A Hidden Markov Model Approach to Available Bandwidth Estimation and Monitoring
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**Available Bandwidth**
Available bandwidth is the non-utilized capacity in a path: \( AB = \text{Capacity} \times [1-\text{Utilization}] \)

Estimation of the available bandwidth could be used in network management, transport layer and routing protocols, overlay networks, traffic engineering, call admission control, and other network applications.

**Problem Statement**
Current available bandwidth estimation techniques cannot be used in every network application needing the estimation due to long estimation times, accuracy errors, and large overhead that they introduce. Reducing estimation time while maintaining accuracy and low intrusion is an open question to researchers.

**Approach**
Hidden Markov Model combined with a moving average technique can be applied to estimate the available bandwidth of an end-to-end path in a fast, accurate, and non intrusive manner. This novel approach is implemented in a software tool called Traceband which is evaluated in a real network that emulates Internet traffic.

**Testbed**

**Results**

<table>
<thead>
<tr>
<th>Tool</th>
<th>Error &amp; Moving Average with</th>
<th>Error &amp; Moving Average without</th>
<th>Estimations per minute</th>
<th>Overhead</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pathload</td>
<td>6.71%± 1.17%</td>
<td>4.88%± 2.13%</td>
<td>1.754 ± 0.066</td>
<td>6.57%± 0.20%</td>
</tr>
<tr>
<td>Spruce</td>
<td>7.77%± 0.98%</td>
<td>3.84%± 1.92%</td>
<td>5.579 ± 0.059</td>
<td>1.41%± 0.02%</td>
</tr>
<tr>
<td>Traceband</td>
<td>8.83%± 0.43%</td>
<td>2.93%± 1.42%</td>
<td>11.645 ± 0.132</td>
<td>1.96%± 0.03%</td>
</tr>
</tbody>
</table>

Traceband is as accurate as Spruce and Pathload but considerably faster, and introduce less overhead. Traceband’s convergence time is demonstrated using bursty cross-traffic, as it is the only tool that accurately reacts to zero-traffic periods.