ISDB-T Transmission Technology
- Single transmission for fixed, vehicular, and handheld receivers -

Kazunori Yokohata
NHK (Japan Broadcasting Corporation) Science & Technical Research Laboratory, Tokyo, Japan
yokohata.k-jm@nhk.or.jp

I. Broadcasting system and services going digital

On December 1, 2003, Japan launched digital terrestrial television broadcasting (DTTB) using the Integrated Service Digital Broadcasting – Terrestrial (ISDB-T) transmission system that is based on Orthogonal Frequency Division Multiplexing (OFDM).

ISDB represents a set of digital broadcasting standards in Japan covering terrestrial, satellite, and cable transmission that share a common format for multiplexing which enables transmissions of high-definition television as well as data broadcasting. Digital broadcasting provides a wide range of convenient services, owing to its high picture and sound quality, interactivity, and storage capability. It is also set to become a foundation on which anyone in the country will be able to benefit from participating in the information and communications technology (ICT) society through one of the most familiar and easy-to-use devices, the television. Japan is in the process of digitizing every broadcasting media, including satellite (ISDB-S), terrestrial (ISDB-T), and cable TV services (ISDB-C) [1]. This paper describes ISDB-T digital terrestrial television broadcasting.

The history of ISDB goes back to the idea of a digital broadcasting system for the 21st century as conceived at the NHK Science and Technical Research Laboratories (STRL) in the 1980s. Envisioning the new age of digital terrestrial broadcasting, NHK developed the Band Segmented Transmission – Orthogonal Frequency Division Multiplexing (BST-OFDM) transmission scheme of ISDB-T in 1996. Based on the requirements specified by the Telecommunication Technology Council (TTC), NHK and Advanced Digital Television Broadcasting Laboratories (DTV-Lab) presented a joint proposal for the ISDB-T system to the Association of Radio Industries and Businesses (ARIB). In 1997, the proposal was designated the draft standard for Digital Terrestrial Television Broadcasting (DTTB) by the TTC. In 1998, field trials for the draft standard were carried out by NHK, and the results of the trials were contributed to ARIB. After discussions in ARIB, the Final Draft Standard for DTTB was approved by the TTC in 1998. Large-scale field trials for the Final Draft Standard using Tokyo Tower were carried out from October 1998 to March 1999 in order to verify the performance in a practical digital-service area. The ISDB-T system was found to offer superior reception characteristics. Consequently, in 1999, it was adopted as Japan's DTTB system [2].

II. Transmission System for ISDB-T

As mentioned above, ARIB in Japan decided the specifications for ISDB-T [3]. The ISDB-T transmission system is also recommended in Recommendation ITU-R BT.1306-3 [4], and its planning criteria are recommended in Recommendation ITU-R BT.1368.

This section briefly describes the transmission scheme of the ISDB-T system [5]. Table 1 shows the related ARIB standards and ITU-R recommendations for ISDB-T.

Table 1 ARIB standards and ITU-R recommendations for ISDB-T

Item	Contents	ARIB Standards	ITU-R Recommendations
Video coding	MPEG-2 Video (ISO/IEC 13818-2)	STD-B32	BT.1208
Audio coding	MPEG-2 AAC (ISO/IEC 13818-7)	STD-B33	BS.1115
Data broadcasting	BML(XHTML), ECMA Script	STD-B24	BT.1699
Multiplex	MPEG-2 Systems (ISO/IEC 13818-1)	STD-B10, STD-B32	BT.1300, BT.1209
Conditional access	Multi 2	STD-B25	---
Transmission	ISDB-T transmission	STD-B31	BT.1306-3 System C
Receiver	ISDB-T receiver	STD-B21	---
Operational guideline	ISDB-T broadcasting operation	TR-B14	---

A. Features of ISDB-T Transmission System

The ISDB-T system is designed to provide reliable high-quality video, sound, and data broadcasting not only for fixed receivers but also for mobile receivers. The system is also rugged because it uses orthogonal frequency division multiplexing (OFDM) modulation, two-dimensional (time-domain and frequency-domain) interleaving, and concatenated error-correction codes. Its band-segmented transmission OFDM (BST-OFDM) consists of 13 OFDM segments. The system has a wide variety of transmission parameters for choosing the carrier modulation scheme, coding rate of the inner error-correcting code, length of time interleaving, etc. These transmission parameters can be set individually for each layer which consists of the segment. Therefore the system is also designed to provide flexibility, expandability, and commonality/interoperability for multimedia broadcasting.

The system supports hierarchical transmissions of up to three layers (Layers A, B, and C). The transmission parameters can be changed in each of these layers. In particular, the center segment of this hierarchical transmission can be received by handheld receivers. Owing to the common structure of the OFDM segment, a one-segment receiver can "partially" receive a program transmitted on the center segment of a full-band ISDB-T signal (partial reception is the name given to the means by which a receiver picks out only part of the transmission bandwidth). The system has three transmission modes (Modes 1, 2, and 3) to enable the use of a wide range of transmitting frequencies, and it has four choices of guard-interval length to enable a better design of a single-frequency network (SFN).

This system uses MPEG-2 Video coding and MPEG-2 advanced audio coding (AAC). Moreover, it adopts MPEG-2 Systems for encapsulating data streams. Therefore, various digital content such as sound, text, still pictures, and other data can be transmitted simultaneously. It has commonality and interoperability with other systems using MPEG-2 Systems, such as ISDB-S, ISDB-C, and ISDB-T_{SB} (Sound broadcasting).

B. Outline

Fig. 1 outlines the entire ISDB-T system. The transmission system, BST-OFDM, configures a transmission band made up of OFDM segments, each having a bandwidth of 6/14 MHz. The transmission parameters may be individually set for each layer, making for flexible channel composition.

Furthermore, to achieve an interface between multiple MPEG-2 transport streams (TSs) and the BST-OFDM transmission system, these TSs are remultiplexed into a single TS. In addition, transmission control information, such as channel segment configuration, transmission parameters, etc., are sent to the receiver in the form of a transmission multiplexing configuration control (TMCC) signal.

C. Basic Transmission Parameters

ISDB-T features three transmission modes having different carrier intervals in order to deal with a variety of conditions such as the variable guard interval as determined by the network configuration and the Doppler shift occurring in mobile reception. Table 2 lists the

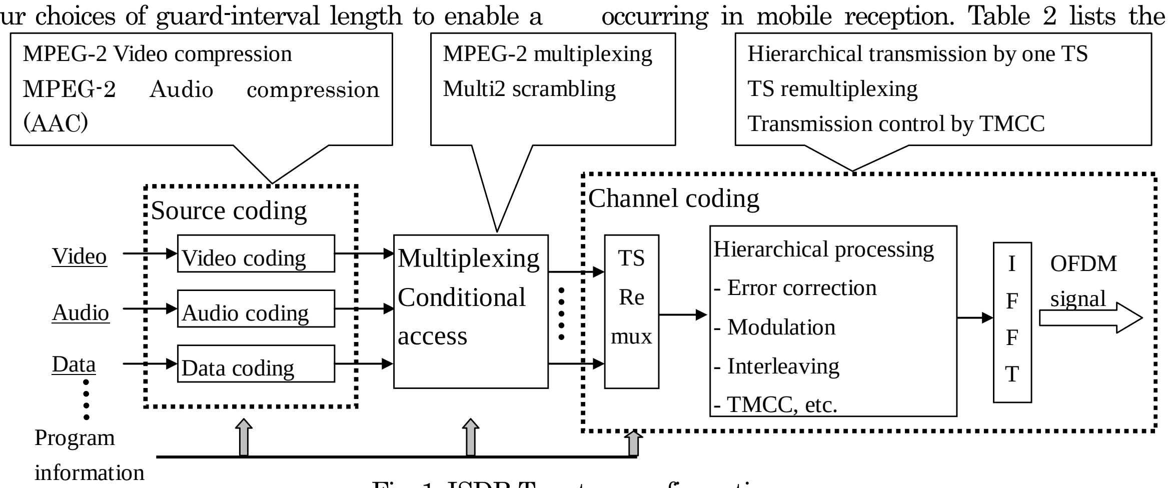

Fig. 1. ISDB-T system configuration

Table 2 Basic transmission parameters of the Japanese ISDB-T 6-MHz System

Transmission Parameter	Mode 1	Mode 2	Mode 3
No. of OFDM segments	13		
Bandwidth	5.575 MHz	5.573 MHz	5.572 MHz
Carrier interval	3.968 kHz	1.984 kHz	0.992 kHz
No. of carriers	1405	2809	5617
Carrier modulation	QPSK, 16QAM, 64QAM, DQPSK		
Effective symbol length	252 ms	504 ms	1.008 ms
Guard-interval length	1/4, 1/8, 1/16, 1/32 of effective symbol length		
No. of symbols per frame	204		
Time interleave	Maximum 4 values : 0, 0.1, 0.2, 0.4 sec		
Frequency interleave	Intra-segment and inter-segment interleaving		
Inner code	Convolutional coding (1/2, 2/3, 3/4, 5/6, 7/8)		
Outer code	RS (204, 188)		
Information bit rate	3.65 Mbps - 23.23 Mbps		
Hierarchical transmission	Maximum 3 levels (Layer A, B, and C)		

basic parameters of each mode in the Japanese 6-MHz system.

One OFDM segment corresponds to a frequency spectrum having a bandwidth of 6/14 MHz (about 430kHz). In Mode 1, one segment consists of 108 carriers, while Modes 2 and 3 feature two times and four times that number of carriers, respectively. Television broadcasting employs 13 segments with a transmission bandwidth of about 5.6MHz. Terrestrial digital audio broadcasting, on the other hand, uses one or three segments. A digital signal is transmitted in sets of symbols. One symbol consists of 2 bits in QPSK and DQPSK, 4 bits in 16QAM, and 6 bits in 64QAM. The effective symbol length is the reciprocal of the carrier interval – this condition prevents carriers in the band from interfering with each other. The guard interval is a time-redundant section of information that adds a copy of the latter portion of a symbol to the symbol's "front porch" with the aim of absorbing interference from multi-path-delayed waves. Accordingly, increasing the guard-interval ratio in the signal decreases the information bit rate.

An OFDM frame consists of 204 symbols with guard intervals attached regardless of the transmission mode. The time interleave length in real time depends on the parameters set at the digital-signal stage and on the guard-interval length, and the values shown in Table 2 for these parameters are consequently approximate.

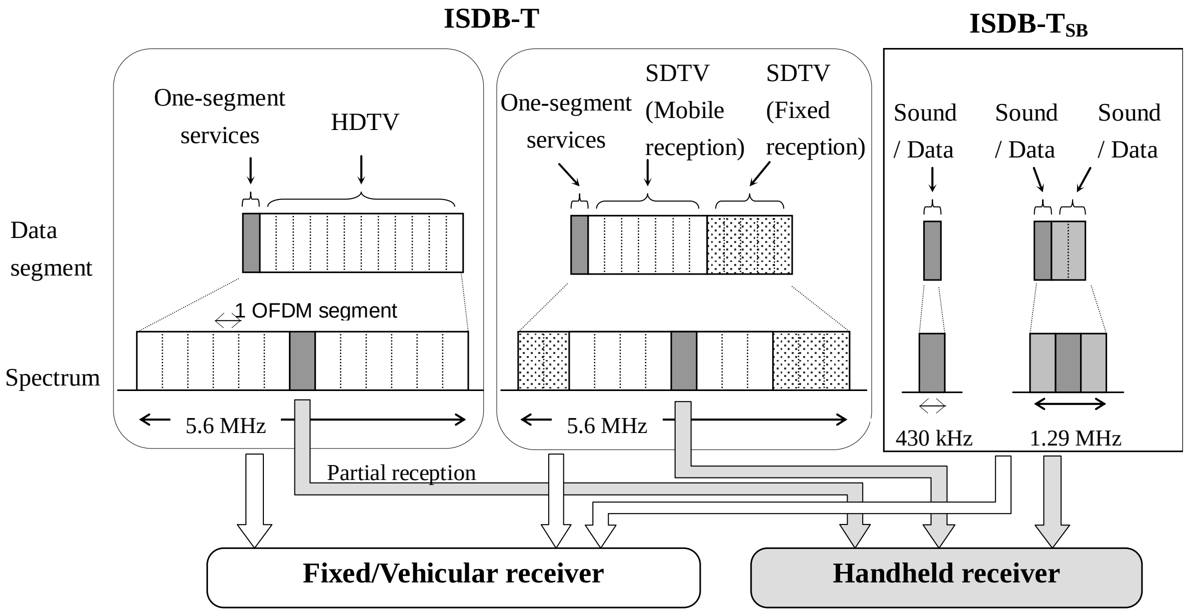

Fig. 2. ISDB-T service examples and transmission signals

The error-correction scheme uses concatenated codes, namely, Reed-Solomon (204,188) code for the outer code and convolutional code for the inner code. The information bit rate takes on various values depending on the selected modulation scheme, inner-code coding rate, and guard-interval ratio. The range shown in Table 2 reflects the minimum and maximum values for 13 segments.

D. Hierarchical Transmission

A mixture of fixed-reception programs and handheld reception programs is made possible through hierarchical transmission achievable by band division within a channel. "Hierarchical transmission" means that the three elements of channel coding, namely, the modulation scheme, the coding rate of convolutional error-correcting code, and the time interleaving length, can be independently selected. Time and frequency interleaving are each performed in their respective hierarchical data segment.

As described above, the smallest hierarchical unit in a frequency spectrum is one OFDM segment. Referring to Fig. 2, one television channel consists of 13 OFDM segments and up to three hierarchical layers (Layers A, B, and C) can be set with regard to these segments. If the OFDM signal is transmitted using only one layer, the layer is A. If the signal is transmitted using two layers, the center "rugged" layer is A and the outer layer is B. If the signal is transmitted using three layers, the center "rugged" layer is A, the middle layer is B, and the outer layer is C. Taking the channel-selection operation of the receiver into account, a frequency spectrum segmented in this way must follow a rule for arranging segments. Specifically, DQPSK segments using differential modulation are placed in the middle of the transmission band, while QPSK and QAM segments using coherent modulation are placed at either end of the frequency band. In addition, one layer can be set for the single center segment as a partial-reception segment for handheld receivers of one-segment services. In this case, the center segment is Layer A. Using the entire 5.6-MHz band in this way is called ISDB-T. Audio broadcasts and one-segment services feature a basic one-segment format as well as a three-segment expanded format, both referred to as ISDB-T_{SB}.

III. Mobile reception of ISDB-T (Handheld and vehicular receivers)

A. One-segment services for handheld receivers

On April 1, 2006, one-segment services (called "One-Seg") commenced for handheld receivers. About 10 million "One-Seg handheld receivers had been shipped as of June, 2007 [6].

NHK STRL has conducted a wide range of research and development on One-Seg [7]. The transmission system is based on hierarchical transmission described in section II.D. On practical DTTB in Japan, it is adopted as ISDB-T transmission parameters that Mode 3, Guard interval length 1/8. The one-segment parameters for handheld receivers are QPSK 2/3 and time interleave I=4 (0.43 sec).

Table 3 lists information bit rate examples. The transmission parameters of QPSK 2/3 for One-Seg and 64QAM 3/4 for fixed reception (12-segment HDTV) correspond to information bit rates of 416.1 kbps and 16.8 Mbps, respectively. Table 4 shows an information bit rate assignment example for one-segment services.

Table 3 Information bit rate example of DTTB (ISDB-T Mode 3, guard interval ratio 1/8)

Handheld reception (one-segment services: partial reception)

Carrier modulation	QPSK		16QAM
Convolutional coding ratio	1/2	2/3	1/2
Information bit rate (kbps)	312.1	416.1	624.1

Fixed reception (12 segment)

Carrier modulation	64QAM				
Convolutional coding ratio	1/2	2/3	3/4	5/6	7/8
Information bit rate (Mbps)	11.2	14.9	16.8	18.7	19.6

Table 4 Information bit rate assignments example for one-segment services (QPSK 2/3)

Assignment	Information bit rate
Video	244kbps
Audio	55kbps
Data	55kbps
Closed caption	5kbps
EPG	20kbps
PSI/SI etc	37kbps
Total	416kbps

B. Emergency warning system (EWS)

ISDB-T has an emergency warning mechanism, which differs from ordinary communications functions, in that can simultaneously send information to a large number of fixed, vehicular, and handheld receivers. EWS promptly and effectively conveys public emergency notices about disasters such as tsunamis or earthquakes. The Activation flag for alert broadcasting is multiplexed with normal broadcast waves, and it requires the TV receiver to monitor the activation flag for alert broadcasting in TMCC carrier [8]. The receiver can detect the activation flag even when it is "stand-by", and it turns on when it receives the activation flag so the user can obtain urgent information.

C. HDTV vehicular reception technology for ISDB-T

ISDB-T enables HDTV reception in motor vehicles. NHK STRL has developed a diversity mobile reception technology that allows viewers to enjoy HDTV programs with clear images, even in a moving car or bus. This technology uses space diversity with from two to four receiving antennas and enables HDTV reception modulated with 64QAM. HDTV services for motor vehicles are the same as in fixed reception [9]. The use of this diversity mobile reception technology means that it is not necessary for broadcasting stations to change the transmission scheme and services for motor vehicles. The HDTV vehicular system is commercially available in Japan.

IV. Single Frequency Network and Broadcast-wave relays

Because it uses the OFDM guard interval, ISDB-T is well suited to a single frequency network (SFN) where several transmitters broadcast at the same frequency in order to make effective use of radio frequency channels. Totally considering, OFDM is frequency effective modulation method by using SFN.

DTTB services will be made available throughout Japan before analog television broadcasting services end in 2011. A large number of relay broadcast stations are required to deliver DTTB signals throughout the country, and reducing the cost of these facilities is a matter of considerable importance. Signals can be delivered to relay stations by dedicated lines such as studio-to-transmitter link/ transmitter-to-transmitter link (STL/TTL) or by performing relay broadcasts. Relaying is especially important because it does not require new frequency resources and keeps the facility costs low. However, since a relay receives, amplifies, and retransmits the broadcast signals from the upper station, there are various factors that cause the quality of the propagated signal to deteriorate. NHK STRL researchers have been researching and developing techniques that will alleviate these adverse effects [10]. Table 5 lists the factors that degrade DTTB relays, together with their countermeasures technology.

V. DTTB systems in the world

Table 6 lists the technical features of the three DTTB systems recommended in Rec. ITU-R BT.1306-3 (ATSC, DVB-T and ISDB-T).

ISDB-T is the most flexible of these systems, because it uses BST-OFDM. It can provide HDTV, multi-channel SDTV, the Electric Program Guide, and data broadcasting. It also enables Internet access, HDTV mobile reception, and television service using one segment for cellular phones. All these services are now offered in Japan. ISDB-T is also the most robust

Table 5 Causes of deterioration of Broadcast- wave Relays and their countermeasures

Deterioration factor	SFN Coupling	Multipath	Fading	Co-Channel Interference
Countermeasure Technology	Loop interference canceller	Multipath equalizer, Diversity receiver	Diversity receiver	Adaptive array antenna
SFN/MFN	SFN	SFN/MFN	SFN/MFN	SFN/MFN

Table 6 Technical features of three DTTB systems

Rec. ITU-R 1306-3		System A	System B	System C
System		ATSC	DVB-T	ISDB-T
modulation		8VSB	OFDM (QPSK, 16QAM, 64QAM MR-16QAM, MR-64QAM)	**BST-OFDM** (DQPSK, QPSK, 16QAM, 64QAM)
Interleaving	Bit/Symbol	Yes	Yes	Yes
	Frequency	-	Yes	Yes
	time	-	-	**0s, 0.1s, 0.2s, 0.4s**
Excess Bandwidth/ Guard Interval		11.5%	1/4, 1/8, 1/16, 1/32	1/4, 1/8, 1/16, 1/32
Configuration signal		-	TPS	TMCC
Information bit rate (Channel bandwidth: 6MHz)		19.39Mbps	3.69-23.5Mbps	3.65-23.2Mbps

transmission system of the three, because it uses OFDM, time-interleaving, etc. Brazilian tests proved that its transmission performance is the best [11]. Consequently, on June 29, 2006, Brazil decided to adopt a terrestrial digital television broadcasting system based on ISDB-T.

VI. Conclusion

NHK has been researching, developing, and enhancing ISDB-T system that was chosen to be the DTTB system in Japan.

ISDB-T is recommended in ITU-R BT1306. It is a robust transmission system because it uses OFDM and time interleaving. HDTV (or multi-channel SDTV) and One-Seg (handheld television service) can be transmitted simultaneously in a channel. ISDB-T enables digital television services for fixed, vehicular, and handheld reception through the use of just one transmission facility. It supports the emergency warning system and enables HDTV reception in motor vehicles.

Saving the frequency resource and reducing the costs of constructing the terrestrial network are important goals. NHK has developed and put into service a single frequency network broadcasting relay technology. An SFN has effective frequency utilization, and such a broadcast-wave relay does not require new frequency resources and keeps the facility costs low.

ISDB-T is also designed to provide flexibility, expandability, and commonality/interoperability for multimedia broadcasting.

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