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Pre-Congestion Notification Using Single Marking for Admission and Pre-
                               emption
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Abstract

   Pre-Congestion Notification [I-D.briscoe-tsvwg-cl-architecture]
   approach proposes the use of an Admission Control mechanism to limit

the amount of real-time PCN traffic to a configured level during the
normal operating conditions, and the use of a Pre-emption mechanism
to tear-down some of the flows to bring the PCN traffic level down to
a desirable amount during unexpected events such as network failures,
with the goal of maintaining the QoS assurances to the remaining
flows. In [I-D.briscoe-tsvwg-cl-architecture], Admission and Pre-
emption use two different markings and two different metering
mechanisms in the internal nodes of the PCN region. This draft
proposes a mechanism using a single marking and metering for both
Admission and Pre-emption, and presents a preliminary analysis of the
tradeoffs. A side-effect of this proposal that a different marking
and metering Admission mechanism than that proposed
in[I-D.briscoe-tsvwg-cl-architecture] may be also feasible.

Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT",
"SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this
document are to be interpreted as described in RFC 2119 [RFC2119].

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1. Introduction

1.1. Changes from -00 version

   Added miscellaneous clarifications based on comments received on
   version -00. Added simulation results for multi-hop topologies and
   video trace data to the Appendix.

1.2. Background and Motivation

   Pre-Congestion Notification [I-D.briscoe-tsvwg-cl-architecture]
   approach proposes to use an Admission Control mechanism to limit the
   amount of real-time PCN traffic to a configured level during the
   normal operating conditions, and to use a Pre-emption mechanism to
   tear-down some of the flows to bring the PCN traffic level down to a
   desirable amount during unexpected events such as network failures,
   with the goal of maintaining the QoS assurances to the remaining
   flows. In [I-D.briscoe-tsvwg-cl-architecture], Admission and Pre-
   emption use different two different markings and two different
   metering mechanisms in the internal nodes of the PCN region.
   Admission Control algorithms for variable-rate real-time traffic such
   as video have traditionally been based on the observation of the
   queue length, and hence re-using these techniques and ideas in the
   context of pre-congestion notification is highly attractive, and
   motivated the virtual-queue-based marking and metering approach
   specified in [I-D.briscoe-tsvwg-cl-architecture] for Admission. On
   the other hand, for Pre-emption, it is desirable to know how much
   traffic needs to be pre-empted, and that in turn motivates rate-based
   Pre-emption metering. This provides some motivation for employing
   different metering algorithm for Admission and for Preemption.

   Furthermore, it is frequently desirable to trigger Pre-emption at a
   substantially higher traffic level than the level at which no new
   flows are to be admitted. There are multiple reasons for the
   requirement to enforce a different Admission Threshold and Preemption
   Threshold. These include, for example:

   o End-users are typically more annoyed by their established call
      dying than by getting a busy tone at call establishment.

   o There are often very tight (possibly legal) obligations on network
      operators to not drop established calls.

   o Voice Call Routing often has the ability to route/establish the
      call on another network (e.g., PSTN) if it is determined at call
      establishment that one network (e.g., packet network) can not
      accept the call. Therefore, not admitting a call on the packet
      network at initial establishment may not impact the end-user. In

contrast, it is usually not possible to reroute an established
call onto another network mid-call. This means that call
Preemption can not be hidden to the end-user.

o Preemption is typically useful in failure situations where some
   loads get rerouted thereby increasing the load on remaining links.
   Because the failure may only be temporary, the operator may be
   ready to tolerate a small degradation during the interim failure
   period.

o A congestion notification based Admission scheme has some inherent
   inaccuracies because of its reactive nature and thus may
   potentially over admit in some situations (such as burst of calls
   arrival). If the Preemption scheme reacted at the same Threshold
   as the Admission Threshold, calls may get routinely dropped after
   establishment because of over admission, even under steady state
   conditions.

These considerations argue for metering for Admission and Pre-emption
at different traffic levels and hence, implicitly, for different
markings and metering schemes.

Different marking schemes require different codepoints. Thus, such
separate markings consume valuable real-estate in the packet header,
especially scarce in the case of MPLS Pre-Congestion Notification
[I-D.davie-ecn-mpls] . Furthermore, two different measurement/
metering techniques involve additional complexity in the datapath of
the internal routers of the PCN domain.

To this end, [I-D.briscoe-tsvwg-cl-architecture] proposes an
approach, referred to as implicit pre-emption marking, that does not
require separate pre-emption marking. However, it does require two
separate measurement schemes: one measurement for Admission and
another measurement for Preemption/Dropping. Furthermore, this
approach mandates that the configured preemption rate be set to a
drop rate. This approach effectively uses dropping as the way to
convey information about how much traffic can "fit" under the
preemption limit, instead of using a separate preemption marking.
This is a significant restriction in that it results in preemption
only taking effect once packets actually get dropped.

This document presents an approach that allows the use of a single
PCN marking and a single metering technique at the internal devices
without requiring that the dropping and pre-emption thresholds be the
same. This document also investigates some of the tradeoffs
associated with this approach.

1.3. Terminology

   o Pre-Congestion Notification (PCN): two algorithms that determine
      when a PCN-enabled router Admission Marks and Pre-emption Marks a
      packet, depending on the traffic level.

   o Admission Marking condition- the traffic level is such that the
      router Admission Marks packets. The router provides an "early
      warning" that the load is nearing the engineered admission control
      capacity, before there is any significant build-up in the queue of
      packets belonging to the specified real-time service class.

   o Pre-emption Marking condition- the traffic level is such that the
      router Pre-emption Marks packets. The router warns explicitly
      that pre-emption may be needed.

   o Configured-admission-rate - the reference rate used by the
      admission marking algorithm in a PCN-enabled router.

   o Configured-pre-emption-rate - the reference rate used by the pre-
      emption marking algorithm in a PCN-enabled router.

   o CLE - congestion level estimate computed by the egress node by
      estimating as the fraction of admission-marked packets it
      receives.

   o PIN - PCN internal node - an internal node in the PCN region.

   o PEN - PCN edge node - an ingress or egress edge node of the PCN
      region.

   o SAR - Sustainable Admission rate - the rate of unmarked traffic
      received by the Ingress PEN from the egress PEN

   o SPR - Sustainable Preemption rate

2. The Single Marking Approach

2.1. High Level description

   The proposed approach is based on several simple ideas:

   o Replace virtual-queue-based marking for Admission Control by
      excess rate marking:

      * meter traffic exceeding the Admission Threshold and mark excess
         traffic (e.g. using a token bucket with the rate configured to

      Admission Rate Threshold)

   * at the edges, stop admitting traffic when the fraction of
      marked traffic for a given edge-to-edge aggregate exceeds a
      configured threshold (e.g. stop admitting when 3% of all
      traffic in the edge-to-edge aggregate received at the ingress
      is marked)

   o Impose a PCN-region-wide constraint on the ratio between the
      Admission threshold on a link and Pre-emption threshold on that
      link (e.g. pre-emption threshold is 20% higher than Admission
      threshold on all links in the PCN region)

   o The edge PCN device determines whether Pre-emption level is
      reached anywhere in the network *implicitly* by measuring the
      amount of unmarked traffic (assuming the marked traffic actually
      is above the threshold triggering blocking admission), i.e. the
      traffic that did not get admission marked. This is analogous to
      the notion of sustainable pre-emption rate in
      [I-D.briscoe-tsvwg-cl-architecture]. The rate of unmarked traffic
      in this case signifies the bottleneck admission threshold. The
      bottleneck pre-emption threshold is by design within the chosen
      ratio of that admission threshold. The ingress PCN edge device
      preempts all traffic above the bottleneck preemption threshold.

   The remaining part of this section gives more detailed of a possible
   operation of the system.

2.2. Operation at the PIN

   The PCN Internal Node (PIN) meters the aggregate PCN traffic and
   marks the excess rate. A number of implementations are possible to
   achieve that. A token bucket implementation is particularly
   attractive because of its relative simplicity, and even more so
   because a token bucket implementation is readily available in the
   vast majority of existing equipment. The rate of the token bucket is
   configured to correspond to the target Admission rate, and the depth
   of the token bucket can be configured by an operator based on the
   desired tolerance to PCN traffic burstiness.

   Note that no preemption threshold is explicitly configured at the
   PIN, and the PIN does nothing at all to enforce it or mark traffic
   based on Pre-emption threshold.

2.3. Operation at the Egress PEN

   The PCN Egress Node (PEN) measures the rate of both marked and
   unmarked traffic on a per-ingress PEN basis, and reports to the

ingress PEN two values: the rate of unmarked traffic from this
ingress PEN, which we deem Sustainable Admission Rate (SAR) and the
Congestion Level Estimate (CLE), which is the fraction of the marked
traffic received from this ingress PEN. Note that Sustainable
Admission Rate is analogous to the sustainable pre-emption rate of
[I-D.briscoe-tsvwg-cl-architecture], except in this case it is based
on the admission threshold rather than pre-emption threshold, while
the CLE is exactly the same as that of
[I-D.briscoe-tsvwg-cl-architecture]. The details of the rate
measurement are outside the scope of this draft.

2.4. Operation at the Ingress PEN

2.4.1. Admission Decision

Just as in [I-D.briscoe-tsvwg-cl-architecture], the admission
decision is based on the CLE. The ingress PEN stops admission of new
flows if the CLE is above a pre-defined threshold (e.g. 3%). Note
that although the logic of the decision is exactly the same as in the
case of [I-D.briscoe-tsvwg-cl-architecture], the detailed semantics
of the marking is different. This is because the marking used for
admission in this proposal reflects the excess rate over the
admission threshold, while in [I-D.briscoe-tsvwg-cl-architecture],
the marking is based on exceeding a virtual queue threshold.
Notably, in the current proposal, if the average sustained rate of
admitted traffic is 5% over the admission threshold, then 5% of the
traffic is expected to be marked, whereas in the context of
[I-D.briscoe-tsvwg-cl-architecture] a steady 5% overload should
eventually result in 100% of all traffic being admission marked. A
consequence of this is that for smooth traffic, the approach
presented here will not mark any traffic at all until the rate of the
traffic exceeds the configured admission threshold by the amount
corresponding to the chosen CLE threshold. At first glance this may
seem to result in a violation of the pre-congestion notification
premise that attempts to stop admission before the desired traffic
level is reached. However, in reality one can simply embed the CLE
level into the desired configuration of the admission threshold.
That is, if a certain rate X is the actual target admission
threshold, then one should configure the rate of the metering device
(e.g. the rate of the token bucket) to X-y where y corresponds to the
level of CLE that would trigger admission blocking decision.

A more important distinction is that virtual-queue based marking
reacts to short-term burstiness of traffic, while the excess-rate
based marking is only capable of reacting to rate violations at the
timescale chosen for rate measurement. Based on our investigation,
it seems that this distinction is not crucial in the context of PCN
when no actual queuing is expected even if the virtual queue is full.

   More discussion on this is presented later in the draft.

2.4.2. Pre-emption Decision

   When the ingress observes a non-zero CLE and Sustainable Admission
   Rate (SAR), it first computes the Sustainable Pre-Emption rate (SPR)
   by simply multiplying SAR by the system-wide constant u, where u is
   the system-wide ratio between pre-emption and admission thresholds on
   all links in the PCN domain: SPR = SAR*u. The ingress PEN then
   performs exactly the same operation as is proposed in
   [I-D.briscoe-tsvwg-cl-architecture] with respect to SPR. Namely, it
   pre-empts the appropriate number of flows to ensure that the rate of
   traffic it sends to the corresponding egress PEN does not exceed SPR.
   Just as in the case of [I-D.briscoe-tsvwg-cl-architecture], an
   implementation may decide to slow down the pre-emption process by
   preempting fewer flows than is necessary to cap its traffic to SPR by
   employing a variety of techniques such as safety factors or
   hysteresis. In summary, the operation of pre-emption at the ingress
   PEN is identical to that of [I-D.briscoe-tsvwg-cl-architecture], with
   the only exception that the sustainable pre-emption rate is computed
   from the sustainable admission rate rather than derived from a
   separate marking. As discussed earlier, this is enabled by imposing
   a system-wide restriction on the pre-emption-to-admission thresholds
   ratio and changing the semantics of the admission marking.

3. Discussion

3.1. Benefits

   The key benefits of using a single metering/marking scheme for both
   Admission and Preemption presented in this document are summarized
   below:

   o Reduced implementation requirements on core routers due to a
      single metering implementation instead of two different ones.

   o Ease of use on existing hardware: given that the proposed approach
      is particularly amenable to a token bucket implementation, the
      availability of token buckets on virtually all commercially
      available routers makes this approach especially attractive.

   o Reduced number of codepoints which need to be conveyed in the
      packet header. If the PCN-bits used in the packets header to
      convey the congestion notification information are the ECN-bits in
      an IP core and the EXP-bits in an MPLS core, as is currently
      proposed in [put marking draft reference here] and
      [I-D.davie-ecn-mpls], those are very expensive real-estate. The

current proposals need 5 codepoints, which is especially important
in the context of MPLS where there is only a total of 8 EXP
codepoints which must also be shared with Diffserv. Eliminating
one codepoint considerably helps.

o A possibility of using a token-bucket-, excess-rate- based
   implementation for admission provides extra flexibility for the
   choice of an admission mechanism, even if two separate markings
   and thresholds are used.

3.2. Tradeoffs, Issues and Discussion

While the benefits of the proposed approach are attractive, there are
several issues and tradeoffs that need to be carefully considered.

3.2.1. Restrictions on Pre-emption-to-admission Thresholds

An obvious restriction necessary for the single-marking approach is
that the ratio of (implicit) pre-emption and admission thresholds
remains the same on all links in the PCN region. While clearly a
limitation, this does not appear to be particularly crippling, and
does not appear to outweigh the benefits of reducing the overhead in
the router implementation and savings in codepoints in the case of a
single PCN domain, or in the case of multiple concatenated PCN
regions. The case when this limitation becomes more inconvenient is
when an operator wants to merge two previously separate PCN regions
(which may have different admission-to-preemption ratios) into a
single PCN region. In this case it becomes necessary to do a
network-wide reconfiguration to align the settings.

3.2.2. Assumptions on Loss

Just as in the case of [I-D.briscoe-tsvwg-cl-architecture], the
approach presented in this draft assumes that the Admission Threshold
is configured at each link below the service rate of the traffic
using PCN. This assumption is significant because the algorithm
relies on the fact that if admission threshold is exceeded, enough
marked traffic reaches the egress PEN to reach the configured CLE
level. If this condition does not hold, then traffic may get dropped
without ever triggering admission decision.

3.2.3. Effect of Reaction Timescale of Admission Mechanism

As mentioned earlier in this draft, there is a potential concern that
slower reaction time of admissions mechanism presented in this draft
compared to [I-D.briscoe-tsvwg-cl-architecture] may result in
overshoot when the load grows rapidly, and undershoot when the load
drops rapidly. While this is a valid concern theoretically, it

should be noted that at least for the traffic and parameters used in
the simulation study reported here, there was no indication that this
was a problem. However, the comparison has so far been done for
Poisson arrivals only. Future work would look in performing a
similar comparison for burstier arrivals.

3.2.4. Performance Implications and Tradeoffs

Replacement of a relatively well-studied queue-based measurement-
based admission control approach by a cruder excess-rate measurement
technique raises a number of algorithmic and performance concerns
that need to be carefully evaluated. For example, a token-bucket
excess rate measurement is expected to be substantially more
sensitive to traffic burstiness and parameter setting, which may have
a significant effect in the case of lower levels of traffic
aggregation, especially for variable-rate traffic such as video. In
addition, the appropriate timescale of rate measurement needs to be
carefully evaluated, and in general it depends on the degree of
expected traffic variability which is frequently unknown.

In view of that, an initial performance comparison of the token-
bucket based measurement is presented in the following section.
Within the constraints of this preliminary study, the performance
tradeoffs observed between the queue-based technique suggested in
[I-D.briscoe-tsvwg-cl-architecture] and a simpler token-bucket-based
excess rate measurement do not appear to be a cause of substantial
concern for cases when traffic aggregation is reasonably high at the
bottleneck links as well as on a per ingress-egress pair basis.
Details of the simulation study, as well as additional discussion of
its implications are presented in section 4.

Also, one mitigating consideration in favor of the simpler mechanism
is that in a typical DiffServ environment, the real-time traffic is
expected to be served at a higher priority and/or the target
admission rate is expected to be substantially below the speed at
which the real-time queue is actually served. If these assumptions
hold, then there is some margin of safety for an admission control
algorithm, making the requirements for admission control more
forgiving to bounded errors - see additional discussion in section 4.

3.2.5. Effect on Proposed Anti-cheating Mechanisms

Replacement of the queue-based admission control mechanism of
[I-D.briscoe-tsvwg-cl-architecture] by an excess-rate based admission
marking changing the semantics of the pre-congestion marking, and
consequently interfereres with mechanisms for cheating detection
discussed in [I-D.briscoe-tsvwg-re-ecn-border-cheat]. Implications
of excess-rate based marking on the anti-cheating mechanisms need to

be considered.

3.2.6. Standards Implications

The change of the meaning of admission marking for pre-congestion
notification from the queue-based to excess-rate marking poses a
question of coexistence of devices having different interpretation of
admissions marking (and hence different metering and marking
mechanisms in the core. The question of how and if the two
mechanisms can co-exist in one PCN region has obvious impact on
standardization efforts, and needs to be carefully considered.

4. Performance Evaluation Comparison

4.1. Relationship to other drafts

Initial simulation results of admission and pre-emption mechanisms of
[I-D.briscoe-tsvwg-cl-architecture] were reported in
[I-D.briscoe-tsvwg-cl-phb]. A follow-up study of these mechanisms is
presented in a companion draft
draft-zhang-cl-performance-evaluation-01.txt. The current draft
concentrates on a performance comparison of the admission control
mechanism of [I-D.briscoe-tsvwg-cl-phb] and the token-bucket-based
admission control described in section 2 of this draft.

4.2. Limitations, Conclusions and Direction for Future Work

Due to time constraints, the study performed so far was limited to a
small set of topologies, described in the Appendix. The key
questions that have been investigated are the comparative sensitivity
of the two schemes to parameter settings and the effect of traffic
burstiness and of the degree of aggregation on a per ingress-egress
pair on the performance of the admission control algorithms under
study. The study is limited to the case where there is no packet
loss. While this is a reasonable initial assumption for an admission
control algorithm that is supposed to maintain the traffic level
significantly below the service capacity of the corresponding queue,
nevertheless future study is necessary to evaluate the effect of
packet loss.

4.2.1. High Level Conclusions

The results of this (preliminary) study indicate that there is a
potential that a reasonable complexity/performance tradeoff may be
viable for the choice of admission control algorithm. In turn, this
suggests that using a single codepoint and metering technique for
admission and pre-emption may be a viable option.

The key high-level conclusions of the simulation study comparing the performance of queue-based and token-based admission control algorithms are summarized below:

1. At reasonable level of aggregation at the bottleneck and per ingress-egress pair traffic, both algorithms perform reasonably well for the range of traffic models considered (see [section 4.3](#). for detail).

2. Both schemes are stressed for small levels of ingress-egress pair aggregation levels of bursty traffic (e.g. a single video-like bursty SVD flow per ingress-egress pair). However, while the queue-based scheme results in tolerable performance even at low levels of per ingress-egress aggregation, the token-bucket-based scheme is substantially more sensitive to parameter setting than the queue-based scheme, and its performance for the high rate bursty SVD traffic with low levels of ingress-egress aggregation is quite poor unless parameters are chosen carefully to curb the error. It should be noted that the SVD traffic model used in this study is expected to be substantially more challenging for both admission and pre-emption mechanisms that the actual video traffic, as the latter is expected to be much smoother than the busrty on-off model with high peak-to-mean ratio we used. This expectation is confirmed by the fact that simulations with actual video traces reported in this version of the draft reveal that the performance of the video traces is much closer to that of VBR voice than of our crude SVD on-off model.

3. Even for small per ingress-egress pair aggregation, reasonable performance across a range of traffic models can be obtained for both algorithms (with a narrower range of parameter setting for the token-bucket based approach) .

4. The absolute value of round-trip time (RTT) or the RTT difference between different ingress-egress pair within the range of continental propagation delays does not appear to have a visible effect on the performance of both algorithms.

[4.2.2](#). Future work

This study is but the first step in performance evaluation of the token-bucket based admission control. Further evaluation should include a range of investigation, including the following:

o fairness issues (how different ingress-egress pairs get access to bottleneck bandwidth)

o interactions between admission control and preemption

o effect of loss of marked packets

o much more

5. **Appendix A**: Simulation Details

5.1. **Network and Signaling Model**

Network topologies used in this study are shown in the Figures below.
The network is modeled as either Single Link (Fig. A.1), Multi Link
Network with a single bottleneck (termed "RTT", Fig. A.2), or a range
of multi-bottleneck topologies shown in Fig. A.3 (termed "Parking
Lot").

```
                     A --- B
```

Figure A.1: Simulated Single Link Network.

```
                 A

                   \

                 B  -  D - F

                  /

                 C
```

Figure A.2: Simulated Multi Link Network.

```
     A--B--C      A--B--C--D      A--B--C--D--E--F
     |  |  |      |  |  |  |      |  |  |  |  |  |
     |  |  |      |  |  |  |      |  |  |  |  |  |
     D  E  F      E  F  G  H      G  H  I  J  K  L

        (a)          (b)               (c)
```

Figure A.3: Simulated Multiple-bottleneck (Parking Lot)Topologies.

Figure A.1 shows a single link between an ingress and an egress node,
all flows enter at node A and depart at node B. In Figure A.2, A set

of ingresses (A,B,C) connected to an interior node in the network
(D). The number of ingresses varied in different simulation
experiments in the range of 2-100. All links have generally
different propagation delays, in the range 1ms - 100 ms. This node D
in turn is connected to the egress (F). In this topology, different
sets of flows between each ingress and the egress converge on the
single link D-F, where pre-congestion notification algorithm is
enabled. The capacities of the ingress links are not limiting, and
hence no PCN is enable on those. The bottleneck link D-F is modeled
with a 10ms propagation delay in all simulations. Therefore the
range of round-trip delays in the experiments is from 22ms to 220ms.
Our simulations concentrated primarily on capacities of 'bottleneck'
links with sufficient aggregation - OC3 for voice and for SVD
traffic, up to 1 Gbps. In the simulation model, a call requests
arrive at the ingress and immediately sends a message to the egress.
The message arrives at the egress after the propagation time plus
link processing time (but no queuing delay). When the egress
receives this message, it immediately responds to the ingress with
the current Congestion-Level-Estimate. If the Congestion-Level-
Estimate is below the specified CLE-threshold, the call is admitted,
otherwise it is rejected. An admitted call sends packets according
to one of the chosen traffic models for the duration of the call (see
next section). Propagation delay from source to the ingress and from
destination to the egress is assumed negligible and is not modeled.

Another type of network of interest is multi-bottleneck (or Parking
Lot, PLT for short) topology. The simplest PLT with 2 bottlenecks is
illustrated in Fig A.3(a). An example traffic matrix with this
network on this topology is as follows:

o   an aggregate of "2-hop" flows entering the network at A and
    leaving at C (via the two links A-B-C)

o   an aggregate of "1-hop" flows entering the network at D and
    leaving at E (via A-B)

o   an aggregate of "1-hop" flows entering the network at E and
    leaving at F (via B-C)

In the 2-hop PLT shown in Fig. A.3(a) the points of congestion are
links A--B and B--C. Capacity of all other links is not limiting.
We also experiment with larger PLT topologies with 3 bottlenecks(see
Fig A.3(b)) and 5 bottlenecks (Fig A.3 (c)). In all cases, we
simulated one ingress-egress pair that carries the aggregate of
"long" flows traversing all the N bottlenecks (where N is the number
of bottleneck links in the PLT topology), and N ingress-egress pairs
that carry flows traversing a single bottleneck link and exiting at
the next "hop". In all cases, only the "horizontal" links in Fig.

A.3 were the bottlenecks, with capacities of all "vertical" links
non-limiting. Propagation delays for all links in all PLT topologies
are set to 1ms.

Due to time limitations, other possible traffic matrices (e.g. some
of the flows traversing a subset of several bottleneck links) have
not yet been considered and remain the area for future investigation.
Our simulations concentrated primarily on the range of capacities of
'bottleneck' links with sufficient aggregation - above 10 Mbps for
voice and 622 Mbps for SVD, up to 2.4 Gbps. But we also investigated
slower 'bottleneck' links down to 512 Kbps in some experiments. In
the simulation model of admission control, a call request arrives at
the ingress and immediately sends a message to the egress. The
message arrives at the egress after the propagation time plus link
processing time (but no queuing delay). When the egress receives
this message, it immediately responds to the ingress with the current
Congestion Level Estimate. If the Congestion Level Estimate is below
the specified CLE- threshold, the call is admitted, otherwise it is
rejected. For preemption, once the ingress node of a PCN region
decides to preempt a call, that call is preempted immediately and
sends no more packets from that time on. The life of a call outside
the domain described above is not modelled. Propagation delay from
source to the ingress and from destination to the egress is assumed
negligible and is not modelled.

5.2. Traffic Models

Four types of traffic were simulated (CBR voice, on-off traffic
approximating voice with silence compression, and on-off traffic with
higher peak and mean rates (we termed the latter synthetic video
(SDV) as the chosen peak and mean rate was similar to that of an MPEG
video stream, although no attempt was made to match any other
parameters of this traffic to those of a video stream), and finally
real video traces. The distribution of flow duration was chosen to
be exponentially distributed with mean 1min, regardless of the
traffic type. In most of the experiments flows arrived according to
a Poisson distribution with mean arrival rate chosen to achieve a
desired amount of overload over the configured-admission-limit in
each experiment. Overloads in the range 1x to 5x and underload with
0.95x have been investigated. Note that the rationale for looking at
the load 1and below is to see if any significant amount of "false
rejects" would be seen (i.e. one would assume that all traffic should
be accepted if the total demand is below the admission threshold).
For on-off traffic, on and off periods were exponentially distributed
with the specified mean. Traffic parameters for each type are
summarized below:

5.2.1. CBR Voice (CBR)

o Average rate 64 Kbps

o Packet length 160 bytes

o packet inter-arrival time 20ms

5.2.2. VBR Voice (VBR)

o Packet length 160 bytes

o Long-term average rate 21.76 Kbps

o On Period mean duration 340ms; during the on period traffic is
   sent with the CBR voice parameters described above

o Off Period mean duration 660ms; no traffic is sent during the off
   period.

5.2.3. "Synthetic Video": High Rate ON-OFF traffic with Video-like
         Mean and Peak Rates ("SVD")

   This model is on-off traffic with video-like mean-to-peak ratio and
   mean rate approximating that of an MPEG-2 video stream. No attempt
   is made to simulate any other aspects of a video stream, and this
   model is merely that of on-off traffic. Although there is no claim
   that this model represents the performance of video traffic under the
   algorithms in question adequately, intuitively, this model should be
   more challenging for a measurement-based algorithm than the actual
   MPEG video, and as a result, 'good' or "reasonable" performance on
   this traffic model indicates that MPEG traffic should perform at
   least as well. We term this type of traffic SVD for "Synthetic
   Video".

o Long term average rate 4 Mbps

o On Period mean duration 340ms; during the on-period the packets
   are sent at 12 Mbps (1500 byte packets, packet inter-arrival: 1ms)

o Off Period mean duration 660m

5.2.4. Real Video Traces (VTR)

   We used a publicly available library of frame size traces of long
   MPEG-4 and H.263 encoded video obtained from
   http://www.tkn.tu-berlin.de/research/trace/trace.html (courtesy
   Telecommunication Networks Group of Technical University of Berlin).

Each trace is roughly 60 minutes in length, consisting of a list of
records in the format of <FrameArrivalTime, FrameSize>. Among the
160 available traces, we picked the two with the highest average rate
(averaged over the trace length, in this case, 60 minutes. In
addition, the two also have a similar average rate). The trace file
used in the simulation is the concatenation of the two. Since the
duration of the flow is much smaller than the length of the trace, we
need to check how does the expect rate of flow related the trace's
long term average. To do so, we simulate a number of flows starting
from random locations in the trace with duration chosen to be
exponentially distributed with mean 1min. The results show that the
expected rate of flow is roughly the same as the trace's average.
Traffic characteristics are summarized below:

o Average rate 769 Kbps

o Each frame is sent with packet length 1500 bytes and packet inter-
   arrival time 1ms

o No traffic is sent between frames.

5.3. Parameter Settings

5.3.1. Queue-based settings

All the queue-based simulations were run with the following Virtual
Queue thresholds:

o virtual-queue-rate: configured admission rate, 1/2 link speed

o min-marking-threshold: 5ms at virtual-queue-rate

o max-marking-threshold: 15ms at virtual-queue-rate

o virtual-queue-upper-limit: 20ms at virtual-queue-rate

At the egress, the CLE is computed as an exponential weighted moving
average (EWMA) on an interval basis, with 100ms measurement interval
chosen in all simulations. We simulated the weight ranging 0.1 to
0.9. The CLE threshold is chosen to be 0.05, 0.15, 0.25, and 0.5.

5.3.2. Token Bucket Settings

The token bucket rate is set to the configured admission rate, which
is half of the link speed in all experiments. Token bucket depth
ranges from 64 to 512 packets. Our simulation results indicate that
depth of token bucket has no significant impact on the performance of
the algorithms and hence, in the rest of the section, we only present

the result with 256 packets bucket depth.

The CLE is calculated in the same way as in queue-based approach with weights from 0.1 to 0.9. The CLE thresholds are chosen to be 0.0001, 0.001, 0.01, 0.05 in this case. Note that the since meaning of the CLE is different for the Token bucket and queue-based algorithms, so there is no direct correspondence between the choice of the CLE thresholds in the two cases.

5.4. Simulation Details

To evaluate the performance of the algorithms, we recorded the actual admitted load at a granularity of 50ms, from which the mean admitted load over the duration of the simulation run can be computed. We verified that the actual admitted load at any time does not deviate much from the mean admitted load in each experiment by computing the coefficient of variation (CV is consistently 0.07 for CBR, 0.15 for VBR, 0.17 for VTR and 0.51 for SVD for all experiments). Finally, the performance of the algorithms is evaluated using a metric called over-admission-percentage, which is calculated as a percentage difference between the mean admitted load and the configured admission rate. Given reasonably small deviation of the admitted rate from the mean admitted in the experiments, this seems reasonable.

5.4.1. Queue-based Results

We found that the virtual-queue admission control algorithm works reliably with the range of parameters we simulated, for all four types of traffic. In addition, for both CBR, VBR and VTR traffic, the performance is insensitive to the parameters change under all tested topologies.

Table A.1 summarized over-admission-percentage values from 15 experiments with different [weight, CLE threshold] settings for CBR, VBR and VTR traffic. For the single bottleneck topologies (S. Link and RTT) the overload column represents the ratio of the demand on the bottleneck link to the configured admission threshold. For parking lot topologies we report the worst case result across all bottlenecks.

While in our simulations we tested the range of overload from 0.95 to 5, we present here only the results of the endpoints of this overload interval. For the intermediate values of overload the results are even closer to the expected ones than at the two boundary loads. The statistics show that for CBR, VBR and VTR traffic these over-admission-percentage values are rather similar across these traffic types, with the admitted load roughly staying within -2%+2% range of

the desired admission threshold, with quite limited variability
across the experiments (see the Standard Deviation column). Note
also that this is not always true for all experiments with 0.95
average load due to the variability of traffic generation.

Over Admission Perc Stats				Over Load	Topo	Type
Min	Mean	Max	SD			
0	0	0	0	0.95	S.Link	CBR
0.224	0.849	1.905	0.275	5		
0	0	0	0	0.95	RTT	
0.200	0.899	1.956	0.279	5		
-1.06	-0.33	-0.15	0.228	0.95	PLT	
-0.58	0.740	1.149	0.404	5		
-1.45	-0.98	-0.86	0.117	0.95	S.Link	VBR
-0.07	1.405	1.948	0.421	5		
-1.56	-0.80	-0.69	0.16	0.95	RTT	
-0.11	1.463	2.199	0.462	5		
-3.49	-2.23	-1.80	0.606	0.95	PLT	
-1.37	0.978	1.501	0.744	5		
0	0	0	0	0.95	S.Link	VTR
-0.53	1.004	1.539	0.453	5		
0	0	0	0	0.95	RTT	
-0.21	1.382	1.868	0.503	5		
0	0	0	0	0.95	PLT	
-0.86	0.686	1.117	0.452	5		

Table A.1 Summarized performance for CBR, VBR and VTR across
different settings.

For SVD, the algorithms does show certain sensitivity to the tested
parameters. Table A.2 recorded the over-admission-percentage for
each combination of weights and CLE threshold.

		EWMA Weights					Over	Topo
		0.1	0.3	0.5	0.7	0.9	Load	
	0.05	-4.87	-3.05	-2.92	-2.40	-2.40		
	0.15	-3.67	-2.99	-2.40	-2.40	-2.40	0.95	
	0.25	-2.67	-2.40	-2.40	-2.40	-2.40		
								Single
C	0.05	-4.03	2.52	3.45	5.70	5.17		Link
L	0.15	-0.81	3.29	6.35	6.80	8.13	5	
E	0.25	2.15	5.83	6.81	8.62	7.95		
T	0.05	-11.77	-8.35	-5.23	-2.64	-2.35		
H	0.15	-9.71	-7.14	-2.01	-2.21	-1.13	0.95	
R	0.25	-5.54	-6.04	-3.28	-0.88	-0.27		
E								RTT
S	0.05	-5.04	-0.65	4.21	6.65	9.90		
S	0.15	-1.02	1.58	7.21	8.24	10.07	5	
H	0.25	-0.76	1.96	7.43	9.66	11.26		
E								
L	0.05	-2.51	-0.85	-0.63	0.025	-0.00		
D	0.15	-1.50	-0.63	-0.02	0.052	-0.02	0.95	
	0.25	-0.26	0.122	0.041	-0.02	0.132		
								PLT
	0.05	-3.50	0.422	1.899	3.339	3.770		
	0.15	-1.04	2.016	3.251	3.880	3.991	5	
	0.25	0.449	2.965	3.066	4.107	4.737		

Table A.2 Over-admission-percentage for SVD

It follows from these results that while performance is tolerable
across the entire range of parameters, choosing the CLE and EWMA
weights in the middle of the tested range appear to be more
beneficial for the overall performance across the chosen range of
overload, assuming the chosen values for the remaining parameters.
The high level conclusion that can be drawn from Table A.2. is that
(predictably) high peak-to-mean ratio SVD traffic is substantially
more stressful to the queue-based admission control algorithm, but a
set of parameters exists that keeps the overadmission within about
-3% - +10% of the expected load even for the bursty SVD traffic.

Note that for SVD traffic these results hold even though there is no
aggregation at all on a per-ingress-egress pair in the chosen RTT
topology there is only a single SVD flow per ingress. In addition,
there seems to be no visible influence by multiple bottleneck
topology, as the results appears to be comparable to the ones in
single bottleneck cases. (Note that it may seem from the data in
A.2, PLT out-performs the Single Link. The reason is that the

bottleneck links in PLT happen to be twice the size of the ones in
SingleLink cases. Given the same admission threshold, this implies
that level of aggregation in PLT is twice as much as in the
SingleLink. Hence, the better results in PLT should be viewed as the
effect of the aggregation rather than the effect multi-bottleneck
topology.)

5.4.2. Token Bucket-based Results

Just as for the case of the queue-based algorithm, under the under-
loaded conditions for voice-like CBR, VBR and VTR traffic the
sensitivity to the tested parameters remains limited for the token-
bucket as well (the latter is summarized in Table A.3).

| Over Admission Perc Stat | | | | Load | Topo | Type |
Min	Mean	Max	SD				
0	0	0	0	0.95	S.Link	
0	0	0	0	0.95	RTT	CBR
-1.17	-0.24	0.023	0.294	0.95	PLT	
-2.00	-0.78	-0.95	0.268	0.95	S.Link	
-2.83	-0.70	-1.20	0.510	0.95	RTT	VBR
-6.19	-2.43	-1.32	1.223	0.95	PLT	
0	0	0	0	0.95	S.Link	
0	0	0	0	0.95	RTT	VTR
0	0	0	0	0.95	PLT	

Table A.3 Summarized performance for CBR, VBR and VTR across
different settings for under-loaded conditions.

However, for the overload conditions (overload greater than 1), the
token bucket-based admission control algorithm shows substantially
higher sensitivity to the parameter settings compared to the virtual
queue based algorithm. Table A.4 shows over-admission-percentage for
different settings. It is important to note here that for the token
bucket-based admission control no traffic will be marked until the
rate of traffic exceeds the configured admission rate by the chosen
CLE. As a consequence, even with the ideal performance of the
algorithms, the over-admission-percentage will not be 0, rather it is

expected to equal to CLE threshold if the algorithm performs as
expected. Therefore, a more meaningful metric for the token-based
results is actually the over-admission-percentage (listed below)
minus the corresponding (CLE threshold * 100). For example, for CLE
= 0.05, one would expect that 5% overadmission is inherently embedded
in the algorithm, with the algorithm by design reacting to 5%
overload (or more) only. Hence, with CLE = 0.05 a 10% over-admission
in the token-bucket case should be compared to a 5% overadmission in
the queue-based algorithm. When comparing the performance of token
bucket (with the adjusted over-admission-percentage) to its
corresponding virtual queue result, we found that token bucket
performs only slightly worse for voice-like CBR VBR, and VTR traffic.

The results for SVD traffic require some additional commentary. Note
from the results in Table A.4. that even for SVD traffic, in the
Single Link topology the performance of the token-based solution is
comparable to the performance of the queue-based scheme in table A.2,
(adjusted by the CLE as discussed above). However, for the RTT
topology, especially for the larger EWMA weights, the performance for
SVD traffic becomes very bad, with up to 42% (adjusted by CLE) over-
admission in a high overload situation (5x). We investigated two
potential causes of this drastic degradation of performance by
concentrating on two key differences between the Single Link and the
RTT topologies: the difference in the round-trip times and the degree
of aggregation in a per ingress-egress pair aggregate.

To investigate the effect of the difference in round-trip times, we
also conducted a subset of the experiments described above using the
RTT topology that has the same RTT across all ingress-egress pairs
rather than the range of RTTs in one experiment. We found out that
neither the absolute nor the relative difference in RTT between
different ingress-egress pairs appear to have any visible effect on
the over-load performance or the fairness of both algorithms (we do
not present these results here as their are essentially identical to
those in Table A.4). In view of that and noting that in the RTT
topology we used for these experiments for the SVD traffic, there is
only 1 highly bursty flow per ingress, we believe that the severe
degradation of performance in this topology is directly attributable
to the lack of traffic aggregation on the ingress-egress pair basis.
We also note that even for this highly challenging scenario, it is
possible to find a range of parameters that limit the overadmission
case for SVD traffic to quite a reasonable range of -3% + 10%
(adjusted by the CLE). Luckily, these are the same parameter
settings that work quite well for the other types of traffic tested.

The overall performance on the multiple-bottleneck topology, for all
types of traffic, is comparable to the ones on the SingleLink, just
as shown in the queue-based results. Again, the results for the PLT

topology may appear better than those of the SingleLink in the table
below. As discussed earlier, this is due to the fact that the
bottleneck capacity of the PLT topology in these experiments is
higher than that of the SingleLink and RTT, topologies (2.4Gbps vs
1Gbps), so the bottleneck aggregation is higher for PLT than for both
single bottleneck topologies. The ingress-egress aggregation of the
PLT topology corresponds to that of a SingleLink.

```
 ---------------------------------------------------------------------
|         |           EWMA  Weights           |Over| Topo | Type|
|         | 0.1  | 0.3  | 0.5  | 0.7  | 0.9  |Load|      |     |
 ---------------------------------------------------------------------
| C 0.0001| -0.99 | 0.09 | 0.24 | 0.41 | 0.43 |    |      |     |
| L 0.001 | 0.02  | 0.37 | 0.43 | 0.46 | 0.45 | 5  | S.   |     |
| E 0.01  | 1.37  | 1.32 | 1.32 | 1.31 | 1.31 |    | Link |     |
|         ------------------------------------------------------     |
| T 0.0001| 6.50  | 7.96 | 8.37 | 8.42 | 8.84 |    |      |     |
| H 0.001 | 7.07  | 8.54 | 8.65 | 8.55 | 8.66 | 5  | RTT  | CBR |
| R 0.01  | 7.93  | 9.08 | 8.71 | 8.63 | 9.40 |    |      |     |
| S ------------------------------------------------------------     |
| H 0.0001| -1.88 | 0.21 | 0.58 | 0.65 | 0.62 |    |      |     |
| L 0.001 | -0.31 | 0.69 | 0.63 | 0.61 | 0.56 | 5  | PLT  |     |
| D 0.01  | 2.032 | 1.98 | 1.97 | 1.99 | 1.96 |    |      |     |
 ---------------------------------------------------------------------
 ---------------------------------------------------------------------
| C 0.0001| -2.95 | -1.39 | -0.63 | 0.23 | 0.78 |    |      |     |
| L 0.001 | -1.51 | -0.23 | 0.44  | 0.63 | 1.39 | 5  | S.   |     |
| E 0.01  | 1.37  | 2.01  | 2.29  | 2.60 | 2.76 |    | Link |     |
|         ------------------------------------------------------     |
| T 0.0001| -1.93 | -0.23 | 0.99  | 2.09 | 3.38 |    |      |     |
| H 0.001 | -0.75 | 0.89  | 2.07  | 3.12 | 4.27 | 5  | RTT  | VBR |
| R 0.01  | 1.91  | 3.42  | 4.35  | 5.36 | 6.38 |    |      |     |
| S ------------------------------------------------------------     |
| H 0.0001| -3.78 | -0.57 | 0.35  | 1.08 | 1.82 |    |      |     |
| L 0.001 | -1.64 | 0.46  | 1.28  | 1.89 | 2.37 | 5  | PLT  |     |
| D 0.01  | 1.871 | 2.74  | 3.24  | 3.39 | 3.86 |    |      |     |
 ---------------------------------------------------------------------
 ---------------------------------------------------------------------
| C 0.0001| -2.37 | 0.00 | 0.79 | 0.83 | 1.07 |    |      |     |
| L 0.001 | -0.64 | 0.67 | 0.79 | 1.04 | 1.08 | 5  | S.   |     |
| E 0.01  | 1.59  | 1.64 | 1.66 | 1.79 | 2.04 |    | Link |     |
|         ------------------------------------------------------     |
| T 0.0001| -1.09 | 0.86 | 1.29 | 1.57 | 1.98 |    |      |     |
| H 0.001 | 0.00  | 1.39 | 1.63 | 1.86 | 2.58 | 5  | RTT  | VTR |
| R 0.01  | 1.99  | 2.32 | 2.88 | 3.54 | 4.35 |    |      |     |
| S ------------------------------------------------------------     |
| H 0.0001| -1.99 | 0.09 | 0.58 | 0.96 | 1.15 |    |      |     |
| L 0.001 | -0.55 | 0.57 | 1.09 | 1.30 | 1.49 | 5  | PLT  |     |
```

```
   | D 0.01  | 2.22  | 2.44  | 2.42  | 2.61  | 2.65  |    |      |     |
    ----------------------------------------------------------------------
    ----------------------------------------------------------------------
   |    0.0001| -10.67|-10.58 | -7.95 | -6.27 | -4.99 |    |      |     |
   |    0.001 | -8.67 | -8.04 | -7.61 | -4.37 | -2.89 |0.95|      |     |
   |    0.01  | -4.28 | -2.59 | -4.44 | -2.13 | -2.20 |    | S.   |     |
   | C -------------------------------------------------| Link |     |
   | L 0.0001| -16.36|-10.24 | -6.50 | -2.17 | 2.74  |    |      |     |
   | E 0.001 | -10.54| -5.63 | -2.70 | 0.94  | 3.54  | 5  |      |     |
   |    0.01  | -4.11 | 1.26  | 5.38  | 5.75  | 8.82  |    |      |     |
   |    -------------------------------------------------------     |
   | T 0.0001| -15.83|-10.35 | -2.96 | 0.17  | 5.42  |    |      |     |
   | H 0.001 | -12.82| -7.62 | -0.47 | 2.24  | 6.59  |0.95|      |     |
   | R 0.01  | -6.17 | -0.11 | 2.16  | 5.28  | 10.34 |    |      |     |
   | E -------------------------------------------------| RTT  | SVD |
   | S 0.0001| -8.51 | 1.86  | 11.14 | 22.51 | 30.24 |    |      |     |
   | S 0.001 | -4.80 | 1.49  | 15.35 | 24.56 | 33.96 | 5  |      |     |
   | H 0.01  | 0.56  | 8.26  | 25.71 | 35.63 | 42.72 |    |      |     |
   | O -----------------------------------------------------------     |
   | L 0.0001| -12.35| -8.73 | -7.46 | -5.97 | -5.95 |    |      |     |
   | D 0.001 | -9.06 | -7.66 | -5.99 | -5.19 | -4.77 |0.95|      |     |
   |    0.01  | -5.13 | -4.77 | -4.62 | -3.54 | -3.52 |    |      |     |
   |    -------------------------------------------------| PLT  |     |
   |    0.0001| -10.07| -5.05 | -3.17 | 0.75  | 2.138 |    |      |     |
   |    0.001 | -7.41 | -3.38 | -0.53 | 1.89  | 5.071 | 5  |      |     |
   |    0.01  | -0.81 | 2.816 | 5.115 | 6.03  | 6.421 |    |      |     |
    ----------------------------------------------------------------------
```
Table A.4. Token bucket admission control performance.

An additional differences in token-bucket case vs the queue-based
admissions in the PLT topology case revealed in our experiments is
that there appears to be a consistent relationship between the
position of the bottleneck link (how far downstream it is) and its
over-admission-percentage. In Table A.5, we show a snapshot of the
behavior with 5 bottleneck topology. Here, the over-admission-
percentage displayed is an average across all 15 experiments with
different [weight, CLE] setting. (We do observe the same behavior in
each of the individual experiment, hence providing a summarized
statistics does not invalidate the results). The data shows the
further downstream the bottleneck is, the more it tends to over-
admit, regardless the type of the traffic. The exact cause of this
phenomenon is yet to be explained, but the effect of it seems to be
insignificant in magnitude, at least in the experiments we ran.

```
    ----------------------------------------------------------
   | Traffic |           Bottleneck LinkId        | Over |
   |  Type   |   1   |   2   |   3   |   4   |   5   | Load |
    ----------------------------------------------------------
   |   CBR   | 0.270 | 0.421 | 0.529 | 0.669 | 0.791 |   5   |
   |----------------------------------------------------------
   |   VBR   | 0.152 | 0.512 | 0.715 | 0.901 | 1.169 |   5   |
   |----------------------------------------------------------
   |   VTR   | 0.350 | 0.492 | 0.756 | 0.874 | 1.125 |   5   |
    ----------------------------------------------------------
```

Table A.5 Summarized performance for CBR, VBR and VTR across the
links in the PLT topology for Token Bucket Admission

6. IANA Considerations

This document places no requests on IANA.

7. Security Considerations

TBD

8. References

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