International Telecommunication Union

ITU-R

Radiocommunication Sector of ITU

Report ITU-R BT.2343-7

(11/2021)

Collection of field trials of UHDTV over DTT networks

BT Series

Broadcasting service (television)

International Telecommunication Union

Foreword

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The regulatory and policy functions of the Radiocommunication Sector are performed by World and Regional Radiocommunication Conferences and Radiocommunication Assemblies supported by Study Groups.

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***Note**: This ITU-R Report was approved in English by the Study Group under the procedure detailed in Resolution ITU-R 1.*

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REPORT ITU-R BT.2343-7

Collection of field trials of UHDTV over DTT networks

(2015-02/2016-10/2016-2018-04/2019-09/2019-2020-2021)

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1 Introduction

Ultra high definition television (UHDTV) is one of the major applications of next-generation digital terrestrial broadcasting. Several countries have already started studies on digital terrestrial broadcasting transmission systems that have significantly expanded their transmission capacities by means of, for example, high multilevel modulation technology. Moreover, some countries have already carried out UHDTV field experiments on digital terrestrial broadcasting to demonstrate the feasibility of these systems. The compilation of a summary of these experiments will offer useful information to administrations and broadcasters wishing to introduce or consider UHDTV broadcasting in the future, as well as to manufacturers wishing to engage with this.

UHDTV production of big live events has already started, notably the 2014 FIFA World Cup in Brazil where three games hosted in the Epic Maracana Stadium were officially produced and distributed worldwide in 4k UHDTV. The EBU, by means of its operational branch (EUROVISION), ensured the worldwide delivery of the three games over its satellite and fibre network.

In Japan, 8K UHDTV field transmission experiments with 4096-QAM and dual-polarized multiple input multiple output (MIMO) technology were conducted in January 2014.

In the Annex, the Report presents an overview of the experiments, key technologies, and the results conducted in various countries.

The intent of this Report is to provide evidence about the suitability of terrestrial television networks to deliver UHDTV services to consumers on a large scale.

2 Status of standardization of UHDTV

2.1 Standardization within ITU

The standardization of parameters for Ultra High Definition is underway at ITU-R and Recommendations and Reports have been published, for example:

- Recommendation ITU-R BT.2020-2 – Parameter values for ultra-high definition television systems for production and international programme exchange.
- Recommendation ITU-R BS.2051 – Advanced sound system for programme production.
- Report ITU-R BT.2246 – The present state of ultra-high definition television.

Other standardization activities on UHDTV are ongoing in ITU-R and ITU-T.

2.2 Standardization within DVB

The standardization process is also well underway at the DVB level, with the Standard TS 101 154 V2.5.1 published (01/2019) as DVB Blue Book A001 (7/2019) Specification for the use of Video and Audio Coding in Broadcasting and Broadband Applications.

2.3 Standardization within TTA

On August 30, 2013, the scenarios for 4K-UHDTV service were described in the Report "TTAR-07.0011: A Study on the UHDTV Service Scenarios and its Considerations".

On May 22, 2014, the technical report "TTAR-07.0013: Terrestrial 4K UHDTV Broadcasting Service" was published.

On October 13, 2014, an interim standard – "TTAI.KO-07.0123: Transmission and Reception for Terrestrial UHDTV Broadcasting Service" – was published based on HEVC encoding, with MPEG-2 TS, and DVB-T2 serving as the standards.

On June 24, 2016, a standard – “TTAK.KO-07.0127: Transmission and Reception for Terrestrial UHDTV Broadcasting Service” – was published based on HEVC encoding, with MMTP/ROUTE IP, and ATSC 3.0 serving as the standards.

3 Field trials of UHDTV over DTT networks

The Annex shows details of trials conducted for UHDTV over terrestrial television networks.

The following Table summarizes the trials and indexes the Annex.

Summary of UHDTV trials on terrestrial television networks

Annex section	Country	Transmitter site	Covering	e.r.p.	DTT system	Channel bandwidth	Transmission mode	Multiplex capacity	Signal bit rate	Video encoding standard	Picture standard	Audio encoding standard	Frequency used
1.2	**Japan**	Hitoyoshi	City of Hitoyoshi	140 W(H) 135 W(V)	ISDB-T[2]	6 MHz	32k *GI* = 1/32 4096-QAM, FEC 3/4 dual-polarized MIMO	91.8 Mbit/s	91 Mbit/s	MPEG-4 AVC/H.264,	7 680 × 4 320 p 59.94 frame/s 8 bits/pixel	MPEG-4 AAC-LC Max. 22.2ch, Max. 1.8 Mb/s	671 MHz (Ch 46 in Japan)
1.3		Hitoyoshi Mizukami	City of Hitoyoshi	Hitoyoshi 140 W(H) 135 W(V) Mizukami 25 W(H) 25 W(V)			Space Time Coding-SFN 32k *GI* = 1/32 4096-QAM, FEC 3/4 dual-polarized MIMO	91.8 Mbit/s	91 Mbit/s (other bit rates also tested)	HEVC	7 680×4 320 p 59.94 frame/s 10 bits/pixel		
1.4		Kinuta Tokyo	Southern area of Tokyo	93 W(H) 93 W(V)			16k *GI* = 1/16 4096 NUC, FEC 3/4 dual-polarized MIMO	84.2 Mbit/s	76 Mbit/s	MPEG-4 AVC/H.264	7 680 × 4 320 p 59.94 frame/s 8 bits/pixel		581 MHz (Ch 31 in Japan)
1.5		Shiba	Central Tokyo	2.1 kW(H) 2.1 kW(V)			16k *GI* = 800/16384 1024 NUC FEC 11/16 SISO and dual-polarized MIMO	32.9~65.8 Mbit/s	28~56 Mbit/s (+ additional 1~2 Mb/s for HDTV)	HEVC	7 680 × 4 320 p 59.94 frame/s 10 bits/pixel	MPEG-H 3D Audio LC level 4 Max. 22.2ch + 3 objects 768 kb/s (512 kb/s to 1.4 Mb/s)	563 MHz (Ch 28 in Japan)
		Higashiyama Nabeta	City of Nagoya	Higashiyama 980 W(H) 980 W(V) Nabeta 81 W(H) 81 W(V)									605 MHz (Ch 35 in Japan)
1.6		Kinuta, Tokyo	Southern area of Tokyo	9.3 W(H) 9.3 W(V) (Ch 31 in Japan) 1.3 W(H) 1.45 W(V) (Ch 34 in Japan)			16k *GI* = 800/16384 1024 NUC FEC 9/16 dual-polarized MIMO Channel bonding	94.8 Mbit/s	80 Mbit/s (+ additional 4.0 Mb/s for HDTV)	HEVC	7 680×4 320 p 59.94 frame/s 10 bits/pixel	No sound included	581 MHz (Ch 31 in Japan) 599 MHz (Ch 34 in Japan)

2 Some parameters are extended from conventional ISDB-T system (System C of Recommendation ITU-R BT.1306).

Summary of UHDTV trials on terrestrial television networks

Annex section	Country	Transmitter site	Covering	e.r.p.	DTT System	Channel bandwidth	Transmission mode	Multiplex capacity	Signal bit rate	Video encoding standard	Picture standard	Audio encoding standard	Frequency used
2.1	**Korea (Republic of)**[3]	Kwan-Ak Mountain	South Metropolitan area of Seoul	36.7 kW	DVB-T2	6 MHz	32k, extended mode, *GI* = 1/16, PP4, 256-QAM, FEC 3/4, 4/5, 5/6	< 35.0 Mbit/s	Variable (some trials at 25~34 Mbit/s)	HEVC Main10 Level 5.1, Max 28 Mbit/s	3 840 × 2 160 p 60 frames/s, 8 bits or 10 bits/pixel	MPEG-4 AAC-LC or Dolby AC-3, Max 5.1Ch, Max 600 kb/s	713 MHz (Ch 54 in Korea)
				12.9 kW									701 MHz (Ch 52 in Korea)
				40.0 kW									707 MHz (Ch 53 in Korea)
		Nam Mountain	Central area of Seoul	2.2 kW									713 MHz (Ch 54 in Korea)
		Yong-Moon Mountain	West Metropolitan area of Seoul	8.3 kW									707 MHz (Ch 53 in Korea)
2.2	**Korea (Republic of)**	Kwan-Ak Mountain	South Metropolitan area of Seoul	39.6 kW	ATSC 3.0	6 MHz	32k, NoC = 0, *GI6_1536*, PP16_2, 256-QAM, 9/15	< 30.0 Mbit/s	Variable (17 Mbit/s)	HEVC Main10 Level 5.1, Variable (15.5 Mbit/s)	3 840 × 2 160 p 60 frames/s, 10 bits/pixel	MPEG-H 3D Audio Max 10.2Ch,	701 MHz (Ch 52 in Korea)
													707 MHz (Ch 53 in Korea)
													762 MHz (Ch 55 in Korea)
		Nam Mountain	Central area of Seoul	18.9 kW									768 MHz (Ch 56 in Korea)
		Gwang-Gyo Mountain	Suwon (Capital city of Gyeonggi province)	7.96 kW									

3 Details for Korea in Table 1 correspond to Phase 3 of the trials. See § 2.1 for more details of Phases 1 and 2.

Summary of UHDTV trials on terrestrial television networks

Annex section	Country	Transmitter site	Covering	e.r.p.	DTT System	Channel bandwidth	Transmission mode	Multiplex capacity	Signal bit rate	Video encoding standard	Picture standard	Audio encoding standard	Frequency used
3.1	**France**	Eiffel Tower	City of Paris	1 kW	DVB-T2	8 MHz	32k, extended mode, *GI* = 1/128, 256-QAM, FEC2/3, PP7	40.2 Mbit/s	Two programmes carried: one at 22.5 Mb/s, one at 17.5 Mbit/s	HEVC	3 840 × 2 160p 50 frames/s 8 bits/pixel	HE-AAC 192 kb/s	514 MHz (Ch 26 in Region 1)
3.2		Eiffel Tower Paris Est Chenevières Meaux Chaville Nantes Toulouse	City of Paris City of Nantes City of Toulouse	5 kW 300 W 40 W 3 W 16 kW 500 W	DVB-T2	8 MHz	32k, extended mode, *GI* = 1/32, 256-QAM, FEC3/5, PP4 or PP6	34.2 Mbit/s (PP4) 34.9 Mbit/s (PP6)	Two to three programmes carried, from 10 to 17 Mbit/s for UHD and from 3 to 17 Mbit/s for HD-1080p Statistical multiplexing of 3 UHD programmes	HEVC	Various combinations between 3 840 × 2 160p 50 frames/s 8 or 10 bits/pixel and 1 920 x 1 080p 50 frames/s 8 or 10 bits/pixel	AAC 2.0 / AC3+ with various bitrates	514 MHz (Ch 26 in Region 1) / 498 MHz (Ch 24 in Region 1)
							32k, extended mode, *GI* = 1/32, 256-QAM, FEC2/3, PP6	38.8 Mbit/s	Two programmes carried: one at 24.8 Mb/s, one at 12.4 Mbit/s Three programmes carried: one UHD at 24 Mb/s, two HD-1080p from 2.5 to 7 Mbit/s		3 840 × 2 160p 50 frames/s 10 bits/pixel 1 920 × 1 080p 50 frames/s 10 bits/pixel	MPEG-H 435 kb/s AC3+ 2.0 235 kb/s AAC 2.0 134 kb/s	

Summary of UHDTV trials on terrestrial television networks

Annex section	Country	Transmitter site	Covering	e.r.p.	DTT System	Channel bandwidth	Transmission mode	Multiplex capacity	Signal bit rate	Video encoding standard	Picture standard	Audio encoding standard	Frequency used
4.1	**Spain**	ETSI Tele-comunicación	Ciudad Universitaria, Madrid	125 W	DVB-T2	8 MHz	32k, extended mode, *GI* = 1/128, 64-QAM, FEC5/6, PP7	36.72 Mbit/s	35 Mbit/s (other bit rates also tested)	HEVC	3 840 × 2 160 p 50 frames/s 10 bits/pixel	E-AC-3 5.1	754 MHz (Ch 56 in Region 1)
4.2.1	**Spain**	ETSI Tele-comunicación	Ciudad Universitaria, Madrid	125 W	DVB-T2	8 MHz	32k, extended mode, *GI* = 1/128, 64-QAM, FEC3/4, PP7	32.6 Mbit/s	30 Mbit/s	HEVC	3 840 × 2 160p 50 frames/s 10 bits/pixel	E-AC-3 5.1	658 MHz (Ch 44 in Region 1)
		Collserola	Barcelona	15 kW									482 MHz (Ch 22 in Region 1)
4.2.2	**Spain**	Torrespaña and San Fernando	Madrid	15 kW Torrespaña 75 W San Fernando	DVB-T2	8 MHz	32k, extended mode, *GI* = 1/8, 256-QAM, FEC2/3, PP2	33.4 Mbit/s	30 Mbit/s	HEVC	3 840×2 160 p 50 frames/s 10 bits/pixel HDR 10 Dolby Vision	AC-4 and E-AC-3 5.1	562 MHz (Ch 32 in Region 1)
		Collserola and Baix Llobregat	Barcelona	10 kW Collserola 12 W Baix LLobregat									650 MHz (Ch 43 in Region 1)
		Valencina	Sevilla	9 kW									594 MHz (Ch 36 in Region 1)
4.2.3	**Spain**	ETSI Tele-comunicación	Ciudad Universitaria, Madrid	125 W	DVB-T2	8 MHz	32k, extended mode, *GI* = 1/8, 256-QAM, FEC2/3, PP2	33.4 Mbit/s	30 Mbit/s	HEVC	3 840×2 160 p 100 frames/s 10 bits/pixel HDR 10 WCG	AC-4 5.1	658 MHz (Ch 44 in Region 1)
		Torrespaña and San Fernando	Madrid	15 kW Torrespaña 75 W San Fernando									562 MHz (Ch 32 in Region 1)
		Collserola and Baix Llobregat	Barcelona	10 kW Collserola 12 W Baix LLobregat									650 MHz (Channel 43 in Region 1)
		Valencina	Sevilla	9 kW									594 MHz (Ch 36 in Region 1)
		Mijas	Malaga	2 kW									514 MHz (Ch 26 in Region 1)

Summary of UHDTV trials on terrestrial television networks

Annex section	Country	Transmitter site	Covering	e.r.p.	DTT System	Channel bandwidth	Transmission mode	Multiplex capacity	Signal bit rate	Video encoding standard	Picture standard	Audio encoding standard	Frequency used
		Monte Pedroso	Santiago de Compostela	9 kW									570 MHz (Ch 33 in Region 1)
4.2.4	**Spain**	ETSI Tele-comunicación	Ciudad Universitaria, Madrid	125 W	DVB-T2	8 MHz	32k, extended mode, *GI* = 1/128, 64-QAM, FEC 5/6, PP7	36.72 Mbit/s	32 Mbit/s	HEVC	7 680 × 4 320 p 50 frames/s 10 bits/pixel HLG WCG	AC-4 5.1.4	658 MHz (Ch 44 in Region 1)
		Torrespaña and San Fernando	Madrid	15 kW Torrespaña 75 W San Fernando			32k, extended mode, *GI* = 1/8, 256-QAM, FEC 2/3, PP2	33.4 Mbit/s					594 MHz (Ch 36 in Region 1)
		Collserola and Baix Llobregat	Barcelona	10 kW Collserola 12 W Baix LLobregat									650 MHz (Ch 43 in Region 1)
		Valencina	Sevilla	9 kW									594 MHz (Ch 36 in Region 1)
		Mijas	Malaga	2 kW									514 MHz (Ch 26 in Region 1)
		Monte Pedroso	Santiago de Compostela	9 kW									570 MHz (Ch 33 in Region 1)
		La Muela	Zaragoza	9 kW									490 MHz (Ch 23 in Region 1)
		Torrente	Valencia	2 kW									634 MHz (Ch 41 in Region 1)
4.3	**Spain**	51 transmitters	50% of Spanish population	Up to 15 kW	DVB-T2	8 MHz	32k, extended mode, *GI* = 1/8, 256-QAM, FEC 2/3, PP2 And 32k, extended mode, *GI* = 1/128, 256-QAM, FEC 2/3, PP7	33.4 Mbit/s	30 Mbit/s	HEVC	3 840 × 2 160 p 100 frames/s 10 bits/pixel HDR 10 WCG	AC-4 5.1	470 MHz – 694 MHz (Ch 21 to 48 in Region 1)
5	**Sweden**	Stockholm Nacka	City of Stockholm	35 kW	DVB-T2	8 MHz	32k, extended mode, *GI* = 19/256, 256-QAM, FEC 3/5, PP4	31.7 Mbit/s	24 Mbit/s	HEVC	3 840 × 2 160 p 29.97 frames/s 8 bits/pixel		618 MHz (Ch 39 in Region 1)

Summary of UHDTV trials on terrestrial television networks

Annex section	Country	Transmitter site	Covering	e.r.p.	DTT System	Channel bandwidth	Transmission mode	Multiplex capacity	Signal bit rate	Video encoding standard	Picture standard	Audio encoding standard	Frequency used
6	**UK**	Crystal Palace	Greater London (serving over 4.5 million households)	40 kW	DVB-T2	8 MHz	32k, extended mode, *GI* = 1/128, 256-QAM, FEC 2/3, PP7	40.2 Mbit/s	Variable (some trials at 35 Mbit/s)	HEVC	Mixture of 3 840 × 2 160 p 50 frames/s and 3 840 × 2 160p 59.94 frames/s Most of the trial at 8 bits/pixel, some at 10 bits/pixel		586 MHz (Ch 35 in Region 1)
		Winter Hill	North-west of England, including Manchester and Liverpool (serving 2.7 million households)	22.5 kW		8 MHz							602 MHz (Ch 37 in Region 1)
		Black Hill	Central Scotland, including Glasgow and Edinburgh (serving 1 million households)	39 kW		8 MHz							586 MHz (Ch 35 in Region 1)
7	**Brazil**	Mt. Sumaré	Parts of Rio de Janeiro metropolitan area	660 W(H) 660 W(V)	ISDB-T[1]	6 MHz	32k *GI* = 1/32 4096-QAM, FEC 3/4 dual-polarized MIMO	91.8 Mbit/s	85 Mbit/s	HEVC	7 680 × 4 320 p 59.94 frame/s 10 bits/pixel	MPEG-4 AAC 1.48 Mb/s	569 MHz (Ch 30 in Brazil)
8.1	**China**	Jiaxing Radio and Television Building	Jiaxing City urban and country side	10 kW	DTMB-A	8 MHz	32k *GI* = 1/64 256APSK FEC 2/3	39.7 Mbit/s	36 Mbit/s	H.265	3 840 × 2 160 p 50 frame/s	MPEG-4 AAC 384 Kbit/s	562 MHz DS-24
8.2		Shenzhen	Xinghe CoCo Park	10W	DTMB-A	8 MHz*4	32k GI = 1/128 256APSK FEC 2/3	200 Mbit/s	120 Mbit/s	AVS3 profile 10	7 680 × 4 320 p 50 frame/s	MPEG-4 AAC 448 Kbit/s	634 MHz, 642 MHz, 650 MHz and 658 MHz

Summary of UHDTV trials on terrestrial television networks

Annex section	Country	Transmitter site	Covering	e.r.p.	DTT System	Channel bandwidth	Transmission mode	Multiplex capacity	Signal bit rate	Video encoding standard	Picture standard	Audio encoding standard	Frequency used
9	**Iran**	Jamaran	City of Tehran	20 kW	DVB-T2	8 MHz	32k, extended mode, *GI* = 1/32, 256-QAM, FEC 3/5, PP6	< 35 Mbit/s	~ 20 Mbit/s	HEVC Main10	3 840 × 2 160 p 50 frames/s 10 bits/pixel	HE-AAC	738 MHz (Ch 54 in Region 1)
		Karkhane ghand	A Part of city of Isfahan	2.5 kW									826 MHz (Ch 65 in Region 1)
		Markaz Isfahan	A Part of city of Isfahan	0.25 kW									810 MHz (Ch 63 in Region 1)
		Own-ebn-ali	A Part of city of Tabriz	0.5 kW									842 MHz (Ch 67 in Region 1)
		Khalaj(kuy tolab)	A Part of city of Mashhad	2 kW									834 MHz (Ch 66 in Region 1)
		Mianrud	A part of city of Shiraz	4 kW									842 MHz (Ch 67 in Region 1)

GI = guard intervals.

Annex

Field experiments of UHDTV terrestrial transmission

1 Japan

1.1 Introduction

Next-generation digital terrestrial television broadcasting will be dominated by UHDTV applications. UHDTV broadcasts consist of a huge amount of data and therefore require large-capacity transmission paths.

Japan is conducting research on large-capacity transmission technology for next-generation digital terrestrial broadcasting systems that will provide large-volume content services such as 8K. In order to transmit the 8K signal, which has a resolution 16 times greater than HDTV, it will be essential to utilize new technologies that expand transmission capacity, such as ultra-multilevel (4096-QAM), orthogonal frequency-division multiplexing (OFDM), and dual-polarized multiple-input multiple-output (MIMO).

This experiment establishes parameters for maximizing transmission capacity. However, in actual implementation, these parameters will have to be decided taking link budget, the transmission network, the receiving environment, and other factors into account.

A Research and Development project on an advanced digital terrestrial television broadcasting (DTTB) system is in progress under the auspices of the Ministry of Internal Affairs and Communications, Japan. The project is aiming at developing an advanced DTTB system. The system being developed in this project (hereafter referred to as advanced system) is under evaluation through field trials in large-scale experimental environments constructed in urban areas.

1.2 8K-UHDTV field experiments in rural area; Hitoyoshi (2×2 MIMO transmission system)

Japan has installed an experimental transmitting station in Hitoyoshi city, Kumamoto prefecture that uses dual-polarized MIMO and ultra-multilevel OFDM technologies. Two 8K field experiments were conducted there: a transmission test and field measurements at 52 points around Hitoyoshi.

Here, Japan reports the results of these experiments, including the required field strength when using 4096-QAM carrier modulation and a channel response analysis of dual-polarized MIMO transmission.

1.2.1 Transmission parameters and experiment area

Table 1 lists the specifications of the 8K field experiments in the Hitoyoshi area.

TABLE 1

Specifications of 8K field experiments in Hitoyoshi

Modulation method	OFDM
Occupied bandwidth	5.57 MHz
Transmission frequency	671.142857 MHz (UHF ch46)
Transmission power	Horizontal polarized waves: 10 W, e.r.p.: 140 W Vertical polarized waves: 10 W, e.r.p.: 135 W

TABLE 1 (*end*)

Carrier modulation	4096-QAM
FFT size (number of radiated carriers)	32k (22,465)
Guard interval ratio (guard interval duration)	1/32 (126 μs)
Error-correcting code	Inner: LDPC, code rate = 3/4 Outer: BCH
Transmission capacity	91.8 Mbit/s
Video coding	MPEG-4 AVC/H.264, HEVC
Audio coding	MPEG-4 AAC
Transmitting station	Established at NHK Hitoyoshi TV relay station
Height of transmitting antenna	632 m above sea level (21 m above ground level)

1.2.2 Transmitting and receiving station equipment

Table 2 shows the requirements for selecting the field experiment locations. The Hitoyoshi area fulfils these requirements and so it was chosen as the place to set up the experimental transmitting station.

Figure 1 shows the transmitting station and equipment and Fig. 2 shows the receiving station and equipment. An 85-inch 8K monitor was used to display the 8K signal. Both the dual-polarized transmitting antenna and the dual-polarized receiving antenna were developed.

Figure 3 is a block diagram of the modulator and demodulator used in the experiments. The input signal is coded with BCH code and low density parity check (LDPC) code, bit interleaved and mapped onto the constellation. After that, the signal is divided into two signals (one for horizontal polarization and the other for vertical) with 3D interleave (time, frequency and inter-polarization). The signals are then converted into time domain signals by inverse fast Fourier transform (IFFT) and guard intervals (*GI*) are added.

The signals from the modulator are converted into RF signals of the same frequency by using up-converters (U/C). The signals are then amplified with a power amplifier (PA) to the desired power level and transmitted as horizontal and vertical polarized waves from a dual-polarized antenna.

The transmitted signals are received by a dual-polarized Yagi antenna. Each received signal is filtered by a band-pass filter (BPF) and input to a variable attenuator (ATT). The signals are then amplified using low noise amplifiers (LNA) and converted into IF signals with a down converter (D/C). The IF signals are then input to the demodulator.

In the demodulator, the active symbol period is extracted from the received signals, which are then converted into frequency domain signals by fast Fourier transform (FFT). The frequency domain signals are de-multiplexed, equalized by MIMO detection, 3D de-interleaved, and used to calculate the log likelihood ratio (LLR). LLRs are de-interleaved and input to the LDPC decoder. Finally, BCH decoding is applied to obtain the output signal.

In the transmission test, compressed 8K signals were transmitted over a single UHF-band channel (6 MHz bandwidth). The distance between the transmitting station and receiving station was 27 km, a typical distance for current digital terrestrial broadcasting.

TABLE 2

Location requirements for 8K field experiments

1	The place should have a vacant UHF single channel for 8K transmission.
2	To analyse the channel response of dual-polarized MIMO transmission, the experiment should be able to be conducted over a large area and over long distances (e.g. transmissions over 20 km).
3	The place should support a current DTTB system.
4	The place should be free of mutual interference from other areas.

FIGURE 1

Transmitting station and equipment

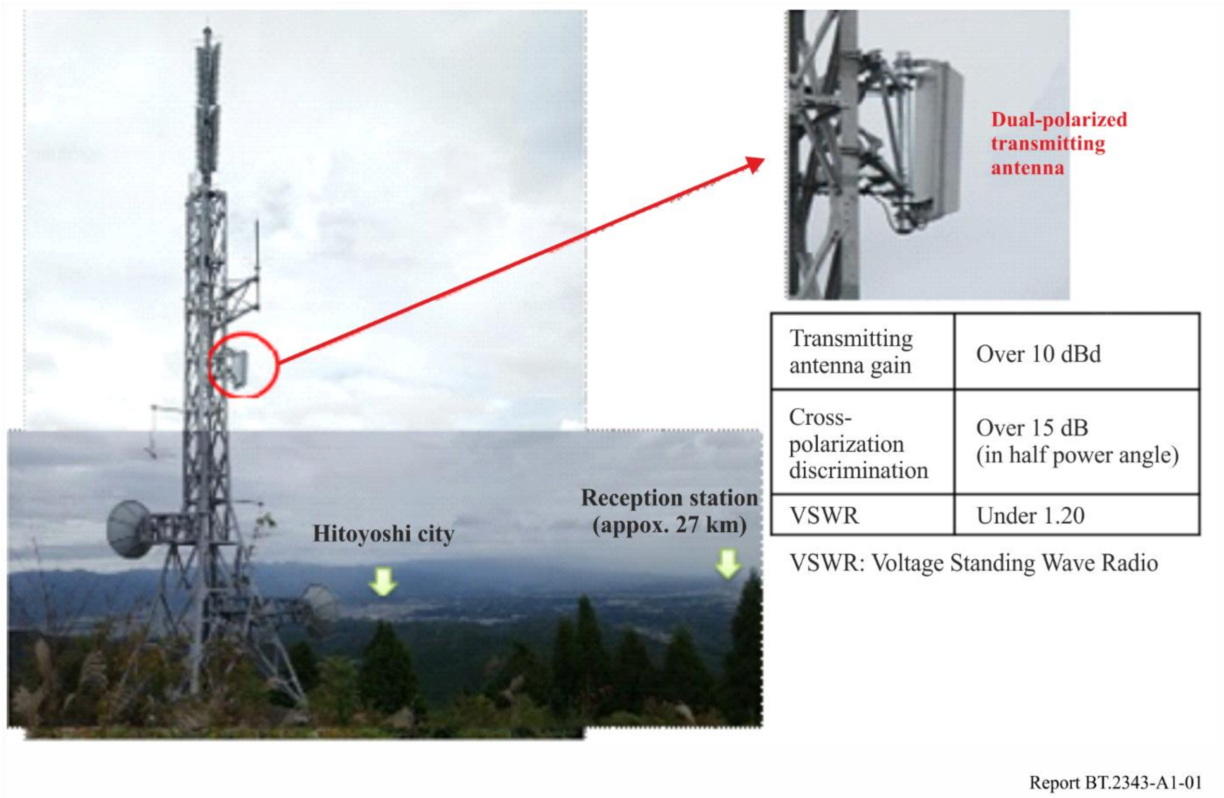


FIGURE 2

Receiving station and equipment

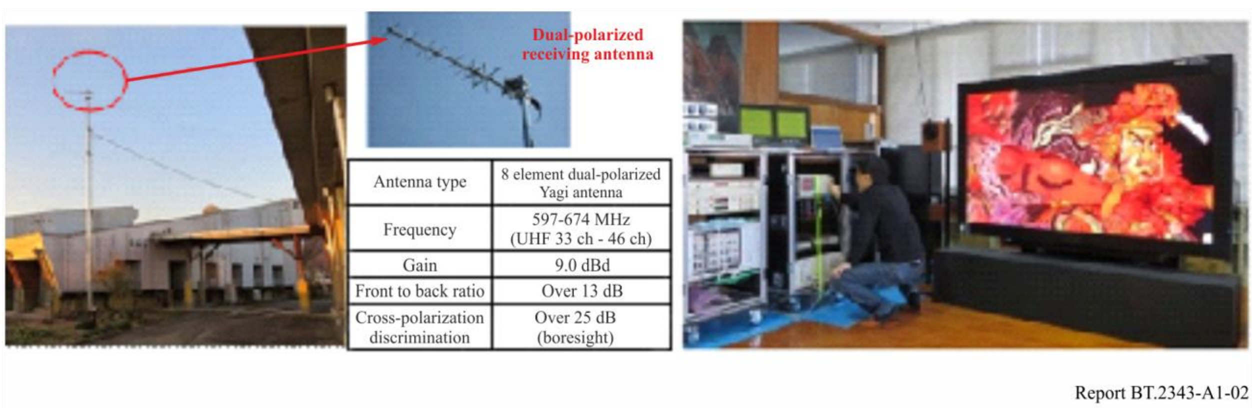
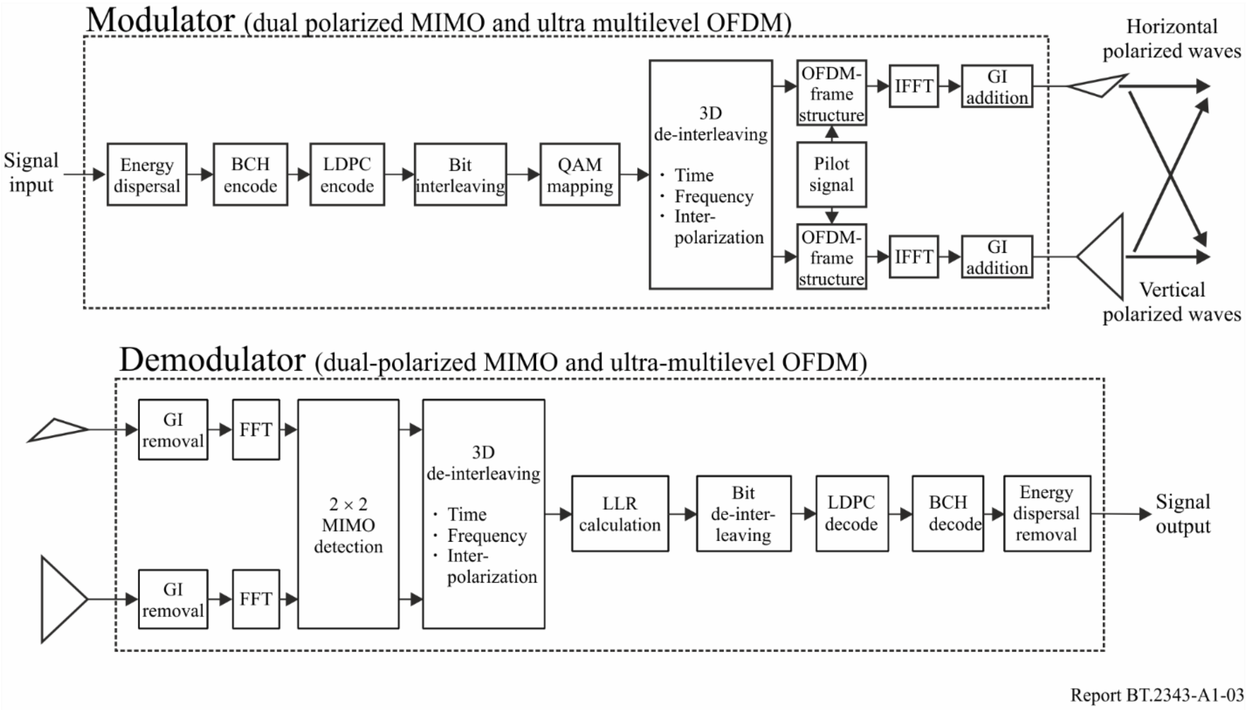


FIGURE 3

Block diagram of 8K experiments



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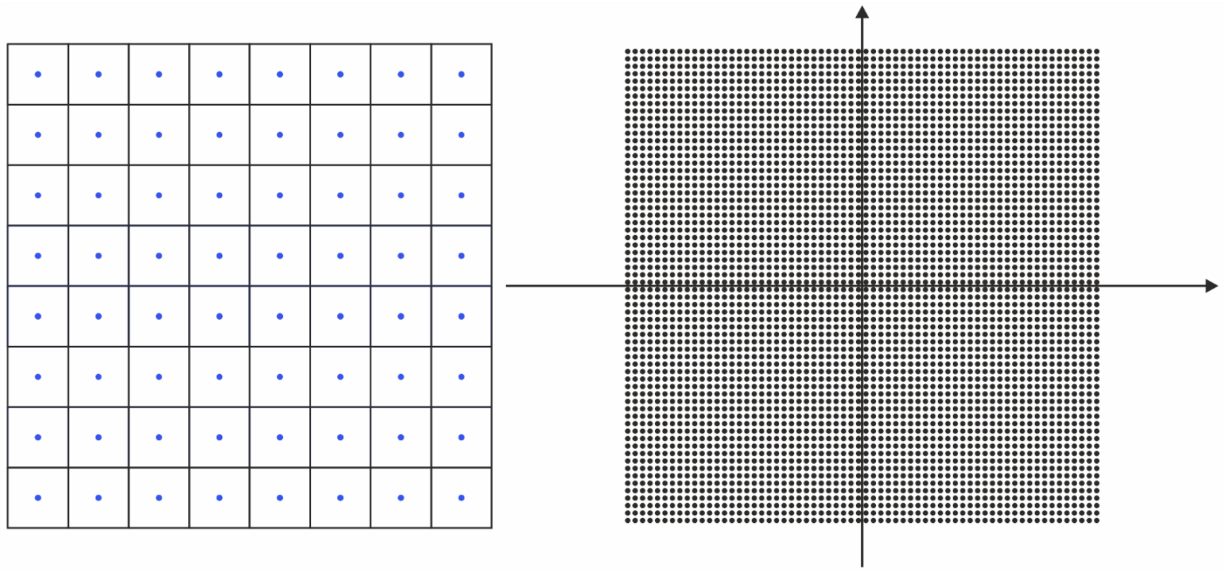
1.2.3 Key technologies

Ultra-multilevel OFDM is a technology that applies a greater number of signal points to data symbols. Carrier modulation schemes up to 64-QAM can be used in current ISDB-T, but up to 4096-QAM can be implemented in the prototype equipment. Figure 4 shows the constellations of 64-QAM and 4096-QAM. 64-QAM can transmit six bits of data per carrier symbol, while 4096-QAM can transmit 12 bits per carrier symbol, which is twice as many as 64-QAM.

FIGURE 4

Constellations of 64-QAM (left) and 4096-QAM (right)



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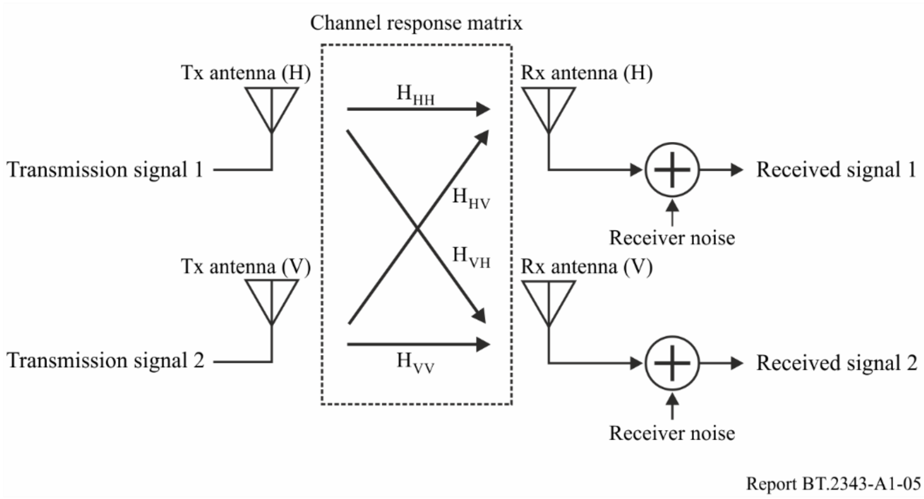
Dual-polarized MIMO is a technology configuring MIMO with two orthogonal polarizations. This technology was used to expand the transmission capacity, and namely each of the two polarized waves transmitted different data. A dual-polarized MIMO using horizontally and vertically polarized waves can be used as the model, as shown in Fig. 5.

FIGURE 5

MIMO transmission model



1.2.4 Field measurement results

For the field test, 52 reception points in the Hitoyoshi area that were 1.3 km to 36.7 km from the transmitter were selected (see Fig. 6). MIMO propagation measurements were conducted at all 52 points and the BER (after the BCH decoding) and receiving margin were measured at each carrier modulation at 30 points.

FIGURE 6

Location of reception points

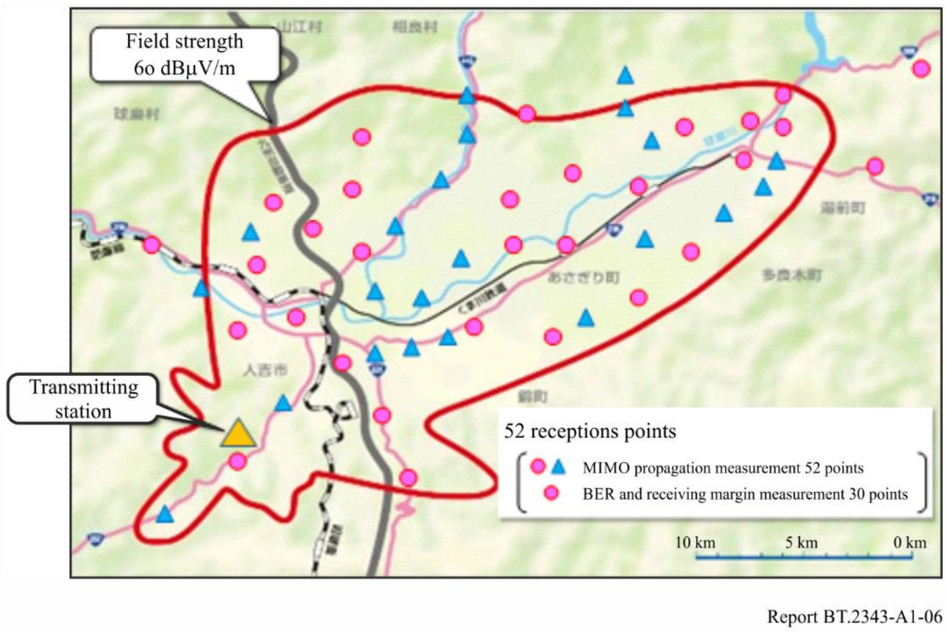
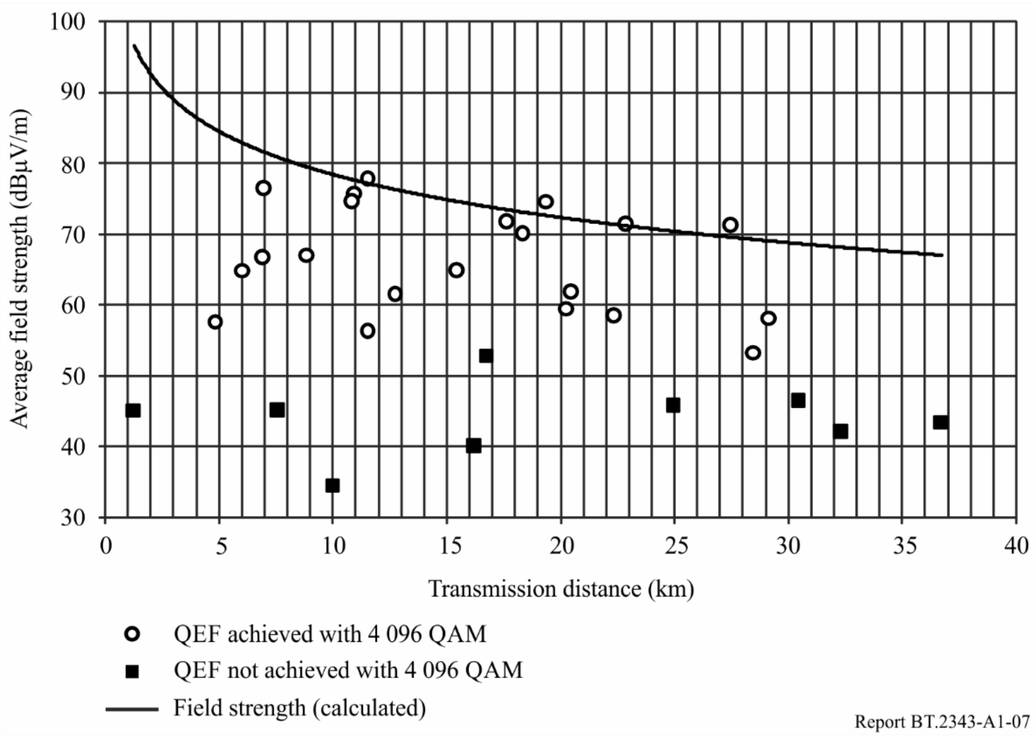


Figure 7 plots the average field strength of the BER and receiving margin measurements at the 30 reception points. The horizontal axis is the transmission distance (km) and the vertical axis is the average field strength of both polarized waves. These results indicate that quasi error free (QEF) transmission is possible with the 4096-QAM carrier modulation scheme. In this Annex, the QEF is defined that there is no error for a measurement time of two minutes.

FIGURE 7

Average field strength vs. transmission distance



The required field strength, which is defined as the lowest field strength for QEF transmission, was determined by decreasing the input signal level of the LNA by using the ATT.

Table 3 lists the average required field strengths, which were calculated by averaging the horizontal and vertical polarized waves. The average required field strength increased by about 5 dB as a result of quadrupling the number of signal points in the constellation.

TABLE 3

Average required field strength for QEF

Carrier modulation scheme	**Average required field strength (dBμV/m)**	**Number of QEF points**
256-QAM	42.4	23
1024-QAM	47.3	22
4096-QAM	52.3	21

The transmission characteristics were analysed at all 52 points of the MIMO propagation measurement. The propagation environment was classified into four categories: line of sight (LoS), non-line of sight (NLOS) with a strong field strength (over 60 dBμV/m), NLOS with a moderate field strength (40-60 dBμV/m), and NLOS with a weak field strength (under 40 dBμV/m).

Figure 8 shows an example of the MIMO channel responses of NLOS with a moderate field strength. An example of the distribution of the condition numbers of the four categories is presented in Fig. 9.

The analysis indicates that the MIMO propagation qualities became worse starting with LoS and followed by NLOS with a strong field strength, NLOS with a moderate field strength, and NLOS with a weak field strength. This order is attributed to the increase of the cross polarized wave components. It was also shown that the condition number increased and the distribution of the condition number spread out in the same order as above.

FIGURE 8

Example of MIMO channel responses of NLOS with a moderate field strength

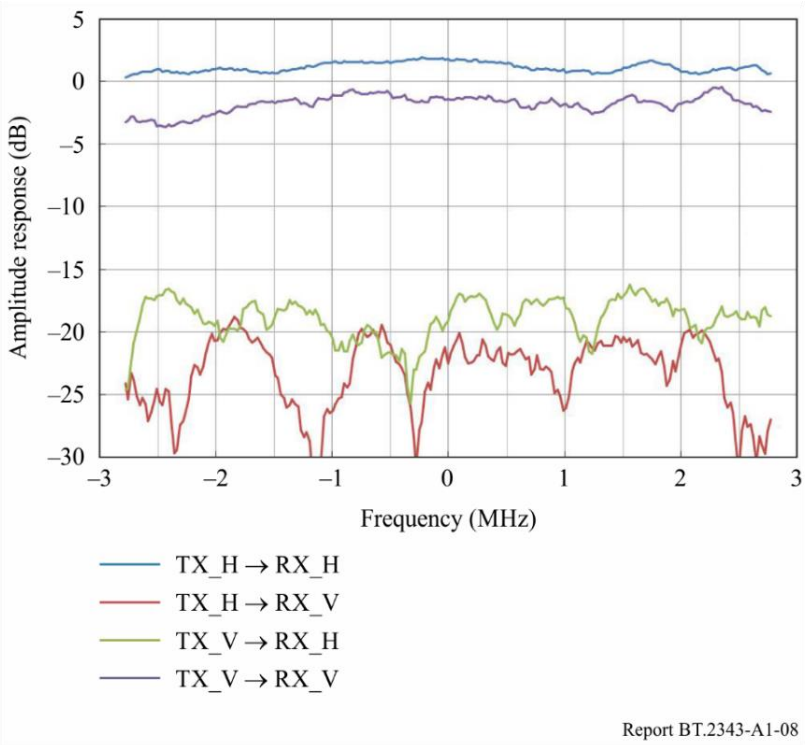
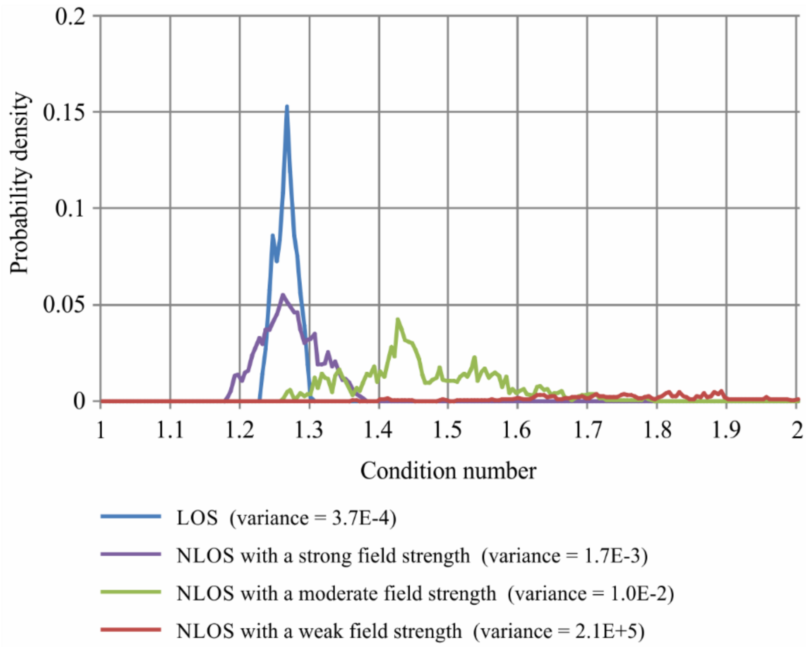


FIGURE 9

Example of distribution of condition number of four categories



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1.3 8K-UHDTV SFN field experiments in rural area; Hitoyoshi (2 × 2 MIMO STC-SFN transmission system)

In February 2015, Japan conducted 8K-UHDTV single frequency network (SFN) field experiments using two transmission stations to form a 2 × 2 MIMO Space Time Coding (STC)-SFN system. In this field experiment, the STC method was employed to improve the reliability of high data rate transmission. In November 2016, an 8K-UHDTV field experiment using high efficiency video coding (HEVC) was conducted. It was confirmed that the video and audio were successfully received within the STC-SFN area.

1.3.1 Overview of 2 × 2 MIMO STC-SFN

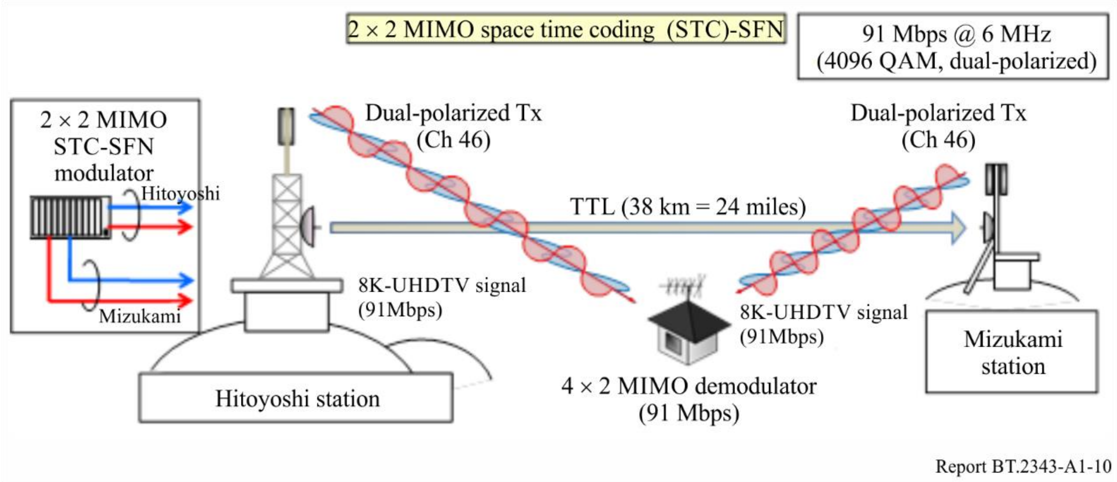
Figure 10 shows the outline of a 2 × 2 MIMO STC-SFN system formed by two experimental stations, namely, the Hitoyoshi and Mizukami stations. The distance between the two stations is 38 km. Both stations use dual-polarized space division multiplexing (SDM) MIMO. The Mizukami station became operational in 2015 and was connected to the Hitoyoshi station by a transmitter to transmitter link (TTL) in the super high frequency (SHF) band.

In this field experiment, the intermediate frequency TTL (IF-TTL) method was used to transmit an OFDM signal from the Hitoyoshi station to the Mizukami station. The transmission frequencies of the two stations were precisely synchronized by rubidium (Rb) oscillator with a global positioning system (GPS) as a backup.

The 2 × 2 MIMO STC-SFN system used in this SFN field experiment employed STC technology as a new feature. The Hitoyoshi station transmitted a 91 Mbit/s 8K-UHDTV signal in a 6 MHz bandwidth UHF channel (channel number 46 in Japan), and the Mizukami station also transmitted using the same channel.

FIGURE 10

Outline of 2 × 2 MIMO STC-SFN transmission system



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1.3.2 Transmission parameters and equipment

Table 4 shows the parameters for MIMO transmission, and Table 5 the specifications of the Hitoyoshi and Mizukami stations. Figure 11 shows the equipment installed in each station, and Fig. 12 shows the transmission and reception antennas for the UHF channel. The transmission antennas at Hitoyoshi and Mizukami have the same characteristics.

TABLE 4

Parameters for MIMO transmission

Modulation method	OFDM
Occupied bandwidth	5.57 MHz
Carrier modulation	4096-QAM
FFT size (number of radiated carriers)	32K (22,465)
Guard interval ratio (guard interval duration)	1/32 (126 μs)
Error-correcting code	Inner code: LDPC, coding rate R = 3/4 Outer code: BCH
Transmission capacity	91.8 Mbit/s

TABLE 5

Specifications of Hitoyoshi and Mizukami stations

	Hitoyoshi station	**Mizukami station**
Transmission frequency	671.142857 MHz (UHF Ch 46 in Japan)	
Transmission power	Horizontal: 10 W Vertical: 10 W	Horizontal: 3 W Vertical: 3 W
e.r.p.	Horizontal: 140 W Vertical: 135 W	Horizontal: 25 W Vertical: 25 W
Transmitting antenna height	632 m above sea level	1 080 m above sea level

FIGURE 11

Equipment of MIMO experimental stations

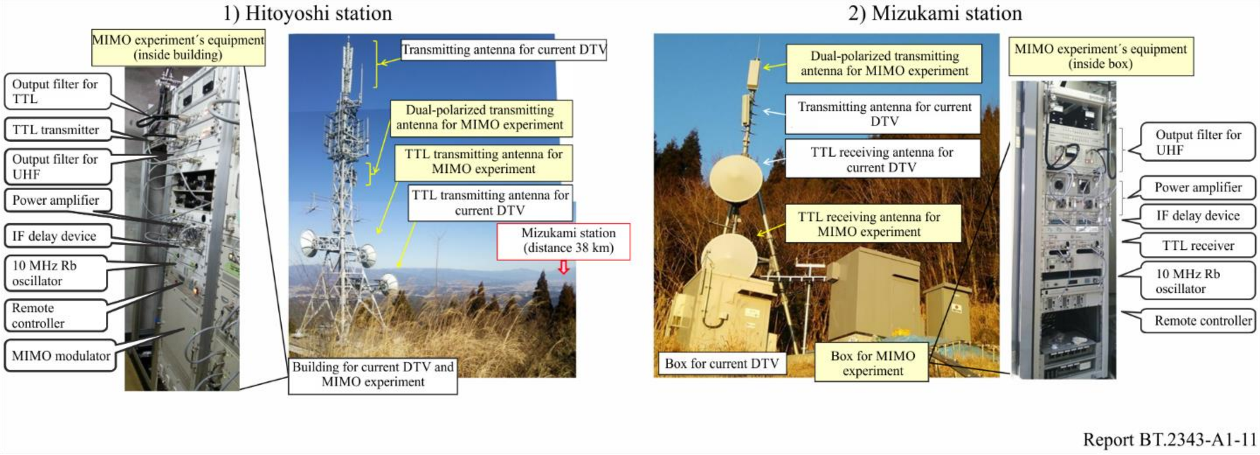
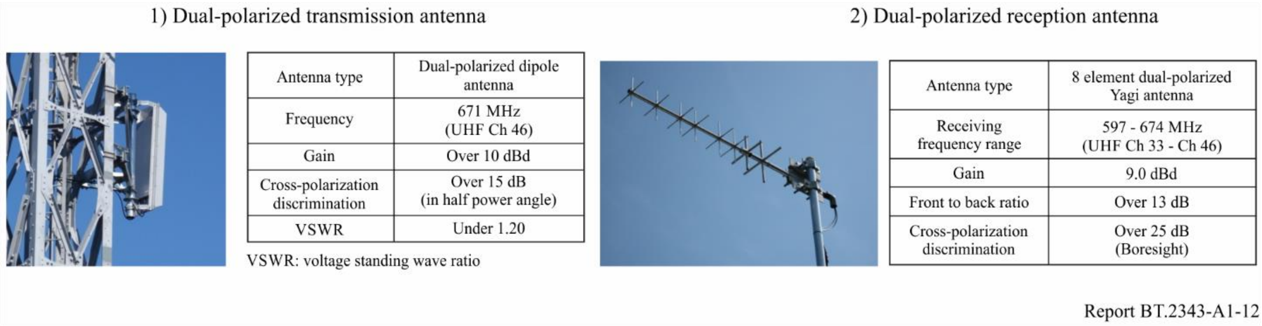


FIGURE 12

Transmission and reception antennas for UHF



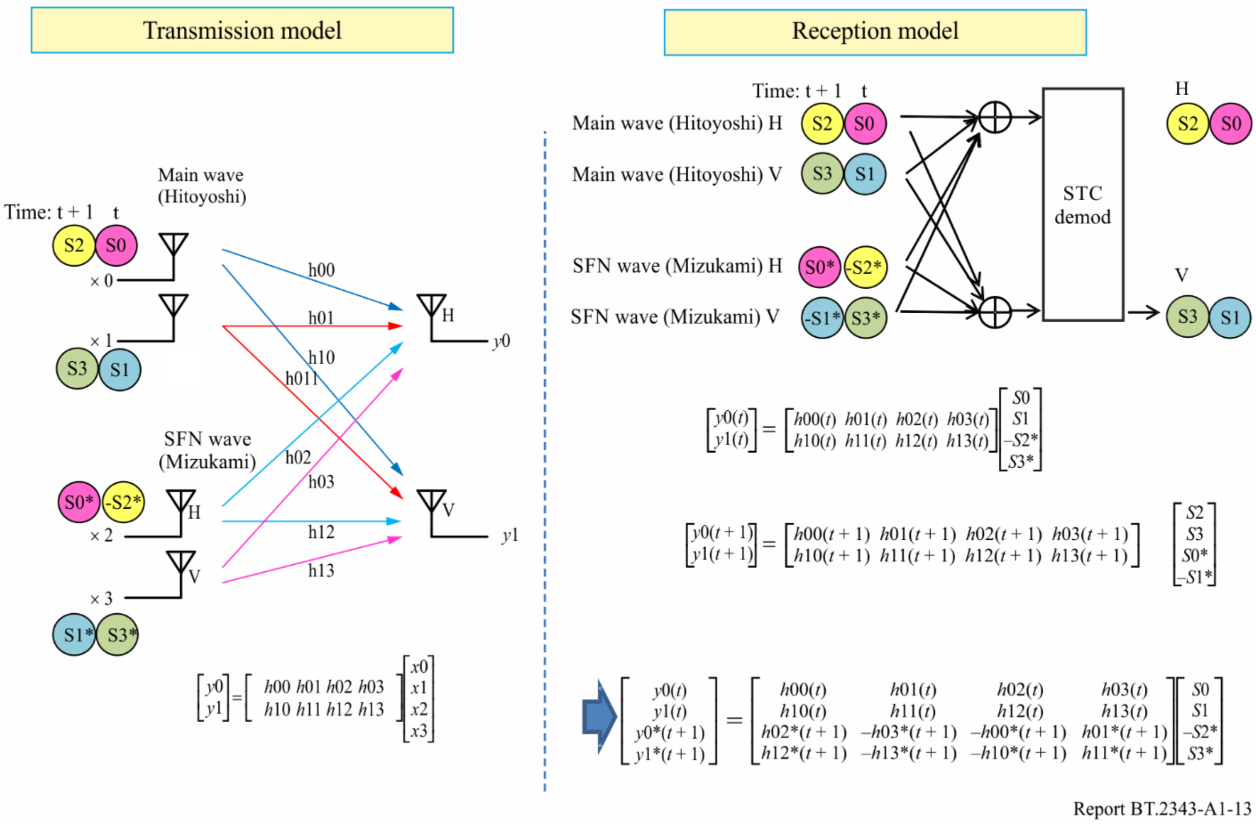
The 2 × 2 MIMO STC-SFN system was developed for this experiment as shown in Fig. 13. STC is a method of encoding carrier symbols. An STC code is applied for the four carrier symbols of the two transmission antennas each of two transmission stations. Here, *s* is a carrier symbol of a constellation with a complex value, and "*" means the complex conjugate. The transmitted symbols s_0, s_1, s_2 and s_3 are encoded, s_0, s_1, $-s_2^*$ and s_3^* are transmitted in time *t*, and s_2, s_3, s_0^* and $-s_1^*$ are then transmitted in time $t+1$, from each antenna. In the transmission model, the transmitting carrier symbols are denoted as x_0, x_1, x_2 and x_3, and the receiving carrier symbols as y_0 and y_1. *h* is the channel response estimated by scattered pilot (SP), and h_{ij} is the component corresponding to the *i*th receiving antenna and *j*th transmitting antenna. In the reception model, the transmitted symbols s_0, s_1, s_2 and s_3 are obtained by decoding the received symbols y_0 and y_1, which are received at two discrete times.

Figure 14 shows the block diagram of the 2 × 2 MIMO STC-SFN system modulator and demodulator used in this field trial. Figure 15 shows the SP patterns of the 2 × 2 MIMO STC-SFN system. To estimate the channel responses of each receiving antenna, four orthogonal SP schemes using sign inversion were investigated. These SP patterns are the extensions of those used by ISDB-T.

In order to adjust the time delay between two transmission waves, IF delay adjustment equipment with a range of 0.1 µs – 10 m s (shown in Fig. 15) was installed at both stations.

FIGURE 13

2 × 2 MIMO STC-SFN system



$$\begin{bmatrix} y0 \\ y1 \end{bmatrix} = \begin{bmatrix} h00 & h01 & h02 & h03 \\ h10 & h11 & h12 & h13 \end{bmatrix} \begin{bmatrix} x0 \\ x1 \\ x2 \\ x3 \end{bmatrix}$$

$$\begin{bmatrix} y0(t) \\ y1(t) \end{bmatrix} = \begin{bmatrix} h00(t) & h01(t) & h02(t) & h03(t) \\ h10(t) & h11(t) & h12(t) & h13(t) \end{bmatrix} \begin{bmatrix} S0 \\ S1 \\ -S2^* \\ S3^* \end{bmatrix}$$

$$\begin{bmatrix} y0(t+1) \\ y1(t+1) \end{bmatrix} = \begin{bmatrix} h00(t+1) & h01(t+1) & h02(t+1) & h03(t+1) \\ h10(t+1) & h11(t+1) & h12(t+1) & h13(t+1) \end{bmatrix} \begin{bmatrix} S2 \\ S3 \\ S0^* \\ -S1^* \end{bmatrix}$$

$$\begin{bmatrix} y0(t) \\ y1(t) \\ y0^*(t+1) \\ y1^*(t+1) \end{bmatrix} = \begin{bmatrix} h00(t) & h01(t) & h02(t) & h03(t) \\ h10(t) & h11(t) & h12(t) & h13(t) \\ h02^*(t+1) & -h03^*(t+1) & -h00^*(t+1) & h01^*(t+1) \\ h12^*(t+1) & -h13^*(t+1) & -h10^*(t+1) & h11^*(t+1) \end{bmatrix} \begin{bmatrix} S0 \\ S1 \\ -S2^* \\ S3^* \end{bmatrix}$$

FIGURE 14

Block diagram of 2 × 2 MIMO STC-SFN system

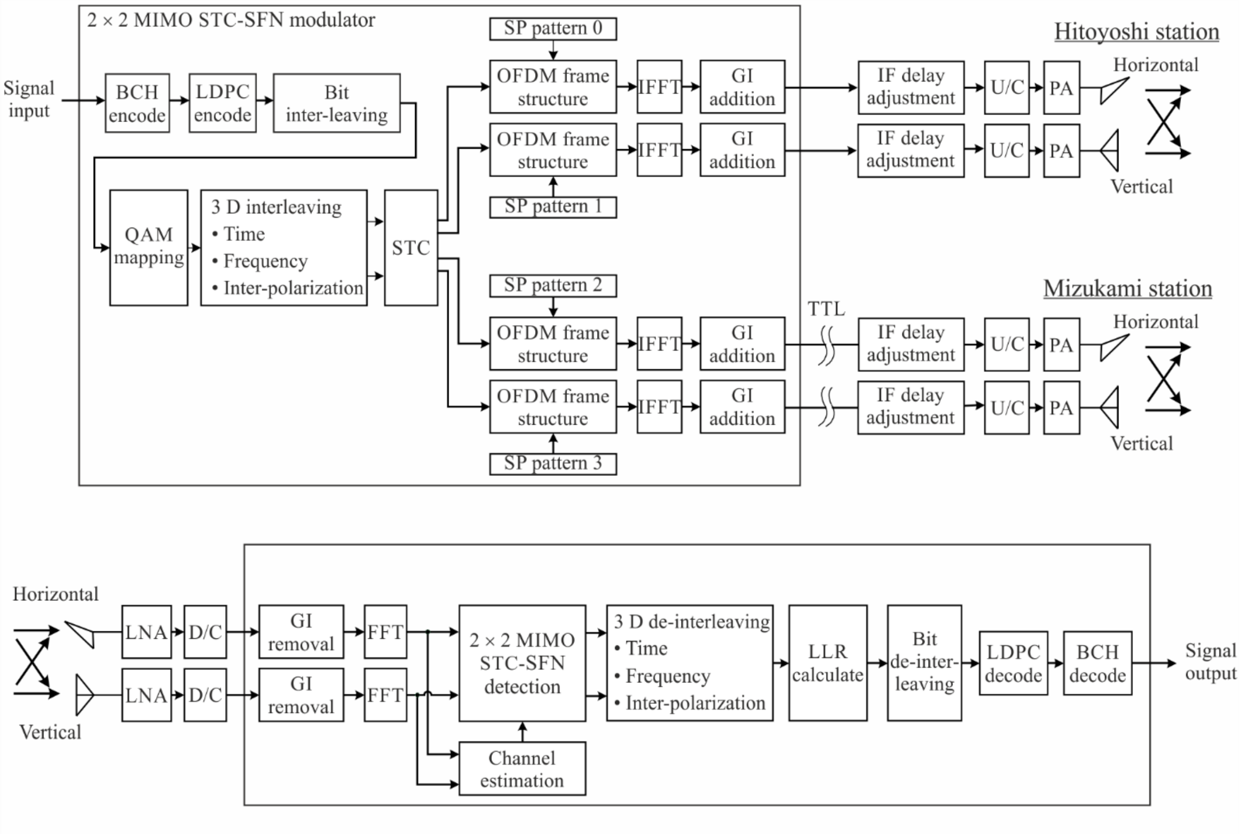


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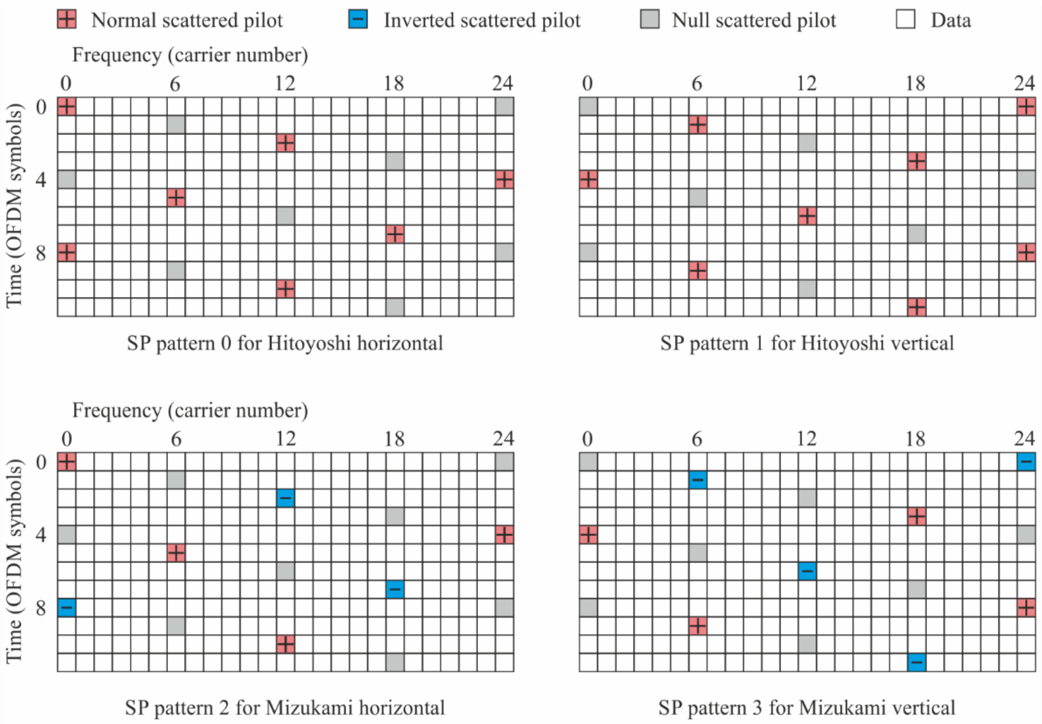
FIGURE 15

Scattered pilot patterns



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1.3.3 Field measurements

The conventional SFN is defined as two geographically distributed stations sending exactly the same signals synchronously using the same frequency. In this conventional SFN, a deep null is generated within the reception spectrum and causes deterioration of signal quality. This problem is caused by an erasure effect, the so-called 0-dB echo effect.

To compare the differences between 2 × 2 MIMO STC-SFN system and conventional SFN system, transmission characteristics were measured at three points (points A, B, and C in Fig. 16) within the area of overlap covered by both the Hitoyoshi and the Mizukami stations. Here, LoS stands for line of sight and NLoS stands for non-line of sight.

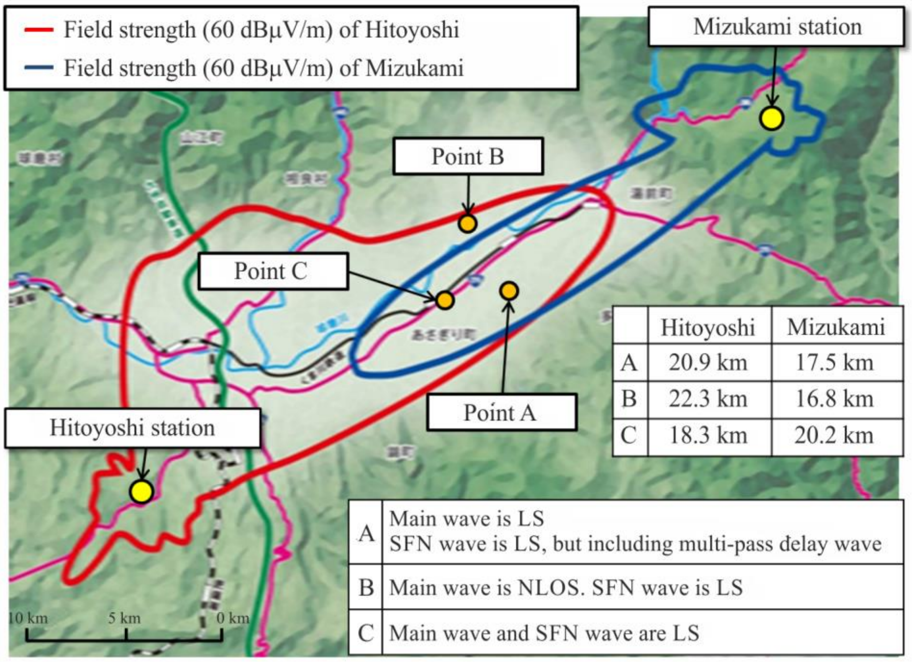
Before measurement, the transmission power and time delay at both stations was adjusted for evaluation under identical conditions. The power ratios of the main and SFN waves were adjusted to 6 dB and the time delay between the main and SFN waves to 2 µs at the receiver inputs at each test point. The power of each wave was defined as the average of the horizontal and vertical waves.

Figure 17 plots the reception powers required for both 2 × 2 MIMO STC-SFN and conventional SFN at all three reception points. This Figure clearly shows that the null is much shallower in the spectrum of 2 × 2 MIMO STC-SFN than in conventional SFN. Furthermore, the power requirement for 2 × 2 MIMO STC-SFN is as much as 3 dB superior to that of the conventional SFN. This decreased null and superior power requirement are clear outcomes of the application of STC technology to SFN.

An 8K-UHDTV field experiment with HEVC was conducted at Point C in Fig. 16. The 8K video compressed with HEVC and a multi-dimensional audio (22.2 channels) compressed with MPEG-4 AAC were transmitted from two experimental stations (Hitoyoshi and Mizukami) to create an STC-SFN. The received signals were demodulated and the 8K video was displayed on an 85-inch LCD display. The transmission parameters were the same as those in the previous § 1.3.2. Figure 18 shows the reception equipment for the demonstration. In this experiment, it was demonstrated that 8K-UHDTV can be successfully delivered with STC-SFN.

FIGURE 16

Measuring points



	Hitoyoshi	Mizukami
A	20.9 km	17.5 km
B	22.3 km	16.8 km
C	18.3 km	20.2 km

A	Main wave is LS SFN wave is LS, but including multi-pass delay wave
B	Main wave is NLOS. SFN wave is LS
C	Main wave and SFN wave are LS

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FIGURE 17

Comparison of 2 × 2 MIMO STC-SFN with conventional SFN

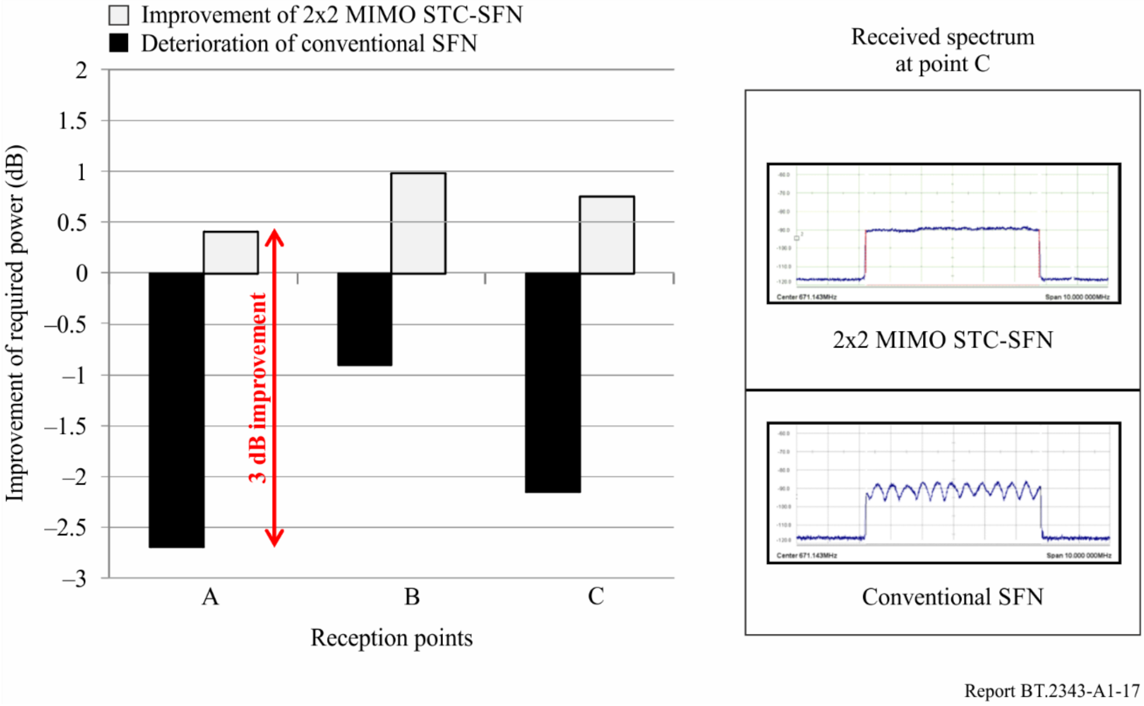

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FIGURE 18

Demonstration of 8K-UHDTV transmission with STC-SFN

a) Demodulator and reception equipment b) Video decoder and monitor

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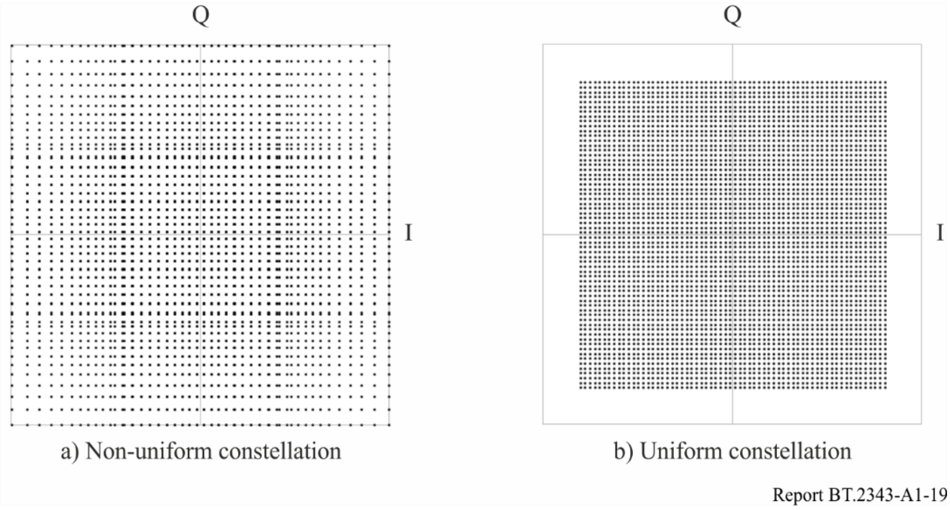
1.4 8K-UHDTV field experiments with non-uniform constellation in urban area; Kinuta, Tokyo (2 × 2 MIMO transmission system)

An 8K-UHDTV field experiment with non-uniform constellation (NUC), in which the signal points in the constellation are distributed non-uniformly, was conducted in an urban area; Kinuta, Tokyo.

1.4.1 Overview of non-uniform constellation

The NUC is a technology to improve the transmission performance by adjusting the distance between the signal points to be suited for the noise in the propagation channel. It is confirmed that the greater number of signal points in the constellation, such as 4096QAM, the larger improvement in performance is obtained. The signal points of the 4096 NUC implemented on the prototype transmission system and conventional 4096 uniform constellation (UC) are depicted in Fig. 19. In this Figure, the average power of NUC is normalized to be the same as that of UC, and the signal points of 4096 NUC are optimized for 30 dB of carrier to noise ratio (*C*/*N*) as the expected *C*/*N* in the transmission channel.

FIGURE 19



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1.4.2 Transmission parameters and equipment

An experimental station was installed on top of the NHK – Science and Technology Research Laboratories (STRL) located in southern Tokyo, and a field experiment was conducted with NUC in an urban area. The transmission parameters are listed in Table 6. The experimental station is composed of two transmitters for horizontally and vertically polarized waves. The experimental signals were received at a reception point 8 km from the transmitting point. The block diagram of the experiment is shown in Fig. 20. In this Figure, horizontal and vertical are expressed as H and V, respectively. The transmitting and receiving antennas are shown in Fig. 21. A dual-polarized dipole antenna was used for the transmitting antenna and a dual-polarized Yagi antenna was used for the receiving antenna. The view from the transmitter toward the reception point and that from the reception point toward the transmitter are shown in Fig. 22. The reception antenna was located at a LOS point, however multipath echoes reflected by the buildings on the propagation path were observed. It was confirmed that MIMO transmission with NUC can deliver 8K video stably in such an urban area. The demonstration of 8K-UHDTV reception with NUC is shown in Fig. 23.

TABLE 6

Specifications of 8K field experiments in urban area (Kinuta, Tokyo)

Modulation method	OFDM
Occupied bandwidth	5.57 MHz
Transmission frequency	581.142857 MHz (UHF ch31)
Transmission power	Horizontal polarized waves: 10 W, e.r.p.: 93 W Vertical polarized waves: 10 W, e.r.p.: 93 W
Carrier modulation	4096 NUC
FFT size (number of radiated carriers)	16k (11,233)
Guard interval ratio (guard interval duration)	1/16 (126 μs)
Error-correcting code	Inner: LDPC, code rate = 3/4 Outer: BCH
Transmission capacity	84.2 Mbit/s

TABLE 6 (*end*)

Video coding	MPEG-4 AVC/H.264
Audio coding	MPEG-4 AAC
Transmitting station	Established at NHK-STRL
Height of transmitting antenna	126 m above sea level (96 m above ground level)

FIGURE 20

Block diagram of 8K experiments in urban area

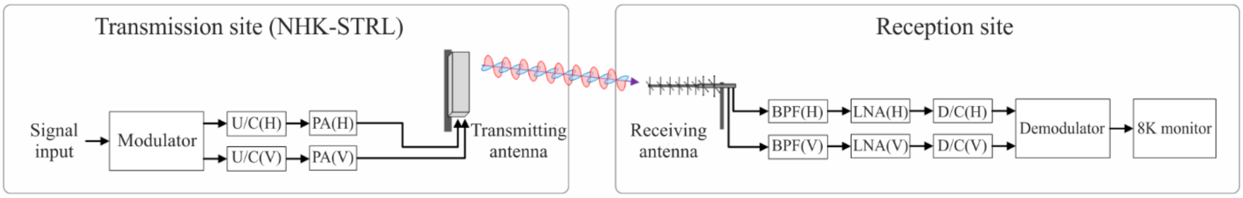

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FIGURE 21

Transmission and reception antennas for experiments in urban area

a) Transmission antenna b) Reception antenna

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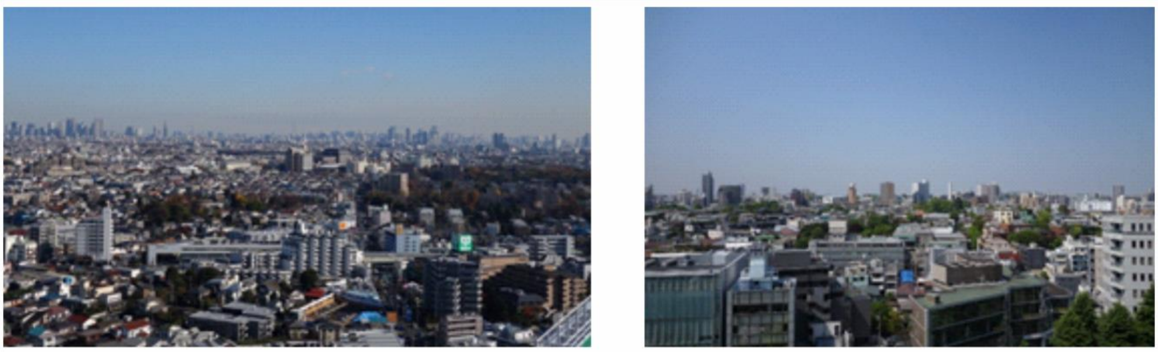
FIGURE 22

View from transmission and reception sites



a) Transmission site toward reception site b) Reception site toward transmission site

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FIGURE 23

Demonstration of 8K-UHDTV transmission with NUC

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1.4.3 Field measurements

The transmission performance of NUC was evaluated at three reception points in Tokyo. The improvement of NUC over UC in the *C*/*N* was investigated. The results are listed in Table 7. It was confirmed that NUC improved the transmission performance by about 1 dB in a MIMO transmission system using 4096-QAM in an urban area.

TABLE 7

Required *C*/*N* improvement of non-uniform constellation over uniform constellation

Reception point	Improvement	Transmission distance
(A) Hanegi park	0.9 dB	4.5 km
(B) NHK Broadcasting Centre	0.9 dB	8.0 km
(C) Meijijingu Gaien	1.0 dB	10.4 km

1.5 4K/8K-UHDTV field experiments with advanced system in urban area; Tokyo and Nagoya

1.5.1 Overview of advanced DTTB system

The objective of the advancement is to provide improved transmission performance compared to ISDB-T in terms of the increased transmission capacity and the reduced *C*/*N* required. The advanced system has been designed to inherit the feature of ISDB-T, i.e. it aims to provide a 4K or 8K UHDTV service for fixed reception and an HDTV service for mobile reception simultaneously by frequency division multiplexing (FDM) within a single channel. It also uses a frequency-segmented structure that allows partial reception. The bandwidth per segment is reduced to increase the number of segments from 13 (for ISDB-T) to 35, allowing for flexible bitrate distribution between layers such as the mobile reception layer and fixed reception layer. The advanced system allows a higher spectral efficiency and/or a transmission robustness with multiple-input multiple-output (MIMO).

A prototype modulator and demodulator for the advanced system were developed and their performances were confirmed through laboratory experiments. The feasibility of the system is being verified through large-scale field trials in urban areas.

1.5.2 Transmission parameters

Field experiments were conducted with the parameters listed in Table 8. The occupied bandwidth was expanded by about 5% compared to that of ISDB-T to increase transmission capacity. The 31 and 4 segments out of 35 segments were assigned for UHDTV and HDTV services, respectively. As for error-correcting code and carrier modulation, low density parity check (LDPC) code and NUCs were used for both UHDTV and HDTV services to enhance transmission robustness.

TABLE 8

Parameters for field experiments of hierarchical transmission in urban area (Tokyo and Nagoya)

Modulation method	OFDM	
Occupied bandwidth	5.83 MHz	
Reception scenario	Fixed (Rooftop)	Mobile (Car-mounted)
Number of segments	31	4
Carrier modulation	1 024 NUC QAM	64 NUC QAM
FFT size (number of radiated carriers)	16 k (15,121)	
Guard interval ratio (guard interval duration)	800/16384 (126 μs)	
Error-correcting code	Inner: LDPC, code rate = 11/16 Outer: BCH	Inner: LDPC, code rate = 7/16 Outer: BCH
Transmission capacity	31.4 Mbit/s (SISO) 62.8 Mbit/s (MIMO)	1.5 Mbit/s (SISO) 3.0 Mbit/s (MIMO)
Video coding	HEVC	
Video format	3840 × 2160/60/P (4K) 7680 × 4320/60/P (8K)	1920 × 1080/60/P (2K)
Video bit rate	SISO: 25 Mbit/s (4K) SISO: 28 Mbit/s (8K)* MIMO: 56 Mbit/s (8K)*	SISO: 1.0 Mbit/s (2K) MIMO: 1.0 Mbit/s (2K)
Audio coding	MPEG-H 3D Audio LC level 4	MPEG-4 AAC
Audio bit rate	768 kb/s (22.2ch + 3 objects)	192 kb/s (2ch)

* Pre-processed before encoding by MPEG-H HEVC with a state-of-the-art software encoder offline taking plenty of time.

1.5.3 Field measurements

To evaluate the performance of the advanced system in different propagation environments, large-scale experimental environments were constructed. Two locations (in the Tokyo and Nagoya areas) were selected to have the same scale as the main stations currently used for terrestrial broadcasting. Figure 24 shows the transmitter sites and assumed coverage areas for the experimental parameters in Table 8. Table 9 lists the specifications of the transmission stations. Each transmission station is equipped with two transmitters and two antennas for horizontally and vertically polarized waves. The directional patterns of transmitting antennas at Nabeta relay station are designed to be selectable.

FIGURE 24

Experimental environments

a) Tokyo area b) Nagoya area

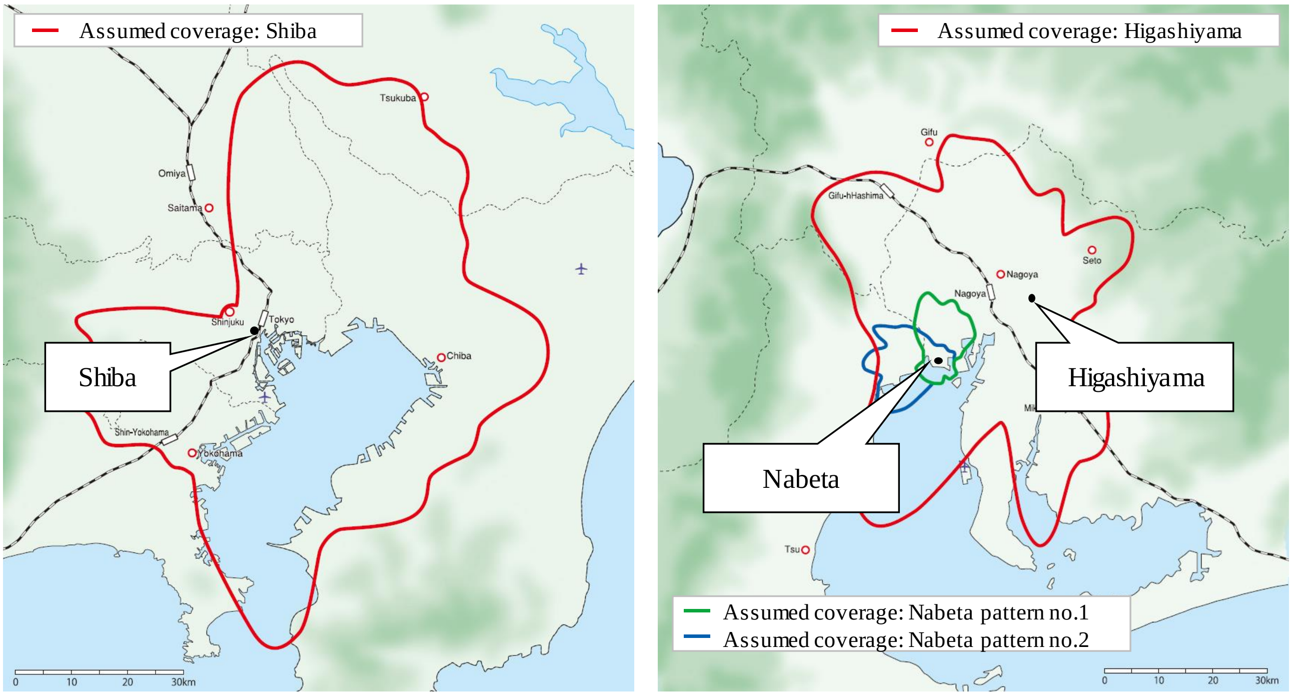


TABLE 9

Specifications of transmission stations

	Tokyo area	Nagoya area	
Transmitter site	Shiba (main station) (Minato Ward, Tokyo)	Higashiyama (main station) (Showa Ward, Nagoya, Aichi)	Nabeta (relay station) (Yatomi, Aichi)
Transmission frequency	563.143 MHz	605.143 MHz	
Polarization	Horizontal, Vertical		
Transmission power	Horizontal: 1 kW Vertical: 1 kW	Horizontal: 1 kW Vertical: 1 kW	Horizontal: 10 W Vertical: 10 W
e.r.p.	Horizontal: 2.1 kW Vertical: 2.1 kW	Horizontal: 980 W Vertical: 980 W	Horizontal: 81 W Vertical: 81 W
Transmitting antenna height	280 m above sea level	203 m above sea level	42.5 m above sea level

Transmission experiments were conducted in the two experimental urban areas. Experiments were launched in November and December 2018 in the Nagoya and Tokyo areas, respectively.

The experiments involved field trials of hierarchical transmission of UHDTV/HDTV using a single channel based on the advanced DTTB system. The UHDTV (4K or 8K) content for fixed reception and HDTV (2K) content for mobile reception shown in Table 8 were recorded in advance in a player, and the video and audio streams were played back at the experimental stations. The block diagram of transmitting and receiving system is shown in Figure 25. UHDTV and HDTV streams from the player are multiplexed by the remultiplexer (remux) into a single IP stream and input to the advanced DTTB modulator. The frequency of two output signals from the modulator are converted and power-amplified by the transmitter. The audio of UHDTV was an object-based audio that transmitted a 22.2 channel audio encoded by MPEG-H 3D Audio and three narration objects in Japanese, English, and French. For the HDTV content, the video was encoded by HEVC and the stereo audio signals were encoded by MPEG-4 AAC.

Figure 26 shows the locations of the transmitting and receiving points in the Tokyo area. The NHK Science and Technology Research Laboratories (NHK-STRL), which is approximately 12 km away from the Shiba station, was selected as the receiving point. On the receiving side, the received spectrum was observed by a spectrum analyser, and the delay profile was confirmed by a signal analyser. The UHDTV signal output from the demodulator was decoded in real time by the HEVC decoder and displayed on a 4K/8K LCD monitor. The 22.2 channel audio was decoded in real-time by MPEG-H 3D Audio decoder, converted to 7.1 channel audio, and reproduced using a commercially available sound bar. The HDTV signal was converted from multicast to unicast, then transmitted via WiFi router, and decoded by an MMT player installed on a tablet or smartphone. Figure 27 shows the spectrum of the received signals. Figures 28 and 29 show the delay profile and constellation of the received signal of SISO transmission using horizontal polarized wave. As for the delay profile, almost no reflected waves were confirmed as shown in Fig. 28. In this experiment, it was demonstrated that UHDTV and HDTV contents can be successfully received with the advanced DTTB system.

FIGURE 25

Block diagram of transmitting and receiving system in Tokyo

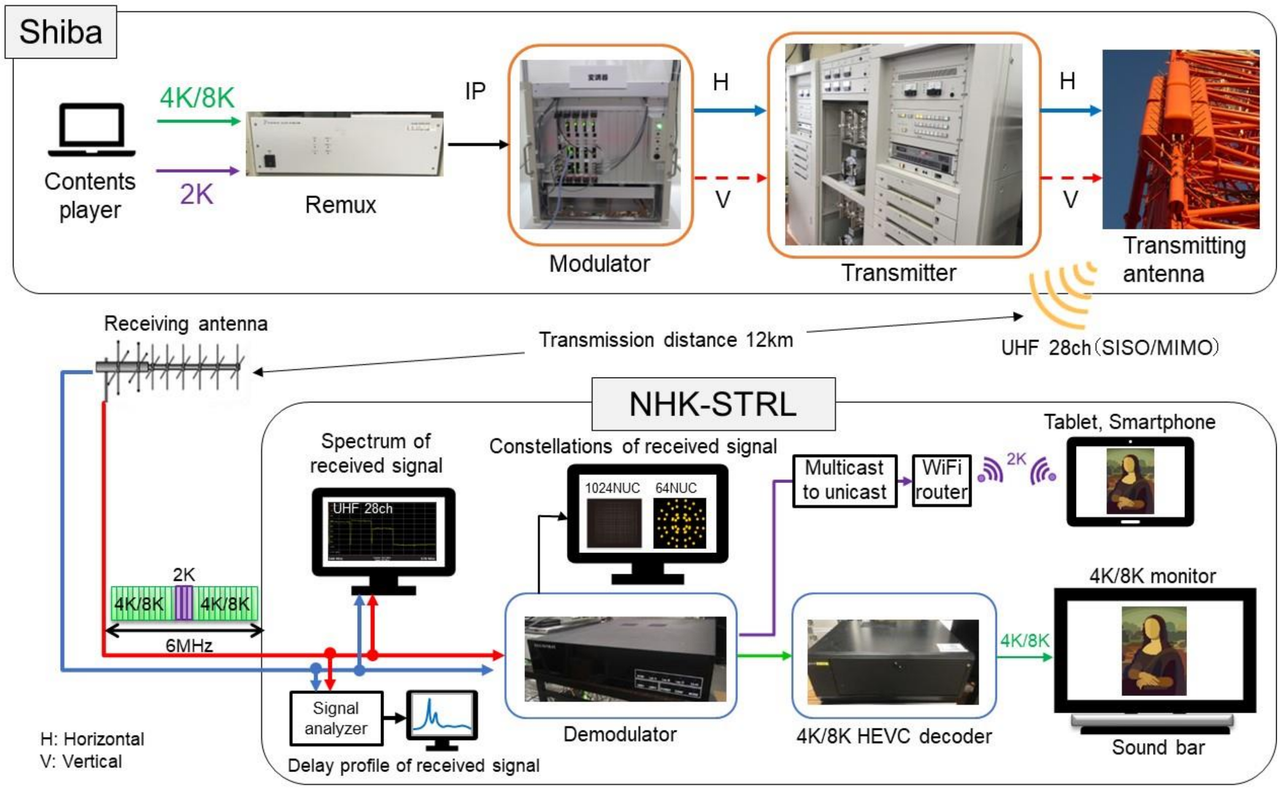


FIGURE 26

Locations of transmitting and receiving points in Tokyo

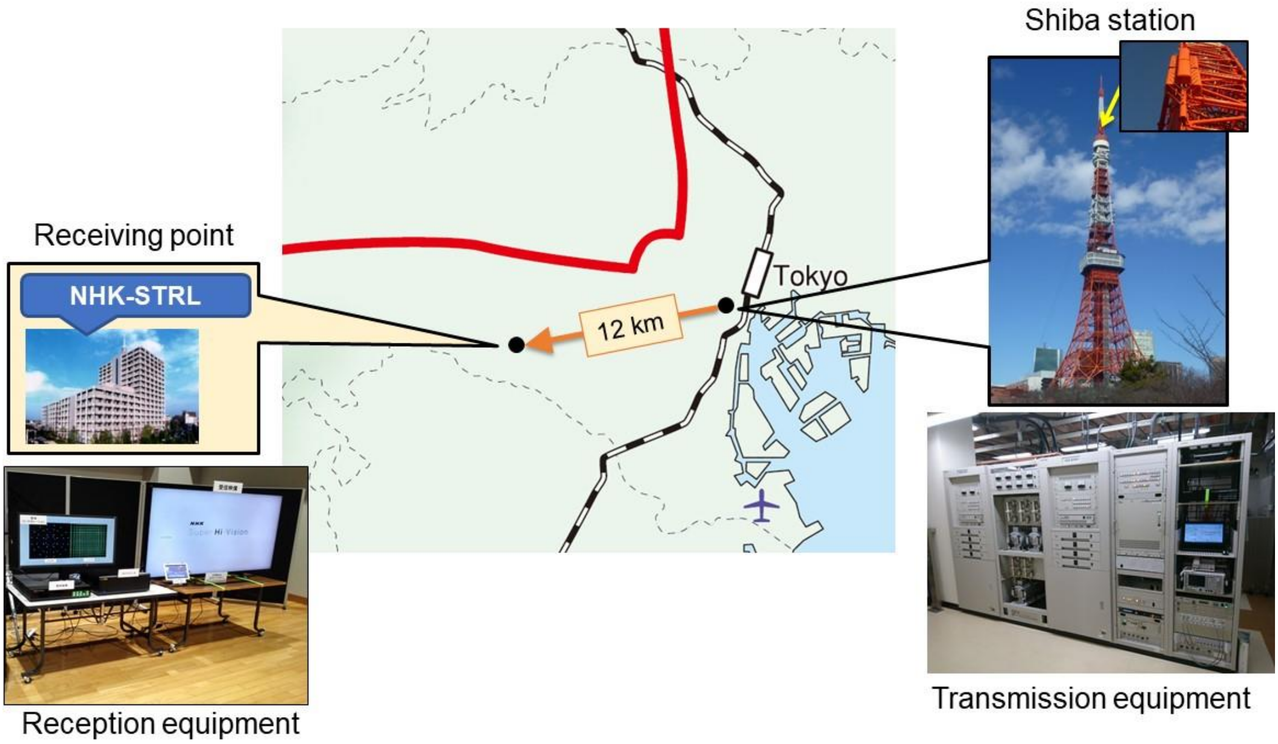
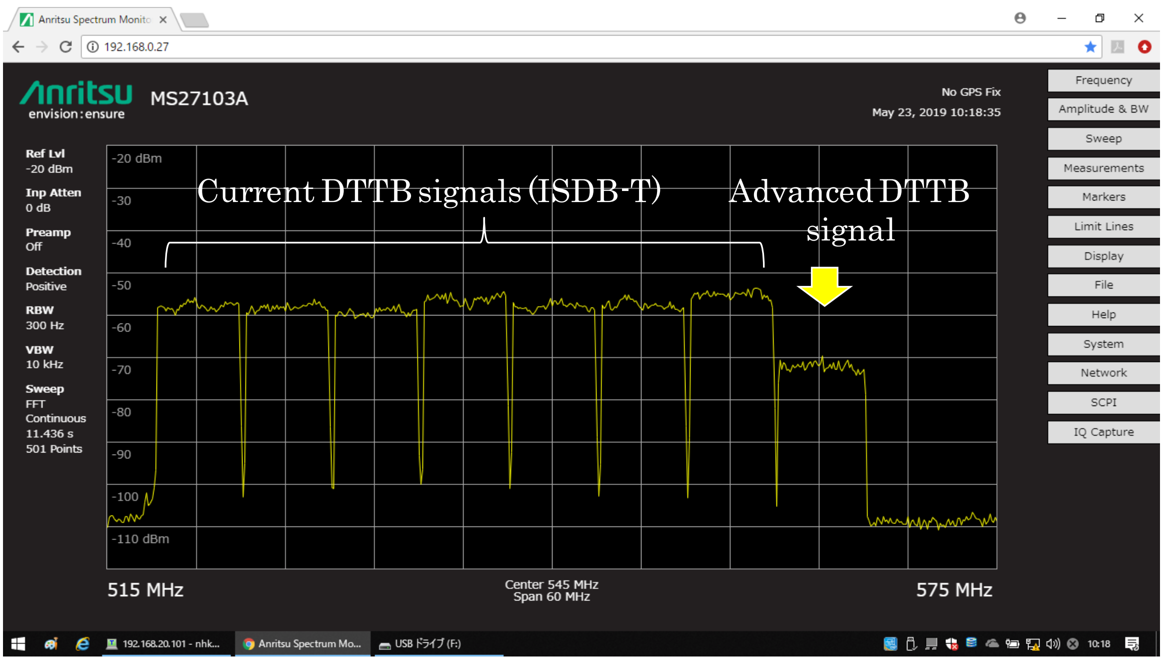


FIGURE 27

Spectrum of received signal at NHK-STRL (SISO)



Note: The advanced DTTB signal was allocated upper-adjacent to the current DTTB signals. The difference in the received power between the advanced DTTB signal and the current DTTB signals is due to the different transmitting power and the transmitting points.

FIGURE 28

Delay profile of received signal at NHK-STRL (SISO)

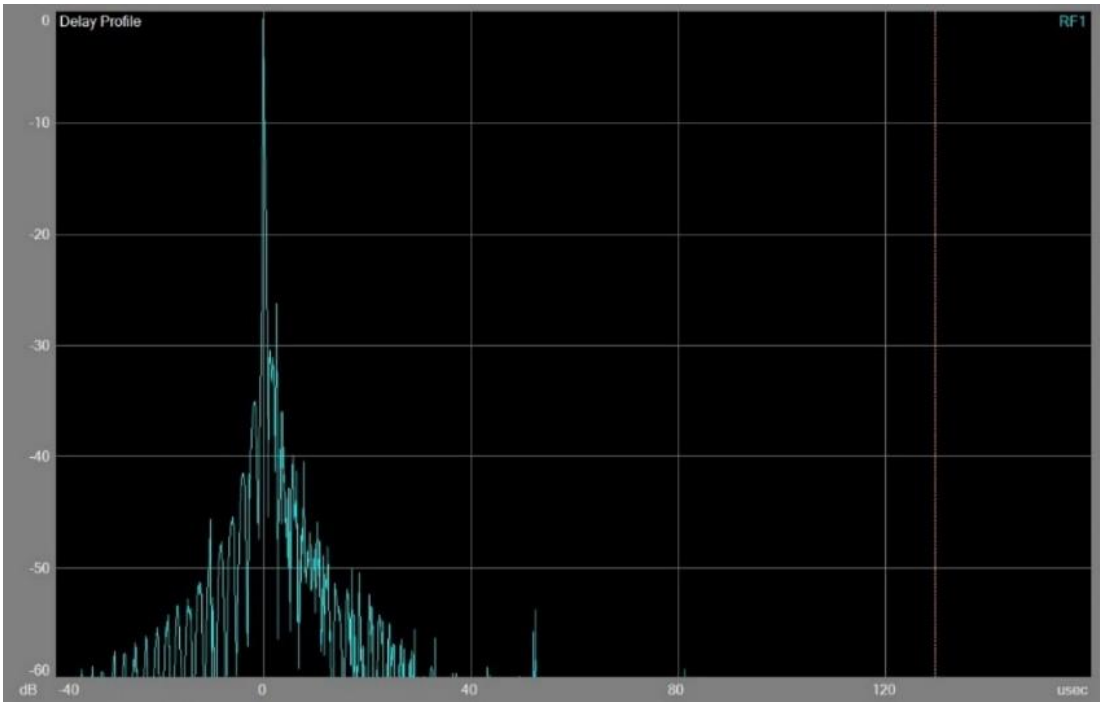
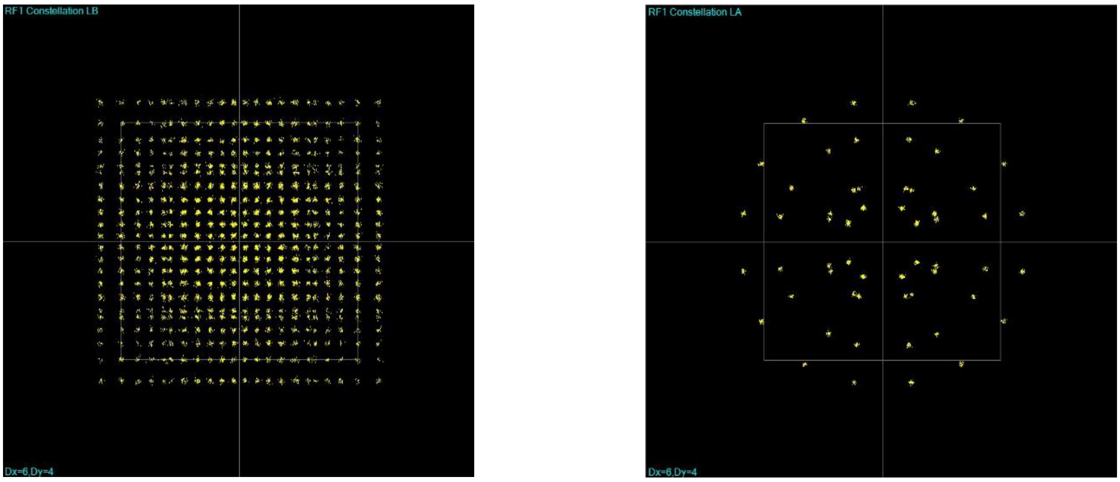


FIGURE 29

Constellations of received signal at NHK-STRL (SISO)

(a) 1024 NUC QAM for UHDTV **(b) 64 NUC QAM for HDTV**



The block diagram of transmitting and receiving system in Nagoya is shown in Fig. 30. Figure 31 shows the locations of the transmitting and receiving points in the Nagoya area. As a receiving point, the Nagoya port building, which is approximately halfway between the Higashiyama and Nabeta experimental stations, was selected. The remultiplexer was installed at the Higashiyama station and the IP packet was sent to the two modulators installed at the Higashiyama and the Nabeta stations. A 200 Mbit/s bandwidth secured line was used as the IP line between the Higashiyama and Nabeta stations. The radio waves were emitted from the two stations to carry out the transmission experiments in a SFN environment. The modulated signals were generated at each transmission timing.

At the receiving point (the Nagoya port building), the receiving antenna was installed facing the Nabeta station. Additionally, the transmission power of the Higashiyama station was adjusted to demonstrate severe SFN reception conditions. As an example, the desired-to-undesired signal ratio (DUR) of 3.2 dB and 1.9 dB for horizontal polarization and vertical polarization between the Nabeta station (D) and the Higashiyama station (U) was demonstrated with the reduction in the transmission power of the Higashiyama station by 5 dB for both polarizations. Regarding the delay setting of the remultiplexer, the transmitting timings of the Higashiyama and the Nabeta stations were aligned at the same time. As the Higashiyama station is geographically 500 m closer to the reception point than the Nabeta station, it was expected that the transmitted signals from the Higashiyama station would arrive 1.6 µs earlier than the signals from the Nabeta station. However, it was confirmed that the signals from the Higashiyama station arrived about 2 µs later than the signals from the Nabeta station. The delay was caused by a feedback compensation circuit installed in the transmitters at the Higashiyama station.

Figures 32, 33 and 34 show examples of the spectrum, delay profiles, and reception constellations of the received signals for MIMO transmission using horizontal and vertical polarizations. For the reception spectrum, ripples caused by the undesired signals from the Higashiyama station were confirmed. For delay profiles, horizontal to horizontal, horizontal to vertical, vertical to horizontal and vertical to vertical components are shown in blue, green, yellow and pink, respectively. The Higashiyama station is located in the direction opposite to the main lobe of the receiving antenna; therefore, many reflected signals transmitted by the Higashiyama station were observed. The demonstration of UHDTV/HDTV reception with the advanced DTTB system in the SFN environment was presented to the press. It was confirmed that even under severe SFN reception conditions, the UHDTV/HDTV video and audio could be received without any transmission errors.

FIGURE 30

Block diagram of transmitting and receiving system in Nagoya

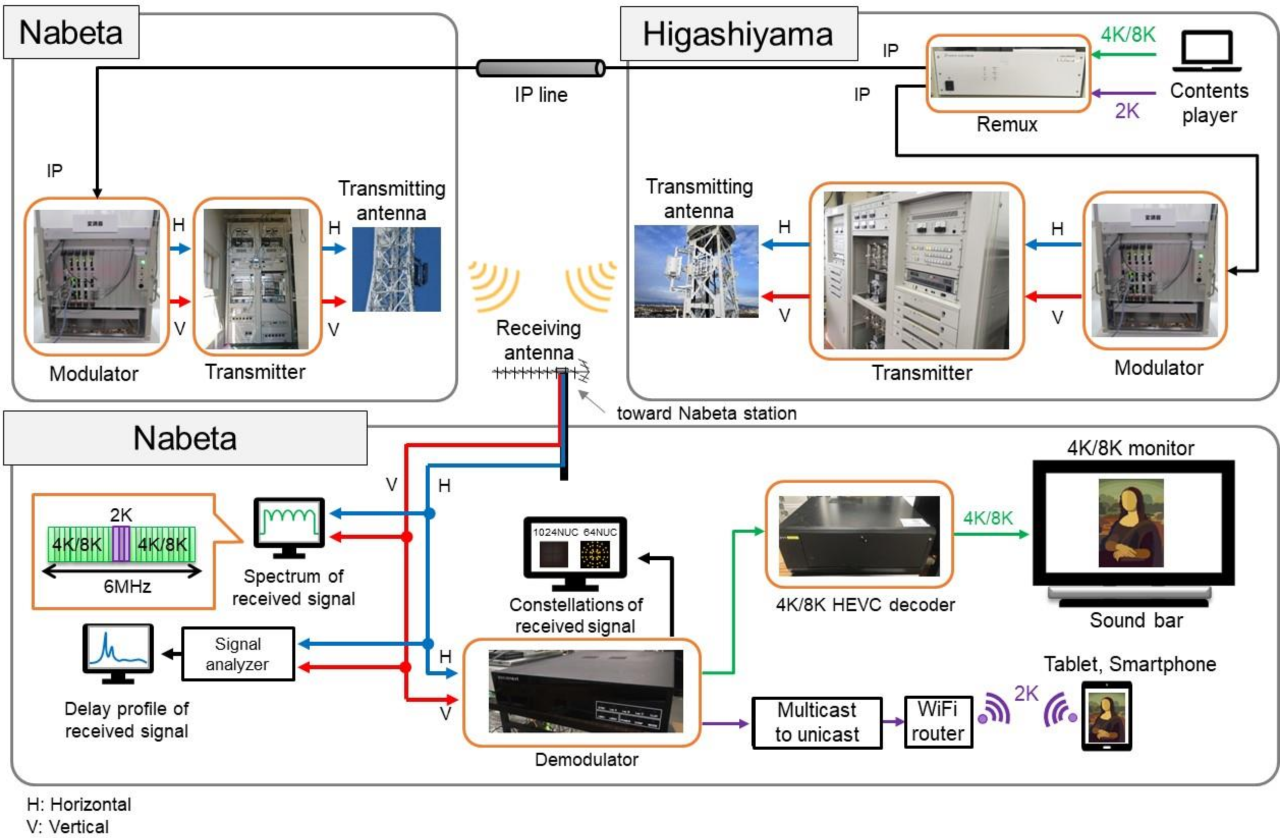


FIGURE 31

Locations of transmitting and receiving points in Nagoya

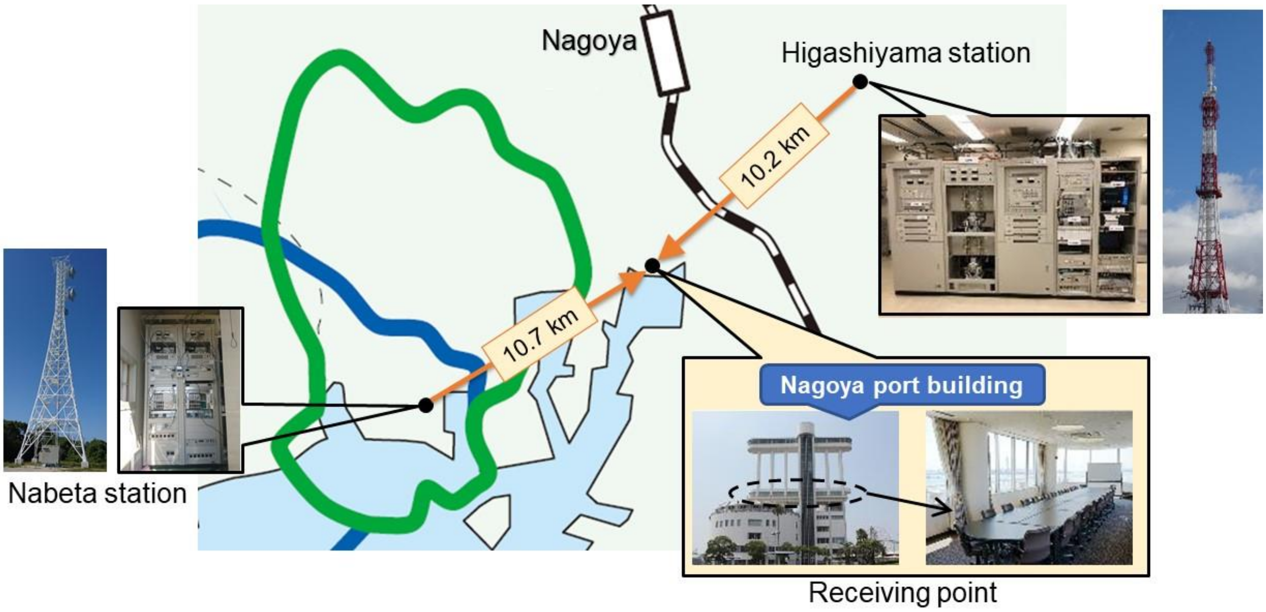


FIGURE 32

Spectrum of received signals at Nagoya port building (MIMO)

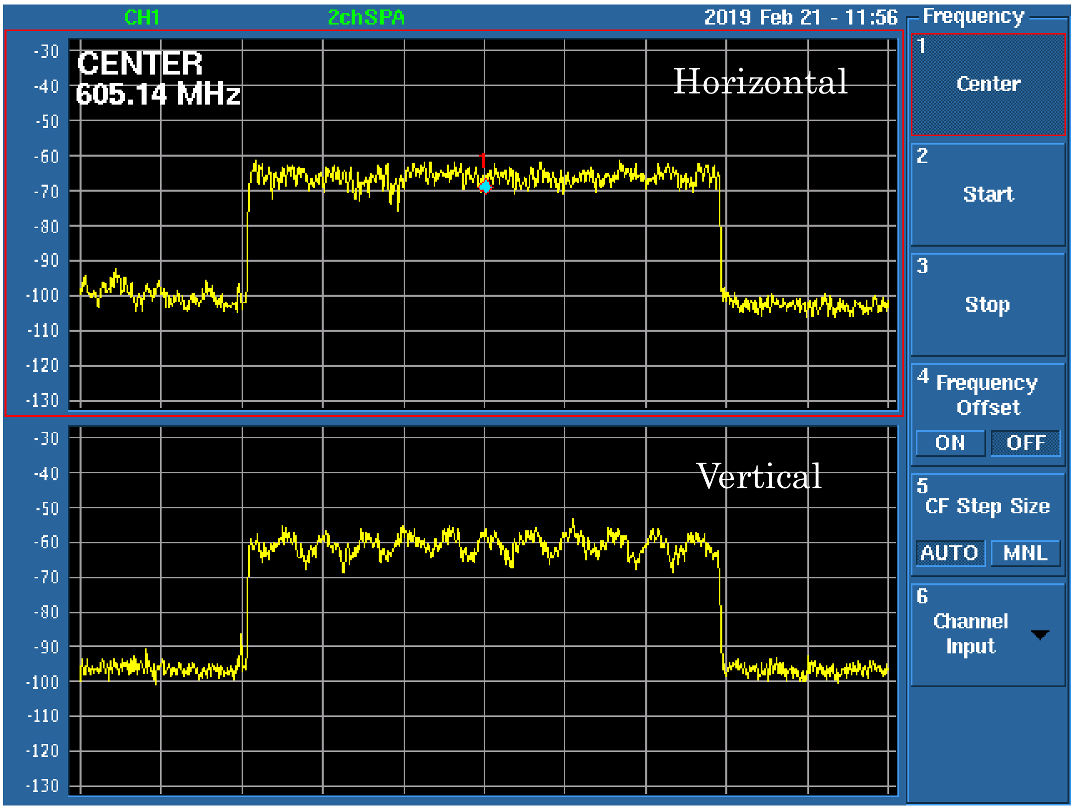


FIGURE 33

Delay profile of received signals at Nagoya port building (MIMO)

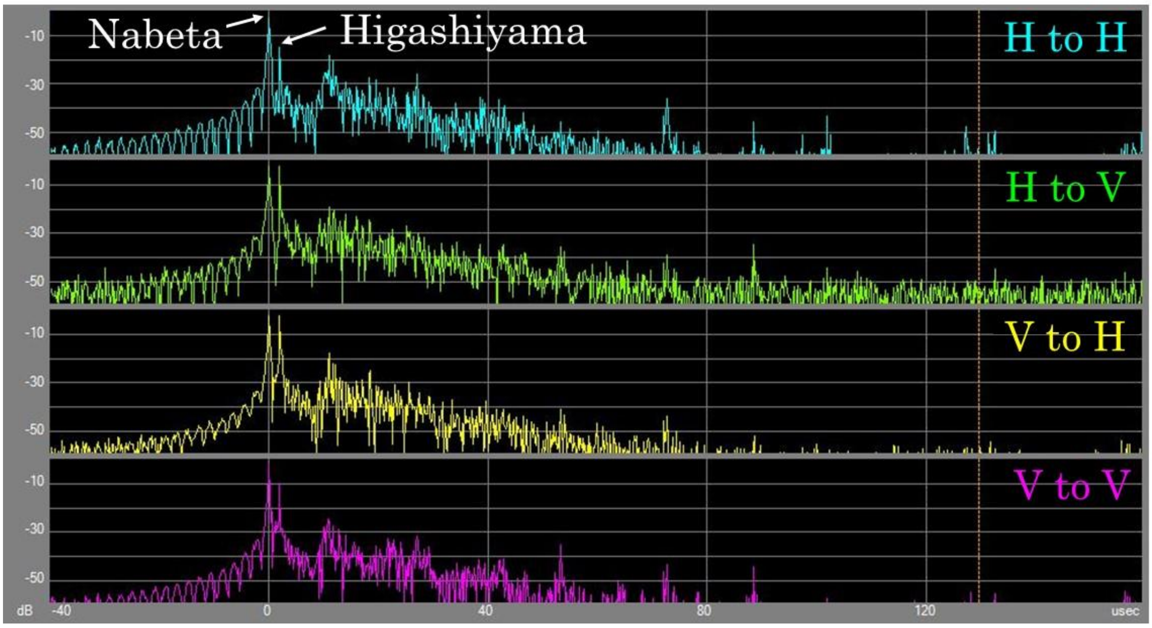
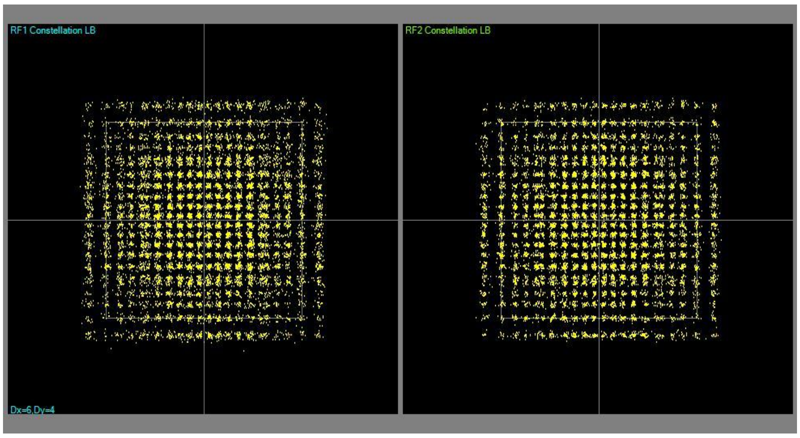


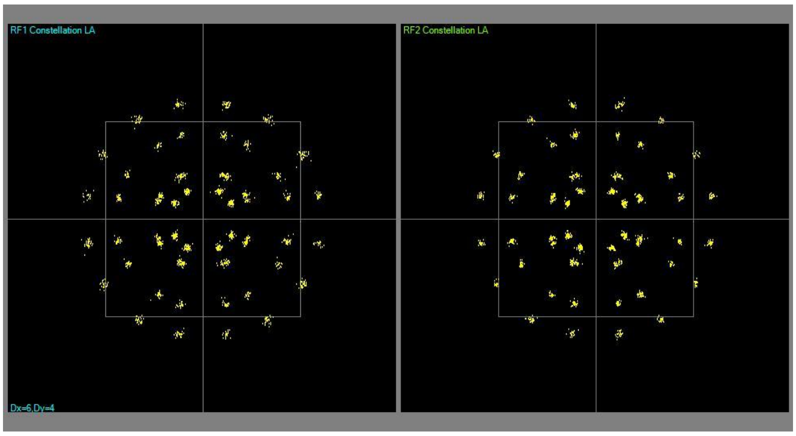
FIGURE 34

Constellations of received signals at Nagoya port building (MIMO)

(a) 1 024 NUC QAM for UHDTV (Horizontal) **(b) 1 024 NUC QAM for UHDTV (Vertical)**



(c) 64 NUC QAM for HDTV (Horizontal) **(d) 64 NUC QAM for HDTV (Vertical)**



Transmission performance of the advanced system is being verified assuming a fixed rooftop reception with a reception antenna at a height of 10 metres and a mobile reception with vehicular external aerials at a height of 2 metres in the Tokyo and Nagoya areas.

The plan is to evaluate the transmission characteristics not only of single-input single-output (SISO), but also MIMO to confirm the gain in the capacity and required *C*/*N* achieved with the advanced system in actual urban reception environments.

1.6 8K-UHDTV field experiments with channel bonding (advanced system, 2 × 2 MIMO, channel bonding)

Channel bonding technologies use two or more radio frequency (RF) channels to transmit data from a single physical layer pipe (PLP) that exceeds the capacity of a single RF channel. These multiple RF channels may be located at any channel frequency and may not necessarily be adjacent to each other. To verify the channel bonding technology, an 8K-UHDTV field experiment of the channel bonding was conducted using two RF channels.

1.6.1 Transmission parameter and equipment

A field experiment was conducted with channel bonding using two RF channels based on the advanced system described in § 1.5. The transmission parameters are presented in Table 10. Each transmitting station for the two individual RF channels was composed of two transmitters for horizontal and vertical polarized waves. A dual-polarized dipole antenna was used for transmitting antennas. Simultaneous transmission of a UHDTV service for fixed reception and an HDTV service for mobile reception was assumed using FDM. A block diagram of the transmitting side is presented in Fig. 35.

TABLE 10

Parameters for field experiments of channel bonding

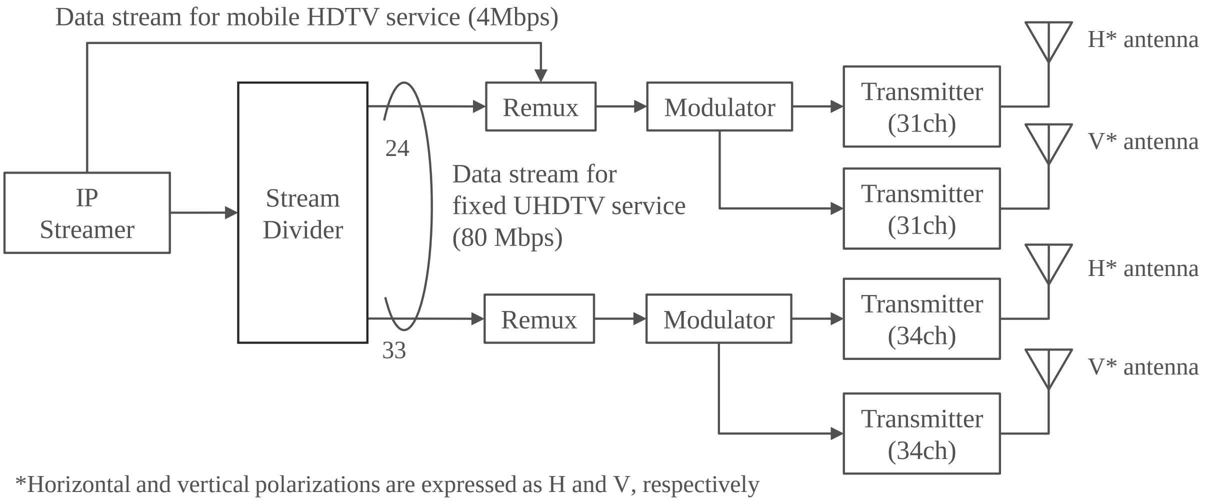
Transmitter site	Kinuta, Tokyo		
Transmission frequency	599.143 (UHF Ch 34)	581.143 MHz (UHF Ch 31)	
Transmission power	Horizontal: 1 W, e.r.p.: 1.3 W Vertical: 1 W, e.r.p.: 1.45 W	Horizontal: 1 W, e.r.p.: 9.3 W Vertical: 1 W, e.r.p.: 9.3 W	
Transmitting antenna height	104 m above sea level (74 m above ground level)	126 m above sea level (96 m above ground level)	
Modulation method	OFDM		
Occupied bandwidth	5.57 MHz	5.57 MHz	
Reception scenario	Fixed (Rooftop)		Mobile (Car-mounted)
Number of segments	33	24	9
Carrier modulation	1024 NUC QAM		16 NUC QAM
FFT size (number of radiated carriers)	16 k (15 121)		
Guard interval ratio (guard interval duration)	800/16 384 (126 μs)		
Error-correcting code	Inner: LDPC, code rate = 9/16 Outer: BCH		Inner: LDPC, code rate = 7/16 Outer: BCH
Transmission capacity (each)	52.4 Mbit/s (MIMO)	38.0 Mbit/s (MIMO)	4.4 Mbit/s (MIMO)

TABLE 10 (*end*)

Transmission capacity(total)	90.4 Mbit/s (MIMO)	
Video coding	HEVC	
Video format	7 680 × 4 320/60/P (8K)	1 920 × 1 080/60/P (2K)
Video bit rate	MIMO: 80 Mbit/s (8K)	MIMO: 4.0 Mbit/s (2K)

FIGURE 35

Block diagram of transmitter site



1.6.3 Field measurement

The transmitted signals were received at a line-of-site point located 4.5 km from the transmitter site. A block diagram of the receiving side is illustrated in Fig. 36. A dual-polarized Yagi-antenna was used to receive both the horizontal and vertical signals. Each signal transmitted in Ch 31 and Ch 34 was demodulated individually. The spectrum, constellations, and bit error rate (BER)s of the received signals are presented in Figs 37, 38 and 39 respectively. The output data streams from the demodulators for the fixed reception UHDTV service were combined and fed to an MPEG media transport (MMT) /high-efficiency video encoding (HEVC) decoder, and the data stream for mobile reception HDTV service was fed to another MMT/HEVC decoder. The decoded UHDTV and HDTV images are displayed in Fig. 40.

FIGURE 36

Block diagram of receiver side

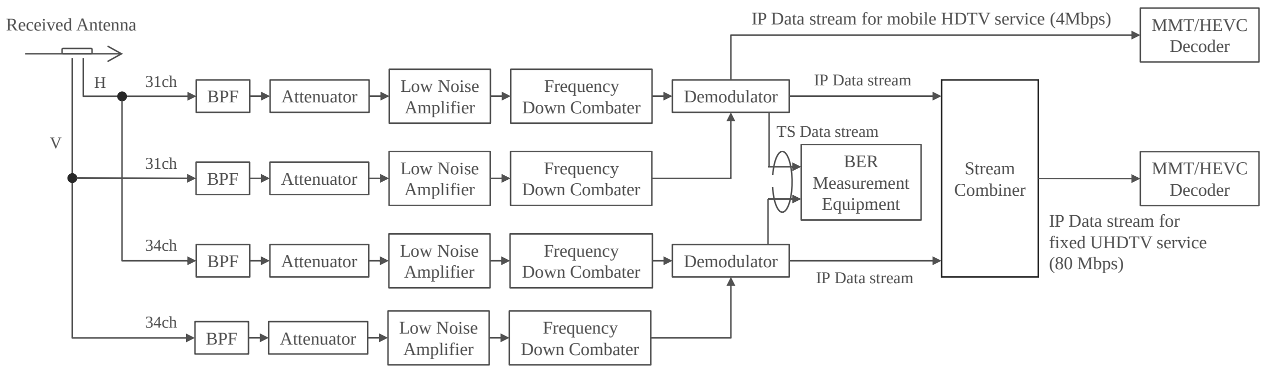
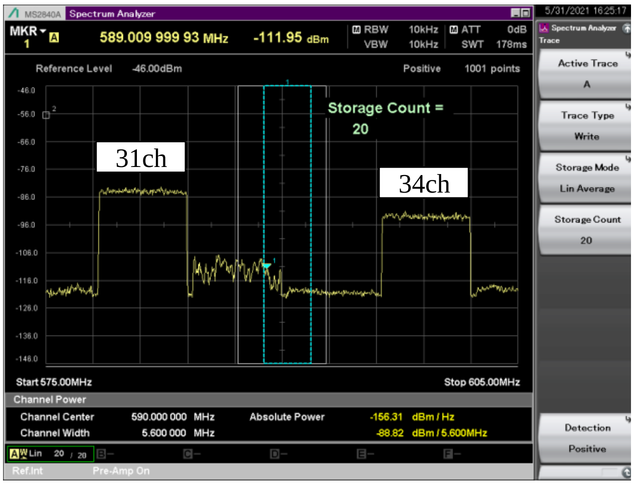


FIGURE 37

Spectrum of received signals

(a) Horizontal

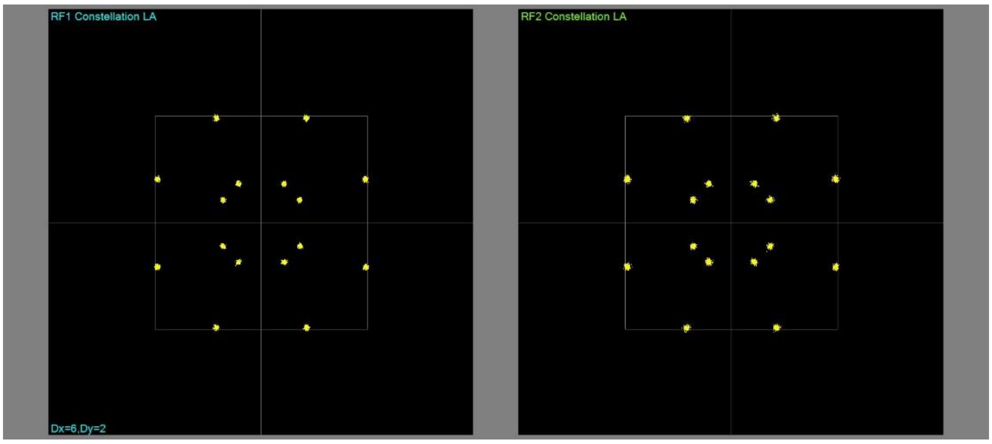


(b) Vertical

FIGURE 38

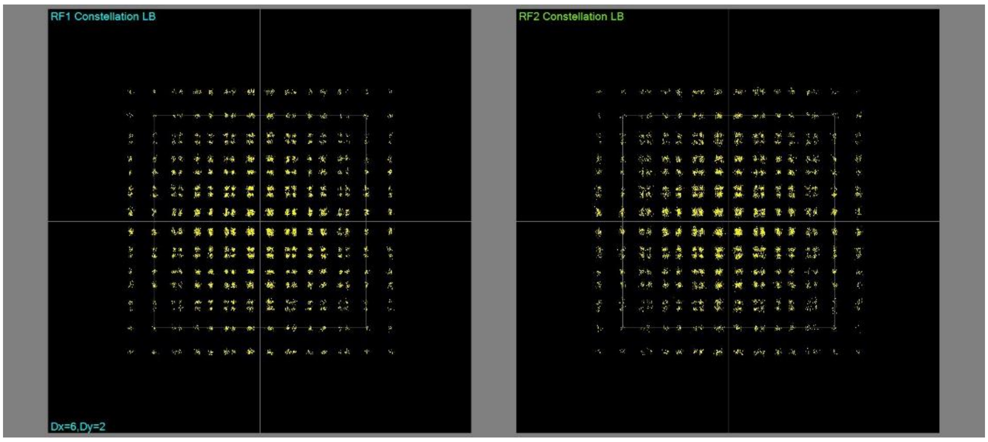
Constellation of received signals

(a) Mobile reception layer – Horizontal (31 ch) **(b) Mobile reception layer – Vertical (31 ch)**



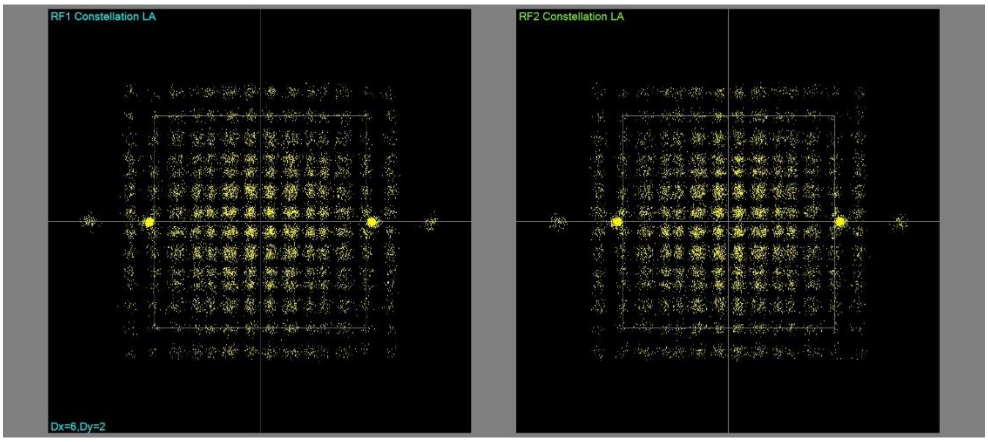
MER = 33.8 dB MER = 33.5 dB

(c) Fixed reception layer – Horizontal (31 ch) **(d) Fixed reception layer – Vertical (31 ch)**



MER = 34.3 dB MER = 34.0 dB

(e) Fixed reception layer – Horizontal (34 ch) **(f) Fixed reception layer – Vertical (34 ch)**



MER = 27.2 dB MER = 27.0 dB

FIGURE 39

Measurement results of bit error rates

(a) Fixed reception layer – 31 ch **(b) Fixed reception layer – 34 ch**

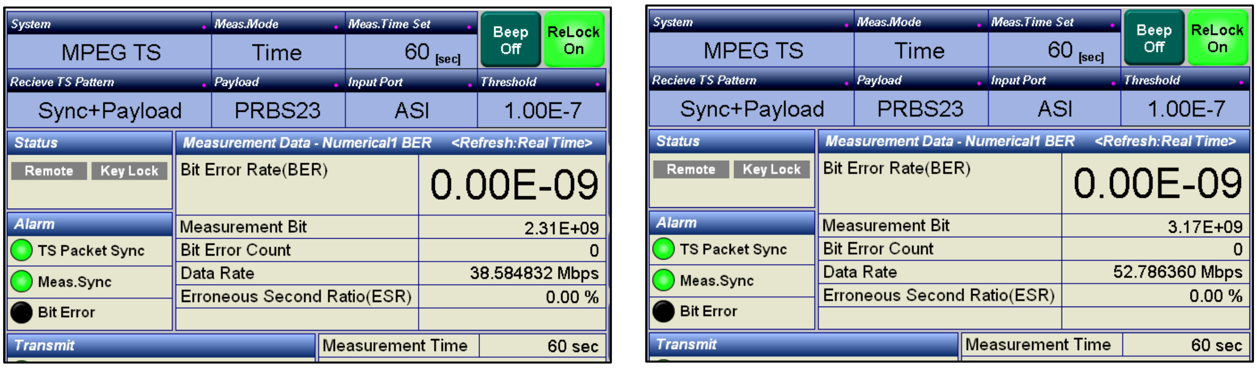


FIGURE 40

Received video of UHDTV and HDTV

1.7 Summary

A number of trials have been conducted to show the viability of 4K/8K UHDTV over-the-air transmission that uses advanced transmission technologies including 4096-QAM carrier modulation, dual-polarized MIMO, 2 × 2 MIMO STC-SFN, non-uniform constellation (NUC), and channel bonding.

2 Republic of Korea

2.1 UHDTV terrestrial trial broadcasting based on DVB-T2

The world's first terrestrial UHDTV trial through the DTT platform in Korea was made possible by the strong resolve of two government bodies in Korea: the Korean Communications Commission (KCC) and the Ministry of Science, ICT and Future Planning (MSIP). They granted permissions and provided support to execute the UHDTV experimental broadcast. This trial was also facilitated by the memorandum of understanding (MOU) signed in April 2012, which confirmed the cooperation of major terrestrial broadcasters in Korea, i.e. KBS, MBC, SBS and EBS, for experimental broadcasts.

Furthermore, most uncertainties regarding the implementation of 4K-UHDTV service within a 6 MHz bandwidth have been resolved and the date for launching 4K-UHDTV via terrestrial broadcast networks can be brought forward. Moreover, the capability of participating broadcasters to produce 4K-UHDTV content has been enhanced up to live production.

2.1.1 Phase 1

September 1 – December 31, 2012

KBS, on behalf of four terrestrial broadcasters, carried out the world's first terrestrial 4K broadcast at 30fps using approximately 32~35 Mbit/s. The transmission was conducted at Kwan-Ak in the south of Seoul.

2.1.2 Phase 2

May 10 – October 15, 2013

Following license renewal, KBS increased the frame rate of 4K contents from 30 to 60 fps at approximately 26~34 Mbit/s. The transmissions continued at Kwan-Ak.

The goal during these phases was to confirm the feasibility of delivering a terrestrial 4K-UHDTV contents using only 6 MHz of channel bandwidth. Thus, the HEVC compression technique, to fit high volumes of 4K video data rates into limited bandwidth, and the DVB-T2 standards, to improve the robustness of over-the-air transmission, were adopted.

Kwan-Ak Mountain Transmission Site

During Phase 1 and 2, KBS operated the Kwan-Ak site only using the parameters shown in Table 11. For the field test, 15 and 10 reception points located 5 km to 52 km, respectively, from the transmitter were selected as shown in Fig. 41.

– In Phase 1, the field test was conducted at 15 points with an almost identical radial distance of 5 km from the transmission site. It was attempted to maintain an equal angle interval for each measuring point, as shown in Fig. 41(a).

– In Phase 2, the field test was conducted at 10 points at distance 10 km to 52 km from the transmission site as shown in Fig. 41(b).

FIGURE 41

Location of reception points during Phase 1 and Phase 2

a) 15 reception points in Phase 1 b) 10 reception points in Phase 2

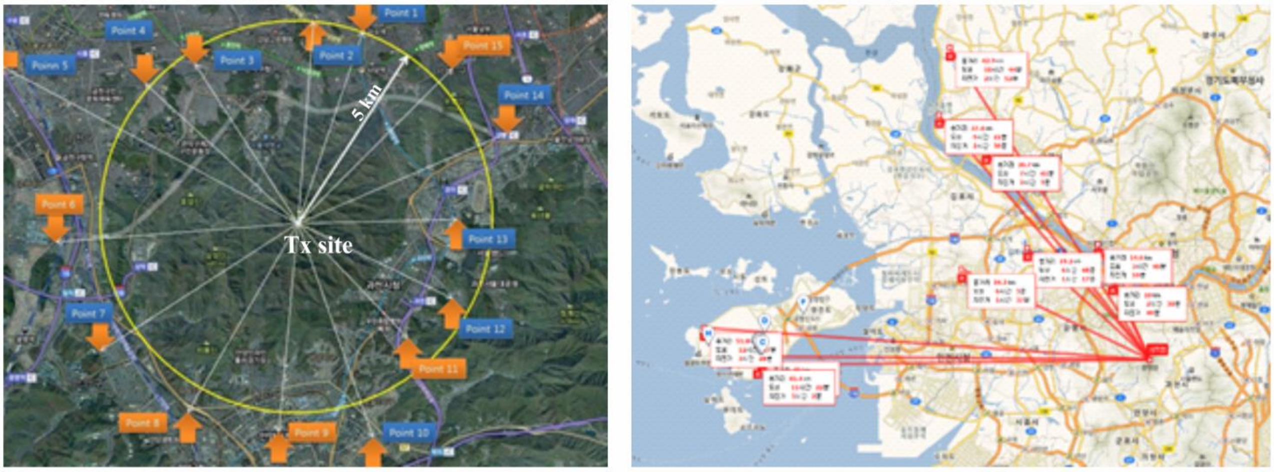


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TABLE 11

Specifications of transmission system during Phase 1 and 2

	Phase 1			Phase 2	
Transmitter site	Kwan-Ak Mountain				
Covering	The Metropolitan area of Seoul				
Nominal power (antenna gain)	100 W (6.01 dBi)				
DTT system	DVB-T2				
Transmission mode	32k, extended mode, *GI* = 1/128, PP7				
Modulation	256-QAM			64-QAM	256-QAM
Number of FEC blocks in interleaving frame	163			123	165
FEC code rate	3/4	4/5	5/6	4/5	5/6
Multiplexing capacity (Mbit/s)	32.8	35.0	36.5	26.5	36.9
Signal bit rate (Mbit/s)	32.0 ~ 35.0			26.0 ~ 34.0	
Video encoding standard	HEVC				
Picture standard	3 840×2 160p, 8 bits/pixel 30 fps			3 840×2 160p, 8 bits/pixel 60 fps	
Frequency used	785 MHz (Ch 66 in Korea)				

2.1.3 Phase 3

March 24, 2014 – March 31, 2015

In Phase 3, in addition to KBS, MSIP granted permission to MBC and SBS for experimental broadcast. KBS and SBS deployed a single frequency network (SFN) for live 4K-UHDTV experiments as listed in Table 12.

TABLE 12

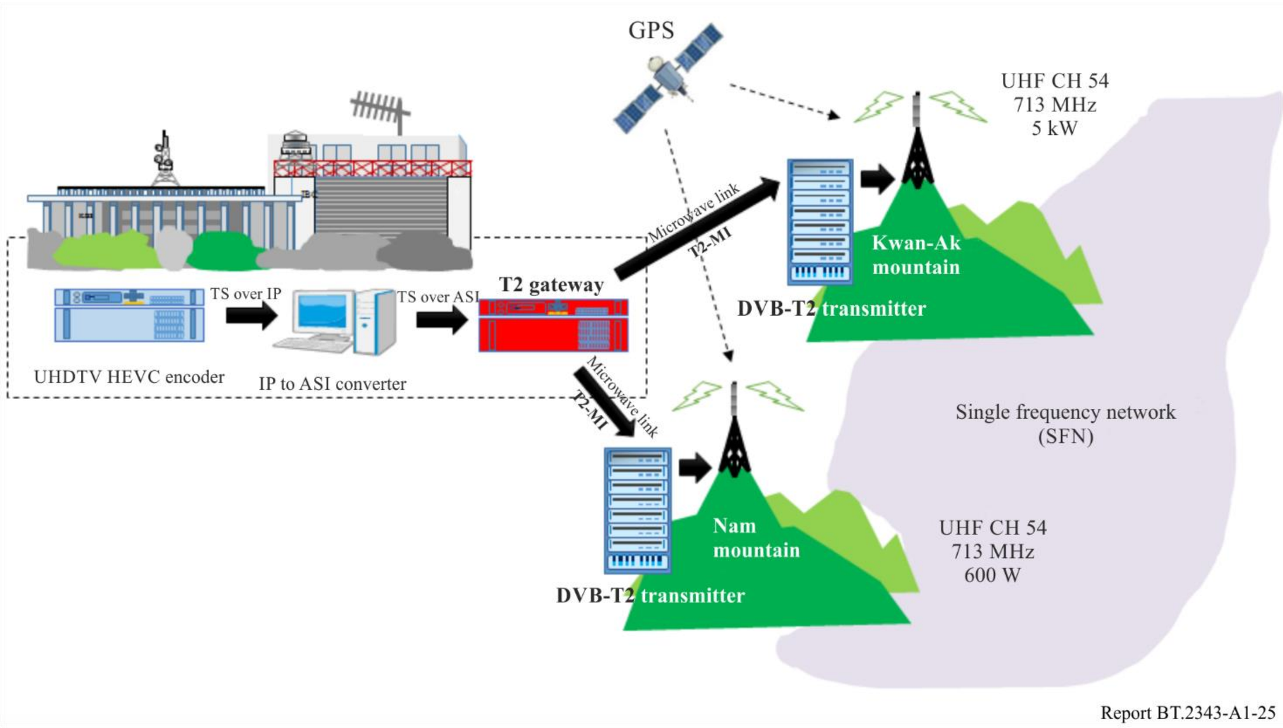
Transmitting power and used channels of transmitter site during Phase 3

Broadcaster Centre frequency (channel number)	KBS 713 MHz (Ch 54)	MBC 701 MHz (Ch 52)	SBS 707 MHz (Ch 53)
Kwan-Ak mountain	5 kW	2.5 kW	5 kW
Nam mountain	600 W	–	–
Yong-Moon mountain	–	–	1 kW

The detailed parameters of the 4K signal transmitted on the DTT platform are listed in Table 13. The experimental broadcast chain of KBS, including content production, encoding, microwave link, is shown in Fig. 42.

FIGURE 42

Transmission chain of the SFN deployed by KBS for 4K-UHDTV experiments in Phase 3



The remarkable feature of Phase 3 was that it involved live 4K-UHDTV experimental broadcasting over an SFN, which was possible due to the development of a real-time encoder for 4K-UHDTV content. KBS hence carried out the world's first live 4K terrestrial broadcast over SFN, of the 2014 Korean Basketball League (KBL) Final.

It also should be emphasized that the release of the DVB-T2 demodulator with the HEVC decoder chipset-embedded 4K-UHDTV at an affordable price has made it easier for people in Seoul to watch 4K programmes through the direct reception using the antenna. That is, anyone who has a 4K-UHD TV can watch 4K contents through the DTT platform.

2014 KBL Final Match

On April 5, 2014, KBS carried out the world's first terrestrial 4K live broadcast. The target of the 4K live broadcast was the final of the KBL in Ulsan in south-eastern Korea, as shown in Fig. 43(a).

Alongside the terrestrial 4K live broadcasting, a public viewing event was also held in Seoul Station, the largest and busiest railway station in Korea. Figure 44 shows the event. The 4K UHDTVs in Fig. 43(b) had a built-in DVB-T2 tuner with the HEVC decoder, which enabled the direct reception of the 4K terrestrial signal to the station.

FIGURE 43

4K live broadcast of the 2014 KBL Final

a) Image of the 4K live broadcast b) People watching the game at Seoul Station

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2014 FIFA World Cup in Brazil

In an attempt to give wider publicity to terrestrial 4K-UHDTV, the following three World Cup matches were broadcast live in 4K-UHD, as shown in Fig. 44. 4K live was fed from Brazil via AsiaSat5, a communications satellite, as shown in Fig. 44.

– Round of 16: Colombia vs. Uruguay

– The Quarterfinal: France vs. Germany

– The Final: Germany vs. Argentina

Images from Brazil were delivered in real-time through the AsiaSat5 communication satellite. The Korean Research Environment Open Network (KREONET) was used to deliver live 4K contents for public viewing events to other provinces.

In order to increase live service coverage of the 4K-UHDTV, two provinces were chosen for the public viewing, Daejeon and Jeju Island, in addition to the metropolitan area of Seoul, as shown in Fig. 45:

– Daejeon is fifth largest metropolis of Korea and approximately 167 km from Seoul. The reception system for the public viewing was set up in the lobby of the KBS's Daejeon station building.

– Jeju is 450 km south of Seoul, and is the largest island in Korea. The reception system for public viewing there was set up in the lobby of the KBS Jeju station building.

FIGURE 44

Transmission configuration established by KBS for the nationwide 4K live broadcast

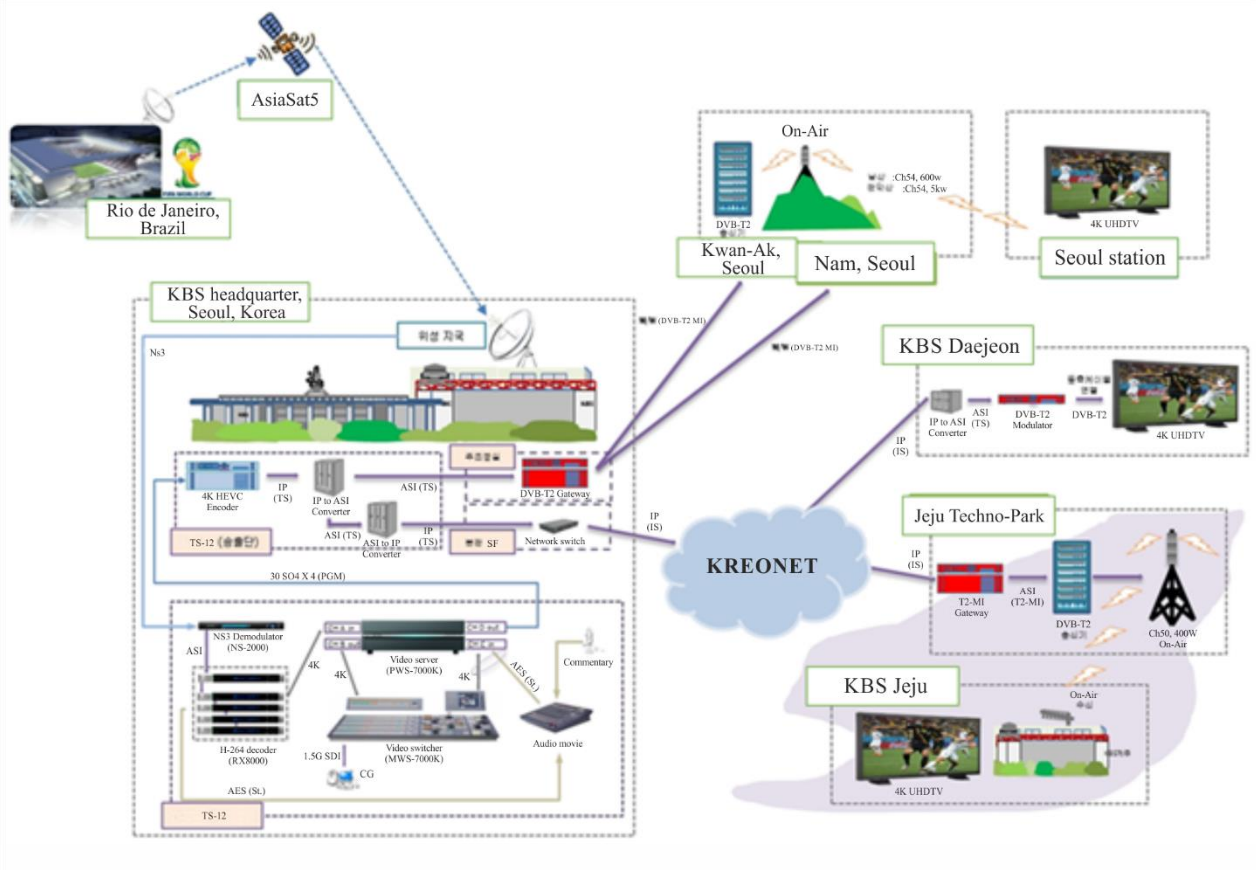

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FIGURE 45

4K live broadcast of the 2014 FIFA World Cup

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A scene of the location for public viewing at (a) the lounge in Seoul Station, (b) the lobby of the KBS Daejeon station building, and (c) the lobby of KBS's Jeju station building.

2014 Incheon Asian Games

With the government's cooperation in support 4K live coverage of the 2014 Incheon Asian Games, each broadcaster picked sporting events that suited its interests:

– KBS chose men and women's volleyball (see Fig. 46).

– MBC chose track-and-field events, as well as the opening and closing ceremonies.

– SBS picked beach volleyball.

There were no public viewing events, because 4K UHD TVs with built-in DVB-T2 tuners along with the HEVC decoder had become widely available by then, and anybody in the metropolitan area of Seoul could have watched the Incheon Asian Games live on 4K UHDTV.

FIGURE 46

4K live broadcast of the 2014 Incheon Asian Games

a) Outside and b) inside the 4K live production studio established near the Volleyball stadium

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ITU Plenipotentiary Conference 2014 (PP-14)

During the ITU PP-14 held at the Busan Exhibition and Convention Center (BEXCO) in Busan, Korea, a local on-air demonstration was watched by several delegates from the Member States as well as Sector Members of the ITU.

A 4K stream was delivered by KREONET from Seoul to Busan, as shown in Fig. 47(a). Consequently, the same 4K contents were broadcasted in both Seoul and BEXCO. The 4K stream was fed into a transmitter installed in BEXCO, and the radio frequency (RF) signal produced by the transmitter was sent to the 4K UHDTV by covering the indoor, as shown in Fig. 47(b).

FIGURE 47

Local on-air demonstration at ITU PP-14 held in Busan, Korea

a) Configuration for delivering 4K contents live from Seoul to Busan

b) Equipment including transmitting antenna for local on-air transmission and the 4K-UHDTV with integrated tuner.

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2.2 UHDTV terrestrial trial broadcasting based on ATSC 3.0

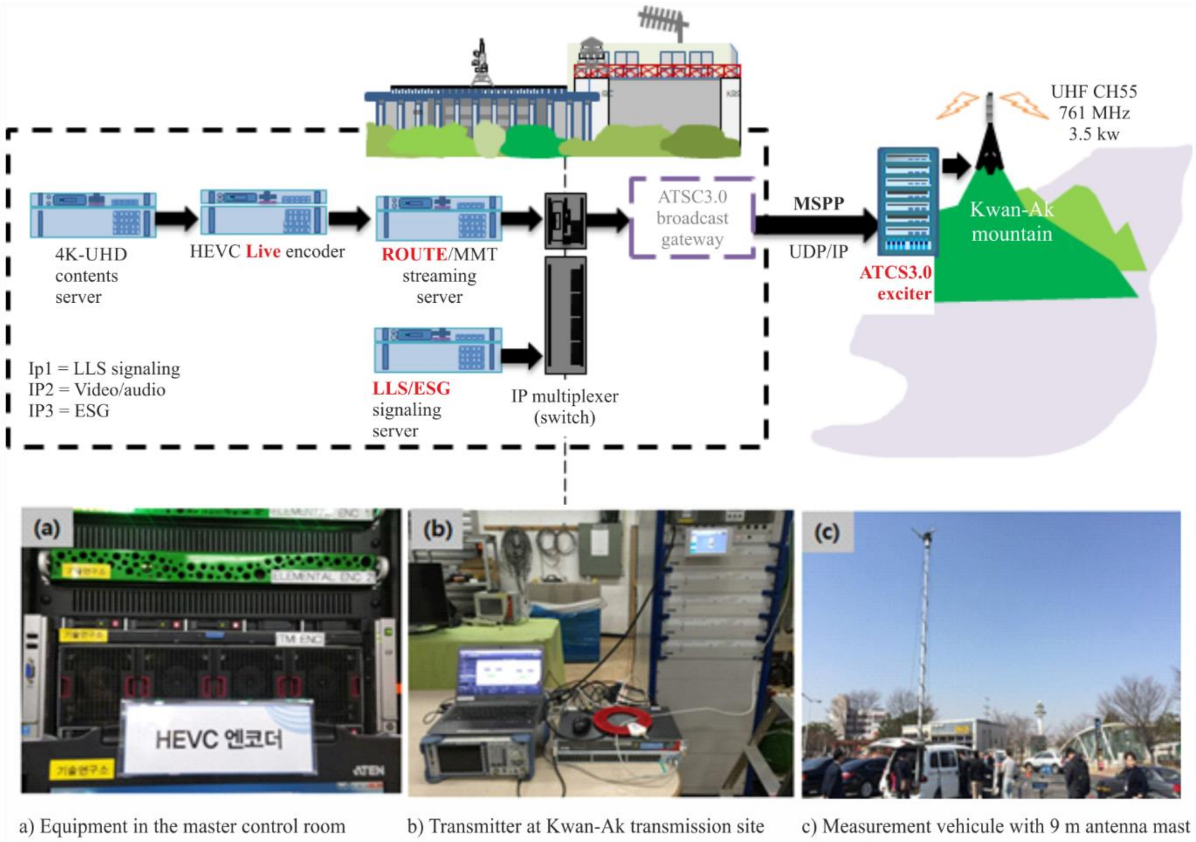
The Republic of Korea also conducted trials based on ATSC 3.0. The results are summarized below.

2016-2017: Experimental Broadcasting Based on ATSC 3.0

On January 17, 2016, the experimental broadcasting using ATSC 3.0 transmitter was initiated. For a single frequency network (SFN), ATSC 3.0 Broadcast Gateway equipment is required, but at the time, the equipment had not been developed, so the experiment was conducted with a multiple frequency network (MFN) using only one transmission station at Kwan-Ak Mountain, as shown in Fig. 48. Through the experimental broadcasting, the technical feasibility of the ATSC 3.0 standard was examined in depth.

FIGURE 48

Transmission chain deployed by KBS for 4K-UHDTV experiments based on ATSC 3.0



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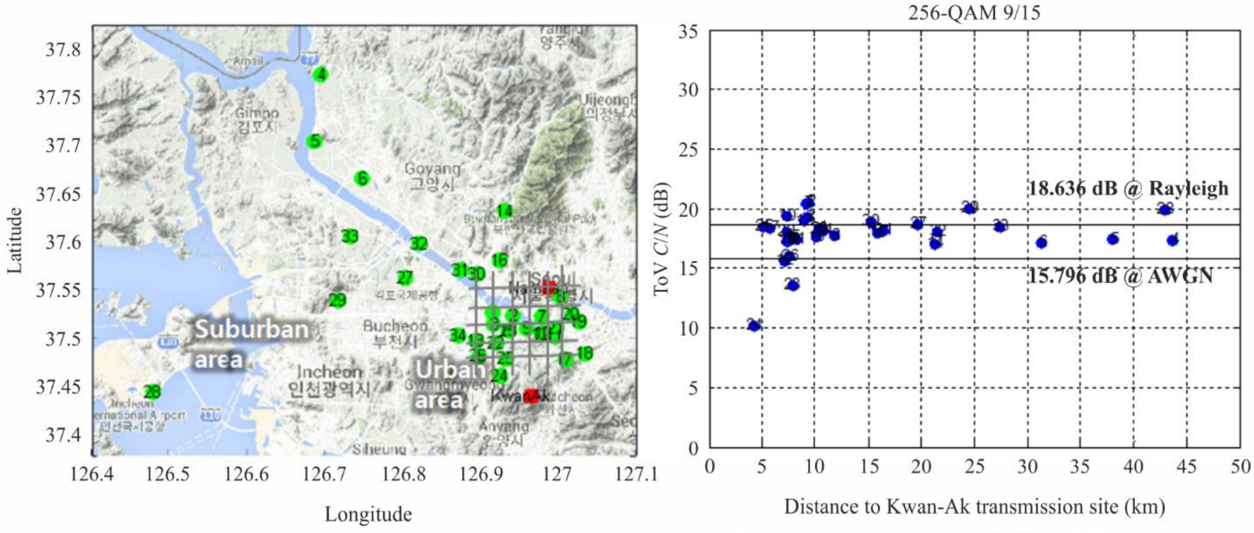
In March 2016, the first field test for the ATSC 3.0 broadcasting was conducted and terrestrial broadcasters and TV manufacturers participated in the measurement campaign for three weeks, supported by the government. Measurement results for 34 locations are shown in Fig. 49.

FIGURE 49

Measurement campaign for ATSC 3.0



a) 34 measurement locations in the metropolitan area of Seoul, Republic of Korea

b) Results on threshold of visibility (ToV) *C*/*N* (carrier-to-noise power ratio)

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On February 2017, the trial broadcast based on ATSC 3.0 systems was begun, and the entire broadcasting system was verified. In particular, on February 10, 2017, as shown in Fig. 50.

FIGURE 50

4K live broadcast of the FIS Freestyle Ski World Cup Finals

a) Shooting ski scene with 4K-UHD camera

b) Inside the 4K live production studio near the ski field

c) Public viewing in the lobby of KBS headquarters in Seoul

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3 France

3.1 Initial experiment (2014-2018)

3.1.1 Introduction

The objective of this experiment was to implement an experimental platform for transmitting linear ultra-high definition television (UHDTV) from the Eiffel Tower with a data rate of 40.215 Mbit/s, aiming at testing the associated new technologies (HEVC encoding of UHD profile, DVB-T2 broadcasting and interoperability with TVs), understanding the possible technical difficulties in this context and demonstrating the corresponding services.

3.1.2 4K-UHDTV field experiment conducted in France

For maximizing the throughput during this experiment, a UHD DVB-T2 multiplex was transmitted from the Eiffel Tower (Paris) according to an MFN (Multi-frequency Network) profile with $GI = 1/128$.

The reception of DVB-T2 multiplex was possible at any point in the DTTB coverage area, having a radius of about (25 km), via a standard fixed rake antenna and a TV set equipped with a DVB-T2 tuner and HEVC chipset set up to decode the UHD programmes.

3.1.2.1 System parameters and coverage area

The system parameters used in the experiment of 4K UHDTV terrestrial transmission conducted in France are presented in Table 13. The coverage of the transmitter is depicted in Fig. 51.

TABLE 13

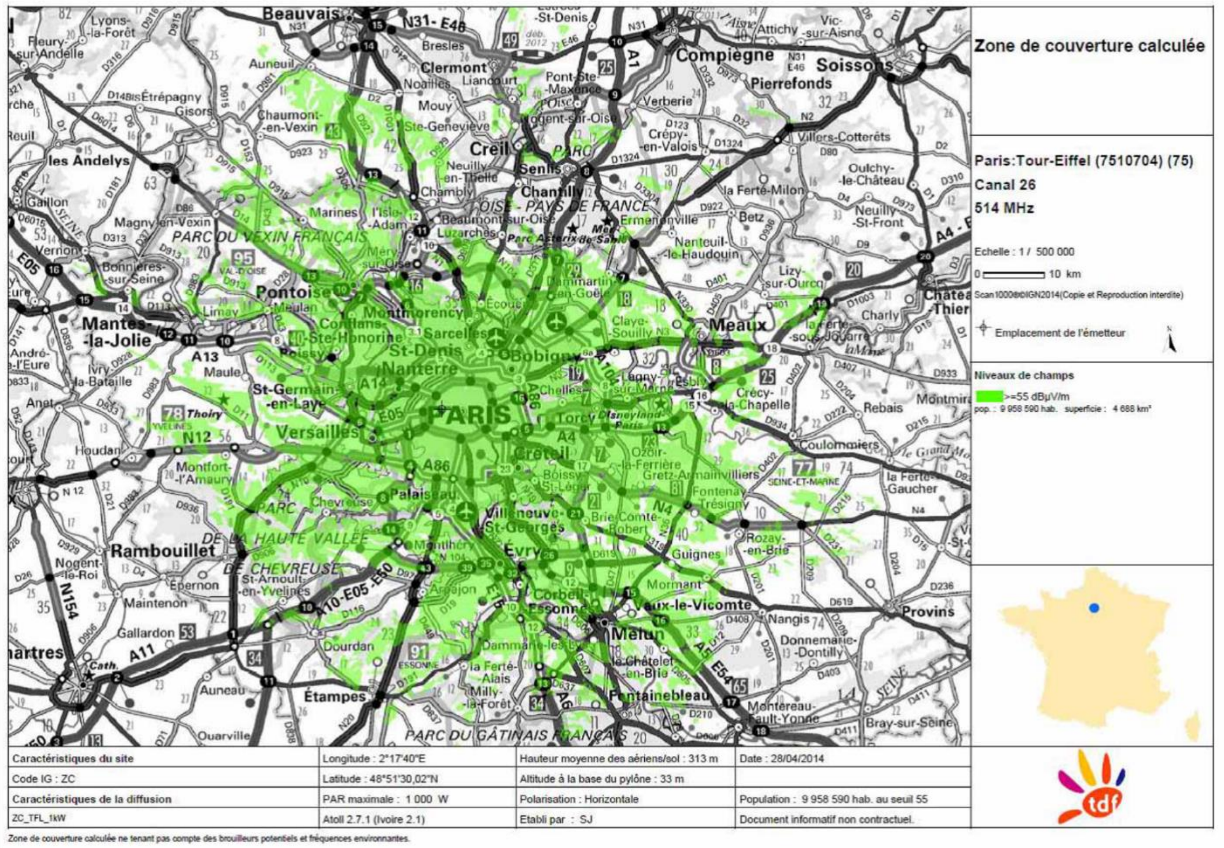
System parameters of 4K UHDTV field experiment in France

Network topology	MFN (DTTB)
Modulation method	OFDM
Channel bandwidth / Occupied bandwidth	8 / 7.77 MHz
Transmission frequency	514.167 MHz (UHF ch26)
Transmission power	100 W, e.r.p.: 1000 W
Transmission mode	SISO
Carrier modulation	256-QAM
C/N (for Rician channel)	19.7 dB
FFT size (number of radiated carriers)	32k (27,841)
Guard interval ratio (guard interval duration)	1/128 (28 μs)
Pilot pattern	PP7
# OFDM symbols	60
Error-correcting code	Inner: LDPC, code rate = 2/3 Outer: BCH
Data rate	40.215 Mbit/s
Video coding	HEVC (2160p(1) UHD-1 phase 1, 8 bit, 50 fps)
Transmitting station	Eiffel Tower
Height of transmitting antenna	313 m
Height of receiving antenna	10 m
Coverage radius	(25 km)
Minimum median field strength	55 dBμV/m at 10 m

(1) 3 840×2 160 (4K)

FIGURE 51

Coverage area of 4K UHDTV field experiments in Paris (France)



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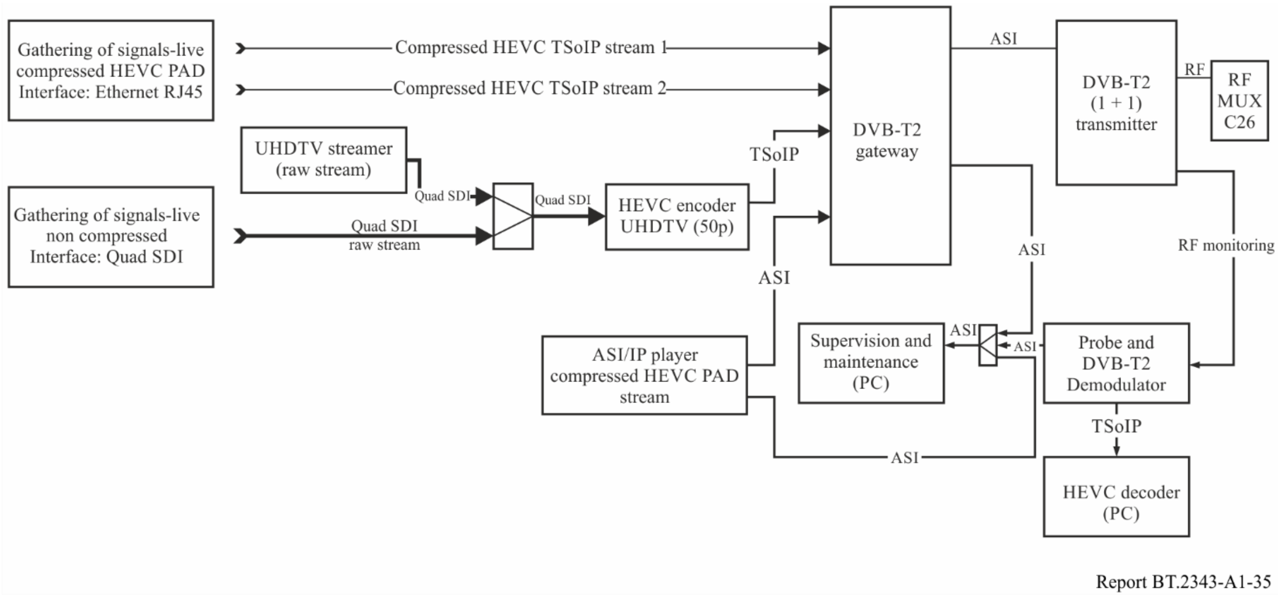
e.r.p. = 1 kW
Coverage radius ≈ 25 km
Minimum median field strength = 55 dBμV/m

3.1.2.2 Implementation of 4K UHDTV terrestrial transmission platform

The implementation of 4K UHDTV terrestrial transmission platform was based on a set of technical links and units most of them being new and requiring specific tests to be able to run the transmission link from the starting point to the end – from the capture of UHD images to the reception on an integrated UHD-1 phase1 TV set. The technical description of the platform is depicted in Fig. 52.

FIGURE 52

Technical description of 4K UHDTV terrestrial transmission platform



3.1.2.3 Live 4K UHDTV terrestrial transmission of the "French Open" international tennis tournament (2014)

Live transmission as well as transmission of pre-recorded and encoded footages were performed during the experiment. Here the only focus is on live transmission of "French Open" international tennis tournament.

The implementation of 4K-UHDTV platform for live transmission (50 fps) of the French Open tournament was a technological challenge. The experiment has demonstrated the feasibility of such broadcasting in DVB-T2 with three different integrated UHD-TV with first embedded HEVC decoding chipset. For the duration of the tournament, two full afternoons (3 and 4 June) were dedicated for broadcasting in live on UHD Programme 1 by means of four moving UHD cameras (actual UHD production). For the rest of the tournament, a fixed UHD camera installed on the main court was used for broadcasting in live on UHD programme 1. A second UHD programme (Programme 2), pre-encoded UHD film (sea, waves with storm, fisher boats), was broadcasted on Brittany:

- UHD Programme 1: 22.5 Mbit/s real-time encoding for live transmission.
- UHD Programme 2: 17.5 Mbit/s pre-recorded and off line encoded.

These two values have been defined for several reasons:

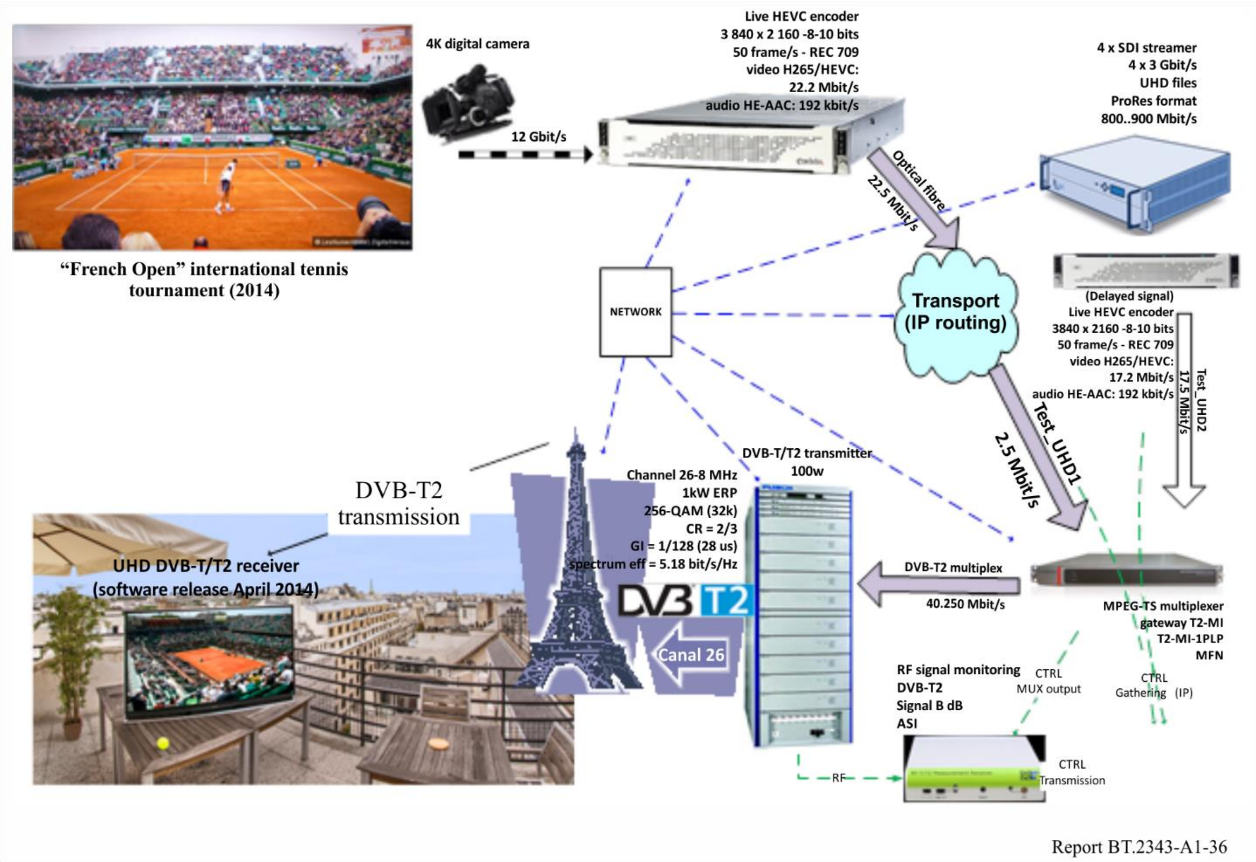
- Off line encoding uses additional HEVC tools that are not implemented in the first generation of real time encoder (no more details from encoder manufacturers at this time) and it represents next versions that will be implemented in live encoders.
- Pre-recorded files represent the same quality of current live encoder at a different bit rate.
- 17 Mbit/s represents the quality of two UHDTV channels in a SFN T2 multiplex of 36 Mbit/s.
- 22 Mbit/s has been set in order to show the impact of an additional 5 Mbit/s on UHDTV quality.

Moreover, two days were devoted to the production of UHDTV images shot by four UHDTV cameras and two HD cameras upscaled to UHD. These two days have permitted the comparison of the quality of image of UHD, HD (1 920×1 080i/25) and SD (720×576i/25) programmes on the same UHDTV screen.

The block diagram of live 4K UHDTV terrestrial transmission platform is depicted in Fig. 53.

FIGURE 53

Live UHDTV terrestrial transmission of the "French Open" tournament



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The experiment permitted, through simulcasting DTTB including images of "French Open" tournament, to compare the perceived quality of UHD, HD and SD programmes, images being presented on the same UHDTV screen.

Demonstrations were performed to have the opinion of professionals as well as home users, some of them discovering UHDTV images for the first time. They were invited to watch TV in the same conditions as in a living room sitting at a distance suitable for a UHDTV screen, which was about 1.5 times the height of the 65 inches TV display. Most of them (about 60 to 70 visitors) felt that the image quality of UHDTV programmes was fairly better than that of SD and HD programmes due to the fact that we could recognize people in the stands even with wide view angle, which is impossible in HD and many other feedbacks: "it is so realistic, like if we look through a window".

3.1.3 Conclusion

This experiment was an important step towards the introduction of the terrestrial UHDTV in France, where the DTTB SD&HD platform is a major platform transmitting linear TV, with a majority of high definition (HD) programmes. It demonstrated the feasibility of live 4K UHDTV terrestrial transmission based on UHDTV (phase 1) specifications and 256 QAM OFDM modulation with two programmes in a DTT Multiplex for the first version of live UHDTV encoders. It also demonstrated the step of quality of UHDTV programmes compared to HD programmes (1 920×1 080i/25).

Consequently, it is concluded that UHDTV will surely be the successor to high definition television (HDTV). Based on this conclusion the aforementioned 4K UHDTV terrestrial transmission platform is maintained in use aiming at supporting the undergoing developments of UHDTV and preparing the introduction of the terrestrial UHDTV in France.

Moreover, based on the currently available information on the issue, from a technical and economical point of view, it can be concluded that it will be possible to transmit three UHDTV (phase 1) programmes in a DVB-T2 multiplex in France by 2017.

3.2 Revised experiment (Started 2018)

The initial experiment had been running for four years when it was decided to expand its reach to lead additional tests. This decision followed the publication, by the CSA – the French broadcast sector regulator, see https://www.csa.fr/ –, of a roadmap for the modernization of the French DTTB platform: the objectives of this roadmap[3] are to study the technical and legal aspects and prepare the platform for the generalized introduction of 4K-UHDTV before the 2024 Olympic Games. The aim of this introduction is to keep the existing network infrastructure and frequency planning as they are, allowing a smooth transition for the viewers by only changing the transport and coding standards from DVB-T / H.264 / E-AC-3 to DVB-T2 / H.265 / NGA.

3.2.1 Network architecture and system parameters

The initial architecture presented in § 3.1 was based on the use of a unique site and meant to explore different implementation strategies for the transmission platform. As it is not representative of the existing network architecture, the network deployment was adapted in several stages as follows:

- On the Paris area, three additional sites were added to the Eiffel Tower initial deployment to form a SFN on channel 26. The Eiffel Tower ERP was increased to 3 kW, while an additional site, terrestrially fed (Paris-Est Chennevières) was set up at 200 W ERP; two gapfillers / on-channel repeaters were also implemented at Meaux (40 W ERP) and Chaville (3W ERP) respectively. This first stage formed the test bed for measurements around the selected system parameters (see below). The SFN delays were selected to optimize the resulting service area, while retaining the ability to adjust the SFN delay on Paris-Est Chennevières to provide levers for exploring the impact of different timings during the measurement campaign.
- The experiment was then expanded with the deployment of two additional sites in two additional cities – Nantes with a 16 kW ERP on the main transmitter covering the surrounding region and Toulouse with a 500 W ERP on a medium tower medium power site covering the city. Both sites were fed from terrestrial links.
- Finally, to cope with 700 MHz band migration constraints, the Paris SFN was switched to channel 24 (498.167 MHz centre frequency), while the Eiffel Tower ERP was increased to 5 kW to expand the coverage further.

For this experiment, a T2 gateway providing a T2-MI stream to the transmitters (except on-channel repeaters) was located at the Eiffel Tower site. The T2-MI transport was done through an IP pipe dimensioned to 50 Mbit/s to cover the necessary overhead for T2-MI to IP encapsulation (~7% overhead for T2-MI over MPEG2-TS to IP) and provide a sufficient FEC protection (5-20% overhead), while leaving headroom for the testing of different DVB-T2 configurations (up to more than 40 Mbit/s net bit rate). Figure 54 below depicts the network architecture after the second stage deployment.

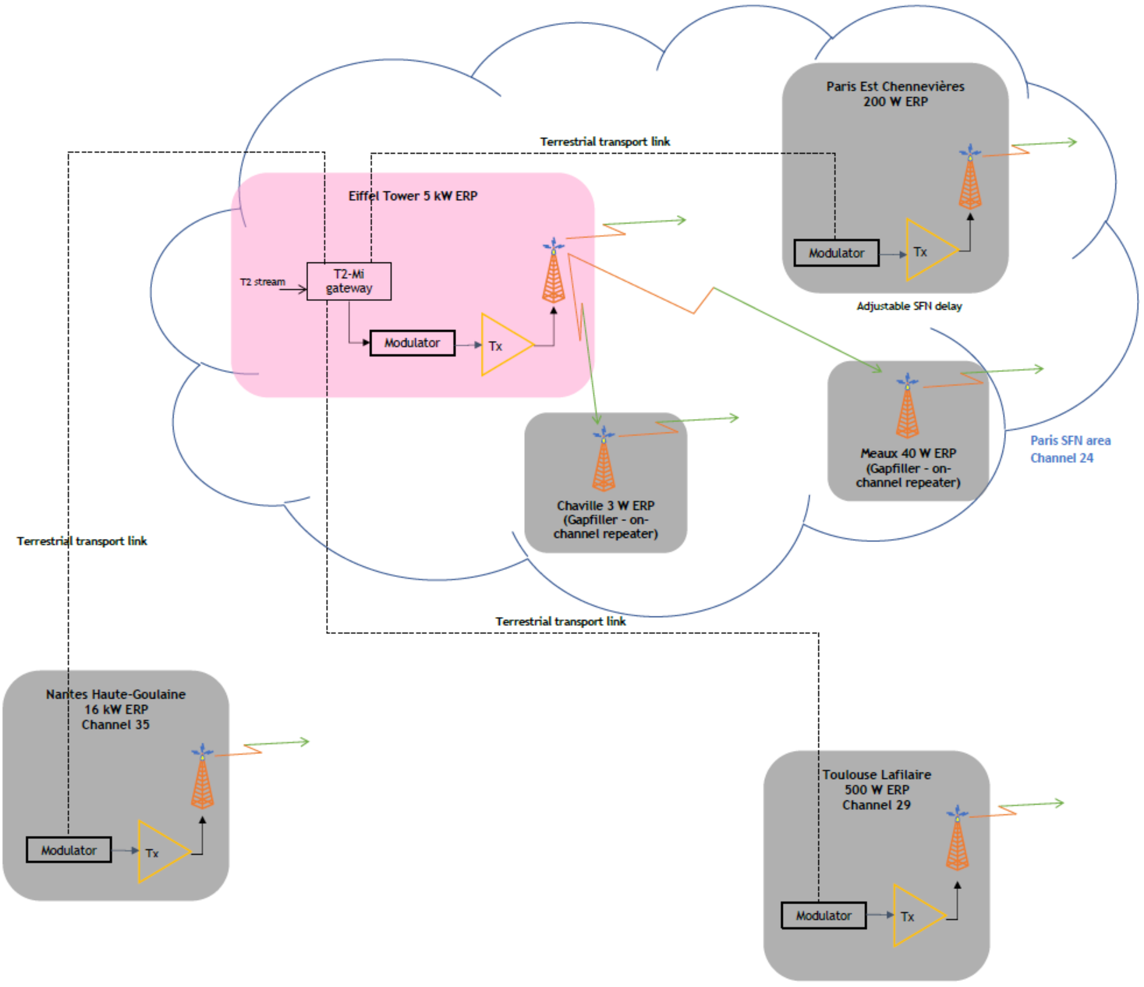
The primary target of the experiment was to explore the behaviour of two candidate sets of DVB-T2 parameters for the switch to an all DVB-T2 landscape in France. As stated before, as the aim is to

[3] The CSA is currently (June 2020) in the process of reviewing this roadmap after a new public consultation on the modernization of the French DTTB platform published in December 2019 with results published in May 2020.

allow a smooth transition for the viewers with no network infrastructure and frequency planning modifications, those two sets were selected to match best the currently deployed DVB-T parameter set for fixed reception, namely 8k FFT with 64-QAM modulation and 3/4 code rate, using a 112 µs guard interval (Rician C/N is 18.6 dB[4], 24.88 Mbit/s net bit rate). Since the experiment did not allow to strictly reproduce existing coverages, the main testing was done around the SFN behaviour relating to each parameter set, specifically when echoes outside of the guard interval are present.

FIGURE 54

Revised network architecture



4 This value is the reference taken for the DVB-T variant used in France. Measurements on modern (post 2012) DVB-T receivers have been used: these modern receivers work close to the theoretical C/N limit as found in ETSI EN 300 744 v1.6.2. DVB-T receivers were massively renewed in France in April 2016, due to the switch-over from MPEG-2 to MPEG-4 coding. This French reference value is thus compared against when evaluating potential DVB-T2 replacement profiles, to allow a disruption-free transition for the viewers.

TABLE 14

DVB-T2 parameter sets for revisited field experiment in France

	1st set (C1)	**2nd set (C'1)**
Modulation method	OFDM	
Channel bandwidth / Occupied bandwidth	8 / 7.77 MHz	
Transmission mode	SISO	
Carrier modulation	256-QAM	
C/*N* (for Rician channel) (dB)	18.0	18.6
FFT size (number of radiated carriers)	32k (27 841)	
Guard interval ratio (guard interval duration)	1/32 (112 μs)	
Pilot pattern	PP6	PP4
# OFDM symbols	58	60
Error-correcting code	Inner: 64k LDPC, code rate = 3/5 Outer: BCH	
Net bit rate (Mbit/s)	34.909	34.271

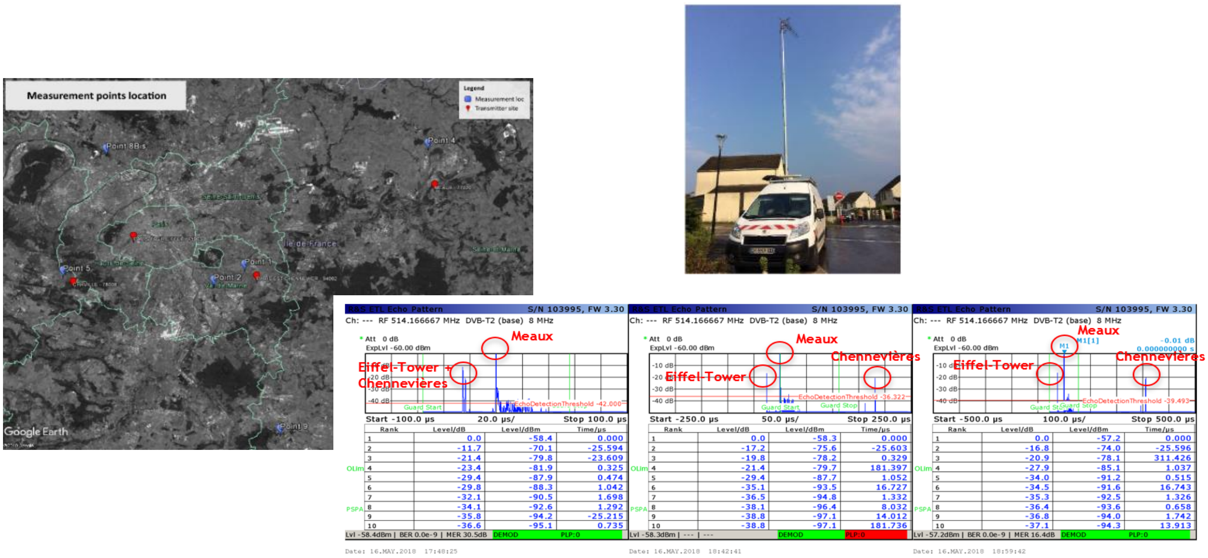
The two selected parameter sets are very close, the main difference being the choice of the pilot pattern which has a direct impact on the ability of receivers to cope with long echoes for SFN reception, to the detriment of the available net bit rate.

3.2.2 Measurements

Those two parameter sets were first qualified in laboratory tests with off-the shelf DVB-T2 / HEVC compatible products, then in the field with a measurement campaign organized to assess the real-life reception of an off-line encoded multiplex with two UHD programmes (one at 12.5 Mbit/s, the other one at 17.5 Mbit/s). During the field measurement campaign, both the parameter set and the SFN delay on the Paris-Est Chennevières transmitter were varied on each measurement location to assess the reception quality (using a professional measurement equipment and an off-the shelf compatible TV set). A specific measurement was set-up at the Meaux gapfiller site, to check the input-output processing of the gapfiller (input/output levels, MER, impulse-response, …).

FIGURE 55

Measurement locations and sample results on a specific location
(with corresponding echo profile when varying the initial delay for the Paris-Est Chennevières transmitter)



The main findings of this measurement campaign are summed-up below:

- Despite the theoretical difference in *C*/*N* between the two parameter sets, there is no noticeable difference between the two when it comes to practical reception, i.e. the effective *C*/*N* for both parameter sets is identical, at approximately 18.2 dB in a Rician environment.
- As expected, the C'1 parameter set was measured as the most tolerant set to (very) long echo delays for SFN reception with the ability to cope with echoes in the range of −170 µs to +280 µs from the main signal, while the C1 parameter set is only able to handle echoes in the range of −20 to +130 µs from the main signal.
- The specific measurement set-up at the Meaux gapfiller site showed no specific difficulty in handling the retransmission of the received signal, despite the relatively low input level received from the Eiffel-Tower, with an output MER above 35 dB.

Complementary information regarding those measurements can be found in Report ITU-R BT.2467-0 Part 2.

3.2.3 Services

In addition to the specific measurement campaign, this revised experiment was used for live testing different services broadcasting:

- Renewal of the "French Open" international tennis tournament broadcast in 2018:
  - For this experiment, the DVB-T2 configuration was set to 32k extended, with a 256-QAM modulation, 2/3 code-rate, PP6 pilot pattern and 1/32 – 112 µs – guard interval, allowing for a total 38.844 Mbit/s net bit rate.
  - A main programme with live UHD HDR-HLG video content along with MPEG-H audio was set-up. This main programme used 24.8 Mbit/s net bit rate (24.1 Mbit/s main court video with 235 kb/s for AC3+ 2.0 and 435 kb/s for MPEG-H audio, with two comments and court ambiance), while a second programme was available at 12.4 Mbit/s (12.3 Mbit/s video loop and 134 kb/s AAC 2.0 audio).
  - This experiment has permitted to assess the interoperability of existing TV sets (HDR and non HDR compatible) with the HDR-HLG content, in comparison to a previous test run on the same type of content in 2016.

  - In addition, the all IP-based transport between the headend and the transmitters proved to be efficient and permitted to validate the adopted FEC protection scheme.
- Evaluation of live HD-SDR produced contents upscaled to UHD and upgraded to HDR10 with SL-HDR2 metadata:
  - A technical platform was set-up to upscale live HD-SDR contents to 4k-UHD and HD-1080p / HDR10 with SL-HDR2 metadata.
  - The live HD-SDR contents were broadcast on an existing national DTTB multiplex using DVB-T/MPEG4 (HD-1080i), while the upscaled contents were broadcast on the experimental network (using DVB-T2 parameter set C'1), on two programmes: one programme for 4k-UHD content with various bitrates (10, 14 and 17 Mbit/s), one programme for HD-1080p with various bitrates (3, 5, 10, 17 Mbit/s). This set-up permitted the direct comparison between HD-1080i and 4k-UHD / HD-1080p / HDR10 variants of the same content.
  - This experiment showed the interest of upgrading to HDR even in the case of native SDR contents.
- Broadcast of a statistical multiplex of three 4k-UHD/HDR (PQ10 / HLG) using 33 Mbit/s out of the 34.271 / 34.909 Mbit/s maximum bitrate. The three programmes were of high / medium / low complexity respectively, and off-line coded. This permitted demonstrating the ability of having at least three UHD programmes in one multiplex on the future French DTTB platform. Based on the possible performance improvement of live HEVC coders and based on those results, it is expected to put four UHD programmes in one multiplex by the time of the full migration of the French DTTB platform.
- Evaluation of different video resolutions / format on three programmes using HEVC encoding:
  - Using the same DVB-T2 parameters as for the "French open" above (38.8 Mbit/s net bit rate), three programmes with the same content but different video format / bitrate were broadcasted to allow for the direct comparison between the different variants.
  - One programme served as a reference with 4k-UHD / BT-2020 / 10 bits HLG at 24 Mbit/s, while the other two programmes varied around HD-1080p / BT-2020 / 10 bits HLG at 7 / 5 / 6 / 4 / 3 / 2.5 Mbit/s.

3.2.4 Conclusion

This revised experiment has permitted to confirm the technical parameters that were foreseen for the transition of the existing DVB-T DTTB networks to DVB-T2. It has successfully permitted to contribute to the establishment of a French specification for IRD receivers for the modernised DTTB platform.

In addition, several service tests were led exploring different parameters / set-ups / … to form a better opinion on the current status of those parameters and help shape future decisions on the subject.

This experimental platform is still on-line at the time, broadcasting the statistical multiplex of three programmes as a showcase of what can be expected on a modernized French DTTB platform.

4 Spain

4.1 UHDTV trial from Museo del Prado (Madrid) – 2014

RTVE, the Spanish public service broadcaster, together with Universidad Politécnica de Madrid (UPM) and other relevant Spanish companies, undertook an Ultra High Definition TV trial in 2014.

RTVE provided a documentary about the Prado Museum, titled "The Passion of the Prado", produced using 4K resolution (3 840×2 160-pixel images) video.

Along the duration of this initiative, different encoding specifications and sets of transmission parameters were used. Meanwhile, manufacturers started to integrate the capacity to decode HEVC/H.265 video in their new flat-screens. As soon as this feature was available, it was used in the trial.

First tests were based on AVC/H.264 video encoding and 25p frame rate. After that, HEVC/H.265 at 50p fps was used to get smoother movements. Several bitrates were also tested from 20 Mbit/s to 35 Mbit/s. In all the cases, the transmission was based on DVB-T2 to ensure a higher spectral efficiency. Since DVB-T2 admits useful bitrates of around 50 Mbit/s, the bitrate of the deployed signal (until 35 Mbit/s) is low enough to integrate more programmes in future tests. The trial covered the area of Ciudad Universitaria (north-west of Madrid city) from a transmitter in the Telecommunication Engineering School (ETSI de Telecomunicación – UPM).

The trial was presented in a technical event in the RTVE Institute on 24th June, 2014. The Table below shows the technical parameters involved in this demonstrator.

FIGURE 56

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Transmission standard	DVB-T2
Bandwidth	8 MHz
Frequency	754 MHz (Ch 56 in Region 1; central frequency)
Power	e.r.p.: 125 W (H)
Carrier modulation	64 QAM
FFT size	32k extended
Guard interval ratio (guard interval duration)	1/128
DVB-T2 FEC	5/6
Pilot pattern	PP7

Theoretical capacity	36.72 Mbit/s
Video coding	HEVC/H.265
Audio coding	E-AC-3 5.1
Total used bitrate	35 Mbit/s
Transmitting station	ETSI de Telecomunicación (UPM).

4.2 Trials by the Chair of RTVE in UPM during the 2016-2021 period

RTVE, the Spanish public service broadcaster, together with Universidad Politécnica de Madrid (UPM) and other relevant Spanish companies that form the Advisory Committee (Cellnex, Dolby, Sapec and Televés Corporation) of the Chair of RTVE at UPM and Abacanto as collaborating entity, have undertaken several Ultra High Definition TV trials in the period 2016-2021.

The Chair, created in January 2015, includes the strategic collaboration among the entities mentioned above in training, research, academic and dissemination activities. However, before the signing of the agreement, RTVE and UPM had already collaborated in experiences such as the first UHD trials in DTT or the first HD trials in DTT with interactive services.

Although it pursues different objectives, the broadcast is a very important part of the activities of the Chair of RTVE at UPM, which has led to the development of a significant number of UHD experiences for these last years. In this way, it has participated in several UHD trials in DTT where it has been possible not only to demonstrate that emissions in UHD are realistic and efficient, but also appreciate the advantages of the use of novel standards, such as DVB-T2, HEVC and AC-4, as different features to reach more efficiency in the use of radio spectrum and better signal with more immersivity thanks to the new features associated to the UHD signal: HDR – High Dynamic Range, HFR – High Frame Rate, WCG – Wider Colour Gamut or NGA – Next Generation Audio.

Moreover, the Chair has placed special emphasis on studying the behaviour of the different elements and components of the end to end value chain for live broadcast, from the signal acquisition to the reception. To do this, the Chair has used different platforms for delivering the content, such as Digital Terrestrial Television (DTT), satellite and Hybrid Broadcast Broadband Television (HbbTV).

Given the nature of the Chair, all experiences have been publicly presented. For this purpose, the Chair has organised workshops and has participated in events and relevant national and international trade fairs to show the results.

Cellnex, advisory committee member of the Chair, maintains an UHD DVB-T2 broadcast trial continuously since its inception in 2016. The trial is being deployed throughout Spain with the aim of increasing the reception. The content used is created and provided, at all times, by RTVE, the

Spanish public service broadcaster, together with Universidad Politécnica de Madrid (UPM) and other relevant Spanish companies that conform the Advisory Committee (Dolby, Sapec and Televés Corporation) and Abacanto as collaborating entity.

The Table below shows the main technical parameters of this network.

Characteristics of the signal	
Video	4K resolution, 50 fps, SDR
Video coding	HEVC/H265
Audio	2.0
Audio coding	E-AC-3
Bitrate total	30 Mbit/s
Characteristics of the transmission	
Transmission standard	DVB-T2
Bandwidth	8 MHz
UHF channels	36 (Madrid), 43 (Barcelona), 36 (Sevilla), 26 (Malaga), 33 (Santiago de Compostela), 23 (Zaragoza), 41 (Torrente), 43 (Teruel), 48 (Oviedo), 42 (Burgos), 42 (León), 21 (A Coruña)
Transmitting station	Mijas – Malaga Ch 26
	Torrespaña and San Fernando de Henares– Madrid Ch 36
	Monte Pedroso – Santiago de Compostela Ch 33
	Collserola and Baix Llobregat – Barcelona Ch 43
	Valencina – Sevilla Ch 36 La Muela – Zaragoza Ch 23
	Torrente – Valencia Ch 41
	Teruel – Teruel Ch 43
	Oviedo-Naranco – Oviedo Ch 48
	Burgos – Burgos Ch 42
	El Portillo – León Ch 42
	Ares – A Coruña Ch 21
Power	e.r.p.: 2 kW (H) Ch 26 (Mijas)
	e.r.p.: 15 kW (H) Ch 36 (Torrespaña)
	e.r.p.: 75 W (H) Ch 36 (San Fernando)
	e.r.p.: 9 kW (H) Ch 33 (Santiago)
	e.r.p.: 10 kW (H) Ch 43 (Collserola)
	e.r.p.: 12 W (H) Ch 43 (Baix Llobregat)
	e.r.p.: 9 kW (H) Ch 36 (Valencina) e.r.p.: 9 kW (H) Ch 23 (La Muela)
	e.r.p.: 2 kW (H) Ch 41 (Torrente)
	e.r.p.: 70 W (H) Ch 43 (Teruel)
	e.r.p.: 70 W (H) Ch 48 (Oviedo)
	e.r.p.: 170 W (H) Ch 42 (Burgos)
	e.r.p.: 200 W (H) Ch 42 (El Portillo)
	e.r.p.: 14 kW (H) Ch 21 (Ares)

Carrier modulation	256-QAM
FFT size	32K extended mode
Guard interval ratio (guard interval duration)	1/8
DVB-T2 FEC	2/3
Pilot pattern	PP2
Theoretical capacity	33.4 Mbit/s

The four main initiatives in which the Chair has participated are described in the sections below.

4.2.1 UHDTV trial from Teatro Real (Madrid) – April 2016

On 21st April 2016, the Chair took part in the innovative live broadcast of the opera Parsifal in UHD, an initiative led by Teatro Real, RTVE and Hispasat. This live broadcast was possible thanks to the collaboration of several companies and organizations. Besides the Chair and the three entities that led the experience, other involved companies were: Kinepolis, Hurí, Ovide, EVS, Dolby, Ericsson, Samsung, Abacanto Soluciones, Sapec, Hewlett Packard Enterprise, Ateme, Albalá, Grass Valley and Crosspoint.

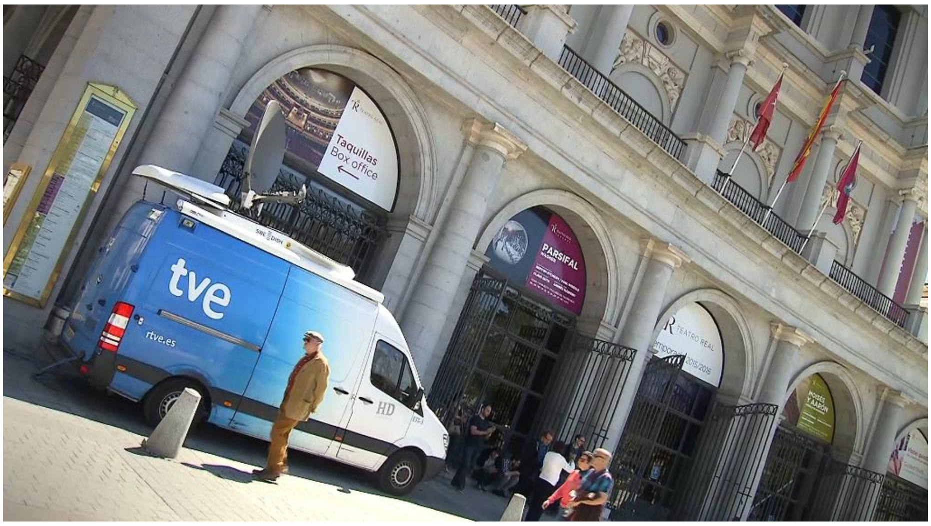
The 4K signal, with a frame rate of 50 images per second, was live produced by RTVE in Teatro Real and was broadcasted via Hispasat after encoding in real time the video in HEVC and the audio in E-AC-3. The final average bitrate was around 30 Mbit/s.

For this event, four reception points were contemplated to receive the signal: in Madrid the Kinepolis cinemas, Prado del Rey auditorium and ETSIT-UPM, and the Tower of Collserola in Barcelona. The Chair broadcasted on the fly the received signal with the new standard of Digital Terrestrial Television (DVB-T2), covering a large area around Ciudad Universitaria in Madrid. The transmission frequency was 658 MHz (UHF channel 44), thanks to the temporal television broadcast license granted by the SEAD (Secretaría de Estado para el Avance Digital). Cellnex did the same from the Collserola broadcasting center, assuring the coverage in Barcelona metropolitan area. The parameters of the COFDM modulation in both DVB-T2 transmissions were: mode 32K extended, guard interval 1/128 and pilot pattern PP7. A single PLP was set with a modulation of 64QAM and FEC 3/4. With this configuration, the useful maximum bitrate was 32.6 Mbit/s.

The Table below shows the technical parameters involved in this initiative.

Characteristics of the signal	
Video	4K resolution, 50 fps, SDR
Video coding	HEVC/H265
Audio	5.1
Audio coding	E-AC-3
Bitrate total	30 Mbit/s
Characteristics of the transmission via Hispasat (satellite)	
Transmission standard	DVB-S2
Frequencies	UP: 14.408 MHz
	DOWN: 11.608 MHz
Polarity	Vertical
Symbol rate	15 Msym
Roll of	0.2

Modulation	8PSK
FEC	3/4
Characteristics of the transmission (DTT)	
Transmission standard	DVB-T2
Bandwidth	8 MHz
UHF channels	44 (Madrid), 22 (Barcelona)
Transmitting station	ETSIT UPM – Madrid ch 44
	Collserola – Barcelona ch 22
Power	e.r.p. : 125 W (H) ch 44 (ETSIT UPM)
	e.r.p. : 15 KW (H) ch 22 (Collserola)
Carrier modulation	64 QAM
FFT size	32K extended
Guard interval ratio (guard interval duration)	1/128
DVB-T2 FEC	3/4
Pilot pattern	PP7
Theoretical capacity	32.6 Mbit/s



4.2.2 UHDTV trial from Palacio Real (Madrid) – July 2017

On 5th July 2017, the Chair participated in the first live TV broadcast in Spain in 4K High Dynamic Range (HDR) technology. The 4K resolution or Ultra High Definition is one of the major technological revolutions of the audiovisual and evolves towards the HDR, a new standard of image quality that increases the brightness and balances light and dark areas.

This pilot was possible thanks to the participation of several companies that collaborated in offering the live broadcast of the Solemn Changing of the Royal Guard from the Royal Palace in Madrid. Entities as Hispasat, Ateme, Loewe, LG, Dolby, Cellnex, Albala, Abacanto, Grass Valley, Crosspoint, EVS, Moncada y Lorenzo, Canon and Hurí made possible the event, together with the collaboration of Patrimonio Nacional and Casa Real.

The 4K signal was encoded using the HEVC video standard with two metadata groups: static metadata compatible with HDR10 and dynamic metadata compatible with Dolby Vision. On the other hand, the audio was encoded using E-AC-3 (5.1) with a bitrate of 128 kbit/s. A secondary audio PID encoded in AC-4 was used as well, with a bitrate of 48 kbit/s. The final bitrate was around 30 Mbit/s.

The TV signal was broadcast on the 4K UHD test channel of Cellnex Telecom from the broadcasting centers of Torrespaña in Madrid (UHF channel 32), in Barcelona (UHF channel 43) and Sevilla (UHF channel 36). The parameters of the modulation in the DVB-T2 transmissions were: mode 32K extended, guard interval 1/8 and pilot pattern PP2. A single PLP was set with a modulation of 256-QAM and FEC 2/3. Using this parameter configuration, the useful maximum bitrate was 33.4 Mbit/s. In order to play the signal, it was necessary to have a TV compatible with the signal characteristics.

The Table below shows the technical parameters involved in this demonstrator.

Characteristics of the signal	
Video	4K resolution, 50 fps, HDR10 and Dolby Vision
Video coding	HEVC/H.265
Audio	5.1
Audio coding	E-AC-3 and AC-4
Bitrate total	30 Mbit/s

Characteristics of the transmission	
Transmission standard	DVB-T2
Bandwidth	8 MHz
UHF channels	32 (Madrid) , 36 (Sevilla), 43 (Barcelona)
Transmitting station	Torrespaña and San Fernando de Henares– Madrid Ch 32
	Collserola and Baix Llobregat – Barcelona Ch 43
	Valencina – Sevilla ch 36
Power	e.r.p.: 15 KW (H) Ch 32 (Torrespaña)
	e.r.p.: 75 W (H) Ch 32 (San Fernando)
	e.r.p.: 10 KW (H) Ch 43 (Collserola)
	e.r.p.: 12 W (H) Ch 43 (Baix Llobregat)
	e.r.p.: 9 KW (H) Ch 36 (Valencina)
Carrier modulation	256-QAM
FFT size	32K extended
Guard interval ratio (guard interval duration)	1/8
DVB-T2 FEC	2/3
Pilot pattern	PP2
Theoretical capacity	33.4 Mbit/s

4.2.3 UHD-Phase 2 complete trial – October 2018

The most complete UHDTV trial, from the technical point of view, was achieved on October 4th, 2018. The event presented the first production and broadcast of UHD1-Phase 2 complete signal in Spain. It was possible thanks to the participation of the Chair of RTVE at UPM, Abacanto Soluciones, SGO, Camaleón Rental, LG and SONY.

The broadcast of the signal was made using the standard DVB-T2, and the signal had the following characteristics: 4K Ultra High Definition, High Frame Rate (HFR) up to 100 frames per second, High Dynamic Range (HDR) as HDR 10, Wider Colour Gamut (WCG) of Recommendation ITU-R BT.2020, and Next Generation Audio (NGA). HEVC and AC-4 was used for video and audio coding respectively.

The DVB-T2 signal was broadcast from the ETSIT UPM in Ciudad Universitaria (Madrid) on channel 44 of UHF band (temporarily assigned to the Chair of RTVE at UPM by the Secretaría de Estado para el Avance Digital for its experimental tests) and on the 4K UHD channels of Cellnex Telecom from the broadcasting centers of Torrespaña and San Fernando de Henares in Madrid (on UHF channel 32), Collserola and Baix Llobregat in Barcelona (on UHF channel 43), Valencina in Sevilla (on UHF channel 36), Mijas in Málaga (on UHF channel 26) and with the collaboration of Televés Corporation, Monte Pedroso in Santiago de Compostela (on UHF channel 33). The configuration used for the transmission in DVB-T2 was: mode 32K extended, guard interval 1/8 and pilot pattern PP2. A single PLP was set with a modulation of 256 QAM and FEC 2/3. With this type of configuration, the useful maximum bit rate was 33.4 Mbit/s.

The Table below shows the technical parameters of this pilot.

Characteristics of the signal	
Video	4K resolution, HFR 100 fps, HDR10 and WCG
Video coding	HEVC/H.265
Audio	5.1
Audio coding	AC-4
Bitrate total	30 Mbit/s

Characteristics of the transmission	
Transmission standard	DVB-T2
Bandwidth	8 MHz
UHF channels	26 (Malaga), 32 (Madrid), 33 (Santiago de Compostela), 36 (Sevilla), 43 (Barcelona), 44 (ETSIT UPM)
Transmitting station	Mijas – Malaga ch 26
	Torrespaña and San Fernando de Henares– Madrid Ch 32
	Monte Pedroso – Santiago de Compostela Ch 33
	Collserola and Baix Llobregat – Barcelona Ch 43
	Valencina – Sevilla Ch 36
	ETSIT UPM – Madrid Ch 44
Power	e.r.p.: 2 KW (H) Ch 26 (Mijas)
	e.r.p.: 15 KW (H) Ch 32 (Torrespaña)
	e.r.p.: 75 W (H) Ch 32 (San Fernando)
	e.r.p.: 9 KW (H) Ch 33 (Santiago)
	e.r.p.: 10 KW (H) Ch 43 (Collserola)
	e.r.p.: 12 W (H) Ch 43 (Baix Llobregat)
	e.r.p.: 9 KW (H) Ch 36 (Valencina)
	e.r.p: 125 W (H) Ch 44 (ETSIT UPM)
Carrier modulation	256-QAM
FFT size	32K extended
Guard interval ratio (guard interval duration)	1/8
DVB-T2 FEC	2/3
Pilot pattern	PP2
Theoretical capacity	33.4 Mbit/s

4.2.4 First worldwide complete pilot broadcast of UHD-8K signal in DVB-T2 – October 2020

On October the 21st, the Chair of RTVE in UPM presented the first complete pilot broadcast, worldwide, of UHD 8K signal in DVB-T2. As on other occasions, the pilot was possible thanks to the collaboration of all the members that make up the Chair's Advisory Committee on technological aspects: Cellnex Telecom, Dolby, Sapec and the Televés Corporation (Gsertel, TRedess and Televés), as well as Abacanto as a supporting entity. SONY collaborated in the capture of the signal, and SGO and Abacanto collaborated in the post-production of the signal. The visualization of the signal was done by Samsung and LG, who prepared two model adapted for the occasion.

The broadcast of the signal was made using the standard DVB-T2, and the signal had the following characteristics:

– 8K resolution. This resolution is characterized by images of 7 680 × 4 320 pixels, four times the resolution of UHD in 4K.
– High Dynamic Range (HDR) with the HLG (Hybrid Log-Gamma) transfer function approved in the STD-B67 standard by the ARIB (Association of Radio Industries and Businesses).
– 50 frames per second refresh rate (HFR – High Frame Rate).
– Extended colour gamut (WCG-Wider Colour Gamut) following the ITU-R BT.2020 Recommendation colour space, 10-bit depth and 4:2:0 subsampling.
– Multichannel audio 5.1.4.

Given the amount of information contained in the signal, very efficient standards were needed to compress and transmit signals with these types of characteristics. The HEVC standard was used for video encoding, the Dolby AC4 standard as an audio encoding format to ensure maximum compression and quality, and the DVB-T2 standard for the transmission of the content.

With a proper adjustment of the compression parameters, it was possible to compress at an average bit rate of 30 Mbit/s of video preserving high viewing quality and, once multiplexed with the audio channels and DVB tables, to keep below 32 Mbit/s, which allowed the transmission on the DVB-T2 channel with the specifications detailed below.

The signal was broadcasted from the TV head-end of the UPM Telecommunications Engineering School, located in the University City of Madrid, on channel 44 of the UHF, temporarily assigned to the RTVE Chair at the UPM by the State Secretariat of Telecommunications and Digital Infrastructures – SETID – for its test broadcasts. The 8K signal was also broadcasted on the UHD channel broadcast by Cellnex Telecom from the broadcasting centers of Torrespaña and San Fernando de Henares in Madrid, on channel 36; Collserola and Baix Llobregat in Barcelona, on channel 43; Valencina in Seville, on channel 36; Mijas in Malaga, on channel 26; Monte Pedroso in Santiago de Compostela, on channel 33; La Muela in Zaragoza, on channel 23; and Torrente in Valencia, on channel 41.

From a technical point of view, the resulting bit rate of the audiovisual content was around 32 Mbit/s. The COFDM modulation parameters used for transmission via DVB-T2 from the UPM head-end were: 32k extended, guard interval of 1/128 and PP7 pilot pattern. A single PLP configuration was used, with 64-QAM modulation and 5/6 FEC. With this configuration, a maximum useful binary rate of around 36 Mbit/s was obtained, which was valid for transmitting the content without any problem and for correctly receiving the signal at the RTVE Institute. For the UHD channel broadcast by Cellnex Telecom, the modulation parameters used for DVB-T2 transmission were: 32K Ext. 256-QAM 2/3 GI 1/8 PP2 SISO. This is also a valid configuration for supporting bit-rate requirements, while committed to maintaining larger scale coverage and service resilience.

The Table below shows the technical parameters of this pilot.

Characteristics of the signal	
Video	8K resolution: 7 680 × 4 320 HFR 50 fps, HLG and WCG
Video coding	HEVC/H.265
Audio	5.1.4
Audio coding	AC-4
Bitrate total	32 Mbit/s
Characteristics of the transmission	
Transmission standard	DVB-T2
Bandwidth	8 MHz
UHF channels	36 (Madrid), 43 (Barcelona), 36 (Sevilla), 26 (Malaga), 33 (Santiago de Compostela), 23 (Zaragoza), 41 (Valencia), 44 (ETSIT UPM)
Transmitting station	Mijas – Malaga Ch 26
	Torrespaña and San Fernando de Henares– Madrid Ch 36
	Monte Pedroso – Santiago de Compostela Ch 33
	Collserola and Baix Llobregat – Barcelona Ch 43
	Valencina – Sevilla Ch 36 La Muela – Zaragoza Ch 23
	Torrente – Valencia Ch 41
	ETSIT UPM – Madrid Ch 44

Characteristics of the transmission	
Power	e.r.p.: 2 KW (H) Ch 26 (Mijas)
	e.r.p.: 15 KW (H) Ch 36 (Torrespaña)
	e.r.p.: 75 W (H) Ch 36 (San Fernando)
	e.r.p.: 9 KW (H) Ch 33 (Santiago)
	e.r.p.: 10 KW (H) Ch 43 (Collserola)
	e.r.p.: 12 W (H) Ch 43 (Baix Llobregat)
	e.r.p.: 9 KW (H) Ch 36 (Valencina) e.r.p.: 9 KW (H) Ch 23 (La Muela)
	e.r.p.: 2 KW (H) Ch 41 (Torrente)
	e.r.p.: 125 W (H) Ch 44 (ETSIT UPM)
Carrier modulation	64-QAM (ETSIT UPM) 256-QAM
FFT size	32K extended mode
Guard interval ratio (guard interval duration)	1/128 (ETSIT UPM) 1/8
DVB-T2 FEC	5/6 (ETSIT UPM) 2/3
Pilot pattern	PP7 (ETSIT UPM) PP2
Theoretical capacity	36.72 Mbit/s (ETSIT UPM) 33.4 Mbit/s

Currently, the Chair research activity continues working in the development of services that allow the use of new generation communication networks (5G) in the professional production of remote events, making use of network edge processing, SDN and NFV capabilities to provide the required QoS.

4.3 UHD Spain coordinated trials starting on 2021

In 2021 the UHD Spain association has been created with the participation of more than 30 companies to join all initiatives in the Spanish industry to help the UHD development in Spain.

The association includes companies from all different constituencies in the industry, all of them are contributing to the UHD development in Spain: Production companies and broadcasters are offering their UHD productions for the trials, Network operators and are using their network to distribute the content through more than 40 different transmitter sites for DTT and also Satellite distribution, technical providers are contributing with transmitters, encoders, playouts, and streaming services and TV manufacturers are also helping providing TV sets for the demos to help the UHD ecosystem and consumer awareness to develop in Spain.

UHD Spain trials consist in two UHD playout systems delivering one HDR and one SDR stream to a Terrestrial and a Satellite network for distribution covering more than 40 cities in terrestrial, all Spain using Satellite. The service was also complemented by an interactive service allowing the SmartTV implementing HbbTV 2.0 to access to the content also using a streaming service.

The list of transmitters and channels used for this trial is available in the UHD Spain webpage www.uhdspain.com.

COMUNIDAD AUTÓNOMA	CIUDAD	CANAL UHF	OFRECIDO POR
Andalucía	Cádiz	44	Axión
	Córdoba	43	Axión
	Granada	48	Axión
	Huelva	38	Axión
	Málaga	26	Cellnex
	Sevilla	36	Cellnex
Aragón	Teruel	43	Cellnex
	Zaragoza	23	Cellnex
Asturias	Oviedo	48	Cellnex
Cantabria	Santander	34	Cellnex
Castilla y León	Ávila	41	Cellnex
	Burgos	42	Cellnex
	León	42	Cellnex
	Palencia	42	Cellnex

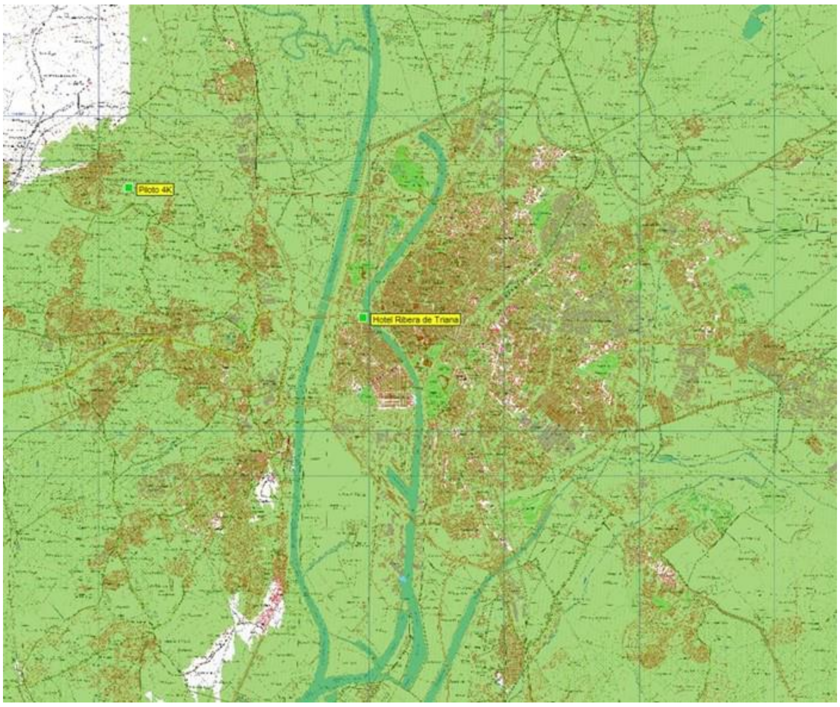
COMUNIDAD AUTÓNOMA	CIUDAD	CANAL UHF	OFRECIDO POR
Castilla y León	Salamanca	33	Cellnex
	Segovia	41	Cellnex
	Soria	46	Cellnex
	Zamora	48	Cellnex
Castilla-La Mancha	Albacete	26	Telecom CLM
	Ciudad Real	33	Telecom CLM
	Cuenca	35	Telecom CLM
	Guadalajara	35	Telecom CLM
	Toledo	35	Telecom CLM
Cataluña	Barcelona	43	Cellnex
	Girona	40	Cellnex
	Lleida	21	Cellnex
	Tarragona	42	Cellnex

COMUNIDAD AUTÓNOMA	CIUDAD	CANAL UHF	OFRECIDO POR
C. Valenciana	Valencia	41	Cellnex
Extremadura	Badajoz	22	Cellnex
	Cáceres	27	Cellnex
Galicia	La Coruña	21	Cellnex
	Santiago de Compostela	33	Cellnex
	Lugo	37	Cellnex
	Ourense	33	Cellnex
	Pontevedra	26	Cellnex
Madrid	Madrid	36	Cellnex
La Rioja	Logroño	41	Cellnex
País Vasco	Vizcaya/Bilbao	24	Cellnex
	Vitoria	47	Cellnex
Islas Baleares	Alfabia	22	Cellnex

The trials include transmitters from three different network operators Cellnex, Axión and Telecom CLM.

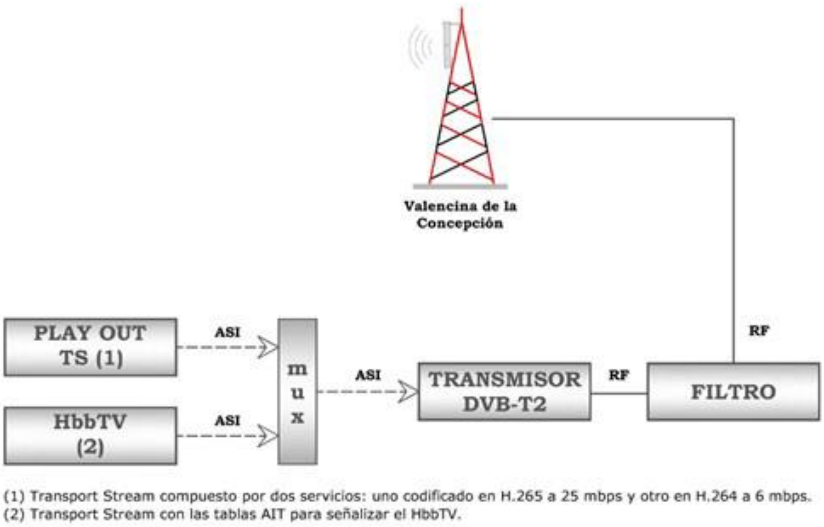
Cellnex network is including 35 transmitter sites and is covering 37% of Spanish population distributed in 31 different provinces in Spain. Cellnex network has been used for the trials described in §§ 4.1 and 4.2.

Axión network is including four transmitters located in Andalucía. Axión and the public broadcaster Radio y Televisión de Andalucía (RTVA) initiated DVB-T2 transmissions in 2016 for the 4K Summit event in Sevilla, using a 500W transmitter with e.r.p. of 10kW from the transmitter site in Valencina.



In addition to the terrestrial coverage UHD content are also available in the HbbTV RTVA platform available in the DVB-T network.

The following image shows the architecture of the service.



In 2017 a new transmitter site in Mijas, covering Malaga using a 300W transmitter with a e.r.p of 6.6 kW from this site, was added to the UHD network starting broadcasts on the occasion of the 4k summit 2017. Transmissions in both HDR formats HLG and PQ10 were broadcasted in order to be able to compare both HDR standards. These HDR broadcasts could be received in both Seville and Malaga.

In 2018 a live transmission of the event "XLII Exhibición de ganches de caballos en Ronda" was broadcasted in UHD as part of the trial.

Since then Axión has added four additional transmitters in:

– Granada: From Parapanda in channel 48 since February 2021.
– Huelva: From Punta Umbría in channel 38 since February 2021.
– Cádiz: From San Cristóbal in channel 44 since March 2021.
– Córdoba: From Lagar de la Cruz in channel 43 since March 2021.

DVB-T2 transmission parameters are:

FFT: 32k.

Guard interval: 1/128.

Mode: Extended.

Used pilot pattern: PP7.

Code rate L1: 1/2.

FEC L1: 16K LDPC.

Constellation: 64-QAM.

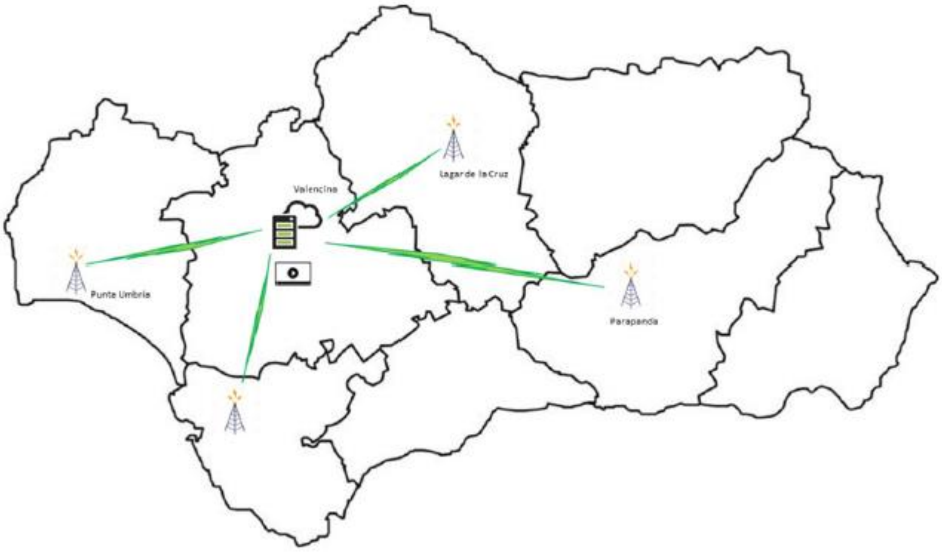
Channel bandwidth: 33.7 Mbit/s.

TS bitrate: 32 Mbit/s.

Video bitrate: 26 Mbit/s (HEVC).

Audio bitrate: 320 kbit/s.

Map of the transmitter sites in Andalucía:



Telecom CLM started emissions in 2019 using two transmitters in SFN configuration to fully cover the city of Toledo, broadcasting in UHD contents from RTVE and Ente Público de Radiotelevisión Castilla la Mancha (CMM).

The following image shows the event where this trial was presented in 2019:

In 2020 the UHD trial in the region of Castilla la Mancha added additional transmitter sites to cover the cities of Ciudad Real, Cuenca, Albacete and Guadalajara using the following parameters:

Characteristics of the signal	
Video	4K resolution, 50 fps, SDR
Video coding	HEVC/H265
Audio	2.0
Audio coding	MPEG Audio Layer 1/2
Bitrate total	30 Mbit/s
Characteristics of the transmission	
Transmission standard	DVB-T2
Bandwidth	8 MHz
UHF channels	35 (Toledo), 33 (Ciudad Real), 35 (Cuenca), 26 (Albacete), 35 (Guadalajara)
Transmitting station	Cerro Palos (Toledo) Ch 35
	Toledo II (Toledo) Ch 35
	Valle Tiétar (Toledo) Ch 35 – coming soon
	La Atalaya (Ciudad Real) Ch 33
	La Mancha (Ciudad Real) Ch 33
	Puertollano (Ciudad Real) Ch 33
	Cuenca I (Cuenca) Ch 35
	Cuenca II (Cuenca) Ch 35
	Chinchilla (Albacete) Ch 26
	Hellín (Albacete) Ch 26 (coming soon)
	Almansa (Albacete) Ch 26 (coming soon)
	Iriepal (Guadalajara) Ch 35
Power	e.r.p.: 20 W – Cerro Palos Ch 35
	e.r.p.: 10 W – Toledo II Ch 35
	e.r.p.: 100 W – Valle Tiétar Ch 35 (coming soon)
	e.r.p.: 100 W – La Atalaya Ch 33
	e.r.p.: 100 W – La Mancha Ch 33
	e.r.p.: 20 W – Puertollano Ch 33
	e.r.p.: 20 W – Cuenca I Ch 35
	e.r.p.: 1 W – Cuenca II Ch 35
	e.r.p.: 500 W – Chinchilla Ch 26
	e.r.p.: 100 W – Hellín Ch 26 (coming soon)
	e.r.p.: 10 W – Almansa Ch 26 (coming soon)
	e.r.p.: 20 W – Iriepal Ch 35
Carrier modulation	256-QAM
FFT size	32K extended mode
Guard interval ratio (guard interval duration)	1/8
DVB-T2 FEC	2/3
Pilot pattern	PP2
Theoretical capacity	33.4 Mbit/s

The network of transmitters in Castilla la Mancha are shown in the following map.

5 Sweden

The transmission was primarily made for the Teracom customer event "TV-Puls" January 23rd 2014, but was on air the week before and two weeks after this date. Two encoded streams were alternately broadcast during this period. Stream 1 was offline encoded. Stream 2 was supplied by a manufacturer, meaning that the parameters of this stream are not known.

The 4k signal was transmitted in the DTT platform with the parameters in Table 1.

6 United Kingdom

The ready availability of 4k material for two major sporting events of great public interest in the summer of 2014 (the FIFA World Cup in Brazil, and the Commonwealth Games in Glasgow) allowed the BBC to run a series of trials concerning distribution of this material. As well as trials of streaming the content online (via DVB-DASH), the BBC's transmission network operator, Arqiva, operated a network of three high-power DTT transmitters broadcasting a multiplex containing one UHDTV service.

The 4k signal was transmitted in the DTT platform with the parameters in Table 1.

The transmissions were successfully received and decoded for a series of public and private demonstrations in all three service area.

7 Brazil

7.1 Introduction

The next generation of television broadcasting systems has the challenge of providing content with high quality UHDTV. Research in modern high bit rate transmission systems, better coding formats and more robust reception have been performed by a number of countries.

Brazilian researches for the next generation broadcasting that contemplates all of those characteristics, began in 2014 in Rio de Janeiro, during FIFA World Cup. DVB-T2 technology was used to transmit some of the soccer matches in 4K UHDTV from TV Globo's (a Brazilian Broadcasting Company) Headquarters (HQ) to a Public Viewing at Leblon, Rio de Janeiro.

During the Rio de Janeiro Olympics in August 2016, TV Globo in collaboration with NHK (Japan Broadcasting Corporation) provided 8K UHDTV Public Viewing (PV) of the Olympic Games for the local viewers. This PV at Museum of Tomorrow was carried out by transmitting 8K UHDTV signal through terrestrial network in UHF band, from Mt. Sumaré station, using multiple-input multiple-output (MIMO) orthogonal frequency division multiplexing (OFDM) transmission technologies, utilizing dual polarization technique which was developed by NHK.

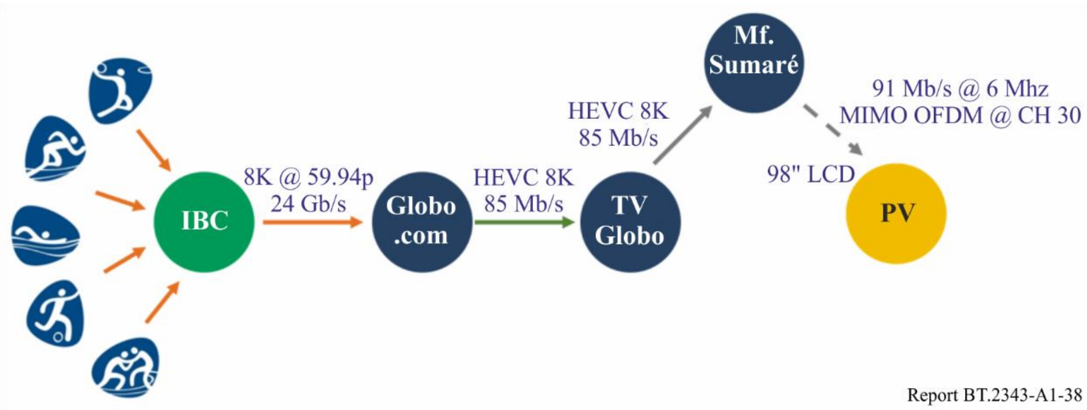
The following sections describe the details of this trial and the tests conducted at the occasion.

7.2 Diagram of the PV

The diagram of 8K transmission for this PV is shown in Fig. 57. First, the uncompressed 8K UHDTV signal provided at the International Broadcasting Centre (IBC) is received at Globo.com. Then the signal is compressed by HEVC encoding and sent to TV Globo Headquarter via optical fibre. From TV Globo HQ, the HEVC encoded signal is transmitted to Mt. Sumaré tower by station to transmitter link (STL). After Mt. Sumaré station receives this STL signal, the signal is modulated and transmitted by both horizontal and vertical polarization waves with a dual-polarized antenna. Reception antenna was installed at the Museum of Tomorrow which was the facility for the PV. Finally, the reception signal was demodulated and decoded to be displayed on a 98-inch LCD monitor.

FIGURE 57

Diagram of 8K terrestrial transmission for the PV



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7.3 Transmission and reception station equipment

Figure 58 shows the transmission station antenna. Transmitting antenna's characteristics are shown in Table 15. Figure 59 shows the reception station antenna. The demonstration was located at the Museum of Tomorrow, in a distance of approximately 8.5 km from the transmission's site. The receiving antenna was located at its rooftop at about 30 metres height. The characteristics of the receiving antenna are shown in Table 16.

FIGURE 58

Transmission station antenna

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TABLE 15

Transmitting antenna's characteristics

Type	Dual-Polarized Panel
Gain	11 dBd
Cross-polarization isolation	~37 dB in 569 MHz
VSWR	< 1.2

FIGURE 59

Reception station antenna

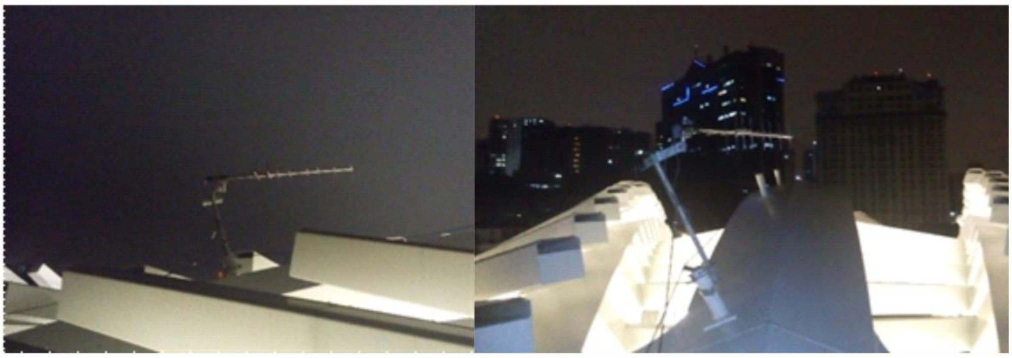

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TABLE 16

Receiving antenna's characteristics

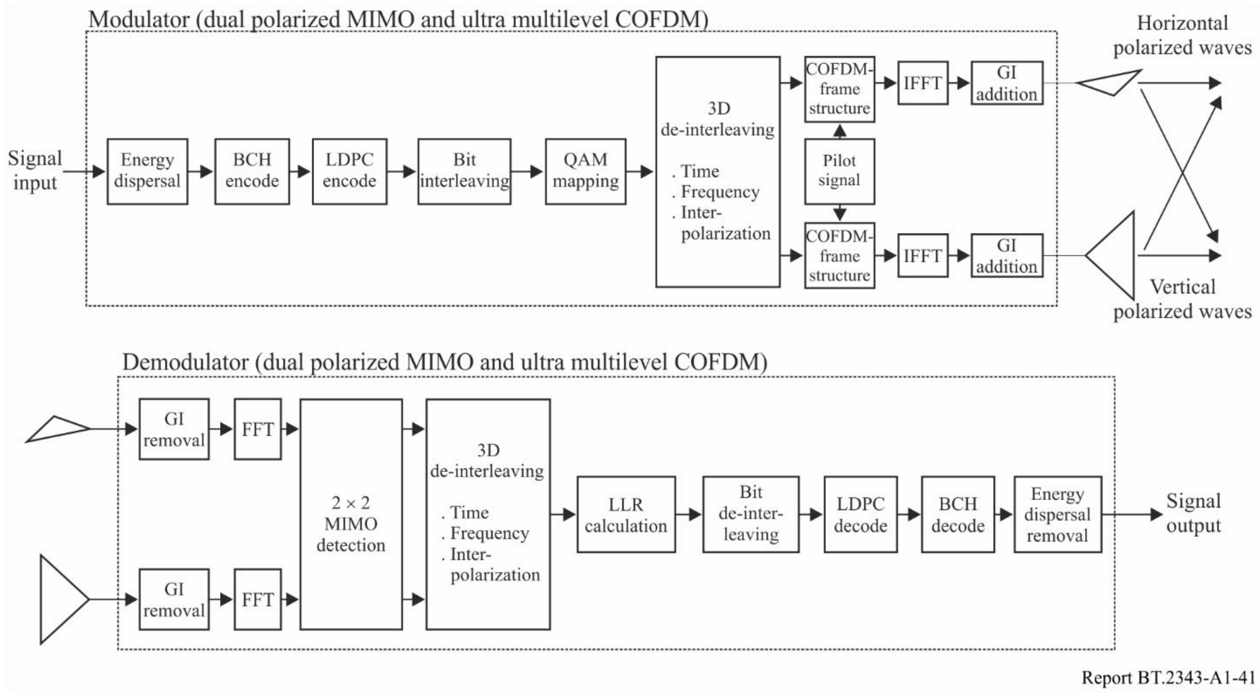
Type	Dual-Polarized, 8-element Yagi
Gain	9 dBd
Cross-polarization isolation	~25 dB in 569 MHz

Figure 60 illustrates the block diagram of the modulator and demodulator used in this PV service. The input signal is protected with BCH code and low density parity check (LDPC) code, bit interleaved and then mapped onto the constellation. After that, the signal is divided into two signals (one for the horizontal polarization and the other for the vertical polarization) with interleaving technique (time, frequency and inter-polarization). Signals are then converted into time domain signals by Inverse fast Fourier transform (IFFT) and guard intervals (GI) are added.

In the demodulator, the active symbol period is extracted from the received signals, which are then converted into frequency domain signals by fast Fourier transform (FFT). The frequency domain signals are de-multiplexed, equalized by MIMO detection, de-interleaved, and used to calculate the log likelihood ratio (LLR). LLRs are de-interleaved and input to the LDPC decoder. Finally, BCH decoding is applied to obtain the output signal.

FIGURE 60

Modulation and demodulation scheme



7.4 Transmission parameters

The transmission parameters of the 8K UHDTV PV service are shown in Table 17.

TABLE 17

Transmission parameters of the 8K UHDTV PV service

Modulation method	COFDM
Occupied bandwidth	5.57 MHz
Transmission frequency	569.142857 MHz (UHF channel 30 in Brazil)
Transmission power	Horizontal polarized waves: 100 W, e.r.p.: 660 W Vertical polarized waves: 100 W, e.r.p.: 660 W
Carrier modulation	4096-QAM
FFT size (number of radiated carriers)	32k (22,465 carriers)
Guard interval ratio (guard interval duration)	1/32 (126 μs)
Error-correcting code	Inner: LDPC, code rate = 3/4 Outer: BCH
Transmission capacity	91.8 Mbit/s
Video coding	HEVC
Audio coding	MPEG-4 AAC
Transmitting station	Mt. Sumaré
Height of transmitting antenna	830 m above sea level
Receiving station	Museum of Tomorrow (approx. 8.5 km from the test transmitting station)
Height of receiving antenna	30 m above sea level (30 m above ground level)

Figure 61 shows the simulated theoretical coverage area.

FIGURE 61

Coverage area

Report BT.2343-A1-42

7.5 Field tests in Rio de Janeiro

Two tests were conducted during the demonstration. The first test consisted in performing measurements across Rio de Janeiro metropolitan area to validate the theoretical coverage and to analyse the reception condition in the many diverse settings. The second test performed was a long-term measurement at a fixed point in order to evaluate the propagation conditions' behaviour at that period.

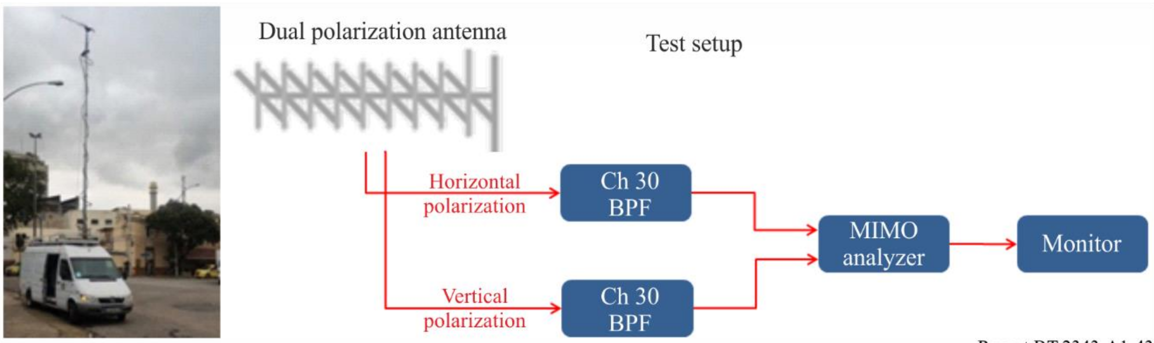
7.6 Measurements

7.6.1 Multiple point measurements

During the period of testing and demonstrating of the technology, 32 measurement points were assessed across Rio de Janeiro metropolitan area. MER, channel response, condition number and the isolation between polarizations were measured with the setup presented in Fig. 62, assembled in the van also shown in Fig. 62.

FIGURE 62

Test setup



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The chosen measurement points and the theoretical coverage are shown in Fig. 63.

FIGURE 63

Measurement points

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The analysis of the data collected shows that, for the 32 measurements points, about 85% can receive the signal properly. The farthest point was in a distance of approximately 42 km and the measurements showed good reception conditions. Another interesting measurement point was in a distance of approximately 36 km in a propagation path over the water which also showed good conditions to receive the signal. The tests demonstrated the feasibility of 8K UHDTV digital terrestrial broadcast in a big city such as Rio de Janeiro using a modest transmitter power.

7.6.2 Single point long-term measurement

During the test period, a similar test setup was installed in a laboratory located at the fifth floor of the Rio de Janeiro State University (UERJ). The MIMO Analyser performed sequential measurements every 30 seconds for 18 days, for the purpose of recording and evaluating the channel's performance variation in a double polarization system. Figure 64 shows the measurement setup installed at the site. No significant variation on reception condition was detected during the observation period.

FIGURE 64

Measurements set up

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7.7 Demonstration

During the Rio de Janeiro Olympics, more than 30,000 people visited the 8K UHDTV PV at Museum of Tomorrow. Figure 65 shows images of the viewing session.

FIGURE 65

Public viewing at Museum of Tomorrow

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7.8 Conclusion

This trial showed the viability of 8K UHDTV over-the-air transmission using single 6 MHz channel utilizing the prototype ISDB-T next generation system developed by NHK Japan. The technical results will be an important starting point for further studies of the evolution of DTTB in Brazil.

8 China

8.1 4K UHDTV trial in Jiaxing (2017)

8.1.1 Introduction

With the quick develop of UHDTV service in China, the terrestrial television broadcasting systems has the challenge of providing content with high quality UHDTV service. Research in modern high bit rate transmission systems, better coding formats and more robust reception have been performed by a number of countries.

On November 9, 2017, the State Administration of Press, Publication, Radio, Film and Television issued the notice on standardizing and promoting the Development of 4K Ultra HDTV service in China.

On October 1, 2018, the CCTV 4K Super HD channel of the China Central Television was officially launched, Beijing Gehua, Guangdong, Shanghai Oriental, Zhejiang, Sichuan, Guizhou, Chongqing, Jiangxi, Anhui, Shaanxi, Jiangsu, Inner Mongolia and Shenzhen Tianwei and other 13 cable TV networks simultaneously opened the 4K Ultra HD channel of the China Central Television.

In 2022, the Winter Olympics in China is planned to use 8K live broadcast.

In order to collect the experience for UHDTV in terrestrial television broadcasting systems, on August 8, 2018, National radio and television administration approved to carry out the terrestrial UHDTV trial in Jiaxing, Zhejiang Province. The trial was made by Jiaxing TV station, Tsinghua University, National engineering Lab. for DTV (Beijing) and Communication University of China.

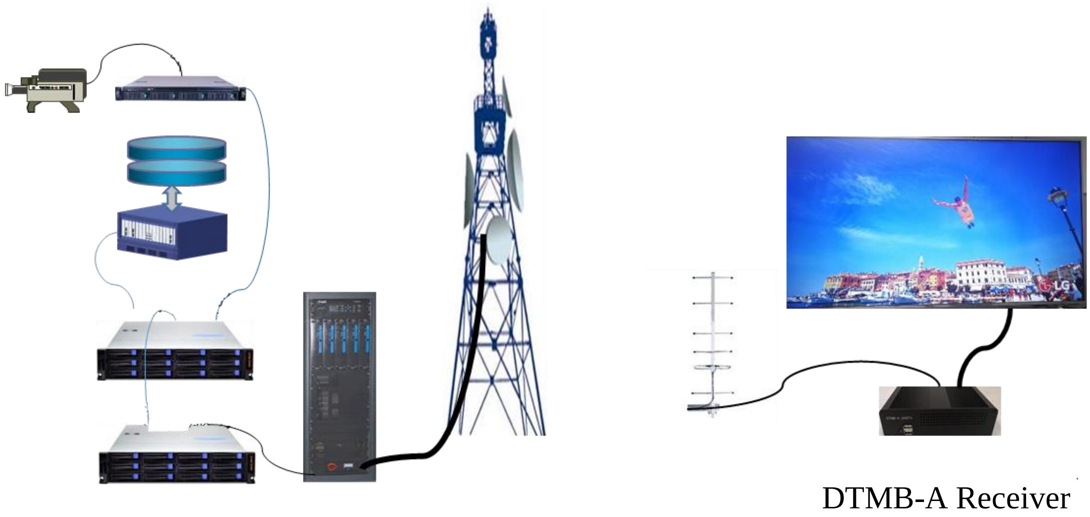
The following sections describe the details of this trial and the tests conducted at Jiaxing.

8.1.2 Diagram of the trial

The diagram of Jiaxing 4K UHDTV terrestrial transmission trial is shown in Fig. 66. The uncompressed 4K UHDTV signal was generate by camera or player, then the signal is compressed by H.265 encoding, after encoder, the signal is modulated and transmitted by antenna. Reception antenna was installed at the test points (Indoor or outdoor). Finally, the reception signal was demodulated and decoded to be displayed on LCD UHDTV monitor.

FIGURE 66

Diagram of Jiaxing 4K UHDTV terrestrial transmission trial



8.1.3 Transmission and reception station equipment

Figure 67 shows the transmission station antenna. The characteristics of transmitting antenna is shown as Table 18. Figure 68 shows the field trial reception station antenna. During the field trial, a demonstration was located at the Jiaxing radio and television centre, in a distance of approximately 2.5 km from the transmission site (Jiaxing Radio and Television Building). The receiving antenna was located at its third floor. The characteristics of the receiving antenna is shown in Table 19.

FIGURE 67

Transmission station antenna

TABLE 18

Transmitting antenna's characteristics

Height above ground	145 m
Type	Horizontal
Gain	11 dBd
VSWR	< 1.2

FIGURE 68

Field trial reception station antenna

TABLE 19

Receiving antenna's characteristics

Type	Yagi antenna
Gain	5 dB
Impedance	75Ω
Interface	F

8.1.4 Transmission parameters

The transmission parameters of the Jiaxing 4K UHDTV terrestrial transmission trial are shown in Table 20.

TABLE 20

Transmission parameters of the Jiaxing 4K UHDTV terrestrial transmission trial

Modulation method	TDS-OFDM
Occupied bandwidth	7.56 MHz
Transmission frequency	562 MHz
Transmission power	Horizontal polarized waves: 1 000 W
Carrier modulation	256APSK
FFT size (number of radiated carriers)	32k
Guard interval ratio (guard interval duration)	1/128
Error-correcting code	Inner: LDPC, code rate = 2/3 Outer: BCH

TABLE 20 (*end*)

Transmission capacity	39.7 Mbit/s
Video coding	H.265
Audio coding	MPEG-4 AAC
Transmitting station	Jiaxing Radio and Television Building
Height of transmitting antenna	156 m above sea level (145 m above ground level)
Receiving station	Jiaxing radio and television center (approx. 2.5 km from the test transmitting station)
Height of receiving antenna	4 m above ground level

8.1.5 Field tests in Jiaxing

Two tests were conducted during the trial. The first test was outdoor reception test, which was conducted at a certain distance between the radioactive roads in Jiaxing City and along Jiaxing City. The second test was an indoor reception test. The test points were distributed inside different buildings in the urban area of Jiaxing.

8.1.6 Measurements

Outdoor field trial

When select the test sites, due to actual conditions, 10 outdoor test points were selected for the outdoor fix reception test and seven test points for the indoor test. In these test points, the receiver was checked if it can properly receive and decode the display of UHDTV programmes. Through recording the receiving signal power of the test signal at the test point to have a preliminary understanding of the coverage of the Jiaxing UHDTV terrestrial broadcasting service. The test results show that the UHDTV test using DTMB-A transmission can cover most areas of Jiaxing city and its suburban areas.

The setup of the outdoor field trial is shown as Fig. 69. The pictures in some test sites are shown as Fig. 70.

FIGURE 69

Test setup

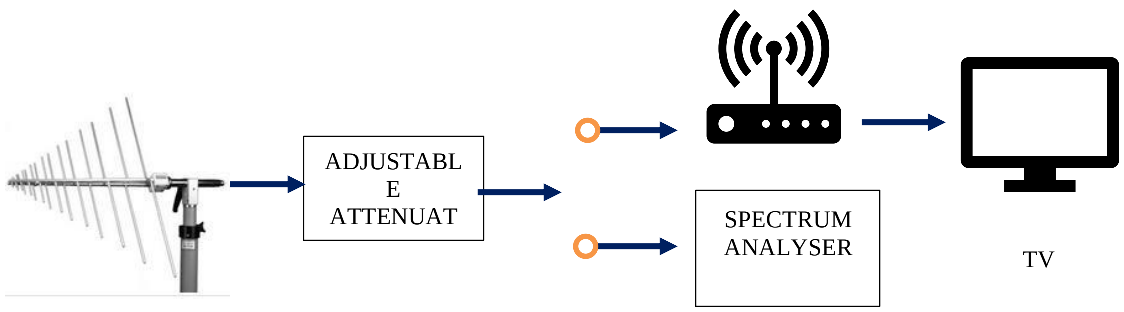


FIGURE 70

Pictures in test site

Suburban road test point

Overpass test point

Suburban TV station test point

Indoor test point

Jiaxing 4K UHDTV terrestrial transmission trial test team

The chosen outdoor field trial measurement points are shown in Fig. 71. Table 21 shows the receiving signal power test results of the outdoor test point.

FIGURE 71

Measurement points of outdoor field trail

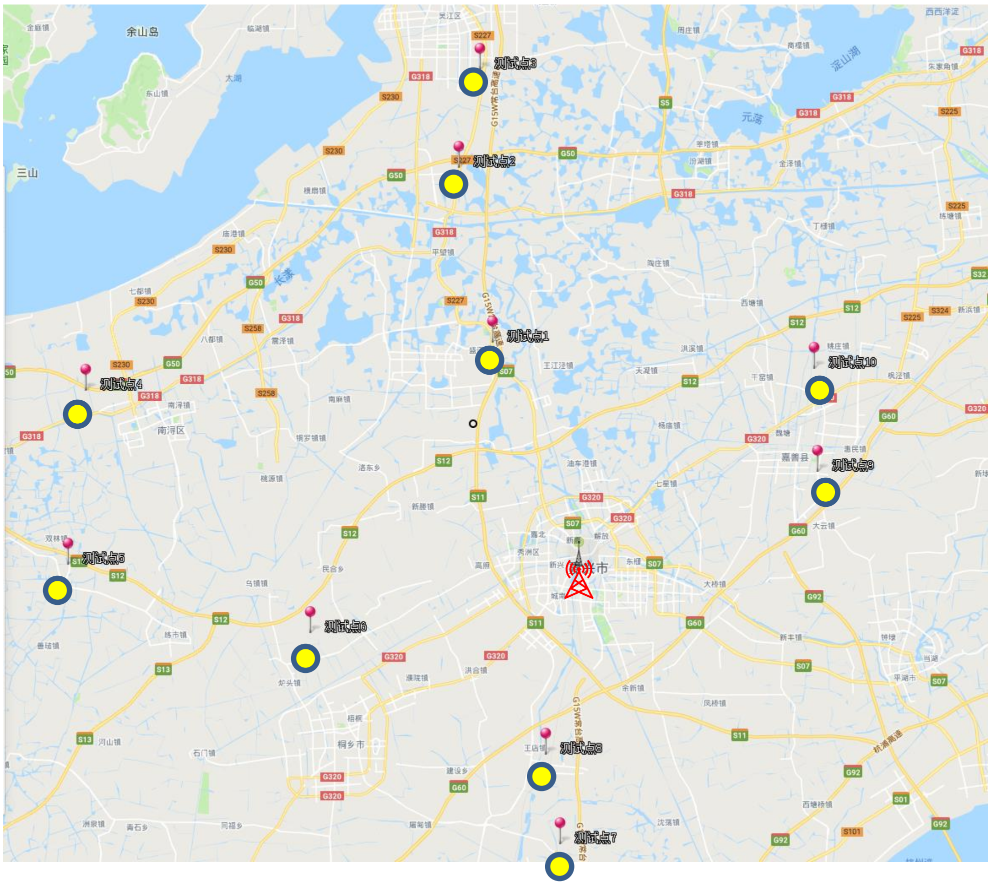


TABLE 21

Test result of outdoor reception

No.	Longitude	Latitude	Distance (km)	Receiving signal power (dBm)	Margin (dB)
1	E 120°40′33″	N30°53′53″	15.0	−52.9	28
2	E 120°38′56″	N31°2′0″	30.0	−65.5	13
3	E 120°39′57″	N31°5′6″	35.0	−65.5	10
4	E 120°20′50″	N30°51′46″	39.0	−72.9	2
5	E 120°19′48″	N30°44′33″	39.5	−68.4	10
6	E 120°32′3″	N30°41′35″	22.0	−65.2	11
7	E 120°43′46″	N30°32′50″	28.2	−66.6	14
8	E 120°43′18″	N30°36′47″	18.2	−50.2	31
9	E 120°56′34″	N30°48′22″	19.4	−61.8	14
10	E 120°56′3″	N30°52′43″	21.5	−70.2	4

Indoor field trial

The chosen indoor field trial measurement points are shown in Fig. 72. Table 22 shows the field strength test results of the indoor test point. The test antenna is Yagi antenna. The test position was close to the window and in the direction of the test tower in the test point. The direction of the antenna was adjusted to maximize the receiving field strength. In all test points, the receiver can work properly, the image is clear, smooth, and there is no mosaic.

FIGURE 72

Measurement points of indoor field trail

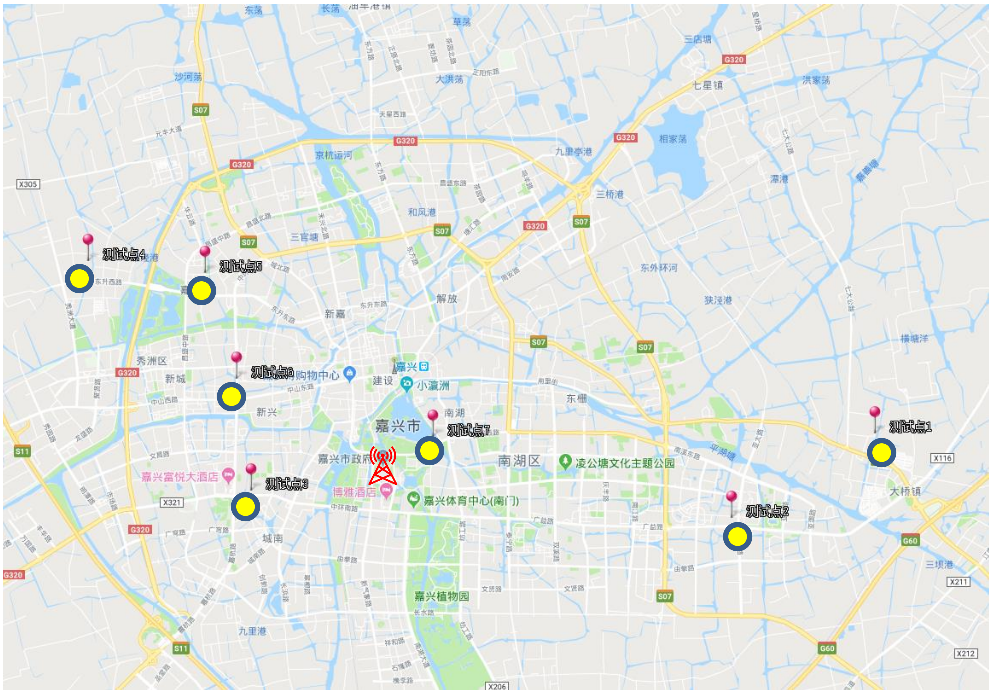


TABLE 22

Test result of indoor reception

	Longitude	Latitude	Distance (km)	Receiving signal power (dBm)	Margin (dB)
1	E 120°51′3″	N30°45′3″	10.8	−50.6	32
2	E 120°49′19″	N30°44′14″	8.7	−57.9	18
3	E 120°43′26″	N30°44′30″	4.2	−36	46
4	E 120°41′28″	N30°46′54″	5	−55.6	27
5	E 120°42′58″	N30°46′44″	2.5	−40.8	37
6	E 120°43′20″	N30°45′38″	2.6	−39	40
7	E 120°45′33″	N30°45′0″	3.5	−35.2	48

8.1.7 Conclusion

This trial showed the viability of 4K UHDTV over-the-air transmission using single 8 MHz channel utilizing DTMB-A system.

Among all the test points, the farthest distance from transmitter to the test points are as below: the north is 35 km; the west is about 39 km, the south is about 28 km, and the east is about 21 km. The seven indoor fixed receiving points are in good condition, the UHDTV signal can be received stable.

The technical results will be an important starting point for further studies of the 8K UHDTV service via terrestrial broadcasting system.

8.2 8K UHDTV trial in Shenzhen (2021)

UHD is considered as a very important service for digital terrestrial TV broadcasting and an important means for live broadcasting at the recently concluded 2020 Tokyo Summer Olympics and the upcoming 2022 Beijing Winter Olympics. China has been actively exploring UHD transmission over DTT network in recent years.

In February 2021, a live demonstration of 8K UHD terrestrial broadcasting in Shenzhen (Guangdong Province, China) was jointly conducted by National Engineering Laboratory for DTV(DTNEL), Tsinghua University, Guangdong UHD Video Innovation Center, and Shenzhen Longgang Institute of Intelligent Video Audio Technology. The demonstration used the second-generation digital terrestrial television system C DTMB-A of Recommendation ITU-R BT.1877. By adopting channel bonding technology, the demonstration system supports a maximum payload rate of 200 Mbit/s and realized the first 8K live broadcast demonstration based on DTT network in China. The trialled demonstration was conducted in Shenzhen Xinghe CoCo Park and displayed on its large outdoor UHD screen as shown in Fig. 73.

FIGURE 73

Shenzhen 8K UHD trial

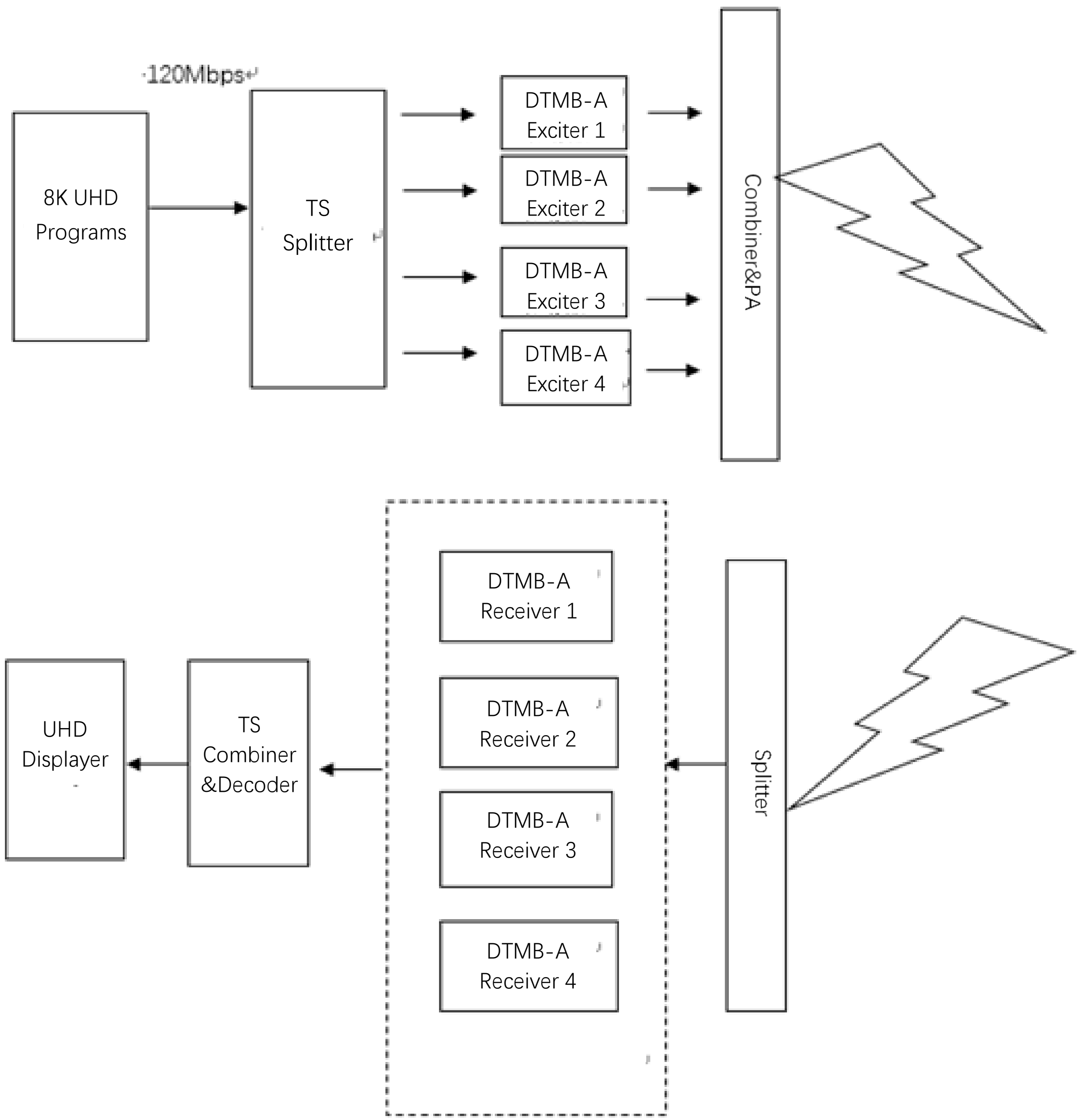
8.2.1 Diagram of the system

The system block diagram of this UHD demonstration is shown in Fig. 74.

The demonstration system receives the 8K IP signal encoded by CCTV, converts this 8K stream of 120 Mbit/s into four TS streams using special designed equipment and distributes them to four DTMB-A exciters, then transmits them to the 8K UHD wireless receiving system via wireless link after amplification by amplifier. After demodulated and decoded by the receiving system, the 8K UHD signal is displayed on the outdoor UHD screen to realizing the demonstration of UHDTV Service over DTT network.

FIGURE 74

System block diagram for the demonstration system



8.2.2 Transmission and reception equipment

Figure 75 shows the equipment used in this UHDTV Service over DTT network demonstration.

In Fig. 75, the TS stream splitter, power amplifier, and four exciters are shown from top to bottom. The 8K UHD signal transmitted from CCTV is divided into 4 parallel TS signals by time slicing in the stream splitter, and then sent to the corresponding exciter; each exciter modulates the input TS signal to RF. The RF output from the exciter is amplified by the power amplifier and sent to the antenna for transmitting.

FIGURE 75

Equipment of transmitter site

At the receiving side, the receiver outputs the demodulated TS stream of 120 Mbit/s to the outdoor UHD screen after decoding by 8K decoder.

FIGURE 76

8K decoder

8.2.3 System parameters

The system parameters for this UHD demonstration are shown in Table 23.

TABLE 23

Transmission parameters of the UHD demonstration over DTT network

Modulation method	TDS-OFDM
RF centre frequency	634 MHz, 642 MHz, 650 MHz and 658 MHz
Occupied bandwidth	7.56 * 4 MHz

TABLE 23 (*end*)

Carrier modulation	256 APSK
FFT size (number of radiated carriers)	32k
Guard interval ratio (guard interval duration)	1/128
Error-correcting code	Inner: LDPC, code rate = 2/3
Transmission capacity	200 Mbit/s
Video coding	AVS3 profile 10 level 10.0.60, 120 Mbit/s
Audio coding	5.1 surround sound, 448 Kbit/s
Transmitting station	Shenzhen Xinghe CoCo Park
Receiving station	Shenzhen Xinghe CoCo Park
UHDTV bit rate	120 Mbit/s

8.2.4 Live demonstration

The traditional Chinese Spring Festival Gala in 2021 was trialled broadcast live in 8K via CCTV's 8K UHDTV pilot channel, which was the first live broadcast of the Spring Festival Gala on an 8K UHDTV channel in China, bringing a stunning audio-visual experience to viewers. The CCTV 8K Spring Festival Gala program on New Year's Eve was clearly presented on the large outdoor UHD screen of Shenzhen Xinghe CoCo Park, attracting many Shenzhen citizens to watch, which are shown in Figs 77 to 79.

The wireless transmission system demonstrated in this trialled demonstration supports payload rate up to 200 Mbit/s transmission by adopting channel bounding technology, which can well support UHD services. The system is expected to support the transmission of multiple 4K or mixed 4K and 8K programmes in the future.

FIGURE 77

Ultra HD demo display screen site

FIGURE 78

View of Ultra HD demo site

FIGURE 79

Ultra HD demo site

9 Iran

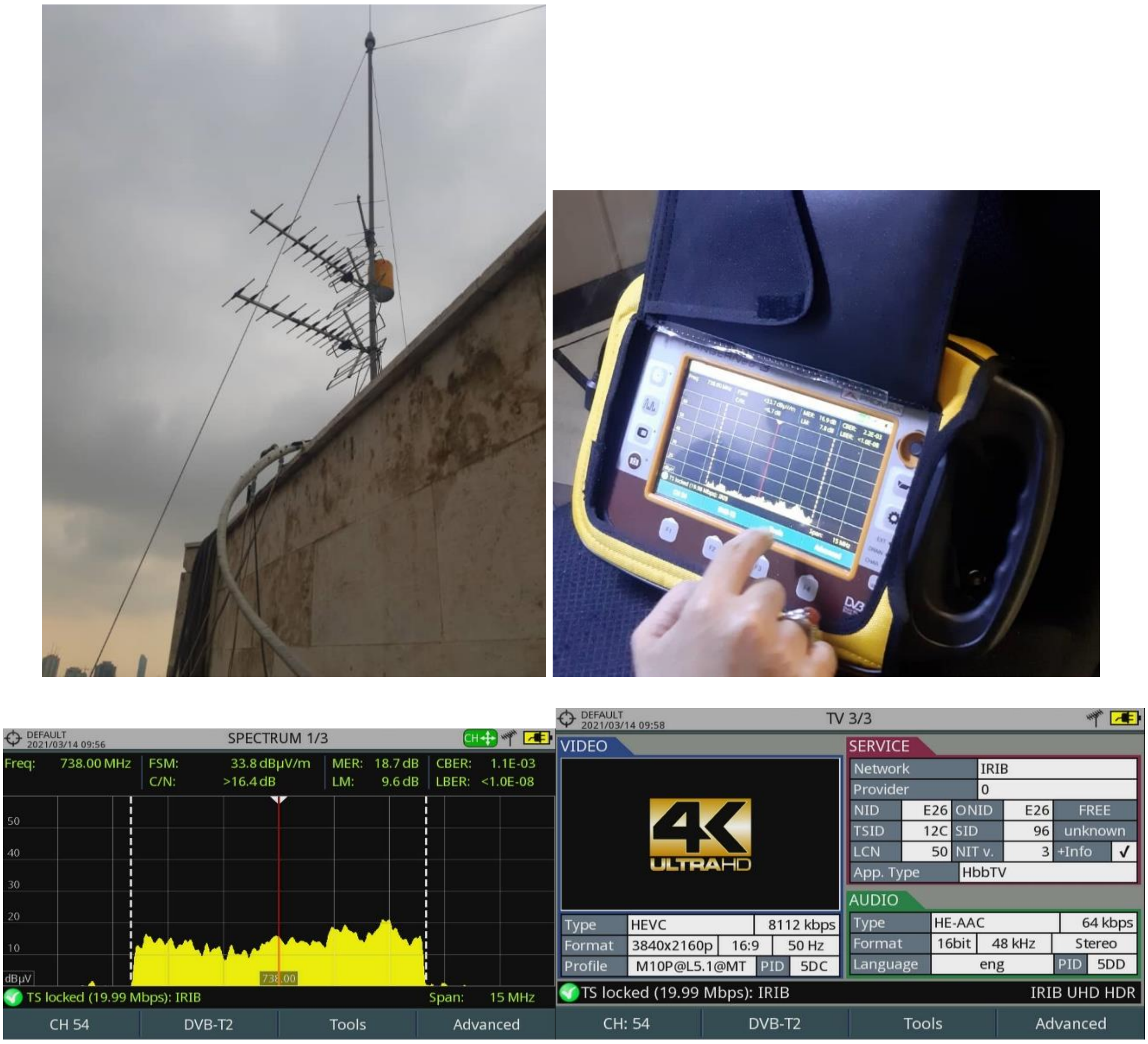
Taking steps towards the future progression for next generations of broadcast systems, which is an obligation for broadcasters, IRIB, the national public service broadcaster of Iran (Islamic Republic of), conducted a 4K (Ultra High Definition) TV broadcast deployment on July 2020 based on the DVB-T2 +HEVC technologies. 4K picture quality and HDR technology were put into implementation during this project. Detailed technical specifications are as follows.

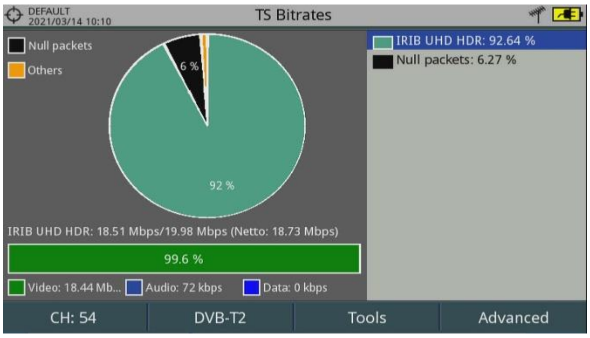
The only viable broadcasting platform in Iran is terrestrial. Seven digital multiplexes are planned in MFN mode using the broadcast UHF frequency band. 96% of population is covered by DTTB now and this portion is going to be increased to 99.9%. The 4K signal occupies one 8MHz frequency channel. Ultra High Definition (UHD) or 4K picture, along with the HDR-HLR 10 and wide colour gamut technologies was chosen. The program uses 6 channel surround sound. Picture frame is 50 fps and compression process used is HEVC Main 10 (10 bit depth). Another option tested during this trial is domestic technology of Hybrid broadband TV (HbbTV) which provides an interaction mechanism between the audience and the broadcaster.The first trial phase of the experiment took place in a TV broadcast station in Tehran and was expanded gradually to other state centres (four of which are mentioned in the table in § 3). The recorded 4K quality streams are HEVC encoded and compressed and then sent to the TV station via optical fiber/satellite links. Some views of trial receiving antenna, measurement and receive activities are shown in Fig. 80.

Recognizing HDR and WCG as new technologies, conversion from BT.709 standard to BT.2020 sounded like a challenge, but undertaking necessary studies smoothed the path. Now, the IRIB 4K channel is available in 31 state centres for 4K TV sets and receivers via terrestrial broadcast and also via BADR-5 satellite broadcast. The content of this channel is primarily concentrated in introducing the beauties of the Iran country.

FIGURE 80

Reception antennas and measurements for 4K UHD signal





The most important measures taken to accomplish this job, from the very first stage to the end, include: upgrading audio/visual production chain, establishing QC cycle and HDR content standardization part, establishing the distribution to transmitting sites, and setting up the necessary equipment for the chain and initiating the HbbTV service and related channel website.

The HEVC/H.265 video encoding at a frame rate of 50 fps is used to achieve the desired picture quality. Technical characteristics of the signal are provided in Table 24. The signal bitrate reaches to 20 Mbit/s. The transmission technology used is DVB-T2 to guarantee the needed capacity. Technical parameters of DVB-T2 mode and transmission system are provided in Table 25.

TABLE 24

Technical characteristics of 4K UHDTV experiment in Iran

Video	4K resolution, 50 fps, HDR10 ,HLG 10, WCG
Video coding	HEVC/H.265
Audio	5.1
Audio coding	HE- AAC
Bitrate total	~ 20 Mbit/s

TABLE 25

Transmission system and T2 parameters of 4K UHDTV in Tehran/Iran

Network topology	MFN (DTTB)
Modulation method	OFDM
Channel bandwidth / Occupied bandwidth	8 / 7.77 MHz
Transmission frequency	738 MHz (UHF Ch 54)
Transmission power	3 000 W
Transmission mode	SISO
Carrier modulation	256-QAM
C/*N* (for Rician channel)	18 dB
FFT size (number of radiated carriers)	32k (27 841)
Guard interval ratio (guard interval duration)	1/32 (28 µs)
Pilot pattern	PP6
# OFDM symbols	60

TABLE 25 (*end*)

Error-correcting code	Inner: LDPC, code rate = 3/5 Outer: BCH
Data rate	~ 35 Mbit/s
Video coding	HEVC (2160p[(1)], 10 bit, 50 fps, HLG10, WCG)
Transmitting station	Jamaran
Height of transmitting antenna	90 m
Height of receiving antenna	10 m
Minimum median field strength	54 dBμV/m at 10 m

[(1)] 3 840×2 160 (4K).

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