Low Buffering and Waiting-Time Video-on-Demand Broadcasting Scheme for WiMAX Systems

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ABSTRACT

Providing video-on-demand (VoD) services for mobile devices in next generation networks such as the worldwide interoperability for microwave access (WiMAX) is an important trend. These multimedia services may require mobile devices keeping a large buffer size for video playing and let mobile devices spend a lot of time for waiting the start of the requested video. To improve this drawback, many mechanisms such as reverse fast broadcasting (RFB) scheme and division-base broadcasting (DBB) scheme are proposed to overcome problems of lowering the buffer size and shortening the waiting time for video playing. However, the required buffer size and waiting time are still not acceptable for wireless environment due to the limited buffer size and mobility consideration of the mobile devices. Thus we first propose a proactive scheme named remainder arrangement broadcasting (RAB) to lower the required buffer size. Then, to shorten the start time of video playing, we add the reactive method to RAB scheme named hybrid RAB (HRAB). Simulation results show that RAB will achieve a lower buffer size, which is under 10%, without requiring large bandwidth and HRAB will shorten the waiting time well.

Keywords

algorithm, broadcasting, buffer, VoD, waiting time, wireless, WiMAX

1. INTRODUCTION

VoD applications have been very popular in recent years. These services are delay sensitive and require a lot of bandwidth and disk spaces. It is a very challenging problem that provides such services for mobile devices in wireless environment. The VoD broadcasting system is a typical client-server architecture and can be divided into to parts: proactive [1, 2, 3, 4, 5, 6, 7, 8] and reactive [9, 10] schemes. In the proactive scheme, a video is split up into a number of segments with the same size, which will be periodically broadcasted at the assigned channel. In the reactive scheme, subscribers may request the server for ordering a video at any time, and then the server will classify the similar requesting time of subscribers into a batch. In the meantime the server broadcasts (or multicasts) the required video at an assigned channel. The 802.16 standard [11, 12] can provide high-speed wireless access in metropolitan area network (WMAN) and contain the characteristics of broadband, seamless handover, quality-of-service (QoS), and high transmission rate in all-IP environment, which makes it suitable for mobile multimedia transmission platform.

In the previous studies, the VoD system focuses on diminishing waiting time and buffer requirement. In the proactive VoD, the maximum waiting time is the transmission time of a segment. If a large number of segments has been periodically broadcasted at the assigned channels, it will reduce both the waiting time and the huge bandwidth. Because of the limited resource, the system can not allocate too many channels to broadcast a large number of segments in wireless network. Most of the time, transmitting is only allowed at a single channel in a wireless network [2]. For this reason, there is a problem of huge waiting time which equals to 2–20% of a video length in video transmission of wireless network. In reverse fast broadcasting (RFB) [1], subscribers need to buffer 25–33% of a video. If a 120 minutes video is playing at a 1 Mbps rate, the video size will be 900 Mbytes, so 225–270 Mbytes of buffering and 2–24 mins of waiting time will be required. For mobile subscriber station (MSS) the loading space is limited and the huge buffering will not be suitable in wireless environment.

In this paper, two methods are proposed to reduce the buffering requirement and the waiting time of subscribers on the WiMAX-VoD system. In order to achieve the minimum buffering requirement, the RAB scheme is proposed to rearrange the order of the segments so they can continuously be played one by one. On the other hand, in order to shorten the subscriber's waiting time, the HRAB scheme is proposed to transfer segments under reactive scheme and higher speed transmission in the architecture of adaptive

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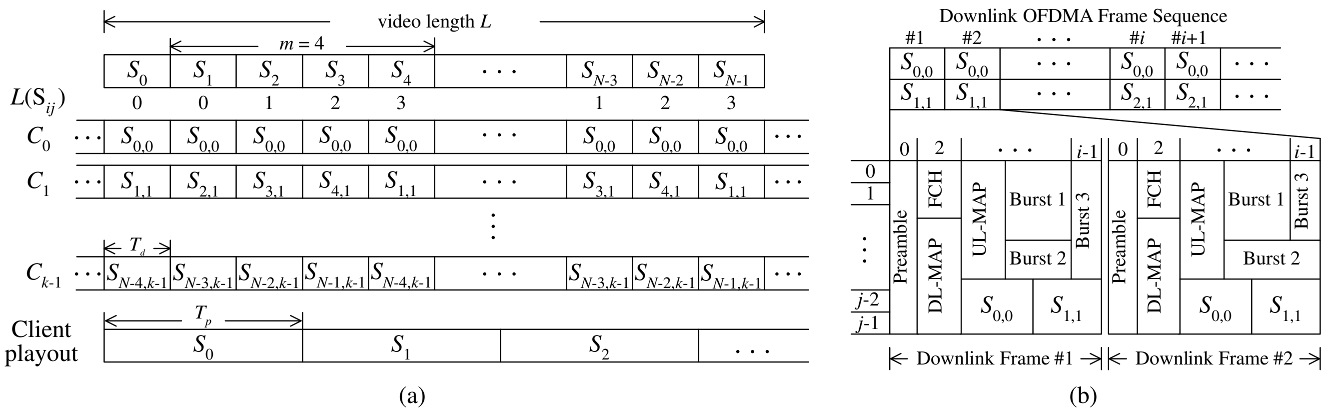

Figure 1: An illustration of the VoD system in WiMAX system; (a) the VoD program (b) the OFDMA downlink frame structure.

modulation and coding (AMC), thus the waiting time will be greatly reduced.

The outline of this paper is as follows. Section 2 describes the system model; Section 3 provides RAB and HRAB schemes in detail; Section 4 describes our implementation of proposed scheme results comparing proposed scheme performance with RFB and DBB schemes. Finally, the conclusion and the future works are discussed in Section 5.

2. SYSTEM MODEL

To evaluate the performance of the video broadcast scheme, a VoD system model is constructed first. Suppose that the VoD broadcasting system will periodically broadcast a video film of size L for supporting VoD services to the subscribers. For the reason of successful transmission possibility, the video film will be divided into N independent segments denoted by $\mathbb{S} = \{S_0, S_1, \ldots, S_{N-1}\}$, where $\mathbb{S}$ represents the set of these segments. The size of segment i denoted as $|S_i| = L/N$ is assumed equal. These segments are scheduled and broadcasted at k independent channels denoted as $\mathbb{C} = \{C_0, C_1, \ldots, C_{k-1}\}$ as shown in Figure 1. In order to service all subscribers, the data rate of each channel is transmitted in the basic rate denoted as D_b and the total needed bandwidth for broadcasting the video film is kD_b. Assume each subscriber needs a video playing rate P_r to play a video and it satisfies the condition $P_r \leq D_b$, which means that the download rate should be faster than the play rate so that the subscriber can obtain enough data for process. This proposition is called the playback ratio α and is given by

$$\alpha = \frac{D_b}{P_r} \geq 1. \quad (1)$$

According to α, the VoD broadcasting system can determine a tolerant time period for the download subscribers that subscribers can just play the needed segment from their buffer if they have downloaded a S_i from the server. Since, in proactive scheme, the first segment S_0 should be repeated in channel C_0 for a new entry, the tolerant time period of each C_i will be

$$\begin{cases} m = 1, & \text{if } C_0 \\ m = \lfloor\alpha\rfloor + 1, & \text{otherwise} \end{cases}, \quad (2)$$

where m represents the number of segments in one period. Let S_{ij} represent S_i allocated in C_j and the group of segments allocated in C_j be $\mathbb{S}_j = \{S_{ij}\}$, where $i = mj - \lfloor\alpha\rfloor + 1, \ldots, mj$ and $j = 1, \ldots, k-1$. That is, $\mathbb{S}$ is partitioned into $\{\mathbb{S}_0, \mathbb{S}_1, \ldots, \mathbb{S}_{k-1}\} = \bigcup_{i\in I} \mathbb{S}_i$, where I is an index set, and allocated into k channels as shown in Figure 1.

Thus, based on k and m, one video film can be divided into N equal size segments and given by

$$\begin{aligned} N &= (k-1)m + 1 \\ &= (k-1)(\lfloor\alpha\rfloor + 1) + 1 \\ &= k\lfloor\alpha\rfloor + k - \lfloor\alpha\rfloor - 1 + 1 \\ &= km - \lfloor\alpha\rfloor. \end{aligned} \quad (3)$$

Notice that, for each new entry, i.e., the new subscriber of the VoD broadcasting, it will spend a waiting time $T_w \leq |S_i|/D_b$ for getting start of video playing whenever they enter the system. In this paper, we assume that S_i can be played immediately as soon as it is being downloaded. The location of S_{ij} denoted as $L(S_{ij})$ is used to indicate the S_i used to broadcast in C_j, where $0 \leq L(S_{ij}) \leq m-1$ and segments in C_j are from $S_{(mj-\lfloor\alpha\rfloor+1)j}$ to $S_{(mj)j}$, where $j \in [1, k-1]$.

The playback time T_p, which is defined as the time the subscriber needs to play a segment, can be calculated as $T_p = |S_i|/P_r$. The download time T_d represents the required time that a segment is downloaded from the server to the subscriber and is equal to $T_d = |S_i|/D_b$. Thus the playback ratio can also be represented as $\alpha = T_p/T_d$ and is subject to $T_d \leq T_p$. Let t_d and t_s denote the time that the subscriber demands the service and the time that the subscriber starts to download the first segment. Thus $T_w = t_s - t_d$, $0 \leq T_w \leq T_d$.

Let t_{ci} denote the starting time of S_{ij} first appears after the demand of the subscriber, t_{ni} represent the starting time of the next S_{ij} appears and $t_{ni} = (t_{ci} + mT_d)$, and t_{ui} denote the time the subscriber needs to demand the segment S_{ij}, where $t_{ni} \leq t_{ui}$. In the reactive scheme, let γ and ρ be the time the server prepares a video film for downloading and the time the subscriber spends for waiting services, respectively. The waiting time ρ satisfies $\gamma \leq \rho \leq T_d$. Thus, the user tolerable waiting time T_w is given below

$$\begin{cases} 0 \leq T_w \leq T_d, & \text{proactive scheme} \\ \gamma \leq T_w \leq \rho, & \text{reactive scheme} \end{cases}. \quad (4)$$

Assume a subscriber needs a minimum required buffer size $\beta(t)$ to store the downloaded file for playing. The buffer size can be calculated as

$$\begin{aligned}\beta(t) &= t(nD_b - P_r) \\ &= t(n\alpha P_r - P_r) \\ &= tP_r(n\alpha - 1), \end{aligned} \tag{5}$$

where n denotes as the number of unplayed segments stored in the buffer during the time interval t. Let D_h and $\lfloor\alpha\rfloor'$ represent the higher channel transmission rate and playback ratio, respectively. The ratio between original transmission rate is $D_h/D_b = \lfloor\alpha\rfloor'/\lfloor\alpha\rfloor = \sigma$; The segment downloading time is $T'_d = T_p/\lfloor\alpha\rfloor'$.

In the system model, the environment is assumed that consists of the following qualities: 1)The subscribers can bring up their demands anytime and download while playing the film when the next S_{00} occurs; 2)The subscriber can download multi-channels' data at the same time; 3)Breaking off is not available when the subscriber is playing films; 4)The subscriber can start playing data as soon as it starts receiving or downloading; 5)The subscriber has its own buffer and it can receive and store new data while playing data; 6)The buffer has enough capacity to store the data; 7)The subscriber starts receiving broadcast data after it demands playing the data.

3. PROPOSED SCHEMES

The transmission system considered in this paper is the IEEE 802.16-2004 standard and the physical (PHY) layer uses orthogonal frequency division multiple access with time division duplex (OFDMA/TDD) scheme for data transmissions. Two channels are used to broadcast video and films ready for broadcasting will be divided into similar sizes at downloading frame and broadcasted cyclically by modulation intensity of the minimum modulation at two virtual VoD channels.

These two virtual VoD channels are constructed by OFDMA burst that also interpret VoD burst's information at DL-MAP. In this system, only two channels are used with the lowest transmission modulation for servicing most subscribers. D_b uses QPSK-1/2 modulation's transmission rate in WiMAX. For example, QPSK-1/2's data rate $\sim$ 3 Mbps; a MPEG1-encoded playback rate $\sim$ 1 Mbps, $\lfloor\alpha\rfloor$ = 3 Mbps/1 Mbps = 3. There are still more encoded formats at the format of video, such as MPEG2, MPEG4, H.264, RM (real media) [15, 16]. In addition, the audio can also be used in this type of application, like moving picture experts group audio Layer3 (MP3)-encoded audio which has a playback ratio of 128 Kbps. In this paper, the $\lfloor\alpha\rfloor$ as integer and larger than 1. By this method the leftover data in the buffer can be broadcasted when MSS is under interference with abnormal video playback or processing handover.

From the framework mentioned above, a subscriber will meet a large buffering capacity which is a heavy burden to the mobile devices. The buffering requirement can be greatly reduced after adding RFB, but segments will still continue to download when $t_{ni} \geq t_{ui}$. However the waiting time is still too long for subscriber with a single channel in wireless. Therefore, the RAB and the HRAB are proposed to the problems of buffer requirement and waiting time.

3.1 RAB Scheme

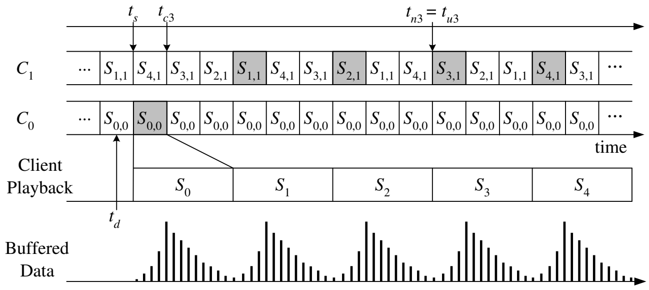

Figure 2: An illustration of segment downloading of RAB when $m = 4$.

Generally the order of the broadcasting scheme is assembled according to the order of the segment. Different channels will have different segments placed. Suppose there are k channels, the segment numbering on the i channel C_j will be 2^{i-1} to $2^i - 1$, but it will be downloading multi-segments at the same time. In order to minimize the buffer requirement, a new segment will be played closely after the previous segment. Such method can be achieved when $t_{ni} = t_{ui}$. In order to reach this goal, the order of segments on a channel must be adjusted.

By using the playback ratio and the order on each channel, the order of a broadcasting period can be recalculated. At the initiation process S_{ij}, $i \in [1, N-1]$, is arranged according to the segment number in the broadcasting period. The server will know the rate of video playback and the smallest rate of transmission in the system, so the $\lfloor\alpha\rfloor$, N and m can be calculated. The location of S_{ij} in broadcasting period is $L(S_{ij})$, and we know the required buffer to play out more than the playing and downloading the film at the same time based on the equation (5). The minimized required-buffer can be achieved as the different time between S_{ij} and $S_{(i+1)j}$, witch is equal to T_p ($\lfloor\alpha\rfloor T_d$). Therefore, we can re-arrange $L(S_{ij})$ within broadcasting period to have the $\lfloor\alpha\rfloor T_d$ intervals between both S_{ij} and $S_{(i+1)j}$, it can be calculated as

$$L(S_{(i+1)j}) = (\lfloor\alpha\rfloor + L(S_{ij})) \textbf{ mod } m. \tag{6}$$

The location of first segment in broadcasting period is 0 as initialization, $L(S_{(i+1)j})$ is calculated by both $L(S_{ij})$ and $\lfloor\alpha\rfloor$ until all locations of segments are re-calculated. If there is 0 after the calculation $L(S_{(i+1)j})$, then the $L(S_{(i+1)j})$ will be placed on the last position. Algorithm 1 presents the detailed descriptions of scheduling $\mathbb{S}$ to corresponding $\mathbb{C}$. In Figure 2, for example, $\lfloor\alpha\rfloor = 3$ and $m = 4$. Therefore, a continuously film will be cut into 5 same sized segments ($N = 5$). S_{00} will be broadcasted at channel 0, and S_{11} to S_{41} will be broadcasted cyclically at channel 1. Segments downloaded by a subscriber are colored gray. Below the graph is the subscriber's usage on the capacity of buffer. $L(S_{11})$ is equal to zero, $L(S_{21}) = (3 + 0)$ **mod** $4 = 3$. After the calculation $L(S_{11})$ to $L(S_{41})$ are $0, 3, 2, 1$, and the location after re-arrangement are $S_{11}, S_{41}, S_{31}, S_{21}$. When subscriber demand the film, it will wait until $d/2$'s time over and then start to download S_{00}. After that, it will download according to the order of the series S_{11} to S_{41}. When a subscriber is downloading the segment, it will follow the algorithm of RFB to make each download correspond to $t_{ni} = t_{ui}$. This will make every $t_{ni} = t_{ui}$ minimized as a

Algorithm 1 RAB Algorithm

The basic date rate D_b and the video playing rate P_r in the system
$\alpha \leftarrow D_b/P_r$
$m \leftarrow \lfloor\alpha\rfloor + 1$
$N \leftarrow km - \lfloor\alpha\rfloor$
for $j = 1$ to $k-1$ **do**
    $L(S_{(jm-\lfloor\alpha\rfloor)j}) \leftarrow 0$
    for $i = (jm - \lfloor\alpha\rfloor + 1)$ to jm **do**
        $L(S_{ij}) \leftarrow (\lfloor\alpha\rfloor + L(S_{(jm-\lfloor\alpha\rfloor)j}))$ **mod** m
    end for
end for
SortSegment($L(S_{ij})$)
for $j = 0$ to $k-1$ **do**
    if $j = 0$ **then**
        $C_0 \leftarrow S_{00}$
    else
        for $l = L(S_{jm-\lfloor\alpha\rfloor,j})$ to $m-1$ **do**
            S_t=MappingSegment(l,j)
            $C_j \leftarrow S_t$
        end for
    end if
end for

result of the data in each buffering.

3.2 HRAB Scheme

On a normal proactive method, the server will frequently broadcast segment S_{00} at channel 0. This way subscribers can receive the first segment anytime after entering the system. The largest waiting time is equal to the transmission time of a segment T_d, and the average waiting time is half of T_d. The length of the waiting time is determined by the number of the segments and the data rate of transmission $T_d = |S_i|/D_b$. In the proposed scheme, the number of segments is small because the playback ratio $\lfloor\alpha\rfloor$ is used as the parameter of segment. Thus the average waiting time is too long for subscribers. For example, an one hour video clip is deviled into five equal segments, $T_p = 60/5 = 12$ mins. Then the transmission time for one segment is $T_d = T_p/\lfloor\alpha\rfloor = 4$ mins, ($\lfloor\alpha\rfloor = 3$), and the average waiting time is $T_d/2$=2 mins. Hence, we use the reactive method to reduce the waiting time.

At tolerate time, when each subscriber requests service from the server, reactive batch scheme can give the same downloaded video to each subscriber after all demand batch and in the AMC scheme is provided within the PHY layer in WiMAX system, so it can supply different modulation on each connection. By using high modulation, the transmission time is shorter than using low modulation and will increase the release of resource soon. Combining the advantage of reactive and the AMC scheme, the waiting time of subscriber will be greatly lowered to the maximum $\rho + \gamma$. The δ can be calculated as

$$\begin{cases} T_w > (\rho+\gamma), & T_w = (\rho+\gamma) \\ T_w \leq (\rho+\gamma), & 0 \leq T_w \leq (\rho+\gamma) \end{cases}. \quad (7)$$

If $T_w > (\rho+\gamma)$, the server will batch the demand within the period after ρ waiting time, and reactively playback segment 0. If $T_w \leq (\rho+\gamma)$, the server will make subscribers wait until the next segment 0 is being broadcasted. Figure 3 assumes $T_w > (\rho+\gamma)$, which will be discuss at normal and the worst conditions.

- **Normal Case:** The subscriber enters the system at time t_{d2}, and provides segment 0 to subscriber with high data rate D'_b (the maximum tolerable high modulation for subscribers) after waiting time T_w. S_{11} can revive right after the S_{00} playback, and then it uses the server broadcasting data to continue receiving.

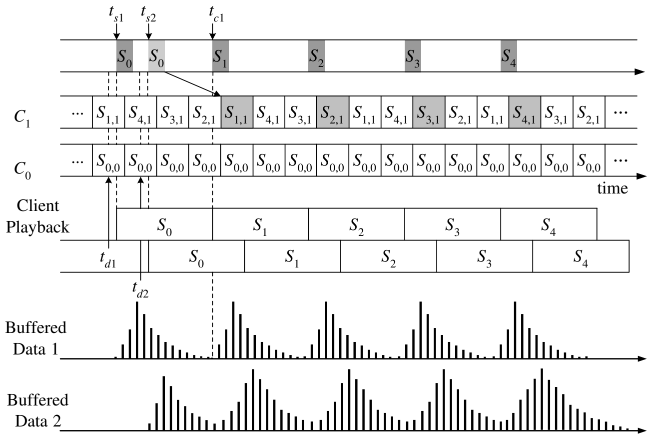

Figure 3: An illustration of segment downloading of HRAB when $m = 4$.

- **Worst Case:** The subscriber enters the system at time t_{d1}, and it also provides segment 0 to subscriber with high data rate after waiting time T_w. However S_1 will not be received after the playback of S_{00}; when the S_{00} finished, the server has to receive the segments coming afterwards. In this case it will can generate more burden to the system comparing with the normal case, but it will only happen on one segment in one broadcasting cycle. Its average appearance probability is $P = 1/m$ plus the tolerable subscriber waiting time ρ. Therefore the probability of the worst case is defined as

$$P_w = \frac{1}{m}(1 - \frac{\rho}{d}). \quad (8)$$

4. SIMULATION RESULTS

The system-specific parameters IEEE 802.16e protocol and the VoD broadcasting system parameters used are shown in Table 1 and Table 2, respectively.

Table 1: Parameters Used in WiMAX

Parameter	Value
Spectrum (GHz)	2.40–2.46
Bandwidth (BW) (MHz)	20
FFT size (N_{FFT})	2048
DL/UL ratio	3:2
OFDMA frame length (ms)	5
Useful symbol time (T_b) (μs)	91.4
Guard time ($T_g = T_b/8$) (μs)	11.4
OFDMA symbol time ($T_o = T_b + T_g$) (μs)	102.9
No. of subchannels	60
No. of OFDMA symbol per frame	48
Avg. time of internet delay (T_{ID}) (ms)	50
Avg. time of frame synchronize (T_{SYN}) (ms)	5
MSS⇆ SBS (1frame*2way) (ms)	10
SBS⇆ TBS (1frame*2way) (ms)	10

Referring to (5), the needed buffer size of downloading and broadcasting can be calculated, and the download time

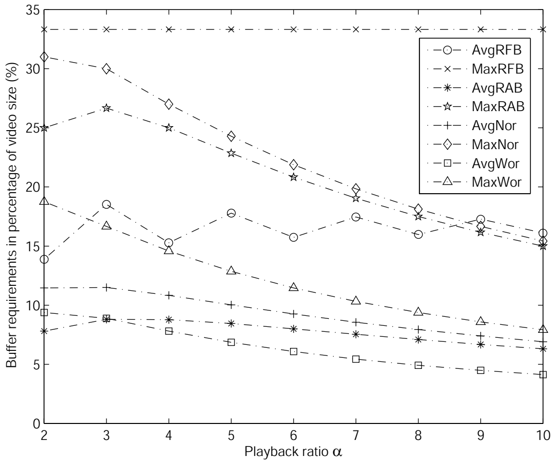

Figure 4: Comparison of required buffers.

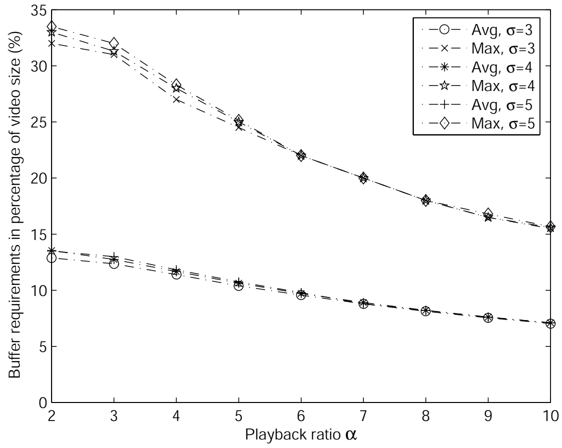

Figure 5: Comparison of required buffers of the HRAB normal case.

Table 2: Parameters Used in VoD

Parameter	Value
Video size L (Mbyte)	900
Number of channels k	2
Minimum transmission rate D_b (Mbps)	2–3
Playback rate P_r (Mbps)	0.3–1
Playback ratio $\lfloor\alpha\rfloor$	2–10
Broadcasting period m	3–11
Number of split video N	4–12
Playing a segment time T_p (s)	1800–600
Downloading a segment time T_d (s)	900–60
Number of downloading segments n	0–2
Preparing time of system γ (s)	1
Waiting time that subscribers can tolerate ρ (s)	10

is denoted as T_d. When the size of a time slot is the downloaded segment time, the total video playing time is $N\lfloor\alpha\rfloor$ slots, and required buffer of each slot has to add up the previous leftover. The first slot can be calculated as

$$\beta_{slot_0} = T_d D_b(n\lfloor\alpha\rfloor - 1), \quad (9)$$

The $i \in [1,\ N\lfloor\alpha\rfloor]$ slot is shown as

$$\beta_{slot_i} = \ \beta_{slot_{i-1}} + T_d P_r(n\lfloor\alpha\rfloor - 1), \quad (10)$$

The total buffer from downloading video and finishing playback will be

$$\beta_{Total} = \sum_{i=1}^{N\lfloor\alpha\rfloor} \beta_{slot_i}. \quad (11)$$

In HRAB scheme, buffer can be calculated as

$$\begin{aligned}\beta_{HRAB} &= T'_d D_b(n\lfloor\alpha\rfloor' - 1)\\ &= \frac{T_d}{\sigma} D_b(n\sigma\lfloor\alpha\rfloor - 1)\\ &= T_d D_b(n\lfloor\alpha\rfloor - \frac{1}{\sigma}). \quad (12)\end{aligned}$$

Figure 4 illustrates the relationship between the buffer requirements in percentage of video size and the playback ratio $\lfloor\alpha\rfloor$ on two channels, and it compares the average and maximum buffer size of RFB (AvgRFB, MaxRFB), RAB (AvgRAB, MaxRAB), HRAB normal (AvgNor, MaxNor) and the worst (AvgWor, MaxWor) case ($\sigma = 2$). As shown in the figure, the average and maximum buffer requirements of RFB is much larger than RAB and HRAB because RFB will not cut more segments as $\lfloor\alpha\rfloor$ increased. For the maximum value, MaxRFB will need 33% of a playing video. The required buffer ranges of MaxRAB, MaxNor and MaxWor are 15% to 26%, 15% to 31%, and 8% to 18%. The MaxNor will use more buffer than MaxRAB since the channel transmission rate used by HRAB is higher than RAB, so it will waste more buffer in downloading s_0. For an average value, AvgRFB and AvgNor need buffer ranges of 14% to 19% and 7% to 12%. AvgRAB and AvgWor can both be lowered to below 10%. Figure 5 and 6 depict the normal and worst case of HRAB when σ increase the needed buffer size. In this case, it will not increase substantially needed buffer requirement as σ increasing, and the download time T'_d will decrease to $1/\ \sigma$ while σ increasing. For the maximum value, the required buffer ranges of $\sigma = 3$ to 5 are 16% to 33% in the normal case and 8% to 22% in worst case. For the maximum value, the required buffer ranges of $\sigma = 3$ to 5 are 7% to 14% in the normal case and 4% to 12% in worst case.

To compare RAB, HRAB, RFB, and DBB of a 7200s video length, the initialization average waiting time are shown in Figure 7. In the RFB scheme the range of waiting time is from 120 to 600s. In the DBB scheme, to use the best average waiting time to compare, the range of waiting time is from 144 to 1440s. The RAB and HRAB each needs 31 to 417s minimum waiting time (depending of the tolerable subscriber's waiting time ρ). In the HRAB, worst case can achieve the minimum buffer requirement and minimum waiting time, but it will cause a heavier burden to the system. Referring to (8) the probability of the worst case can be calculated, shown in table 3.

Table 3: Probability in worst case

Playback Ratio ($\lfloor\alpha\rfloor$)	1	2	3	4	5
Probability (%)	49.79	32.96	24.47	19.33	15.85
Playback Ratio ($\lfloor\alpha\rfloor$)	6	7	8	9	10
Probability (%)	13.33	11.40	9.87	8.61	7.57

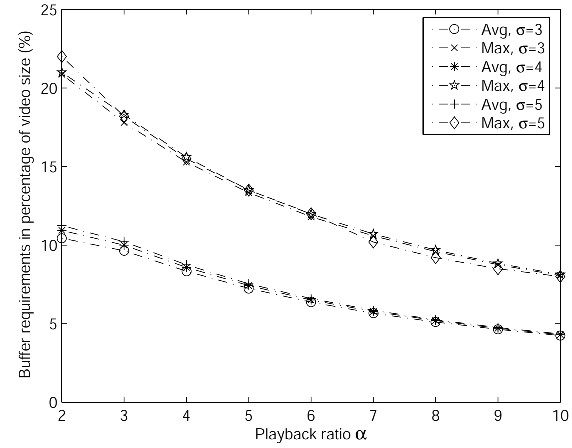

Figure 6: Comparison of required buffers of the HRAB worst case.

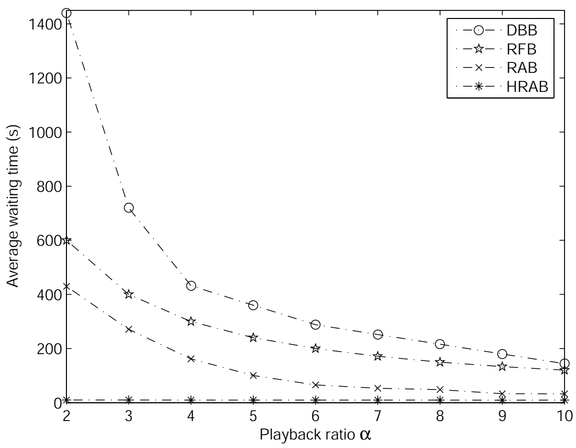

Figure 7: Average waiting time.

5. CONCLUSIONS

This paper proposes the RAB and HRAB schemes to reduce the size of required buffer and the waiting time of scribers in the WiMAX-VoD system according to the parameter α, which is obtained from the ratio of download rate and video playing rate. Simulation results show that RAB and HRAB can efficiently decrease the required size of buffering under 10% of the size of video and reduce the waiting time as lower as possible for subscribers. Specifically, since it only require the subscriber to maintain a lower buffer size, it is very suitable for applications in mobile devices. Moreover, by considering the mobility of MSSs, the RAB can be investigated further for supporting VoD broadcasting among mobile wireless network. In the future, power saving framework and current VoD broadcasting system will be added into the system for further analysis and comparison.

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