ABSTRACT
The IETF NSIS (Next Steps in Signaling) working group has developed a new solution for providing QoS in a Diffserv region called Resource Management in Diffserv QoS Model (RMD-QOSM). In parallel, the IETF PCN (Congestion and Pre-Congestion-Notification) working group is active on developing similar solutions. In this paper a preliminary performance evaluation study is made of a solution that is a modified version of the “single marking” solution proposed in [CZF+07]. This solution, which is denoted in this paper as PCN_based, could be considered by the PCN WG as one of the possible alternatives that can provide QoS in a Diffserv domain. The preliminary study is based on the performance of the severe congestion detection and handling mechanisms used by the PCN_based solution. Furthermore, this paper presents a preliminary performance comparison between the PCN_solution and the RMD-QOSM solution.

Keywords
Differentiated Services, congestion, RMD, PCN, Quality of Service

1. INTRODUCTION
With the ongoing broadening of people’s private Internet connections the number of applications using real-time media streams like video-conferencing and Voice Over IP (VOIP) has grown significantly and is bound to keep growing in the near future. A reliable network service is imperative for these types of applications to be able to function properly. The network has to provide a stable data stream for a considerable amount of time. In other words the network has to provide the Quality of Service (QoS) required by such real time media streams.

Currently, the Internet provides a best-effort service that might not be able to support the QoS requirements imposed by the real time media streams. Therefore, the Internet Engineering Task Force (IETF) has developed several QoS architectures, that should solve this problem. The main QoS architectures that have been specified by the IETF are the Integrated Services (IntServ) [RFC1633] and the Differentiated Services (DiffServ) [RFC2474], [RFC2475], [RFC2638]. At the moment, the IETF is working on extending the DiffServ architecture to provide admission control extensions and severe congestion handling solutions [Bad06], [Csa02], [Wes03]. In particular, the Next Steps in Signaling (NSIS) working group [NSIS] is working on the Resource Management in DiffServ QoS Model (RMD-QOSM) [Bad06], [Wes03] and the Congestion and Pre-Congestion Notification (PCN) working group [PCN] is working on PCN solutions [Bri06a], [Bri06b], [CZF+07]. A severe congestion situation occurs when a failure, such as link or node failure, causes traffic to be rerouted that severely overloads the new path. Once a link starts getting overloaded, delays often become unpredictable and packets might start getting dropped. In other words, the QoS experienced by the flows that are routed through the overloaded link(s) is likely to be degraded severely. In order to quickly remedy this situation and restore the QoS for as many flows as possible, a severe congestion handling mechanism is required. The solution that solves the severe congestion situation is denoted in this paper as severe congestion detection and handling. Note however, that such a solution is denoted in the IETF PCN WG as flow termination.

This paper focuses on a preliminary performance evaluation study of a modified version of the “single marking” solution proposed in [CZF+07]. This solution that is denoted in this paper as PCN_based, could be considered by the PCN WG as one of the possible alternatives that can provide QoS in a Diffserv domain. The preliminary study is based on the performance of the severe congestion detection and handling mechanisms used by the PCN_based solution. Furthermore, this paper presents a preliminary comparison between the PCN_based solution and the RMD-QOSM solution based on the performance of the severe congestion detection and handling mechanisms.

It is important to note that the admission control mechanism specified in the “single marking” [CZF+07] is outside the scope of this paper.

The rest of this paper is organized in the following way. Section 2 provides an overview of the RMD-QOSM framework and Section 3 describes the PCN based solution. Section 4 describes the performed simulation experiments and their derived results. Section 5 provides the conclusions and recommendations for future work.

2. RMD-QOSM
In order to improve upon the best-effort service supported by the protocols used in the current Internet several solutions have been developed to provide QoS support. The Differentiated Services (DiffServ) architecture has been developed to improve upon the Integrated Services (IntServ) [RFC1633] architecture which performed poorly from the point of view of scalability. This poor scalability is caused by the fact that each node in an IntServ domain keeps state-information for every flow in the domain. The maintenance of the per flow states in high-speed backbone networks that support millions of flows is very complex and most probably not possible. The QoS signaling protocol that is used in the Intserv architecture is the Reservation Protocol (RSVP) [RFC2205].

DiffServ has been developed to cope with these scalability issues. For this purpose DiffServ uses traffic class classification instead of per flow classification and it offers a per-class service rather than a per-flow-service. This requires the per-flow state to be kept only at the edge (ingress and egress)-nodes, leaving...
the interior nodes (nodes within the DiffServ domain) to support only per class features. DiffServ relies on two major concepts. The DiffServ Code Point (DSCP) [RFC2474] is used by packets to identify a traffic class. Each traffic class is associated with a Per Hop Behaviour (PHB) ([RFC3246], [RFC3247]) which indicates the observable performance behaviour of a node for each traffic class. Using the combination of the DSCP and PHB concepts the interior nodes do not have to maintain a per-flow state, resulting in improved scalability.

The DiffServ architecture however does not provide the ability to reserve resources or obtain information on resource availability within the domain. DiffServ also does not provide internal admission control within the DiffServ-aware domain. The RMD-QOSM extends the DiffServ architecture to provide these capabilities.

The RMD-QOSM is being developed in the IETF Next Steps In Signaling (NSIS) working group [NSIS] to extend the capabilities of DiffServ. NSIS provides a model for the DiffServ based network entities taking part in control signaling and for the relationship between signaling and the rest of the network operation.

The NSIS overall protocol suite is decomposed into a generic (lower) layer named NSIS Transport Layer Protocol (NTLP [SH06]), and a separate upper layer, which is different for each signaling application, known as NSIS Signaling Layer Protocol (NSLP). An example of such a signaling application is the QoS signaling application (QoS-NSLP [Man07]).

The QoS NSLP protocol establishes and maintains reservation states at nodes along the path of a data flow for providing forwarding resources for that flow. In QoS-NSLP the operation of the signaling protocol is separated from the Resource Management Function (RMF) in the nodes. Each RMF is associated with a QoS Model (QOSM) that uses an object denoted as QSPEC [ABK06] to carry the actual QoS parameters. The QSPEC parameters are interpreted and implemented accordingly to this QOSM. With QoS-NSLP, an end system can make end-to-end resource reservations across a mixed wireless and wireline network, and implement those reservations sensibly at each point in the network. One of the QOSMs that can be used in sections of heterogeneous networks is the Resource Management in DiffServ (RMD) QoS Model (RMD-QOSM) [Bad06]. The RMD concept was developed to provide dynamic resource reservation within a DiffServ domain in a scalable way, see [Wes02], [Csa03].

When an external application has reserved resources within the RMD-QOSM domain, it expects to receive a certain QoS for its flows when they pass through the domain. In fact, by admitting the flows into the domain, RMD-QOSM guarantees that this will be fulfilled. However, during a severe congestion, where the QoS of ongoing flows will be severely degraded, a severe congestion handling mechanism is required.

### 2.1 Severe congestion handling

RMD-QOSM uses two types of severe congestion solutions. One solution uses refresh messages that, during severe congestion, are marked when they are passing through a congested node. The other solution is based on a rate proportional marking approach that uses two DSCP values for marking to distinguish between data packets. The one can inform that a data packet has passed a congested node, denoted as "affected DSCP", and the second one can be used to inform the rate of congestion, denoted as "encoded DSCP".

The severe congestion handling mechanism used in RMD-QOSM is described in [Bad06], [Dim06].

In this section a very brief explanation of the rate proportional mechanism will be given. The RMD-QOSM severe congestion solution is composed of two parts, i.e., severe congestion detection and severe congestion handling (or solving).

The severe congestion detection is performed in the RMD-QOSM interior nodes, where the severe congestion notification and marking takes place. When a severe overload (or congestion) takes place then the interior node starts encoding marking packets (bytes) proportional to the value of the excess traffic. The excess traffic is the traffic that is above a certain threshold which overloads the interior node. The rest of the packets (bytes) that are passing through the severe congested interior node and are not 'encoded' marked are marked as 'affected'.

The severe congestion handling (or solving) is performed at the ingress and egress edge-nodes of the RMD-QOSM domain.

The version of the RMD-QOSM severe congestion algorithm that is investigated in this paper maintains ingress-egress aggregated states. Each ingress-egress aggregated state maintains information about all flows that are using the same ingress and egress pair.

Since severe congestion is often caused by overload on a link, solving the severe congestion and maintaining the quality of service for as many on-going flows as possible, a part of the on-going flows has to be terminated. Edge nodes can do that based on the excess rate of severe congestion they learn from the interior nodes. The excess traffic rate that caused the severe congestion is calculated by measuring the rate of the received 'encoded' marked bytes that are arriving at the egress node. This rate represents the severe congested bandwidth that should be terminated, which can be translated into a number of flows that has to be terminated. In order to do that the egress node records per ingress-egress pair, the identity of the flows with "affected" and "encoded" marked data packets. For termination, per ingress-egress pair, only flows that are marked 'encoded' and 'affected' are chosen. Furthermore, when the egress node maintains flows that are identified by a different priority, the low priority flows are first chosen for termination. If this is not enough then medium priority flows are chosen. If this is also not enough to solve the severe congestion then also high priority flows are chosen for termination.

For each flow that has to be terminated, the egress notifies the ingress of the RMD-QOSM domain, which terminates the flow.

### 3. PCN

The original Pre-Congestion Notification solution has been developed by Briscoe et al. [Bri06a], [Bri06b] with the same goals in mind as RMD-QOSM from the point of view of the severe congestion handling. This solution can be used in DiffServ domains, to provide the admission control and severe congestion handling support.

Please note that the RMD-QOSM framework supports resource reservation, admission control and severe congestion handling features. The PCN solution specified in [Bri06a] can only support a simple admission control feature and a severe congestion handling (or pre-emption) feature.

The PCN severe congestion handling solution, specified in [Bri06a], however, differs from the RMD-QOSM solution in the way of how the severe congestion is detected by the interior nodes and handled by the edge nodes. The PCN solution
specified in [Bri06a] uses two main thresholds in the interior nodes, similar to the RMD-QOSM solution, one for admission control and the other one for severe congestion detection. When the load on the link increases above the ‘admission control’ threshold then packets will be marked with ‘admission control’ DSCP. When the load on the link increases further above the ‘severe congestion’ (or pre-emption) threshold, the packets are marked with ‘severe congested’ DSCP. Two DSCP values are used during this marking process. It is important to note that both thresholds should be set below the capacity of the link. Note also that the rate of marked and unmarked packets cannot exceed the capacity of the link. This means that the marking rate is proportional to the excess rate above the admission threshold. However, the marking rate cannot be higher than the rate value equal to the difference between the link capacity and the admission threshold.

The egress node receives the ‘admission control’ marked packets and calculates, per ingress-egress pair, the Congestion Level Estimate (CLE) that can be used as an indication of whether new flows can be admitted or not.

The CLE is the number of admission marked packets divided by the number of unmarked packets calculated as an exponentially weighed moving average. The egress also calculates, per ingress-egress pair, the Sustainable Aggregate Rate (SAR), which is the actual rate of the received unmarked packets. Both values are sent to the ingress node. The ingress node uses the CLE value for admission control, i.e., when the CLE is higher than a certain threshold, requests for new flows are rejected. The SAR value is used to calculate the amount of flows that has to be terminated in order to stop the severe congestion situation. This is accomplished by measuring, per ingress-egress pair, the incoming load and subtracting the SAR from it in order to calculate the congested bandwidth and subsequently the number of flows that has to be terminated.

### 3.1 Single marking

In order to improve on the PCN solution proposed in [Bri06a] a modified version has been proposed in [CZF+07], where only one single marking procedure is needed for admission control and severe congestion (or pre-emption). Reducing the number of DSCP’s is favourable for the simplification of the complexity of both the interior nodes and the ingress/egress nodes, since only a single metering implementation is required. Since the rate at which admission has to be stopped is preferably significantly lower than the rate at which severe congestion (or preemption) is required, which is the main argument for having two different markings, the single marking solution has to provide for different levels of admission and severe congestion as well. To do this the solution introduces a system-wide constant \( u \) which is the ratio preemption threshold/admission threshold.

To detect possible severe congestion an interior node ‘admission control’ marks packets according to the admission threshold. The marking rate is proportional to the excess rate above the admission threshold. However, the marking rate cannot be higher than the rate equal to the difference between the link capacity and the admission threshold. An egress node receives (part of) these marked packets and starts a measurement of marked as well as unmarked packets. The sustainable aggregate rate (SAR) is calculated by measuring the amount of unmarked packets received during the measurement period and divide it by the length of the measurement period. The congestion level estimate (CLE) is calculated in a similar way as specified in [Bri06a]. Both values are calculated for each ingress-egress pair node and they are reported to these ingress nodes. Each ingress node calculates the sustainable preemption rate (SPR) by simply multiplying SAR with the system-wide constant \( u \). Preemption of flows only takes place when the rate of all flows sent by the ingress node exceeds the SPR. The number of flows that has to be terminated is calculated in the following way. The incoming load, per ingress-egress pair, is measured and the SPR is subtracted from it in order to calculate the congested bandwidth and subsequently the number of flows that has to be terminated.

An ingress node decides whether new flows will be allowed on the PCN aware-region based on the CLE. If the CLE is above a certain threshold, no new flows will be allowed on the PCN aware region.

In order to ensure admission marked packets arrive at an egress node, the admission threshold is set to a rate significantly lower than the link bandwidth. In normal operation bandwidth usage on a link is therefore restricted to the admission threshold.

### 3.2 PCN_based

This section describes the severe congestion solution that is based on a combination of the single marking algorithm [CZF+07] and the severe congestion solution specified in [Bud06], which is denoted in this paper as PCN_based.

The interior nodes support a significant part of the features specified in [CZF+07]. In particular, a single marking threshold is used for admission control and severe congestion. However, the main difference between this solution and the ‘single marking’ solution is related to the value of the used admission control threshold. In this solution it is assumed that the complete capacity of the link can be used and therefore, it is assumed that the admission control threshold can be set to 100%. The system-wide constant \( u \) is also used and, similar to the ‘single marking’ solution, is the ratio preemption threshold/admission threshold, which is set to 1.2.

The marking rate is proportional to the excess rate above the admission threshold. However, the marking rate cannot be higher than the rate value equal to 16.7% (100% - 100%/u) of the maximum capacity of the link. This is required in order to assure that the SPR calculated at an egress is equal or smaller than 100% of the maximum capacity of the link. The packets that are marked according to the excess rate are marked with ‘encoded’ DSCP. Similar to the RMD-QOSM solution, the rest of the packets that are passing through a congested node are marked with ‘affected’ DSCP.

At the egress the rate of ‘encoded’ packets is used to calculate, per ingress-egress pair, the value of the CLE and the rate of the ‘affected’ marked packets is used to calculate the SAR.

The main difference with the ‘single marking’ and RMD-QOSM solutions is that the overloaded bandwidth, or bandwidth to be terminated, is calculated at the ingress in the following way:

- during one measurement period the SAR is calculated by measuring the bandwidth of the received affected marked bytes.
- SPR is calculated by \( SPR = SAR * u \)
- the overloaded bandwidth, or bandwidth to be terminated, is calculated by:
  1. calculate the "sum of the reserved aggregated bandwidth" (per ingress-egress pair)
  2. "overloaded bandwidth" = "sum of the reserved aggregated bandwidth" - SPR
3. select the flows that have to be terminated in the same way as specified in [Dim06], see also Section 2.1.

For each flow that has to be terminated, the egress notifies the ingress of the domain, which terminates the flow.

4. PRELIMINARY PERFORMANCE EVALUATION

The preliminary steps of the performance evaluation of the RMD-QOSM and PCN-based severe congestion solutions have been done using simulations. These simulations were performed using the Network Simulator (NS) [NS2] environment which was chosen due to the fact that the RMD-QOSM simulation model was already available, see [Dim06], [Sto06].

In order to compare both solutions a simulation model for the PCN_based solution has been developed in the NS2 simulation environment, by reusing as much as possible the existing RMD_QOSM simulation model.

4.1 Common settings
Both simulations were performed using the following simulation settings.

4.1.1 Network topology

The used network topology is depicted in Figure 1 and is the same as the one that has been used in the simulation experiments described in Section 8.3 of [Dim06]. It consists of five nodes (0 through 4). Nodes 0 and 2 are the ingress nodes, nodes 1 and 3 internal nodes and node 4 is the egress node. Traffic is sent from both ingress nodes at the depicted rate. Figures 1a and 1b depict the traffic loads on the links before and during the severe congestion respectively.

4.1.2 Performance parameters
The parameters used to simulate both the RMD-QOSM and PCN_based model are the following.

- **Link bandwidth** for each link is 10 Mbps with a propagation delay of 2 ms.

- All generated flows are CBR (constant bit rate) and have a packet size of 40 bytes and a rate of 16 Kbps (50 packets / second).

- It is assumed that at the time a severe congestion situation occurs all flows are generated. Therefore, flows are generated using a uniform distribution, which ensures that all flows are generated during the period from 5 seconds to 35 seconds. Furthermore, it is considered that the holding time of the flows is higher than the simulation duration.

- Simulation duration is 120 seconds where the severe congestion (i.e. link failure) occurs at 100 seconds.

- The admission threshold is set to 100% of the link bandwidth. This is because it is assumed that in the worst case the link will be 100% utilized. Note that the RMD-QOSM model uses in addition to the admission control threshold also a severe congestion threshold. This threshold was set to 103% of the link bandwidth. The severe congestion restoration threshold is set to 100% of the link bandwidth.

- The measurement period for both admission marking in the interior nodes and for the measurement of marked packets in the egress node is set to 50 ms.

- The packet size for signaling messages is 44 bytes.

- dsRED queues are used in all simulations. Two physical queues are used. Physical queue 1 (signaling messages) has priority 0 (i.e. highest priority) with a size of 44 Kbytes. Physical queue 2 is used for data packets and receives a lower priority 1. The use of physical queue 2 is different for the RMD-QOSM and the PCN_based models. In RMD-QOSM this physical queue 2 consists of two virtual queues, where virtual queue 1 with size of 65 Kbytes is used to enqueue ‘encoded’ marked packets and virtual queue 2 of size 58 Kbytes is used to en-queue unmarked and affected marked packets. Physical queue 2 used in the PCN_based simulation model consists of only one virtual queue of size 123 Kbytes used to en-queue all types of data packets.

- Generated flows: the bandwidth before severe congestion is 10 Mbps from node 0 to 4 and 7 Mbps from node 2 to 4. The generated bandwidth for the different priority classes is shown in Table 1. The number between braces represents the exact rate. Since one flow represents 16 Kbps of bandwidth not all rates can be achieved exactly.

<table>
<thead>
<tr>
<th>Source – destination</th>
<th>0 - 4</th>
<th>2 - 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Load</td>
<td>7Mbps (6.992 Mbps)</td>
<td>10 Mbps (9.984 Mbps)</td>
</tr>
<tr>
<td>High priority</td>
<td>3 Mbps (2.992 Mbps)</td>
<td>7 Mbps (6.992 Mbps)</td>
</tr>
<tr>
<td>Medium priority</td>
<td>2 Mbps</td>
<td>1 Mbps (0.992 Mbps)</td>
</tr>
<tr>
<td>Low priority</td>
<td>2 Mbps</td>
<td>2 Mbps</td>
</tr>
</tbody>
</table>

**Table 1 Flow sizes**

4.1.3 Performance measures
To compare the performance of both solutions 2 performance measures are used.

- Severe congestion detection and handling time. This is the time the solution needs to solve the severe congestion (i.e. the time it takes until no more packets are dropped at the congested link).

- Link load after stabilization; the link load of the congested link after the severe congestion has been solved.

4.2 RMD-QOSM experiment
The evaluation of the RMD-QOSM solution had been performed in [Dim06]. The detailed description of the experiments can be found in section 8.3 of [Dim06]. Only one RMD-QOSM experiment is used and compared to the PCN_based solution due to the fact this is the only experiment...
that uses ingress/egress pair aggregates to calculate the link overload and to handle the severe congestion situation. The additional parameters used in the RMD-QOSM experiment are:

- The remark proportion $N$ is set to 2 (see Section 6.5.1 in [Dim06]).
- The number of cells for the sliding window mechanism is set to 8, see [Dim06].
- The packets are ‘encoded’ and ‘affected’ marked after they are de-queued from the output queue and are passed to the output link.
- The severe congestion solution described in Section 2.1 is used.

The severe congestion is simulated by dropping link 0-1 at 100 seconds. This results in flows from node 0 being rerouted via 0-3-4. Since link 3-4 already had a load of 7 Mbps from node 2, a total of 17 Mbps needs to be handled, an overload of 7 Mbps (i.e., 70% severe congestion). Node 3 starts marking packets it sends over the link 3-4 which triggers node 4 (the egress node) to start a measurement of ‘encoded marked’ and ‘affected marked’ packets and determines the number of flows to drop.

Since the overload on link 3-4 is 7 Mbps, the amount of flows representing 7 Mbps has to be stopped. The number of flows that will be stopped is divided over the ingress nodes according to the rate at which they are sending traffic. Thus, 4.12 Mbps from node 0 and 2.88 Mbps of flows from node 2 are expected to be dropped. Taking account of flow priority 2 Mbps of low priority flows and 0.88 Mbps of medium priority flows are expected to be dropped from node 2. From node 0 2 Mbps of low priority, 1 Mbps of medium priority and 1.12 Mbps of high priority flows are expected to be dropped.

The simulation results for the RMD-QOSM experiments are depicted in figures Figure 2 through Figure 4 (copied from [Dim06]). The measurements for low, medium and high priority flows as well as the total link bandwidth are shown in purple (i.e., usually lowest line), blue (i.e., usually line located higher than low priority line), red (i.e., usually line located higher than medium priority line and lower than the total link bandwidth line) and black (i.e., the top line) lines respectively. Figure 2 shows the link load on link 0-3. After link 0-1 is dropped, all flows from node 0 to 4 are rerouted via node 3. Figure 2 shows a spike in load after 100 seconds because all traffic from node 0 is sent to node 3. After the severe congestion is handled link loads for the different priorities are 0 Mbps for low priority, approximately 1.2 Mbps for medium priority and 3 Mbps for high priority flows. Therefore the total load is approximately 4.12 Mbps.

**Figure 2 Load on link 0-3 RMD-QOSM (copied from [Dim06])**

The load on link 2-3 is depicted in Figure 3. Before severe congestion occurs the link loads are as they are defined in Table 1. After the severe congestion has been handled all low and medium priority flows have been dropped and approximately 5.88 Mbps of the original 7 Mbps of high priority flows remain.

Figure 4 shows the load on link 3-4. Before severe congestion the link loads are the same as for link 2-3. As can be seen from this figure the time used to detect and handle severe congestion is approximately 0.25 seconds and the link bandwidth after handling the severe congestion is approximately 10 Mbps. Furthermore the amount of flows of different priority is – again by approximation – as expected.

The loads for links 0-1 and 1-4 are omitted here since they trivially show a load of 7 Mbps – traffic from node 0-4 – before severe congestion which drops to 0 Mbps after 100 seconds.

**Figure 3 Load on link 2-3 RMD-QOSM (copied from [Dim06])**

**Figure 4 Load on link 3-4 RMD-QOSM (copied from [Dim06])**

### 4.3 PCN_based experiment

The preliminary evaluation of the PCN_based severe congestion solution has been conducted similarly to the RMD_QOSM severe congestion experiments. A few parameters are different though, mostly since the features are not used in the PCN_based solution.

- The sliding window mechanism is not used.
- The remark proportion $N$ (see Section 6.5.1 in [Dim06]) is set to 1, meaning that there is a 1 to 1 relation between the value of the excess traffic and the marking of packets.
- The queue size for all packets is 123 Kb (3088 packets). Since only one queue is used in the PCN_based solution
the size of this queue is the sum of the queues of the RMD-QOSM.

- The severe congestion solution described in Section 3.2 is used.

Since the same link loads are used as in the RMD-QOSM simulation experiments, similar results as shown in section 4.2 are expected.

An important difference between the RMD-QOSM simulation model and the PCN_based model is the use of a single queue for both marked and unmarked packets in an internal node. This queue is used to store packets before they are sent over a link, dropping packets when its maximum size is reached. In RMD-QOSM there are different queues for packets with ‘encoded marked’ DSCP and other packets. Only one queue is used, since the ‘single marking’ solution is in favor of using only one queue for all the data packets. However, using two different queues provides more control over the sort of packets that will be dropped. In other scenario’s, particularly using other network topologies, the use of two different queues can be beneficial. Note however, that due to the fact that in the used network topology (figure 1), the severe congestion occurs at the last link before the egress nodes, the length of the used queues does not affect the way of how the ‘encoded’ marked packets are dropped. This is because the data packets are ‘encoded’ and ‘affected’ marked after they are de-queued from the output queue and are passed to the output link.

Figure 5 Load on link 0-3 PCN_based
The preliminary simulation results of the PCN_based solution are depicted in figures Figure 5 through Figure 7. The colour scheme for these figures is the same as the one used in figures Figure 2 through Figure 4.

The link load on link 0-3 is shown in Figure 5. The loads before and after severe congestion are approximately the same as those for RMD-QOSM depicted in Figure 2 for RMD-QOSM.

Figure 6 Load on link 2-3 PCN_based
Figure 6 shows the link load for link 2-3. After severe congestion all low and medium priority flows are dropped leaving approximately 5.88 Mbps of high priority traffic.

Figure 7 Load on link 3-4 PCN_based
Figure 7 shows the link load for link 3-4. The loads are approximately the same as those for RMD-QOSM depicted in Figure 4. The link load after the severe congestion has been solved is 10 Mbps consisting of flows of different priorities at their expected levels. The severe congestion detection and handling time is approximately 0.2 seconds.

Once again the loads for the links 0-1 and 1-4 are omitted for triviality reasons.

4.4 Comparison
From the point of view of functionality complexity it can be observed that the PCN_based solution is slightly better than the RMD-QOSM solution, since it does not need to use a sliding window algorithm and a remark proportion feature at the interior nodes. However, the PCN_based mechanism might be less accurate than the RMD-QOSM solution during the calculation of the excess traffic rate at the egress. This is because the RMD-QOSM is ‘encoded’ marking packets proportionally to the excess traffic, i.e., traffic above the severe congestion threshold. In this way the egress node can accurately calculate the excess traffic rate. In the PCN_based solution the excess rate is indirectly calculated by using the throughput and the reserved bandwidth.

Based on the obtained preliminary performance evaluation experiments it can be observed that both solutions provide a similar performance from the point of view of severe congestion detection and handling time and as well as the link load after stabilization. The number of flows that has been stopped by the severe congestion handling mechanism is approximately the same for both solutions, resulting in a similar use of bandwidth (i.e. the restoration threshold) on the congested link after the congestion has been solved.

Note however, that due to lack of available time only a preliminary performance comparison has been accomplished. In order to fully compare the two severe congestion solutions from the performance point of view more experiments have to be performed, see Section 5.2.

5. CONCLUSIONS AND FUTURE WORK
5.1 Conclusions
Based on the preliminary performance evaluation experiments it can be observed that the PCN_based solution for severe congestion handling can provide a reasonably fast and reliable method for handling severe congestion situations. It performs
similar to the RMD-QOSM solution in link bandwidth utilization after severe congestion and it has a similar severe congestion handling time. The PCN_based solution is slightly less complex than the RMD-QOSM solution, since it does not need to use a sliding window algorithm and a remark proportion feature at the interior nodes. However, the PCN_based mechanism might be less accurate than the RMD-QOSM solution during the calculation of the excess traffic rate at the egress.

5.2 Future work

The performance evaluation of the PCN_based severe congestion solution to severe congestion is only a small part of the required (complete) performance evaluation. This section describes various experiments that would contribute to an overall evaluation of the PCN_based severe congestion solution.

5.2.1 PCN_based

To complete the evaluation of the PCN_based solution the following experiments are suggested:

- Admission control: Since only the severe congestion detection and handling algorithm of the PCN_based solution has been evaluated, the collaboration an admission control mechanism is required to complete the evaluation of the PCN_based severe congestion solution.

- Topology: The experiments in this paper describe only a single topology. In order to fully evaluate the severe congestion handling mechanism, other topologies should be assessed. The availability of the RMD-QOSM solution and the experiments done by [Dim06] provide an excellent base for further simulation experiment.

- Queue size: The effect of using different queue sizes for ‘encoded marked’ and ‘affected marked’ should be assessed. The experiment in this paper uses only one queue for all packets. In combination with different topologies, the size of different queues and queue size should be evaluated.

5.2.2 PCN/Single marking

Since the PCN_based solution differs from the PCN and single marking solutions a few recommendation for further research are suggested:

- Flow control: In PCN_based, the determination which flows have to be stopped is done in the egress node while in PCN the ingress node decides this. Moving the flow stopping mechanism to the ingress will provide a more PCN-compliant solution.

- Admission threshold: The PCN_based solution uses an admission threshold of 100% of the link bandwidth to be able to use the complete bandwidth of a link. PCN however uses an admission threshold “significantly lower” [CZF+07] than the link bandwidth. Experiments using this lower threshold are suggested.

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