Congestion Management – Congestion Isolation

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Agenda

- Low-Latency, Lossless, Large-Scale DCNs
- Challenges going forward
- Solution Goals
- Congestion Isolation Details
- Simulation Analysis
- Next Steps
The Case for Low-latency, Lossless, Large-Scale DCNs

- More and more latency-sensitive applications are being deployed in data centers
  - Distributed Storage
  - AI / Deep Learning
  - Cloud HPC
  - High-Frequency Trading

- RDMA is operating at larger scales thanks to RoCEv2
  - Chuanxiong Guo, et. al., Microsoft, ”RDMA over Commodity Ethernet at Scale”, SIGCOMM 2016

- The scale of Data Center Networks continues to grow
  - Larger, faster clusters are better than more smaller size clusters
  - Server growth continues at 25% - 30% putting pressure on cluster sizes and networking costs
Lossless DCN state-of-the-art

- DCN is primarily an L3 network
- ECN used for end-to-end congestion control
- Congestion feedback can be protocol and application specific
- PFC used as a last resort to ensure lossless environment, or not at all in low-loss environments.
- Traffic classes for PFC are mapped using DSCP as opposed to VLAN tags
Scaling larger makes lossless more difficult

- Increased number of congestion points
- More data in-flight
- Increased RTT and delay for congestion feedback
- Increased switch buffer requirements
- Increased use of PFC
- Increased number of victim flows due to HoLB
Switch buffer growth is not keeping up

KB of Packet Buffer by Commodity Switch Architecture

Commodity Shallow Buffer Switches in DCNs are desirable:
- Low Latency
- Low Cost

However, packet loss can create performance issues:

Source: “Congestion Control for High-speed Extremely Shallow-buffered Datacenter Networks”. In Proceedings of APNet’17, Hong Kong, China, August 03-04, 2017, https://doi.org/10.1145/3106989.3107003
Concerns about over-using PFC

- HoL blocking
- Congestion spreading
- Buffer Bloat, increasing latency
- Increased jitter reducing throughput
- Deadlocks
Goals

- Support larger, faster data centers (Low-Latency, High-Throughput)
- Support lossless transfers
- Improve performance of TCP and UDP based flows
- Reduce pressure on switch buffer growth
- Reduce the frequency of relying on PFC for a lossless environment

- Eliminate or significantly reduce HOLB caused by over-use of PFC
Isolate the congestion to mitigate HOLB

Isolate

Congestion

Congestion

Flow Queue

Normal Queue

PFC

HOL

CIP

CIP
Congestion Isolation

**Definition:** An approach to isolate flows causing congestion and signal upstream to isolate the same flows to avoid head-of-line blocking.

The approach involves:

1. Identifying the flows creating congestion (e.g. perhaps already done for QCN and/or ECN)
2. Using implementation specific approaches to dynamically adjust the traffic class of offending flows without packet re-ordering (e.g. DVL – Dynamic Virtual Lanes)
3. Signaling upstream indications via a Congestion Isolation Packet (CIP)
Congestion Isolation with Dynamic Virtual Lanes

**Non-Congested Flow Queue**: Normal priority queues. Higher scheduling priority than Congested Flow Queue.

**Congested Flow Queue**: At least one of 8 priority queues. Lower scheduling priority than Non-Congested Flow Queue. Scheduling assures no out-of-order packets with Non-Congested Flow Queue. There can be multiple congested flow queues (use 5-tuple hash to map one).

1) When congestion occurs, detect the congested flow, record it in the flow table.
3) When Congested Flow Queue exceed the threshold, send CIP (including the flow info, such as 5-tuple info) to upstream to isolate the congested flow.

CIP: Congestion Isolation Packet

2) Isolate the subsequent packets of congested flow to Congested Flow Queue.
4) Upstream switch receive CIP, parse the 5-tuple, check the flow table and isolate the congested flow into Congested Flow Queue.
5) When Congested Flow Queue exceed the threshold, send CIP (including flow info) to upstream to isolate this congested flow.

Congestion Isolation with Dynamic Virtual Lanes

Switch A

Switch B
Congestion Isolation with Dynamic Virtual Lanes

6) When Congested Flow Queue exceed the high-level threshold, Queue Level Pause is triggered, such as PFC.

Switch A

Transmit Queue

Switch B

Transmit Queue

Congested Flow Queue

PFC Pause

Non-Congested Flow Queue

Congested Flow Queue

PFC Pause

Non-Congested Flow Queue

Non-Congested Flow

Congestion Isolation with Dynamic Virtual Lanes
Congestion Isolation Packet

- Objectives/Requirements:
  - Provide upstream neighbor with an indication that a flow has been isolate
  - Provide upstream neighbor with flow identification information
  - No adverse effects of single packet loss
  - Low overhead

## Format of Congestion Isolation Packet

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dest MAC Address</td>
<td>Upstream Port Mac Address</td>
</tr>
<tr>
<td>Src MAC Address</td>
<td>Current Output Port Mac Address</td>
</tr>
<tr>
<td>Ethertype = 0x8809</td>
<td>New Ethernet Type</td>
</tr>
<tr>
<td>Flow Identification Data (TBD)</td>
<td>Flow identifying Information (e.g. IP Header, Transport Header, Virtualization/Tunnel encapsulation).</td>
</tr>
<tr>
<td>CRC</td>
<td></td>
</tr>
</tbody>
</table>
Handling the potential out-of-order problem

Red is judged as a congested flow
Set markers and queue packet in congested queue

Congested Queue Mark Counter  Non-Congested Queue Mark Counter

Congested flow Queue

Non Congested
Non-congesting flows may continue to enter the non-congested queue.
Congested Queue
Mark Counter

Non-Congested Queue
Mark Counter

1
<
1

Congested flow Queue

Non Congested

Schedule: Blocked

Congested Queue

Non-Congested Queue
Subsequent red packets queue in the congested queue

Congested Queue Mark Counter < Non-Congested Queue Mark Counter

Congested flow Queue

Non Congested

Schedule: Blocked
Congested Queue Mark Counter  Non-Congested Queue Mark Counter

\[ 1 < 1 \]

Congested flow Queue

Non Congested

Schedule: Blocked
Purple is judged as a congested flow.
Set markers and queue packet in congested queue.

Schedule: Blocked
Congested Queue Mark Counter \( \leq \) Non-Congested Queue Mark Counter

Congested flow Queue: 6 4 T 5 4 T

Non Congested: T 2 2 T 1 3 2

Schedule: Blocked

Non-congested queue drains while congested queue is blocked
Initial marker reaches head of non-congested queue
Congested queue mark counter is now greater

Congested Queue Mark Counter > Non-Congested Queue Mark Counter

Congested flow Queue

Schedule: Blocked

Non Congested
Decrement congested queue mark counter and schedule congested flow queue
Congested Queue Mark Counter  Non-Congested Queue Mark Counter

1 1

Congested flow Queue

Schedule: WRED

Non Congested
Congested Queue
Mark Counter

1

Non-Congested Queue
Mark Counter

1

Congested flow Queue

Schedule: WRED
Marker reaches head of congested flow queue: block scheduling.

Schedule: Blocked
**Congested Queue Mark Counter**

**Non-Congested Queue Mark Counter**

\[
\begin{array}{c}
< \\
1 \\
1 \\
\end{array}
\]

**Congested flow Queue**

<table>
<thead>
<tr>
<th>7</th>
<th>6</th>
<th>5</th>
<th>4</th>
<th>T</th>
</tr>
</thead>
</table>

**Non Congested**

| 3 | 3 | T |

**Schedule: Blocked**

Client or partner's logo is placed in the top right corner.
Congested queue mark counter is greater than non-congested queue mark counter.

Congested flow Queue: 8 7 6 5 4 T
Non Congested: 3 3

Schedule: Blocked
Decrement congested queue mark counter and schedule congested flow queue.

Schedule: WRED
Congested Queue
Mark Counter

0

Congested flow Queue

7 8 7 6 5 6 4

Non Congested

Schedule: WRED

Non-Congested Queue
Mark Counter

0
Simulation Set-up

- OMNET++ Platform
- 2 Tier CLOS: 100G interface with 200ns of link latency 200ns (about 40m)
- Scale: 128 ~ 1152 servers, 24 ~ 72 switches
- Traffic Patterns:
  - Several regional all to all with some persistent incast
  - Flow size distribution is from 5 different real data center applications:
    - Enterprise IT, WebServer, Hadoop, Data Mining, Cache-Follower
- Compared Solutions:
  - PFC+ECN with CI: Congestion Isolation is implemented along with PFC+ECN
  - PFC+ECN without CI: Just PFC+ECN
  - All solutions include small flow prioritization mechanism
Traffic Pattern 1: Data Mining

Mice: Under 100-KB Flow Completion Times

The most pronounced difference in Flow Completion Times between the Cisco and Arista switches occurs when we focus on the smallest flow sizes, under 100 kilobytes, as shown in the following graph.

<table>
<thead>
<tr>
<th>Traffic Pattern 1: Data Mining</th>
<th>Traffic Pattern 1: Data Mining</th>
</tr>
</thead>
<tbody>
<tr>
<td>The mainstream definition of the Mice: Flows under 100KB</td>
<td></td>
</tr>
<tr>
<td>In Data Mining workload, the proportion of the Mice is about 82%</td>
<td></td>
</tr>
</tbody>
</table>

(Source: Miercom/Cisco, 2016, Speeding Applications in Data Center Networks)

The traffic applied in the testing was modelled to reflect real-world data-mining applications. Elephant flows comprised just about 5 percent of the number of flows, but 95 percent of the total data volume. The following chart shows the TCP flow size distribution for this data-mining application. Custom scripts were written to create random flows, which collectively followed distribution based on these percentages.

The key metric sought from this testing was Flow Completion Time, or FCT – the time it took each flow to finish. Flow completion time is used instead of typical metrics such as: average link...
Traffic Pattern 2: Enterprise IT

In addition to the data mining traffic profile, we also ran the tests with a typical large enterprise IT data center traffic profile that we gathered from analysis of a real data center. The following graph shows the flow sizes distribution.

- In Enterprise IT workload, the proportion of the Mice is much bigger, about 95%

Average Flow Completion Time is a popular metric to evaluate network performance.
Traffic Pattern 3~5

(a) Web servers
(b) Cache follower
(c) Hadoop

- In Web Server workload, the proportion of the Mice is about 92%
- In Cache Follower workload, the proportion of the Mice is about 60%
- In Hadoop workload, the proportion of the Mice is about 90%

(Source: Facebook, 2015, Inside the Social Network's (Datacenter) Network)
PFC+ECN with CI VS. PFC+ECN without CI

- CI reduces the count of PAUSE Frames sent to NICs of servers, so it can alleviate the HOL Blocking of the NIC, which can improve the performance of mice flows.
- In the PFC+ECN without CI, we also prioritize the mice.

- 25% reduction in Average flow completion time (all flows)
- 26% reduction in Average flow completion time (>10MB flows)
- 26% reduction in Average flow completion time (1MB~10MB flows)
- 36% reduction in Average flow completion time (100KB~1MB flows)
- 15% reduction in Average flow completion time (<100KB flows)
Why PFC+ECN with CI outperforms PFC+ECN without CI

- CI reduces the pause frame count by 53%.
- CI reduces the CNP count by 57%.
- The count of new control message generated by CI is much less than the count it reduces the count of Pause frames.
- It has the same order-of-magnitude with large flow count.
Why PFC+ECN with CI outperforms PFC+ECN without CI

- 96.6% of the pause frames are generated by congested flow queues

- The count of isolated flows is quite small. In our simulation with 22188 flows and 1152 server nodes. The proportion is 2% for total flows, and 12% for large flows.
- So the HOLB only occurs among the congested flows
Comparison for different scale

Average flow completion time (128 servers)

Average flow completion time (288 servers)

Average flow completion time (512 servers)

Average flow completion time (1152 servers)
Comparison for different workload – Flow Completion Times

- **Enterprise IT Workload** (95% mice flow): 11%
- **Webserver Workload** (92% mice flow): 19%
- **Hadoop Workload** (90% mice flow): 22%
- **Data Mining Workload** (82% mice flow): 25%
- **Cache Follower Workload** (60% mice flow): 46%
Summary

- Current data center design will be challenged to support the needs of large scale, low-latency, lossless networks.

- Congestion Isolation provides the following benefits:
  - Supports lossless as well as low-latency
  - Mitigates Head-of-Line blocking caused by PFC
  - Improves average flow completion times
  - Reduces or eliminates the need for PFC on non-congested flow queues

- Next Steps
  - Call for interest in creating a project
  - Respond to comments and feedback
Thank you

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Options for reliable CIP transmission

- Send several (such as 3) CIPs in succession to provide redundancy.

- Send CIPs periodically. Upstream send an ACK when it has received a CIP. Downstream stop to send CIP until it has received an ACK.

- Send CIPs periodically. Upstream mark the subsequent packets when it has received a CIP. Downstream will know that the upstream has isolated successfully according to the marked packets and stop sending CIPs.
Buffer requirement of CI

- CI makes intelligent use of buffer memory.

- CI can leverage the existing low priority queue to isolate congested flows, so it won’t increase the switch buffer size.

- Theoretically, CI can reduce the switch buffer requirement because it alleviates the HOLB and decreases arising of queue building up (need to research further).