Distributed Multimedia systems:

INF 5040/9040 autumn 2008

Lecturer: Frank Eliassen

Outline

- Requirements of multimedia
- Media synchronization
- QoS management
- Streaming over the Internet
  - Compensating for quality degradation
    - Jitter-compensation
    - Compression
    - Traffic shaping
    - Media scaling (stream adaptation)
  - Continuous media distribution services

Literature

- CDK4: Chapter 17
- TvS2: Chapter 4.4

- Recommended (not examinable):
  - Wu, D. et al., "Streaming video over the Internet: approaches and directions", IEEE Trans. Circuits Syst. Video Technol., 11 (3), 282-300, 2001
  - J. Liu et al., ”Opportunities and Challenges of Peer-to-Peer Internet Video Broadcast”, *Proceedings of the IEEE*, Vol. 96, No. 1. (2008), pp. 11-24.

What is multimedia?

- Digital multimedia
  - Computer-controlled integration of text, graphics, still images, moving pictures, animation, sound, and any other medium
  - All the above data types are represented, stored, transmitted, and processed digitally.
- Continuous vs discrete media
  - A continuous media type has an implicit time dimension, while a discrete type does not.
  - Timing plays a crucial role in continuous media (e.g., correct play out time of audio samples)
- Focus of this lecture: continuous media (audio/video)

Key requirements from multimedia

- the need to represent continuous media in distributed systems
  - programming models (middleware abstractions)
  - representation
- the need for real time synchronization mechanisms
- the need to specify and dynamically change the Quality of Service (QoS) of the transmission (and thus presentation) of continuous media
  - e.g., balance cost and quality

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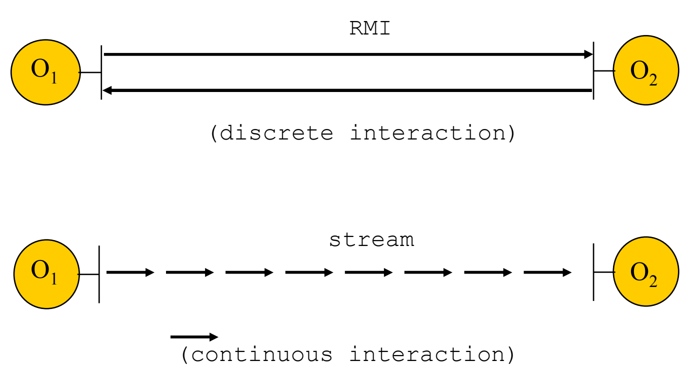
Support for continuous media: Programming models



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Support for multimedia: Representation

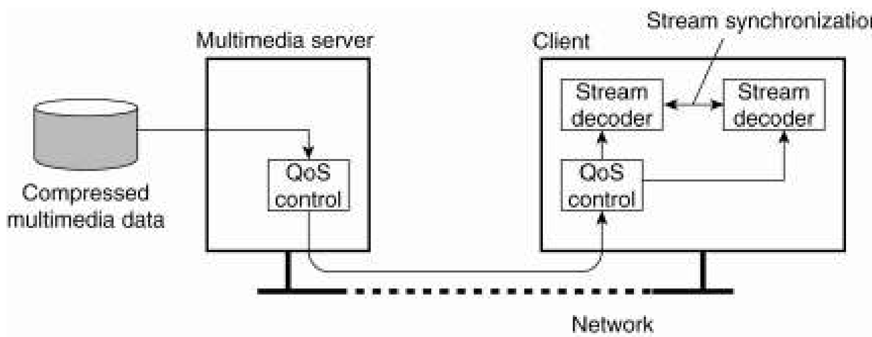
- Continuous representation media
  - the temporal relationship between data items of the stream must be preserved
  - Audio:
    - built up of series of audio samples (e.g., 16 bit) representing amplitudes
    - must be played back at same rate as it was sampled (e.g. 44100 Hz)
  - Motion (video):
    - built up of series of images (frames)
    - must be displayed at a uniform spacing in time, (e.g., 30-40 msec per image).

Support for multimedia: Systems support

- Commitments
  - Continuous media requires a commitment to provide a given level of service
    - e.g.,. 25 frames per second of video
  - This commitment must last for the whole life time of the interaction

General architecture for QoS-aware streaming

- QoS-aware streaming of stored multimedia data over a network



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Real time synchronization

- Different forms of synchronization
  - intra media (e.g., maintain uniform time spacing of a single continuous media stream)
  - inter media: synch of video and audio stream (lip synchronization) and text streams (subtitles) etc.
  - synchronization of distributed state
    - stop video operation should be observed by all within 500 ms
  - external synchronization
    - synchronization of time based streams with data in other formats (animations, slides, white-boards, shared documents)
- Consequences of distribution (multiple sources &sinks)
  - must support synchronization of arbitrary configurations of media sources and sinks (distributed orchestra: synchronization within 50 ms)

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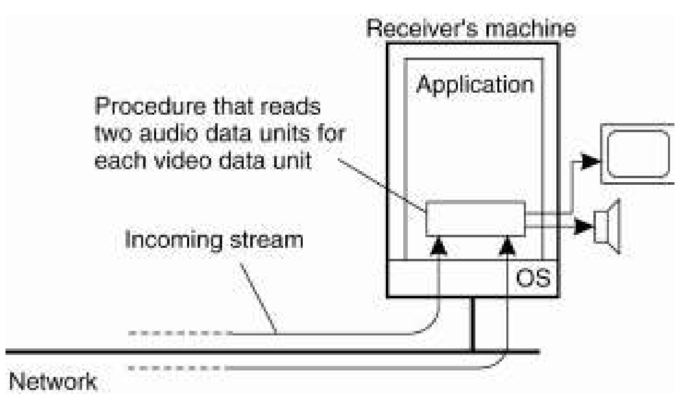
Distribution of synchronization mechanisms

- Receiving side of a complex stream (stream consisting of many substreams) need to know how to do the synchronization (synchronization specification)
- Common practice: multiplex substreams into one stream when single source (implicit synch spec)
  - This is the approach of MPEG. Each data element in multiplexed stream is time stamped (playout time)
- Synchronizing independent substreams at receiving side can be extremely difficult as delay may vary unpredictably between different channels
  - may use timestamps also here

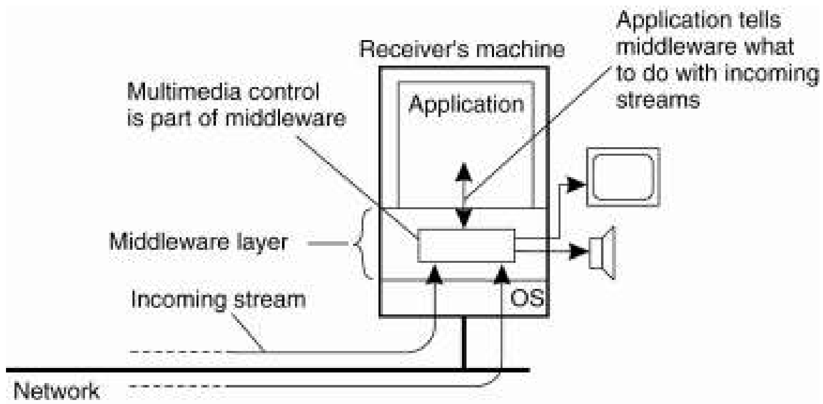
Synchronization mechanisms (1/2)

- The principle of explicit synchronization on the level of data units.



Synchronization mechanisms (2/2)

- The principle of synchronization as supported by high-level interfaces.



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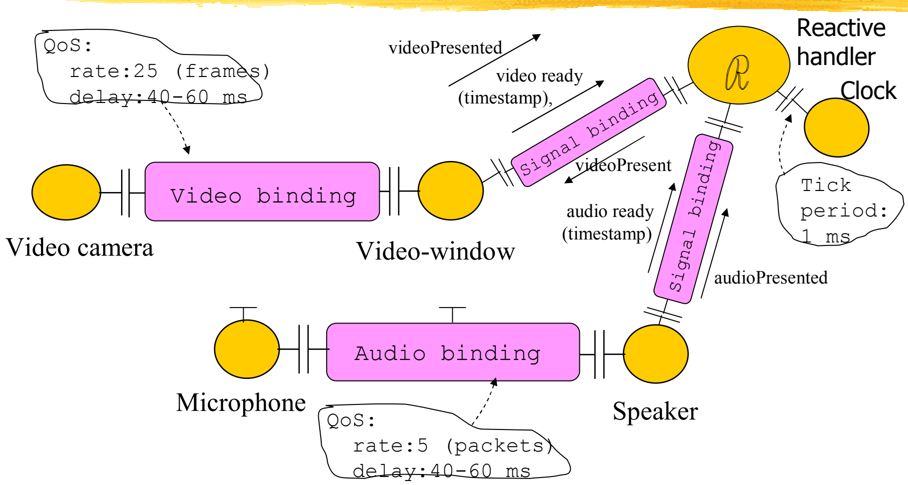
Lip sync using reactive handlers[1]



[1] Adapted from G. Blair, J.B. Stefani, Open Distributed Processing and Multimedia, Addison-Wesley, 1997

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A closer look at QoS

- IDL tells us "what" can or should be done
- Quality of Service is the non-functional "how" to the functional "what".
- Quality of Service (QoS)
  - An abstract specification of the non-functional requirements to a service
- QoS management
  - Monitoring and control of a system to ensure that it fulfills the required QoS

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QoS: question of resource management

- QoS guarantees requires that resources are allocated and scheduled to multimedia applications under real time requirements
  - need for QoS-driven resource management when resources are shared between several application and some of these have real time deadlines

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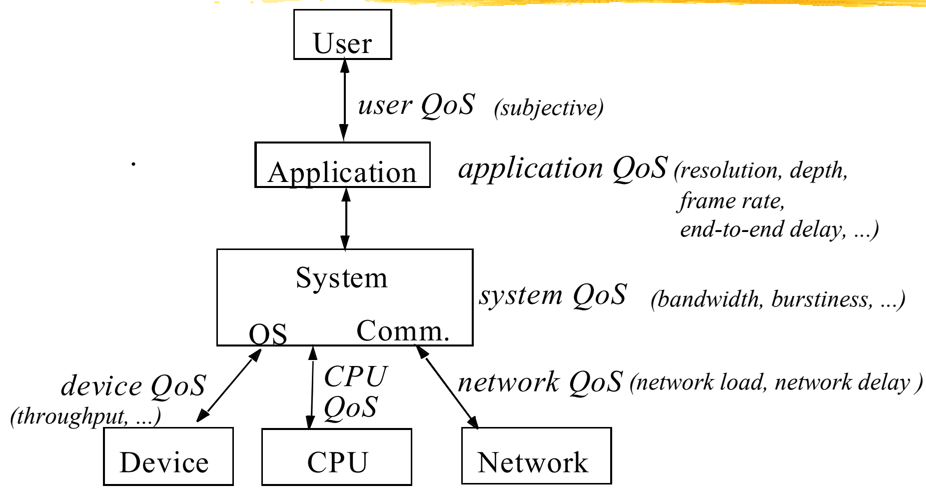
QoS-driven resource management

- Requires translation of application level QoS requirements to lower level resource needs that are communicated to resource managers
- Resource manager:
  - Performs admission control and scheduling
  - Schedules multimedia tasks such that resources are available when there is a need for them
- Resources:
  - Shared: CPU, network adapter, buffer, comm. bandwidth, disc, …
  - Exclusive: camera, speaker, special hardware units, …

Tasks in QoS management

- QoS specification
- QoS parameter translation and distribution
- QoS negotiation
  - admission control/reservation
- QoS monitoring
- QoS renegotiation/resource adaptation/QoS adaptation
- resource deallocation

QoS specification and translation: Layer/component specific QoS-model



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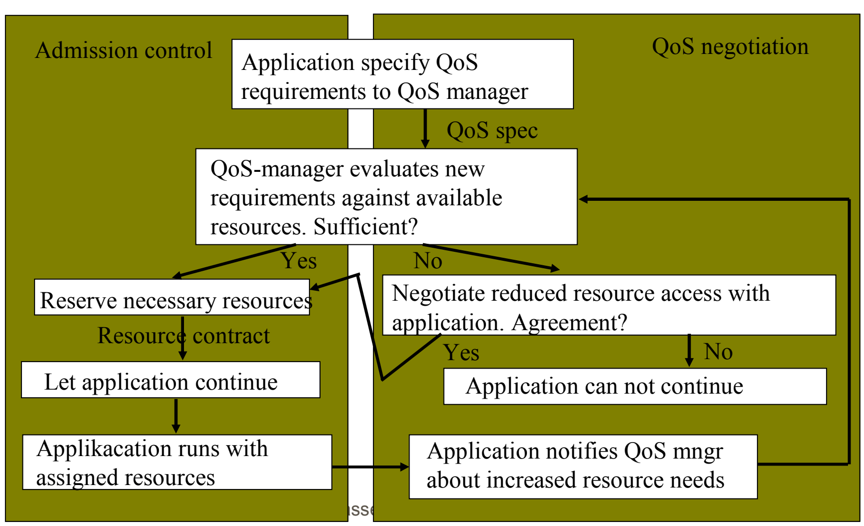
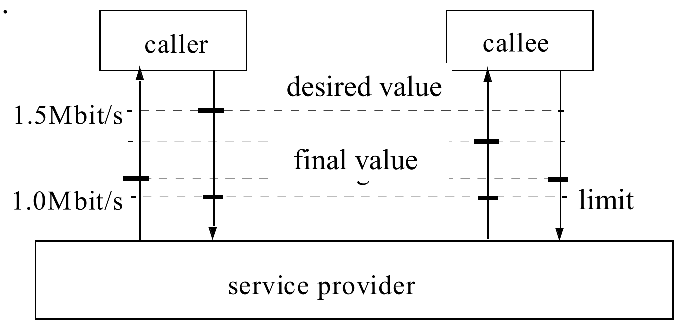
QoS negotiation



Example QoS negotation

- For each parameter, specify
  - desired value and lowest acceptable value
- Ex.: Bandwidth : {1.5Mbit/s,1.0Mbit/s}



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QoS models for streaming

- Usually expressed as a set of QoS categories and dimensions
- QoS dimension – an aspect of QoS that can be measured on a stream
  - *delay, throughput, ...*
- QoS category: a grouping of QoS dimensions
  - Represents a type of user or application requirements
- Example (QML)

```
type Performance = contract {
  delay: decreasing numeric msec;
  throughput: increasing numeric mb/sec;
};
```

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QoS categories for streaming

QoS categories	Ex. QoS-dimentions for stream interaction	Ex. QoS-dimensions for discrete interaction
Timeliness	End-to-end delay, max allowed jitter	End-to-end delay per interaction
Volume	Observed throughput as frames per second	Observed throughput as bytes per second
Reliability	% frame loss, bit error rate per frame	bit error rate in individual interactions

Varying committment levels: "best effort" vs guaranteed

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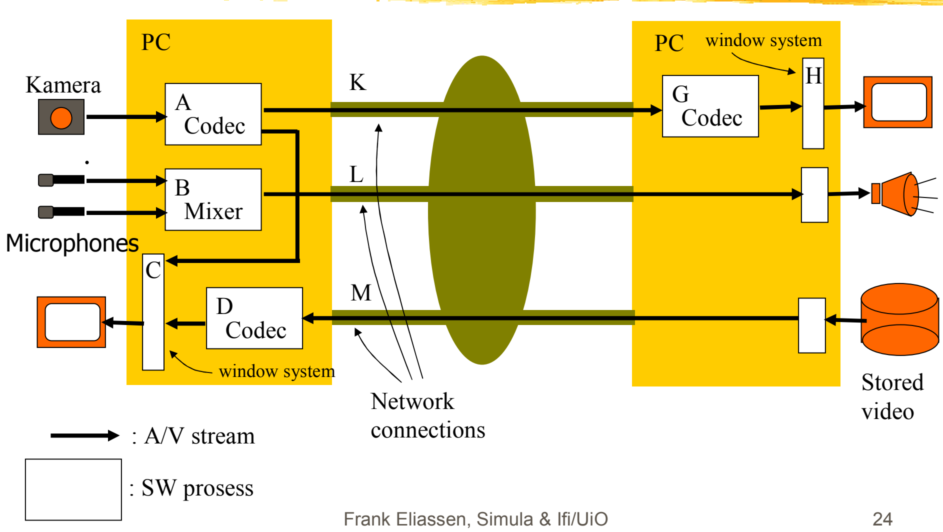
Example: resource needs A/V streaming app.



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Example (cont'd): Resource needs

Component	Bandwidth	Latency	Loss rate	Resource needs
Camera	Out: 10 frames sec/raw video 640x480x16bits		Null	
A Codec	In: 10 frames sec/raw video Out: MPEG-1 stream	Interactive	Low	10 ms CPU every 100 ms 10 Mbyte RAM
B Mixer	In: 2x44 Kbits/sec audio Out: 1x44 Kbits/sec audio	Interactive	Very low	1 ms CPU every 100 ms 1 Mbyte RAM
H Vindow-system	In: variable Out: 50 frames/sec framebuf.	Interactive	Low	5 ms CPU every 20 ms 5 Mbyte RAM
K Network connection	In/out: MPEG-1 stream ca. 1.5 Mbits/sec	Interactive	Low	1.5 Mbits/sec, stream prococol w/low loss rate
L Network connection	In/out: Audio 44Kbits/sec	Interactive	Very low	44 Kbits/sec, stream protocol w/ very low loss rate

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Admission control

- QoS values must be mapped to resource requirements
- Admission test for
  - schedulability
    - can the CPU slots be assigned to tasks such that all tasks receives sufficient slots?
  - buffer space
    - e.g., for encoding/decoding, jitter removal buffer, ...
  - bandwidth
    - e.g., MPEG1 stream with VCR quality generates about 1.5 Mbps
  - availability/capabilities of devices
  - …

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Resource allocation/reservation

- Made according to service type
  - different services may have different policies
- *Pessimistic*
  - consider worst case
  - guaranteed deterministic quality of service
  - under utilization of resources
- *Optimistic*
  - considers average case
  - statistical guaranteed quality of service
- *no reservation*
  - "best effort" (adapt dynamically in stead?)

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Resource allocation in Internet?

- IntServ: new service model for Internet
  - 3 classes of service, differently priced
  - Best effort service (as today's Internet)
  - Controlled-load service
    - network will appear lightly loaded
  - Guaranteed service
    - gives guaranteed bandwidth and max delay
  - Based on new protocols (RSVP and IPv6)
    - many open issues, including scalability issues and payment model
- Alternative model: DiffServ
  - All flows/packets aggregated into three different QoS classes

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Resource management in end systems

- Make CPU available for all multimedia applications when it is needed
- Real time requirements ⇒ OS must use real time scheduling
- Observation: Time critical operation in multimedia applications are often *periodic*
- *Common assumption*
  - Processing of continuous media data must occur in exact pre-determined, periodical intervals. Operations on these data occur again and again, and must be completed by certain deadlines
- *Problem for scheduling*
  - Find a feasible schedule that allows all time critical continuous media tasks to reach their deadlines

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EDF and RM

- Two algorithms for scheduling of periodic tasks
- *Earliest Deadline First (EDF)*
  - Tasks with the earliest deadline have highest priority
  - Dynamic and optimal algorithm;
    - by arrival of new task, must calculate a new priority order
- *Rate Monotonic (RM)*
  - Tasks with shortest period have highest priority
  - Optimal for periodic tasks
- *Deadline violations*
  - aborts task that can not reach their deadlines
  - application specific handling by suitable language mechanisms (e.g., callbacks)

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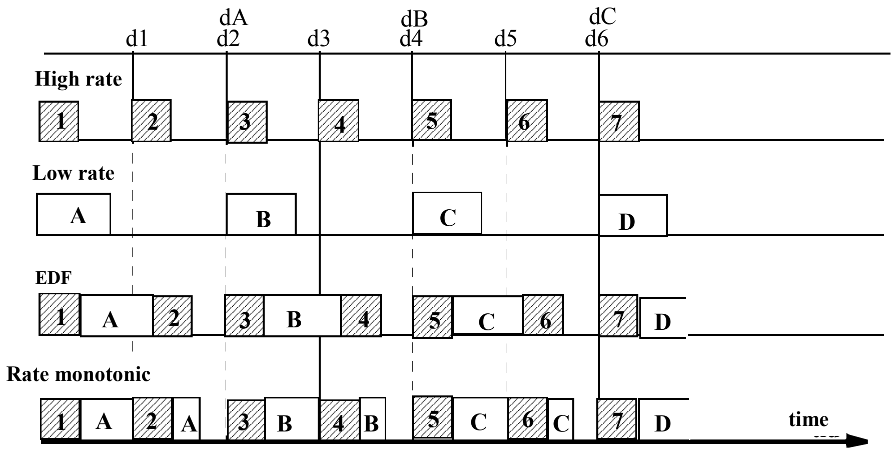
EDF vs RM



Streaming over the Internet

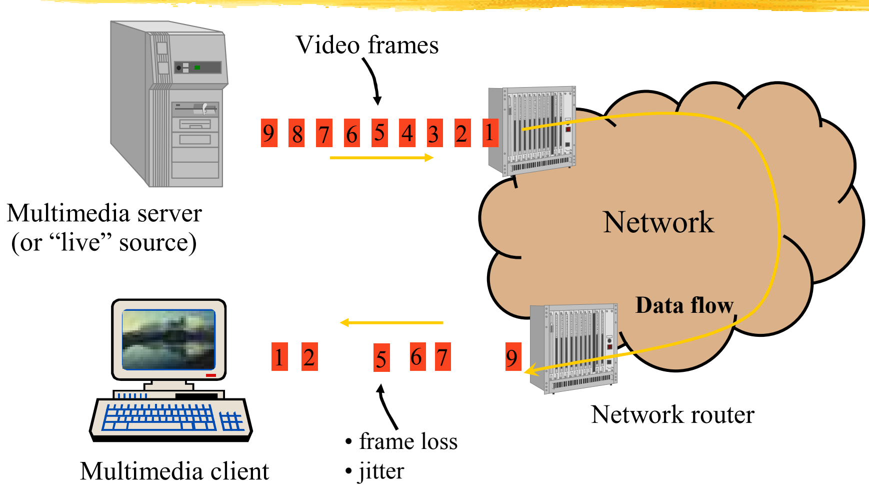
- **Characteristics of the Internet**
  - Internet is based on TCP/IP (Transmission Control Protocol / Internet Protocol)
  - TCP/IP
    - is robust
    - is implemented over most network types
    - enable a wide spectrum of applications (file transfer, email, distributed computing, etc.)
    - preserves content (retransmisson)

Unfortunately ...

… time based continuous media and Internet as we know it, is not a perfect match:

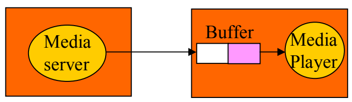
- Internet is based on the principle of "best effort"
  - provides no guaranties wrt bandwidth and delay!!
- No assumptions is made regarding underlying hardware
- In contrast, satisfaction of requirements to streaming of continuous media depends on knowledge about available resources

Quality degradation in networks

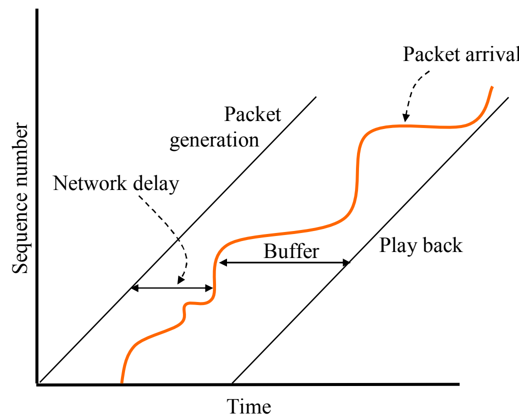


Compensating for jitter

Playout buffer:



Typical method for Internet streaming (RealNetworks, Windows Media Player, QuickTime)



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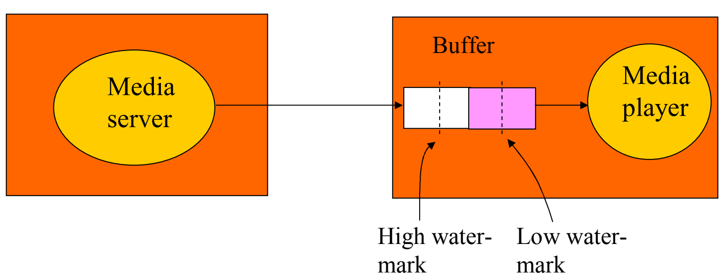
Streaming based on watermarks



- The server sends data as fast as possible until high watermark is reached in the buffer. The player then asks the server to pause
- When low watermark is reached in the buffer, the player asks the server to send more data as above

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Reducing resource needs: Compression

- Three reasons for compression:
  - multimedia data requirements to storage capacity
  - relatively slow external storage devices
  - transmission capacity in networks
- Illustrative calculations
  - 620 x 560 pixels pr. frame, 24 bits per pixel => ca. 1 MB per frame
  - Rate: 30 framer per sec => 30 MB/s (or 240 Mbit/s)
  - In comparison: CD-ROM: 0.15 - 4.8 MB/s
    RAID: typical 10 - 100 MB/s
    ISDN: typical 64 - 128 Kbit/s
    ADSL: typical 2-6Mbit/s downstream,
    256-625 Kbit/s upstream
    UMTS: up to 2Mbit/s

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Use of compression

- Compress prior to storing/transmission
- Decompress prior to presentation
- Typical compression rates for modern open image and video compression standards:
  - H.261 px64: 100:1 - 2000 : 1 (video telephony ISDN 64Kbits - 2Mbps)
  - MJPEG: < 70 : 1 (studio quality: 8 - 10 Mbps)
  - MPEG-1: < 200 : 1 (VCR quality: 1.5 Mbps)
  - MPEG-2: < 200 : 1 (HDTV/DVD quality: 10 - 20 Mbps)
  - MPEG-4/H.264 AVC : many profiles, flexible
  - ***NEW:*** H.264 AVC: SVC extension: independently scalable in many quality dimensions, flexible
- Compression algorithms can be *lossless* or *lossy* and are typically *asymmetric*

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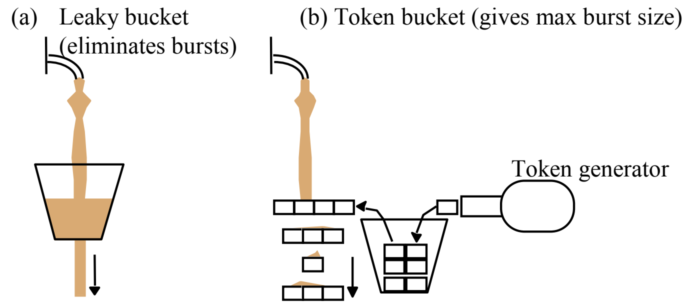
Handling "stream burstiness" by traffic shaping

- Compression leads to temporal variation in bandwidth consumption
- Regulating the degree of variation in bandwidth of a stream (burst: #media packets with too early arrival)
- Regulating by "smoothing" buffer at sender side



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QoS parameters for streams: RFC 1363 flow spec

- Protocol version
- Max transmission unit
- Token bucket rate
- Token bucket size
- Max transmission rate
- Min delay noticed
- Max delay variation
- Loss sensitivity
- Burst loss sensitivity
- Loss interval
- Quality of guarantee

Bandwidth including degree of burstiness (Max transmission unit, Token bucket rate, Token bucket size, Max transmission rate)

Minimum delay and and max acceptable jitter (Min delay noticed, Max delay variation)

Total no of acceptable losses over given time interval, plus max no of consecutive message losses (Loss sensitivity, Burst loss sensitivity, Loss interval)

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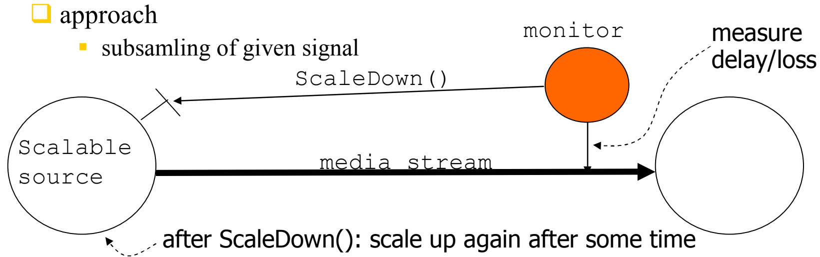
Compensating for variation in bandwidth: Stream adaptation

- When QoS can not be guaranteed
  - applications must adapt to changes in resource availability
  - for continuous media streams: adjust presentation quality
- Basis for adaptation
  - drop some of the data
- Insufficient bandwidth and no video data is dropped
  - => arbitrary data is lost (=> visual noise in video)

Media scaling

- Adapt a stream to available bandwidth
  - simplest for “live” streaming
    - can dynamically choose encoding
  - for stored streams
    - depends on encoding method what forms of scaling that are possible
  - approach
    - subsamling of given signal



Issue: who decides how to scale - sender or receiver?

Video scaling (1/2)

- Temporal scaling
  - reduce frame rate
  - simplest for streams based on intra frame coding (e.g., Motion JPEG)
  - more complex for streams based på inter frame coding (delta-compression) which are most modern encoding schemes
- Spatial scaling
  - reduce no of pixels in each frame in video-stream
  - (often) based on hierarchical encoding (e.g., JPEG and MPEG-2)
- Quality/SNR scaling
  - filtering higher frequencies in video signal
  - implies loss of quality (i.e. loss of details)
- SVC extension of H264 AVC combines all of the above

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Video - scaling (2/2)

- Amplitude scaling
  - reduce color depth for every pixel
  - e.g., used in H.261 to achieve constant bandwidth
- Color space scaling
  - reduce resolution of color space (reduce pixmap)
  - e.g, switch from color to grey scale

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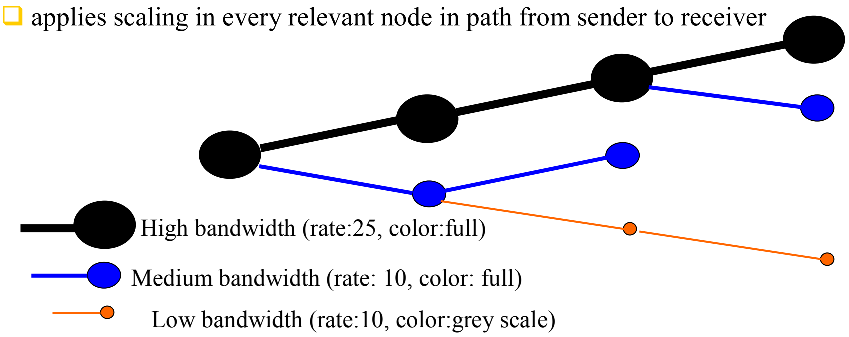
Continuous media distribution services

- Usually overlay networks (on top of IP) designed with the aim providing QoS and delivering continuous media to many receivers in a cost effective way
- Different content to many receivers (like in VOD)
  - Content replication: caching, mirroring (e.g., Akamai)
- Same content to many receivers (like in broadcast)
  - Application level multicast (IP multicast not ubiquiuous)
  - P2P streaming (student presentation next week)
- Same content to heterogeneous receivers
  - Adjust to resource poorest receiver, or
  - (Overlay) Network filtering (based on media scaling)

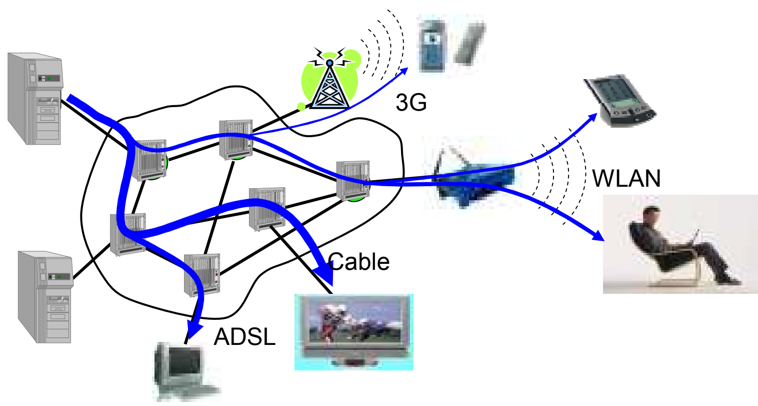
Media distribution service using network filtering

- Filtering in network (e.g., using overlay). Example:
  - Distribution-tree with filtering, adapting QoS to each receiver
  - applies scaling in every relevant node in path from sender to receiver



- Network filtering can also be used in P2P streaming

Media distribution service with in-network filtering



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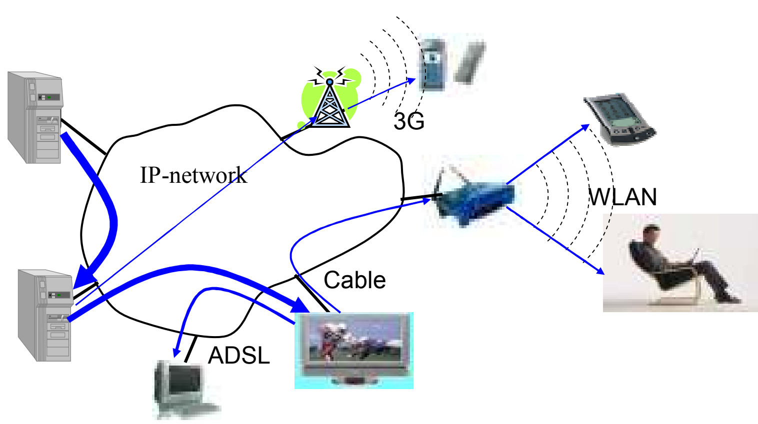
Media distribution service with peer filtering



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Summary

- Multimedia applications require mechanisms that enable them to handle large amounts of time dependent data
- Most important mechanism: QoS management
- QoS is a question of resource management
- Resource management implies
  - admission control
  - scheduling function
- When resources can not be reserved, adaptation (media scaling & rate control) is the (only) alternative

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