Preliminary Performance Evaluation of Admission Control in Load Control Pre-Congestion Notification (LC-PCN)

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ABSTRACT
The Differentiated Service (DS) framework has been developed by the Internet Engineering Taskforce (IETF) to provide Quality of Service (QoS) on the Internet. Load Control Pre-Congestion Notification (LC-PCN) is a measurement based DiffServ implementation that uses Admission Control and Flow Termination to control the load in a domain. In this paper a preliminary performance evaluation of Admission Control in LC-PCN is presented. The Admission Control algorithm performs well. It is accurate and prevents packet loss in admitted flows.

Keywords
QoS, DiffServ, Performance Evaluation, Admission Control, PCN, Load Control

1. INTRODUCTION
Quality of Service (QoS) is needed in networks for streaming data in applications such as Voice over IP (VoIP). This means that a certain minimum bandwidth and maximum delays and drop rates can be guaranteed by the network provider for a certain flow of data. The Internet Engineering Task Force (IETF) has developed the Integrated Services (IS) framework to provide QoS on the Internet [1]. In IntServ, QoS is provided by requesting a level of service on a network for individual flows or a class of flows. This is called resource reservation. In the case of resource reservation for individual data flows state information for each flow is stored in each node on the path of the flow. This limits the scalability of IntServ domains. To overcome complexity and scalability issues in IntServ, the Differentiated Services (DS) framework has been developed [2]. In a DiffServ domain interior and edge nodes in a domain have different functionality. Per-flow administration is kept at the edge nodes and only per-class administration is done at the interior nodes (see Figure 1).

In particular, the interior nodes only keep traffic class states. Flows are grouped in classes based on the DiffServ Codepoint (DSCP) field carried in the packet header and are treated according to the Per-Hop Behavior (PHB) for that DSCP. This makes DiffServ more scalable than IntServ. IntServ, however, offers more accurate QoS support. In [3] it is discussed if a balance can be found between scalability and accuracy. A combination of the IntServ and DiffServ approaches is seen as a promising solution in both [4] and [3]. A framework for providing IntServ over DiffServ has been described in [5]. If IntServ over DiffServ is used the Resource Reservation Protocol (RSVP) can be used for end-to-end IntServ reservations, while parts of the underlying network use DiffServ for scalable QoS.

Resource management in DiffServ domains can be done by Admission Control and severe congestion handling (or Flow Termination). The Admission Control mechanism deals with incoming resource reservation requests. Flow Termination deals with overload situations, such that the load is reduced and packet loss in admitted flows is kept to a minimum.

Several implementations of resource management in the DiffServ architecture have been proposed.

In [6] the Resource Management in DiffServ (RMD) framework is presented that provides resource reservation in DiffServ domains. In [7] RMD is described and its performance is compared to the performance of RSVP. In [8] and [9] a QoS model based on RMD (RMD-QOSM) is described that includes Admission Control and Flow Termination. The performance of severe congestion handling algorithms has been evaluated in [10] and [11].

Recently the Congestion and Pre-Congestion Notification Working Group (PCN-WG) of the IETF is working on specifying additional QoS features, such as Admission Control and Flow Termination, which can be applied in DiffServ regions.

The Pre-Congestion Notification (PCN) architecture is described in [12]. PCN uses marking of packets to distribute information about (pre)congestion in a DiffServ domain. In a PCN-enabled DiffServ domain there are PCN-enabled interior routers that are configured with a predefined admission-rate and a pre-emption-rate. If the admission-rate is exceeded packets are marked with “admission marking” so that the edge routers can detect early that a link is getting lightly congested and that it might be needed to reject new flows. If the pre-emption-rate is exceeded no new flows are admitted and existing flows may be pre-empted. The
pre-emption-rate is higher than the admission-rate and both values are typically lower than the physical link rate. The pre-emption-rate prevents that too many flows are admitted. When too many flows are admitted the network can become overloaded, thus causing packet loss and other decrease in QoS in admitted flows. Because admission is based on packet marking the sudden increase of load is not immediately noticed, which might cause that too many flows are admitted at once, which together can cause an overload. The admission-rate provides a safety buffer for dealing with such situations.

The Admission Control and Flow Termination features are based on PCN egress measurements of the received marked packet rates. As mentioned previously, the marking of the packets is accomplished at the PCN interior nodes. Based on the measurements new flows can be admitted or rejected and existing flows might be terminated if a link in the domain is pre-congested. Admission Control is done under normal operation circumstances, while Flow Termination is expected to be needed only in exceptional cases.

Several solutions have been proposed within the IETF PCN-WG for the support of the Admission Control and Flow Termination features, such as the ones specified in [13], [14], [15], [16], [17], and [18].

Performance of Admission Control functions in DiffServ is important for keeping delays low and link utilization high. For keeping delays low it is important that the Admission Control algorithm is fast. For a high link utilization it is important that the Admission Control algorithm does not deny incoming requests if not necessary. This means the algorithm should be accurate.

No performance evaluation has been done for Admission Control in Load Control PCN (LC-PCN) [18]. In this paper a preliminary evaluation of the performance of the proposed Admission Control functions in LC-PCN is presented.

The main research question that is answered by this paper is:

- How is the Admission Control algorithm in LC-PCN performing?

Subquestions are:

1. What is LC-PCN and how does it function?
2. What is the goal of Admission Control in DiffServ domains?
3. What are criteria for evaluating the performance of the Admission Control algorithm?
4. What are performance measures for evaluating these criteria?
5. How does the algorithm perform in terms of these criteria?

The first four questions are answered by studying the literature on DiffServ, LC-PCN and performance criteria. The fifth question is answered by doing simulation experiments in ns-2 [19]. The ns-2 simulation environment is chosen due to the following reasons. The ns-2 simulation environment is largely used by the IETF community. Moreover, this research activity will use as much as possible ns-2 simulation models that were developed in previous research activities, see [10], [11], [20], and [21].

Figure 2: States of operation in LC-PCN. Each node starts in the PCN normal state. Transitions between states are based on the number of marked packets that is measured.

The paper is outlined as follows. In Section 2 LC-PCN is described. In Section 3 performance criteria and measurements for Admission Control in DiffServ are defined. In Section 4 the simulation experiments and measurements are described. In Section 5 the results of the experiments are presented. In Section 6 conclusions are presented and recommendations are given for future work.

2. LC-PCN AND ADMISSION CONTROL IN DIFFSERV

Load Control PCN (LC-PCN), see [18], is a solution that specifies algorithms that could be used to support the PCN Admission Control and Flow Termination features.

In LC-PCN packets can be marked using a PCN_Marking DSCP and a PCN_Affected DSCP encoding. The first is mainly used to trigger Admission Control, the latter is used to trigger Flow Termination. Note however, that the PCN_Marking DSCP encoding scheme is used in both the Admission Control and Flow Termination features.

The Ingress and egress nodes maintain reservation states for each flow (based on source address, source port, target address, target port and protocol name). Interior nodes provide a per traffic class (per PHB) classification and forwarding behavior. The following description of the behavior of the nodes is per PHB.

Each interior node can (for each PHB) operate in three PCN states, Normal, Admission Control and Flow Termination. In Figure 2 the transitions between the states are shown. Each node starts in the PCN Normal state.

The nodes are configured with a predefined Termination offset rate \( r_{AO} \) and Admission offset rate \( r_{AO} \). From this, two boundary rates, the PCN upper rate \( r_{\text{upper}} \) and the PCN lower rate \( r_{\text{lower}} \), are calculated:

\[
\begin{align*}
    r_{\text{upper}} & = \text{Maximum PHB capacity} - r_{AO} \\
    r_{\text{lower}} & = r_{\text{upper}} - r_{AO}
\end{align*}
\]

The interior node measures the number of bytes of all incoming packets and the number of bytes of incoming marked packets during an interval \( T \). The rate of received bytes is calculated:

\[
    r_{\text{incoming}} = \frac{\text{incoming bytes}}{T}
\]

When \( r_{\text{incoming}} \) exceeds \( r_{\text{lower}} \), event A is triggered and the
algorithm is in Admission Control state (see Figure 2). If the rate\textsubscript{upper} is exceeded event B is triggered and the algorithm enters the Flow Termination state. Event C occurs when rate\textsubscript{incoming} has dropped below rate\textsubscript{lower} and event D when rate\textsubscript{incoming} has dropped below rate\textsubscript{upper}.

When operating in PCN Admission Control state a number of packets is marked with PCN\_Marking encoding. When operating in PCN Flow Termination state a number of packets is marked according to the excess rate measured by the PCN interior node. A multiplier \( N \geq 1 \) can be set to alter the sensitivity of the algorithm. All the packets belonging to the same PHB that are passing through the PCN interior node and do not have to be remarked using the PCN\_Marking encoding, will have to be remarked using the PCN\_Affected encoding.

The number of packets that is remarked in PCN Admission Control state using the PCN\_Marking encoding calculated using Equation 1.

\[
\text{bytes to mark} = \begin{cases} 
(rate_{\text{overload}} - rate_{\text{incoming}\_\text{marking}}) \cdot T / N, \\
0, \\
\text{if rate}_{\text{incoming}\_\text{marking}} = 0 \\
\text{or rate}_{\text{incoming}\_\text{marked}} \leq rate_{\text{FAO}} \\
\text{otherwise} 
\end{cases}
\]

Where the overload rate

\[
rate_{\text{overload}} = rate_{\text{incoming}} - rate_{\text{lower}}
\]

and the incoming marking rate

\[
rate_{\text{incoming}\_\text{marking}} = \text{marked received bytes} \cdot N / T
\]

The number of packets that is remarked in PCN Flow Termination state using the PCN\_marking encoding is calculated using Equation 2. For Flow Termination a sliding window is used to prevent that the algorithm triggers Flow Termination at the egress node each interval until the overload is resolved. Because of the delay between the detection of an overload and the overload being resolved during \( T \) times the size of the sliding window only packets that exceed the PCN upper rate plus the sum of the contents of the sliding window are marked. After each interval the sliding window is updated.

\[
\text{bytes to mark} = \begin{cases} 
(rate_{\text{overload}} - rate_{\text{incoming}\_\text{marking}}) \cdot T / N, \\
0, \\
\text{if rate}_{\text{incoming}\_\text{marking}} = 0 \\
\text{or rate}_{\text{incoming}\_\text{marked}} \leq rate_{\text{TO}} \\
(rate_{\text{overload}} - rate_{\text{TO}}) \cdot T / N, \\
\text{otherwise} 
\end{cases}
\]

where

\[
rate_{\text{overload}} = rate_{\text{incoming}} - rate_{\text{upper}} - \sum_{i=1}^{n} \text{sliding window}_i
\]

\[
rate_{\text{incoming}\_\text{marking}} = \text{marked received bytes} \cdot N / T
\]

At the egress nodes the marked packets are counted. rate\textsubscript{incoming\_marked} is calculated as in the interior nodes. The egress router has two predefined rates, the PCN lower rate egress rate\textsubscript{lower\_egress} and the PCN upper rate egress rate\textsubscript{upper\_egress}:

\[
\begin{align*}
rate_{\text{lower\_egress}} &= A \cdot rate_{\text{FAO}} \\
rate_{\text{upper\_egress}} &= rate_{\text{lower\_egress}} + F \cdot rate_{\text{FAO}} \pm \text{error}
\end{align*}
\]

where \( 0 < A < 1 \) (typically \( A \) is around 1%), \( 1 \geq F > A \), and error is the multicongestion error.

When in Flow Termination state the egress node will signal to the ingress node which flows should be terminated.

Admission Control is done by probing. When a new flow is offered to the ingress node a probe packet (a data packet with IP Router Alert option set) will be sent that has the same headers as a normal packet for that flow would have, to ensure that the packet follows the same route as packets of the new flow. In this paper it is considered that when the interior node operates in Admission Control state then the probe packet is marked. When the probe packet arrives at the egress node the egress node determines if the new flow should be admitted.

When the probe packet is PCN\_marked the flow is rejected. Otherwise the flow is admitted. The decision of the egress router is signalled to the ingress router, which informs the sender of the request (see Figure 4).

Different Flow Termination behavior is defined for unidirectional and bidirectional flows. In this paper only unidirectional flows are considered.

Different priorities can be used for the flows. When flows are terminated, the flows with the lowest priority will be terminated before flows with a higher priority. This way high priority flows, such as emergency calls, are less likely to be terminated and more likely to be admitted. In this paper only one priority level will be used.

3. PERFORMANCE CRITERIA AND MEASURES FOR ADMISSION CONTROL

3.1 Performance Criteria

In this section the performance criteria are defined. Measures for these criteria are given in Section 3.2.

Performance criteria for QoS have been developed by the Telecommunication Standardization Sector (ITU-T) [22]. A framework for describing and measuring QoS is given in [23]. Performance parameters for audio and video applications and recommended values can be found in [24]. Different types of application are distinguished that require different QoS demand in terms of loss and delay. For VoIP applications a delay lower than 150 ms and a delay variation (jitter) of less than 1 ms are preferred and an information loss ratio of less than 3% is considered acceptable. For videophone applications the same demands hold, accept for the loss rate that should be lower than 1%. The delay variation can be dealt with using a de-jitterizing buffer. The higher the varia-
Flow Request

(a) Admitted flow

Flow Request

(b) Rejected flow

Figure 4: Admission Control in LC-PCN using probe packets. When a flow request arrives at the ingress node a probe packet is sent. If the probe packet arrives unmarked at the egress node a Flow Admitted message is signalled to the ingress node (a). If a marked probe packet arrives at the egress node, e.g. when a link on the path is precongested, a Flow Rejected message is signalled to the ingress node (b).

Figure 5: Flow Termination in LC-PCN. If packets with PCN_Affected marking are received at the egress node, it will signal the ingress node with a Flow Termination message.

For the delay to be kept low the Admission Control algorithm and the packet marking should be fast. In the case of a link failure that causes a flow to be terminated, fast Flow Termination and Admission Control algorithms can help keeping the delay caused by rerouting to a minimum.

Performance requirements differ for different classes of network traffic. Several performance criteria that are used are delay, jitter (delay variation) and loss ratio. For an Admission Control algorithm the following criteria can be considered:

- **Setup delay** The time it takes to admit or reject a requested flow.
- **End-to-end delay** The time it takes for packets of a certain flow to travel from source to destination.
- **Accuracy of Admission Control** If a flow is admitted, will this severely impact the data performance of the ongoing/admitted flows? Is a flow rejected accurately and based on accurate network measurements?
- **Blocking probability of flows** The probability that offered flows are rejected. This is related to the accuracy of the Admission Control algorithm. If the algorithm is accurate then no flows are rejected when the load of the network is lower than the PCN lower rate rate_{lower}.
- **Packet dropping probability** The probability that packets belonging to ongoing flows are dropped due to the load generated by packets belonging to a flow that has been just admitted.

Due to time constraints, only the accuracy of Admission Control, the blocking probability of flows and the packet dropping probability will be considered in this paper.

### 3.2 Performance Measures

The following performance measures are considered in this paper.

- **Total rate of the admitted calls** The number of flows that is admitted per second.
- **Flow blocking probability** The probability that a requested flow is rejected. This is calculated using Equation 3.

\[
P_B = \frac{rate_R}{rate_O}
\]  

(3)

where rate_R is the number of rejected flows, rate_O is the rate of offered flows rate_R + rate_A, where rate_A is the rate of admitted flows, and P_B is the probability that admitted flows are rejected.
Figure 6: Experiment network topology.

Let $rate_{\text{flows,lower}}$ (flows/s) be the rate of flows that corresponds to $rate_{O}$ (MBit/s). Ideally only flows should be rejected when $rate_{O}$ exceeds $rate_{\text{flows,lower}}$. The ideal line for $P_{B}$ is:

$$P_{B,\text{ideal}} = \begin{cases} 0, & \text{if } rate_{O} \leq rate_{\text{flows,lower}} \\ \frac{rate_{O} - rate_{\text{flows,lower}}}{rate_{O}}, & \text{otherwise} \end{cases}$$

Packet dropping probability

The probability that packets of admitted flows are dropped. This should be zero. The packet dropping probability is calculated using Equation 5.

$$P_{B,\text{packets}} = \frac{\#\text{packets}_B}{\#\text{packets}_O}$$

where $\#\text{packets}_B$ is the number of packets that are dropped of admitted flows, $\#\text{packets}_O$ is the number of offered packets of admitted flows and $P_{B,\text{packets}}$ is the probability that packets of admitted flows are dropped.

4. SIMULATION EXPERIMENTS

In this section the chosen simulation setup and the network topology and simulation parameters that are used are described and explained.

For the simulations ns-2 [19] has been used. Earlier simulation studies of RMD and PCN based models have been done in [10], [11], [20] and [21], which have served as examples.

For this experiment the topology in Figure 6 has been used. This simple topology is chosen, because only the throughput and dropping probability have to be measured in an Admission Control scenario. There are two 100 MBit/s duplex links and one 10 MBit/s link. In the experiment it is considered that the 10 Mbit/s link is the bottleneck, i.e. the capacity of that link determines the maximum throughput of the network. The propagation delay of links is set to 2 ms.

In the LC-PCN nodes a separate virtual queue is used for every DSCP. In the experiment only one PHB class is used for data. Another class is used for signaling packets. Because the load of the signaling packets is small enough to be neglected, the full link capacity is assigned to the data PHB. The signaling packets, however, have another DSCP and therefore use a different virtual queue and do not suffer loss caused by high loads of data flows. For each DSCP a virtual queue with size 20 is used for marked packets and a queue with size 10 is used for normal packets. For the tracing of dropped packets a LossMonitor is used.

For the experiment the following LC-PCN parameters have been used. $rate_{O}$ and $rate_{F}$ are both set to 1 Mbit/s. The lower rate $rate_{\text{lower}}$ for the 10 Mbit/s link is then 8 Mbit/s and $rate_{\text{upper}}$, 9 Mbit/s. $T$ is set to 1 s, the multiplier $N$ is set to 1, $A$ is set to 1%, $F$ is set to 1 and the multicongestion error $error$ is set to 0.

It is expected that the LC-PCN algorithms ensure that the throughput load will not exceed the lower rate of 8 Mbit/s.

Voice over IP (VoIP) telephone calls are taken as input application. Both Constant Bitrate (CBR) and Variable Bitrate (VBR) flows are used. In the first experiment series CBR flows with packets of length 60 bytes, bitrate 24 kbps and packet interval 0.020 s are generated and offered to the ingress node. These parameters are taken from [21].

In the second series VBR flows are generated that approximate G.729 VBR traffic with an On/Off Period Ratio of 0.4. The burst time is set to 1000 ms, the idle time to 1500 ms. The packet size if 60 bytes and the average rate during On periods is 9.6 kbps. These parameters are taken from [25] and [26].

In the experiment the holding time of flows was exponentially distributed with a mean of 180 s (3 minutes).

The intervals between the arrival of flows are exponentially distributed, since the flows of telephone calls can be said to be independent of each other.

For both experiments series 12 different simulations have been done with the average input load varying from 1 Mbit/s till 13 Mbit/s. For each input load 5 independent replications have been conducted. For each replication a new substream is used for random number generation.

The mean arrival interval that is required to generate these input loads can be calculated using Equation 6.

$$\text{Mean arrival interval} = \frac{\text{Mean holding time}}{\text{Flow rate}}$$

where $\text{Mean holding time}$ is the mean holding time of a flow, i.e. 180 s. $\text{Load}$ is the required generated load, that varies from 1 Mbit/s till 15 Mbit/s. $\text{Flow rate}$ is the bitrate of a single flow, i.e. 24 kbps for CBR flows and 0.4 · 9.6 kbps for VBR flows, and $\text{Mean arrival interval}$ is the mean of the interval between the arrival of two subsequent flows at the ingress node. The calculated mean interval times for the different generated loads for both the CBR experiments and the VBR experiments are in Table 1.

<table>
<thead>
<tr>
<th>Load Mbit/s</th>
<th>CBR flows/s</th>
<th>VBR flows/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>0.231</td>
<td>1.447</td>
</tr>
<tr>
<td>3.0</td>
<td>0.694</td>
<td>4.340</td>
</tr>
<tr>
<td>5.0</td>
<td>1.157</td>
<td>7.234</td>
</tr>
<tr>
<td>6.0</td>
<td>1.389</td>
<td>8.681</td>
</tr>
<tr>
<td>7.0</td>
<td>1.620</td>
<td>10.127</td>
</tr>
<tr>
<td>7.5</td>
<td>1.736</td>
<td>10.851</td>
</tr>
<tr>
<td>8.0</td>
<td>1.852</td>
<td>11.574</td>
</tr>
<tr>
<td>8.5</td>
<td>1.968</td>
<td>12.297</td>
</tr>
<tr>
<td>9.0</td>
<td>2.083</td>
<td>13.021</td>
</tr>
<tr>
<td>10.0</td>
<td>2.315</td>
<td>14.468</td>
</tr>
<tr>
<td>11.0</td>
<td>2.546</td>
<td>15.914</td>
</tr>
<tr>
<td>13.0</td>
<td>3.009</td>
<td>18.808</td>
</tr>
</tbody>
</table>
Table 2: The mean throughput of CBR flows with different input loads

<table>
<thead>
<tr>
<th>Input (flows/s)</th>
<th>Mean throughput (flows/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.244</td>
<td>0.244 ± 0.011</td>
</tr>
<tr>
<td>0.702</td>
<td>0.702 ± 0.027</td>
</tr>
<tr>
<td>1.186</td>
<td>1.186 ± 0.057</td>
</tr>
<tr>
<td>1.390</td>
<td>1.390 ± 0.075</td>
</tr>
<tr>
<td>1.620</td>
<td>1.619 ± 0.059</td>
</tr>
<tr>
<td>1.745</td>
<td>1.721 ± 0.060</td>
</tr>
<tr>
<td>1.868</td>
<td>1.772 ± 0.049</td>
</tr>
<tr>
<td>1.976</td>
<td>1.797 ± 0.025</td>
</tr>
<tr>
<td>2.102</td>
<td>1.820 ± 0.028</td>
</tr>
<tr>
<td>2.342</td>
<td>1.844 ± 0.035</td>
</tr>
<tr>
<td>2.588</td>
<td>1.838 ± 0.013</td>
</tr>
<tr>
<td>3.056</td>
<td>1.825 ± 0.036</td>
</tr>
</tbody>
</table>

5. SIMULATION RESULTS AND ANALYSIS

The results for the CBR experiments are in Table 2. The left column shows the measured input rate. The second column shows the 95% confidence interval for the measured throughput rate (the rate of admitted flows) in flows/s.

The measured rate of admitted flows and the rate of rejected flows and their confidence intervals are shown in Figure 7.

Ideally the rate of rejected flows should be 0 up to an input rate of 1.852 flows/s, which corresponds to a load of 8 MBit/s. Up to that point the number of admitted flows should be equal to the number of offered flows. From that point onwards the rate of rejected flows should be the rate of offered flows minus 1.852 flows/s and the number of admitted flows should be 1.852 flows/s. The rate of offered flows is shown in the figure as the rate of admitted flows plus the rate of rejected flows. The level of 1.852 flows/s is also shown.

The figure shows that the LC-PCN algorithms ensure that the throughput load does not exceed the 8 MBit/s boundary. It also shows that the distance between the ideal line and the measurements is small, i.e. the Admission Control algorithm is very accurate.

This is confirmed in Figure 8 that shows the measured blocking probability and the ideal line, which is described in Section 3.2. The blocking probability should be 0 up to rate_{lower,flows} = 1.852 flows/s. From that point it should be the rate of offered flows minus 1.852 flows/s divided by the rate of offered flows (the dotted line in the figure). The measurements (the dashed line) are close to the ideal line. The blocking of flows starts a bit earlier than expected, which can be explained by variations in the rate of offered flows. Because the interval between flows being offered is randomized, even with an average of 1.852 flows/s, somewhere during the simulation the rate could be higher than the PCN lower rate, thus causing blocking of flows.

The results for the VBR experiments are shown in Table 3. The left column shows the measured input rate. The second column shows the 95% confidence interval for the measured throughput rate (the rate of admitted flows) in flows/s.

The rate of admitted flows and the rate of rejected flows are shown in Figure 9. The ideal lines for VBR flows are the same as for CBR flows.
Table 3: The mean throughput of VBR flows with different input loads

<table>
<thead>
<tr>
<th>Input (flows/s)</th>
<th>Mean throughput (flows/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.442</td>
<td>1.442 ± 0.097</td>
</tr>
<tr>
<td>4.364</td>
<td>4.364 ± 0.056</td>
</tr>
<tr>
<td>7.257</td>
<td>7.257 ± 0.068</td>
</tr>
<tr>
<td>8.779</td>
<td>8.779 ± 0.064</td>
</tr>
<tr>
<td>10.199</td>
<td>10.199 ± 0.104</td>
</tr>
<tr>
<td>10.974</td>
<td>10.914 ± 0.066</td>
</tr>
<tr>
<td>11.746</td>
<td>11.239 ± 0.112</td>
</tr>
<tr>
<td>12.430</td>
<td>11.278 ± 0.109</td>
</tr>
<tr>
<td>13.064</td>
<td>11.360 ± 0.132</td>
</tr>
<tr>
<td>14.512</td>
<td>11.388 ± 0.082</td>
</tr>
<tr>
<td>15.886</td>
<td>11.499 ± 0.090</td>
</tr>
<tr>
<td>18.880</td>
<td>11.511 ± 0.178</td>
</tr>
</tbody>
</table>

CBR flows, except that for rate flows lower 11.574 flows/s is used.

Figure 10 shows the blocking probability for VBR flows.

Again, the measured values are close to the ideal lines.

In Figure 11 the blocking probability for both CBR (represented by ‘+’) and VBR (represented by ‘×’) flows is shown. The x-axis shows the input load in flows/s converted to the corresponding load in Mbit/s (see Table 1). Because the lines now have the same scales, they can be compared. The line that is closest to the ideal line represents the highest accuracy.

The differences between the blocking probability lines for CBR and VBR flows and the ideal line are so small that it can be said that the LC-PCN algorithm is accurate for both CBR and VBR traffic. The largest difference between the measured values and the ideal line is at an input load of 8 MBit/s, where the difference between the ideal blocking probability and the measured blocking probability with CBR flows is 0.029. As said before, this can be explained from the variations in the actual offered load. With a load of 8 MBit/s no flows should be blocked. But with an average load of 8 MBit/s there are moments during the experiment where the load exceeds the 8 MBit/s boundary and hence flows are blocked. The more flows are offered, the more the algorithms can control the actual rate of admitted flows. This can be seen in the graph. After the input load of 8 MBit/s the measurements converge to the ideal line.

No dropped packets were detected during the CBR and VBR simulations. That is less than the maximum acceptable loss rate of 3%, mentioned in Section 3.1. so in terms of packet dropping probability LC-PCN performs very well for CBR and VBR flows. This also means that the chosen offsets rateAO and rateTO are large enough to prevent that packets of admitted flows are dropped.

6. CONCLUSIONS AND FUTURE WORK

In this paper the performance of Admission Control in Load Control PCN (LC-PCN) has been evaluated.

Firstly, Load Control PCN (LC-PCN) and its Admission Control and Flow Termination functions were described and it was explained how LC-PCN works. Secondly, performance criteria for Admission Control algorithms in DiffServ domains have been given. It was explained that the goal of Admission Control is to contribute to a better Quality of Service (QoS) for flows in Diff-
References


Figure 11: The measured blocking probability for CBR and VBR flows and the ideal line.


