CIS-6930: Distributed Multimedia Systems

Enhancing aggregate QoS for video streaming

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Anubha
Some Key Terms

Introduction

MPEG Video Dispersion Strategies

Altruistic Routing

ALTRA – based Video Streaming

Conclusion
KEY TERMS

- **Diff –Serv** (Differentiated Service architecture by IETF)
- **MPLS** (Multi-Protocol Label Switching)
- **LSP** (Label Switched Paths)
- Ingress Node
- Egress Node
Some Key Terms

Introduction

MPEG Video Dispersion Strategies

Altruistic Routing

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Conclusion
Recent times has seen a proliferation of multimedia applications.

Hence, we need a network infrastructure that can meet the QoS requirements of the multimedia traffic.

Multimedia Traffic requirements:
Guaranteed end to end quality and high bandwidth requirement.
MPEG occupies large portion of the Internet traffic, hence, efficient transport mechanisms for MPEG traffic are crucial.

In this paper, authors propose a set of multi-path streaming models for MPEG video traffic transmission and a routing scheme to search for altruistic multiple paths in the network for aggregate video streaming.
Due to decoding dependencies, MPEG’s frames are very sensitive to packet loss/error. Thus, routing for delivering MPEG streams is important.

The approach proposed by the authors employees existing application level knowledge of the MPEG video structure

It does not requiring new video compression algorithms or additional bandwidth.
The network model assumes:

- Diff-Serv aware MPLS infrastructure
- Number of available LSPs (paths) between the ingress node and the egress node.
- Each LSP has attributes such as path delay, bandwidth, and loss rate.
- Aggregates of MPEG video streams are dispersed into several LSPs at the ingress node before it is sent to the egress node.
The network model assumes:

- Service differentiation for each packet is determined at the ingress according to the proposed dispersion models.
The network model assumes:

- MPEG video streams are composed of groups of picture (GOP).

- GOP is defined by two parameters - N and M.
  - N - distance between two I-frames. (Also the # of frames in GOP)
  - M - distance between two anchor (I or P) frames.
Each GOP consists of one I-frame \((N-M)/M\) P-frames, and \((N(M-1))/M\) B-frames.

Authors assume for simulation that a B-frame can usually fit into a single packet, each I-frame can fit into 8 packets and each P-frame can fit into 3 packets.

To measure performance of the proposed models, authors define these metrics:
average frame damage rate: 
- Number of damaged frames at the egress node divided by the total number of transmitted frames at the ingress node.

average effective frame rate:

In the following sections, if model \( m_i \) has an average effective frame rate of \( r_i \) and model \( m_j \) has an average effective frame rate of \( r_j \), then the improvement of \( m_j \) over \( m_i \) is defined as:

\[
\text{Improvement} = \frac{(r_j - r_i)}{r_i}
\]
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Authors propose five MPEG video dispersion strategies:

- **Packet-Based Dispersion**
  - Video streams are mixed and treated packet by packet.
  - This mixed sequence is dispersed into the available paths one by one.
  - Two schemes can be implemented for this strategy: round robin or weighted round robin.
(a) Round robin dispersion

(b) Weighted round robin dispersion

Fig. 3. Packet-based dispersion.
Frame - Based Dispersion

Packets belonging to a frame (I, P, or B) are transmitted as a unit along a path.

Fig. 4. Frame-based dispersion.
Individual frames belonging to a GOP might traverse different paths.

Since one lost packet will damage the frame it belongs to, this approach reduces the number of frames affected in case of a burst of packet loss.
GOP - Based Dispersion

In this model, frames belonging to a GOP are transmitted along the same path.
Since a GOP is at higher logical data block level w.r.t frame, this approach reduce damage propagation and avoids massive frame errors.

This is because, in case of burst errors over several frames it is better if all these erroneous frames belong to a single GOP rather than a different GOPs.

GOP-based model can improve quality by about 5–13% as compared to previous models.
Fig. 5. Aggregate quality improvement at Loss(0.001, 0.01, 0.1).
Stream - Based Dispersion

This model dispenses the aggregate traffic based on individual streams.
Since a sequence/stream is the largest MPEG video object, this model has a higher error resistant capability than all previous models.

In the previous graph, we noted that the stream based and GOP Based dispersion strategies have very similar performance.

The quality improvement is no more than 2%, because frame damage has low probability of being carried over to other GOPs’ frames.
The stream-based dispersion has the disadvantage of unbalanced stream quality.

As, we saw in the graph, all other models have a negligible unbalanced performance, the stream-based model has a very high performance variance.

Hence, GOP based dispersion is better approach than the stream based model because although it has a very similar performance without the above disadvantages of unbalanced stream quality.
Priority - Based Dispersion

In this approach, MPEG stream is dispersed based on relative importance of the frames.
In MPEG’s encoding algorithm, I-frames are the most important and B-frames are the least important frames.

But, not all P-frames are of equal importance. Within a GOP, errors in the nth P-frame will propagate to the (n+1)th P-frame. Hence, the nth P-frame is more important than the (n+1)th P-frame.

Hence, authors define the priorities in a GOP as:
Comparison of Dispersion Strategies

MPEG Dispersion - Loss/Damage Effect

Average frame damage rate vs. Error burst

Fig. 10. Average frame damage rate, with Loss(0.001, 0.01, 0.1).
Comparison of Dispersion Strategies

MPEG Dispersion - Loss/Damage Effect

Fig. 11. Average frame damage rate, with Loss(0.03, 0.03, 0.03).
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Altruistic Routing

Why Altruistic Routing is Needed?

Many proposed QoS routing algorithms consume resources more than necessary.

An over-committing network resource increases the possibility of blocking future requests.

ALTRA
A sample Network

\(d: \text{Delay}; w: \text{Bandwidth}\)
A Sample Network

Paths

<table>
<thead>
<tr>
<th>Path</th>
<th>d</th>
<th>w</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-&gt;3-&gt;2-&gt;0</td>
<td>37</td>
<td>4</td>
</tr>
<tr>
<td>4-&gt;3-&gt;2-&gt;1-&gt;0</td>
<td>37</td>
<td>6</td>
</tr>
<tr>
<td>4-&gt;5-&gt;3-&gt;2-&gt;0</td>
<td>34</td>
<td>3</td>
</tr>
<tr>
<td>4-&gt;5-&gt;3-&gt;2-&gt;1-&gt;0</td>
<td>34</td>
<td>3</td>
</tr>
<tr>
<td>4-&gt;5-&gt;6-&gt;7-&gt;0</td>
<td>37</td>
<td>3</td>
</tr>
<tr>
<td>4-&gt;5-&gt;7-&gt;0</td>
<td>38</td>
<td>3</td>
</tr>
</tbody>
</table>
Key terms

- Dijkstra's Algorithm
- Shortest-Widest Algorithm
- Widest-Shortest Algorithm
- Delay-favored algorithm
- Bandwidth-favored algorithm
A Sample Network

- R(D=37; W=4)
- Delay <= 37
- Bandwidth >= 4
- Paths retrieved by Dijkstra’s Algorithm by
  - Paths
  - 4->5->3->2->0
  - 4->5->3->2->1->0
  - d w
    - 34 3
    - 34 3
Drawback of 1-metric routing algorithms

- The conventional algorithm, such as Dijkstra’s Algorithm serve their purposes well if the application requires only one metric to be met.

- But, most multimedia applications need to be satisfied with multiple-constraints.
2-metric routing example with unbalanced commitment of resources

- Request R1(D=40, W=2)
- Followed by the Request R2(D=34, W=3)
- Widest-Shortest delay Algorithm would assign following paths to R1

<table>
<thead>
<tr>
<th>Paths</th>
<th>d</th>
<th>w</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-&gt;5-&gt;3-&gt;2-&gt;0</td>
<td>34</td>
<td>3</td>
</tr>
<tr>
<td>4-&gt;5-&gt;3-&gt;2-&gt;1-&gt;0</td>
<td>34</td>
<td>3</td>
</tr>
</tbody>
</table>
Parameters left for R2(D=34, W=3)

<table>
<thead>
<tr>
<th>Paths</th>
<th>d</th>
<th>w</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-&gt;3-&gt;2-&gt;0</td>
<td>37</td>
<td>4     : d&gt;D</td>
<td></td>
</tr>
<tr>
<td>4-&gt;3-&gt;2-&gt;1-&gt;0</td>
<td>37</td>
<td>6     : d&gt;D</td>
<td></td>
</tr>
<tr>
<td>4-&gt;5-&gt;3-&gt;2-&gt;0</td>
<td>34</td>
<td>1     : w&lt;W</td>
<td></td>
</tr>
<tr>
<td>4-&gt;5-&gt;3-&gt;2-&gt;1-&gt;0</td>
<td>34</td>
<td>1     : w&lt;W</td>
<td></td>
</tr>
<tr>
<td>4-&gt;5-&gt;6-&gt;7-&gt;0</td>
<td>37</td>
<td>1     : w&lt;W</td>
<td></td>
</tr>
<tr>
<td>4-&gt;5-&gt;7-&gt;0</td>
<td>38</td>
<td>1     : w&lt;W</td>
<td></td>
</tr>
</tbody>
</table>

Path computation for R2 would FAIL.
Solution: Altruistic Routing

A strategy that selects a routing path which is acceptable, if not necessarily the best, with respect to the users QoS’s requirements.

Advantages

- Network utilization is increased.
- Load is more evenly balanced.
- Congestion becomes less likely
ALTRA-2 algorithm

\begin{algorithm}
1 \( \mathcal{P}_0 \leftarrow \text{find\_all\_qualified\_paths}(\ ) \)
2 \hspace{1em} \textbf{while} (|\mathcal{P}_0| > 0) \{ \\
3 \hspace{2em} \text{if} (\text{in\_favor\_of\_delay}) \\
4 \hspace{3em} p \leftarrow \text{narrowest\_shortest}(\mathcal{P}_0) \\
5 \hspace{2em} \text{else if} (\text{in\_favor\_of\_bandwidth}) \\
6 \hspace{3em} p \leftarrow \text{shortest\_narrowest}(\mathcal{P}_0) \\
7 \hspace{2em} l \leftarrow \text{critical\_link}(p) \\
8 \mathcal{P}_1 \leftarrow \mathcal{P}_0 \\
9 \mathcal{P}_0 \leftarrow \forall p_i \in \mathcal{P}_0 \text{ and } l \notin p_i \\
10 \}
11 \text{output } \mathcal{P}_1
\end{algorithm}
ALTRA-2 algorithm

1. \( \mathcal{P}_0 \leftarrow \text{find_all_qualified_paths()} \)
2. while \( |\mathcal{P}_0| > 0 \) {
3.     if (in\_favor\_of\_delay)
4.         \( p \leftarrow \text{narrowest_shortest}(\mathcal{P}_0) \)
5.     else if (in\_favor\_of\_bandwidth)
6.         \( p \leftarrow \text{shortest_narrowest}(\mathcal{P}_0) \)
7.     \( l \leftarrow \text{critical\_link}(p) \)
8. \( \mathcal{P}_1 \leftarrow \mathcal{P}_0 \)
9. \( \mathcal{P}_0 \leftarrow \forall p_i \in \mathcal{P}_0 \text{ and } l \notin p_i \)
10. }
11. output \( \mathcal{P}_1 \)

// In line 4, for delay-favored algorithm, Path# 3 would be chosen

// In line 7, critical\_link is found to be link (4,5)

// In line 8, path set is saved

// In line 9, paths are removed containing critical\_link
A Sample Network

Paths

<table>
<thead>
<tr>
<th>Path</th>
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ALTRA-2 algorithm

// In line 4, for delay-favored algorithm, Path# 3 would be chosen

// In line 7, critical_link is found to be link (4,5)

// In line 8, path set is saved

// In line 9, paths are removed containing critical_link
## Result by ALTRA-2

<table>
<thead>
<tr>
<th>Run</th>
<th>$P_0$ after step 2</th>
<th>$p$</th>
<th>$l$</th>
<th>$P_1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>{1,2,3,4,5}</td>
<td>3</td>
<td>(4,5)</td>
<td>{1,2,3,4,5}</td>
</tr>
<tr>
<td>2</td>
<td>{1,2}</td>
<td>1</td>
<td>(2,0)</td>
<td>{1,2}</td>
</tr>
<tr>
<td>3</td>
<td>{2}</td>
<td>2</td>
<td>(2,1)</td>
<td>{2}</td>
</tr>
</tbody>
</table>
Simulation Model

- Node #
- Link #
- Random numbers
- Topology generator
- Request generator
- Bandwidth adjustment
- Routing engines
- Path(s)
Simulation Model

1. **Topology generator** -> Include parameters \( N(\text{nodes}), L(\text{links}) \), and a random number seed. Network topologies are randomly generated.

2. **Request Generator** -> Carries request requirements; Maximum delay, minimum bandwidth & maximum loss rate.

3. **Routing Engine** -> Searches a path on the network topology. Connection denial if no path is qualified.
Simulation Results

- The concepts of hot spots represent the popularity of servers.

- In this simulation, a parameter is assigned to a node to represent its popularity.

- The definition of hot spot can be symmetric.

- In this simulation, source or destination based hot spots will exhibit similar behavior.
Examples of 50% hot spots

(a) An example of destination-based hot spot
(b) An example of source-based hot spot
Simulation Results

- The performance measurement for this simulation model is Average Request blocking Ratio.

- Improvement of ALTRA-2 algorithm compared to Widest-shortest delay algorithm.

- i.e. Compare BR_{altra-2} and BR_{wsd}.
Simulation Results

100% Hot Spot

Percentage

Blocking effect on 100% hot spot.
Simulation Results

Average Blocking Performance

Blocking effect with various hot spot percentages.
ALTRA-k algorithm

ALTRA-k algorithm

0. input \( k \) metrics \((m_1, \ldots, m_k)\)
1. \( P_0 \leftarrow \text{find\_all\_qualified\_paths()}\)
2. while \(|P_0| > 0\) {
   3. \( p \leftarrow \mathcal{F}_{m_k}(\mathcal{F}_{m_{k-1}}(\cdots(\mathcal{F}_{m_1}(P_0))\cdots)\)
   4. \( l \leftarrow \text{critical\_link}(p)\)
   5. \( P_1 \leftarrow P_0\)
   6. \( P_0 \leftarrow \forall p_i \in P_0 \text{ and } l \notin p_i\)
3. } \)
8. output \( P_1 \)

\( \mathcal{F}_{\text{delay}} = \text{shortest}(\cdots), \mathcal{F}_{\text{bandwidth}} = \text{narrowest}(\cdots) \), \( \mathcal{F}_{\text{reliability}} = \text{most\_reliable}(\cdots)\).
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Authors investigate the performance obtained by applying ALTRA routing to the proposed dispersion models.

Frame type Based Dispersion

Authors simplify the priority-based strategy by limiting the frame priority assignment to only three levels: one for I-frames, one for P-frames, and one for B-frames. Hence, frame-type based model.
ALTRA – based Video Streaming(2)

- This dispersion strategy introduces the following impacts on QoS requirements:
  - Bandwidth
    - The bandwidth requirement can be decomposed into three smaller requirements.
    - The relative bandwidth requirement for three sub-streams is:

\[
R_1 : R_p : R_B = S_1 : \frac{S_P(N - M)}{M} : \frac{S_B N(M - 1)}{M}
\]
Reliability

- I-frames can be decoded independently.
- P-frames needs the previous I-frames, and B-frames need previous and future I- and P-frames for decoding.

Thus, high-quality delivery of the I-frames can prevent a cascading damage effect on the P- and B-frames.
ALTRA – based Video Streaming

- System should select a channel with higher reliability for I-sub-streams
- System can choose a less reliable channel for B-sub-streams.
Delay

Timely and Synchronized arrival of I, P and B frames is important for the displaying an MPEG video

Dispersion based on frame types generates paths which have strong inter-path delay dependencies.

Authors illustrate that all the corresponding QoS Requirements are fulfilled.
**Performance Blocking Ratio Improvement**

**Blocking Ratio** =
\[
\frac{\text{failed requests}}{\text{total requests that arrive}}
\]

**Characteristics of Simulation System:**

1. \(n\) disjoint data channels; \(m\) arriving requests at a given time

2. \((d_i = 1 <= i <= n) \& (D_i = 1 <= i <= m)\) are distributed among \(n\).

\[
\min(D_i) \geq \min(d_i) \& 0 < d(i+1) - d_i \leq T_{frame}
\]
3. Each data channel has \((R_i + R_p + R_b)\) – unit bandwidth capacity and is randomly assigned a reliability level, either \(r_1, r_2, r_3\).

- Now set \(m=n\); without altruistic routing concept, make a baseline.
- Analyze the performance of three systems
## Performance Blocking Ratio Improvement

### MPEG dispersion bandwidth ratio

<table>
<thead>
<tr>
<th>MPEG $(N,M)$</th>
<th>GOP</th>
<th>Dispersion $(R_I, R_P, R_B)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>(15,3)</td>
<td>IBBPBBPBBPBBPBBPBB</td>
<td>(4,6,5)</td>
</tr>
<tr>
<td>(9,3)</td>
<td>IBBPBBPBBPBBPBB</td>
<td>(4,3,3)</td>
</tr>
<tr>
<td>(6,2)</td>
<td>IBPBPPB</td>
<td>(8,6,3)</td>
</tr>
</tbody>
</table>
Performance Blocking Ratio Improvement

![Graph showing blocking ratio improvement with respect to the number of data channels. The graph includes curves for different channel configurations: (4,6,5), (4,3,3), and (8,6,3).]
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Conclusion

- The performance of various MPEG models have been compared model by model.
- GOP and priority based models are the best.
- GOP based approach outperforms the priority-based approach when the variation of network link loss rate is small.
Conclusion

- When small links demonstrate, priority based models outperforms.
- ALTRA algorithms were proposed to effectively implement the altruistic routing.
- The analysis provides guidelines for designing live-video streaming and routing system when traffic dispersion is employed.
Positives And Negatives

Positives

– Author’s approach doesn’t require new video compression algorithms or additional bandwidth.

– Author’s proposed dispersion strategies choose paths on network metrics, so sharing of links and nodes does not matter.

Negatives

– Approach assumes presence of Diff-Serve aware MPLS networks.

– The relative priority within P frames is not considered in the final analysis.
Thank You

Your Questions