbol)	Code rate of LDPC code (x/16)												
	2	3	4	5	6	7	8	9	10	11	12	13	14
QPSK(2)	-4.25	-2.90	-1.80	-0.80	0.05	0.90	1.70	2.40	3.15	3.90	4.70	5.60	6.65
16QAM (4)	-1.60	0.15	1.80	3.25	4.45	5.55	6.60	7.60	8.55	9.50	10.60	11.70	12.95
64QAM (6)	0.35	2.65	4.55	6.15	7.75	9.10	10.55	11.80	12.90	14.15	15.35	16.70	18.15
256QAM (8)	1.90	4.65	6.70	8.80	10.60	12.15	14.00	15.55	17.05	18.50	20.00	21.60	23.35
1024QAM (10)	3.55	6.35	8.95	11.20	13.40	15.20	17.40	19.25	21.05	22.95	24.85	26.85	28.85
4096QAM (12)	4.85	8.00	10.80	13.40	15.75	17.90	20.55	22.65	24.95	27.15	29.40	31.75	34.10

TABLE IX
METHOD 1-3: NUCS BICM SELECTION RESULTS AND AVERAGE REQUIRED CNR FOR AWGN AND 3-DB ECHO CHANNELS

Carrier modulation (bit/symbol)	Code rate of LDPC code (x/16)												
	2	3	4	5	6	7	8	9	10	11	12	13	14
QPSK(2)	-4.10	-2.75	-1.60	-0.60	0.35	1.25	2.15	2.95	3.85	4.75	5.90	7.10	8.70
16QAM (4)	-1.35	0.50	2.25	3.60	4.80	6.00	7.15	8.30	9.30	10.40	11.60	12.95	14.60
64QAM (6)	0.75	3.05	4.95	6.65	8.35	9.65	11.10	12.45	13.65	15.00	16.30	17.80	19.65
256QAM (8)	2.30	5.00	7.25	9.35	11.15	12.80	14.75	16.35	17.85	19.35	20.90	22.65	24.70
1024QAM (10)	3.90	6.80	9.55	11.85	14.05	15.90	18.20	20.10	21.85	23.85	25.90	27.80	30.05
4096QAM (12)	5.25	8.60	11.45	14.05	16.45	18.70	21.40	23.50	25.90	28.00	30.35	32.85	35.30

TABLE X
METHOD 1-4: NUC BICM SELECTION RESULTS AND AVERAGE REQUIRED CNR FOR AWGN, 3-DB, 10-DB ECHO CHANNELS

Carrier modulation (bit/symbol)	Code rate of LDPC code (x/16)												
	2	3	4	5	6	7	8	9	10	11	12	13	14
QPSK(2)	-4.13	-2.77	-1.63	-0.63	0.30	1.17	2.07	2.83	3.70	4.57	5.60	6.73	8.17
16QAM (4)	-1.40	0.43	2.17	3.53	4.73	5.90	7.03	8.13	9.13	10.20	11.37	12.63	14.20
64QAM (6)	0.67	2.97	4.87	6.53	8.20	9.53	11.00	12.30	13.47	14.80	16.07	17.53	19.27
256QAM (8)	2.23	4.93	7.13	9.23	11.03	12.67	14.57	16.17	17.67	19.17	20.70	22.40	24.37
1024QAM (10)	3.83	6.73	9.40	11.70	13.90	15.73	18.00	19.90	21.67	23.63	25.63	27.57	29.77
4096QAM (12)	5.17	8.47	11.30	13.90	16.30	18.50	21.20	23.30	25.67	27.80	30.13	32.57	35.00

TABLE XI
METHOD 2: NUC BICM SELECTION RESULTS AND REQUIRED CNR FOR 3-DB ECHO CHANNEL

Carrier modulation (bit/symbol)	Code rate of LDPC code (x/16)												
	2	3	4	5	6	7	8	9	10	11	12	13	14
QPSK(2)	-3.9	-2.5	-1.3	-0.3	0.8	1.7	2.8	3.7	4.8	5.9	7.4	9.0	11.2
16QAM (4)	-1.0	1.0	2.9	4.1	5.3	6.6	7.9	9.2	10.3	11.6	12.9	14.5	16.7
64QAM (6)	1.3	3.6	5.5	7.3	9.1	10.4	11.9	13.3	14.6	16.1	17.5	19.2	21.5
256QAM (8)	2.9	5.5	8.0	10.1	11.9	13.7	15.7	17.4	18.9	20.5	22.1	24.0	26.4
1024QAM (10)	4.4	7.5	10.3	12.7	14.9	16.8	19.2	21.2	22.9	25.0	27.2	29.0	31.6
4096QAM (12)	5.8	9.4	12.3	14.9	17.4	19.7	22.5	24.6	27.1	29.1	31.6	34.2	36.8

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TABLE XII
METHOD 1-1: UC BICM SELECTION RESULTS AND REQUIRED CNR FOR AWGN CHANNEL

Carrier modulation (bit/symbol)	Code rate of LDPC code (x/16)												
	2	3	4	5	6	7	8	9	10	11	12	13	14
QPSK(2)	-4.3	-3.0	-1.9	-0.9	-0.1	0.8	1.5	2.2	2.9	3.6	4.4	5.2	6.2
16QAM (4)	-1.3	0.6	2.0	3.3	4.5	5.5	6.6	7.6	8.5	9.4	10.4	11.4	12.6
64QAM (6)	1.0	3.2	5.0	6.7	8.2	9.5	10.9	12.1	13.2	14.4	15.6	16.8	18.2
256QAM (8)	2.7	5.3	7.5	9.5	11.4	13.1	14.9	16.3	17.7	19.1	20.6	22.0	23.7
1024QAM (10)	4.2	7.1	9.7	12.2	14.4	16.3	18.6	20.3	22.1	23.7	25.4	27.2	29.0
4096QAM (12)	5.5	8.8	11.7	14.5	17.1	19.5	22.1	24.4	26.3	28.4	30.3	32.3	34.4

TABLE XIII
METHOD 2: UC BICM SELECTION RESULTS AND REQUIRED CNR FOR 3-DB ECHO CHANNEL

Carrier modulation (bit/symbol)	Code rate of LDPC code (x/16)												
	2	3	4	5	6	7	8	9	10	11	12	13	14
QPSK(2)	-3.9	-2.5	-1.3	-0.3	0.8	1.7	2.8	3.7	4.8	5.9	7.4	9.0	11.2
16QAM (4)	-0.6	1.2	2.8	4.3	5.5	6.8	8.0	9.1	10.2	11.5	12.8	14.6	16.7
64QAM (6)	1.9	4.1	6.0	7.8	9.3	10.8	12.3	13.6	14.9	16.3	17.8	19.4	21.8
256QAM (8)	3.4	6.3	8.7	10.9	12.7	14.5	16.3	17.9	19.4	21.0	22.5	24.4	26.8
1024QAM (10)	5.1	8.3	11.1	13.6	15.8	17.8	20.2	21.9	23.8	25.5	27.4	29.4	32.0
4096QAM (12)	6.7	10.0	13.2	16.1	18.7	21.2	23.8	26.0	28.0	30.2	32.3	34.6	37.5

and (16QAM, 12/16) were excluded, and (16QAM, 5/16) survived. Method 1 is a simple procedure, but the BICM combination excluded was limited to BICMs that had overlapping spectral efficiency.

2) *Method 2: Two-step selection*

For step 1, BICM combinations having the same spectral efficiency with a higher required CNR for the AWGN channel were excluded as with Method 1-1 in step 1.

Table XI shows the BICM selection results for NUCs after step 2 for Method 2. The combinations excluded in step 1 (Method 1-1) are shown in black, and those cut out in step 2 are shown in gray. Explaining the excluded combination example, (QPSK, 11/16) had a spectral efficiency of 1.38 bit/symbol, and the required CNR for the 3-dB echo channel was 5.9 dB. In comparison, (16QAM, 6/16) showed a spectral efficiency of 1.50 bit/symbol with the required CNR of 5.3 dB. In this example, (QPSK, 11/16) that had a smaller spectral efficiency and a higher required CNR than (16QAM, 6/16) was excluded. As in the case just described, if other BICM combinations with high spectral efficiency and low required CNR were available, the undesirable BICMs would be excluded. From Table XI, a BICM combinations with a high code rate and low order modulation tended to be excluded in the BICM selection in step 2 due to their worse transmission performance in echo channels.

For UCs, the BICM selection results for step 1 (Method 1-1) and step 2 are shown in Tables XII and XIII. The combinations excluded in step 1 are shown in black, and those cut out in step 2 are shown in gray in Table XIII. The BICM selection results of UCs were not completely the same as those for NUCs, but BICM combinations with high code rate and low order modulation or low code rate and high order modulation are not recommended for practical use.

VI. CONCLUSION

Aiming to enhance the functionality and quality of digital terrestrial television broadcasting, NHK has been studying a new transmission scheme for simultaneously providing Super Hi-Vision broadcasting for fixed reception and high-definition broadcasting for mobile reception on a single channel. While inheriting the features of the ISDB-T scheme such as the hierarchical transmission function based on a segment structure, the new advanced ISDB-T has new features: an enhanced signal structure and the latest technology for improving transmission performance and capacity. In particular, the flexibility of allocating bandwidth to multiple services for different receiving modes such as fixed reception and mobile reception is improved. Moreover, by introducing the latest LDPC code, NUC, MISO/MIMO technology for improving performance and capacity, the new transmission scheme attains a higher spectral efficiency, larger capacity, and better transmission robustness than ISDB-T.

The fixed reception performance of all BICM combinations of the advanced ISDB-T was evaluated for AWGN and echo channels. As a result of an evaluation by computer simulation, several BICM selection methods were demonstrated to select the recommended combination for fixed reception. It was confirmed that BICM combinations with a high code rate and low modulation order or low code rate and high modulation order were not recommended. In an echo channel with DUR = 10 dB, the degradation in the required CNR was below 1 dB for all combinations of BICM regardless of whether NUCs or UC were used.

In the future, we will evaluate other transmission parameters, verify them in indoor experiments and field experiments, and proceed with demonstrations that will contribute to the formulation of a link budget and planning parameters for the practical application of advanced ISDB-T broadcasting networks.

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REFERENCES

[1] ARIB STD-B31 ver. 2.2, Transmission System for Digital Terrestrial Television Broadcasting, 2014.

[2] R.W. Chang and R.A. Gabby, "A Theoretical Study of Performance of an Orthogonal Multiplexing Data Transmission Scheme," IEEE Trans on Commun., COM-16, pp. 529-540, 1968.

[3] M. Nakamura et al., "A Study on the Transmission System for Advanced ISDB-T," Proc. IEEE International Symposium on Broadband Multimedia Systems and Broadcasting, 2019.

[4] N. Shirai et al., "Transmission System Design of UHD-1/4K and UHD-2/8K Terrestrial Television Broadcasting and its Performance Proof by Large-scaled Field Experiments," SMPTE Motion Imaging Journal, vol. 126, issue 6, pp. 35-42, 2020.

[5] ARIB STD-B44 ver. 2.1, Transmission System for Advanced Wide Band Digital Satellite Broadcasting (ISDB-S3), 2016.

[6] A. Guillén i Fàbregas, A. Martinez, and G. Caire, "Bit-interleaved Coded Modulation," Foundations and Trends in Communications and Information Theory, vol. 5, no. 1-2, pp. 1-144, 2008.

[7] G.D. Forney Jr. and L-F Wei, "Multidimensional Constellations - Part I: Introduction, Figures of Merit, and Generalized Cross Constellations," IEEE Journal on Selected Areas in Communications, vol. 7, no. 6, pp. 877-892, 1989.

[8] S.M. Alamouti, "A Simple Transmit Diversity Technique for Wireless Communications," IEEE J. Select. Areas Commun., vol. 16, no. 8, pp. 1451-1458, 1998.

[9] R.V.L. Hartley, "Transmission of Information," Bell System Technical Journal, 1928.

[10] G.J. Foschini, "Layered Space-time Architecture of Wireless Communication in a Fading Environment when using Multiple Antennas," Bell Labs. Tech. J., vol. 1, no. 2, pp. 41-59, 1996.
[11] H. Jin, A. Khandekar, and R. McEliece, "Irregular Repeat-accumulate Codes," Proc. 2nd Int. Symp. Turbo Codes, Related Topics, pp. 1-8, 2000.
[12] T. Richardson and R. Urbanke, "Multi-edge Type LDPC Codes," Proc. Workshop Honoring Prof. Bob McEliece 60th Birthday, Pasadena, CA, USA, pp. 24–25, 2002.
[13] Recommendation. ITU-R BT.1869-0, "Multiplexing Scheme for Variable-length Packets in Digital Multimedia Broadcasting Systems," 2010.
[14] ETSI EN 302 755 V1.4.1, Digital Video Broadcasting (DVB); Frame Structure, Channel Coding and Modulation for a Second Generation Digital Terrestrial Television Broadcasting System (DVB-T2), 2015.
[15] A/322:2017, ATSC Standard: Physical Layer Protocol, 2017.
[16] D. E. Hocevar, "A Reduced Complexity Decoder Architecture via Layered Decoding of LDPC Codes," Proc. IEEE Workshop on Signal Processing Systems, 2004.

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