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Dynamic Block-Based HTTP Adaptive Streaming Scheme in Multiple Wireless Networks

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ABSTRACT Multipath-based hypertext transfer protocol (HTTP) adaptive streaming (MPHAS) has been studied due to the increasing use of mobile devices equipped with multiple network interfaces and the prevalence of high-quality video streaming services. However, the existing MPHAS schemes undergo a degraded quality of experience (QoE) in multiple wireless networks. The segment request-based MPHAS (SR-MPHAS) encounters frequent quality switching, and the block request-based MPHAS (BR-MPHAS) causes results in playback stalling and inefficient bandwidth utilization, according to slow responsiveness. In this paper, we propose a dynamic block-based MPHAS (DBAS) to improve the QoE by overcoming the limitations of the existing schemes in multiple wireless networks. We propose buffer-based block length adaptation and QoE-based block quality adaptation to reduce the frequency of quality switching and to improve the responsiveness to network changes. Moreover, we propose a partial request-based block scheduler to mitigate segment reordering. The experimental results show that the DBAS improves the QoE by reducing the quality switching frequency and rapidly adapting to abrupt changes in the bandwidth.

INDEX TERMS HTTP adaptive streaming, multipath-based transmission, multiple wireless networks, quality of experience.

I. INTRODUCTION

Cisco's Visual Networking Index revealed that world-wide video traffic accounted for 75% of the total Internet traffic in 2017, and this traffic is expected to reach 82% by 2022 [1]. Due to the increasing demand for video streaming services, it has become more important to provide a high quality of experience (QoE) to users. The most popular video streaming method that is used by many researchers and practitioners is a hypertext transfer protocol (HTTP) adaptive streaming (HAS) [2]–[4], which provides continuous video playback via adaptive quality selection, according to the network changes.

Currently, the number of people using video streaming services is increasing rapidly due to the increase in mobile devices that support multiple network interfaces. Moreover, the demand for ultra-high definition (UHD) video streaming services, which requires enhanced bandwidth to provide high quality video streaming, is increasing [5]. However, single path-based HAS (SPHAS) systems, which request video segments with a single network interface are limited in providing a high QoE, due to the limited bandwidth.

Recently, research on multipath-based HAS (MPHAS), which is capable of providing a high-quality video streaming service by utilizing the multipath to guarantee high bandwidth, has been conducted [6], [7]. Depending on the method of requesting the video segment, MPHAS can be classified as a segment request-based MPHAS (SR-MPHAS) or a block request-based MPHAS (BR-MPHAS). The SR-MPHAS operates by downloading one segment at a time through the multipath and follows this by requesting the next segment. BR-MPHAS operates by downloading a block, which is a set of multiple segments with the same video quality, through the multipath, and this is followed by requesting the next block. Since MPHAS requests video segments based on the multipath, it is advantageous by providing users with a better QoE than the SPHAS based on a stable bandwidth. However, the existing MPHAS schemes provide a low QoE, in a multiple

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wireless network environment. Due to the shorter segment request period, SR-MPHAS exhibits a faster response to network changes and provides continuous playback. However, in environments where the bandwidth frequently changes, such as wireless networks, SR-MPHAS frequently switches the video quality. Moreover, BR-MPHAS has a longer quality decision cycle than the SR-MPHAS, which is advantageous since it reduces the quality switching frequency in wireless network environments. However, if there is a significant change in the bandwidth, BR-MPHAS may exhibit poor playback and inefficient bandwidth utilization because of its slow responsiveness to changes in the network. In MPHAS, the client downloads video segments through different physical paths, so the buffer occupancy may decrease due to the delay caused by the difference in the speed of the network between the paths, which is called the segment reordering problem. For example, when a client simultaneous requests segment of index 1 through a faster path and segments of index 2 and 3 through a slower path, the faster path downloads begin after the slower path downloads finish, which results in a delay. Consequently, an unstable buffer occupancy and inefficient bandwidth utilization can lower the QoE. Such additional delays reduce the client's buffer occupancy and lead to inconsistent video quality.

In this paper, we propose a dynamic block-based MPHAS (DBAS) to improve the QoE by reducing quality switching and by improving the responsiveness to network changes in the existing MPHAS schemes for multiple wireless networks. DBAS employs a) a buffer-based block length adaptation algorithm considering the buffer occupancy and variation rate and b) a QoE-based block quality adaptation algorithm considering the network, buffer, and content characteristics, to reduce the quality switching frequency and to quickly adapt to network changes. Furthermore, we propose a segmentation request-based block scheduling scheme to alleviate segment reordering.

The remainder of this paper is organized as follows. Section II describes the concept of HAS and MPHAS. Section III describes the DBAS scheme. In Section IV, we evaluate the performance of the proposed DBAS scheme using the NS-3 simulator. Finally, we conclude the paper and discuss future work in Section V.

II. RELATED WORKS

A. HTTP ADAPTIVE STREAMING

The existing multimedia streaming services mainly use the Real-time Transport Protocol (RTP) and the Real-time Transport Control Protocol (RTCP) based on the User Datagram Protocol (UDP) [8]. However, RTP has the disadvantage of limited service due to firewall or Network Address Translation (NAT) and an additional streaming server. Recently, HTTP adaptive streaming (HAS) based on the Transmission Control Protocol (TCP) has been attracting attention.

HAS operates as shown in Fig. 1. In an HAS server, a video, which is encoded at different resolutions, frame rates and bitrates, is divided into short length segments, according to its

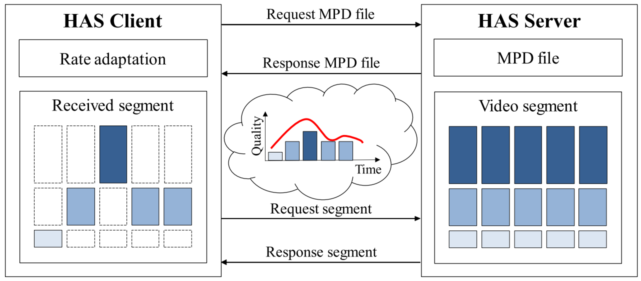

FIGURE 1. Concept of HTTP adaptive streaming.

quality. The HAS server records the video bitrate, resolution, codec and playback parameters and segments the duration, size and address in a media presentation description (MPD) file [9]. The client, with a video player and a video playback quality adaptation algorithm, can request and download the MPD files and video segments from the server, via an HTTP GET message. Using the throughput of the downloading segment, quality adaptation is performed by requesting different quality segments according to the changing network environment. Typical HAS services include Apple's HTTP live streaming (HLS) [10], Adobe's HTTP dynamic streaming (HDS) [11], and Microsoft's smooth streaming [12]. Moreover, dynamic adaptive streaming over HTTP (DASH) has been employed as the standard HAS by the Moving Picture Experts Group (MPEG) and the 3rd Generation Partnership Project (3GPP) [13].

Methods for improving the HAS quality adaptation algorithms in various environments, have been investigated [14]. Segment aware rate adaptation (SARA), a buffer-based algorithm, considers the actual segment sizes and buffer occupancy simultaneously. SARA calculates the segment download rate using the weighted harmonic mean and determines the optimal operational quality [15]. Further, low-latency prediction-based adaptation (LOLYPOP), a rate adaptation scheme, predicts the accurate TCP throughput by comparing various smoothing schemes. LOLYPOP achieves low latency and haptic quality improvement simultaneously, in wireless network environments [16]. The queueing theory approach to DASH rate adaptation (QUETRA) scheme models a DASH client as an M/D/1/K queue. QUETRA determines the optimal quality by calculating the expected buffer occupancy using the video bitrate, network throughput and buffer occupancy [17]. XMAS employs a client-side traffic shaping technique to limit QoE degradation, which arises due to the ON-OFF segment request pattern in multiple HAS client environments; and consequently improves the HAS QoE [18]. SATE is proposed as a HAS that uses a QoE based objective function to reduce the quality switching frequency and to respond quickly to bandwidth changes [19]. MiSAL is proposed as a quality adaptation algorithm based on the client's buffer, channel bandwidth and RTT to improve QoE by reducing the quality switching frequency [20].

Existing approaches described above have a problem that bandwidth utilization is limited due to streaming using only a single path.

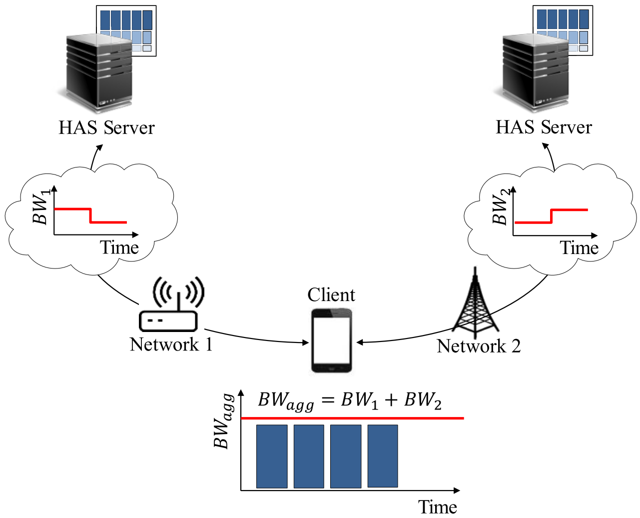

FIGURE 2. Concept of MPHAS.

B. MULTI PATH-BASED HTTP ADAPTIVE STREAMING

Depending on the number of network paths used for downloading video segments, HAS has been classified as a single path-based HAS (SPHAS) approach and a multipath-based HAS (MPHAS) approach. For continuous video playback, the SPHAS approach employs a single network path to download video segments by selecting the appropriate video quality in a changing network. However, due to the limited bandwidth, the SPHAS approach has difficulty in continuously playing high quality video content due to the limited bandwidth. The bandwidth of the network is limited in size and it is unpredictably altered. Therefore, SPHAS, due to using a single network path, is limited in streaming high quality video.

The MPHAS approach for downloading video segments using multiple network interfaces has been studied to solve the problem of QoE degradation due to the limited bandwidth of SPHAS [6], [7]. As shown in Fig. 2, MPHAS downloads video segments by requesting them simultaneously through multiple network interfaces, which provide higher bandwidth and enable concurrent higher quality video segments within the time required for SPHAS. Therefore, MPHAS attains higher network bandwidth following multiple paths and prevents the QoE degradation.

The MPHAS approach can be divided into a) segment request-based MPHAS (SR-MPHAS) schemes and b) block request-based MPHAS (BR-MPHAS) schemes according to the video segment request method. The SR-MPHAS scheme requests every segment only after the previous segment is downloaded. A representative SR-MPHAS scheme is the QAVS (Quality Adaptive Video Streaming) scheme. The QAVS improves the average video quality and mitigates playback stalling by pipelining HTTP requests over 3G and Wireless Local Area Network (WLAN) links [6]. The QAVS exhibits reduced video-less intervals that result from sequential streaming of HTTP requests. Therefore, the video

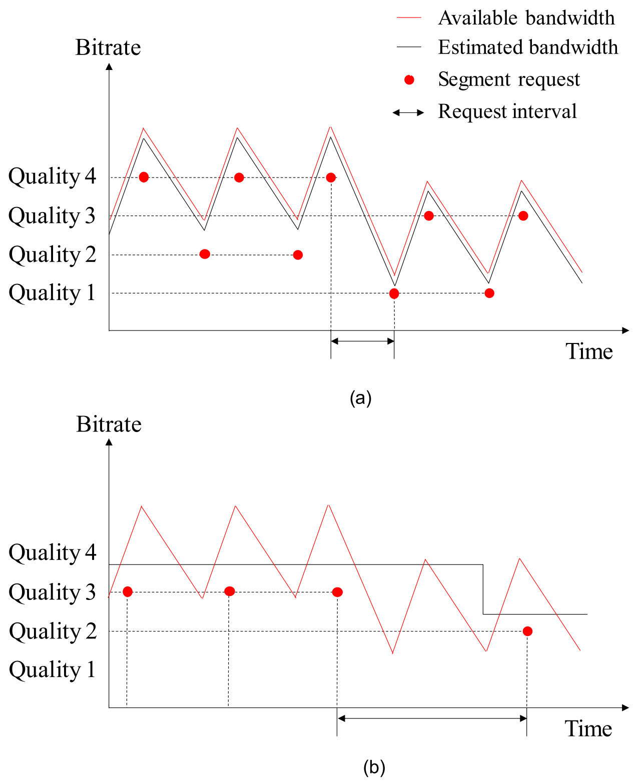

FIGURE 3. QoE degradation in existing MPHAS schemes. (a) Frequent quality switching in SR-MPHAS. (b) Slow responsiveness in BR-MPHAS.

segments are divided into logical sub-segments and consequently a partial request message is transmitted to each download link.

The size of the sub-segments requested for each path are calculated as the ratio of the throughput of each path over the aggregated available bandwidth of the entire link. The segment transmission time is calculated to request the highest quality possible within the transmission deadline. Therefore, MPHAS provides higher video quality with shorter delays, due to the segment-reordering. However, QAVS encounters frequent quality switching in environments with a frequently changing bandwidth, such as wireless network environments.

The BR-MPHAS scheme downloads a set of multiple segments with the same quality as a block and requests the next block. Control theoretic rate adaptation (CTRA), an example of BR-MPHAS [7], adapts the block lengths according to the network bandwidth and the block-based quality according to the network bandwidth and buffer occupancy. Following the block length and quality, CTRA requests path-bandwidth specific video segments. The CTRA exhibits slower responses to bandwidth switching for longer blocks. For blocks longer than the maximum block length, the shortest bandwidth segment is omitted.

The current MPHAS schemes encounter QoE degradation problems, such as frequent quality switching and slow responsiveness to network changes, as shown in Fig. 3. Meanwhile, the SR-MPHAS scheme suffers from frequent quality switching due to shorter request interval, and BR-MPHAS

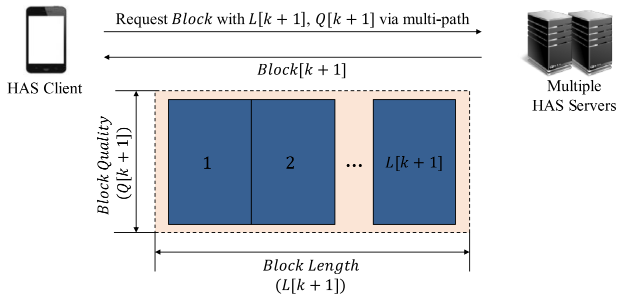

FIGURE 4. Concept of DBAS.

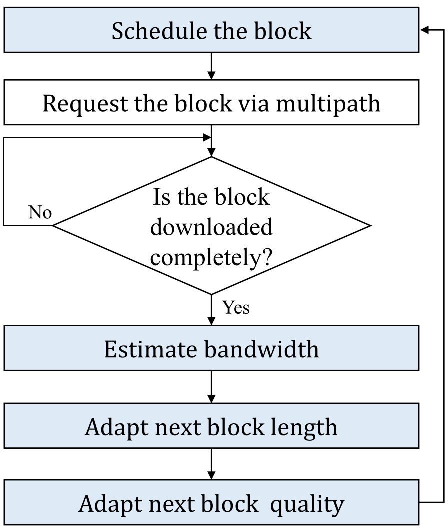

FIGURE 5. Flowchart of DBAS.

suffers slower responses to network alterations due to longer request intervals.

III. DYNAMIC BLOCK-BASED MPHAS (DBAS)

We propose DBAS that exhibits lower quality switching and enhanced responsiveness across multiple wireless network environments. For clarity, we assume that DBAS follows two paths.

The DBAS aims to provide enhanced QoE by dynamically determining the length and quality of the blocks according to changing network conditions, as shown in Fig. 4. The DBAS has two goals that are decreasing the quality switching frequency and enhancing the responsiveness to network changes.

Functionally, the DBAS consist of four phases: block scheduling, block-based bandwidth estimation, block length adaptation and block quality adaptation as shown in Fig. 5.

The DBAS employs a partial request-based block scheduling algorithm to determine the requested sub-block size for each path to mitigate the segment reordering problem. Furthermore, the DBAS requests video segments over the multipath, downloads the requested block, estimates the aggregated bandwidth of the multipath using the block download speed and measures the quantity of each path for block

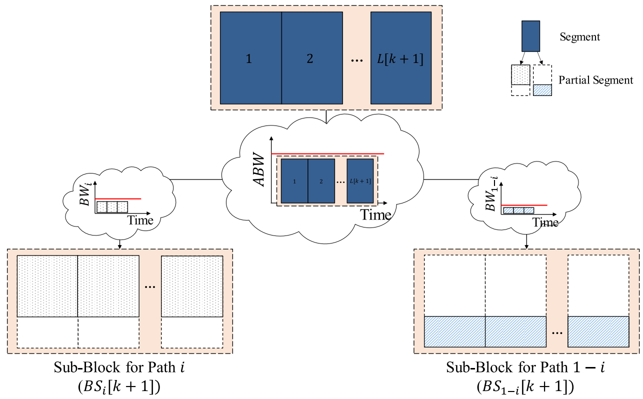

FIGURE 6. Partial request-based block scheduling.

scheduling. Furthermore, the DBAS determines the buffer-based block length. To improve the QoE, the DBAS could comprehensively determine the optimal block quality according to network, buffer and content information.

A. PARTIAL REQUEST-BASED BLOCK SCHEDULER

The DBAS employs a partial request-based block scheduling algorithm to mitigate segment reordering. The partial request-based block scheduling algorithm determines the size of a video chunk to be requested for each path considering the difference in the network speeds of the paths. This scheduling method alleviates the problem of unnecessary buffer occupancy due to the difference in the network speed of each path. HTTP/1.1 provides a partial request feature that requests part of an object by specifying a byte range value of an object called the HTTP range request. In DBAS, this feature is utilized for the partial request-based block scheduling. When a block is requested through multiple paths, the size of the requested sub-block in each path is proportional to the bandwidth of the respective path, as shown in Fig. 6. A sub-block is a part of a block and constitutes multiple sub-segments. The size of the requested sub-block, $BS_i\,[k+1]$ and $BS_{1-i}\,[k+1]$ for each path is calculated using the ratio of the path bandwidth and the sum of the bandwidths of all the paths, as shown in (1) and (2).

$$BS_i\,[k+1] = \frac{Th_i}{Th_i + Th_{1-i}} \cdot BS[k+1] \quad (1)$$

$$BS_{1-i}\,[k+1] = BS\,[k+1] - BS_i[k+1] \quad (2)$$

where, Th_i and Th_{1-i} denote the throughputs of path i and path $1-i$, respectively; and $BS[k+1]$ denotes the size of $Block[k+1]$, which is the $(k+1)$-th block.

B. BLOCK-BASED BANDWIDTH ESTIMATION

DBAS indirectly estimates the aggregated bandwidth, based on the block download speed. In a multipath environment. DBAS also measures the throughput of each path, to determine the size of the sub-blocks for the request segment.

DBAS measures the aggregated bandwidth, $ABW[k]$, based on the download rate of the k-th requested block and the measured Th_i and Th_{1-i}. $ABW[k]$ is calculated by dividing the size of the block by the download time for the block, as shown in (3).

$$ABW[k] = BS[k]/BFT[k] \tag{3}$$

Th_i and Th_{1-i} are calculated by dividing the size of the requested sub-block for each path and the time to download the sub-blocks as shown in (4).

$$\begin{aligned} Th_i[k] &= BS_i[k]/BFT_i[k] \\ Th_{i-1}[k] &= BS_{1-i}[k]/BFT_{1-i}[k] \end{aligned} \tag{4}$$

where, $BS[k]$ denotes the byte size of $Block[k]$, and BFT denotes the time taken to download $Block[k]$. The byte size of the sub-blocks downloaded through the path i and path $1-i$. $BFT_i[k]$ and $BFT_{1-i}[k]$ denote the downloading time for the sub-block, through path i and path $1-i$, respectively.

C. BUFFER-BASED BLOCK LENGTH ADAPTATION

The block length affects the QoE. The shorter the block length is, the shorter the request interval. Therefore, the block length could quickly adapt to the network variation, resulting in seamless playback and high bandwidth utilization. However, in an environment with frequent bandwidth variation, such as wireless networks, frequent quality switching might occur. Further, the longer the block length is, the longer the requesting interval, which effectively reduces the quality switching frequency. However, longer request intervals are unable to adapt quickly to the network bandwidth alterations, which might result in playback stalling and inefficient bandwidth utilization. Such frequent quality switching and slow responsiveness could lower the QoE. Therefore, the appropriate block length must be determined to achieve a higher QoE in changing network environments.

DBAS determines the appropriate block length by considering the buffer occupancy, $B[k]$, and the buffer variation rate, $\beta[k]$, in an altering network environment. According to the buffer occupancy, the operation could be classified into two modes: *Segment Request Mode* (SRM) and *Block Request Mode* (BRM), as shown in (5).

$$\begin{cases} Block\ Request\ Mode, & if\ B_{low} \le B[k] \le B_{high} \\ Segment\ Request\ Mode, & otherwise \end{cases} \tag{5}$$

With either an extremely high or extremely low buffer occupancy ($B[k] > B_{high}$ or $B[k] < B_{low}$), DBAS operates in SRM. In SRM, DBAS fixes the block length to 1, to limit the bandwidth depletion and playback stalling due to buffer overflow. With a moderate buffer occupancy ($B_{low} < B[k] < B_{high}$), when the occupancy is considered stable, DBAS operates in BRM. In BRM, the block length is adjusted on the basis of the buffer variation rate. $\beta[k]$ is expressed by dividing the difference between the current buffer amount and the previous buffer amount, when the segment download is completed by the maximum buffer amount, as shown in (6).

$$\beta[k] = (B[k] - B[k-1])/B_{max} \tag{6}$$

where, $B[k]$ denotes the buffer occupancy after downloading the requested block; and $Block[k]$ and $B[k-1]$ denote the buffer occupancy after downloading the prior requested block, $Block[k-1]$. B_{max} denotes the maximum value of buffer occupancy.

The positive or negative state of the buffer variation rate indicate the appropriateness of the block length for the current network bandwidth. A positive buffer variation rate ($\beta[k] \ge 0$) indicates the suitability of the current block length for the current network and that the network was stable, while a negative rate ($\beta[k] < 0$) indicates an unsuitable block length and unstable network.

Therefore, in BRM, DBAS adjusts the block length, $L[k+1]$, according to buffer variation rate to reduce the quality switching frequency and to improve the responsiveness to network alterations, as shown in (7).

$$L[k+1] = \begin{cases} \min(L[k]+1, L_{max}), & if\ \beta[k] \ge 0 \\ \lceil L[k]/2 \rceil, & otherwise \end{cases} \tag{7}$$

For a positive buffer variation rate, DBAS considers that the network is stable and increases the block length by 1 to limit the playback stalling that is caused by sudden bandwidth alterations. However, for a negative buffer variation rate, DBAS considers that the network is unstable and reduces the block length by half, to improve the responsiveness to network alterations. L_{max} represents the maximum block length. Since significantly longer blocks cannot adequately cope with bandwidth changes, the maximum block length was fixed to avoid slow responsiveness. DBAS effectively responses to bandwidth changes by additively increasing or multiplicatively decreasing the block length according to the buffer variation. Therefore, this scheme reduces unnecessary quality switching and playback stalling.

D. QoE-BASED BLOCK QUALITY ADAPTATION

Dividing a video having a variable bitrate (VBR) into multiple segment results in segments with different sizes [21]. Owing to the segment size differences, the downloading time for a segment is altered. Conventional HAS quality adaptation algorithms determine the quality of segments based on the video quality, as specified in the MPD file, without considering VBR characteristics. Since quality decision algorithms do not consider VBR characteristics, incompatible quality is possible for the current network conditions. Such poor-quality decisions result in an unstable buffer occupancy and inconsistent quality request patterns.

The VBR is prominent in a multi-segment block. Since the block has a long video length, the block quality determination that is not suitable for the current network due to the VBR characteristic likely increasing the instability of the buffer occupancy. Therefore, determining a suitable block quality for network alteration is important.

Further, DBAS determines the appropriate quality by comprehensively considering the network, buffer and content characteristics to improve the QoE. DBAS block quality

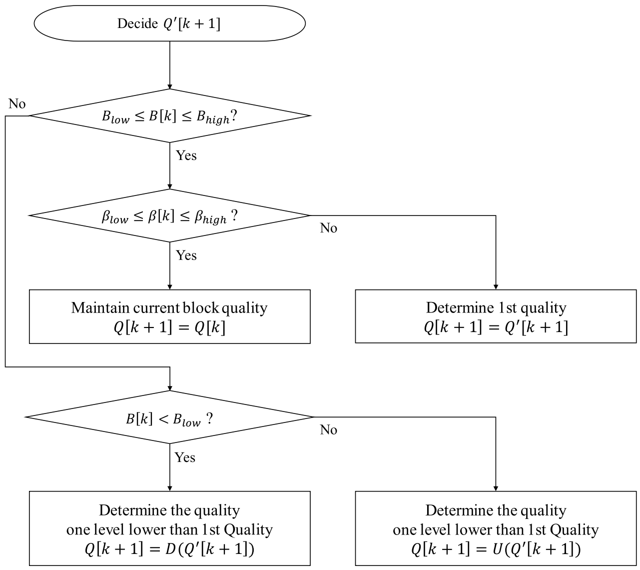

FIGURE 7. Flowchart of QoE-based block quality adaptation.

control improves the QoE through a two-step quality decision method. In the first quality decision, the block quality is determined by considering the VBR characteristics of the segment to determine the quality suitable for the network situation. The second quality decision serves to reduce the frequency of the quality change and to fine-tune the quality determined in the first quality decision considering the buffer variation rate. DBAS improves the QoE by resolving playback stalling, frequent quality changes and low bandwidth utilization through these quality decision processes.

In the first quality decision, DBAS determines the block quality considering the network and VBR characteristics to stabilize the buffer occupancy. First, DBAS calculates the average block bitrate list, b_{k+1}^{R}, as shown in (8). Then, as shown in (9), DBAS determines that $Q^{'}[k+1]$ as the highest quality in the list, b_{k+1}^{R}, below the integrated bandwidth.

$$b_{k+1}^{R} = \sum\nolimits_{i=1}^{L\lfloor k+1 \rfloor} S_{k+1}^{R}[i] / (\tau \cdot L[k+1]) \quad (8)$$

$$Q'[k+1] = \max(R | b_{k+1}^{R} \leq ABW[w]) \quad (9)$$

where, $S_{k+1}^{R}[i]$ denotes the size of a segment with index i in the $(k+1)$-th block with quality list R. τ denotes the segment duration.

In the second quality decision, DBAS regulates $Q'[k+1]$ by considering buffer occupancy and variation rate, to improve the QoE. An extremely high buffer occupancy ($B[k] > B_{high}$), is likely to consume bandwidth due to the buffer overflow. Therefore, this is adjusted one level above the basal quality. However, an extremely lower buffer occupancy ($B[k] < B_{low}$), could result in halted playback due to buffer underflow. Therefore, DBAS adjusts the quality to one level lower than $Q'[k+1]$. U and D are the functions that return one level above and below the argument, respectively as shown in Fig. 7.

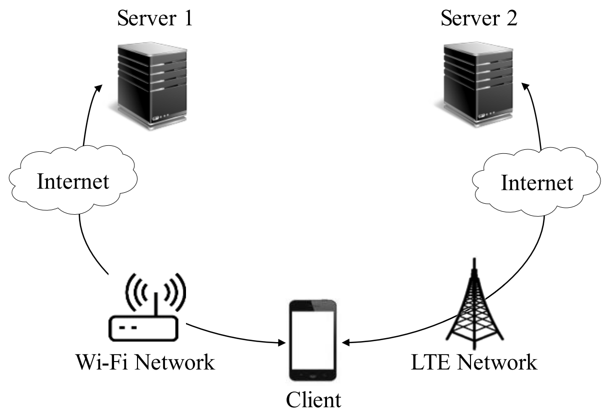

FIGURE 8. Simulation topology.

A moderate buffer occupancy ($B_{low} \leq B[k] \leq B_{high}$) is considered stable, and the regulated quality, $Q[k+1]$, is determined considering the buffer variation rate, to reduce the quality switching frequency and to faster adapt to network alterations. For the buffer variation rates, either a higher β_{high} or lower β_{low} than the buffer variation rate threshold is used, an abrupt network bandwidth variation is considered and the secondary quality is set to $Q'[k+1]$ to faster adapt to network variations.

IV. PERFORMANCE EVALUATION

This section describes the simulation that compared the performance of the proposed DBAS scheme with the existing MPHAS schemes in multiple wireless network environments.

A. EXPERIMENTAL ENVIRONMENT

To evaluate the performance of the DBAS scheme, a network simulator, NS-3 was used and the simulation environment was constructed as shown in Fig. 8. The same video and MPD files were stored on two servers, and the video was composed of 12 kinds of video quality: 700, 1000, 2000, 4000, 5000, 6000, 10000, 12000, 14000, 16000, 20000, and 24000 (Kbps). The video segment length was set to 2 s. The video content used in the simulation reflected the VBR characteristics. Fig. 9 depicts the segment size according to the segment index of the video content. The client implemented the HTTP adaptive streaming player by configuring a Wi-Fi and an LTE network interface to simultaneously request segments using two wireless network interfaces. The experiment was conducted for 300 s using DBAS and the two existing schemes QAVS and CTRA for the client in two scenarios (Scenario 1 and Scenario 2). In Scenario 1, the bandwidths of the Wi-Fi and LTE networks change frequently; meanwhile, in Scenario 2, the bandwidth of the Wi-Fi and LTE networks change frequently, and the bandwidth of the LTE network is significantly reduced by introducing competing CBR traffic between 100 and 200 s.

The client's maximum buffer occupancy of B_{max} is set to 60 s. The low and high buffer occupancy thresholds of B_{low} and B_{high} in the CTRA and DBAS are set to 20 s

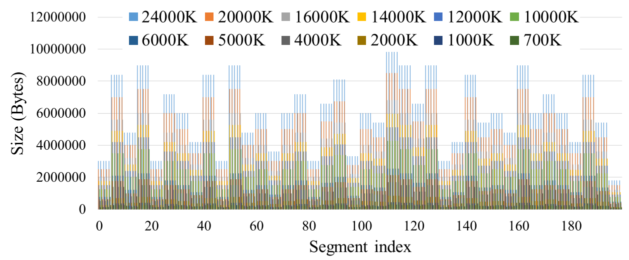

FIGURE 9. Segment size according to segment index.

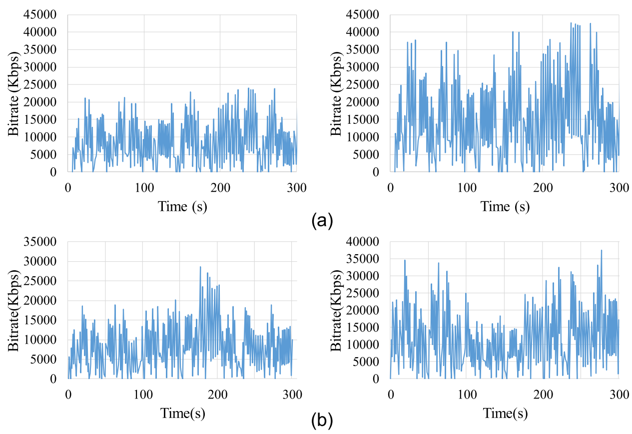

FIGURE 10. Bandwidth change of the Wi-Fi network and LTE network in the simulation. (a) Bandwidth of the Wi-Fi network (Left) and LTE network (Right) for Scenario 1. (b) Bandwidth of the Wi-Fi network (Left) and LTE network (Right) for Scenario 2.

and 40 s, respectively; and the low and high buffer variation rate thresholds of β_{low} and β_{high} are set to -0.15 and 0.15, respectively. L_{max} is experimentally determined and set to 4.

The threshold of the buffer variation rate determines the reaction rate of the DBAS to a network change. If the threshold of the buffer variation rate is too small, there is a problem in that the unnecessary quality switching increases because DBAS reacts quickly to changes in the network. If the threshold of buffer variation rate is too large, DBAS causes playback stalling. Therefore, the appropriate threshold value was determined through repeated experiments.

B. SCENARIO 1: FREQUENT BANDWIDTH CHANGE

Fig. 11 shows the video quality and buffer occupancy of QAVS, CTRA, and DBAS in Scenario 1. QAVS exhibits stable but lower buffer occupancy with frequent bandwidth alterations. QAVS exhibits faster adaptation to network changes and plays videos continuously. However, QAVS experiences frequent quality switching with bandwidth alterations.

BR-MPHAS-based CTRA requests video segments in blocks, and quality switching frequency is significantly reduced due to longer segment request intervals. CTRA employs a buffer occupancy-based quality adaptation algorithm and results in higher average video quality than QAVS. However, CTRA with segment-based scheduling is unstable since DBAS requests video segments in blocks, like CTRA,

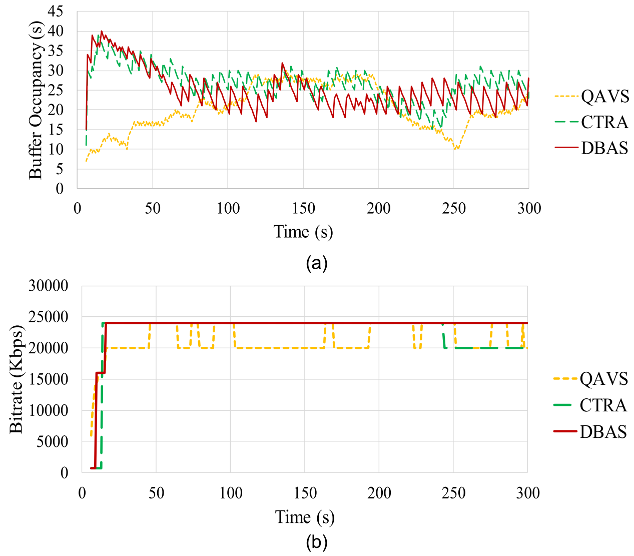

FIGURE 11. QAVS, CTRA, and DBAS in Scenario 1. (a) Video quality. (b) Buffer occupancy.

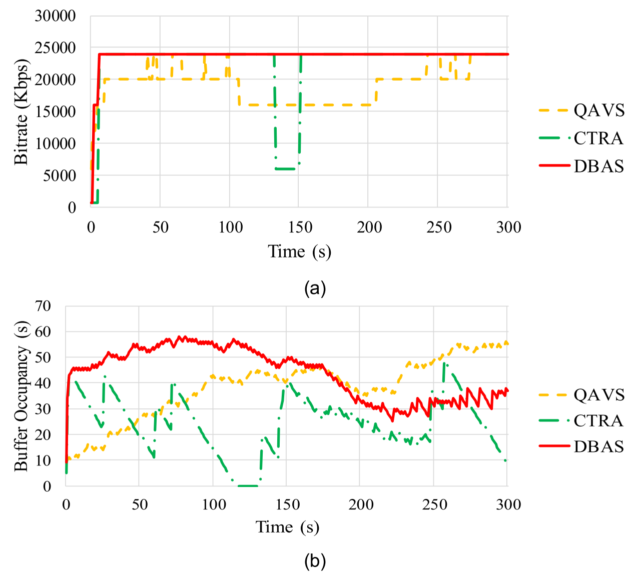

FIGURE 12. QAVS, CTRA, and DBAS in Scenario 2. (a) Video quality. (b) Buffer occupancy.

and the buffer occupancy suffers due to segment reordering. Therefore, the quality switching frequency remained low, even with frequent bandwidth variation. Moreover, the QoE-based block quality adaptation algorithm increases the average video quality in DBAS compared to that in QAVS. Furthermore, the DBAS requests appropriately sized video segments in each path using the partial request-based block scheduling, which reduces segment reordering. Therefore, after 240 s, DBAS exhibits more stable buffer occupancy than CTRA. DBAS continuously requests higher quality than CTRA.

C. SCENARIO 2: ABRUPT BANDWIDTH CHANGE

Fig. 12 shows the video quality and buffer occupancy of QAVS, CTRA and DBAS in Scenario 2. As in Scenario 1, QAVS unnecessarily switches the video quality according to bandwidth fluctuation. When the bandwidth drops rapidly, QAVS exhibit stable bandwidth occupancy due to a shorter request interval. However, due to the fast response, this scheme obtains the lowest video quality.

CTRA requests high quality from 0 to 100 seconds. However, when the bandwidth of LTE rapidly drops, CTRA causes playback stalling. The reason is that the response to the bandwidth variation is slow due to the block length according to the bandwidth ratio in each path. Additionally, even if CTRA receives the requested segment first using Wi-Fi, the video does not play due to the segment reordering problem. Subsequently, CTRA requests low quality segments to increase the buffer occupancy.

DBAS respond rapidly to the additive increase and multiplicative decrease of the block length even if the bandwidth is rapidly changed. DBAS has no delay according to segment reordering due to the partial request method, and its buffer occupancy is stable. As a result, the quality of the video is maintained according to the high utilization of the bandwidth of each path.

D. QoE EVALUATION

In this section, we present the evaluation of the QoE using objective metrics and compare the performance of each schemes based on the experimental results of Scenario 1 and Scenario 2. The average values of QoE metrics from five repeated experiments are measured. We use the average video quality, quality switching frequency, and play back stalling duration as the metrics to analyze the QoE.

We measure the average video quality to quantitatively evaluate the performance of each scheme [22] using equation (10).

$$R_{avg} = \frac{1}{k}\sum\nolimits_{i=1}^{k} Q[i] \quad (10)$$

where, $Q[i]$ denotes the video quality of segment with index i. k denotes the total number of video segments to be requested for playback. The higher average video bitrate improves users' QoE.

Further, the video quality switching frequency is measured along with the average video quality for the quantitative evaluation. The quality switching frequency has a more dominant effect on QoE than the average video quality [23], [24]. The quality switching frequency is calculated using (11).

$$R_{var} = \sum\nolimits_{i=1}^{k} f(Q[i])$$

$$where\, f(Q[i]) = \begin{cases} 1, & if\ i = 1 \\ 1, & if\ Q[i-1] \neq Q[i] \\ 0, & otherwise \end{cases} \quad (11)$$

In (11), $f(Q[i])$ has a value of 1 if the quality of the previous and current segments is unequal and it has a value of 0 if they equal. The quality switching frequency is calculated by adding these values for all the segments. Greater quality switching frequency results in a lower QoE. The video playout time is measured for the quantitative evaluation. Table 1 and Table 2 show the averages of the QoE metric comparison results repeatedly tested in Scenario 1 and Scenario 2.

TABLE 1. QoE metrics comparison in Scenario 1.

	QAVS	CTRA	DBAS
Average Video Quality (Kbps)	22853.2	21304.3	23922.6
Quality Switching Frequency	12.4	2	1.6
Playback Stalling Duration (s)	0	0	0

TABLE 2. QoE metrics comparison in Scenario 2.

	QAVS	CTRA	DBAS
Average Video Quality (Kbps)	20075.1	22099	23922.6
Quality Switching Frequency	12.4	4	1.4
Playback Stalling Duration (s)	0	17.3	0

In Scenario 1, all the schemes play video seamlessly due to the multipath-based transmission, which guarantees stable bandwidth. However, QAVS exhibits lower video quality and higher quality switching frequency. Comparatively, DBAS performs better than QAVS. DBAS achieves a 4.7% higher average video quality and an 87.1% lower quality switching frequency than QAVS. Moreover, DBAS achieves a 12.3% higher average video quality, and similar quality switching frequency compared to CTRA.

In Scenario 2, DBAS achieves a 19.2% higher average video quality and a 88.7% lower quality switching frequency than QAVS. Moreover, DBAS achieves a 8.2% higher average quality and a 65% lower quality switching frequency than CTRA, and no playback stalling occurred.

Hence, the proposed DBAS improves the QoE by reducing the quality switching frequency while providing improved video quality compared to that of the existing schemes, even in a wireless environment where the bandwidth change is very severe.

V. CONCLUSION

HAS services are being employed extensively due to the increasing demand for video streaming services. As mobile terminals support multiple network interfaces and high bandwidth services, such as UHD video streaming, the applicability of MPHAS to simultaneously downloading and streaming video segments, using multipaths, has been investigated.

Here, we propose DBAS with improved QoE, by addressing the limitations in the existing MPHAS schemes, in multiple wireless networks. DBAS uses a buffer-based block length adaptation algorithm and a QoE-based block quality adaptation algorithm to reduce the frequent quality switching in wireless network environments and to adapt quickly to the rapidly changing network environments. We propose a partial request-based block scheduler to prevent segment reordering.

NS-3 was used to compare the performance of DBAS with the existing MPHAS schemes. DBAS improves the QoE by reducing the quality switching frequency and playback stalling and providing higher average video quality than existing MPHAS schemes, in multiple wireless networks.

We will implement the proposed DBAS scheme in real-world multimedia streaming systems to investigate its actual applicability and to evaluate its performance.

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