Transmission System of 4K/8K UHDTV Satellite Broadcasting

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SUMMARY 4K/8K satellite broadcasting featuring ultra-high definition video and sound was launched in Japan in 2018. This is the first 8K ultra high definition television (UHDTV) broadcasting in the world, with 16 times as many pixels as HDTV and 3D sound with 22.2ch audio. The large amount of information that has to be transmitted means that a new satellite broadcasting transmission system had to be developed. In this paper, we describe this transmission system, focusing on the technology that enables 4K/8K UHDTV satellite broadcasting.

key words: 4K/8K, UHDTV, satellite broadcasting, ISDB-S3, LDPC

1. Introduction

4K/8K ultra-high definition TV (UHDTV) satellite broadcasting began in Japan on December 1st, 2018. Japan Broadcasting Corporation (NHK) began offering the world's first 8K broadcasting service, and commercial broadcasting companies began offering 4K channels through broadcasting and 110-degree communications satellites (respectively BS and CS broadcasting). The broadcasting satellite is located about 36,000 km above the equator, and radio waves from it can be received with a parabolic dish antenna with a diameter of about 45 cm. 8K broadcasting services convey a stronger sense of reality than is possible with other forms of television and can now be viewed all over Japan.

4K/8K broadcasting is characterized by ultra-high-definition image quality with four times (for 4K) and 16 times (for 8K) the number of pixels compared with the HDTV (2K) of conventional terrestrial and satellite broadcasting. In addition to the high resolution, the frame rate is increased for smoother reproduction of fast movements, the color gamut is expanded for reproducing more natural colors, and the brightness range of the video is wider [1], [2]. As for audio, 22.2 channel audio is available; viewers can enjoy the sense of reality it offers by installing rows of speakers covering the vertical and horizontal direction [3]. 8K programs, however, contain so much information it would be impossible to transmit them without compression. Here, the digital data of a 8K program is compressed using MPEG-H High Efficiency Video Coding (HEVC, ITU-T H.265) [4], [5] and MPEG-4 Advanced Audio Coding (AAC) [6].

Fig. 1 Broadcasting-Communication integrated service in 4K/8K UHDTV satellite broadcasting.

The video and audio are multiplexed using MPEG Media Transport (MMT) and Type Length Value (TLV) packet format. MMT has a mechanism that allows signals transmitted through different channels (e.g., broadcast and communication) and then synchronized and played together by using common timing information [7]. This enables advanced services that integrate broadcasting with communications to be accessed via home TVs (Fig. 1). In TLV multiplexing, information indicating the type and length of data is multiplexed in the header, and arbitrary variable length data such as IP (Internet Protocol) packets containing MMT can be transmitted [8]. The video and audio signals are converted into MMT packets, then into IP packets, and multiplexed in the TLV packet format.

Conventional digital HDTV broadcasting over BS/110-degree CS satellites in Japan uses the Integrated Services Digital Broadcasting-Satellite (ISDB-S) transmission system [9], [10]. ISDB-S was developed by NHK. It can be used for broadcasting multiple high-definition programs with a single satellite transponder. It has been used for many years in Japan. However, because the maximum information that one transponder can transmit is about 52 Mbps, it is not possible to use it to transmit 8K programs which contain a larger amount of information. To overcome this problem, NHK led the research, development and standardization of an advanced version of ISDB-S; ISDB-S3 was standardized in Japan in 2014 and became an international standard in 2016 [11], [12]. Here, 4K/8K satellite broadcasting uses the 16APSK (error correction coding rate 7/9) modulation scheme, which ISDB-S3 supports. With this scheme, a sin-

Manuscript received November 8, 2019.

Manuscript revised February 7, 2020.

Manuscript publicized April 21, 2020.

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DOI: 10.1587/transcom.2019CBI0001

gle satellite transponder can transmit at 100 Mbps, twice as much as before, and can broadcast three channels of 4K programming or one channel of 8K programming per transponder [13].

In this paper, we summarize the transmission system for 4K/8K UHDTV satellite broadcasting. Section 2 describes the requirements for UHDTV satellite broadcasting. Section 3 explains the details of the transmission system for 4K/8K UHDTV satellite broadcasting and reviews the transmission performance of the system determined in transmission simulations and experiments. Section 4 describes the link budget for 4K/8K UHDTV satellite broadcasting. Section 5 discusses future directions of this research.

2. Requirements for UHDTV Satellite Broadcasting

In 2012, the Ministry of Internal Affairs and Communications of Japan established a Study Group for the Advancement of Broadcasting Services and established the UHDTV Working Group and a roadmap showing the start time and the goals for practical use of 4K/8K broadcasting services and receivers. The roadmap indicated that UHDTV satellite test broadcasting would be launched in 2016 and UHDTV satellite full (regular) broadcasting would be launched in 2018. Broadcasters and manufacturers proceeded to develop broadcasting facilities according to the roadmap.

In response to the roadmap, in May 2013, the Information and Communications Council laid out new technical conditions for more efficient transmissions in order to promote and put into practical use UHDTV with spatial resolution exceeding that of HDTV. The Broadcasting System Committee in the Council examined the technical conditions in consideration of compatibility with existing broadcasting systems and trends in international standardization. A report on the technical conditions for basic satellite broadcasting and general satellite broadcasting was compiled to facilitate a smooth introduction of UHDTV services [14].

In the report, the following points were indicated as the basic requirements for the UHDTV satellite broadcasting system.

- (1) Realization of high-quality, multi-functional and diverse services through UHDTV broadcasting.
- (2) Consideration of future technological trends, adoption of feasible technology, and adoption of extensible methods that consider the addition of future services and functions.
- (3) Interoperability with existing broadcasting services and other digital broadcasting media as much as possible, as well as the ability to cope with new services through communications.
- (4) Consideration of the technical conditions of the latest broadcasting systems such as ones for advanced wideband digital satellite broadcasting (Information and Communication Council Report dated July 29, 2008) or transmission systems for advanced narrowband CS digital broadcasting (Information and Communication

Council Report dated July 20, 2006) and cases where it is appropriate to use the same technologies.

The requirements for the transmission system are as follows: 1) Secure as much transmission capacity as possible to transmit various services including the UHDTV service, while making effective use of frequency. 2) Receive signals as stably as possible even at a low carrier-to-noise ratio (C/N). 3) Ensure efficiency and robustness to the non-linear characteristics of the satellite transponder. 4) Account for the characteristics of the receiving antenna (including a small-diameter dish antenna with an aperture diameter of 45 cm).

In response to these requirements, a new transmission system was researched and developed. The following sections describe it.

3. Transmission System

3.1 System Architecture

ISDB-S3 is a new technical standard for 4K/8K satellite broadcasting. It calls for improving transmission performance in various ways over that of the ISDB-S conventional satellite broadcasting system. Table 1 shows ISDB-S3 transmission specifications. The main features are a very small roll-off factor of 0.03 for the raised-cosine square-root Nyquist filters implemented in the transmitter and receiver, the use of amplitude and phase-shift keying (APSK) modulation, and the concatenation of inner LDPC and outer BCH codes for forward error correction (FEC), and a pilot symbol, which is used to reduce degradation due to the nonlinear characteristics of the satellite transponder.

Figure 2 shows the function block diagram indicating the basic structure of the channel coding in ISDB-S3. The structure comprises three parts, one part for processing the main signal, a second part for processing the control signal, and a third part for modulating and multiplexing. MPEG-2 transport stream (TS) or TLV stream are inputted to the main signal part, and the transmission and multiplexing configuration and control (TMCC) signal, which is control information for transmitting the main signal, is generated using the transmission parameters in the control signal part. The main signal and control signal are outer coded, energy dispersed and inner coded.

Figure 3 shows the frame structure of the baseband sig-

Table 1 ISDB-S3 Transmission specifications.

Item	Specification
Modulation	$\pi/2$ shift BPSK, QPSK, 8PSK, 16APSK, 32APSK
FEC	Inner FEC : LDPC, Outer FEC : BCH
TMCC Signal	Control information (modulation scheme, coding rate, multiplexing data format, etc.)
Frame Structure	120 slots/frame
Symbol Rate	33.7561 Mbaud
Roll-off Factor	0.03
Other	Use of pilot signal to improve degradation due to nonlinear characteristics on satellite

Fig. 2 Function block diagram of ISDB-S3.

Fig. 3 Frame structures of TMCC, main signal in the baseband, and modulation signal.

nal and modulated signal in ISDB-S3. There are two types of frames in the baseband signal, a TMCC signal frame (upper left in Fig. 3) and the main signal frame (upper right in Fig. 3). The main signal frame has 120 slots, and each slot is composed of a slot header, main signal data which include concatenated TLV packets or concatenated TS packets excluding the first byte (sync byte) of each TS packet, error correcting outer-code (BCH) parity bits, stuffing bits, and error correcting inner-code (LDPC) parity bits. The TMCC signal frame includes synchronization signals for frame synchronization and slot synchronization, a pilot signal, and TMCC information with BCH and LDPC parity bits. The TMCC information is updated for each frame, and the transmission mode (modulation, coding rate of inner code, back-off of satellite output), transmission stream ID, etc., are designated by their slot position in the frame.

The frame structure of the modulation signal is indicated at the bottom of Fig. 3. ‘T’ in the frame indicates four symbols of the TMCC signal, and these symbols are modulated by $\pi/2$ -shift BPSK. ‘T’ is inserted periodically and helps with carrier recovery at the receiver side. ‘P’ in the frame indicates the 32 symbols of the pilot signal modulated by the same modulation as the data modulation. ‘P’ is also transmitted periodically and helps with the nonlinearity estimation. On the receiver side, the averaged ‘P’ is used as the reference point of the minimum Euclidean distance so that a more accurate likelihood ratio of each decoded bit can be provided to the LDPC decoder. Finally, a modulation frame that is time-division multiplexed by an IQ signal sequence is obtained by adding a frame/slot synchronization signal to the main signal, TMCC signal, and pilot signal.

3.2 Forward Error Correction

ISDB-S3 uses concatenated codes of LDPC and BCH with various coding rates as error correction codes. The LDPC code is a linear code with a sparse check matrix that has a low density of non-zero components. It is a powerful error correction code that can obtain transmission characteristics approaching the Shannon limit when an appropriate check matrix is used. Since the parity check matrix of LDPC is very sparse, it can be encoded and decoded with fewer computations than other non-sparse linear codes of the same code length.

LDPC codes are classified into regular LDPC code, in which the row weight and column weight in the check matrix are constant, and non-regular LDPC code, in which they are not constant. Various methods of constructing LDPC code have been proposed, and it has been reported that regular LDPC code with column weight 3 has good performance and that non-regular LDPC code with appropriately selected row and column weights is more efficient than regular LDPC code [15]. While the LDPC code increases in coding gain as the code length increases, the calculations associated with the coding also increase. To solve this problem, the computational complexity is reduced by using an algebraic structure such as a low density generator matrix (LDGM), which allows codewords to be obtained directly from the parity check matrix by making the submatrix of the parity check matrix have a lower triangular structure [16], [17].

Figure 4 shows the LDPC code check matrix in ISDB-S3. It is an LDGM-type irregular matrix with a code length of 44,880 bits, and 11 different coding rates can be used with it [18], [19]. The left submatrix (H_A) corresponds to a pseudo-random matrix. In order to improve the performance of the LDPC code, it is particularly important to incorporate randomness in the design of H_A . The entries of H_A are cyclically configured while maintaining randomness by reading out random and appropriately arranged initial values every 374 bits and cyclically shifting them by a number of cycles q defined for each coding rate. By adopting the LDGM structure for the right submatrix (H_B), it is possible to obtain parity bits sequentially using a parity check equation. It is also

Fig. 4 LDPC code check matrix in ISDB-S3.

Fig. 5 C/N vs. BER (16APSK(7/9)).

important to eliminate cyclic structures such as cycle 4 and cycle 6 as much as possible in the LDPC code check matrix because those cycles affect the independence of the extrinsic information exchanged in the iterative decoding [20]. The check matrix in ISDB-S3 is designed to have no cycles of length 4 and 6. This is done by avoiding the generation of a cyclic structure by multiplying the code rate dependent constant q , which is used for the cyclically shift arrangement of "1" in the check matrix, by our carefully chosen number. Figure 5 shows the C/N versus bit error rate (BER) characteristics before and after error correction by LDPC and BCH in 16APSK (7/9). If cycle 4 and 6 are not removed, an error floor occurs near $\text{BER} = 1 \times 10^{-8}$, but if they are removed, there is no error floor even at $\text{BER} = 1 \times 10^{-11}$.

After LDPC code decoding, errors are corrected to be below the practical bit error rate by using an outer code (BCH code) with a correction capability of 12 bits per codeword. Most of the bit errors occurring on the satellite transmission path are corrected by the LDPC code, while the BCH code plays a role of a protection function as a countermeasure against an error floor occurring after the LDPC decoding.

3.3 Modulation

PSK (BPSK, QPSK, 8PSK) are usually used as modulation schemes for satellite broadcasting because they are suitable for low C/N operation, highly efficient frequency utilization, and nonlinear operation of satellite transponders. As well as these schemes, ISDB-S3 uses APSK modulation schemes. Figure 6 shows modulation constellations of

Fig. 6 Modulation constellations.

Fig. 7 Radius ratio vs. BER in 16APSK(7/9) and 32APSK(7/9).

five different modulation schemes ($\pi/2$ -shift BPSK, QPSK, 8PSK, 16APSK, 32APSK) in ISDB-S3. The 16APSK modulation constellation (Fig. 6(d)) is composed of two concentric rings of 4 and 12 uniformly spaced PSK points; the inner ring has radius R_1 and the outer ring radius R_2 . The 32APSK modulation constellation (Fig. 6(e)) is composed of three concentric rings of 4, 12, and 16 uniformly spaced PSK points; the inner ring has radius R_1 , the middle ring radius R_2 , and the outer ring radius R_3 . The optimum ratios of the outer circle radius to the inner circle radius, $\gamma = R_2/R_1$ in 16APSK and $\gamma_1 = R_2/R_1$ and $\gamma_2 = R_3/R_1$ in 32APSK, differ for each modulation scheme and coding rate [21]. The BER characteristics with respect to the radius ratio of 16APSK (7/9) and 32APSK (7/9) are shown in Fig. 7. The bit error rate is minimized at $\gamma = 2.87$ for 16APSK (7/9) and at $\gamma_1 = 2.87$ and $\gamma_2 = 5.33$ for 32APSK (7/9). The optimum radius ratios shown in Table 2 were obtained by conducting a computer simulation that varied the radius ratio with a constant amount of added noise and found the radius ratio that minimized the bit error rate [22]. The simulation did not consider the characteristics of the satellite transponder, and a linear transmission path was assumed. Conventionally, the radius ratio had been optimized using

Table 2 Optimum radius ratio.

Coding rate (approximation)	Radius ratio	
	γ ($=\gamma_1$)	γ_2
41/120 (1/3)	3.09	6.53
49/120 (2/5)	2.97	7.17
61/120 (1/2)	3.93	8.03
73/120 (3/5)	2.87	5.61
81/120 (2/3)	2.92	5.68
89/120 (3/4)	2.97	5.57
93/120 (7/9)	2.87	5.33
97/120 (4/5)	2.73	5.05
101/120 (5/6)	2.67	4.80
105/120 (7/8)	2.76	4.82
109/120 (9/10)	2.69	4.66

ideal codes, but here, the optimization was done in combination with practical LDPC codes. The optimum values of γ_1 for 32APSK are the same as the optimum values of γ for 16APSK. It is considered that this is because the signal positions of the 1st and 2nd circles of 32APSK are exactly the same as the inner and outer circles of 16APSK.

Bit interleaved coded modulation (BICM) [23] is applied to 8PSK, 16APSK, and 32APSK. LDPC codes are unevenly distributed in correction capability in the codeword; that is, the error correction capability depends on the position of the bit within the codeword. In the modulation constellation of ISDB-S3, bit errors tend not to occur on the LSB side among the bits that constitute the symbol. The interleaving is configured on the basis of these characteristics of LDPC codes and modulation schemes. Here, as the forward interleaving, the MSB side of the LDPC code with high correction capability is supplied to the MSB side with the high error rate among the bits constituting each modulation symbol. There are LDPC codes with a coding rate whose distribution of correction capability is reversed. In this case, backward interleaving is used. The interleaver direction for read-out was chosen to be the one giving the best performance in a computer simulation applying the FEC of this system to an additive white Gaussian noise (AWGN) model. Figure 8 indicates the interleaving structures for 16APSK, and Table 3 indicates the BICM interleaver directions for each modulation scheme and coding rate in ISDB-S3.

ISDB-S3 also supports the hierarchical modulation used in conventional BS digital broadcasting and can transmit multiple modulation schemes combined in a time division manner. By applying a modulation method with low required C/N such as QPSK to part of the transmitted signal, it is possible to prevent interruptions of broadcasting service due to rain.

3.4 Roll-Off Rate, OBO and Symbol Rate

Besides increasing the number of bits allocated per symbol by using APSK modulation, the transmission rate was enlarged by increasing the symbol rate; this involved investigating the roll-off rate of the modulation signal. The occupied bandwidth for 4K/8K satellite broadcasting must

(a) forward direction read-out. **(b) backward direction read-out.****Fig. 8** Bit interleaving (16APSK).**Table 3** Interleaver directions.

Modulation	Inner Coding Rate			
	1/3, 2/5	1/2, 3/5, 2/3, 3/4	7/9	4/5, 5/6, 7/8, 9/10
8PSK	Backward	Forward	Forward	Forward
16APSK	Backward	Forward	Forward	Forward
32APSK	Backward	Forward	Backward	Forward

be within 34.5 MHz, as specified by the Radio Act of Japan. There is a trade-off relationship between the roll-off rate and symbol rate in terms of transmission capacity expansion and transmission degradation for band-limiting waveform shaping filters (roll-off filters) to satisfy the occupied bandwidth rule of 34.5 MHz. Here, we conducted laboratory experiments simulating a satellite transmission line using a prototype transceiver. Assuming widespread reception in ordinary homes, we prototyped a receiver using consumer-level hardware and evaluated the transmission performance with it. Under the condition that the occupied bandwidth was 34.5 MHz, the roll-off rate was lowered while increasing the symbol rate. Figure 9 shows the measurement system in the experiments. The satellite simulator was mainly composed of an input de-multiplexer (IMUX), an output multiplexer (OMUX) and a TWTA. These were the main components determining the transmission characteristics and simulated

Fig. 9 Measurement system.

Fig. 10 IMUX and OMUX characteristics.

Fig. 11 TWTA characteristics.

the transponder characteristics of a broadcasting satellite. The RF characteristics of the IMUX, OMUX and TWTA are shown in Figs. 10 and 11.

We measured the required C/N of 16APSK (3/4) by changing the combination of roll-off factor (α) and symbol rate (Sr) for different values of output back off (OBO) to determine the optimum roll-off rate, OBO and maximum symbol rate for an occupied bandwidth of 34.5 MHz [24]. OBO is the ratio of the maximum operating output power to the saturated output power of the traveling wave tube amplifier (TWTA) on the satellite. The required C/N was defined as the smallest C/N at which the bit error rate (BER)

Fig. 12 Information bit rate vs. required C/N (16APSK (3/4)) with combination of roll-off factor (α) and symbol rate (Sr) for different values of output back-off (OBO).

is 1×10^{-11} . Figure 12 shows the required C/N vs. information bit rate for different values of OBO. It was assumed that the satellite was equipped with an amplifier with the rated output power that yielded an equivalent isotropically radiated power (EIRP) of 60 dBW (amplifier output power of 120 W), which is the upper limit of EIRP specified by the Radio Regulations when the OBO was set to the value. We tested four OBO values, OBO = 1.7 dB (equivalent to a rated power of 178 W), OBO = 2.2 dB (equivalent to a rated power of 200 W), OBO = 3.0 dB (equivalent to a rated power of 240 W) and OBO = 5.0 dB (equivalent to a rated power of 380 W). For comparison, the characteristics of IF loopback are indicated in the figure. The results show that the IF-loopback performance (the dotted line) significantly deteriorates when the roll-off factor is less than 0.02. The cause of the transmission degradation that occurs when the roll-off rate drops from 0.03 to 0.02 is considered to be that the FIR raised-cosine square-root Nyquist filter in the receiver cannot sufficiently follow the steep roll-off characteristics due to the limited number of taps of the digital filter. The results also show that increasing OBO improves performance, but that the C/N improvement is less than 1.0 dB in going from an OBO of 2.2 dB to an OBO of 5.0 dB. Furthermore, the performance degradation at $\alpha = 0.02$ and $\alpha = 0.01$ gets worse as OBO decreases. On the basis of these results, we selected $\alpha = 0.03$ as the modulation signal parameter of this system.

Transmission performance improves as the OBO value increases, but the excessive increase in the rated output power leads to an increase in the scale of satellite systems such as the power system and exhaust heat system. At the time of the experiment, a TWTA with a rated power of about 220 W was commercially available; therefore, we decided that a proper OBO value would be 2.2 dB.

The maximum symbol rate for $\alpha = 0.03$ is 33.8 Mbaud from Fig. 12. The symbol rate for the ISDB-S3 system was adjusted so that the information bit rate was an integer and the symbol rate was in units of Mbaud within four digits after the decimal point to match the transmission frame struc-

ture and accommodate a variable information rate. Finally, 33.7561 Mbaud was decided as the symbol rate in consideration of adaptability to the transmission frame in ISDB-S3. By reducing the roll-off rate to 0.03 and increasing the symbol rate to 33.7561 Mbaud, the frequency utilization efficiency increases by about 17% in comparison with that of ISDB-S (roll-off rate 0.35, symbol rate 28.86 Mbaud).

3.5 Pilot Signal

Since APSK modulates the amplitude in addition to the phase of the carrier wave, it is susceptible to the nonlinearity of the satellite transponder. ISDB-S3 introduces a pilot signal that transmits known signal points periodically and intermittently in the same modulation scheme as the main signal modulation to reduce the performance degradation due to the nonlinearity of the satellite transponder. When the transmission signal is affected by the nonlinear characteristics of the TWTA on satellite, the deviation from the ideal signal point caused by nonlinear distortion can be measured by averaging the pilot signal at the receiver. Using the average values enable optimal error correction decoding even if nonlinear distortion occurs.

Specifically, the modulation constellations of 16APSK and 32APSK are affected by the non-linearity of the satellite transponder and the signal points on the outer circle of the constellation have amplitude and phase distortions compared to the ones on the inner circle. These distortions cause cycle slip in carrier regeneration and degrade the performance of receivers. Therefore, by averaging the pilot signals over several seconds and detecting signal points after transmission in the receiver, the phase error table used for carrier regeneration can be rewritten so as to correspond to the signal points after the non-linear effect and the cycle slip can be reduced. Also, by rewriting the likelihood table for LDPC decoding in the same way, it is possible to suppress the deterioration of LDPC decoding. We used the satellite simulator to test the effect of using the pilot signal to reduce the required C/N in the 32APSK (4/5) transmission. The results confirmed that the required C/N improved by about 1.4 dB [25].

3.6 Transmission Performance

Figure 13 compares the transmission performance calculated in a computer simulation (bold lines) and IF-loopback transmission (dotted lines) measured in the experimental system depicted in Fig. 9 in terms of C/N vs. BER for $\pi/2$ -shift BPSK (1/2), QPSK (1/2), 8PSK (3/4), 16APSK (7/9), and 32APSK (4/5) in the ISDB-S3 system. The transmission performance in the computer simulation was calculated with an AWGN model and a maximum of 50 LDPC decoding iterations. It was found that the implementation loss in the system was within 0.4 dB in every modulation scheme.

Figure 14 shows the required C/N vs. information bit rate characteristics, which were obtained in actual satellite transmission experiments using ISDB-S3. The OBO in the

Fig. 13 Transmission performance (simulation and IF loopback).

Fig. 14 Required C/N vs. information bit rate.

satellite transponder was set to 2.2 dB. The points of each modulation scheme in Fig. 14 indicate results for error correction coding rates of 1/3, 2/5, 1/2, 3/5, 2/3, 3/4, 7/9, 4/5, 5/6, 7/8, 9/10 from lower to upper, respectively. This evaluation confirmed that 16APSK (coding rate 7/9) can be used to transmit at the 100 Mbps necessary for one 8K UHDTV program, and its required C/N is 12.2 dB.

4. Link Design

The effects of rain attenuation cannot be avoided in satellite broadcasting in the 12-GHz band. Therefore, the system design must take rain attenuation into account. It does so by considering service availability in the worst month of the rainy season in Japan. The annual service availability can be calculated from the system margin, which is the difference between the required C/N and the noise power.

Table 4 shows an example of the link design calculated assuming reception of a 16APSK (7/9) signal of 4K/8K satellite broadcasting in Tokyo using a 45-cm parabolic dish antenna. Table 5 shows the link design in Naha (the prefectural capital of Okinawa, the southernmost prefecture of Japan) using a 75-cm parabolic dish antenna. The rated output power of the satellite transponder is the upper limit of

Table 4 Link design (16APSK(7/9), receiving point: Tokyo).

Parameter	Unit	Clear Sky	Rainfall
Satellite EIRP	dBW	60.0	60.0
Free Space Propagation Loss	dB	205.6	205.6
Overall Atmospheric Absorption Attenuation	dB	0.1	4.0
Receiving Antenna Diameter	cm	45.0	45.0
Receiving Antenna Gain	dB	33.5	33.5
Pointing Loss	dB	0.1	0.1
Receiver Input	dBW	-112.3	-116.2
p.f.d.	dBW/m ²	-102.6	-102.6
G/T	dB/K	12.5	9.0
LNC Noise Figure	dB	1.0	1.0
Reception Bandwidth	MHz	33.7561	33.7561
Noise Input	dBW	-132.3	-128.8
Cross Polarized Wave Interference C/I	dB	22.9	22.9
Downlink C/N	dB	20.1	12.6
Adjacent Channel Interference	dB	60.3	60.3
Overall C/(N+I)	dB	18.2	12.2
Required C/N	dB	12.2	12.2
System Margin	dB	6.0	0.0
Annual Service Availability	%		99.93
Service Availability in the Worst Month	%		99.70

Table 5 Link design (16APSK(7/9), receiving point: Naha).

Parameter	Unit	Clear Sky	Rainfall
Satellite EIRP	dBW	57.0	57.0
Free Space Propagation Loss	dB	205.4	205.4
Overall Atmospheric Absorption Attenuation	dB	0.1	5.2
Receiving Antenna Diameter	cm	75.0	75.0
Receiving Antenna Gain	dB	37.9	37.9
Pointing Loss	dB	0.1	0.1
Receiver Input	dBW	-110.6	-115.7
p.f.d.	dBW/m ²	-105.3	-105.3
G/T	dB/K	17.0	12.9
LNC Noise Figure	dB	1.0	1.0
Reception Bandwidth	MHz	33.7561	33.7561
Noise Input	dBW	-132.3	-128.3
Cross Polarized Wave Interference C/I	dB	22.9	22.9
Downlink C/N	dB	21.7	12.6
Adjacent Channel Interference	dB	54.5	54.5
Overall C/(N+I)	dB	19.3	12.2
Required C/N	dB	12.2	12.2
System Margin	dB	7.1	0.0
Annual Service Availability	%		99.92
Service Availability in the Worst Month	%		99.69

EIRP (60 dBW) set by the Radio Regulations at the center of the coverage area. The system margins turn out to be 6.0 dB in Tokyo and 7.0 dB in Naha. They correspond to an annual service availability of 99.93% (worst month service time rate 99.70%) in Tokyo and 99.92% (worst month service time rate 99.69%) in Naha; i.e., a sufficient service time rate can be achieved.

5. Future Prospects

Broadcasting technology has evolved over the years in pace with the Olympic Games, the World Cup, and other global sports events. The first public viewing of the Olympic Games in 8K UHDTV was held in London in 2012, while 8K programming of the Rio Olympic Games and the PyeongChang Winter Olympic Games were broadcast live in Japan using the ISDB-S3 system. The world's first regular 8K UHDTV broadcasting started in 2018 in Japan and has been provided stably since then. In 2020, the year of the Tokyo Olympic and Paralympic Games, it is expected that many people will have TV sets equipped for UHDTV including 8K and they will enjoy the games broadcasted with so much presence and reality that they may feel as if they were on the actual track or field. Because of its extremely precise and detailed images and three-dimensional sound, the 8K UHDTV system has various possibilities for new services, and its potential applications go beyond broadcasting to the world of medicine, education, museums, digital cinema, signage, industrial design, crime prevention, and security. Even now, technologies are being developed for even more advanced broadcasting and applications.

6. Conclusion

This paper discussed a new transmission system designed for 4K/8K UHDTV satellite broadcasting, called ISDB-S3. After giving an outline and the details of the system, we described the transmission performance of the system by reviewing the results of simulations and experiments. We also calculated the link budget, which confirmed that the system can provide sufficient annual service availability.

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