Distributed Video Systems

Chapter 7

Parallel Video Servers

Part 2 - A Push-Based Parallel Video Server

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- Design Challenges
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  - Video playback continuity
  - Buffer requirement
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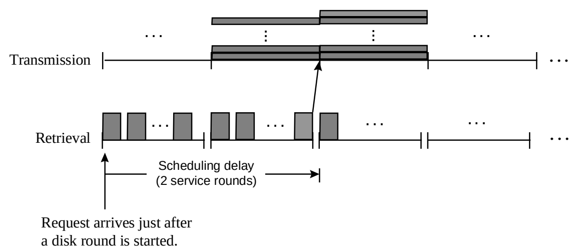
7.2 Inter-Server Scheduling

- Problem
  - Centralized scheduling cannot be done because the servers are independent and connected by a network only.
- Key to Perform Scheduling
  - Knowledge of a global time or clock!
- Solution
  - Make use of a distributed clock-synchronization algorithm such as NTP [Mills 1991] to partially synchronize the server clocks.
  - Perform scheduling locally and independently at each server according to the local clock.

- Concurrent-Push Algorithm
  - All servers transmits video data continuously to a video client concurrently.
  - Let video playback bit-rate be R_V, and there are N_S servers. Then the per-server transmission rate would be R_V/N_S to maintain a correct aggregate rate.
  - Scheduling at a server:



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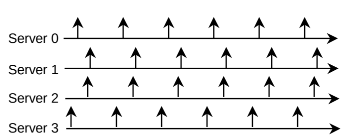
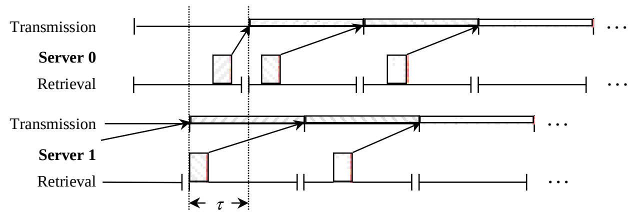
- Concurrent-Push Algorithm
  - Transmission from all servers:

- In reality, transmission is most likely done in packets:



Note that exact synchronization is not possible due to *clock jitters* among servers.

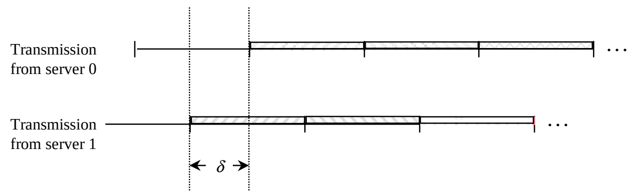
- Concurrent-Push Algorithm
  - Server Clock Jitter



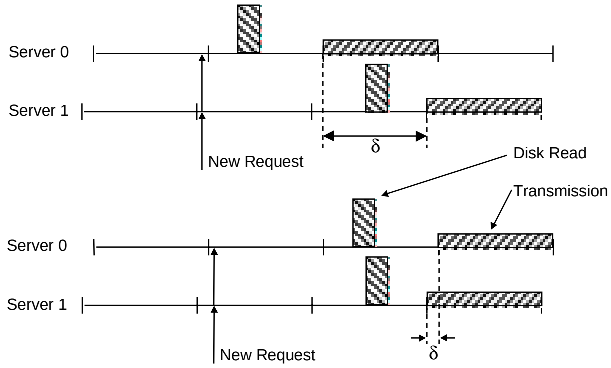
- The amount of clock jitter depends on the clock-synchronization protocol, the network parameters, etc., but is bounded.
- Current protocols can easily synchronize the server clocks to within 100ms on a LAN.

- Transmission Jitter
  - Let $T_{i,j}$ be the time server i ($0 \le i < N_S$) starts transmitting the $(jN_S+i)^{th}$ block of a video stream.
  - Definition of transmission jitter:

$$\delta = \max\left\{ \left| T_{i,j} - T_{k,j} \right| \, | \, \forall i, k, j \right\}$$



- Transmission Jitter
  - Looks the same as clock jitter, isn't it?
  - Consider these two cases:

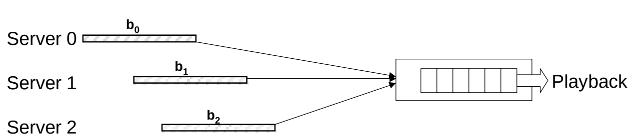


A small clock jitter can lead to a big transmission jitter!

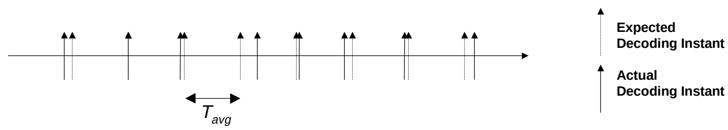
- Transmission Jitter
  - Worst-Case = $\delta \le T_F$

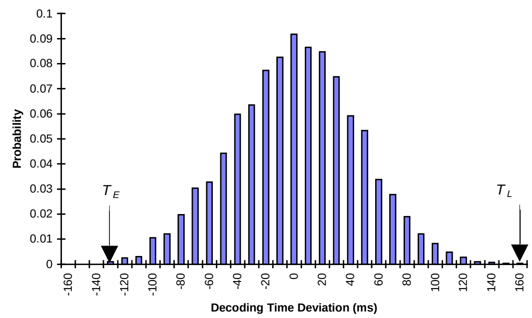
where $T_F = \dfrac{N_S Q}{R_V}$ I.e. time to send one video block of *Q* bytes

  - Problem
    - The bound increase with N_S (no. of servers).
    - Transmission jitter affects client buffer requirement.



- Video Block Consumption Model
  - Bounded variations with an average rate.





- Video Block Consumption Model
  - Bounded variations with an average rate.
    - Decoding-time deviation bounds:
      - Max. lag in decoding: $T_L = \max\{T_{DV}(i) \mid \forall i \geq 0\}$
      - Max. lead in decoding: $T_E = \min\{T_{DV}(i) \mid \forall i \geq 0\}$
      - Peak-to-Peak Decoding-time Deviation:

$$T_{DV} = T_L - T_E$$

      - Time between consumption of any two video blocks *i*,*j* is:

$$\underbrace{\max\{((j-i)T_{avg} - T_{DV}),0\}}_{\text{Min. time interval}} \leq t \leq \underbrace{((j-i)T_{avg} + T_{DV})}_{\text{Max. time interval}}$$

- Client Buffer Requirement
  - Buffer Management
    - Total $L_C = Y + Z$ buffers, with *Y* prefilled before playback starts.
    - The L_C buffers are managed as a circular buffer.
    - A client receives video transmissions from N_S servers simultaneously. Hence *Y* must be multiples of N_S.
  - Video Block Groups
    - Group *n* consists of video blocks nN_S to $(n+1)N_S-1$.
  - Objective
    - To find the minimum number of buffers *Y* needed such that video playback continuity can be guaranteed despite *delay and delay jitters*, *server clock jitters*, and *decoding-time variations*.
    - To find a similar *Z* to prevent client buffer overflow.

- Client Buffer Requirement
  - Buffering for continuity (i.e. underflow)
    - Among the N_S servers, let the earliest transmission for the first round start at time t_0, then the last transmission for the first round must start at time $t_0+\delta$.
    - Therefore the time for video block group *i* to be completely filled, denoted by *F*(*i*), is bounded by

$$\left((i+1)T_F + t_0 + f^-\right) \le F(i) \le \left((i+1)T_F + t_0 + \delta + f^+\right) \quad (10)$$

where f^+ ($f^+ \ge 0$) and f^- ($f^- \le 0$) are used to model the maximum transmission time deviation due to randomness in the system, including transmission rate deviation, CPU scheduling, bus contention, etc.

- Client Buffer Requirement
  - Buffering for continuity (i.e. underflow)
    - Assume the client starts playing video after filling the first *y* groups of buffers (i.e. $Y = yN_S$);
    - The playback time for video block group 0 is simply given by $F(y-1)$; and for an arbitrary group *i* becomes:

$$\left\{iN_S T_{avg} + F(y-1) + T_E\right\} \le P(i) \le \left\{iN_S T_{avg} + F(y-1) + T_L\right\} \quad (11)$$

    - For continuity, a video block must arrive before playback:

Worst case: $$\underbrace{\max\{F(i)\}}_{(10)} < \underbrace{\min\{P(i)\}}_{(11)}$$

- Client Buffer Requirement
  - Buffering for continuity (i.e. underflow)
    - Substituting and solving gives *y* as:

$$y > 2 + \frac{f^+ - f^- - T_E}{T_F}$$

    - Hence *Y* can be obtained from

$$Y = \left\lceil 2 + \frac{f^+ - f^- - T_E}{T_F} \right\rceil N_S$$

Note the dependency on N_S

  - Buffering to prevent overflow:

$$Z = \left\lceil 2 + \frac{f^+ - f^- + T_L}{T_F} \right\rceil N_S$$

7.3 Performance Modeling and Analysis

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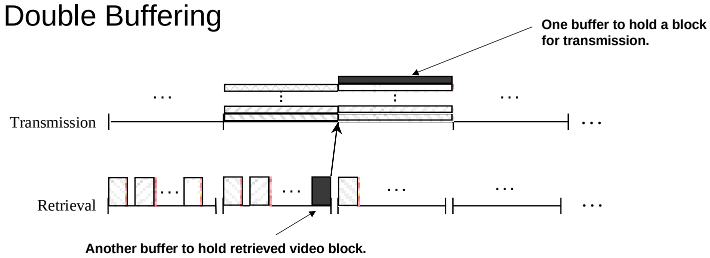
- Server Buffer Requirement
  - Double Buffering



  - Assume each additional server can increase the system capacity by Λ clients, then the per-server buffer requirement is given by

$$B_{server} = 2\Lambda N_S Q$$

7.3 Performance Modeling and Analysis

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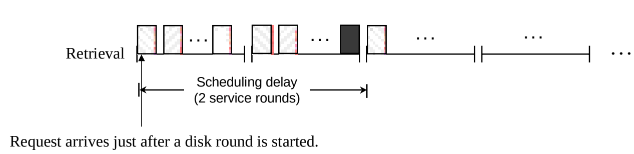
- System Response Time
  - The time from the user requests for a new video session to the time actual video playback starts.
  - Sums of scheduling delay and prefill delay.
  - Scheduling delay
    - the time from a client sending a new-session request to the time transmission starts at the server.
    - Worst-case scheduling delay is $D_S = \frac{2N_S Q}{R_V}$



7.3 Performance Modeling and Analysis

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- System Response Time
  - Prefill delay
    - the time from the server starts transmission to the time the first *y* groups of client buffers are fully filled with data.
    - Worst-case can be determined from (10):

$$D_P = \max\{F(y-1)\} - t_0$$

or

$$D_P = yT_F + \max\{\delta\} + f^+ = (y+1)T_F + f^+$$
$$= \left(3 + \left\lceil \frac{f^+ - f^- - T_E}{T_F} \right\rceil \right) T_F + f^+$$

- Note that $T_F = \dfrac{N_S Q}{R_V}$

Hence the response time is also proportional to N_S.

7.3 Performance Modeling and Analysis

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- Summary of Results
  - Server Buffer Requirement:

$$B_{server} = 2\Lambda N_S Q$$

  - Client Buffer Requirement:

$$Y = \left\lceil 2 + \frac{f^+ - f^- - T_E}{T_F} \right\rceil N_S \quad \text{and} \quad Z = \left\lceil 2 + \frac{f^+ - f^- + T_L}{T_F} \right\rceil N_S$$

  - System Response Time:

$$D_S = \frac{2N_S Q}{R_V} \quad \text{and} \quad D_P = \left(3 + \left\lceil \frac{f^+ - f^- - T_E}{N_S Q} R_V \right\rceil \right) \frac{N_S Q}{R_V} + f^+$$

7.4 Asynchronous Grouped-Sweeping Scheme

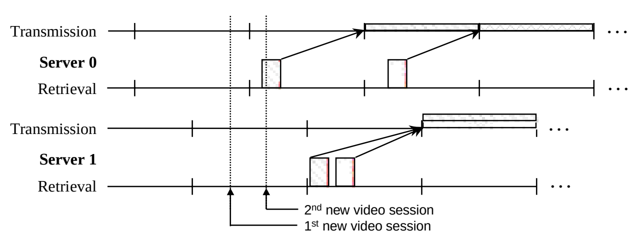
- Reducing Server Buffer Requirement
  - By dividing a service round from serving ΛN_S requests to N_S rounds, each serving only Λ requests.
  - The idea is same as GSS and the buffer requirement is reduced to

$$B_{server} = QN_S\Lambda\left(1+\frac{1}{N_S}\right)$$

  - Simple huh? Not quite!

7.4 Asynchronous Grouped-Sweeping Scheme

- Inconsistent Group Assignments
  - An Example:



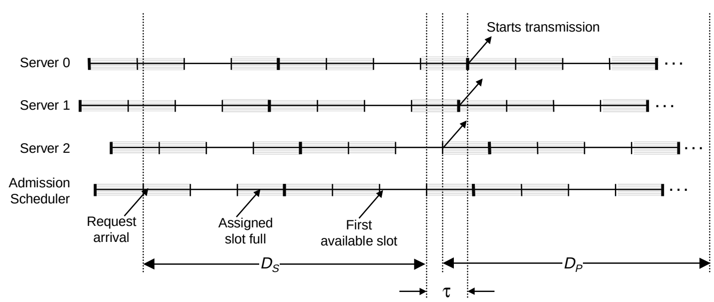
  - The group assignments among servers will become inconsistent and some servers can become overloaded in one group while others are not.

- Inconsistent Group Assignments
  - Solution: Admission Scheduling
    - An admission scheduler is used to control the admission of all new video sessions.
    - Inconsistent group assignment is prevented by delaying the admission of new sessions by

$$\Omega = \left\lceil \frac{\tau N_S}{T_F} \right\rceil + 1$$

    - The idea is to admit a new session to a service round guaranteed to have not yet started in *any* of the servers.

- Inconsistent Group Assignments
  - Solution: Admission Scheduling



    - With admission scheduling in place, we can prove that the transmission jitter becomes the same as the clock jitter τ.

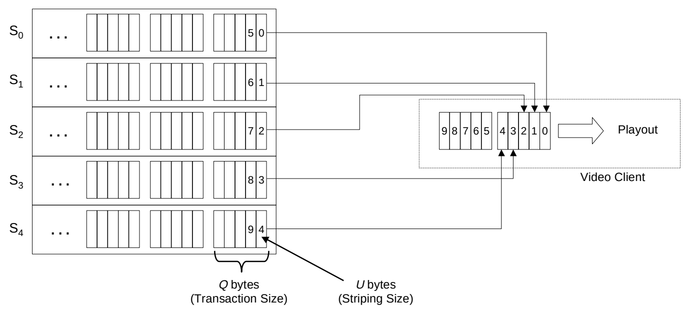
7.4 Asynchronous Grouped-Sweeping Scheme

- Inconsistent Group Assignments
  - Solution: Admission Scheduling
    - Side Benefits
      - Reduced client buffer requirement (δ becomes τ where $\delta \geq \tau$).
      - Reduced prefill delay (same reason).
    - Tradeoff
      - Additional scheduling delay due to the added artificial delay as well as the delay incurred in finding a service round that is not full.
      - The extra scheduling delay depends on the system utilization.

7.5 Sub-Schedule Striping

- Motivation
  - AGSS reduces server buffer requirement substantially but only reduces client buffer requirement slightly.
  - We can further reduce the client buffer requirement and consequently prefill delay by decoupling striping from disk retrieval.
- Principle
  - In conventional disk scheduling, each disk transaction retrieves a data block of *Q* bytes, which contains *continuous* video data.
  - It doesn't have to be continuous video data.

- Principle
  - Striping Size = *U* bytes
  - Retrieval Size = *Q* bytes



- Performance Impact
  - Assuming we maintain $U=Q/N_S$, then:
    - Client buffer requirement becomes

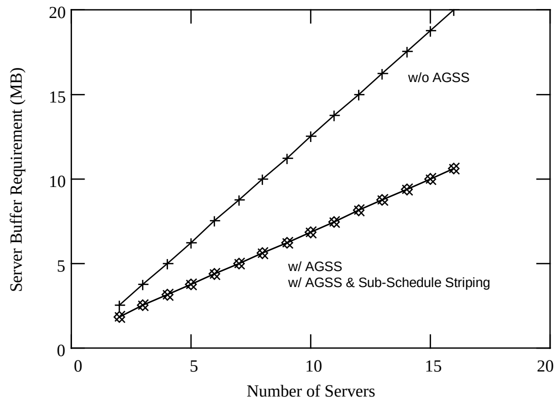
$$Y > 1 + \left(\frac{f^+ - f^- - T_E + \tau}{T_{avg}} \right) \quad \text{and} \quad Z > 1 + \left(\frac{f^+ - f^- + T_L + \tau}{T_{avg}} \right)$$

    - And prefill delay becomes

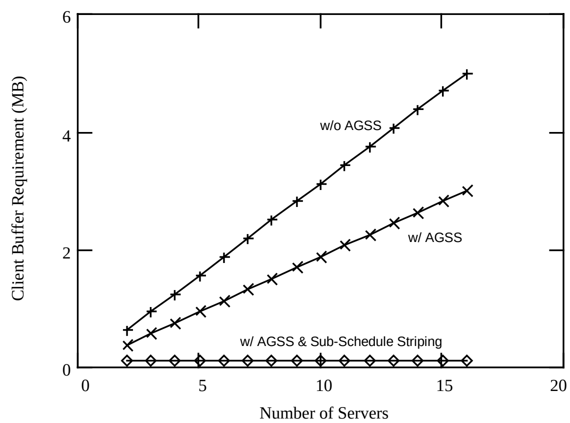
$$D_P = YT_{avg} + f^+ + \tau$$

    - Both are now independent of N_S!
    - Any tradeoff?

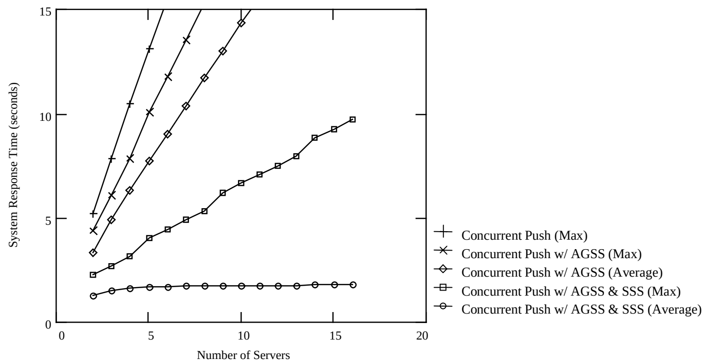
- Server Buffer Requirement



- Client Buffer Requirement



- System Response Time



- How scalability is the architecture?
  - Limited by server memory size:
    - Using servers with 256MB buffer memory, we can scale up to 408 servers, serving 3672 video streams at 90% utilization.
    - Using servers with 1GB buffer memory, we can scale up 14400 video streams with a client-server ratio of 250 (64 servers) at 90% utilization.
  - Limited by client processing capability:
    - Larger N_S results in smaller striping units.
    - Smaller striping units incurs more processing overhead at the client since resequencing is required.
    - Using 1KB striping units and 64KB transaction size, we can scale to at most 64 servers.