Hindawi
Wireless Communications and Mobile Computing
Volume 2019, Article ID 1649413, 9 pages
https://doi.org/10.1155/2019/1649413

Research Article

Implementation and Field Trials of OFDM-Based Digital Video Broadcasting System in Commercial Broadcasting Network for Multichannel UHD Service

Sang-Jung Ra,[1] Myung-Sun Baek ,[1] Jin-Hyuk Song,[1] Dong-Joon Choi,[1] Joon-Young Jung,[1] and Cheol-Sung Kim[2]

[1]*Media Transmission Research Group, Electronics and Telecommunication Research Institute (ETRI), Daejeon, Republic of Korea*
[2]*Electronics and Communication Engineering, Chonnam National University, Republic of Korea*

Correspondence should be addressed to Myung-Sun Baek; sabman@etri.re.kr

Received 5 October 2018; Accepted 10 December 2018; Published 1 January 2019

Guest Editor: Seok-Chul Kwon

This paper describes design and implementation of an OFDM-based digital video broadcasting system test platform for multichannel ultra-high definition (UHD) broadcasting services. The developed digital video broadcasting system test platform has been installed in commercial broadcasting station, and trial broadcasting service of the system has been performed through the commercial in-service network. For the performance measurement, field test is also executed. To evaluate the practical performance of the implemented system, a commercial broadcasting set-top box is used. Furthermore, by using measurement receiver, various system performances have been evaluated such as BER, PER, and CNR. Because high efficiency video coding (HEVC) can successfully transmit multimedia contents with a raw data rate of 51.6 Mbps, a multichannel UHD service can be serviced in a single physical 6MHz channel.

1. Introduction

Recently various advanced broadcasting technologies have been investigated and developed [1–4]. In the terrestrial broadcasting system, the transmission standards supporting 4K ultra-high definition (UHD) broadcasting service have been investigated and developed [5, 6]. Besides, for multichannel UHD broadcasting services, an orthogonal frequency division multiplexing- (OFDM-) based digital video broadcasting system was designed [7, 8].

In this paper, an OFDM-based digital broadcasting transmission system was designed and implemented to support multichannel UHD service. First, the threshold of visibility of the designed system is evaluated in both additive white Gaussian noise (AWGN) and fading channel. And the evaluated threshold of visibility (ToV) performance of the designed system is compared to that of the existing digital broadcasting systems [9, 10]. After the ToV performance evaluation, for the implementation, field programmable gate arrays (FPGAs) were used. Furthermore, to evaluate the performance of the implemented transmission system, field trials were performed through the commercial in-service network [11] in Daejeon, Korea. In the field trials, the distance between the implemented transmitter and the measurement receiver was 27.1 km, and in the middle of the test route, an amplifier station was adopted. To check the smooth operation of the implemented system, a commercial set-top box (STB) was used.

In addition, to evaluate the performance, a spectrum analyzer and real-time transport stream analyzer were considered. The test results showed a smooth operation and superior performance of the implemented OFDM-based digital video broadcasting system transmitter.

The rest of this paper is organized as follows. Section 2 introduces the system model of the implemented system. Section 3 describes the hardware implementation and major system parameters. Section 4 describes the field test conditions. Test results are provided in Section 5. Finally, concluding remarks are given in Section 6.

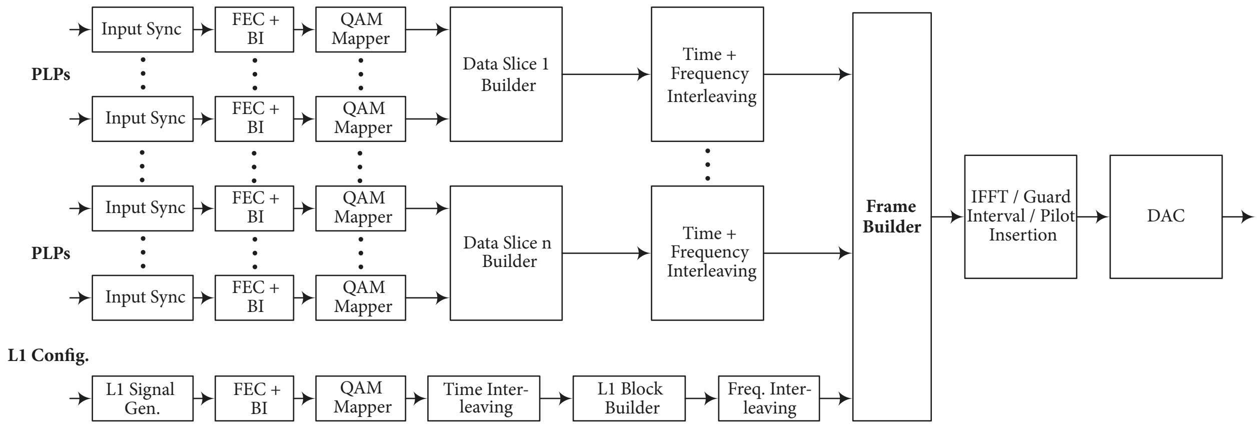


Figure 1: OFDM-based digital video broadcasting system transmitter structure.

2. Implemented OFDM-Based Digital Video Broadcasting System Model

The implemented OFDM-based digital video broadcasting structure is depicted in Figure 1. As shown in Figure 1, the transmitter is composed of physical layer pipe (PLP) processing, a frame builder, and an OFDM generation block. A PLP is used as an independent logical channel. Each PLP processing block consists of a data input processing block, forward error-correction code (FEC) and bit interleaving block, and QAM mapping block. The FEC is composed of the Bose–Chaudhuri–Hocquenghem (BCH) outer code and low density parity check (LDPC) inner code. Whereas LDPC is a very powerful technique for correcting transmission errors, it produces an error floor condition. BCH can remove the error floor caused by the LDPC decoder of the receiver. FEC encoded bits are then mapped to quadrature amplitude modulation (QAM) symbols and are finally assigned to each subchannel for the OFDM symbol [7, 12].

Next, a data slicer generates one or more slices of data PLP. One data slice or a combination of multiple data slices generates a transmission frame. The transmission frame is transmitted through the inverse fast Fourier transform (IFFT) and digital-analog conversion (DAC) in an OFDM block to produce a radio frequency (RF) signal.

Finally, an L1 signaling block is transmitted into the preamble part of the frames for transmission information. This is related to the position of the data slice, which can be tuned to a data slice to be received at the receiver [7, 12].

A receiver operating within a traditional 6 or 8 MHz TV tuner bandwidth can extract that part of the broad transmission signal that contains the desired service. This part consists of a data slice that never exceeds the traditional bandwidth of a receiver tuner [7, 12, 13].

3. Hardware Implementation and Major Parameters of OFDM-Based Digital Broadcasting System

Figure 2 depicts the implemented OFDM-based digital broadcasting system with FEC encoder, modulator, and DAC converter. For a convenient implementation, each implemented board uses the same FPGA. In implemented board, operation of the FEC encoder and the modulator is controlled by control PC. The DAC module converts complex digital signal to 44 MHz IF analog signal. RF upconverter is designed independently and converts 44MHz IF signal to wanted RF signal. The control module is designed for the implemented board control. Tables 1–3 show the use of the implemented

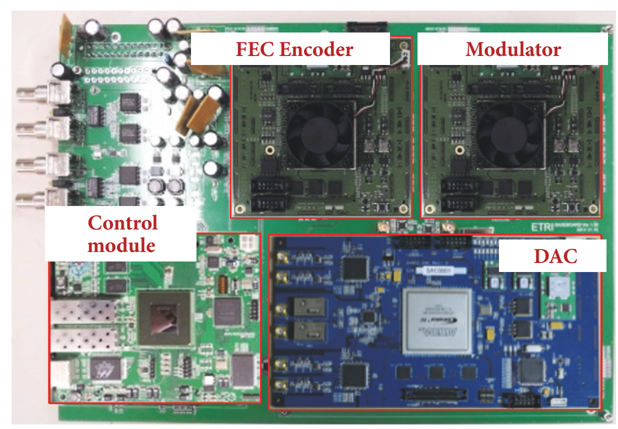


Figure 2: Implementation of the OFDM-based digital video broadcasting system transmitter.

Table 1: Hardware resources of FEC encoder.

Family		Stratix IV
Device		EP4SE530H40C4
Logic utilization	Combinational ALUTs	7,957 / 424,960 (2%)
	Memory ALUTs	0 / 212,480 (0%)
	Dedicated logic registers	8,061 / 424,960 (2%)
Total registers		8208
Total block memory bits		7,198,555 / 21,233,664 (34%)
DSP block 18-bit elements		0 / 1,024 (0%)
Total PLLs		1 / 12 (8%)

Table 2: Hardware resources of modulator.

Family		Stratix IV
Device		EP4SE530H40C4
Logic utilization	Combinational ALUTs	944 / 424,960 (< 1%)
	Memory ALUTs	0 / 212,480 (0%)
	Dedicated logic registers	1,049 / 424,960 (< 1%)
Total registers		1136
Total block memory bits		9,309,105 / 21,233,664 (44%)
DSP block 18-bit elements		0 / 1,024 (0%)
Total PLLs		1 / 12 (8%)

Table 3: Hardware resources of digital-to-analog converter.

Family		Stratix IV
Device		EP4SE530H40C4
Logic utilization	Combinational ALUTs	24,191 / 424,960 (6%)
	Memory ALUTs	1,748 / 212,480 (< 1 %)
	Dedicated logic registers	29,311 / 424,960 (7%)
Total registers		29608
Total block memory bits		11,476,625 / 21,233,664 (54%)
DSP block 18-bit elements		840 / 1,024 (82%)
Total PLLs		1 / 12 (8%)

Table 4: Implemented OFDM-based digital broadcasting system parameters.

Parameters	Value
RF frequency (Start frequency)	**225MHz** **(132.696)**
FFT size	4096
Number of OFDM carriers	3408
Bandwidth	6 MHz
Guard interval (GI)	1/64, 1/128
Modulation order	16QAM - 4096 QAM
Code rate (LDPC)	2/3, 3/4, 4/5, 5/6, 9/10
L1 time interleaver (TI) depth	8 OFDM symbols
Data slice TI depth	8 OFDM symbols
Video encoding	HEVC

transmitter. For a convenient implementation, we implement the board using the same FPGA. Table 4 shows the major system parameters of the implemented digital broadcasting system for 6MHz bandwidth [7, 14].

Among the parameters of Table 4, to achieve multichannel UHD broadcasting services with 51.6Mbps, 1/64 guard interval (GI), 4096 QAM, and 9/10 coderate are selected for our field trial.

The system configuration and equipment setup are shown in Figure 3. At the transmitting side, an MPEG-2 TS generator is used for generating the HEVC stream and is interfaced through DVB-ASI. In the broadcasting network, both optical fiber and coaxial network are used. Optical fiber is used from transmission station to entrance of the reception building, and the coaxial network is used for the in-building broadcasting cable. The broadcasting network is utilized by a multisystem operator (MSO) in Korea.

At the receiving end, the STB receives the downstream signals and interfaces with an UHD display, a monitoring PC, and a stream analyzer. The STB consists of a tuner, demodulator, and HEVC decoder. The tuner can support digital reception for digital TV standards.

4. Field Test Condition

To evaluate the performance of the implemented OFDM-based digital video broadcasting system transmitter, field trials are performed in a commercial in-service network environment. Figure 4 shows the field test bed for the implemented OFDM-based digital video broadcasting system. In the implemented system, a board-type FEC encoder and modulator are developed, which are controlled by a PC. The RF up-converter translates the IF frequency signal of 44 MHz into the desired RF channel. In this test, 225MHz is considered as RF center frequency.

The route used for the field trials is described in Figure 4. The head-end is located at Seonhwa-dong, Jung-Gu, Daejeon, Korea. From this head-end, the downstream signals were transmitted to a laboratory in ETRI thorough Yuseong station which acts as an amplifier for boosting the signals. Figure 5 shows the configuration of the broadcasting network. The broadcasting network is connected to a head-end through fiber optics and the laboratory is approximately 27.1 km away from Seonhwa station. An Optical Network Unit (ONU) converts the optical signals into RF signals for the final distribution through a coax network. The network configuration of the filed trial is depicted in Figure 6.

5. Performance Evaluation

5.1. ToV Performance Evaluation and Comparison. To check the ToV of the designed system, BER performance is evaluated in both AWGN and fading channel environments. Furthermore, the evaluated performance of the designed system is compared to that of the existing digital broadcasting system.

Table 5 shows the system parameter comparison between the existing transmission schemes [9, 10] and the implemented transmission scheme. The existing transmission method currently being used is based on a single carrier and can transmit a maximum of 38.8Mbps, while the implemented transmission method is based on a multicarrier and transmits a maximum above 51Mbps to provide a transmission rate that is improved by about 30%. In the case of [9], 1024-QAM-based system has been designed and implemented for UHD cable TV. Furthermore, the data rate of the system of [9] is similar to that of the implemented system with 1024QAM. Therefore, in this subsection, the ToV performance between the designed scheme of [9] and the implemented system of this paper is compared.

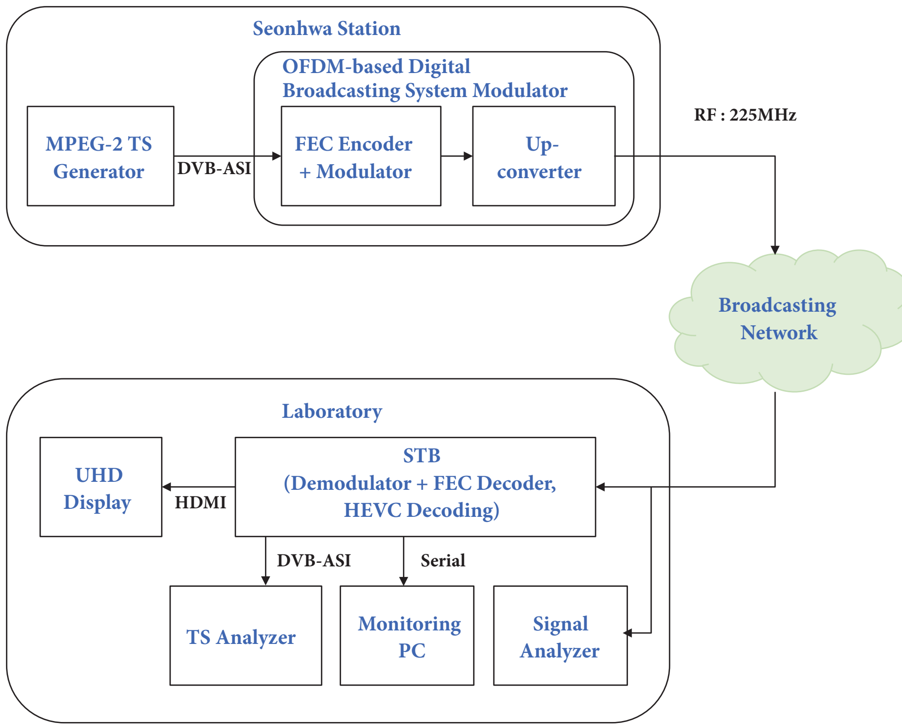


Figure 3: System configuration and equipment setup.

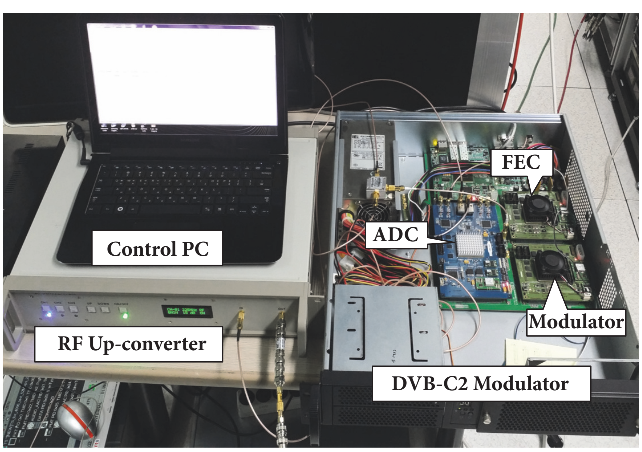


Figure 4: Implemented OFDM-based digital video broadcasting system modulator.

Figure 7 shows the BER performance of the designed digital video broadcasting system according to the modulation and coderate in AWGN channel. In the case of 1024QAM with 9/10 coderate, the transmission rate is 48.84Mbps and the ToV is about 29.35dB. Since the ToV of the system in [9] is 32.7dB, the performance of the designed system is about 3dB better than that of the system of [9] in the similar transmission condition. And the ToV of the 4096QAM with 9/10 coderate is about 35dB. Therefore, in the case of the designed system with 4096QAM and 9/10 coderate, if the SNR of the transmission channel is higher than that of 35dB, the multichannel UHD service can be successfully served.

Table 5: Comparison between existing and implemented system.

	Existing	Designed [9]	Implemented	
Standard	ITU-T J.83-B	ITU-T J.83-B	OFDM-based DVB	
Transmission	Single Carrier	Single Carrier	Multi-Carrier	
Bandwidth	6 MHz	6 MHz	6 MHz	
Modulation	256QAM	1024QAM	1024QAM	4096QAM
Post-FEC Data Rate (Mbps)	38.80	48.54	48.84	51.82

Figure 8 describes the BER performance in echo channel 1 of Table 6 [15]. In this fading channel, the ToVs of 4096QAM with 9/10 coderate and 1024QAM with 9/10 coderate are about 36.3dB and 30.7dB, respectively. The ToV performance of fading channel is about 1.5dB worse than that of AWGN channel, and because this fading channel model properly reflects the practical broadcasting network environment, higher SNR should be guaranteed than 36.3dB to serve multichannel UHD contents with 4096QAM in in-service broadcasting network.

5.2. Field Trial Results and Discussions. As mentioned before, for accomplishment of a stream bitrate of 51.6 Mbps, the

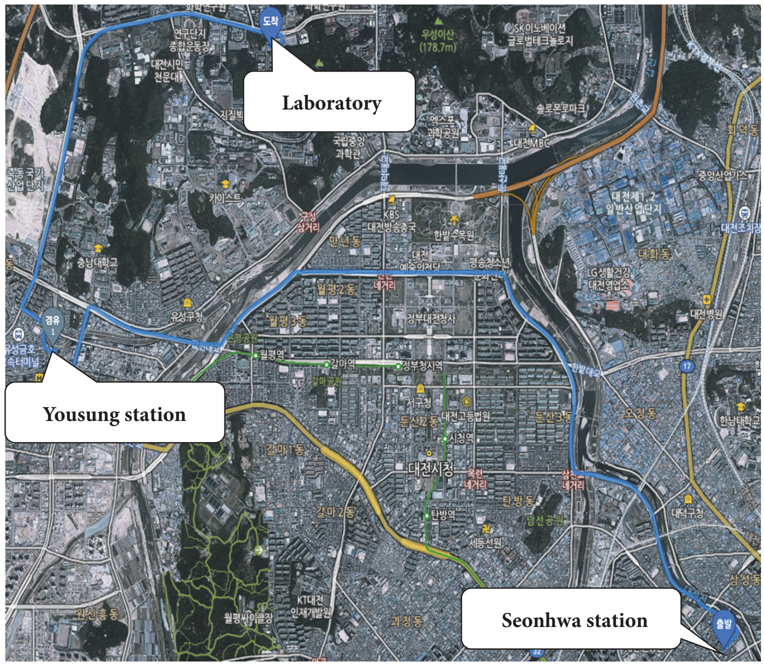
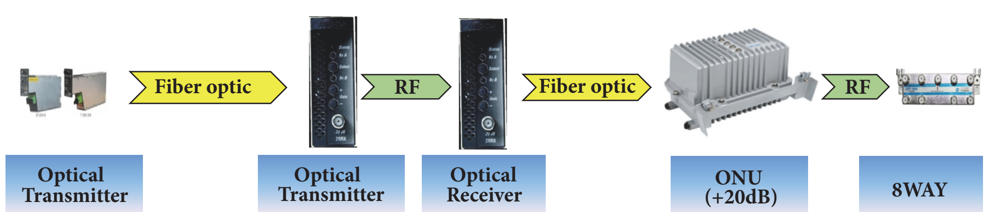


Figure 5: The route used for field trials (Seonhwa station: transmission station, Yousung station: amplification station).

(a) Filed test route structure



(b) Field test network feature

Figure 6: Broadcasting network configuration.

4096 QAM and 9/10 LDPC code rate are considered. In our paper, the achieved stream bitrate of 51.6Mbps means data transmission rate without header and pilot symbols. Figure 9 shows the frequency response of the received broadcasting signal. The spectrum result describes that the center frequency is 225 MHz, and the measured input power of the analog-to-digital converter (ADC) is -27.48 dBm within 6 MHz channel bandwidth. Figure 10 shows the constellation of the received signal after equalization process. The data for the constellation was dumped and depicted in a monitoring PC connected to the receiver. As in the figure, the constellation of the equalized received signal shows clear QAM points.

The received signaling information is checked by commercial received signal analyzer in Figure 3. This commercial signal analyzer displays L1 signaling part 2 data and the FEC frame header as described in Figure 11. All parameters are the same as shown in Table 4. This means that the implemented FEC encoder and modulator work properly.

Table 6: Channel profile of echo channel 1.

Power [dB]	Delay [ns]	Phase [rad]
-11	38	0.95
-14	181	1.67
-17	427	0.26
-23	809	1.20
-32	1633	1.12
-40	3708	0.81

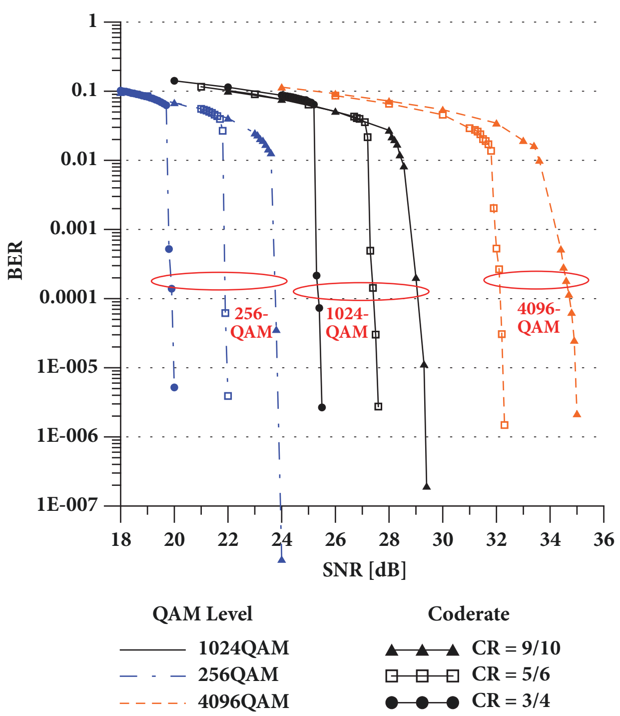


Figure 7: BER performance of designed digital video broadcasting system in AWGN channel.

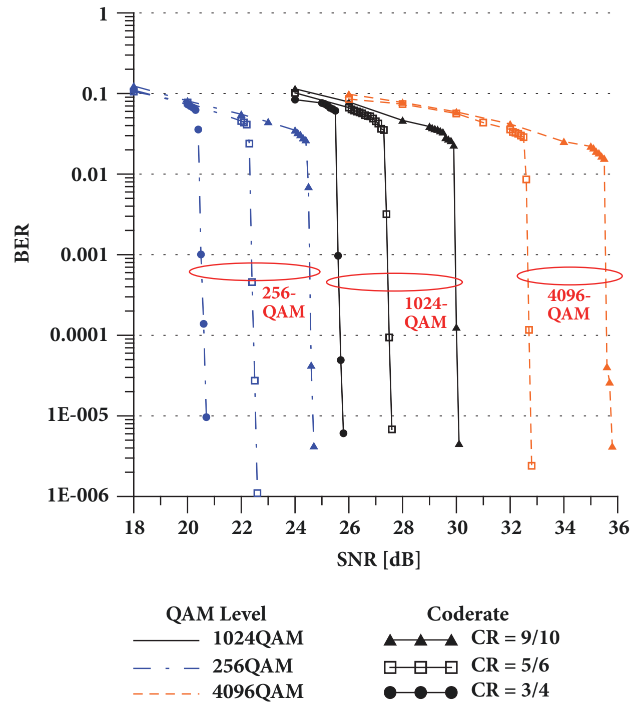


Figure 8: BER performance of designed digital video broadcasting system in fading channel (echo channel 1).

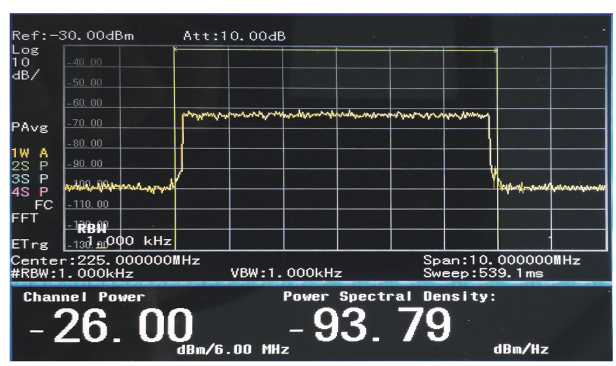


Figure 9: Received DVB-C2 signal in the frequency domain.

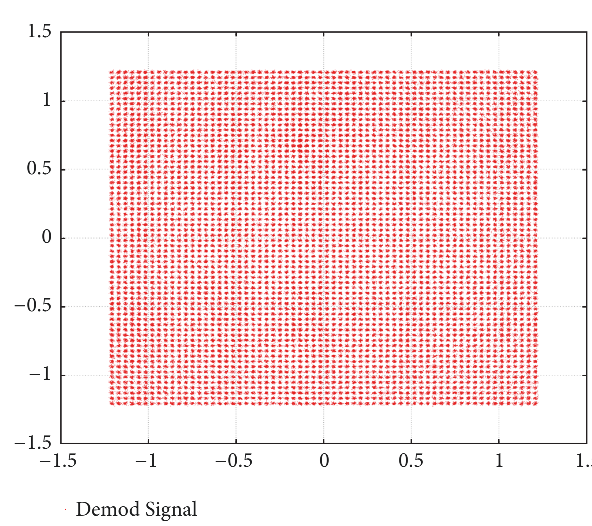


Figure 10: 4096-QAM Constellation for the Received DVB-C2 signal.

The results of the field trials were used mainly to evaluate two aspects: the reception performance and the seamless stream reception status. To measure the reception performance, commercial STB is modified. From the modified STB, serial interface output data is gathered by monitoring PC. Figure 12 shows the measured carrier-to-noise ratio (C/N) and BER after the BCH decoder in a commercial STB. The value of the measured C/N is 40.25 dB. This value is superior to the required ToV (36.3 dB) as shown in Figure 8. That is, analog parts such as RF upconverter and a digital logic block were properly developed. In addition, the measured BER was zero because of the superior C/N at the receiver. The receiver system configuration is shown in Figure 13. As expected, the video stream is clearly played on UHDTV. Moreover, a seamless playback is achieved.

Furthermore to check the accomplishment of 51.6 Mbps stream bitrate, the bitrate of received signal is monitored by TS analyzer of Figure 3. Figure 14 describes the results of TS

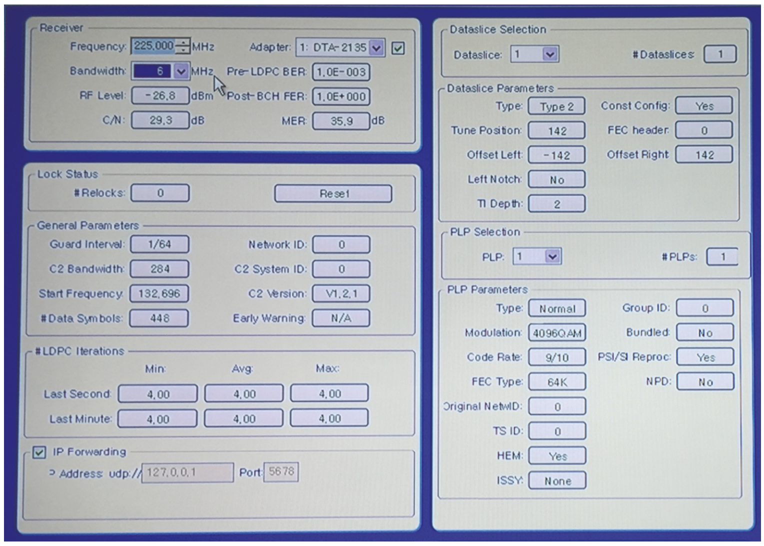


FIGURE 11: L1 signaling part 2 data and FEC frame header information.

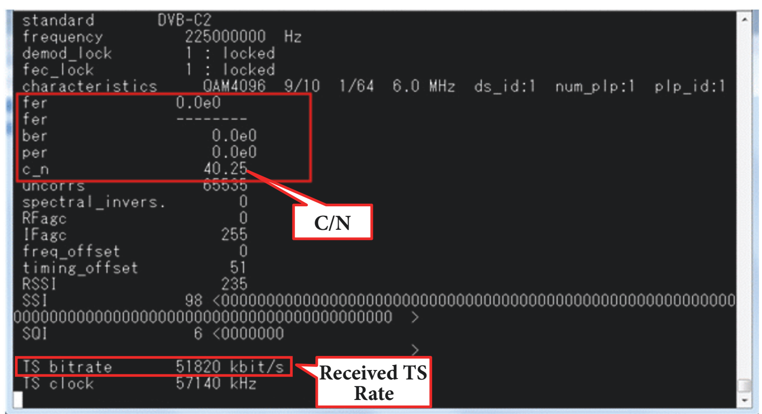


FIGURE 12: The measured C/N and BER after BCH in commercial STB.

FIGURE 13: The receiver system configuration.

analyzer. As in the figure, the receiver can obtain constant 51.6Mbps from the developed system.

6. Conclusions

OFDM-based digital video broadcasting system transmitter was implemented with FPGAs for multichannel UHD services, and the implemented transmitter was tested over a commercial in-service broadcasting network. In addition, the performance of the implemented system was measured by a commercial STB and signal analyzer. The test results show that the implemented OFDM-based digital video broadcasting transmitter can achieve the 51.6Mbps transmission rate for multichannel UHD broadcasting services. In addition, various test results were described such as received signal spectrum, BER performance, and CNR of 4096QAM related

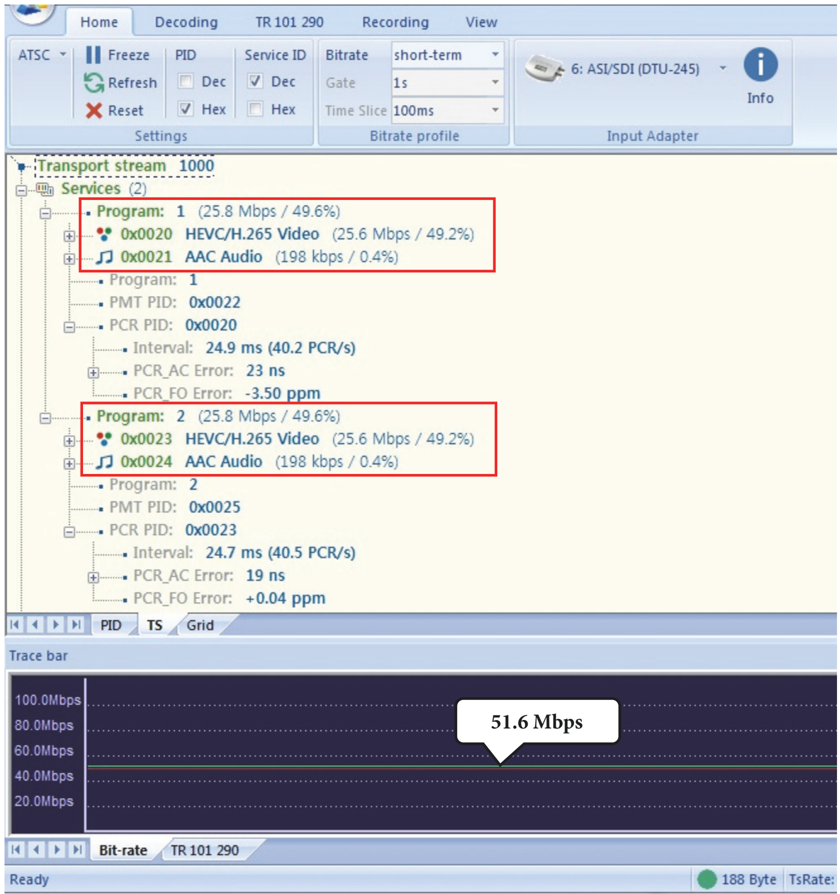


Figure 14: Received stream bitrate described in TS analyzer.

to the performance and physical network status. These test results can provide basic information for OFDM-based digital video broadcasting technology in many countries and may lead to the development of a next-generation digital broadcasting system.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This work was supported by the Institute for Information & communications Technology Promotion (IITP) grants funded by the Korean government (MSIP) No. 2016-0-00106, Development of the RF-Signal over IP Technology for the Smart Media Services Based on Optical IP Network.

References

[1] K. Park, N. Kim, and B.-D. Lee, “Performance evaluation of the media-transport technologies for the next-generation digital broadcasting systems,” *IEEE ACCESS*, vol. 5, pp. 4125–4131, 2017.

[2] T. T. Adeliyi and O. O. Olugbara, “Fast Channel Navigation of Internet Protocol Television Using Adaptive Hybrid Delivery Method,” *Journal of Computer Networks and Communications*, vol. 2018, Article ID 2721950, 11 pages, 2018.

[3] J. Seok, Y. Kim, M. Ki, H. Y. Kim, and J. S. Choi, “Fast prediction mode decision in HEVC Using a pseudo rate-distortion based on separated encoding structure,” *ETRI Journal*, vol. 38, no. 5, pp. 807–817, 2016.

[4] B. Kwon and S. Lee, “Effective Interference Nulling Virtual MIMO Broadcasting Transceiver for Multiple Relaying,” *IEEE Access*, vol. 5, pp. 20695–20706, 2017.

[5] Digital Video Broadcasting (DVB); frame structure channel coding and modulation for a second generation digital terrestrial television broadcasting system (DVB-T2), ETSI EN 302 755 V1.3.1, Apr. 2012.

[6] *ATSC: ATSC Physical Layer Protocol Standard*, document A/322, Adv. Television Syst. Committee, Washington, DC, USA, Sep. 2016.

[7] ETSI EN 302 769 v1.2.1, Digital Video Broadcasting(DVB) ; Frame structure channel coding and modulation for a second

generation digtial transmission system for cable systems (DVB-C2), Apr. 2011.

[8] . Jae-Ho Lee, . Dong-Joon Choi, . Namho Hur, and . Whan-Woo Kim, “Performance Analysis of a Proposed Pre-FEC Structure for a DVB-C2 Receiver,” *IEEE Transactions on Broadcasting*, vol. 59, no. 4, pp. 638–647, 2013.

[9] S.-H. Kim, J. Choi, J. Kim, M. S. Hossen, and K.-D. Kim, “Design and implementation of the 1024-QAM RF transmission system for UHD cable TV broadcasting,” in *Proceedings of the 16th International Conference on Advanced Communication Technology: Content Centric Network Innovation!, ICACT 2014*, pp. 1317–1324, Republic of Korea, February 2014.

[10] P. K. Sinha, P. Biswas, and A. Sinha, “Design and implementation of high speed digital multi-programme system based on ITU-T J.83 annexures A and C,” in *Proceedings of the 2015 IEEE International Conference on Signal Processing, Informatics, Communication and Energy Systems, SPICES 2015*, India, February 2015.

[11] W. Xiang, G. Wu, Q. Ling, and L. Wang, “Piecewise patching for time-shifted TV over HFC networks,” *IEEE Transactions on Consumer Electronics*, vol. 53, no. 3, pp. 891–897, 2007.

[12] S. Ra, J. Song, J. Bae et al., “Performance measurement of high-efficient OFDM based transmission system in commercial HFC network,” in *Proceedings of the 2016 IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB)*, pp. 1-2, Nara, Japan, June 2016.

[13] T. Kamata, K. Okui, M. Fukasawa, T. Matsuoka, and K. Taniguchi, “Low-power zero-IF full-segment ISDB-T CMOS tuner with tenth-order baseband filters,” *IEEE Transactions on Consumer Electronics*, vol. 57, no. 2, pp. 403–410, 2011.

[14] J. Lee, W. You, J. Oh, S. Ra, and J. Jung, “Performance analysis and implementation of a DVB-C2 transceiver,” in *Proceedings of the 18th International Conference on Advanced Communications Technology, ICACT 2016*, pp. 612–616, Republic of Korea, February 2016.

[15] DVB Document A147, Digital Video Broadcasting (DVB), Implementation Guidelines for a second generation digital cable transmission system (DVB-C2), March 2013.