# A Multiple-Stream Multimedia Presentation Middleware Based on Multicast Communications *

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## ABSTRACT

The Internet explosion impels the extensive demands for distributed multimedia presentations (DMPs), which provide multiple users with QoS-controlled multimedia services under multicast communications, such as media distribution and virtual classroom. In this paper, we propose and develop a multiple-stream multimedia middleware, which is named Mcast. Mcast (i) provides a flexible authoring tool to allow users to author a multiple-stream multimedia presentation in a multicast environment and (ii) achieves smooth multimedia presentations with the temporal control mechanism. This paper describes the major considerations and techniques that are involved in the design and implementation of Mcast. System developers can incorporate Mcast to develop multiple-stream multimedia presentation based on multicast communications.

## 1 INTRODUCTION

With the advances of computer and communication technologies, distributed multimedia presentations (DMPs), e.g., video distribution and virtual classroom, become popular applications [1, 2, 3]. DMPs can be characterized by the integrated multicast communications and presentation of multiple continuous and static media. Based on multicast communications, the server transmits data to multiple recipients simultaneously, each of who has the same multicast address [4]. A continuous medium, such as video or audio, is a time-dependent medium that possesses temporal relations between media units [5]. A static medium, such as text or still image, is a time-independent medium that has no temporal relation between media units, but may have inter-media temporal relations with other media streams. Since the transmission delay is undeterministic in a distributed environment, temporal anomalies always exist during a multimedia presentation [6]. Thus, one of the important issues in implementing DMPs is to resolve the multiple-stream multimedia synchronization problem that is associated with the multicast delivery [7].

The goal of multiple-stream multimedia synchronization is to keep temporal relations of media streams as much as possible during the presentation. Multiple streams mean that media streams are retrieved from their own media bases and are transmitted via independent network channels with different network QoS (Quality-of-Service) requirements [8, 9]. Therefore, the delay variance of multicast communications and the respective features of multiple streams complicate the multimedia synchronization reams complicate the multimedia synchronization [10]. In a multicast environment, suitable synchronization and presentation schemes that can guarantee temporal relations of multiple streams are essentially required. In order to support multiple-stream multimedia presentations over multicast-capable Internet, a middleware named Mcast is proposed and developed.

Mcast is based on Multicast Multimedia Communication Network ($M^3CN$), which is a three level hierarchical architecture [11]. As depicting in Figure 1, the $M^3CN$ consists of a WAN and a lot of LANs that are attached with the WAN. Each LAN is composed of a local Multicast MultiMedia Server ($M^3$ server) and clients. An $M^3$ server transmits media units to clients via LAN and WAN. Clients of a presentation group, which are scattered over different LANs, present the same multimedia resource simultaneously.

In $M^3CN$, the concept of a "virtual server" is adopted. A virtual server receives media units from the "physical server", which owns the presentation resource, and re-transmits media units to clients. The virtual server is a local server of a LAN and compen-

*The research is supported by the National Science Council of the Republic of China under the grant NSC 88-2219-E-006-012.

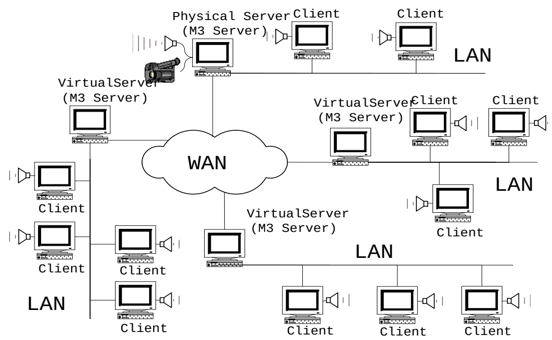


Figure 1: The network architecture of Multicast Multimedia Communication Network.

sates for WAN's anomalies by means of pre-depositing some media units and achieving corresponding synchronization schemes. The concept of virtual servers simplifies the overhead of synchronization control in clients because WAN's asynchronous anomalies are compensated and media streams are synchronized at virtual servers.

Mcast is based on the proposed $M^3CN$ architecture and contains synchronization/presentation mechanisms to achieve multiple-stream multimedia temporal control. Mcast also provides generic supports for media specifications and multicast environment setup. System developers can incorporate Mcast to develop DMPs more efficiently and effectively in a multicast environment.

The rest of the paper is organized as follows. Section 2 describes main considerations in designing DMPs. Section 3 describes the proposed control schemes for resolving multiple-stream multimedia synchronization and presentation. issues of achieving multiple-stream multimedia synchronization in a multicast environment. Section 4 describes the network and system architecture of Mcast. Section 5 describes the software architecture and development techniques of Mcast. Finally, Section 6 concludes this paper.

# 2 MAIN CONSIDERATIONS

In designing DMPs, there are three essential considerations, which are (1) the communication network architecture and multicasting protocols, (2) the synchronization control mechanism, and (3) the media presentation control mechanism. Based on the three essential considerations, we discuss some related works of DMPs as follows.

1. Communication network architecture and multicast protocols. A feasible multicast network architecture allows scalable and efficient implementations on variable network backbones. The provision of scalability allows lots of users to participate in a DMP without any network restriction and severe performance degradation [12]. The main functionality of multicast protocols includes the group management and the multicast routing. The group management protocol allows multiple participants to join and leave an existing DMP dynamically. Internet Group Management Protocol(IGMP)is the well-know group management protocol on Internet [4]. Multicast routing protocols achieve efficient media transmission routing from the source to multiple receivers across WAN [13]. MBone that provides group management and multicast routing capabilities is the most popular multicast environment over Internet/InternetII [14]. Based on the underlined multicast environment, suitable multiple-stream synchronization and presentation controls are devised to achieve smooth multimedia presentations.

2. Synchronization control mechanism. Multimedia synchronization is used to compensate for the network and media processing anomalies induced in DMPs [5, 15]. In order to avoid degrading the presentation quality, the synchronization management overhead, such as buffer requirement and processing overhead, should be reduced as much as possible. In Reference [3], the authors proposed a Multimedia Multiparty Teleconferencing (MMT) system, which is a JPEG-based system over ATM networks. The MMT system adopts a video-mixing technique to achieve a videoconferencing system. Nevertheless, the MMT system does not address any control scheme to achieve multimedia synchronization and the overhead of buffer management is dramatically increased when end users are increased. In Reference [16], a hierarchical architecture is proposed to efficiently reduce the buffer requirement at the end user. In the hierarchical architecture, users are divided into several groups and a local distributor is elected in each group to control media mixing and media transmission between groups. Although the hierarchical architecture can reduce the buffer requirement at the end user, the number of control messages and computing overhead in constructing groups and in electing the local distributors can not be neglected, especially, for real-time applications. The authors of [7] proposed an M-ary multicast tree (K-AMT) architecture for group multimedia applications. The leaf nodes of the K-AMT tree are multimedia data sources and destinations. Nonleaf nodes are responsible for synchronizing media streams, which are received from leaves, and then forward the synchronized streams to destinations. The K-AMT tree architecture provides scalable and real-time multicast multimedia services. But, the multi-level K-AMT induces additional transport delays when the height of the hierarchy increases.

3. Media presentation control mechanism. The me-

dia presentation mechanism has to present continuous media streams and static media streams simultaneously. Communication protocols and presentation controls for continuous media streams and static media streams are different. For continuous media, a DMP adopts an unreliable but more real-time communication protocol, e.g., UDP, to transmit media units because of the tolerance of media loss and the high volume of media units. Presentation controls for continuous media are needed to achieve the real-time requirement as much as possible. For static media, a reliable communication protocol, e.g., TCP or RMTP (Reliable Multicast Transport Protocol) [17], is adopted to prevent media loss. The urgency of real-time and the requirement of a tight temporal relation for static media is much less than that for continuous media. The completeness of presentation control is much required for static media. Therefore, the combination of continuous and static media makes a DMP more complicated and is not easy to achieve. Reference [18] adopted layered video streams. With hierarchical video compression, a server divides a medium stream into several layered streams, e.g., a stream of the base layer and one or more streams of the enhancement layer. A server transmits each layered stream by means of a different multicast groups. The intermediate nodes selectively transmit layered streams according to the link capability and traffic situation. A client then joins and gets only these available layered streams as client's capability allowed. However, the presentation control of combing the continuous and static media is absent.

# 3 RESOLUTIONS OF TEMPORAL CONTROL

A multiple-stream multimedia presentation consists of several kinds of media, such as video, audio, text, and image. Each medium stream has its own presentation schedule and may have related temporal relations with other media streams. However, the diversity and heterogeneity of multicast environments inevitably disturb the temporal relations of media, when media are across networks. In order to have a consistent presentation, clients of a multicast group have to present synchronized media according to the presentation schedule as much as possible. Based on the synchronization points defined in the presentation schedule, clients synchronize media streams with suitable synchronization scheme. The issues of achieving multiple-stream multimedia synchronization at the presentation layer are as follows. (i) Designers have to specify the related synchronization points between/among multiple streams. According to these specific synchronization points, an accurate presentation schedules that define temporal relations of multiple streams are achieved. (ii) Based on presentation schedules, designers adopt suitable and practical synchronization schemes to achieve a smooth DMP.

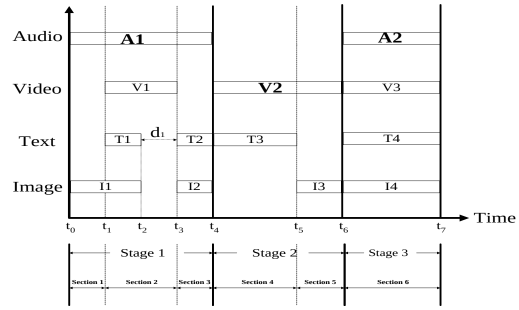


Figure 2: The presentation time bar chart of an illustrative multimedia presentation.

In this section, we specify the temporal distinction of a multiple-stream multimedia presentation in order to induce adequate synchronization points. Then, we describe the synchronization and presentation schemes to achieve smooth DMPs, which are composed of continuous and static media.

## 3.1 Types of Synchronization Points

Figure 2 depicts a presentation example with a time-bar chart. In the presentation example, there are four kinds of media streams, including video, audio, text, and image. Each medium stream is presented or is idle during some time periods and may be related with other streams. In order to identify the temporal relations among multiple media streams, we propose three kinds of temporal synchronization points, which are the stages, sections, and segments.

1. Stage. A presentation stage is a semantic cut of a multimedia presentation. For example, let the multimedia presentation be CNN news broadcast about the chess race between world chess champion Gary Kasparov and supercomputer Deep Blue. Figure 2 depicts the presentation as follows. (1)The news reporter reports the news about a chess race between Gary Kasparov and Deep Blue. The news reporter's audio, Gary Kasparov's video, and the related news texts and images are presented. (2)Gary Kasparov thinks and moves a piece. Then, the video of chess explanation, the texts, and the images about the introduction of Gary Kasparov are presented. (3)An agent moves the piece according to Deep Blue's determination. The background music and some auxiliary texts and images are always presented.

Thus, the presentation depicted in Figure 2 is divided into three stages. At the commencement of each stage, inter-media synchronization among related media streams is required to achieve a consistent presentation.

2. Section: A presentation section represents that some media objects have temporal relations. Steinmetz specified the temporal relations with thirteen different relations, which are the equal, start, before, meet, during, overlap, finish relations, and their reversed relations [6]. Based on these possible temporal relations, a presentation stage can be specified into several presentation sections. One medium object's presentation in a section depends on another medium object's presentation status and a cut point between two presentation sections is a synchronization point. For example, the text of news and the video of Gary Kasparov appear when a specific audio is presented. As depicted in Figure 2, the presentation of the audio object $A1$ starts the presentations of $V1$ and $T1$ at synchronization point $t_1$, i.e.,at the end(commencement) of section 1 (section 2). The object $V1$ finishes and the objects $T2$ and $I2$ start at synchronization point $t_3$, i.e., at the end (commencement) of section 2 (section 3). At the commencement of each section, an inter-media synchronization control is required to achieve a consistent presentation.

3. Segment: In a presentation section, it is possible that a medium stream has no medium object presented during some time periods. A presentation period is denoted as an active segment; an idle period is denoted as an idle segment. In Figure 2, the text medium has two segments in section 2. The first segment displays the text object $T1$ and the idle segment lasts $\delta_1$ time units. With the help of presentation segments, the presentation section can be resolved.

   Based on the concept of stages, section, and segments, we (i)clearly specify the temporal relations among multiple streams and (ii)develop the authoring tool and the temporal control system of Mcast.

### 3.2 Synchronization Control Scheme

Based on the concept of different synchronization point types, we propose the stage-master-based synchronization scheme to solve the multiple-stream multimedia synchronization problem. The stage-master-based synchronization is a refinement of the master-based scheme, which is adopted by Yang et al.[19]. Yang demonstrates that the audio stream is always the master stream since humans are more sensitive to variations in audio. However, in some presentation examples, the audio stream is not always available during the whole presentation, e.g., a piece of silent news. During this silent period, the inter-media synchronization control can not be achieved due to the absent master stream.

In order to solve the problem of the absent master stream, each presentation stage is associated with a master stream to coordinate the presentation and the master stream is changeable between stages. Based on the stage-master-based synchronization scheme, the master stream dominates the commencement and finish of media presentations within the presentation stage. (1) If a slave stream finishes its presentation earlier than the master stream at a synchronization point, the slave stream has to block or extend its presentation until the master stream finishes its presentation. (2) When the master stream finishes its presentation at a synchronization point, the late slave streams have to discard media units to keep pace with the master stream. (3) The master is changeable from one stage to the other stage.

In Mcast, the criterion of selecting a master medium in a stage is based on the human sensitivity about the media. The general principle is as follows. (1) If audio exists in a stage, an audio stream is the master; (2) if audio is absent in a stage, the video stream becomes the master; (3) if there is no continuous medium stream, one of the static media streams is selected to be the master. In Figure 2, the audio stream A1, the video stream V2, and the audio stream A2 are the masters of stages 1, 2, and 3, respectively.

### 3.3 Presentation Control Scheme

In order to compensate jitter anomalies, one can adopt the blocking scheme for the audio medium and the non-blocking scheme for video medium to achieve intra-medium synchronization. Figure 3-(a) depicts an illustrated example for the video stream. When medium unit $k$ was presented at time $t$, the next medium unit $k+1$ should be presented at time $t+\theta$, where $\theta$ is the presentation duration of a medium unit. Unfortunately, medium unit $k+1$ does not arrive on time. Hence, medium unit $k$ is re-presented at time $t+\theta$ according to the non-blocking scheme. During the time of re-presenting medium unit $k$, medium units $k+1$ and $k+2$ arrive before time $t+2\theta$. At time $t+2\theta$, the "expected" medium unit is presented. Should the "expected" medium unit be unit $k+1$ or unit $k+2$? In order to solve the above problem, two presentation schemes that are considered:(i) the time-oriented and (ii) the content-oriented schemes.

If the main concern is (i) to satisfy time-related

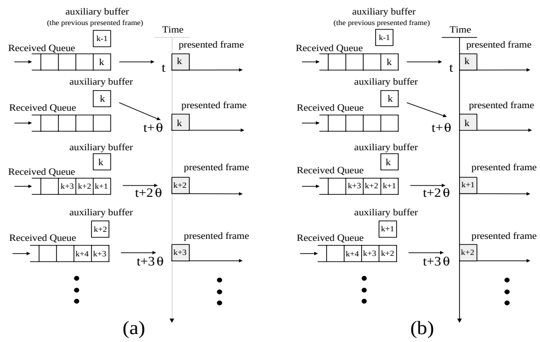


Figure 3: An example of (a) the time-oriented presentation control, and (b) the content-oriented presentation control for a video stream.

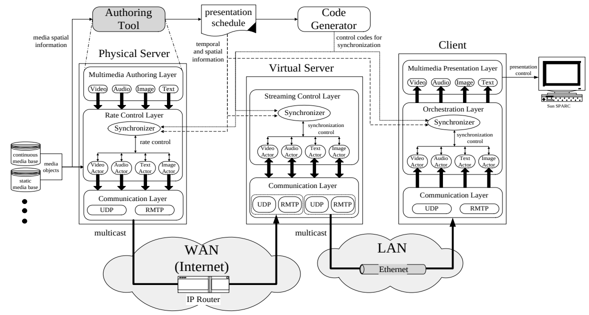


Figure 4: The abstract network and system architecture of Mcast.

temporal relations and (ii) to keep the actual presentation time length equal the nominal presentation time length as much as possible, the time-oriented presentation scheme can be adopted. The "expected" medium unit should be the one that is closest to the nominal one. In Figure 3-(a), medium unit $k+2$ is presented at time $t+2\theta$ and medium unit $k+1$ is discarded. The mathematic formula for obtaining the expected medium unit is as follows. At time $t+i\theta$, assume that (1) the last presented medium unit is medium unit $k+j$, and (2) the received queue contains media units $k+r_1$, $k+r_2$, ..., and $k+r_n$. Let the expected medium unit be $k+m$ at time $t+i\theta$. Then, $m$ is the maximum number of the subset of $(j, r_1, r_2, ..., r_n)$, in which all of the elements in the subset are less than or equal to $i$, i.e., $m = MAXIMUM\{x \in A \mid x \leq i\}, A = \{j, r_1, r_2, ..., r_n\}$. The time-oriented scheme is suitable for the continuous media. The drawback of the time-oriented scheme is that there may be some flickers at the synchronization point when several delayed media units are discarded at the same time.

If the main concern is to keep the completeness of a media presentation as much as possible, the content-oriented presentation scheme can be adopted. Each medium unit is presented as much as possible. In Figure 3-(b), medium unit $k+1$ is presented at time $t+2\theta$ and medium unit $k+2$ is presented at time $t+3\theta$. The mathematics formula for obtaining the expected medium unit is as follows. At time $t+i\theta$, We assume that (1) the last presented medium unit is medium unit $k+j$, and (2) the received queue contains media units $k+r_1$, $k+r_2$, ..., and $k+r_n$. Let the expected medium unit be $k+m$ at time $t+i\theta$. Then, $m$ is the minimum number of the subset of $(j, r_1, r_2, ..., r_n)$, in which all of the elements in the subset are less than or equal to $i$, i.e., $m = MINIMUM\{x \in A \mid x \leq i\}, A = \{j, r_1, r_2, ..., r_n\}$. The content-oriented scheme is suitable for the static media and the content-critical continuous media. The drawbacks of the content-oriented scheme are twofold. (i) The total presentation time may be become longer than the nominal presentation time, and (ii) more inter-media asynchronous anomalies may exist until an inter-media synchronization is achieved.

# 4 NETWORK AND SYSTEM ARCHITECTURE

The Mcast system is composed of the physical server system (PSS), the virtual server system (VSS), and the client system (CS). Figure 4 depicts the abstract system and network communication architecture of Mcast. The underlined network communication is based on MBone [20], which provides multicast transmission across Internet.

1. The Physical Server System: Main functions of the physical server system are (1) to store media resources that are requested by WAN's virtual servers, (2) to store the presentation schedule that contains temporal and spatial relations of media objects, and (3) to multicast requested media objects to WAN's virtual servers and LAN's clients. Based on the requirement of the above three main functions, the physical server system is composed of three system layers. The upper layer is the multimedia authoring layer, which provides a multiple-stream multimedia authoring tool to allow people to author a multimedia presentation and to generate the corresponding presentation schedule. The presentation schedule records the temporal and spatial relations of media streams and is multicasted to virtual servers and clients. The middle layer is the rate control layer, which is responsible for retrieving media objects from media bases and transmitting these media objects with a streaming manner, i.e., to keep a continuous and steady multicasting. The rate control layer is composed of two kinds of components, which are Actor and Synchronizer components. Each

medium stream is controlled by an independent Actor. The Actor is responsible for retrieving media objects from the media base, and then multicasting these media objects with a suitable rate control. The Synchronizer is responsible for coordinating rate control among media Actors. The lowest layer is the communication layer, which is responsible for media transmission. Functions of communication layer include (1) IP multicasting, which is based on UDP and is used to transmit continuous media, and (2) RMTP (Reliable Multicast Transport Protocol), which provides reliable multicasting and is used to transmit static media and the presentation schedule [17]. A system manager can specify a communication configuration that contains the multicast group address, and communication socket ports by means of the authoring tool.

2. The Virtual Server System: The virtual server system is a transceiver. After receiving media objects, the virtual server system stores them in the media buffer temporarily. According to the presentation schedule, the virtual server system re-multicasts media units to the designated group members with the proposed synchronization and presentation control, which are responsible for compensating WAN's anomalies. As that is depicted in Figure 4, the virtual server system is composed of two system layers. The upper layer is the streaming control layer, which is responsible for multiple-stream synchronization and presentation with a streaming manner. The Actor component of the virtual server system is more complicated than that of the physical server system. The Actor is responsible for receiving media objects from the WAN side, and then executing intra-media synchronization to compensate jitter anomalies. After achieving the intra-medium synchronization control, the Actor re-multicasts these synchronized media objects to LAN's clients with the proposed presentation control. The Synchronizer is responsible for inter-media synchronization to coordinate Actors' behavior and to compensate skew anomalies. The low layer is the communication layer, which is composed of WAN and LAN parts. Both of WAN and LAN parts have their respective pair of UDP and RMTP connections, which are responsible for transmitting continuous and static media respectively.

3. The Client System: The main function of the client system is to compensate LAN's anomalies by using proposed synchronization and presentation control, and then to achieve a smooth presentation. The client system is composed of three system layers. The upper layer is the multimedia presentation layer, which provides users with a multiple-stream multimedia presentation environment. The middle layer is the orchestration layer, which is responsible for jitter and skew compensation, and for multimedia synchronization and presentation control across multiple streams. The Actor is responsible for the intra-media synchronization and the medium presentation control. The Synchronizer is responsible for the inter-media synchronization to compensate skew anomalies. The lowest layer is the communication layer, which is responsible for receiving media objects.

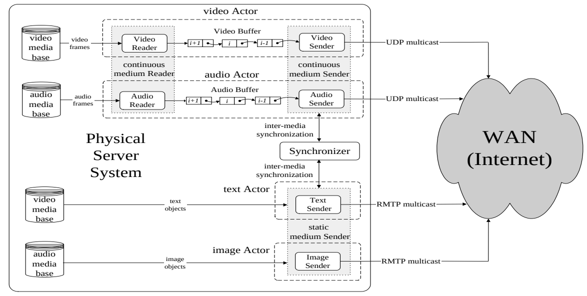


Figure 5: Architecture of the physical server system.

# 5 SOFTWARE ARCHITECTURE AND SYSTEM DEVELOPMENT

This Section describes the software architecture and prototype implementation of the physical server system (PSS), the virtual server system (VSS), and the client system (CS).

## 5.1 Physical Server System (PSS)

Three main components of the PSS are Synchronizer, Media Sender, and Continuous Media Reader, which are depicted in Figure 5.

1. Synchronizer. Synchronizer is responsible for the coarse-grain synchronization to achieve section and stage synchronization based on the parallel-last scheme. With the parallel-last scheme, each medium stream can be completely transmitted regardless of media processing anomalies.

2. Media Sender. Media Sender is responsible for retrieving media units from media buffers, and then transmits them to networks. Moreover, the media sender should cooperate with Synchronizer to achieve inter-media synchronization.

3. Continuous Media Reader. Continuous Media Reader is responsible for retrieving continuous media units from the media base and then puts them into media buffers. The purpose of media buffers is to compensate the irregular media retrieval time from the media base. For static me-

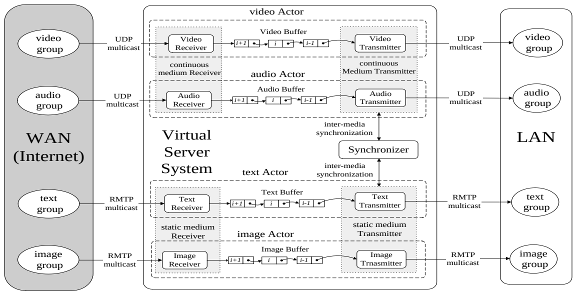


Figure 6: Architecture of the virtual server system.

dia, since (1) the volume of media units is much less than that of continuous and (2) temporal requirement is not critical, static media units is directly retrieved from media bases by the corresponding Media Senders.

Rate control is used to keep a continuous and steady multicasting for continuous media streams. For example, assume that the default transmission rate of a video stream is 15 frames-per-second (fps). Hence, Media Reader has to retrieve a video frame for every 1/15 second from the video base and put the video frame into the video buffer. However, since a regular operating system, e.g., Unix and Windows NT, is a time-sharing and a multiple-process system. It is difficult to exactly control what time to retrieve a video frame and what time to accurately multicast a video frame. Due to the inaccuracy execution-time, Media Reader can not retrieve media units from the media base with a constant retrieving rate. As a result, the media buffer may become empty because Media Sender multicasts media units with the default transmitting rate. Under the situation of buffer empty, Media Sender has to suspend its work and then waits for Media Reader to retrieve media units into buffer. The suspending time induces a discontinuous transmission. In order to solve the problem of discontinuous transmission, Mcast adopts a "Low/Upper Water mark (LW/UW)" skill. The LW and UW are thresholds. If the buffer length is less than LW, then Media Reader increases the retrieving rate. To prevent buffer overflow, when the buffer length exceeds UW, Media Reader suspends until the buffer length is less than UW. When the buffer length is between LW and UW, the retrieval rate is normal.

## 5.2 Virtual Server System (VSS)

Three main components of VSS are Media Receiver, Media Transmitter, and Synchronizer, which are depicted in Figure 6. These three components of VSS are similar to those in PSS. That is, functions of Media Receiver (Media Transmitter) in VSS are similar to those of Media Reader (Media Sender) in PSS. For simplicity, we only describe main features and functionality of VSS.

- Media Receiver. Because of the characteristics of static media, Static Media Receiver can not lose any medium unit. Thus, RMTP is used between the virtual servers and the physical server for static media. With the reliability function of RMTP, each static media unit can be received.

- Media Transmitter. Media Transmitter retrieves one medium unit from the media buffer and then re-multicasts the medium unit to LAN's clients according to the schedule description file. Two types of Media Transmitter are Continuous Media Transmitter and Static Media Transmitter, which are responsible for multicasting continuous and static media units respectively. RMTP is also used to transmit static media for the reason of reliability.

- Synchronizer. Synchronizer is also responsible for coarse-grain synchronization and to coordinate Transmitters' behavior.

In VSS, the master-medium-based synchronization control combining with the adopted presentation scheme, which is either the content-oriented or the time-oriented scheme, is executed at each synchronization point.

## 5.3 Client System (CS)

CS starts the presentation after some commencement control is done, i.e., after pre-depositing some media units in the buffer to compensate LAN's anomalies. Three main components of CS are Media Gather, Media Presenter, and Synchronizer, which are depicted in Figure 7. In CS, an additional function of Media Presenter is to achieve the fine-grain synchronization between continuous media under the condition that a tight temporal relation between audio and video streams, e.g., lip synchronization, is needed.

The master Media Presenter controls fine-grain synchronization by issuing fine-grain control messages to all of the other non-master Media Presenters at the fine synchronization point. The slower Media Presenters have to keep pace with the fastest Presenter by discarding some media units to reach fine-grain synchronization points. Synchronizer controls the coarse-grain synchronization between two consecutive sections. Furthermore, at the beginning of each section, Synchronizer has to assign one Presenter as the master and issues the fine-grain synchronization flag to the master Presenter in order to notify whether the fine-grain synchronization is needed or not in this section.

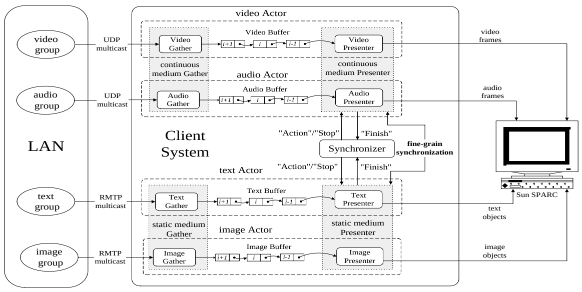


Figure 7: Architecture of the client

# 6 CONCLUSION

This paper describes the major considerations, resolutions, and techniques that are involved in designing and implementing the multiple-stream multimedia presentations based on multicast communications. According to the design and development considerations, we propose (1) the stage-master-based scheme, which is suitable for multiple-stream multimedia synchronization, and (2) the time-oriented and content-oriented schemes, which are respectively suitable for continuous and static media. Based on the proposed synchronization/presentation schemes, we develop the Mcast multimedia middleware. Using Mcast, developers can develop multicast multiple-stream multimedia presentations for various applications.

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