

Chapter 16

Multimedia Network Communications and Applications

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Characteristics of Multimedia Data

- **Voluminous** — they demand very high data rates, possibly dozens or hundreds of Mbps.
- **Real-time and interactive** — they demand low delay and synchronization between audio and video for “lip sync”. In addition, applications such as video conferencing and interactive multimedia also require two-way traffic.
- **Sometimes bursty** — data rates fluctuate drastically, e.g., no traffic most of the time but burst to high volume in video-on-demand.

16.1 Quality of Multimedia Data Transmission

- **Quality of Service (QoS)** depends on many parameters:
 - **Data rate:** a measure of transmission speed.
 - **Latency (maximum frame/packet delay):** maximum time needed from transmission to reception.
 - **Packet loss or error:** a measure (in percentage) of error rate of the packetized data transmission.
 - **Jitter:** a measure of smoothness of the audio/video playback, related to the variance of frame/packet delays.
 - **Sync skew:** a measure of multimedia data synchronization.

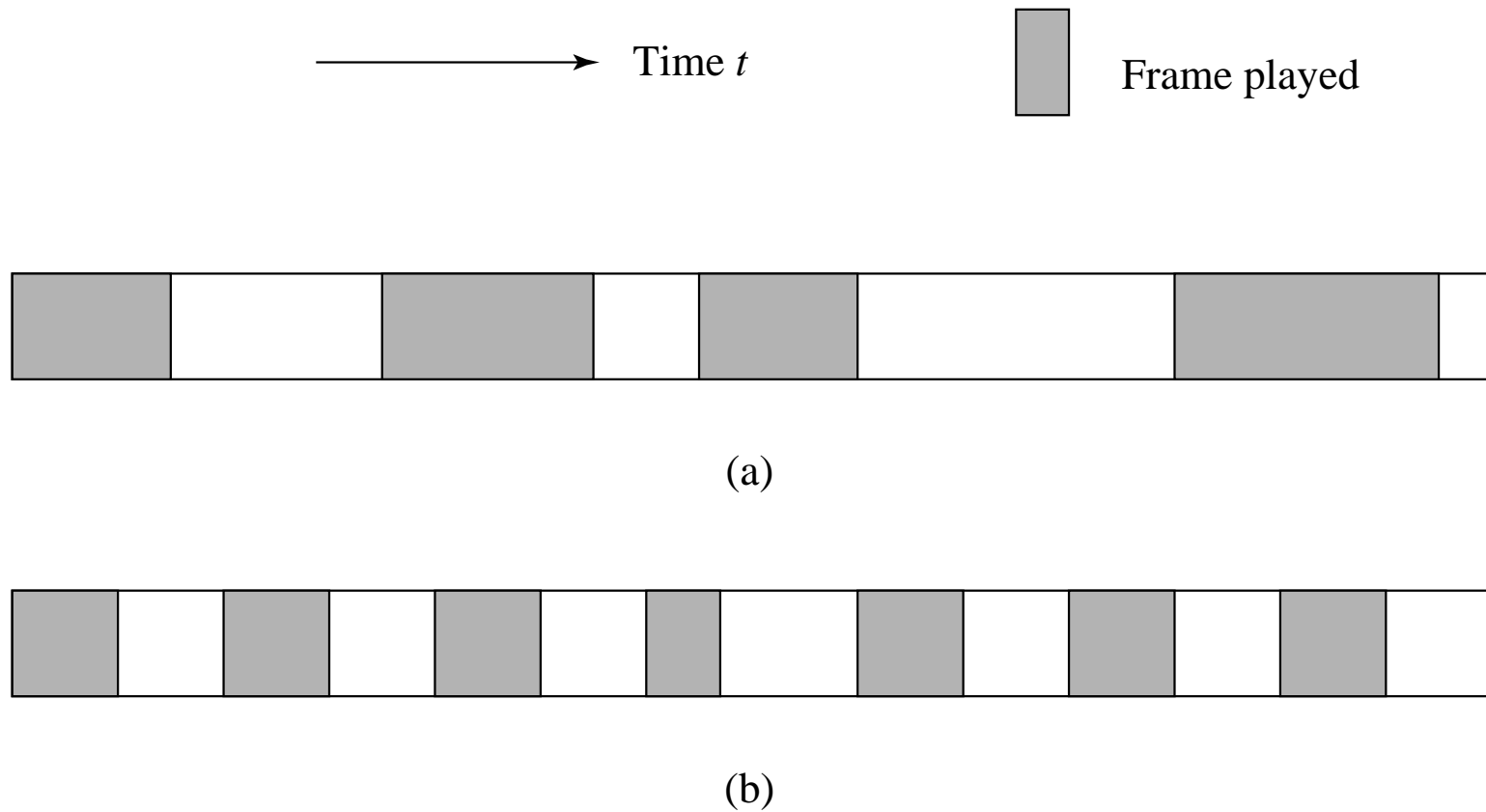


Fig. 16.1: Jitters in frame playbacks. (a) High jitter, (b) Low jitter.

Multimedia Service Classes

- **Real-Time** (also *Conversational*): two-way traffic, low latency and jitter, possibly with prioritized delivery, e.g., voice telephony and video telephony.
- **Priority Data**: two-way traffic, low loss and low latency, with prioritized delivery, e.g., E-commerce applications.
- **Silver**: moderate latency and jitter, strict ordering and sync. One-way traffic, e.g., streaming video, or two-way traffic (also *Interactive*), e.g., web surfing, Internet games.
- **Best Effort** (also *Background*): no real-time requirement, e.g., downloading or transferring large files (movies).
- **Bronze**: no guarantees for transmission.

Table 16.1: Requirement on Network Bandwidth / Bit-rate

Application	Speed Requirement
Telephone	16 kbps
Audio-conferencing	32 kbps
CD-quality audio	128–192 kbps
Digital music (QoS)	64–640 kbps
H. 261	64 kbps–2 Mbps
H. 263	< 64 kbps
DVI video	1.2–1.5 Mbps
MPEG-1 video	1.2–1.5 Mbps
MPEG-2 video	4–60 Mbps
HDTV (compressed)	> 20 Mbps
HDTV (uncompressed)	> 1 Gbps
MPEG-4 video-on-demand (QoS)	250–750 kbps
Videoconferencing (QoS)	384 kbps–2 Mbps

Table 16.2: Tolerance of Latency and Jitter in Digital Audio and Video

Application	Avg Latency Tolerance (msec)	Avg Jitter Tolerance (msec)
Low-end videoconf. (64 kbps)	300	130
Compressed voice (16 kbps)	30	130
MPEG NTSC video (1.5 Mbps)	5	7
MPEG audio (256 kbps)	7	9
HDTV video (20 Mbps)	0.8	1

Perceived QoS

- Although QoS is commonly measured by the above technical parameters, QoS itself is a **“collective effect of service performances that determine the degree of satisfaction of the user of that service”**.
- In other words, it has everything to do with how the user *perceives* it. For example, in real-time multimedia:
 - Regularity is more important than latency (i.e., jitter and quality fluctuation are more annoying than slightly longer waiting).
 - Temporal correctness is more important than the sound and picture quality (i.e., ordering and synchronization of audio and video are of primary importance).
 - Humans tend to focus on one subject at a time. User focus is usually at the center of the screen, and it takes time to refocus especially after a scene change.

QoS for IP Protocols

- **IP** is a *best-effort* communications technology — hard to provide QoS over IP by current routing methods.
 - Abundant bandwidth improves QoS, but unlikely to be available everywhere over a complex networks.
- **DiffServ** (Differentiated Service) uses DiffServ code [*TOS* (Type of Service) octet in IPv4 packet, and Traffic Class octet in IPv6 packet] to classify packets to enable their differentiated treatment.
 - Widely deployed in intra-domain networks and enterprise networks as it is simpler and scales well.
 - Emerging as the de-facto QoS technology in conjunction with other QoS.

QoS for IP Protocols (Cont'd)

- **MPLS** (*Multiple Protocol Label Switching*) facilitates the marriage of IP to OSI Layer 2 technologies.
 - Creates tunnels: **Label Switched Paths (LSP)** — IP network becomes connection-oriented.
 - Main advantages of MPLS:
 1. Support Traffic Engineering (TE), which is used essentially to control traffic flow.
 2. Support VPN (Virtual Private Network).
 3. Both TE and VPN help delivery of QoS for multimedia data.

Prioritized Delivery

Used to alleviate the perceived deterioration (high packet loss or error rate) in network congestion.

- **Prioritization for types of media:**
 - Transmission algorithms can provide prioritized delivery to different media.
- **Prioritization for uncompressed audio:**
 - PCM audio bitstreams can be broken into groups of every n th sample.
- **Prioritization for JPEG image:**
 - The different *scans* in Progressive JPEG and different resolutions of the image in Hierarchical JPEG can be given different priorities.
- **Prioritization for compressed video:**
 - Set priorities to minimize playback delay and jitter by giving highest priority to I-frames for their reception, and lowest priority to B-frames.

16.2 Multimedia over IP

A *broadcast* message is sent to all nodes in the domain, a *unicast* message is sent to only one node, and a *multicast* message is sent to a set of specified nodes.

- **IP-Multicast:**

- Anonymous membership: the source host multicasts to one of the IP-multicast addresses — doesn't know who will receive.
- Potential problem: too many packets will be traveling and alive in the network — use time-to-live (TTL) in each IP packet.

- **MBone** (Multicast Backbone) — based on the IP-multicast technology:

- Used for audio and video conferencing on the Internet .
- Uses a subnetwork of routers (*mrouters*) that support multicast to forward multicast packets.

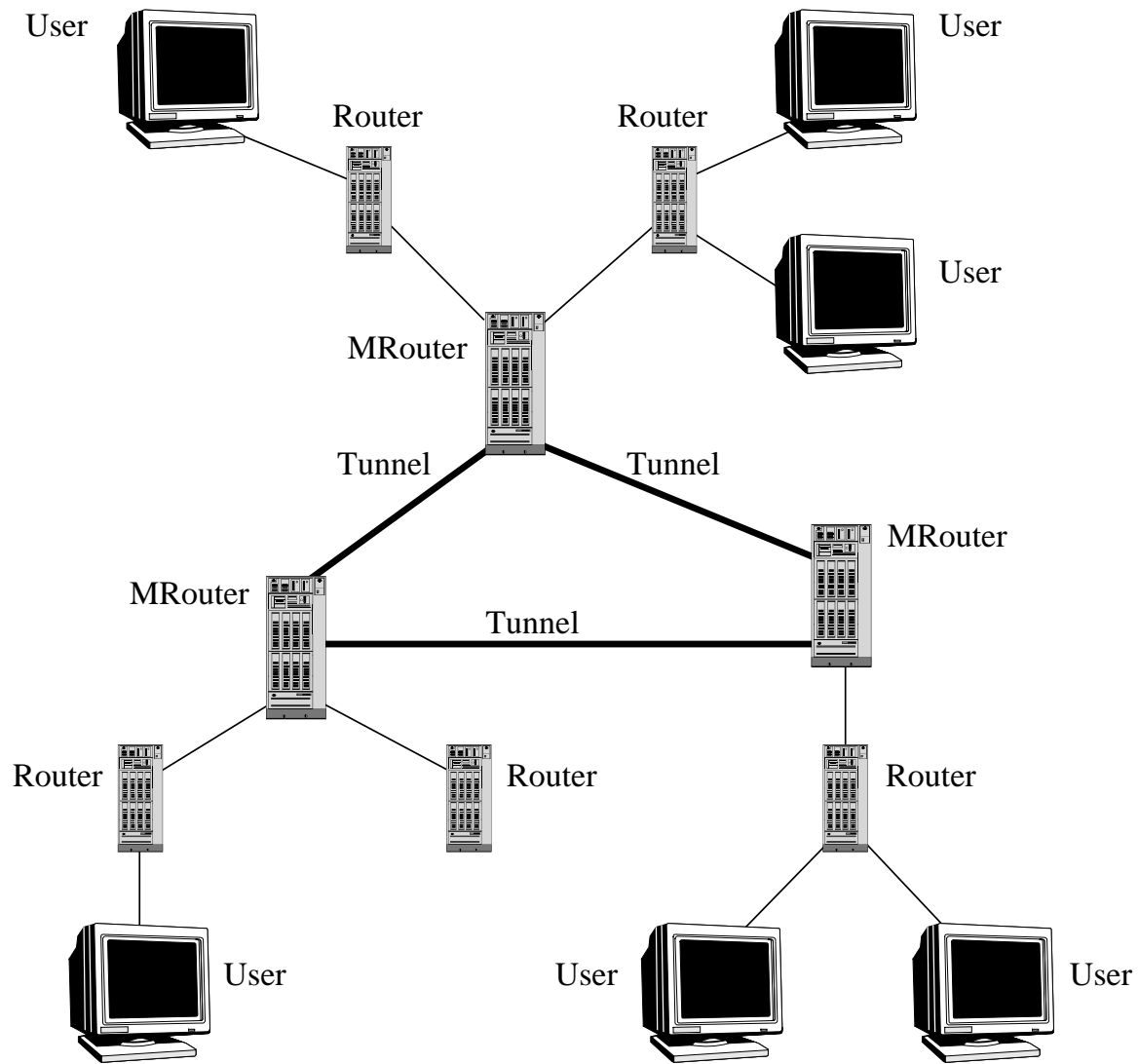


Fig. 16.2: Tunnels for IP Multicast in MBone.

Internet Group Management Protocol (IGMP)

- Designed to help the maintenance of multicast groups.
- Two special types of IGMP messages are used:
 - **Query** messages are multicast by routers to all local hosts to inquire group membership.
 - **Report** is used to respond to query, and to join groups.
- On receiving a query, members wait for a random time before responding.
- Routers periodically query group membership, and declare themselves group members if they get a response to at least one query. If no responses occur after a while, they declare themselves as non-members.

RTP (Real-time Transport Protocol)

- Designed for the transport of real-time data such as audio and video streams:
 - Primarily intended for multicast.
 - Used in *nv* (*network video*) for MBone, Netscape LiveMedia, Microsoft Netmeeting, and Intel Videophone.
- Usually runs on top of UDP which provides efficient (but less reliable) connectionless datagram service:
 - RTP must create its own *timestamping* and *sequencing* mechanisms to ensure the ordering.

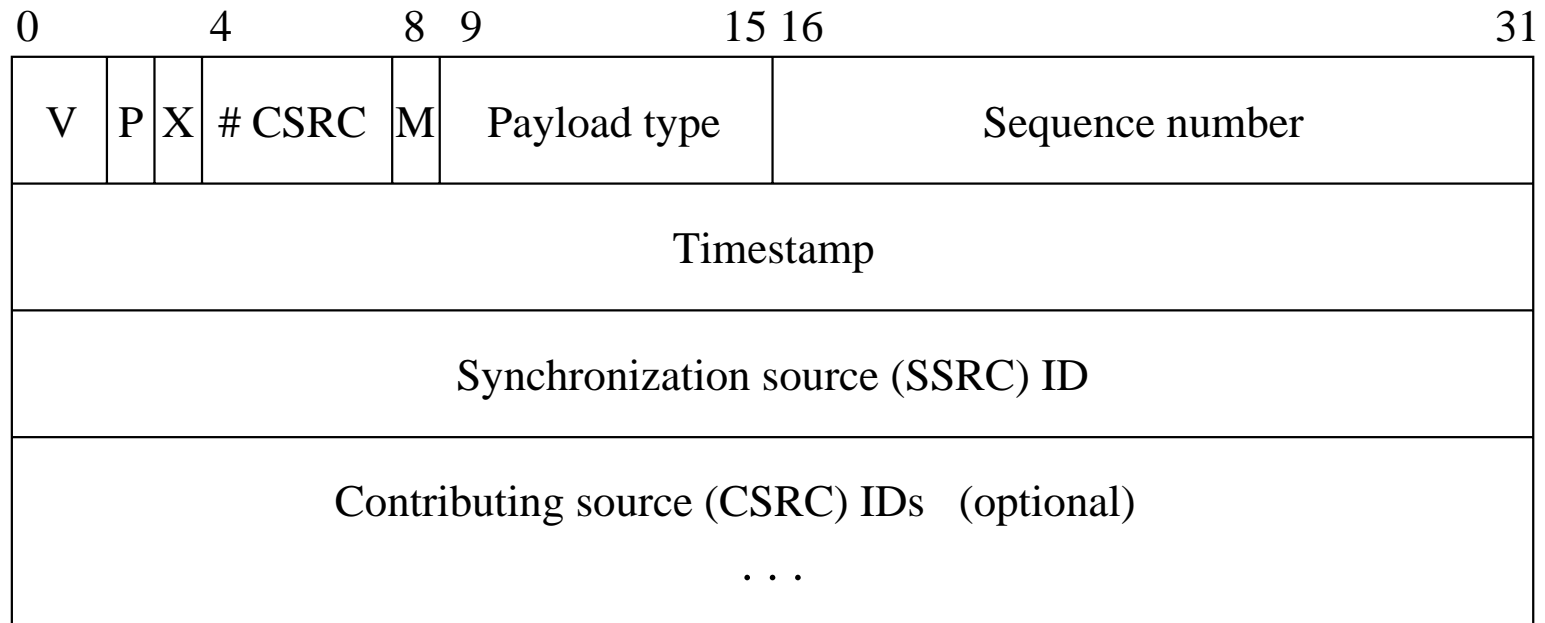


Fig. 16.3: RTP Packet Header.

Additional Parameters in RTP Header

- **Payload Type:** indicates the media data type as well as its encoding scheme.
 - E.g., PCM, H.261/H.263, MPEG 1, 2, and 4 audio/video, etc.
- **Timestamp:** records the instant when the first octet of the packet is sampled.
 - With the timestamps, the receiver can play the audio/video in proper timing order and synchronize multiple streams.
- **Sequence Number:** complements the function of timestamping.
 - Incremented by one for each RTP data packet sent so to ensure that the packets can be reconstructed in order by the receiver.

Additional Parameters in RTP Header (Cont'd)

- **Synchronization Source (SSRC) ID:** for identifying sources of multimedia data.
 - Incremented by one for each RTP data packet sent so to ensure that the packets can be reconstructed in order by the receiver.
- **Contributing Source (CSRC) ID:** for source identification of contributors, e.g., all speakers in an audio conference.

RTCP (Real Time Control Protocol)

- A companion protocol of RTP:
 - Monitors QoS in providing feedback to the server (sender) and conveys information about the participants of a multi-party conference.
 - Provides the necessary information for audio and video synchronization.
- RTP and RTCP packets are sent to the same IP address (multicast or unicast) but on different ports.

Five types of RTCP packets

1. **RR (Receiver Report)** — to provide quality feedback (number of last packet received, number of lost packets, jitter, timestamps for calculating round-trip delays).
2. **SR (Sender Report)** — to provide information about the reception of RR, number of packets/bytes sent, etc.
3. **SDES (Source Description)** — to provide information about the source (e-mail address, phone number, full name of the participant).
4. **Bye** — the end of participation.
5. **APP (Application specific functions)** — for future extension of new features.

RSVP (Resource ReSerVation Protocol)

- Developed to guarantee desirable QoS, mostly for multicast although also applicable to unicast.
 - A general communication model supported by RSVP consists of m senders and n receivers, possibly in various multicast groups (e.g. Fig. 16.4(a)).
- The most important messages of RSVP:
 - (1) A **Path** message is initiated by the sender, and contains information about the sender and the path (e.g., the previous RSVP hop).
 - (2) A **Resv** message is sent by a receiver that wishes to make a reservation.

Main Challenges of RSVP

- (a) There can be a large number of senders and receivers competing for the limited network bandwidth.
- (b) The receivers can be heterogeneous in demanding different contents with different QoS.
- (c) They can be dynamic by joining or quitting multicast groups at any time.

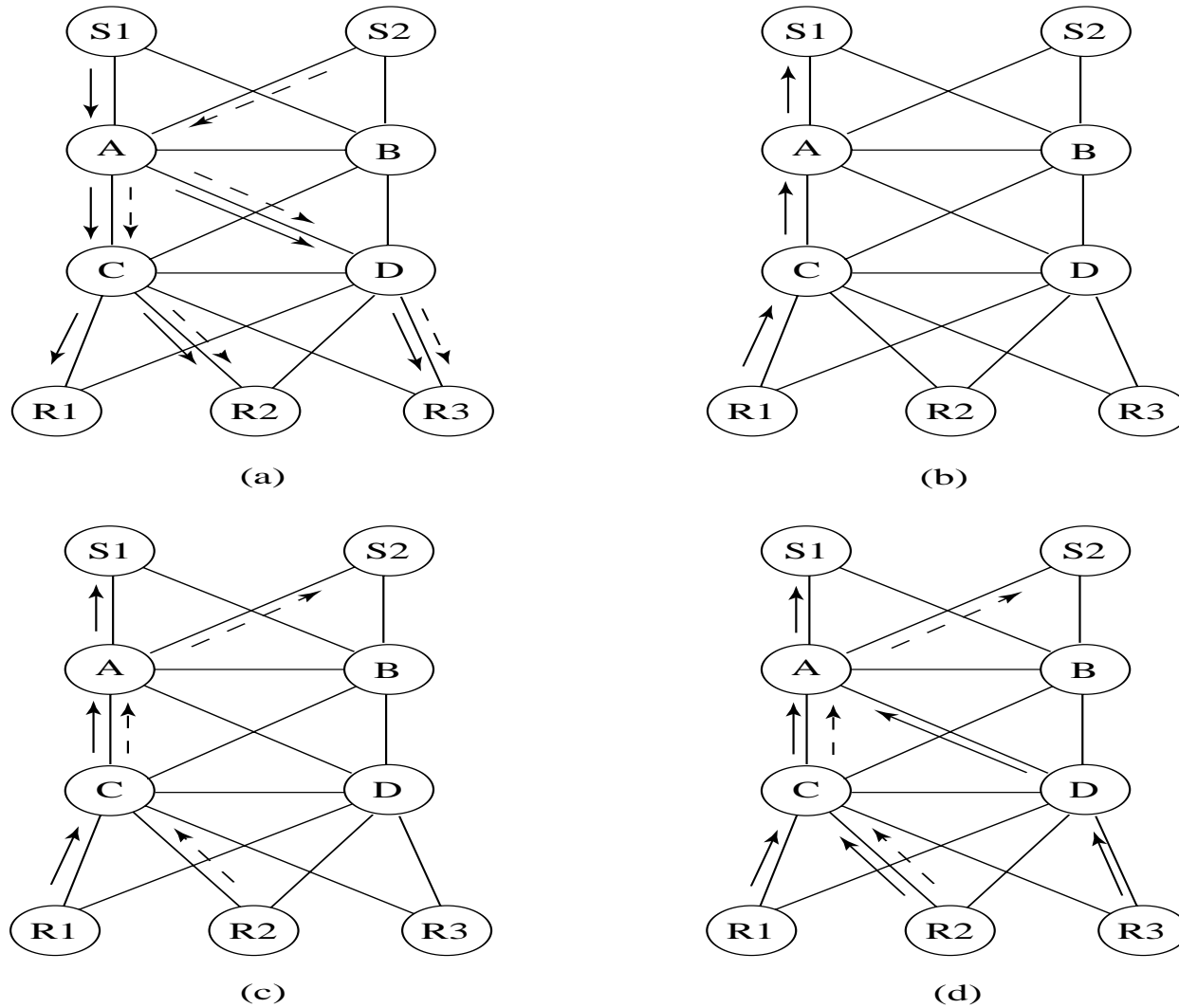


Fig. 16.4: A scenario of network resource reservation with RSVP.

About the Example in Fig. 16.4

- Fig. 16.4 depicts a simple network with 2 senders (S1, S2), three receivers (R1, R2, and R3) and 4 routers (A, B, C, D):
 1. In (a), **Path** messages are sent by both S1 and S2 along their paths to R1, R2, and R3.
 2. In (b) and (c), R1 and R2 send out **Resv** messages to S1 and S2 respectively to make reservations for S1 and S2 resources. Note that from C to A, two separate channels must be reserved since R1 and R2 requested different data streams.
 3. In (d), R2 and R3 send out their **Resv** messages to S1 to make additional requests. R3's request was merged with R1's previous request at A and R2's was merged with R1's at C.

RTSP (Real Time Streaming Protocol)

- **Streaming Audio and Video:**

- Audio and video data that are transmitted from a *stored media server* to the client in a data stream that is almost instantly decoded.

- **RTSP Protocol:** for communication between a client and a stored media server (Fig. 16.5).

1. **Requesting presentation description:** the client issues a DESCRIBE request to the Stored Media Server to obtain the presentation description — media types, frame rate, resolution, codec, etc.
2. **Session setup:** the client issues a SETUP to inform the server of the destination IP address, port number, protocols, TTL (for multicast).
3. **Requesting and receiving media:** after receiving a PLAY, the server started to transmit streaming audio/video data using RTP.
4. **Session closure:** TEARDOWN closes the session.

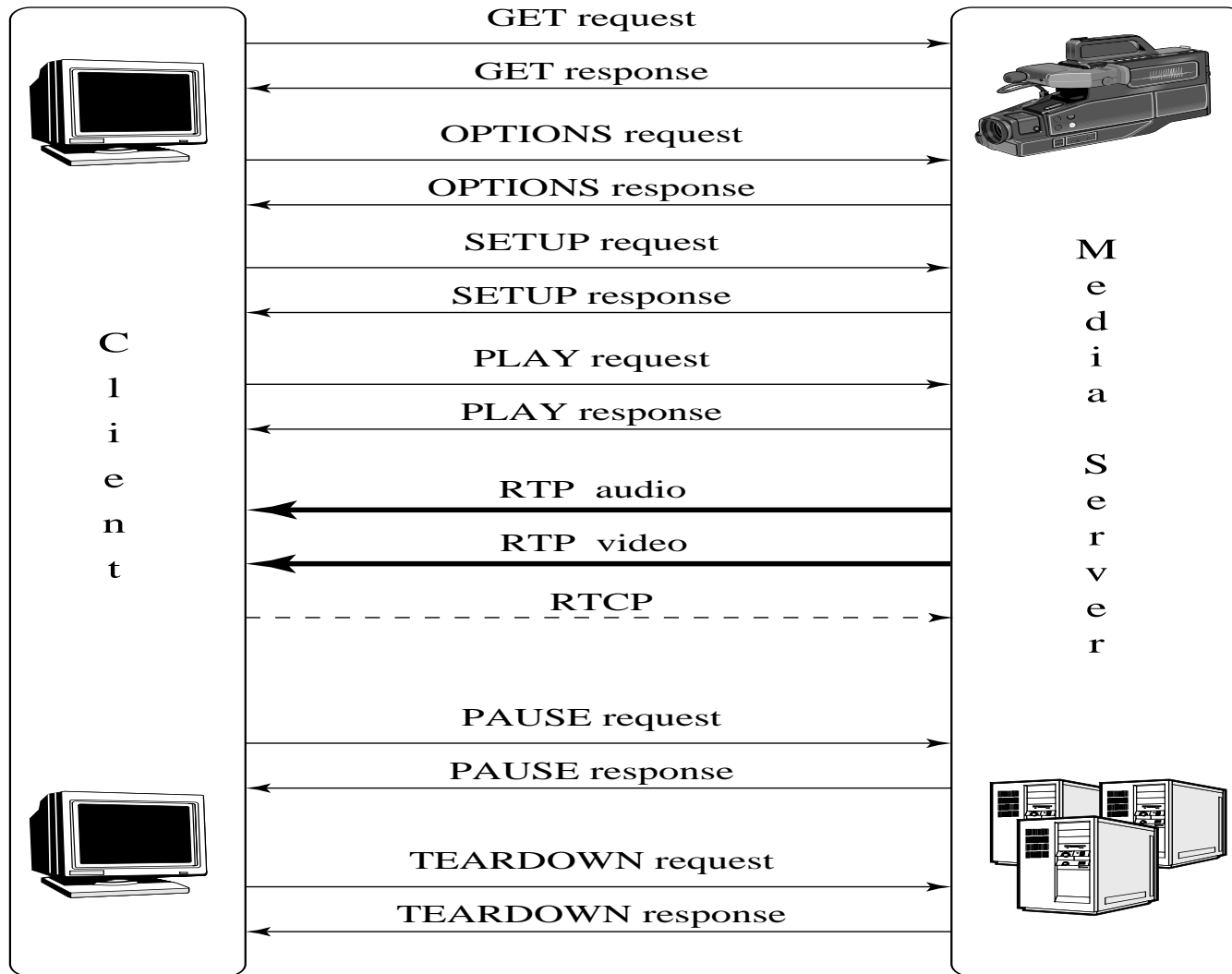


Fig. 16.5: A possible scenario of RTSP operations.

Internet Telephony

- Main advantages of Internet telephony over *POTS* (*Plain Old Telephone Service*):
 - Uses packet-switching — network usage is much more efficient (voice communication is bursty and VBR encoded).
 - With the technologies of multicast or multipoint communication, multi-party calls are not much more difficult than two-party calls.
 - With advanced multimedia data compression techniques, various degrees of QoS can be supported and dynamically adjusted according to the network traffic.
 - Good graphics user interfaces can be developed to show available features and services, monitor call status and progress, etc.

Internet Telephony (Cont'd)

- As shown in Fig. 16.6, the transport of real-time audio (and video) in Internet telephony is supported by RTP (whose control protocol is RTCP).
- Streaming media is handled by RTSP and Internet resource reservation is taken care of by RSVP.

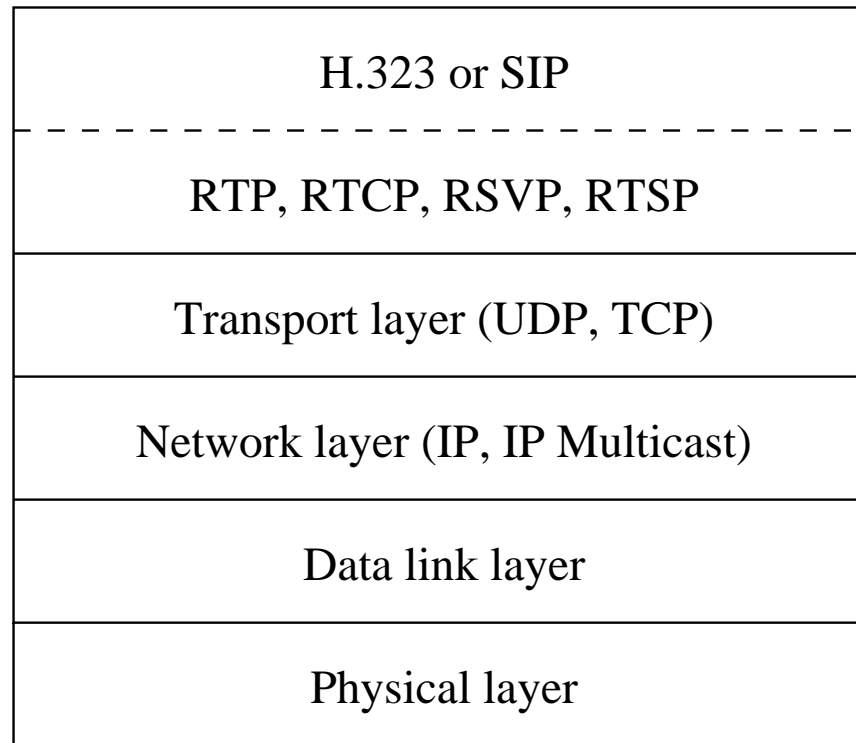


Fig. 16.6: Network Protocol Structure for Internet Telephony.

H.323

- A standard for packet-based multimedia communication services over networks that do not provide a guaranteed QoS.
 - It specifies **signaling protocols**, and describes terminals, multipoint control units (for conferencing) and gateways for the integration of Internet telephony with *GSTN* data terminals.

- The H.323 signaling process consists of two phases:
 1. **Call setup**: The caller sends the gatekeeper (GK) a RAS Admission Request (ARQ) message which contains the name and phone number of the callee.

 2. **Capability exchange**: An H.245 control channel will be established, of which the first step is to exchange capabilities of both the caller and callee.

SIP (Session Initiation Protocol)

- An application-layer control protocol in charge of the establishment and termination of sessions in Internet telephony.
 - SIP is a text-based protocol, also a client-server protocol.
- SIP can advertise its session using email, news group, web pages or directories, or *SAP* — a multicast protocol.
- The *methods* (commands) for clients to invoke:
 - **INVITE**: invites callee(s) to participate in a call.
 - **ACK**: acknowledges the invitation.
 - **OPTIONS**: enquires media capabilities without setting up a call.
 - **CANCEL**: terminates the invitation.
 - **BYE**: terminates a call.
 - **REGISTER**: sends user's location info to a Registrar (a SIP server).

Scenario of a SIP Session

- Fig. 16.7 A scenario when a caller initiates a SIP session:
 - Step 1. Caller sends an "INVITE john@home.ca" to the local Proxy server P1.
 - Step 2. The proxy uses its DNS (Domain Name Service) to locate the server for john@home.ca and sends the request to it.
 - Step 3,4. john@home.ca is current not logged on the server. A request is sent to the nearby Location server. John's current address john@work.ca is located.
 - Step 5. Since the server is a Redirect server, it returns the address john@work.ca to the Proxy server P1.

- Step 6. Try the next Proxy server P2 for john@work.ca.
- Step 7,8. P2 consults its Location server and obtains John's local address john_doe@my.work.ca.
- Step 9,10. The next-hop Proxy server P3 is contacted, it in turn forwards the invitation to where the client (callee) is.
- Step 11-14. John accepts the call at his current location (at work) and the acknowledgments are returned to the caller.

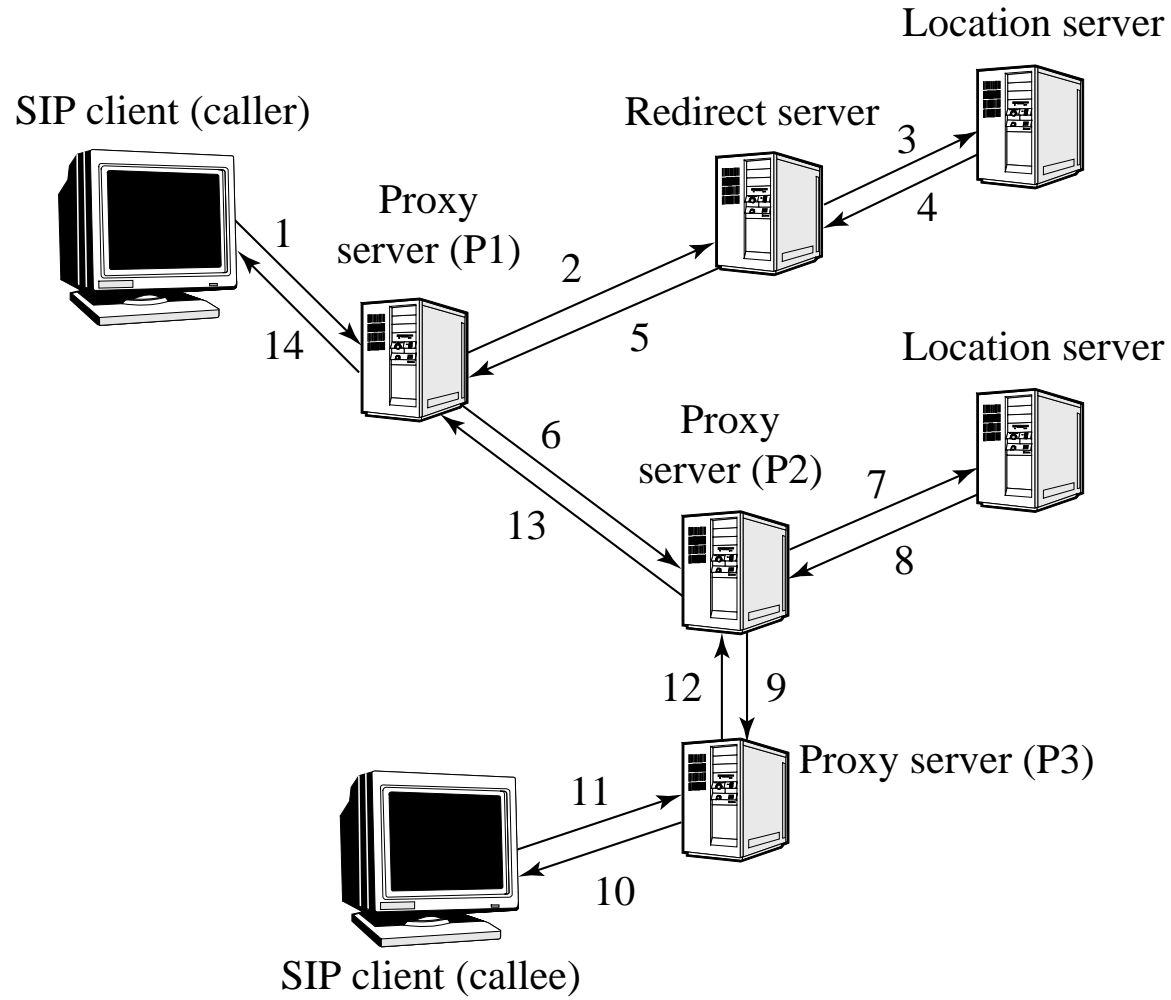


Fig 16.7: A possible scenario of SIP session initiation.

16.3 Multimedia over ATM Networks

- **Video Bit-rates over ATM:**

- **CBR** (Constant Bit Rate): if the allocated bit-rate of CBR is too low, then cell loss and distortion of the video content are inevitable.
- **VBR** (Variable Bit Rate): the most commonly used video bit-rate for compressed video, can be further divided into:
 - * *rt-VBR* (real-time Variable Bit Rate): for compressed video.
 - * *nrt-VBR* (non real-time Variable Bit Rate): for specified QoS.
- **ABR** (Available Bit Rate): data transmission can be backed off or buffered due to congestion. Cell loss rate and minimum cell data rate can sometimes be specified.
- **UBR** (Unspecified Bit Rate): no guarantee on any quality parameter.

ATM Adaptation Layer (AAL)

- Converts various formats of user data into ATM data streams and vice versa.
- Different types of protocols of (AAL):
 - **AAL Type 1:** supports real-time, constant bit rate (CBR), connection-oriented data streams.
 - **AAL Type 2:** intended for variable bit rate (VBR) compressed video and audio (inactive).
 - **AAL Types 3 and 4:** have been combined into one type — AAL Type 3/4. It supports variable bit rate (VBR) of either connection-oriented or connectionless general (non real-time) data services.
 - **AAL Type 5:** the new protocol introduced for multimedia data transmissions, promising to support all classes of data and video services (from CBR to UBR, from rt-VBR to nrt-VBR).

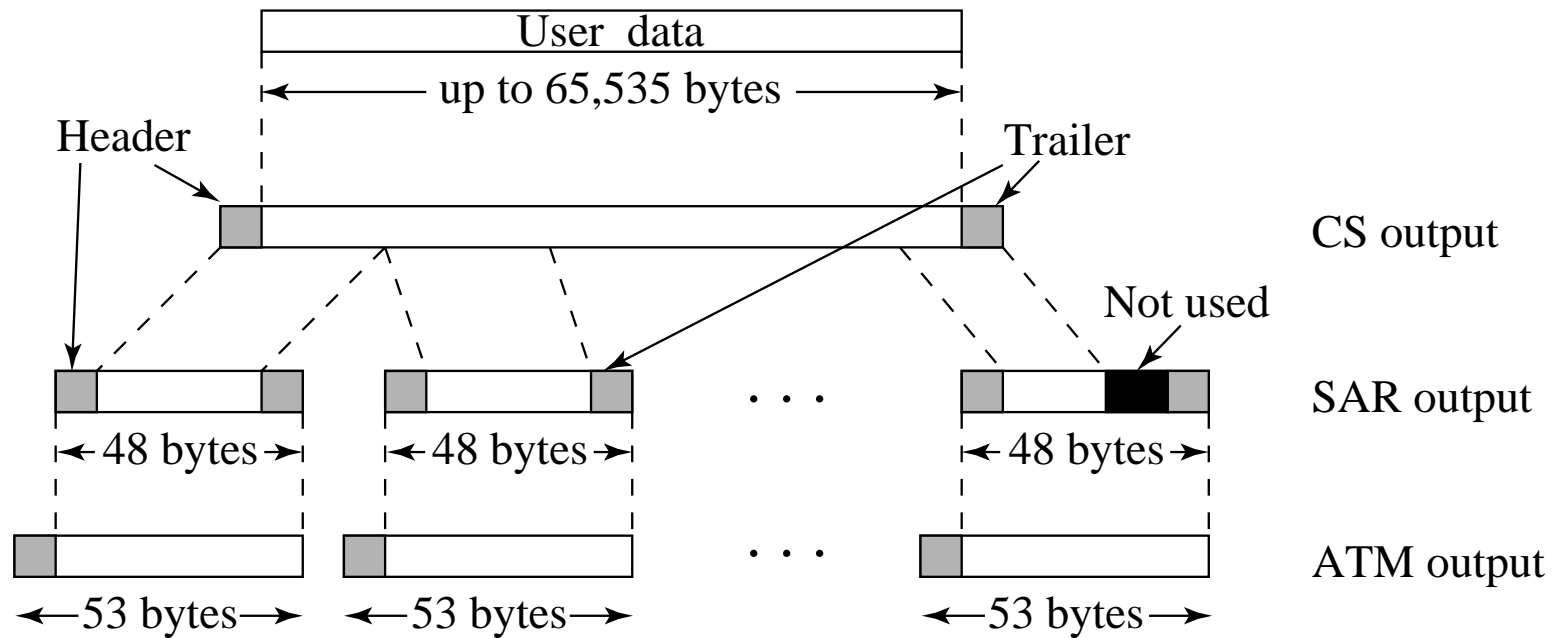


Fig. 16.8: Headers and Trailers added at the CS and SAR sublayers

- Headers and trailers are added to the original user data at the CS (Convergence Sublayer) and SAR (Segmentation And Reassembly sublayer) — eventually form the 53-byte ATM cells with the 5-byte ATM header appended.

Table 16.3: Comparison of AAL Types

	AAL 1	AAL 3/4	AAL 5
CS Header/Trailer Overhead	0 byte	8 bytes	8 bytes
SAR Header/Trailer Overhead	1 or 2 bytes	4 bytes	0 byte
SAR Payload	47 or 46 bytes	44 bytes	48 bytes
CS Checksum	None	None	4 bytes
SAR Checksum	None	10 bits	None

- AAL 3/4 has an overhead of designating 4 bytes header/trailer for each SAR cell, whereas AAL 5 has none at this sublayer. Considering the numerous number of SAR cells, this is a substantial saving for AAL 5.
- As part of the SAR trailer, AAL 3/4 has a (short) 10-bit “Checksum” for error checking. AAL 5 does it at the CS and allocates 4 bytes for the Checksum.

Table 16.4: Support for Digital Video Transmission

Video Requirement	Support in ATM	Support w/t ATM
Bandwidth	Scalable to several Gbps	Up to 100 Mbps
Latency and Jitter	QoS support	RSVP
CBR or VBR	AAL 1, 2, 5, LAN emulation, circuit emulation,etc.	ISDN and ADSL
Multicasting	Multicast switch, or permanent virtual circuit	IP-multicast or Protocol Independent Multicast (PIM)

MPEG-2 Convergence to ATM

- The ATM Forum has decided that MPEG-2 will be transported over AAL5:
 - Two MPEG-2 packets (each 188 bytes) from the Transport Stream (TS) will be mapped into one AAL-5 SDU (Service Data Unit).
- When establishing a virtual channel connection, the following QoS parameters must be specified:
 - Maximum cell transfer delay.
 - Maximum cell delay.
 - Cell Loss Ratio (CLR).
 - Cell Error Ratio (CER).
 - Severely Errored Cell Block Ratio (SECBR).

Multicast over ATM

- Multicast in ATM networks had several challenges:
 - ATM is connection-oriented; hence ATM multicasting needs to set up all multipoint connections.
 - QoS in ATM must be negotiated at the connection set-up time and be known to all switches.
 - It is difficult to support multipoint-to-point or multipoint-to-multipoint connections in ATM, because AAL 5 does not keep track of multiplexer number or sequence number.

16.4 Transport of MPEG-4

- **DMIF in MPEG-4:** An interface between multimedia applications and their transport. It supports:
 1. Remote interactive network access (IP, ATM, PSTN, ISDN, mobile).
 2. Broadcast media (cable or satellite).
 3. Local media on disks.
- A single application can run on different transport layers as long as the right DMIF is instantiated.
- Fig. 16.9 shows the integration of delivery through three types of communication mediums.
- **MPEG-4 over IP:** MPEG-4 sessions can be carried over IP-based protocols such as RTP, RTSP, and HTTP.

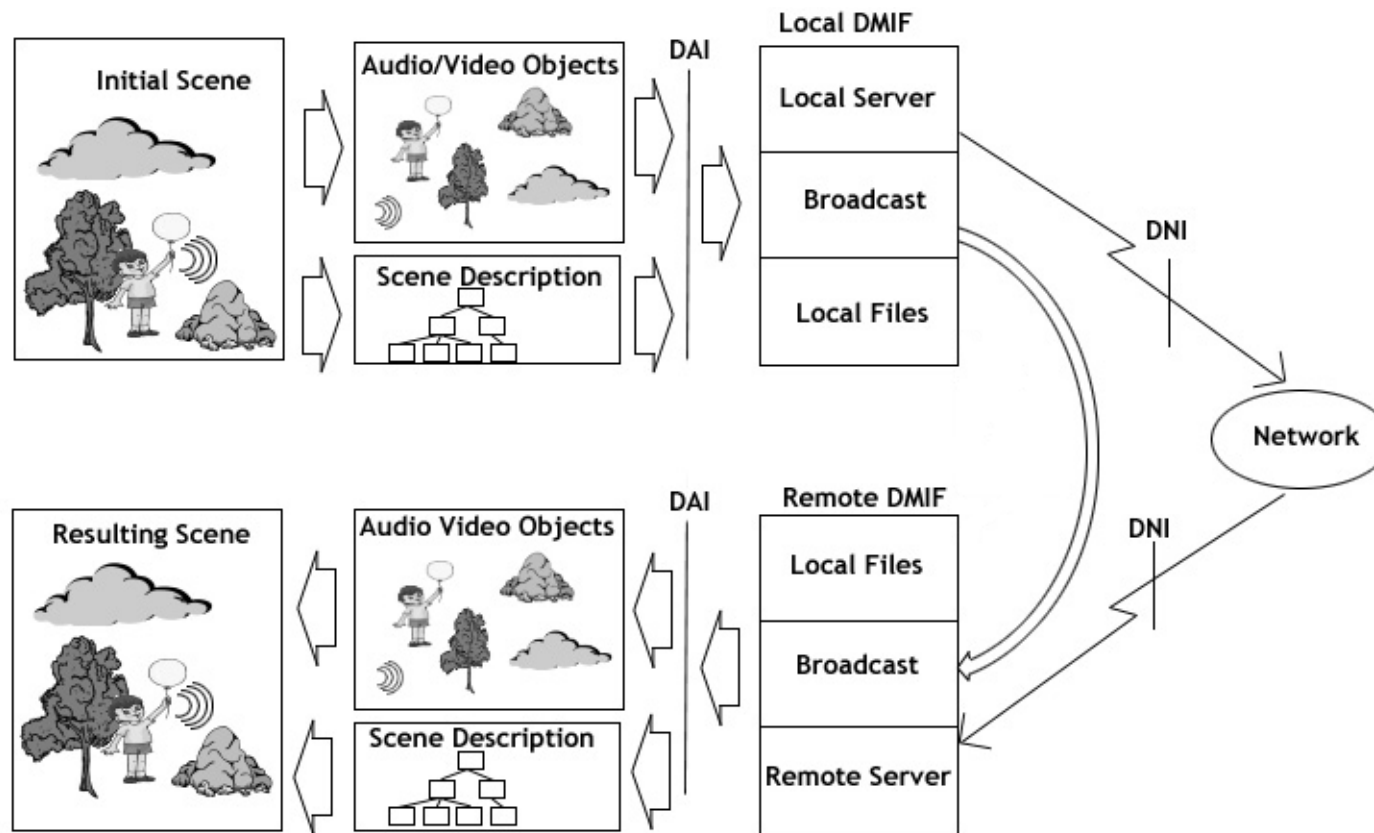


Fig. 16.9: DMIF — the multimedia content delivery integration framework.

16.5 Media-on-Demand (MOD)

- **Interactive TV (ITV) and Set-top Box (STB)**

- ITV supports activities such as:

1. TV (basic, subscription, pay-per-view).
2. Video-on-demand (VOD).
3. Information services (news, weather, magazines, sports events, etc.).
4. Interactive entertainment (Internet games, etc.).
5. E-commerce (on-line shopping, stock trading).
6. Access to digital libraries and educational materials.

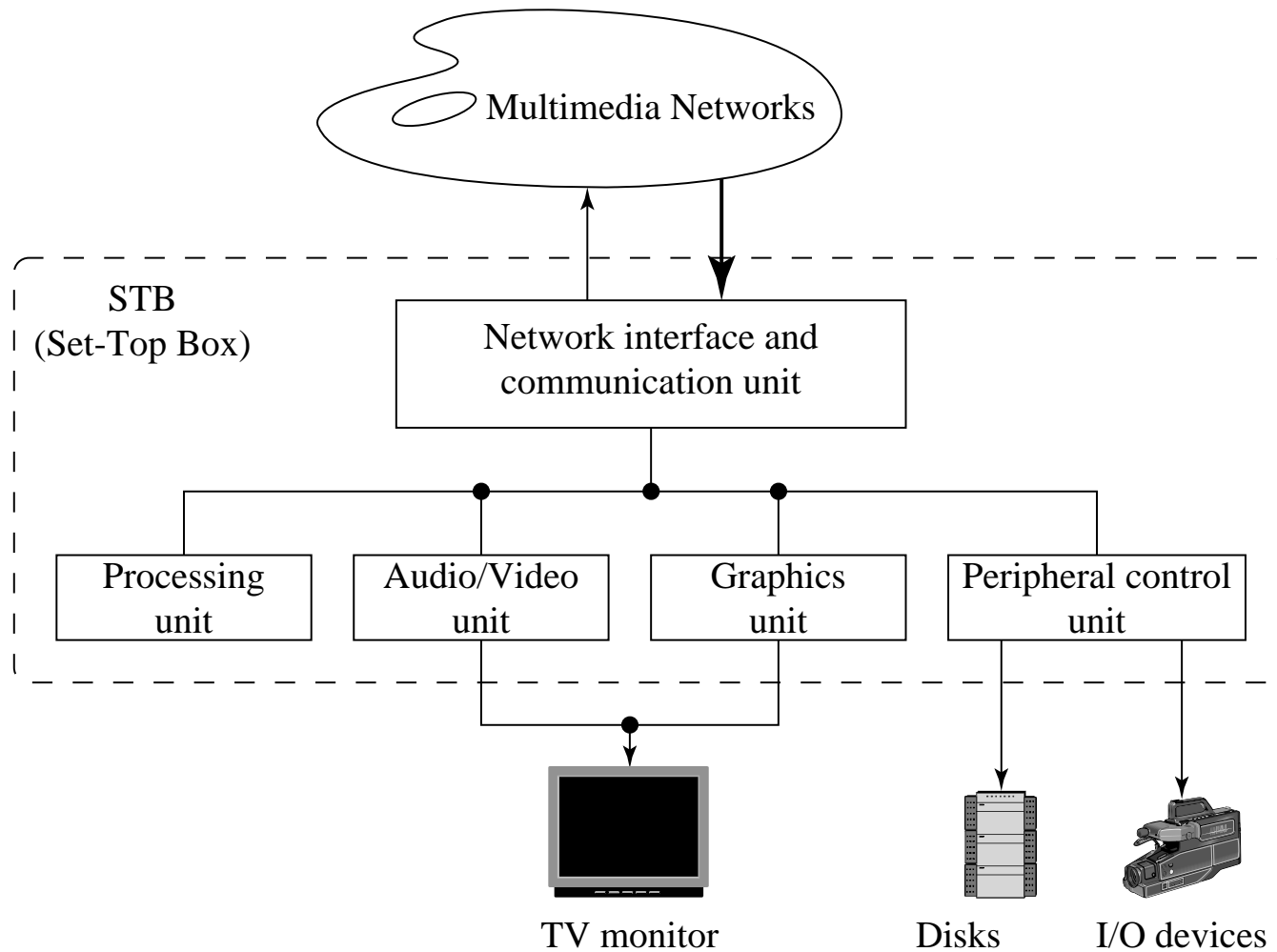


Fig. 16.10: General Architecture of STB (Set-top Box).

Set-top Box (STB)

- Set-top Box (STB) generally has the following components:
 1. **Network Interface and Communication Unit:** including tuner and demodulator, security devices, and a communication channel.
 2. **Processing Unit:** including CPU, memory, and special-purpose operating system for the STB.
 3. **Audio/Video Unit:** including audio and video (MPEG-2 and 4) decoders, DSP (Digital Signal Processor), buffers, and D/A converters.
 4. **Graphics Unit:** supporting real-time 3D graphics for animations and games.
 5. **Peripheral Control Unit:** controllers for disks, audio and video I/O devices (e.g., digital video cameras), CD/DVD reader and writer, etc.

Broadcast Schemes for Video-on-Demand

- **Staggered Broadcasting**

- For simplicity, assume all movies are of length L (seconds).
- The available high bandwidth B of the server (measured as the multiple of the playback rate b) is usually divided up into K logical channels ($K \geq 1$).
- Assuming the server broadcasts up to M movies ($M \geq 1$), they can be periodically broadcast on all these channels with the start-time of each movie staggered — *Staggered broadcasting*.
- If the division of the bandwidth is equal amongst all K logical channels, then the access time (longest waiting time) for any movie is actually independent of the value of K , i.e.,

$$\delta = \frac{M \cdot L}{B}$$

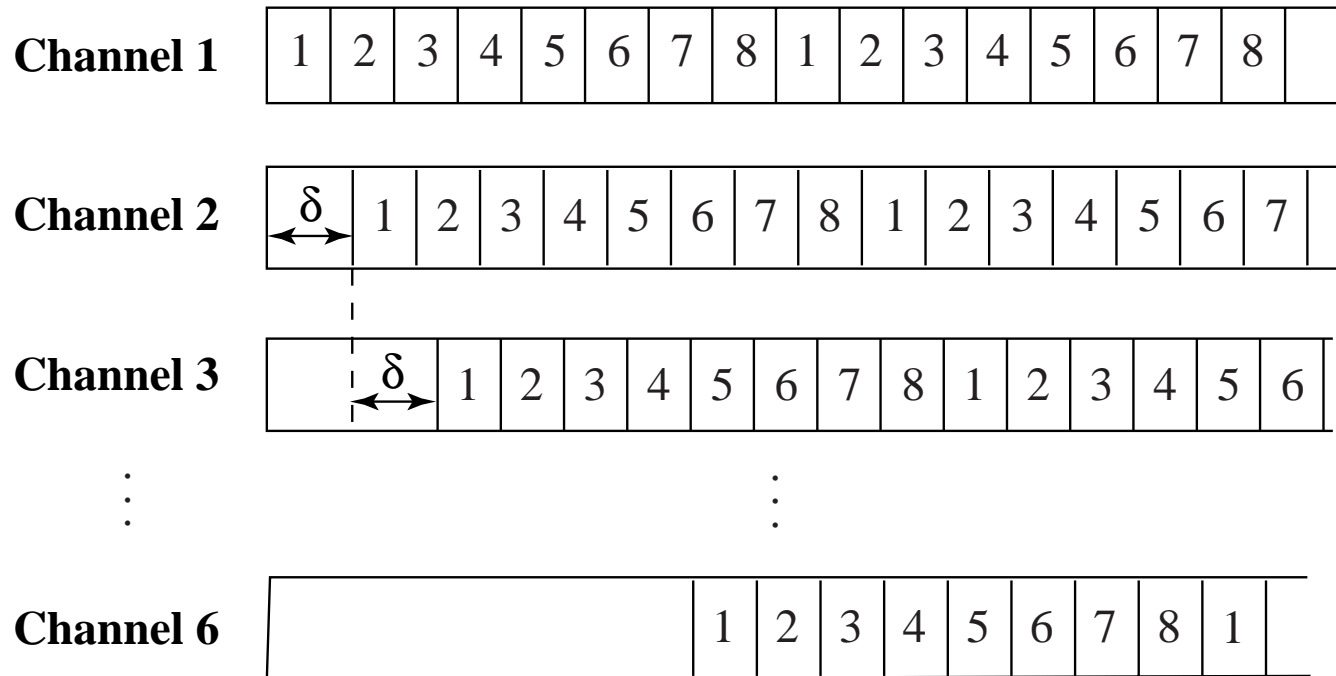


Fig. 16.11: Staggered Broadcasting with $M = 8$ movies and $K = 6$ channels.

Pyramid Broadcasting

- **In Pyramid Broadcasting:**
 - Movies are divided up into segments of increasing sizes, i.e., $L_{i+1} = \alpha \cdot L_i$, where L_i is the size (length) of Segment S_i and $\alpha > 1$.
 - Segment S_i will be periodically broadcast on Channel i . In other words, instead of staggering the movies on K channels, the segments are now staggered.
 - Each channel is given the same bandwidth, and the larger segments are broadcast less frequently.
 - Since the available bandwidth is assumed to be significantly larger than the movie playback rate b (i.e. $B \gg 1$), it is argued that the client can be playing a smaller Segment S_i and simultaneously receiving a larger Segment S_{i+1} .

Pyramid Broadcasting (cont'd)

- To guarantee a continuous playback, the necessary condition is:

$$\textit{playback_time}(S_i) \geq \textit{access_time}(S_{i+1}) \quad (16.1)$$

The $\textit{playback_time}(S_i) = L_i$. Given the bandwidth allocated to each channel is B/K , $\textit{access_time}(S_{i+1}) = \frac{L_{i+1} \cdot M}{B/K} = \frac{\alpha \cdot L_i \cdot M}{B/K}$, which yields

$$L_i \geq \frac{\alpha \cdot L_i \cdot M}{B/K} \quad (16.2)$$

Consequently,

$$\alpha \leq \frac{B}{M \cdot K} \quad (16.3)$$

Pyramid Broadcasting (cont'd)

- The access time for Pyramid broadcasting is determined by the size of S_1 . By default, we set $\alpha = \frac{B}{M \cdot K}$ to yield the shortest access time.
- The access time drops exponentially with the increase in the total bandwidth B , because α can be increased linearly.

Skyscraper Broadcasting

- A main drawback of the above Pyramid Broadcasting scheme is the need for a large storage space on the client side because the last two segments are typically 75-80% of the movie size.
- Instead of using a geometric series, *Skyscraper broadcasting* uses $\{1, 2, 2, 5, 5, 12, 12, 25, 25, 52, 52, \dots\}$ as the series of segment sizes to alleviate the demand on a large buffer.

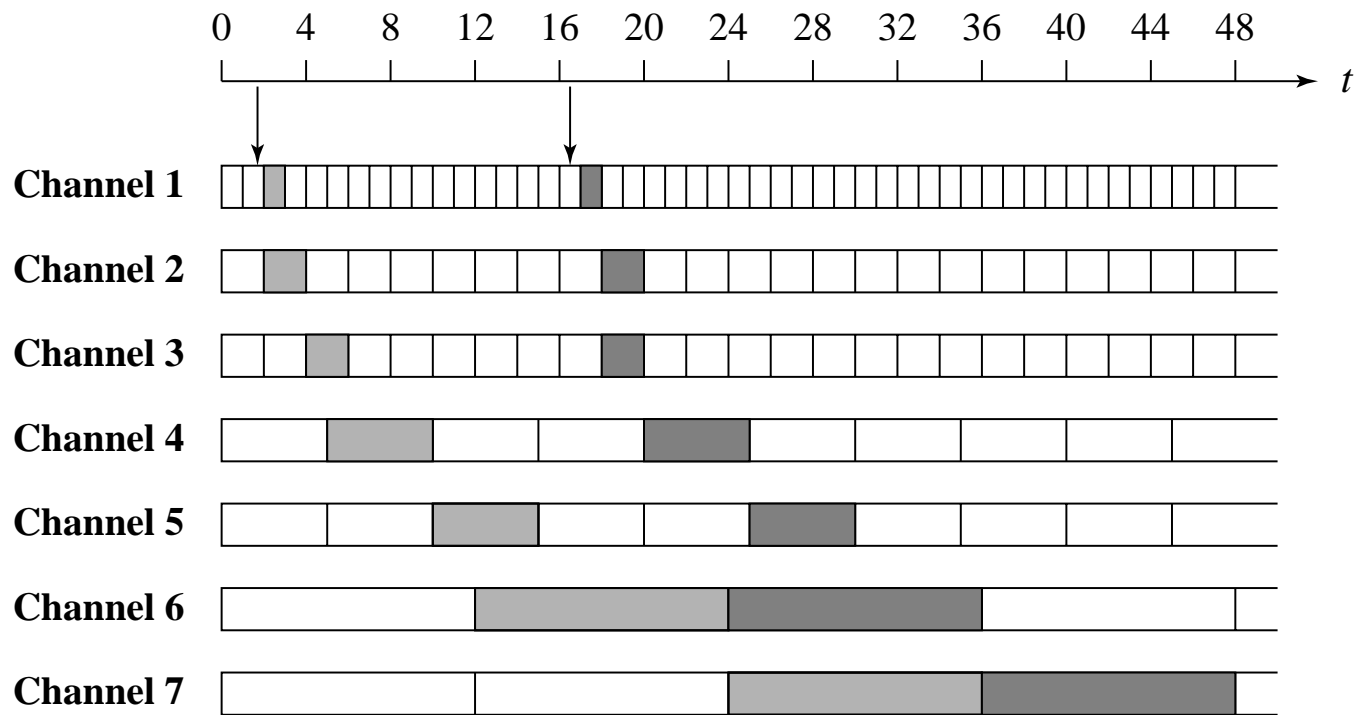


Fig. 16.12: Skyscraper broadcasting with seven segments.

- As shown in Fig 16.12, two clients who made a request at time intervals (1, 2) and (16, 17), respectively, have their respective transmission schedules. At any given moment, no more than two segments need to be received.

Harmonic Broadcasting

- Adopts a different strategy in which the size of all segments remains constant whereas the bandwidth of channel i is $B_i = b/i$, where b is the movie's playback rate.
- The total bandwidth allocated for delivering the movie is thus

$$B = \sum_{i=1}^K \frac{b}{i} = H_K \cdot b \quad (16.8)$$

where K is the total number of segments, and $H_K = \sum_{i=1}^K \frac{1}{i}$ is the *Harmonic number* of K .

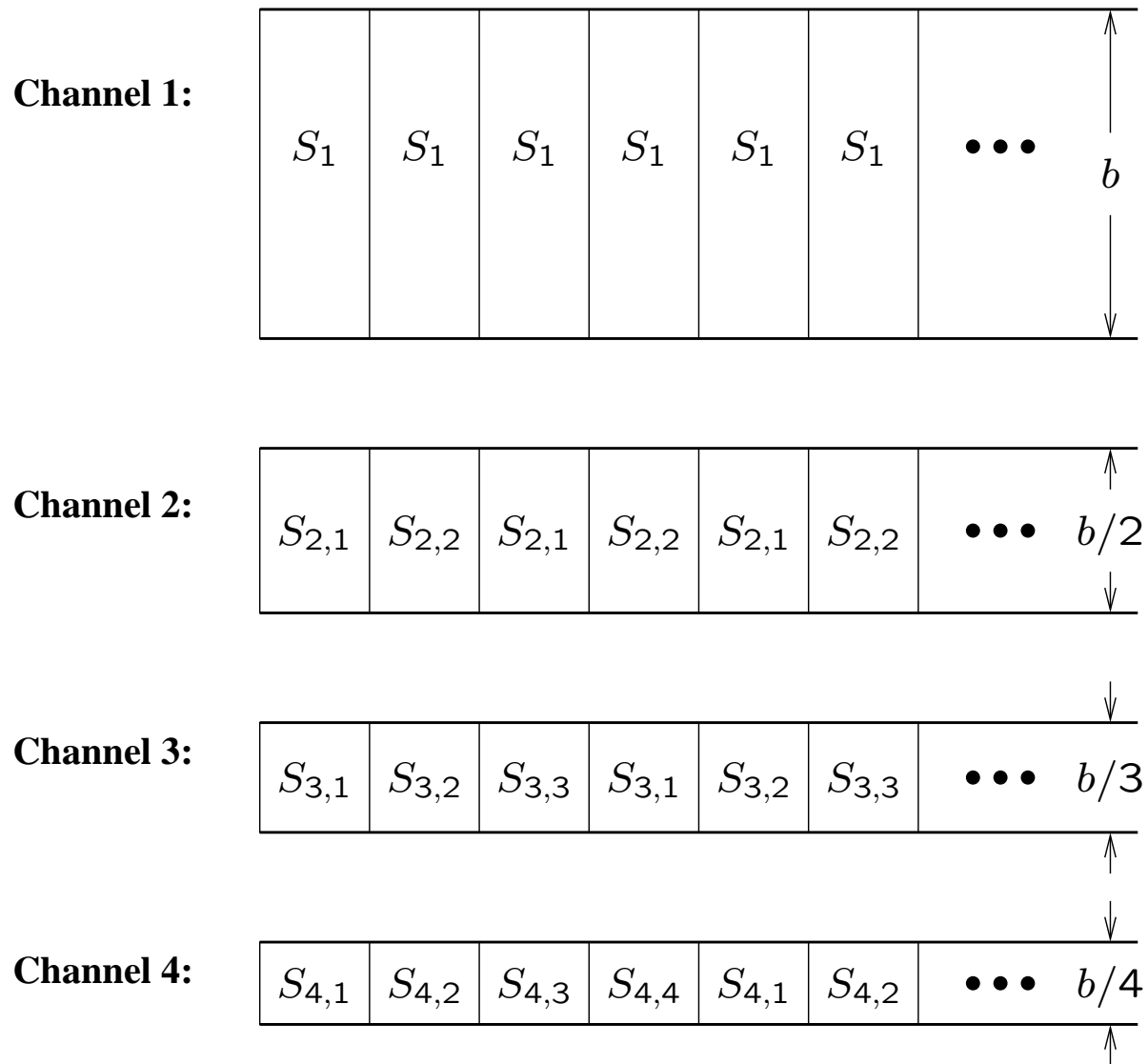


Fig. 16.14: Harmonic Broadcasting.

- As Fig. 16.14 shows: after requesting the movie, the client will be allowed to download and play the first occurrence of segment S_1 from Channel 1. Meanwhile, it will download all other segments from their respective channels.
- The advantage of Harmonic broadcasting is that the Harmonic number grows slowly with K .
- For example, when $K = 30$, $H_K \approx 4$. Hence, the demand on the total bandwidth (in this case $4 \cdot b$) is modest.
- It also yields small segments — only 4 minutes ($120/30$) each in length. Hence, the access time for Harmonic broadcasting is generally shorter than pyramid broadcasting.

Pagoda Broadcasting

- Harmonic broadcasting uses a large number of low-bandwidth streams, while Pyramid broadcasting schemes use a small number of high-bandwidth streams.
- Harmonic broadcasting generally requires less bandwidths than Pyramid broadcasting. However, it is hard to manage a large number of independent data streams using Harmonic broadcasting.
- Paris, Carter, and Long presented *Pagoda Broadcasting*, a frequency broadcasting scheme, that tries to combine the advantages of Harmonic and Pyramid schemes.

Slot	1	2	3	4	5	6	7	8	9	10	11	12	13
Channel 1	S_1	S_1	S_1	S_1	S_1	S_1	S_1	S_1	S_1	S_1	S_1	S_1	S_1
Channel 2	S_2	S_4	S_2	S_5	S_2	S_4	S_2	S_5	S_2	S_4	S_2	S_5	S_2
Channel 3	S_3	S_6	S_8	S_3	S_7	S_9	S_3	S_6	S_8	S_3	S_7	S_9	S_3

Fig. 16.15: First three channel-segment maps of Pagoda Broadcasting.

- Partitions each video into n fixed-size segments of duration $T = L/n$, where T is defined as a time slot. Then, it broadcasts these segments at the consumption bandwidth b but with different periods.

Stream Merging

- More adaptive to dynamic user interactions. It achieves this by dynamically combining multicast sessions.
- Makes the assumption that the client's receiving bandwidth is higher than the video playback rate.
- The server will deliver a video stream as soon as it receives the request from a client.
- Meanwhile, the client is also given access to a second stream of the same video, which was initiated earlier by another client.

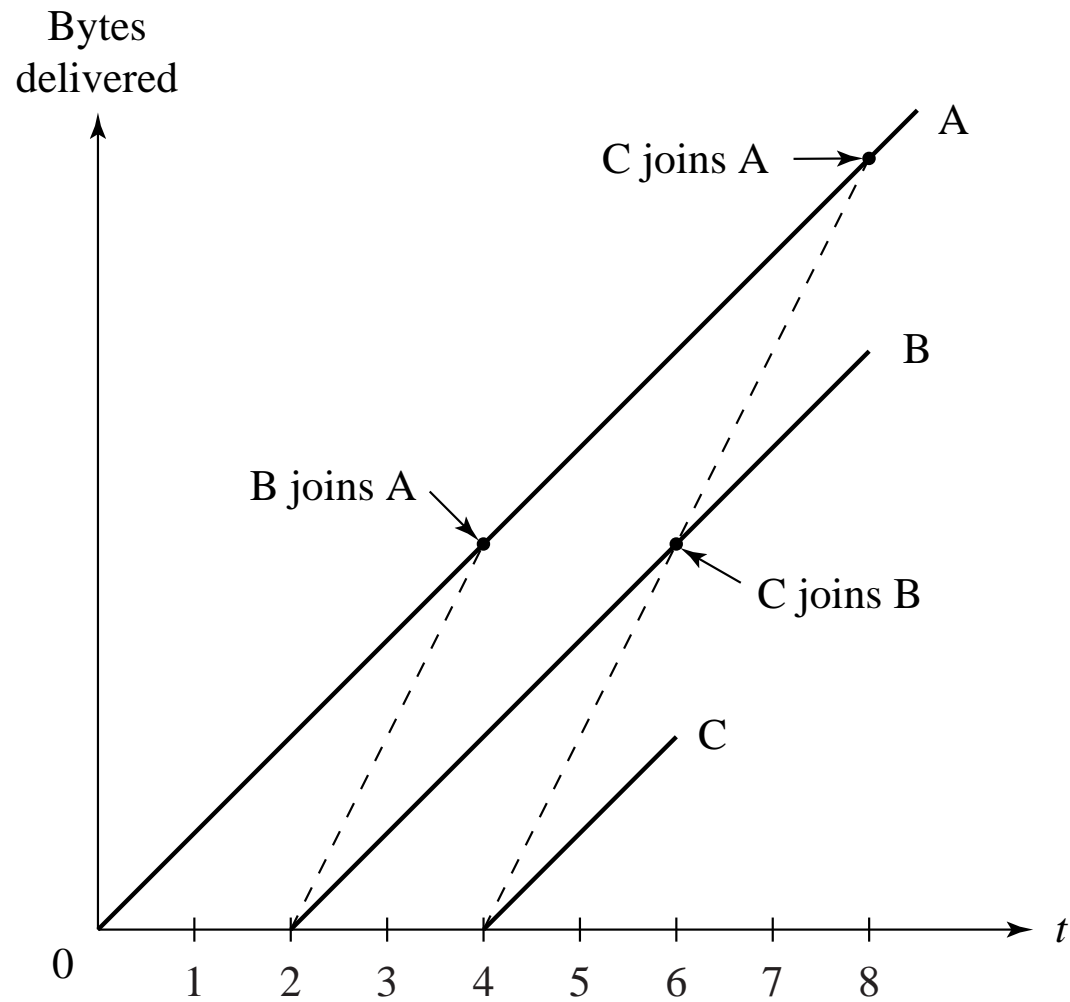


Fig. 16.16: Stream merging.

- As shown in Fig. 16.16, the “first stream” B starts at time $t = 2$. The solid line indicates the playback rate, and the dashed line indicates the receiving bandwidth which is twice of the playback rate. The client is allowed to prefetch from an earlier (“second”) stream A which was launched at $t = 0$. At $t = 4$, the stream B joins A.
- A variation of Stream merging is *Piggybacking*, in which the playback rate of the streams are slightly and dynamically adjusted so as to enable merging (piggybacking) of the streams.

Buffer Management

- To cope with the VBR and network load fluctuation, buffers are usually employed at both sender and receiver ends:
 - A **Prefetch Buffer** is introduced at the client side. If the size of frame t is $d(t)$, the buffer size is B , and the number of data bytes received so far (at play time for frame t) is $A(t)$, then for all $t \in 1, 2, \dots, N$, it is required that

$$\sum_{i=1}^t d(i) \leq A(t) \leq \sum_{i=1}^{t-1} d(i) + B. \quad (16.9)$$

- When $A(t) < \sum_{i=1}^t d(i)$, we have inadequate network throughput, and hence buffer *underflow* (or *starvation*), whereas when $A(t) > \sum_{i=1}^{t-1} d(i) + B$, we have excessive network throughput and buffer *overflow*.
- Both are harmful to smooth and continuous playback. In buffer underflow there is no available data to play, and in buffer overflow media packets must be dropped.

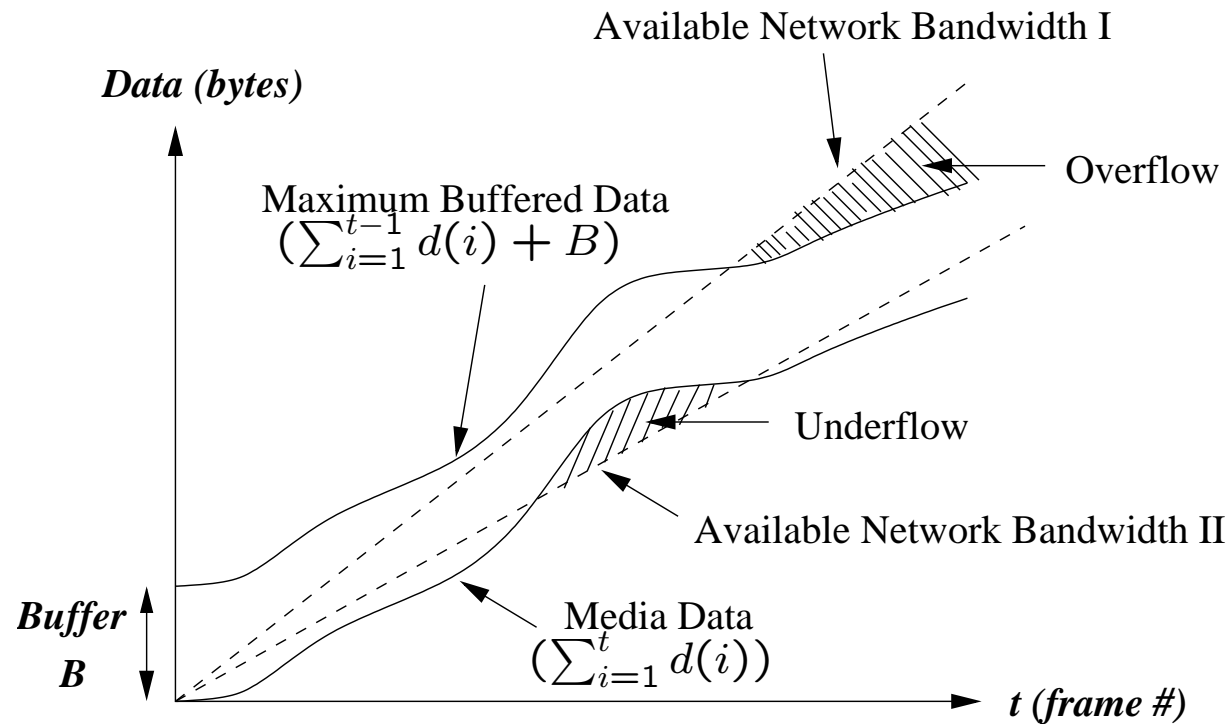


Fig. 16.17: The data that a client can store in the buffer assists the smooth playback of the media when the media rate exceeds the available network bandwidth

- Fig. 16.17 illustrates the limits imposed by the media playback (consumption) data rate and the buffered data rate (the transmission rates are the slopes of the curves).

An Optimal Plan for Transmission Rates

- It is possible to utilize the prefetch buffer more efficiently for the network given knowledge about the data rate characteristics of the media stored on the server:
 - The media server can plan ahead for a transmission rate such that the media can be viewed without interruption and the amount of bandwidth requested for reservation can be minimized.
 - **Optimal work-ahead smoothing plan:** a unique plan that minimize not only peak rate but also the rate variability.
 - Minimizing rate variability is important since it implies a set of piece-wise constant rate transmission segments. Therefore, some processing and network resources can be minimized as well as less frequent changes in bandwidth reservation.

An Optimal Plan for Video and Buffer Size

- Take video as an example (can be extended for general media), it is more practical to approximate the video data rate by considering the total data consumed by the time each I-frame should be displayed.
 - The approximation could be made coarser by only considering the total data consumed at the first frame after a scene transition, assuming the movie data-rate is constant in the same scene.
 - Define $d(t)$ to be the size of frame t , where $t \in 1, 2, \dots, N$ and N is the total number of frames in the video. Similarly, define $a(t)$ to be the amount of data transmitted by the video server during the playback time for frame t (in short call it at time t). Let $D(t)$ be the total data consumed and $A(t)$ be the total data sent at time t . Formally:

$$D(t) = \sum_{i=1}^t d(i) \quad (16.10)$$

$$A(t) = \sum_{i=1}^t a(i) \quad (16.11)$$

- Let the buffer size be B . Then at any time t the maximum total amount of data that can be received without overflowing the buffer during the time $1..t$ is $W(t) = D(t-1) + B$. Now it is easy to state the conditions for a server transmission rate that avoids buffer overflow or underflow:

$$D(t) \leq A(t) \leq W(t) \quad (16.12)$$

- In order to avoid buffer overflow or underflow throughout the video's duration, Eq.(16.12) has to hold for all $t \in 1, 2, \dots, N$. Define S to be the server transmission schedule (or plan), i.e. $S = a(1), a(2), \dots, a(N)$. S is called a *feasible transmission schedule* if for all t , S obeys Eq. (16.12).
- Figure 16.8 illustrates the bounding curves $D(t)$ and $W(t)$, and shows that a constant (average) bit-rate transmission plan is not feasible for this video because simply adopting the average bit-rate would cause underflow.

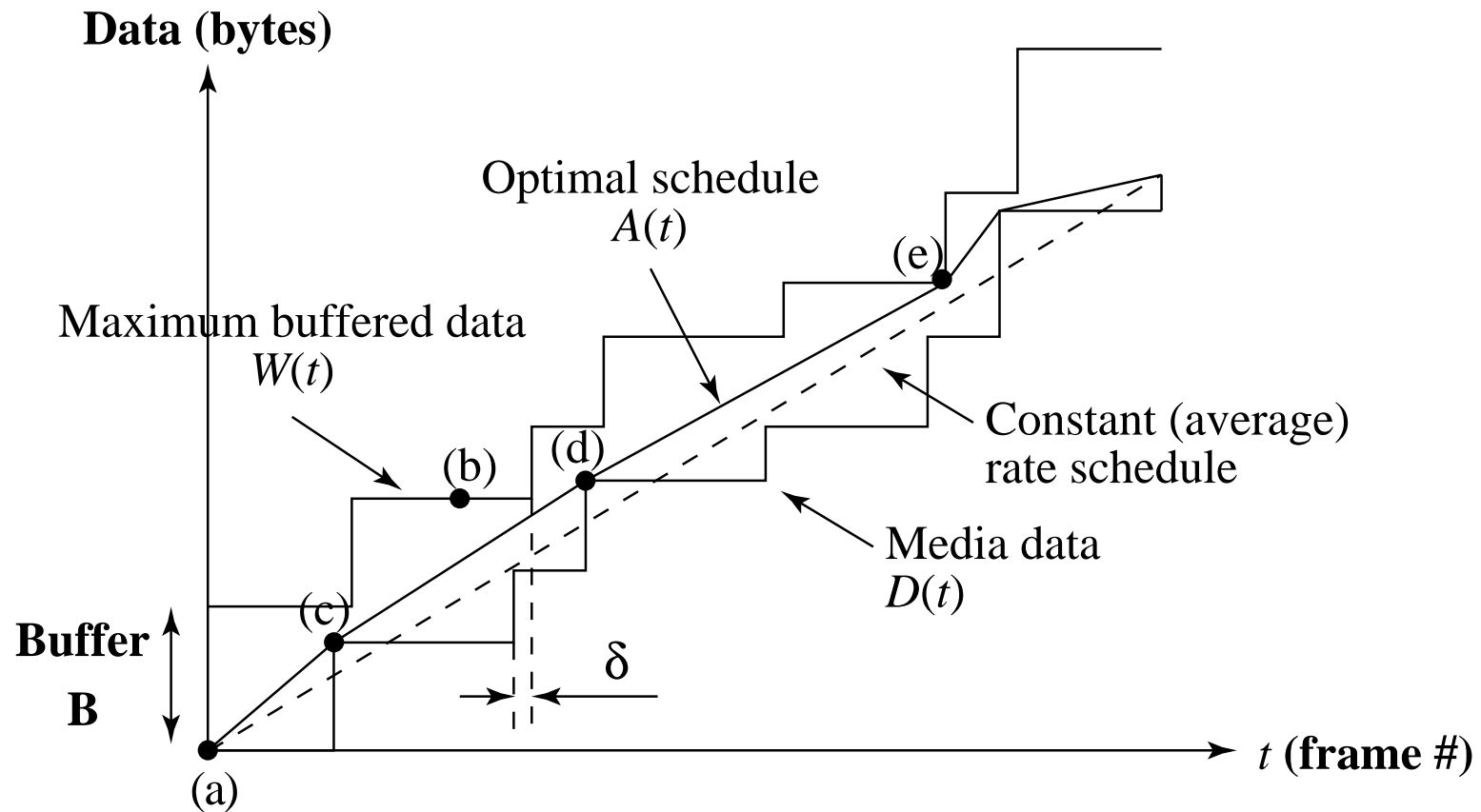


Fig 16.18: The optimal smoothing plan for a specific video and buffer size. In this case it is not feasible to transmit at the constant (average) data rate

16.6 Further Exploration

- **Text books:**

- *Multimedia: Computing, Communications & Applications* by S. Steinmetz and K. Nahrstedt
- *Emerging Multimedia Computer Communication Technologies* by C.H. Wu and J.D. Irwin
- *Readings in Multimedia Computing and Networking* by K. Jeffay and H. Zhang
- *Video Processing and Communications* by Y. Wang et al.

- **Web sites:** → [Link to Further Exploration for Chapter 16..](#) including:

- Links to ITU-T recommendations.
- Links to MBone sites.
- Links to RTP, RTSP, SIP Pages.
- Introductions and White Papers on ATM by another client.
- Introductions and White Papers on DVB.

- **RFCs** (can be found from IETF):

- Criteria for evaluating reliable multicast transport protocols.
- Protocols for real-time transmission of multimedia data (RTP, RTSP, and RSVP).
- Protocols for VoIP (SIP, SDP, and SAP).
- DiffServ and MPLS IETF.