A STUDY ON THE TRANSMISSION SCHEME FOR THE ADVANCED ISDB-T AND VERIFICATION BY LARGE-SCALE FIELD EXPERIMENTS IN JAPAN

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ABSTRACT

Japan Broadcasting Corporation (NHK) has been conducting research on the development of advanced terrestrial broadcasting technology to transmit ultra-high definition television signals. To analyze the transmission characteristics of the proposed system, we designed a prototype modulator and demodulator and measured its performance through laboratory experiments. Further, we also evaluated the proposed system via large-scale field trials in conditions similar to those of actual broadcast propagation environments.

This paper presents the concept and specifications of the advanced ISDB-T system under study. The verification results of a computer simulation, and laboratory and large-scale field experiments are also described.

INTRODUCTION

In Japan, 4K/8K ultra-high definition television (UHDTV) (1) broadcasting by satellite was launched on December 1, 2018. Meanwhile, several studies on a next-generation digital terrestrial television broadcasting (DTTB) system have been conducted widely in Japan. Since 2007, Japan Broadcasting Corporation (NHK) has been conducting research and development on large-capacity transmission technologies for terrestrial 4K/8K UHDTV broadcasting. We have successfully carried out 8K transmission experiments using higher-order modulation and dual-polarized multi-input multi-output (MIMO) technologies (2), and mobile reception experiments of 2K (HDTV) using dual-polarized MIMO technology (3).

Since 2016, we have been researching and developing transmission systems for a next-generation DTTB as a part of the research program “Research and Development for Advanced Digital Terrestrial TV Broadcasting System” under the auspices of the Ministry of Internal Affairs and Communications, Japan. We have proposed a system called the advanced Integrated Services Digital Broadcasting-Terrestrial (advanced ISDB-T) (4). The transmission characteristics of the advanced ISDB-T exceed those of ISDB-T (5). In this paper, we describe the concept and specifications of the advanced ISDB-T. We also present the verification results of a computer simulation, and laboratory and large-scale field experiments.

CONCEPT AND FEATURES OF THE ADVANCED ISDB-T

In Japan, 8K UHDTV broadcasting by satellite has been launched. In this regard, we developed the advanced ISDB-T, a DTTB system with the goal of transmitting 4K/8K video. Table 1 lists the transmission parameters of the advanced ISDB-T and ISDB-T. The advanced ISDB-T inherits the features of ISDB-T. A new signal frame structure was applied to enable flexible bandwidth allocation to multiple services for different reception scenarios such as fixed reception and mobile reception. In addition, transmission technologies, such as the latest error correction code and modulation scheme, were introduced to improve frequency usage efficiency. The main features of the advanced ISDB-T are as follows.

Note that, in this paper, SISO means a single-input single-output system that transmits using single polarization waves (either horizontally polarized or vertically polarized).

	Advanced ISDB-T			ISDB-T (Mode3)
Channel bandwidth	6 MHz			6 MHz
Occupied bandwidth	5.83 MHz			5.57 MHz
Number of segments	35			13
Bandwidth of segment	167 kHz			429 kHz
FFT size	8,192 (8k)	16,384 (16k)	32,768 (32k)	8,192 (8k)
Number of carriers	7,561	15,121	30,241	5,617
Scattered pilot ratio	1/3, 1/6, 1/12, 1/24, 1/48			1/12
Carrier modulation scheme	QPSK, 16QAM, 64QAM, 256QAM, 1024QAM, 4096QAM (UC, NUC)*			QPSK, 16QAM, 64QAM (UC)
Number of OFDM symbols per a OFDM frame	224	112	56	204
Effective OFDM symbol length	1,296 ms	2,592 ms	5,184 ms	1,008 ms
Guard interval ratio	1/4, 1/8, 800/8192	1/4, 1/8, 1/16, 800/16384	1/8, 1/16, 1/32, 800/32768	1/4, 1/8, 1/16, 1/32
IFFT sampling frequency	512/81 = 6.32… MHz			512/63 = 8.12… MHz
Inner code	LDPC code			Convolutional code
Outer code	BCH code			RS code
System	SISO, MIMO			SISO

*UC: Uniform constellation, NUC: Non-uniform constellation

Table 1 – Transmission parameters of the advanced ISDB-T and ISDB-T

Inherited Features and Improved Structure of ISDB-T

The advanced ISDB-T inherits features of ISDB-T. The advanced ISDB-T is capable of providing UHDTV services for fixed reception and HDTV services for mobile reception in one channel. Therefore, the advanced ISDB-T can transmit up to three layers (layers A, B, and C) with different transmission capacities and robustness. Similar to ISDB-T, an advanced ISDB-T adopts frequency division multiplexing and segmented OFDM structure. The advanced ISDB-T has an increased number of segments, i.e., it has 35 segments compared to the ISDB-T's 13. Therefore, the number of segments assigned to each layer can be selected more flexibly in comparison to ISDB-T. Moreover, to enable broadcasters to flexibly select the transmission capacity and robustness for each layer depending on the service, the advanced ISDB-T can select transmission parameters (modulation scheme, coding rate, time interleaving length, pilot ratio, and number of segments) independently for each layer.

Increase in Transmission Capacity

To increase the transmission capacity, transmission parameters such as occupied bandwidth, modulation scheme, and fast Fourier transform (FFT) size of the advanced ISDB-T were modified from those of the ISDB-T. First, the occupied bandwidth of the advanced ISDB-T was extended by approximately 5% over that of ISDB-T. Second, higher-order modulation schemes such as 256QAM, 1024QAM, and 4096QAM were added to the advanced ISDB-T to increase its transmission capacity. Furthermore, the FFT size was increased to four times that of the ISDB-T, resulting in a longer effective OFDM symbol length. The guard interval (GI) ratio of the advanced ISDB-T was also smaller than that of the ISDB-T. Thus, the transmission capacity was increased.

BASIC PERFORMANCE OF THE ADVANCED ISDB-T FOR FIXED RECEPTION

The basic performance of the advanced ISDB-T for fixed reception in an AWGN channel was evaluated by a computer simulation. Figure 1 shows the relationship between the required CNR of the SISO system and the transmission capacity per 6 MHz. In this simulation, the number of segments was set to 35. The transmission capacity of the advanced ISDB-T can be set flexibly in the range of 1 Mbps to 53 Mbps by suitable transmission parameter. Compared to the operated parameters of ISDB-T in Japan, the transmission capacity of the advanced ISDB-T can be increased by approximately 10 Mbps with the same required CNR, and the required CNR can be improved by approximately 7 dB with the same transmission capacity.

The transmission capacity can be increased by using a MIMO technology. Figure 2 shows the relationship between the required CNR and transmission capacity for the SISO and MIMO systems. When the required CNR is set to 20–25 dB, the transmission capacity of the SISO system becomes 30–38 Mbps, and the transmission capacity of the MIMO system becomes 60–76 Mbps. Because the transmission capacity of the ISDB-T is approximately 18 Mbps, it is possible to realize a transmission capacity of up to 2 times for SISO systems and up to 4 times for MIMO systems.

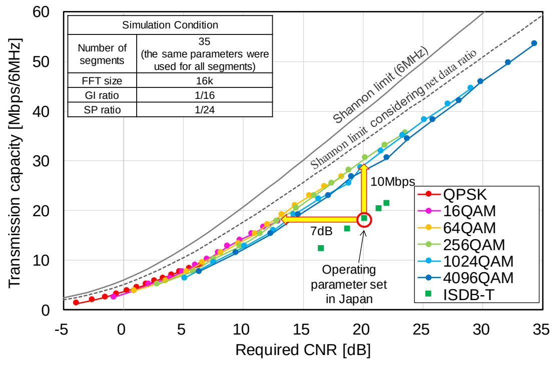


Figure 1 – Relationship between transmission capacity and required CNR for SISO system (Results of computer simulation)

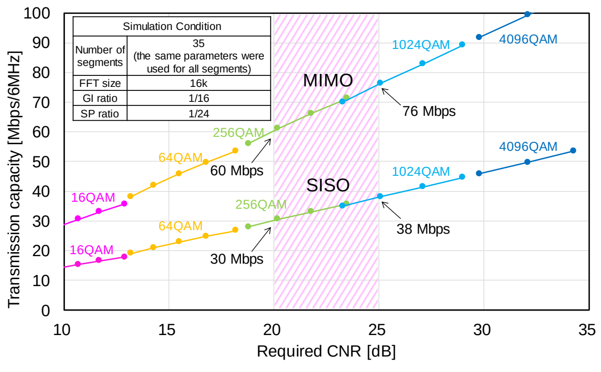


Figure 2 – Transmission capacity for SISO and MIMO systems (Results of computer simulation)

RESULTS OF LABORATORY EXPERIMENTS FOR FIXED RECEPTION

We developed an experimental modulator and demodulator that implements the advanced ISDB-T and then conducted laboratory experiments to evaluate its transmission characteristics in an AWGN environment. Figure 3 shows photographs of the equipment, and Figure 4 shows an example of its BER performance, i.e., relationship between CNR and BER before BCH decoding. The simulation values shown in Figure 2 were calculated using an iterative decoding scheme with LDPC, considering the intended implementation of the device. We measured a minimum CNR where the BER was 1×10^{-7} or less before BCH decoding. The value of CNR is referred to as the required CNR. The measured required CNR was 21.0 dBm, and the difference between the simulation and experimental values was 0.6 dB. The experimental equipment could be implemented with an error of 0.6 dB. Note that the outer code performance of the advanced ISDB-T is equal to that of DVB-T2 (6). Therefore, the BER requirements of the advanced ISDB-T are the same as those of DVB-T2 (7).

Next, we evaluated the required CNR for all possible combinations of carrier modulation parameters and coding rates. Figure 5 shows the relationship between the required CNR and the transmission capacity per channel (6 MHz). In this experiment, all characteristics, including the lowest required CNR parameters and the highest transmission capacity parameters, were considered. The transmission capacity of the proposed implementation for all combinations was within 3 dB of the Shannon limit considering net data ratio.

(a) Modulator (b) Demodulator

Figure 3 – Experimental equipment for the advanced ISDB-T

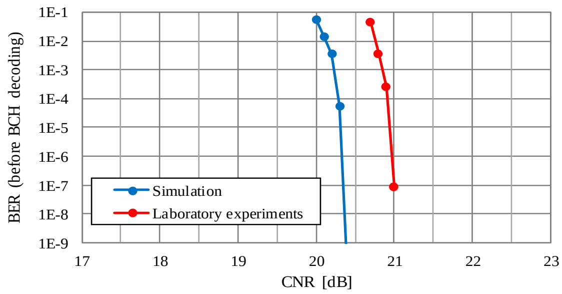


Figure 4 – Example of BER performance (FFT size: 16k, pilot ratio: 1/12, 256QAM, coding rate: 12/16, guard interval ratio: 1/16, SISO)

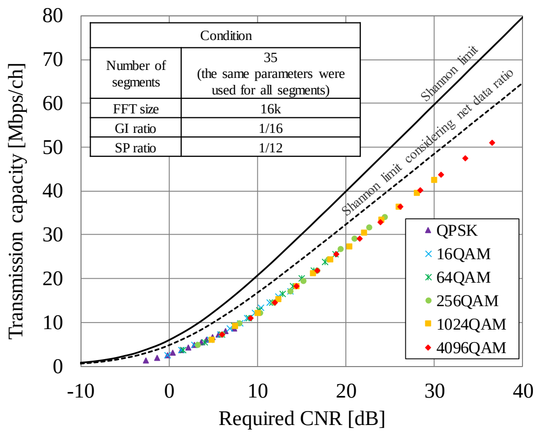


Figure 5 – Relationship between required CNR and transmission capacity for SISO system (Results of laboratory experiments)

RESULTS OF FIELD EXPERIMENTS FOR FIXED RECEPTION

Parameters

We selected two parameters that would be equal to the required CNR and GI of ISDB-T operated in Japan. Table 2 lists these parameters.

Next, we describe the bit rates of the selected parameters. The maximum video bit rates for broadcasting emission using the high efficiency video coding (HEVC/H.265) standard are recommended to be 30–40 Mbps for 4K and 80–100 Mbps for 8K (8). Moreover, a next-generation video coding standard, versatile video coding (VVC), is under development (9). The coding efficiency of VVC has been targeted to be 30% better than that of HEVC. The maximum video bit rates using VVC are estimated to be 21 Mbps for 4K and 56 Mbps for 8K. Therefore, set of parameters (I) assumes that 4K video can be transmitted. In contrast, set of parameters (II) assumes that 8K video can be transmitted if all segments are used as fixed reception, i.e. if 35 segments are assigned to fixed reception, the transmission capacity becomes 58.3 Mbps.

	(I)	(II)
Number of layers	2	
Number of segments for mobile reception	4	
Number of segments for fixed reception	31	
FFT size	16k	
Guard interval ratio	800/16384	
SP ratio	1/12	
Carrier modulation	256QAM	
Code rate	12/16	
Required CNR	21.0 dB	
System	SISO	MIMO
Transmission capacity for fixed reception	26.1 Mbps	52.3 Mbps
Remarks	Required CNR equal to that of ISDB-T	

Table 2 – Parameters of field experiments

Field Experiments

To evaluate the performance of the advanced ISDB-T in different propagation environments, we selected 26 reception points within the contour. Table 3 summarizes the specifications of the transmitter site (10). Figure 6 shows the locations of the transmitter site and the reception points. At each point, the required power, i.e. the minimum value of the received power to achieve Quasi Error Free (QEF) transmission, was measured. Figure 7 shows a block diagram of transmission and reception for field experiments. We transmitted signals of the advanced ISDB-T (Figure 7 (a)) and then received signals and measured the BER (Figure 7(b)). The required power was measured by attenuating the received

Transmitter site	Shiba (Minato-ku, Tokyo)
Transmission frequency	563.143 MHz (Ch 28 in Japan)
Polarization	Horizontal and/or vertical
Transmission power	Horizontal: 1 kW, Vertical: 1 kW
Transmitting antenna height	280 m above sea level

Table 3 – Specification of the transmitter site

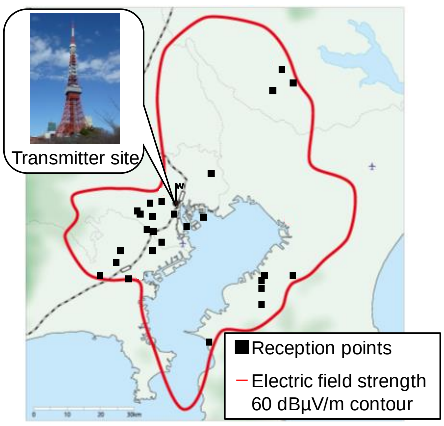
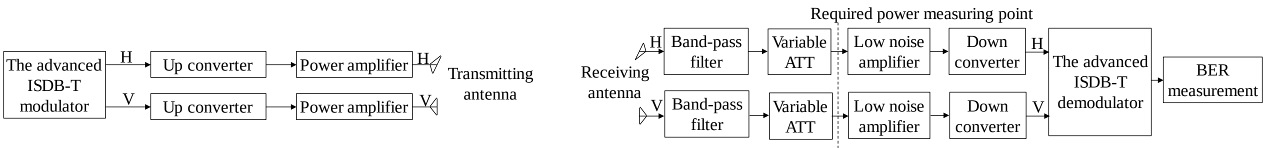


Figure 6 – Locations of reception points



(a) Transmitter site

(b) Reception point

Figure 7 – Block diagram of transmitter site and reception point

signals with variable attenuators (ATTs). In MIMO conditions, the signals were attenuated by a constraint that the value of the two ATTs was the same. During this experiment, we evaluated two parameters listed in Table 2 assuming fixed reception at a height of 10 m.

Results of Degradation

We investigated the degradation caused by real propagation environments which mainly caused by multipath interference. This degradation is the difference between the required power determined by the laboratory experiments and that determined by the field experiments. Figure 8 shows an example of how to calculate the degradation.

Table 4 presents the results. The degradation for the sets of parameters (I) and (II) ranged from 0.1 to 1.7 dB, and 0.1 to 2.9 dB, respectively. The median degradation of each parameter was approximately 1 dB. Note that the required power for the set of parameters (II) under MIMO conditions was the average of the required power for horizontal polarization and that for vertical polarization. The degradation of the MIMO tended to be slightly larger than that of the SISO. We think that one of the causes of the degradation is the difference in field strength between horizontal and vertical polarizations. Figure 9 shows the degradation for the set of parameters (II) versus the difference in field strength between the two polarizations. When the difference in field strength is large, the deterioration also tends to be large.

Set of parameters	Minimum	Maximum	Median
(I)	0.1 dB	1.7 dB	0.8 dB
(II)	0.1 dB	2.9 dB	1.2 dB

Table 4 – Degradation results of field experiments

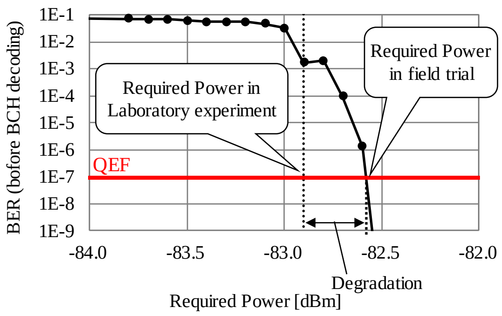


Figure 8 – Example of degradation calculation (set of parameters (I), distance: 16.5 km)

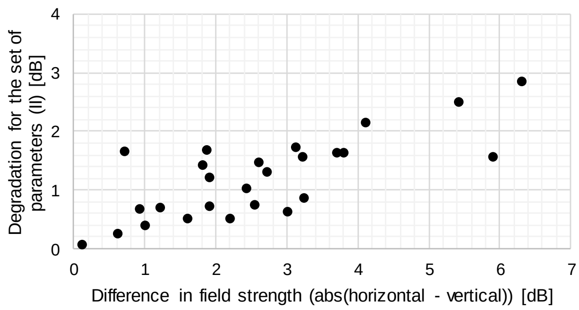


Figure 9 – Degradation for the set of parameters (II) versus the difference in field strength between horizontal and vertical polarizations

4K/8K Video Transmission Experiment

4K/8K video transmission experiment was conducted at one of 26 points in the field experiment. Figure 10 shows the reception point, the distance is approximately 12 km. On the transmitter site, the compressed video signal is an input to the modulator, and then on the receiving point, the output of the demodulator is connected to the HEVC decoder and displayed on LCD. The number of segments was 35 and the required CNR was 21.0 dB. Table 5 lists conditions of the 4K/8K transmission experiment, there were 3 types of video bit rates. Figure 11 shows an example of the received 8K video signal. In addition, because HEVC was used for the video coding system in this experiment, we used pre-processing equipment (11) to improve the coding image quality of the video including the reduction of compression artifacts such as block distortion.

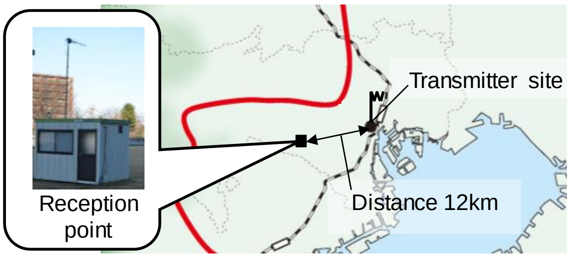


Figure 10 – The reception point for the 4K/8K video transmission experiment

Figure 11 – Example of the received 8K video signal (condition (ii))

Condition	Transmission parameters								Video format	Video coding	Video bit rates	Remarks
	System	Number of segments	FFT size	Guard interval ratio	SP ratio	Carrier modulation	Code rate	Required CNR				
(i)	SISO	35	16k	800/16384	1/12	256QAM	12/16	21.0 dB	4K 60P	HEVC	25 Mbps	Assume 4K video bit rates with VVC
(ii)									8K 60P		28 Mbps	Half bit rates of condition (iii)
(iii)	MIMO										56 Mbps	Assume 8K video bit rates with VVC

Table 5 – Conditions of the 4K/8K video transmission experiment

CONCLUSION

We developed an experimental modulator and demodulator in which the advanced ISDB-T was implemented. Laboratory experiments were conducted to evaluate its transmission performance. Furthermore, we carried out large-scale field experiments, which were preliminary field experiments, to evaluate its performance in a propagation environment similar to that of an actual broadcast.

In the future, we will conduct a field experiment in which the number of reception samples is increased, in order to develop a link budget model for fixed reception. We also plan to evaluate the transmission performance of mobile reception in a large-scale field experiment and the transmission performance in SFN environments, not only for fixed reception but also mobile reception.

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