Synchronous 2D/3D Switching System for Service-Compatible 3DTV Broadcasting

Sangjin Kim and Taehyun Jeon

This paper proposes a new broadcasting system for the service-compatible 3DTV in which the 3D service can coexist with the conventional digital TV broadcast. In the proposed system, the commercial 3DTV service can be implemented via the existing DTV channel without utilizing the dedicated 3DTV system. This 2D/3D system interworks with the conventional system and can switch to 2D or 3D service according to the broadcast programming and schedule. The system also provides a mechanism that can prevent the synchronization mismatch between left and right video streams and between the stream and the associated signaling in the 2D/3D transition periods. The picture quality measurements are carried out based on the ITU-R recommended test to check the level of quality of service provided by the proposed scheme. The conformity tests are also performed with the conventional channel and the receiver for the DTV system to confirm the feasibility of the proposed one for the commercial service.

Keywords: 3DTV, service-compatible, 3D multiplexer, 2D/3D switch, video quality.

Manuscript received Aug. 30, 2013; revised Nov. 25, 2013; accepted Dec. 3 2013.

Sangjin Kim (phone: +82 10 3150 6229, ksjsbs@seoultech.ac.kr) is with SBS, Seoul and with the Graduate School of NID Fusion Technology, Seoul National University of Science and Technology, Seoul, Rep. of Korea.

Taehyun Jeon (corresponding author, thjeon@seoultech.ac.kr) is with the Department of Electrical and Information Engineering, Seoul National University of Science and Technology, Seoul, Rep. of Korea.

I. Introduction

The service-compatible 3DTV broadcast is a method in which the left and right video data are encoded and transmitted independently to provide the 3DTV broadcasting service while maintaining the compatibility to the conventional DTV. The conventional DTV video stream with a data rate of 17.5 Mbps is transformed with a high-efficiency MPEG-2 encoder into a 12-Mbps stream and assigned to the left image for the service-compatible 3DTV system. An additional 6-Mbps data stream is assigned to the right image through the H.264 codec. With this assignment, the legacy receiver provides the DTV service via the base 12 Mbps video stream while the 3DTV service can be provided through the additional right image as well as the left base image [1], [2]. This service is expected to be a spectral efficient broadcasting scheme especially when the new channels for the 3DTV are not available in the current dedicated frequency band for the terrestrial digital television. Due to the restriction of additional channel assignments, it is more reasonable for the legacy and the new 3DTV service to share the same band in the frequency domain. Under this arrangement the 3DTV service should be available only in the pre-scheduled time period without confliction between the existing and the newly introduced services [3], [4].

Some of the essential systems should be developed for the successful deployment of the service-compatible 3DTV scheme. There have been various research and development activities to solve the problems of the signaling for the left and right images, the signaling for the 2D and 3D broadcast, and the remultiplexer for the synchronization of the left and right images [2]. Other related efforts made in the field include the test broadcasting service, the conformity test to the conventional DTV receiver, and the picture quality evaluation for the newly introduced 3DTV service [3], [4]. Along with the related R&D activities to expedite the commercialization of this scheme, the standard of transmission and reception for the service-compatible 3DTV was developed first in the Republic of Korea in 2011 [5]. The ATSC (Advanced Television System Committee) also accommodated this service as one of the 3DTV standards in 2012, which made the service globally available [6].

In 2011, the pilot test for the service-compatible 3DTV was performed in the Republic of Korea via the experimental terrestrial broadcasting channel. In 2012, the demonstration service was provided through the commercial broadcast channel during the off-air period also in the Republic of Korea. Those services, however, could be broadcast only through the experimental frequency band or during the time when the regular 2D service was not provided. This broadcasting service system was not designed to take care of the potential problems that might occur in the transition period when the 2D or 3D services are being switched to the other service. In other words, it does not provide the flexibility to operate the system in either 2D mode or 3D mode depending on the scheduled program but only serves as a dedicated 3D transmission system.

One of the essential function blocks for the service-compatible 3DTV broadcasting system is the 3D remultiplexer. The purpose of this block is to synchronize the MPEG-2 encoder output stream for the left image and the H.264 encoder output for the right image. Although there has been an effort for the development of the 3D remultiplexer, more research is required for the deployment of the system to coexist with the conventional DTV service in the real broadcasting environments [7]. The additional developments of the transmission system architecture need to be further pursued to prevent the abnormal stages in the transition period for both 2DTV and 3DTV receivers.

In this paper, a new transmission system architecture is proposed for the service-compatible 3DTV in which the 3D content is delivered without interrupting the existing DTV broadcast. Detailed operations of the core blocks are also discussed, which include the 2D/3D service change controller and the 2D/3D program and system information protocol (PSIP) encoder [8].

In the feasibility test, the picture qualities of the two video streams (the conventional 17.5-Mbps DTV video stream generated by the conventional encoder and the 12.5-Mbps DTV video stream generated by the high efficiency encoder) in the service-compatible 3DTV broadcast are compared based on the ITU-R recommendation. The proposed system is also applied to the commercial DTV receiver for the conformity test. With the thorough laboratory tests completed, the 3DTV service based on the proposed system architecture is successfully transmitted via the commercial broadcast channel. The 3DTV content utilized in this test is from the London Olympics in 2012. This successful transmission confirms that when the proposed system interworks with the existing DTV infrastructure, it satisfies the compliance requirements for commercial use.

With this proposed system, the potential problems of synchronization between the left image and the right image and the discrepancy between the video and the corresponding signaling are expected to be prevented. In the next section, the conventional service-compatible 3DTV broadcasting system is discussed. The discussion of the proposed system architecture for the 2D/3D service follows in section III. Experiment results regarding the picture quality, the receiver conformity, and the transmission test for the proposed system are discussed in section IV. Section V provides the concluding remarks.

II. System Model for Service-Compatible 3DTV Broadcasting

The service-compatible 3DTV scheme adopts the MPEG-2 system (ISO/IEC 13818-1) as a means of multiplexing to maintain the backward compatibility to the existing DTV broadcast [9]. The base video stream keeps the conventional MPEG-2 video codec while the additional stream is generated by the H.264 video codec [10], [11]. To increase the level of system integrity, the system must operate in a unified system architecture wherein the MPEG-2 encoder and H.264 encoder are synchronized by a single control signal. One of the methods to realize the service-compatible 3D service is to utilize the 3D remuliplexier in which the video streams from two independent codecs are synchronized. This scheme can provide the equivalent operation without a unified system architecture while providing a feasible solution at the evolving stage of the 3DTV services. The 3D remultiplexer takes a measurement of the processing time delay between two codecs. Based on the measured delay, either the base or the additional video stream is adjusted to the other such that two streams share the same presentation time stamp (PTS) value [7].

In general, the commercially available multichannel video encoder does not provide the time-based synchronization between MPEG-2 and H.264 codecs. The processing delay, however, is maintained in a constant level once the systems start the operations. Inside the 3D remultiplexer, the elementary streams for the left and right images are obtained by the transport stream (TS) de-multiplexer. The elementary stream for the left image is passed into the buffer, which controls the delay difference caused by the codecs. After the delay compensation is done, each elementary stream is synchronized with the same updated PTS. Also, inside the 3D remultiplexer, two stereoscopic descriptors for the 3DTV broadcast service are located in the program map table (PMT) for the program specific information (PSI) [6].

The 3D remultiplexer, however, might not be enough for the service-compatible 3DTV transmission, in which case the system requires the alternating services between 2DTV and 3DTV following the program schedules. This cannot prevent the mismatches in synchronization between the left image and right image and the discrepancy between the stream and the associated signaling in the transient period of the service switching from 2D to 3D and vice versa. Since the 3D service should be transmitted for the specified period of time, there should be a stepwise control depending on the program schedule information. To realize the selective transmission of the desired service, it is essential to adopt a controller for the 2D/3D service change. The purpose of this system is to control the multichannel video encoder, the 2D/3D PSIP encoder, the video router, and the remultiplexer, whose definitions and operation details are discussed in later sections. This requires the automatic switch controller for the 2D/3D service without which the broadcast operator manually sets up the relatively complex configurations of the involved systems. This prohibits the practical management of the real broadcast system.

An alternative system is to build a parallel architecture wherein the 2D stream and 3D stream go through the independent chain and one of the streams is selected at the ending point of the system. To realize such a system architecture, a TS level switcher is required, which enables the seamless switching of the video stream and audio stream (Fig. 1) [12].

However, the currently available TS switcher can only handle the TS packet-based switching. Because of this reason,

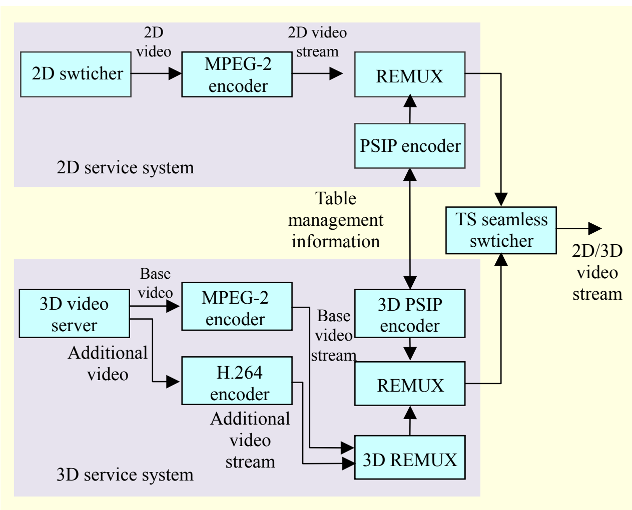

Fig. 1. Block diagram for 2D/3D service-compatible broadcast system.

the continuity of the stream and the characteristic of the group of pictures are destroyed during the switching period. This problem results in abnormal video and audio for the viewer due to the decoding failure on the receiver side.

In this paper, a new system architecture is proposed, in which the 2D/3D switching is implemented at the baseband stage rather than at the transport stream. The proposed system is expected to provide a feasible solution for the service-compatible 3D broadcast with the currently available technologies. The following section discusses more details on how each functional block is controlled in the proposed system architecture.

III. Proposed System Architecture for the 2D/3D Sevice

The block diagram for the proposed system is shown in Fig. 2, in which the service-compatible 3DTV broadcast blocks interwork with the conventional 2D systems. The shaded blocks represent the modified or added subsystems for the realization of the 3DTV service. As shown in the figure, the 2D/3D service change controller takes the 2D/3D program schedule information from the automatic program controller (APC) and determines the service type of the broadcast. Based on this information, the 2D/3D service change controller performs the switching operation by controlling the 2D/3D video router, the 2D/3D PSIP encoder, the remultiplexer, and the multichannel video encoder. One of the main goals in this service switching procedure is to eliminate the potential discrepancy between the video/audio stream and the signaling generated by the PSIP encoder.

The 2D/3D PSIP encoder generates the service information for the 3DTV as well as the conventional DTV broadcast. This information includes the additional virtual channel and the related electronic program guide (EPG) for the 3DTV service. This PSIP encoder also automatically removes the allocated virtual channel once the 3DTV service is completed. The 2D/3D service change controller issues the command that determines the type of provided TV service. The 2D/3D video router selects the appropriate video stream and audio stream for the 2D/3D broadcast service. In the case of the 2D broadcast, the streams from the 2D switcher are transmitted, while the video stream and audio stream from the 3D video server are transmitted for the 3D service. The 3D video server carries out the synchronization procedure between the left and the right images, which compose the 3DTV video stream. The new features added in the proposed system include the automatic and manual program transmission in accordance with the broadcast schedule. It is expected that the system architecture evolves to have the 3D master switcher connected with

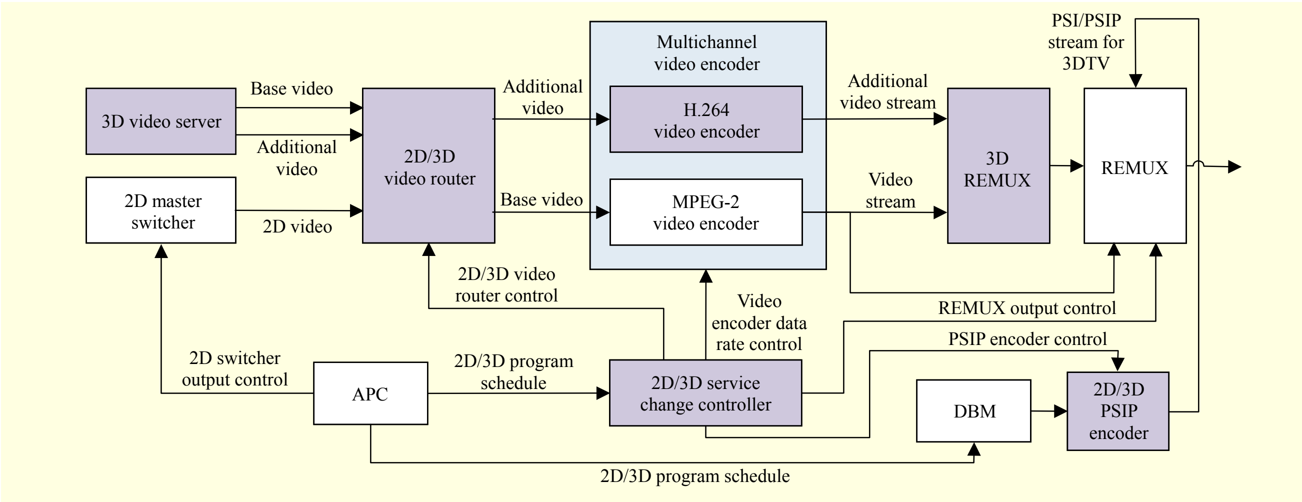

Fig. 2. Block diagram for proposed service-compatible 3DTV transmission system.

multiples of 3D video server outputs. This architecture is likely to be more suitable for the situation when the 3DTV service occupies more time slots as the demand for 3D content grows in the future.

In the conventional system architecture, the operator adjusts the delays between the left and the right image to obtain the optimum synchronization [7]. In the proposed system, the 3DTV remultiplexer replaces this procedure with the automatic detection of the image synchronization utilizing the advanced image processing. This could help reduce the management burden incurred during the service switch between 2DTV and 3DTV.

In the following sections, some of the core blocks of the proposed system are discussed in detail, including the 2D/3D service change controller and the 2D/3D PSIP encoder.

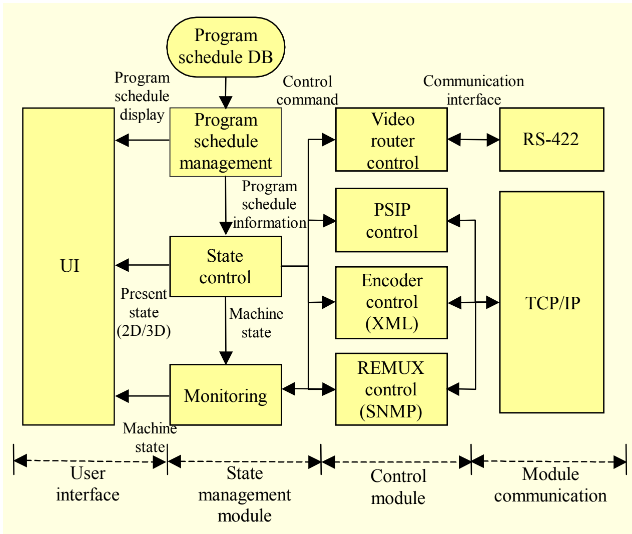

Fig. 3. Internal structure of 2D/3D service change controller.

1. 2D/3D Service Change Controller

The block labeled “2D/3D service change controller” figures out the current broadcast status based on the 2D/3D program schedule and controls the related function blocks accordingly. This block controls four subsystems, which include the 2D/3D PSIP encoder, 2D/3D video router, multichannel video encoder, and the remultiplexer. The internal architecture is summarized in Fig. 3.

The state management module carries out the functions of program schedule management, state control, and monitoring. The control module checks the state of each subsystem through the communication module and applies the necessary control. The user is also able to monitor the program schedule via the user interface (UI), check the status of the associated blocks, and take measures if necessary.

The program schedule management block inside the state management module periodically (1-second interval) reads the updated schedule from the program schedule database and maintains the latest schedule information internally. Once the program schedule is updated, this information is displayed in the UI and transferred to the state control module at the same time. The state control module determines whether the currently on air program is the 2D service or 3D service based on the schedule information from the program schedule management module. Based on the current states of the related blocks collected from the monitoring module, the consecutive orders are issued to change the state of the associated blocks. At this time, careful sequential control orders are made to prevent the abnormal state of the broadcasting. In other words, the control order for the next target block is issued after confirming the successful state change of the current block by observing

http://dx.doi.org/10.4218/etrij.14.2113.0035

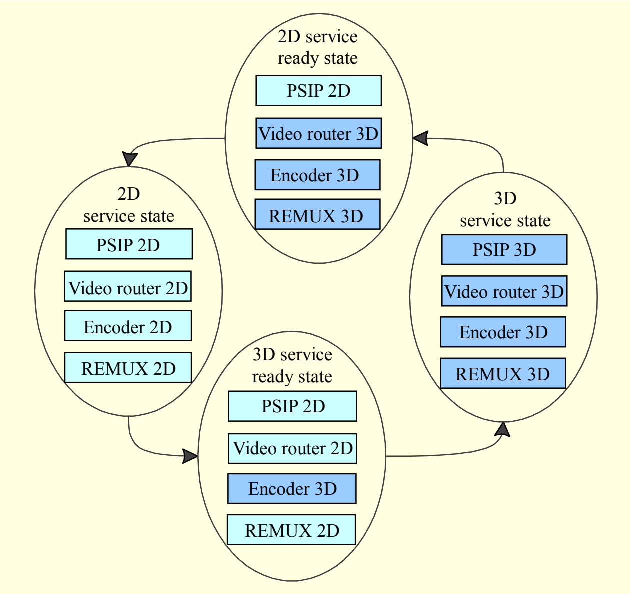

Fig. 4. Configurations of associated blocks for different broadcasting states.

through the monitoring module. The monitoring module figures out the state of the subsystems through the thread that is independent of the state control action.

There exist four states of the broadcast service, as shown in Fig. 4. Also shown are the configurations of associated subsystems for each broadcast state. The 2D service state shown in Fig. 4 represents the period when the 2D program is on air. In this period of time, all subsystems are configured for the 2D broadcast state. The 3D service-ready state shown in the same figure is activated 10 seconds before the 3D program starts. In this state, the encoder is configured for the 3D broadcast in which the encoder output is ready for the dual video streams. At this stage, the broadcasting stream is still a single stream since the video encoder input is the 2D content and the remultiplexer is operating in the 2D state. One of the reasons that the encoder is changed into the 3D service-ready state is to carry out the video synchronization process based on the dual stream input. The 3D remultiplexer located between the encoder and the remultiplexer (Fig. 2) should complete this synchronization procedure before the 3D broadcasting service. This procedure can provide the solution for the mismatch between the left and the right images, which is one of the important elements for the 3DTV broadcast.

At this stage, the left image signal, which is transmitted through the MPEG-2 encoder, is changed into the 12-Mbps video stream before the 3DTV service begins. The other reason for the early change of the encoder mode is to transmit the dual stream for the 3DTV before the PSIP is set for the associated service. This makes the clear definition for the sequential steps for the PSIP signaling and the real transmitted streams. With this manner, the potential abnormal functions at the receiver can be prevented by securing the 3DTV streams at the first step and the related signaling next. Without this protocol, the viewers might choose the 3DTV channel even when the 3DTV signal is not ready during the 2D/3D service transition period.

The 3D service state shown in Fig. 4 represents the stage at which the 3D program is on air and the related subsystems are maintained in the 3D state. The 2D service-ready state is entered into about five seconds before the 2D program starts. In this state only, the PSIP is first changed into 2D mode. The purpose of this change procedure is to prevent the viewers from choosing the 3DTV channel when only the 2D stream is available. This can be achieved by closing the 3D PSIP-related signaling before the 2D program starts.

The state transition flow can be summarized as follows. During the 2D service state, the 2D program is on air and the 3D service-ready state is initiated 10 seconds before the 3D program begins. Once the 3D program starts, the 3D service state is activated. After the 3D broadcast has ended, the state is changed into the 2D service-ready state five seconds before the 2D program begins. Following the start of the 2D program, the transition flows into the 2D service state.

In the normal mode, the 2D/3D service change controller interworks with the program schedule, and the state transition is triggered with an automatic procedure (Fig. 2). The proposed system includes a manual mode in which the operator can set the desired state to accommodate special cases.

The control module shown in Fig. 3 performs the operation that controls four subsystems connected to the 2D/3D service change controller (Fig. 2). The video router control unit drives the 2D/3D video router to select the video stream fed to the encoder input. The encoder input is either the 2D video input or 3D video input depending on the current broadcast state. This control part is implemented with the RS-422 serial communication protocol.

The PSIP control module (Fig. 3) drives the 2D/3D PSIP encoder shown in Fig. 2 through the TCP/IP protocol. The descriptor for 3D video transmission is added to the associated table in the PSIP.

The bit rate of the multichannel video encoder is changed through the encoder control module when the state is switched from the 2D service state to the 3D service-ready state, as shown in Fig. 4. To change the bit rate, the profiles for both 2D and 3D are predefined to control the output of the MPEG stream. The resulting bit rate is adjusted according to the associated profile. In this profile change procedure from 2D to 3D, the bit rate of the left channel is first decreased to 12 Mpbs and the right channel is then enabled with 6 Mbps. This can prevent the total bit rate of the video stream from exceeding the allowable bandwidth, which is about 19.39 Mbps. To realize

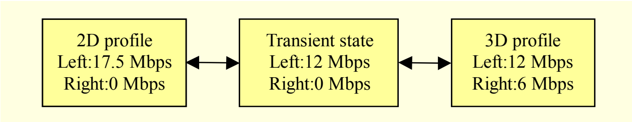

Fig. 5. Block diagram of profile change for control of multichannel encoder.

this step-by-step procedure, the additional transient state is required internally, as shown in Fig. 5. This mandates that the switching procedure between 3D and 2D always experiences the transient state. With this additional state, the bit rate of the multichannel video encoder output stream can be maintained in a stable manner.

The remultiplexer control unit drives the remultiplexer to filter out the right channel in the dual stream at the output of the 3D remultiplexer. In the proposed system architecture, path 1 is set to the single stream in which the right channel is already filtered out, while path 2 is set to the dual streams. Path 1 is selected when 2D service is on and path 2 is for 3D service. The remultiplexer is controlled by the TCP/IP communication with the Simple Network Management Protocol.

2. 2D/3D PSIP Encoder

The internal structure of the 2D/3D PSIP encoder is summarized in Fig. 6. In the 2D/3D PSIP encoder the PSI/PSIP table generation function is additionally developed and included in the legacy PSIP encoder, which serves for the 2DTV broadcast. The service controller (SC) listener forwards the 2D/3D service change request from the 2D/3D service change controller to the program service information data (PSID) collector. The PSIP collector gathers the program and service information for the 2D/3D broadcast and forwards them to the UI and PSIP encoder. The UI unit displays the service status according to the current service information. The

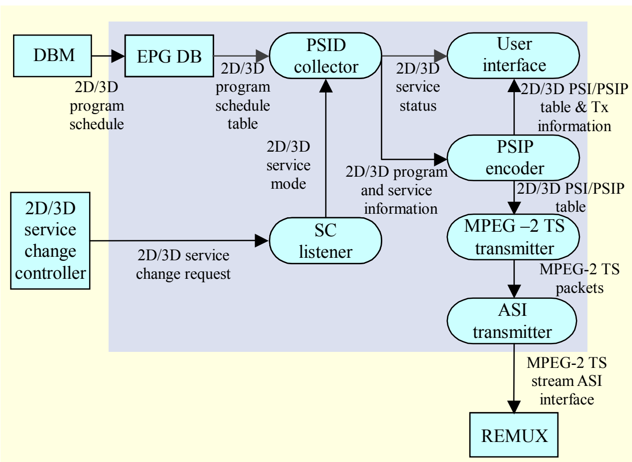

Fig. 6. Internal block diagram for 2D/3D PSIP encoder.

PSIP encoder generates and transports the PSI/PSIP table following the current service and program information. In the case of 3DTV service, the PSIP encoder creates the PMT for both 2D and 3D broadcasting service. At the same time, additional information for two virtual channels is included in the TVCT (Terrestrial Virtual Channel Table). Once the 3DTV program schedule is registered in the EPG database via a database manager, the PSID collector delivers the 3DTV schedule to the PSIP encoder. The PSIP encoder creates and transports the event information table for the 3DTV channel.

IV. Experiment Results

1. Picture Quality Test

In the service-compatible 3DTV broadcasting environment, the viewers of the conventional DTV are supposed to watch only the base left image, which is encoded with high efficiency encoded 12-Mbps video stream. The high efficiency encoder has a relatively longer processing delay characteristic since it adopts a more complex compression algorithm. This sophisticated algorithm is unavoidable to provide the compatible video quality with less bit numbers per unit time. On the other hand, from the conventional DTV customer's point of view, it is very important to confirm the effect of the decrease of the bit rate on the quality of service. Since it is expected that the majority of the viewer relies on the conventional DTV receivers especially at the early stage of the 3D service, the quality difference should be verified between the conventional 17.5-Mbps video stream and the newly introduced 12-Mbps video stream. For this test, we select six video samples to represent different types of content, so as to encompass the wide range of video characteristics in terms of complexity and motion. The edited video samples for the quality test come from the areas of sports, drama, and entertainment. In this test, we utilize the picture quality measurement system whose evaluation process is highly correlated with the ITU-R standardized Double Stimulus Continuous Quality Scale (DSCQS) method [13]. The numerical DSCQS value represents the extent to which the video under test has degenerated from the original form. The comparisons are performed between the 17.5-Mbps stream and the original data. The same tests are done between the 12-Mpbs stream and the original data. The highest value indicates the worst picture quality. The ITU-R recommended DSCQS method subdivides the entire range of the DSCQS values into three categories: high quality field (0 to 18), medium quality field (18 to 36), and poor quality field (36 and higher). The final evaluation is done based on the relative occurrence ratio of each of the three quality categories [14].

http://dx.doi.org/10.4218/etrij.14.2113.0035

Table 1. DSCQS test results for 17.5-Mbps encoded content and 12-Mbps encoded content.

		Average	0 - 18 (%)	18 - 36 (%)	36 - 100 (%)
Drama	17.5 Mbps	3.71	99.93	0.06	0.00
	12 Mbps	5.63	99.52	0.47	0.00
Soccer	17.5 Mbps	8.55	96.71	3.28	0.00
	12 Mbps	9.70	95.27	4.72	0.00
Basketball	17.5 Mbps	15.71	69.01	30.96	0.01
	12 Mbps	14.91	82.84	17.15	0.00
Baseball	17.5 Mbps	10.09	79.22	20.53	0.23
	12 Mbps	10.17	81.06	18.93	0.00
Talk show	17.5 Mbps	6.68	99.37	0.62	0.00
	12 Mbps	8.91	95.15	4.47	0.37
Pop music show	17.5 Mbps	13.47	84.72	15.23	0.04
	12 Mbps	14.6	77.95	22.03	0.00

The guideline of ITU-R states the conditions of the acceptable video stream for broadcast. According to the guideline, the high quality fields should occupy more than 75% of the total fields if there is no poor quality field observed. The test includes six edited samples: drama, soccer, basketball, baseball, talk show, and pop music show. The test results with the MPEG-2-encoded 17.5-Mbps video streams are summarized in Table 1. The same tests are performed for the high efficiency encoded 12-Mpbs streams, whose results are shown in the same table (shaded boxes) for the base video in the 3D service.

The column labeled "Average" indicates the mean DSCQS value, which is taken over all fields of the related encoded video data and the original video data. The results indicate that the 12-Mbps streams experience more degradation in quality than the corresponding 17.5-Mbps streams experience, except in the case of basketball. In the high quality category (labeled "0 - 18"), pop music show in the 12-Mpbs stream results in about a 7% degradation over that in the 17.5-Mbps stream, whereas basketball and baseball show superior performance, which is opposite from the results obtained with the other content. Particularly, the basketball content case shows about a 13% point increase over that in the 17.5-Mbps stream. From this result, it can be conjectured that the high efficiency encoder performs better when the video stream includes relatively fast-moving content. The overall test results represent satisfactory performance regarding the ITU-R guideline. Each video sample exceeds the minimum requirement of 75% in the high quality field (labeled "0 - 18"), including the worst case, which is 77.96% for pop music show. Likewise, the ratio of the category labeled "36 - 100" does not exceed the maximum of 0.4%. In conclusion, the evaluation reveals that the 12-Mbps encoded data under test represents acceptable video streams for the broadcasting service.

2. Conformity Test for Receiver

The 2D/3D or 3D/2D switching tests are performed for the proposed system and the 3DTV enabled receiver connected through the RF cable transmission in the broadcasting station. A picture of the proposed 3DTV broadcasting service system under test is shown in Fig. 7. In this conformity test channel, number 6-1 is given to the conventional service and number 6-3 is given to the 3D service. The functionality of the 2D/3D service change controller is checked for all four possible states to confirm the stable transition between the 2D service and the 3D service. The functions of the related subsystems are also checked, which include the 2D/3D PSIP encoder, 2D/3D video router, multichannel encoder, and remultiplexer. This test is applied for both the DTV receiver and the 3DTV receiver.

One of the main contributions to the stable broadcasting service, especially during the service switching period, is to secure the synchronization between the left and right images 10 seconds before the opening of the 3D service. This is implemented through the 3D remultiplexer at the 3D ready state. The potential timing mismatch between the PSIP signaling and the stream due to the change of the 2D/3D channel formation can be prevented by the proposed strategy of preparing the stream first and the signaling next. Through this method, the 3D channel (number 6-3) can be generated and closed in a stable manner.

The key configurations of the related systems for the

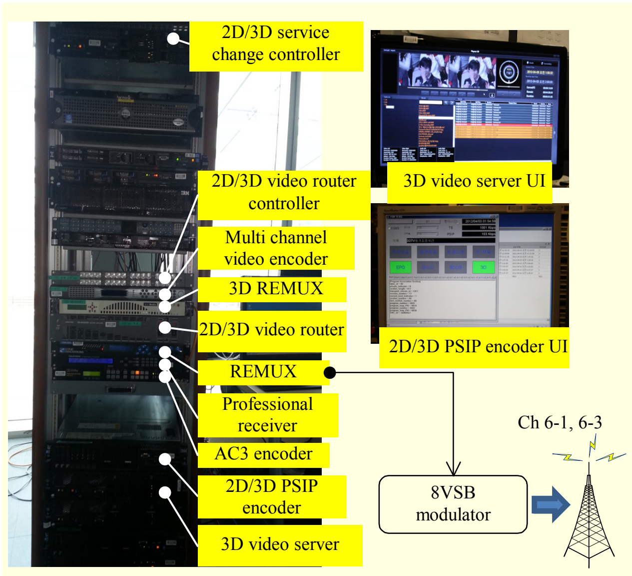

Fig. 7. Transmission system for service-compatible 3DTV.

Table 2. Configurations of transmission systems for state of 2D/3D service change controller.

Service state		2D	3D ready	3D	2D ready
Video encoder	MPEG-2	17.5 Mbps	12 Mbps	12 Mbps	12 Mbps
	H.264	N/A	6 Mbps	6 Mbps	6 Mbps
Channel	Ch 6-1	On	On	On	On
	Ch 6-3	N/A	N/A	On	N/A
Video router output	Additional video	Off	2D	3D_L	3D_L
	Base video	2D	2D	3D_R	3D_R
PSIP 3D descriptor		Off	Off	On	Off
REMUX		Path 1	Path 1	Path 2	Path 2

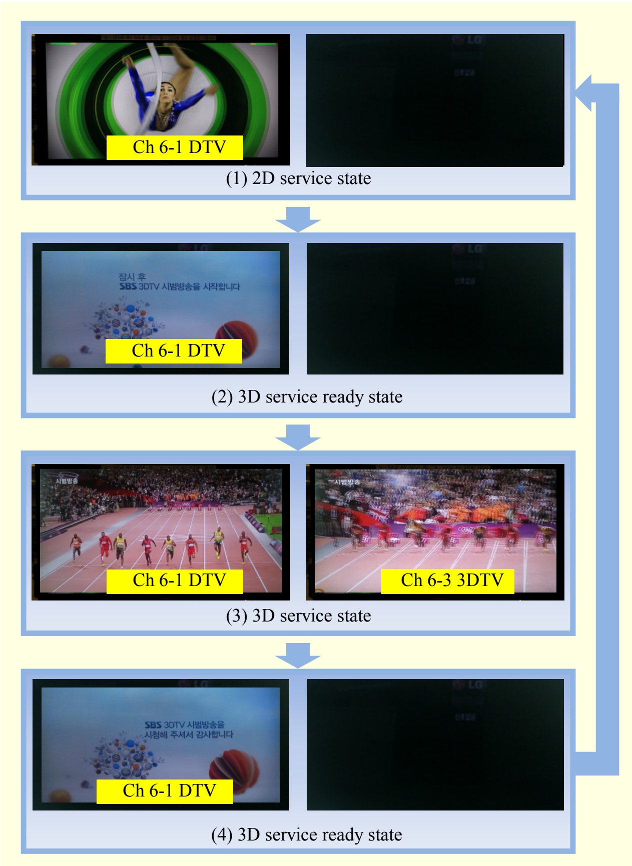

Fig. 8. Operation of 3DTV receiver according to 2D/3D service change controller.

transmission are summarized in Table 2 according to the state of the 2D/3D service change controller. For each of four states, it is clear that the appropriate controls are applied for the 2D/3D or 3D/2D service change. Some of the actual photographs of the 3DTV monitors are shown in Fig. 8 for each service state.

3. Commercial Broadcasting Transmission

The actual commercial 3D broadcasting transmission is carried out using the proposed 2D/3D service-compatible 3DTV system. The transmitted stream is based on the 3D content from the 2012 London Olympics, which was broadcast through the experimental 3D channel. In the process of the live broadcast, a portion of the original content experienced a synchronization mismatch between the left and right video images due to the long-distance delivery, the 24/30 frame conversion, and the synchronization problems of the ENG camera in the field.

The actual 3D content for the transmission is 30 hours long and post-edited to compensate for the synchronization mismatch problems. The EPG controlled by the 2D/3D PSIP is provided to the 3DTV viewers. Also, to promote the 3D channel for the viewers who are currently watching other channels or just turn on the TV, a periodic subtitle announcement is displayed to let the viewers know there is a 3D channel (for example, channel number 6-3) available for them. The transmission coverage includes the metropolitan area of Seoul in the Republic of Korea, where the viewers can access the service by the terrestrial DTV directly or by the retransmission through the analog cable TV.

V. Conclusion

Since 2012, receivers have been introduced that can support service-compatible 3DTV. Also, the content of major sporting events is produced in the 3D format. Along with these trends, the advancement of the 2D/3D conversion technologies enables the on-demand supply of the 3D content for the 3DTV service. In this paper, new system architecture was introduced to deploy the service-compatible 3DTV in the field, which can interwork with the DTV system. The proposed system can enable the smooth transition between two different services by eliminating the potential synchronization and signaling mismatch problems. The detailed functions of the related internal subsystems were also discussed. To confirm the feasibility of the proposed system, extensive tests both at the laboratory and in the field were carried out, which included a quantitative picture quality test, a conformity test, and, finally, a commercial broadcasting transmission.

References

[1] N. Hur et al., "An HDTV-Compatible 3DTV Broadcasting System," *ETRI J.*, vol. 26, no. 2, Apr. 2004, pp. 71-82.
[2] K. Yun et al., "Efficient Multiplexing Scheme of Stereoscopic Video Sequence for Digital Broadcasting Service," *ETRI J.*, vol.

32, no. 6, Dec. 2010, pp. 961-964.
[3] W. Baek, S. Lee, and J. Kim, "Korean Terrestrial 3DTV Broadcasting System: Current Status," *IEEE Int. Conf. Consum. Electron.*, Berlin, Germany, Sept. 6-8, 2011, pp. 889-891.
[4] N. Hur et al., "3DTV Broadcasting and Distribution Systems," *IEEE Trans. Broadcast.*, vol. 57, no. 2, June 2011, pp. 395-407.
[5] TTAK.KO-07.0100, "Standard of Transmission and Reception for Terrestrial 3DTV Broadcasting — Part I: Existing Channel," 2011.
[6] ATSC A/104, "ATSC 3D-TV Terrestrial Broadcasting," 2012.
[7] G. Lee et al., "Delivery System and Receiver for Service-Compatible 3DTV Broadcasting," *IEEE Int. Conf. Consum. Commun. Netw.*, Las Vegas, NV, USA, Jan. 11-14, 2013, pp. 805-808.
[8] ATSC A/65, "Program and System Information Protocol for Terrestrial Broadcast and Cable," 2013.
[9] ISO/IEC 13818-1, "Information Technology— Generic Coding of Moving Pictures and Associated Audio Information: Systems," 2007.
[10] ISO/IEC 13818-2, "Information Technology — Generic Coding of Moving Pictures and Associated Audio Information: Video," 2007.
[11] ISO/IEC 14496-10, "Information Technology — Coding of Audio-Visual Objects-Part 10: Advanced Video Coding," 2012.
[12] W. O'Grady, M. Balakrishnan, and H. Radha, "Real-Time Switching of MPEG-2 Bitstreams," *Int. Broadcast. Convention*, Amsterdam, the Netherlands, Sept. 12-16, 1997, pp. 166-170.
[13] ITU-R Rec. BT.500-13, "*Methodology for the Subjective Assessment of the Quality of Television Pictures*," 2012.
[14] ITU-R Rec. BT.1122-1, "*User Requirements for Emission and Secondary Distribution Systems for SDTV, HDTV and Hierarchical Coding Schemes*," 1995.

Sangjin Kim received his BS and MS degrees from Yonsei University, Seoul, Rep. of Korea, in 1989 and 1991, respectively, both in electrical engineering. He is currently pursuing his PhD degree in broadcasting and telecommunication engineering at Seoul National University of Science and Technology in Seoul, Rep. of Korea. He joined the SBS Institute of Technology in 1991 and is currently with the New Media Project Team at SBS. He has standardized and developed DTV, T-DMB, and 3DTV systems and specifications. His current research interests include the 3DTV broadcasting system, mobile broadcasting system, hybrid broadcasting service, and UHDTV broadcasting system. He was a recipient of the Broadcasting Engineering Excellence Award from the Asian Broadcasting Union in 2007.

Taehyun Jeon received his BS degree from Yonsei University, Seoul, Rep. of Korea, in 1989 and his MS and PhD degrees from the University of Minnesota, Minneapolis, MN, USA, in 1993 and 1997, respectively, all in electrical engineering. From 1991 to 1997, he was a research assistant with the University of Minnesota. Upon completion of his graduate studies, he joined Motorola, Inc., where he worked on the advanced read channel architecture development. From 1998 to 2001, he worked at Texas Instruments, Inc., San Jose, CA, USA, as a member of the technical staff. From 2002 to 2005, he worked as a senior member of the research staff at ETRI, Daejeon, Rep. of Korea, where he participated in the high capacity wireless local area network system development project. He is currently a faculty member of the Department of Electrical and Information Engineering at Seoul National University of Science and Technology in Seoul, Rep. of Korea. His current research interests include communication theory and signal processing for high capacity wireless and wireline data transmission systems.