Oh et al. EURASIP Journal on Wireless Communications and Networking (2015) 2015:128
DOI 10.1186/s13638-015-0362-x

EURASIP Journal on Wireless Communications and Networking
a SpringerOpen Journal

RESEARCH Open Access

A study of development of transmission systems for next-generation terrestrial 4 K UHD and HD convergence broadcasting

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Abstract

The worldwide transition from analog to digital broadcasting has now been completed, and the need to study next-generation standards for ultra-high-definition TV (UHDTV) broadcasting, as well as broadcasting and communication convergence systems is rapidly growing. In particular, high-resolution mobile broadcasting services are needed to satisfy recent consumer demands. Therefore, the development of highly efficient convergence broadcasting systems that provide fixed/mobile broadcasting through a single channel is needed. In this paper, a service scenario and the requirements for providing 4 K UHD and high-definition (HD) convergence broadcasting services through a terrestrial single channel are analyzed by employing the latest transmission and video codec technologies. Optimized transmission parameters for 6- and 8-MHz terrestrial bandwidths are drawn, and receiving performances are measured under additive white Gaussian noise (AWGN) and time-varying typical urban (TU)-6 channel to find the threshold of visibility (TOV). From the results, reliable receiving of HD layer data can be achieved at a 6-MHz bandwidth when the maximum receiver velocity is 140 km/h and no higher due to the limit of bandwidth. When the bandwidth is extended to 8 MHz, reliable receiving of both 4 K UHD and HD layer data can be achieved under a very fast fading multipath channel.

Keywords: Digital convergence broadcasting; 4 K UHD broadcasting; Mobile HD broadcasting; Digital broadcasting transmission systems

1 Introduction

Worldwide transition from analog to digital broadcasting has now been completed, and the need to develop new standards for next-generation ultra-high-definition TV (UHDTV) broadcasting, as well as broadcasting and communication convergence systems in preparation for the post high-definition (HD) period is rapidly growing. In November 2011, the Future of Broadcast Television (FoBTV) Committee, consisting of 14 organizations including the Advanced Television Systems Committee (ATSC), Digital Video Broadcasting (DVB), European Broadcasting Union (EBU), Electronics and Telecommunications Research Institute (ETRI), etc., was established with a focus on the development of future broadcasting systems. In addition, the development of ATSC 3.0 systems in the USA, DVB 2.0 systems in Europe, and Integrated Services Digital Broadcasting (ISDB) and terrestrial mobile multimedia (Tmm) systems in Japan is currently in progress or has been completed. Therefore, for Korea, it is essential to develop original technologies and a new service model for next-generation convergence broadcasting systems.

In Korea, terrestrial fixed HD broadcasting services are provided by employing ATSC 8-vestigial side band (VSB) systems [1] through a 6-MHz bandwidth, while mobile digital multimedia broadcasting (DMB) services are provided using modified Eureak-147 systems [2,3] through a 1.536-MHz bandwidth with quarter video graphics array (QVGA) (320 × 240) resolution, as shown in Figure 1. However, low-resolution DMB systems do not satisfy consumer needs, and recent viewers prefer mobile broadcasting services based on mobile communication long-term evolution (LTE) systems. In addition, the transmission technologies in ATSC 8-VSB systems

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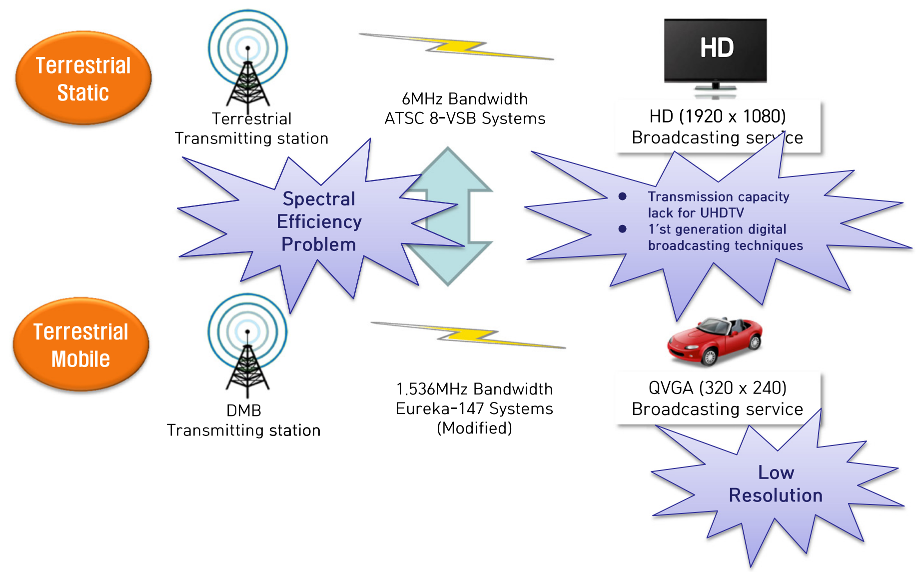

Figure 1 Terrestrial, static, and mobile digital broadcasting services, systems, and problems in Korea.

were developed in the 1990s. Consequently, the required data rate for UHDTV broadcasting services cannot be achieved through their use [4]. Furthermore, each bandwidth channel is allocated for mobile fixed and broadcasting services. Therefore, the development of convergence broadcasting systems that can provide both terrestrial fixed UHD and high-resolution mobile broadcasting services through a single channel is needed.

Meanwhile, a research and development project which aims to develop convergence broadcasting and monitoring systems that provide optimized and high-quality broadcasting services for both fixed and mobile receivers based on broadcasting and communication networks has began recently in Korea.

In this paper, the possibility of employing 4 K UHD and HD transmission through a terrestrial single channel was examined by employing the latest transmission and video codec technologies. To accomplish this, a multiple-physical layer pipe (M-PLP), transmission technologies in DVB-T2 systems [5] and scalable high-efficiency video coding (SHVC) technologies [6,7] were considered. A concept diagram of terrestrial 4 K UHD and HD broadcasting services was explained, and the required data rate was calculated by employing the SHVC method. The subsequent transmission system structure was shown, after which the optimized transmission parameters for 6- and 8-MHz bandwidths were proposed. The receiving performances under additive white Gaussian noise (AWGN) and typical urban (TU)-6 channels were then examined to find the threshold of visibility (TOV) using computer simulations.

2 DVB-T2 terrestrial digital broadcasting transmission systems and HEVC-SHVC A/V codec

2.1 DVB-T2 terrestrial broadcasting transmission systems

The DVB-2nd Generation Terrestrial (T2) system [5] is the European second generation terrestrial digital broadcasting transmission system. Standardization of this system was completed in 2009, and test broadcasting services employing DVB-T2 systems are currently in operation in Europe. DVB-T2 systems are based on the orthogonal frequency division multiplexing (OFDM) technique [8] and adopt the state-of-the-art channel coding technique such as low-density parity check (LDPC) and Bose Chaudhuri Hocquenghem (BCH) concatenated code, quadrature phase shift keying (QPSK) to 256 quadrature amplitude modulation (QAM) constellation, and various sizes of fast Fourier transform (FFT), guard interval (cyclic prefix, CP), and pilot patterns for maximizing data transmission capacity, as shown in Table 1. Various interleaving techniques, such as bit, cell, time and frequency interleaving, rotation constellation scheme, and cyclic Q-delay technique have been employed in DVB-T2 systems to combat the time-varying channel.

Table 1 DVB-T2 broadcasting systems and transmission modes

Channel coding	LDPC and BCH
Code rate	1/2, 3/5, 2/3, 3/4, 4/5, 5/6
Constellation	QPSK, 16 QAM, 64 QAM, 256 QAM
Guard interval	1/4, 19/256, 1/8, 19/128, 1/16, 1/32, 1/128
FFT size	1 K, 2 K, 4 K, 8 K, 16 K, 32 K
Pilot mode	PP1 to PP8

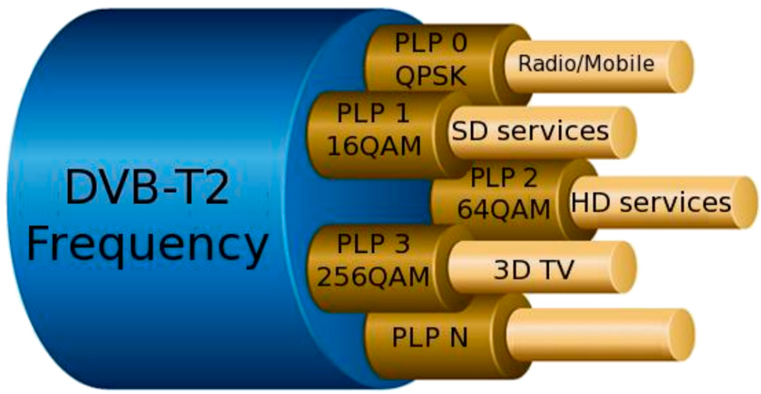

Figure 2 Concept of M-PLP technique [15].

In particular, the M-PLP multiplexing technique is employed in DVB-T2 systems to multiplex and transmit multiple layer broadcasting service signals. As shown in Figure 2, in this technique, different layers of PLP data are encoded and modulated according to each code rate and constellation point, and then multiplexed into a single frame for transmission. For example, PLP 1 data are encoded by the 3/4 code rate and modulated by 16 QAM to provide a standard-definition (SD) broadcasting service, while PLP 3 data are encoded by the 4/5 code rate and modulated by 256 QAM for the HD broadcasting service, as shown in Figure 2. M-PLP data are multiplexed into a single frame, as shown in Figure 3, and transmitted under the same channel conditions. Under the same channel conditions, the SD broadcasting data transmitted in the PLP1 layer are more robust against channel errors than the HD broadcasting data in PLP 3 due to the lower code rate and constellation point. Therefore, each receiver selectively acquires PLP layer data depending on the channel conditions. The FFT and CP sizes of OFDM symbols in a transmit frame do not change [5], and P1 and P2 OFDM symbols, shown in Figure 3, are used to carry additional system information.

2.2 High-efficiency video coding-scalable HEVC video compression technique

The high-efficiency video coding (HEVC) technique is a next-generation video compression technique, which aims to have a maximum compression ratio increase of 50% over H.264. HEVC is suitable for ultra-high-resolution and picture video content during UHDTV broadcasting times and employs various techniques such as wide resolution, increased bit depth, losses codec, and scalable coding [6]. Among these, scalable HEVC is designed to lower the implementation complexity so as to solve the high-complexity problem of the scalable coding technique in H.264 [7]. Final standardization and reference software for the HEVC codec (HM 16.3) and SHVC (SHM 8.0) was released at the end of February 2015 by the Joint Collaborative Team on Video Coding (JCT-VC).

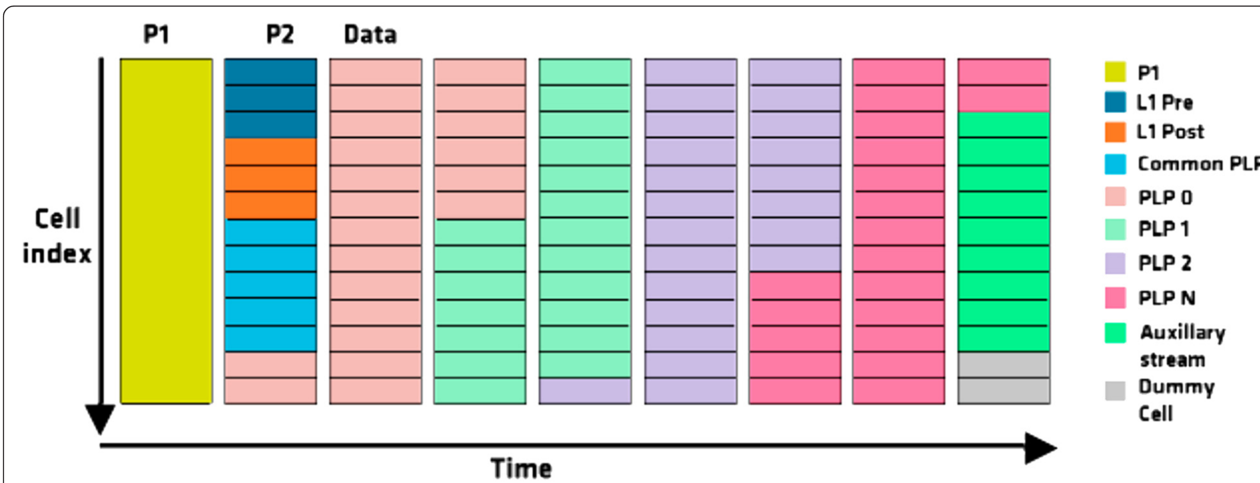

Figure 3 Diagram of multiplexing M-PLP data in a single transmission frame [15].

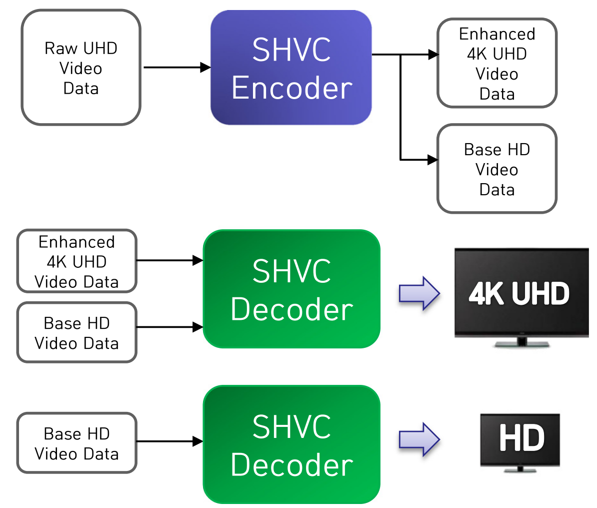

Figure 4 SHVC video compression technique.

A concept diagram of SHVC is shown in Figure 4. By employing SHVC, two types of compressed video data are acquired from the original raw video source: UHD-enhanced video data and HD base video data. Although HD video can be played by decoding the HD base video data, full UHD video can only be played by decoding both the UHD-enhanced video data and the HD base video data via SHVC.

As shown in Figure 5, when considering the worst-case scenario and real-time encoding, the compressed data rate when employing the state-of-the-art HEVC encoder is expected to be 25 Mbps for a single 4 K UHD video and 7 Mbps for a single HD video. With employment of SHVC, the maximum decrease in the rate of about 16.5% [7] and in the average data rate of about 15% is achieved for 4 K UHD-enhanced video data compared to the single 4 K UHD video data. Thus, the compressed data rate would be 21.25 Mbps for the 4 K UHD-enhanced video data, whereas the HD base video data rate remains the same (i.e., 7 Mbps).

3 Terrestrial 4 K UHD and HD digital convergence broadcasting transmission systems through a single channel

3.1 Service model of terrestrial 4 K UHD and HD convergence broadcasting through a single channel

Figure 6 shows a diagram of the terrestrial 4 K UHD and HD convergence broadcasting service through a single channel. SHVC technology was employed, for which a standard is currently in development. For single channel broadcasting, raw UHD video data are compressed using SHVC, and three types of data layers are acquired: 8 K UHD-enhanced, 4 K UHD-enhanced, and HD base video data. At terrestrial broadcasting stations, the 4 K UHD-enhanced and HD base video data are transmitted through a single channel using convergence broadcasting systems. The mobile viewers then selectively receive the HD base video data, while the fixed receivers get both 4 K UHD-enhanced and HD base video data for 4 K UHD broadcasting. If the fixed receivers are connected to a communication network, the 8 K UHD-enhanced data is received, after which the 4 K UHD-enhanced HD base video data from the broadcasting network and the 8 K

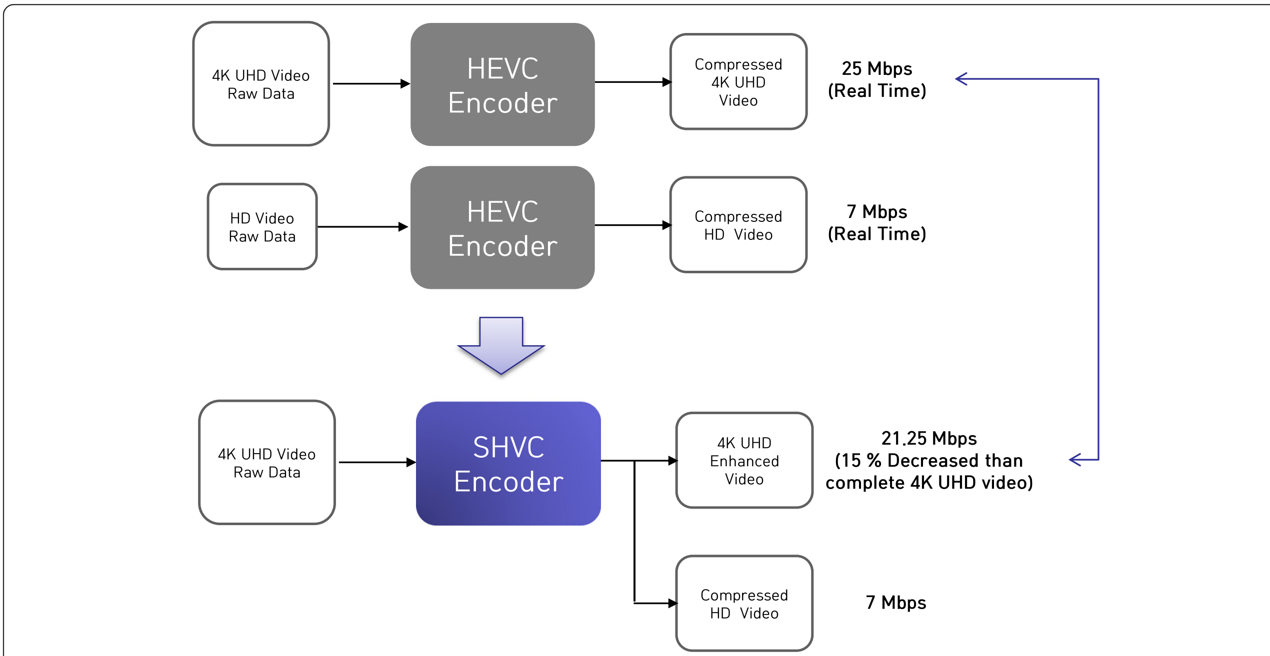

Figure 5 4 K UHD-enhanced and HD base video data capacity employing SHVC.

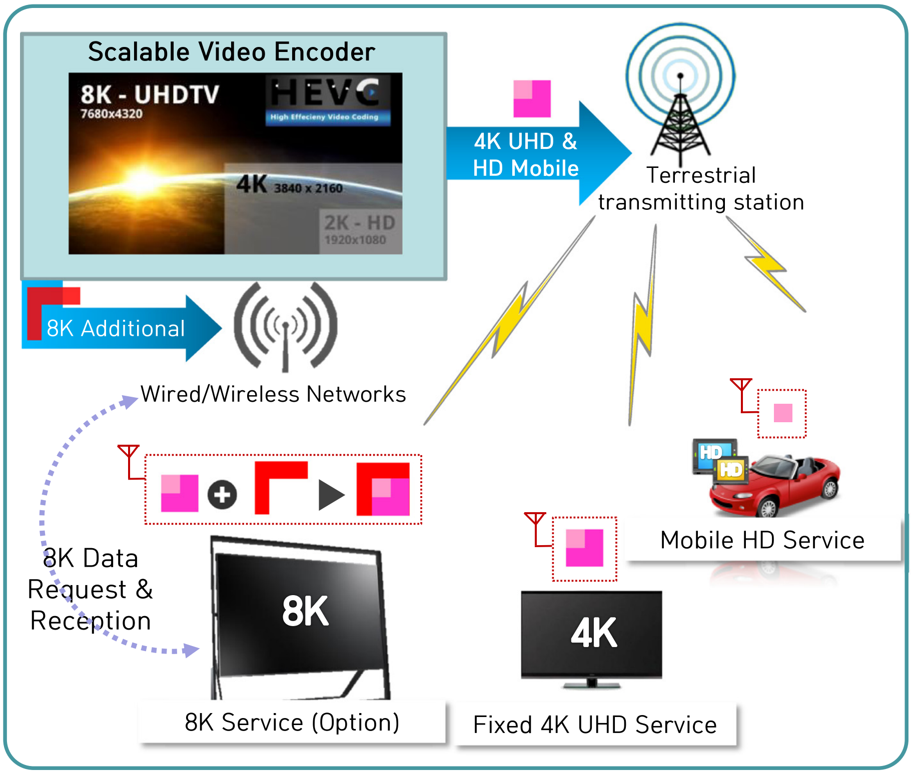

Figure 6 Concept diagram of terrestrial 4 K UHD and HD convergence broadcasting service through a single channel.

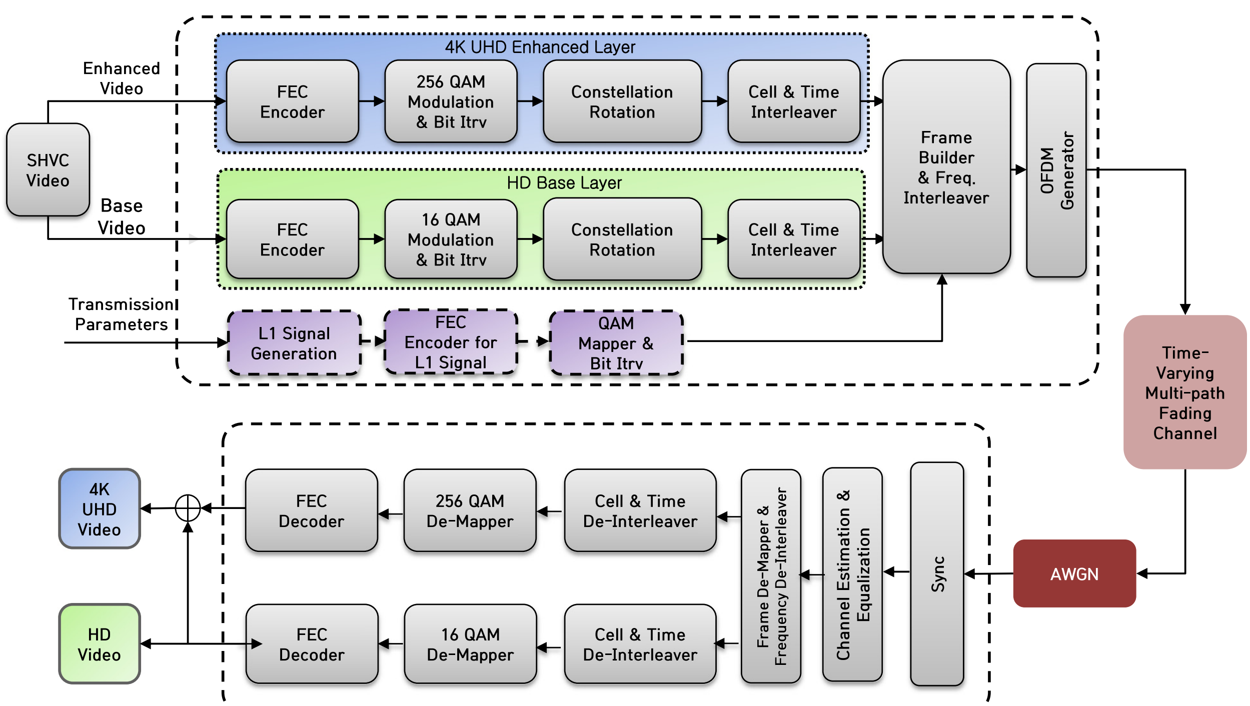

Figure 7 Structure of terrestrial 4 K UHD and HD convergence broadcasting transmission systems through a single channel.

UHD-enhanced data are combined to provide an 8 K UHD broadcasting service. Herein, we focused on 4 K and UHD convergence broadcasting systems for the transmission of 4 K UHD-enhanced and HD base video data through a terrestrial broadcasting channel.

To examine the possibility of using a terrestrial 4 K UHD and HD convergence broadcasting service, the transmission availability of the compressed 4 K UHD-enhanced and HD base data rate through a single terrestrial channel, which was analyzed in Section 2–2, needs to be examined. As in Section 2–2, the 4 K UHD-enhanced video data should be transmitted at the rate of 21.25 Mbps and the HD base video data should be transmitted at the rate of 7 Mbps in a single channel bandwidth to provide the convergence broadcasting service. If the performance of the real-time encoder is improved or non-real-time video data are used for transmission, the required data rate would be decreased.

3.2 The structure of terrestrial fixed 4 K UHD and mobile HD convergence broadcasting transmission systems through a single channel

Figure 7 shows the structure of terrestrial 4 K UHD and HD convergence broadcasting transmission systems. As shown in the figure, the latest transmission techniques, LDPC [9] and BCH channel codes [10,11], and the M-PLP method in DVB-T2 systems are employed. 4 K UHD-enhanced and HD base data are encoded, interleaved, and modulated by each PLP layer. After PLP layer processing, the two sets of PLP data and the additional system information data are multiplexed into a single transmission frame, as shown in Figure 8. The single transmission frame is composed of a P1 symbol, consisting of 2,048 sub-carriers, several P2 symbols, of which the size is dependent on the FFT size of the OFDM symbol, and data sub-carriers, which are used for transmission of data from the two PLP layers.

After the two PLP layers are multiplexed into a single transmission frame, frequency interleaving and OFDM symbol modulation are applied and then the signals are transmitted after OFDM modulation is transmitted through a single frequency channel. At the receiver side, synchronization and channel equalization are achieved over the OFDM symbol level from the received signal. After frequency de-interleaving, the received frame is de-multiplexed into two PLP layers, and decoding is achieved for each layer. The fixed receiver uses the data from both decoded layers for the 4 K UHD video play, while mobile viewers selectively use the decoded HD base video data for HD play.

Table 2 Requirements for drawing the optimized transmission parameters for a 6-MHz bandwidth

4 K UHD-enhanced layer portion in a frame	60%
HD base layer portion in a frame	40%
Maximum length of a frame	250 ms [5]
Elementary period T for a 6-MHz bandwidth	7/48 μs [5]

4 Optimized transmission parameters and computer simulation results

Based on the required data rate in Section 3, optimized transmission parameters for transmitting the PLP layer data through a 6-MHz bandwidth was drawn and the receiving performances of each parameter were analyzed using computer simulations under various channel conditions. The data rate of each PLP layer depends on the transmission mode (constellation point, code rate, FFT and CP size, pilot mode, the number of sub-carriers, the number of active sub-carriers, the portion of system information, etc.) [5]. Thus, the optimized parameters for a 6-MHz bandwidth to meet the requirements in Table 2 are shown in Table 3. Note that if extended transmission mode is available by FFT size [5], extended transmission mode is applied.

Every supported constellation point in the DVB-T2 systems was considered for the 4 K UHD and HD layer. However, it was found that the required data rate (Section 2–2) could be met when 256 QAM was used for the 4 K UHD layer data and 16 QAM for the HD layer data. In addition, the 16 K and 32 K FFT sizes were excluded when drawing the optimized parameters to consider HD layer data transmission in a mobile channel

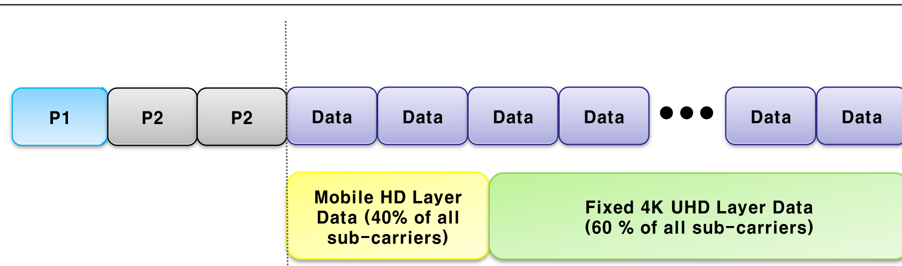

Figure 8 Transmission frame structure for terrestrial 4 K UHD and HD convergence broadcasting.

Table 3 Optimized transmission parameters for a 6-MHz bandwidth (4 K UHD layer: 256 QAM modulation, HD layer: 16 QAM modulation)

Number	Total data rate (bps)	4 K layer data rate (bps)	HD layer data rate (bps)	4 K layer code rate	HD layer code rate	FFT size	Guard interval	Pilot mode	Number of syms[a]	Frame length	Extended mode	Frame-closing symbol
1	28,439,336	21,329,502	7,109,834	4/5	4/5	8,192	1/128	PP7	200	243.51 ms	Yes	No
2	29,344,584	22,234,750	7,109,834	5/6	4/5	8,192	1/128	PP7	200	243.51 ms	Yes	No
3	28,949,373	21,712,029	7,237,343	5/6	5/6	8,192	1/32	PP7	200	249.16 ms	Yes	No

[a]Number of OFDM symbols in a frame.

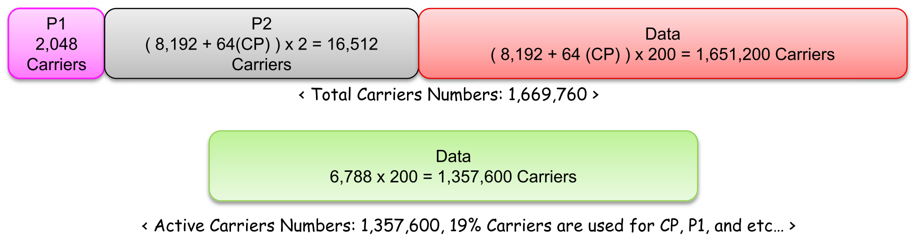

Figure 9 Number of total carriers and active carriers in a frame of transmission parameter no. 1.

environment. Due to the limit of a 6-MHz bandwidth, the minimum FFT size of the optimized parameters was restricted to 8,192 with a high code rate. In addition, the maximum guard interval size of the optimized parameters was restricted to 1/32. Thus, the degradation of receiving performances in time-varying channel environments can be estimated when employing optimized transmission parameters.

The number of total and active sub-carriers depends on the FFT and CP size, the number of OFDM symbols in a frame, and the pilot mode. Only active sub-carriers are used for real data transmission, while residual sub-carriers are used for pilot or system information transmission. Figure 9 shows the number of total and active sub-carriers when employing transmission parameter no. 1. A single transmission frame is composed of a P1 symbol, which consists of 2,048 sub-carriers, several P2 symbols, of which the size depends on the FFT size of the OFDM symbol, and data OFDM symbols. The P1 and P2 symbols are used for system synchronization and system information (FFT and CP size, the number of OFDM symbols in a frame) transmission. The number of sub-carriers for the P1 symbol, K_{P1}, is always 2,048, and the number of P2 symbols, N_{P2}, is 2 when the FFT size, K_{FFT}, is 8,192. In transmission parameter no. 1, the CP size was 1/128, the frame closing symbol was not used, and the number of OFDM data symbols per frame, N_{data}, was 200. Thus, the number of total sub-carriers per frame, K_{frame}, was calculated as in (1) and shown in Figure 9:

$$\begin{aligned} K_{\mathrm{frame}} &= K_{\mathrm{P1}} + (N_{\mathrm{P2}} + N_{\mathrm{data}})\left(K_{\mathrm{FFT}} + \frac{K_{\mathrm{FFT}}}{128}\right) \\ &= 2,048 + (2+200)\cdot\left(8,192 + \frac{8,192}{128}\right) \\ &= 1,669,760 \end{aligned} \quad (1)$$

Although all 8,192 sub-carriers in an OFDM symbol can be used for pure data transmission, sub-carriers of the edge band, referred to as virtual carriers [12], are reserved to prevent adjacent channel interference. In addition, sub-carriers are used for transmitting pilots, and extended transmission mode is applied. Thus, the number of active sub-carriers per OFDM symbol, C_{data}, is 6,788 [5], and the number of active sub-carriers per frame, C_{frame}, is written as follows:

$$C_{\mathrm{frame}} = C_{\mathrm{data}} \times N_{\mathrm{data}} = 6,788 \times 200 = 1,357,600. \quad (2)$$

Elementary period, T, for 6 MHz (which indicates the time interval of the transmission sample) is 7/48 μs, and the period of time of a frame, T_{F}, can be written as follows:

$$\begin{aligned} T_{\mathrm{F}} = K_{\mathrm{frame}} \times T &= 1,669,760 \times \left(\frac{7}{48}\,\mu\mathrm{s}\right) \\ &= 243.5067\,\mathrm{ms}. \end{aligned} \quad (3)$$

As in (3), 1,357,600 active sub-carriers are transmitted for 243.5067 ms, and the number of active sub-carriers for 1 s, $C_{\mathrm{frame/sec}}$, can be calculated as in (4):

Table 4 Computer simulations environmental conditions

Channel environment	Additive white Gaussian noise (AWGN), typical urban (TU)-6 channel
Channel estimation method using pilot symbol	Least-square method [16]
Channel interpolation method in frequency domain	Cubic-spline interpolation method [17] (the number of pilot symbols for interpolation: 12 symbols)
Channel interpolation method in time domain	Linear interpolation [18]
Center frequency	476 MHz (digital TV channel no. 14 in Korea)

Table 5 TU-6 channel profile

Tap number	Delay (μs)	Power (dB)	Fading model
1	0.0	−3.0	Rayleigh
2	0.2	0.0	Rayleigh
3	0.5	−2.0	Rayleigh
4	1.6	−6.0	Rayleigh
5	2.3	−8.0	Rayleigh
6	5.0	−10.0	Rayleigh

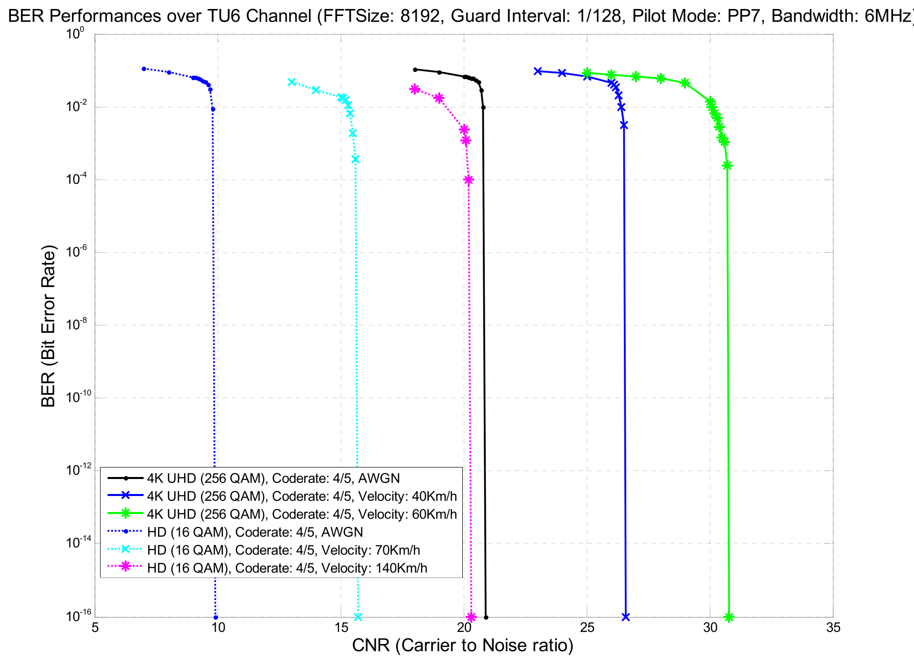

Figure 10 BER performances under TU-6 channel and AWGN (transmission parameter no. 1, 6 MHz bandwidth).

$$C_{\text{frame/sec}} = 1,357,600/(1,669,760 \cdot T) \cong 5,575,206. \quad (4)$$

Using (4), when the portion of the 4 K UHD layer in active sub-carriers is 60%, 256 QAM (8 bits per constellation point) is employed and the code rate is 4/5, for which the 4 K UHD layer data rate $R_{4\text{KUHD}}$ is calculated as:

$$R_{4\text{KUHD}} = C_{\text{frame/sec}} \times 8 \times 0.6 \times \frac{51,648}{64,800} \cong 21,329,502\,\text{bps}. \quad (5)$$

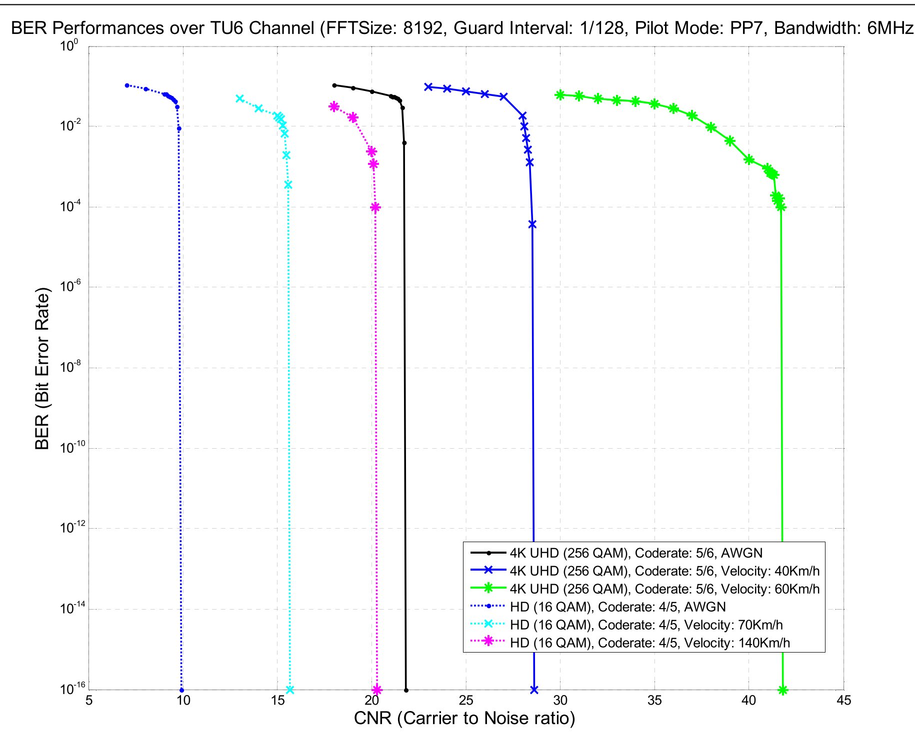

Figure 11 BER performances under TU-6 channel and AWGN (transmission parameter no. 2, 6 MHz bandwidth).

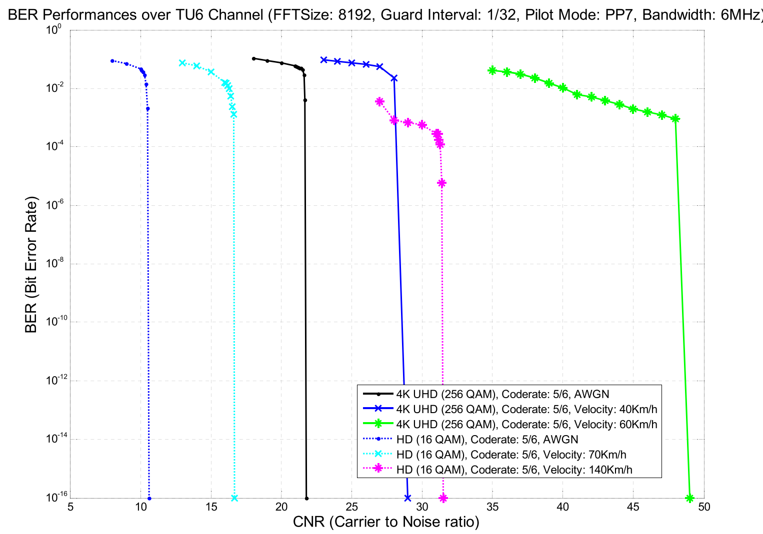

Figure 12 BER performances under TU-6 channel and AWGN (transmission parameter no. 3, 6 MHz bandwidth).

Moreover, when the portion of the HD layer in the active sub-carriers is 40%, 16 QAM (4 bits per constellation point) is employed and the code rate is 4/5, for which the HD layer data rate, R_{HD}, is calculated as:

$$R_{\mathrm{HD}} = C_{\mathrm{frame/\,sec}} \times 4 \times 0.4 \times \frac{51,648}{64,800} \cong 7,109,834\,\mathrm{bps} \quad (6)$$

Using the optimized transmission parameters, the receiving performances were analyzed using computer simulations under environmental conditions in Table 4. In Table 5, TU-6 channel profile which is employed for computer simulations is listed, and time-varying Rayleigh fading channel model is implemented by the method in [13]. Note that the decoding of the received system information and receiver synchronization was assumed to be ideal.

Figures 10, 11, and 12 show the bit error rate (BER) performance versus carrier-to-noise ratio (CNR) of transmission parameter nos. 1 to 3 in Table 3 for 6-MHz bandwidth in AWGN and TU-6 channels. The TOV performance of the optimized transmission parameters is presented in Table 6. The TOV data indicates both the receiving performances of less than 3×10^{-6} BER [14] and the limit of reliable broadcasting performance at the transmission system level. Generally, a return path does not exist in the broadcasting environment. Thus, only when the CNR is greater than the TOV can seamless broadcasting services be provided to viewers. For the TOV of optimized transmission parameter no. 2 in Table 6, reliable HD broadcasting can be achieved when the velocity of the receiver is 70 km/h and the CNR is greater than 15.6 dB.

The TOV of a 4 K UHD layer when the velocity of the receiver was 40 km/h was in the range of 26.6 to 28.6 dB, while the range of 30.8 to 40.8 was found when the velocity of the receiver was 60 km/h. Reliable receiving of the 4 K UHD layer data in mobile channels may not be achievable because the TOV's at every transmission parameter were above 26 dB. However, fixed receivers were assumed for the 4 K UHD layer transmission, as described in Section 3–1, and a TOV at 4 to 5 dB higher CNR than the AWGN may be required for a static channel situation of the fixed receivers. In the case of HD layer data transmission, BER performances under TU-6 are more important than for 4 K UHD layers. When the code

Table 6 Threshold of visibility (TOV) of optimized transmission parameters for a 6-MHz bandwidth

4 K UHD layer			
Parameter no.	**AWGN**	**TU-6 (40 km/h)**	**TU-6 (60 km/h)**
1	20.8 dB	26.6 dB	30.8 dB
2	21.8 dB	28.6 dB	41.8 dB
3	21.8 dB	28.6 dB	41.8 dB
HD layer			
Parameter no.	**AWGN**	**TU-6 (70 km/h)**	**TU-6 (140 km/h)**
1	9.9 dB	15.6 dB	20.3 dB
2	9.9 dB	15.6 dB	20.3 dB
3	10.6 dB	16.7 dB	31.5 dB

Table 7 Requirements for drawing the optimized transmission parameters for an 8-MHz bandwidth

4 K UHD-enhanced layer portion in a frame	60%
HD base layer portion in a frame	40%
Maximum length of a frame	250 ms [5]
Elementary period *T* for a 6-MHz bandwidth	7/48 μs [5]

Table 8 Optimized transmission parameters for an 8-MHz bandwidth (4 K UHD layer: 256 QAM modulation, HD layer: 16 QAM modulation)

Number	Total data rate (bps)	4 K layer data rate (bps)	HD layer data rate (bps)	4 K layer code rate (bps)	HD layer code rate	FFT size	Guard interval	Pilot mode	Number of syms[a]	Frame length	Extended mode	Frame-closing symbol
1	30,318,345	23,101,054	7,217,290	4/5	3/4	1,024	1/8	PP2	1,900	243.51 ms	No	Yes
2	30,251,372	23,039,165	7,197,955	4/5	3/4	2,048	1/8	PP2	950	243.51 ms	No	Yes
3	31,008,536	23,919,515	7,089,020	3/4	2/3	2,048	1/16	PP4	1,000	249.16 ms	No	Yes
4	30,508,286	23,245,780	7,262,506	4/5	3/4	4,096	1/8	PP2	475	241.64 ms	No	Yes
5	31,294,731	24,140,281	7,154,449	3/4	2/3	4,096	1/16	PP4	500	240.13 ms	No	Yes

[a]Number of OFDM symbols in a frame.

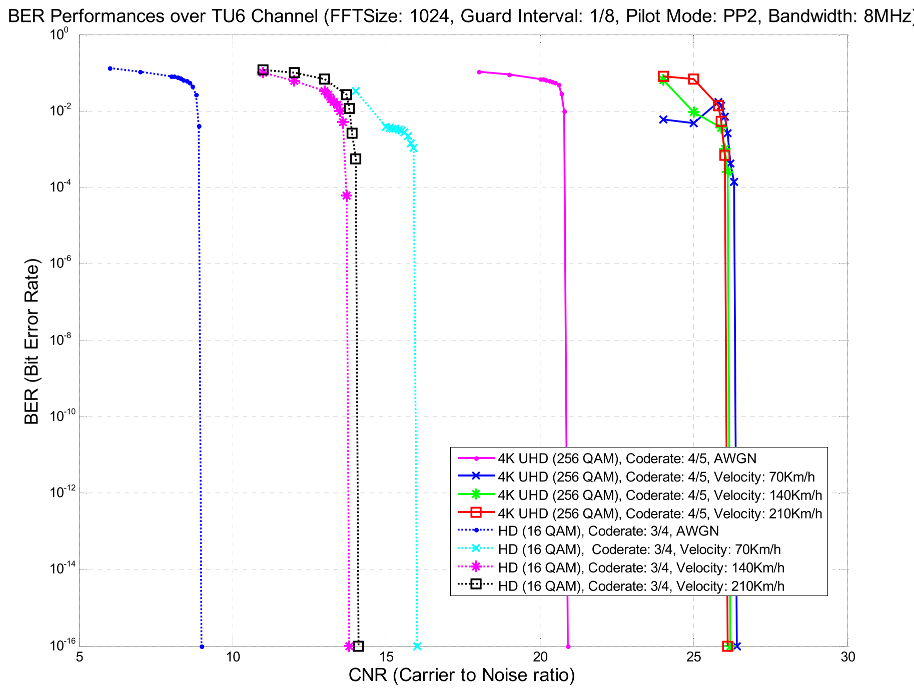

Figure 13 BER performances under TU-6 channel and AWGN (transmission parameter no. 1, 8 MHz bandwidth).

rate of 4/5 was used in transmission parameter nos. 1 and 2 of Table 3, the TOV of 15.6 dB (70 km/h of receiver velocity) and 20.3 dB (140 km/h of receiver velocity) was observed. Thus, reliable receiving can be achieved at a receiver velocity environment of under 140 km/h. For the no. 3 transmission parameter, the guard interval size was increased but the code rate was also increased, and the receiving performance was more degraded than in the case of parameter nos. 1 and 2.

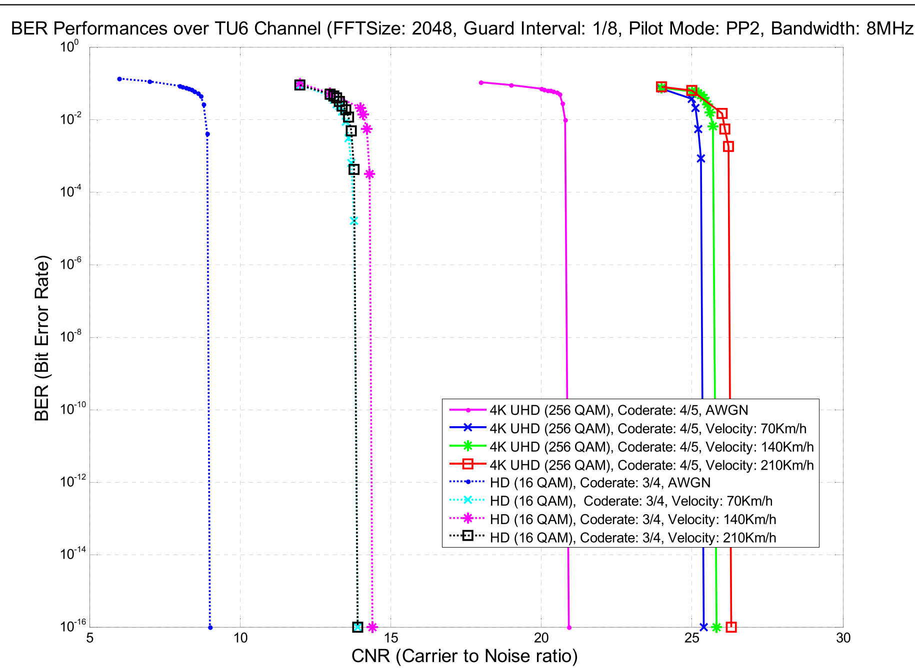

Figure 14 BER performances under TU-6 channel and AWGN (transmission parameter no. 2, 8 MHz bandwidth).

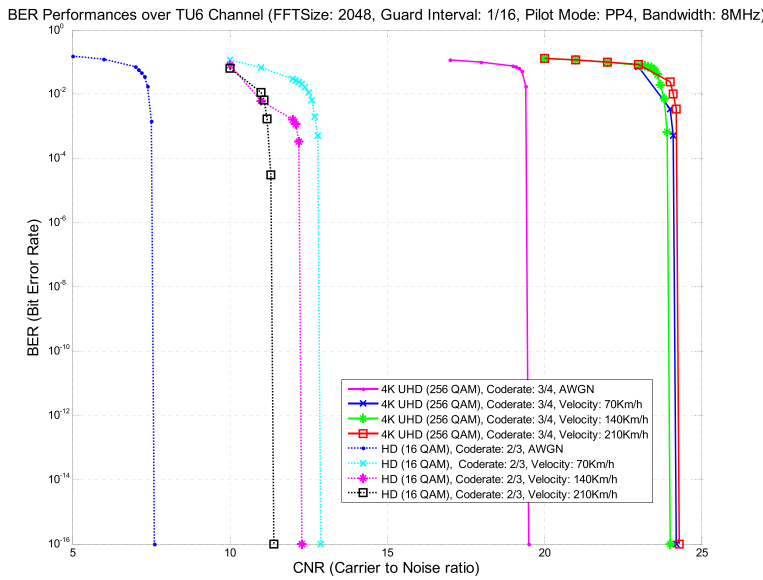

Figure 15 BER performances under TU-6 channel and AWGN (transmission parameter no. 3, 8 MHz bandwidth).

In Europe, an 8-MHz bandwidth is allocated for terrestrial channels, and the extension of the bandwidth for terrestrial channels is currently being discussed among governments, broadcasters, and mobile service providers globally. To consider these points and overcome the limitations of the 6-MHz bandwidth, the optimized transmission parameters were re-drawn for the 8-MHz bandwidth. The optimized parameters for the 8-MHz bandwidth which meet the requirements in Table 7 are listed in Table 8.

Every supported constellation point in the DVB-T2 systems was considered for the 4 K UHD and HD layer. However, similar to the case of a 6-MHz bandwidth, the required rate could be met when 256 QAM was used for

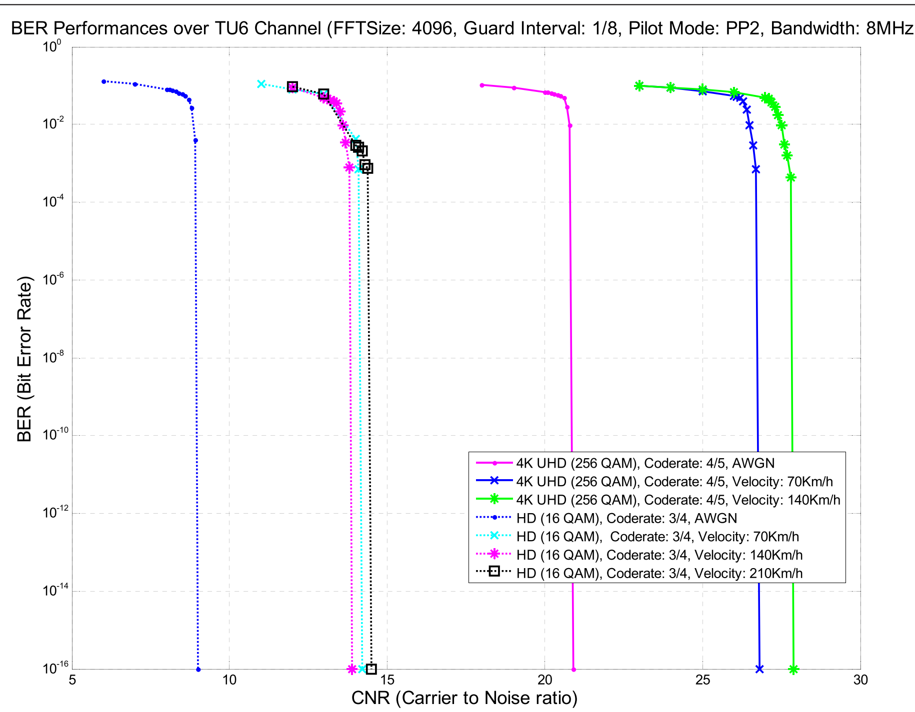

Figure 16 BER performances under TU-6 channel and AWGN (transmission parameter no. 4, 8 MHz bandwidth).

the 4 K UHD layer data and 16 QAM for the HD layer data. The maximum code rate was restricted to 3/4, and the pilot modes 4, 5, 6, 7, and 8 were excluded in consideration of the HD layer under the mobile channel environment.

By extending the bandwidth from 6 to 8 MHz, the maximum FFT size of the transmission parameters in Table 8 could be limited to 4,096. While the code rates of the HD layer for a 6-MHz bandwidth were 4/5 and 5/6, which are quite high, the lowest code rates of the HD layer and 4 K UHD layer were 2/3 and 3/4, respectively. In pilot pattern, the frequency of the pilots was increased by selecting PP2 and PP4 mode. In transmission parameter nos. 2 and 3 and 4 and 5, FFT size was the same at 2,048 and 4,096, respectively, and the code rate was lowered by reducing the guard interval. Commonly, the extended transmission mode was not used, and the frame-closing symbol (last OFDM symbol of the data OFDM symbols, which carries more pilots than normal data OFDM symbols) was used.

Using optimized transmission parameters for the 8-MHz bandwidth, the receiving performances were analyzed using computer simulations. Figures 13, 14, 15, 16, and 17 show the BER performances versus CNR of the transmission parameters in Table 8 under AWGN and TU-6 channels.

Figures 13, 14, 15, 16, and 17 show the BER performances versus CNR of transmission parameter nos. 1 to 5 for an 8-MHz bandwidth, listed in Table 8, under AWGN and TU-6 channels (70, 140, and 210 km/h). The TOV performances of the optimized transmission parameters in Table 8 are summarized in Table 9. For all transmission parameters under the TU-6 channel, the TOV of the 4 K UHD layer was 24.3 to 28.1 dB, while that of the HD layer was 12.8 to 16.0 dB. From the results, reliable receiving of the 4 K UHD layer data under a static channel can be achieved, and reliable receiving of HD layer data under a very fast fading TU-6 channel at a maximum velocity of 210 km/h can be achieved at a

Table 9 Threshold of visibility (TOV) of optimized transmission parameters for an 8-MHz bandwidth

Parameter no.	AWGN	TU-6 (70 km/h)	TU-6 (140 km/h)	TU-6 (210 km/h)
4 K UHD layer				
1	20.9 dB	26.4 dB	26.2 dB	26.1 dB
2	20.9 dB	25.4 dB	25.8 dB	26.3 dB
3	19.5 dB	24.2 dB	24.0 dB	24.3 dB
4	20.9 dB	26.8 dB	27.9 dB	X
5	19.5 dB	24.3 dB	24.6 dB	28.1 dB
HD layer				
1	9.0 dB	16.0 dB	13.8 dB	14.1 dB
2	9.0 dB	13.9 dB	14.4 dB	13.9 dB
3	7.6 dB	12.9 dB	12.3 dB	11.4 dB
4	9.0 dB	14.2 dB	13.9 dB	14.5 dB
5	7.6 dB	12.8 dB	12.4 dB	12.2 dB

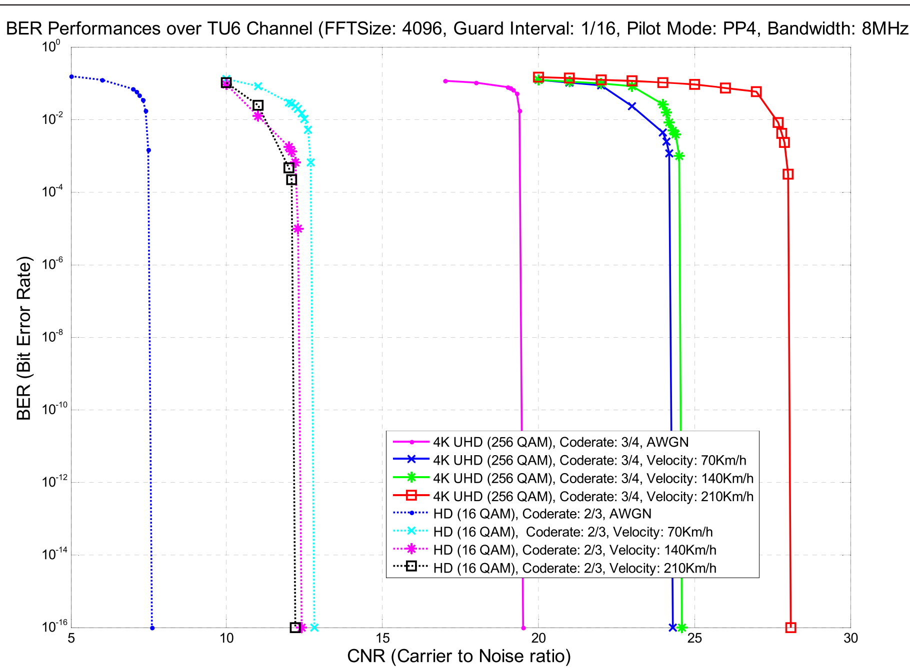

Figure 17 BER performances under TU-6 channel and AWGN (transmission parameter no. 5, 8 MHz bandwidth).

reasonable TOV. It is significant that there was not a large performance difference between parameter no. 1 and no. 2, implying that the receiving performance does not differ between 1024 and 2048 FFT size at the 210 km/h maximum velocity of the receiver. In addition, when the code rate was decreased as a result of decreasing the guard interval size, as in parameter nos. 2 and 3 and 4 and 5, more improvement of the receiving performance was obtained under a mobile situation than in the case of the other parameters. Lastly, when the FFT size was sufficiently small, the receiving performances of the very fast fading channel (receiver velocity: 210 km/h) were better than those of the slow fast fading channel (receiver velocity: 70 km/h).

5 Conclusions

In this paper, the transmission requirements for proving a terrestrial 4 K UHD and HD convergence broadcasting service through a single channel were analyzed, and a service model of the terrestrial 4 K UHD and HD broadcasting services was explained. In addition, the required data rate when employing the latest SHVC video codec technology was forecasted, and the optimized transmission parameters for 4 K UHD and HD convergence broadcasting were drawn by employing the latest transmission technologies as in DVB-T2 systems. The receiving performances of the optimized transmission parameters under AWGN and time-varying TU-6 channel situations were then measured to find the TOV's. From the results, for the 6-MHz bandwidth, reliable receiving of the HD layer data could be achieved when the receiver velocity was a maximum of 140 km/h and no higher due to the limit of bandwidth. When the bandwidth was extended to 8 MHz, the reliable receiving of both 4 K UHD and HD layer data was achieved under a very fast fading multipath channel.

The M-PLP technique, which was considered in this paper, employs different code rates and constellation points for each layer of data and multiplexes differently encoded layers of data into a single frame, with no change of the FFT or CP sizes within a frame. However, the FFT size should be increased and the CP size should be decreased for the 4 K UHD layer; the opposite is true for the HD layer because of the different spectral efficiency and channel conditions. Additionally, HD base layer data are more important than 4 K UHD-enhanced layer data for reliable SHVC decoding; thus, the FFT size should be decreased and the CP size should be increased so that the HD layer will be robust to multipath channel. Recently, DVB-T2 Lite profile employing future extension frame (FEF) transmission technology [5] has been introduced, which can allow adjustment of the FFT and CP size for each layer. Therefore, the development of convergence broadcasting transmission systems by FEF multiplexing techniques will continue.

In future work, the peak signal-to-noise ratio (PNSR) performance for transmitted and received video in a time-varying multipath channel should be measured once a commercial-level real-time SHVC encoder and decoder has been developed. In addition, if the performance of a real-time encoder is improved or non-real-time video data are used for transmission, the required data rate used in this study would decrease. Thus, in these cases, the optimized parameters should be re-calculated for all bandwidth channels.

Competing interests
The authors declare that they have no competing interests.

Acknowledgements
This paper was supported by Konkuk University in 2012.

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Received: 13 October 2014 Accepted: 15 April 2015
Published online: 03 May 2015

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