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DASH Live Broadcast Traffic Model: A Time-Bound Delay Model for IP-Based Digital Terrestrial Broadcasting Systems

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Abstract: This paper proposes a live broadcast traffic model for an internet protocol (IP)-based terrestrial digital broadcasting system to transmit dynamic adaptive streaming over hypertext transfer protocol (DASH) media. The IP-based terrestrial digital broadcasting systems such as Advanced Television Systems Committee (ATSC) 3.0 transmit media content (e.g., full high definition and ultra-high definition) in units of DASH segment files. Although the DASH segment file has the same quality and playback time, the size of each DASH segment file can vary according to the media composition. The transmission resource of the terrestrial broadcasting system has increased the transmission capacity of broadcasting with new technologies. However, the transmission capacity is still limited and fixed compared to wired broadcasting networks. Therefore, a problem occurs with the efficiency of broadcasting resources and transmission delay when transmitting a variable segment file to a terrestrial digital broadcasting network. In this paper, the resource efficiency and transmission delay results that occur when transmitting the actual DASH segment file are simulated through the live broadcast traffic model, and the maximum delay time that a viewer accessing the terrestrial broadcast can experience is presented.

Keywords: live broadcast traffic model; token bucket; leaky bucket; ATSC 3.0; DASH; ultra-high definition (UHD)

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1. Introduction

The major digital TV standards are Advanced Television Systems Committee (ATSC) [1], Digital Video Broadcasting (DVB) [2], Integrated Services Digital Broadcasting (ISDB) [3], Digital Terrestrial Multimedia Broadcast (DTMB) [4], and so on. Each standard has developed its technology independently. Each standard has technological strengths, but the economic feasibility is poor due to overlapping investments in technology and market divisions. In addition, they are incompatible because they use different technologies. Accordingly, global cooperation is needed for next-generation terrestrial digital broadcasting to prevent the divide between technology and the market. Thus, the future of broadcast television (FOBTV) was established [5]. The FOBTV defines the use cases for next-generation broadcasting systems and technical issues to realize the system. Among these, this paper focuses on the uniform protocol stack and ultra-high definition television (UHDTV).

The uniform protocol stack demonstrates the policy of FOBTV toward a global standard. Therefore, the ATSC standardized the next-generation broadcasting system, ATSC 3.0, as an all internet protocol (IP)-based system [6].

Moreover, UHDTV supports a 4K (3840 × 2160) or 8K (7680 × 4320) display resolution and has a display resolution that is 4 or 16 times clearer than full high definition (FHD) (1920 × 1080). This depends on the resolution, frame rate, bit depth, and so on of the media content; thus, the volume of media content to be transmitted increases. Higher quality results in a higher required transmission bit rate [7]. Terrestrial broadcasting technology has increased the broadcasting network resources due to the development of technologies, such as the error correction code, diversity technologies (multiple input and multiple output, space-time coding, and time-frequency splicing), and signal processes, but it is still limited and fixed compared to communication networks. It is also important to increase the terrestrial broadcasting network resources with new technologies, but it is key to analyze and use the given broadcasting network resources efficiently.

The transmission delay of media is a major issue in IP-based transmission systems. The delay affects the quality of experience (QoE) [8]. It analyzes the delay affecting QoE. It checks video playback end-to-end delay and average buffering delay of YouTube, over-the-top (OTT) service, and Internet Protocol television (IPTV) through simulation. There is a proposed method to improve QoE by reducing delay [9]. It transmits MPEG-DASH (dynamic adaptive streaming over hypertext transfer protocol) over Ethernet and Wi-Fi and analyzes the broadcast delay between recording and viewing. It tries to reduce the broadcast delay by analyzing the characteristics of the MPEG-DASH protocol. There is a proposed QoE model [10]. The experiment is performed with a network emulator and a Wi-Fi AP. In DASH, it transmits segment files with different quality depending on network bandwidth fluctuation. It is presented a novel user experience model that can quantitatively measure the user experience of DASH video by taking into account both spatial and temporal artifacts.

There are performed experiments in real networks such as an LTE wired network. It is performed on the SK mobile IPTV service [11]. An HD media is transmitted in LTE networks. In the experimental results, the initial playback time satisfies the QoE sufficiently. However, even with LTE that supports up to 150 Mbps, the overall quality including the transmission success rate is limited. The paper [12] focuses on an experimental model that creates 8K UHD contents and measures the transmission delay in the wired network path length of about 600 km. The paper [13] focuses on actual implementation and field tests in IP-based convergence of terrestrial broadcast and broadband networks using ATSC 3.0 standard. When a receiver cannot find a segment with a $(t + 1)$ over broadcast, it will be able to request and receive the segment with $(t + 1)$ over broadband. Based on the real test in the paper [13], another study investigates the reliability gain of broadcast and broadband cooperation [14]. It describes the system models of broadcast and broadband networks as well as the delivery failure performance of cooperative over broadcast and broadband networks. The proposed system primarily utilizes a broadcast transmission for streaming, while broadband backup transmissions are requested whenever the broadcast signal is not decodable. As above, the papers that focus on IP-based broadcast delay have proposed a method or a QoE model to improve QoE. The experimental environment of the papers is an emulator or local network, and the actual experimental paper focuses on the success of implementation and data transmission. These papers experiment in LTE networks or combine terrestrial broadcast and broadband.

The author thinks there is no related research about the delay and resource efficiency of the terrestrial broadcast network when transmitting DASH segment files especially in the terrestrial broadcasting networks, despite there being a problem due to the *fixed resources* and the *variability of the DASH segment file size* of UHD media. This paper proposes a transmission structure using the token bucket and leaky bucket methods already widely used in the IP system for analysis of the delay and resource efficiency. Therefore, the structure can be used without restrictions in an IP-based system and can be easily implemented. The proposed transmission structure can accommodate the burst characteristics of the DASH segment file and the characteristics of a broadcasting system that must be transmitted at a constant speed. In addition, this paper proposes a transmission structure capable of transmitting a best-effort service for the efficient use of broadcast transmission resources during media transmission.

This paper models and analyzes the proposed transmission structure based on modeling the efficiency of the broadcasting resources when the real DASH media are transmitted. Moreover, the transmission delay simulation results are presented. The analyzed transmission delay is expected to contribute to synchronization in heterogeneous networks and can prepare for the delay. The proposed model is expected to contribute to future system development because it can check the maximum delay of users accessing broadcasting.

2. Background and Related Work

2.1. Transmission Scheme in a Broadcasting Network

One of the characteristics of the terrestrial broadcasting network is *fixed resources*. The method of transmitting a DASH segment file in a terrestrial broadcasting network with a fixed bandwidth can be expressed as the file broadcast scheme and live broadcast scheme as presented in Figure 1.

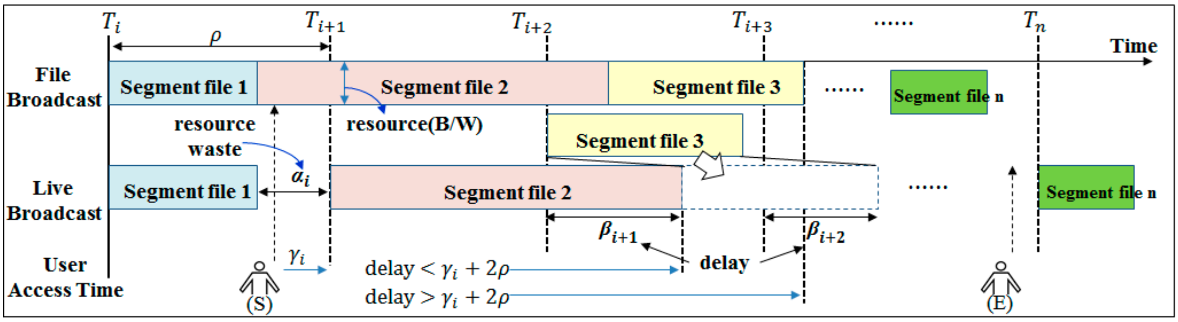

Figure 1. Transmission schemes that transmit segment files of variable sizes in a broadcasting network with fixed resources. The file broadcast scheme successively transmits segment files. The live broadcast scheme periodically transmits segment files.

The file broadcast scheme in Figure 1 transmits the next segment file after the first segment file is transmitted. The file broadcast scheme has mainly used the on-demand method in a communication network environment and is not unsuitable for use in a broadcasting network where an unspecified majority of people watch the same contents at the same time. For example, when a user (S) in Figure 1 accesses the file broadcast scheme, the segment File 2 cannot be displayed normally because part of the segment File 2 is not received. Therefore, the total delay time for the user (S) is greater than $\gamma_i + 2\rho$ because segment File 3 must be received and displayed. The bigger problem is that the user (E) in Figure 1 may not be able to watch the contents normally because the user cannot receive the segment file.

The live broadcast scheme in Figure 1 transmits segment files periodically (ρ). Therefore, when the user (S) in Figure 1 approaches the live broadcast scheme, segment File 2 can be received and watched normally after the delay time γ_i, and the total delay time is less than $\gamma_i + 2\rho$. In addition, the live broadcast scheme is suitable as a broadcasting network transmission scheme because users can watch the broadcasting contents regardless of when they access it.

2.2. Efficiency of Terrestrial Broadcasting Network Resources and Transmission Delay Issues

The live broadcast scheme in Figure 1 displays the problem of the resource efficiency and transmission delay due to the "*fixed resources*" and "*variability of the DASH segment file size*" when a segment file is transmitted in the broadcasting network. Even though the DASH segment files have the same quality and playback time, the size of each DASH segment file is variable according to the media composition [15]. For example, 4K or 8K content has more data than the FHD content, so each DASH segment file has more variability than the FHD DASH segment file.

The problem of resource efficiency in the live broadcast scheme in Figure 1 occurs in the following situations. For the DASH segment, File 1 starts transmission at time T_i and completes transmission before time T_{i+1}. The display starts time of the DASH segment File 1 is T_{i+1}, and assuming the playback time is ρ, the display ends at time T_{i+2}. Since the live broadcast scheme transmits periodically, segment File 2 starts transmission at time T_{i+1}. Therefore, resource α_i is wasted.

The problem of transmission delay in the live broadcast scheme in Figure 1 occurs in the following situations. It is expected that DASH segment File 2 starts transmission at time T_{i+1} and transmission is complete before time T_{i+2}. However, since because transmission is completed in time $(T_{i+2} + \beta_{i+1})$, the transmission delay of segment File 2 is as much as β_{i+1}. Segment File 3 can be transmitted within time ρ, but a delay occurs that is as much as β_{i+2} due to the influence of the segment File 2.

Resource efficiency and the transmission delay occur due to the *fixed resources* and *variability of the DASH segment file size*, which are characteristics of the terrestrial broadcasting network. Greater variability in the DASH segment file size results in greater resource efficiency and transmission delay problems.

2.3. Related Work

In terrestrial broadcast systems, IP systems have already been used in ATSC-M/H [16], HbbTV [17], and DVB-H [18]. However, the IP system transmits nonreal-time data or plays a role in interactive service. In addition, it plays the role of transmitting media data or nonreal-time data using MPE [19], unidirectional lightweight encapsulation (ULE) [20], generic stream encapsulation (GSE) [21], and so on to maintain compatibility with the existing broadcasting system. The reason the IP system simply transmits in the broadcasting system is that sufficient broadcasting systems exist (see Table 1). For example, it is known that service is possible with a bandwidth of about 5 to 6 Mbps for FHD. In addition, multimode service, which provides multiple media services to a single channel, is provided under the terms multiplex in the UK, multicasting in the US, and multi-program in Japan.

Table 1. Capacity of broadcast network at 6 Mhz (Mbit/s) [22].

Broadcast Network	ATSC		DVB-T	DVB-T2	DVB-H	ISDB-T	DTMB
	A/53	A/153					
Mbit/s	19.39	0.029 to 21.5	3.7 to 31.7	7.4 to 50.3	3.7 to 23.751	3.651 to 23.234	4.81 to 32.49

In addition, some studies have analyzed the DASH performance in the internet and 5G networks where the speed varies according to time [23] and studies that propose a QoE model considering DASH's ARG algorithms [24]. Various studies exist on transmitting DASH over the internet and communication networks. However, it is difficult to find similar studies that propose a transmission structure and a delay model in a terrestrial broadcasting system. Therefore, the proposed delay model in this paper is valuable for the IP-based terrestrial broadcasting system.

3. Proposal Transmission Structure for an IP-Based Terrestrial Broadcasting System

3.1. Resource Efficiency and Transmission Delay in Broadcasting Systems

In terrestrial broadcasting systems, transmission delay can occur when transmitting media as follows: (i) creating original media by shooting, (ii) compressing the generated original media, (iii) transmitting compressed media through a physical link, (iv) wirelessly transmitting media over a physical link, and (v) receiving media and playback over the user's terminal. This paper does not discuss (i), (ii), and (v) because these are not delayed occurrences due to media transmission.

Item (iv) is a physical link, where the resources are fixed, and the delay is constant. The delay occurring in (iv) consists of the transmission delay and propagation delay. The transmission delay is determined by the bandwidth and the volume of transmitted data. For example, 1 Mbyte of data transmitted through a 1 Mbps bandwidth has a transmission delay of 8 s. The propagation delay is determined by the signal speed and the physical distance between the transmitter and receiver but is a very short time for terrestrial waves.

For radio signal propagation at 3×10^8 m/s, a propagation delay of 1 ms occurs when sending the signal to a receiver 30 km away.

Therefore, the delay and resource efficiency occurring in (iii) are analyzed in this paper. As mentioned, because the delay occurring in (iv) is constant, only the delay in (iii) must be analyzed. The resources that can be allocated in (iii) cannot exceed the resources in (iv). In addition, because (iv) plays a role in transmitting the media in (iii) as it is, the efficiency of resources generated in (iii) is the same as the efficiency of resources generated in (iv).

3.2. Proposal for an Internet Protocol-Based Terrestrial Broadcast Transmission Structure

The transmission structure proposed in this paper uses a token bucket and leaky bucket. The DASH segment files are variable in size and must be transmitted within a limited time; thus, they have a burst characteristic. However, the broadcasting network transmits at a constant bit rate (CBR). Therefore, as illustrated in Figure 2, this paper proposes a structure that combines the token bucket and leaky bucket.

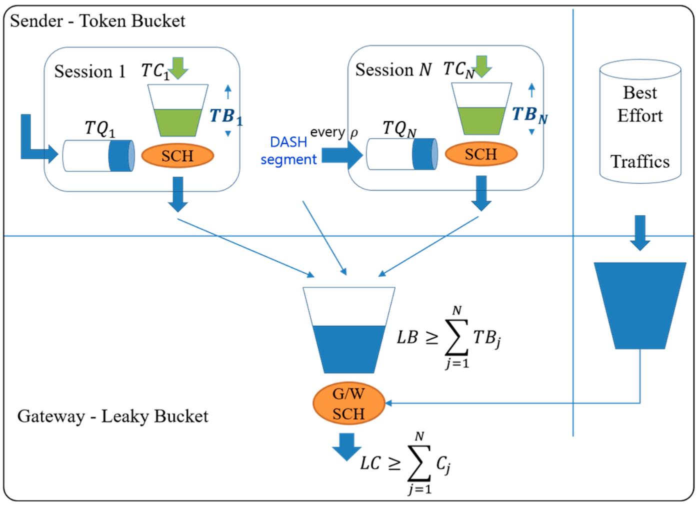

Figure 2. Proposal for the transmission structure for an internet protocol (IP)-based terrestrial digital broadcasting system. The token bucket can accommodate burst segment files, and the leaky bucket can be transmitted at a constant bit rate (CBR).

A token bucket can accommodate a certain level of burst occurrence, and the leaky bucket can be transmitted at a CBR. Conceptually, multiple token buckets are used in consideration of multiple services (sessions). In addition, to efficiently use broadcast transmission resources, this paper proposes a structure that can serve by combining the best-effort traffic.

The operation of the transmission structure proposed in this paper is as follows. The DASH segment file is input to each token bucket queue $TQ_1 \sim TQ_N$ for every unit time ρ. Each token bucket can transmit data at a rate of as much as the token generation (service bit rate) $TC_1 \sim TC_N$ that generates tokens per unit time ρ. The amount of data that each token bucket can transmit with the maximum burst is limited to the size of each token bucket $TB_1 \sim TB_N$. At this time, to avoid overflow, the total sum of $TC_1 \sim TC_N$ should be less than or equal to the service bit rate, LC, of the leaky bucket, and the total sum of $TB_1 \sim TB_N$ should be less than or equal to the leaky bucket size LB.

The main cause of delay is when a DASH segment file larger than the token generation ratio is input to the queue. The delay increases in proportion to the volume of data remaining in the queue.

The leaky bucket transmits data for the same size per unit time ρ, and the delay of the leaky bucket is constant. If the leaky bucket has a remaining resource, the best-effort traffic can be transmitted using these resources to increase their efficiency.

4. DASH Live Broadcast Traffic Model

The DASH segment file is transmitted using the live broadcast scheme in this paper. The DASH live broadcast traffic model consists of the token bucket and leaky bucket. The proposed IP-based transmission structure in this paper uses several token buckets conceptually in consideration of several services (sessions). However, the total size and service bit rate of the token buckets cannot be larger than that of a leaky bucket. Therefore, in this paper, modeling is performed on the assumption that the total sizes of the token bucket and leaky bucket and the service bit rate are the same.

4.1. Time-Bound Token Bucket Traffic Model

In the live broadcast scheme, the segment files are entering the token bucket queue every unit time ρ. At this time, it is assumed that the size of the token bucket queue is sufficiently large because there should not be any loss of data. When the proposed token bucket size of the ith segment is L_i, the token generation rate is TC, and the token bucket size is TB, the bandwidth capacity bound satisfies Equation (1) and the bandwidth over-traffic bound Equation (2):

$$\sum_{i=1}^{N} MIN(L_i,\ TC) \leq TC{\cdot}N{\cdot}\rho \tag{1}$$

$$\textstyle\sum_{i=M}^{N}(L_i -\ TC{\cdot}\rho) \leq TB\ (M < N). \tag{2}$$

Equation (1) indicates the amount of data transmitted by the token bucket, and the data are transmitted within the time limit. In this case, N denotes the number of segment files to be transmitted. Equation (2) indicates the characteristics of the token bucket, which transmits more data than the token bucket instantaneously at a certain unit time (segment files M to N ($M < N$)). At this time, the amount of data to be transmitted may exceed 1 times the size of the token bucket, but not more than twice that.

Figure 3 illustrates the number of tokens in the token bucket at time T_i denoted as $TB(i)$, and the volume of data remaining in the token bucket queue after transmittal is denoted as $TQ(i)$. The amount of data $TQ(i+1)$ remains in the token bucket queue at time T_{i+1}, which satisfies Equation (3):

$$TQ(i+1) = \max(0, TQ(i) + L_i\ -\ \min(L_i, TB(i) + TC{\cdot}\rho)). \tag{3}$$

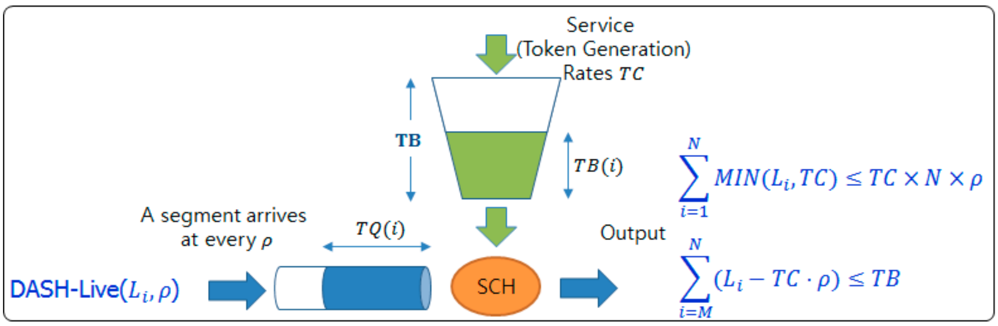

Figure 3. Time-bound token bucket traffic model.

The delay is determined by the amount of data $TQ(i+1)$ remaining in the token bucket queue. Therefore, if the maximum queuing delay is T_q, it can be denoted as follows in Equation (4):

$$T_q = \max\{TQ(i)/TC,\ TQ(i+1)/TC,\ \ TQ(i+2)/TC\ ,\ \ldots,\ TQ(N)/TC\}\ \ (i = 1,2,3,\ldots,\ N). \tag{4}$$

Therefore, because the segment file remaining in the token bucket queue is always smaller than the segment file that generates the maximum queuing delay T_q, it can be denoted as follows in Equation (5):

$$TQ(i) \leq T_q \cdot TC \quad (i = 1, 2, 3, \ldots, N). \tag{5}$$

The maximum queuing delay T_q increases as the remaining data in the token bucket queue increases.

4.2. Time-Bound Leaky Bucket Traffic Model

The leaky bucket receives the data sent from the token bucket and sends the data at a CBR. The proposed leaky bucket has a CBR service denoted as LC. The leaky bucket size is denoted as LB. The amount of data in the leaky bucket at time T_i is denoted as $LB(i)$, and the amount of data received from the token bucket is denoted as $R(i)$. Thus, the bandwidth capacity bound of the leaky bucket satisfies Equation (6):

$$\sum_{i=1}^{C} MIN(R(i) + LB(i),\ LC) \leq LC \cdot C \cdot \rho. \tag{6}$$

Equation (6) calculates the amount of data transmitted by the leaky bucket, transmitting data within the time limit. At this time, C indicates how many times data are received from the token bucket. There are data in the leaky bucket after transmitting. The amount of data remaining in the leaky bucket satisfies the following Equation (7):

$$\sum_{i=1}^{C} (R(i) + LB(i) - \ LC \cdot \rho) \leq LB. \tag{7}$$

Equation (7) reveals that the amount of data remaining in the leaky bucket is smaller than the leaky bucket size, LB, after the data are transmitted. In addition, the amount of data $LB(i+1)$ remaining in the leaky bucket at time T_{i+1} satisfies Equation (8):

$$LB(i+1) = \max(0,\ R(i) + LB(i) - LC \cdot \rho). \tag{8}$$

The delay is determined according to the amount of data $LB(i+1)$ in the leaky bucket, and the maximum buffering delay of the leaky bucket can be obtained by LB/LC.

4.3. Maximum Delay Analysis

In the transmission structure proposed in this paper, the maximum total delay Δ_O can be expressed as the sum of the maximum queuing delay generated in the token bucket queue and the maximum buffering delay generated in the leaky bucket as follows in Equation (9):

$$\Delta_O = \text{Max}(\delta_i) \leq T_q + \frac{LB}{LC} + \sigma,\ (i = 1, 2, 3, \ldots, N) \tag{9}$$

where δ_i represents the delay, and σ represents the propagation delay, packet processing delay, and so on. This time is very short. Therefore, this paper assumes that $\sigma = 0$ for simplicity.

It is critical to predict the maximum delay because the viewers can receive service smoothly after the maximum delay when accessing the broadcast service. Therefore, the maximum delay $D_{init}(0)$ that the users can experience when they access the live broadcast scheme is as follows:

$$D_{init}(0) = \Delta_O + \rho = T_q + \frac{LB}{LC} + \rho. \tag{10}$$

5. Simulation

In this section, the DASH dataset to be simulated is analyzed. The DASH dataset analyzes the resolution, playback time, number of segment files, average file size, maximum file size, and standard deviation to compare the media. The analyzed DASH dataset is simulated and discussed as the live broadcast traffic model.

5.1. DASH Dataset Analysis

The seven DASH datasets used in this paper are summarized in Tables 2 and 3. Table 2 summarizes the media 'Big Buck Bunny', 'Of Forest and Men', and 'The Swiss Account' provided by ITEC [25] and is encoded in AVC/H.264 codec. 'Big Buck Bunny' and 'The Swiss Account' are FHD, and 'Of Forest and Men' is SD (1024 × 576). Although it is a 1-s playback segment file, the number of segment files and total playback time do not match exactly. The reason is that the playback time of the last segment file may be shorter than 1 s (e.g., 'Big Buck Bunny' and 'Of Forest and Men'), and the playback time of each segment file or the last segment file may be longer than 1 s (e.g., 'The Swiss Account' has 3451 segment files, but the total playback time is 3453.98 s).

Table 2. Dynamic adaptive streaming over hypertext transfer protocol (DASH) dataset (AVC/H.264).

	ITEC-Dynamic Adaptive Streaming over HTTP		
Name	**Big Buck Bunny**	**Of Forest and Men**	**The Swiss Account**
Resolution	1920 × 1080 (1080 p)	1024 × 576 (SD)	1920 × 1080 (1080 p)
Playback time of segment file(s)	1	1	1
Number of segment files (total s)	597 (596.46)	454 (453.20)	3451 (3453.9)
B/W(MPD)(Kbit/s)	4728	3894	4714
Average file size (Kbit)	4724	3888	4718
Maximum file size (Kbit)	9087	5549	8018
Standard deviation (Kbit)	1970	1610	1030
Skewness	0.23	−1.04	−1.2
Kurtosis	2.14	2.6	6.3

Table 3. DASH dataset (high efficiency video coding-HEVC).

	4Ever Project	**Drama**		
Name	**Dashevc-Live-4K V11**	**liveMainAV**	**DASH Fast**	**DASH Slow**
Resolution	3840 × 2106 (4K)	3840 × 2106 (4K)	3840 × 2106 (4K)	3840 × 2106 (4K)
Playback time of segment file(s)	2	2	1	1
Number of segment files (total s)	72 (151.85)	120 (240)	60 (60)	60 (60)
fps	60	90,000/1501 = 59.95	90,000/1502 = 59.92	90,000/1501 = 59.96
B/W(MPD)(Kbit/s)	18,363	17,744	20,019	20,019
Average file size (Kbit)	18,916	24,415	20,019	16,587
Maximum file size (Kbit)	21,688	32,439	24,010	21,586
Standard deviation (Kbit)	2439	2195	1662	2115
Skewness	−1.8	0.56	0.11	0.44
Kurtosis	6.9	4.93	2.99	2.78

In Table 2, B/W denotes the bandwidth described in the media presentation description (MPD). The average file size represents the average size of the media segment files analyzed in this paper and is slightly different from MPD's B/W. The standard deviation refers to the degree of fluctuation of the media. Comparing the standard deviation of the three media files, 'Big Buck Bunny' has relatively more fluctuation.

Table 3 lists the 4K DASH dataset, which is encoded with the HEVC [26] codec. 'Dashevc-live-4K V11' is a dataset provided by the 4Ever project [27]. The remaining three media types are dramas. 'DASH fast' and 'DASH slow' are the same drama, and in the simulation result of the graph, 'DASH fast' requires a higher bit rate than 'DASH slow'. The DASH dataset in Table 3, excluding 'Dashevc-live-4K V11', is part of the media segment files. The Table 3 analysis results reveal that the B/W of MPD and the average file size are about 7 Mbps for the large and 170 Kbps for the smallest.

Considering the average file size, the standard deviation of each media in Table 3 is considerably smaller than for each media in Table 2. Comparing the mean and standard deviation, 'Big Buck Bunny' and 'Of Forest and Men' is about 1/2.4, and 'The Swiss

Account' is about 1/4.5. However, 'liveMainAV' is about 1/11. In addition, 'DASH fast' is 1/12, and 'DASH slow' is only 1/7. This is because the media content 'Dasheve-live-4K V11' does not change much over time, and the rate control technology for 'liveMainAV', 'DASH fast', and 'DASH slow' is applied. Rate control technology compresses the original media at the target bit rate as much as possible when encoding, so the standard deviation of the segment files is reduced.

5.2. Simulation Results and Discussion

In this section, the MATLAB simulation is based on the proposed live broadcast traffic model to analyze the results. The simulation sets the average file size of the DASH dataset to the minimum service bit rate and the maximum file size of the DASH dataset to the maximum service bit rate. The reason for setting the minimum service bit rate as the average file size for the DASH dataset is that 100% of the bandwidth is used when transmitting with the average file size.

In the simulation, the DASH segment files are transmitted in increments of 100 kbps from the minimum service bit rate to the maximum service bit rate. The bandwidth efficiency, maximum total delay, and average delay results are given for each service bit rate.

5.2.1. Simulation Results

Figures 4–10 illustrate the simulation results by the live broadcast scheme, and Tables 4 and 5 summarize part of the simulation results. Figures 4–6 and Tables 4–6 present the simulation results of the media summarized in Table 2, and Figures 7–10 and Tables 7–10 list the simulation results of the media summarized in Table 3.

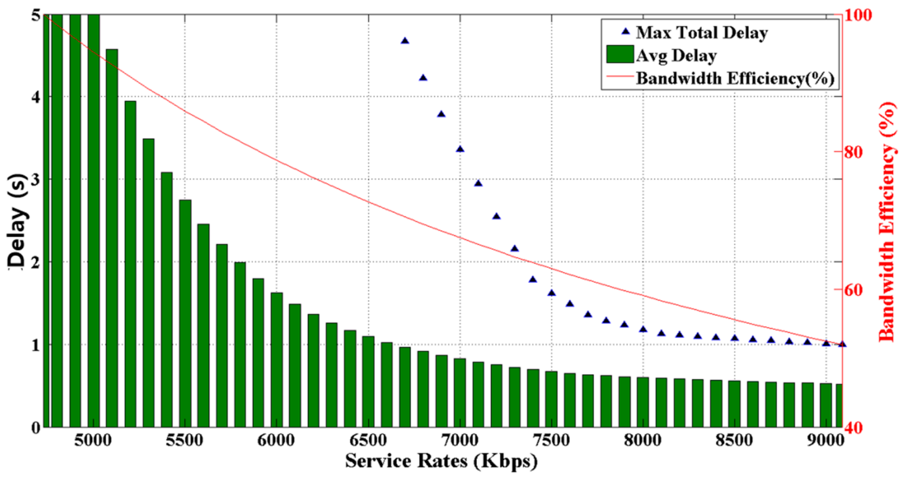

Figure 4. Simulation results of 'Big Buck Bunny'.

Table 4. Simulation results of 'Big Buck Bunny'.

Bandwidth Efficiency and Delays per Service Bit Rate.							
Service Bit Rate (Kbps)	**4724.64**	**5500**	**6500**	**7000**	**7500**	**8500**	**9087.56**
B/W efficiency (%)	100.0	85.9	72.7	67.5	63.0	55.6	52.0
Max total delay (s)	28.8	12.8	5.6	3.4	1.6	1.1	1.0
Average delay (s)	10.4	2.7	1.1	0.8	0.7	0.6	0.5

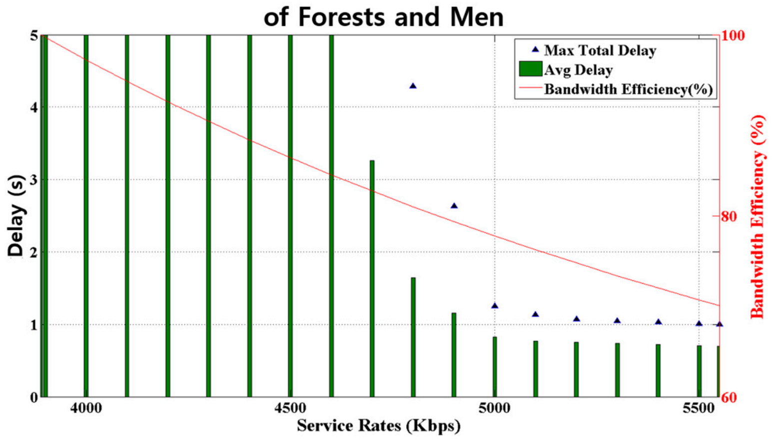

Figure 5. Simulation results of 'of Forests and Men'.

Table 5. Simulation results of 'of Forest and Men'.

Bandwidth Efficiency and Delays per Service Bit Rate.						
Service Bit Rate (Kbps)	**3887.98**	**4000**	**4500**	**5000**	**5500**	**5549.41**
B/W efficiency (%)	100.0	97.2	86.4	77.8	70.7	70.1
Max total delay (s)	63.4	54.5	20.5	1.3	1.0	1.0
Average delay (s)	32.1	26.5	7.5	0.8	0.7	0.7

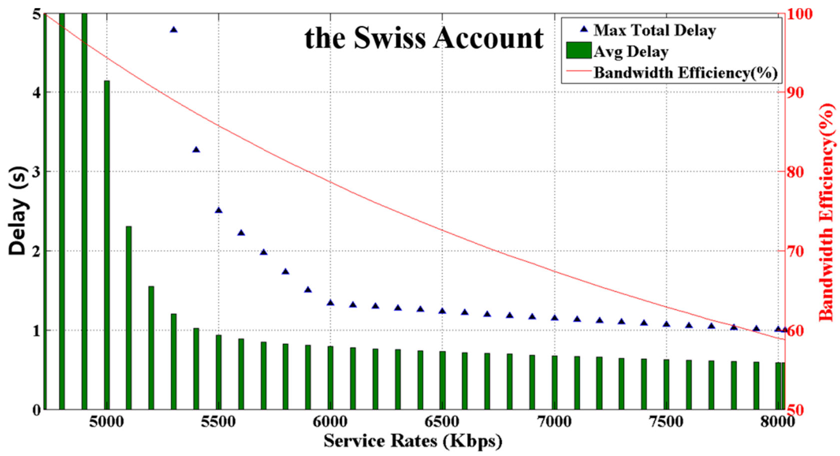

Figure 6. Simulation results of 'The Swiss Account'.

Table 6. Simulation results of 'The Swiss Account'.

Bandwidth Efficiency and Delays per Service Bit Rate.							
Service Bit Rate (Kbps)	**4718.2**	**5000**	**5500**	**6000**	**6500**	**7000**	**8028.1**
B/W efficiency (%)	100.0	94.4	85.8	78.6	72.6	67.4	58.8
Max total delay (s)	99.4	13.8	2.5	1.3	1.2	1.1	1.0
Average delay (s)	45.6	4.1	0.9	0.8	0.7	0.7	0.6

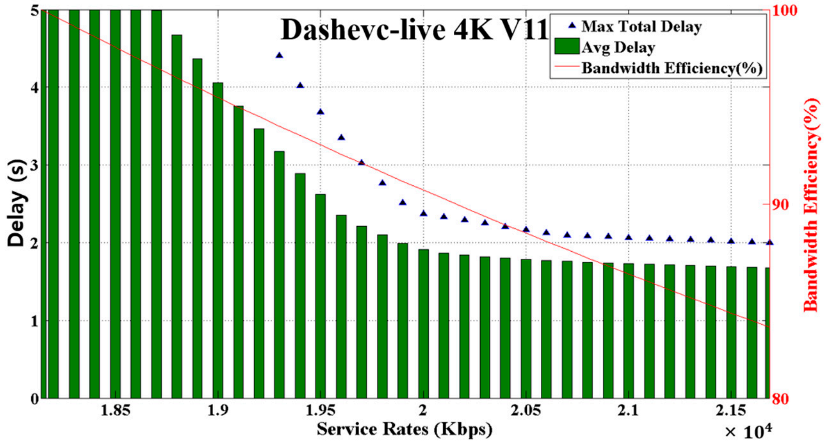

Figure 7. Simulation results of 'Dashevc-live 4K V11'.

Table 7. Simulation results of 'Dashevc-live 4K V11.

Bandwidth Efficiency and Delays per Service Bit Rate.							
Service Bit Rate (Kbps)	**18,140.8**	**19,000**	**20,000**	**20,500**	**21,000**	**21,500**	**21,688.4**
B/W efficiency (%)	100.0	95.5	90.7	88.5	86.4	84.4	83.6
Max total delay(s)	12.1	6.3	2.4	2.2	2.1	2.0	2.0
Average delay (s)	6.8	4.1	1.9	1.8	1.7	1.7	1.7

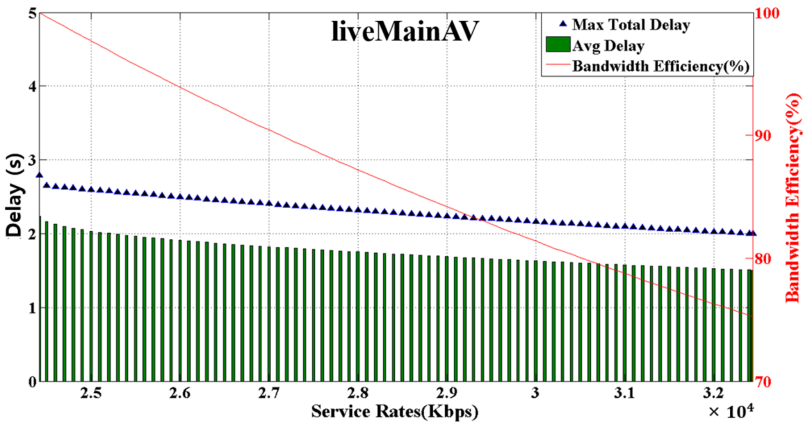

Figure 8. Simulation results of 'liveMainAV'.

Table 8. Simulation results of 'liveMainAV'.

Bandwidth Efficiency and Delays per Service Bit Rate.							
Service Bit Rate (Kbps)	**24,415.6**	**24,500**	**25,000**	**26,000**	**27,000**	**32,000**	**32,438.9**
B/W efficiency (%)	100.0	99.7	97.7	93.9	90.4	76.3	75.3
Max total delay(s)	2.8	2.6	2.6	2.5	2.4	2.0	2.0
Average delay (s)	2.2	2.2	2.0	1.9	1.9	1.5	1.5

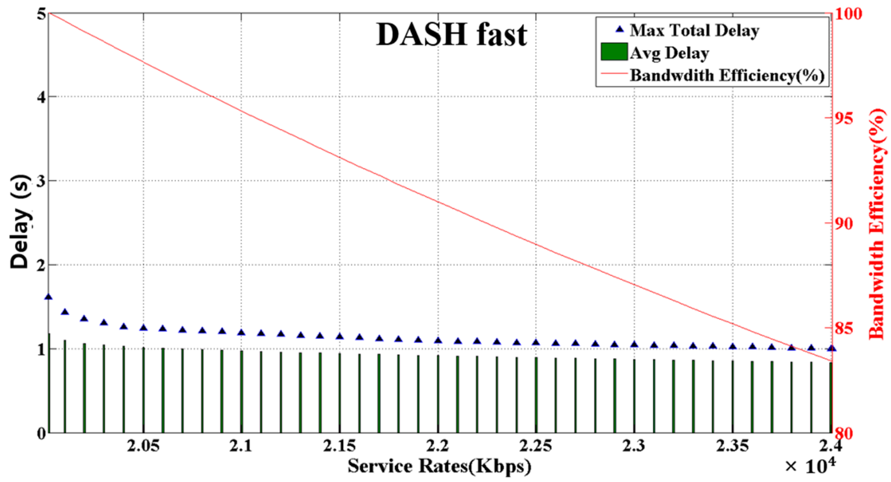

Figure 9. Simulation results of 'DASH fast'.

Table 9. Simulation results of 'DASH fast'.

Bandwidth Efficiency and Delays per Service Bit Rate.							
Service Bit Rate (Kbps)	**20,018.5**	**21,000**	**22,000**	**23,000**	**23,500**	**24,000**	**24,009.8**
B/W efficiency (%)	100.0	95.3	91.0	87.0	85.2	83.4	83.4
Max total delay(s)	1.6	1.2	1.1	1.0	1.0	1.0	1.0
Average delay (s)	1.2	1.0	0.9	0.9	0.9	0.8	0.8

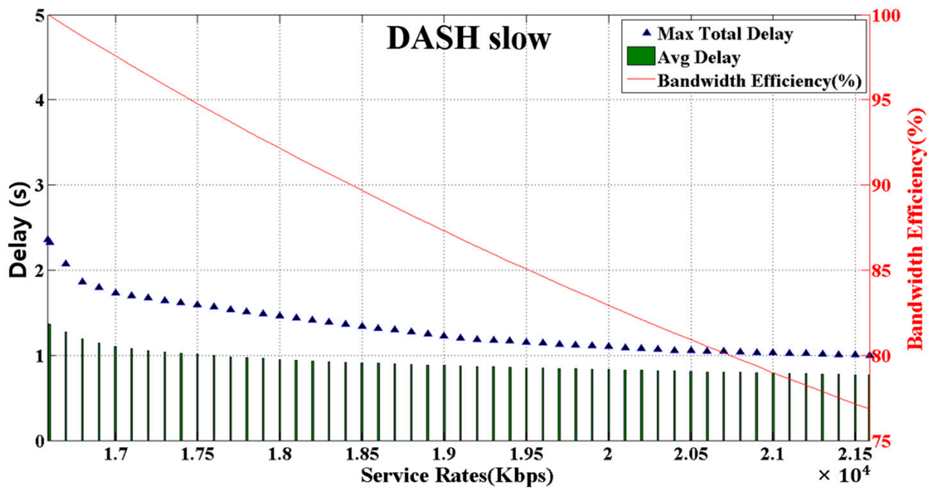

Figure 10. Simulation results of 'DASH slow'.

Table 10. Simulation results of 'DASH slow'.

Bandwidth Efficiency and Delays per Service Bit Rate.							
Service Bit Rate (Kbps)	**16,587.2**	**18,000**	**19,000**	**20,000**	**21,000**	**21,500**	**21,586.2**
B/W efficiency (%)	100.0	92.2	87.3	82.9	79.0	77.1	76.8
Max total delay(s)	2.4	1.5	1.2	1.1	1.0	1.0	1.0
Average delay (s)	1.4	1.0	0.9	0.8	0.8	0.8	0.8

Regarding the results of Figures 4–6, it can be easily predicted that the quality of service deteriorates significantly when transmitting at the minimum service bit rate. For example, in the case of 'Big Buck Bunny', a maximum total delay of 28.8 s occurs at a minimum service bit rate of about 4.724 Mbps, and the B/W efficiency is 100%. The same results can be confirmed for the rest of the media.

In contrast, when transmitting at the maximum bit rate, the minimum delay time is satisfied, but the B/W efficiency deteriorates. The same results are confirmed for the rest of the media.

Figure 7 reveals a pattern similar to the results of Figures 4–6, but Figures 8–10 indicate that the maximum total delay, which seriously affects the service, is not high even at the minimum service bit rate. The reason is that 'Dashevc-live-4K V11' did not use rate control technology when encoding, and the other media did use the rate control technology when encoding.

Rate control technology compresses media at a target bit rate as much as possible, so it can reduce the standard deviation of the segment files and the transmission delay. However, the media quality is relatively poor. Therefore, the encoding should be performed in consideration of the media quality when using the rate control technology.

The simulation results of this paper reveal the B/W efficiency and transmission delay outcomes in media transmission. However, the results do not include the protocol overhead. Nevertheless, it can be easily assumed that no problem is likely to occur in servicing the FHD media in Table 2. This is because the service experience is already abundant, and transmission resources are sufficient. Therefore, the media can be created by adjusting the desired encoding option according to the media type. However, considering the protocol overhead of Table 3 UHD media, transmission resources may be insufficient even for a single media service. For example, in the case of ATSC 3.0, transmission resources are about 25 Mbps, but the media 'liveMainAV' has a maximum delay of 2.6 s at 25 Mbps.

5.2.2. Discussion of the Bit-Rate Allocation According to Media Characteristics

The analysis of media characteristics (e.g., average size, maximum size, standard deviation, kurtosis, etc.) based on the live broadcast scheme proposed in this paper helps to determine the service bit rate. For example, the 'Big Buck Bunny', which has the highest standard deviation in Table 2, should allocate relatively more resources than the average service bit rate when compared to the rest of the media to reduce the delay. 'Big Buck Bunny' requires 7500 Kbps B/W for a 1.60-s delay, but 'Of Forest and Men' requires 5000 Kbps for a 1.3-s delay, and 'The Swiss Account' requires 6000 Kbps for a 1.3-s delay.

Kurtosis can determine the distribution of file size, and 'The Swiss Account' has a relatively higher kurtosis value than other media: that means the degree to which the media segment file size is concentrated in the average size. Therefore, as a result of the simulation of Figure 5 for 'The Swiss Account', it can be observed that the maximum total delay decreases sharply compared to the increase rate of the other two media service bit rates.

For 'Of Forest and Men', the standard deviation is relatively lower than that of the 'Big Buck Bunny'. The average B/W is also low, and the maximum file size is small. It is an SD media, but its B/W efficiency is higher than that of other media. The reason can be observed by comparing the kurtosis and skewness. The '+' of the skewness means that many files with segment files are smaller than the average size. In addition, the '−' of skewness means that many files are larger than average. It has a lower kurtosis and higher skewness than 'The Swiss Account'. In addition, the kurtosis is higher, and the skewness is lower than that of 'Big Buck Bunny'. This means that relatively many segment files are larger than the average. Moreover, the B/W efficiency increases because the standard deviation is low. If the service bit rate is guaranteed to be more than a certain degree, the delay is greatly reduced. When increasing from 4500 Kbps to 5000 Kbps, the maximum total delay decreases significantly (see Table 5).

The delay is one of the important factors that affect the quality of the user service. If the delay of the media service can be predicted, the effect on the service quality can be minimized, and it can greatly help in determining the transmission service bit rate. For example, if the media is the 'Dashevc-live-4K V11' service and the total delay target is 2 s, the service bit rate can be set to 21.5 Mbps (see Table 7). At this time, the efficiency of resources is about 84.4%, so the best-effort service can be used at about 15.6%. In the case of the media 'liveMainAV', the maximum total delay is 2.6 s at 25 Mbps, so the quality of service cannot be satisfactory. In this case, it can be supplemented using 2.3% of the B/W (approximately 2.3% of 25 Mbps is 575 Kbps). For example, if advertisement media is transmitted along with the media, it can playback at the time of delay and receive the media during the playback time of the advertisement media; thus, the media service quality can be supplemented. In the case of 'DASH fast' and 'DASH slow', the service bit rate can be assigned as 23 Mbps and 21 Mbps, respectively, and the remaining B/W can be assigned to the user service.

6. Conclusions and Future Work

This paper studies the problem that occurs when the resources are limited and the segment files of variable sizes are transmitted in a terrestrial broadcasting network. This paper proposes a transmission structure that can accommodate the burst characteristics of DASH segment files and terrestrial broadcasting networks that transmit at a CBR. Live broadcast traffic modeling is performed based on the proposed transmission structure. The transmission structure proposed in this paper is simple to implement and flexible because it uses the token bucket and leaky bucket already widely used in the IP system. Therefore, the proposed transmission structure can be easily modified and used in all IP-based systems.

The *delay* is one of the important factors that affects the quality of the user service. If the delay of the media service can be predicted, it greatly helps improve the service quality. Additionally, the proposed live broadcast traffic model is flexible regardless of the media type. In this respect, the proposed live broadcast traffic model is highly valuable.

This paper presents the results of resource efficiency and transmission delay for a single media transmission. The authors plan to research how each media service affects other media services when transmitting multiple media in the future. The delay analyzed in this paper is expected to be used for synchronization studies for hybrid delivery services for broadcast and broadband networks.

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