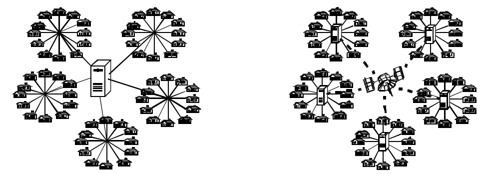
INF 5070 – Media Servers and Distribution Systems:

Distribution – Part I

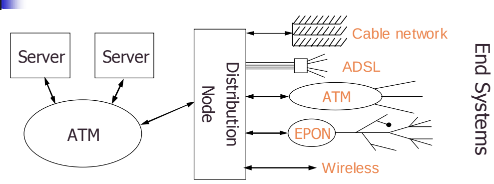
17/10 – 2005

Video on Demand Problem



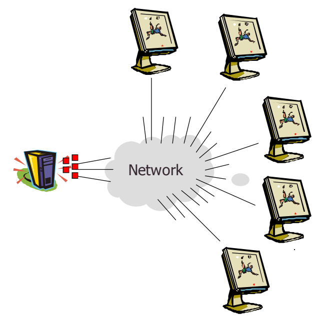
- Central or island approaches
- Dedicated infrastructure
  - Expensive
  - Only successful for in-house use and production
- No public VoD success in trials and standardization
- Technological advances in servers and distribution

ITV Network Architecture Approaches

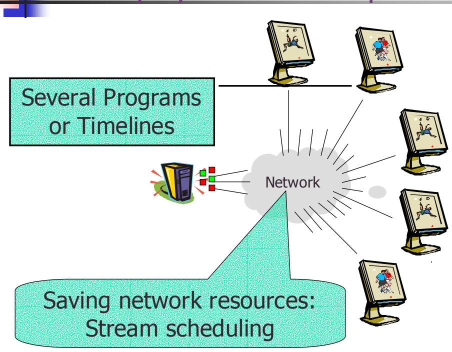


- Wide-area network backbones
  - ATM
  - SONET
- Local Distribution network
  - HFC (Hybrid Fiber Coax)
  - ADSL (Asymmetric Digital Subscriber Line)
  - FTTC (Fiber To The Curb)
  - FTTH (Fiber To The Home)
  - EPON (Ethernet Based Passive Optical Networks)
  - IEEE 802.11

Delivery Systems Developments



Delivery Systems Developments



From Broadcast to True Media-on-Demand

[Little, Venkatesh 1994]

- Broadcast (No-VoD)
  - Traditional, no control
- Pay-per-view (PPV)
  - Paid specialized service
- Quasi Video On Demand (Q-VoD)
  - Distinction into interest groups
  - Temporal control by group change
- Near Video On Demand (N-VoD)
  - Same media distributed in regular time intervals
  - Simulated forward / backward
- True Video On Demand (T-VoD)
  - Full control for the presentation, VCR capabilities
  - Bi-directional connection

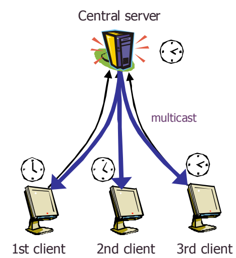
Optimized delivery scheduling

- Background/Assumption:
  - Performing all delivery steps for each user wastes resources
  - Scheme to reduce (network & server) load needed
  - Terms
    - Stream: a distinct multicast stream at the server
    - Channel: allocated server resources for one stream
    - Segment: non-overlapping pieces of a video
  - Combine several user requests to one stream
- Mechanisms
  - Type I: Delayed on-demand delivery
  - Type II: Prescheduled delivery
  - Type III: Client-side caching

Type I: Delayed On Demand Delivery

Optimized delivery scheduling

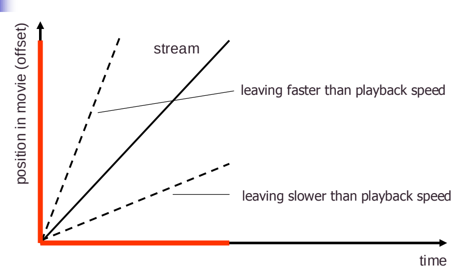
- Delayed On Demand Delivery
  - Collecting requests
  - Joining requests
  - Batching
    - Delayed response
  - Content Insertion
    - E.g. advertisement loop
  - Piggybacking
    - "Catch-up streams"
    - Display speed variations
  - Typical
    - Penalty on the user experience
    - Single point of failure



Batching & Content Insertion

- **Batching Operation**
  [Dan, Sitaram, Shahabuddin 1994]
  - Delay response
  - Collect requests for same title
- Batching Features
  - Simple decision process
  - Can consider popularity
- Drawbacks
  - Obvious service delays
  - Limited savings
- **Content Insertion**
  [Krishnan, Venkatesh, Little 1997]
  - Reserve news or ad channels
  - Fill gaps from ad channel
- Content Insertion Features
  - Exploits user perception
  - Fill start gaps
  - Force stream joins by insertion
  - Increase forced joining after server crashes

Graphics Explained



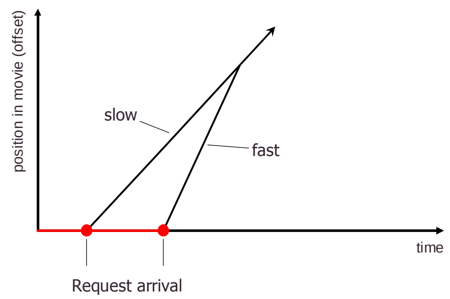
- Y - the current position in the movie
  - the temporal position of data within the movie that is leaving the server
- X - the current actual time

Piggybacking

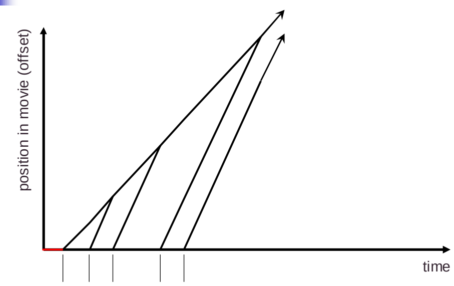
[Golubchik, Lui, Muntz 1995]

- Save resources by joining streams
  - Server resources
  - Network resources
- Approach
  - Exploit limited user perception
  - Change playout speed
    - Up to +/- 5% are considered acceptable
- Only minimum and maximum speed make sense
  - i.e. playout speeds
    - 0
    - +10%

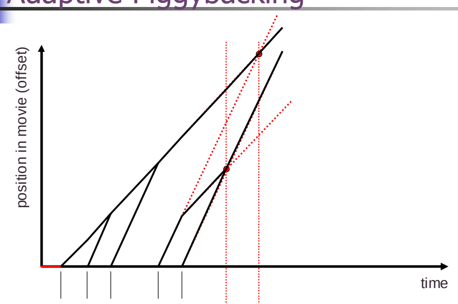
Piggybacking



Piggybacking



Adaptive Piggybacking



[Aggarwal, Wolf, Yu 1996]

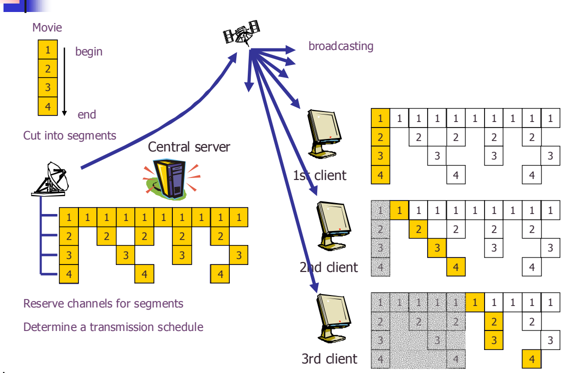
Type II:
Prescheduled Delivery

Optimized delivery scheduling

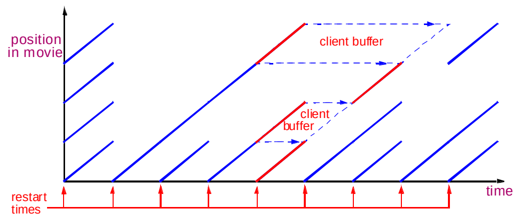
- Prescheduled Delivery
  - No back-channel
  - Non-linear transmission
  - Client buffering and re-ordering
  - Video segmentation

  - Examples
    - Staggered broadcasting, Pyramid b., Skyscraper b., Fast b., Pagoda b., Harmonic b., …
  - Typical
    - Good theoretic performance
    - High resource requirements
    - Single point of failure

Optimized delivery scheduling



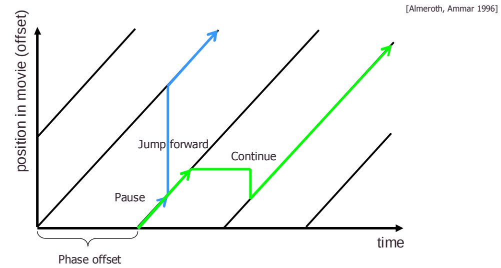
Prescheduled Delivery



- Arrivals are not relevant
  - users can start viewing at each interval start

Staggered Broadcasting

[Almeroth, Ammar 1996]



- Near Video-on-Demand
  - Applied in real systems
  - Limited interactivity is possible (jump, pause)
  - Popularity can be considered → change phase offset

Pyramid Broadcasting

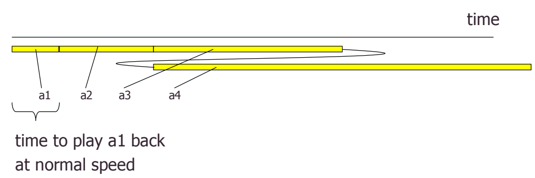
[Viswanathan, Imielinski 1996]

- Idea
  - Variable size segments $a_1 \dots a_n$
  - One segment repeated per channel
  - Fixed number of HIGH-bitrate channels C_i with bitrate B
  - Several movies per channel, total of m movies (constant bitrate 1)
  - Segment length is growing exponentially
- Operation
  - Client waits for the next segment a_1 (on average ½ len(d_1))
  - Receives following segments as soon as linearly possible
- Segment length
  - Size of segment a_i: $len(a_i) = \alpha^{i-1} \cdot len(a_1)$
  - α is limited
  - $\alpha > 1$ to build a pyramid
  - $\alpha \leq B/m$ for sequential viewing
  - $\alpha = 2.5$ considered good value
- Drawback
  - Client buffers more than 50% of the video
  - Client receives all channels concurrently in the worst case

Pyramid Broadcasting

- Pyramid broadcasting with B=4, m=2, α=2
- Movie a

$$len(a4) = \alpha \cdot len(a3) = \alpha^2 \cdot len(a2) = \alpha^3 \cdot len(a1)$$



Pyramid Broadcasting

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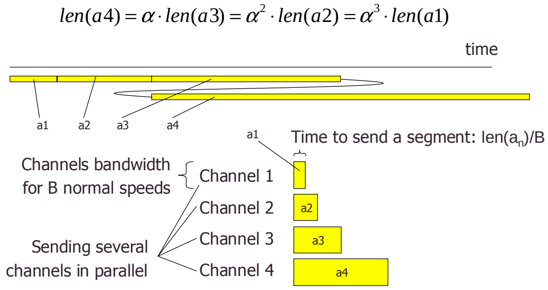

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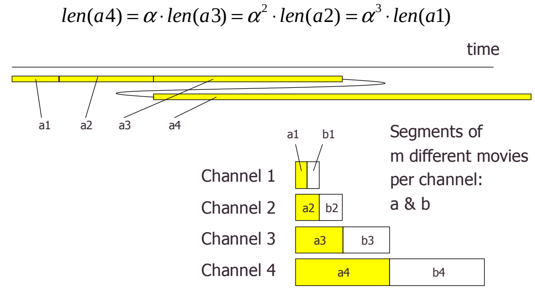

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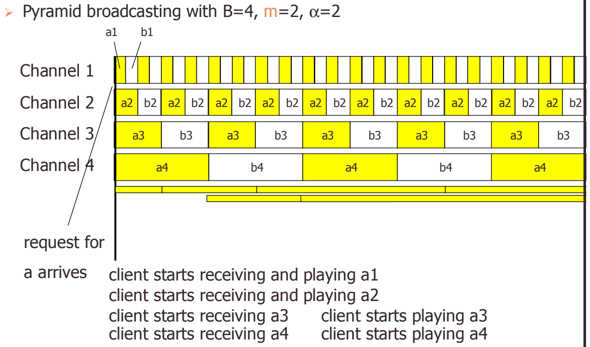

Pyramid Broadcasting

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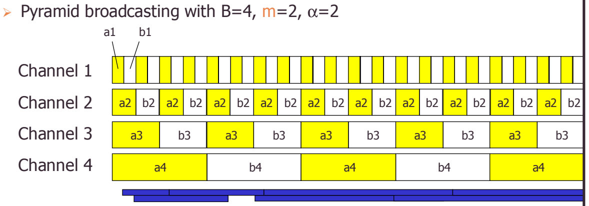
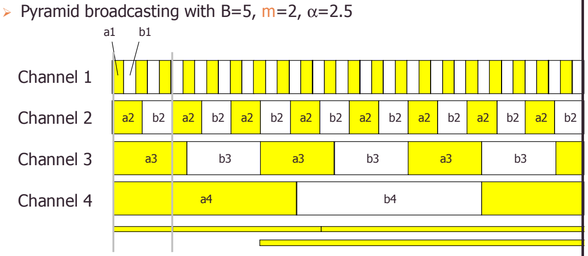


Pyramid Broadcasting

- Pyramid broadcasting with B=5, m=2, α=2.5

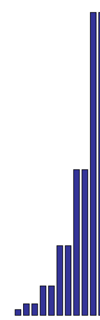


- Choose m=1
  - Less bandwidth at the client and in multicast trees
  - At the cost of multicast addresses

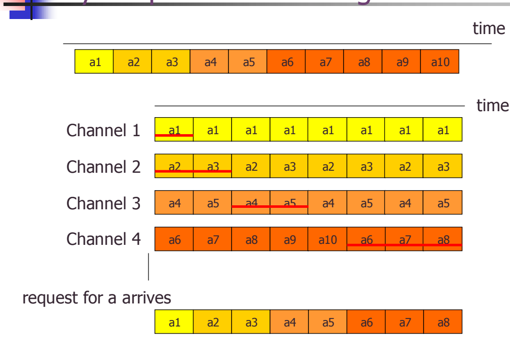
Skyscraper Broadcasting

[Hua, Sheu 1997]

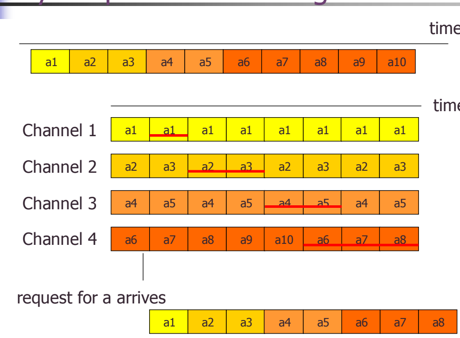
- Idea
  - Fixed size segments
  - More than one segment per channel
  - Channel bandwidth is playback speed
  - Segments in a channel keep order
  - Channel allocation series
    - *1,2,2,5,5,12,12,25,25,52,52, ...*
  - Client receives at most 2 channels
  - Client buffers at most 2 segments
- Operation
  - Client waits for the next segment a1
  - Receive following segments as soon as linearly possible



Skyscraper Broadcasting



Skyscraper Broadcasting

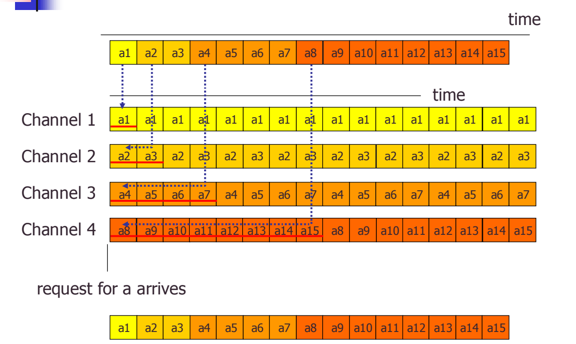


Other Pyramid Techniques

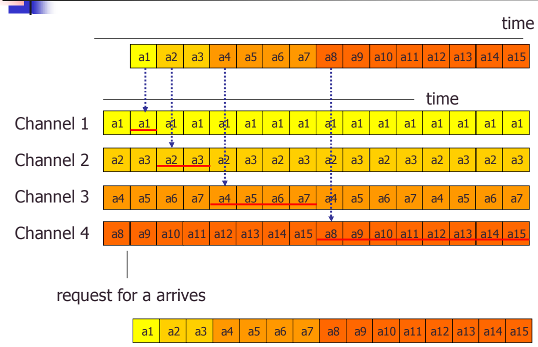
[Juhn, Tseng 1998]

- Fast Broadcasting
  - Many more, smaller segments
    - Similar to previous
    - Sequences of fixed-sized segments instead of different sized segments
  - Channel allocation series
    - Exponential series: *1,2,4,8,16,32,64, ...*
  - Segments in a channel keep order
  - Shorter client waiting time for first segment
  - Channel bandwidth is playback speed
  - Client must receive all channels
  - Client must buffer 50% of all data

Fast Broadcasting



Fast Broadcasting

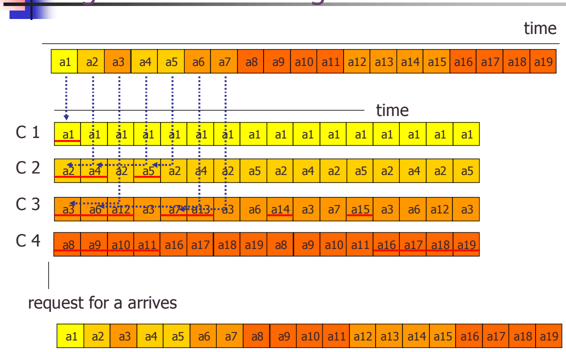


Other Pyramid Techniques

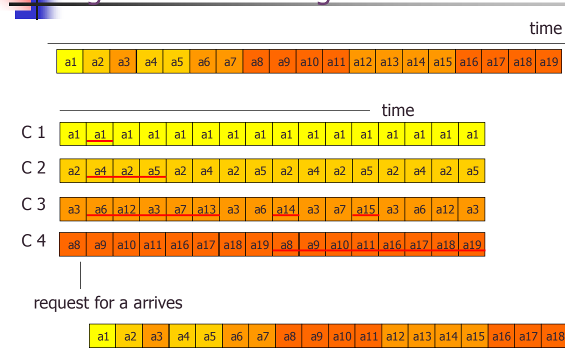
[Paris, Carter, Long 1999]

- Pagoda Broadcasting
  - Channel allocation series
    - *1,3,5,15,25,75,125*
  - Segments are ***not*** broadcast linearly
  - Consecutive segments appear on pairs of channels
  - Client must receive up to 7 channels
    - For more channels, a different series is needed !
  - Client must buffer 45% of all data
  - Based on the following
    - Segment 1 – needed every round
    - Segment 2 – needed at least every 2nd round
    - Segment 3 – needed at least every 3rd round
    - Segment 4 – needed at least every 4th round
    - …

Pagoda Broadcasting



Pagoda Broadcasting

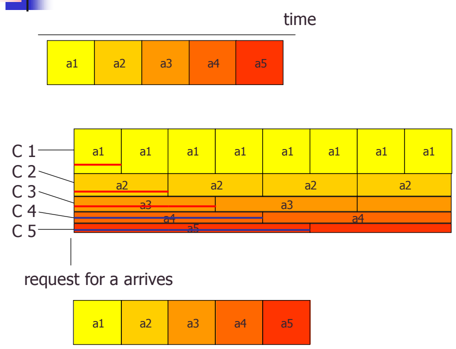


Harmonic Broadcasting

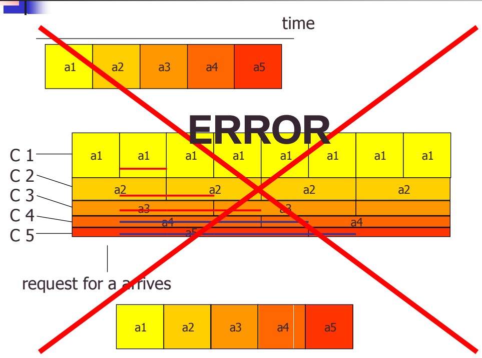
[Juhn, Tseng 1997]

- Idea
  - Fixed size segments
  - One segment repeated per channel
  - Later segments can be sent at lower bitrates
  - Receive all other segments concurrently
  - Harmonic series determines bitrates
    - Bitrate(a_i) = Playout-rate(a_i)/i
    - Bitrates 1/1, 1/2, 1/3, 1/4, 1/5, 1/6, …
- Consideration
  - Size of a_1 determines client start-up delay
  - Growing number of segments allows smaller a_1
  - Required server bitrate grows very slowly with number of segments
- Drawback
  - Client buffers about 37% of the video for >=20 channels
  - (Client must re-order small video portions)
  - Complex memory cache for disk access necessary

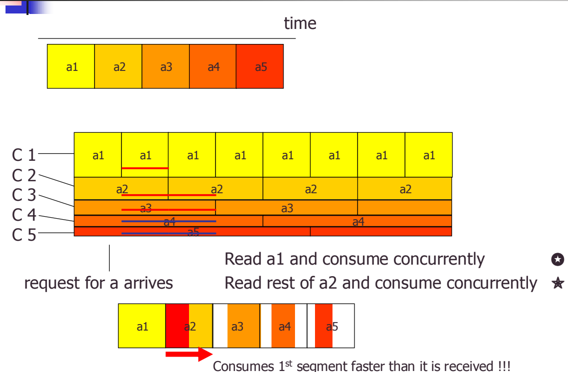
Harmonic Broadcasting



Harmonic Broadcasting



Harmonic Broadcasting



Other Harmonic Techniques

[By Paris, Long, …]

- Delayed Harmonic Broadcasting
  - Wait until a_1 is fully buffered
  - All segments will be completely cached before playout
  - Fixes the bug in Harmonic Broadcasting
- Cautious Harmonic Broadcasting
  - Wait an additional a_1 time
  - Starts the harmonic series with a_2 instead of a_1
  - Fixes the bug in Harmonic Broadcasting

Other Harmonic Techniques

- Polyharmonic Broadcasting
  - Generalizes CHB waiting time to m>=1 times for a_1
  - Client starts buffering immediately
  - Reduce bandwidth on subsequent channels
    b/(m+i-1) instead of b/i
  - Converges to standard Harmonic Broadcasting behavior

Prescheduled Delivery Evaluation

- Techniques
  - Video segmentation
  - Varying transmission speeds
  - Re-ordering of data
  - Client buffering
- Advantage
  - Achieve server resource reduction
- Problems
  - Tend to require complex client processing
  - May require large client buffers
  - Are incapable (or not proven) to work with user interactivity
    - Current research to work with VCR controls
  - Guaranteed bandwidth required

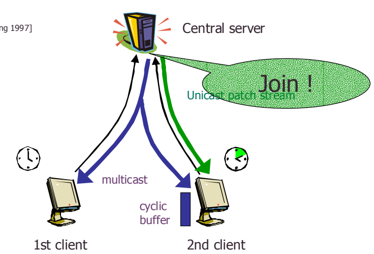
Type III: Client Side Caching

Optimized delivery scheduling

- Client Side Caching
  - On-demand delivery
  - Client buffering
  - Multicast complete movie
  - Unicast start of movie for latecomers (patch)
- Examples
  - Stream Tapping, Patching, Hierarchical Streaming Merging, …
- Typical
  - Considerable client resources
  - Single point of failure

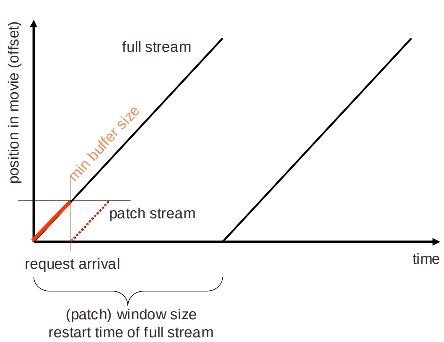
Optimized delivery scheduling

- Patching
  [Hua, Cai, Sheu 1998, also as Stream Tapping Carter, Long 1997]

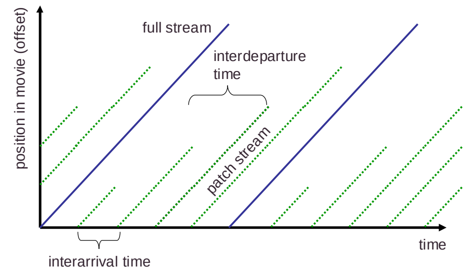


- Server resource optimization is possible

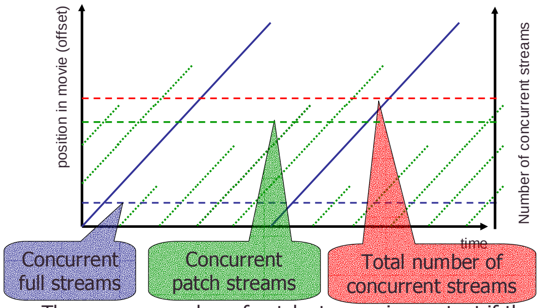
Optimized delivery scheduling



Optimized delivery scheduling

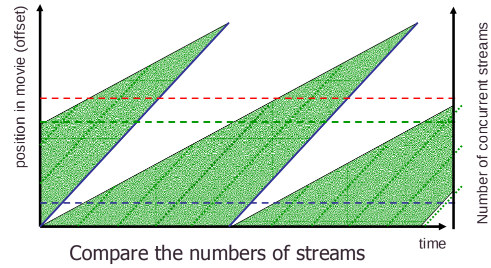


Optimized delivery scheduling



The average number of patch streams is constant if the arrival process is a Poisson process

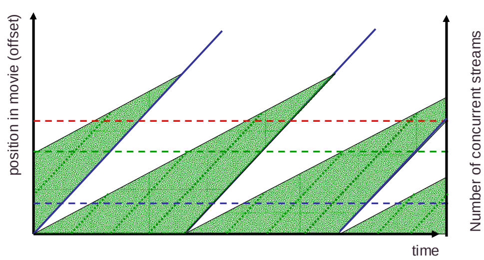
Optimized delivery scheduling



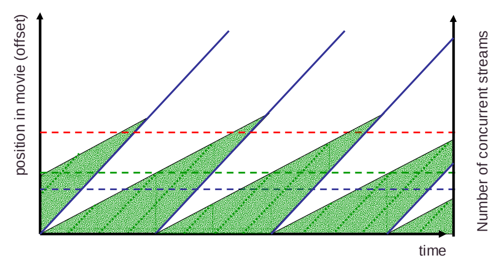
Compare the numbers of streams

Shown patch streams are just examples
But always: patch end times on the edge of a triangle

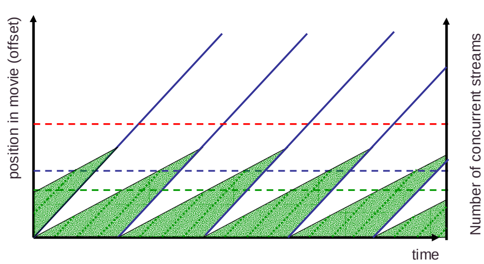
Optimized delivery scheduling



Optimized delivery scheduling



Optimized delivery scheduling



Optimized delivery scheduling

- Minimization of server load
- Minimum average number of concurrent streams
- Depends on
  - F movie length
  - Δ_U expected interarrival time
  - Δ_M patching window size
  - C_U cost of unicast stream at server
  - C_M cost of multicast stream at server
  - S_U setup cost of unicast stream at server
  - S_M setup cost of multicast stream at server

Optimized delivery scheduling

- Optimal patching window size
  - For identical multicast and unicast setup costs
  - For different multicast and unicast setup costs

$$\Delta_M = \sqrt{2 \cdot F \cdot \Delta_U}$$

$$\Delta_M = \sqrt{2 \cdot \frac{S_M + C_M F}{C_U} \cdot \Delta_U}$$

Movie length

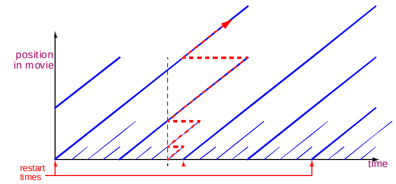
Unicast Interarrival time

Patching window size

- Servers can estimate Δ_U
  - And achieve massive saving

Unicast	7445 Mio $
Greedy patching	3722 Mio $
λ-patching	375 Mio $

Multistream Patching



- Operation
  - Take maximum # of parallel streams at client
  - Segment streams with a 50% overlap
  - Apply patching recursively

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HMSM

[Eager, Vernon, Zahorjan 2001]

- Hierarchical Multicast Stream Merging
- Key ideas
  - Each data transmission uses multicast
  - Clients accumulate data faster than their playout rate
    - multiple streams
    - accelerated streams
  - Clients are merged in large multicast groups
  - Merged clients continue to listen to the same stream to the end
- Combines
  - Dynamic skyscraper
  - Piggybacking
  - Patching

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HMSM

- Always join the closest neighbour
- HMSM(n,1)
  - Clients can receive up to n streams in parallel
- HMSM(n,e)
  - Clients can receive up to n full-bandwidth streams in parallel
  - but streams are delivered at speeds of e, where e << 1
- Basically
  - HMSM(n,1) is another recursive application of patching

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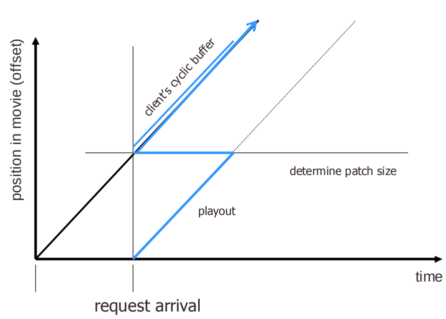
HMSM(2,1)



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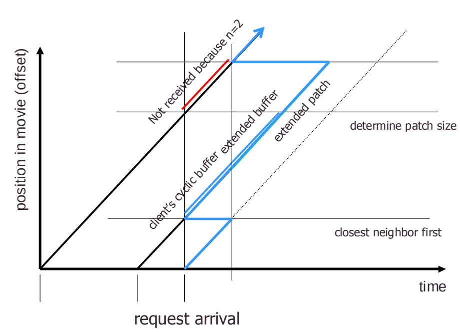
HMSM(2,1)



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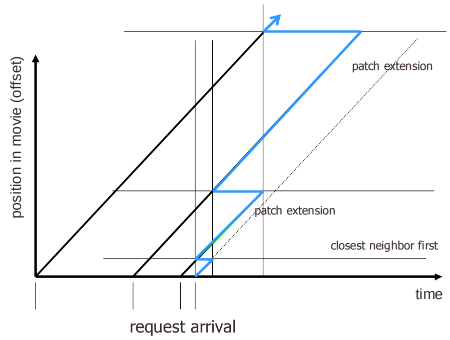
HMSM(2,1)



Client Side Caching Evaluation

- Techniques
  - Video segmentation
  - Parallel reception of streams
  - Client buffering
- Advantage
  - Achieves server resource reduction
  - Achieves True VoD behaviour
- Problems
  - Optimum can not be achieved on average case
  - Needs combination with prescheduled technique for high-popularity titles
  - May require large client buffers
  - Are incapable (or not proven) to work with user interactivity
  - Guaranteed bandwidth required

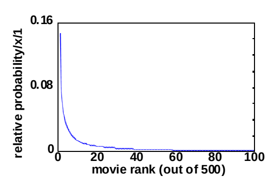
Overall Evaluation

- Advantage
  - Achieves server resource reduction
- Problems
  - May require large client buffers
  - Incapable (or not proven) to work with user interactivity
  - Guaranteed bandwidth required
- Fixes
  - Introduce loss-resistant codecs and partial retransmission
  - Introduce proxies to handle buffering
  - Choose computationally simple variations

Optimized delivery scheduling

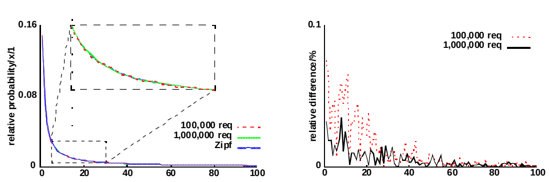
- Optimum depends on popularity
  - Estimate the popularity of movies
  - Frequently used: Zipf distribution

$$z(i) = \frac{C}{i}, C = 1 / \sum_{l=1}^{N} \frac{1}{l}$$



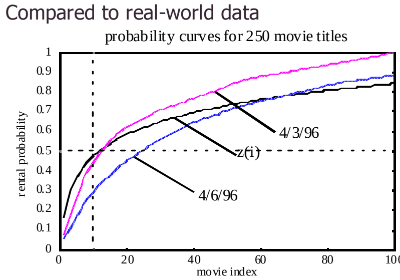
Optimized delivery scheduling

- Problem
  - Being Zipf-distributed is only an observed property



Optimized delivery scheduling

- Density function of the Zipf distribution
  - Compared to real-world data



Optimized delivery scheduling

- Conclusion
  - Major optimizations possible
  - Independent optimizations don't work
- Centralized systems problems
  - Scalability is limited
  - Minimum latency through distance
  - Single point of failure
- Look at distributed systems
  - Clusters
  - Distribution Architectures

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