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PAPER

An Effective Hybrid Harmonic Staircase Broadcasting Protocol (HaSB) for Video-on-Demand System

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ABSTRACT

Video on demand (VoD) system is a service that enables the users to choose a video at any time and watch it. VoD systems have different protocols with different strategies for dividing the video segment and sending it by channels. The protocols in VoD have different analyses depending on several metrics that assess the performance, such as server bandwidth, client waiting time, and client buffer requirement. That can help the user to watch the video at any time they are needed, which reduces the waiting time when they select the video and start watching it. This paper proposes a new hybrid broadcasting protocol to link the advantages of harmonic and staircase broadcasting protocols for VOD to reduce the delay time once the viewer starts to stream the video and view it, where the buffer requirement of the client is reduced. HaSB protocols have integrated harmonic broadcasting (HB) protocol and staircase broadcasting protocol (SB) to obtain the strengths of small client waiting time and low client buffer space. Furthermore, HaSB has improved the buffer requirement in HB protocols and improved the waiting time in staircase broadcasting protocols. Finally, the obtained results show that the waiting time is 15 seconds and the buffer requirement is less than 25% with a bandwidth of Mbps. HaSB can produce a suitable result in reducing the waiting time and buffer requirement when compared with other broadcasting protocols.

KEYWORDS

video on demand (VoD), harmonic broadcasting (HB) protocol, staircase broadcasting protocol (SB), HaSB protocol

1 INTRODUCTION

Video on demand (VoD) service has been experiencing explosive growth with the rapid advancement in wireless networks. Considering the forecast that 75% of the mobile data traffic in the world will be consumed by video by 2029 [1]. VOD is widely used in our daily lives and typically requires particular quality of service (QoS) parameters to be achieved [2–4]. Furthermore, several proposed techniques for the VOD assist a viewer in viewing a video in less waiting time.

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The server permits the user to view any selected videos to enjoy seamless video playback control without any delays. The primary cause of the VOD's great success is that every customer needs a unique channel with high bandwidth and high-quality video data. Additionally, the VOD service enables real-time viewing or "downloading" of the film, which is then brought to a Set-Top Box (STB) and begins to play [1]. Aside from that, the VOD, which breaks a video into several chunks, is the primary task for the broadcast protocol. The segments are inside the server and are broadcast over channels in a cycle. However, in the client, users must wait for the first segment that is received by particular channels before they may download or view a movie. All of the video's segments are saved in the buffer before the first one begins to play, and hence, they may all be accessible for playback and watched one after the other.

Additionally, several broadcasts have been enhanced and created during the past few years to provide VOD services. In the previous research paper [5], the most relevant broadcasting protocols were discussed based on the client waiting time versus server bandwidth and bandwidth requirements with a buffer at the client end, such as staggered broadcasting (SB) [6]. The server allows K channels to carry out the video program's transmission. There is a constant rate b, or the same pace of video playing, in every channel. In SB, the maximum client waiting time is denoted as L/K, where L represents the duration of the video program. With the pyramid broadcasting (PyB) protocol [7], a video program is segmented into different K parts of progressively larger geometric sizes. These pieces are afterward directed over several channels by using an identical bandwidth.

A video program is fragmented into 2(K-1) segments in the fast broadcasting (FB) protocol [8], where K represents the number of accessible channels. The broadcast portions 2i-1 to 2i-n in chronological order on channel Ci. It is believed that the maximum client waiting time is L/(2K-1). The FB protocol attains a lower client waiting time when compared to the combined use of the SB and PyB protocols. The authors suggested a new pagoda broadcasting protocol (NPaB) [9] based on the pagoda broadcasting scheme (PB) [10] to fragment a video program into fixed-size segments and map it into equal bandwidth of data channels.

The appropriate lowering frequencies are consumed to conduct the process. This protocol led to the NPaB protocol taking a shorter waiting time than the FB protocol. By putting out the recursive frequency splitting (RFS) protocol, Paris and Long [11] have developed the NPaB protocol. The client's waiting time is served as the basis for this improvement. Furthermore, broadcasting a section extremely near its frequency based on this protocol is the fundamental idea behind the RFS protocol. [12] has suggested the greedy broadcasting protocol, which is identical to the RFS protocol, and dignified the segment-to-channel mapping as a Windows scheduling problem. However, the RFS protocol, where the number of video segments refers to N, is influenced by the computational complexity of O(N Log N). The first stage in the harmonic broadcasting (HB) protocol [13] [14] is to break a video into different equal-sized segments. These segments are then further horizontally split into different sub-segments of equal sizes. Based on the harmonic series is this further division.

The sub-segments of a similar segment Si are aired with bandwidth b/i on a similar channel. In [11], a piece of evidence is detailed such that the HB protocol consumes the same server bandwidth while requiring the least amount of client waiting time. Similarly, it is shown in [15] that video data delivery over this protocol cannot be sustained at a predetermined time. In contrast, the highlighted issue was overcome by the quasi-harmonic broadcasting (QHB) and cautious harmonic broadcasting (CHB) protocols that were presented [15].

The reduction of client waiting times is the primary goal of all the aforementioned studies. Nevertheless, for clients to receive and store video data, they need to have more bandwidth and buffers. Several studies have looked into ways to reduce buffer and bandwidth needs at the client end to address this weakness. The skyscraper broadcasting (SkB) protocol, which enables the client to download video material over two channels, was proposed in [16]. A customer can be able to download video data from a limited number of channels with the support of the customer-centric approach (CCA) [17]. It is commonly known that this protocol is a generalization of the SkB protocol since every transmission group may receive more than two channels. Nevertheless, unlike the SkB protocol, the CCA protocol could make use of additional client bandwidth. As a result, protocols cut down on client wait times. To methodically examine the resource requirements, [18] developed the GDB protocol (i.e. client buffer space, server bandwidth, and client bandwidth).

Similar to the FB protocol, the Staircase Broadcasting (StB) protocol [19] acquires a similar client waiting time. A client must buffer 25% of the video that is currently playing. This is half of what the Facebook protocol calls for. Additionally, the StB protocol requires double as much client bandwidth as the video playback rate. The Modified Staircase Broadcasting (MSB) protocol supports smaller waiting times, increased client bandwidth, and client buffer space in comparison to the StB protocol [20].

The interleaving staircase harmonic broadcasting (ISHB) protocol combines the SB and HB protocols [21]. The objective of this protocol is to attain a favorable trade-off between client buffer space and waiting time. There exists a theoretical lower bound for the HB protocol, which is somewhat less than the client waiting time. Compared to ISHB, the SB procedure has a longer waiting period. Furthermore, it shares the SB protocol's client buffer space. Furthermore, the ISHB protocol may be able to prevent the deterioration of visual quality brought on by packet loss. While just 25% of a playing video is delayed, the Facebook protocol has the same client waiting time as the reverse fast broadcasting (RFB) protocol [22]. Both the RFS and the RFB are combined in the hybrid broadcasting (HyB) protocol in [22–23]. The reverse greedy disk-conserving broadcasting (RGDB) protocol [24] is an extension of the GDB protocol that uses reverse segment transmission and lazy segment downloading to produce a client buffer space that is 33%–50% lower than that of the GDB protocol. To reduce the client buffer space, a set of broadcasting protocols was recently presented by [25–27] that combine the SB protocol with the PB, SB, FB, RHB, and PFB protocols. Many more relevant broadcasting protocols have been introduced in [26]. This paper discusses two of the most important protocols used for the VOD system (HB and SB protocols) [28–29].

2 RELATED RESEARCH

2.1 Harmonic broadcasting

Similar to staggered broadcasting, HB dates back to [3], [4], and [5]. When compared to other earlier-developed protocols, it has the lowest bandwidth to achieve the shortest access time. One issue with this protocol is that it occasionally fails to send data on time. Juhn recommended a delay at the beginning of video consumption as a solution to this problem in [4], [5]. After that, the problem arises directly.

The HB protocol fragments the video into k same-size segments {S1, S2, S3, …, Sk} and sends them in different logical channels to decrease the bandwidth. The size of the i[th] segment is S_i, where this segment splits vertically into sub-segments with a similar size {S_i1, S_i2, S_i3, …, S_ik}. Assume that there is a video with length D the consumption rate of the video is b, and the size of the video is S = D*b, and afterwards, the viewer waiting time is represented as follows:

$$d = \mathrm{D/N} \quad (1)$$

Where N is a positive integer. Furthermore, every segment is transmitted into multiple channels with different bandwidths b/i, where b denotes the stream's bit rate {b, b/1, b/2, b/3, …, b/i} respectively within each channel, (see Figure 1). The total bandwidth for a video can be represented as follows:

$$\mathrm{B} = \sum_{i=0}^{n} \mathrm{b}/\mathrm{i} = \mathrm{Hn} * \mathrm{b} \quad (2)$$

Where, $\mathrm{Hn} = \sum_{i=1}^{n} \mathrm{i}/\mathrm{n}$ is denotes the harmonic number of N.

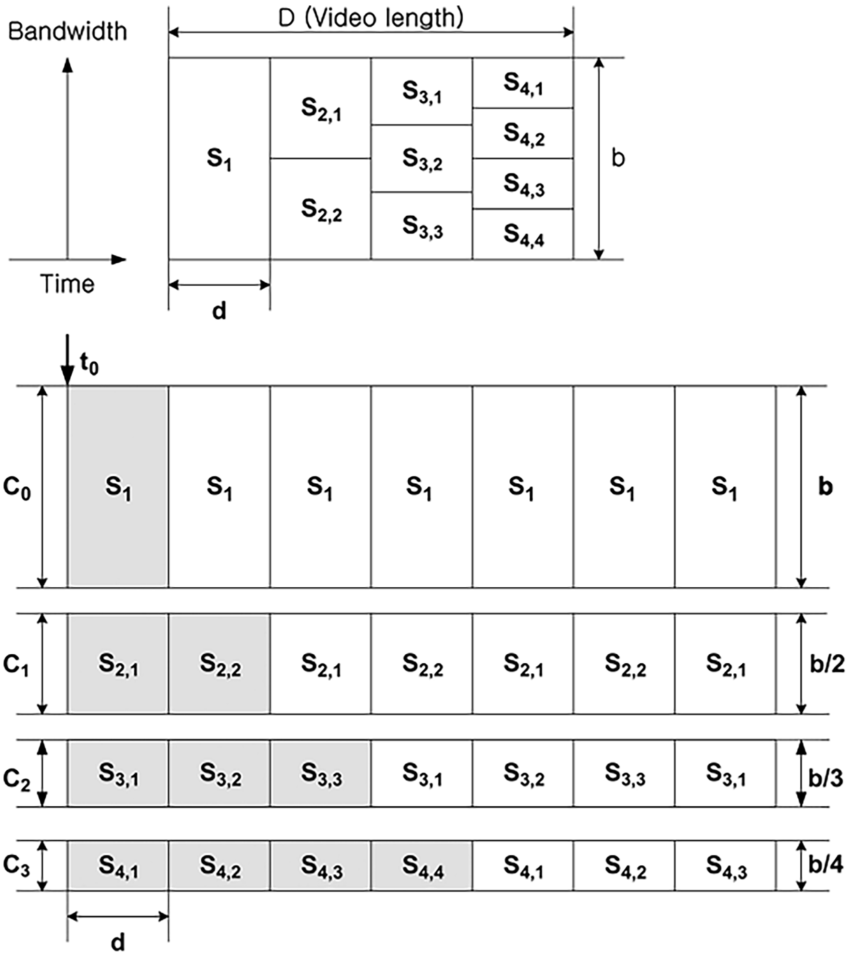

Fig. 1. Harmonic broadcasting (N = 4)

To decrease system complexity and client waiting times, Figure 1 illustrates an increase in the number of segments. However, assuming the time that can start to load the S_1 from C_1 at t_0, HB has local storage on the client side to play the video. It is necessary to buffer the time, which begins at t_0 + (i – 1) d and ends at t_0 + i*d from C_i + 1 to C_N. To write the data through to the buffer during this time interval, the data size is represented as follows:

$$I_i = \frac{S}{N} * \sum_{j=i+1}^{N} 1/j[1 <= i < N] \quad (3)$$

To display the amount of output data that should be read from the buffer between t_0 + (i – 1) d and t_0 + i*d, the following formula for this action is represented as follows:

$$O_i = \frac{S}{N} * i - 1/i[1 <= i < N] \quad (4)$$

Moreover, the following can be used to display the buffer size requirement:

$$Z_i = I_i \text{ and, } Z_i = Z_i - 1 + I_i - O_i \quad (5)$$

The requirements of the disk transfer rate that represent the read and write requirements from t_0 + (i – 1) d to t_0 + i*d are $W_i = b * \sum_{j=i+1}^{N} 1/i[1 <= i < N]$ and, $W_N = 0$. In the read transfer rates R_i = b*(i – 1)/i [1 <= i < N], then the disk transfer rate requirements are ω = W_i + R_i. If N = 1. This implies that it is not necessary to obtain disk transfer rate requirements. Nonetheless, if N >= 2 has ω1 = ω2 = b*(1/2 + … + 1/N) = b* (HN – 1) and {ωi < ω2, i > 2}, then the requirement of the disk transfer rate will be (HN – 1)*b. Additionally, the HB protocol obtains efficient results in decreasing the viewer's waiting more than other existing protocols when the video length is 120 minutes, and four video channels are allocated bandwidth with a consumption rate of 10 Mbps.

In comparison to other protocols, for instance, pyramid, permutation-based pyramid, staircase, and rapid broadcasting protocols, HB performs more effectively in terms of spectator waiting time, with a duration of approximately four minutes. Moreover, disk I/O rates of about 30 Mbps obtain the most effective results when HB is being consumed. About 3.4 GB of local storage exists, which is superior to a rapid permutation-based pyramid, and pyramid broadcasting, though not superior to staircase broadcasting within the same scenario [6].

The implementation of the HB protocol is more challenging compared to other protocols since it requires client and server-side channel number management. The client is concurrently receiving video content from many channels [7]. The data can be reserved in the client cache by the client; however, the cache space should account for more than 40% of the video [6].

Once the first part of the movie ends downloading and the following segment is accessible in the cache, the client starts streaming the video. According to the protocol, consumers start to receive segment S1's second instance at time t_0. The user will be prepared to eat segment S_2 at time t_0 + d, and S_2 will need to consume one sub-segment $S_{2,2}$. Furthermore, at time t_0 + 3d/2, it may need all of the data from $S_{2,1}$, but it would not obtain it until time t_0 + 2d. Therefore, the client can use data before commencing to alleviate the waiting time issue. Since HB reduces efficiency, waiting times cannot occur, but they should be kept to a minimum waiting time. Eventually, a difficulty with this protocol is that data delivery is not shown always timely where Cautious-Harmonic, Quasi-Harmonic, and Polyharmonic Broadcasting protocols are used to address this issue.

2.2 Staircase broadcasting protocol

The fundamental benefit of Staircase Broadcasting (SB), which was developed by Juhn and Tseng [8], is that it enhances the required buffer. However, the viewer's waiting time is equally important as a rapid broadcasting to the client. A video is split into N horizontally and vertically oriented segments, each segment having the same size as S. This implies that the video splits vertically into segments and divides the segments horizontally into sub-segments, where N will be as follows:

$$N = \sum_{i=0}^{\beta-1} 2^i - 1 = 2\beta - 1 \quad (6)$$

S_i denotes the i*th* segments's size, and β is the number of staircase channels. The channel is split horizontally into 2^i sub-channels, and in each sub-channel in C_i, the bandwidth obtains b/2i, and every data segment is split into 2_i sub-segment in C_i. The sub-segments in the Ci will start from {Sv |v = 2i, …….., 2i + 1 – 1}. Additionally, {SV,u | u = 1, ……, 2i} represents 2i sub-segments of Sv. Each sub-segment's data segment is joined to create a thinner data stream. Additionally, every data stream is regularly broadcast (see Figure 2).

Assume that certain buffers on the client side can hold movie fragments while the user is viewing a movie. To save the data segments of a movie, they should adhere to particular procedures. The following procedures are involved when watching a movie. Initially, the server provides the client with the channel assignment and the data size for each available segment. As a result, clients begin to download segment S1's first data, and other data segments are received and consumed at some other time. Let Sv denote the data segment in C_i. The segments are expected to download at t0 from the first channel, C_1, and the waiting time of S1 in channel 1 is represented by the period time d. At t0 + (v – 2i)d, the Sv data stream is expected to begin downloading where it begins to consume the Sv at t_0 + (v – 1)d after restructuring the narrower data stream into its playback data stream. At t_0 + vd, the Sv terminates loading a thinner data stream.

The amount of time a viewer should wait in staircase broadcasting is the same amount of time it takes to reach the first section on Channel C_0. The longest possible waiting time occurs accordingly. The video has a duration of D, which is split into sub-segments N, and which obtains a maximum waiting time as follows:

$$d = D/N = D/2^{\beta} - 1 \quad (7)$$

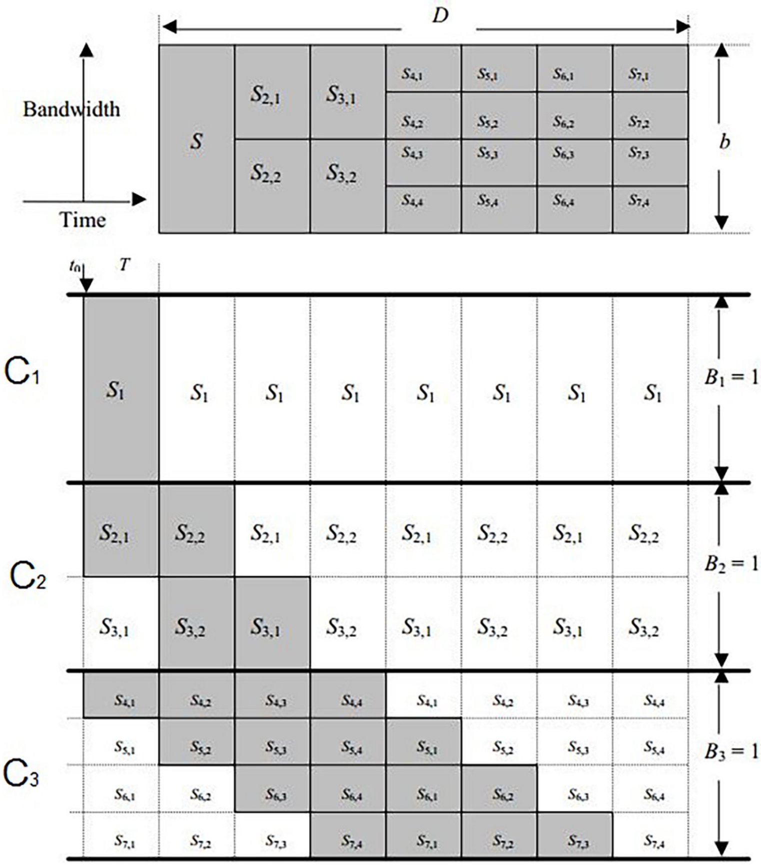

Fig. 2. Staircase broadcasting protocol

Since the requirements in the first channel are disrupted, the client buffer does not need to buffer them. The client needs to buffer one sub-segment from C1 in the first d interval, or the time between t_0 and $t_0 + d$. The client also needs to keep other data in the buffer. Another illustration would be if the client had to buffer one S2 sub-segment on the same channel during the second d interval. The client is also required to store further S3 sub-segments. The highest amount of buffer needed is as follows:

$$Z = \sum_{i=1}^{2^{\beta-1}-1} i\left((Db / N) / 2^{\beta-1}\right)$$

$$Z = \frac{2^{\beta-1}-1}{2(2^{\beta}-1)} Db < Db / 4 \tag{8}$$

Compared to other protocols, this protocol acquires a smaller buffer, allowing the client to keep data that is less than 25% of the overall movie size. The requirements to write and read data to disk and to buffer are known as the disk transfer rate. The requirements to read and write data to disk in every channel represent the overall requirements to write and read from the server. For example, when $\beta = 2$, the client reads and writes on channels C0 and C1, and the disk transfer value peaks between t0 + d and t0 + 2d. Sub-segment S3 is written to the disk at a rate of b/2, while S2 is read from the disk at a rate of b/2 immediately. As a result, this protocol performs more effectively than other protocols when buffer requirements are taken into consideration and the disk transfer rate turns out to be less than three channels. Moreover, the waiting time is less than 8 minutes when the server has four video channels and a 120-minute video; for the fast broadcasting protocol, the buffer required is around 2.1 gigabytes, and the disk transfer is 20 Mbps [9] [11].

3 THE PROPOSED METHOD

3.1 The overall system architecture for the new hybrid protocol

This section presents the overall system architecture for the produced hybrid broadcasting protocol, which is called the harmonic staircase boadcasting (HaSB) protocol for mobile VOD systems.

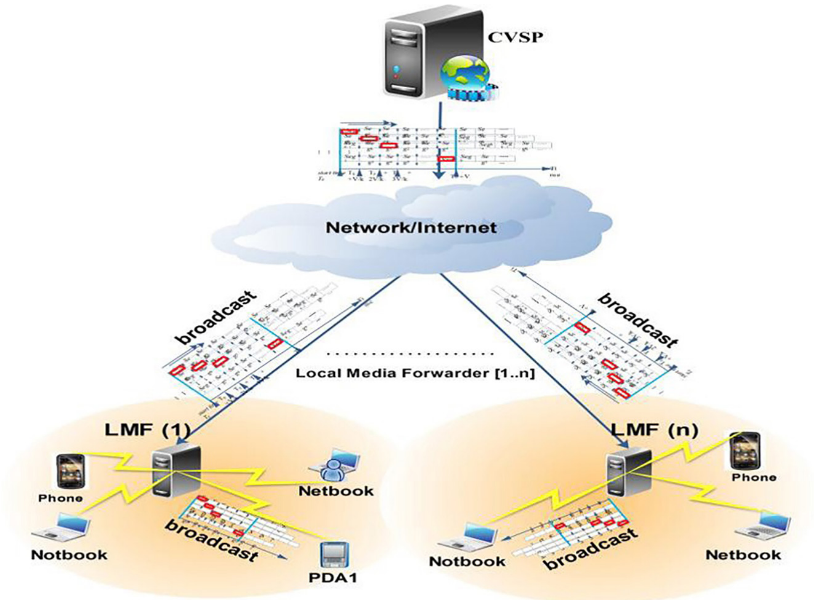

Fig. 3. The system architecture for the new hybrid harmonic staircase broadcasting

The central VOD services provider (CVSP), local media forwarder (LMF), networks, mobile clients, and broadcasting techniques represent the five primary categories in which the key components of the system architecture for the new HaSB broadcasting techniques can be split (see Figure 3).

The primary component of the CVSP is a server or cluster of servers that offer VOD services to the final mobile clients. It provides a VOD service for storage. Media forwarders are used to deliver VOD service to the final customer. Additionally, CVSP is in charge of keeping an eye on all clients via various media forwarders. It monitors how mobile clients move across various infrastructures to deliver services without interruption.

By adhering to the WiFi standards, the LMF is in charge of delivering VOD services within buildings or a restricted broadcast range. The earlier publications provided a brief explanation of each system component by highlighting details about the analysis model of CVSP and LMF [2] [26] [30–32]. However, this paper concentrates on the up-to-date HaSB broadcasting techniques.

3.2 Hybrid harmonic staircase broadcasting for VOD

The hybrid protocol combines two protocols and is called the HaSB protocol. Additionally, the VOD needs to make improvements to many techniques to make the user more comfortable. There should be a reduction in the waiting time when users start watching the video on time. The method should first minimize the waiting time at the buffer requirement and the client, which is the main aim of this paper. On the other hand, it can be demonstrated that the server can send the video by fragmenting it into multiple segments and sending them through multiple channels where the client can keep the data within the client buffer requirement.

Due to the efficient consumption of bandwidth for video transmission, the HB protocol demonstrates promising results for the viewer's waiting time. The staircase broadcasting protocol performs efficiently in buffer storage at the end user, which is also bandwidth efficient. These beneficial aspects of both harmonic and staircase broadcasting are linked in the proposed protocol of this paper.

The video is split into two fragments; the first uses the HB protocol, and the second uses the staircase broadcasting protocol. Assume that the server has 10 Mbps of free bandwidth and those 10Mbps bandwidth are split into logical channels. Every physical channel is split into around C_i logical channels. Every logical channel in return contains a partition of the video, which contains vertical and horizontal partitions. This implies that the video is split into N segments, and thus, each segment will be divided horizontally into sub-segments $S_{i,j}$, where i is equal to the number of segments starting from (1 <= i <= N) and j is equal to the number of sub-segments (1 <= j <= N). Figure 4 shows that video is divided into segments, and each segment allocates one logical channel from the HaSB protocol.

Assume that there exists a movie with length D and playback rate b in the HaSB, then the video's size is as follows:

$$S = D*b \tag{9}$$

The HaSB splits a video length D into two halves, Da and Db, which are available on the server side. Every component has a unique protocol. The functions in the staircase broadcasting protocol, particularly in the second portion, and the HB protocol in the first. The second part is Sb = Db* b, while the size of the segment in Da is Sa = Da* b.

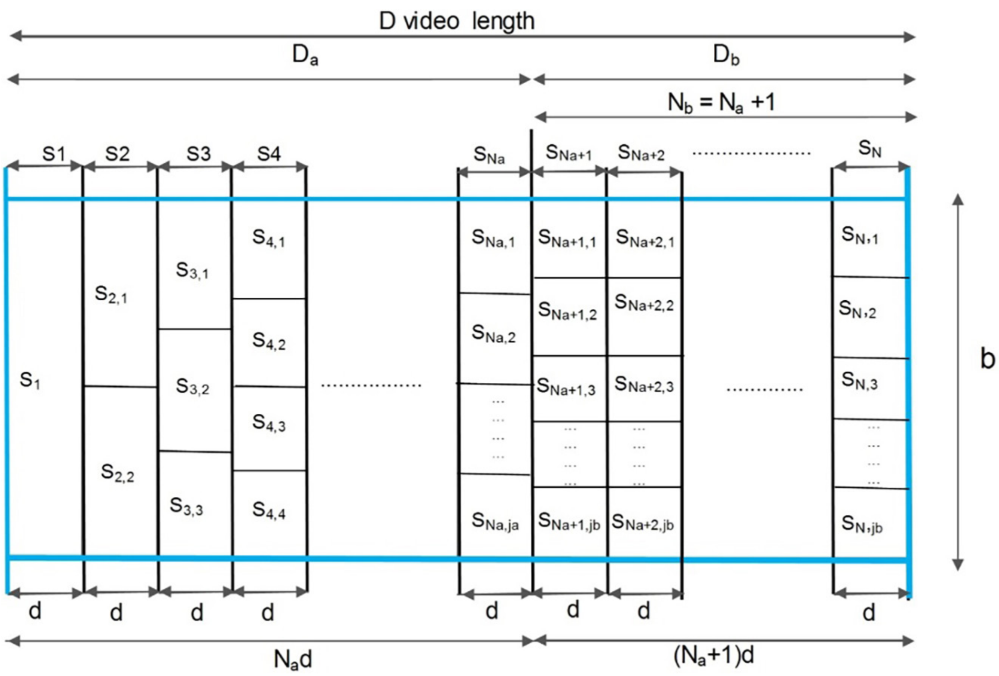

Fig. 4. The basic partition operation of the harmonic staircase broadcasting

The video is split into equal N segments. The D_a is split into equal N_a segments, and each segment in the D_a will be divided into sub-segments horizontally as shown in Figure 4. The first channel does not need to be divided into sub-segments, while the second channel will be divided into two sub-segments, and S_3 will be divided into three sub-segments horizontally with the same size, and so on. The data segment S's in D_a contains length L_a, and each segment in D_a begins from $1 \le i \le N_a$. Accordingly, the value of (L_a) is as follows:

$$L_a = D_a/N_a \tag{10}$$

In the second part, D_b, the protocol of the HaSB assumes that N_b segments are split into a similar segment size starting from $\{N_a + 1 \le i \le N\}$, where every segment from D_b is split into a similar number of sub-segments horizontally. That means segment number S_{Na+1} will be divided into Na + 1 sub-segments. Furthermore, the segment number S_{Na+2} will be divided into the same segment S_{Na+1} to Na + 1 sub-segment and so on until segment S_N. Each channel has a single segment where the data segment S's length (L_b) in D_b is represented as follows:

$$L_b = D_b/N_b \tag{11}$$

Where the channels are equivalent to the number of the segments in the second part. These segments represent a similar size to the segments in D_a. The overall data segment video length is represented as follows:

$$L = D/(N_a + N_b) \tag{12}$$

The segments of the N harmonic staircase broadcasting contain a sequence of the entire segments constituting the entire video, $S = \{S_1 \bullet S_2 \bullet S_3 \bullet \ldots\bullet S_N\}$. Figure 5 depicts an example of the HaSB protocol partition, which has four segments in the first part, D_a, and five segments in the second part, D_b.

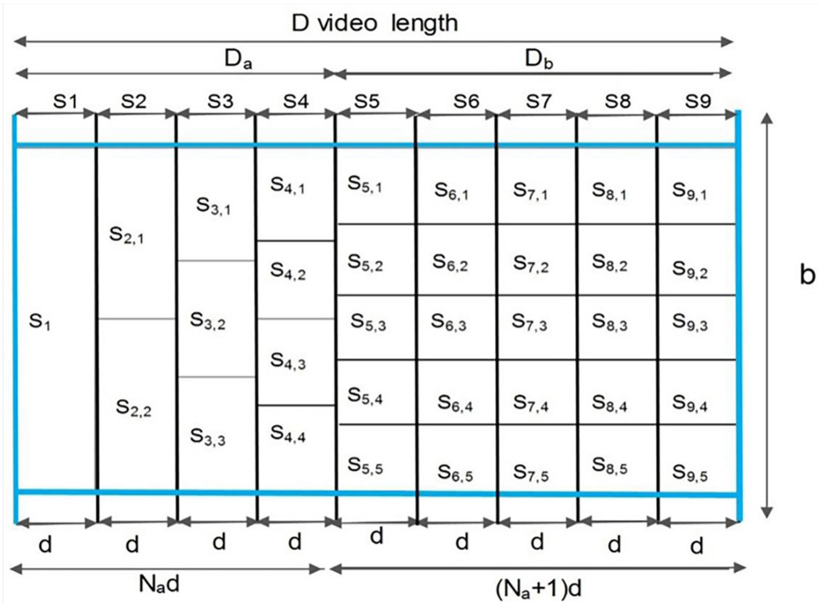

Fig. 5. An example of the HaSB protocol for a video with nine segments

In HaSB, D_a is divided into segments S_i, and S_i is divided into sub-segments equally $\{S_{1,1}, \ldots, S_{i,ja}\}$ and horizontally. It is equal to $(1 \le i, j_a \le N_a)$, where i is the number of video segments and j_a is the number of the sub-segments for each segment. Furthermore, each segment is divided into sub-segments that depend on channel number. For instance, assume that this protocol only has four segments, starting from S_1 until S_4; the overall number of channels in D_a contains four channels. The number of the channel in D_b is β, where $\beta = N_a + 1$. In D_b, the segment is divided into N sub-segments equally $\{S_{1,1},\ldots, S_{i,jb}\}$ and in a horizontal manner starting from ($N_a + 1 \le i,j_b \le N$), where i is the number of video segments in D_b and j_b is the number of the sub-segments for each segment in D_b. In other words, each segment has the same number of sub-segments in D_b. The division of each segment depends on the number of segments of D_b. The number of segments in the second part is represented as follows:

$$N_b = N_a + 1 \tag{13}$$

Where N_b is the total number of segments in the second part that can be determined when N_a is known. For instance, assume that N = 9 and $N_a = 4$, the number of N_b is five segments, while the number of channels in N_b is β = 5 logical channels within a single main staircase channel. Figure 6 demonstrates the first part, D_a, which includes four segments. The second part, D_b includes five segments from the HaSB, and each channels has a different bandwidth. In the first channel, C_1 has one segment without dividing it into sub-segments. C_2 has one segment with two sub-segments, $S_{2.1}$ and $S_{2.1}$, and C_3 has three sub-segments, $S_{3.1}$, $S_{3.2}$, and $S_{3.3}$, with the same size, and the last channel will have four sub-segments. In D_b, the number of segments is equal to five segments: S_5, S_6, S_7, S_8, and S_9, where each segment is divided into five sub-segments, which means that S_5 will have $S_{5.1}$, $S_{5.2}$, $S_{5.3}$, $S_{5.4}$, and $S_{5.5}$, and so on until the last segment will have the same number of sub-segments, where all these segments have horizontal partitions.

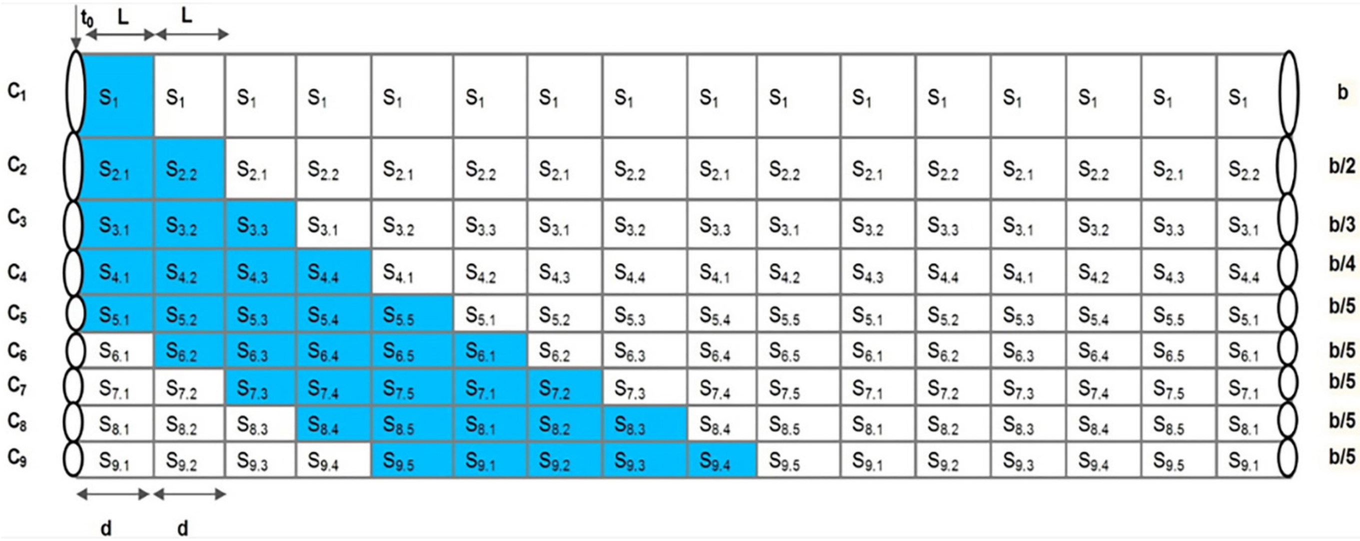

Fig. 6. The bandwidth for each channel in the harmonic staircase broadcasting protocol

In the first portion of the harmonic staircase broadcasting, D_a, each channel Ci has a variable bandwidth starting at ($1 \le i \le N_a$). As seen in Figure 6, each channel has b/i. The total bandwidth for the first segment of the video, Da is represented as follows:

$$B_a = \sum_{i=1}^{Na} \frac{b}{i} = H_N * b \tag{14}$$

Where, $HN = \sum_{n=1}^{Na} 1/n$ denotes the harmonic number of N. In the second part D_b, the bandwidth is represented as follows:

$$B_b = \sum_{i=Na+1}^{N} \frac{b}{i+1} = mb \qquad \text{(where m = 1Mbps)} \tag{15}$$

The total bandwidth for the entire video of the two parts (i.e. D_a and D_b) is represented as follows:

$$B = \sum_{i=1}^{Na} \frac{b}{i} + \sum_{i=Na+1}^{N} \frac{b}{i+1} = H_N b + mb \tag{16}$$

Where $H_N = \sum_{n=1}^{N_a} 1/n$ is called the harmonic staircase broadcasting number of N. The bandwidth of D_b will be equal to 1 Mbps, so D_b will just have 1 Mbps from the total bandwidth. The number of channels in the second section will match the number of segments in the D_b, and it is situated from staircase broadcasting. Logical channels will be utilized for transmitting each segment, and the bandwidth is split into one main staircase channel where the first channel is equal to $b/N_a + 1$, where $N_a + 1$ means the number of segments. Suppose that you have a video of N = 9 segments, and the number of segments in D_a is equal to four segments with four logical channels where the bandwidth for every channel is b/i. The second part contains five segments and the bandwidth is split into these channels. If the number of the channels is five channels inside one main staircase channel. The 1 Mbps of the bandwidth will be divided into all channels inside the main staircase channel. The value will be for each channel {1/5, 1/5, 1/5, 1/5, 1/5} that will be equal to 1 Mbps in the second part D_b.

Assume that when the user plays and watches the video, there is a buffer (disk space) on the client side for storing the data segments. The clients will wait for the first segment, $S_{1,}$ until the download of C_1^{Da} terminates. After that, start downloading the sub-segment from the channel C_2^{Da} to C_{Na+1}^{Da}. The clients are starting to download all the sub-segments until downloading all channels from C_i^{Da} where {i = 2, …, N}. At time t_0 until $t_0 + d$, the client will download the sub-segments $S_{2.1}$, $S_{3.1}$, $S_{4.1}$, and $S_{5.1}$ from channels C_1 until C_5. In time $t_0 + d$ until $t_0 + 2d$, the client will download the other sub-segments starting from S3.2, S4.2, S5.2, and S6.2 from channels C1 until C6, and so on. At the same time, the client directly downloads sub-segments from the second part until C_N^{Db}, where there are some sub-segments from the second part already finished downloading. The second part, D_b contains one main staircase channel with 1 Mbps of bandwidth. Nonetheless, the number of channels inside this main channel is $N_a + 1$. If $N_a + 1$ is equal to 5, the number of channels will be five channels. The client stops downloading from the last channel, C_N^{Db} and consumes the last sub-segment for SN. The entire data segment SN from the most recent channel is transmitted to the client.

At last, the client begins downloading the segments from the Da, beginning at t_0 and continuing until t_0 + id. At (t_0 + (N_a + 1) d), the client begins to play back the data stream and begins downloading from Si + 1; it ends at t_0 + Nd. The client buffer will initially be written with the segment Si's previously received Na sub-segments. At time t_0, the client begins playing the video. The video segments that the client obtains are shown in the highlighted region in Figure 6. At t_0, the client starts playing these parts. Furthermore, it creates the bandwidth for every channel.

3.3 Viewer's waiting time in the harmonic staircase broadcasting

In the proposed protocol, assume that the end user's set-top boxes (STBs) have sufficient disk space to buffer the required video. The maximum waiting time for this protocol is equal to the first segment from the first channel when the S_1 begins to request a video. $D = (D_a + D_b)$ is the length of the video, which calculates the maximum waiting time (d) as follows:

$$d = D/N, \text{ where } N = N_a + N_b \quad (17)$$

Where $N_b = N_a + 1$ according to equation (15), then $\beta = N_a + 1$. For instance, assume that the HaSB has N = 9. The number of segments N is divided in the first part into four segments and five segments in the second part. Four logical channels, $\{C_1^{D_a}, C_2^{D_a}, C_3^{D_a}$, and $C_4^{D_a}\}$, are used by the D_a. Starting from $\{C_5^{D_b},\ldots\ldots\ldots C_9^{D_b}\}$, D_b uses 5 channels. Each D_b channel will have a bandwidth of 1 Mbps, and the waiting period will be equal to d = D/9. The customer will then have to wait the longest possible.

For instance, when the duration is around 120 minutes N = 35 is the same as the total number of HaSB protocol segments. Da's length is approximately 58 minutes, whereas Db's is approximately 62 minutes. The maximum waiting time is 3.4 minutes according to the number of segments. When the server allocates around 4.5 Mbps from the server bandwidth and gives it for each harmonic number H_N channel, where $H_N = \sum_{n=1}^{Na} 1/n$ and for one staircase channel. Furthermore, if the number of segments increases, the value for waiting time decreases. The relationship between the waiting time of the bandwidth and the viewer, according to equations 16 and 17 is illustrated respectively. It can be inferred that the bandwidth and the viewer's waiting time have a noticeable relationship. For instance, the waiting period in the HaSB is one second if the bandwidth is distributed evenly among all channels at a rate of about 10 Mbps. This indicates that the initial segment's size is decreasing and the number of segments is increasing.

3.4 Client buffer requirement

At the end user's "clients," the video data is staring to download more than video channel simultaneously. That because the consumption rate of the video is less than the downloading rate. The first part D_a belongs to HB protocol starting from $C_1^{D_a}$ to $C_i^{D_a}$, on the next part D_b belongs to staircase starting from $C_{i+1}^{D_b}$ to C_N. When the client starts to download the first segment S_1 from the first channel $C_1^{D_a}$ at time (t_0) where this segment cannot buffer. It will be consumed immediately. There are some data segments that need to be stored in the buffer during (t0) to (t0 + Nd). There are sub-segments that come from $C_{i+1}^{D_b}$ to C_N that need to be stored starting at time t_0 until $t_0 + Nd$.

According to the client buffer requirement in the harmonic staircase broadcasting, the maximum buffer requirement Z can be calculated in HaSB. The time that a client begins to receive video data at t_0. The period of a time slot is d = D/N. The data needs to be stored in a buffer that will increase or decrease the size with time. In the increased data size rate in the D_a that need to write in the buffer in first part of the video (see Figure 7). Hence, there is no buffer requirement for channel C_1. In the second channel $C_2^{D_a}$, the sub-segment in this channel needs to be stored in the buffer at time. Hence the sub-segment has +1/2 from $C_2^{D_a}$ channel during time (t_0) to (t_0 + d) is buffered one sub-segment of segment S_2 and the other sub-segment will be consumed directly. At the same time, the client will store other sub-segment like $S_{3.1}$, $S_{4.1}$ and $S_{5.1}$. Hence the buffer has –1/2 sub-segment for channel C_2 during time t_0 + d to t_0 + 2d. At time t_0 + d to t_0 + 2d the client needs to store sub-segments in a buffer, such as $S_{3.2}$ and $S_{4.2}$ from C_3 and C_4, in a buffer between time t_0 + d and t_0 + 2d. The final sub-segment from S_3 will be eaten at time t_0 + 3d. Since all of S3's sub-segments are maintained in the buffer, the client can view every one of them. Additionally, certain portions from channels C_4, C_5, and further channels are simultaneously preserved. After that, the final sub-segment $S_{5.5}$ from the second half of D_b will be consumed at times t_0 + 4d to t_0 + 5d, while other sub-segments such as $S_{6.5}$, $S_{7.5}$, $S_{9.5}$, and so forth are stored.

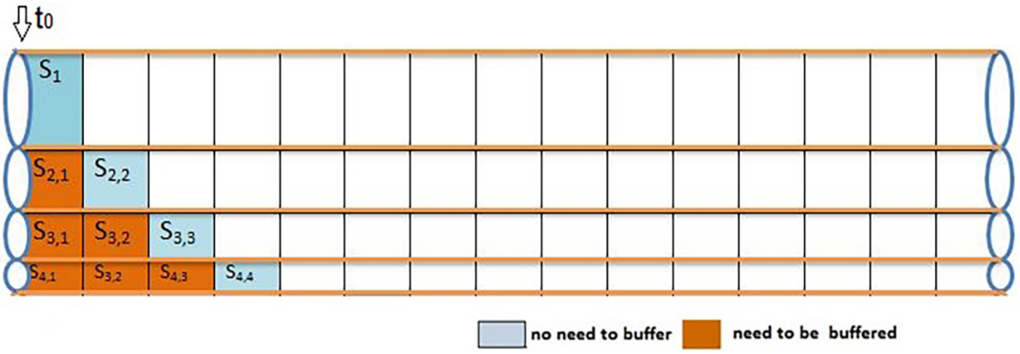

Fig. 7. The first part of the HaSB protocol that needs to buffer

The client in D_b must ascertain the number of segments Nb to determine the number of channels β. For instance, the second half of D_a will have five channels if the first component D_a only has four channels (see Figure 8). The buffer holds the first sub-segment from the first channel in D_b from time t_0 to t_0 + d. It will therefore be put in the buffer with + 1/(N_a + 1). The buffer contains two sub-segments ($S_{5.2}$ and $S_{6.2}$) representing the time interval from t_0 + d to t_0 + 2d, which is equal to +2/(N_a + 1), and three sub-segments ($S_{5.3}$, $S_{6.3}$, and $S_{7.3}$) should be in the buffer between times t_0 + 2d and t_0 + 3d. These sub-segments are equal to +3/(N_a + 1), and so on until the video's final channels. Figure 8 demonstrates which segments should be in the buffer and which segments should be played by the client directly in the second portion of the video stream. Additionally, the buffer must release the segments after a certain amount of time or until there is no more room in the buffer to hold fresh segments. A new sub-segment can then be stored in the buffer.

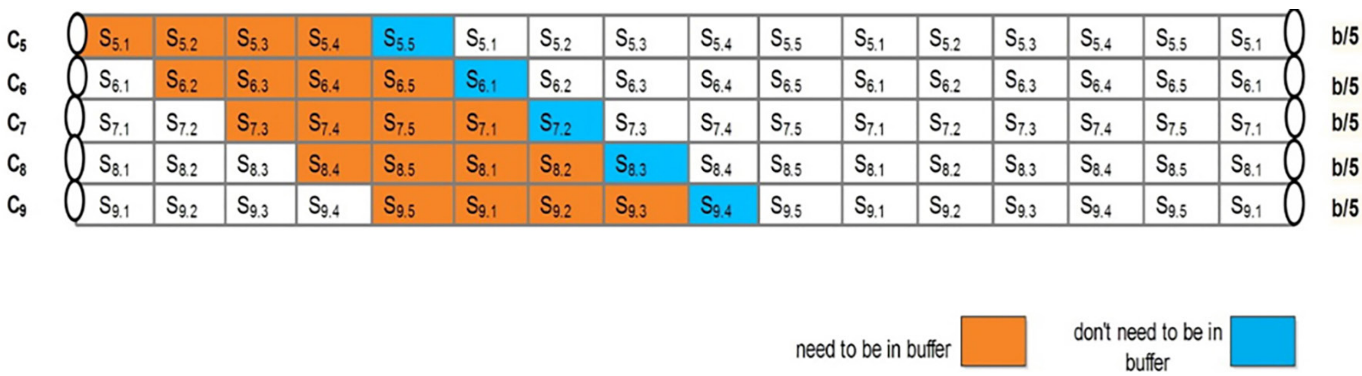

Fig. 8. The second part of the HaSB protocol that needs to buffer

On the second part's final row, which runs from $N_a + 1$ to N. Which segments should be buffered and how clients release segments from the buffer once they have completed viewing the video data are both depicted in Figure 9. First, the data is kept in the buffer in one sub-segment for the time interval t_0 to $t_0 + d$, and in the buffer in two segments for the time interval $t_0 + d$ to $t_0 + 2d$. Therefore, for the last row from time $t_0 + d$ to $t_0 + 2d$, the number of sub-segments required to buffer is equal to $+ 2/(N_a + 1)$. The user uses the final sub-segment from the final channel, Na + 1. Moreover, up until the final channels, or between t_0 + Na + 1d and t_0 + Nd, certain sub-segments should be kept in the buffer. The final sub-segment received will be consumed by the client. As a result, from time $t_0 + (N_a + 1)d$ to $t_0 + (N_a + 2)d$, and hence, the client obtains $(–1/(N_a + 1))$ in the final row.

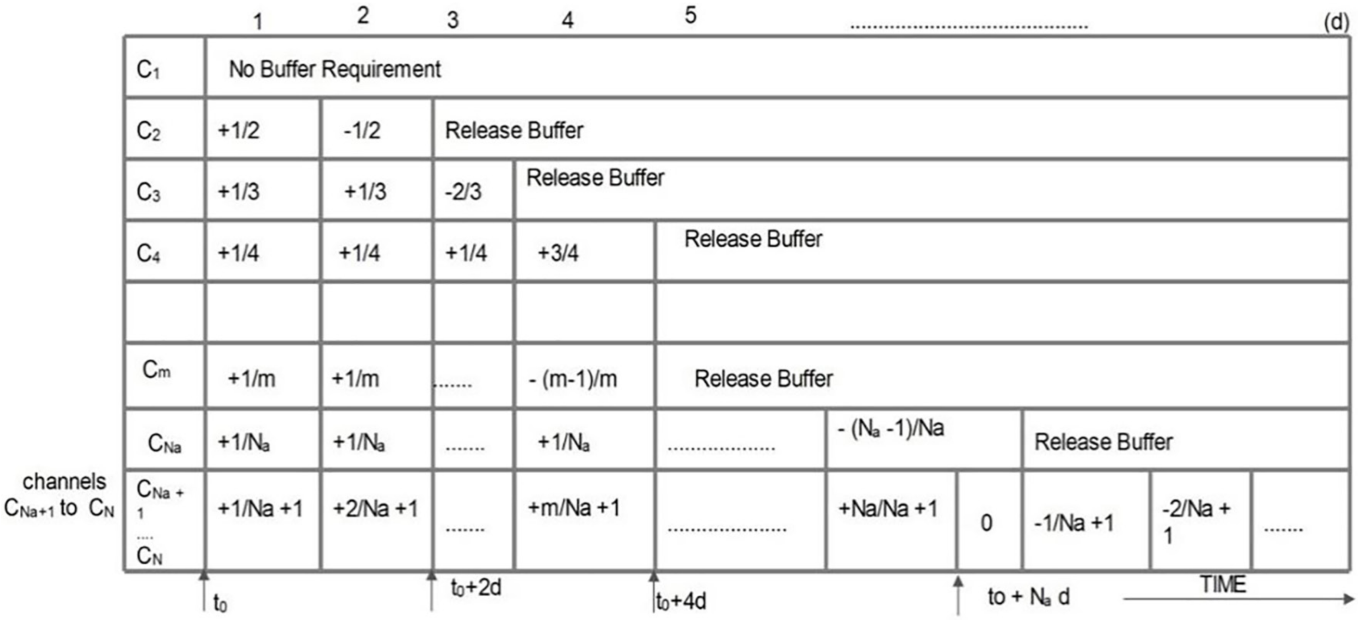

Fig. 9. Client buffer increased and decreased rates in size of data segments

Figure 9 illustrates how the client can release the buffer from the channels and when the client begins watching the video and begins buffering some sub-segments by the specified time in the staircase broadcasting protocol. The segments will be removed from the buffer by the client. The mathematical model is used to determine the size of the video that has to be stored in the buffer. The client just buffers the incoming data for the remaining segments at this point because it has already played segments 1 to N.

Additionally, the total buffer requirements increase to their maximum value (Z). The final row fills to its utmost. The following equation indicates the fraction of video data that requires buffering by the staircase broadcasting protocol as follows:

$$Z = \sum_{i=1}^{Na} \frac{i}{Na + 1} / N \tag{18}$$

$$Z = \frac{Na}{4Na + 2} \approx \frac{1}{4} = 0.25$$

If the buffer demand is within the percentage of the video length, the demand is about 0.25 when the number of segment N is being increased and large.

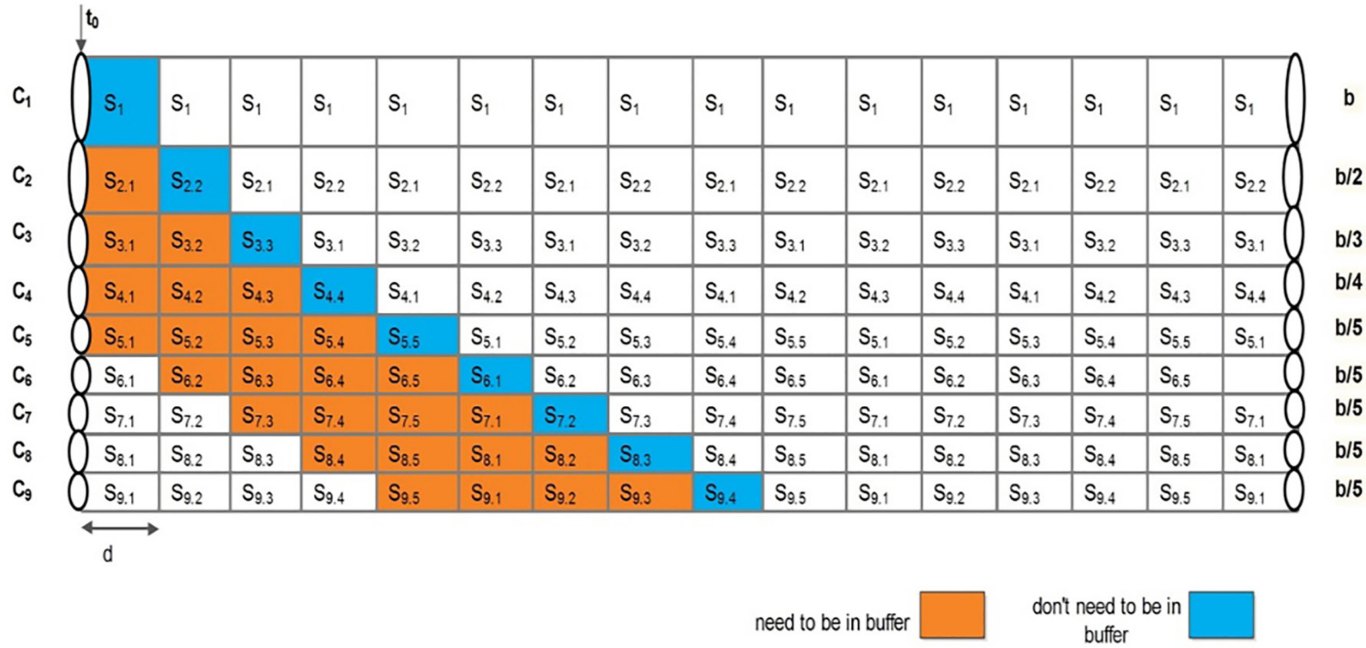

Fig. 10. The total buffer in the harmonic staircase broadcasting at t_0

The sub-segments that should be maintained in the buffer from t_0 + d to t_0 + Nd are described in Figure 10, along with the sub-segments that are not required to be kept there. The second primary objective of this study is accomplished by the HaSB protocol's usage of the staircase broadcasting on the final channel to lower the size buffer requirement on the client side.

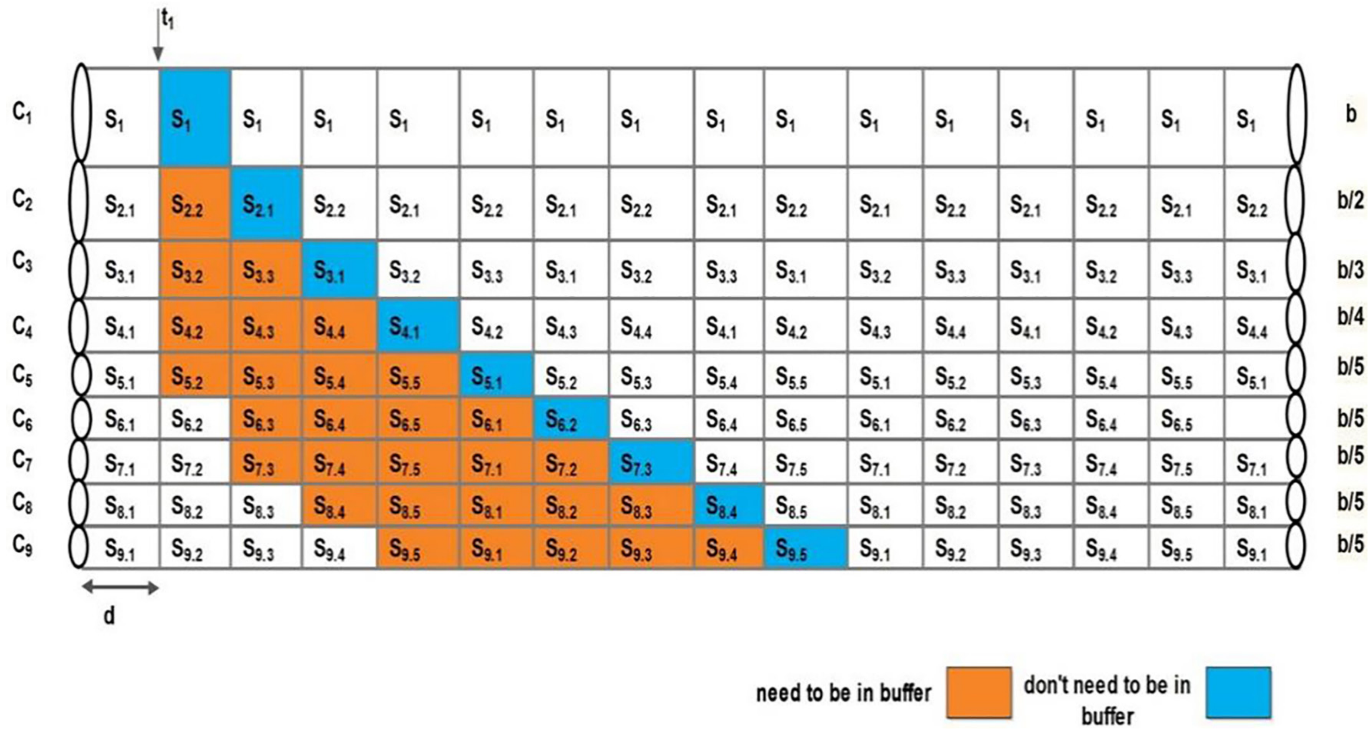

Fig. 11. The end user is starting to download from t1

To ascertain which scenario best fits the buffer requirement, the client should begin receiving the video at t_0 or t_1 (see Figure 10). That can use up one channel's worth of subsegments. As a result, at time t_1. Figure 11 indicates that the waiting period is equal to t_0, at which point the client will use the first sub-segment from the majority of the channels. Thus, the mathematical models in t_0 and t_1 that are compared with other protocols have a waiting time test. The proposed HaSB protocol has a mathematical model to calculate the waiting time, the bandwidth, and the buffer requirement. HaSB has decreased the waiting time in the SB. It has also decreased the buffer requirement in the HB. HaSB has a good waiting time and buffer requirement when compared with other protocols. Finally, this section presented the mathematical model of HaSB protocol.

4 HaSB SCENARIO

In this section, introduce one of the scenarios that will show how the server broadcasts the video to the clients by HaSB protocol and how the clients can receive the video from the server and start to play it-back. This scenario will demonstrate just two times, t_0 and $t_{1,}$ in the result. There are two clients that need to receive a different video from the server at the same time. The client 1 wants to receive video 1, and the client 2 needs to receive video 2. As shown in the Figure 12, explains the steps in the scenario of how the HaBS works.

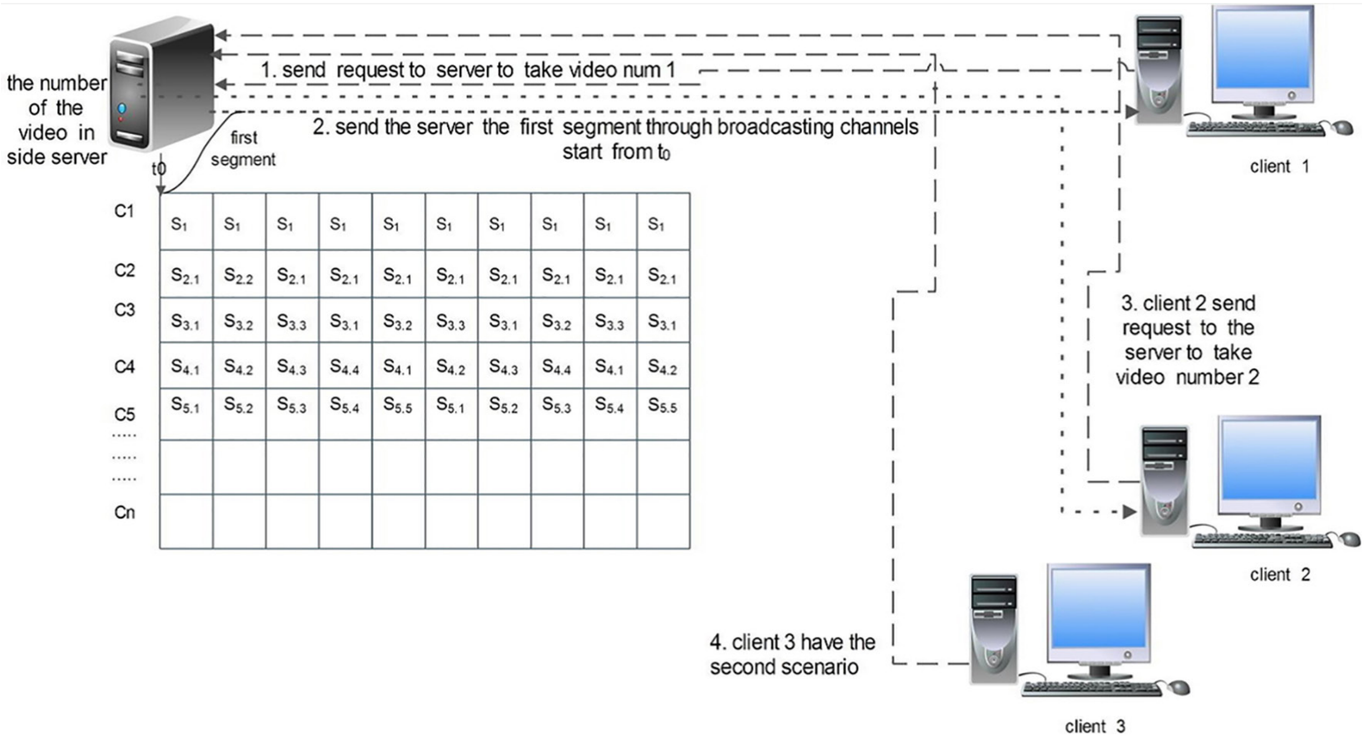

Fig. 12. HaSB scenario model

1. The client1 sends a request to the server to take video 1 (v1).
2. The server gets a request from the client1 and sends video 1 (v1).
3. Find the channels from the server and the server is going to broadcast the segment 1 (S1) very soon at t0 through HaSB protocol.

4. The client waits to join the channels.
5. Download segment 1 (S1), and start playing back the video.
6. The server directly sends all segments by different logical channels at the same time to the client 1, through HaSB protocol.
7. Quit the channels.

In addition, the client follows the same steps when the client wants to receive other video. For example, client 2 needs to receive video 2 (v2) at the same time. If there is any client request the video 1, it arrives at time t1. Go to the second scenario.

5 MATHEMATICAL RESULT

These outcomes rely on the equation that is described in the second section. Here, the outcome for client-side buffer requirements and waiting times is determined by server bandwidth and is compared to other protocols. The waiting time reduces, and the bandwidth of this protocol increases as the number of segments rises. According to the mathematical model, the optimal outcome occurs when the client begins downloading the first segment at t_0. This is because the waiting time at t_1 is the same regardless of the user's starting point. Furthermore, if any client arrives late, then the waiting time will increase more than when it starts at t_0. Finally, the worst case is if the client misses the first segment from the first channel. Table 1, shows the parameter that was used for the proposed HaSB protocol. The client will start downloading the first segment from the first channel at time t_0 where the waiting time for the client starting from t0 is similar to the client starting from t_1, but for the buffer requirement, the client starting from t_0 and t_1 will consume the last received sub-segment for each channel.

Table 1. HaSB parameters

Parameter	Notation	Default Value
Total server bandwidth	B	10 Mbp
Video length	L	120 minute
Number of segment	N	9
Number of broadcast channels	C	9
Video Consumption Rate	R	1.5
Number of Video	V	1

5.1 Client waiting time vs. server bandwidth

Two major protocols are used to make a hybrid broadcasting protocol HB and SB. It is called the HaSB. It is suggested that the HB shorten the devices' wait times. Whereas the harmonic number (HN) increases as the device waiting time decreases. As an illustration, suppose HN has six video channels. The waiting period is less than a minute because the video is 120 minutes long. When assigned $H_N = 5$, the waiting period for this HB will be 1.5 minutes. The number of segments increases, it will decrease waiting time.

The SB protocol has proposed to decrease the buffer requirement, but SB has a high waiting time compared to other protocols. The waiting time is decreased when the bandwidth network increases. If the number of channels is equal to 5, then the waiting time will be equal to 3.9 minutes, but when the video allocates seven channels, the waiting time will be less than one minute.

When comparing the HaSB protocol to other protocols, such as the staircase broadcasting protocol, FB, harmonic staggered broadcasting, and PyB, it can be observed that the HaSB protocol has a shorter waiting time than these protocols. Furthermore, staircase broadcasting has one main channel if bandwidth is equivalent to 7 Mbps, which indicates the server allows for 6 Mbps from the first portion and HN equals 6 video channels and 1 Mbps from the second half.

The waiting time for the HaSB is accordingly 15 seconds; however, it is 57 seconds in SB as opposed to 11 seconds in HB. This indicates that the waiting time in SB has decreased and the outcomes are close to HB. Moreover, the HaSB has about two minutes, and the waiting time in the HaSB is reduced to be close to HB when it utilizes 5 Mbps.

It can be depicted from Figure 13 that the HaSB's waiting time decreases as the bandwidth and harmonic channel are increased. This leads to an increase in the segment number, which in turn causes the initial segment's size to decrease as the number of segments rises. It can also be depicted from Figure 13 that the HaSB scheme uses the least amount of bandwidth, except for the HB scheme. To compare the HaSB protocol, the following schemes will use 9.7 Mbps, 9.46 Mbps, 12.76 Mbps, 13 Mbps, more than 15 Mbps, and 10.5 Mbps, respectively, to be equal to one second: HB, SB, FB, PyB, and harmonic staggered with coefficient (H = 3).

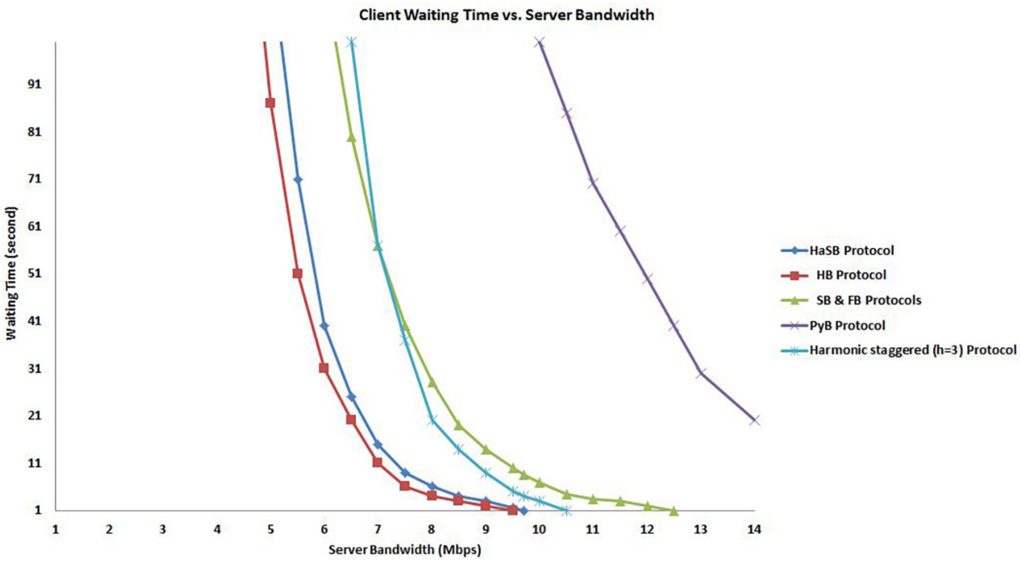

Fig. 13. A mathematical model of the waiting time vs. bandwidth

The waiting time for the HaSB scheme is slightly higher than the HB scheme because HaSB uses other protocols. If the bandwidth is equal to 6 Mbps, the waiting time can be equal to 40 seconds in HaSB, but in HB it will be around 33 seconds. The value of HaSB allocates five video channels from HB and one staircase channel from SB. The numbers of segments in the second part are more than in the first part in HaSB.

In HaSB, the video size for each part will be near each other, but the size for the second part is higher than the first part, but not too much. In the end, the HaSB benefits from HB, and the client's wait time to be close to the HB is shortened. When combining staircase broadcasting with HB, the most crucial factor is to minimize the waiting time. Additionally, by utilizing the HB, the results fulfill the first goal of the HaSB hypothesis. Each segment of the HaSB video will be relatively close to the other, with the second segment having a slightly larger size than the first. The benefit of HB is ultimately realized in the HaSB, and the client's waiting time to get close to the HB is shortened. When stairwell broadcasting is linked to HB, cutting down on waiting times is crucial. Additionally, the results use the HB to accomplish the first goal of the HaSB hypothesis.

5.2 Client buffer requirement

Harmonic staircase broadcasting has a relationship between maximum buffer requirement and bandwidth requirement. The buffer demand rises with bandwidth and remains within the upper bound of the greatest percentage of video data that the buffer can hold. The client's maximum buffer requirement for HB is increased, and hence, the HaSB should use appropriate staircase broadcasting techniques to reduce the amount of video within the buffer.

The maximum buffer needed on the client side is less for the HaSB protocol. For instance, assume that the duration of the data movie is 120 minutes. For HB, SB, FB, harmonic staggered broadcasting, and other scenarios, the maximum buffer required is 37%, 25%, 25%, and 47% of the total video time, respectively. The most crucial factor is that HB's buffer requirements must be lowered so that it can be close to SB.

Similarly, equation (18) states that HaSB has a maximum buffer demand of around 25%, which must be held in the buffer. In contrast to other protocols such as HB, FB, and so forth, the HaSB reduces the buffer required as the number of segments grows.

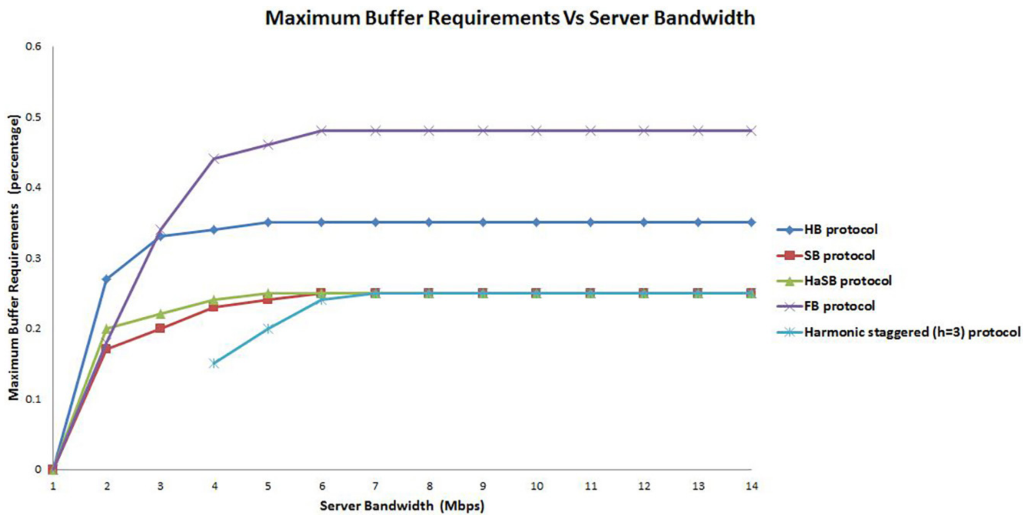

Fig. 14. A mathematical model of the maximum buffer requirement vs. bandwidth

Consequently, the maximum buffer requirement, like staircase broadcasting, is around 25%. When the bandwidth is equal to 4 Mbps, the buffer data at the client side will keep the same amount of data the video needs to store in the buffer. Since the client has played segments numbered 1 to N. The client is only buffering the incoming data of the remaining segments at this time. Where the second part has stored sub-segments in the buffer more than the first part, but it can release the segments when the buffer is full. The main objective is achieved due to using the staircase broadcasting that helps us to decrease the value of the buffer requirement at the client using horizontal partition for the segments, so it can consume some of the other sub-segments. Considering the graph in Figure 14, the HaSB has a reduced buffer demand when compared to other protocols. When the client begins downloading the video from t_0, the current value for harmonic staircase broadcasting is 25%, starting at about 4 Mbps in comparison with other protocols. FB and HB perform worse than the HaSB. Lastly, depending on server bandwidth, the HaSB's two goals from HB and SB are to decrease client-side waiting times and buffer requirements.

Many previous related studies investigated and explored the issue of reducing the time spent in waiting for viewing a video and many researchers used the broadcast scheme for this purpose. The problem that HB protocal has high percentage for buffer requirement at the client that need to reduce it, but the waiting time has better result. Furthermore, the SB protocal has good result for buffer requirement at the client, but the client need to wait more than other protocol like HB. Thus the client need to less waiting time and buffer requirement to watching the video.

6 CONCLUSION

The features of the VoD and some of the periodic broadcast approaches are briefly explained in the second part's literature study. Different algorithms are used in each of these strategies to reduce the client's waiting time, and different techniques are used to divide the video into segments to reduce both the buffer required and the waiting time. As soon as the video is delivered from the server to the client, these protocols might assist the user in viewing it.

For this protocol, the HaSB has a mathematical model that computes the requirements of the buffer, bandwidth, and waiting time. The SB's waiting time has shortened thanks to the HaSB. Additionally, it has reduced the amount of buffer needed in the HB. Compared to other protocols, the HaSB has an efficient buffer requirement and waiting time.

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