Impacts of User Behavior on Continuous Playback in Tree-based Video-on-Demand Streaming over P2P Networks

By:
Hanif Rahbari

Under Supervision of:
Dr. Mehdi Dehghan (Amirkabir Univ. of Technology)
Dr. Hamid R. Rabiee (Sharif Univ. of Technology)

September 2010
Agenda

- P2P Video Streaming
- Continuous Playback in a VoD Tree-Based System
- User Behavior
- Study the Impact of User Behavior
- Simulation
- Conclusion and Future Work
Agenda

>>> P2P Video Streaming
Continuous Playback in a VoD Tree-Based System
User Behavior
Study the Impact of User Behavior
Simulation
Conclusion and Future Work
Video Streaming Models

- Client/Server Model
- Content Distribution Network (CDN) Model
  - Extension of Client/Server model
  - YouTube!
- IP Multicast
- Peer-to-Peer (P2P) Networks Model
  - Build upon an overlay network
  - Being both client and server
  - Resource sharing → More Scalable
Classification of Video Streaming over P2P Networks

- Content Delivery Topology
  - Mesh
  - (Multi-)Tree

- A/synchronized Content Delivery
  - Live
  - Video-on-Demand (VoD)
Agenda

- P2P Video Streaming
- >>> Continuous Playback in a VoD Tree-Based System
- User Behavior
- Study the Impact of User Behavior
- Simulation
- Conclusion and Future Work
DirectStream - A VoD Tree-Based System
How does it work?

- Local Memory:
- Video Length:
DirectStream - A VoD Tree-Based System (Con’d)
How does it work?
DirectStream - A VoD Tree-Based System (Con’d)
How does it work?
DirectStream - A VoD Tree-Based System (Con’d)
How does it work?
DirectStream – A VoD Tree-Based System (Con’d)

- Scalable
- Buffering last $b$ minutes
  - No explicit delayed playback
- Supports VCR functionalities
  - Pause, Jump Forward/Backward, …
- Parent Selection Algorithm
  - Distance-Bandwidth Ratio Metric
    - Load Balancing
    - Traffic Reduction
  - Smallest value is preferred
    - $n_i$: Number of hops
    - $x_i$: Available Bandwidth

\[ \frac{n_i^r}{x_i} \]
Parent Selection

New node:  
Physical node:  

\[ n_i^r / x_i = n_2^r / x_2 = 3^r / x_2 \]
DirectStream – Features

- Scalable
- Considering Continuous Playback
  - Multiple backup parents
- VCR Functionalities
- Proximity Awareness
  - Underlying overlay network

DirectStream – VCR Functionalities

- **Pause**
  - Removes temporarily
  - All children require recovery process

- **Forward Jump**
  - New position > parent’s position
    - Recovery process
  - All children require recovery process

- **Jump Backward**
  - New position < parent’s position – buffer size
    - Recovery process
  - All children require recovery process
QoS Challenges in P2P Video Streaming

- Bandwidth
- Delay
- Jitter
- Packet Loss
- High Dynamics (in P2P networks)
  - Peer churn
  - Providing continuous playback
    - Tackling interruption(s) and reconstructing the overlay
DirectStream – User Interactions

A Selfish User!
The Causes of Discontinuous Playback

- Bandwidth Fluctuations
- Client Early Departure and Overlay Distortion
  - Selfish/Malicious nodes
  - Unexpectedly stopping video playback
  - User interactions
Discontinuous Playback (An Example)
Mitigating the Causes of Interruption

- **Re-active Approach**
  - Be prepared for a suitable reaction!
  - Data buffering (Delayed playback)
  - Multiple backup parents
    - Inefficient use of bandwidth
    - Reduction in system scalability
  - Multiple Description Coding (MDC)
    - Mesh-based topology

- **Pro-Active Approach**
  - Incentive mechanism(s)
Agenda

P2P Video Streaming
Continuous Playback in a VoD Tree-Based System

>>> User Behavior

Study the Impact of User Behavior Simulation

Conclusion and Future Work
User Behavior

- User Behavior includes:
  - Sent time in system
  - Interactions (VCR)
  - Video (Content) popularity

- Statistical Models are available
  - Using information extracted from the server logs (LNE TV)
  - Take advantage of this models to anticipate the future behavior of a typical user

- User Behavior Influences:
  - Simulations and evaluations
  - Protocol design

Networking Seminar – Fall 2010
User Behavior – Modeling

- User Behavior Model demonstrates:
  - A Conceptual model for user behavior
  - Dependence structure among variables
  - Number of concurrent users
  - Sent time in system
  - User interactions statistical model
  - Re-watch requests

User Behavior – Conceptual Model

- **Session Layer**: Session #1 starts and continues for a duration longer than $t_{off}$ and more than 30 minutes, followed by Session #2.

- **Request Layer**:
  - Request #1: Long video
  - Request #2: Short video
  - Request #3: Long video

- **ON-OFF States**:
  - Session #1: ON-OFF-ON-OFF-ON
  - Requests:
    - Request #1: Play, Pause, Play, Pause, Play, Stop

**Client Activities**
User Behavior – Statistical Properties

- Dependence Structure
  - Video length dependent parameters

- User’s Request Length
  - Short Video $L < 300$
    - Users with complete watch: 3%
    - 60% of users depart before the middle of video
  - Long video $L > 300$
    - Users with complete watch: 1%
    - 80% of users depart before the middle of video

- High Dynamics!
User Behavior – Statistical Properties (Con’d)

- VCR Functionalities
  - Short video
    - 61% without any pause
    - 93% without forward jump
    - 96% without backward jump
  - Long video
    - 64% without any pause
    - 21% have only 1 pause
    - 83% without forward jump
    - 91% without backward jump

- Not Very High Dynamics
User Behavior – System Parameters

- **Scalability**
  - Self-scalability

- **Performance Evaluation of Hard/Soft Cache**
  - Hard cache has better performance

- **Performance Evaluation of Different replacement Algorithms**

- **Continuous Playback?**

Agenda

P2P Video Streaming
Continuous Playback in a VoD Tree-Based System
User Behavior
>>> Study the Impact of User Behavior
Simulation
Conclusion and Future Work
Inclusion of User Behavior in Directstream

- New node prefers current nodes to the server

Contacting Server if

- No candidate node
  - More candidates: less probability of contacting server
  - Systems with more buffers: more candidates

- Lack of the bandwidth
  - More bandwidth: less probability of contacting server

Node Early Departure

- Recall: 80% of nodes depart the video before the middle of the video!
Effects of User Departure on Sub-tree(s)
Effects of User Departure on Sub-tree(s) (Con’d)

- New node prefers current nodes to the server
  - Increase in depth of sub-tree(s) ($b = 4$)
    - $T = 10$
    - $T = 20$
1. Capacity redemption in some nodes for child’s departure
   - Less probability to contact server
   - Increase in depth and width of sub-tree
   - Increase in scalability

2. Replacement of old nodes with new ones
   - Increase the potential of admitting new nodes
   - Increase in depth and width of sub-tree (more recent buffers)

3. Node departure faces all children to interruption
   - More depth in sub-tree: More the possibility of facing interruption
Continuous Playback – Performance Metrics

- 3 Types of System Responses to New Requests:
  - Rejection
  - Admission but with interruption(s)
  - Admission without interruption

- Metric #1: Rejection Probability
- Metric #2: Percentage of admitted but interrupted clients
- Metric #3: Percentage of interrupted clients per admitted clients.
- Metric #4: Average number of interrupts per admitted clients.
- Metric #5: Average number of interrupts per interrupted clients.
More Elaboration on Studying the Effect of Some Parameters

- Reliable Path from Parent to Server
- Definition 1: The probability of Complete view in all parents
  - Depth of the node
  - Age of all the parents
    - Old viewers have less tendency to leave watching
    - Take advantage of statistical model
  - i.i.d. random variables

\[
P_{\text{reliable}}^i = p(\text{complete view}|t)
= \frac{p_{100}}{p_{t/1}}
= \prod_{i=1}^{n} P_{\text{reliable}}^i
\]
More Elaboration on Studying the Effect of Some Parameters (Con’d)

- Definition 2: The probability of no jumps/pause in all parents
  - Depth of the node
  - Number of pause/jump in parent nodes
    - Take advantage of statistical model
  - i.i.d. random variables

\[
P_{\text{no pause}} = \prod_{j=1}^{n} P_{\text{no pause}}^{j} \cdot P_{\text{no jump}}
\]

\[
P'_{\text{robust}} = \prod_{j=1}^{n} P_{\text{no pause}}^{j} \cdot P_{\text{no jump}}
\]
More Elaboration on Studying the Effect of Some Parameters (Con’d)

- Tendency to choose more reliable parents
  - Anticipation based on user behavior

- Combination with Distance-Bandwidth Ratio
  - Violation from scalable criteria
    - Degradation in scalability

- Parent Selection Algorithm for both definitions
  - N candidates
  - Select k best candidates
  - Select the most robust parent
Agenda

P2P Video Streaming
Continuous Playback in a VoD Tree-Based System
User Behavior
Study the Impact of User Behavior
>>> Simulation
Conclusion and Future Work
Simulation - Setup

- Topology: A network with 100 nodes which represent local networks
  - 12 stub networks
  - 1 transit network
- Topology Generated by GT-ITM tool
- 1 Video with CBR (Constant Bit Rate)
- MATLAB
- Long Video
Simulation - Parameters

- Normalized Workload (x-axis)
  - Arrival Rate (Poisson)
  - 1 - 1000

- Buffer Memory (Colored Lines)
  - = 5% of video length (black)
  - = 10% of video length (blue)
  - = 20% of video length (red)

- Confidence Intervals
  - 95%
Simulation – Validation

Server in Stub Domain (QoS)

- unicast
- buffer-size = 5
- buffer-size = 10
- buffer-size = 15
- buffer-size = 20

Server in Stub Domain - Without interactions

- Transit domain: buffer-size = 5%
- Transit domain: buffer-size = 10%
- Stub domain: buffer-size = 5%
- Stub domain: buffer-size = 10%

Networking Seminar – Fall 2010
Simulation – DirectStream with User Behavior

- Rejection Probability
  - Redemption of resources because of users early departure
    - Self-Scalability

Without User Behavior

With User Behavior

Server in Transit Domain - Without interactions

Server in Transit Domain - With interactions

Client rejection probability

Normalized workload

Networking Seminar – Fall 2010
Simulation – The Effect of Arrival Rate

- Direct Relation between Workload and metric #2
  - Because of increase in number of nodes and so increase in distance to server

```
Server in Transit Domain - With interactions

- buffer-size = 5%
- buffer-size = 10%
- buffer-size = 20%
```

> Normalized workload

> Number of Clients with Interrupt(s) (%)
Simulation – The Effect of Buffer Size

- Direct Relation Between Buffer Size and Number of Interruptions
  - More candidates and thus less tendency to contact server
  - Left: \( b = 2 \), Right: \( b = 2 \)

![Diagram showing network topology and candidate nodes with buffer sizes]
Simulation – Buffer Size vs. Arrival Rate

- Analogous Systems

- Similarity:
Similar Interrupted nodes in High Load

100: Turning-Point
- Almost Balanced Tree
- Increase in RP
- Independence from buffer size
Simulation – Interrupted Nodes

- The Order Inverts after Turning-point (100)
  - More choices: much balanced
Simulation – Parent Selection Based on Definition 1

- Age and depth of the parent(s)
- Improved Continuous Playback
  - Low workload
    - Slight improvement in 5% & 20%
  - High workload
    - Improves all
Simulation – Parent Selection Based on Definition 1

- **# of Interrupts**
  - Before TP (100)
    - Decreased
  - Around TP (100)
    - Increased!
  - After TP (100)
    - Decreased

- **Fairness**
  - Improved
Simulation – Definition 1 (Age and Depth of parent(s))

- Improvement in some points (green: Improvement)
- Scalability!

<table>
<thead>
<tr>
<th>Buffer Size</th>
<th>Normalized Workload</th>
<th>Metric #1</th>
<th>Metric #2</th>
<th>Metric #3</th>
<th>Metric #4</th>
<th>Metric #5</th>
</tr>
</thead>
<tbody>
<tr>
<td>5%</td>
<td>50</td>
<td>-43.10%</td>
<td>6.40%</td>
<td>4.50%</td>
<td>1.50%</td>
<td>-2.90%</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>-35.90%</td>
<td>1.60%</td>
<td>-2.60%</td>
<td>-3.40%</td>
<td>-0.60%</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>-32.80%</td>
<td>3.60%</td>
<td>-4.10%</td>
<td>0.20%</td>
<td>4.60%</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>-22.80%</td>
<td>0.80%</td>
<td>-6.40%</td>
<td>-2.40%</td>
<td>4.30%</td>
</tr>
<tr>
<td></td>
<td>1000</td>
<td>-23.40%</td>
<td>13.00%</td>
<td>5.40%</td>
<td>10.70%</td>
<td>5.10%</td>
</tr>
<tr>
<td>10%</td>
<td>50</td>
<td>-36.70%</td>
<td>5.40%</td>
<td>2.60%</td>
<td>8.20%</td>
<td>6.40%</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>-39.10%</td>
<td>-0.40%</td>
<td>-3.80%</td>
<td>-0.80%</td>
<td>3.00%</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>-46.30%</td>
<td>-0.30%</td>
<td>-6.20%</td>
<td>-4.60%</td>
<td>1.80%</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>-30.90%</td>
<td>-3.00%</td>
<td>-8.80%</td>
<td>-4.80%</td>
<td>4.40%</td>
</tr>
<tr>
<td></td>
<td>1000</td>
<td>-34.65%</td>
<td>7.70%</td>
<td>3.50%</td>
<td>5.90%</td>
<td>2.30%</td>
</tr>
<tr>
<td>20%</td>
<td>50</td>
<td>-74.20%</td>
<td>2.20%</td>
<td>-0.30%</td>
<td>11.00%</td>
<td>4.20%</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>-57.70%</td>
<td>3.00%</td>
<td>0.50%</td>
<td>12.60%</td>
<td>3.10%</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>-56.80%</td>
<td>6.90%</td>
<td>4.00%</td>
<td>19.70%</td>
<td>4.70%</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>-59.00%</td>
<td>-1.00%</td>
<td>-4.00%</td>
<td>9.20%</td>
<td>2.60%</td>
</tr>
<tr>
<td></td>
<td>1000</td>
<td>-58.90%</td>
<td>11.80%</td>
<td>9.30%</td>
<td>19.20%</td>
<td>1.30%</td>
</tr>
</tbody>
</table>
Simulation – Definition 2 (Age and VCR Prob. of parent(s))

- No Visible Improvement
  - Because of Similarity between candidates
- Scalability!

<table>
<thead>
<tr>
<th>Buffer Size</th>
<th>Normalized Workload</th>
<th>Metric #1</th>
<th>Metric #2</th>
<th>Metric #3</th>
<th>Metric #4</th>
<th>Metric #5</th>
</tr>
</thead>
<tbody>
<tr>
<td>5%</td>
<td>50</td>
<td>-2.20%</td>
<td>-3.60%</td>
<td>-3.50%</td>
<td>-5.10%</td>
<td>-2.30%</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>-18.30%</td>
<td>6.80%</td>
<td>3.60%</td>
<td>3.60%</td>
<td>0.00%</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>-25.40%</td>
<td>1.60%</td>
<td>-6.90%</td>
<td>-3.70%</td>
<td>3.30%</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>-19.40%</td>
<td>0.50%</td>
<td>-5.40%</td>
<td>-3.90%</td>
<td>1.50%</td>
</tr>
<tr>
<td></td>
<td>1000</td>
<td>-27.10%</td>
<td>9.60%</td>
<td>0.70%</td>
<td>5.40%</td>
<td>4.70%</td>
</tr>
<tr>
<td>10%</td>
<td>50</td>
<td>-78.50%</td>
<td>1.50%</td>
<td>-4.20%</td>
<td>-12.50%</td>
<td>-8.60%</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>-55.20%</td>
<td>-5.10%</td>
<td>-10.10%</td>
<td>-9.80%</td>
<td>0.30%</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>-38.50%</td>
<td>-0.10%</td>
<td>-4.50%</td>
<td>-3.10%</td>
<td>1.50%</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>-29.10%</td>
<td>-0.20%</td>
<td>-3.70%</td>
<td>-2.20%</td>
<td>1.60%</td>
</tr>
<tr>
<td></td>
<td>1000</td>
<td>-36.40%</td>
<td>4.70%</td>
<td>0.40%</td>
<td>3.90%</td>
<td>3.50%</td>
</tr>
<tr>
<td>20%</td>
<td>50</td>
<td>-69.40%</td>
<td>2.40%</td>
<td>0.40%</td>
<td>2.70%</td>
<td>-3.60%</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>-65.10%</td>
<td>-0.60%</td>
<td>-3.90%</td>
<td>6.00%</td>
<td>-0.20%</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>-61.70%</td>
<td>-0.70%</td>
<td>-4.00%</td>
<td>8.90%</td>
<td>1.90%</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>-56.60%</td>
<td>-3.60%</td>
<td>-6.30%</td>
<td>2.80%</td>
<td>-0.50%</td>
</tr>
<tr>
<td></td>
<td>1000</td>
<td>-55.40%</td>
<td>11.80%</td>
<td>9.60%</td>
<td>18.30%</td>
<td>0.60%</td>
</tr>
</tbody>
</table>
Agenda

P2P Video Streaming
Continuous Playback
User Behavior
User Behavior in A Tree-Based Approach
Simulation

>>> Conclusion and Future Work
Conclusion

- **User Behavior**
  - **High Dynamics**
    - Frequent changes in network topology
  - **Effective in performance evaluation**
    - Evaluating the scalability of a specific system
  - **Effective in evaluating continuous playback**
    - This work is the first one
  - **Effective in protocol design**
    - Much balanced tree
Conclusion

- Considering current system:
  - In a typical Tree-based system
    - From continuous playback point of view
      - Worsening with increase in arrival rate
      - In low arrival rate: smaller buffer size is better
      - In moderate arrival rate (TP): No difference between buffers
      - In low arrival rate: bigger buffer size is better
    - From scalability point of view
      - DirectStream has good scalability
      - Bigger buffer sizes decrease rejection probability
Conclusion (Con’d)

- Considering future systems:
  - Trade-off between scalability and continuous playback
    - Parent selection with regard to depth, improves continuous playback
    - Parent selection with regard to age of parents, in most cases, improves continuous playback
    - Parent selection with regard to number of pauses/jumps do not provide useful improvement
Future Works

- Evaluating continuous playback in mesh-based systems
- Investigating the effect of selfish/malicious nodes on continuous playback
  - Exploiting incentive mechanism and game theory for improve in continuous playback
- Exploiting depth and age of nodes in protocol design
- More accurate use of statistical parameters
- Classification of users based on their behavior
- Developing a mathematical model for Continuous Playback
- Investigating the effect of BW
- Study of user behavior in a real P2P system
- …
Main References


