ITUPublications

International Telecommunication Union
Radiocommunication Sector

Report ITU-R BT.2343-11

(03/2026)

BT Series: Broadcasting service (television)

Collection of field trials of ultra high definition television over digital terrestrial television broadcasting networks

Foreword

The role of the Radiocommunication Sector is to ensure the rational, equitable, efficient and economical use of the radio-frequency spectrum by all radiocommunication services, including satellite services, and carry out studies without limit of frequency range on the basis of which Recommendations are adopted.

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

Policy on Intellectual Property Right (IPR)

ITU-R policy on IPR is described in the Common Patent Policy for ITU-T/ITU-R/ISO/IEC referenced in Resolution ITU-R 1. Forms to be used for the submission of patent statements and licensing declarations by patent holders are available from https://www.itu.int/ITU-R/go/patents/en where the Guidelines for Implementation of the Common Patent Policy for ITU-T/ITU-R/ISO/IEC and the ITU-R patent information database can also be found.

Series of ITU-R Reports

(Also available online at https://www.itu.int/publ/R-REP/en)

Series	Title
BO	Satellite delivery
BR	Recording for production, archival and play-out; film for television
BS	Broadcasting service (sound)
BT	**Broadcasting service (television)**
F	Fixed service
M	Mobile, radiodetermination, amateur and related satellite services
P	Radio-wave propagation
RA	Radio astronomy
RS	Remote sensing systems
S	Fixed-satellite service
SA	Space applications and meteorology
SF	Frequency sharing and coordination between fixed-satellite and fixed service systems
SM	Spectrum management
TF	Time signals and frequency standards emissions

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

Electronic Publication
Geneva, 2026

© ITU 2026

All rights reserved. No part of this publication may be reproduced, by any means whatsoever, without written permission of ITU.

REPORT ITU-R BT.2343-11

Collection of field trials of ultra high definition television over digital terrestrial television broadcasting networks

(2015-02/2016-10/2016-2018-04/2019-09/2019-2020-2021-2023-2024-2025-2026)

TABLE OF CONTENTS

Page

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 more efficient technologies. Moreover, some countries have already carried out UHDTV field experiments on digital terrestrial television broadcasting (DTTB) to demonstrate the feasibility of these systems, and some are already regularly operating UHDTV services over DTTB networks. 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 European Broadcasting Union (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, which only reflects the views and information of the contributing country(ies).

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 within ITU-R

The standardization of Ultra High Definition television and related technologies is constantly evolving at ITU-R, and several Recommendations and Reports have been published, for example:

- Recommendation ITU-R BS.2051 – Advanced sound system for programme production.
- Recommendation ITU-R BT.1122 – User requirements for codecs for emission and secondary distribution systems for SDTV, HDTV, UHDTV and HDR-TV.
- Recommendation ITU-R BT.1877 – Error-correction, data framing, modulation and emission methods and selection guidance for second generation digital terrestrial television broadcasting systems.
- Recommendation ITU-R BT.2020 – Parameter values for ultra-high definition television systems for production and international programme exchange.
- Recommendation ITU-R BT.2075 – Integrated broadcast-broadband system.
- Recommendation ITU-R BT.2100 – Image parameter values for high dynamic range television for use in production and international programme exchange.
- Recommendation ITU-R BT.2133 – Transport of advanced immersive audio-visual content in IP-based broadcasting systems.
- Recommendation ITU-R BT.2144 – Guidance for the introduction of new DTTB systems, technologies and applications in the broadcasting service.
- Report ITU-R BS.2493 – Practical implementation of broadcast systems using audio codecs for ITU advanced sound systems.
- Report ITU-R BT.2246 – The present state of ultra-high definition television.
- Report ITU-R BT.2267 – Integrated broadcast-broadband systems.

- Report ITU-R BT.2400 – Usage scenarios, requirements, and technical elements of a global platform for the broadcasting service.
- Report ITU-R BT.2420 – Collection of usage scenarios of advanced immersive sensory media systems (AISM).
- Report ITU-R BT.2485 – Advanced network planning and transmission methods for enhancements of digital terrestrial television broadcasting.
- Report ITU-R BT.2522 – A framework for the future of broadcasting.

3 Field trials of UHDTV over DTTB 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.	DTTB system	Channel bandwidth	Transmission mode	Multiplex capacity	Signal bit rate	Video encoding standard	Picture standard	Audio encoding standard	Frequency used
1.1	**Japan**	Hitoyoshi	City of Hitoyoshi	140 W(H) 135 W(V)	ISDB-T[1]	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)
		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		
		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)
1.2		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] 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.	DTTB system	Channel bandwidth	Transmission mode	Multiplex capacity	Signal bit rate	Video encoding standard	Picture standard	Audio encoding standard	Frequency used
1.3.1	Japan	Shiba	Central Tokyo	2.1 kW	ISDB-T[2] (Advanced DTTB system)	6 MHz	16k-FFT *GI* = 800/16384 1024 NUC LDPC code 9/16	21.5 Mbit/s	9.0 Mbit/s × 2	VVC Main 10 Level 5.1	3 840 × 2 160 p 59.94 frame/s 10 bits/pixel	MPEG-H 3D A Baseline profile 22.2ch 512 kbit/s + 4 objects 48 kbit/s × 4	563 MHz (Ch 28 in Japan)
		Higashiyama	City of Nagoya	980 W									605 MHz (Ch 35 in Japan)
		Osaka	City of Osaka	4.6 kW									509 MHz (Ch 19 in Japan)
		Fukuoka	City of Fukuoka	1.5 kW									701 MHz (Ch 51 in Japan)
		Shiba	Central Tokyo	2.1 kW	ISDB-T[3] (Compatible DTTB system using LDM)		8k-FFT *GI* = 1/8 – During transition[3] QPSK LDPC code 4/16 (new service) 64-QAM Convolutional code code rate 2/3 (existing service) Injection level 21 dB – After transition 256-QAM NUC LDPC code 11/16	– During transition[4] 2.17 Mbit/s (new service) 14.9 Mbit/s (existing service) – After transition 24.1 Mbit/s	– During transition[4] 1.6 Mbit/s (new service) 12.5 Mbit/s (existing service) – After transition 16.5 Mbit/s	HEVC	– During transition[4] 1 920×1 080 p 59.94 frame/s (new service) 1 440×1 080i 59.94 frame/s and 320 × 240 (existing service) – After transition 3 840 × 2 160 p 59.94 frame/s	MPEG2-AAC 201 kbit/s	563 MHz (Ch 28 in Japan)
		Higashiyama	City of Nagoya	980 W									605 MHz (Ch 35 in Japan)
		Osaka	City of Osaka	4.6 kW									509 MHz (Ch 19 in Japan)
		Fukuoka	City of Fukuoka	1.5 kW									701 MHz (Ch 51 in Japan)

---

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

[3] During the transition, the existing DTTB service will be simultaneously provided within the same RF channel.

Summary of UHDTV trials on terrestrial television networks

Annex section	Country	Transmitter site	Covering	e.r.p.	DTTB system	Channel bandwidth	Transmission mode	Multiplex capacity	Signal bit rate	Video encoding standard	Picture standard	Audio encoding standard	Frequency used
1.3.2		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)	ISDB-T[3]		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)
2.1	**Korea (Republic of)[4]**	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)

---

[4] 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.	DTTB system	Channel bandwidth	Transmission mode	Multiplex capacity	Signal bit rate	Video encoding standard	Picture standard	Audio encoding standard	Frequency used
2.2	Korea (Republic of)	Kwan-Ak Mountain	South Metropolitan area of Seoul	39.6 kW	ATSC 3.0		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									
2.3		Jeju TechnoPark	South area of Jeju city of Jeju province	1 kW			16k, GI7_2048, SP3_4, QPSK, 2/15 ~ 4096-QAM, 13/15	Variable	Variable	HEVC Main10 Level 5.1, Variable	1 280 × 720 p 60 frames/s 8 bits/pixel or 3 840 × 2 160 p 60 frames/s, 10 bits/pixel	MPEG-H 3D Audio	689 MHz (Ch 50 in Korea)
2.4		Jeju TechnoPark	South area of Jeju city of Jeju province	520 W	ATSC 3.0	6 MHz	16k, GI5_1024, SP6_2, LDM (16k): QPSK, 4/15 + 64-QAM, 10/15 TDM (8k+32k): QPSK, 11/15 + 256-QAM, 12/15	< 30.0 Mbit/s	Variable	HEVC Main10 Level 5.1, Variable	1 280 × 720 p 60 frames/s 8 bits/pixel and 3 840 × 2 160 p 60 frames/s, 10 bits/pixel	MPEG-H 3D Audio	689 MHz (Ch 50 in Korea)

Summary of UHDTV trials on terrestrial television networks

Annex section	Country	Transmitter site	Covering	e.r.p.	DTTB system	Channel bandwidth	Transmission mode	Multiplex capacity	Signal bit rate	Video encoding standard	Picture standard	Audio encoding standard	Frequency used
2.5	**Korea (Republic of)**	Jeju TechnoPark	South area of Jeju city of Jeju province	2.7 kW			16k, GI5_1024, SP6_2, LDM (16k): QPSK, 4/15 + 64-QAM, 10/15 TDM (8k+32k): QPSK, 11/15 + 256-QAM, 12/15	< 30.0 Mbit/s	Variable	HEVC Main10 Level 5.1, Variable	1 280 × 720 p 60 frames/s 8 bits/pixel and 3 840 × 2 160 p 60 frames/s, 10 bits/pixel	MPEG-H 3D Audio	689 MHz (Ch 50 in Korea)
		Venture Maru	Central area of Jeju city of Jeju province	2.2 kW			16k, GI5_1024, SP6_2, LDM (16k): QPSK, 4/15 + 64-QAM, 10/15 TDM (8k+32k): QPSK, 11/15 + 256-QAM, 12/15	< 30.0 Mbit/s	Variable	HEVC Main10 Level 5.1, Variable	1 280 × 720 p 60 frames/s 8 bits/pixel and 3 840 × 2 160 p 60 frames/s, 10 bits/pixel	MPEG-H 3D Audio	689 MHz (Ch 50 in Korea)
2.6		Gam-Ak Mountain	North area of Gyeonggi province	890 W(H) 890 W(V)			32k, GI2_384, MP32_2, 256-QAM, 11/15, 1024-QAM, 13/15, 4096-QAM, 12/15, 13/15 Dual-polarized MIMO	< 113 Mbit/s	Variable (Max. 113 Mbit/s)	HEVC Main10 Level 5.1, Variable	7 680× 4 320 p 60 frames/s, 10 bits/pixel	MPEG-H 3D Audio	768 MHz (Ch 56 in Korea)

Summary of UHDTV trials on terrestrial television networks

Annex section	Country	Transmitter site	Covering	e.r.p.	DTTB system	Channel bandwidth	Transmission mode	Multiplex capacity	Signal bit rate	Video encoding standard	Picture standard	Audio encoding standard	Frequency used
2.7	**Korea (Republic of)**	Gam-Ak Mountain	North area of Gyeonggi province	260 W(H) 890 W(V)			16k, GI5_1024, MP6_2, LDM (16k): QPSK, 4/15 + 64-QAM, 10/15 LDM Core-layer: SISO LDM Enhance-layer: MIMO Dual-polarized MIMO	< 113 Mbit/s	Variable (Max. 113 Mbit/s)	HEVC Main10 Level 5.1, Variable	1 280 × 720 p 60 frames/s 8 bits/pixel and 3 840 × 2 160 p 60 frames/s, 10 bits/pixel	MPEG-H 3D Audio	768 MHz (Ch 56 in Korea)
2.8		Gam-Ak Mountain	South Metropolitan area of Seoul	39.6 kW	ATSC 3.0	6 MHz	8k, GI16_1536, SP4_2, TDM (8k+32k): 64-QAM, 5/15 + 256-QAM, 8/15	< 30.0 Mbit/s	Variable	HEVC Main10 Level 5.1, Variable	1 280 × 720 p 60 frames/s 8 bits/pixel and 3 840 × 2 160 p 60 frames/s, 10 bits/pixel	MPEG-H 3D Audio	768 MHz (Ch 56 in Korea)
		Nam Mountain	Central area of Seoul	18.9 kW									
		Gwang-Gyo Mountain	Suwon (Capital city of Gyeonggi province)	7.96 kW									
2.9		Gam-Ak Mountain	North area of Gyeonggi province	890 W (701 MHz) 890 W (768 MHz)	ATSC 3.0 ATSC 3.0	6 MHz 6 MHz	32k, GI4_768, MP16_2, 4096 NUC, 12/15 Channel bonding	< 102.9 Mbit/s	Variable	HEVC Main10 Level 5.1, Variable	3 840 × 2 160 p 60 frames/s, 10 bits/pixel	MPEG-H 3D Audio	701 MHz (Ch 52 in Korea) 768 MHz (Ch 56 in Korea)

Summary of UHDTV trials on terrestrial television networks

Annex section	Country	Transmitter site	Covering	e.r.p.	DTTB system	Channel bandwidth	Transmission mode	Multiplex capacity	Signal bit rate	Video encoding standard	Picture standard	Audio encoding standard	Frequency used
2.10	**Korea (Republic of)**	Gam-Ak Mountain	North area of Gyeonggi province	890 W (H) 890 W (V) (768 MHz)			32k, GI4_768, MP16_2, 16 NUC, 7/15 256 NUC, 9/15 Layered MIMO Type A	< 70.3 Mbit/s	Variable	HEVC Main10 Level 5.1, Variable	3 840 × 2 160 p 60 frames/s, 10 bits/pixel and 1920 × 1080 p 60 frames/s, 10 bits/pixel and 1280 × 720 p 60 frames/s, 10 bits/pixel	MPEG-H Audio	768 MHz (Ch 56 in Korea)
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 × 2 160 p 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			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 × 2 160 p 50 frames/s 8 or 10 bits/pixel and 1 920 × 1 080 p 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 × 2 160 p 50 frames/s 10 bits/pixel 1 920 × 1 080 p 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.	DTTB 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		ETSI Tele-comunicación	Ciudad Universitaria, Madrid	125 W			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		Torrespaña and San Fernando	Madrid	15 kW Torrespaña 75 W San Fernando			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		ETSI Tele-comunicación	Ciudad Universitaria, Madrid	125 W			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.	DTTB 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		51 transmitters	50% of Spanish population	Up to 15 kW			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)

Summary of UHDTV trials on terrestrial television networks

Annex section	Country	Transmitter site	Covering	e.r.p.	DTTB system	Channel bandwidth	Transmission mode	Multiplex capacity	Signal bit rate	Video encoding standard	Picture standard	Audio encoding standard	Frequency used
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)
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 × 2 160 p 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									602 MHz (Ch 37 in Region 1)
		Black Hill	Central Scotland, including Glasgow and Edinburgh (serving 1 million households)	39 kW									586 MHz (Ch 35 in Region 1)
7.1	**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)

Summary of UHDTV trials on terrestrial television networks

Annex section	Country	Transmitter site	Covering	e.r.p.	DTTB system	Channel bandwidth	Transmission mode	Multiplex capacity	Signal bit rate	Video encoding standard	Picture standard	Audio encoding standard	Frequency used
7.2	**Brazil**	Penna Hill	Parts of Rio de Janeiro metropolitan area	500 W(H) 500 W(V)	ATSC 3.0	6 MHz	16k GI4_768 dual-polarized MIMO MP8_2 null pilot encoding 98 OFDM symbols/subframe CTI 1024 LDM CL (PLP0): 16-QAM NUC, FEC 8/15 LDM EL (PLP1): QPSK, FEC 8/15 LDM Injection Level: 9 dB	LDM CL (PLP0): 21.5 Mbit/s LDM EL (PLP1): 10.7 Mbit/s	LDM CL (PLP0): 14.5 Mbit/s LDM EL (PLP1): 7.5 Mbit/s	VVC Main Tier Main 10 Profile LDM CL (PLP0): Level 5.1 LDM EL (PLP1): Level 4.1	LDM CL (PLP0): 3 840 × 2 160 p 59.94 frames/s 10 bits/pixel HDR10 WCG LDM EL (PLP1): 1 920 × 1 080 p 59.94 frames/s 10 bits/pixel HDR10 WCG	MPEG-H 3D Audio BL level 3 5.1.4ch + 3 objects (540 kb/s)	569 MHz (Ch 30 in Brazil)
7.3		Sumaré Hill	Parts of the Rio de Janeiro metropolitan area	15.7 kW (H) 15.7 kW (V)	ATSC 3.0	6 MHz	16k GI4_768 dual-polarized MIMO MP8_2 null pilot encoding 98 OFDM symbols/frame CTI 1024 LDM CL (PLP0): 16-QAM NUC, LDPC 7/15 LDM EL (PLP1): QPSK, LDPC 8/15 LDM Injection Level: 9 dB	LDM CL (PLP0): 18.83 Mbit/s LDM EL (PLP1): 10.77 Mbit/s	LDM CL (PLP0): 10.5 Mbit/s LDM EL (PLP1): 6.5 Mbit/s	LDM CL (PLP0): LCEVC plus VVC Main Profile Level 3 LDM EL (PLP1): VVC Main Tier Main 10 Profile Level 4.1	LDM CL (PLP0): 3 840 x 2160 p 59.94 frames/s 10 bits/pixel HDR10 WCG LDM EL (PLP1): 1 920 x 1080 p 59.94 frames/s 10 bits/pixel HDR10 WCG	MPEG-H 3D Audio BL Level 3 5.1.4ch + 5 objects (540 kbit/s)	273 MHz (A new spectrum band in Brazil)

Summary of UHDTV trials on terrestrial television networks

Annex section	Country	Transmitter site	Covering	e.r.p.	DTTB system	Channel bandwidth	Transmission mode	Multiplex capacity	Signal bit rate	Video encoding standard	Picture standard	Audio encoding standard	Frequency used
7.3	**Brazil**	Penna Hill	Parts of the Rio de Janeiro metropolitan area	5.8 kW (H) 5.8 kW (V)	ATSC 3.0	6 MHz	16k GI4_768 dual-polarized MIMO MP8_2 null pilot encoding 98 OFDM symbols/frame CTI 1024 LDM CL (PLP0): 16-QAM NUC, LDPC 7/15 LDM EL (PLP1): QPSK, LDPC 8/15 LDM Injection Level: 9 dB	LDM CL (PLP0): 18.83 Mbit/s LDM EL (PLP1): 10.77 Mbit/s	LDM CL (PLP0): 10.5 Mbit/s LDM EL (PLP1): 6.5 Mbit/s	LDM CL (PLP0): LCEVC plus VVC Main Profile Level 3 LDM EL (PLP1): VVC Main Tier Main 10 Profile Level 4.1	LDM CL (PLP0): 3 840 × 2160 p 59.94 frames/s 10 bits/pixel HDR10 WCG LDM EL (PLP1): 1 920 × 1080 p 59.94 frames/s 10 bits/pixel HDR10 WCG	MPEG-H 3D Audio BL Level 3 5.1.4ch + 5 objects (540 kbit/s)	273 MHz (A new spectrum band in Brazil)
8.1	**China**	Jiaxing Radio and Television Building	Jiaxing City urban and countryside	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			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, 658 MHz
8.3		Beijing	Beijing Institute of Information Technology	10 W			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, 658 MHz
8.4		Beijing	Shunyi	1KW	DTMB	8 MHz	64QAM, PN420, FEC/0.8	28 Mbit/s	32.486 Mbit/s	H.265	3 840 × 2 160 p 50 frame/s	MPEG-4 AAC 384 kbit/s	490 MHz

Summary of UHDTV trials on terrestrial television networks

Annex section	Country	Transmitter site	Covering	e.r.p.	DTTB 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 has been conducting research and development on an advanced DTTB system. The objective of the advancement is to provide improved transmission performance compared with ISDB-T in terms of increased transmission capacity and reduced C/N required. The advanced system has been designed to provide UHDTV services for fixed reception together with HDTV services for mobile reception simultaneously. R&D projects on the advanced DTTB system have been conducted in three phases.

- Phase 1: R&D project on basic technologies for a next-generation DTTB system (2013-2016)
- Phase 2: R&D project on an advanced DTTB system (2016-2018)
- Phase 3: Technical verification of the advanced DTTB system (2019-2022)

1.1.1 R&D project on basic technologies for a next-generation DTTB system (2013-2016)

In order to provide 8K video services, new transmission technologies that expand transmission capacity, such as ultra-multilevel modulation (e.g. 4096-QAM), low density parity check (LDPC) code, and dual-polarized multiple-input multiple-output (MIMO), were researched in the first R&D project during 2013 to 2016.

An experimental station for 8K-UHDTV transmissions was set up in Hitoyoshi city, Kumamoto prefecture, using dual-polarized MIMO and ultra-multilevel OFDM technologies. The field experiment performed in January 2014 was the world’s first 8K-UHDTV terrestrial transmission (91 Mbit/s) over a long distance (27 km) using a single UHF channel (6 MHz).

Another experimental station for 2 × 2 MIMO Space Time Coding – single frequency network (STC-SFN) was installed in the same city in 2015. A field experiment showed significant improvements over conventional SFN. In 2016, an 8K-UHDTV field experiment with high efficiency video coding (HEVC) was conducted using the two experimental stations, in which 8K video and audio was stably received in the STC-SFN.

Another experimental station was installed in Kinuta, Setagaya-ku, Tokyo and an 8K-UHDTV field test with a non-uniform constellation (NUC) was conducted by NHK science and technologies research laboratories (STRL). The experimental results showed that NUC improved the transmission performance.

1.1.2 R&D project on advanced DTTB system (2016-2018)

The second R&D project was launched in 2016 and was aimed at developing an advanced DTTB system, advanced technologies for mobile services, and large-scale transmission technologies. Performance evaluations in the form of field trials in large-scale experimental environments were carried out in urban areas. This project continued under the auspices of the Ministry of Internal Affairs and Communications until 2018. At the end of this project, an advanced DTTB system for a next-generation ISDB-T system was developed and its performance was verified in field trials using prototype modulators and demodulators. The trials carried out during this R&D project are detailed in § 1.2.

1.1.3 Technical verification of advanced DTTB system (2019-2022)

Trials were conducted to verify the transmission performance and feasibility of the system. Additional features were also demonstrated. The trials conducted during the technical verification are detailed in § 1.3.

1.2 Trials on R&D phase of advanced DTTB system (2016-2018)

1.2.1 Overview of tentative advanced DTTB system on R&D phase

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 ultra-multilevel carrier modulation (support 256-QAM, 1024-QAM, 4096-QAM) with NUC, LDPC code and 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.

1.2.2 Transmission parameters

Field experiments were conducted with the parameters listed in Table 1. 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, LDPC code and NUCs were used for both UHDTV and HDTV services to enhance transmission robustness.

TABLE 1

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

TABLE 1 (*end*)

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)	800/16 384 (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	3 840 × 2 160/60/P (4K) 7 680 × 4 320/60/P (8K)	1 920 × 1 080/60/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)

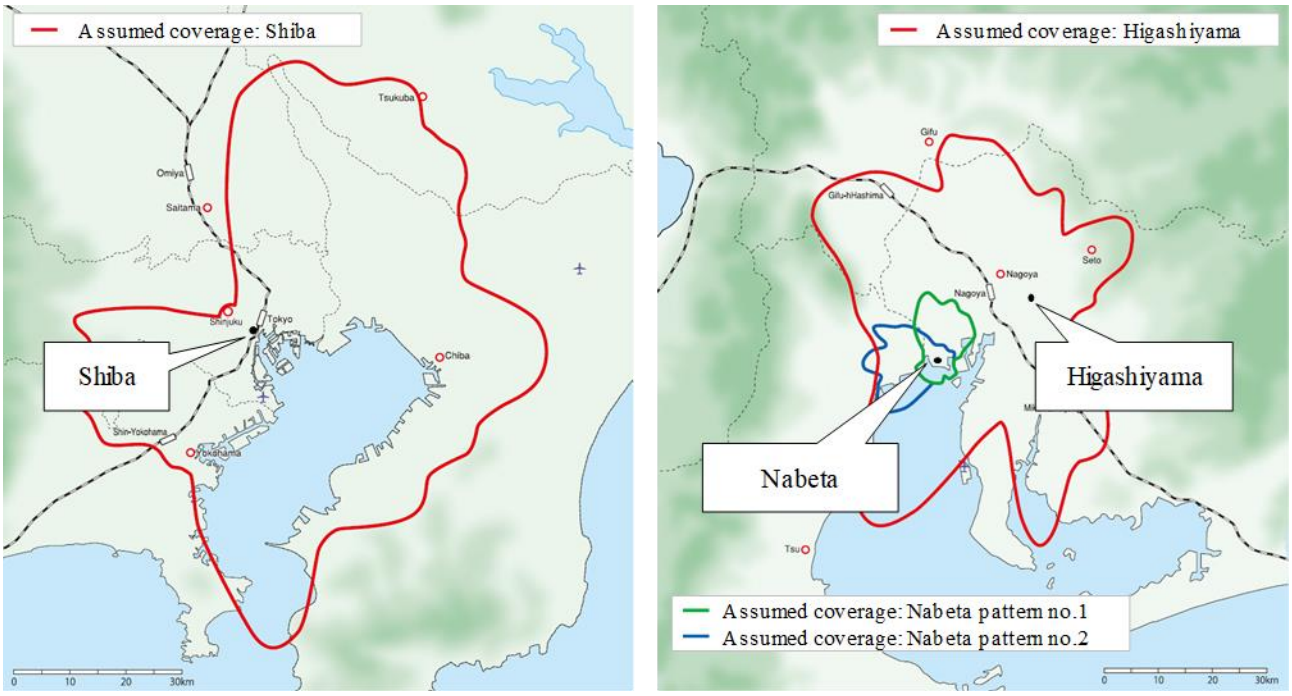
* Pre-processed before encoding by MPEG-H HEVC with a state-of-the-art software encoder offline taking plenty of time.

1.2.3 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 1 shows the transmitter sites and assumed coverage areas for the experimental parameters in Table 1. Table 2 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 1

Experimental environments



a) Tokyo area

b) Nagoya area

TABLE 2

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 1 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 Fig. 2. 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 3 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 4 shows the spectrum of the received signals. Figures 5 and 6 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. 5. In this experiment, it was demonstrated that UHDTV and HDTV contents can be successfully received with the advanced DTTB system.

FIGURE 2

Block diagram of transmitting and receiving system in Tokyo

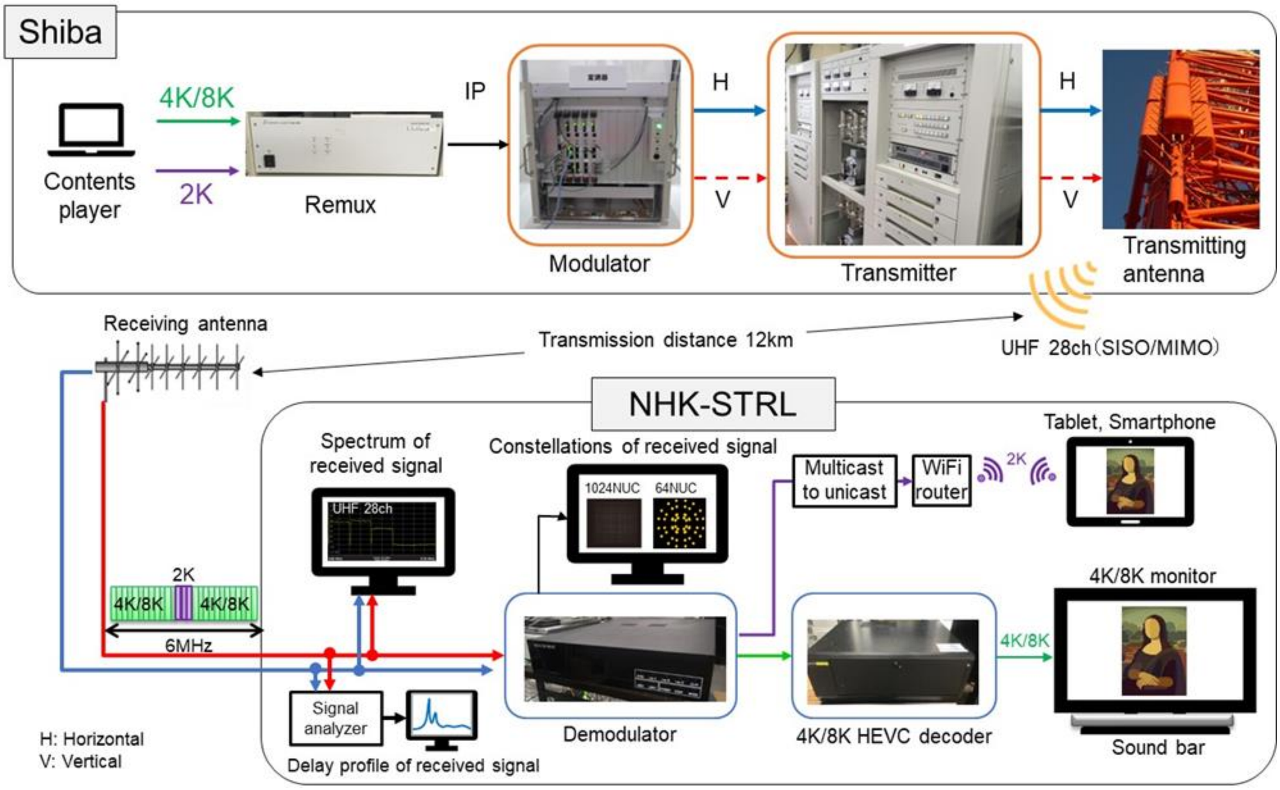


FIGURE 3

Locations of transmitting and receiving points in Tokyo

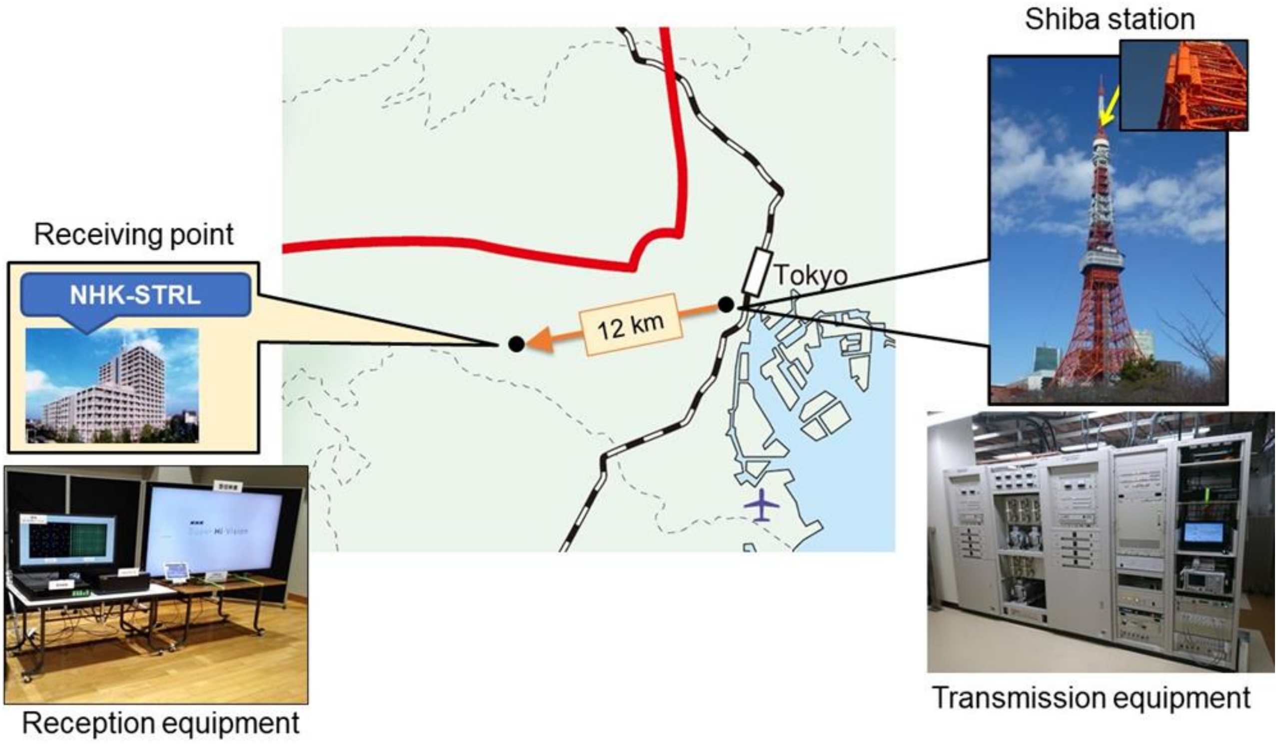
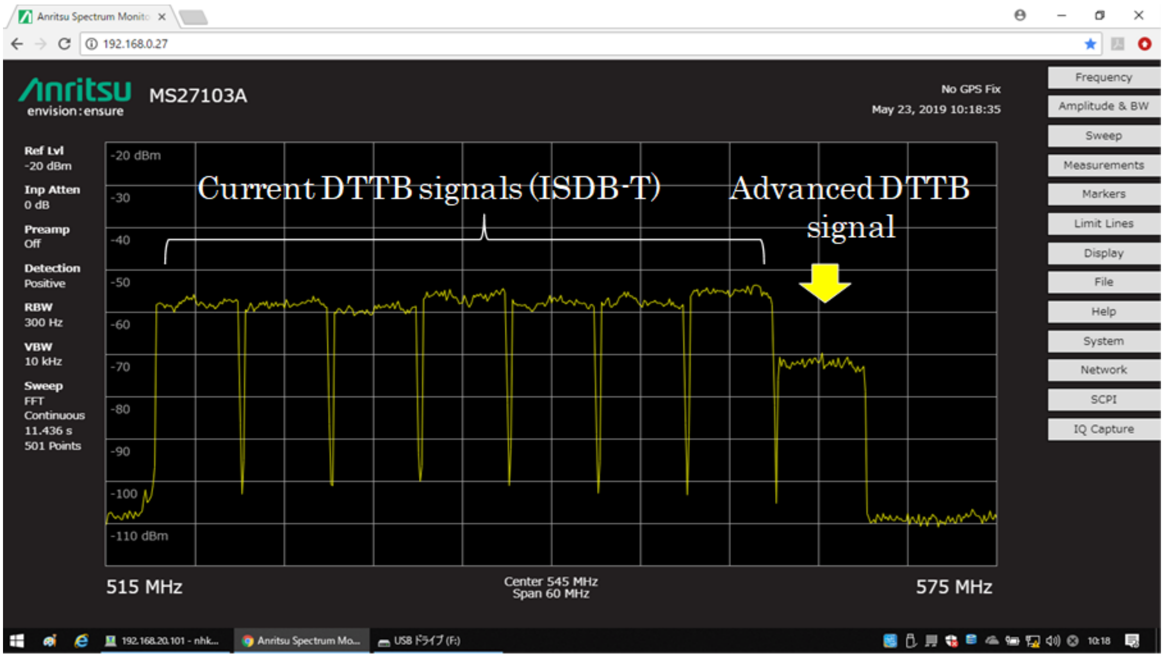


FIGURE 4

Spectrum of received signal at NHK-STRL (SISO)



Ref Lvl -20 dBm
Inp Atten 0 dB
Preamp Off
Detection Positive
RBW 300 Hz
VBW 10 kHz
Sweep FFT Continuous 11.436 s 501 Points
Center 545 MHz
Span 60 MHz

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 5

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

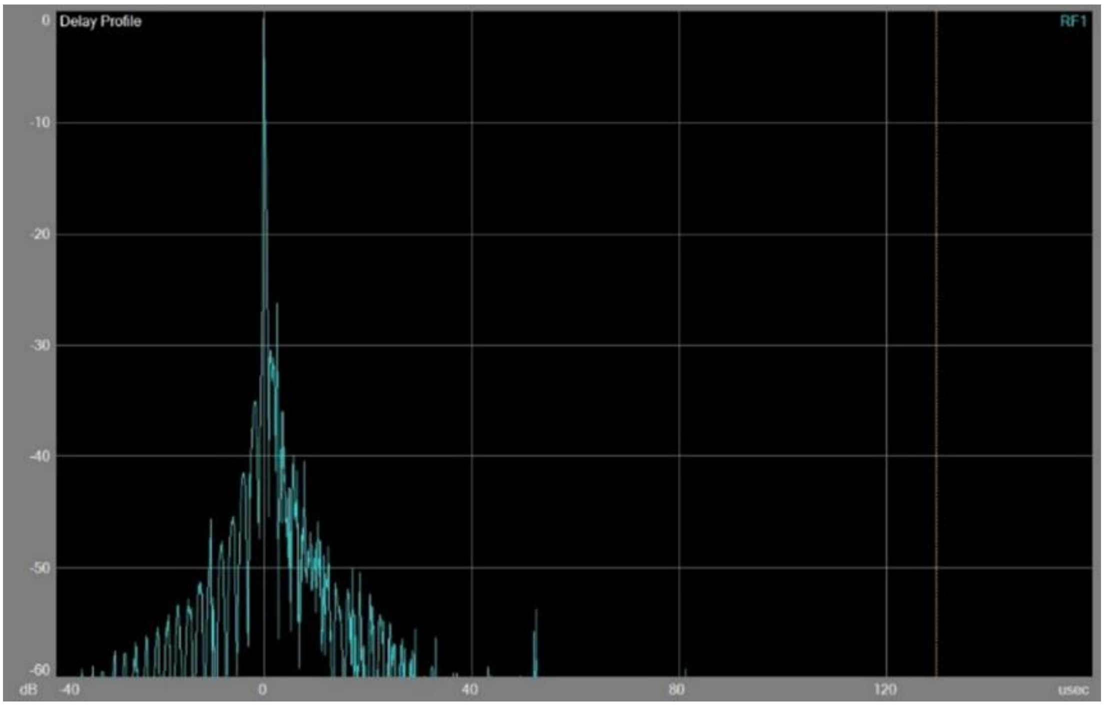
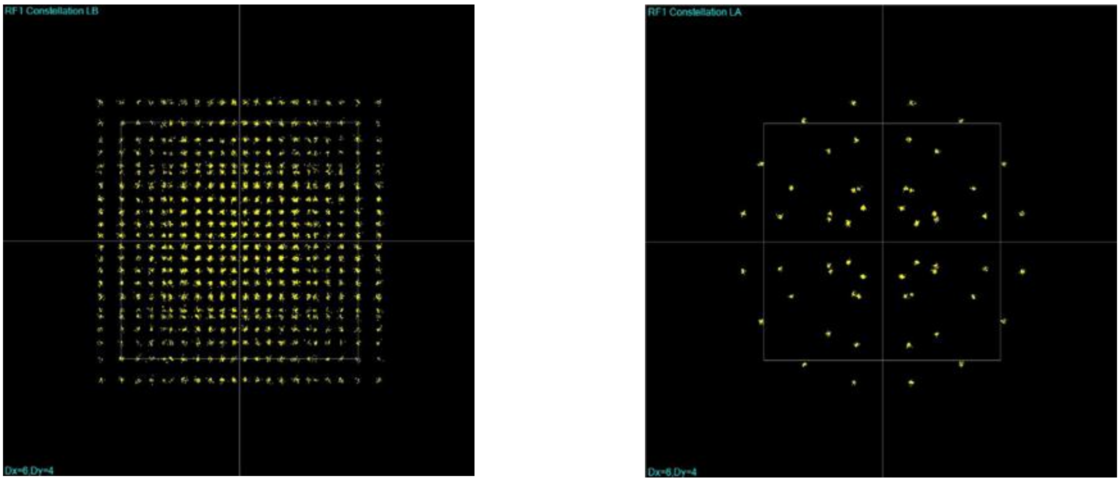


FIGURE 6

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. 7. Figure 8 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 9, 10 and 11 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 7

Block diagram of transmitting and receiving system in Nagoya

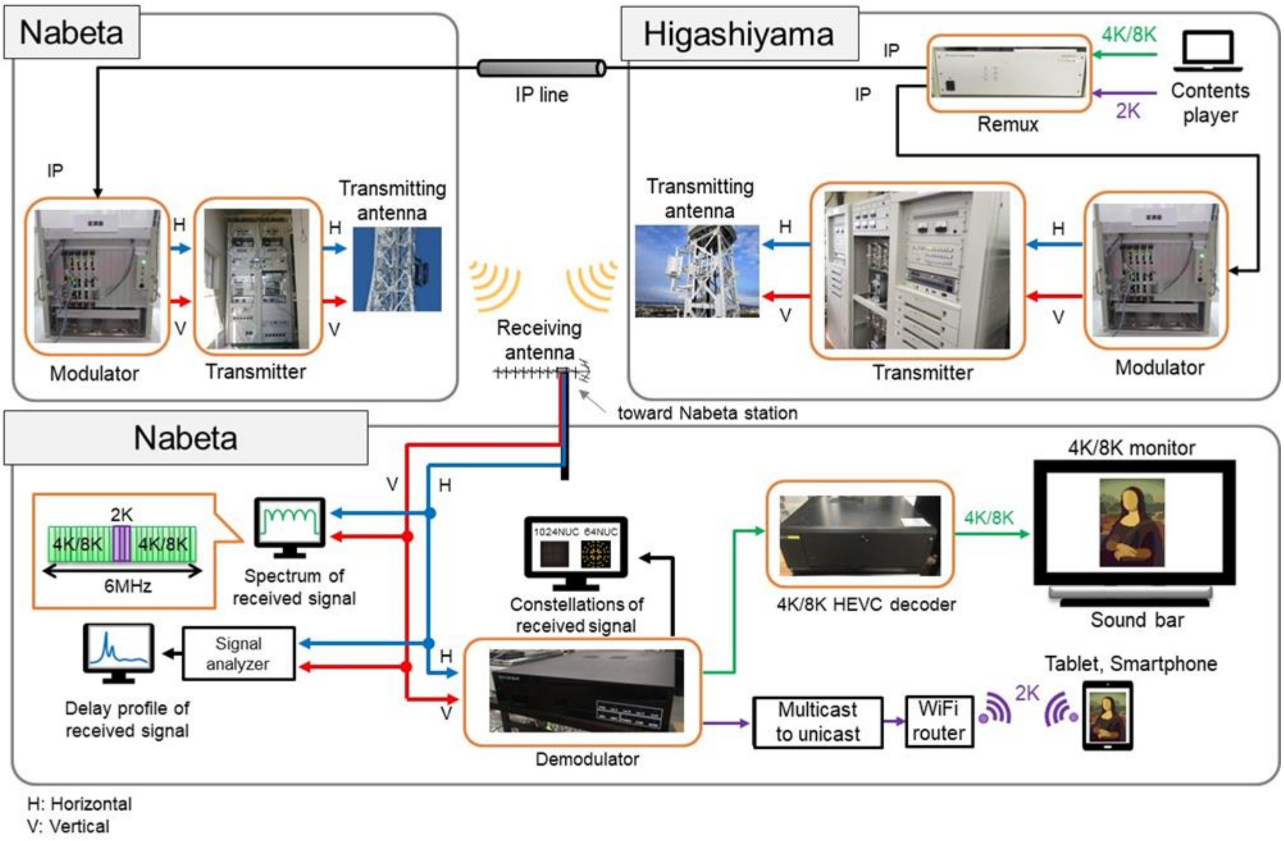


FIGURE 8

Locations of transmitting and receiving points in Nagoya

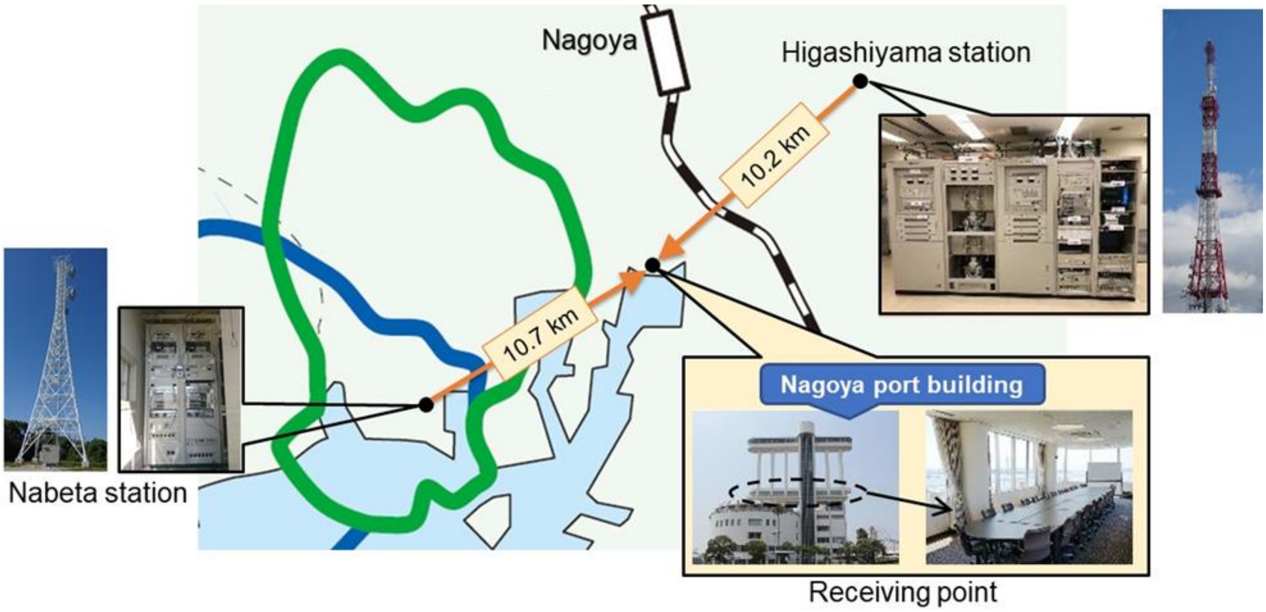


FIGURE 9

Spectrum of received signals at Nagoya port building (MIMO)

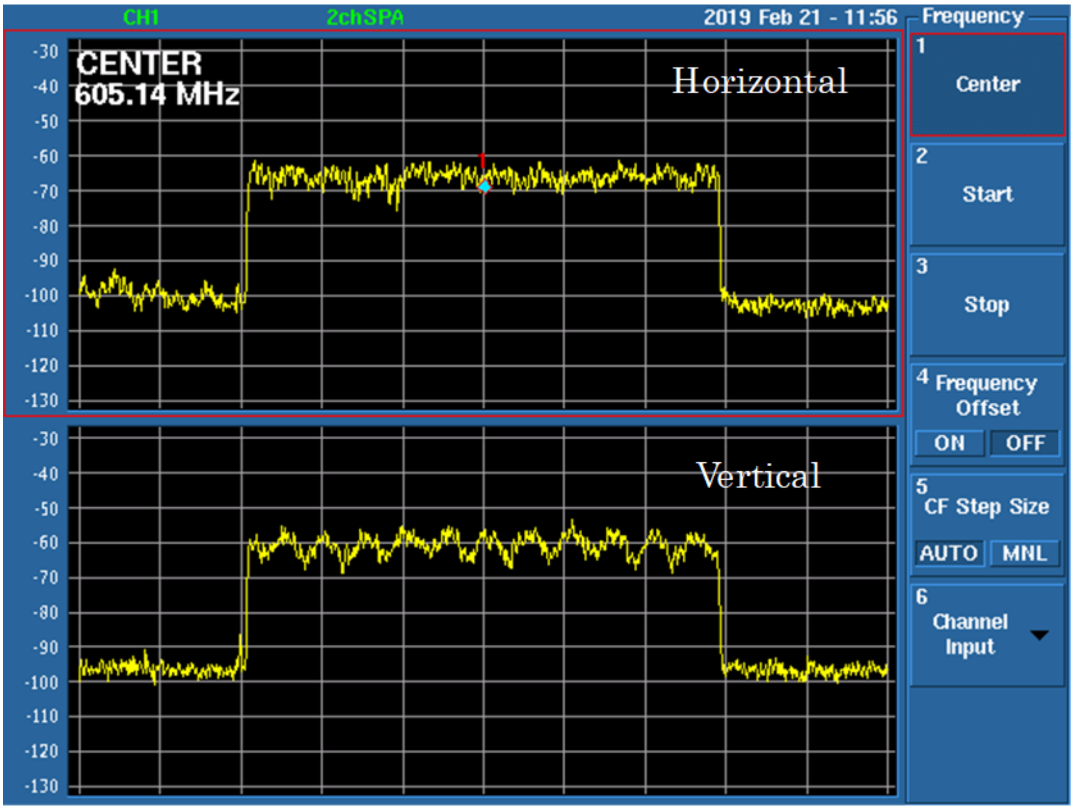


FIGURE 10

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

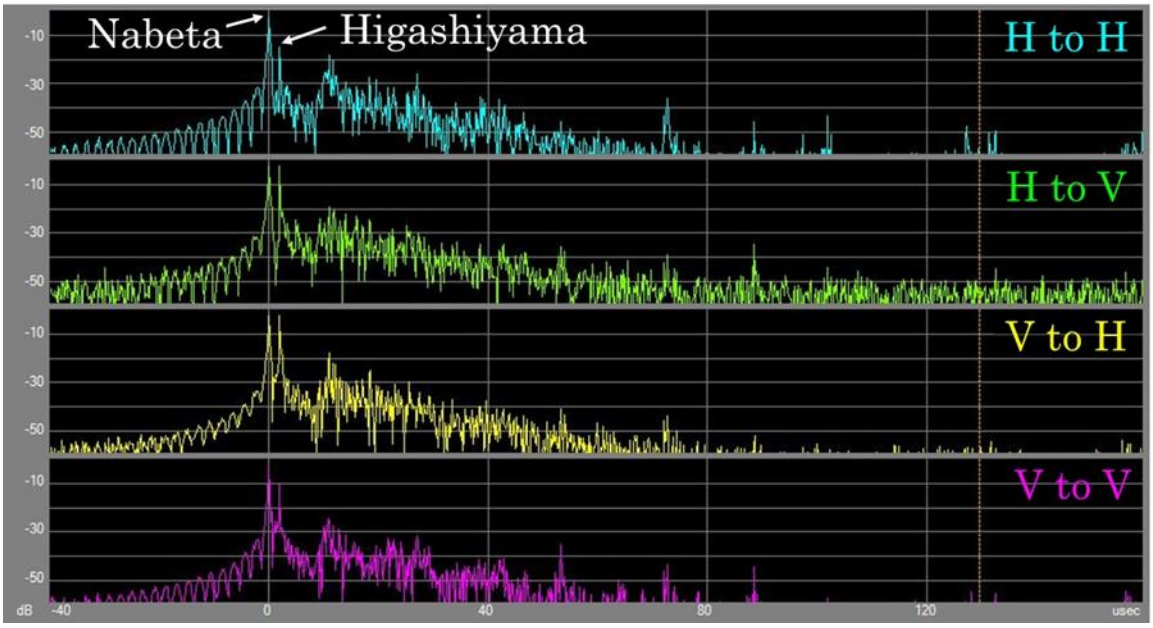
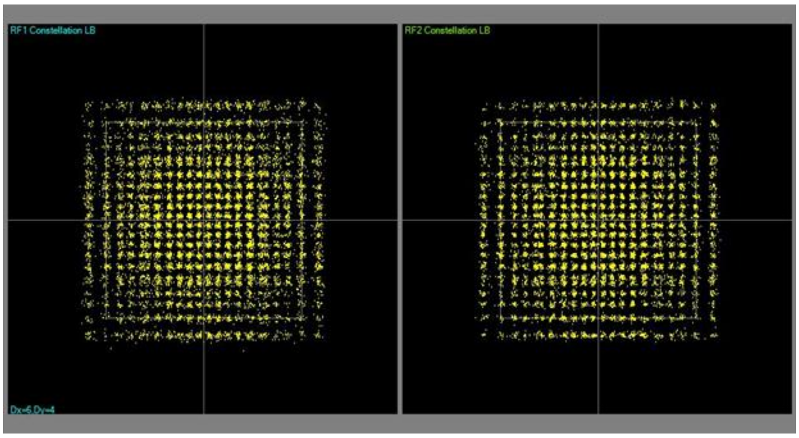


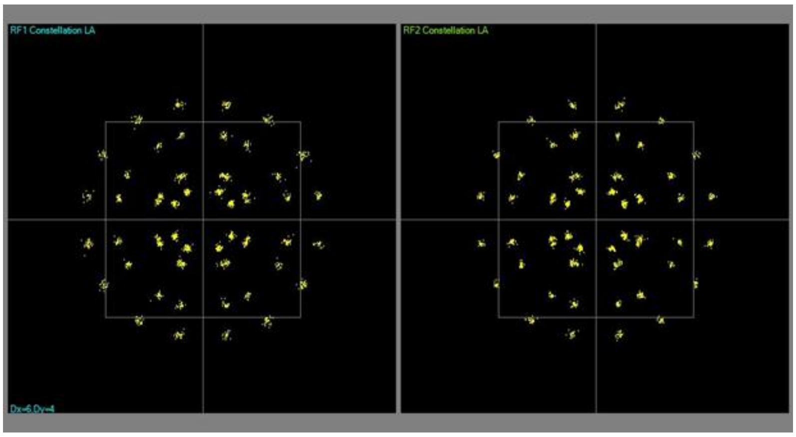
FIGURE 11

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.

1.3 Trials in verification phase of advanced DTTB system (2019-2022)

Trials were conducted to verify the transmission performance and feasibility of new DTTB systems using advanced transmission technologies. To conclude the verification phase, end-to-end technical demonstrations were conducted in four metropolitan areas in Japan.

1.3.1 End-to-end demonstration of an advanced DTTB system

Objectives of the field experiments were to verify the interconnectivity of all layers of the prototype equipment and the feasibility of the next-generation DTTB systems. Two new DTTB systems were verified. One system, the advanced DTTB system, adopts various advanced transmission technologies for improved transmission performance that will enable delivery of new services in one RF channel. Another system, the compatible DTTB system using LDM, transmits the new and current services simultaneously using layered division multiplexing (LDM) in one RF channel. End-to-end technical demonstrations were conducted and were on-aired from large-scale experimental stations in four metropolitan cities in Japan from November 2022 to January 2023.

1.3.1.1 Overview of tentative advanced DTTB system

1.3.1.1.1 Advanced DTTB system

The objective of the advanced DTTB system is to provide improved transmission performance compared with ISDB-T in terms of increased transmission capacity and reduced *C*/*N* required in order to deliver new services in one RF channel. The advanced system has been designed to inherit the features of ISDB-T; i.e. it aims to provide a 4K or 8K UHDTV services for fixed reception and an HDTV service for mobile reception simultaneously by frequency division multiplexing (FDM) within a single RF 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 flexible bitrate distribution between layers such as the mobile reception layer and fixed reception layer. Depending on the upgraded BICM technologies used, frequency utilization improves by 1.7 times in comparison with ISDB-T at the same required *C*/*N*. R&D continues with the goal of making further improvements to the performance and provide additional features including hybrid FDM/TDM, LDM, channel bonding, and low-delay transmission.

1.3.1.1.2 Compatible DTTB system

The objective of the compatible DTTB system is to deliver new DTTB services together with existing services in the same RF channel as used for the current DTTB services during the transitional period The system has backward compatibility with ISDB-T, i.e. the system inherits the physical layer protocol of ISDB-T, so that existing commercial ISDB-T receivers can detect and demodulate the signal for existing services. This method is assumed to be used in circumstances where a vacant channel cannot be identified or created to introduce a new DTTB service. The compatible DTTB system multiplexes an existing DTTB signal and a new DTTB signal in the physical layer with Layered Division Multiplexing (LDM). Figures 12 and 13 show a brief block diagram and the signal structure of the system, respectively. The signal for the new service is modulated with the bit-interleaved coded modulation (BICM) technologies of the advanced DTTB system, i.e. higher-order modulations, NUCs and LDPC code, and the other blocks are the same as in ISDB-T. The injection level is defined as the power ratio between the existing ISDB-T signal and the signal for the new service. Carrier power of the signal for the new service is set much lower than the carrier power of the ISDB-T signal.

The transmission capacity and the service areas of the existing service and new service are in a trade-off. If the transmission capacity of the existing service is maintained, the service area of the existing service will be reduced due to interference from the signal of the new service. If the service area of existing service is to be retained, the transmission capacity of the existing service needs to be reduced to improve robustness against interference. To reduce the interference to the existing service, the transmission power of the new service needs to be decreased, i.e. injection level needs to be increased, thereby reducing the service area of the new service. In the case where a higher-order modulation scheme (e.g. 64-QAM-7/8) is used for the existing service and/or under an SFN environment, the injection level may need to be increased. On the other hand, in the case where the existing service uses a lower-order modulation scheme (e.g. 16-QAM-2/3), the injection level may be reduced. To achieve the same service area for the new service as the existing service even with the reduced transmission power, transmission parameters offering higher robustness must be employed, which reduces the transmission capacity. If a narrow service area is acceptable for the new service, transmission parameters offering higher transmission capacity can be used to deliver UHDTV.

FIGURE 12

Compatible DTTB system using LDM

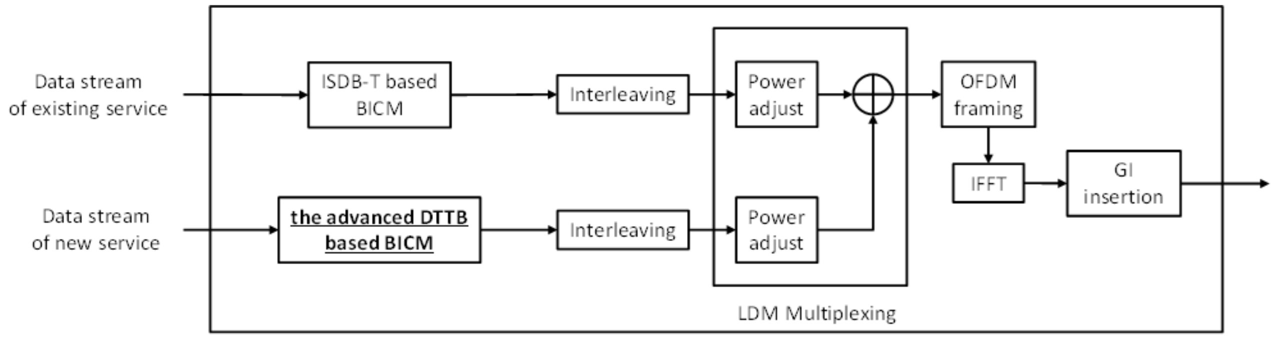
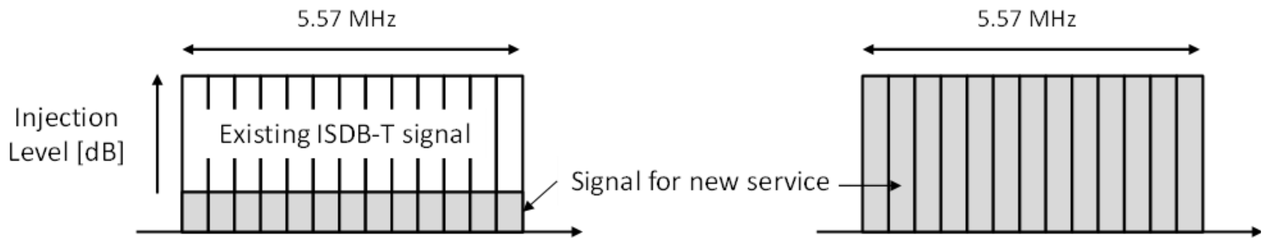


FIGURE 13

Signal structure of compatible DTTB system using LDM

a) During transition **b) After transition**



1.3.1.2 Transmission parameters

A prototype modulator and demodulator were developed for the two systems and their performances were confirmed in laboratory experiments. The feasibility of the systems was verified through large-scale field trials in four metropolitan cities in Japan.

The parameters listed in Table 3 were used in the field experiments of the advanced DTTB system. The occupied bandwidth was expanded by about 5% compared with that of ISDB-T to increase transmission capacity. 26 and 9 segments out of 35 segments were assigned for UHDTV (fixed reception) and HDTV (mobile reception) services, respectively. As for error-correcting code and carrier modulation, low density parity check (LDPC) code and NUCs were used for the UHDTV and HDTV services to enhance transmission robustness. Real-time encoder and decoders implementing Versatile Video Coding (VVC) and MPEG-H 3D Audio were used.

TABLE 3

Parameters for field experiments of the advanced DTTB system

Modulation method	OFDM	
Occupied bandwidth	5.83 MHz	
Multiplexing system	FDM	
Reception scenario	Fixed (Rooftop)	Mobile (Car-mounted)
Number of segments	26	9
Carrier modulation	1 024 NUC QAM	16 NUC QAM
FFT size (number of radiated carriers)	16k (15,121)	
OFDM symbol duration	2 592 µs	
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	21.5 Mbit/s	2.2 Mbit/s
Video coding	VVC Main10	
Video format	3 840 × 2 160/60/P (4K)	1 920 × 1 080/60/P (2K)
Video bit rate	9.0 Mbit/s (4K) * 2	0.7 Mbit/s (2K) * 2
Audio coding	MPEG-H 3D Audio Baseline Profile	
Audio bit rate	704 kbit/s (22.2ch + 4 objects)	96 kbit/s (2ch + 2 objects)

The parameters listed in Table 4 and Table 5 were used in the field experiments of the compatible DTTB. Two parameter sets were verified: one for during the transition and the other for after the transition. The occupied bandwidth and the OFDM signal structure were the same as in ISDB-T. The parameter set for during the transition is for transmitting both the existing and new services in one RF channel using LDM. 12 segments and 1 segment were assigned out of 13 segments to the existing HDTV (fixed reception) and SDTV (mobile reception) services, respectively, and 13 segments were assigned to the new service (fixed reception). As for the error-correcting code and carrier modulation, LDPC code and NUCs were used in the new service layer. The injection level was set to 21 dB. As for the required *C*/*N*, the fixed layers of the existing service and new service are approximately 20 dB, which is the same as the current link budget in Japan. The parameter set for after the transition is to transmit new services in one RF channel. 13 segments were assigned to the new service, and LDPC code and NUCs were also used. 256 NUC QAM with a code rate of 11/16 for the LDPC code was used.

TABLE 4

Parameters for field experiments of compatible DTTB system using LDM (during the transition)

Modulation method	OFDM		
Occupied bandwidth	5.57 MHz		
Multiplexing system	LDM		
Injection Level	21 dB		
Service	New service	Existing service	
Reception scenario	Fixed (Rooftop)		Mobile (Car-mounted)
Number of segments	13	12	1
Carrier modulation	QPSK	64-QAM	QPSK
FFT size (number of radiated carriers)	8k (5 617)		
OFDM symbol duration	1 008 µs		
Guard interval ratio (guard interval duration)	1/8 (126 µs)		
Error-correcting code	Inner: LDPC code rate = 4/16 Outer: BCH	Inner: Convolutional Code, code rate = 2/3 Outer: Reed-Solomon	Inner: Convolutional Code, code rate = 2/3 Outer: Reed-Solomon
Transmission capacity	2.17 Mbit/s	14.9 Mbit/s	416 kbit/s
Video coding	HEVC	MPEG-2	H.264
Video format	1 920 × 1 080/60/P	1 440 × 1 080/60/I (2K)	320 × 240/15/I (QVGA)
Video bit rate	1.6 Mbit/s (1)	12.5 Mbit/s	220 kbit/s
Audio coding	MPEG-2 AAC	MPEG-2 AAC	
Audio bit rate	201 kbit/s	201 kbit/s	51 kbit/s

(1) Offline encoding.

TABLE 5

Parameters for field experiments of compatible DTTB system using LDM (after the transition)

Modulation method	OFDM
Occupied bandwidth	5.57 MHz
Service	New service
Reception scenario	Fixed (Rooftop)
Number of segments	13
Carrier modulation	256 NUC QAM
FFT size (number of radiated carriers)	8k (5 617)
OFDM symbol duration	1 008 µs
Guard interval ratio (guard interval duration)	1/8 (126 µs)

TABLE 5 (*end*)

Error-correcting code	Inner: LDPC: code rate = 11/16 Outer: BCH
Transmission capacity	24.1 Mbit/s
Video coding	HEVC
Video format	3 840 × 2 160/60/P (4K)
Video bit rate	16.5 Mbit/s (1)
Audio coding	MPEG-2 AAC
Audio bit rate	201 kbit/s

(1) Offline encoding.

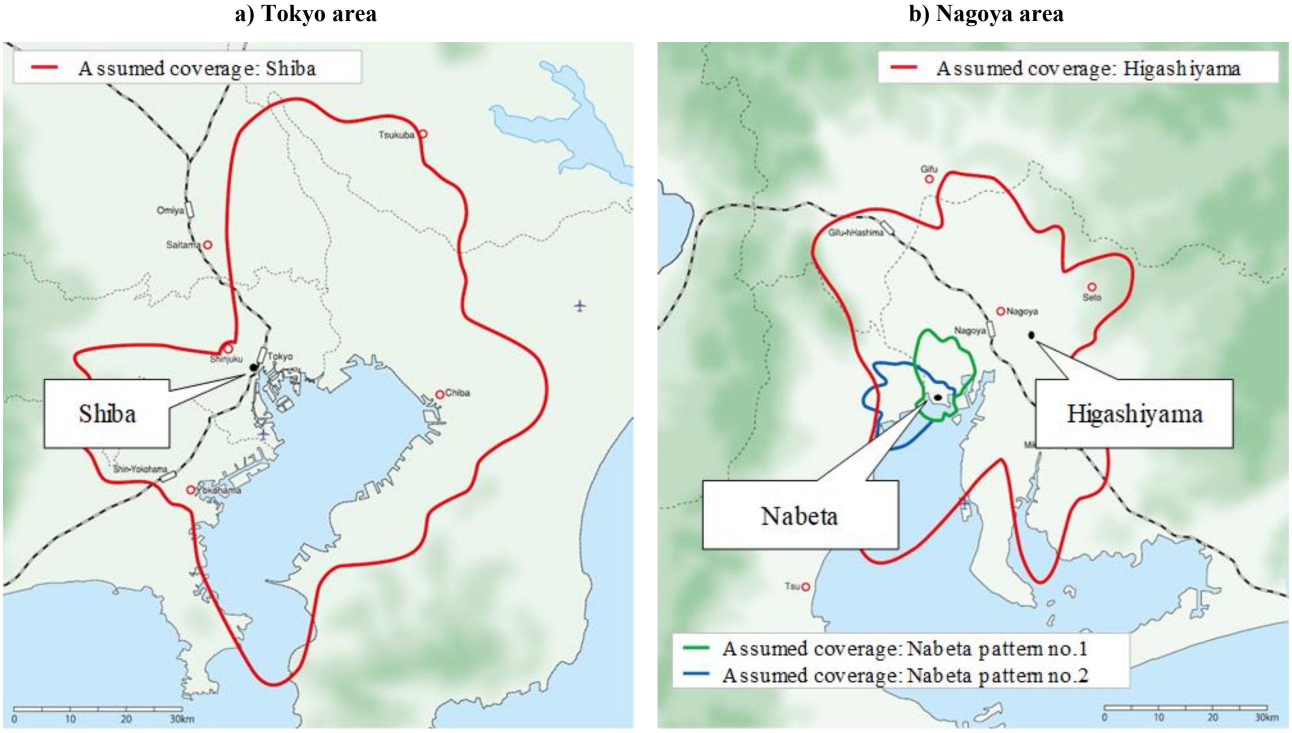
1.3.1.3 Field trials

1.3.1.3.1 Experimental environment

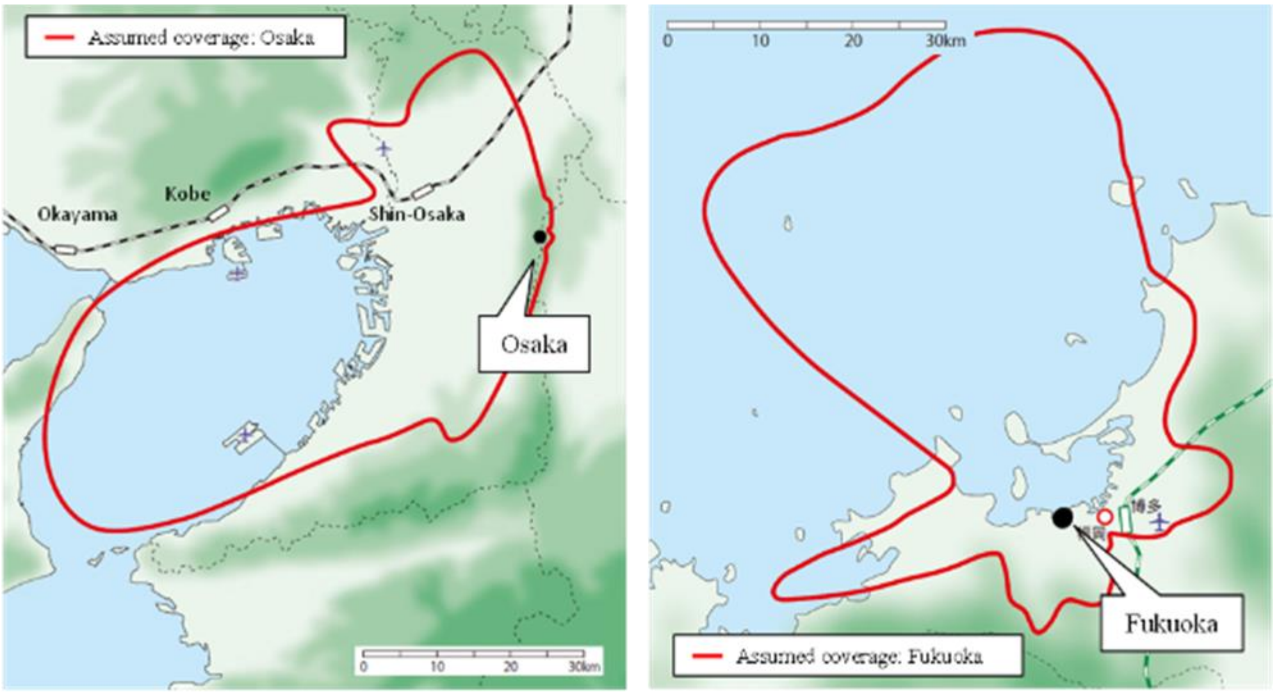
Large-scale experiments were conducted to evaluate the performance of the new DTTB systems in different propagation environments in four metropolitan cities, Tokyo, Nagoya, Osaka and Fukuoka. Figure 14 shows the transmitter sites and assumed coverage areas for the experimental parameters in Tables 3 to 5. Table 6 lists the specifications of the transmission stations. These coverage areas were on the same scale as those of currently used main DTTB stations. Although each transmission station is equipped for MIMO with two transmitters and two antennas for horizontally and vertically polarized waves, the end-to-end demonstrations used the SISO system with horizontal polarization. Figures 15 to 18 show the locations of the transmitting and receiving sites in the four areas.

FIGURE 14

Experimental environments



a) Tokyo area **b) Nagoya area**



c) Osaka area

d) Fukuoka area

TABLE 6

Transmission parameters

	Tokyo area	**Nagoya area**	**Osaka area**	**Fukuoka area**
Transmitter site	Shiba (Tokyo)	Higashiyama (Nagoya City, Aichi)	Osaka (Higashi Osaka City, Osaka)	Fukuoka (Fukuoka City, Fukuoka)
Transmission frequency	563.143 MHz UHF 28ch	605.143 MHz UHF 35ch	509.143 MHz UHF 19ch	701.143 MHz UHF 51ch
Polarization	Horizontal, Vertical			
Transmission power	Horizontal: 1 kW, Vertical: 1 kW			
e.r.p.	Horizontal: 2.1 kW Vertical: 2.1 kW	Horizontal: 980 W Vertical: 980 W	Horizontal: 4.6 kW Vertical: 4.6 kW	Horizontal: 1.5 W Vertical: 1.5 W
Transmitting antenna height	280 m above sea level	203 m above sea level	570 m above sea level	218 m above sea level

FIGURE 15

Locations of transmitting and receiving sites in Tokyo

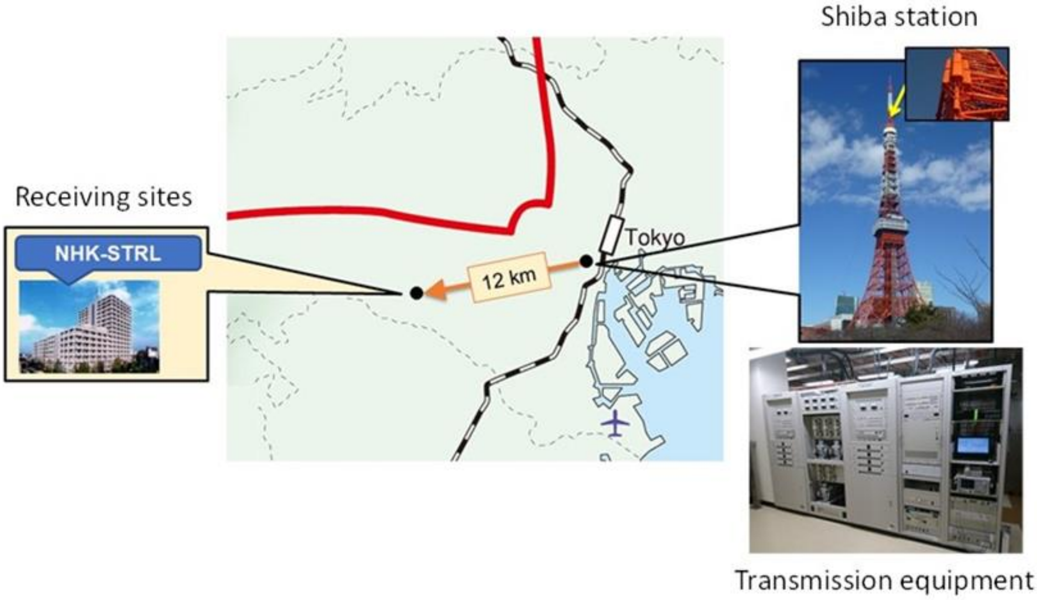


FIGURE 16

Locations of transmitting and receiving sites in Nagoya

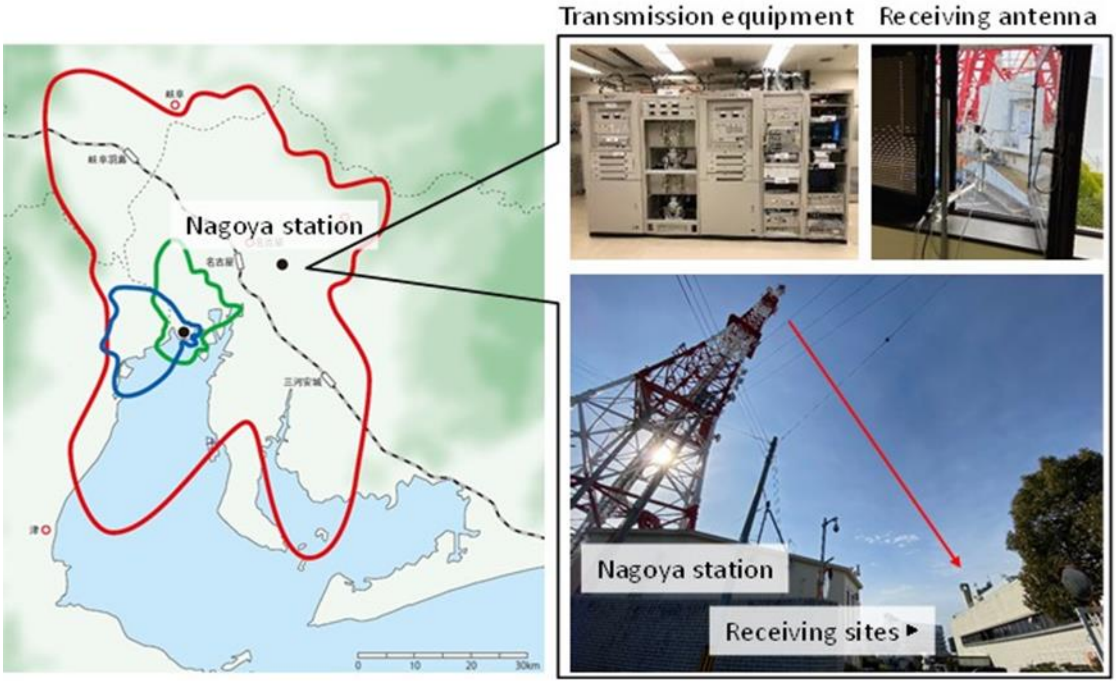


FIGURE 17

Locations of transmitting and receiving sites in Osaka

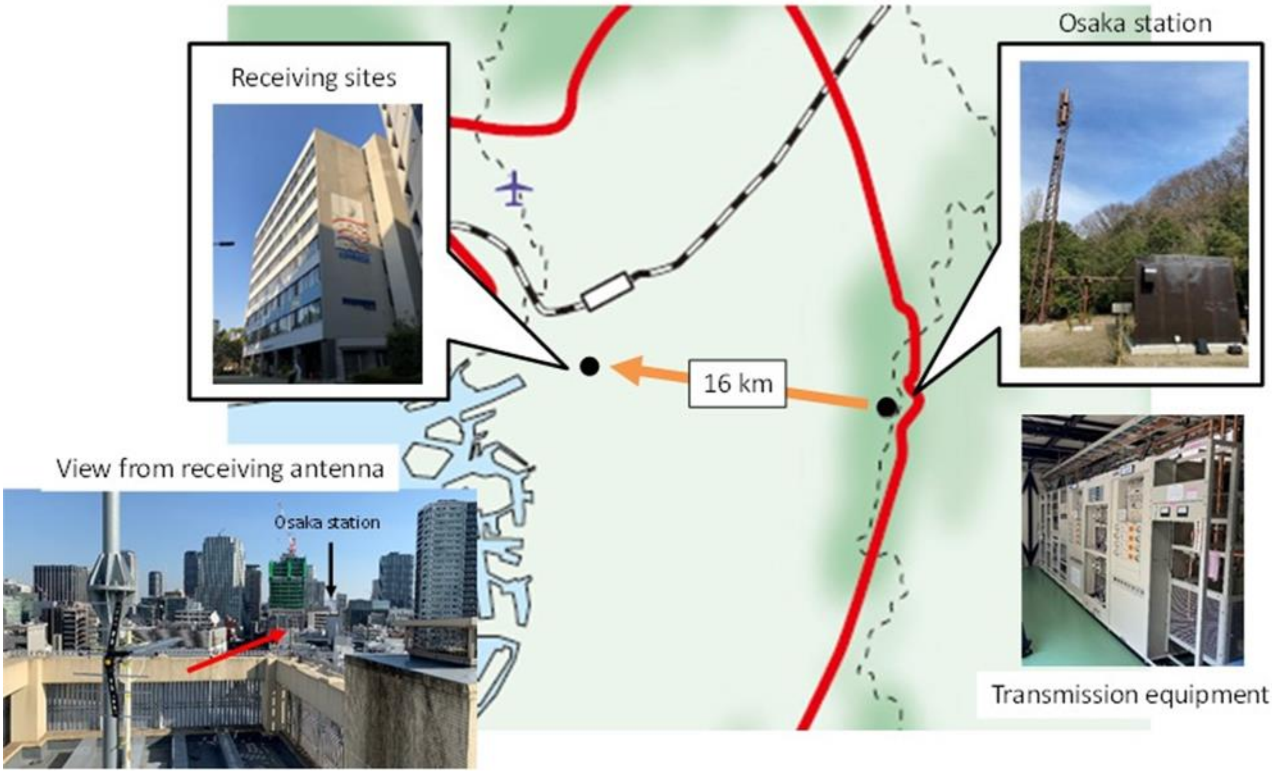
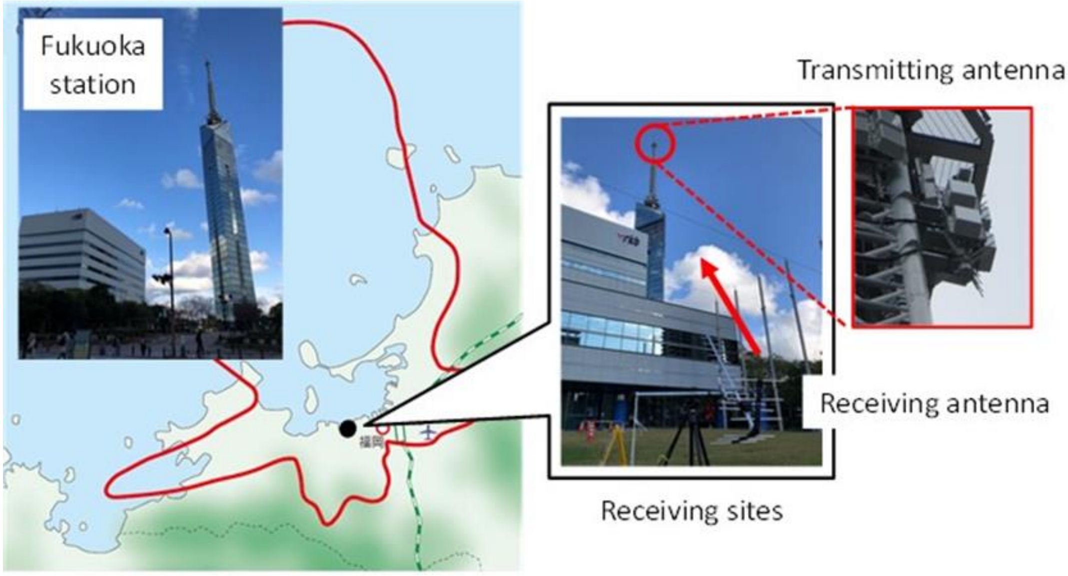


FIGURE 18

Locations of transmitting and receiving sites in Fukuoka



1.3.1.3.2 Trials of the advanced DTTB system

The demonstration of the advanced DTTB system involved field trials of hierarchical transmission of two UHDTV (fixed reception) and one HDTV (mobile reception) signal. The block diagrams of the transmitting and receiving systems are shown in Fig. 19.

Figure 20 shows the spectrum of the received signals in Tokyo. Figures 21 and 22 show the delay profile and constellation of the received signal. As for the delay profile, there were almost no reflected waves (Fig. 22). The end-to-end connection using the real-time VVC/MPEG-H 3DA encoder/decoder, re-multiplexer and modulator/demodulator of the advanced DTTB system was successfully demonstrated in all four areas.

FIGURE 19

Block diagram of transmitting and receiving systems of the advanced DTTB system

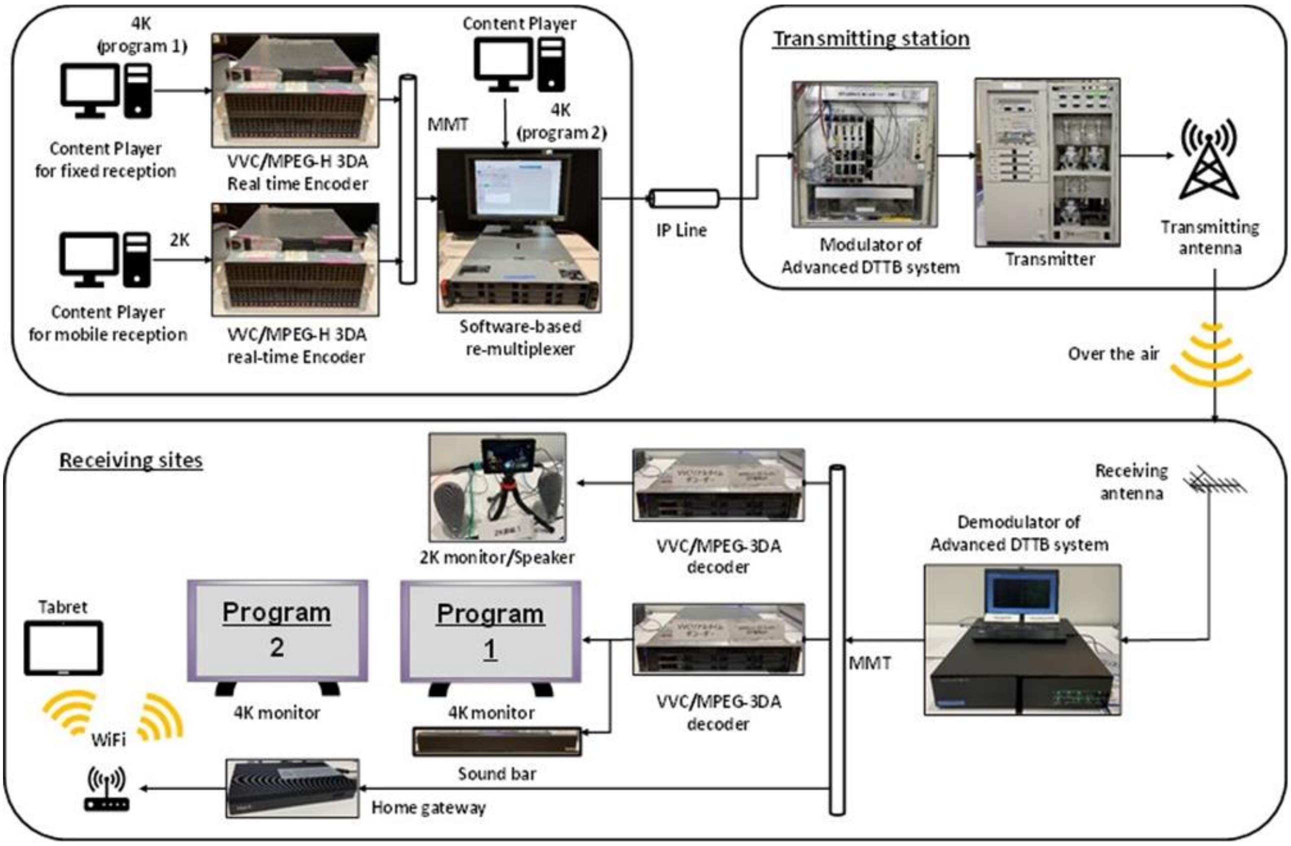
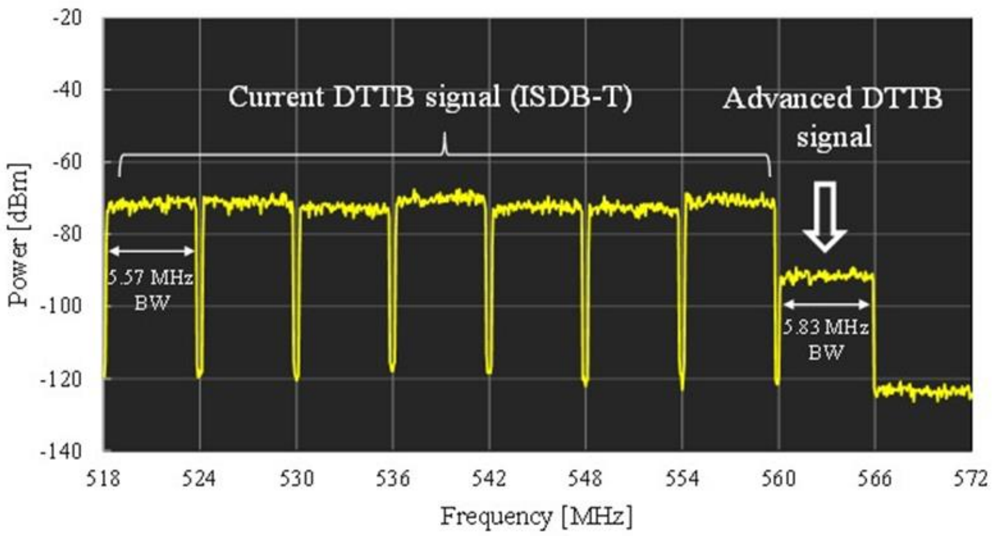


FIGURE 20

Spectrum of received signal



Note to Fig. 20: This Figure shows the receiving signal in Tokyo. The advanced DTTB signal was allocated upper-adjacently to the current DTTB signals. The difference in received power between the advanced DTTB signal and the current DTTB signals is due to the different transmitting powers and transmitting points.

FIGURE 21

Delay profile of received signal

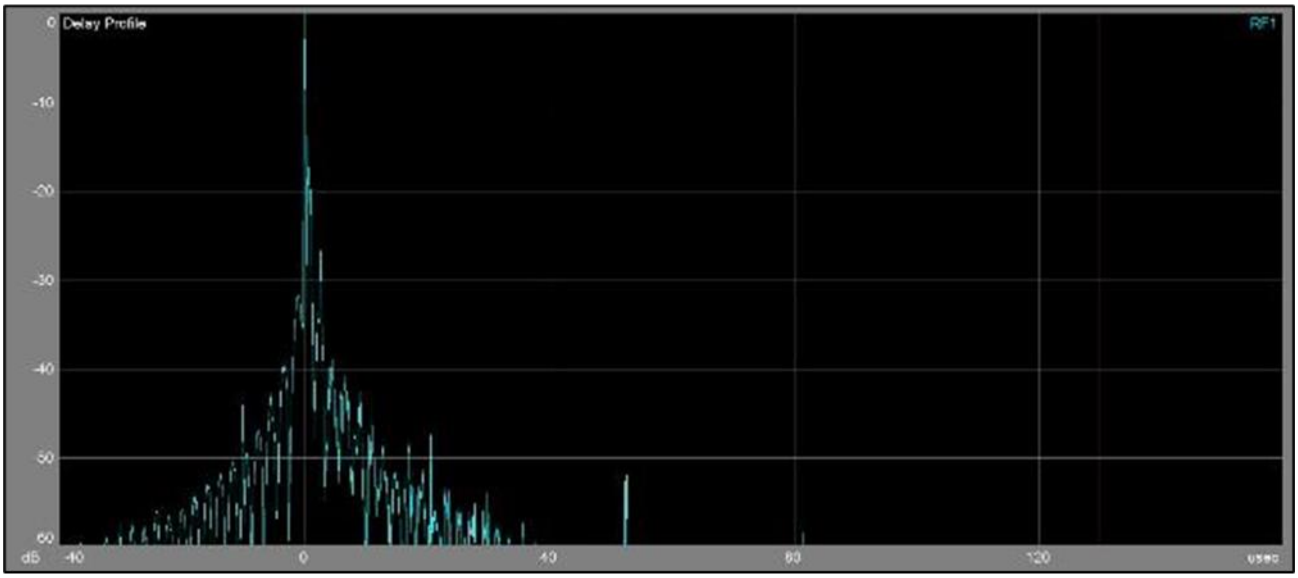
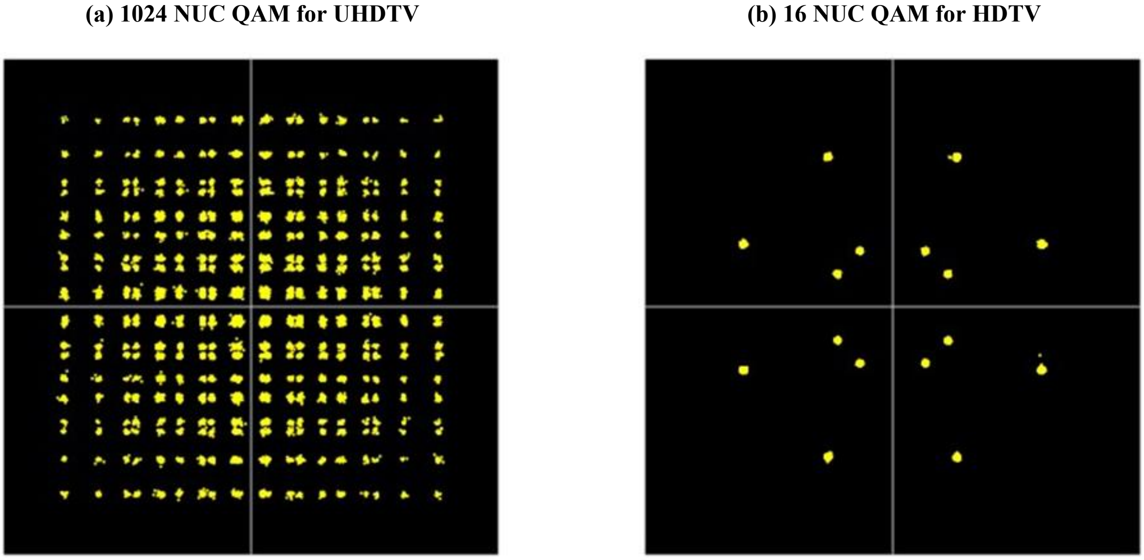


FIGURE 22

Constellations of received signal of the advanced DTTB system


(a) 1024 NUC QAM for UHDTV

(b) 16 NUC QAM for HDTV

1.3.1.3.3 Trials of the compatible DTTB system

The demonstration of the compatible DTTB system aimed to show feasibility of the two transmission modes for during and after the transition. The block diagram of the transmitting and receiving systems is shown in Fig. 23.

Figure 24 shows the spectrum of the received signals in Tokyo. Figures 25 and 26 show the constellation of the received signals for during the transition and for after the transition. In the constellation for during the transition (Fig. 25), both the mobile and fixed layers of the existing service signals were multiplexed with the QPSK modulated signals for new service. This demonstrated that, using the compatible DTTB system, a new service can be received by new receivers while existing commercial ISDB-T receivers can receive the existing service.

FIGURE 23

Block diagram of transmitting and receiving system of compatible DTTB system

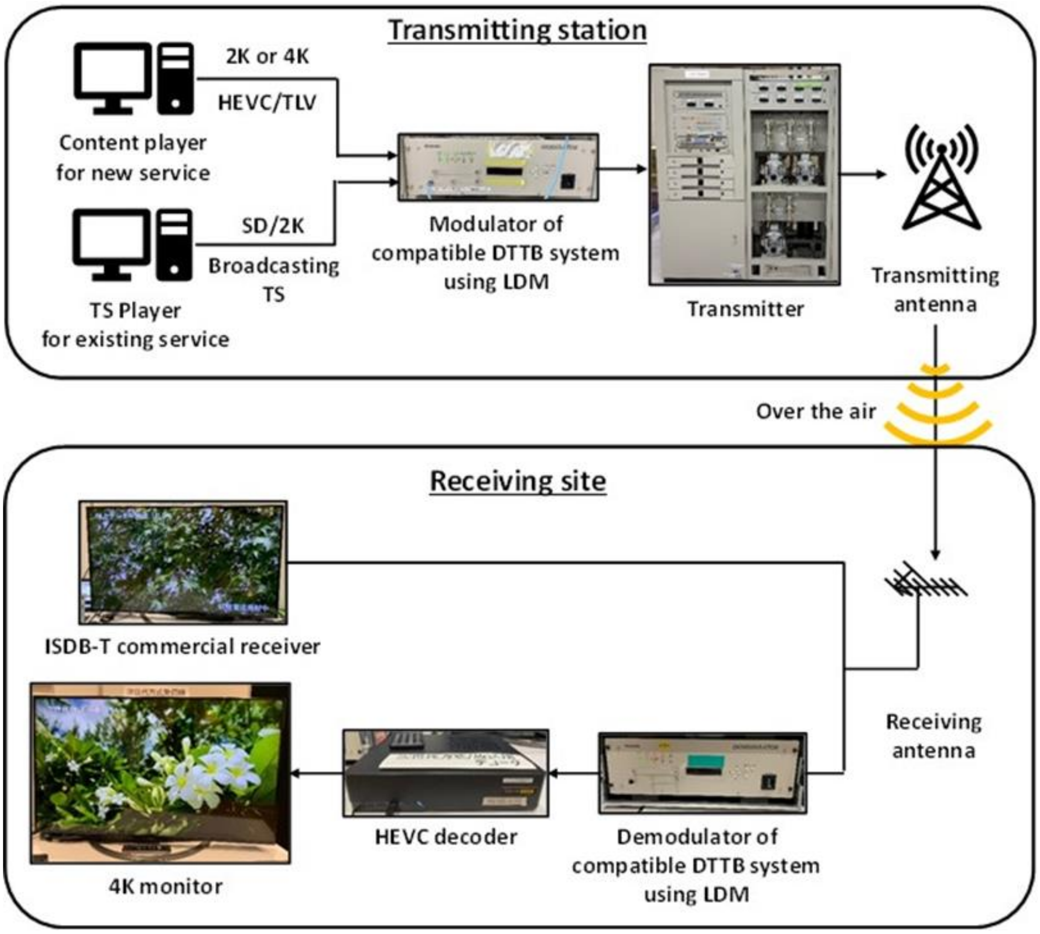
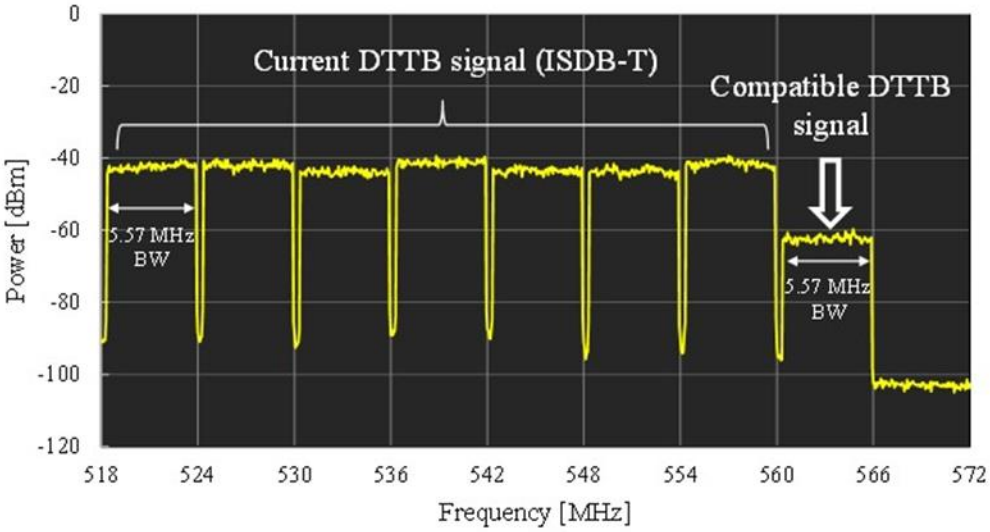


FIGURE 24

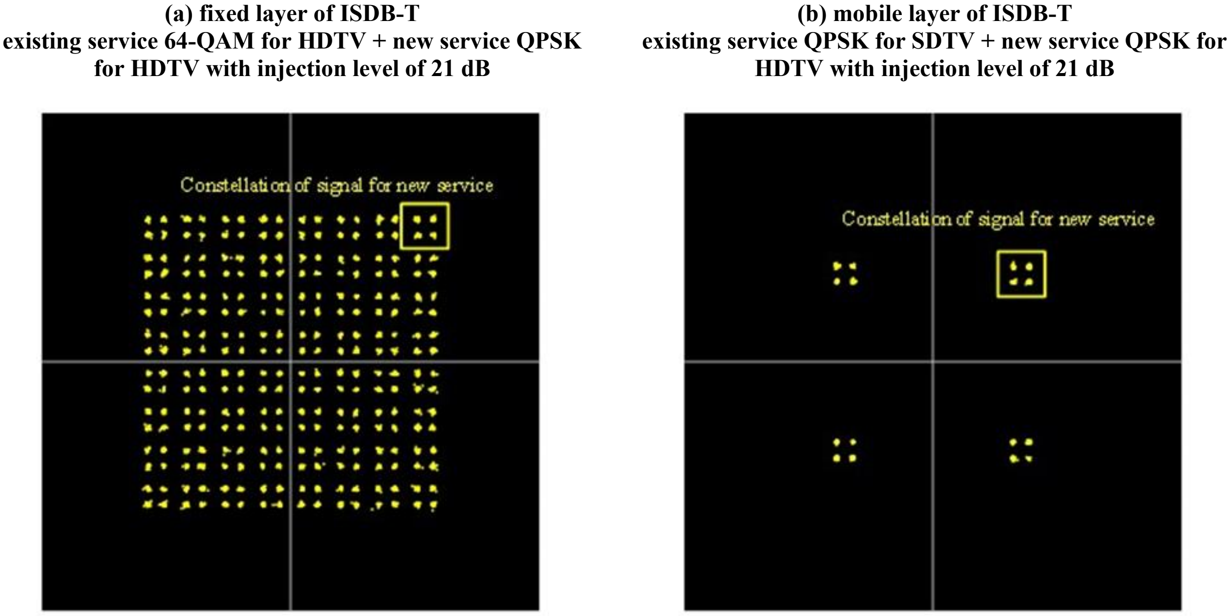
Spectrum of received signal



Note to Fig. 24: This Figure shows the receiving signal in Tokyo. The compatible DTTB signal was allocated upper-adjacently to the current DTTB signals. The difference in received power between the compatible DTTB signal and the current DTTB signals is due to the different transmitting powers and transmitting points.

FIGURE 25

Constellations of received signal
(Compatible DTTB system with parameters set for during the transition)



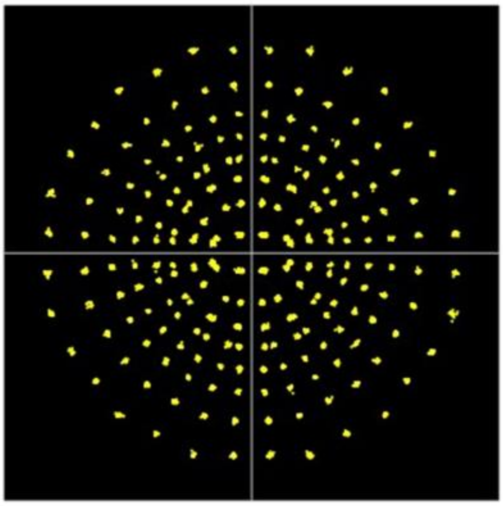
(a) fixed layer of ISDB-T
existing service 64-QAM for HDTV + new service QPSK for HDTV with injection level of 21 dB

(b) mobile layer of ISDB-T
existing service QPSK for SDTV + new service QPSK for HDTV with injection level of 21 dB

FIGURE 26

Constellations of received signal
(Compatible DTTB system with parameters set for after the transition)

256 NUC QAM for UHDTV



1.3.2 8K-UHDTV field experiments for the verification of 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.

1.3.2.1 Transmission parameter and equipment

A field experiment was conducted with channel bonding using two RF channels based on the advanced system described in § 1.2. The transmission parameters are presented in Table 7. 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. 27.

TABLE 7

Parameters for field experiments of channel bonding

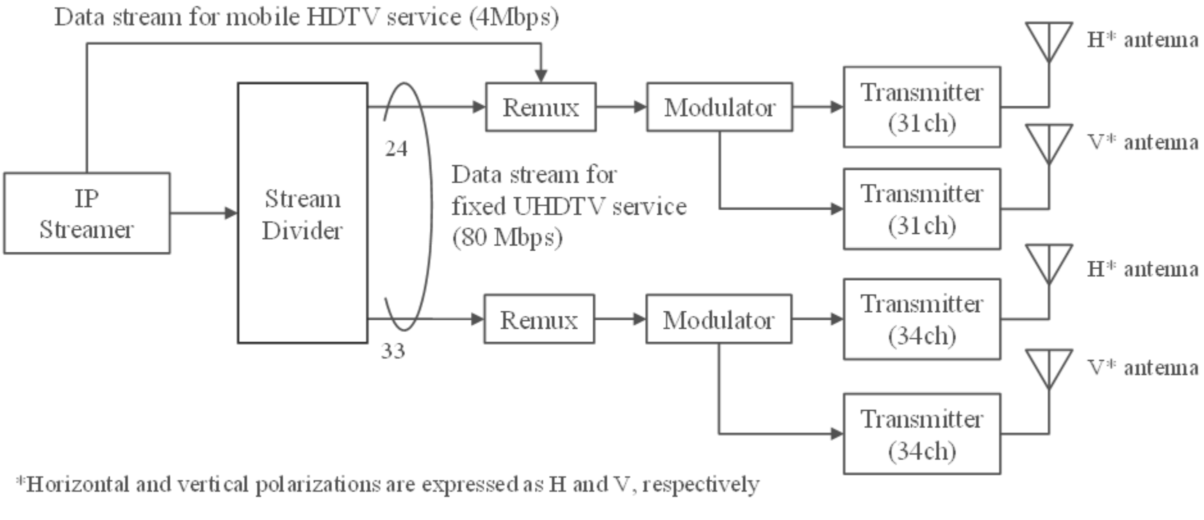
<table>
<tr><td>Transmitter site</td><td colspan="3">Kinuta, Tokyo</td></tr>
<tr><td>Transmission frequency</td><td>599.143 (UHF Ch 34)</td><td colspan="2">581.143 MHz (UHF Ch 31)</td></tr>
<tr><td>Transmission power</td><td>Horizontal: 1 W, e.r.p.: 1.3 W
Vertical: 1 W, e.r.p.: 1.45 W</td><td colspan="2">Horizontal: 1 W, e.r.p.: 9.3 W
Vertical: 1 W, e.r.p.: 9.3 W</td></tr>
<tr><td>Transmitting antenna height</td><td>104 m above sea level
(74 m above ground level)</td><td colspan="2">126 m above sea level
(96 m above ground level)</td></tr>
<tr><td>Modulation method</td><td colspan="3">OFDM</td></tr>
<tr><td>Occupied bandwidth</td><td>5.57 MHz</td><td colspan="2">5.57 MHz</td></tr>
<tr><td>Reception scenario</td><td colspan="2">Fixed
(Rooftop)</td><td>Mobile
(Car-mounted)</td></tr>
</table>

TABLE 7 (*end*)

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)
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 27

Block diagram of transmitter site



1.3.2.2 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. 28. 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 29, 30 and 31 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. 32.

FIGURE 28

Block diagram of receiver side

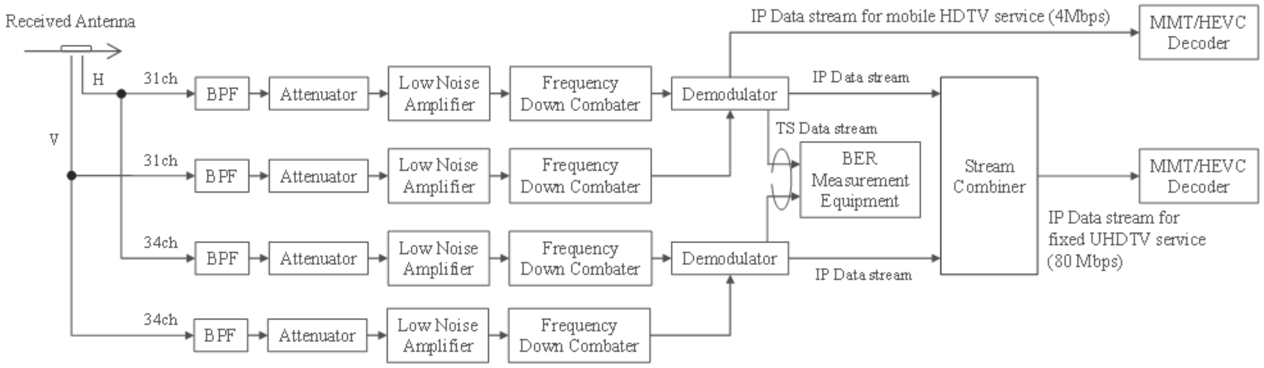
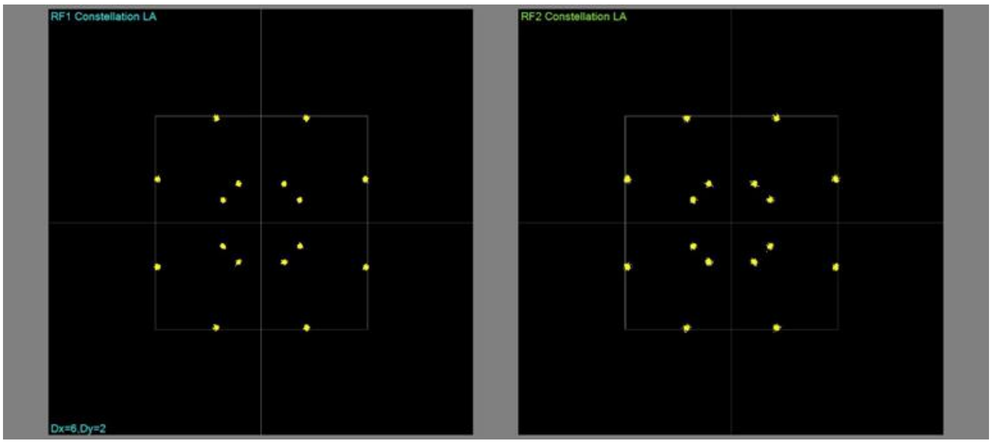


FIGURE 29

Spectrum of received signals

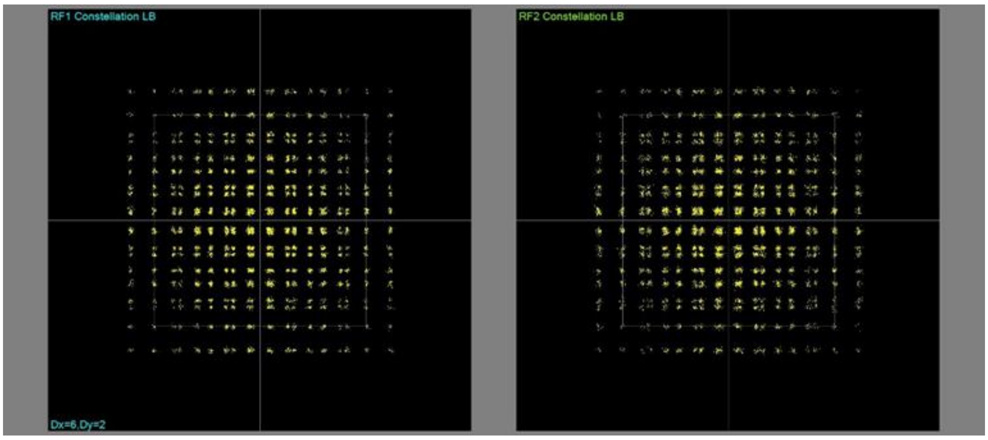
FIGURE 30

Constellation of received signals



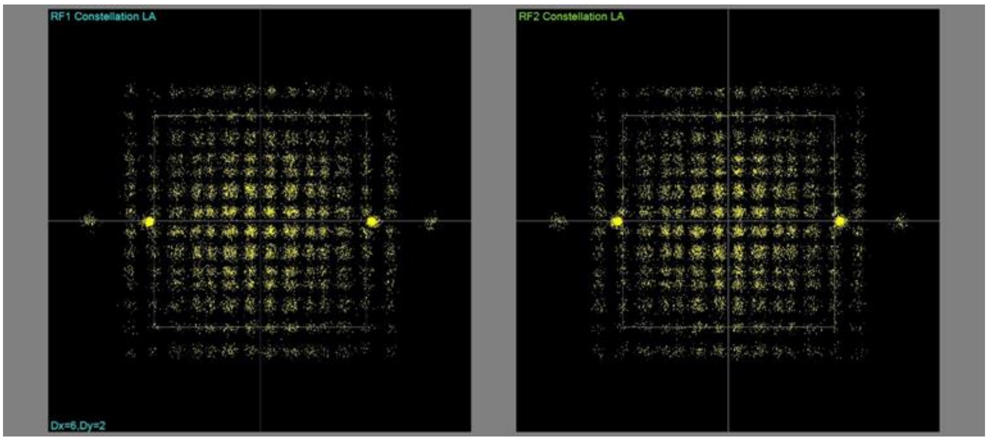
MER = 33.8 dB MER = 33.5 dB

(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)

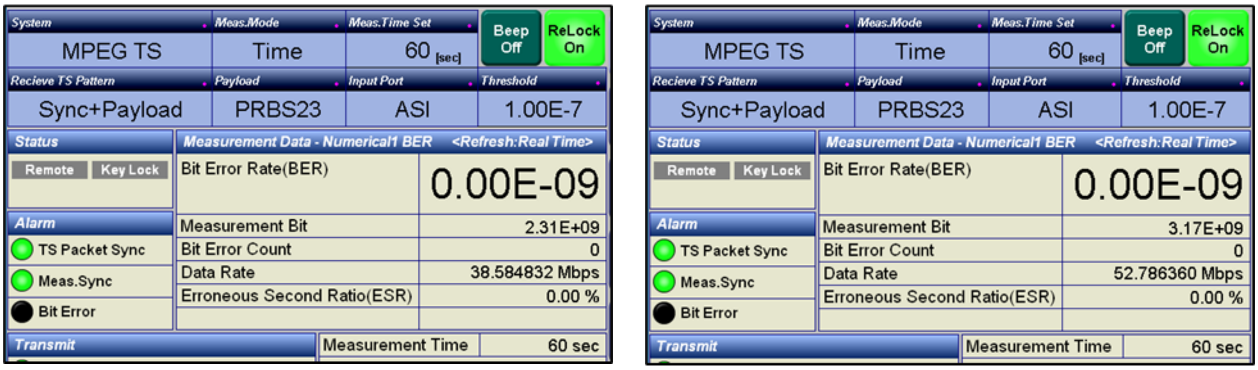


MER = 27.2 dB MER = 27.0 dB

FIGURE 31

Measurement results of bit error rates

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



(a)

System	Meas.Mode	Meas.Time Set		
MPEG TS	Time	60 [sec]	Beep Off	ReLock On
Recieve TS Pattern	Payload	Input Port	Threshold	
Sync+Payload	PRBS23	ASI	1.00E-7	

Status: Remote | Key Lock

Alarm: ● TS Packet Sync, ● Meas.Sync, ● Bit Error

Measurement Data - Numerical1 BER <Refresh:Real Time>

Bit Error Rate(BER)	0.00E-09
Measurement Bit	2.31E+09
Bit Error Count	0
Data Rate	38.584832 Mbps
Erroneous Second Ratio(ESR)	0.00 %

Transmit | Measurement Time | 60 sec

(b)

System	Meas.Mode	Meas.Time Set		
MPEG TS	Time	60 [sec]	Beep Off	ReLock On
Recieve TS Pattern	Payload	Input Port	Threshold	
Sync+Payload	PRBS23	ASI	1.00E-7	

Status: Remote | Key Lock

Alarm: ● TS Packet Sync, ● Meas.Sync, ● Bit Error

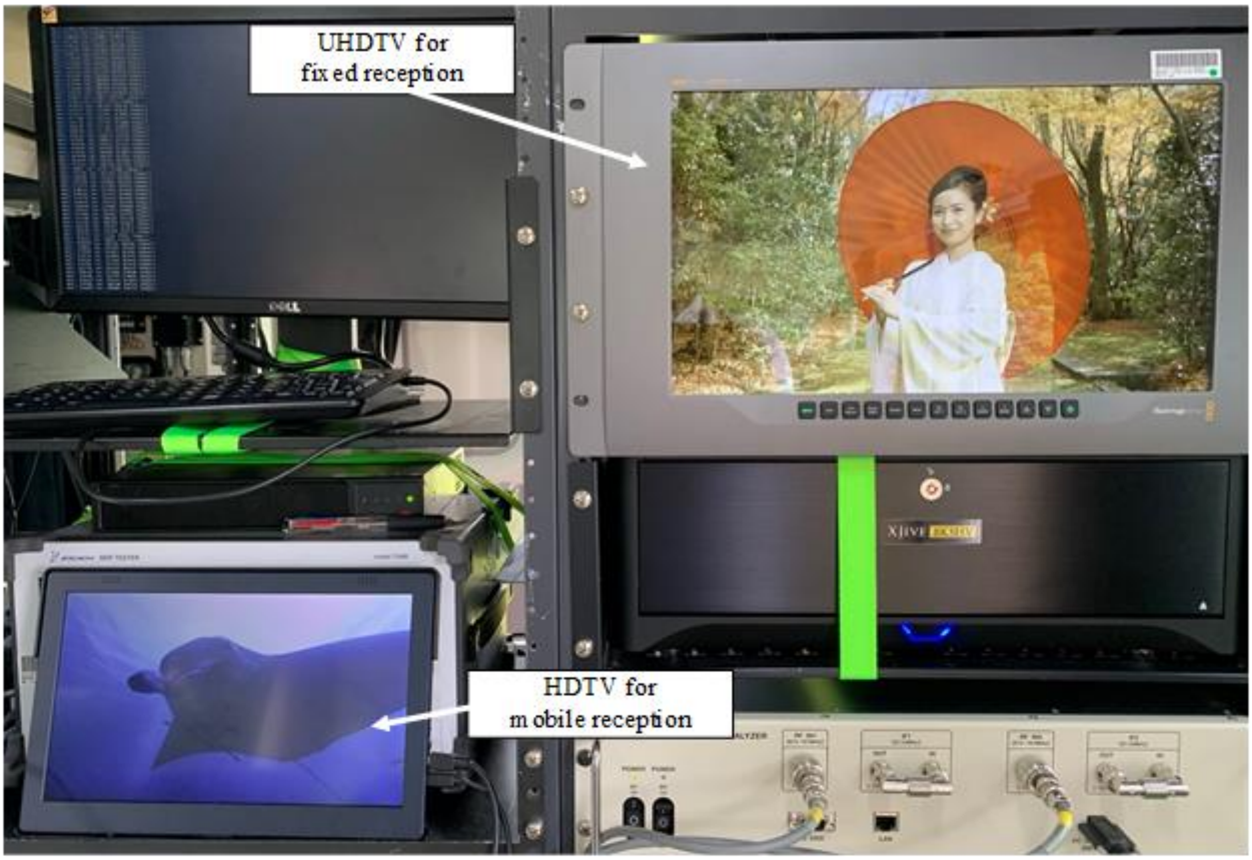
Measurement Data - Numerical1 BER <Refresh:Real Time>

Bit Error Rate(BER)	0.00E-09
Measurement Bit	3.17E+09
Bit Error Count	0
Data Rate	52.786360 Mbps
Erroneous Second Ratio(ESR)	0.00 %

Transmit | Measurement Time | 60 sec

FIGURE 32

Received video of UHDTV and HDTV



1.4 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), layered division multiplexing (LDM), 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 DTTB 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.

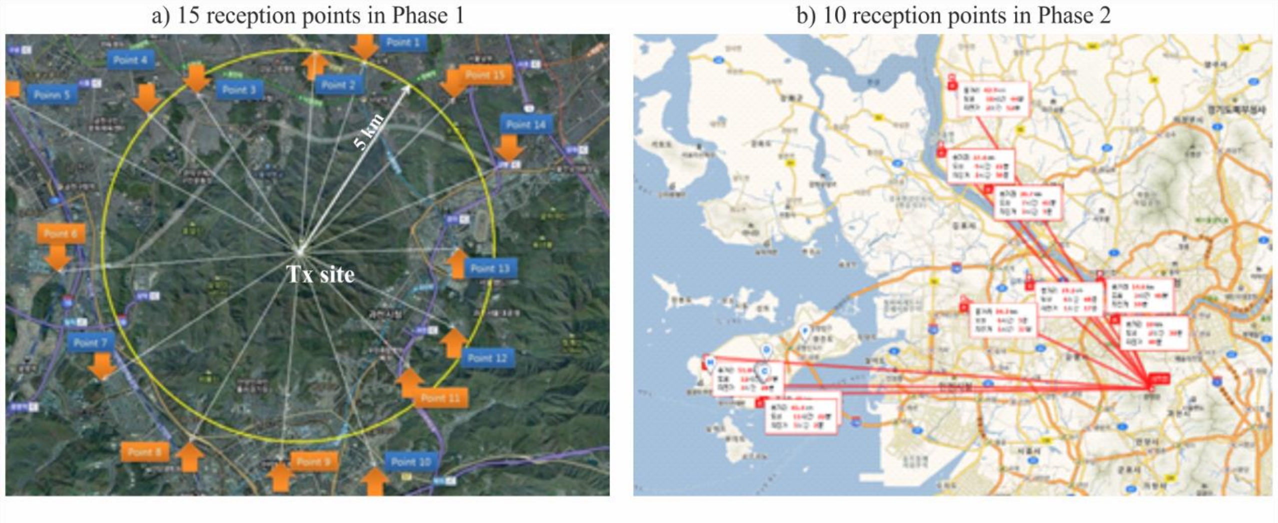
Kwan-Ak Mountain Transmission Site

During Phase 1 and 2, KBS operated the Kwan-Ak site only using the parameters shown in Table 8. 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. 33.

- 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. 33(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. 33(b).

FIGURE 33

Location of reception points during Phase 1 and Phase 2



a) 15 reception points in Phase 1

b) 10 reception points in Phase 2

Report BT.2343-A1-24

TABLE 8

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)				
DTTB 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 9.

TABLE 9

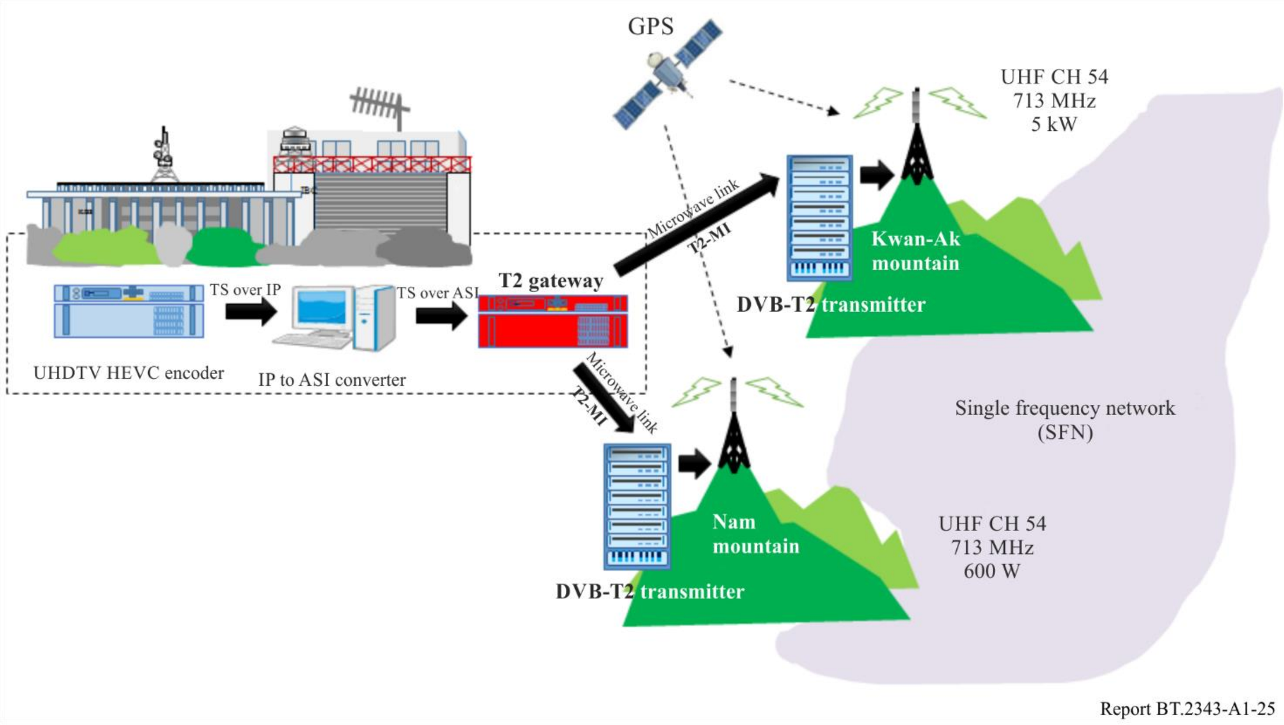
Transmitting power and used channels of transmitter site during Phase 3

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 DTTB platform are listed in Table 22. The experimental broadcast chain of KBS, including content production, encoding, microwave link, is shown in Fig. 34.

FIGURE 34

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 DTTB 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. 35(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 36 shows the event. The 4K UHDTVs in Fig. 35(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 35

4K live broadcast of the 2014 KBL Final

a) Image of the 4K live broadcast

b) People watching the game at Seoul Station

Report BT.2343-A1-26

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. 36. 4K live was fed from Brazil via AsiaSat5, a communications satellite, as shown in Fig. 36.

– 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.

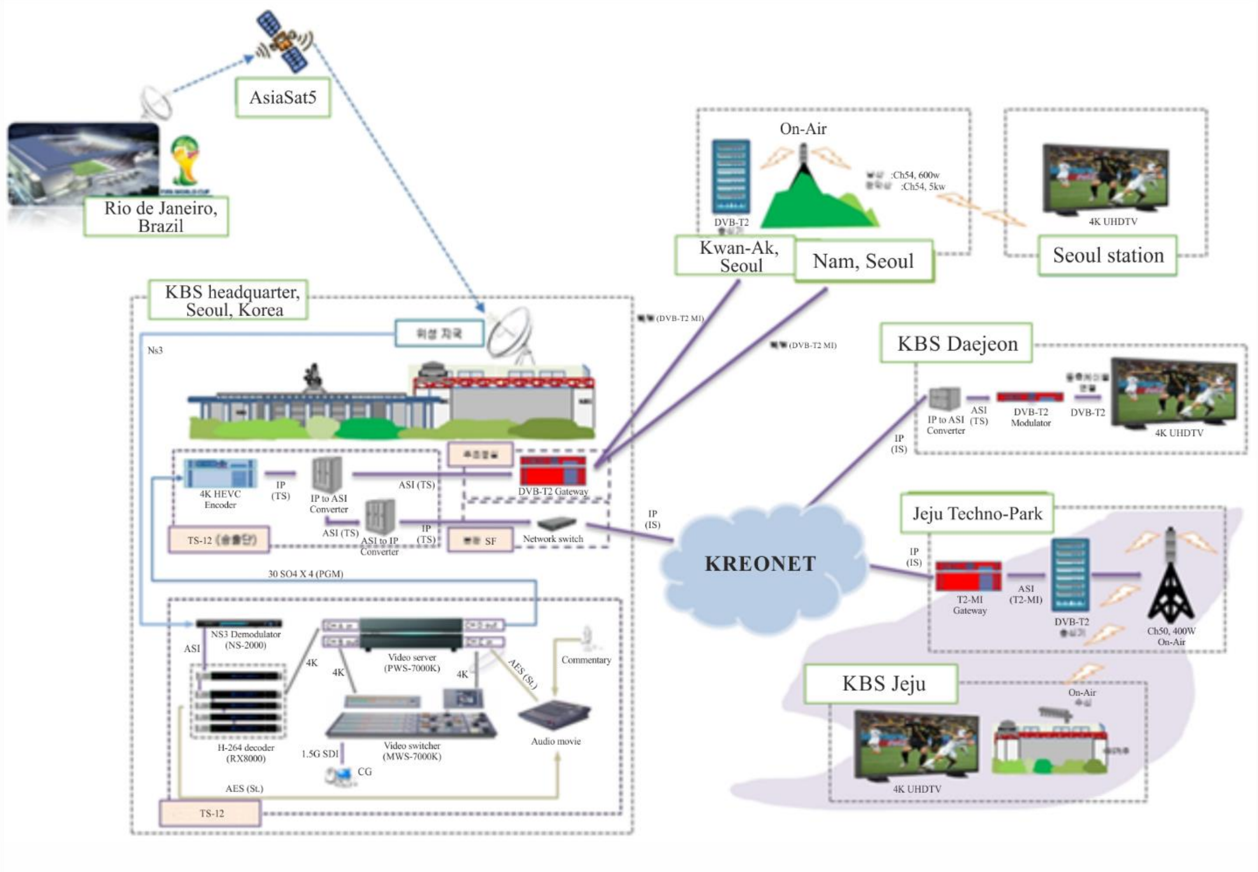
In order to increase live service coverage of the 4K-UHDTV, two provinces were chosen for the public viewing, Daejeon and Jeju Island, in addition to the metropolitan area of Seoul, as shown in Fig. 37:

– 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 36

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



Report BT.2343-A1-27

FIGURE 37

4K live broadcast of the 2014 FIFA World Cup

Report BT.2343-A1-28

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. 38).
- – 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 38

4K live broadcast of the 2014 Incheon Asian Games

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

Report BT.2343-A1-29

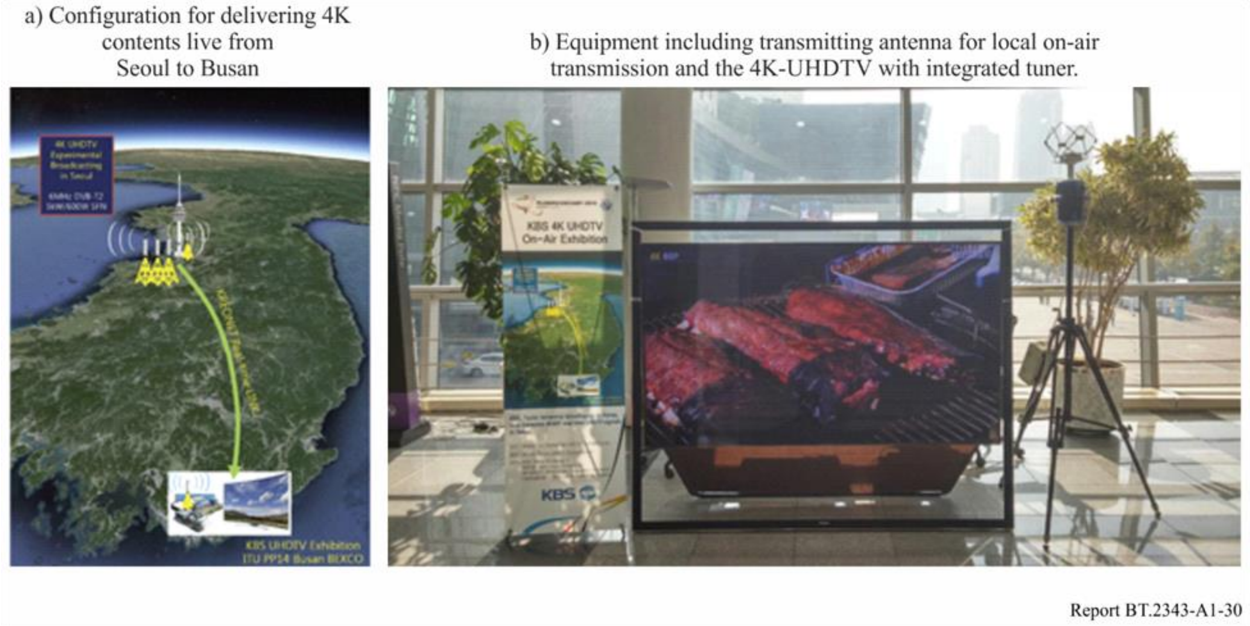
ITU Plenipotentiary Conference 2014 (PP-14)

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. 39(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. 39(b).

FIGURE 39

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.

Report BT.2343-A1-30

2.2 UHDTV terrestrial trial broadcasting based on ATSC 3.0

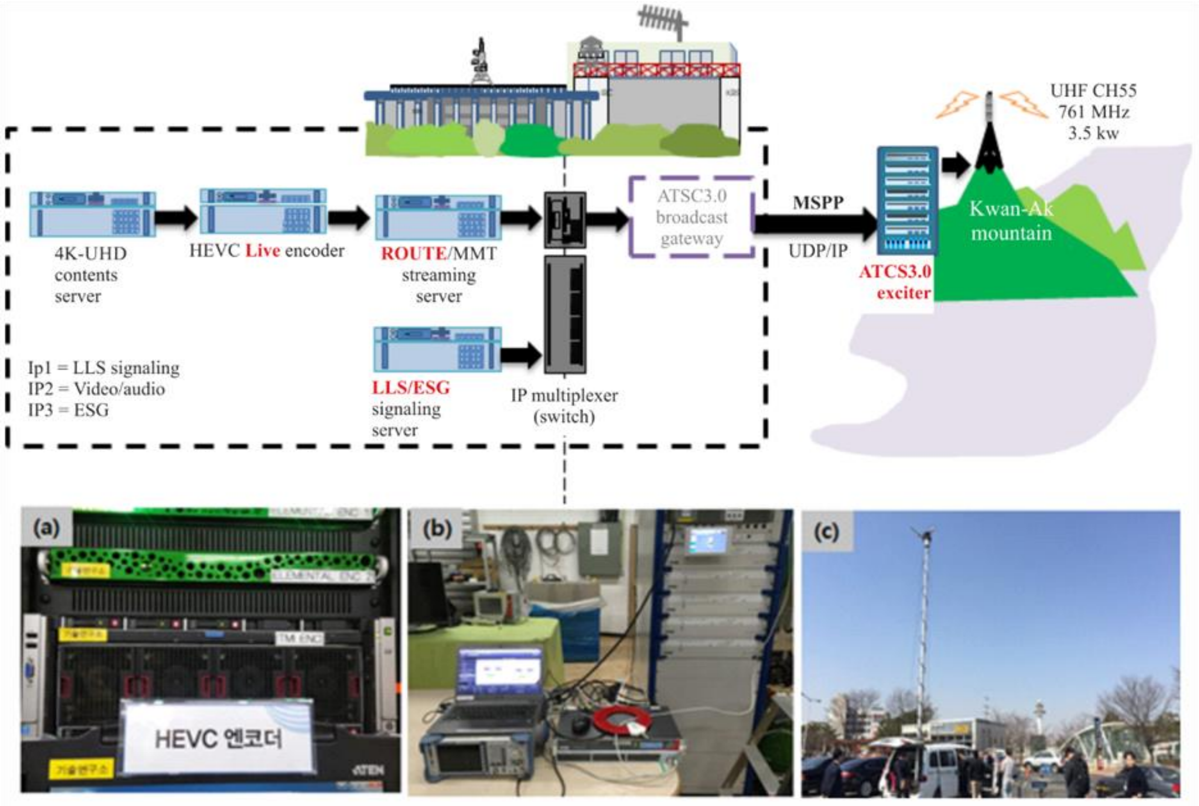
The Republic of Korea also conducted trials based on ATSC 3.0. The results are summarized below.

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. 40. Through the experimental broadcasting, the technical feasibility of the ATSC 3.0 standard was examined in depth.

FIGURE 40

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



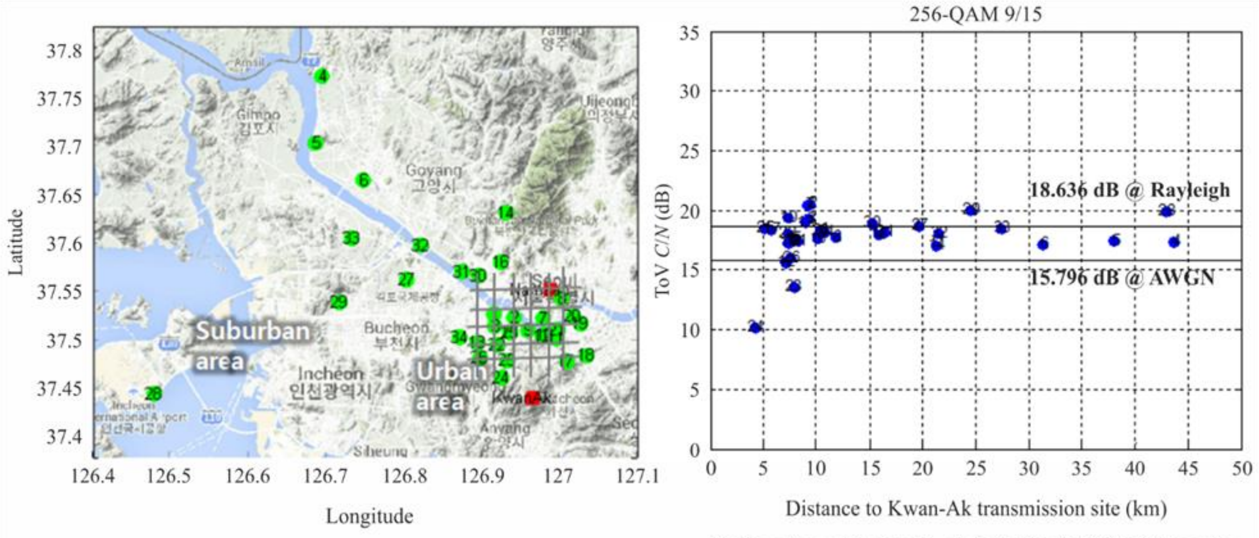
a) Equipment in the master control room b) Transmitter at Kwan-Ak transmission site c) Measurement vehicule with 9 m antenna mast

Report BT.2343-A1-31

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. 41.

FIGURE 41

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)

Report BT.2343-A1-32

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. 42.

FIGURE 42

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

Report BT.2343-A1-33

2.3 Extensive experiments for ATSC 3.0 system performance evaluation

2.3.1 Overview

Extensive verifications were conducted to evaluate the system performance of the ATSC 3.0 physical layer thoroughly. The ATSC 3.0 physical layer, including bit-interleaved coded modulation (BICM), orthogonal frequency division multiplexing (OFDM), and time and frequency interleavers, was verified in various channel conditions. The system performance was measured through computer simulations, laboratory tests, and field tests.

The experiments evaluated the net system performance for each system parameter configuration, specifically focusing on a modulation and coding (ModCod) combination. The system performance was quantified in terms of the signal-to-noise ratio (SNR) required for successful decoding. Table 10 presents the detailed system parameter configurations considered in every experiment case.

Every possible ModCod combinations defined in ATSC 3.0 were tested under the reference configuration of other parameters. As a representative profile, 16k-FFT OFDM was used for the entire experiments, where it avoids possible tuner phase noise impact of 32k-FFT and is feasible to both fixed and mobile receptions. To offer baseline figures, pilot boosting was not applied. If pilot boosting is used, the measured values can be re-computed by adding the power reduction values presented in Table B.4.1 of Document A/327, *ATSC Standard: Guidelines for the Physical Layer Protocol*.

The system performance was measured under three different channel models: Additive White Gaussian Noise (AWGN), Rician (DVB-F1), and Rayleigh (DVB-P). Rician channel herein consists of one main line-of-sight (LoS) signal and 20 multipath signals without Doppler shift. Rayleigh channel herein has one main non-LoS path and 19 multipath signals without Doppler shift. Computer simulations and laboratory verifications were conducted over the exact channel models, assisted by accurate channel generations. A fading channel generator programme and an off-the-shelf radio channel simulator were used for this purpose. Field evaluation took place at the site locations where the channel response features resembled the channel models AWGN, DVB-F1, and DVB-P1. To distinguish the real channel conditions from the formulaic channel models, the terms *AWGN-like*, *Rician-like*, and *Rayleigh-like* are used to refer to the fading situations realized in the field experiments.

TABLE 10

System parameters for simulations, laboratory tests, and field tests

Frame Length (Symbol Aligned Mode)		255.33 ms (Including the bootstrap)
Bandwidth		6 MHz
RF channel		50 (Centre frequency = 689 MHz)
Preamble parameters	FFT Size	16K
	Guard interval	GI7_2048
	Pilot Pattern	$SP\_D_x = 3$
	Signaling Protection	L1-Basic Mode 1
	# of Preamble Symbols	1
Payload OFDM parameters	FFT Size	16K
	Guard interval	GI7_2048
	Pilot pattern	$SP\_D_x = 3$, $SP\_D_y = 4$
	Pilot boosting	No pilot boosting
	# of payload symbols	94
	Time interleaver	CTI (1024 depth)
	Frequency interleaver	On
Payload BICM parameters	Inner/outer code	LDPC 2/15~13/15 (64800, 16200) /BCH
	Constellation	QPSK ~ 4096-NUQAM for AWGN, Rician and Rayleigh QPSK ~ 256-NUQAM for TU-6

2.3.2 Computer simulation

The computer simulations were accomplished by an extensive, physical layer end-to-end simulator. The simulator was fully compliant with the ATSC 3.0 standard but assumed perfect synchronization, phase-noise-free demodulation, perfect clock recovery, and ideal channel estimation. In addition, the LDPC code decoding submodule applied the sum-product algorithm, which is known as the best-accurate, high-complexity algorithm. Hence, the computer simulation results were considered the theoretical limits that each ModCod combination in ATSC 3.0 can achieve.

The required SNRs were measured at the minimum SNR point where quasi-error-free (QEF) decoding was guaranteed. The QEF criterion herein refers to the state when frame error rate (FER) lies below 10^{-4}, equivalently, the state with bit error rate (BER) $\leq 10^{-6}$. The SNR levels were measured over a 6 MHz noise bandwidth.

2.3.3 Laboratory test

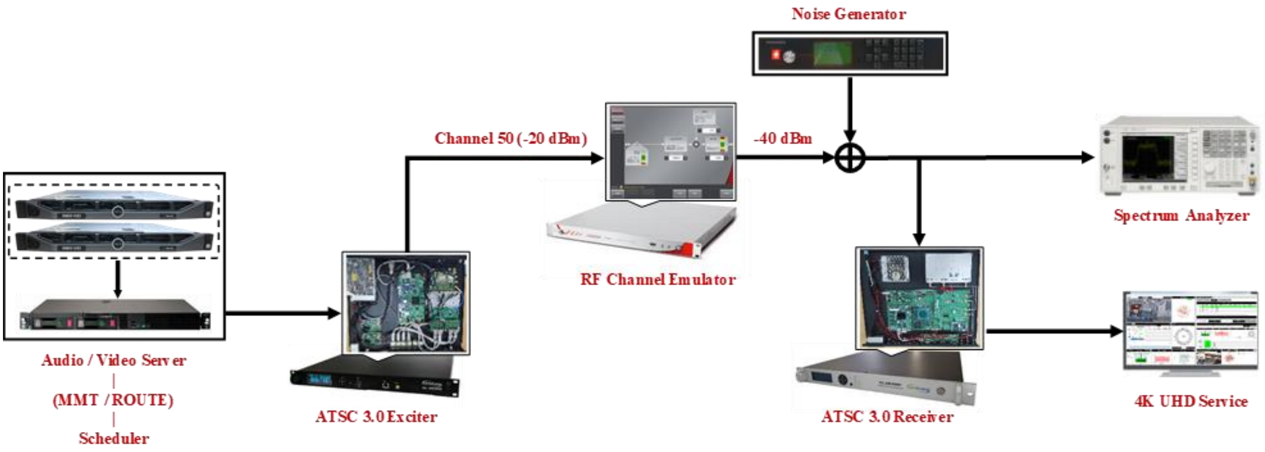
The laboratory tests were based on the off-the-shelf exciter and professional receiver fully compliant with the ATSC 3.0 physical layer standards. Figure 43 illustrates the end-to-end testbed system designed for laboratory tests. The experiments were conducted by injecting artificial noise signals incrementally into the ATSC 3.0 radio signals received at the professional receiver until the QEF state was lost. Every measurement was obtained in the 6 MHz-wide radio band of Channel 50, centred at 689 MHz.

The professional receiver accomplished the synchronization by using a cross-correlation scheme and applied the discrete Fourier transformation (DFT)-based algorithm for channel estimation. For LDPC code decoding, the scaled min-sum algorithm was employed. To avoid possible hardware-limited performance loss that can appear at high operating SNR test cases, such as 4k-NUC configurations, 16-bit high-resolution analogue-to-digital converters (ADCs) were used, ensuring a wider dynamic range.

As with the computer simulations, the required SNRs were measured at FER = 10^{-4} (BER = 10^{-6}). For calculating the error rate, simple syndrome checks were applied over the received LDPC codewords.

FIGURE 43

ATSC 3.0 laboratory test configuration



2.3.4 Field test

The field tests took place in Jeju Island, Republic of Korea, and the studio and transmit system were constructed at the Jeju Techno Park building therein. The transmit tower was deployed at (33˚27' 03.37" N, 126˚34' 18.96" E), 357 m above mean sea level. Additionally, the antenna was 21 m above ground level supported by the building and tower structure. The net effective isotropic radiated power (EIRP) of the broadcast signal was 1000 W, and the signals were transmitted over Channel 50 (centered at 689 MHz).

The field evaluations shared the same ATSC 3.0 hardware systems (e.g. exciter, receiver, noise generator, and spectrum analyzer) with the laboratory test. Figure 44 shows the transmitter and field measurement facilities employed in the experiments. The measurement procedure was driven similarly to Fig. 43 that described the laboratory tests, while the field experiments dealt with the real, air interface channels. Figure 45 portrays the receive-end measurement system exploited in this field experiment. For signal reception, a Yagi antenna with 11 dB gain was used, which was raised 9 m above the ground during the measurements. As shown in Fig. 45, a chain of measurement apparatus, including a professional receiver, noise generator, spectrum analyzer, were integrated into a vehicle-type platform. The measurement data were gathered from various locations over Jeju City and averaged to obtain the expected performance subjected to each channel type, i.e. AWGN-like, Rician-like, and Rayleigh-like.

Similarly, the required SNRs were measured at FER = 10^{-4} (BER = 10^{-6}), over a 6 MHz noise bandwidth. The syndrome check method was applied to find whether the LDPC codeword was decoded successfully.

FIGURE 44

ATSC 3.0 field test configuration – Transmitter facilities

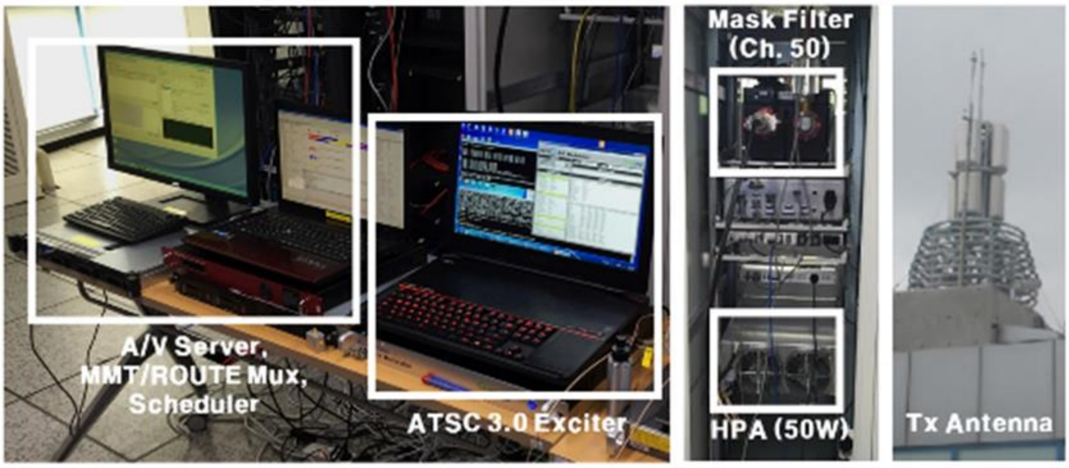


FIGURE 45

ATSC 3.0 field test configuration – Field measurement facilities

2.3.5 Experiment results: data

The system performance results measured under AWGN, Rician, and Rayleigh channels are shown in Table 11, Table 12 and Table 13, respectively.

TABLE 11

Required C/N for BER = 10^{-6} after LDPC and BCH decoding under AWGN channel

	LDPC Code length, bits		**2/15**	**3/15**	**4/15**	**5/15**	**6/15**	**7/15**	**8/15**	**9/15**	**10/15**	**11/15**	**12/15**	**13/15**
QPSK	64 800	Lab test	−4.0	−3.1	−2.0	−1.0	0.5	0.9	2.0	2.8	3.7	4.2	5.1	6.0
		Simulation	−6.1	−4.2	−2.8	−1.6	−0.4	0.4	1.3	2.1	2.9	3.7	4.6	5.6
		Field test	−3.9	−2.9	−1.9	−0.7	0.7	1.1	2.2	2.9	3.9	4.4	5.3	6.2
	16 200	Lab test	−4.2	−2.8	−1.6	−0.7	0.7	1.4	2.1	2.8	3.7	4.2	5.1	6.1
		Simulation	−5.5	−3.7	−2.3	−1.2	−0.2	0.6	1.5	2.3	3.1	3.9	4.8	5.8
		Field test	−4.1	−2.7	−1.5	−0.5	0.9	1.6	2.3	2.9	3.9	4.5	5.3	6.3
16-NUQAM	64 800	Lab test	−1.8	0.7	2.1	3.6	5.5	5.9	7.2	8.3	9.2	10.1	11.1	12.3
		Simulation	−2.6	−0.1	1.6	2.9	4.4	5.4	6.5	7.5	8.5	9.6	10.7	11.9
		Field test	−1.6	0.9	2.4	3.7	5.7	6.1	7.3	8.5	9.4	10.5	11.4	12.6
	16 200	Lab test	−1.4	1.0	2.6	3.8	5.5	6.3	7.4	8.3	9.4	10.2	11.3	12.5
		Simulation	−2.1	0.4	2.0	3.3	4.6	5.7	6.6	7.7	8.7	9.8	10.9	12.2
		Field test	−1.3	1.2	2.9	3.9	5.8	6.5	7.6	8.6	9.6	10.5	11.8	12.8
64-NUQAM	64 800	Lab test	0.5	3.0	4.9	6.5	8.9	9.5	11.3	12.6	13.8	15.0	16.3	17.6
		Simulation	−0.2	2.4	4.3	6.1	7.8	9.1	10.5	11.7	13.0	14.4	15.7	17.3
		Field test	0.6	3.2	5.2	6.9	9.2	9.6	11.4	12.8	13.9	15.2	16.6	17.7
	16 200	Lab test	0.9	3.5	5.3	6.9	9.1	10.4	11.7	12.7	14.0	15.1	16.4	17.9
		Simulation	0.4	2.8	4.7	6.8	8.1	9.5	10.7	12.0	13.2	14.7	16.0	17.4
		Field test	1.2	3.7	5.5	7.1	9.3	10.6	11.9	12.9	14.2	15.5	16.5	18.1
256-NUQAM	64 800	Lab test	2.3	4.8	7.2	9.1	11.7	12.7	14.9	16.5	18.3	19.7	21.3	23.0
		Simulation	1.7	4.4	6.7	8.7	10.9	12.2	14.1	15.7	17.3	18.9	20.6	22.4
		Field test	2.5	5.0	7.3	9.3	11.8	12.9	15.0	16.8	18.5	19.9	21.6	23.4
	16 200	Lab test	2.7	5.3	7.8	9.5	11.8	13.8	15.4	16.6	18.4	19.8	21.5	23.3
		Simulation	2.4	4.8	7.2	9.0	11.1	12.8	14.4	16.1	17.5	19.2	20.9	22.8
		Field test	2.9	5.6	8.1	9.8	12.1	14.1	15.6	16.8	18.5	19.9	21.7	23.4
1024-NUQAM	64 800	Lab test	3.8	6.8	9.4	11.7	14.4	16.0	18.5	20.6	22.5	25.3	26.4	28.4
		Simulation	3.4	6.3	8.9	11.2	13.8	15.4	17.7	19.7	21.6	23.6	25.7	27.8
		Field test	4.1	7.2	9.7	11.9	14.5	16.4	18.7	20.8	22.8	25.2	26.6	28.5
4096-NUQAM	64 800	Lab test	5.2	8.5	11.5	14.1	17.0	19.1	21.7	24.0	26.5	28.7	30.8	33.4
		Simulation	4.7	8.0	10.8	13.6	16.3	18.3	20.9	23.3	25.8	28.1	30.5	33.1
		Field test	5.4	8.8	11.9	14.2	17.1	19.3	22.1	24.2	26.7	28.9	31.5	34.0

TABLE 12

Required C/N for BER = 10^{-6} after LDPC and BCH decoding under Rician (DVB-F1) channel

			2/15	**3/15**	**4/15**	**5/15**	**6/15**	**7/15**	**8/15**	**9/15**	**10/15**	**11/15**	**12/15**	**13/15**
QPSK	64800	Lab test	−4.3	−2.9	−1.8	−0.8	0.9	1.2	2.4	3.2	4.1	4.7	5.7	6.8
		Simulation	−6.0	−4.2	−2.7	−1.5	−0.2	0.7	1.6	2.5	3.4	4.2	5.2	6.4
		Field test	−3.7	−2.3	−1.2	0.0	1.4	2.1	3.2	4.2	5.1	5.8	7.0	8.7
	16200	Lab test	−3.9	−2.7	−1.4	−0.4	1.1	1.7	2.5	3.2	4.2	4.8	5.8	7.0
		Simulation	−5.5	−3.6	−2.2	−1.1	0.1	1.0	1.8	2.7	3.5	4.4	5.4	6.6
		Field test	−3.6	−2.1	−0.9	0.4	1.8	2.3	3.2	3.9	5.0	6.1	7.2	8.5
16-NUQAM	64800	Lab test	−1.6	0.9	2.4	3.8	5.8	6.2	7.7	8.9	9.8	10.8	11.9	13.1
		Simulation	−2.5	0.1	1.8	3.2	4.7	5.6	6.8	7.9	9.0	10.1	11.2	12.6
		Field test	−1.0	1.5	2.7	4.5	6.1	6.9	8.6	9.9	10.6	11.8	13.1	14.4
	16200	Lab test	−1.1	1.1	2.9	4.1	6.0	6.9	7.9	8.8	9.9	10.9	11.9	13.4
		Simulation	−2.0	0.6	2.2	3.6	4.9	5.9	7.0	8.1	9.2	10.3	11.4	12.9
		Field test	−0.5	1.8	3.7	4.8	6.7	7.5	8.6	9.8	11.3	12.2	13.6	14.9
64-NUQAM	64800	Lab test	0.7	3.3	5.1	7.0	9.4	10.0	11.9	13.2	14.5	15.7	17.1	18.6
		Simulation	0.1	2.6	4.6	6.4	8.2	9.3	10.9	12.1	13.5	14.9	16.2	17.8
		Field test	1.3	3.8	5.9	7.5	10.0	10.7	12.4	14.0	15.3	16.4	18.0	19.5
	16200	Lab test	1.2	3.8	5.7	7.2	9.6	11.0	12.2	13.4	14.6	15.8	17.2	18.7
		Simulation	0.6	3.1	5.1	7.2	8.5	9.9	11.1	12.4	13.7	15.1	16.5	18.1
		Field test	2.0	4.5	6.6	8.1	10.5	11.8	13.1	14.5	15.7	17.2	18.7	20.5
256-NUQAM	64800	Lab test	2.6	5.2	7.6	9.6	12.3	13.3	15.6	17.1	19.1	20.2	21.8	23.5
		Simulation	2.0	4.7	7.0	9.0	11.2	12.6	14.5	16.1	17.7	19.4	21.0	22.9
		Field test	3.3	6.3	8.3	10.4	13.1	14.1	16.5	18.1	19.5	21.3	23.1	24.8
	16200	Lab test	3.1	5.8	8.3	10.0	12.6	14.4	16.3	17.3	18.8	20.3	21.9	23.8
		Simulation	2.5	5.2	7.6	9.4	11.4	13.1	14.8	16.5	18.0	19.7	21.3	23.3
		Field test	3.9	6.6	9.1	10.9	13.4	15.6	17.3	18.1	20.2	21.5	23.3	25.2
1024-NUQAM	64800	Lab test	4.2	7.2	9.9	12.2	15.0	16.7	18.9	21.0	23.0	25.9	27.6	29.7
		Simulation	3.5	6.6	9.3	11.6	14.2	15.8	18.0	20.2	22.0	24.1	26.2	28.3
		Field test	5.1	8.5	10.9	13.2	15.9	17.6	20.0	22.2	23.9	26.5	28.3	30.8
4096-NUQAM	64800	Lab test	5.6	8.9	12.1	14.8	17.4	19.9	22.2	25.0	27.8	29.9	32.9	35.8
		Simulation	5.0	8.3	11.2	14.0	16.7	18.8	21.4	23.8	26.2	28.4	31.0	33.5
		Field test	6.6	9.6	13.1	15.8	18.7	21.0	23.4	26.0	28.9	31.0	33.9	37.1

TABLE 13

Required *C*/*N* for BER = 10^{-6} after LDPC and BCH decoding under Rayleigh (DVB-P1) channel

			2/15	**3/15**	**4/15**	**5/15**	**6/15**	**7/15**	**8/15**	**9/15**	**10/15**	**11/15**	**12/15**	**13/15**
QPSK	64800	Lab test	−3.1	−1.8	−0.4	1.1	2.9	3.1	4.4	5.6	6.6	7.9	9.7	12.0
		Simulation	−5.7	−3.7	−2.0	−0.6	0.8	1.8	3.2	4.3	5.5	6.8	8.5	10.7
		Field test	−3.9	−2.5	−1.0	0.1	1.7	2.2	3.5	4.6	5.6	6.6	8.3	10.1
	16200	Lab test	−3.4	−1.4	0.2	1.6	3.0	3.5	4.8	5.7	6.9	8.1	10.0	12.6
		Simulation	−5.1	−3.1	−1.5	−0.2	1.0	2.3	3.3	4.5	5.7	7.2	8.9	11.2
		Field test	−4.0	−2.1	−0.7	0.4	1.8	2.3	3.3	4.4	5.6	6.5	8.5	10.6
16-NUQAM	64800	Lab test	−0.1	2.6	3.7	5.0	7.3	7.9	9.6	11.1	12.5	13.6	15.4	17.7
		Simulation	−1.9	0.7	2.6	4.2	5.9	7.1	8.5	9.8	11.3	12.7	14.3	16.6
		Field test	−1.2	1.6	2.9	4.4	6.5	7.1	8.7	10.2	11.3	12.0	14.2	15.7
	16200	Lab test	0.5	2.8	4.1	5.7	7.5	8.6	9.8	11.2	12.6	13.9	15.7	18.2
		Simulation	−1.2	1.3	3.3	4.6	6.3	7.5	8.8	10.1	11.5	13.0	14.7	17.0
		Field test	−0.5	1.8	3.2	4.6	6.3	7.5	8.7	10.0	11.2	12.5	14.1	16.5
64-NUQAM	64800	Lab test	2.7	4.4	6.5	8.4	11.0	11.8	13.7	15.4	16.9	18.4	20.3	22.7
		Simulation	0.8	3.5	5.8	7.6	9.8	11.1	12.7	14.1	15.6	17.4	19.2	22.6
		Field test	1.6	3.7	5.7	7.8	9.9	10.7	13.0	14.6	15.9	16.6	18.5	21.1
	16200	Lab test	2.9	4.9	7.1	8.9	11.2	12.7	14.3	15.5	17.0	18.5	20.5	23.2
		Simulation	1.5	4.1	6.4	8.1	10.0	11.5	13.0	14.4	15.9	17.6	19.5	22.0
		Field test	1.6	4.0	6.0	8.1	10.1	11.5	13.2	14.4	16.0	17.4	19.6	21.7
256-NUQAM	64800	Lab test	4.1	6.8	9.2	11.3	14.2	15.3	17.7	19.3	21.3	23.0	24.2	27.5
		Simulation	2.8	5.8	8.3	10.5	13.0	14.4	16.4	18.1	20.0	21.7	23.8	26.4
		Field test	2.9	6.0	8.1	10.5	13.3	14.5	16.4	18.0	20.3	21.8	23.2	26.0
	16200	Lab test	4.5	7.4	10.0	11.9	14.3	16.7	18.4	19.4	21.4	23.1	24.5	28.0
		Simulation	3.6	6.5	9.1	11.1	13.3	15.1	16.8	18.6	20.2	22.2	24.2	26.8
		Field test	3.5	6.6	9.2	11.0	13.5	15.4	17.3	18.3	20.2	21.8	23.8	26.4
1024-NUQAM	64800	Lab test	5.4	8.8	11.6	14.0	17.1	18.7	21.3	23.7	25.9	27.7	29.6	32.2
		Simulation	4.7	7.9	10.9	13.1	15.9	17.7	20.2	22.4	24.3	26.4	28.6	31.3
		Field test	5.0	8.2	11.1	12.9	16.1	17.9	20.2	22.8	24.8	26.8	29.6	32.0
4096-NUQAM	64800	Lab test	6.9	10.6	13.7	16.5	20.0	22.0	24.6	27.8	29.8	32.5	35.2	38.0
		Simulation	6.1	9.8	12.9	15.7	18.9	20.9	23.6	26.4	28.6	31.1	33.6	36.3
		Field test	6.5	10.0	12.9	16.1	18.9	21.0	23.9	26.9	29.5	32.5	35.8	38.9

2.3.6 Summary of results

For different ATSC 3.0 modulation and code combinations, the results from computer simulation, laboratory test, and field test are generally well-aligned for each of the AWGN, Rician, and Rayleigh channels. The overall tests demonstrated that the ATSC 3.0 physical layer is fully capable of handling various real field environments, and can provide a high degree of flexibility ranging from ultra-robust service (negative SNR operation with QPSK and 2/15 LDPC code) to very high-throughput service (over 50 Mbit/s with 4096-NUC and 13/15 LDPC code in a 6-MHz SISO channel.

The tests demonstrate that the long-length 64800-bit LDPC codes have an advantage of about 0.2 to 0.7 dB over the short-length 16200-bit LDPC codes. Since the short-length LDPC codes have lower decoding complexity and power consumption, they could be recommended for mobile and handheld applications.

2.4 ATSC 3.0 LDM/TDM Performance Comparison Field Test

2.4.1 Overview

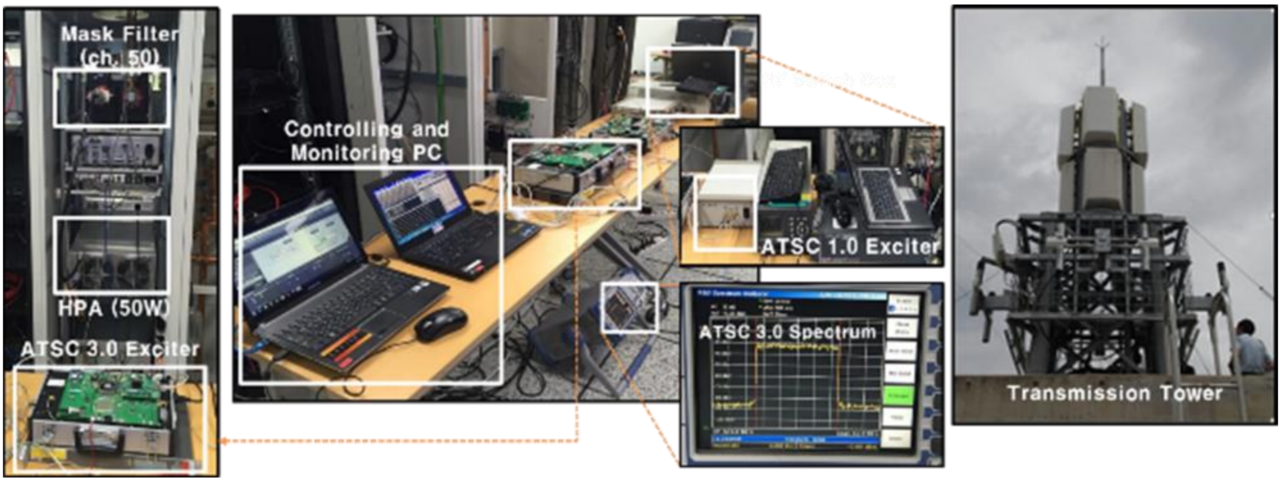
The ATSC 3.0 physical layer offers three different types of multiplexing schemes for providing multiple broadcasting content simultaneously in a single RF channel. Among them, layered division multiplexing (LDM), newly introduced in ATSC 3.0, provides significant gain over the traditional multiplexing techniques such as time division multiplexing (TDM) or frequency division multiplexing (FDM). In order to provide a detailed performance comparison of LDM and TDM technologies, extensive field tests were conducted in various reception scenarios such as rooftop, indoor, and mobile reception. In addition, the ATSC 1.0 DTV signal was also tested under rooftop and indoor reception environments so as to compare with the ATSC 3.0-based LDM and TDM signals.

2.4.2 Test facilities and parameters

The field tests were conducted on Jeju Island, South Korea, and the transmitter facilities were installed at the Jeju Techno Park building as shown in Fig. 46. The transmit tower was deployed at 357 m above mean sea level. The height of transmitting antenna was about 21 m above ground level and the transmission power was 520 watts effective isotropic radiated power (EIRP). One of the ATSC 1.0, ATSC 3.0 LDM and ATSC 3.0 TDM signals was selected at any one time, and transmitted over channel 50 (centred at 689 MHz).

FIGURE 46

Transmitter facilities in Jeju Techno Park



At the reception sites, rooftop and mobile tests were conducted using two different test vehicles that were equipped with a 9-metre height Yagi (11 dB gain) antenna and a 2-metre height omni-directional (0 dB gain) antenna (heights above ground level), respectively. Figures 47 and 48 show the two test vehicles equipped with receiving antennas and test equipment inside the vehicles. As shown in Figs 47 and 48, an ATSC 3.0 receiver, a commercial ATSC 1.0 DTV receiver, video monitors, a spectrum analyzer, and a noise generator were installed in the two test vehicles. Each test vehicle was also equipped with a low noise amplifier, in order to receive and analyze the low-power received signal. In the case of the indoor reception test, a 1.5-metre height omni-directional antenna and portable spectrum analyzer were used inside the buildings of each reception site as shown in Fig. 49.

FIGURE 47

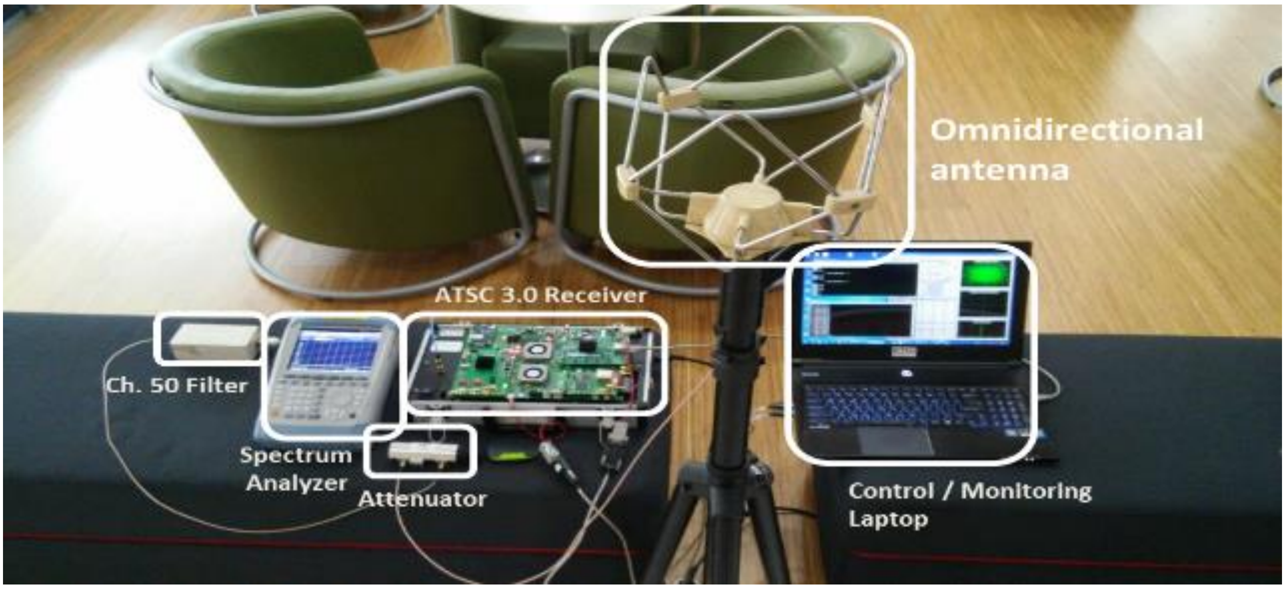
Fixed reception facilities

FIGURE 48

Mobile reception facilities

FIGURE 49

Indoor reception facilities



For the test measurements, the LDM system was configured as a core-layer (CL) signal with data rate of 2.6 Mbit/s and an enhanced-layer (EL) signal with data rate of 19.6 Mbit/s; the TDM system was configured as a first subframe (TDM-Sub1) signal with data rate of 2.7 Mbit/s and a second subframe (TDM-Sub2) signal with data rate of 19.9 Mbit/s. Table 14 presents the detailed system parameter configurations used in this field test. The performance of the LDM and TDM systems was verified by measuring the following parameters: the reception power (or the field strength) for all scenarios, the threshold of visibility (TOV) of errors in fixed rooftop reception, the marginal (minimal) reception power in indoor reception, and the erroneous second ratio (ESR5) in mobile reception.

TABLE 14

System parameters for field test

		LDM	TDM
Frame length (symbol aligned mode)		251.33 ms	
Occupied BW		5.832844 MHz	
RF channel		50 (centered at 689 MHz)	
Preamble	FFT Size	16K	
	Guard interval	148.15 μs	
	Pilot Pattern	SP_Dx = 6	
	Signaling Protection	L1-Basic/Detail Mode 1	
	# of Preamble Symbols	1	
Payload (HD)	HD service	Core layer	
	FFT Size	16K	
	Guard interval	148.15 μs	
	Pilot pattern	SP_Dx = 6, SP_Dy = 2	
	Pilot boosting	1.6 dB	
	# of payload symbols	98	
	Time interleaver	CTI (1024 depth)	CTI (1024 depth)

TABLE 14 (*end*)

	Frequency interleaver	On	On
	Inner/outer code	4/15-LDPC(64800)/BCH	11/15-LDPC(64800)/BCH
	Constellation	QPSK	QPSK
	Data rate	2.5905 Mbit/s	2.7457 Mbit/s
Payload (UHD)	UHD service	Enhanced layer	2nd subframe
	FFT Size	16K	32K
	Guard interval	148.15 µs	148.15 µs
	Pilot pattern	SP_Dx = 6, SP_Dy = 2	SP_Dx = 12, SP_Dy = 2
	Pilot boosting	1.6 dB	3.2 dB
	# of payload symbols	98	30
	Time interleaver	CTI (1024 depth)	CTI (1024 depth)
	Frequency interleaver	On	On
	Inner/outer code	10/15-LDPC(64800)/BCH	12/15-LDPC(64800)/BCH
	Constellation	64-NUC	256-NUC
	Data rate	19.5596 Mbit/s	19.8971 Mbit/s
	Injection level	4 dB	N/A

2.4.3 Field measurements

2.4.3.1 Fixed rooftop reception

For fixed rooftop reception, forty test locations in Jeju City and its surrounding area were selected as shown in Fig. 50. At each reception site, the reception power and TOV were measured. Note that TOV is the minimum signal-to-noise ratio that is required to receive signals without any visual errors; which is determined by observing video quality in a 60-second interval during each test. If the LDM, TDM, and ATSC 1.0 signals have one or more error hits during the 60 second interval, the reception is recorded as failed reception. Figure 59 shows the reception power at each test site. In this fixed rooftop reception test, the maximum and minimum reception powers were −48.57 dBm and −85.4 dBm, respectively, and the received power averaged over the forty test locations was −63.53 dBm.

FIGURE 50

Rooftop test locations and measured reception power

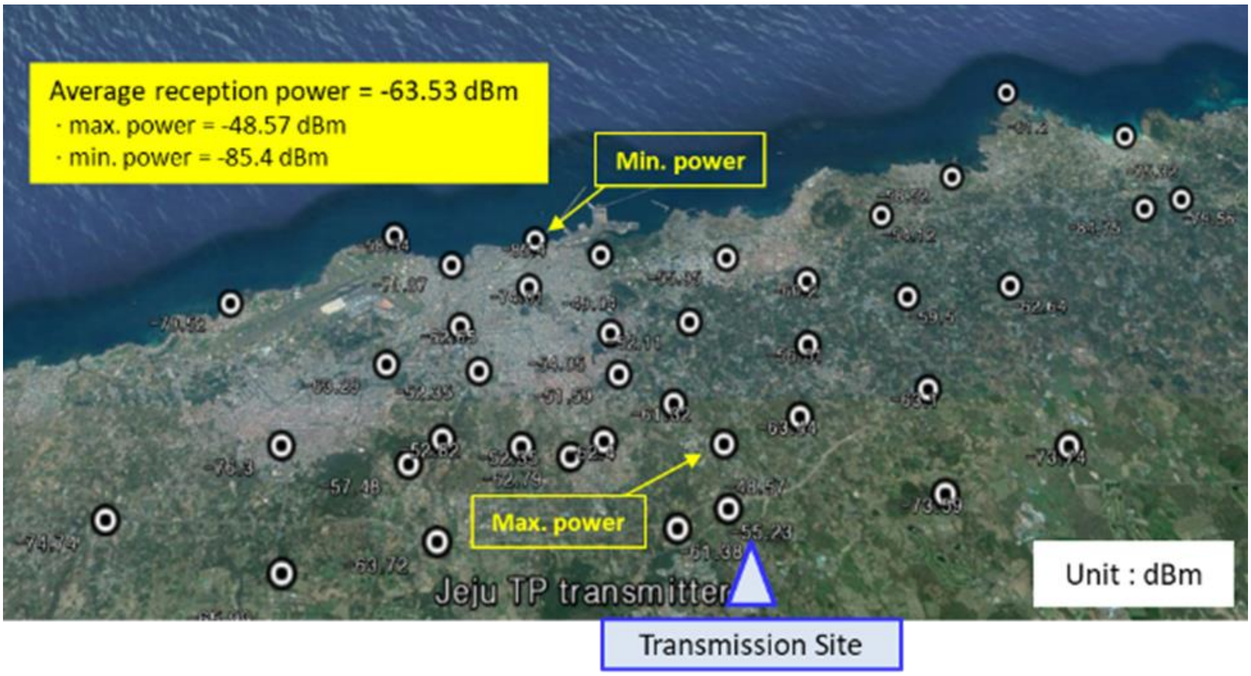
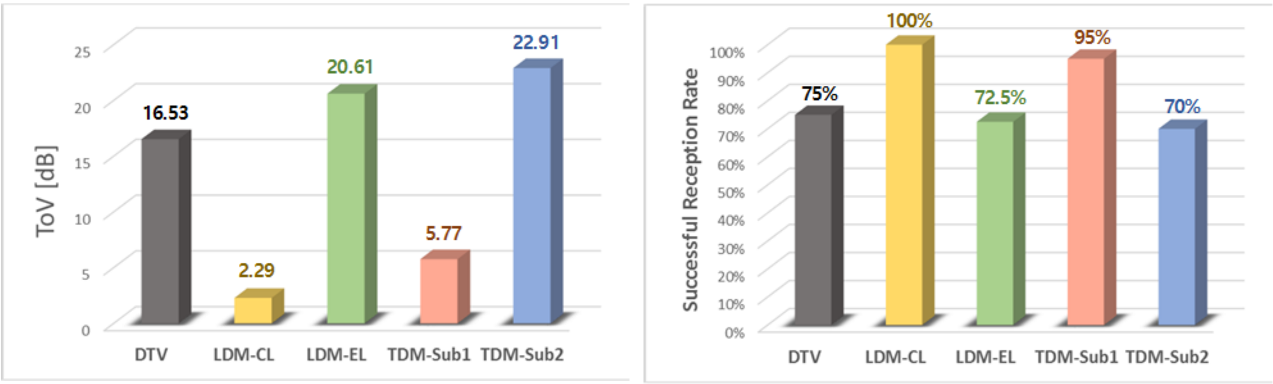


Figure 51(a) shows the average TOV under fixed rooftop reception conditions. According to the measurements, the average TOV values of ATSC 1.0, LDM-CL, LDM-EL, TDM-Sub1, and TDM-Sub2 signals were 16.53 dB, 2.29 dB, 20.61 dB, 5.77 dB and 22.91 dB, respectively. This shows that the LDM-CL and EL signals were 3.48 dB and 2.3 dB more robust than the TDM-Sub1 and Sub2 signals, respectively, so the total LDM gain was 5.78 dB.

Figure 51(b) shows the successful reception rates in fixed rooftop reception conditions. Since the LDM-CL signal was 3.48 dB more robust than the TDM-sub1 signal, and 14.24 dB more robust than the ATSC 1.0 signal, the successful reception rate increased from 95% to 100% and from 75% to 100%, respectively. Similarly, the successful reception rate of LDM-EL increased from 70% to 72.5%.

FIGURE 51



(a) Average TOV for fixed rooftop reception

(b) Successful reception rates for fixed rooftop reception

2.4.3.2 Indoor reception

For indoor reception, twenty test locations were selected in Jeju City and its surrounding area as shown in Fig. 52. At each reception site, the reception power and marginal reception power were measured. The marginal reception power indicates the minimum reception power that is required to receive without any error after attenuating the input signal, and this measurement is determined by observing video quality during a 60-second interval. Figure 52 shows the reception power received by a 1.5-metre height omni-directional antenna at each test site. In this indoor reception test, the maximum and minimum reception powers were −64.9 dBm and −89.5 dBm, respectively, and the received power averaged over the twenty sites was −82.33 dBm.

FIGURE 52

Indoor test locations and measured reception power

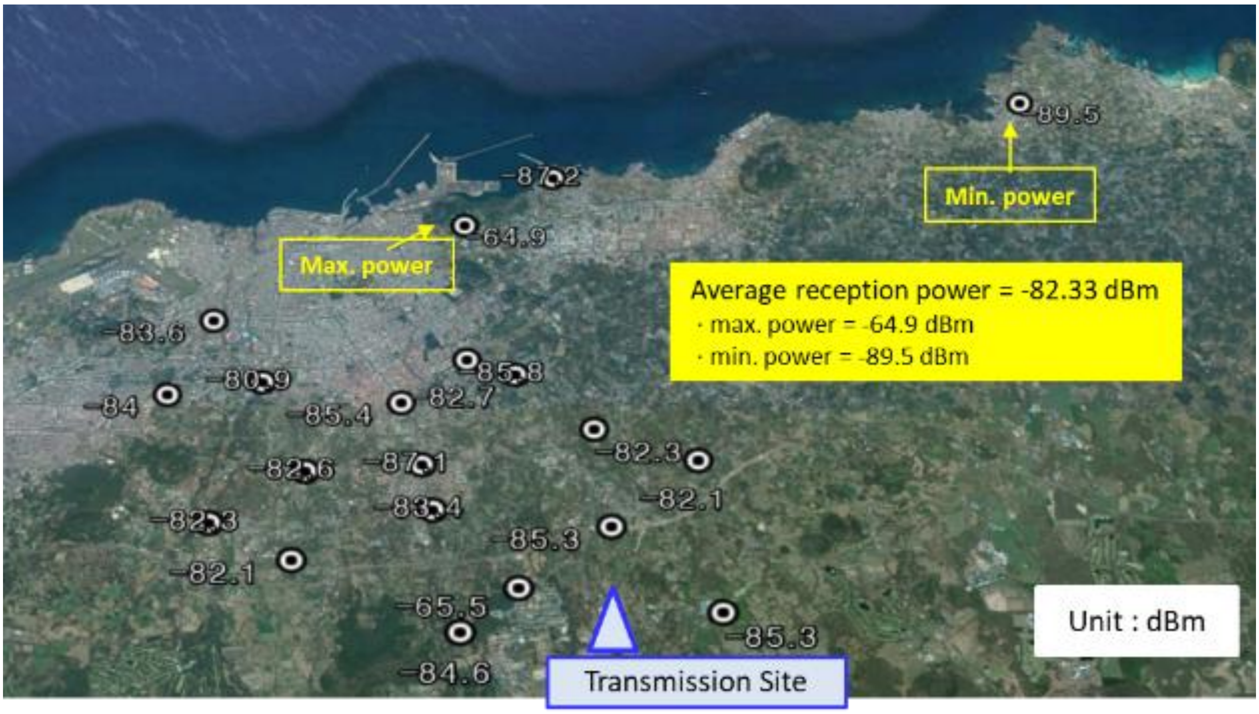
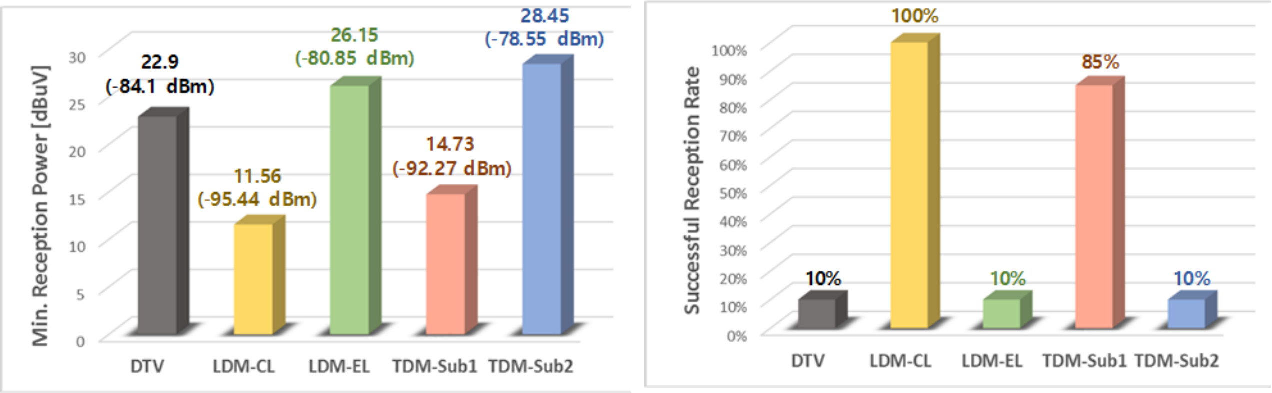


Figure 53(a) shows the reception power for indoor reception. According to the measurements, the average marginal reception powers of the ATSC 1.0, LDM-CL, LDM-EL, TDM-Sub1, and TDM-Sub2 signals were −84.1 dBm, −95.44 dBm, −80.85 dBm, −92.29 dBm and −78.55 dBm, respectively. The LDM-CL and EL signals were 3.17 dB and 2.3 dB more robust than the TDM-Sub1 and Sub2 signals, respectively, so the total LDM gain over TDM was 5.47 dB.

Figure 53(b) shows the successful reception rate for indoor reception. According to the measurements, the successful reception rates of ATSC 1.0, LDM-CL, LDM-EL, TDM-Sub1, and TDM-Sub2 signals were 10%, 100%, 10%, 85% and 10%, respectively. The successful reception rate of the LDM-CL signal was greatly improved from 10% to 100% compared to the ATSC 1.0 signal, and from 85% to 100% compared to the TDM-Sub1 signal due to the lowest operating SNR. Note that these LDM-EL, TDM-Sub2, and ATSC 1.0 signals are intended for rooftop reception, and therefore, they are not suitable for the use cases of indoor reception.

FIGURE 53



(a) Average marginal reception power for indoor reception

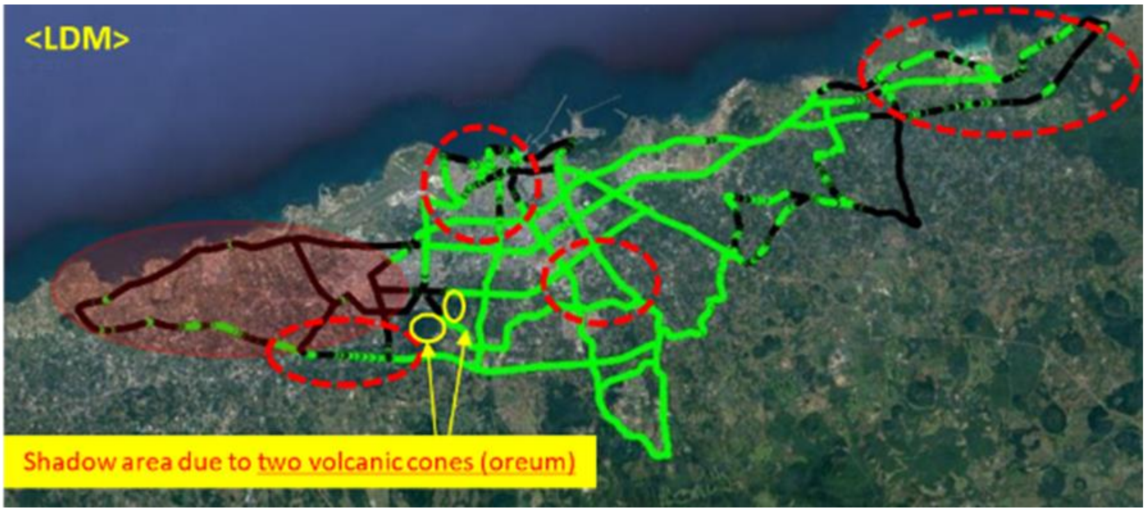
(b) Successful reception rates for indoor reception

2.4.3.3 Mobile reception

The mobile reception test was conducted in the selected routes of downtown and surrounding areas in Jeju City as shown in Fig. 54. While the mobile test vehicle was taking the selected routes, measurements such as the reception power, determination of reception success or failure, and speed of the test vehicle were collected every second. In the mobile measurements, only LDM-CL and TDM-Sub1 were tested and compared with each other because they were intended for a mobile HD service. When 20 seconds of data were accumulated, ESR5 was computed, which corresponded to 95% successful reception probability in mobile environments. Figures 54(a) and (b) show the measured results of reception success or failure of LDM-CL and TDM-Sub1 signals in the mobile test routes, respectively. In Fig. 54, the green and black colours represent successful and failed reception areas, respectively. Note that if there was more than one frame error in one second, reception failure was recorded. As shown in Fig. 54, the coverage of the LDM-CL signal was quite wider than that of the TDM-Sub1 signal.

FIGURE 54

(a) Mobile reception test results for LDM (Green colour: reception success, Black colour: reception fail)



(b) Mobile reception test results for TDM (Green color: reception success, Black color: reception fail)

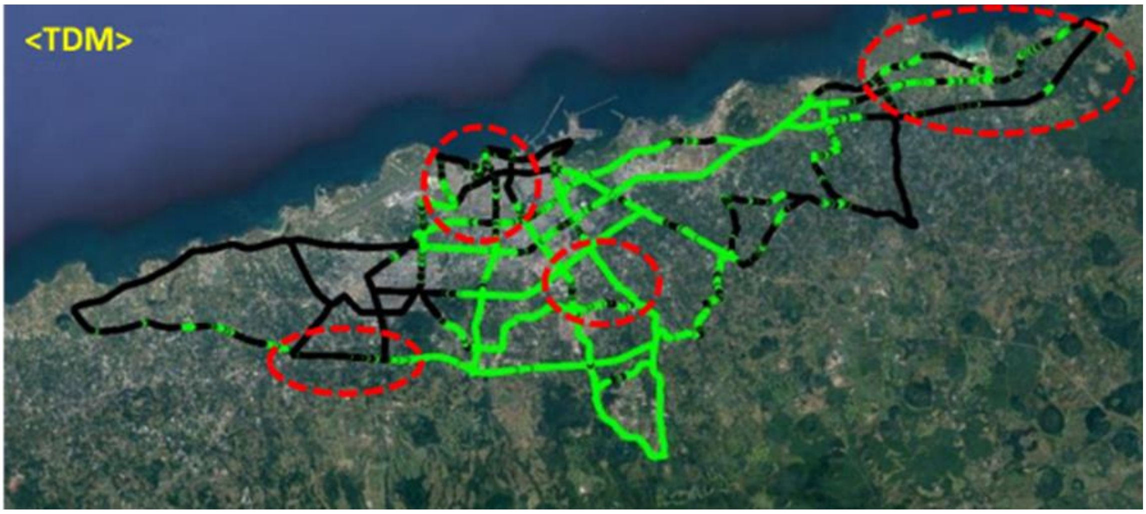
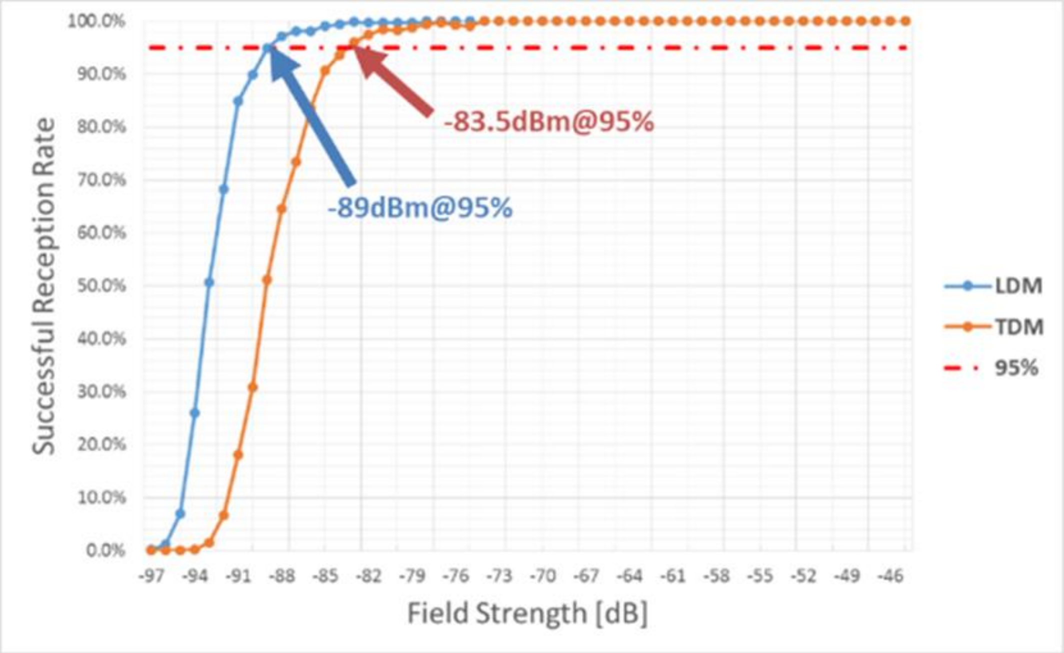


Figure 55 shows the successful reception rate versus reception power for the LDM-CL and TDM-Sub1 signals. According to Fig. 55, when reception power was greater than −89 dBm and −83.5 dBm, respectively, the LDM-CL and TDM-Sub1 signals were successfully received over 95% of time, which corresponded to a 1 second error in a 20 second interval, i.e. the ESR5 criterion. As shown in Fig. 55, the LDM-CL signal has 5.5 dB performance gain over the TDM-Sub1 signal in the mobile environment.

FIGURE 55

Successful reception rate versus reception power for LDM-CL and TDM_Sub1 signals in mobile reception



2.4.4 Summary of field test results

Field test parameters were varied to compare ATSC 3.0 LDM and TDM in the following scenarios: TOV in fixed reception, marginal reception power in indoor reception, and ESR5 in mobile reception. First, for fixed rooftop reception, the LDM-CL and EL signals had 3.48 dB and 2.3 dB gain compared to the TDM-Sub1 and Sub2 signals, respectively, with a total LDM gain of 5.78 dB. Because of this large gain, the successful reception ratio of the LDM configuration was higher than that of TDM.

Second, for indoor reception, the LDM-CL and EL signals had 3.17 dB and 2.3 dB gain compared to the TDM-Sub1 and Sub2 signals, respectively, and the total LDM gain over TDM was 5.47 dB. Due to this gain, LDM is seen to provide better feasibility for indoor reception than TDM. Finally, for mobile reception, the LDM-CL had 5.5 dB better performance than TDM, considering the ESR5 criterion.

The field test results demonstrate that, since LDM has around 5 to 6 dB gain over TDM, the LDM mode can provide a more efficient method to deliver a variety of services (e.g. mobile, indoor and stationary services) with different robustness within a single RF channel. Furthermore, it is also demonstrated that, in case of indoor and mobile reception, since there exist large penetration and antenna losses which weaken signal field strength considerably, LDM should be considered over TDM.

Particular configurations of LDM can therefore be expected to achieve an improved efficiency of bit delivery when compared to TDM alone. This also suggests the higher capability of LDM over TDM in carrying multiple services, with each service optimally configured for robustness and payload.

2.5 UHDTV terrestrial SFN trial based on ATSC 3.0

2.5.1 Overview of ATSC 3.0 SFN with MISO, TDCFS

In conventional SFN, separately located transmitters emit identical signals. These signals are independently propagated toward the receiving antenna like the delayed multipath channel to interfere with each other positively or negatively. When two transmitted signals arrive at the receiver with the opposite phase and comparable power almost at the same time, resulting in canceling each other, the reception area generally located in the center of the overlapped area seems to be out of the SFN coverage, or the reception performance probably deteriorates. ATSC 3.0 adopted transmitter diversity code filter sets (TDCFS) as a multiple-input single-output (MISO) SFN to avoid the dropout of the received signal. TDCFS is a linear frequency domain pre-distortion technique applying the transmit linear filter before OFDM waveform generation. While the input of TDCFS is the same for all transmitters, the output has a low cross-correlation to each other. Therefore, the radiated signals are highly likely to arrive in different forms at the receivers. There are three SFN modes in ATSC 3.0 depending on the TDCFS and its filter length: MISO OFF (conventional SFN), MISO 64 (TDCFS with filter length 64), and MISO 256 (TDCFS with filter length 256).

2.5.2 Test facilities and parameters

ATSC 3.0 SFN broadcasting system was verified in real field environments. Two ATSC 3.0 transmission sites were constructed in Jeju city, Republic of Korea. Figure 56 shows the transmission facilities. The distance between the two sites is about 7 km. Tx #1 was a broadcast studio equipped with HD and 4K-UHD encoded media source, ATSC 3.0 multiplexer, ATSC 3.0 broadcast gateway, and transmitter with high power amplifier and spectrum mask. Tx #2 was only equipped with an ATSC 3.0 transmitter and connected with the broadcast gateway by dedicated broadband networks. Since the broadcast gateway and two transmitters were connected with GPS, two transmitters could operate synchronously in the time and frequency domain, composing SFN. ATSC 3.0 multiplexer saved HD and 4K-UHD media encoded following MPEG-H audio codec and HEVC video codec and multiplexed the two media in real-time based on MPEG Media Transport (MMT) or Real-time Object Delivery over Unidirectional Transport (ROUTE) protocol.

FIGURE 56

Two transmission sites in Jeju city and their facilities for ATSC 3.0 SFN broadcasting

In order to broadcast the mobile HD service and fixed 4K-UHD service simultaneously, two physical layer pipes (PLPs) were used, serving different robustness and transmission capacity. Layered division multiplexing (LDM) and time division multiplexing (TDM) schemes were used to combine multiple PLPs in the same RF channel, comparing the receiving performance gain of ATSC 3.0 multiplexing schemes. Table 15 describes the physical layer parameters of ATSC 3.0 SFN field trials for LDM and TDM configurations. PLP0 with a robust modulation and code combination was intended for the mobile HD service, and PLP1 with a high order modulation and code combination was designed for the fixed 4K-UHD service. Therefore, mobile and fixed field trials could have been conducted for ATSC 3.0 SFN broadcasting systems.

TABLE 15

ATSC 3.0 SFN physical layer configuration parameters for field trial

(a) LDM configuration

Frequency used				689 MHz (Ch 50 in Korea)
Channel bandwidth				6 MHz
Preamble parameters	FFT size			16k
	Guard interval			148.15 µs
	Pilot pattern			SP_Dx=6
1st Subframe	Subframe OFDM parameters	FFT size		16k
		Guard interval		148.15 µs
		Pilot pattern		SP6_2
	BICM parameters	PLP0 (core layer)	Inner code	BCH
			Outer code	4/15-LDPC (64800)
			Constellation	QPSK
			Transmission capacity	2.5 Mbit/s
		PLP1 (enhanced layer)	Inner code	BCH
			Outer code	10/15-LDPC (64800)
			Constellation	64-NUC
			Injection level	−4 dB
			Transmission capacity	19.5 Mbit/s
Audio coding				MPEG-H
Video coding				HEVC

TABLE 15 (*end*)

(b) TDM configuration

Frequency used				689 MHz (Ch 50 in Korea)
Channel bandwidth				6 MHz
Preamble parameters	FFT size			8k
	Guard interval			148.15 μs
	Pilot pattern			SP_Dx=3
1st Subframe	Subframe OFDM parameters	FFT size		8k
		Guard interval		148.15 μs
		Pilot pattern		SP6_2
	BICM parameters	PLP0 (core layer)	Inner code	BCH
			Outer code	11/15-LDPC (64800)
			Constellation	QPSK
			Transmission capacity	2.7 Mbit/s
2nd Subframe	Subframe OFDM parameters	FFT size		32k
		Guard interval		148.15 μs
		Pilot pattern		SP12_2
	BICM parameters	PLP0 (core layer)	Inner code	BCH
			Outer code	12/15-LDPC (64800)
			Constellation	256-NUC
			Transmission capacity	19.8 Mbit/s
Audio coding				MPEG-H
Video coding				HEVC

2.5.3 Field measurements

The fixed reception field test was conducted over ten measurement points in the overlapped areas of two transmitters where the two transmitter identification (TxID) signals were distinctively detected. From the detected TxID signals, the arrival timing delay and the power difference could be measured for all measurement points. In addition, the threshold of visibility (ToV) was measured for each combination of two PLPs, two multiplexing schemes, and three SFN modes by adding a noise signal to the received signal. ToV was measured by adding a noise signal to a received signal until forward error correction (FEC) error rate acquired less than 10^{-4}.

Figure 57 shows the locations of measurement points with measured received signal strengths in the dBm scale and two transmission sites. Figure 58 presents the measured time and frequency responses at point 7 for the LDM configuration with three SFN modes. When TDCFS was used, the received signal spread out in the time domain, the distinct regular ripples in MISO OFF were replaced by much more shallow ripples. The longer filter length was used, the fewer nulls were achieved in the frequency domain. Table 16 describes the measured received signal strengths, arrival delays, and ToVs and the calculated averages and successful reception rates. The power imbalances between two received signals from Tx #1 and Tx #2 were in the range of 0 dB to 5 dB. The average ToVs for twelve cases were similar. The highest gain of the transmitter diversity was commonly achieved at measurement point 6, where the two transmitted signals arrived at the receiver almost at the same time, the worst receiving environment in the SFN coverage. The average ToVs of PLP0 and PLP1 of the LDM configuration was less than those of TDM configuration, resulting in multiplexing gain of LDM over TDM remains valid in SFN.

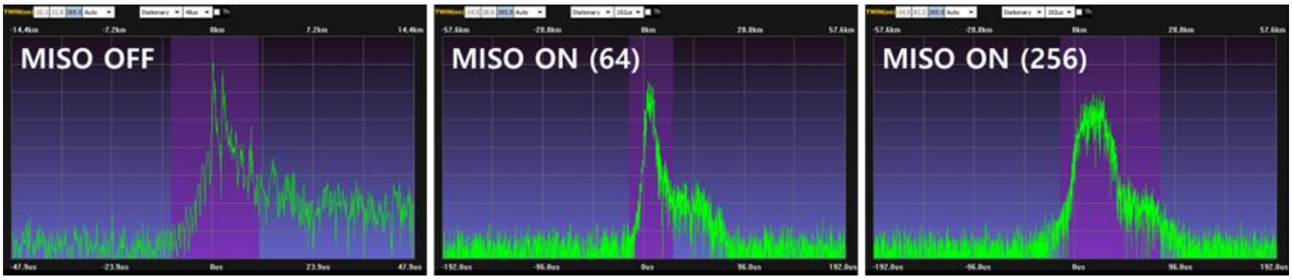
FIGURE 57

Locations of measurement points with measured received signal strength in dBm scale and two transmission sites

FIGURE 58

Measured data at fixed reception point 7

(a) Channel time response (impulse response) of the first subframe of the LDM-configured signal according to SFN modes



(b) Channel frequency response of the first subframe of the LDM-configured signal according to SFN modes

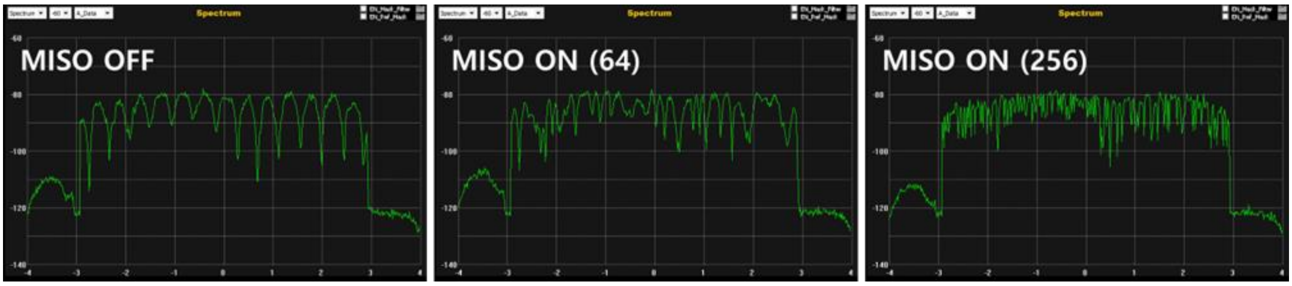


TABLE 16

Fixed reception test results over ten measurement points

	Received Signal Strength (dBm)	Delay (µs)	ToV (dB)											
			LDM						**TDM**					
			PLP 0 (SFN modes)			**PLP 1 (SFN modes)**			**PLP 0 (SFN modes)**			**PLP 1 (SFN modes)**		
			OFF	**64**	**256**	**OFF**	**64**	**256**	**OFF**	**64**	**256**	**OFF**	**64**	**256**
1	−64.34	16.5	6.2	6.3	6.4	26.5	26.1	26.5	12.1	12.2	12.6	28.8	29	29.1
2	−65.81	3.5	3.9	4.5	4.5	23.3	23.9	23.9	9.3	10.4	9.5	25.1	26.5	26.2
3	−69.94	7.1	4.6	4.9	4.9	24.5	24.7	24.4	10.4	11.9	11.9	26.3	26.8	26.7
4	−49.15	12.3	3	3.1	3.6	22	22	22.2	6.7	6.8	7.2	23.3	23.4	23.5
5	−78.51	2.5	4	4.9	4	–	–	–	9.8	11.3	10.4	–	–	–
6	−63.75	0.1	5.1	4.5	3.8	25.3	24.6	24.4	10.2	10	9.6	25.9	25.6	25.6
7	−58.61	2.3	3.8	4.8	4	23.7	24.6	23.7	9.5	10.7	9.5	25.8	26.7	26.6
8	−71.24	4.3	3.9	5.6	4.8	23.1	–	23.5	8.1	11	9.3	–	–	–
9	−78.03	1.4	5.3	5.3	5.1	–	–	–	10.2	11.7	11.7	–	–	–
10	−84.22	4.3	4.6	4.4	4.4	–	–	–	10	10.6	10.8	–	–	–
Average	−68.4	5.43	4.4	4.8	4.5	24.1	24.3	24.1	9.6	10.6	10.2	25.9	26.3	26.3
Successful Reception Rate			100%	100%	100%	70%	60%	70%	100%	100%	100%	60%	60%	60%

Only PLP0 targeted for the mobile HD service was considered in the mobile test. The mobile field test data, including the received signal strength, GPS position, speed, the number of FEC frame errors, and so on, was measured every second. Figures 59(a) and (b) demonstrate the field strength range along the test route. The received signal strength was similar for all six test cases because the test vehicle moved along the same direction. The areas colored red were expected as the coverage edge or shaded area by the hills or mountains. Figures 59(d) and (d) also show the successes and failures of reception along the test route for all six test cases. Green denotes reception with no errors, and black denotes the reception with at least one FEC frame errors. The areas enclosed by pink dotted lines show that the MISO OFF case was achieved more robust reception performance than MISO 64 and MISO 256 cases. The orange dotted circle areas are that MISO 64 and MISO 256 showed better performance than MISO OFF. Unlike the fixed reception test, there were no remarkable differences among the MISO schemes.

FIGURE 59

Mobile field test results along the test routes for three SFN modes

(a) Received signal strength for the LDM configuration

(b) Received signal strength for the TDM configuration

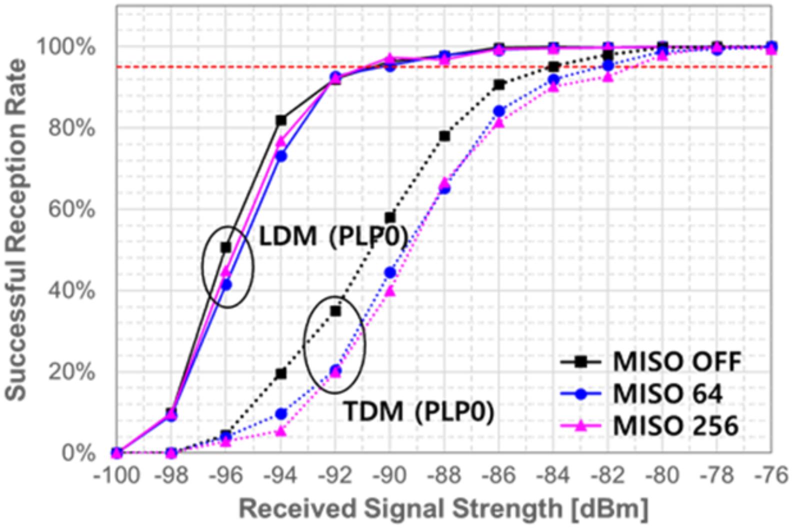
(c) Reception success (green mark) and failure (black mark) for the LDM configuration

(d) Reception success (green mark) and failure (black mark) for the TDM configuration

Figure 60 shows the successful reception rate curves for the six tests. The successful reception rates are all erroneous seconds to all observed seconds, given the received signal strength. For the LDM configuration, the successful reception rates were almost the same among MISO modes. For the TDM configuration, MISO OFF was slightly better than the other two cases. Like the fixed reception test, the LDM reception performance was 6 dB more robust than the TDM cases.

FIGURE 60

Successful reception rate versus received signal strength with 95% successful reception rate line



2.5.4 Summary of test results

The field tests evaluated the effect of transmitter diversity based on the TDCFS scheme in ATSC 3.0 SFN broadcasting. The HD and 4K-UHD services were delivered in two PLPs, which were combined in the same RF channel using LDM and TDM. Depending on combinations of the TDCFS and multiplexing schemes, fixed reception tests were conducted at ten different measurement sites, while the mobile reception tests were conducted along selected mobile testing routes. When the SFN broadcasting system was installed, the field strength was enhanced, especially in the downtown areas of Jeju-City, and the edges of the service coverage were well extended toward the east and west sides without additional frequency resources.

The frequency and time responses of signals received at the same test location were changed by applying MISO based on TDCFS. The testing results showed that, in some cases, SFN with MISO based on the TDCFS scheme was able to prevent performance degradation by reducing the correlation of transmitted signals when two transmitted signals were distinctly visible and serious spectrum ripples were present.

It was also observed that the worst cross-interference might affect the fixed receiving condition more than mobile reception. Most coverage areas, however, are not likely to have the worst channel condition except for the equidistant area from transmitters, where the MISO scheme is not required. However, if broadcasters design their systems to avoid blind areas in the coverage that are hard to predict, it is recommended to configure ATSC 3.0 SFN broadcasts using the MISO scheme.

The ATSC 3.0 standard allows the MISO scheme to be independently applied for each subframe, so that, like the TDM configuration, if different subframes are designed for mobile services and fixed services, one solution would be to adopt MISO for only one of the subframes.

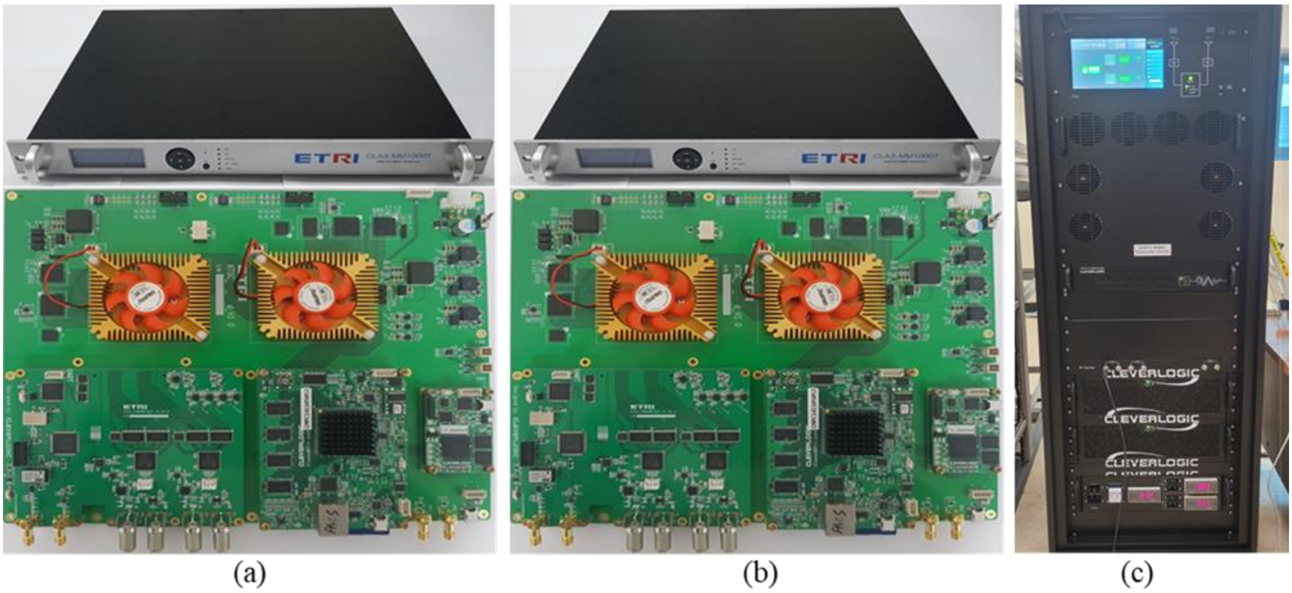
2.6 ATSC 3.0 MIMO 8K-UHD Test

2.6.1 Overview

In 2020, ETRI, KBS, CLEVERLOGIC and AGOS conducted a field trial of the ATSC 3.0 MIMO system for 8K terrestrial broadcasting. A field-programable gate-array (FPGA) based 2x2 MIMO transmitter and receiver were used for the field trial. Figure 61 shows the ATSC 3.0 MIMO modulator(a), demodulator(b), and transmitter(c) used for the field trial.

FIGURE 61

(a) ATSC 3.0 MIMO modulator (b) ATSC 3.0 MIMO demodulator (c) ATSC 3.0 MIMO transmitter



2.6.2 Field trial description

For performance verification in a realistic environment, the field trial was carried out at the transmission site currently used for a UHD broadcasting service. The field trial of the ATSC 3.0 MIMO system was conducted in the north Gyeonggi area of South Korea, which is located on the north side of Seoul and near the military demarcation line. The transmission tower is located at the top of Gamak mountain. The transmission antenna's height is 619 m above mean sea level. For the transmission antennas, commercial panel-type cross-polarized MIMO antennas with 12 dBi gain are installed at the transmission tower. It supports the maximum input power of 200 W, where each polarization has 100 W. The map and Figures of the transmission tower are shown in Fig. 62.

FIGURE 62

ATSC 3.0 MIMO transmission tower

FIGURE 63

ATSC 3.0 MIMO measurement test vehicle

Figure 63 presents the MIMO dedicated test vehicle's external and internal appearance. A dual-polarized antenna is placed at the top of the vehicle. The maximum height of the receiving antenna is 9 m from the ground. The required equipment for receiving and measuring the ATSC 3.0 MIMO signal is deployed inside the vehicle.

TABLE 17

ATSC 3.0 MIMO physical layer configuration parameters for field trial

Configuration		**Config. #1**	**Config. #2**	**Config. #3**	**Config. #4**
Preamble parameters	FFT size	32K	32K	32K	32K
	GI length	55.56 µs (GI2_384)	55.56 µs (GI2_384)	55.56 µs (GI2_384)	55.56 µs (GI2_384)
	Pilot pattern	SP_Dx=32	SP_Dx=32	SP_Dx=32	SP_Dx=32
	Signaling protection	L1-Basic/Detail Mode 1	L1-Basic/Detail Mode 1	L1-Basic/Detail Mode 1	L1-Basic/Detail Mode 1
	# of preamble symbols	1	1	1	1
Payload OFDM parameters	FFT size	32K	32K	32K	32K
	GI length	55.56 µs (GI2_384)	55.56 µs (GI2_384)	55.56 µs (GI2_384)	55.56 µs (GI2_384)
	Pilot pattern	MP 32_2	MP 32_2	MP 32_2	MP 32_2
	Pilot boosting	5.4 dB	5.4 dB	5.4 dB	5.4 dB
	# of payload symbols	49	49	49	49
	Time interleaver	CTI depth of 1024	CTI depth of 1024	CTI depth of 1024	CTI depth of 1024
	Frequency interleaver	On	On	On	On
	Subframe boundary symbol	First/Last: On/On	First/Last: On/On	First/Last: On/On	First/Last: On/On
Payload BICM parameters	Outer code	BCH	BCH	BCH	BCH
	Inner code	11/15 LDPC (64800)	13/15 LDPC (64800)	12/15 LDPC (64800)	13/15 LDPC (64800)
	Constellation	256-NUC	1024-NUC	4096-NUC	4096-NUC
MIMO precoding	Stream combining	On	On	On	On
	IQ interleaving	On	On	On	On
	Phase hopping	On	On	On	On
Data rate		63 Mbit/s	94 Mbit/s	104 Mbit/s	113 Mbit/s

Four physical layer configurations with different data rates from 63 Mbit/s to 113 Mbit/s were used to evaluate the ATSC 3.0 MIMO performance. The detailed configurations are shown in Table 17. Configuration #1 was selected for a reliable transmission parameter set that can be practically used for the ATSC 3.0 MIMO transmission. Configuration #4 was set to verify the feasibility of the maximally achievable data rate in the ATSC 3.0 MIMO system. Accordingly, configuration #4 consists of the 4096-NUC and the 13/15 LDPC code rate, which is the maximum modulation order and code rate that the ATSC 3.0 physical layer specification supports.

2.6.3 Field trial results

The minimum received signal strength was measured for the field trial. The target FER was set to 10^{-4}. Six test locations were chosen for the field trial. Each test location has a different propagation environment, including distance from the transmitter. The locations and the brief field trial results are shown in Fig. 64. Measurement location #2 is the closest one to the transmission site, with a line-of-sight (LOS) path. As shown in Fig. 64, all test configurations including configuration #4 were successfully received at location #2. As shown in Table 17, since configuration #4 provides a data rate of 113 Mbit/s, the field trial demonstrates that the ATSC 3.0 MIMO system can support 113 Mbit/s in a real broadcasting environment. Measurement location #1 is about 8 km away from the transmitter. The results show that data rates up to 104 Mbit/s can be supported at this location.

Therefore, it can be seen that the ATSC 3.0 MIMO system can reliably support a data rate of over 100 Mbit/s in a 6-MHz channel, which should extend to even higher rates in 7- and 8-MHz channels.

FIGURE 64

Field trial measurement locations and the test results

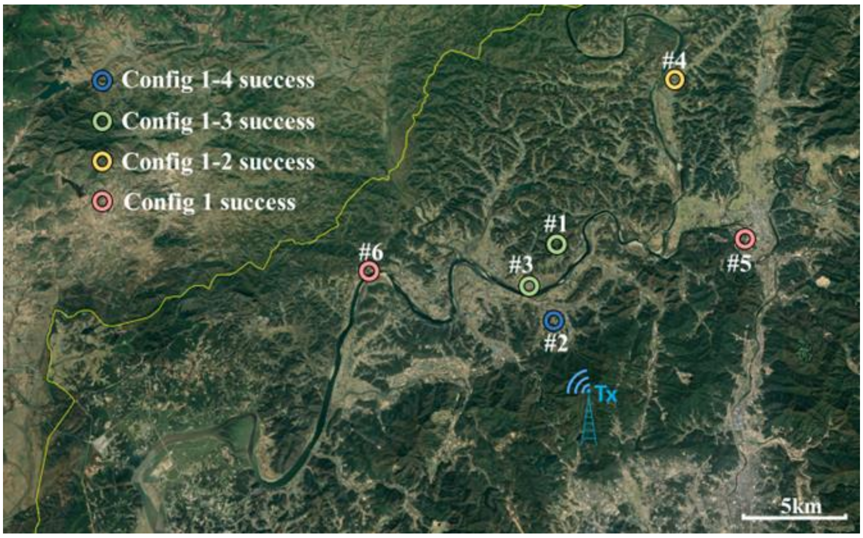


FIGURE 65

(a) ATSC 3.0 MIMO demodulator GUI (b) XPD measurement result at field trial point #3
(c) Condition number measurement result at field trial point #3

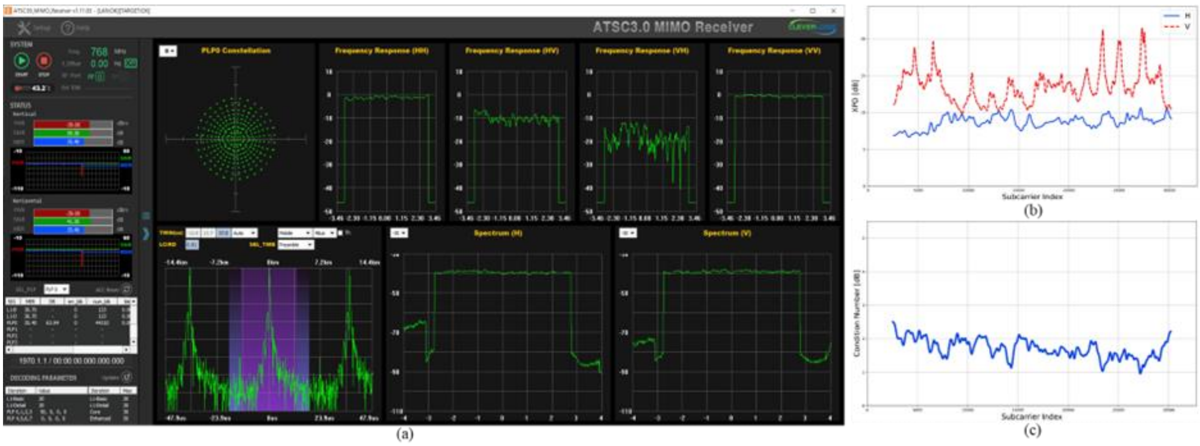


Figure 65(a) shows a snapshot of GUI monitoring for the ATSC 3.0 MIMO demodulator. It presents received signal power, signal-to-noise ratio (SNR), modulation error ratio (MER), and spectrum received signal for each polarization. It also shows constellation and frequency response for each MIMO channel. As examples of the MIMO channel characteristic measurement, XPD value and condition number for each subcarrier at field trial point #3 are drawn in Fig. 65(b) and Fig. 65(c), respectively. XPD represents how much cross-polarization interference occurs. *Condition number* represents the independence of polarization from multipath. The higher value of XPD and the smaller value of the condition number means the channel is suitable for the MIMO transmission. The minimum received signal strengths required to achieve FER of 10^{-4} are shown in Table 18. The measured values vary depending on the field trial measurement locations due to the channel environment and distance.

TABLE 18

Minimum received signal strength measurement results

Minimum received signal strength (dBm)								
Configuration	**Config. #1**		**Config. #2**		**Config. #3**		**Config. #4**	
Polarization	H	V	H	V	H	V	H	V
Field Test Point #1	−80	−80	−69	−69	−64	−64	–	–
Field Test Point #2	−83	−83	−74	−74	−70	−70	−61	−61
Field Test Point #3	−82	−82	−71	−71	−68	−68	–	–
Field Test Point #4	−82	−81	−72	−71	–	–	–	–
Field Test Point #5	−80	−77	–	–	–	–	–	–
Field Test Point #6	−81	−78	–	–	–	–	–	–

2.6.4 Summary of results

The field test evaluated ATSC 3.0 MIMO system performance for 8K-UHD broadcasting services by measuring the minimum acceptable received signal strength for various physical layer configurations. The evaluation results demonstrate that data rates up to 113 Mbit/s can be achieved within a 6 MHz bandwidth in a real terrestrial broadcasting network using the ATSC 3.0 MIMO system, representing an approximate doubling of payload capacity over SISO. In addition, the cross-polarized MIMO channel characteristic was measured to analyze a realistic MIMO broadcasting channel environment. The measurement results over several test points have been compared in terms of XPD and condition number, together with corresponding MIMO transmission test results. In conclusion, the various test results successfully demonstrated the feasibility of terrestrial 8K-UHD services using the ATSC 3.0 MIMO system.

2.7 ATSC 3.0 MIMO field trial

2.7.1 Overview

The universalization of smartphones causes enormous demands for mobile broadcasting services. One solution to this challenge is the use of MIMO for data rate enhancement. The MIMO technology utilizes multiple transmit and receive antennas, whereas mobile receivers are usually equipped with one antenna. As a result, the mobile receivers cannot decode the signal transmitted from the MIMO transmitter. Therefore, a proper multiplexing method between mobile and MIMO-based enhanced services should be considered.

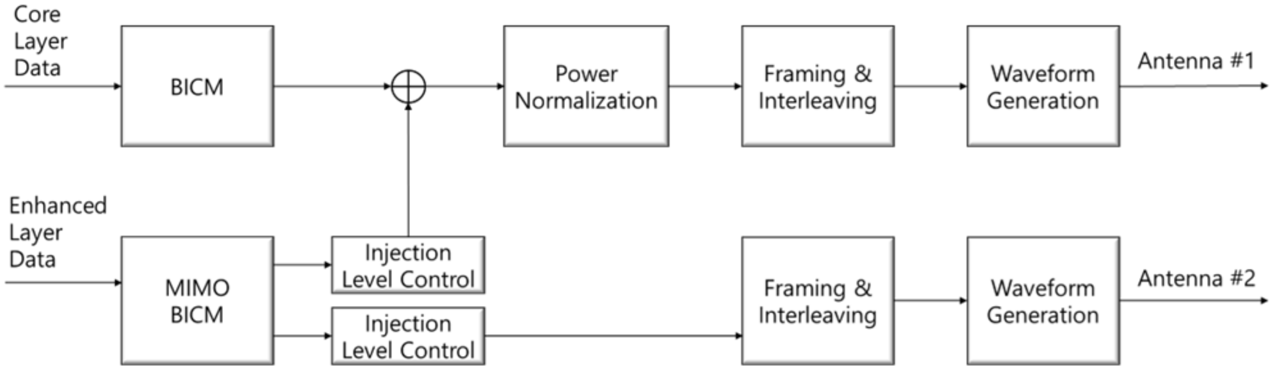
Several DTTB transmission systems support various multiplexing methods, such as TDM (Time Division Multiplexing) and FDM (Frequency Division Multiplexing). In addition, the ATSC 3.0 transmission systems supports LDM (Layered Division Multiplexing), which is known to provide performance gain over other methods. Adopting the LDM for the MIMO system means the mobile broadcasting signal is transmitted on the core-layer, whereas the MIMO signal is transmitted on the enhanced-layer. mobile receivers can then decode the core-layer signal, whereas fixed MIMO receivers, such as those used for UHD-TV, can decode both core- and enhanced-layer signals. For terrestrial broadcasting, which utilizes the UHF (Ultra-High Frequency) band, MIMO systems usually consider the cross-polarization antenna to guarantee isolation between the two antennas. The MIMO signal for enhanced-layer is transmitted on both polarizations. However, considering interferences from the other polarization, the core-layer signal needs to be transmitted on one polarization.

2.7.2 Field trial description

The structure of the ATSC 3.0 LDM-MIMO transmitter is shown in Fig. 66. The enhanced-layer data is MIMO encoded via MIMO BICM (Bit-Interleaved Coded Modulation) block. The injection level control block adjusts the transmission power of the enhanced-layer signal according to the LDM injection level. The core-layer data is encoded via the BICM block, which is the same as the conventional SISO (Single-Input Single-Output) BICM block. It is combined with one of the enhanced-layer signals to generate the LDM signal. The combined LDM signal is normalized and transmitted via antenna #1 after the framing, the interleaving, and the waveform generation. On the other hand, another enhanced-layer signal is transmitted via antenna #2 without the LDM signal generation process. As a result, the core-layer signal is only transmitted through antenna #1. Antenna #1 is horizontal when antenna #2 is vertical, and vice versa. If core-layer transmission occurs in both polarization antennas, the same signal from the other polarization can cause destructive interferences. The core-layer receiver structure is the same as the conventional ATSC 3.0 receiver. The receiving antenna is changed depending on the measurement configuration.

FIGURE 66

ATSC 3.0 LDM-MIMO transmitter structure



The field trial was conducted in the north Gyeonggi-do province of South Korea, with a transmitter is located close to the military demarcation line. The antennas used for the field trial are shown in Fig. 67. For the transmit antenna, panel antennas with 12 dBi gain were used. A disk-shaped omni-directional antenna, and a dipole antenna, are used for the horizontal and vertical plane receive antennas, respectively. A test vehicle installed with receive antenna and corresponding receiver is used for receiving performance evaluation. The test vehicle travels around the transmission site for a 5 km path. The channel environment consists of a dominant LOS (Line-of-Sight) and remaining NLOS (Non-LOS) signals.

FIGURE 67

(a) Transmit antenna (b) Horizontal plane receive antenna (c) Vertical plane receive antenna

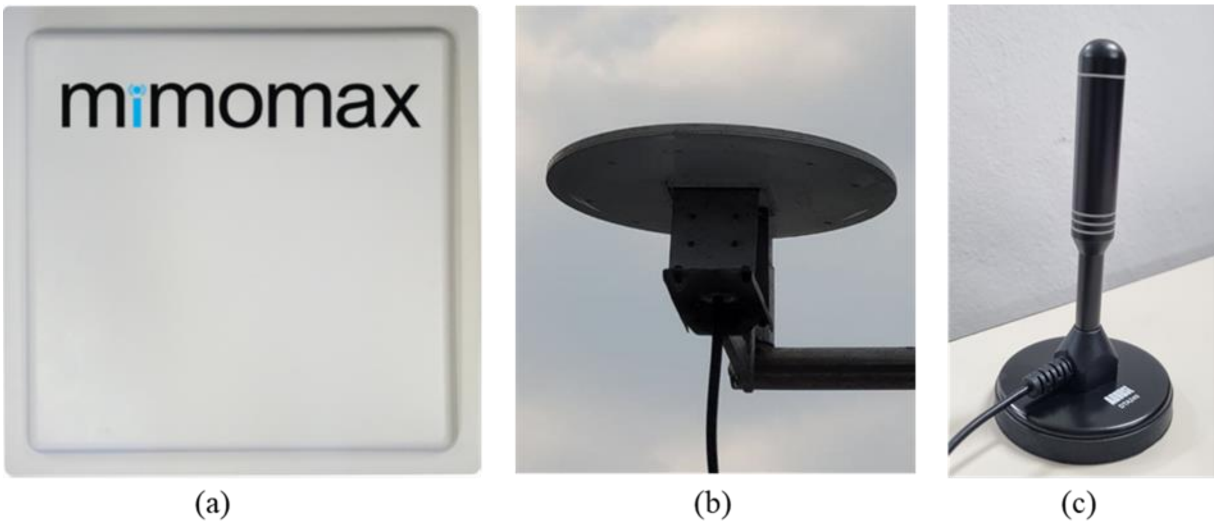


Table 19 shows the system configuration for the field trial. For the MIMO pilot pattern, the Walsh-Hadamard pilot pattern is used. The Walsh-Hadamard pattern provides the same pilot pattern as the SISO for antenna #1, thus the conventional receivers can perform channel estimation using the pilot. The transmission power of antenna #1 was set to 100 W (amplifier output). Considering the −4 dB injection level of the LDM, the transmission power of antenna #2 was set to 29 W (amplifier output). The RF center frequency was 768 MHz.

TABLE 19

System parameters for field tests

OFDM Parameters	FFT size		16K
	GI length		148.15 µs (GI5_1024)
	# of payload symbols		98
	Time interleaver		CTI depth of 1024
	Frequency interleaver		On
	Injection level		−4.0 dB
BICM Parameters	Core Layer	Outer code	BCH
		Inner code	4/15 LDPC (64800)
		Constellation	QPSK
		Data rate	2.5 Mbit/s
	Enhanced Layer	Outer code	BCH
		Inner code	10/15 LDPC (64800)
		Constellation	64-NUC
		Data rate	38.9 Mbit/s
MIMO Parameters	Pilot	Encoding	Walsh-Hadamard
		Boosting	1.6 dB
		Pattern	MP 6_2
	Precoding	Stream combining	On
		IQ interleaving	On
		Phase hopping	On

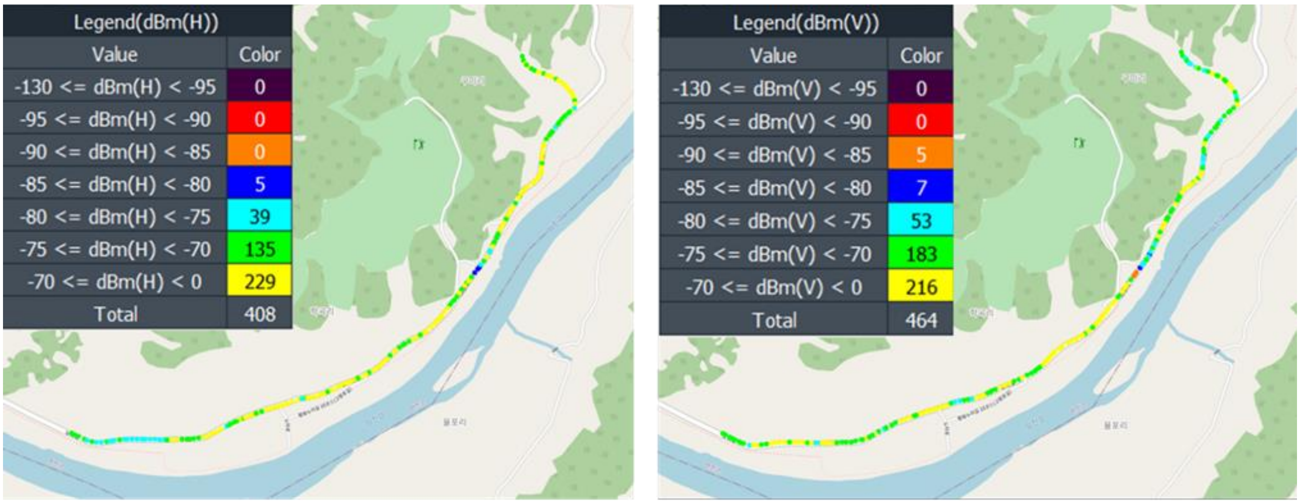
2.7.3 Field trial results

The field trial was carried out to measure the error performance of the ATSC 3.0 LDM-MIMO system. An error occurrence in the FEC (Forward Error Correction) block was considered as the criterion for the reception success or failure. In other words, if any FEC error occurs within one second, the measurement point is recorded as a reception failure. A measurement point with no FEC error per recorded second is recorded as a reception success.

Figure 68 shows the measured results of the received signal strength for each polarization. As shown there, the received signal strength statistic of each polarization is similar to each other. Moreover, as shown in Table 20, the difference in the average received signal strength between polarizations is only 1.1 dB. In other words, both polarizations provide similar statistical propagation properties from the perspective of the received signal strength.

FIGURE 68

Received signal strength of (a) H-plane (b) V-plane

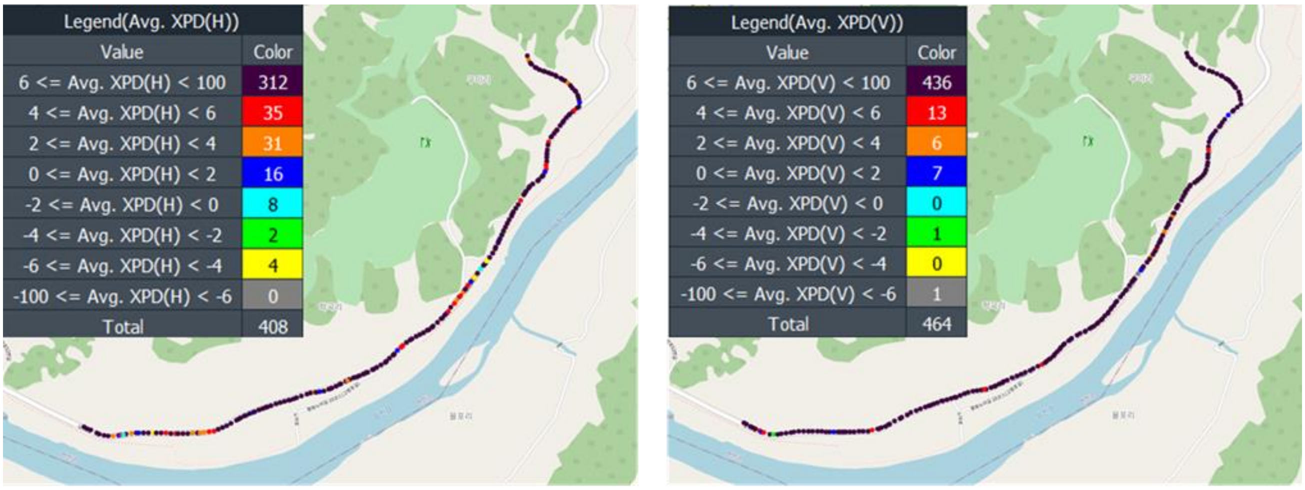


(a) (b)

Measurement results of the XPD (Cross-Polarization Discrimination) for horizontal and vertical polarization are shown in Fig. 69(a) and (b), respectively. Since a lower XPD value means a higher interference from the other polarization, locations with a lower XPD values are essential for the error performance perspective. Moreover, a negative XPD value means interference from another polarization is more significant than the desired signal. As shown in Fig. 69, the XPD distribution of the vertical polarization is much better than that of the horizontal polarization. In most locations, the vertical polarization provides XPD values over 6 dB. However, the horizontal polarization provides much lower XPDs than that of the vertical polarization. The average measured XPD value for each polarization is shown in Table 20. The average XPD of the vertical polarization is 5.4 dB larger than that of the horizontal polarization. This means that the vertical polarization is robust to cross-polarization interference in a mobile environment.

FIGURE 69

XPD of (a) H-plane (b) V-plane

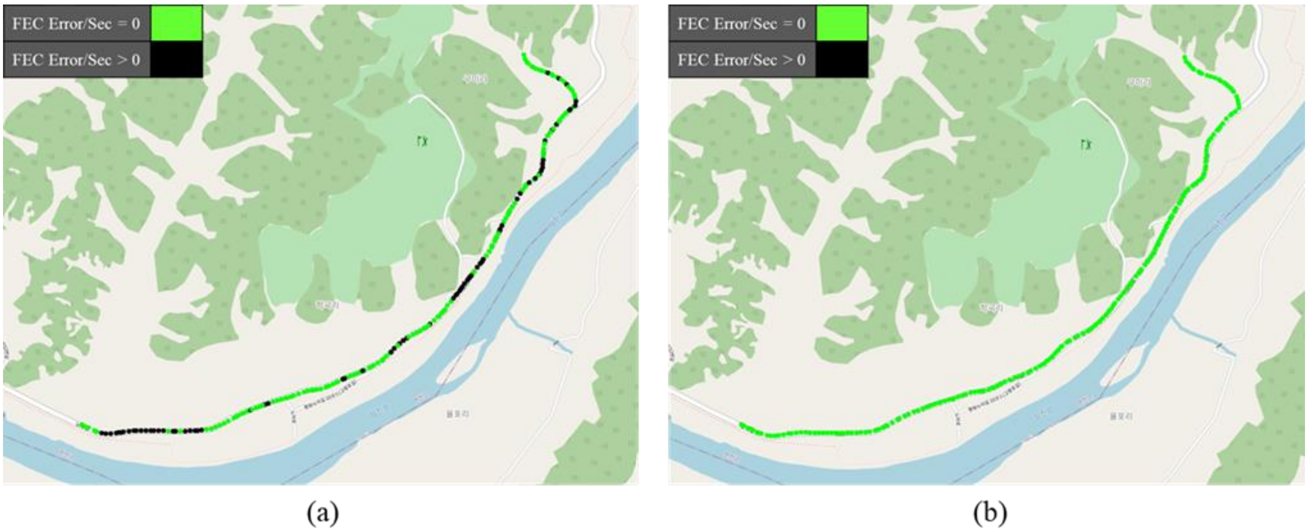


(a) (b)

The FEC error performance for each polarization is shown in Fig. 70. The green dot means FEC error-free, whereas the black dot indicates error occurrence in a given location. The core-layer transmission on the vertical polarization shows a reception success rate of 100% for the field trial. Horizontal polarization, however, failed to decode the core-layer FEC block in many locations.

FIGURE 70

FEC error/sec of (a) H-plane (b) V-plane



(a) (b)

The FEC error-free rate is shown in Table 20. The horizontal plane provides a 69.8% successful decoding rate, whereas the vertical plane perfectly decoded FEC blocks in all locations. The overall field trial results prove that the vertical polarization provides robustness to cross-polarization interference in a mobile environment.

TABLE 20

Measurement results of ATSC 3.0 LDM-MIMO system field trial

	H-plane	V-plane
Average received signal strength (dBm)	−69.7	−70.8
Average XPD (dB)	11.3	16.7
FEC error free rate	69.8%	100%

2.7.4 Summary

A system architecture and field trial results of ATSC 3.0 LDM-MIMO technology, which is backward-compatible with the legacy ATSC 3.0 SISO technology, are presented in this section. Using the LDM-MIMO technology, mobile and fixed services can be provided simultaneously. The field trial results showed that the vertical polarization is suitable for mobile broadcasting services using the ATSC 3.0 LDM-MIMO system.

2.8 Field verification of ATSC 3.0 and 1.0 Integrated-MATV System over Digital Terrestrial Television Broadcasting (DTTB) in Single Frequency Networks (SFN)

2.8.1 Overview

In Korea (Republic of), where over 60% of the population resides in high-rise apartment complexes and similar shared housing, it is common for terrestrial broadcasting to be watched through an MATV (Master Antenna Television) system. With both ATSC 1.0 and ATSC 3.0 broadcasting in widespread use, it is becoming necessary to adapt MATV systems to provide a transition path towards the eventual shutoff of ATSC 1.0 services. As residential penetration of ATSC 3.0 receivers has not yet been fully achieved, adaptation of MATV systems to provide backward compatibility will ensure that viewers of ATSC 1.0 services will not lose access to DTTB services when ATSC 1.0 services are terminated.

This section presents a conceptual solution to this transition need, which is equally applicable in regions undergoing a transition from ATSC 1.0 to ATSC 3.0.

Currently, in Korea (Republic of), there are two types of traditional MATV systems:

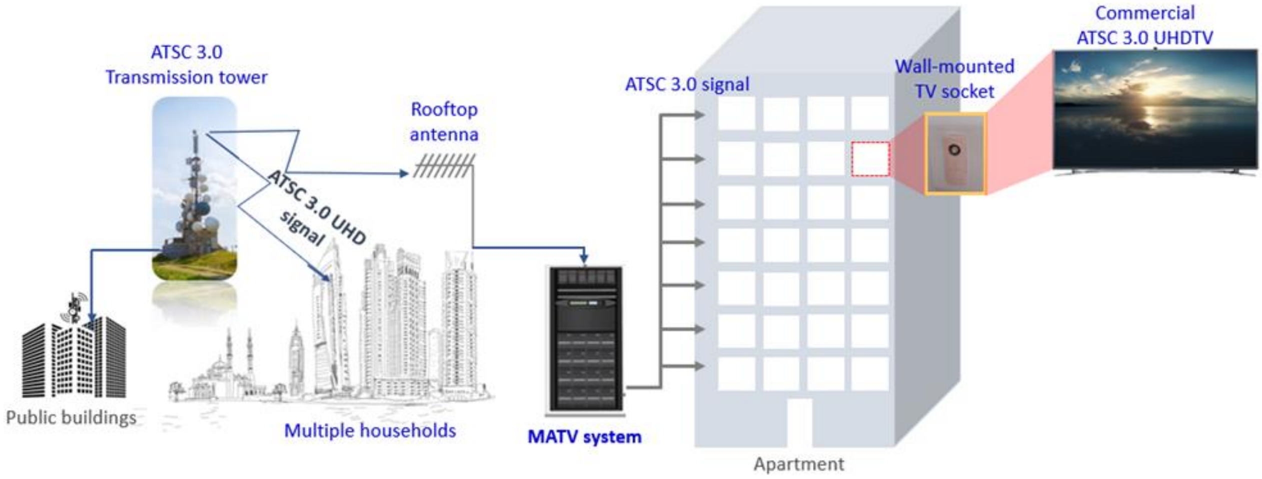
– ATSC 3.0 MATV, which redistributes the received (distorted) ATSC 3.0-based UHDTV signal as a clean ATSC 3.0-based UHDTV signal.

– ATSC 1.0 MATV, which redistributes the received (distorted) ATSC 1.0-based HDTV signal as a clean ATSC 1.0-based HDTV signal.

Figure 71 shows the overall concept of the traditional MATV system.

FIGURE 71

The concept of the traditional MATV system



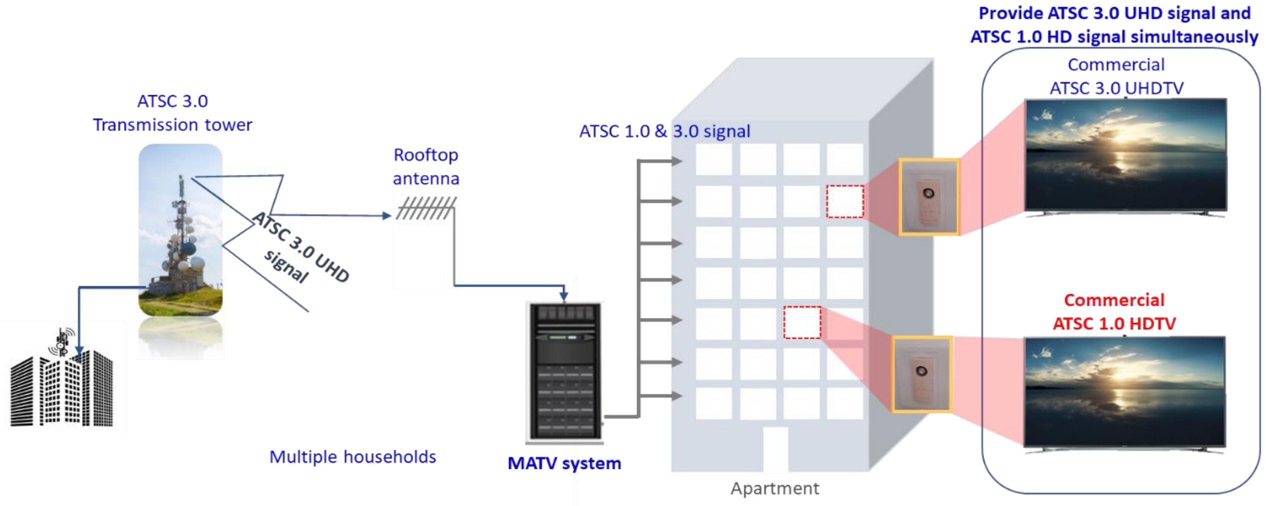
First, ATSC 3.0-based UHDTV broadcast signals are received and distributed to MATV systems via rooftop antennas. Subsequently, a MATV system generates improved-quality ATSC 3.0-based UHDTV signals and redistributes them to individual households. This flow represents the fundamental concept of the MATV system.

Meanwhile, the shutdown of ATSC 1.0-based HDTV broadcasting in Korea (Republic of) is planned to commence in 2027. After the shutdown of ATSC 1.0-based broadcasting, households without ATSC 3.0-based TVs would render the HDTV service-oriented MATV system obsolete. Consequently, a solution is essential to enable individuals without ATSC 3.0-based TVs to receive ATSC 3.0-based services.

To solve this issue, a new MATV system has been developed and verified. As shown in Fig. 72, the newly developed Integrated-MATV system receives ATSC 3.0-based terrestrial UHDTV broadcast signal and then converts it into both ATSC 3.0-based UHDTV and ATSC 1.0-based HDTV signals simultaneously. When it converts the ATSC 3.0 signal to ATSC 1.0 signal, video and audio transcoding (HEVC to MPEG-2 TS and AC4 to AC3 conversions) is also performed. By doing so, even households without UHD receivers can continue watching terrestrial broadcasting after the shutdown of ATSC 1.0-based HDTV broadcasting. A recommended solution for the conversion of ATSC 3.0 signals to ATSC 1.0 signals is described in [ATSC A/370].

FIGURE 72

The concept of the ATSC 3.0 and 1.0 Integrated-MATV system



2.8.2 Field Test Facilities

Integrated-MATV systems were installed in seven apartment complexes in Korea (Republic of), and a field test was conducted for system verification. Figure 73 shows field test facilities installed in the management offices of each apartment complex. A wideband UHF antenna was installed on the rooftop for the reception of ATSC 3.0-based UHDTV broadcast signals. The rooftop antenna receives an ATSC 3.0-based UHDTV broadcast signal, which is then delivered to the Integrated-MATV system.

The Integrated-MATV system converts this signal into ATSC 3.0-based UHDTV and ATSC 1.0-based HDTV signals simultaneously, as shown in Fig. 74.[5] For this purpose, the Integrated-MATV system includes an ATSC 3.0 demodulator & modulator, a media converter, and an ATSC 1.0 modulator. The media converter performs the functions below:

- HEVC-to-MPEG-2 video transcoding;
- MPEG-H-to-AC3 audio transcoding;
- ATSC 3.0-to-ATSC 1.0 protocol conversion;
- MPEG-2 TS stream multiplexing and media sync.

---

[5] One method for performing this conversion is described in the ATSC A/370 Recommended Practice: Conversion of ATSC 3.0 Services for Redistribution.

The converted signals are distributed to the monitoring system and individual households. The monitoring system is used to check the proper functioning of the Integrated-MATV system remotely in real-time. Figure 75 shows the captured screen of the monitoring system's web GUI, displaying the operational status of Integrated-MATV systems installed in seven regions (highlighted by red points). Figure 76 provides detailed information on collected monitoring data, such as received power, SNR, MER, and FEC Block Errors for the ATSC 3.0 signal.

FIGURE 73

Field test facilities

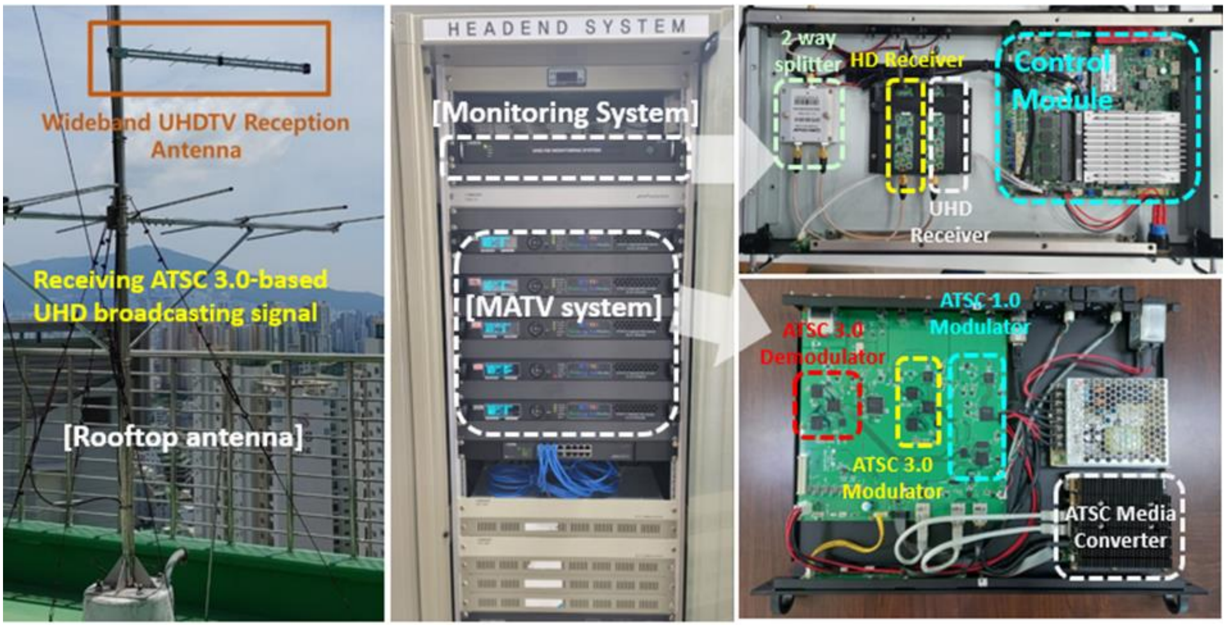


FIGURE 74

The structure of the Integrated-MATV system

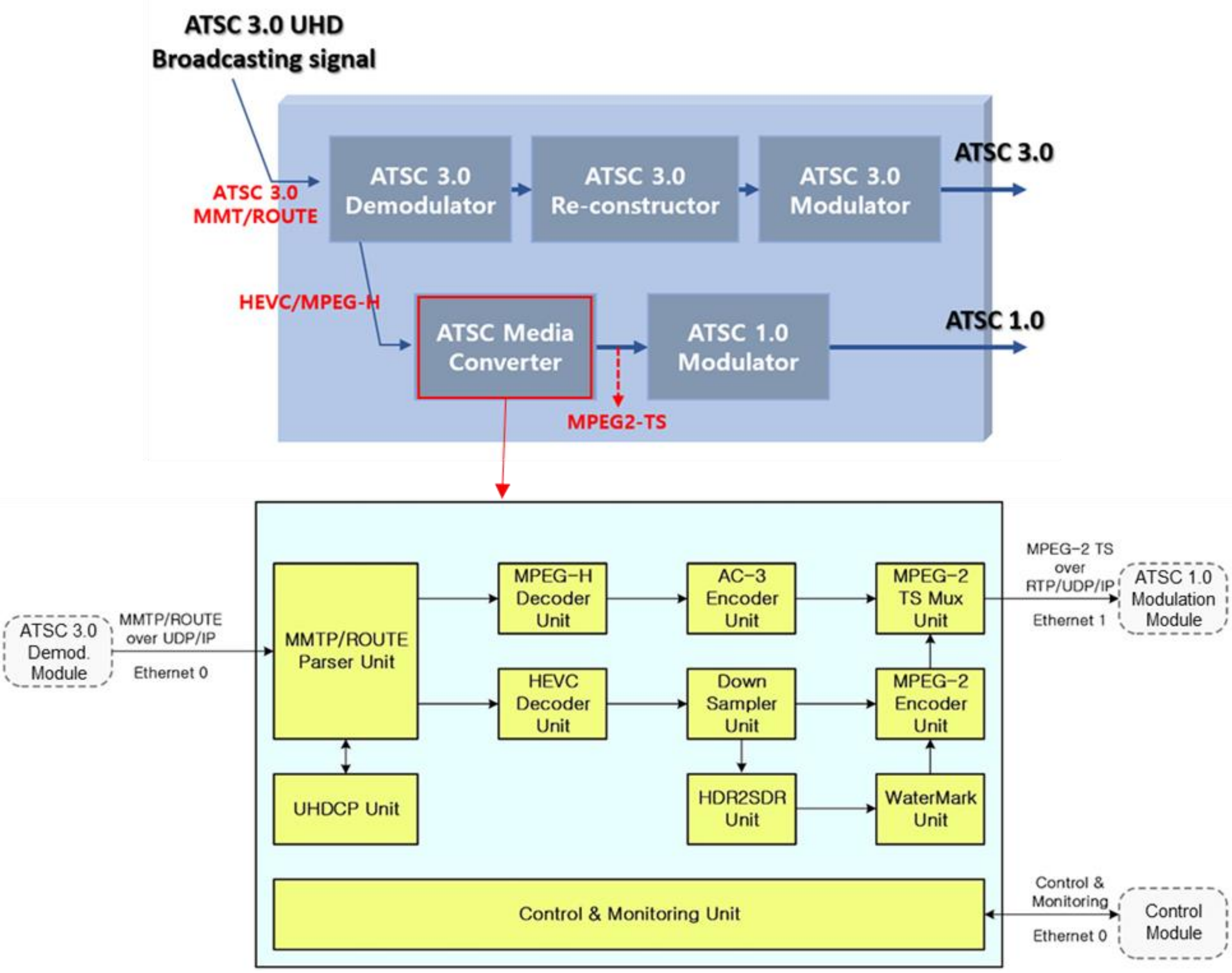
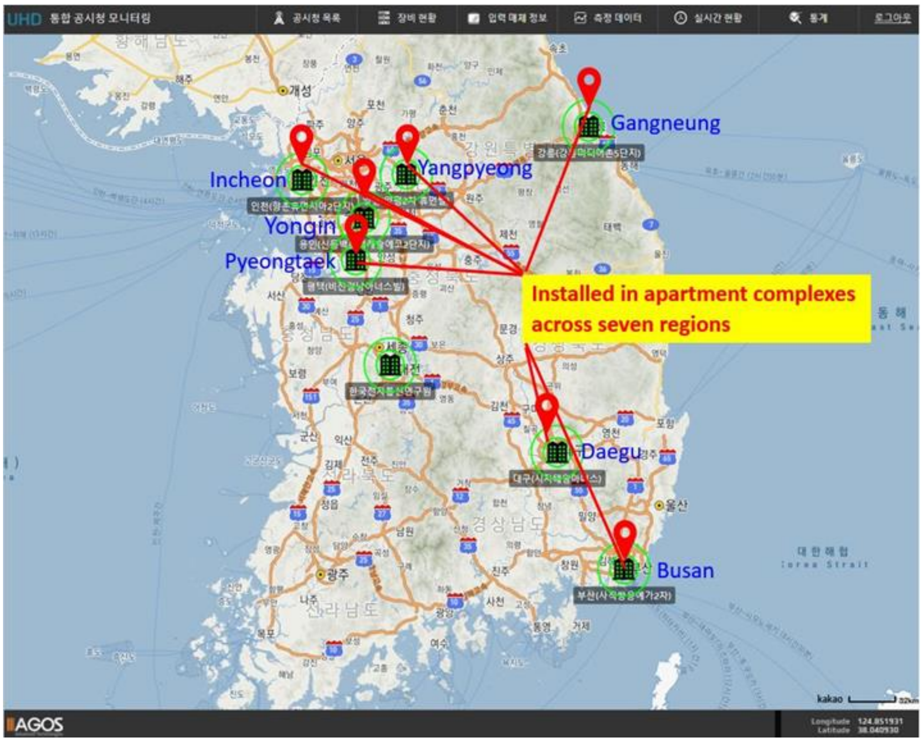


FIGURE 75

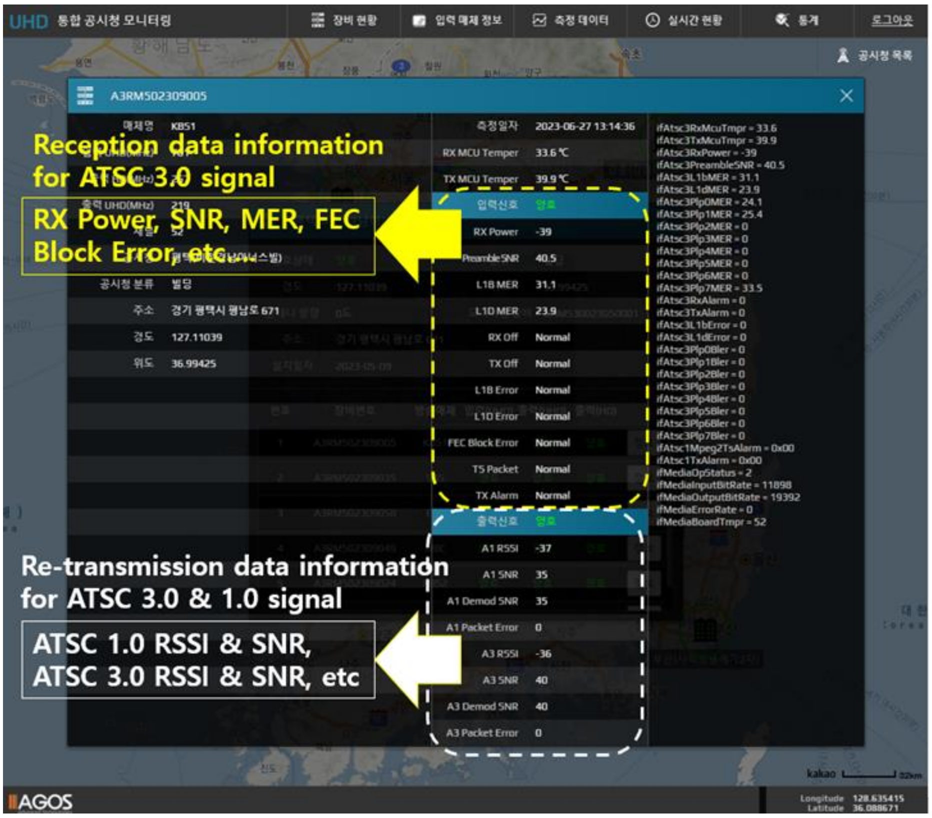
Field test regions in the monitoring web GUI



Installed in apartment complexes across seven regions

FIGURE 76

Detailed information on monitoring data



A3RM502309005

매체명 KBS1
출력 UHD(MHz) 219
채널 52
공시청 분류 빌딩
주소 경기 평택시 평남로 671
경도 127.11039
위도 36.99425

측정일자 2023-06-27 13:14:36
RX MCU Temper 33.6 ℃
TX MCU Temper 39.9 ℃
입력신호 양호
RX Power -39
Preamble SNR 40.5
L1B MER 31.1
L1D MER 23.9
RX Off Normal
TX Off Normal
L1B Error Normal
L1D Error Normal
FEC Block Error Normal
TS Packet Normal
TX Alarm Normal
출력신호 양호
A1 RSSI -37
A1 SNR 35
A1 Demod SNR 35
A1 Packet Error 0
A3 RSSI -36
A3 SNR 40
A3 Demod SNR 40
A3 Packet Error 0

```
ifAtsc3RxMcuTmpr = 33.6
ifAtsc3TxMcuTmpr = 39.9
ifAtsc3RxPower = -39
ifAtsc3PreambleSNR = 40.5
ifAtsc3L1bMER = 31.1
ifAtsc3L1dMER = 23.9
ifAtsc3Plp0MER = 24.1
ifAtsc3Plp1MER = 25.4
ifAtsc3Plp2MER = 0
ifAtsc3Plp3MER = 0
ifAtsc3Plp4MER = 0
ifAtsc3Plp5MER = 0
ifAtsc3Plp6MER = 0
ifAtsc3Plp7MER = 33.5
ifAtsc3RxAlarm = 0
ifAtsc3TxAlarm = 0
ifAtsc3L1bError = 0
ifAtsc3L1dError = 0
ifAtsc3Plp0Bler = 0
ifAtsc3Plp1Bler = 0
ifAtsc3Plp2Bler = 0
ifAtsc3Plp3Bler = 0
ifAtsc3Plp4Bler = 0
ifAtsc3Plp5Bler = 0
ifAtsc3Plp6Bler = 0
ifAtsc3Plp7Bler = 0
ifAtsc1Mpeg2TsAlarm = 0x00
ifAtsc1TxAlarm = 0x00
ifMediaOpStatus = 2
ifMediaInputBitRate = 11898
ifMediaOutputBitRate = 19392
ifMediaErrorRate = 0
ifMediaBoardTmpr = 52
```

Reception data information for ATSC 3.0 signal

RX Power, SNR, MER, FEC Block Error, etc

Re-transmission data information for ATSC 3.0 & 1.0 signal

ATSC 1.0 RSSI & SNR, ATSC 3.0 RSSI & SNR, etc

2.8.3 Field Test Results for Verification of Integrated MATV System

Field tests were carried out to verify that the new Integrated-MATV system operates smoothly in the SFN environment. Integrated-MATV systems were installed in seven apartment complexes in Korea (Republic of). Four apartments were selected from Seoul-metropolitan areas such as Incheon, Pyeongtaek, Yongin, and Yangpyeong. The remaining apartments were chosen from Pusan, Daegu, and Gangneung. Field tests were conducted for the major broadcasting channels in Korea (Republic of), namely KBS1, KBS2, MBC, EBS, and SBS, at each test point.

Input of Integrated-MATV System

Figures 77 and 78 show the field test results in the Yongin area. In this example, the operational network provided by KBS, offering ATSC 3.0 UHDTV services on UHF Channel 56 (768 MHz), was utilized. The TxID signals were buried at a 24 dB injection level, i.e., the TxID signals were emitted at a power level 24 dB lower than the broadcast service signals. Figure 77 shows the simultaneous detection of two distinct TxID signals from each SFN transmitter in this region, providing evidence of the SFN environment. The two SFN transmitters (Tx1 and Tx2), which emit different TxID signals, are 12.2 km and 24.3 km away from the receiving point, respectively, and the time delay between the two signals is 37.5 μs.

FIGURE 77

SFN channel profile in the Yongin area (Detected by TxID signal)

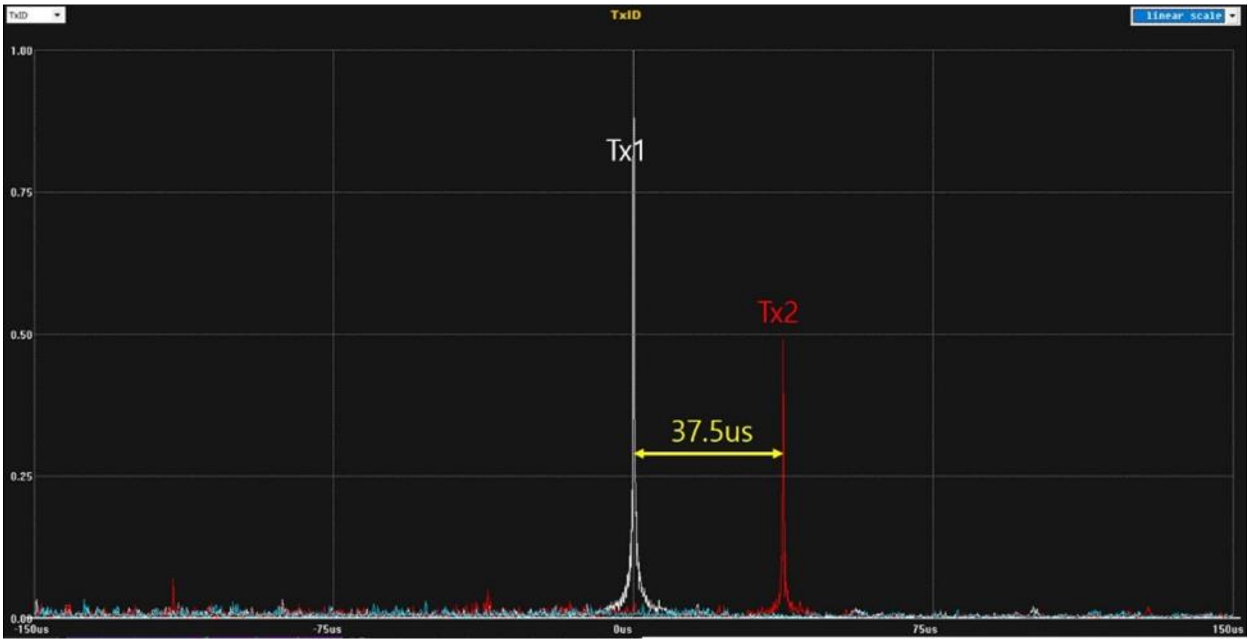


Figure 78 shows the characteristics of the received On-Air ATSC 3.0-based UHDTV signal. The On-Air ATSC 3.0-based UHDTV signal is delivered to the Integrated-MATV system via a UHF directional antenna. The received signal power is −57 dBm, and signal to noise ratio (SNR) is 22 dB at the directional antenna output. In addition, the received signal shows 64-NUC and 256-NUC delivered through two subframes. The received signal shows a channel profile with one dominant multipath and a frequency response. The constellations are not clean, and the frequency response is not flat due to the SFN.

FIGURE 78

Signal characteristics of input to Integrated-MATV system (measured at antenna stage)

Freq. 768 MHz

STATUS time : 9

PWR -57.05 dBm

SNR 22.55 dB

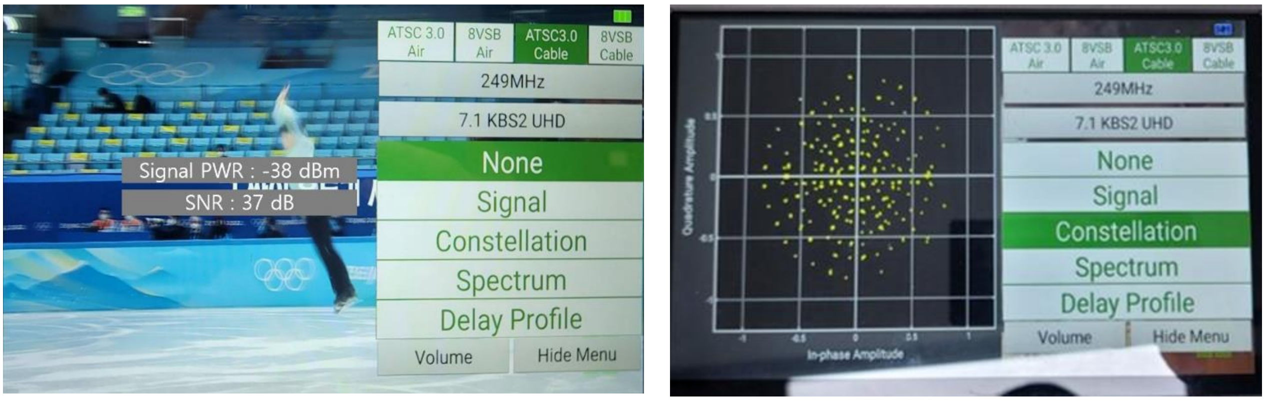
MER 14.03 dB

ATSC 3.0 output of Integrated-MATV system

The analysis results of the ATSC 3.0 output in the Integrated-MATV system are shown in Fig. 79. The Integrated-MATV system transmits the ATSC 3.0 signal at the signal power of −37 dBm on the 249 MHz channel. The measured ATSC 3.0 signal at the randomly selected household has a signal power of −38 dBm, SNR of 37 dB, and clean 256-NUC. The result shows that the Integrated-MATV provides better and cleaner signal quality. Table 21 summarizes these results.

FIGURE 79

An example of a remodulated ATSC 3.0 signal in Integrated-MATV system



(a) Program of UHDTV output

(b) Constellations

249MHz

7.1 KBS2 UHD

Signal PWR : -38 dBm

SNR : 37 dB

ATSC 1.0 output of Integrated-MATV system

The analysis results of the ATSC 1.0 output in the Integrated-MATV system are shown in Fig. 80. The Integrated-MATV system emits the ATSC 1.0 signal at the signal power of −37 dBm on the 291 MHz channel. The measured ATSC 1.0 signal at the randomly selected household has a signal power of −38 dBm, SNR of 34 dB, and clean 8-VSB constellations. The results show that the measured signal quality is good enough to provide a clean ATSC 1.0 signal. Table 21 summarizes these results.

FIGURE 80

An example of a remodulated ATSC 1.0 signal in Integrated-MATV system

(a) Program of HDTV output **(b) Constellations**

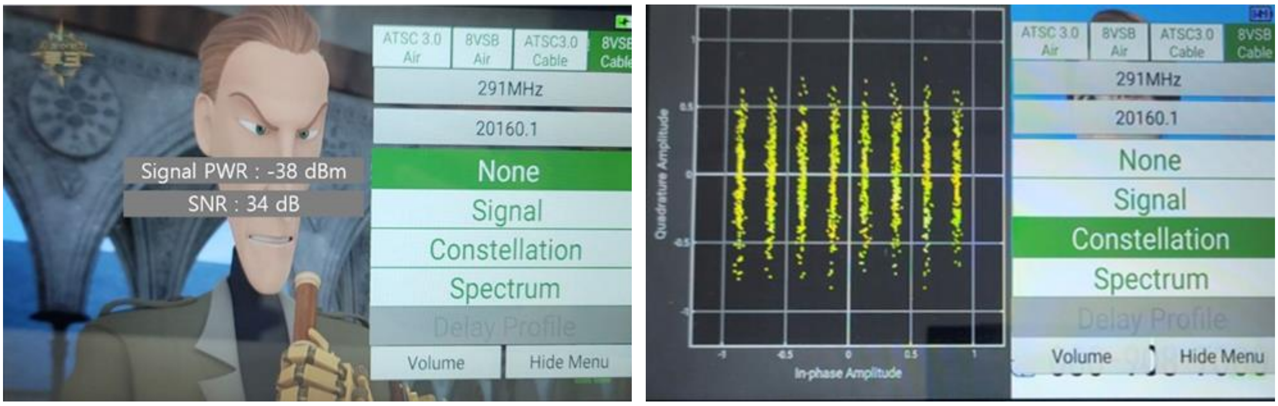


TABLE 21

Summary of numerical results

	Power (dBm)	SNR (dB)
Received ATSC 3.0 signal	−57	22
Re-transmitted ATSC 3.0 signal	−37	
Typical household received ATSC 3.0 signal	−38	37
Re-transmitted ATSC 1.0 signal	−37	
Typical household received ATSC 1.0 signal	−38	34

2.8.4 Summary

To address potential issues arising after the shutdown of ATSC 1.0-based HDTV broadcasting, a new Integrated-MATV system has been developed and verified. The Integrated-MATV system was installed in apartment complexes in 7 different regions, and its performance has been monitored and analyzed remotely. The test results show that the newly developed Integrated-MATV system worked effectively in the real field, even in SFN environments. The Integrated-MATV system will play a dominant role in expanding the ATSC 3.0-based UHDTV broadcasting coverage area. Furthermore, the Integrated-MATV system will effectively support the shutdown of ATSC 1.0 in Korea (Republic of).

2.9 ATSC 3.0 Channel Bonding field trial

2.9.1 Overview

Channel bonding technology in ATSC 3.0 combines two RF channels such that they are handled as a single logical channel to expand the overall service data rate. This scheme enables up to twice the data capacity compared to a single RF channel and supports high transmission rates exceeding 100 Mbit/s. The bonded RF channels may be located either adjacent or non-adjacent to each other, which requires the receiver to be equipped with two independent RF tuners. ATSC 3.0 specifies two channel bonding modes: (1) channel bonding with SNR averaging and (2) plain channel bonding. In channel bonding, a common payload stream is split into two substreams. Channel bonding with SNR averaging aims to achieve frequency diversity gain by exchanging modulated cells between the two RF channels, such that adjacent cells are received through different fading conditions. In contrast, in plain channel bonding, two substreams are independently transmitted over the two RF channels without any interaction between them. Experimental verification of the two channel bonding modes has been conducted in a fixed reception scenario using FPGA-based prototype transmitter and receiver systems, demonstrating that channel bonding operates reliably under real field environments.

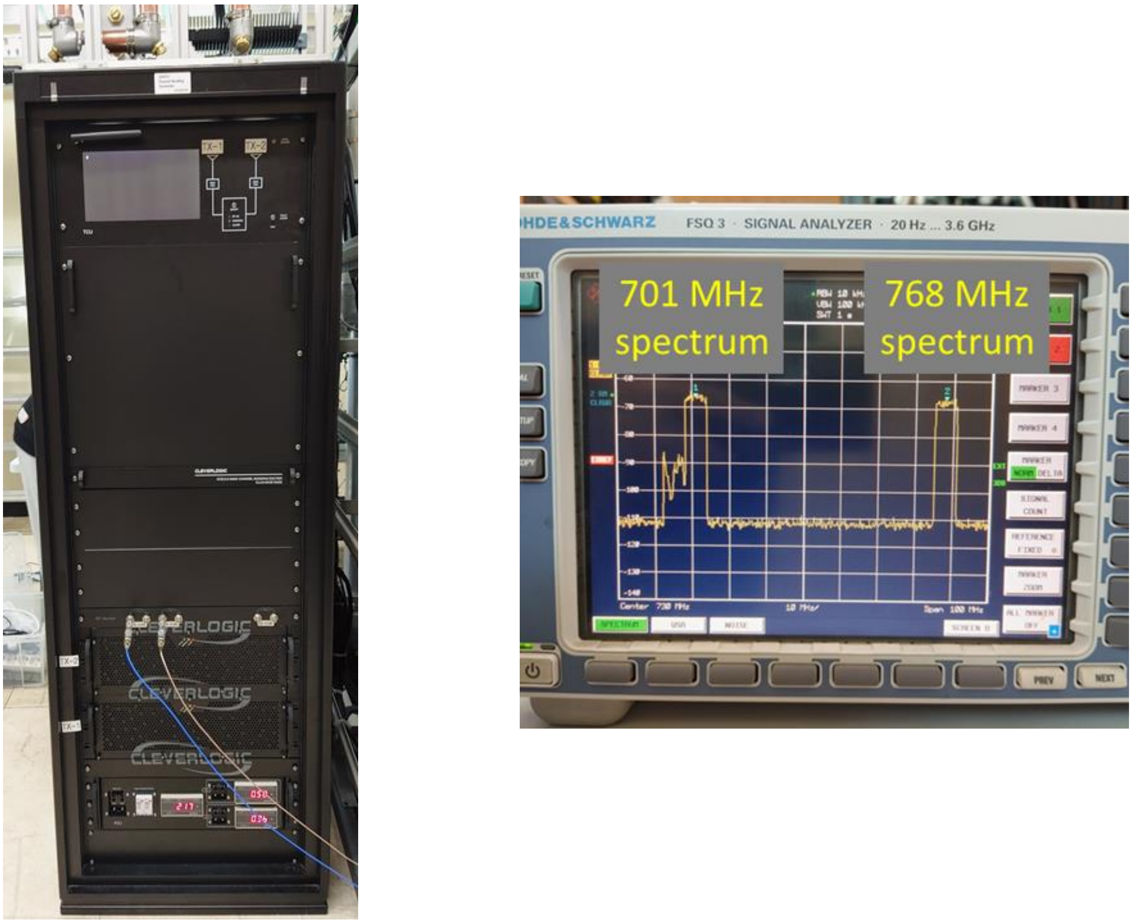
2.9.2 Field trial description

The primary objectives of the field trial were to verify the feasibility of real-time operation of the ATSC 3.0 channel bonding system under practical transmission conditions; to assess its capability to support multiple 4K or 8K UHD media services; and to evaluate the fixed reception performance of both channel bonding modes.

Physical layer configuration was designed for the experiment, as summarized in Table 22. The configuration employed a 32k FFT size, 12/15 LDPC code, and 4096 non-uniform constellations, achieving a bit rate of 102.9 Mbit/s, which is sufficient for multiple 4K UHD or 8K UHD media streaming.

The test site was located in northern Gyeonggi Province, South Korea, and was operated by the Korean Broadcasting System (KBS). Two non-adjacent RF channels, centred at 701 MHz and 768 MHz, were assigned for the field test. Figure 81(a) shows the implemented ATSC 3.0 channel bonding transmission system. The transmitter, equipped with two high-power amplifiers and two channel masks dedicated to each RF channel, was deployed at the transmission site. As shown in Fig. 81(b), adjacent channel was observed on the lower sideband of the 701 MHz channel.

FIGURE 81



(a) channel bonding transmitter and modulator (b) Received signal spectrum measured at the transmission site

TABLE 22

System parameters of 4K UHDTV field experiment in France

Parameters	Configuration
FFT size	32k
Guard interval	GI4_768 (111.111 µs)
Pilot pattern	SP16_2
Time interleaver	CTI (1024)
Outer code	BCH
Inner code	LDPC (64800) 12/15
Constellation	4096 NUC
Data rate	102.9 Mbit/s
Required SNR (at AWGN)	30.7 dB

2.9.3 Field trial results

Measurements were conducted at three locations situated to the north of the transmission site. Since the configuration requires a high SNR, the locations were carefully selected to ensure line-of-sight (LOS) reception conditions.

Figure 82 shows that four 4K UHD streams were successfully delivered by the channel bonding system and simultaneously displayed on a monitor inside the test vehicle.

At each location, the fixed reception performance of both plain channel bonding and channel bonding with SNR averaging was evaluated in terms of threshold of visibility (ToV) and minimum received signal strength (RSS), after orienting the receiving antenna to maximize both SNR and modulation error ratio (MER). Note that identical levels of noise and attenuation were applied to both RF channels, even in cases where one of the RF channels could still be successfully decoded in the plain channel bonding mode. A log-periodic (LP) antenna was used during the measurements.

Figure 83 provides an overview of the measurement software used to collect signal strength, spectrum data, and time/frequency responses of each RF channel. Table 23 summarizes the measured results at each location for both channel bonding modes.

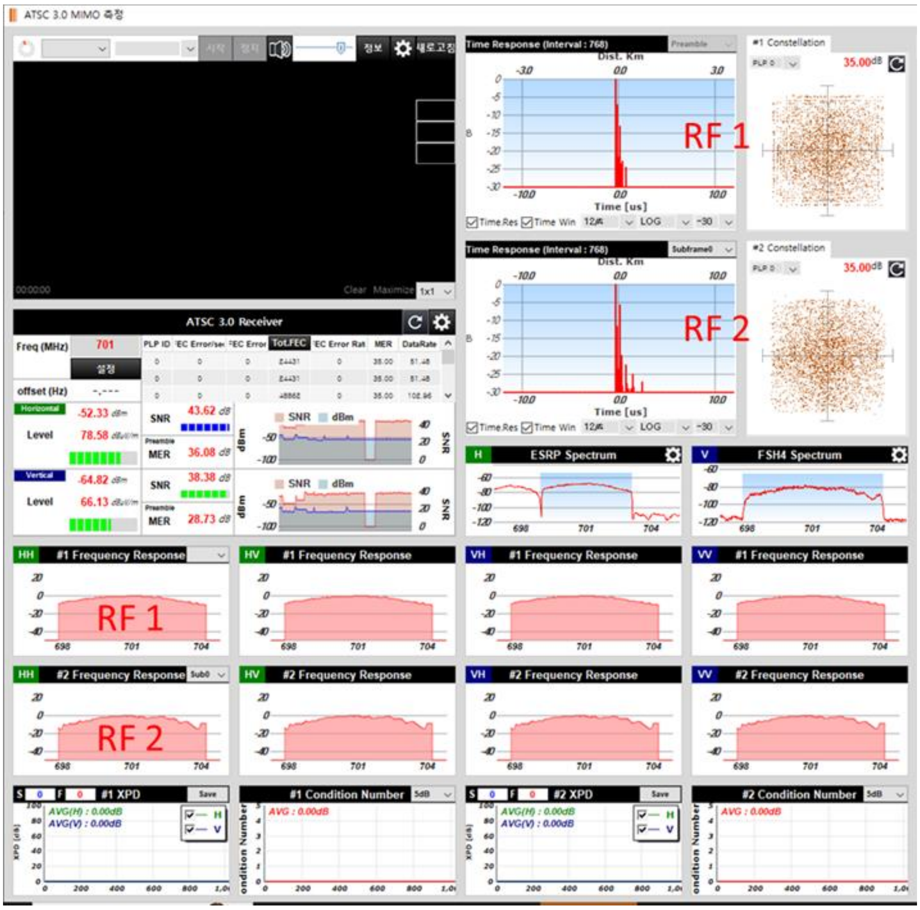
In the configuration, the measured ToV and minimum RSS results between the two modes show a meaningful difference between the two modes. Channel bonding with SNR averaging achieved slightly better performance. Due to identical noise level and attenuation, the reception performance of plain channel bonding was limited by one channel having less received signal strength and more severe degradation.

FIGURE 82

Simultaneously received four 4K UHD streams on the test vehicle side

FIGURE 83

Screenshot of the measurement software for the channel bonding field verification



☑ Time Res ☑ Time Win 12㎲ LOG -30

Freq (MHz) 701
설정
offset (Hz) -.---

PLP ID	FEC Error/sec	FEC Error	Tot.FEC	FEC Error Rat	MER	DataRate
0	0	0	84431	0	35.00	51.48
0	0	0	84431	0	35.00	51.48
0	0	0	48862	0	35.00	102.96

Horizontal Level -52.33 dBm 78.58 dBuV/m
SNR 43.62 dB
Preamble MER 36.08 dB

Vertical Level -64.82 dBm 66.13 dBuV/m
SNR 38.38 dB
Preamble MER 28.73 dB

TABLE 23

Measurement data for each measurement point and channel bonding modes in a fixed reception scenario

Point No.	Modes	Plain channel bonding		Channel bonding with SNR averaging	
		RF 1	RF 2	RF 3	RF 4
1	RSS (dBm)	−40.14	−47.1	−40.03	−49.7
	ToV (dB)	41.94	34.89	39.91	30.65
	Minimum RSS (dBm)	−58.22	−65.28	−63.29	−70.65
2	RSS (dBm)	−55.24	−57.44	−54.59	−57.85
	ToV (dB)	35.31	33.21	34.76	31.92
	Minimum RSS (dBm)	−64.25	−66.24	−67.13	−69.65
3	RSS (dBm)	−35.08	−37.82	−35.38	−38.98
	ToV (dB)	34.48	32.66	36.9	31.34
	Minimum RSS (dBm)	−60.89	−63.71	−64.49	−67.87

2.9.4 Summary

Field experimental verification of ATSC 3.0 channel bonding was conducted in a fixed reception scenario using FPGA-based prototype systems. Both plain channel bonding and channel bonding with SNR averaging achieved reliable performance under real field environments and demonstrated stability in supporting high-throughput services such as 8K UHD and multiple 4K UHD streams over non-adjacent RF channels. These results validate that ATSC 3.0 channel bonding is a practical and efficient method for flexible spectrum usage and enhanced capacity, while maintaining backward compatibility with legacy ATSC 3.0 services.

Plain channel bonding assigns an entire forward error correction (FEC) block across the two RF channels without interworking between them. In contrast, channel bonding with SNR averaging exchanges modulated symbols between the two RF channels after modulation and coding, resulting in adjacent symbols being exposed to independently varying fading conditions. Accordingly, channel bonding with SNR averaging demonstrated a slight performance advantage due to interworking and frequency diversity gain.

2.10 ATSC 3.0 Layered MIMO Type A field trial

2.10.1 Overview

Multiple-input multiple-output (MIMO) technology in ATSC 3.0 is based on spatial multiplexing technique using a pair of cross-polarized transmitting antennas to achieve up to near twice the channel capacity compared to conventional single-input single-output (SISO) system within a single RF channel. Layered division multiplexing (LDM) is one of the physical layer signal multiplexing techniques in ATSC 3.0, which allows two signals with different robustness to share the same frequency and time resources. Layered MIMO technology combines LDM and MIMO. In particular, Layered MIMO Type A enables two MIMO signals to deliver via the common RF resources.

LDM in ATSC 3.0 classifies different signals into a Core Layer and an Enhanced Layer. The two layers are generated through independent bit-interleaved coded modulation (BICM) processes and are superimposed with different signal power levels. Layered MIMO Type A follows the same process as SISO. The MIMO signals corresponding to the Core Layer and Enhanced Layer each independently generate two streams for horizontal and vertical polarizations. The Core and Enhanced Layer signals corresponding to the same polarization are then superimposed to create a single transmit signal per polarization.

Experimental verification of Layered MIMO Type A has been conducted using FPGA-based prototype transmitter and receiver systems. The field trial demonstrated that Layered MIMO Type A achieves channel capacity gains exceeding those of conventional SISO transmission and successfully delivers multiple media services. The verification was conducted under two reception conditions: fixed reception with rooftop-mounted antennas and indoor reception with antennas installed indoors.

2.10.2 Field trial description

The primary objective of the field trial was to verify the feasibility of real-time operation of the Layered MIMO Type A system under practical transmission conditions; to assess the increased data rate capability to serve different robustness in a single RF channel; and to evaluate the reception performance.

The physical layer configuration was designed for the experiment, as summarized in Table 1. Both the Core Layer and Enhanced Layer were configured for fixed reception environments, employing a common 32k FFT size. The Core Layer used 16 NUC with LDPC code rate 7/15, achieving a bit rate of 19.6 Mbit/s, while the Enhanced Layer used 256 NUC with LDPC code rate 9/15, resulting in a bit rate of 50.7 Mbit/s. All MIMO precoding functions of stream combining, phase hopping, and IQ interleaving were applied to both layers. The power level difference between the two layers was set to 10 dB, making the Core Layer more robust with sufficient capacity to serve 4K-UHD service.

The test site was located in northern Gyeonggi Province, South Korea, and was operated by the Korean Broadcasting System (KBS). The RF channel, which is centred at 768 MHz, was assigned for the field test, with authorization granted for both horizontal and vertical polarizations.

TABLE 24

System parameters for field tests

OFDM parameters	FFT size		32K
	GI length		111.111 µs (GI4_768)
	Number of payload symbols		49
	Time interleaver		CTI depth of 1024
	Frequency interleaver		On
	Injection level		−10.0 dB
BICM parameters	Core layer	Outer code	BCH
		Inner code	7/15 LDPC (64800)
		Constellation	16-NUC
		Data rate	19.6 Mbit/s
		Operating *C/N*	7.6 dB
	Enhanced layer	Outer code	BCH
		Inner code	9/15 LDPC (64800)
		Constellation	256-NUC
		Data rate	50.7 Mbit/s
		Operating *C/N*	26.3 dB
MIMO parameters	Pilot	Encoding	Null Pilot
		Boosting	3.8 dB
		Pattern	MP 16_2
	Precoding	Stream combining	On
		IQ interleaving	On
		Phase hopping	On

2.10.3 Field trial results

The field trial was conducted in the northern direction from the transmission tower, with separate evaluations performed for the Core layer and the Enhanced layer.

Fixed reception measurements were conducted at seven locations, with transmission tower-to-test vehicle distances ranging from approximately 6.7 km to 22 km. Measurement point 1 was the farthest from the transmission site while point 7 was the nearest. The MIMO antenna used for fixed reception testing was a commercially available linear dual-polarized log-periodic (LP) antenna with approximately 4 dBi gain and typical 15 dB cross-polarization rejection, with the two polarization elements arranged in a crossed configuration. It was externally mounted on the vehicle and supported by a height-adjustable mast. At each measurement point, a 360-degree azimuthal rotation of the antenna was performed to assess the field strength, signal-to-noise ratio (SNR), and modulation error ratio (MER).

After each directional evaluation, the receiving antenna was oriented in the direction providing the optimal signal quality. (In addition, to improve reception performance, the antenna height could be increased up to 10 m above ground level using the mast.) The measurement criteria included received signal strength, cross-polarization discrimination (XPD) derived from channel estimation as an indicator of cross interference between the cross-polarized antennas, threshold of visibility (ToV), and minimum received signal strength. In these measurements, a frame error rate (FER) of 10^{-4} was treated as equivalent to the subjective ToV. The subjective ToV was the measured carrier-to-noise ratio (C/N) value, determined by gradually adding noise to the received signal using a noise generator until the FER exceeded 10^{-4}. The minimum received signal strength was obtained by attenuating the received signal without adding any noise.

Table 25 summarizes the results measured at the seven locations. The Core Layer was successfully decoded at all locations, showing reliable ToV and minimum received signal strength values across the measurement area. The average ToV of the Core Layer remained within 10 dB, indicating more robust reception characteristics suitable for wide-area 4K-UHD service. The Enhanced Layer was not successfully decoded at points 1 and 5, for the following reasons: At point 1, reception was limited by insufficient field strength due to the long distance from the transmission tower. At point 5, co-channel interference at 768 MHz prevented the SNR required for Enhanced Layer reception. Figure 84 shows media streams that were successfully decoded and displayed inside the measurement vehicle.

Indoor reception tests were conducted at three locations using a simplified test procedure. The receiving antenna used was also a commercially available directional flat panel antenna with greater than 13 dB cross-polarization rejection, as shown in Fig. 84. At each site, it was positioned in the direction providing the most-stable propagation conditions, with the antenna height set to approximately 1.5 m above the floor. Furthermore, only the received signal strength and the minimum received signal strength were numerically measured. While the XPD values could not be measured from the channel estimation, the level of the cross interference between the two polarizations was qualitatively assessed using the channel response presented by the measurement software. Figure 85 shows the indoor reception setup and a screenshot of the measurement software.

Table 26 summarizes the indoor reception results. Both the Core and Enhanced Layers were successfully received at all indoor test locations.

FIGURE 84

Simultaneously received media streams on the test vehicle side

TABLE 25

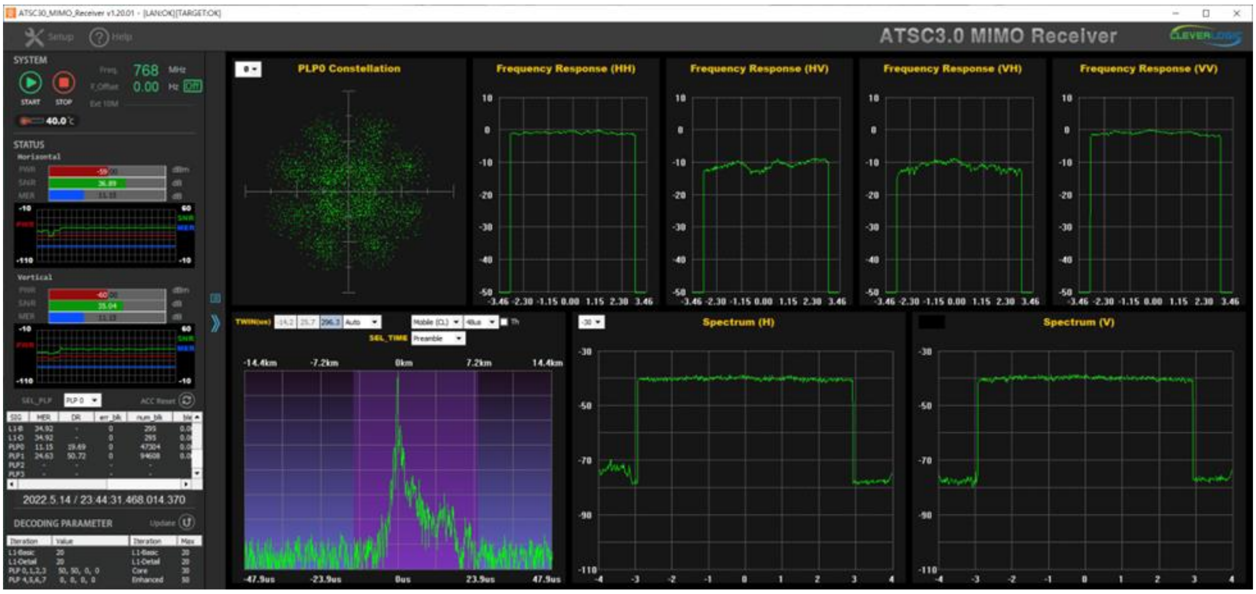
Measurement data for each measurement point in the fixed reception tests

Measurement point No.			1	2	3	4	5	6	7
Received signal strength (dBm)		H	−74.0	−62.4	−59.2	−66.1	−61.3	−48.9	−59.2
		V	−76.4	−58.5	−58.3	−66.1	−59.8	−49.1	−57.7
XPD (dB)		H	27.1	6.8	28.8	29.4	32.5	22.7	19.6
		V	14.6	14.0	17.3	34.4	15.7	19.7	21.6
ToV (dB)	Core layer	H	8.8	8.8	9.2	9.2	9.8	9.8	10.8
		V	5.6	11.7	9.1	10.2	10.6	8.7	11.5
	Enhance layer	H	Fail	32.0	28.5	28.3	Fail	29.2	30.7
		V	Fail	33.6	28.7	30.2	Fail	28.1	31.4
Minimum received signal strength (dBm)	Core layer	H	−95.6	−94.3	−95.4	−96.0	−94.0	−93.3	−94.9
		V	−97.2	−95.8	−95.1	−94.2	−93.8	−94.7	−93.6
	Enhance layer	H	Fail	−76.4	−77.2	−77.1	Fail	−76.8	−77.5
		V	Fail	−75.5	−76.2	−74.2	Fail	−77.2	−75.7

FIGURE 85

a) Indoor reception test setup

b) Screenshot of the measurement software at measurement point 3



SIG	MER	DR	err_blk	num_blk	ble
L1-B	34.92	-	0	295	0.0
L1-D	34.92	-	0	295	0.0
PLP0	11.15	19.69	0	47304	0.0
PLP1	24.63	50.72	0	94608	0.0
PLP2	-	-	-	-	
PLP3	-	-	-	-	

Iteration	Value	Iteration	Max
L1-Basic	20	L1-Basic	20
L1-Detail	20	L1-Detail	20
PLP 0,1,2,3	50, 50, 0, 0	Core	30
PLP 4,5,6,7	0, 0, 0, 0	Enhanced	30

TABLE 26

Measurement data for each measurement point in the indoor reception tests

Measurement point No.	Received signal strength (dBm)		Minimum received signal strength (dBm)			
			Core layer		Enhanced layer	
	H	V	H	V	H	V
1	−55.5	−58.7	−89.3	−90.8	−72.6	−75.1
2	−54.4	−64.2	−85.3	−88.5	−68.5	−76.6
3	−61.2	−61.7	−92.2	−92.9	−74.3	−74.6

2.10.4 Summary

Layered MIMO Type A technology in ATSC 3.0 was evaluated through field trials covering both fixed and indoor reception environments. The trials successfully demonstrated that simultaneous transmission of the two signals supports different robustness levels using transmitter and receiver platforms. The system proved capable of delivering multiple high-capacity 4K-UHD streams by exploiting spatial multiplexing and a layered multiplexing structure within a single RF channel, confirming its viability for practical deployment.

Layered MIMO Type A adopts a two-layer architecture in which the Core Layer and the Enhanced Layer generate independent MIMO streams for horizontal and vertical polarizations through separate BICM and MIMO precoding processes. The parameter configuration for this field trial is a representative case demonstrated in South Korea. By configuring the Core Layer with lower-order modulation and coding, the system achieves robust reception and wide-area coverage. In contrast, the Enhanced Layer employs higher-order modulation and coding to support additional high-capacity services beyond those typically provided by existing terrestrial broadcasters. This layered architecture enables the simultaneous support of wide-area coverage and high-throughput services using shared spectrum resources.

Bibliography

[ITU-R BT.2468]	Recommendation ITU-R BT.2468-1 (03/2021), Guidance for selection of system parameters and implementation of second generation DTTB systems
[ATSC A/300]	ATSC Standard A/300:2024-04 (04/2024), ATSC 3.0 SYSTEM
[ATSC A/370]	ATSC Recommended Practice ATSC A/370:2024-04 (04/2024), Conversion of ATSC 3.0 Services for Redistribution

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 27. The coverage of the transmitter is depicted in Fig. 86.

TABLE 27

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 ch 26)
Transmission power	100 W, e.r.p.: 1 000 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

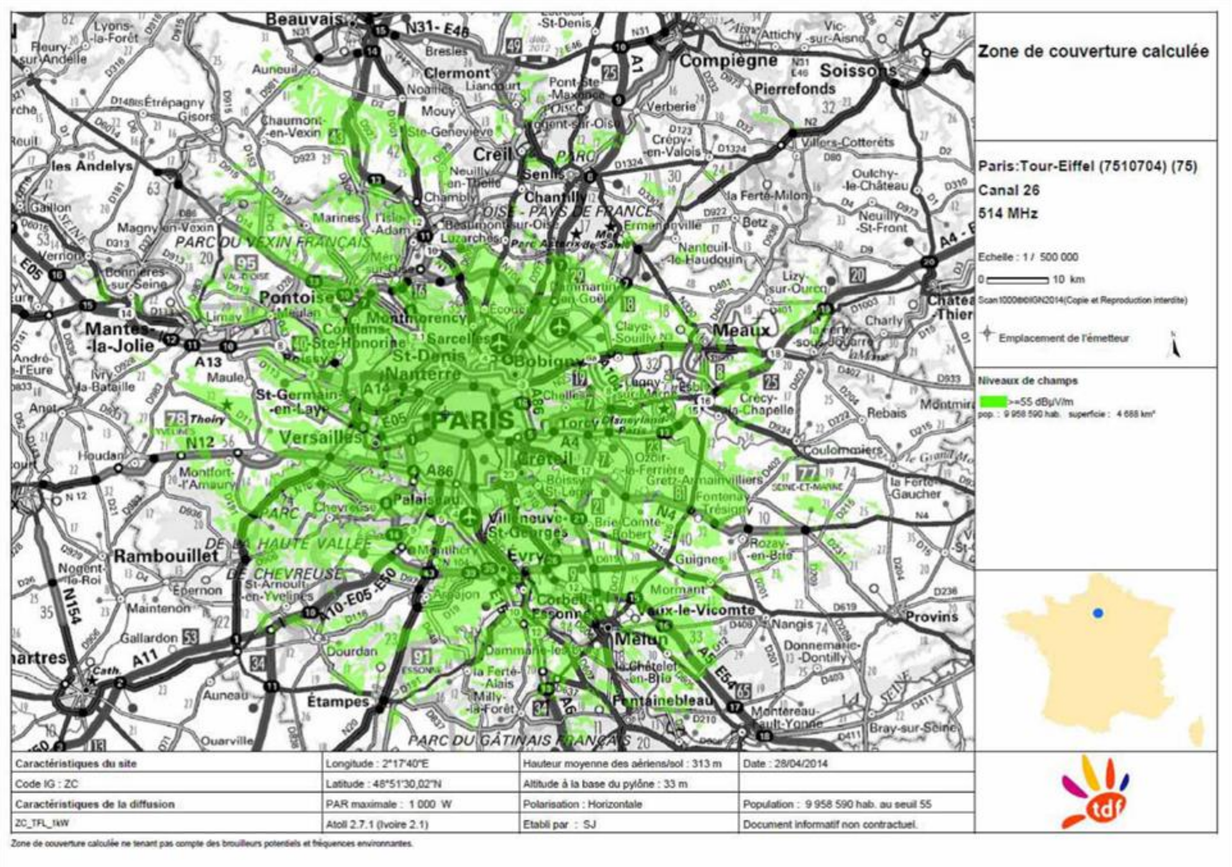
TABLE 27 (*end*)

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 86

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



Caractéristiques du site	Longitude : 2°17'40"E	Hauteur moyenne des aériens/sol : 313 m	Date : 28/04/2014
Code IG : ZC	Latitude : 48°51'30,02"N	Altitude à la base du pylône : 33 m	
Caractéristiques de la diffusion	PAR maximale : 1 000 W	Polarisation : Horizontale	Population : 9 958 590 hab. au seuil 55
ZC_TFL_1kW	Atoll 2.7.1 (Ivoire 2.1)	Etabli par : SJ	Document informatif non contractuel.

Zone de couverture calculée ne tenant pas compte des brouilleurs potentiels et fréquences environnantes.

Report BT.2343-A1-34

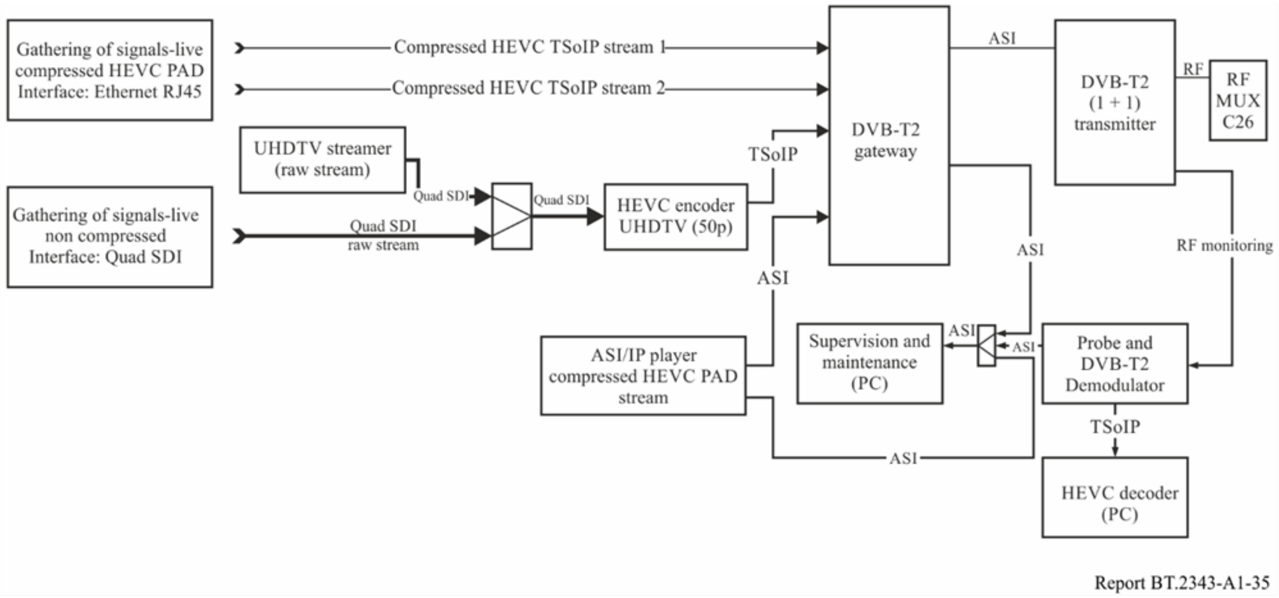
e.r.p. = 1 kW
Coverage radius ≈ 25 km
Minimum median field strength = 55 dBμV/m

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. 87.

FIGURE 87

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 offline encoded.

These two values have been defined for several reasons:

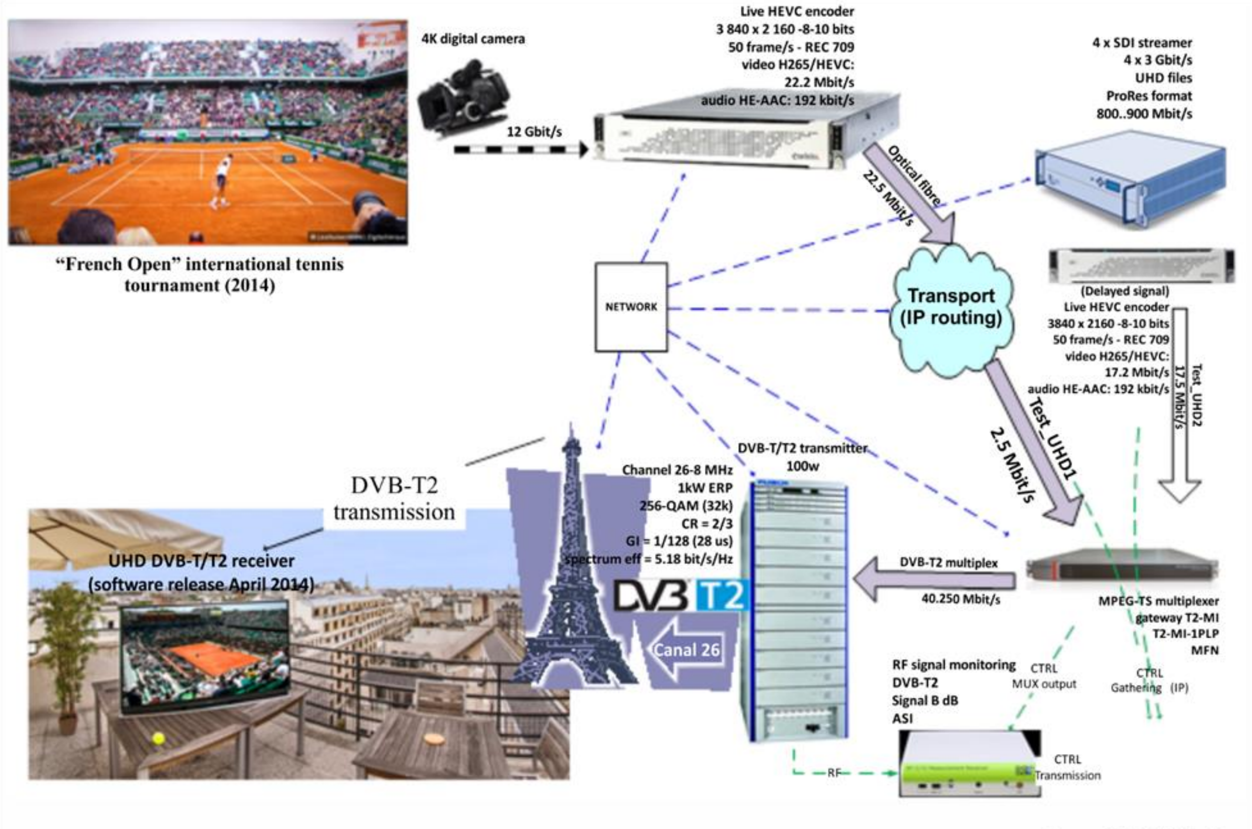
- Offline encoding uses additional HEVC tools that are not implemented in the first generation of real time encoder (no more details from encoder manufacturers at this time) and it represents next versions that will be implemented in live encoders.
- Pre-recorded files represent the same quality of current 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. 88.

FIGURE 88

Live UHDTV terrestrial transmission of the "French Open" tournament



Report BT.2343-A1-36

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 DTTB 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[6] 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 89 depicts the network architecture after the second stage deployment.

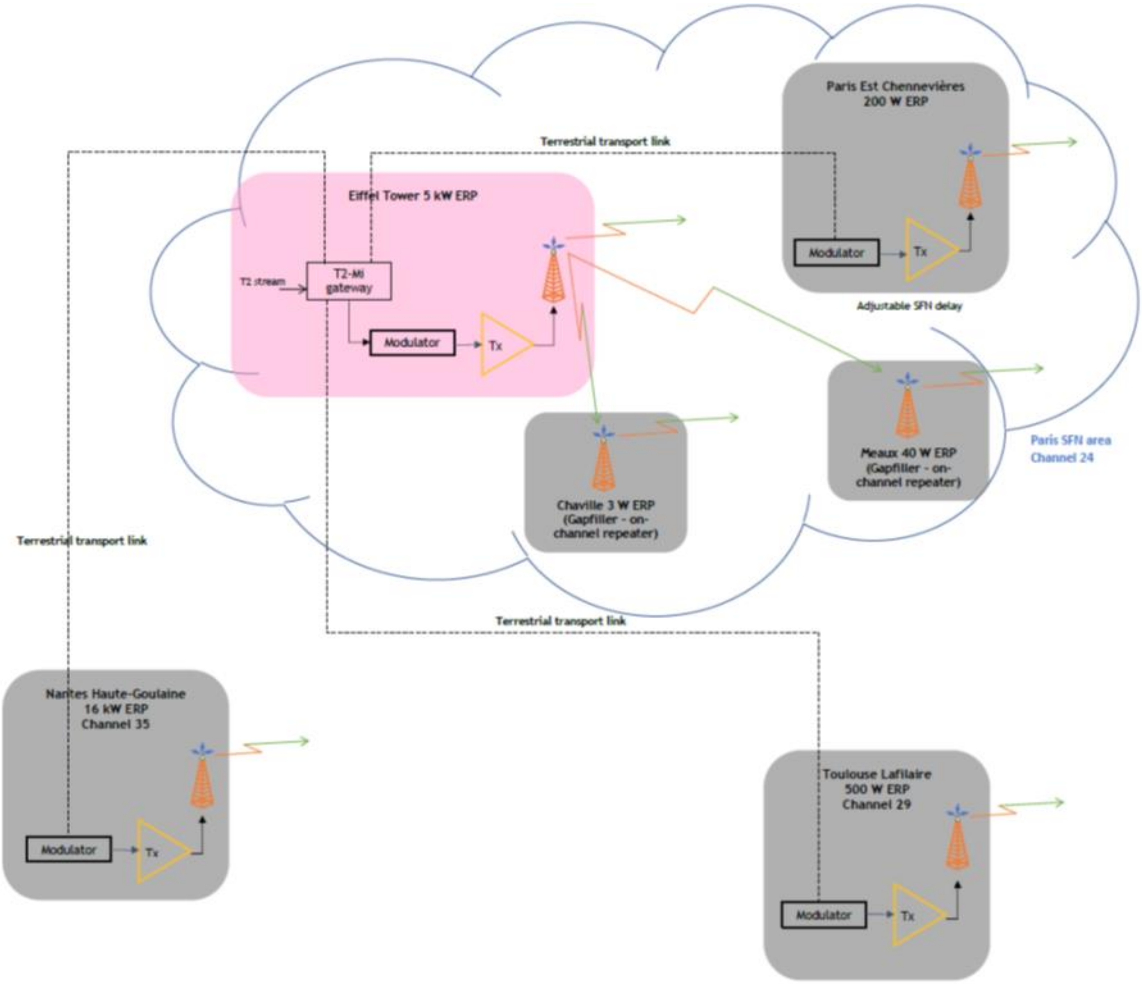
---

[6] 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.

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 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[7], 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 89

Revised network architecture



---

[7] 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 28

DVB-T2 parameter sets for revisited field experiment in France

	1st set (C1)	**2nd set (C'1)**
Modulation method	OFDM	
Channel bandwidth / Occupied bandwidth (MHz)	8 / 7.77	
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

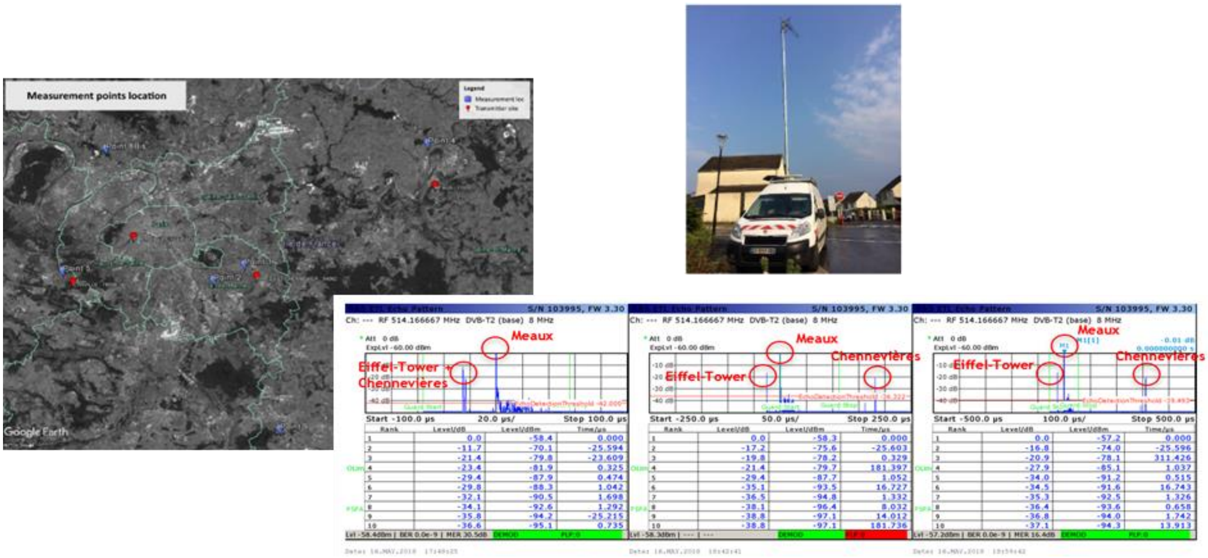
The two selected parameter sets are very close, the main difference being the choice of the pilot pattern which has a direct impact on the ability of receivers to cope with long echoes for SFN reception, to the detriment of the available net bit rate.

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 90

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



S/N 103995, FW 3.30
Ch: --- RF 514.166667 MHz DVB-T2 (base) 8 MHz
Att 0 dB
ExpLvl -60.00 dBm
Start -100.0 µs 20.0 µs/ Stop 100.0 µs

Rank	Level/dB	Level/dBm	Time/µs
1	0.0	-58.4	0.000
2	-11.7	-70.1	-25.594
3	-21.4	-79.8	-23.609
4	-23.4	-81.9	0.325
5	-29.4	-87.9	0.474
6	-29.8	-88.3	1.042
7	-32.1	-90.5	1.698
8	-34.1	-92.6	1.292
9	-35.8	-94.2	-25.215
10	-36.6	-95.1	0.735

Lvl -58.4dBm | BER 0.0e-9 | MER 30.5dB

S/N 103995, FW 3.30
Ch: --- RF 514.166667 MHz DVB-T2 (base) 8 MHz
Att 0 dB
ExpLvl -60.00 dBm
Start -250.0 µs 50.0 µs/ Stop 250.0 µs

Rank	Level/dB	Level/dBm	Time/µs
1	0.0	-58.3	0.000
2	-17.2	-75.6	-25.603
3	-19.8	-78.2	0.329
4	-21.4	-79.7	181.397
5	-29.4	-87.7	1.052
6	-35.1	-93.5	16.727
7	-36.5	-94.8	1.332
8	-38.1	-96.4	8.032
9	-38.8	-97.1	14.012
10	-38.8	-97.1	181.736

Lvl -58.3dBm | --- | ---

S/N 103995, FW 3.30
Ch: --- RF 514.166667 MHz DVB-T2 (base) 8 MHz
Att 0 dB
ExpLvl -60.00 dBm
Start -500.0 µs 100.0 µs/ Stop 500.0 µs

Rank	Level/dB	Level/dBm	Time/µs
1	0.0	-57.2	0.000
2	-16.8	-74.0	-25.596
3	-20.9	-78.1	311.426
4	-27.9	-85.1	1.037
5	-34.0	-91.2	0.515
6	-34.5	-91.6	16.743
7	-35.3	-92.5	1.326
8	-36.4	-93.6	0.658
9	-36.8	-94.0	1.742
10	-37.1	-94.3	13.913

Lvl -57.2dBm | BER 0.0e-9 | MER 16.4dB

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 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 24 June 2014. The Table below shows the technical parameters involved in this demonstrator.

FIGURE 91

Report BT.2343-A1-37

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.

Chair of RTVE in UPM

rtve POLITÉCNICA

Advisory Committee:

cellnex DOLBY sapec Televes

Collaborating entity:

abacanto

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 DTTB or the first HD trials in DTTB 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 DTTB 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/H.265
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 64-QAM 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/H.265
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 bit rate of 128 kbit/s. A secondary audio PID encoded in AC-4 was used as well, with a bit rate 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 centres 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 4, 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 centres 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 21, 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 Recommendation ITU-R BT.2020 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

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.

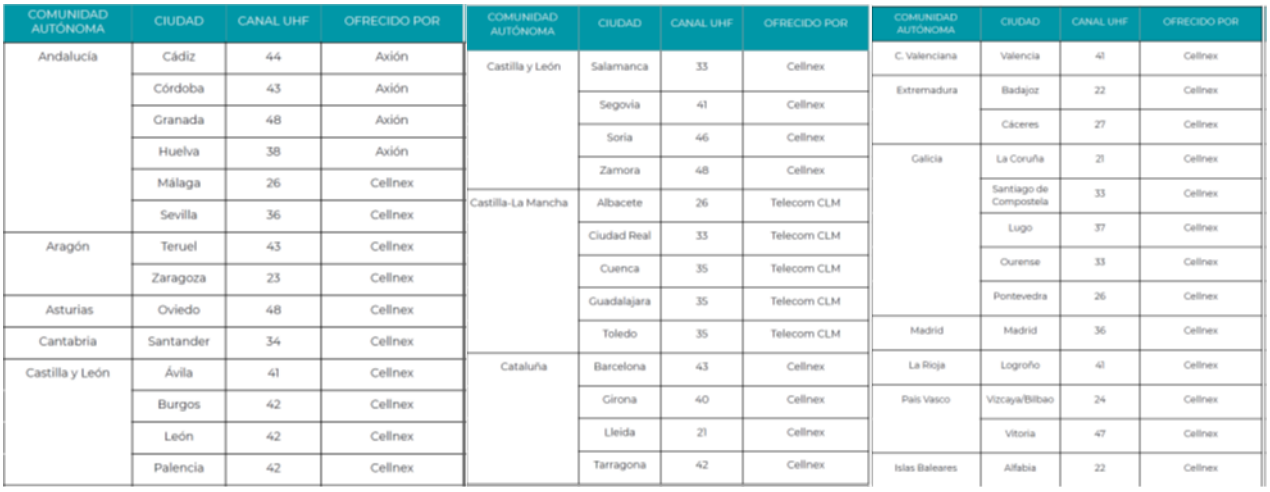
4.3 UHD Spain coordinated trials starting on 2021

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 DTTB 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.

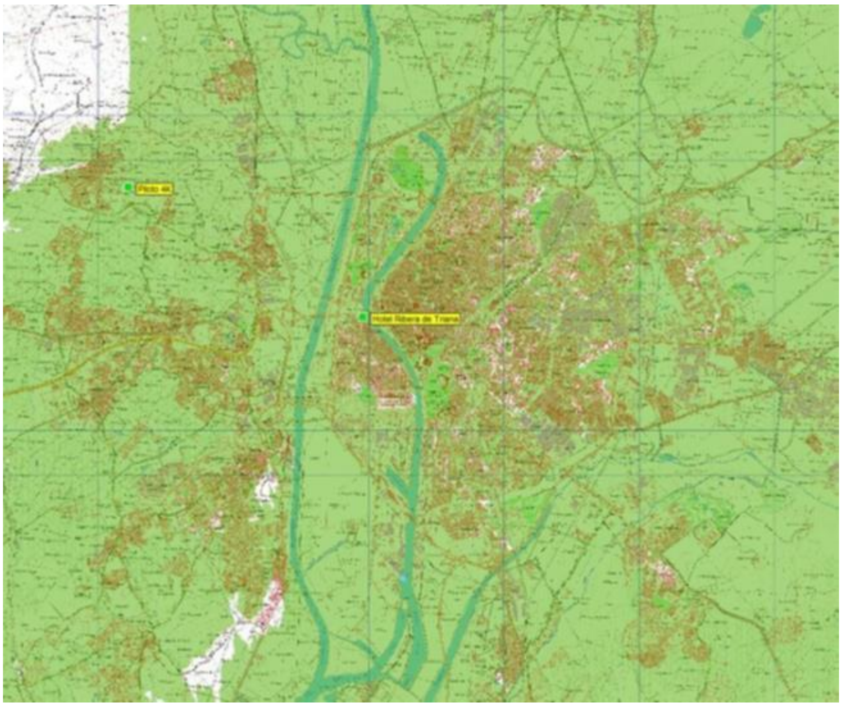


COMUNIDAD AUTÓNOMA	CIUDAD	CANAL UHF	OFRECIDO POR
Andalucía	Cádiz	44	Axión
	Córdoba	43	Axión
	Granada	48	Axión
	Huelva	38	Axión
	Málaga	26	Cellnex
	Sevilla	36	Cellnex
Aragón	Teruel	43	Cellnex
	Zaragoza	23	Cellnex
Asturias	Oviedo	48	Cellnex
Cantabria	Santander	34	Cellnex
Castilla y León	Ávila	41	Cellnex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

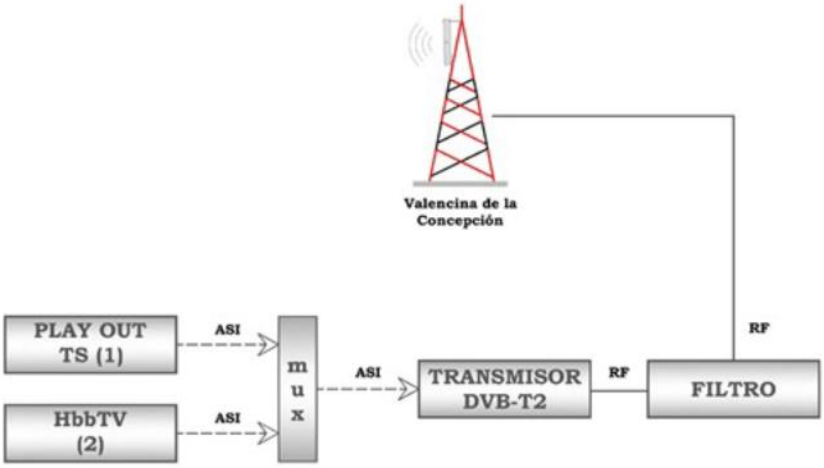
Cellnex network is including 35 transmitter sites and is covering 37% of Spanish population distributed in 31 different provinces in Spain. Cellnex network has been used for the trials described in §§ 4.1 and 4.2.

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 500 W transmitter with e.r.p. of 10 kW 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.



(1) Transport Stream compuesto por dos servicios: uno codificado en H.265 a 25 mbps y otro en H.264 a 6 mbps.
(2) Transport Stream con las tablas AIT para señalizar el HbbTV.

In 2017 a new transmitter site in Mijas, covering Malaga using a 300 W 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.

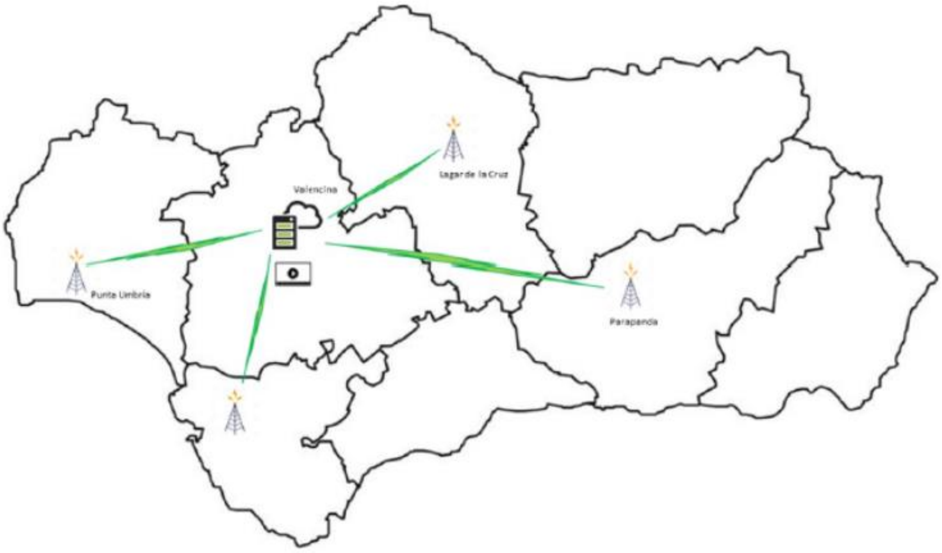
Since then Axión has added four additional transmitters in:

- 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/H.265
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
Characteristics of the transmission	
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 DTTB 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 DTTB transmitters broadcasting a multiplex containing one UHDTV service.

The 4K signal was transmitted in the DTTB 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 areas.

7 Brazil

Free-to-air terrestrial television is the main audiovisual distribution platform in Brazil, covering almost all Brazilian households and used in more than 70% of them. It secures most of the Brazilian population free-of-charge, universal and democratic access to information and entertainment made by Brazilians for Brazilians. It is, therefore, a crucial element in fostering social cohesion and shaping national and cultural identity.

For its first generation Digital Terrestrial Television Broadcasting (DTTB) system, after thorough testing and careful studies, the Brazilian Government adopted in June 2006 the ISDB-T standard, incorporating technological innovations that were deemed relevant, such as MPEG-4 AVC (H.264) video coding, MPEG-4 AAC audio coding, an appropriate closed caption character set for the Brazilian Portuguese, and a new middleware for interactive applications (Ginga).

The SBTVD Forum was created by the Brazilian Presidential Decree No. 5 820 /2006 to advise the Brazilian Government regarding policies and technical issues related to the approval of technical innovations, specifications, development, and implementation of the Brazilian Digital Terrestrial Television System (SBTVD). The SBTVD Forum is composed of representatives of the broadcasting, academia, transmission, reception, and software industry sectors and has the participation of Brazilian Government representatives as non-voting members.

The SBTVD Forum developed the first SBTVD standards, published in 2007, allowing the official opening of transmissions in that same year. Since then, the standards have been continuously revised and updated by the Forum. The technological innovations proposed by Brazil were incorporated into the International ISDB-T standard, which is currently adopted by 20 countries.

Brazilian researches for the next-generation DTTB system to enable UHDTV transmission began in 2014 in Rio de Janeiro, during the FIFA World Cup. TV Globo (a Brazilian Broadcasting Company), in partnership with HBS (Host Broadcast Services), NEC and Sony, used DVB-T2 technology to transmit some of the football matches in 4K UHDTV from TV Globo's Headquarters (HQ) to a Public Viewing at Shopping Leblon, Rio de Janeiro. The 4K UHDTV production format had been tested by TV Globo in partnership with Sony the previous year at the 2013 FIFA Confederations Cup. Also, at the 2014 FIFA World Cup, TV Globo advanced on trialling the production in 8K UHDTV format (which it had tested for the first time in the 2013 Rio Carnival Samba School Parade) in partnership with NHK (*Nippon Hōsō Kyōkai* – Japan Broadcasting Corporation), NTT (Nippon Telegraph and Telephone Corporation) and RNP (*Rede Nacional de ensino e Pesquisa* – Brazilian National Education and Research Network), offering a Public Viewing in that quality at CBPF (*Centro Brasileiro de Pesquisas Físicas* – Brazilian Centre for Research in Physics), Rio de Janeiro.

During the Rio de Janeiro Olympics in August 2016, TV Globo in collaboration with NHK provided 8K HDR UHDTV Public Viewing (PV) of the Olympic Games for the local viewers. This PV at the Museum of Tomorrow, Rio de Janeiro, was carried out by transmitting an 8K HDR UHDTV signal through a terrestrial network in the 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.

Section 7.1 describes the details of this trial and the tests conducted at the occasion.

In 2016, the SBTVD Forum decided to work on updating the Brazilian DTTB system in two steps: extending the life span of the existing DTTB system as much as possible through a backwards-compatible evolution (TV 2.5 Project) and starting the development of the next-generation DTTB system (TV 3.0 Project), that would finally enable free-to-air UHDTV over DTTB networks.

The TV 2.5 Project comprised new Integrated Broadcast-Broadband functionalities and improved audiovisual quality (Brazilian DTTB used 1 080i / 29.97fps / 8-bit / BT.709 / H.264 HiP@4.0 video and 5.1 LC/HE-AAC@L4 audio). To introduce new IBB functionalities, a new receiver profile for

the middleware Ginga (receiver profile D, a.k.a. “DTV Play”) was developed, as detailed in Recommendation ITU-R BT.2075 and Report ITU-R BT.2267. Three new optional immersive audio codecs (MPEG-H Audio, E-AC-3 JOC, and AC-4) were introduced to improve the audio quality while retaining AAC main audio for backward compatibility. In addition, two new optional HDR video formats (SL-HDR1 dynamic metadata and HLG “preferred transfer characteristics” signalling) were introduced to improve the video quality while keeping the BT.709 video for backward compatibility. The TV 2.5 revision of the Brazilian DTTB standards is available at https://forumsbtvd.org.br/legislacao-e-normas-tecnicas/normas-tecnicas-da-tv-digital/english/.
In 2024, after validation tests, the SBTVD Forum decided to include the Low Complexity Enhancement Video Coding (MPEG-5 Part 2 – LCEVC) in the TV 2.5 standards, allowing the use of an enhancement layer that enables scaling the video to 1 080p / 59.94fps / 10-bit in a backwards-compatible way.

Before the beginning of the TV 3.0 Project, TV Globo also performed field trials during the 2018 FIFA World Cup and the Rock in Rio 2019. In the 2018 FIFA World Cup, TV Globo, in partnership with 20 other companies, used ATSC 3.0 to provide a 4K HDR UHDTV transmission over DTTB in Rio de Janeiro. In collaboration with NHK, it also produced an 8K HDR UHDTV signal and provided a Public Viewing at the Museum of Tomorrow, Rio de Janeiro. In the Rock in Rio 2019, TV Globo, in partnership with Rohde & Schwarz, Technicolor, Yamaha, Dolby and Fraunhofer IIS, transmitted HD HDR over the air in Rio de Janeiro using both TV 2.5 and 5G Broadcast and also provided an 8K HDR UHDTV Public Viewing at the concert venue.

After the TV 3.0 Project started in 2020, TV Globo interrupted the sequence of UHDTV over DTTB transmission tests it had been carrying out at major sporting events since 2014, awaiting the results of the tests and the SBTVD Forum’s over-the-air physical layer technology recommendation. It continued, however, to test UHDTV production formats with Internet distribution and Public Viewings. During the 2020 Summer Olympics, postponed to 2021 due to the COVID-19 pandemic, TV Globo, in partnership with NHK, OBS (Olympic Broadcasting Services), and Intel, provided a free-to-view 8K HDR UHDTV signal over the Internet for compatible TV sets in Brazil using its streaming app Globoplay.

The TV 3.0 Project started in 2020 and was divided into three phases.

In Phase 1 (2020), the new system’s requirements were defined, and a Call for Proposals (CfP) was issued. The CfP received, in total, considering its six system components (Over-the-air Physical Layer, Transport Layer, Video Coding, Audio Coding, Captions and Application Coding), 36 responses from 21 different organizations worldwide. Some similar proposals were merged for testing and evaluation, resulting in 30 candidate technologies.

Then, in Phase 2 (2021), the candidate technologies were tested and evaluated. The technologies to be used in most system components were selected (except for the Over-the-air Physical Layer).

After the conclusion of Phase 2, TV Globo, in partnership with several other companies, exhibited TV 2.5 (HD HDR over-the-air) and TV 3.0 (4K HDR UHDTV over-IP) trials during the FIFA World Cup 2022.

Phase 3 (2022-2024) comprised additional tests (including a subjective assessment of the TV 3.0 real-time video coding technologies quality for the determination of the required bitrate, as well as laboratory and field tests to select the Over-the-air Physical Layer technology), R&D on adaptations and extensions to the transport layer and application coding technologies, technical standardization and technology demonstrations.

In April 2023, the Brazilian Presidential Decree No. 11,484, which provides the guidelines for the evolution of the Brazilian DTTB system and for ensuring the availability of radio spectrum for its deployment, was published (available at http://www.planalto.gov.br/ccivil_03/_ato2023-2026/2023/decreto/D11484.htm, in Portuguese only).

It establishes that the next-generation DTTB system in Brazil, called TV 3.0, shall have the following characteristics:

I audiovisual quality superior to that of the first-generation Brazilian DTTB system;

II fixed reception, with external and internal antenna, and mobile reception;

III integration between contents transmitted by the broadcasting service and over the internet;

IV app-based user interface;

V content segmentation according to viewers' geographic location;

VI customization of content according to viewers' preferences;

VII optimized use of the radio frequency spectrum destined for terrestrial television broadcasting; and

VIII new forms of access to cultural, educational, artistic, and informative contents.

It states that the Ministry of Communications will support the SBTVD Forum so that the studies related to the technological innovations that may comprise TV 3.0 are completed by 31 December 2024, including the technical requirements for the receivers that will allow the adaptation from the current digital television technology to TV 3.0.

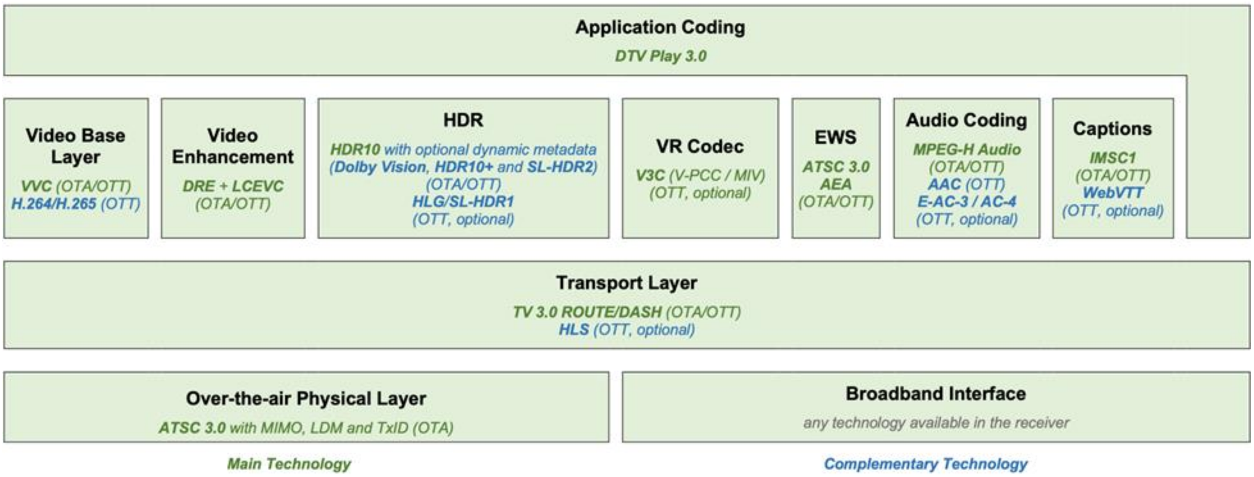
It determines that the National Telecommunications Agency (Anatel) shall conduct studies on the frequency planning of TV 3.0 until 31 December 2024, and promote actions to ensure:

I regulatory stability, through the availability of frequency bands necessary for the evolution of terrestrial television broadcasting; and

II implementation of digital terrestrial television in Brazil and its technological evolution.

Finally, it states that the Ministry of Communications will constitute and coordinate a working group to propose regulations for TV 3.0, with the participation of representatives from Anatel, the Ministry of Science, Technology, and Innovation, the Ministry of Finance, the SBTVD Forum and entities representing the broadcasting sector. The deadline for the completion of activities by the working group is 31 December 2024.

Having completed its tests, as well as the analysis of market and intellectual property aspects of the candidate technologies, in July 2024, the SBTVD Forum submitted to the Brazilian Ministry of Communications its recommendations for the technological innovations that may comprise TV 3.0, as shown in the summary diagram below:



Below is a list of all the technical publications produced by the SBTVD Forum, with the support and monitoring of the Brazilian Ministry of Communications, within the scope of the TV 3.0 Project:

Date	Title	Link
17 July 2020	Call for Proposals: TV 3.0 Project	https://forumsbtvd.org.br/wp-content/uploads/2020/07/SBTVDTV-3-0-CfP.pdf
28 January 2021	Call for Prototypes: MIMO Indoor Antennas – TV 3.0 Project	https://forumsbtvd.org.br/wp-content/uploads/2021/01/SBTVD-TV_3_0-CfP-MIMO_2021-01-28.pdf
15 March 2021	CfP Phase 2 / Testing and Evaluation: TV 3.0 Project	https://forumsbtvd.org.br/wp-content/uploads/2021/03/SBTVD-TV_3_0-P2_TE_2021-03-15.pdf
3 December 2021	Testing and Evaluation Report: TV 3.0 Project – Over-the-air Physical Layer Laboratory Tests	https://forumsbtvd.org.br/wp-content/uploads/2021/12/SBTVD-TV_3_0-PL-Lab-Report.pdf
3 December 2021	Testing and Evaluation Report: TV 3.0 Project – Over-the-air Physical Layer Field Tests	https://forumsbtvd.org.br/wp-content/uploads/2021/12/SBTVD-TV_3_0-PL-Field-Report.pdf
3 December 2021	Testing and Evaluation Report: TV 3.0 Project – Transport Layer	https://forumsbtvd.org.br/wp-content/uploads/2021/12/SBTVD-TV_3_0-TL-Report.pdf
3 December 2021	Testing and Evaluation Report: TV 3.0 Project – Video Coding	https://forumsbtvd.org.br/wp-content/uploads/2021/12/SBTVD-TV_3_0-VC-Report.pdf
3 December 2021	Testing and Evaluation Report: TV 3.0 Project – Audio Coding	https://forumsbtvd.org.br/wp-content/uploads/2021/12/SBTVD-TV_3_0-AC-Report.pdf
3 December 2021	Testing and Evaluation Report: TV 3.0 Project – Captions	https://forumsbtvd.org.br/wp-content/uploads/2021/12/SBTVD-TV_3_0-CC-Report.pdf
3 December 2021	Testing and Evaluation Report: TV 3.0 Project – Application Coding	https://forumsbtvd.org.br/wp-content/uploads/2021/12/SBTVD-TV_3_0-AP-Report.pdf
6 November 2023	TV 3.0 Project – Phase 3 – Over-the-air Physical Layer Laboratory Tests	https://forumsbtvd.org.br/wp-content/uploads/2023/11/SBTVD-TV_3_0-P3-PL-Lab-Report.pdf
29 February 2024	TV 3.0 Project – Phase 3 – Real-Time Video Coding Subjective Quality Assessment	https://forumsbtvd.org.br/wp-content/uploads/2024/03/SBTVD-TV_3_0-P3-VC-Report.pdf
19 July 2024	TV 3.0 Project – Phase 3 – Over-the-air Physical Layer Field Tests	https://forumsbtvd.org.br/wp-content/uploads/2024/07/SBTVD-TV_3_0-P3-PL-Field-Report.pdf

As described in § 7.2, during the 2024 Summer Olympics, TV Globo, in partnership with several other companies, exhibited an experimental 4K HDR live DTTB transmission in Rio de Janeiro, using the technologies recommended by the SBTVD Forum for the Brazilian TV 3.0 Project. In partnership with OBS and Intel, it also provided a Public Viewing in Rio de Janeiro of an 8K HDR UHDTV live signal received directly from Paris over the public Internet.

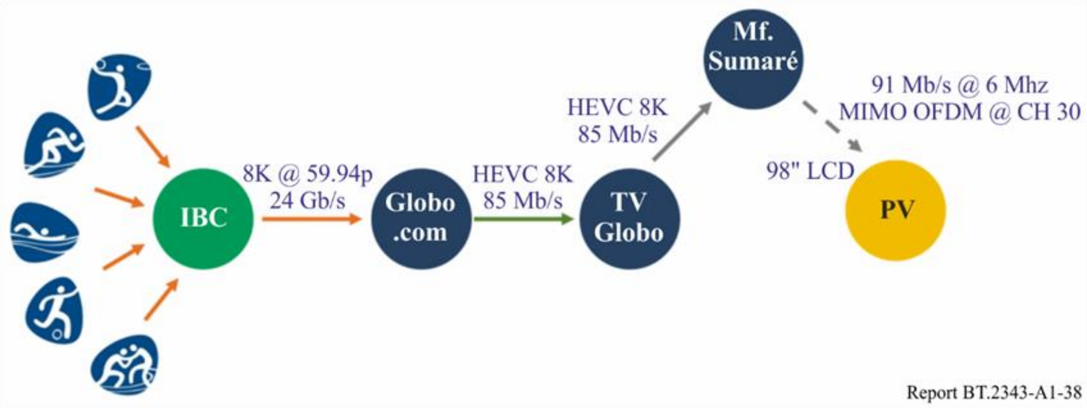
7.1 2016 Summer Olympics

7.1.1 Diagram of the PV

The diagram of 8K transmission for this PV is shown in Fig. 92. 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 92

Diagram of 8K terrestrial transmission for the PV



Report BT.2343-A1-38

7.1.2 Transmission and reception station equipment

Figure 93 shows the transmission station antenna. Transmitting antenna’s characteristics are shown in Table 29. Figure 94 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 30.

FIGURE 93

Transmission station antenna

Report BT.2343-A1-39

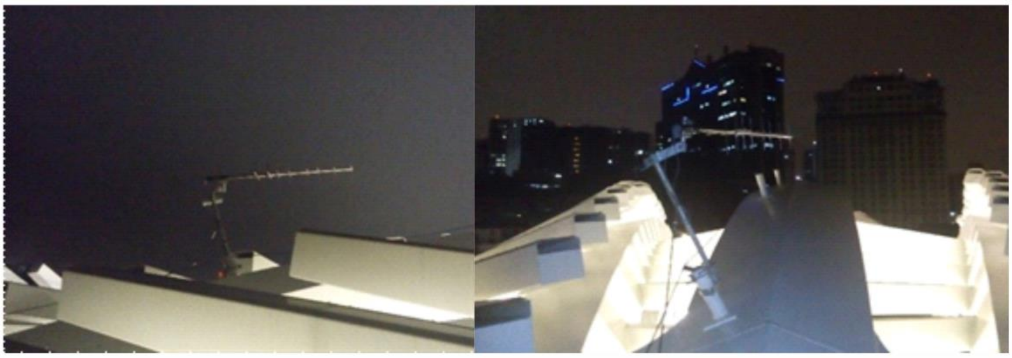
TABLE 29

Transmitting antenna's characteristics

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

FIGURE 94

Reception station antenna



Report BT.2343-A1-40

TABLE 30

Receiving antenna's characteristics

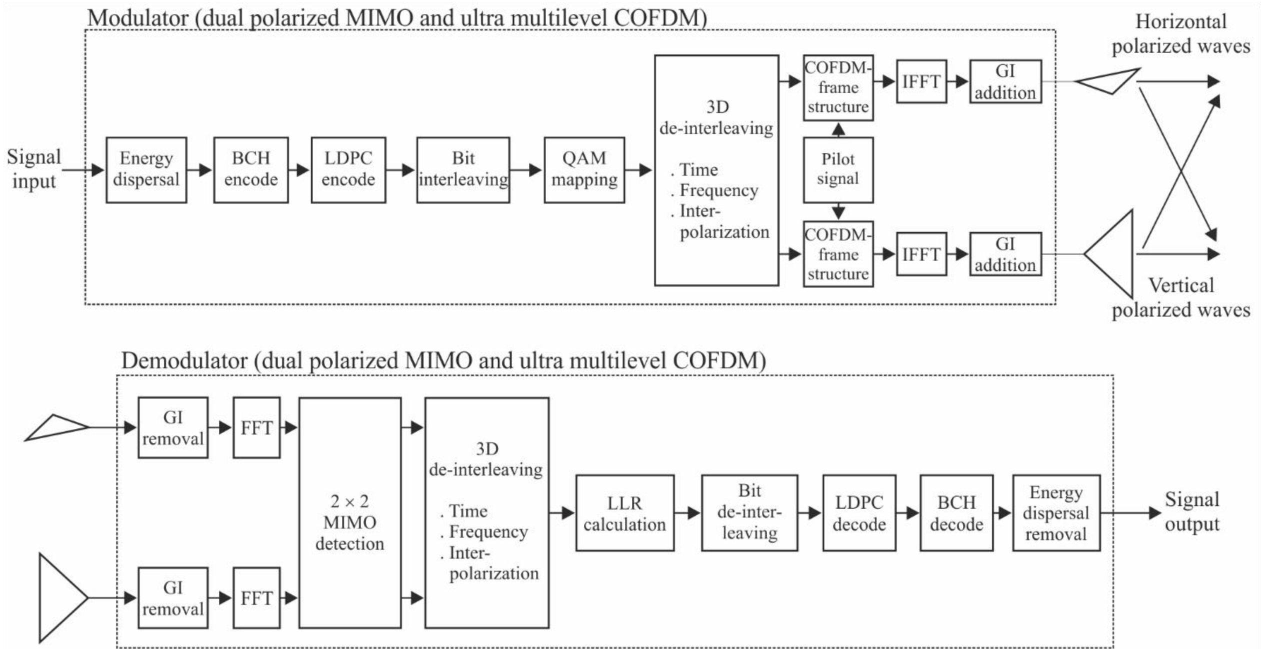
Type	Dual-Polarized, 8-element Yagi
Gain	9 dBd
Cross-polarization isolation	~25 dB in 569 MHz

Figure 95 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 95

Modulation and demodulation scheme



Report BT.2343-A1-41

7.1.3 Transmission parameters

The transmission parameters of the 8K UHDTV PV service are shown in Table 31.

TABLE 31

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 96 shows the simulated theoretical coverage area.

FIGURE 96

Coverage area

Report BT.2343-A1-42

7.1.4 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.

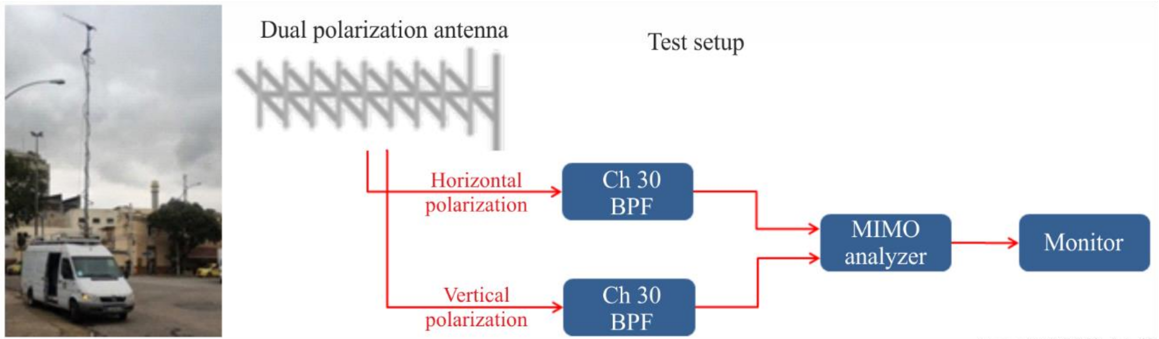
7.1.5 Measurements

7.1.5.1 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. 97, assembled in the van also shown in Fig. 97.

FIGURE 97

Test setup



Report BT.2343-A1-43

The chosen measurement points and the theoretical coverage are shown in Fig. 98.

FIGURE 98

Measurement points

Report BT.2343-A1-44

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.

7.1.5.2 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 99 shows the measurement setup installed at the site. No significant variation on reception condition was detected during the observation period.

FIGURE 99

Measurements set up

Report BT.2343-A1-45

7.1.6 Demonstration

During the Rio de Janeiro Olympics, more than 30 000 people visited the 8K UHDTV PV at Museum of Tomorrow. Figure 100 shows images of the viewing session.

FIGURE 100

Public viewing at Museum of Tomorrow

Report BT.2343-A1-46

7.1.7 Summary

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.

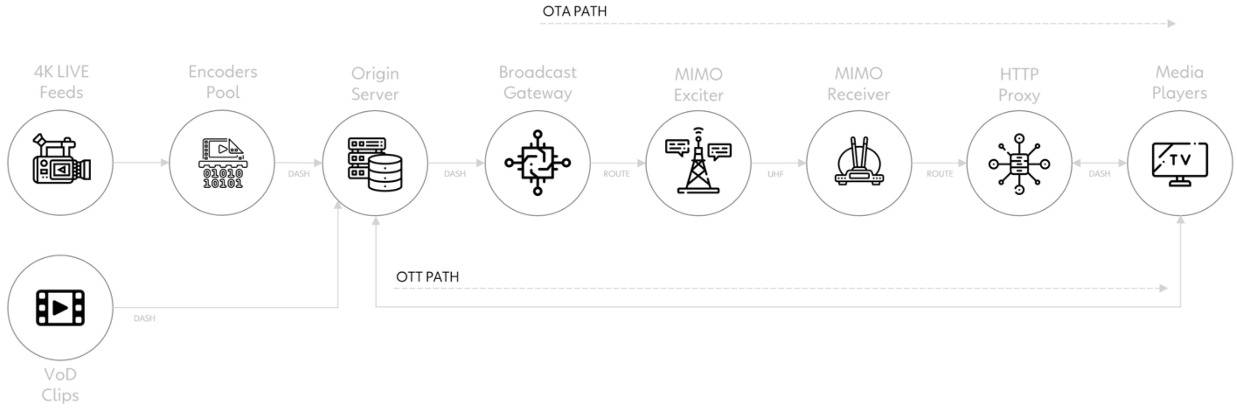
7.2 2024 Summer Olympics

7.2.1 TV 3.0 Trial Diagram

The test setup used during the 2024 Summer Olympics, depicted in Fig. 101, was designed to allow the technologies recommended by the SBTVD Forum for the TV 3.0 Project to be trialled in a live 4K HDR UHDTV production, with over-the-air (OTA) transmission via DTTB and over-the-top (OTT) transmission via the Internet.

FIGURE 101

2024 Summer Olympics TV 3.0 Trial Diagram



There were four live feeds in 4K HDR UHDTV, carrying three different sports competitions, one of them in two feeds with different commercials.

The live feeds contained 3 840 × 2 160 p, 59.94 frames/s, 10 bits/pixel, PQ (Perceptual Quantization, as defined in Recommendation ITU-R BT.2100) video and 5.1.4 (defined as 4+5+0 Sound System D in Recommendation ITU-R BS.2051) audio with three objects (Sportscaster 1, Sportscaster 2 and audio description).

The two live feeds corresponding to the same sports competition with different commercials were used for the over-the-air (OTA) transmission via DTTB. One of them, used in the first Physical Layer Pipe, was encoded in real-time using VVC (Versatile Video Coding, as defined in Recommendation ITU-T H.266), Main Tier, and Main 10 Profile, with Level 5.1 (in original resolution) at 14 Mbit/s. The other, used in the second Physical Layer Pipe, was encoded in real-time using VVC, Main Tier, and Main 10 Profile, with Level 4.1 (downscaled to 1 920 × 1 080) at 7 Mbit/s. Both of them were encoded using HDR10 media profile required static metadata (mastering display colour volume metadata as defined in SMPTE ST 2086) and using MPEG-H 3D Audio (as defined in ISO/IEC 23008-3), Baseline Profile, with Level 3 at 540 kbit/s.

The other two live feeds were used for the over-the-top (OTT) transmission via the Internet. One of them was encoded in real-time using VVC, Main Tier, and Main 10 Profile, with Level 5.1 (in original resolution) at 14 Mbit/s. The other was encoded in real-time using VVC Base Layer, Main Tier, and Main 10 Profile, with Level 4.1 (1 920 × 1 080), and MPEG-5 Part 2 LCEVC (Low Complexity Enhancement Video Codec, as defined in ISO/IEC 23094-2) Enhancement Layer, Main Profile, with Level 3 (3 840 × 2 160), at 14 Mbit/s (total video coding bitrate, i.e., Base Layer + Enhancement Layer). Both of them were encoded using HDR10 media profile required static metadata and using MPEG-H 3D Audio, Baseline Profile, with Level 3 at 540 kbit/s.

The video clips for on-demand consumption over the Internet had the same baseband signal configuration. They were encoded in non-real-time software using the same technologies and configurations as the live feed in the first Physical Layer Pipe of the over-the-air (OTA) transmission via DTTB.

The encoders (both real-time and non-real time) provided their outputs in MPEG DASH (Dynamic Adaptive Streaming over HTTP, as defined in ISO/IEC 23009-1) streams compliant with CMAF (Common Media Application Format, as defined in ISO/IEC 23000-19) media profiles. The encoders' outputs fed a DASH origin server, which provided audiovisual content to both the over-the-air (OTA) transmission via DTTB and the over-the-top (OTT) transmission via the Internet.

In the OTA signal path, the DASH streams were input to an ATSC 3.0 Broadcast Gateway (modified to support VVC) that provided the ROUTE (Real-time Object delivery over Unidirectional Transport, as defined in ATSC A/331) packaging and signalling. The Broadcast Gateway output fed a prototype ATSC 3.0 MIMO Exciter (based on ATSC A/322:2024-04, with extensions to support the simultaneous usage of MIMO, LDM and TxID). The exciter fed two power amplifiers (one for each polarization) that fed a transmitting antenna system that consisted of a circular arrangement of 2 horizontal / vertical 1-meter-high dual-polarized panels (one level, two faces at 90 degrees). The signal was received using a prototype 2 × 2 cross-polarized MIMO indoor antenna inside a building at around 6.6 km distance under near-line-of-sight conditions. The receiving antenna outputs (horizontal and vertical) fed a prototype ATSC 3.0 MIMO receiver (also based on ATSC A/322:2024-04, with extensions to support the simultaneous usage of MIMO, LDM and TxID) that fed an HTTP Proxy, that unpacked the ROUTE signal and served as another DASH server.

Finally, the media players (implemented either built-in TV sets or in set-top boxes), controlled by applications under an application-based television broadcasting paradigm, were able to playback audiovisual content transmitted both over-the-air (through the HTTP Proxy) or over-the-top (through the Origin Server.

7.2.2 Over-the-air transmission parameters

The transmission parameters used in the 2024 Summer Olympics TV 3.0 trial over-the-air transmission are shown in Table 32.

TABLE 32

2024 Summer Olympics TV 3.0 trial over-the-air transmission parameters

Modulation method	2 × 2 cross-polarized MIMO ATSC 3.0 (based on ATSC A/322:2024-04, with extensions to support the simultaneous usage of MIMO, LDM and TxID)
Occupied bandwidth	5.83 MHz
Transmission frequency	569.142857 MHz (UHF channel 30 in Brazil)
Transmission power	Horizontal polarized waves: 90 W, e.r.p.: 500 W Vertical polarized waves: 90 W, e.r.p.: 500 W

TABLE 32 (*continued*)

FFT size (number of radiated carriers)	16k (13 825 carriers)
Guard interval ratio (guard interval duration)	768/16384 (111 µs)
Pilot Pattern	MP8_2 (Dx = 8, Dx = 2)
MIMO Pilot Encoding	Null pilot
Frame Duration	98 OFDM symbols / subframe (250 ms)
Time interleaving	CTI 1024
LDM CL (PLP0)[8] Carrier modulation	16-QAM Non-Uniform Constellation
LDM CL (PLP0) Error-correcting code	Inner: LDPC (64800), code rate = 8/15 Outer: BCH
LDM CL (PLP0) Transmission capacity	21.5 Mbit/s
LDM CL (PLP0) Video coding	3 840 × 2 160 p, 59.94 frames/s, 10 bits/pixel, HDR10, WCG, VVC, Main Tier, Main 10 Profile, Level 5.1 at 14 Mbit/s
LDM CL (PLP0) Audio coding	5.1.4ch + 3 objects, MPEG-H 3D Audio, Baseline Profile, Level 3 at 540 kbit/s
LDM EL (PLP1)[9] Carrier modulation	QPSK
LDM EL (PLP1) Error-correcting code	Inner: LDPC (64800), code rate = 8/15 Outer: BCH
LDM EL (PLP1) Transmission capacity	10.7 Mbit/s
LDM EL (PLP1) Video coding	1 920 × 1 080 p, 59.94 frames/s, 10 bits/pixel, HDR10, WCG, VVC, Main Tier, Main 10 Profile, Level 4.1 at 7 Mbit/s
LDM EL (PLP1) Audio coding	5.1.4ch + 3 objects, MPEG-H 3D Audio, Baseline Profile, Level 3 at 540 kbit/s
LDM Injection Level	9 dB
Transmitting station	Penna Hill
Height of transmitting antenna	158 m above sea level
Transmitting antenna system	circular arrangement of 2 horizontal / vertical 1-meter-high dual-polarized panels (one level, two faces at 90°)
Transmitting antenna system gain	9.2 dBd
Transmitting antenna system cross-polarization isolation	35 dB
Transmitting antenna system VSWR	< 1.1
Receiving station	ION Intelligent Center (approx. 6.6 km from the test transmitting station)
Height of receiving antenna	10.5 m above sea level (4.5 m above ground level)

---

[8] LDM CL (PLP0) refers to the first Physical Layer Pipe used, multiplexed in the Core Layer of a Layered Division Multiplexing.

[9] LDM EL (PLP1) refers to the second Physical Layer Pipe used, multiplexed in the Enhanced Layer of a Layered Division Multiplexing.

TABLE 32 (*end*)

Receiving antenna gain	−0.15 dBd
Receiving antenna cross-polarization isolation	≥ 20 dB

The usage of LDM in this trial was simply to validate its performance as a stand-alone feature, considering that such a non-orthogonal physical layer pipe multiplexing scheme can be significantly more efficient than FDM or TDM. Among the many possible use cases for LDM, it can be used for local service insertion, enabling geo-targeted content delivery within an SFN.

7.2.3 Over-the-air reception condition

Even using low-power transmission and a prototype 2 × 2 cross-polarized MIMO indoor reception antenna inside a building under a near-line-of-sight condition, the signal reception was stable, with no reception errors recorded during the whole duration of the trial (three weeks), despite receiving the signal with significant cross-polarization leakage. Figure 102 illustrates the signal reception condition.

FIGURE 102

2024 Summer Olympics TV 3.0 trial over-the-air reception condition

Freq. 569 MHz
F_Offset 0.00 Hz Off
Ext 10M
50.6 ℃

Horizontal: PWR -6?.00 dBm, SNR 28.6 dB, MER 9.30 dB

Vertical: PWR -6?.00 dBm, SNR 30.0 dB, MER 9.30 dB

SEL_PLP PLP 0

SIG	MER	DR	err_blk	num_blk	ble
L1-B	22.00	-	0	4769555	0.0
L1-D	22.70	-	0	4769555	0.0
PLP0	9.30	21.54	0	740582448	0.0
PLP1	19.24	10.76	0	370291228	0.0
PLP2	-	-	-	-	
PLP3	-	-	-	-	

1970.1.1 / 00:00:00.000.000.000

DECODING PARAMETER

Iteration	Value	Iteration	Max
L1-Basic	20	L1-Basic	20
L1-Detail	20	L1-Detail	20
PLP 0,1,2,3	50, 50, 0, 0	Core	30
PLP 4,5,6,7	0, 0, 0, 0	Enhanced	50

7.2.4 TV 3.0 Technology Demonstration Public Viewing

TV Globo's demonstration of TV 3.0 technologies during the 2024 Summer Olympics was made possible by the engagement of multiple partners, including Ateme, MainConcept, Fraunhofer IIS, V-Nova, LG, ENENSYS, Harmonic, JIUZHOU, Hisense, MediaTek, Mirakulo, Salsa Sound, SAPEC, Realtek, Intel, OBS, Spin Digital, Samsung, mediathand, Tolka, Amlogic, Pebble and Videodata. Figure 103 illustrates the Public Viewing provided within Globo's premises in ION Intelligent Center, Rio de Janeiro.

FIGURE 103

2024 Summer Olympics TV 3.0 Technology Demonstration Public Viewing

7.2.5 Summary

The technologies recommended by the SBTVD Forum for the TV 3.0 Project enable much higher spectral and energy efficiency than the Brazilian first-generation DTTB system. That set of technologies enabled the simultaneous reception of a 4K HDR UHDTV and a 1080p HDR programme service, multiplexed in different PLPs with different levels of robustness (16-QAM NUC 8/15 for the LDM CL PLP and QPSK 8/15 LDM EL PLP), both with excellent subjective quality, from a low power transmission (500 W e.r.p. per polarization), using a prototype 2 × 2 cross-polarized MIMO indoor reception antenna inside a building located at 6.6 km from the transmission site, under a near-line-of-sight condition, with no reception errors recorded during the whole duration of the trial (three weeks). This trial was a first step towards implementing the full stack of technologies recommended by the SBTVD Forum for TV 3.0. All the technology components are already available and working properly, but some are still prototypes and/or require integration before final products can be made available for transmission and reception. Brazil will continue to foster the technological development of TV 3.0, the implementation of related products and services, and the capacity building of broadcasters and the associated ecosystem to ensure the future of free-to-air terrestrial television with the best quality and user experience accessible to everyone.

7.3 2025 DTV+ Pilot Stations MIMO Indoor and mobile reception test

7.3.1 Overview

The first-ever large-scale transmission of the ATSC 3.0 system in Brazil, known as TV 3.0 or DTV+, started in April 2025 in TV Globo facilities in Rio de Janeiro city and is expected to remain on air until the end of March 2026. This experiment is called DTV+ Pilot Stations and aims to validate ATSC 3.0 components and configurations under real-world conditions, serving as a technical and operational reference for the commercial phase.

Two high-power high-tower stations were deployed in Rio de Janeiro, featuring the usage of a single frequency network in a 6 MHz channel in the new spectrum band, MIMO Type A transmission, TxID (Transmitter Identification), and Layered Division Multiplexing (LDM). The first station is located in Sumaré Hill, Rio's main and highest transmission site, which has a 3 kW transmitter power per polarization, and covers the South Zone, North Zone, and Downtown areas of the city. The second station is located in Penna Hill, Rio's third most important transmission site, which has a 1 kW transmitter power per polarization and covers the Barra da Tijuca area, where Globo's broadcast headquarters is located. Figure 104 illustrates the Sumaré and Penna stations.

Table 33 summarises the initial transmission pattern used in the DTV+ Pilot Stations. By design, DTV+ is a digital terrestrial television system targeting indoor reception.

FIGURE 104

Sumaré and Penna stations: transmitters and antennas

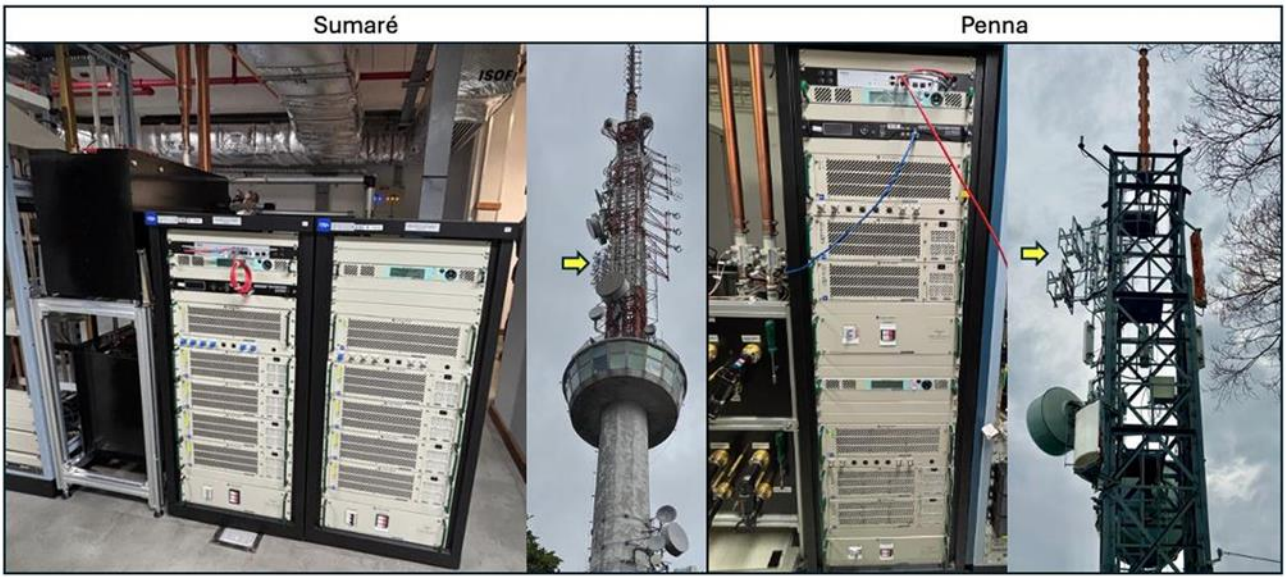


TABLE 33

2024 Summer Olympics TV 3.0 trial over-the-air transmission parameters

Modulation method	2 × 2 cross-polarized MIMO ATSC 3.0 (based on ATSC A/322:2024-04, with extensions to support the simultaneous usage of MIMO, LDM, and TxID)	
LDM layer	Core	Enhanced
Bandwidth	6 MHz	
Useful bandwidth	5.83 MHz	
MIMO scheme	MIMO Type A	

TABLE 33 (*end*)

Carrier modulation	16-QAM	QPSK
Carrier constellation	Non-uniform constellation	Uniform constellation
Inner rate	LDPC 7/15	LDPC 8/15
LDPC frame length	64 800 bits	
Outer Code	BCH	
Injection level	Not applicable	11 dB
iFFT size	16K	
Guard interval ratio	GI4_768	
Pilot pattern	MP8_2 (Dx = 8, Dy = 2)	
Pilot encoding	Null Pilot	
Number of OFDM symbols	98	
Time interleaver	CTI depth of 1024	
Transmission capacity	18.83 Mbit/s	10.77 Mbit/s
Theoretical required AWGN CNR	7.66 dB	9.70 dB
Theoretical required Rayleigh CNR	10.00 dB	14.00 dB
Video coding	3840 × 2160 p, 59.94 frames/s, 10 bits/pixel, HDR10, WCG, LCEVC+VVC, Main Profile, Level 3 at 10 Mbit/s	1920 × 1080 p, 59.94 frames/s, 10 bits/pixel, HDR10, WCG, VVC, Main Tier, Main 10 Profile, Level 4.1 at 6 Mbit/s
Audio coding	5.1.4ch + 5 objects, MPEG-H 3D Audio, Baseline Profile, Level 3 at 540 kb/s	5.1.4ch + 5 objects, MPEG-H 3D Audio, Baseline Profile, Level 3 at 540 kb/s

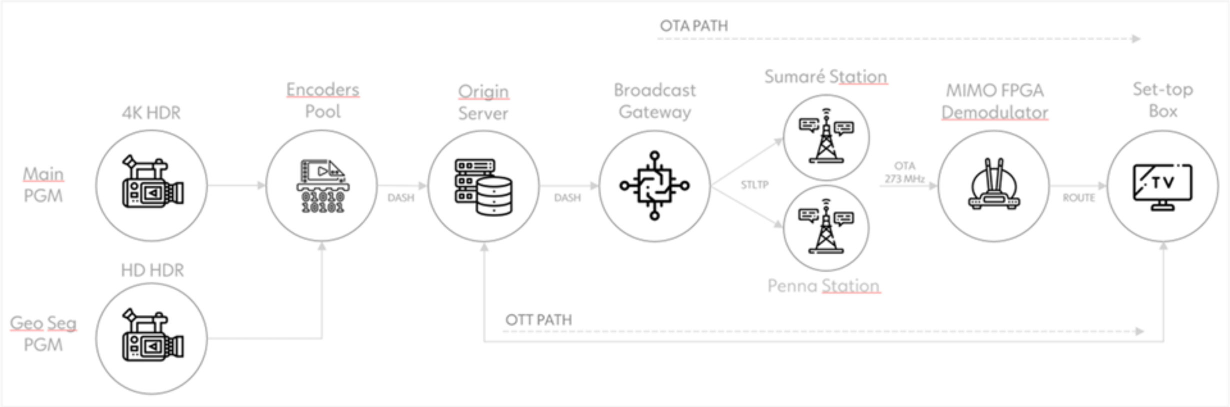
The core layer in the DTV+ Pilot Stations operation was assigned to carry the 2160p HDR main program with personalized and immersive audio provided by the MPEG-H codec. The employed video codec is a combination of LCEVC together with VVC, which delivers the 4K HDR video at an astonishing 10 Mbit/s. The excess bit rate of 8 Mbit/s is on purpose, leaving vacancies for future applications, such as datacasting. The MPEG-H codec used a bit rate of 540 kbit/s to deliver immersive audio composed of a 5.1+4H speaker layout plus up to five mono audio objects.

The enhanced layer in the DTV+ Pilot Stations operation was assigned to carry the 1080p HDR feed, also with personalized and immersive audio provided by the MPEG-H codec with the same bitrate and speaker layout as the 2160p HDR feed. The 1080p HDR feed uses the VVC codec at a bit rate of 6 Mbit/s, and its main purpose is to power geographical segment program user cases.

The DTV+ Pilot Stations system overview diagram is shown in Fig. 105.

FIGURE 105

DTV+ Pilot Stations system overview diagram



The indoor reception setup was composed of an earlier 2x2 passive indoor MIMO antenna, a prototype FPGA MIMO demodulator acting as the external 2x2 MIMO RF front-end and a set-top box hosting the DTV+ middleware and media decoding capabilities. Figure 106 shows the indoor reception setup.

FIGURE 106

DTV+ indoor reception setup

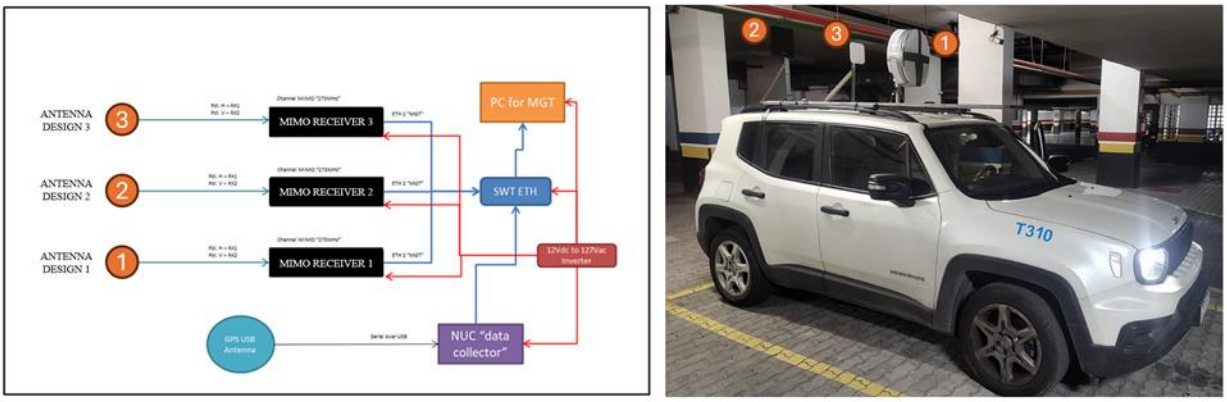
The set-top box in Fig. 107 is based on Realtek SoC RTD1319D and supports 2160p HDR live decoding of LCEVC, VVC, and MPEG-H content using a transport layer with ROUTE and DASH. In future implementations, this essential MIMO demodulation feature is expected to be fully integrated into the set-top box hardware, eliminating the need for an external FPGA MIMO demodulator.

7.3.2 Mobile field test

The primary objective of the mobile trial was to verify the real-world performance of the earlier designs of the 2x2 MIMO passive indoor antenna in a mobile reception scenario using the same transmission pattern in Table 33. Figure 107(a) shows the block diagram for the mobile setup assembled to simultaneously measure the reception data for three MIMO receptions, and Fig. 107(b) illustrates the three MIMO antennas under test assembled on the rooftop of the van. Table 34 summarizes the antennas’ characteristics.

FIGURE 107

MIMO mobile test setup



(a) (b)

TABLE 34

2x2 MIMO antennas characteristics

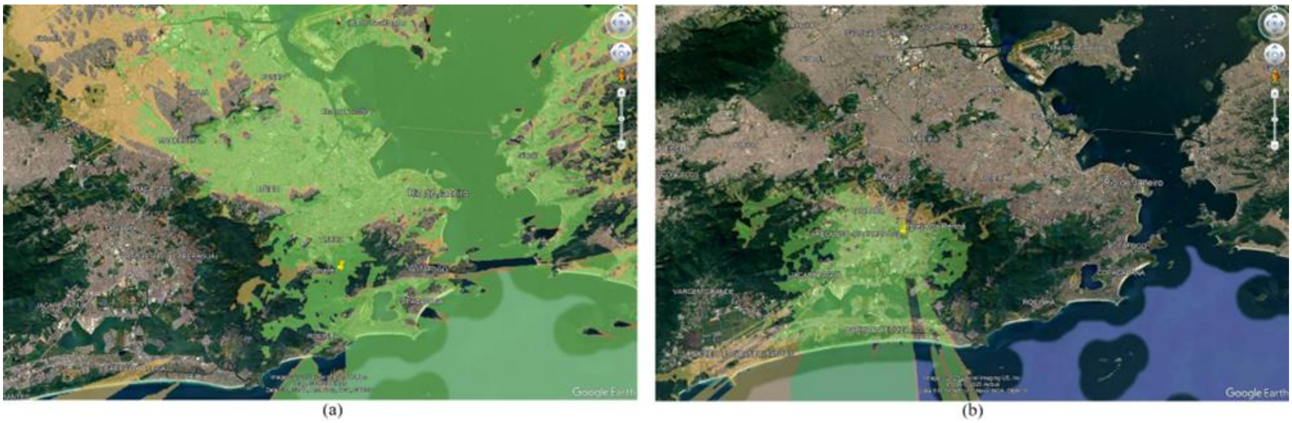
Parameter	Antenna design 1	Antenna design 2	Antenna design 3
Type	Biconical	Panel	Panel
Irradiation pattern	Omnidirectional	Omnidirectional	Omnidirectional
Gain	~ 4dBi (174 to 698 MHz)	−3 dBi (174 to 698 MHz)	−3 dBi (174 to 470 MHz) −5 dBi (470 to 698 MHz)
Polarization isolation	≥ 20 dB	≥ 20 dB	≥ 20 dB
Impedance	75 Ω	75 Ω	75 Ω

The routes for the mobile test measurements were traced based on field strength predictions, previously made considering the elevation model of Rio de Janeiro city. Figure 108(a) and (b) show field strength predictions for Sumaré and Penna stations, respectively. The colours represent the minimum field strength to receive Core and Enhanced Layers.

Predicted field strength greater than 86 dBμV/m was considered to receive PLP1, as the Enhanced Layer, and painted in green. Predicted field strength between 82 dBμV/m and 86 dBμV/m was considered to receive PLP0, as the Core Layer, and painted in orange.

FIGURE 108

DTV+ Pilot Stations field strength predictions



(a) (b)

The measurements were collected over two weeks, in July 2025, with more than 34 000 data points collected for each set of antennas plus receiver. The FPGA MIMO demodulator used in this test provides the total number of ATSC 3.0 blocks received and the blocks received with errors. With these two values, it is possible to directly calculate the Block Error Rate, defined as the ratio between the number of errored blocks and the total number of received blocks. Since these data can be collected individually per PLP, Block Error Rate becomes one of the key aspects to analyse the performance of the three available mobile reception.

The measured points were plotted on a map and classified as successful or not, according to their Block Error Rate. Points with successful reception were marked in blue, while those with unsuccessful reception were marked in red. The results were also segmented by receiving antenna and coverage area. Across all three antennas, the success rate varied between the Sumaré and Penna coverage zones, and for this reason, the results were calculated separately. Figures 109 to 111 show the reception success rate for PLP0 (Core Layer) obtained with each set of antenna plus receiver.

The reception success rates for PLP1 (Enhanced Layer) were also calculated and are shown in Fig. 112, alongside those obtained for PLP0 and segmented by coverage area. It is possible to observe the performance differences between the antenna designs. The antenna design 1 achieves at least 20 percentage points more than the other tested antennas in both PLP0 and PLP1.

The large volume of data enabled analysis beyond the geographic dimension. With this dataset, it was possible to correlate the reception success rate with signal strength. Figure 113 shows the success percentage for each dBm value, separated by the set of reception used during the measurements.

FIGURE 109

Antenna design 1 and Receiver 1 – Reception success rate

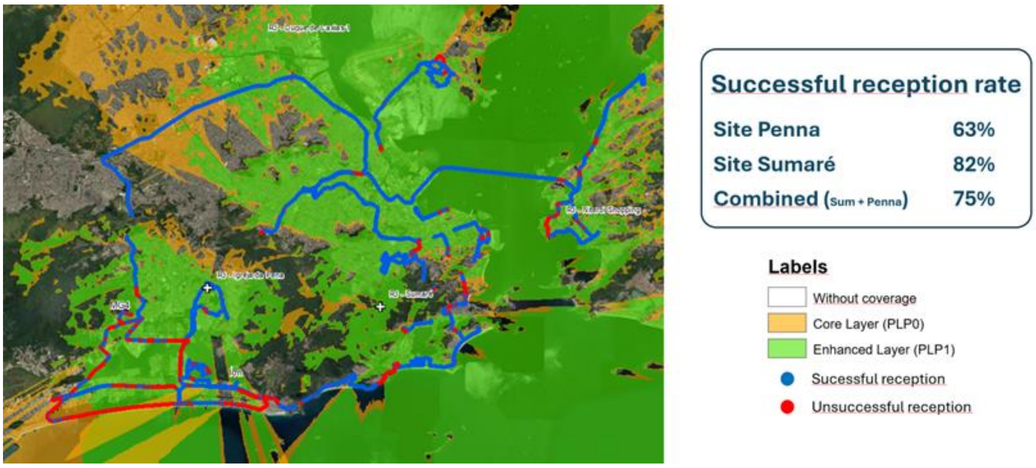


FIGURE 110

Antenna design 2 and Receiver 2 – Reception success rate

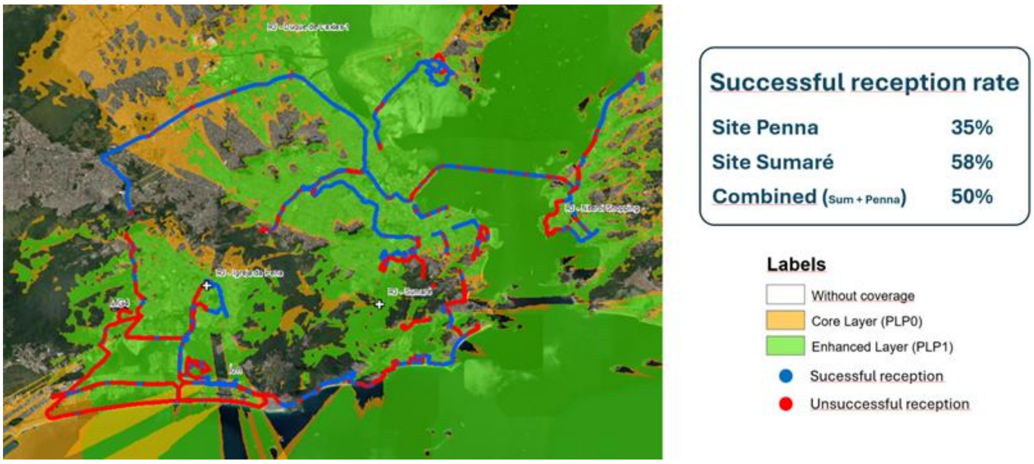


FIGURE 111

Antenna design 3 and Receiver 3 – Reception success rate

FIGURE 112

Reception success rate for PLP0 and PLP1

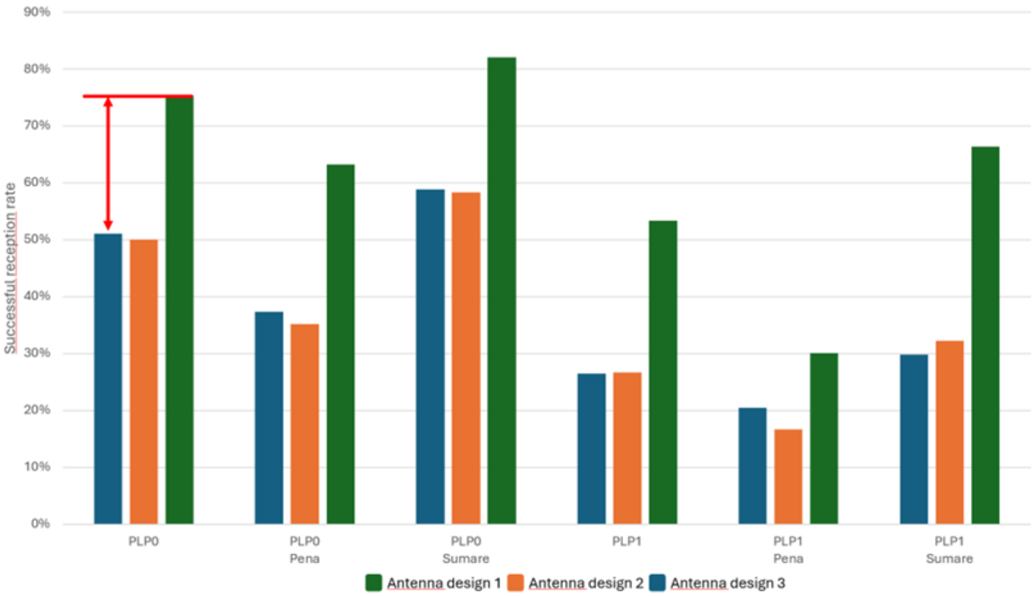
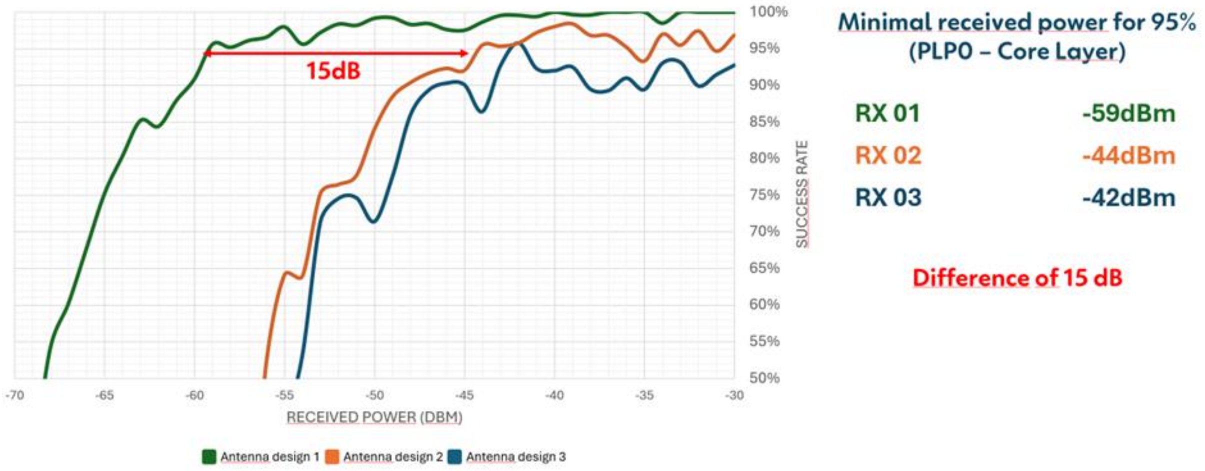


FIGURE 113

PLP0 reception success



7.3.3 Indoor reception test

The indoor reception trial was performed over two months, in November and December 2025, and it was conducted inside forty households of TV Globo employees who kindly granted access to their living rooms to perform the indoor reception measurements. For the indoor reception test, it was decided to disable the LDM, which reduced the minimal required CNR for PLP0, and concentrate efforts on the performance evaluation of five new different 2x2 MIMO passive indoor antenna designs (named C, G, M, N, and O) and the performance of three transmission patterns using Sumaré and Penna stations. Table 35 summarizes the three transmission patterns used, and Fig. 114 makes a comparison of these three new transmission patterns, the previous transmission pattern from Table 33, and the current ISDB-Tb transmission patterns used in Brazil.

TABLE 35

Transmission patterns for the indoor reception tests

Transmission pattern ID	ID016	ID019	ID022
Modulation method	2 × 2 cross-polarized MIMO ATSC 3.0 (based on ATSC A/322:2024-04, with extensions to support the simultaneous usage of MIMO, LDM, and TxID)		
Layer	Single PLP	Single PLP	Single PLP
Bandwidth	6 MHz		
Useful bandwidth	5.83 MHz		
MIMO scheme	MIMO Type A		
Carrier modulation	16-QAM	64-QAM	16-QAM
Carrier constellation	Non-uniform constellation	Non-uniform constellation	Non-uniform constellation
Inner rate	LDPC 7/15	LDPC 4/15	LDPC 5/15
LDPC frame length	64 800 bits		
Outer code	BCH		
iFFT size	16K		
Guard interval ratio	GI4_768		
Pilot pattern	MP8_2 (Dx = 8, Dy = 2)		
Pilot encoding	Null Pilot		

TABLE 35 (*end*)

Number of OFDM symbols	98		
Time interleaver	CTI depth of 512		
Transmission capacity (Mbit/s)	18.83 Mbit/s	16.06 Mbit/s	13.42 Mbit/s
Theoretical required AWGN CNR	5.78 dB	4.71 dB	3.38 dB
Theoretical required Rayleigh CNR	7.37 dB	6.20 dB	4.72 dB

An additional objective of the indoor reception tests was to investigate the feasibility of MIMO indoor reception under a strong depolarization scenario. In previous laboratory experiments using the FPGA MIMO demodulator with transmission pattern ID016, it was observed that MIMO depolarization is not an impediment for the indoor reception if the mitigation techniques present in ATSC 3.0 are enabled (Stream Combining, IQ Interleaving, and Phase Hopping). In the end, the depolarization acts as a penalty for the indoor reception, as summarized in Fig. 115.

All forty points selected for indoor reception tests are represented in Fig. 116. These points were selected based on the employee location over the electric field strength levels. The measurement setup was composed of a tripod that positioned the antenna under test over 0,8 m above ground, RF attenuators to decrease the received signal to the point where the FPGA MIMO demodulator starts to register blocks received with errors. Therefore, for each point, for each antenna design, and for each transmission pattern, it was possible to obtain the reception margin. Figure 117 summarizes the results, and Fig. 118 illustrates sample points measured for antenna design C using transmission pattern ID016 transmitted by Sumaré station.

FIGURE 114

Comparison between ISDB, SISO, and MIMO transmission patterns

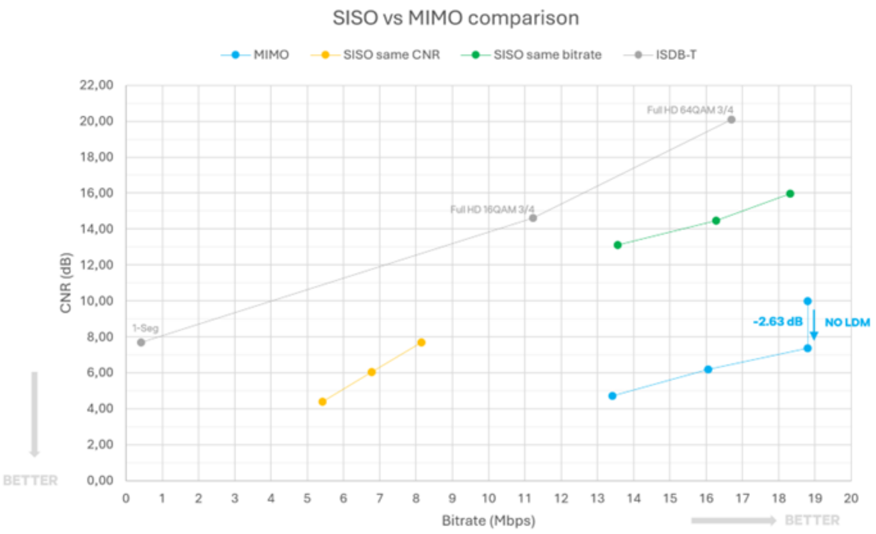


FIGURE 115

MIMO depolarization penalty in AWGN reception scenario

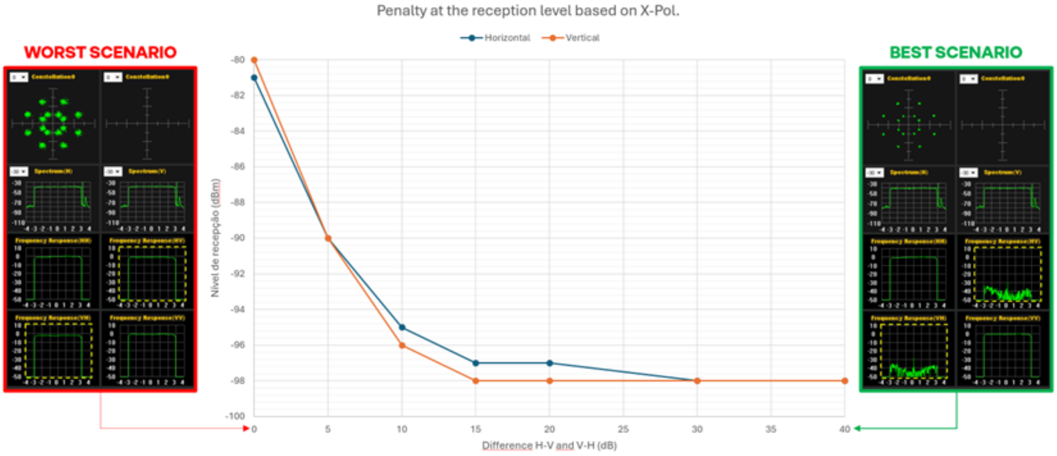


FIGURE 116

Indoor reception test points

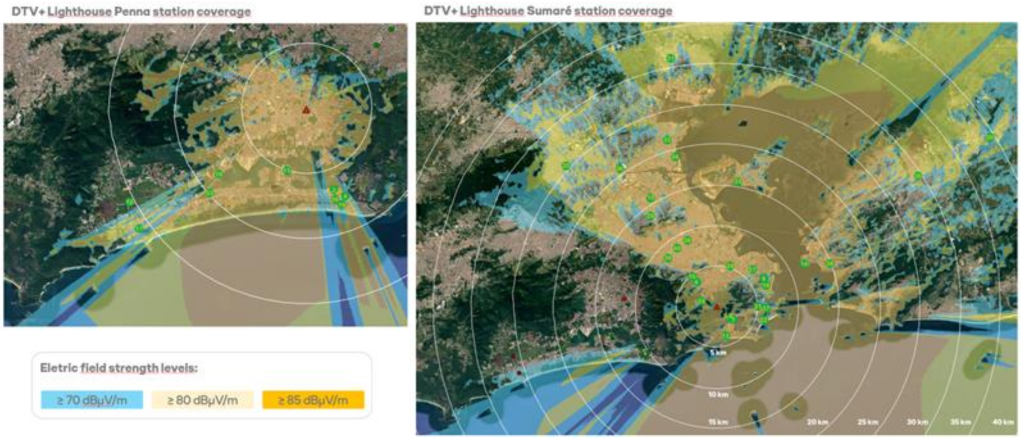


FIGURE 117

Indoor reception test results

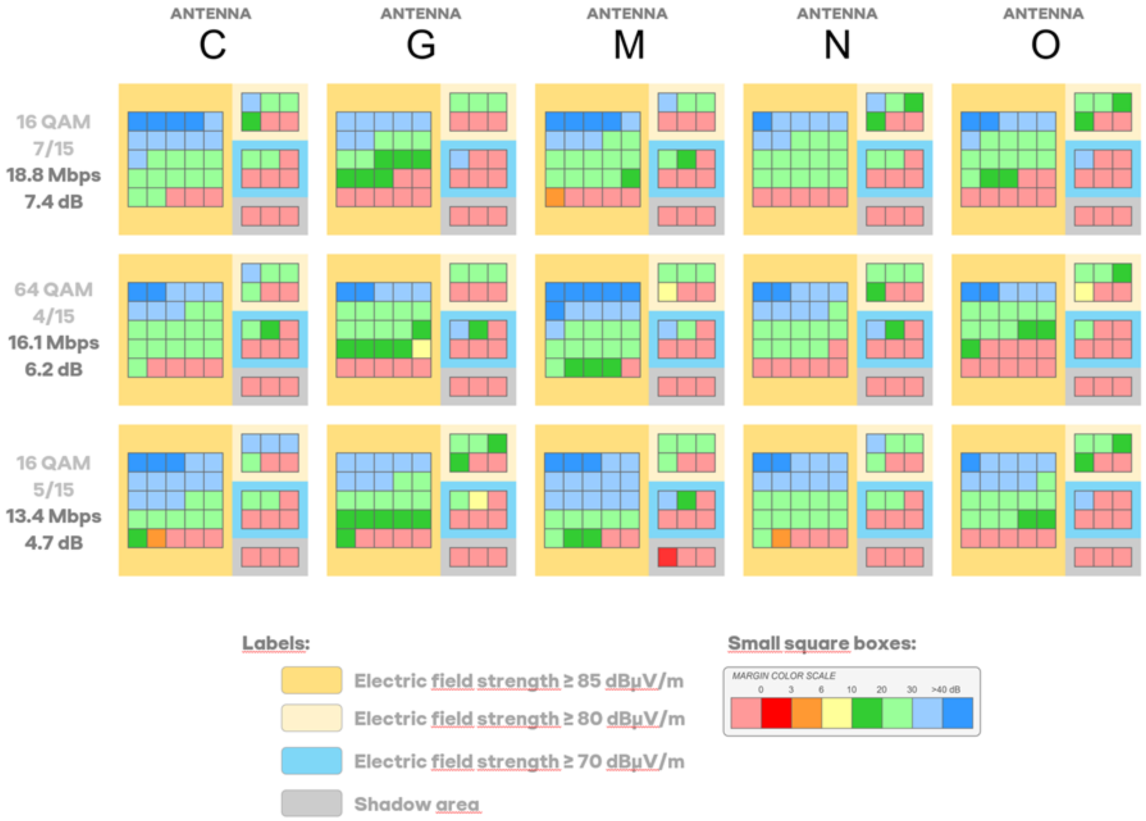
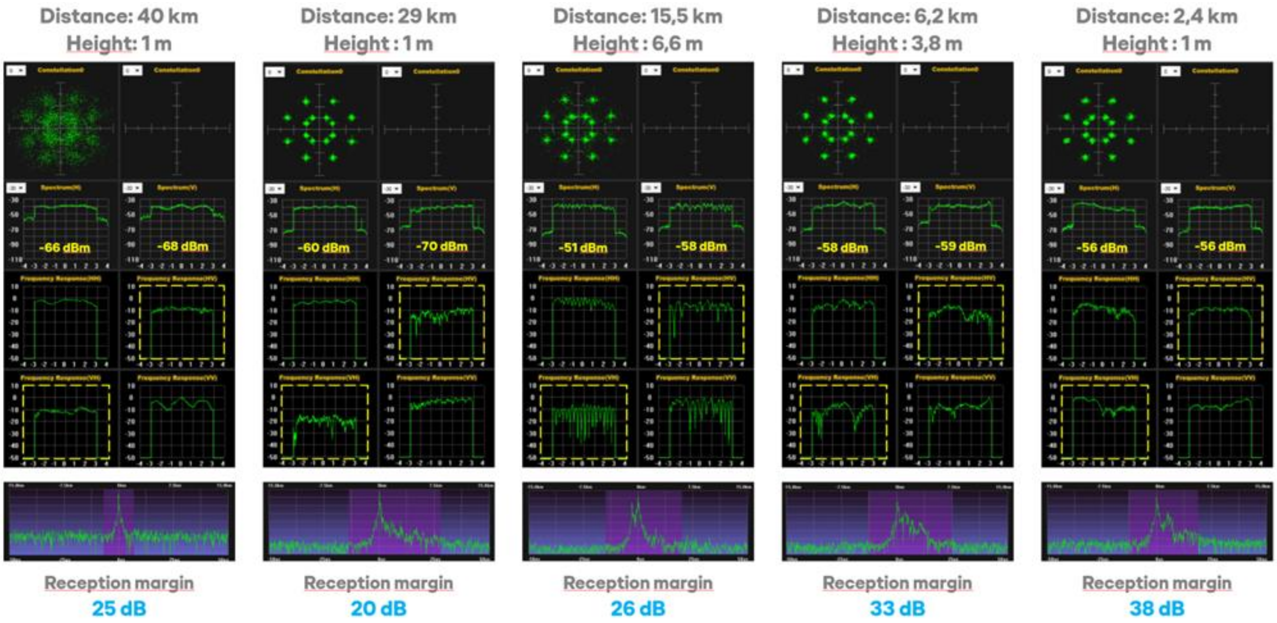


FIGURE 118

Indoor reception test sample points



7.3.4 Summary

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.

The measurements from the mobile reception test revealed that, even using medium power, Sumaré's ERP was 15.7 kW, and Penna's ERP was 5.8 kW; more than 70% of measured points had good reception when considering both stations. Looking specifically at Sumaré's area, more than 80% of the measured points had good reception from that station.

The measurements from the indoor reception test revealed that MIMO indoor reception is feasible even in scenarios where the depolarization of the signal is very high. On the other hand, the points where the indoor reception was not feasible are the points where the received power is weak, signalling that either increasing the electric field strength or using an active MIMO indoor antenna may solve the case. More work is scheduled to address the case of active MIMO indoor antennas. Also, indoor tests revealed that the commercial receiving antenna needs to evolve its performance to make indoor reception and DTV+ deployments successful.

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. 119. 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 119

Diagram of Jiaxing 4K UHDTV terrestrial transmission trial

8.1.3 Transmission and reception station equipment

Figure 120 shows the transmission station antenna. The characteristics of transmitting antenna are shown in Table 36. Figure 121 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 are shown in Table 37.

FIGURE 120

Transmission station antenna

TABLE 36

Transmitting antenna's characteristics

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

FIGURE 121

Field trial reception station antenna

TABLE 37

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 38.

TABLE 38

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
Transmission capacity	39.7 Mbit/s

TABLE 38 (*end*)

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 selecting the test sites, due to actual conditions, dix 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. 122. The pictures in some test sites are shown as Fig. 123.

FIGURE 122

Test setup

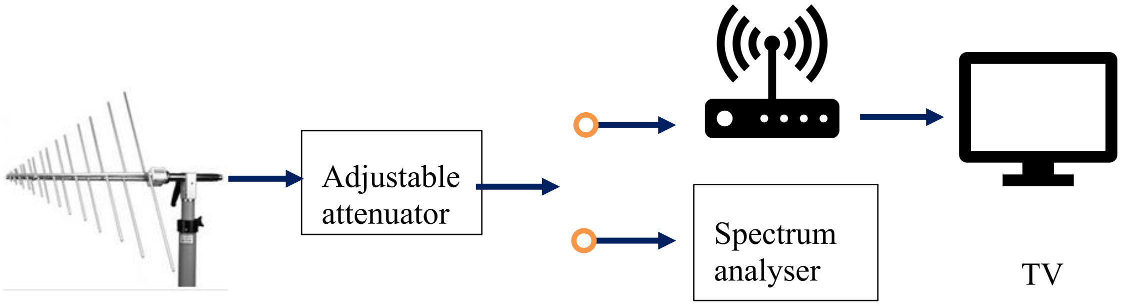


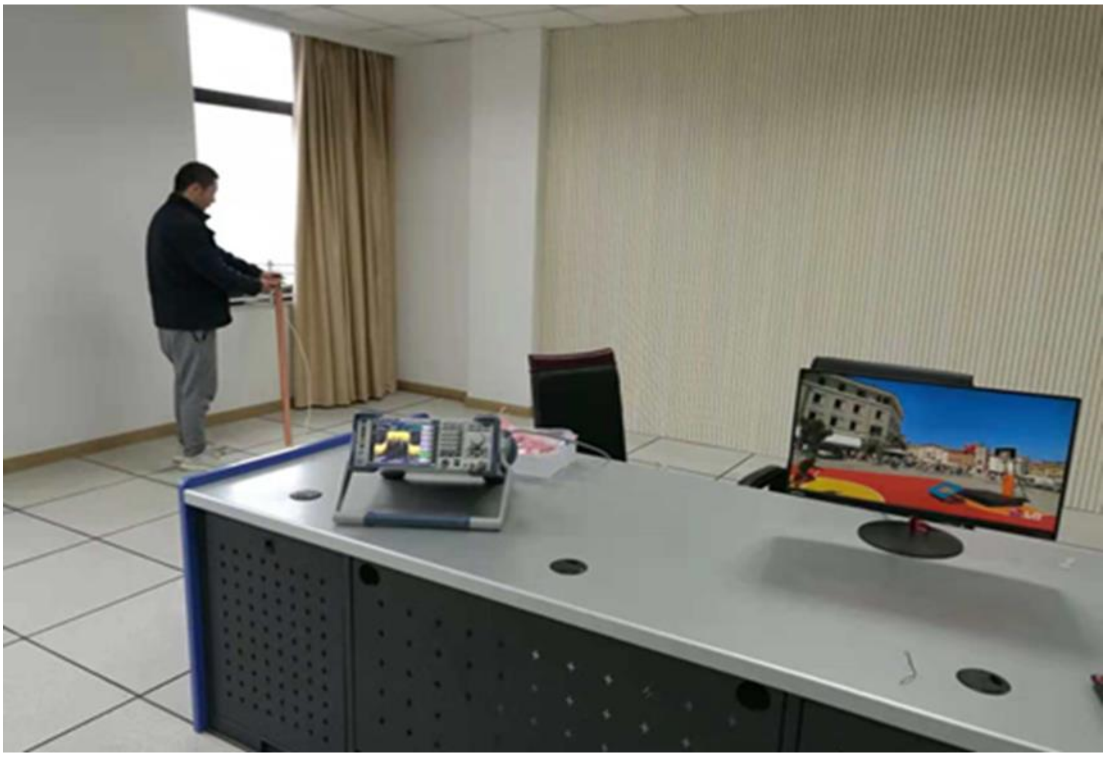
FIGURE 123

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. 124. Table 39 shows the receiving signal power test results of the outdoor test point.

FIGURE 124

Measurement points of outdoor field trail

TABLE 39

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. 125. Table 40 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 125

Measurement points of indoor field trail

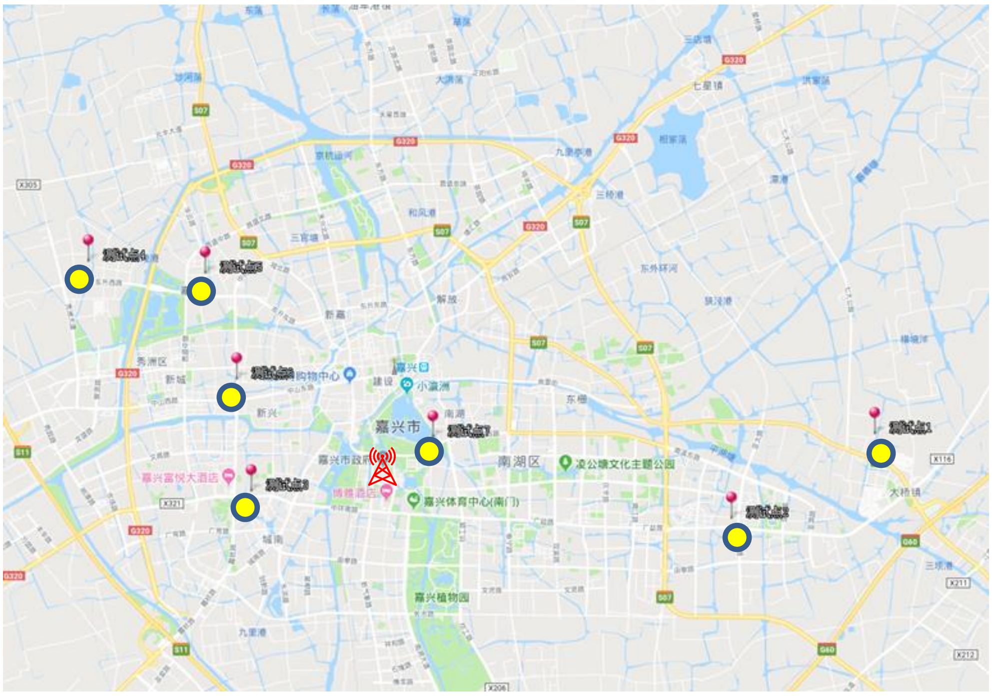


TABLE 40

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 digital terrestrial multimedia broadcast-advanced (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 DTTB 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 DTTB 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. 126.

FIGURE 126

Shenzhen 8K UHD trial

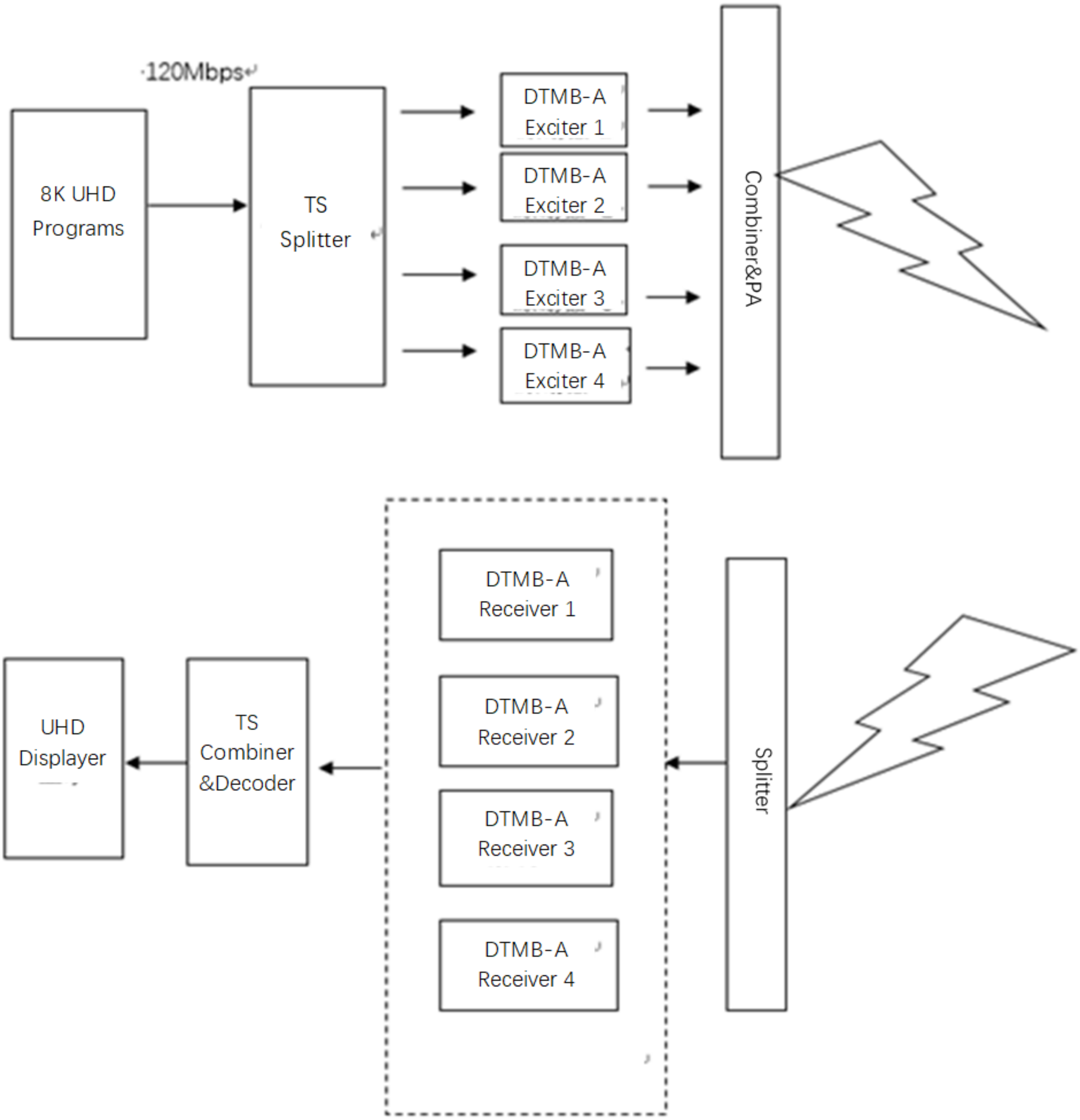
8.2.1 Diagram of the system

The system block diagram of this UHD demonstration is shown in Fig. 127.

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 realize the demonstration of UHDTV Service over DTTB network.

FIGURE 127

System block diagram for the demonstration system



8.2.2 Transmission and reception equipment

Figure 128 shows the equipment used in this UHDTV Service over DTTB network demonstration.

In Fig. 128, 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 four 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 128

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 129

8K decoder

8.2.3 System parameters

The system parameters for this UHD demonstration are shown in Table 41.

TABLE 41

Transmission parameters of the UHD demonstration over DTTB network

Modulation method	TDS-OFDM
RF centre frequency	634 MHz, 642 MHz, 650 MHz and 658 MHz
Occupied bandwidth	7.56 × 4 MHz
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
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 trialed 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 130 to 132.

The wireless transmission system demonstrated in this trialed 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 130

Ultra HD demo display screen site

FIGURE 131

View of Ultra HD demo site

FIGURE 132

Ultra HD demo site

8.3 Field trial of DTMB-A+5G 8K UHD Integrated Transmission System

8K ultra high definition (UHD) is an important business in digital television broadcasting, and 8K outdoor large screen is a hot spot for UHD applications. In January 2022, the Ministry of Industry and Information Technology, the Ministry of Transport, the Ministry of Culture and Tourism, the National Radio and Television Administration, and China Media Group jointly promoted the implementation of the "Hundred Cities and Thousand Screens Plan" in China.

In 2022, the DTMB-A+5G 8K UHD integrated transmission system was jointly developed and conducted by National Engineering Laboratory for DTV (DTNEL), Tsinghua University, Peony Group.

The system can choose to use DTMB-A or 5G channel to transmit 8K UHD programmes according to the actual network situation.

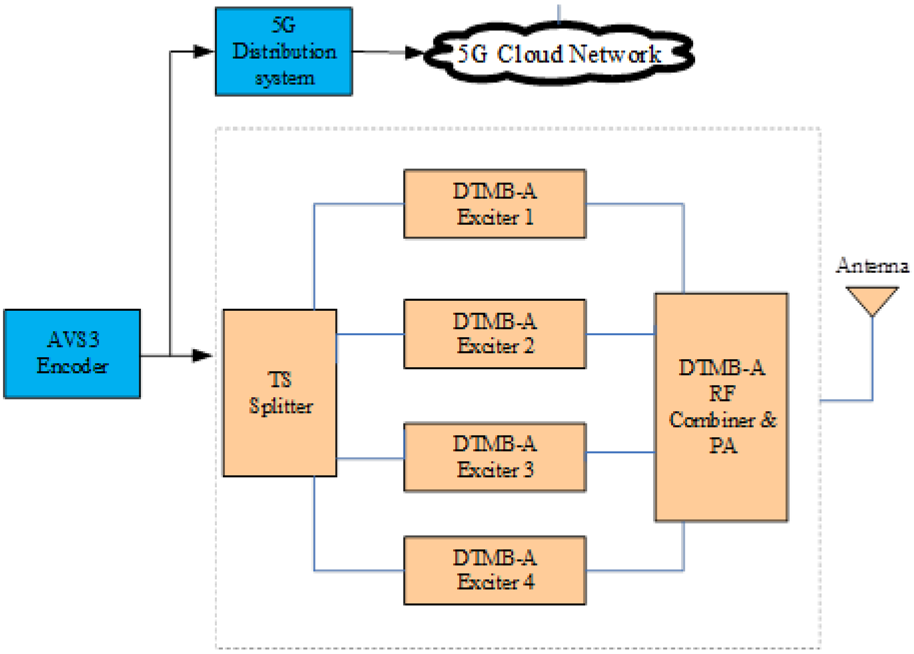
For the terrestrial broadcasting transmission system, the demonstration used the second-generation digital terrestrial television system C DTMB-A of the Recommendation ITU-R BT.1877. The 8K UHD integrated transmission system supports multi-channel binding technology, and the system supports a maximum payload rate of 200 Mbit/s. According to the actual payload rate of the required transmission programme, the channel binding of the 8K UHD integrated transmission system can support 2, 3, or 4 DTT channels in China to save frequency resource usage.

8.3.1 Block diagram of the system

The system block diagram of the DTMB-A+5G 8K UHD integrated transmission system is shown in Fig. 133.

FIGURE 133

Diagram of the DTMB-A+5G 8K UHD Integrated Transmission System



The 8K UHD programme comes from the self-developed comprehensive test sequence HEVC TS on the 8K video cloud of Peony Group. The program is transmitted simultaneously through the DTMB-A channel and 5G network. Figure 134 shows the main control interface of the video cloud.

FIGURE 134

Platform of 8K UHD programme cloud

清华DTMB-A测试

- 灼映云为清华大学信息科学与技术国家实验室DTMB-A 8K直...

通州5G+8K冬奥科技馆

- 灼映云为通州5G+8K冬奥主题体验馆提供5G+8K超高清直...

8K超高清播放机测试

- 牡丹自研的8K超高清播放机支持常见的8K编码格式并向下...

京东中小企业电脑节

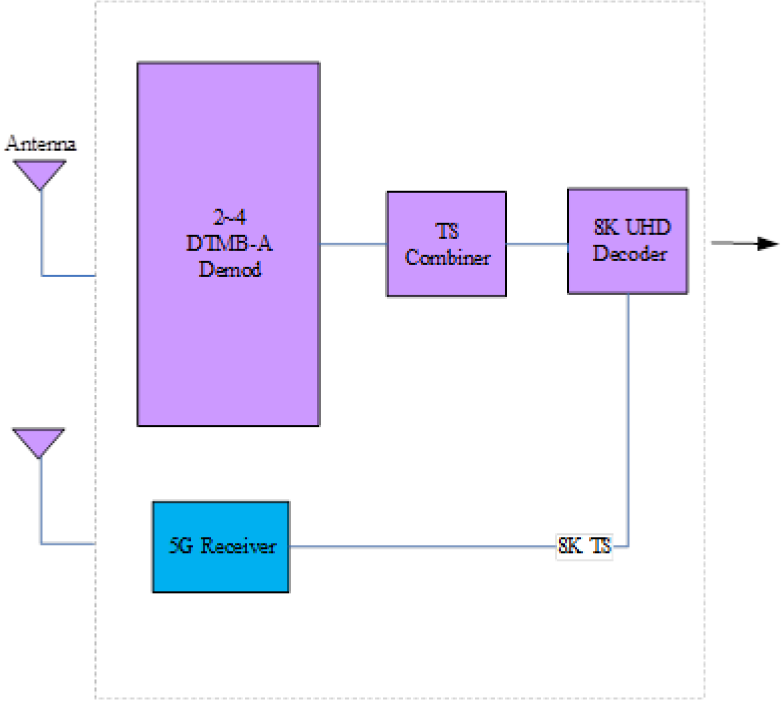
- 灼映云为“京东中小企业电脑节园区巡礼”启动仪式，提供超...

The receiver diagram of the DTMB-A+5G 8K UHD integrated transmission system is shown in Fig. 135. This system can perform AVS3 encoding on the programs of 8K cameras, and then send them to the self-developed equipment. The 8K UHD TS is divided into multiple (2, 3 or 4) TS and can be assigned to the corresponding DTMB-A exciter. After amplification by the power amplifier, the RF signal of DTMB-A is transmitted to the 8K UHD receiver over the air. Meanwhile, the 8K UHD programme is delivered through the 5G distribution system simultaneously and stored in the cloud network system. When the programme is on-demand, the 8K UHD program is transmitted to the receivers through the 5G network.

The DTMB-A+5G 8K UHD integrated transmission system receiver can be demodulated and decoded by the DTMB-A DTT system to display the 8K UHD programme on screen, achieving UHD transmission demonstration. On the other hand, the receiver can realize on-demand 8K programmes on the 8K video cloud network, achieving transmission and demonstration experiments of 8K UHD programmes through the 5G transmission network.

FIGURE 135

The receiver diagram of the DTMB-A+5G 8K UHD integrated transmission system



8.3.2 Transmission and reception equipment

Figure 136 shows the equipment used in this DTMB-A+5G 8K UHD integrated transmission system demonstration.

In Fig. 136, all the devices at the right of the red arrows are explained here. Device 1 is a video signal generator that provides a lossless UHD 8K test programme to the system. Device 7 is an AVS3 encoder that encodes SDI signals, IP signals, or ASI signals of 8K UHD program as AVS3 or H.265. The encoded TS streams were sent to the TS splitter (Device 2), simultaneously, to the 5G distribution system through the internet. Device 2, the TS splitter can selectively split the TS into multiple (2, 3 or 4) TS allocation to the corresponding DTMB-A exciters. Device 3 are DTMB-A exciters numbered as 1-4, which modulates the TS allocated by the TS splitter. The RF output from the exciters is amplified by a power amplifier (device 4) and sent to the antenna for transmission.

FIGURE 136

The transmitted devices of the system

At the receiving end, the receiver which is shown in Fig. 137 will demodulate and decode 8K UHD programme and output it to the 8K display screen.

FIGURE 137

The receiver of DTMB-A/5G 8K UHD

8.3.3 System parameters

The system parameters for this DTMB-A+5G 8K UHD integrated transmission system demonstration is shown in Table 42.

TABLE 42

Transmission parameters of the UHD demonstration over DTT network

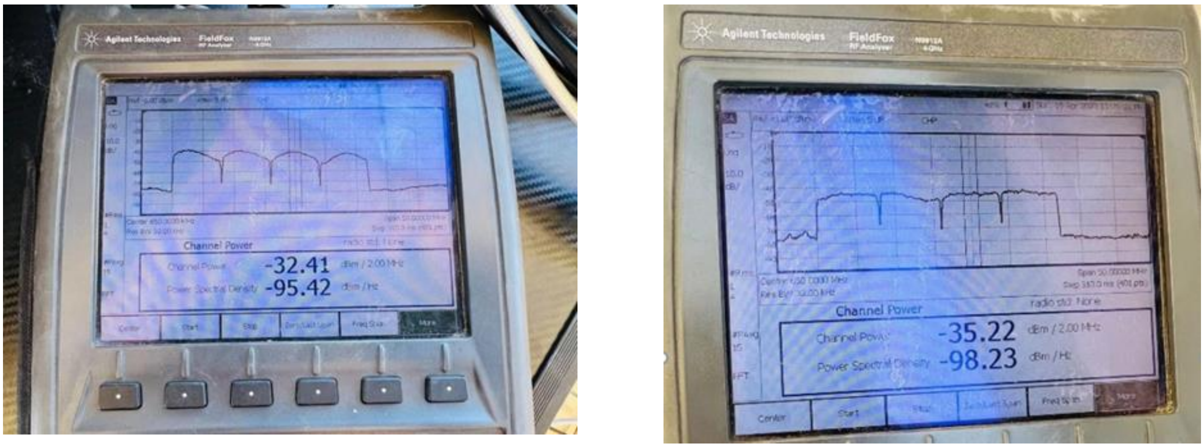
Modulation method	TDS-OFDM
RF centre frequency	634 MHz, 642 MHz, 650 MHz and 658 MHz
Occupied bandwidth	7.56 × 4 MHz
Carrier modulation	256APSK
FFT size (number of radiated carriers)	32k
Guard interval ratio (guard interval duration)	1/128
Error-correcting code	Inner: LDPC, code rate = 2/3
Payload data rate	157.6 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	Beijing, Mudanyuan
Receiving station	Beijing, Mudanyuan
UHDTV bit rate	120 Mbit/s

8.3.4 Field demonstration

In May 2023, the second Workers' Games of Beijing Electric Control Group were held at Beijing Institute of Information Technology. And the DTMB-A+5G 8K UHD integrated transmission system provides live services for the sports games. Simultaneously, the 5G distribution system also distributes the meeting scene to the internet, making it convenient for users to watch or review in the cloud. Figure 138 shows the DTMB-A spectrum at the transmission monitoring port and the reception spectrum during on-site live streaming system debugging. Figures 139 and 140 show the on-site debugging and testing images for the sports meet.

FIGURE 138

DTMB-A spectrum at transmitter and receiver



(A) DTMB-A RF spectrum at transmission monitoring port (B) The reception spectrum at receiver

The programme source of the live broadcast system for this sports meet comes from the 8K camera with 4X12G SDI output. And the 8K@P50 programme source is handed over to the input of the 8K AVS3 encoder. The encoding parameter is AVS3 8K@P50 with 120 Mbit/s. The encoder output via the ASI interface was sent to the TS splitter for 4-channel allocation. The 4-channel ASI is then distributed among four DTMB-A exciters, which use 256APSK, FEC 2/3, 32K FFT, PN256, etc. The four modulation frequencies are 634 MHz, 642 MHz, 650 MHz, and 658 MHz. The four RF signals modulated by the exciter are combined and output to the transmitter with a transmission power of 1 W (small coverage with low power transmission). One 8K UHD receiver is placed below the podium stand (see Fig. 140), and the other is placed in the broadcasting vehicle in the northwest direction of the sports venue. At both receiving points, the DTMB-A+5G 8K UHD receivers can work normally with on error. Figure 139 also shows the reception scene in the broadcasting vehicle.

FIGURE 139

The reception scene in the broadcasting vehicle

FIGURE 140

On-site debugging below the podium stand

The receiver of DTMB-A+5G 8K UHD integrated transmission system also carried out the reception test of 8K UHD programmes on the 5G link by using 8K video cloud on-demand, successfully achieving 8K UHD TV programs on the peony 8K video cloud. Figure 141 shows the reception of 8K UHD programmes with 5G link in mobile vehicles.

FIGURE 141

Reception of 8K UHD programmes with 5G link in mobile vehicles

8.3.5 Conclusion

The 5G+8K UHD integrated transmission demonstration system can support up to 200 Mbit/s UHD programmes through optional channel binding. The receiver can also provide on-demand services for 8K UHD programmes over the 5G network. And receiver can switch freely between the two networks. Diversified reception services can effectively support the development of UHD services, and the system is expected to support the mixed broadcasting of multi-channel 4K or 4K and 8K programs in the future.

8.4 Field trial of 4K ultra high-definition television terrestrial transmission based on DTMB

8.4.1 Introduction

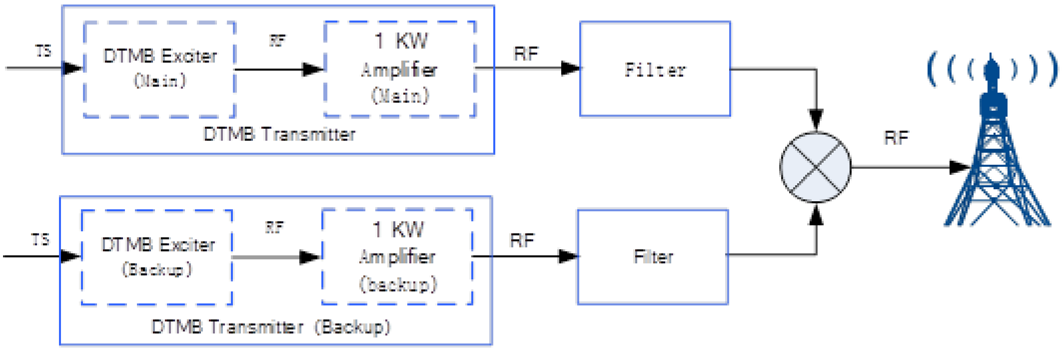
In October 2025, the National Engineering Laboratory for Digital TV (Beijing), in collaboration with Tsinghua University and Sumavision, carried out field trials on a 4K Ultra high-definition television (UHDTV) terrestrial broadcasting transmission system based on DTMB, with support from the Beijing Municipal Radio and Television Bureau and the Shunyi District Converged Media Center of Beijing.

8.4.2 Transmission and Receiving System of field trial

The block diagram of the terrestrial digital television transmission system is shown in Fig. 142. The system operates with a transmission power of 300 W and utilizes a RF channel with central frequency of 490 MHz (DS-15 in China). Based on this existing transmission system, a DTMB 4K UHDTV program terrestrial transmission system was established for the field trial.

FIGURE 142

Diagram of the existing digital television transmission system



The DTMB 4K UHDTV terrestrial transmission system comprises subsystems such as 4K UHDTV video and audio encoding, DTMB channel modulation and transmission, DTMB reception and demodulation, as well as 4K UHDTV video and audio decoding and playback. In the experimental system, a 4K UHDTV signal source is used to generate dynamic uncompressed 4K UHDTV programs. The 4K UHDTV coded stream, encoded by the 4K UHDTV encoder, is sent to the DTMB exciter and then amplified by the transmitter for broadcasting. Additionally, the transmitting front-end employs a 4K UHDTV decoder to monitor the encoded 4K UHDTV stream. The DTMB+4K UHDTV set-top box in the field trial receives signals through a Yagi antenna. During the field trial, a DTMB signal field strength meter and an adjustable attenuator are utilized to measure RF signal strength and reception margin. Refer to Fig. 143 for the block diagram of transmission system and reception system. Figure 144 shows the layout of transmitter site.

FIGURE 143

Diagram for 4K UHDTV terrestrial transmission and testing system

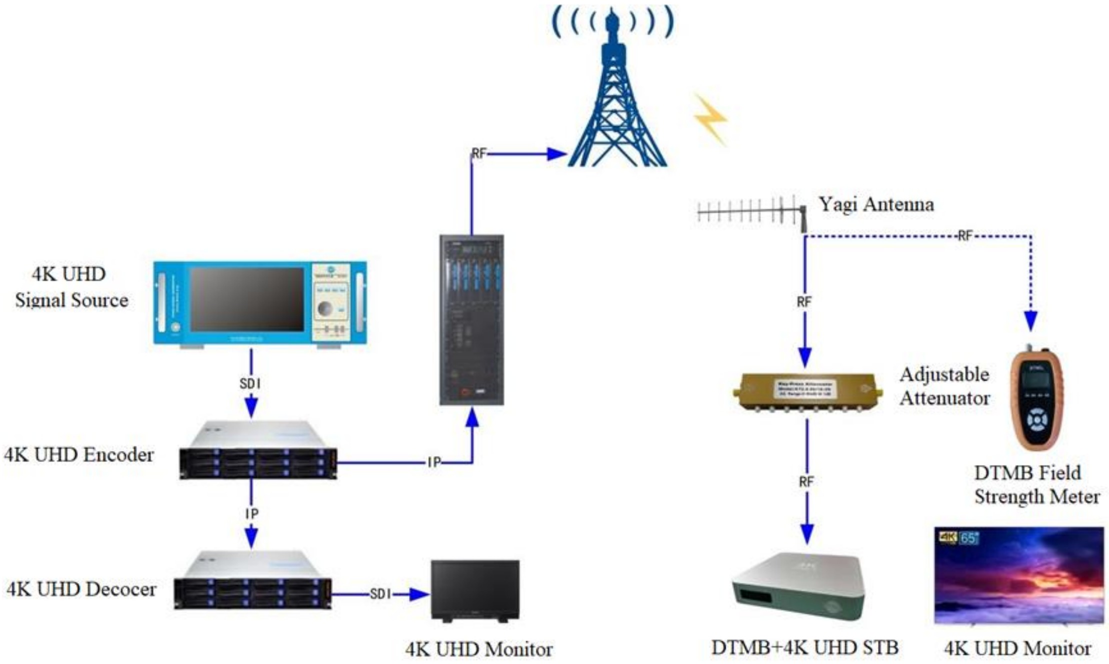


FIGURE 144

DTMB+4K UHDTV transmission system

8.4.3 System parameters and testing methods

8.4.3.1 DTMB transmission

This DTMB 4K UHDTV transmission field trial utilizes the existing terrestrial digital television transmission infrastructure, with transmission parameters shown in Table 43. Information on some of the transmitter equipment used in the field trial is shown in Table 44. The resolution of the program used for the field trial is 3840×2160, the frame rate is 50 frames per second, and the encoded stream rate is 28 Mbit/s.

TABLE 43

Parameters for UHDTV terrestrial transmission field trial

Transmitting antenna height	97 m
Altitude of transmitting antenna	40 m
Transmitting antenna form and polarization mode	6-layer 4-sided four dipole transmitting antenna, vertically polarized
Transmission channel	DS-15 (Centre frequency 490 MHz)
DTMB mode	64QAM, PN420, FEC/0.8
Max. payload data rate	32.486 Mbit/s
Transmitter power	1 kW ERP

TABLE 44

Device list at transmission side

No.	Devices	Model	Manufacturer
1	4K UHDTV signal generator	SG8000	DTNEL
2	4K UHDTV encoder	10K118	Sumavision
3	4K UDH decoder	10K218	Sumavision
5	DTMB transmitter	--	BBEF

The signal shoulder and MER from the transmitter monitoring port are illustrated in Figs 145 and 146.

FIGURE 145

Shoulder of DTMB transmitting signal

Agilent Spectrum Analyzer - Swept SA

Marker 1 Δ 4.200000000 MHz

PNO: Fast
IFGain:Low

Trig: Free Run
Atten: 6 dB

Avg Type: Log-Pwr

ΔMkr1 4.20 MHz
-44.49 dB

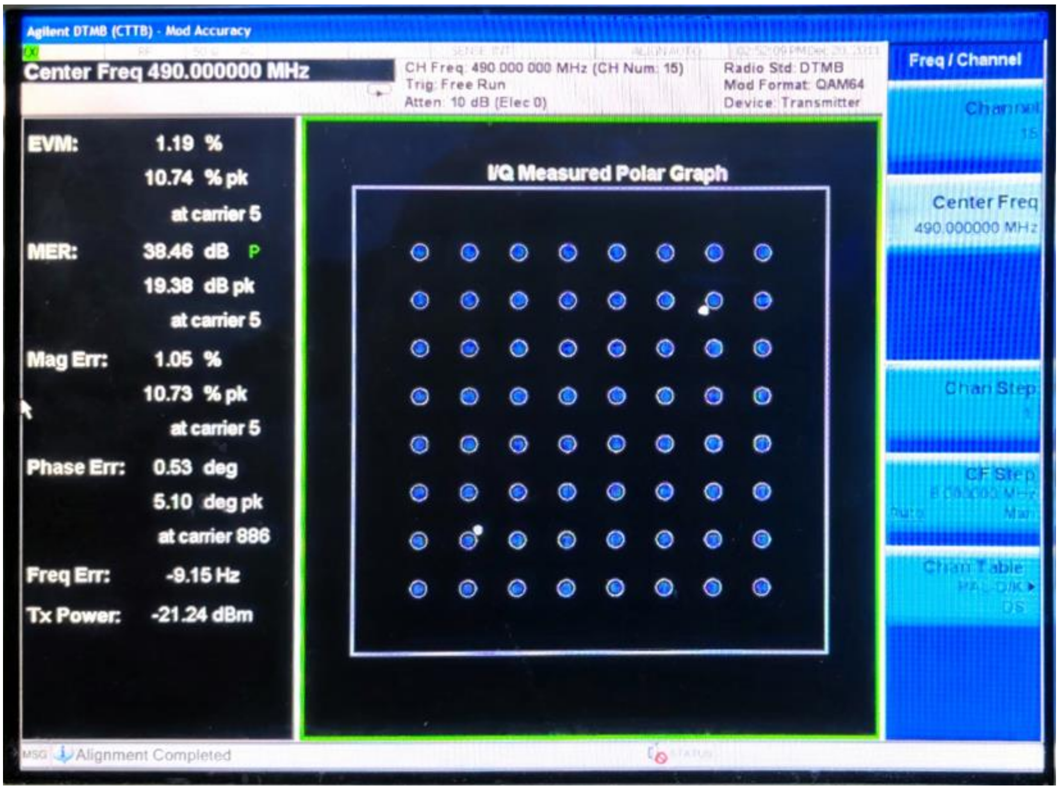
10 dB/div Ref -16.00 dBm

Center 490.00 MHz
#Res BW 100 kHz
#VBW 1.0 kHz
Span 20.00 MHz
#Sweep 100 ms (1001 pts)

Alignment Completed
Meas Uncal

FIGURE 146

MER of DTMB transmitting signal



Agilent DTMB (CTTB) - Mod Accuracy

Center Freq 490.000000 MHz

CH Freq: 490.000 000 MHz (CH Num: 15)
Trig: Free Run
Atten: 10 dB (Elec 0)

Radio Std: DTMB
Mod Format: QAM64
Device: Transmitter

EVM: 1.19 %
10.74 % pk
at carrier 5

MER: 38.46 dB P
19.38 dB pk
at carrier 5

Mag Err: 1.05 %
10.73 % pk
at carrier 5

Phase Err: 0.53 deg
5.10 deg pk
at carrier 886

Freq Err: -9.15 Hz

Tx Power: -21.24 dBm

Alignment Completed

8.4.3.2 DTMB signal reception

The field trial selects multiple points for fixed-point testing via UHF antennas. A DTMB field strength meter is used to test the received signals parameter such as receiving field strength, MER, and *C*/*N*. Cooperate with an adjustable attenuator to record the threshold for reception of the DTMB+4K set-top box. The DTMB+4K set-top box supports the demodulation and decoding of DTMB and DTMB-A, supports 3 840×2 160p video display, and is compatible with various video formats.

TABLE 45

Devices of the receiving side

No.	Devices	Model	Manufacturer
1	Yagi antenna	YAGI-016	DTNEL
2	Adjustable attenuator	N/A	Shanghai Huaxiang
3	DTMB+4K UHDTV STB	NELSTB-A.8001	DTNEL
5	DTMB field strength meter	BXT-02TA	DTNEL

8.4.4 Testing data of field trial

Based on the theoretically predicted coverage area, combined with local actual conditions and test time, the field trial test point was selected. Thirty outdoor fixed signal receiving points were selected from four directions for the field trial. The distribution of the field trial points is shown in Fig. 147. Under the condition that the receiver can normally receive, decode and display UHDTV programs, the received signal field strength of each test point was recorded, and the reception signal margin was tested. The location of this test point is shown in Fig. 147. Partial test results are listed in Table 46.

FIGURE 147

Distribution overview of test points

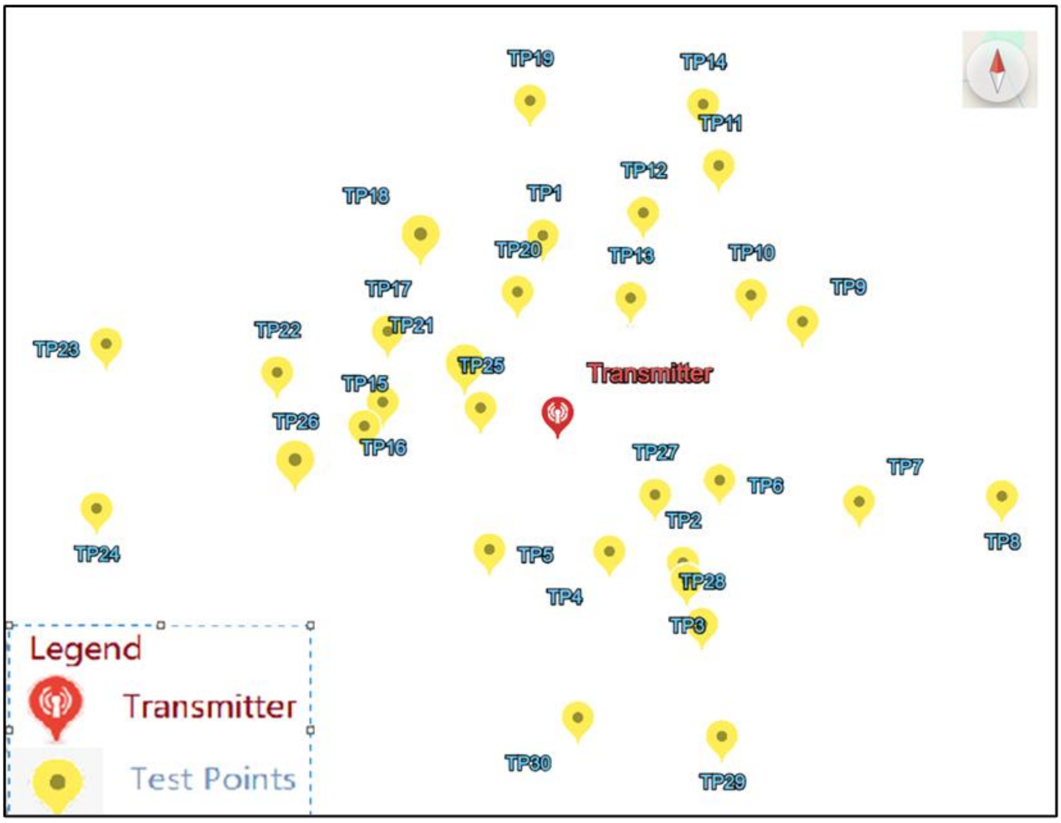


TABLE 46

Test results of partial outdoor test points

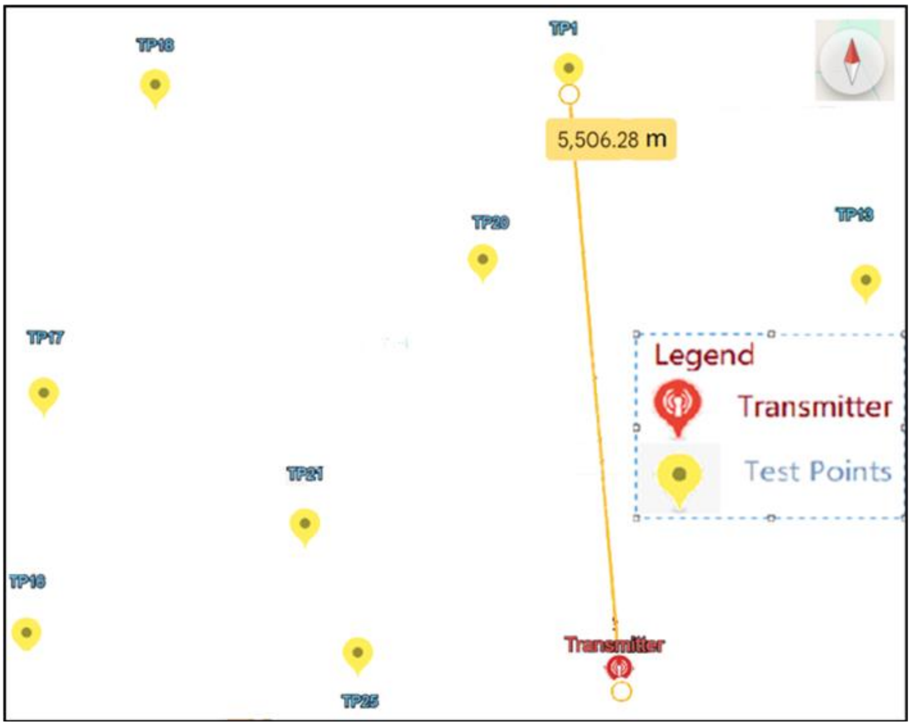
Testing point	Distance (km)	Receiving antenna height (m)	Receiving antenna altitude (m)	Field strength (dBµv)	MER (dB)	C/N (dB)	Signal margin (dB)	Note
TP 1	5.54	4	41	49	24	26	11	Intersection of two roads
TP 2	6.1	4	29	34	19.5	24	0	Build shadow
TP 3	6.58	4	28	31	18	21	0	Build shadow
TP 4	4.6	4	37	37	18	21	3	Roadside, low traffic
TP 5	4.75	4	35	37	17	20	0	Build shadow Vegetation impact
TP 6	5.49	4	29	42	23	24	9	Roadside, high traffic

The detailed information of test point 1 is as follows:

Test point 1 is located near a hotel. This test point l is located directly north of the transmitting tower, approximately 30 to 40 meters northwest of the intersection of two roads, with a straight-line distance of 5.54 km from the transmitting tower. These test points are located on the roadside with relatively open in the surrounding area, resulting in high signal quality. The location of this test point is shown in Fig. 148.

FIGURE 148

The positional relationship between test point 1 and the transmitting tower



There are two major traffic roads around this test point. Meanwhile, the point is also located on the take-off and landing flight path of Airport. The hotel is a concrete building with a maximum of five floors. The traffic conditions of the surrounding roads and the nearby environment of this test point are shown in Fig. 149.

FIGURE 149

Surrounding environment of test point 1

On October 21, 2025, the testers of the project team conducted the test at this test point. During the test, the two main surrounding roads had heavy traffic flow, with continuous vehicle passing through (including large vehicles), meanwhile taking off planes keep passing through the sky. The weather was sunny to cloudy with a 2-level wind force. Specific test data are shown in Table 47.

TABLE 47

Testing parameters of test point 1

Parameter	**Value**
Temperature (°C)	16
Wind power (level)	2
Distance (km)	5.54
Relative transmitting tower direction	North
Receiving antenna height (m)	4
Receiving antenna altitude (m)	41
Field strength (dBμv)	49
MER (dB)	24
C/N (dB)	26
Attenuator attenuation value (dB)	11

8.4.5 Conclusions

The results of field testing show that existing DTMB infrastructure can support 4K UHDTV terrestrial transmission by only replacing the video encoder with a 4K UHDTV encoder while keeping other components unchanged. Under the parameters shown in Table 1, with the use of a 4-meter directional receiving antenna, the following coverage effects achieved:

1) The maximum coverage distance can reach 14 km.
2) In different test directions, the coverage distance can reach 11~12 km.
3) Within a straight-line distance of 6 km from the transmitting station, stable reception can be achieved.
4) In the urban-rural fringe areas within a straight-line distance of 10 km from the transmitting station, reception is generally stable when the transmission path is line-of-sight or near line-of-sight; reception may fail if the reception path is blocked by a building.

9 Iran

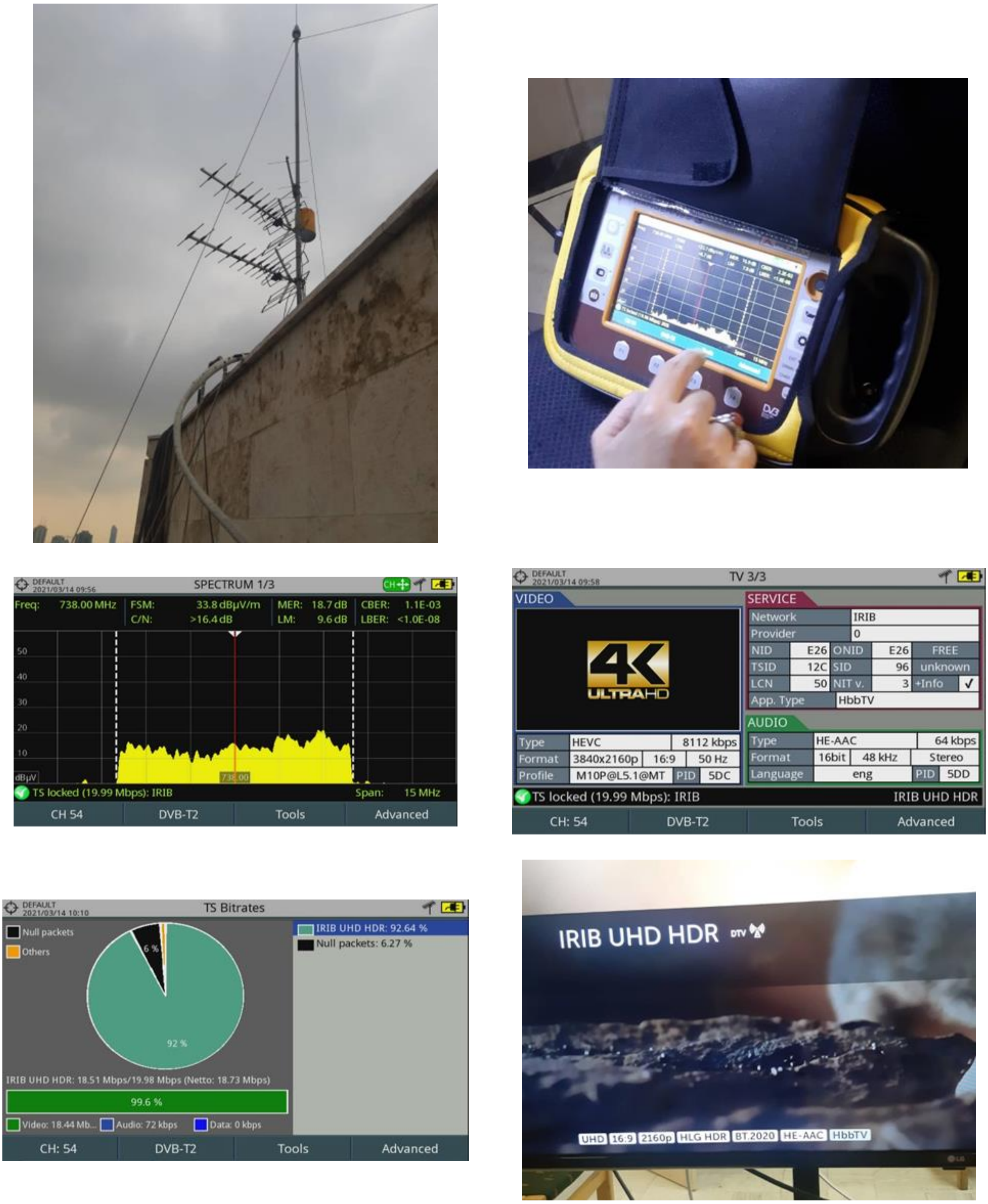
Taking steps towards the future progression for next generations of broadcast systems, which is an obligation for broadcasters, IRIB, the national public service broadcaster of Iran (Islamic Republic of), conducted a 4K (Ultra High Definition) TV broadcast deployment on July 2020 based on the DVB-T2 +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 programme uses six 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 fibre/satellite links. Some views of trial receiving antenna, measurement and receive activities are shown in Fig. 150.

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 150

Reception antennas and measurements for 4K UHD signal



DEFAULT 2021/03/14 09:56 SPECTRUM 1/3

Freq: 738.00 MHz
FSM: 33.8 dBµV/m
C/N: >16.4 dB
MER: 18.7 dB
LM: 9.6 dB
CBER: 1.1E-03
LBER: <1.0E-08

TS locked (19.99 Mbps): IRIB
Span: 15 MHz

DEFAULT 2021/03/14 09:58 TV 3/3

VIDEO
Type: HEVC, 8112 kbps
Format: 3840x2160p, 16:9, 50 Hz
Profile: M10P@L5.1@MT, PID 5DC

SERVICE
Network: IRIB
Provider: 0
NID: E26, ONID: E26, FREE
TSID: 12C, SID: 96, unknown
LCN: 50, NIT v.: 3, +Info ✓
App. Type: HbbTV

AUDIO
Type: HE-AAC, 64 kbps
Format: 16bit, 48 kHz, Stereo
Language: eng, PID 5DD

TS locked (19.99 Mbps): IRIB
IRIB UHD HDR

DEFAULT 2021/03/14 10:10 TS Bitrates

IRIB UHD HDR: 92.64 %
Null packets: 6.27 %
IRIB UHD HDR: 18.51 Mbps/19.98 Mbps (Netto: 18.73 Mbps)
99.6 %
Video: 18.44 Mb... Audio: 72 kbps Data: 0 kbps

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 48. 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 49.

TABLE 48

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 49

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
Error-correcting code	Inner: LDPC, code rate = 3/5 Outer: BCH
Data rate	~35 Mbit/s
Video coding	HEVC (2160p(1), 10 bits, 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).
