A Study on Feasibility of Dual-Channel 3DTV Service via ATSC-M/H

Byung-Yeon Kim, Min-Suk Bang, Sung-Hoon Kim, Jin Soo Choi, Jinwoong Kim, Dong-Wook Kang, and Kyeong-Hoon Jung

This paper analyzes the feasibility of a new 3DTV broadcasting service scenario via Advanced Television Systems Committee Mobile/Handheld (ATSC-M/H). We suggest a dual-channel system in which a left-view image is encoded by MPEG-2 with HD quality and a small-sized right-view image is encoded by AVC. Also, the left view is transmitted through ATSC main channel and the right view is transmitted through ATSC-M/H channel. Although the transport stream formats of two channels are different from each other, we demonstrate that it is possible for the ATSC 2.0 decoder to synchronize the display of the left and right views when both encoders use a common wall clock and time stamp. We also propose a program specific information descriptor which guarantees full compatibility with the conventional 2D HDTV and emerging mobile TV services. Finally, we provide the results of subjective visual quality assessment of the proposed system in support of its 3DTV service quality.

Keywords: 3DTV, ATSC-M/H, dual-channel, time stamp, DSCQS.

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Byung-Yeon Kim (phone: +82 2 910 5073, nick.kimby@gamil.com), Min-Suk Bang (bmons85@kookmin.ac.kr), Dong-Wook Kang (dwkang@kookmin.ac.kr), and Kyeong-Hoon Jung (corresponding author, khjung@kookmin.ac.kr) are with the School of Electrical Engineering, Kookmin University, Seoul, Rep. of Korea.

Sung-Hoon Kim (steve-kim@etri.re.kr), Jin Soo Choi (jschoi@etri.re.kr), and Jinwoong Kim (jwkim@etri.re.kr) are with the Broadcasting & Telecommuications Convergence Research Laboratory, ETRI, Daejeon, Rep. of Korea.

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I. Introduction

The evolution of broadcasting from analog to digital has been a worldwide trend for decades. The recent interest of broadcasters and manufactures is moving toward another up-and-coming application area. The mobile application is one of the most promising areas. That is the very reason why the Advanced Television Standard Committee (ATSC) is developing its mobile/handheld (M/H) standard as a next step after ATSC 1.0 in North America.

ATSC 1.0, which is described in ATSC A/53 [1], is a standard for the existing digital television (DTV) service. It adopts vestigial sideband (VSB) for RF transmission, and the available data rate is up to 19.2 Mbps within 6 MHz bandwidths. ATSC M/H standard [2] shares the same RF channel as ATSC 1.0 and defines how to multiplex one or more mobile, pedestrian, and handheld services by using a portion of total bandwidth of 19.2 Mbps.

Meanwhile as 3D applications spread quickly and widely, the demand for 3DTV is increasing in many countries. ATSC also has tried to add 3DTV service in ATSC M/H platform and made several examples of bitrate allocation for 3DTV and mobile services as shown in Table 1 where it is assumed that standard definition TV (SDTV) services are fixed at 4.7 Mbps and mobile is fixed at 3 Mbps.

Scenario 1 corresponds to the typical DTV environment in ATSC 1.0, and the available bandwidth is fully used for high definition TV (HDTV) or 3DTV service. In scenario 2, the HDTV rate is reduced due to the additional mobile service. The 3DTV in scenarios 3 and 4 is considered as an independent stereoscopic service and there is no room for HDTV bandwidth. Scenarios 5 and 6 assume the use of interview

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Table 1. 3DTV scenarios in ATSC-M/H. (Mbps)

	Scenario	HDTV	SDTV	Mobile	3DTV
1	HD only service	19.2			
2	HD and mobile	16.2		3	
3	SD and 3DTV		4.7		14.5
4	SD, mobile, and 3DTV		4.7	3	11.5
5	HD and 3D enhancement	12			7.2
6	HD, mobile, and 3D enhancement	10.1		3	6.1
7	SD, HDTV and/or 3DTV		4.7		14.5
8	SD, mobile, HDTV, and/or 3DTV		4.7	3	11.5

codec, that is, the second view or supplemental information for 3DTV is transmitted with 2D HDTV service and the 3D enhancement rate is about 60% of the main HDTV rate. In scenarios 7 and 8, the main 2D program is offered by SDTV service and the remaining rate is expected to be used for HD 3DTV simulcast with advanced codec.

The major problem in the above scenarios is that the sacrifice of bitrate for HDTV service is inevitable to add mobile or 3DTV services. That means the service quality of conventional DTV is likely to deteriorate according to the amount of bitrate reduction. Also, some scenarios require a new advanced codec like Advanced Video Coding (AVC) instead of general MPEG-2 to enjoy HD quality service.

To overcome these shortcomings, we suggest a new 3DTV service scenario where the left view is transmitted through the HDTV channel and the right view is transmitted through a mobile channel. Each channel can be used for its own purpose, that is, 2D HDTV or 2D mobile service. Since there is no additional bitrate for 3DTV, the quality degradation of 2D HDTV service with legacy ATSC 1.0 receiver can be minimized. Meanwhile, the ATSC 2.0 receiver, an extended ATSC receiver with dual codec, can decode both left and right views and generate 3D program with HD quality.

The paper is organized as follows. In section II, the service scenario of the proposed 3DTV is presented. In section III, the synchronization issue under two distinct transport streams and the program map table (PMT) descriptor to satisfy the compatibility with legacy ATSC system are discussed in depth. Also, the objective and subjective qualities are discussed in section IV to prove the feasibility of the proposed 3DTV system. Finally, the conclusion is given in section V.

II. Proposed Dual-Channel 3DTV System

The block diagram of the proposed 3DTV system is shown in

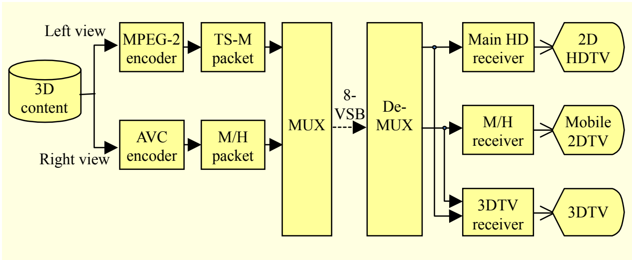

Fig. 1. Proposed dual-channel 3DTV system.

Fig. 1. Its overall structure consists of two channels; each channel may have different spatial and/or temporal resolution as well as employ different encoders and protocols.

When the stereoscopic 3D content is given, the first step is to decompose it into left and right views. The left view moves to the upper HD channel, where MPEG-2 encoding and transport stream (TS) packetizing schemes are used. On the contrary, the right view is delivered to the lower M/H channel, where AVC encoding and M/H packetizing are adopted. The most outstanding distinction between the two channels is the spatial resolution since the HD channel is primarily for the conventional DTV service and the M/H channel is for mobile service of which display is constrained to relatively small size. At transmitter, both streams from two channels are multiplexed and modulated by A/153. The HD left and M/H right streams can be used for the conventional 2D HD and 2D mobile broadcasting services, respectively. Also, if both streams are decoded with the ATSC 2.0 receiver of dual codec, 3D HDTV service becomes available.

The proposed system has the essential advantage over various 3D bundle scenarios in Table 1. The spectral efficiency for 3DTV can be improved, that is, three kinds of service are possible within 6-MHz bandwidth while minimizing the quality deterioration of conventional HDTV. Also, the backward compatibility can be fully guaranteed since the proposed system does not affect the ATSC M/H standard at all.

Meanwhile, there are some requirements for the system to be successfully implemented. Firstly, the synchronization between the left and right views is an issue since the timing models in the TS-M and M/H channels are different from each other. Also, the program specific information (PSI) descriptor needs to be modified not to disturb the normal operation of the legacy ATSC receiver.

Another issue is the quality of the dual-channel 3DTV system in which there is a severe difference in resolutions of the TS-M and M/H channels. In relation to this mismatch, the binocular suppression theory is worthy of note. It says that when the qualities of the left and right views are different, the perceived quality of the stereoscopic views is close to that of the higher quality view [3], [4]. Based on the effect, Fehn and others have proposed a scheme of asymmetric coding of stereoscopic video in which the left-view images are encoded with the full resolution, while the right-view images are encoded after down sampling [5].

III. Realization of Dual-Channel 3DTV System

1. Synchronization Scheme

In an ATSC-M/H frame, the transport stream unit consists of TS-M and M/H streams, each of which is independent of the other [6]. In addition, the two streams are operated under different timing models. That is the reason why the synchronization scheme is indispensible.

In the TS-M stream, presentation time stamp (PTS), display time stamp (DTS), and program clock reference (PCR) are employed. PTS and DTS are included in packetized elementary stream (PES) header and the PCR is regularly transmitted to let the decoder know the reference timing information. Meanwhile, in the M/H stream, the presentation timing of each access unit (AU) is determined by analyzing three timestamps: timestamp in a real-time transport protocol (RTP) packet header and NTP_timestamp and RTP_timestamp in the RTP control protocol sender report (RTCP_SR) packet. NTP_timestamp plays a similar role to PCR in the TS-M stream, that is, to set the reference time in the decoder.

Therefore, for ATSC 2.0 receivers to synchronize left-view and right-view images, the two timing models of the TS-M and M/H streams need to be unified at the encoder side. Figure 2 depicts the general idea of the synchronization scheme in which a common wall clock is employed. The upper part corresponds to the conventional TS-M channel and the high-quality left view and its audio data are encoded by MPEG-2 and AC-3, respectively. Also, the PTS information is straightforwardly carried on the PES header. In the lower M/H channel, the same PTS is put as an RTP_timestamp in the RTP packet header. One may note that there is a 1-bit difference in length between PTS and RTP_timestamp. However, this mismatch becomes a trivial problem by ignoring the most significant bit of PTS because it means about a 12-hour difference in time. Meanwhile, PCR and RTP_timestamp are generated by the common wall clock.

By using this synchronization scheme, the ATSC 2.0 receiver can successfully generate 3D content by playing a right-view image when its RTP_timestamp coincides with the PTS of the left-view image.

2. Interoperability of 3DTV Service

It is required that the proposed system provide the

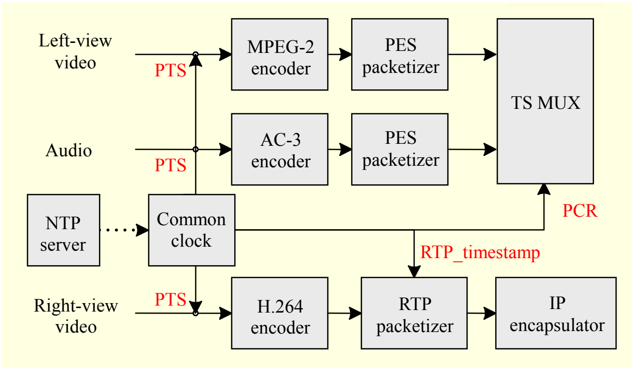

Fig. 2. Synchronization scheme.

conventional HDTV and mobile TV services as well as 3DTV service. Also, a receiver needs to know whether the program is 3D or not, and if it is 3D, how to access the information about right view images in M/H channel.

The standard ATSC-M/H signaling channel is similar to the PSI of the MPEG-2 system [7]. To satisfy the backward compatibility to the legacy ATSC system, the PMT descriptor for the 3D service should follow it too. Table 2 lists the syntax of the PMT descriptors for 3DTV service.

Content_descriptor classifies whether the current content is of 2D or 3D mode. Table 3 shows the possible values of the Content_descriptor.

Right_baselayer_descriptor follows when 3D mode is active. It enables the receiver to know how to access the M/H packets containing the right-view streams. Since encapsulated IP protocol is used for the M/H channel, access control to a specific service in the M/H framing has the layered structure with two steps. The first step is analyzing fast information channel (FIC) data to choose the proper ensemble containing the right-view stream. The second step is to acquire packets having the specific Internet protocol (IP) multicast address and user datagram protocol (UDP) destination port number.

The third content type of Content_descriptor is used when there is an enhancement data for the right view images. A type of scalable coding or supplementary data can be added to improve the final visual quality of 3D content.

In this case, the data can be transmitted through the TS-M channel to avoid placing an extra burden for the M/H channel. Therefore, signaling information based on the MPEG-2 system such as Elementary_PID and AVC_video_descriptor is used to access the enhancement data.

The last part of the descriptors is for the main video and audio information, which follows the MPEG-2 system standard.

3. Prototype System of Dual-Channel 3DTV

The prototype system shown in Fig. 3 was demonstrated at

Table 2. PMT descriptor for 3DTV service.

Syntax	Bits	Value
Table_ID	8	0x02
Section_syntax_indicator	1	1
‘0’	1	0
Reserved	2	3
Section_length	12	
Program_number	16	
Reserved	2	3
Version_number	5	2
Current_next_indicator	1	2
Section_number	8	0
Last_section_number	8	0
Reserved	3	7
PCR_PID	13	0x11
Reserved	4	15
Program_info_length	12	3
Content_descriptor		
descriptor_tag	8	0x36
descriptor_length	8	2
content_type	16	
if (content_type& 0x01)		
{		
Right_baselayer_descriptor		
descriptor_tag	8	0x64
descriptor_length	8	10
stream_type	8	
Reserved	3	7
right_Elementary_PID	13	0x111
FIC_number	16	
IP_address	32	
UDP_port	16	
}		
if(content_type == 0xc3)		
{		
stream_type	8	0x1B
Reserved	3	7
Elementary_PID	13	0x110
Reserved	4	15
ES_info_length	12	4
AVC_video_descriptor	32	
}		
// main video		
// main audio		

Table 3. Content_type in Content_descriptor.

Value	Type
11000100	2D
11000001	3D without enhancement layer
11000011	3D with enhancement layer

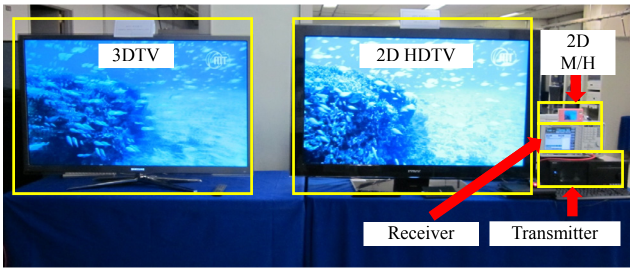

Fig. 3. Prototype system of dual-channel 3DTV.

the 2011 National Association of Broadcasters Show by ETRI. The 3DTV and 2DTV monitors were 55 inches diagonal, while the 2D M/H TV monitor was 3.5 inches diagonal.

Left-view video was encoded by using the Electra 8000 of Harmonics. The frame format of the video was 1080p, and the bitrate of the encoded stream was 12 Mbps. Right-view video was encoded by using the KE-MH10 of Kai Media with two options. One had a video format of 240p and the bitrate of 420 kbps. The other had a video format of 480p and the bitrate of 1.5 Mbps. They were transported through channel 0 and 1 of the M/H channel, respectively.

ATX2000 of DTVinteractive was used as the transmitter. The signaling information of the M/H channel 0 consisted of IP address 239.1.56.8 and UDP port numbers 9000 and 9001 for video RTP and video RTCP, respectively, while that of the M/H channel 1 consisted of IP address 239.1.56.7 and UDP port numbers 9000 through 9003 for video RTP, video RTCP, audio RTP, and audio RTCP, respectively. In addition, HD MAX Stick-K2 of Cobalt was used as the receiver.

This prototype has successfully demonstrated that 2D HDTV, 2D mobile TV, and 3D HDTV can be serviced simultaneously by using the proposed 3DTV system.

IV. Visual Quality Assessment of 3DTV

1. Test Sequences and Simulation Setup

We used five stereoscopic video sequences for the quality assessment test: ‘TTA_1,’ ‘TTA_2,’ ‘TTA_3,’ ‘TheEye,’ and ‘Dzignlight.’ First three sequences were provided by the Telecommunications Technology Association (TTA) and

Fig. 4. Test sequences.

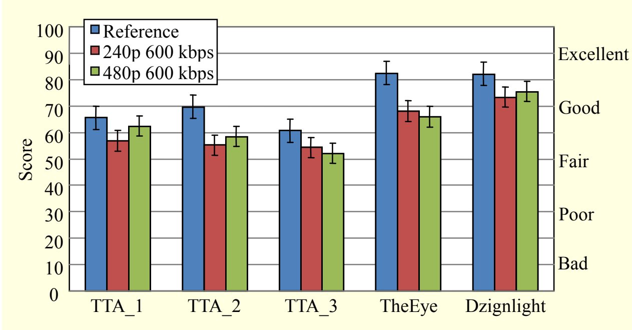

Fig. 6. DSCQS results of 3DTV test sequences.

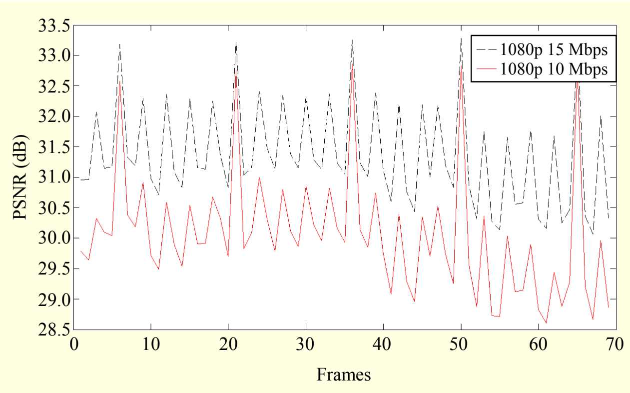

Fig. 5. PSNRs of 2D HDTV for TTA_2 sequence.

others are downloaded from www.3dtv.at website. Each sequence is 15 s in duration and the vertical resolution is 1080p lines. Figure 4 shows sample shots of test sequences.

In our simulation, 15 Mbps is allocated for the HD channel and the left view is encoded by MPEG-2 MP@HL while maintaining the original resolution. The remaining 4.2 Mbps can be used for the M/H channel. However, the payload data rate is much smaller than that due to the large overhead in mobile environment. By considering the serial concatenated convolutional code (SCCC), training signal, audio data, and so on, we calculated that about 600 kbps is available for the coding of real video data. A/153 standard defines 240p and 480p resolution for M/H service resolution. Thus, the right view is encoded by AVC with 600 kbps rate in two ways; one is 240p and the other is 480p.

2. Visual Quality Assessment

When mobile TV or 3DTV services are added, the bitrate reduction and quality degradation of the conventional 2D HDTV is unavoidable. Therefore, before we move on the assessment result of 3DTV, it is worthwhile to examine the quality of it.

The target of comparison is scenario 6 in Table 1, since it can provide HDTV, mobile TV, and 3DTV services simultaneously like what we proposed. In scenario 6, the bitrate for HDTV is reduced about 9 Mbps. In contrast, only 4 Mbps is reduced in the proposed system.

We calculated PSNR to measure the objective qualities of 2D HDTV in both scenarios. The PSNR values of the encoded left view of the TTA_2 sequence are shown in Fig. 5, where the upper line is for 15 Mbps MPEG-2 encoding and the lower line is for 10 Mbps MPEG-2 encoding. It can be noticed that our scenario has about 1.5-dB gain over scenario 6. Similar tendency occurs in every test sequence: 1-dB gain to 3-dB gain over scenario 6.

To measure the ultimate visual quality of 3DTV, the double-stimulus continuous quality-scale (DSCQS) method [8] was used for subjective quality assessment. Twenty assessors participated in the experiment. Their ages ranged from 21 to 37 with an average of 26. The 3D display was a 47-inch light emitting diode (LED) monitor of shutter glasses type (LG 47LX9500 3DTV). The viewing distance was 3.3 times longer than the height of 3DTV display. Figure 6 shows DSCQS results of subjective quality assessment when the left view is 15 Mbps MPEG-2 encoded with 1080p resolution and the right view is 600 kbps AVC encoded with 240p and 480p.

The target of comparison in this experiment is also scenario 6, in which the 10 Mbps MPEG-2 and 6 Mbps AVC encoding was employed for the left and right views, respectively. Even though the quality gap between the left and right views is large in the proposed 3DTV system, the DSCQS ratings of it are close to that of the scenario 6. In general, they fall between ‘fair’ and ‘good’ and the visual quality is quite satisfactory subjectively. This result strongly supports the feasibility of the proposed dual-channel 3DTV system via ATSC-M/H.

3. Quality Improvement via Enhancement of Right View

According to binocular suppression theory, the resolution of a better view is known as a more critical factor on 3D visual quality. However, we found that the overall quality depends on

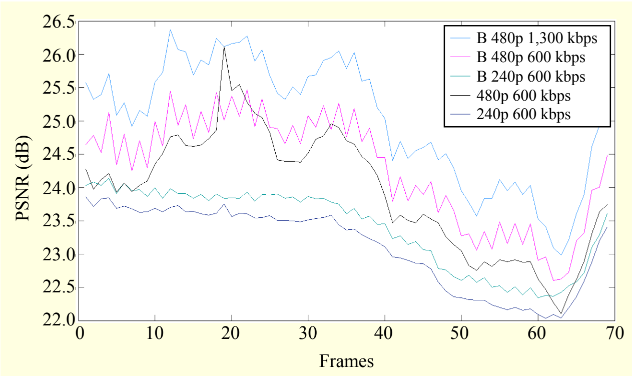

Fig. 7. PSNRs of M/H right view for TTA_2 sequence.

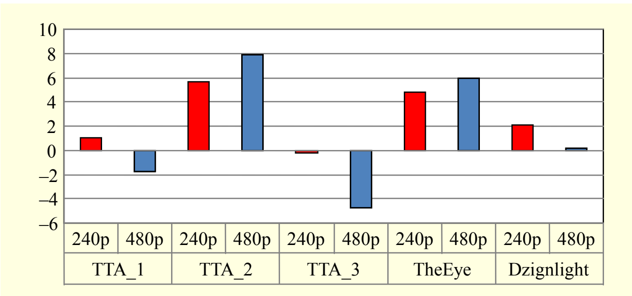

Fig. 8. DSCQS differences by adopting 'B-slice mode.'

both views and there is a possibility of better 3DTV service if small-sized image for the right view could be properly enhanced.

Therefore, we propose 'B-slice mode' to enhance the right view. In this mode, the right view is encoded by AVC main profile. I-slice and P-slice are transmitted through M/H channel and the quality of each I-slice or P-slice is expected to be improved because the frame rate is halved under the same bitrate. The remaining B-slice can be transmitted through an HD channel as optional information with a designated packet identifier. Because the amount of data for B-slice is very small compared to that of HDTV, it is not a heavy load in the HD channel. Also, we increased the bitrate of the M/H channel up to 1,300 kbps to get better quality. This value is calculated by considering the case of 1/2-rate SCCC and VSB rate of 4 Mbps.

From Fig. 7, we can look into the PSNR variation of M/H right view for TTA_2 sequence after 'B-slice mode' was adopted. Compared with Fig. 5, these PSNRs decreased by 6 dB to 8 dB in value due to the quality gap of M/H channel. Note that PSNRs increase at least 1 dB but may increase up to 2 dB by adopting 'B-slice mode'.

Meanwhile, Fig. 8 shows the DSCQS differences of 240p and 480p mode at 600 kbps before and after adopting 'B-slice mode.' The positive value means the score is improved. The DSCQS were slightly improved by adopting 'B-slice mode' in most cases. As a general tendency, the higher the resolution and

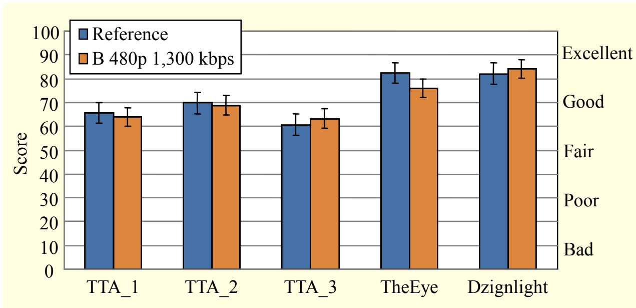

Fig. 9. DSCQS of 480p at 1,300 kbps with 'B-slice mode.'

bitrate, the better the objective and subjective quality is.

The most impressive result comes with 480p at 1,300 kbps with 'B-slice mode'. As shown in Fig. 9, the subjective quality of it is almost the same as that of scenario 6.

V. Conclusion

In this paper, we proposed a new ATSC-M/H-based 3DTV service scenario. The left view is transmitted through the ATSC main channel, and the right view is delivered through the M/H channel. Each view can be used for its own purpose, that is, the left view is for 2D HDTV and the right view is for 2D mobile TV. When the ATSC-M/H terminal with a dual codec is available, both views can be used to generate the 3DTV with practically HD quality.

To overcome the mismatch between the timing models for the TS-M and M/H channels, we suggest a synchronization scheme that uses the common wall clock and PTS as the PES timestamp for the left-view images and as the RTP timestamp for the right-view images. We also presented the PMT descriptor for the 3DTV service, which is compatible with the conventional ATSC service. A demonstration of the prototype system shows clearly that the ATSC-M/H system can handle 2D HDTV, 2D mobile TV, and 3D HDTV services simultaneously.

Also, we evaluated the visual quality of resulting 3DTV contents. Even though there are considerable resolution and quality gaps between the left and right views, the DSCQS ratings of the resulting 3D sequence fall between 'fair' and 'good' and generate quite satisfactory results in many cases. This result supports the feasibility of the proposed dual-channel 3DTV system. Also, we tried to employ the 'B-slice mode' to improve the quality of small-sized right view. The PSNR gap between the left and right views is decreased, and the subjective quality of 3D sequence is slightly improved.

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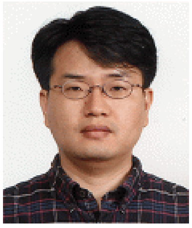
Byung-Yeon Kim received the BS in electrical engineering from Kookmin University, Seoul, Rep. of Korea, in 2010. Since 2010, he has been studying for his master's in electrical engineering from the same university. He is currently interested in 3DTV video quality and digital broadcasting systems.

Min-Suk Bang received the BS in electrical engineering from Kookmin University, Seoul, Rep. of Korea, in 2010. Since 2010, he has been studying for his master's in electrical engineering from Kookmin University, Seoul, Rep. of Korea. He is currently interested in 3DTV, broadcasting systems, and signal processing.

Sung-Hoon Kim received BS, ME, and PhD in electronics engineering from Kookmin University, Seoul, Rep. of Korea, in 1994, 1996, and 2007, respectively. Since 2000, he has been a senior member of staff in the Broadcasting & Telecommunications Convergence Media Research Department, ETRI. His research interests are digital signal processing in the field of video communication, Mobile DTV, 3DTV, and UHDTV broadcasting systems.



Jin Soo Choi received the BE, ME, and PhD in electronic engineering from Kyungpook National University, Rep. of Korea, in 1990, 1992, and 1996, respectively. Since 1996, he has been a principal member of the engineering staff in ETRI, Daejeon, Rep. of Korea. He has been involved in developing the MPEG-4 codec system, data broadcasting system, and 3D/UHDTV broadcasting system. His research interests include visual signal processing and interactive services in the field of the digital broadcasting technology.

Jinwoong Kim received both his BS and MS in electronics engineering from Seoul National University, Seoul, Rep. of Korea, in 1981 and 1983, respectively. He received the PhD in electrical engineering from Texas A&M University, Texas, USA, in 1993. He has been with ETRI since 1983 and is a principal member of research staff in the Broadcasting and Telecommunications Media Research Department. His areas of interest include digital broadcasting systems, digital video compression and coding, 3DTV, UHDTV, and digital holography.

Dong-Wook Kang received the BS, MS, and PhD from the Department of Electronics Engineering, Seoul National University, Seoul, Rep. of Korea, in 1986, 1988, and 1995, respectively. In 1995, he joined the Department of Electrical Engineering, Kookmin University, Seoul, Rep. of Korea, in 1995, where he is now a professor. He is a trustee of the Korean Society of Broadcasting Engineers. His research areas include video coding and multimedia signal processing.

Kyeong-Hoon Jung received the BS, MS, and PhD from the Department of Electronics Engineering, Seoul National University, Seoul, Rep. of Korea, in 1987, 1989, and 1996, respectively. After working at the Korea Broadcasting Institute from 1991 to 1997, he joined Handong University as a faculty member in the School of Computer Science and Electronics Engineering. In 2005, he transferred to Kookmin University, where he is now a professor in the School of Electrical Engineering. His research focuses on broadcasting systems, video coding, and multimedia signal processing.