Why Are You Still Using Shortest Path?
- Path Selection Strategy Utilizing High-functional Nodes -

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Introduction

- Live streaming media
  - Delay-sensitive, Allowable delay

- Path selection for live streaming
  - Unicast - Shortest Path
  - Multicast
    - Shortest Path Tree (SPT)
    - Minimum Spanning Tree (MST)
  - Multicast Tree Reconfiguration
    - Shortest Path as alternative path

Is Shortest path selection really efficient?
What's Multicast Tree Reconfiguration?

- Avoid bottleneck link
- Set alternative path
- Reconfigure part of multicast tree

Generally, shortest path is selected as an alternate path.

Recover and maintain QoS of end receiver.
Problem on Networks with High-functional Nodes

- High-functional node
  - Special capability to maintain performance of application

Which Path Is Better to maintain higher QoS against traffic variation?
Path Selection Utilizing High-functional Nodes

- On network with high-functional nodes
  - Application QoS varies depending on the number of high-functional nodes and their location on the path

Shortest path is not always most appropriate due to lack of high-functional nodes

It doesn’t matter which path is taken as long as application QoS is sufficient

We should select a path that can utilize high-functional nodes
QMLLS Router as High-functional Node

- QoS Multicast for Live Streaming (QMLLS) Protocol
- QMLLS router (relay node) partly placed on path
  - Loss detection, Retransmission

Reduce retransmission delay
Reduce end-to-end delay

Maintain application QoS reducing end-to-end total loss

Packets lost on path
Packet exceeding allowable delay

sender
QMLLS router
buffer
Retransmission
NACK
QMLLS router
buffer
Normal node
QMLLS router
receiver
Path Selection Strategy (1/2)

1. Delay
   - As short as possible (comparable to shortest path)

2. Allowable delay
   - **Remaining time** against allowable delay -
   - As long as possible (for future retransmission delay)

\[ \text{Remaining time} \quad \left( D - d \right) \text{ [ms]} \]
Path Selection Strategy (2/2)

3. Number of relay nodes
   - As many as possible

4. Distance between two adjacent relay nodes
   - As short as possible

Greater potential to maintain application QoS despite packet loss

The shorter each distance is, the shorter retransmission delay becomes
Path Selection Method 1: PSDR*

- Path Selection considering strategies 1, 2 and 3
- Each candidate path is evaluated using evaluation function

\[ EV = r \left( D - d \right) \]

- Number of relay nodes \( r \): Larger \( r \) is preferable (strategy 3)
- Delay on path \( d \): Smaller \( d \) is preferable (strategy 1)
- Remaining time \( (D - d) \): Larger \( (D - d) \) is preferable (strategy 2)

Select path which has max value for \( EV \) for reconfiguration

* Path Selection considering Delay and Relay nodes
Path Selection Method2 PSDR-DP*

- Path Selection considering strategy 4, in addition to PSDR
- Eliminate any candidate paths with extremely long delay link first

**Path Elimination Inequality**

\[ l_{k \text{max}} < L_{\text{max}} \times \alpha \]

**Evaluation function for PSDR**

\[ EV = r(D - d) \]

\( \alpha \): Parameter for adjusting the number of eliminated candidates
(0 \( \leq \alpha \leq 1.0 \))

**Symbols**

- \( L_{\text{max}} \): Max delay link on shortest path
- \( l_{\text{max}} \): Max delay link on each candidate path

*PSDR with a limited Distance between relay nodes using Parameters
Path Selection Method 3: PSDR-RP*

- Path Selection considering strategy 4, in addition to PSDR
- Eliminate any unsuitable path with extremely long delay link first
  - consider relationship between retransmission on $l_{\text{max}}$ and remaining time

Path Elimination Inequality

$$l_{k\text{ max}} < (D - d) \times \beta$$

Evaluation Function for PSDR

$$EV = r(D - d)$$

\[\begin{align*}
\beta &: \text{Parameter for adjusting the number of eliminated candidates } (0 \leq \beta \leq 1.0) \\
D &: \text{end-end Allowable delay} \\
d &: \text{end-end delay of candidate path} \\
l_{\text{max}} &: \text{max delay link of candidate path}
\end{align*}\]

*PSDR with limitations on the Retransmission delay using Parameters
## Proposed three path selection methods

<table>
<thead>
<tr>
<th>Path elimination inequality</th>
<th>PSDR</th>
<th>PSDR-DP</th>
<th>PSDR-RP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n/a</td>
<td>$l_{max} &lt; \alpha L_{max}$</td>
<td>$l_{max} &lt; \beta (D - d)$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Path selection function</th>
<th>$EV = r (D - d)$</th>
<th>$EV = r (D - d)$ (applied to remaining candidates)</th>
<th>$EV = r (D - d)$ (applied to remaining candidates)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Path selection strategy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>delay</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Allowable delay</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>No. of relay nodes</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Location of Relay nodes</td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
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Evaluations -simulation conditions-

- Proposed vs. shortest path tree (SPT) reconfiguration
- 100 random network topologies with 60 nodes
  - Assume a link with max delay as a bottleneck -> Reconfigure
  - Evaluate receiver of reconfigured path in disjoint tree
- Simulation conditions
  - Packet drop rate at each node is varied randomly as traffic variation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBR rate</td>
<td>500 kbps</td>
</tr>
<tr>
<td>Packet size</td>
<td>200 byte</td>
</tr>
<tr>
<td>Allowable delay ($D$)</td>
<td>100 ms</td>
</tr>
<tr>
<td>Link bandwidth</td>
<td>10 Mbps</td>
</tr>
<tr>
<td>Delay on the link</td>
<td>1 - 30 ms</td>
</tr>
<tr>
<td>Random loss rate at node</td>
<td>0 - 0.1</td>
</tr>
</tbody>
</table>
End-to-end total loss rate on receiver

End-to-end loss rate using SPT and PSDR

Differences in loss rates compared to SPT
(loss of PSDR) – (loss of SPT)

*The orders of network topologies on X-axis in both graphs are the same
Reduction in loss rate

- Differences in loss rate compared to SPT

(loss rate for each proposed method) – (loss rate for SPT) on each topology

Proposed path selection can select paths that reduce end-to-end loss rate better than SPT
Strategy Satisfied - Delay on Path (strategies 1, 2)

- Fraction of delay on selected path
  - (delay by proposed method) / (delay by SPT)

Proposed path selection can select paths with slightly larger or comparable delay to SPT.

Small delay within allowable delay for live streaming media.
Strategy Satisfied - No. of High-functional Nodes (strategy3)

- Fraction of no. of high-functional nodes on selected path
  - (no. of high-functional nodes of proposed) / (those of SPT)

- Proposed path selection can select paths with more high-functional nodes than SPT

Immediate loss detection and recovery to maintain application QoS
Strategy Satisfied - Distance between high-functional nodes

- Fraction of max distance on selected path

  - $\frac{l_{\text{max}}}{L_{\text{max}}}$

PSDR, PSDR-DP ($\alpha = 0.7$), and PSDR-RP ($\beta = 0.45$) can avoid paths with large distance between relay nodes.

Reduce retransmission delay between each relay nodes.
Conclusion

- Path selection strategy considering high-functional nodes
- Path selection method (PSDR, PSDR-DP and PSDR-RP)
- Proposed path selections utilize high-functional nodes and maintain required application QoS better than shortest path method

Proposed path selection methods can reconfigure multicast tree so that it has tolerance to traffic variations
Future Works

- Apply our method to a model with both high-functional node and normal node
- Apply our methods to ALM (Application Level Multicast)
- Look into the complexity of proposed approach vs. shortest
- Discuss bottleneck link