Network Best Practices for Artificial Intelligence Data Centre

Chris Lapp
Solutions Engineer
America's Cloud & AI Infrastructure
BRKDCN-2921

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About Me

- Based In Ontario Canada
- @Cisco 4.5 years
- Background in M&E Engineering

Agenda

- Why AI is important today and, in the future
- Network For AI Cluster
- Traffic Load-balancing
- Automation and Visibility
- The Blueprint For Today

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What do you think about AI

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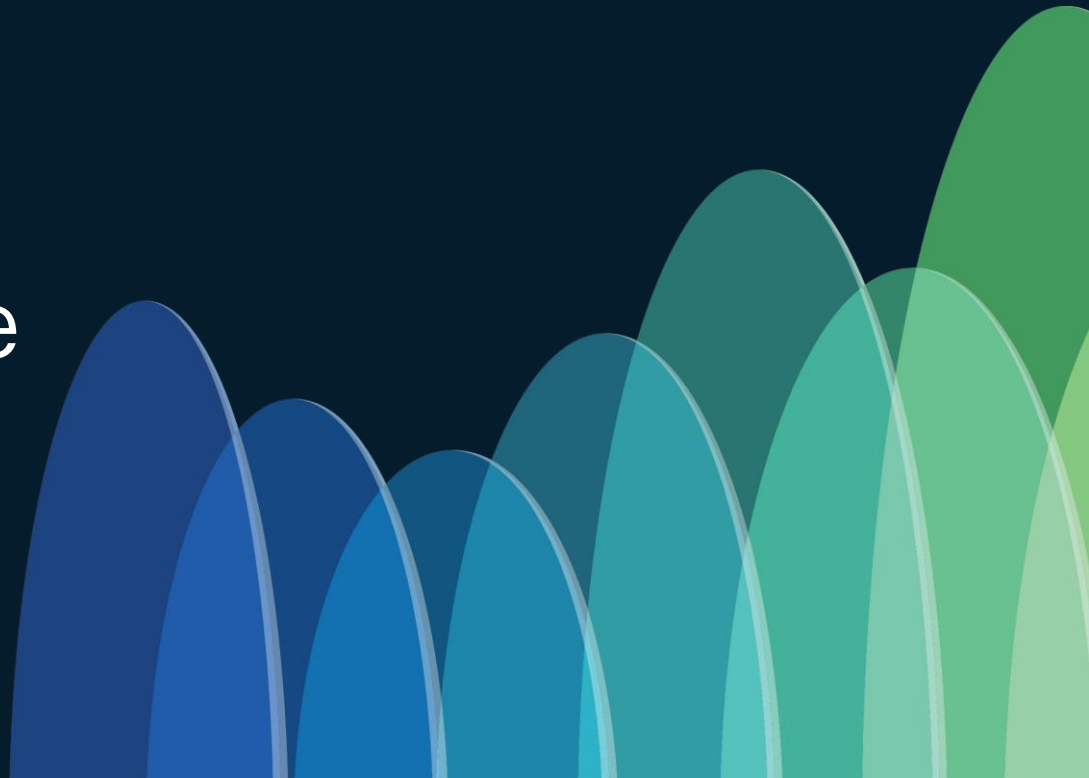
Why AI is important today and, in the future



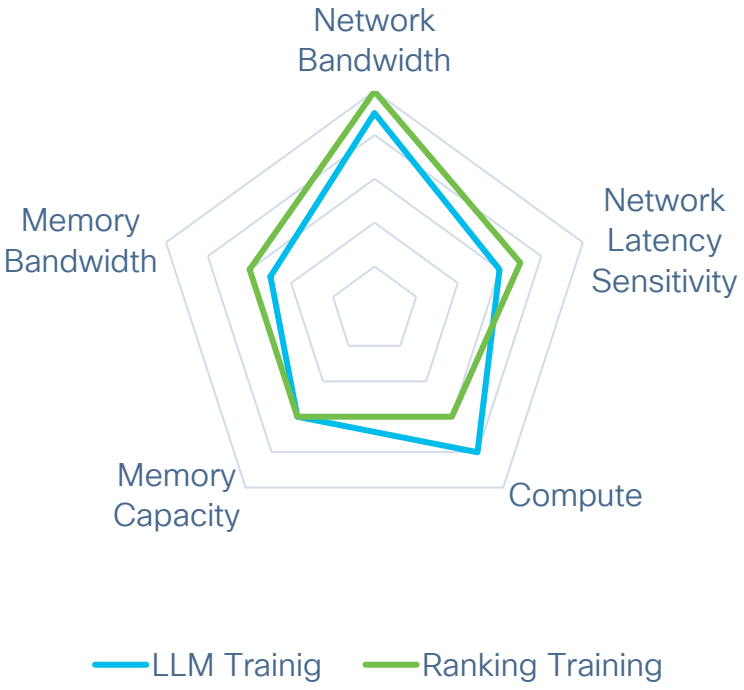
AI/ML can help many industries

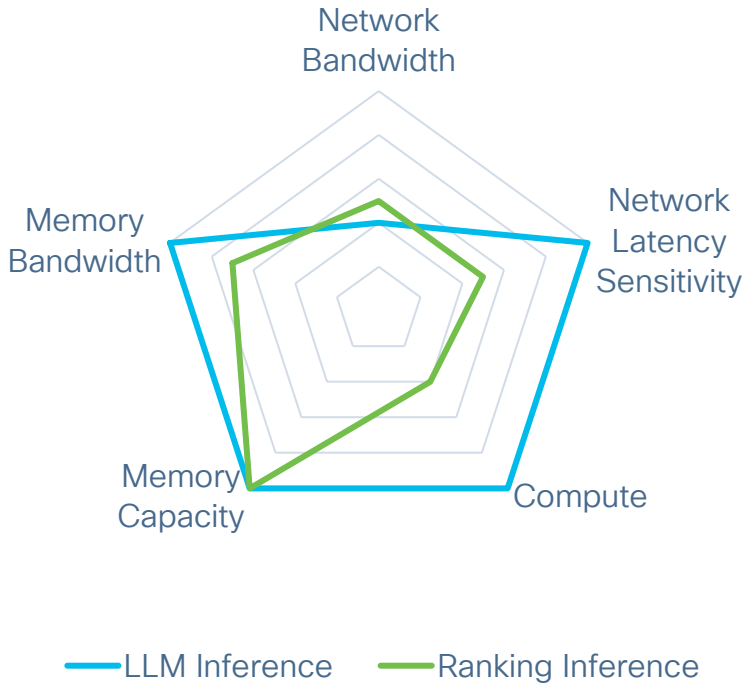
Healthcare	Financial Services	Public Sector	Media and Entertainment	Manufacturing	Retail
Medical Risk Prediction	High Frequency Trading Analysis	Intelligent Public Transport	Content Generation	Visual Inspection	Personalized Recommendation
Early diagnostics	Quant Research	Security Log Analytics	Natural Language Processing	Anomaly Detection	Demand Forecasting
Medical Research	Fraud and Risk Analytics	Disaster Recovery Assistance	Content Classification	Asset Management	Visual Search

AI cluster types and interaction with network

	Distributed Training	Production Inference
Node to Node Bandwidth	High	Low
Key Metric	Training time of a model	High Availability and Latency
Operational Mode	Model training is offline	Usually online, requires real time response
Infrastructure requirement	Large network with many GPU/CPU hosts	Smaller network with mid size of CPU/GPU hosts

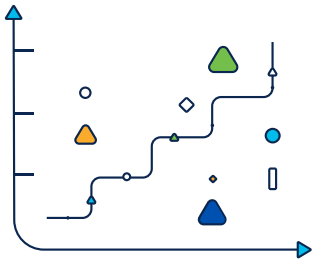
Training vs Inference





Large-scale distributed training

- Key Challenge of Training Cluster
  - Model Doubles every 2 months
  - Bigger model, higher accuracy
  - Most common single training runs on 512 GPUs



- Cluster Key Components
  - Compute Nodes
  - Network
  - Distributed File System/Storage
  - Job Scheduling and Orchestration
  - Software Framework for AI model

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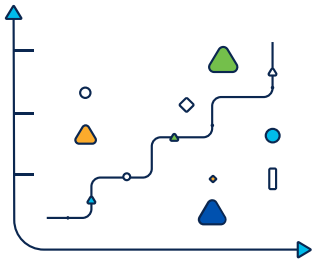

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Audience Q&A

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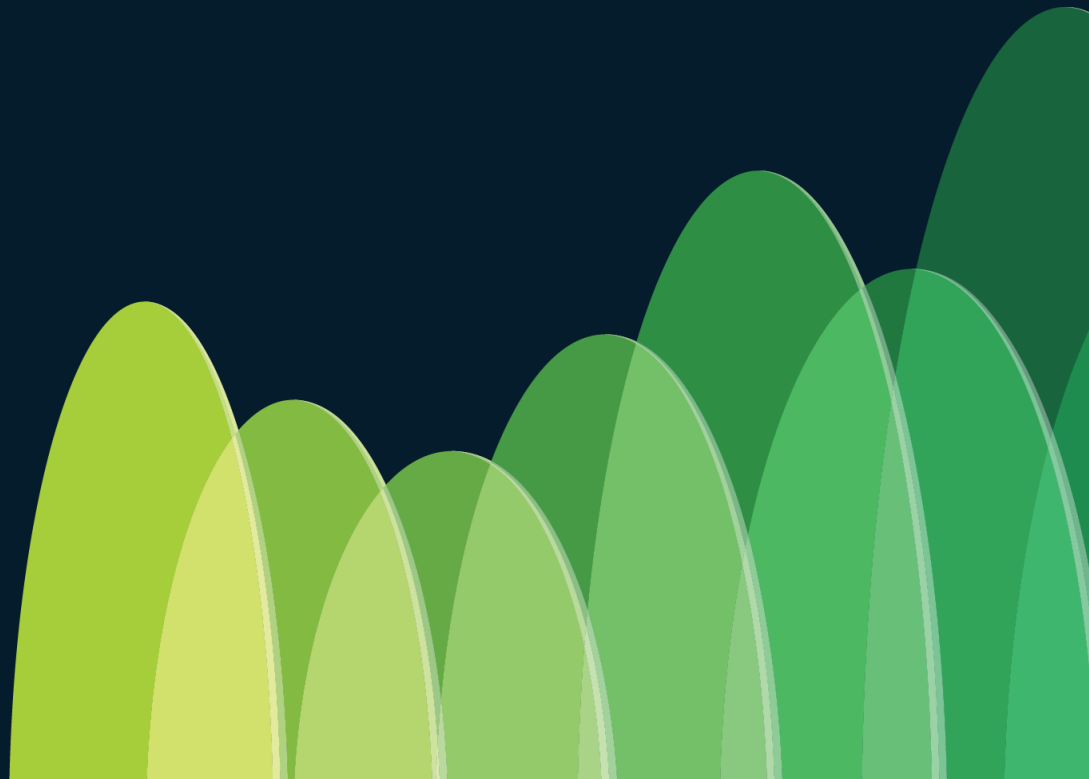
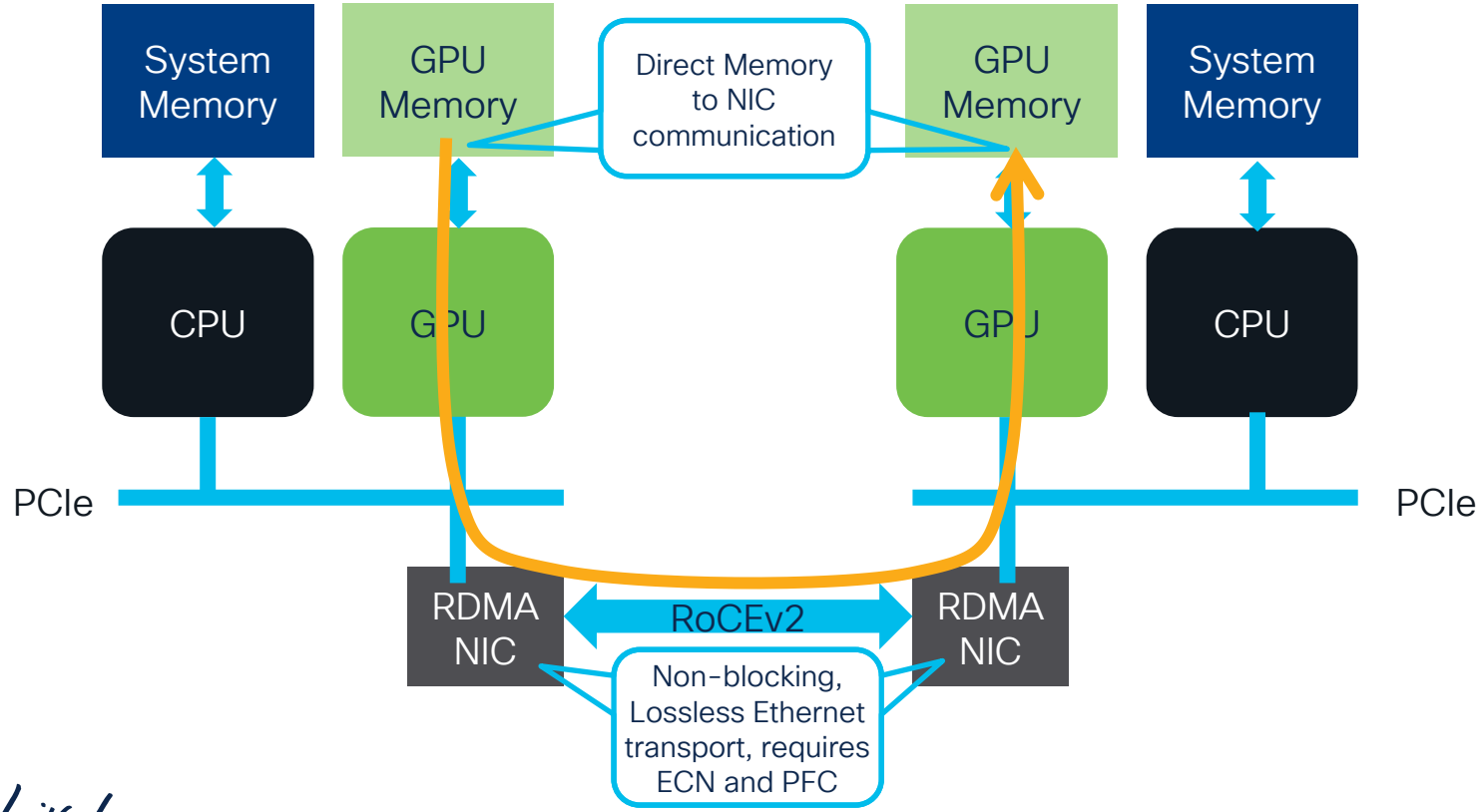
Network For AI Cluster



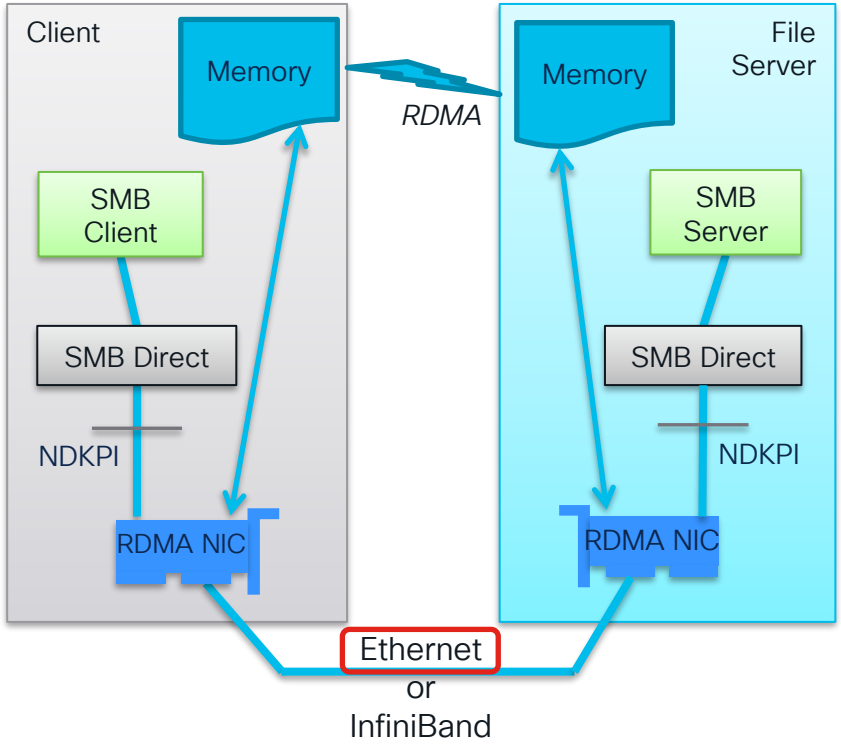
cisco Live!

RoCEv2 – benefits and requirements



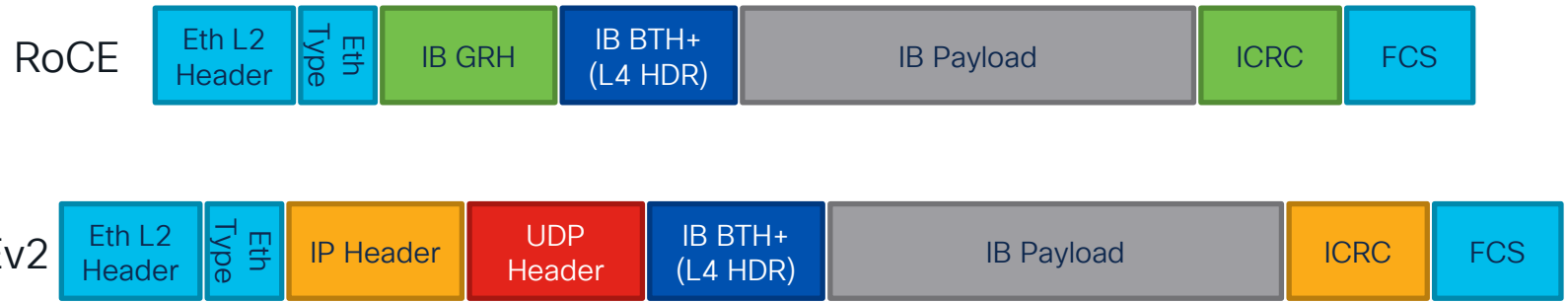
RDMA – remote data memory access

- Allows application software to communicate directly with the hardware (RDMA NIC)
- Bypasses OS stack
- RDMA delivers, low latency, high throughput, zero copy capabilities
- RDMA Hardware Technologies
  - RoCE: RDMA over Converged Ethernet
  - iWARP: RDMA over TCP/IP
  - Infiniband



RoCEv2 – basics

- Extension of RoCE protocol that involves a simple modification of the RoCE packet format
- Carry IP header and UDP header that serves as a stateless encapsulation layer for RDMA transport over IP



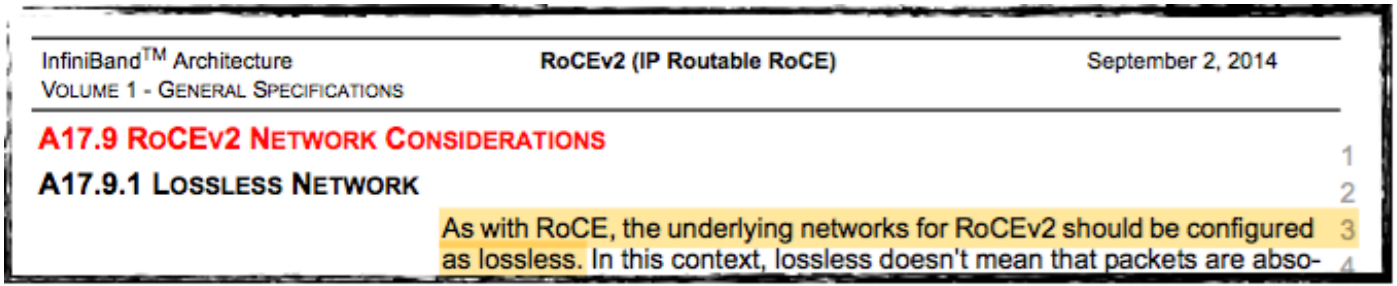
Source: https://en.wikipedia.org/wiki/RDMA_over_Converged_Ethernet

RoCEv2

- Uses well-known UDP Destination Port (dport) value 4791
- UDP Source Port (sport) serves as opaque flow identifier that can be used by networking infrastructure for packet forwarding optimizations (e.g., ECMP)
- Supports both IPv4 and IPv6
- Makes use of ECN field in IPv4/6 header for signaling of congestion

RoCEv2 End-To-End lossless behavior

- Requires PFC to be enabled for RoCEv2 transport
- Traffic priority to be preserved between Layer 2 and Layer 3 network
  - Packet/Flow identification follows standard practices of IP/Ethernet networks (i.e., DSCP/802.1Q)
- ECN marking (WRED or consider AFD)
- Configure ETS
  - 802.1Qaz ETS



InfiniBand™ Architecture
VOLUME 1 - GENERAL SPECIFICATIONS

RoCEv2 (IP Routable RoCE)

September 2, 2014

A17.9 RoCEv2 Network Considerations

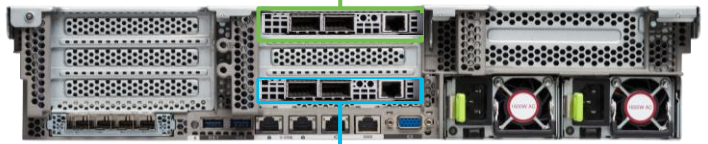
A17.9.1 Lossless Network

As with RoCE, the underlying networks for RoCEv2 should be configured as lossless. In this context, lossless doesn't mean that packets are abso-

Networks – Why do I need them?

UCS C240 M7 Rack Server
Up to 2 GPUs

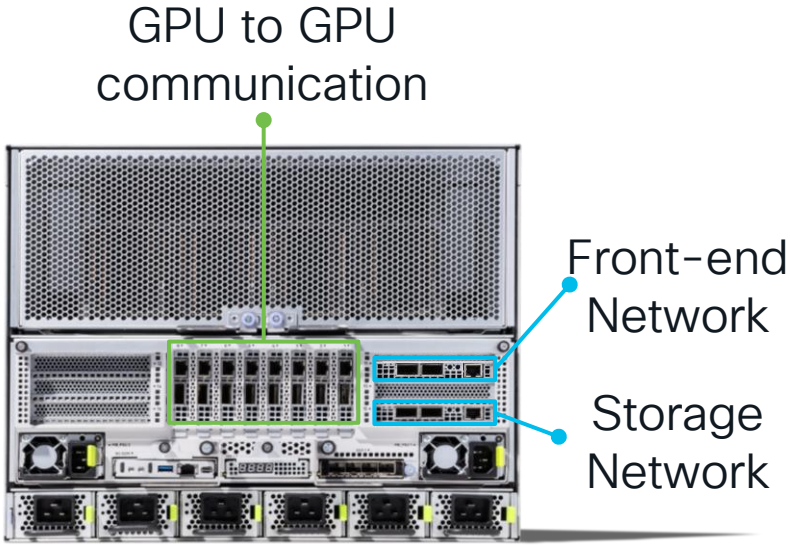
GPU to GPU
communication



Front-end and
Storage Network

Networks – Why do I need them?

UCS C885A M8 Rack Server
8 GPUs



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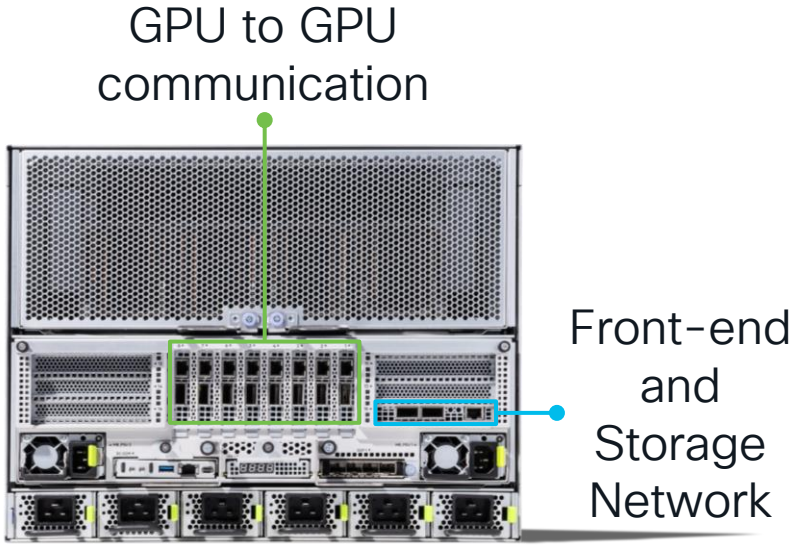
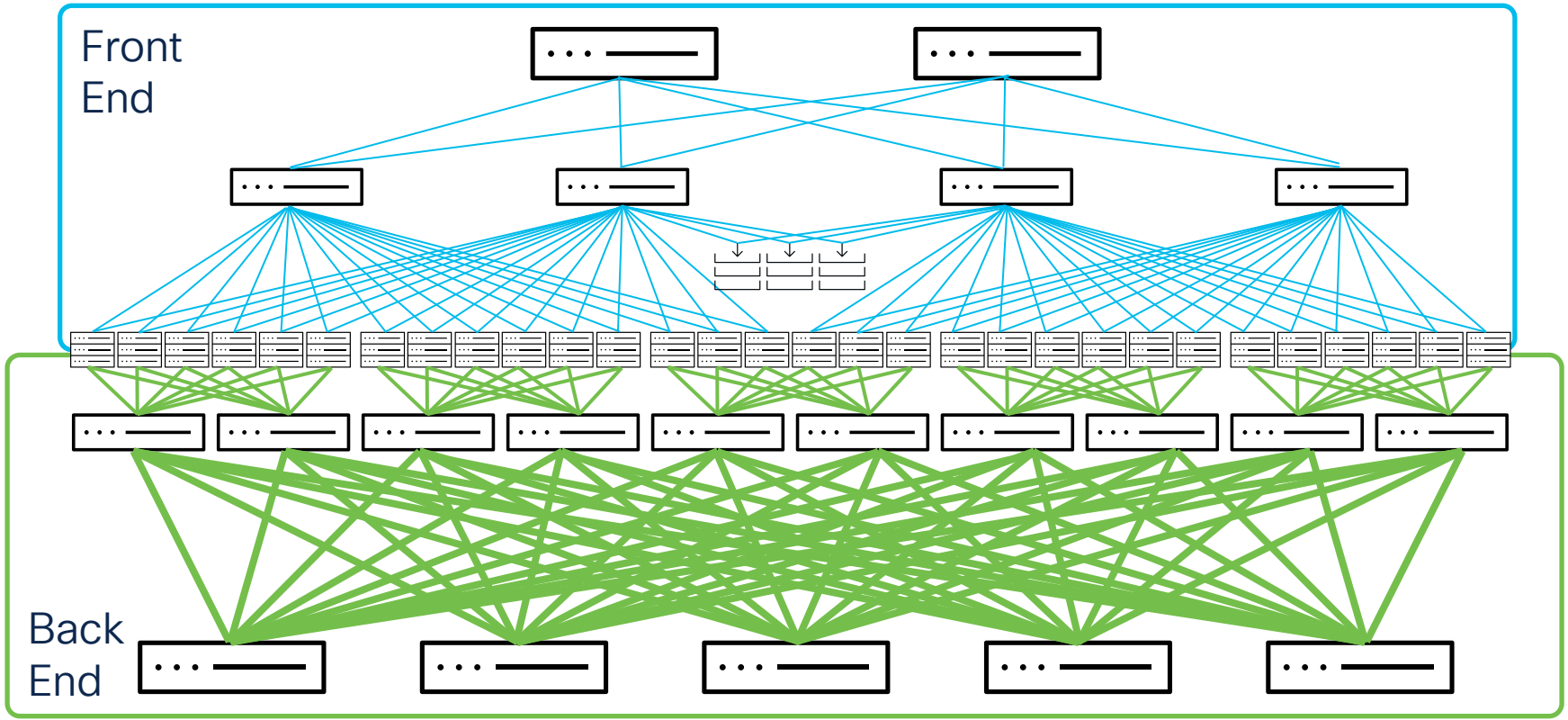


Non-blocking network



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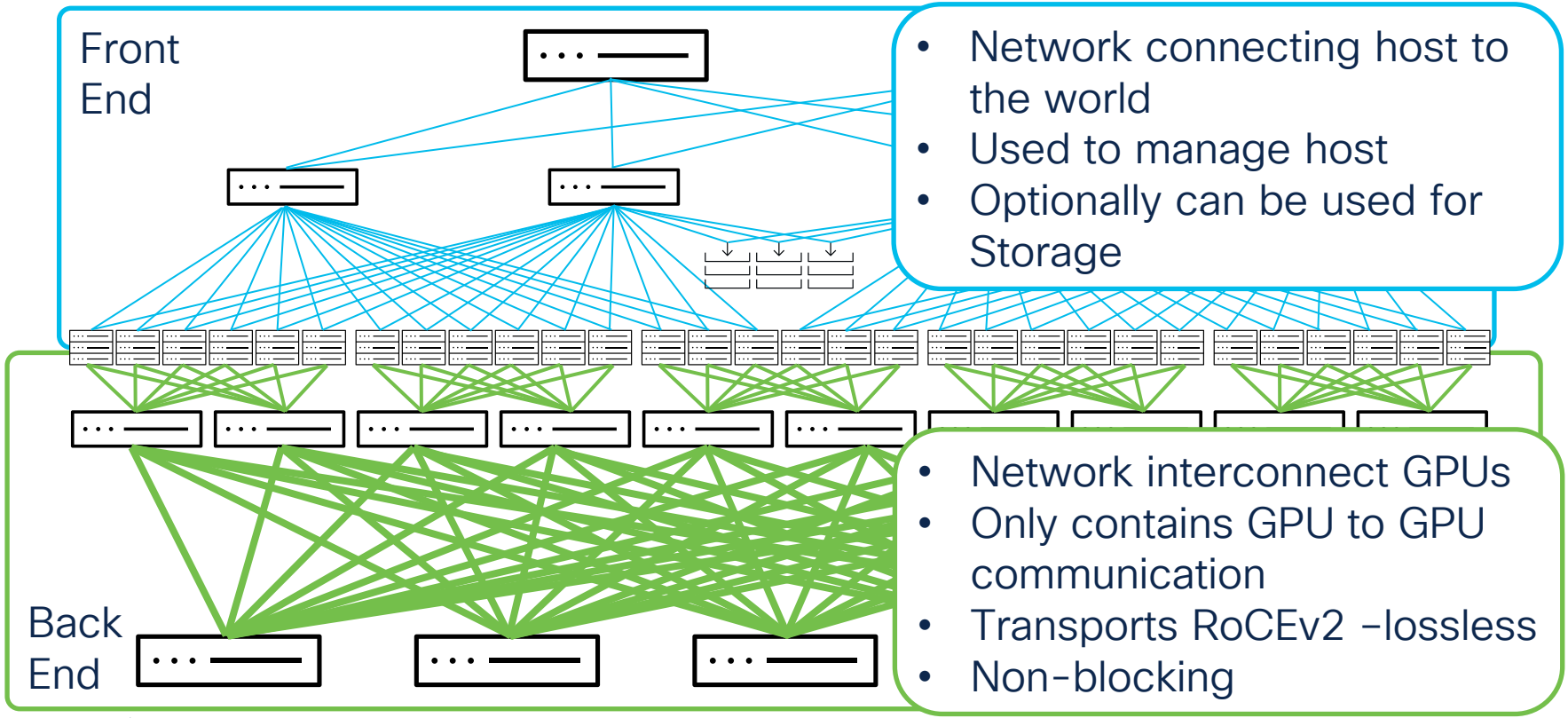

- Network connecting host to the world
- Used to manage host
- Optionally can be used for Storage

- Network interconnect GPUs
- Only contains GPU to GPU communication
- Transports RoCEv2 –lossless
- Non-blocking

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Audience Q&A

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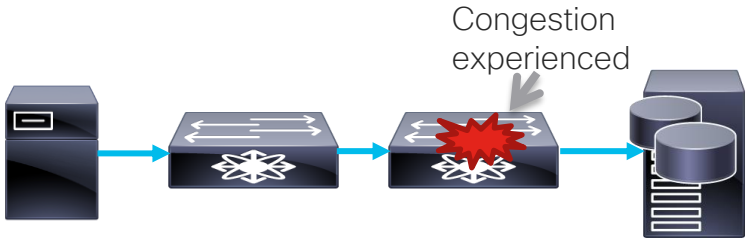
Explicit Congestion Notification (ECN)

- IP Explicit Congestion Notification (ECN) is used for congestion notification.
- ECN enables end-to-end congestion notification between two endpoints on IP network
- ECN uses 2 LSB of Type of Service field in IP header



ECN	ECN Behavior
00	Non ECN Capable
10	ECN Capable Transport (0)
01	ECN Capable Transport (1)
11	Congestion Encountered

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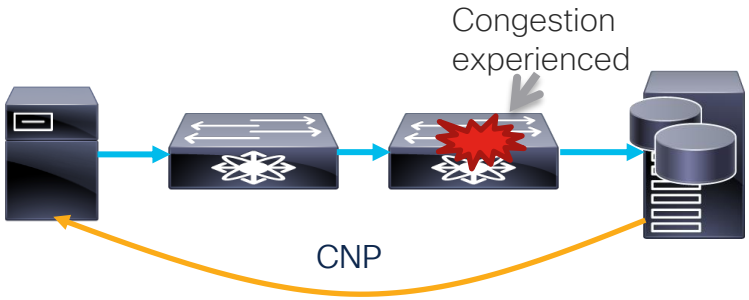
- In case of congestion, ECN gets transmitting device to reduce transmission rate using Congestion Notification Packet (CNP) without pausing traffic.



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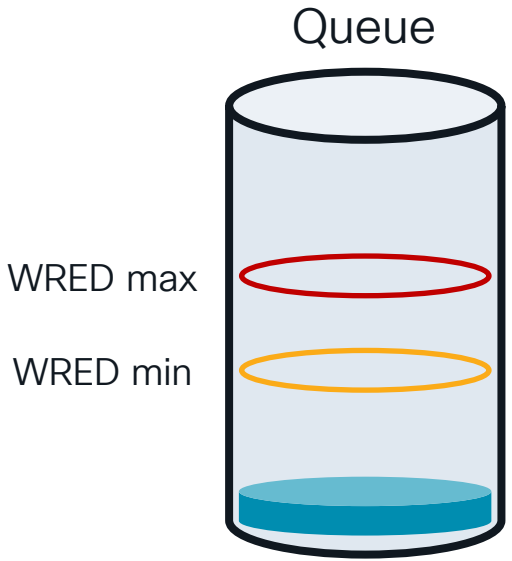
- ECN is not marked when buffer usage is below WRED min threshold



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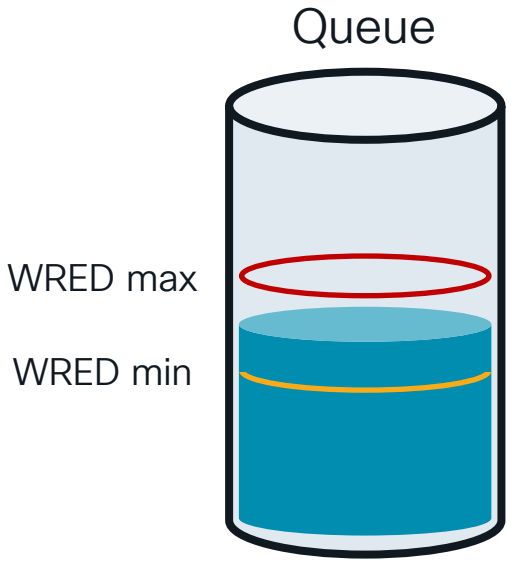

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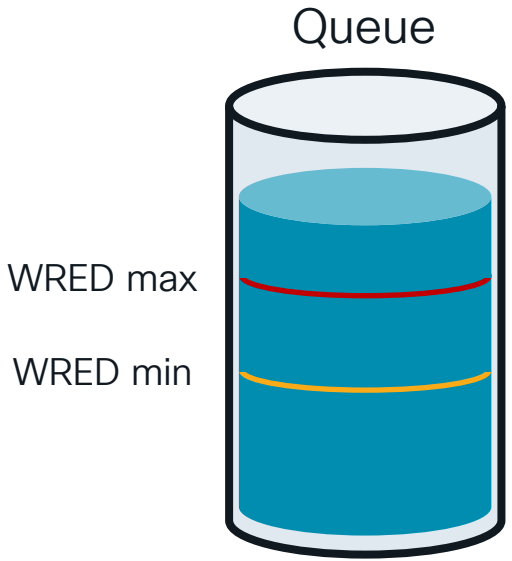
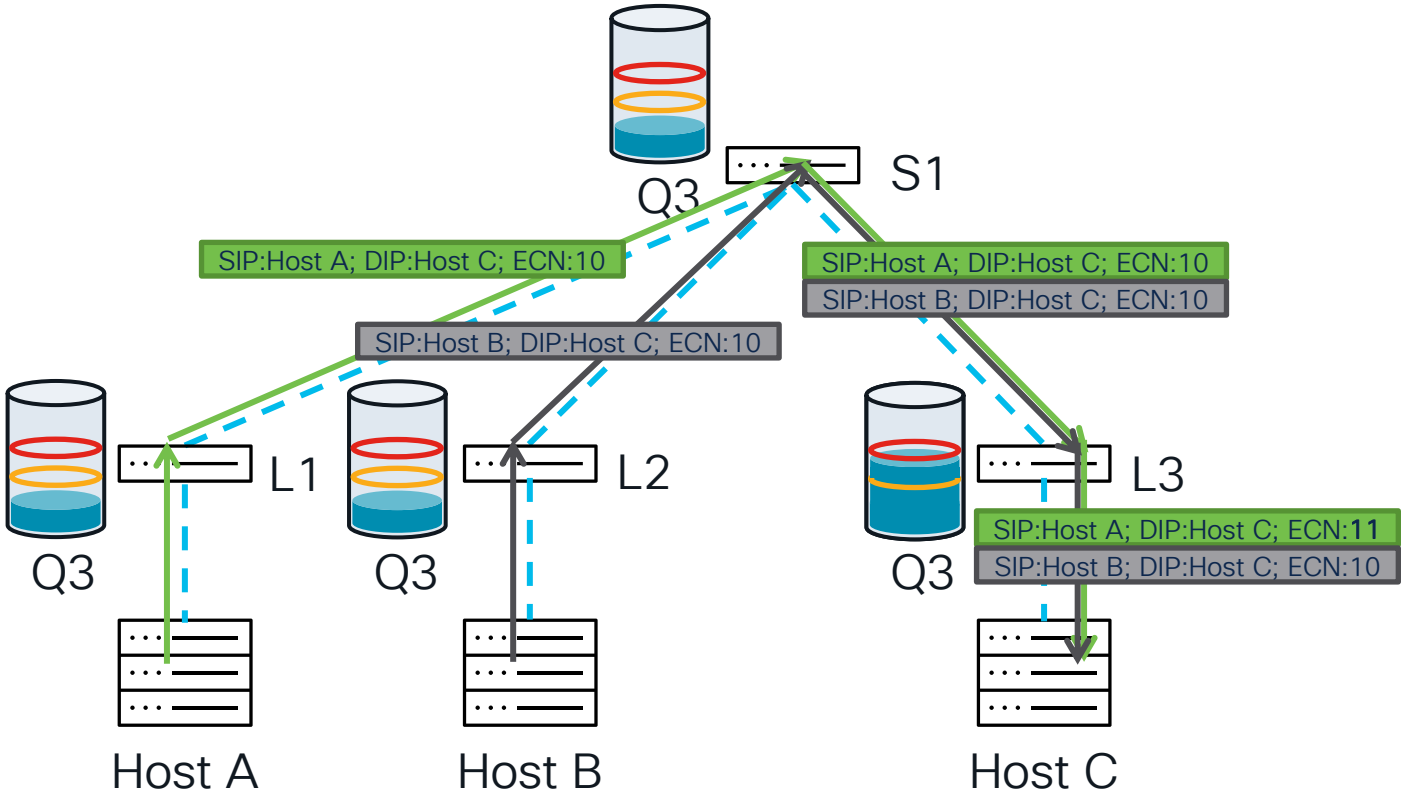
- After buffer usage crosses MAX threshold, every ECN capable packet will be marked with Congestion Encountered



Explicit Congestion Notification – End to End



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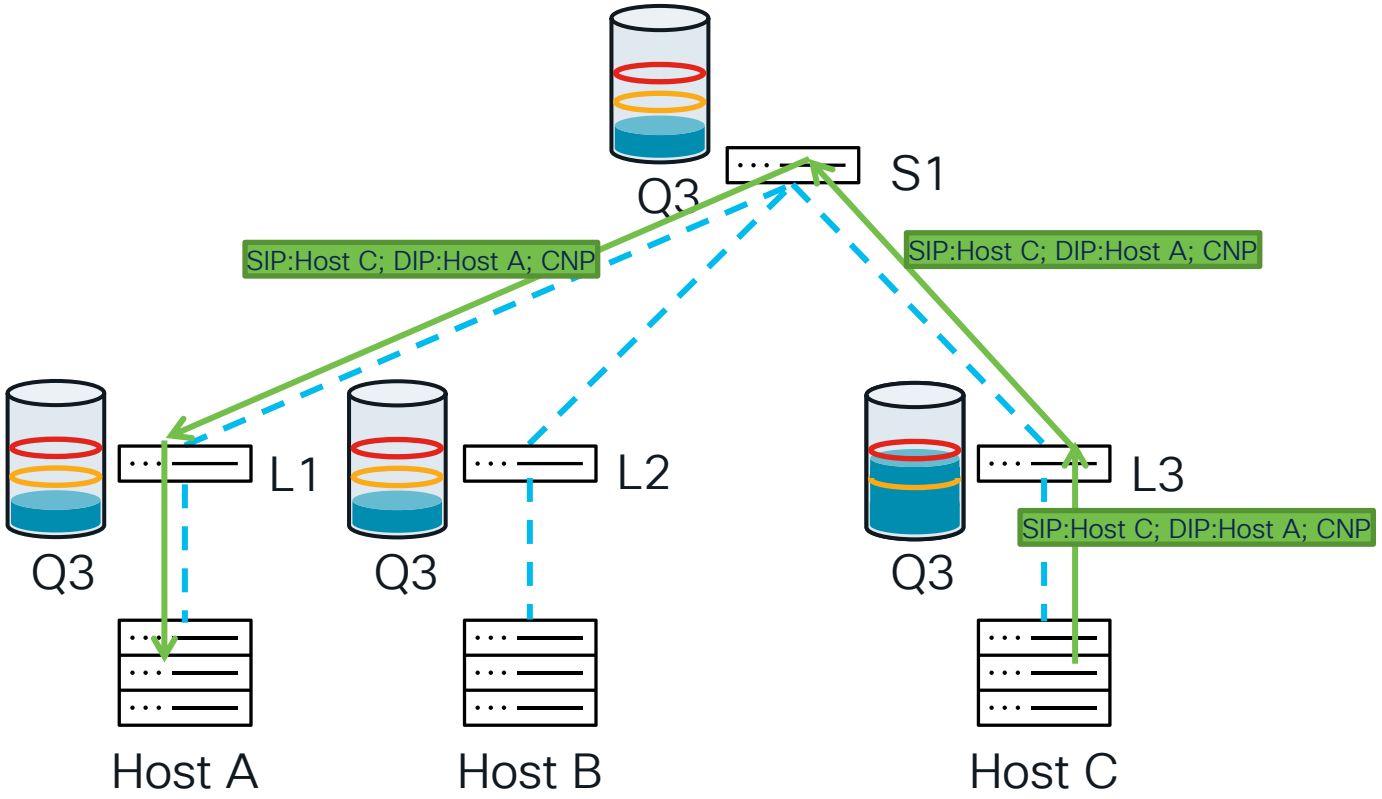

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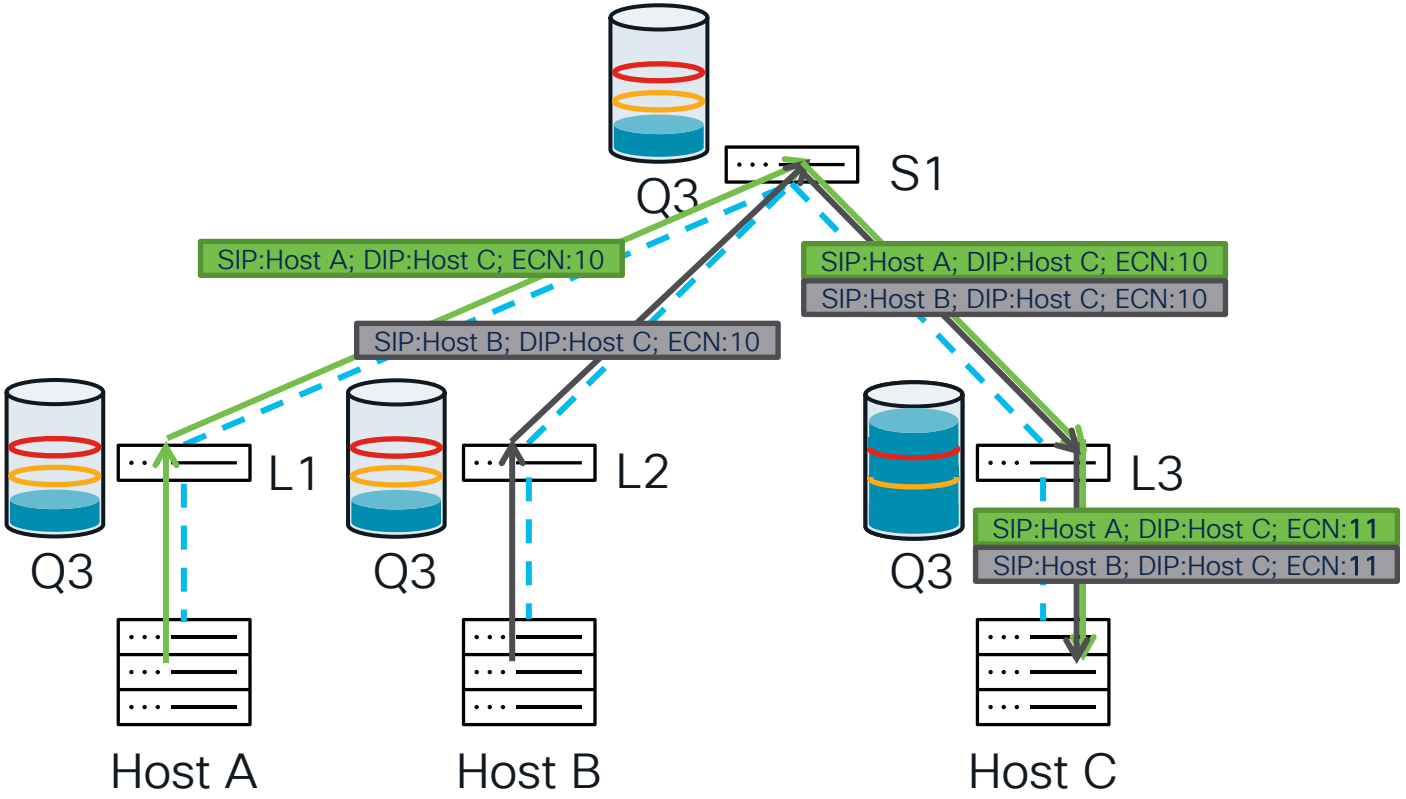

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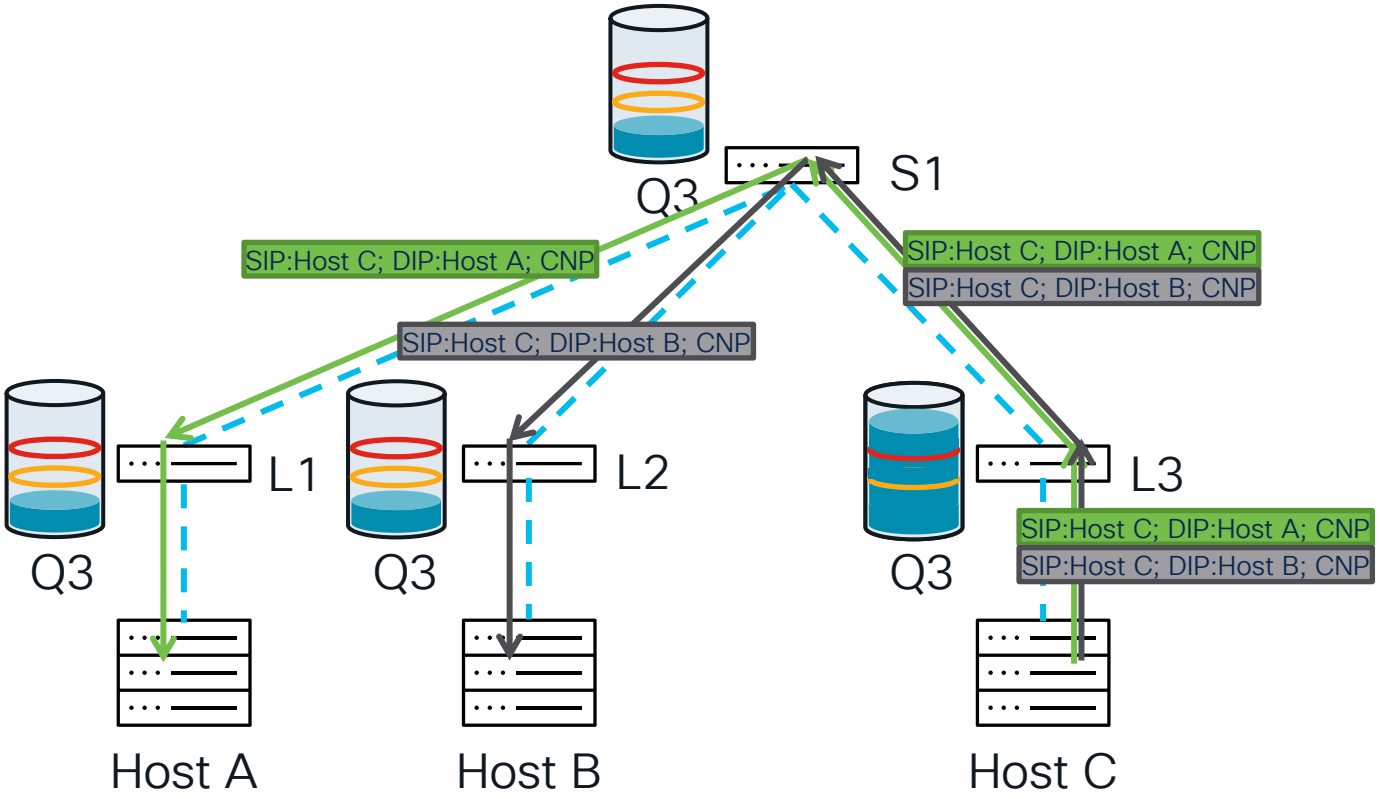

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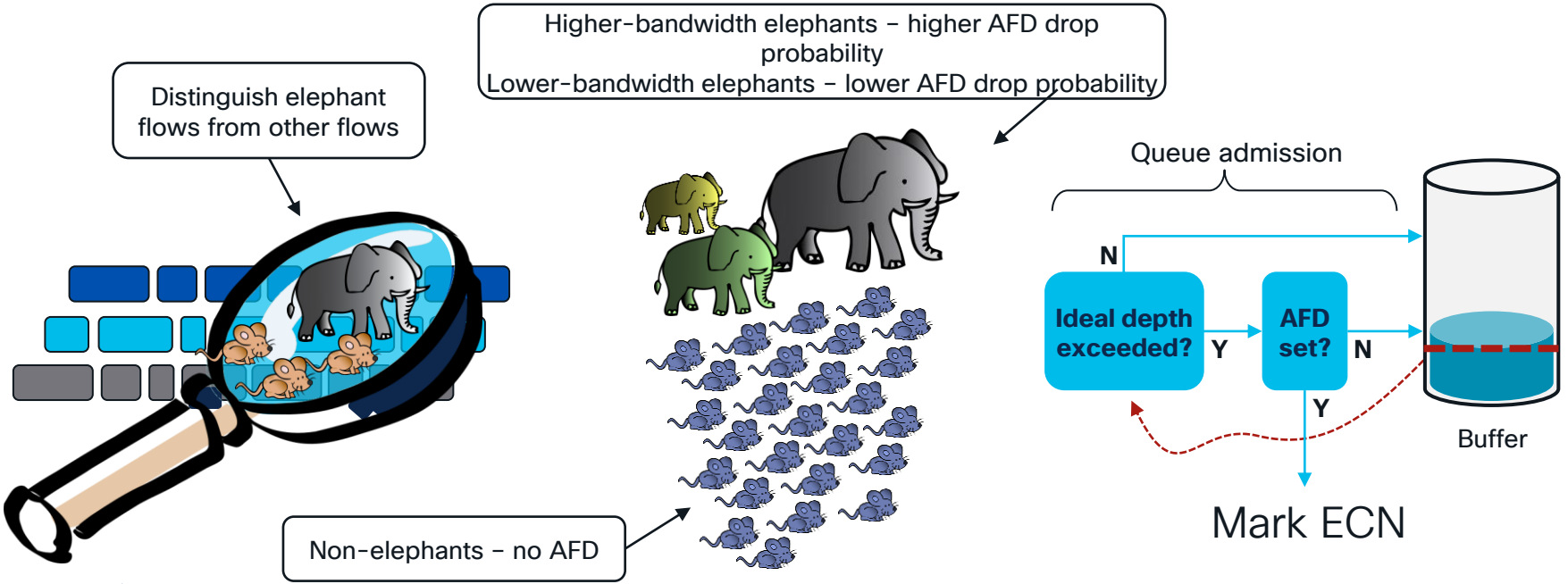
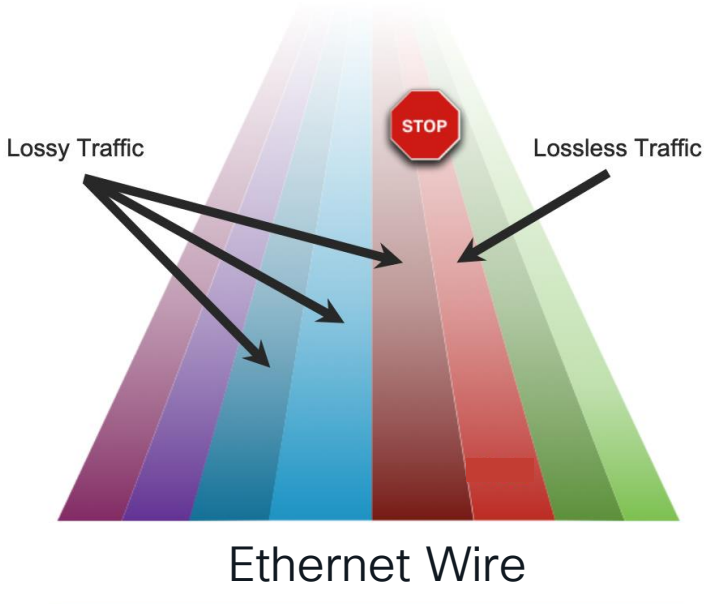
Approximate Fair Drop (AFD)

Maintain throughput while minimizing buffer consumption by elephant flows – **keep buffer state as close to the ideal as possible**



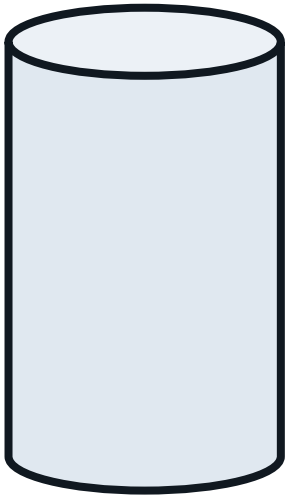
Priority Flow Control

- Flow Control Mechanism – 802.1Qbb
- A.k.a "Lossless Ethernet”
- PFC enables Flow Control on a Per-Priority basis
- PFC is also called Per-Priority-Pause
- Therefore, we have the ability to have lossless and lossy priorities at the same time on the same wire
- Allows traffic to operate over a lossless priority independent of other priorities
- Other traffic assigned to other priority will continue to transmit and rely on upper layer protocols for retransmission



PFC – How pause frames are sent

- PFC sets thresholds in no-drop queue
- Headroom is present to accommodate “in flight” packets



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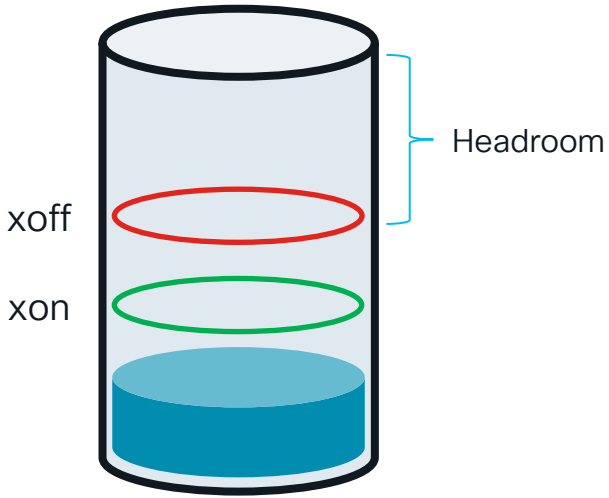

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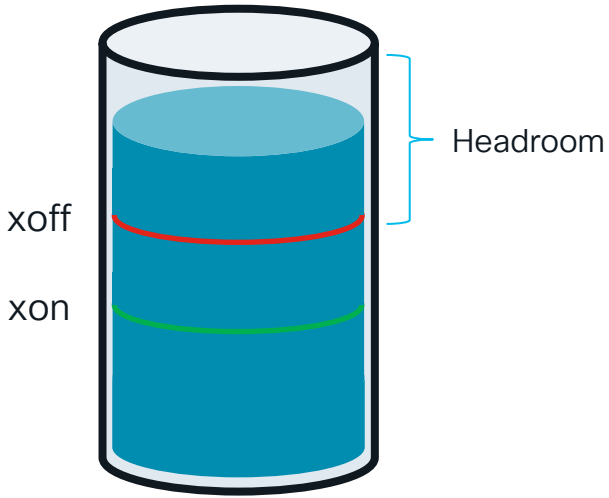

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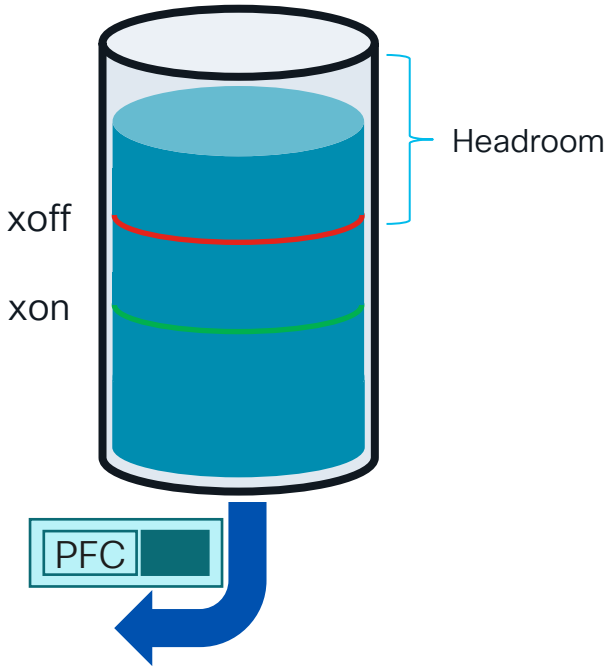

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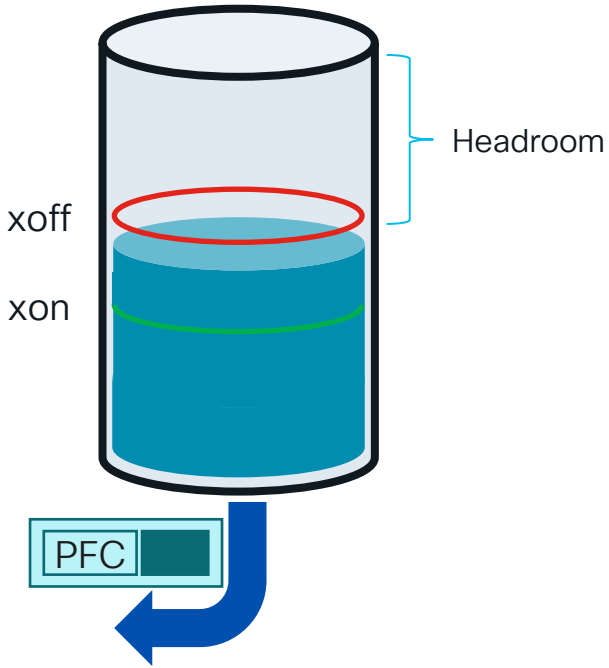

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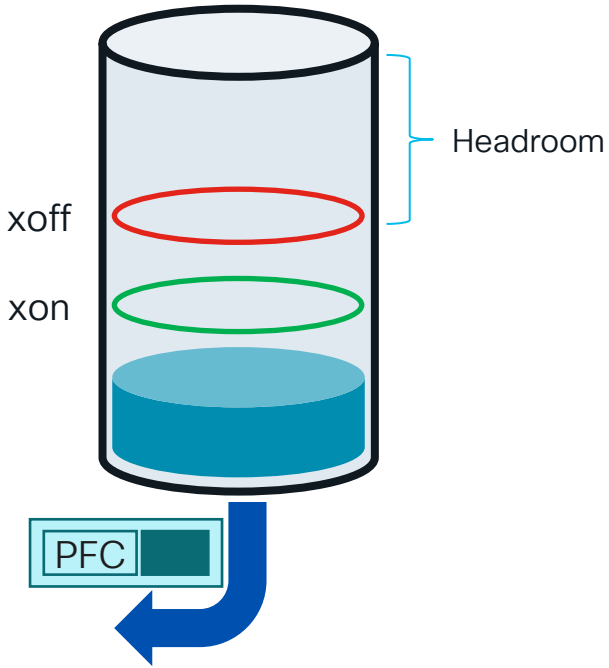

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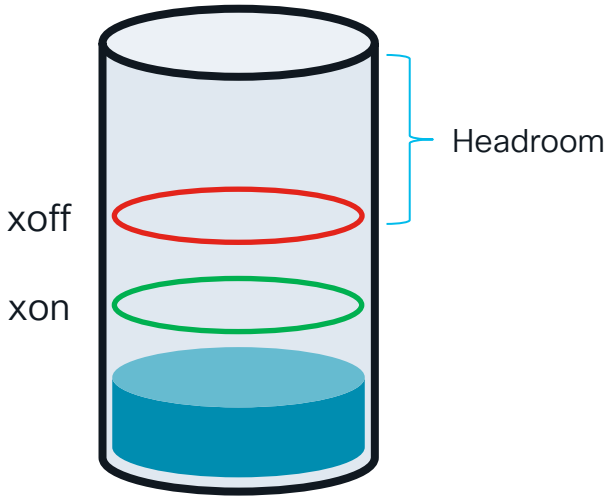
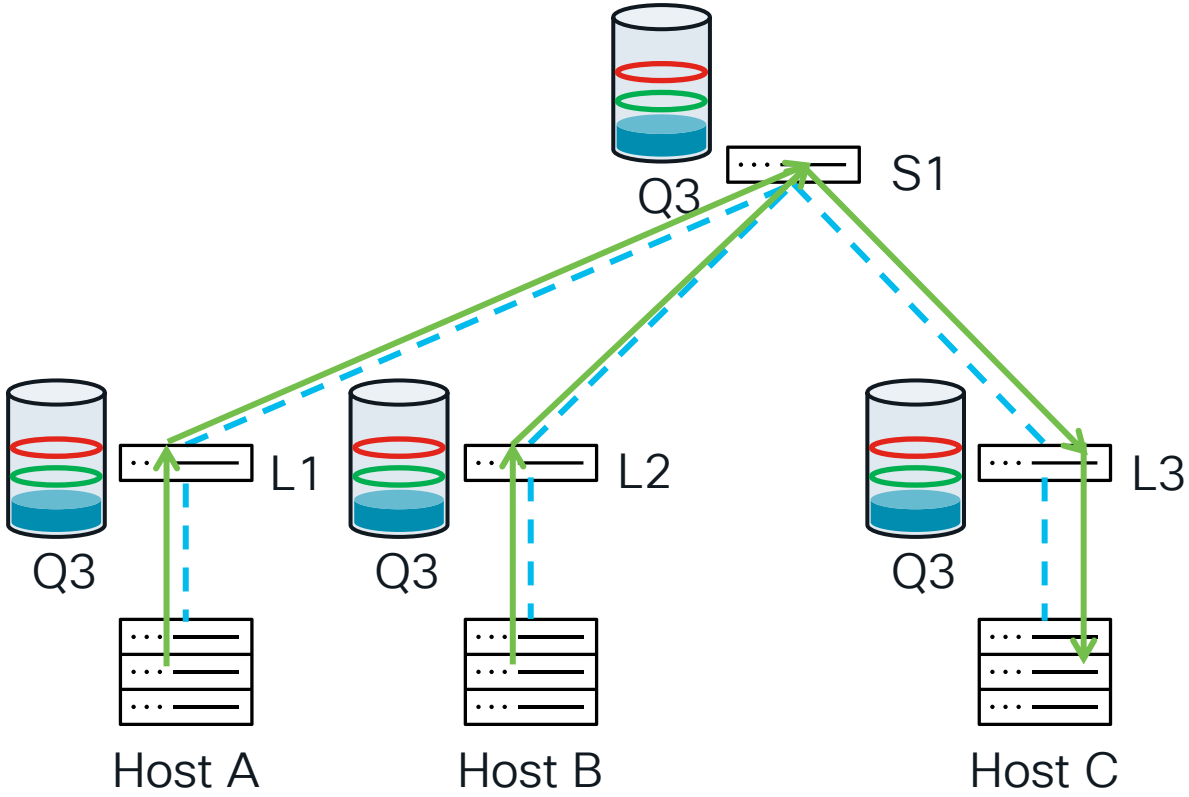


PFC hop by hop



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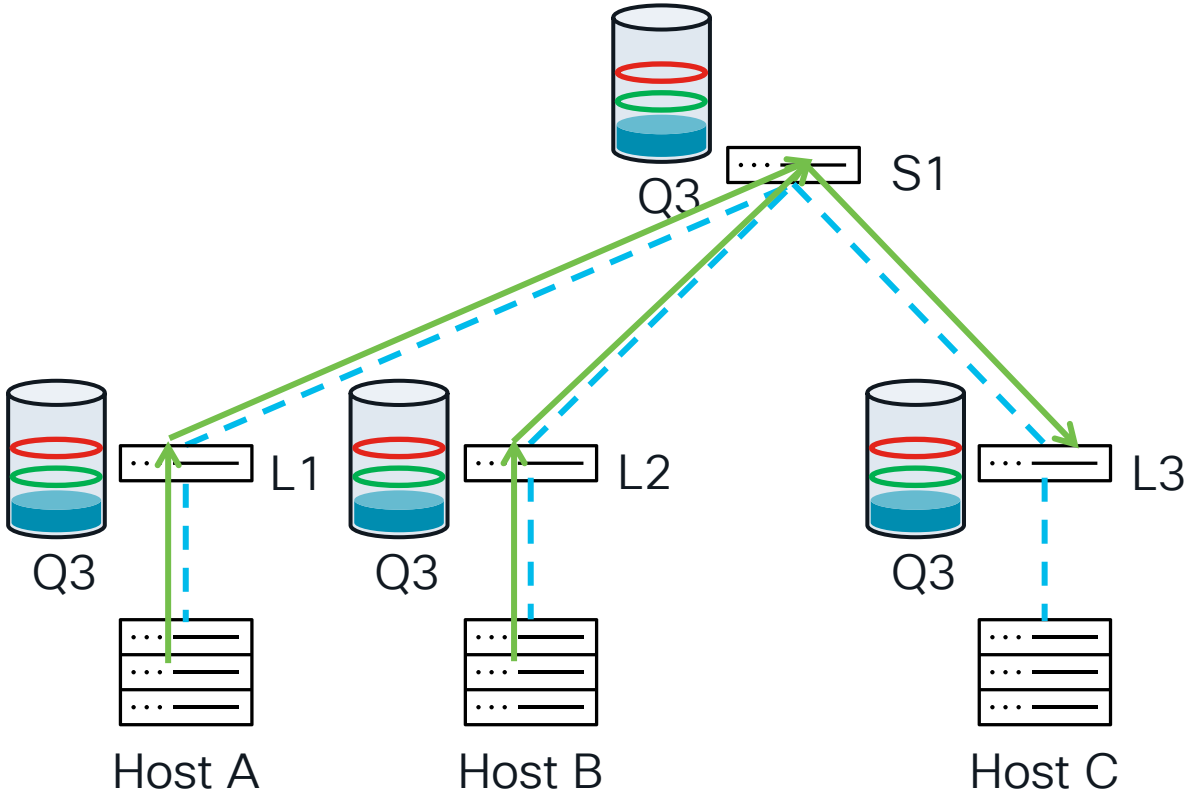

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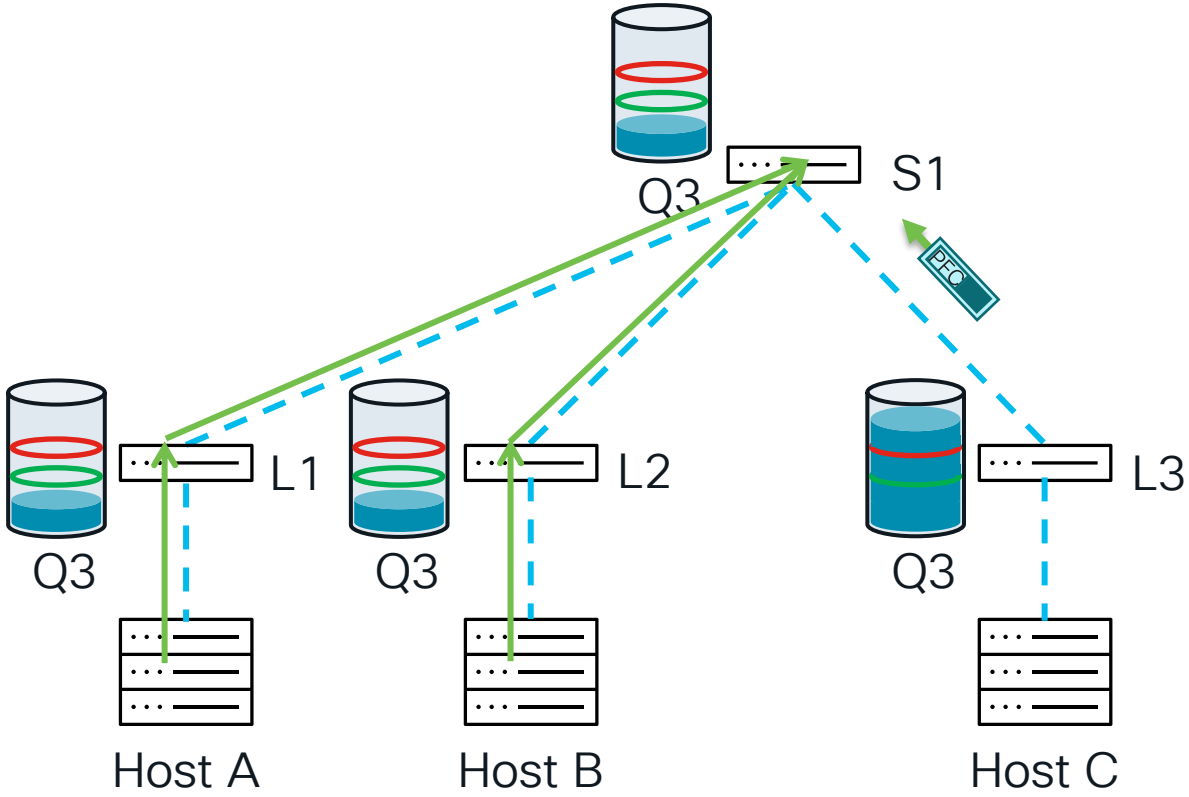

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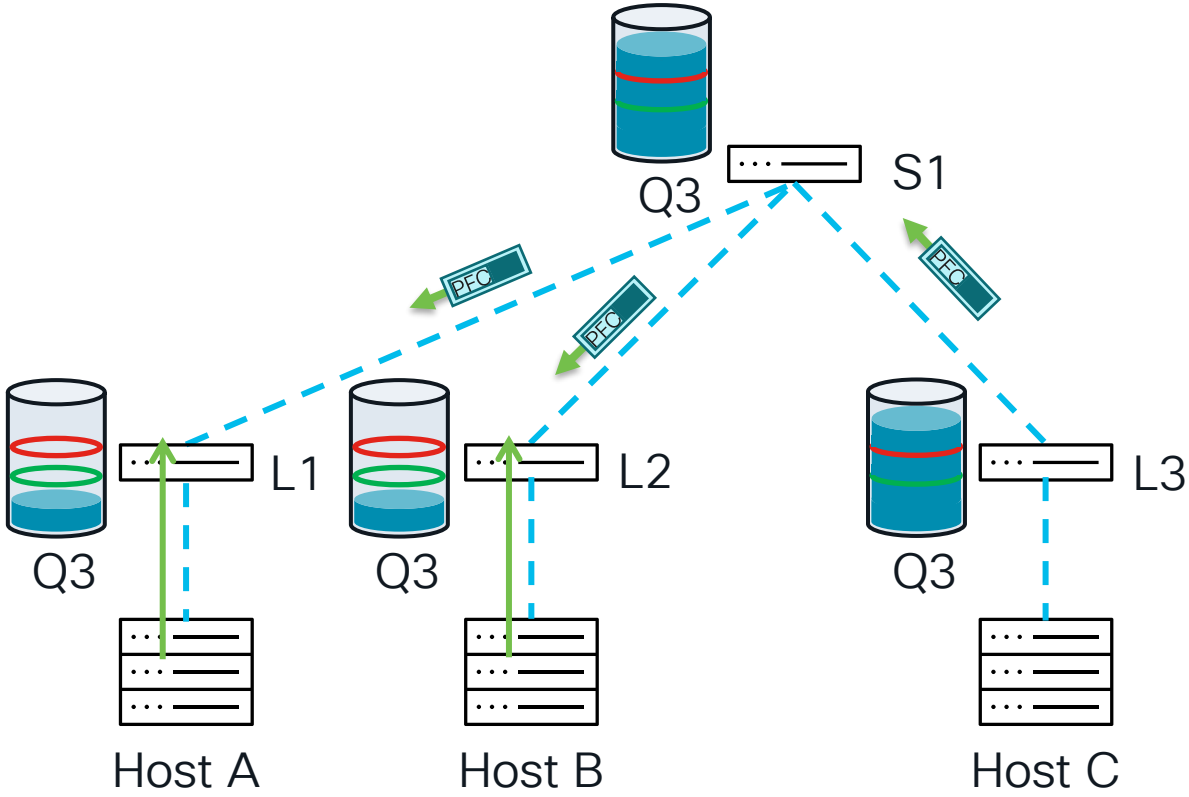

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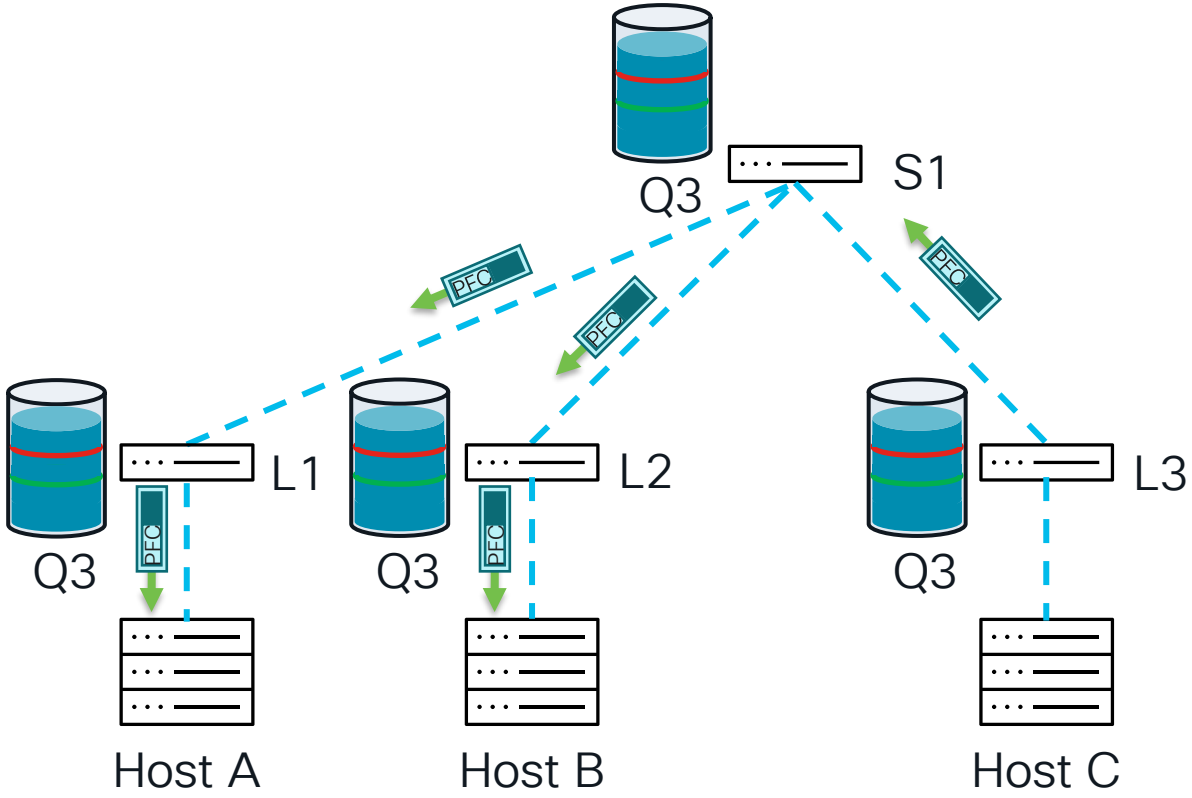

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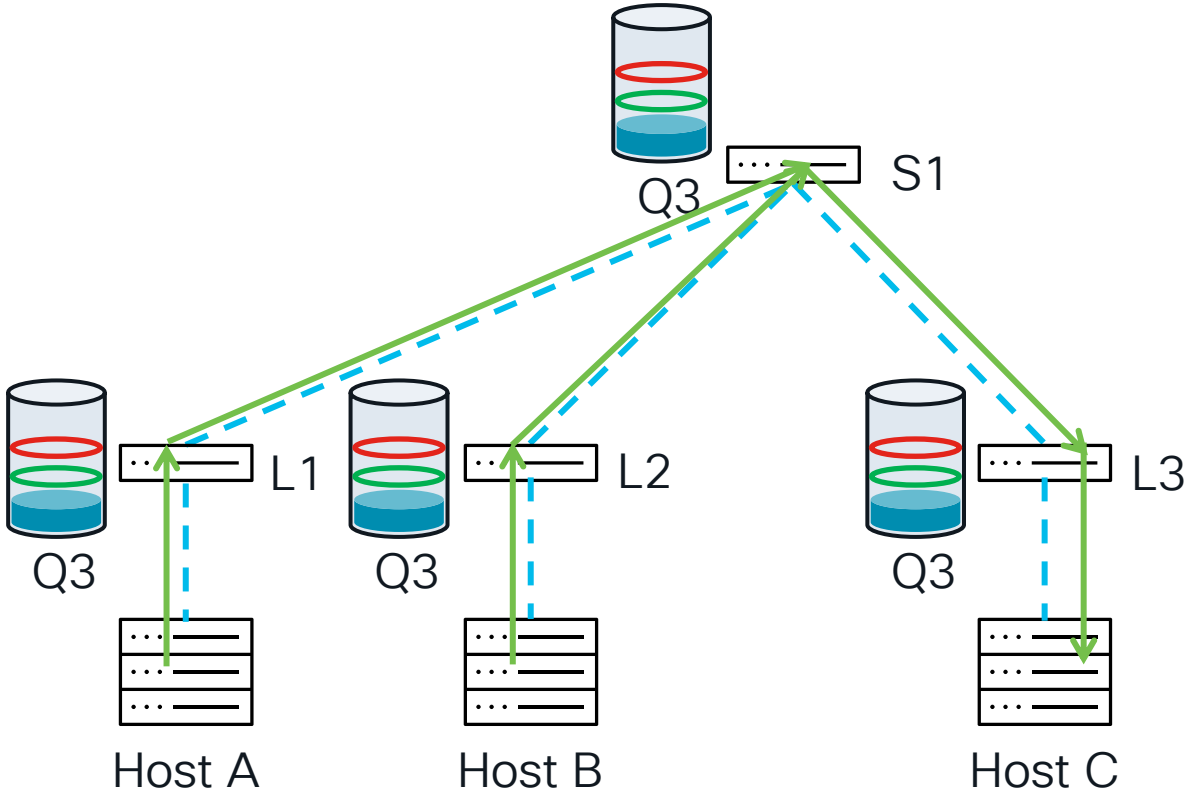
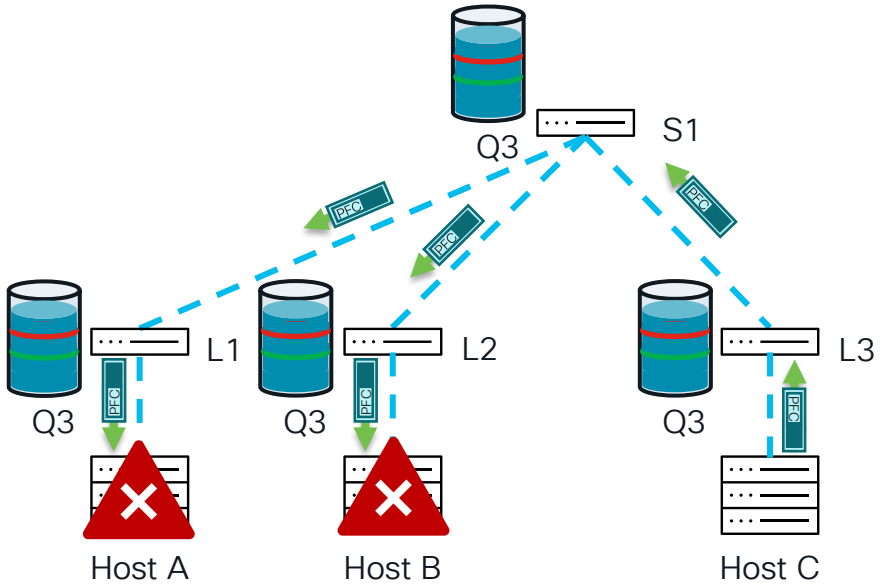


PFC storm

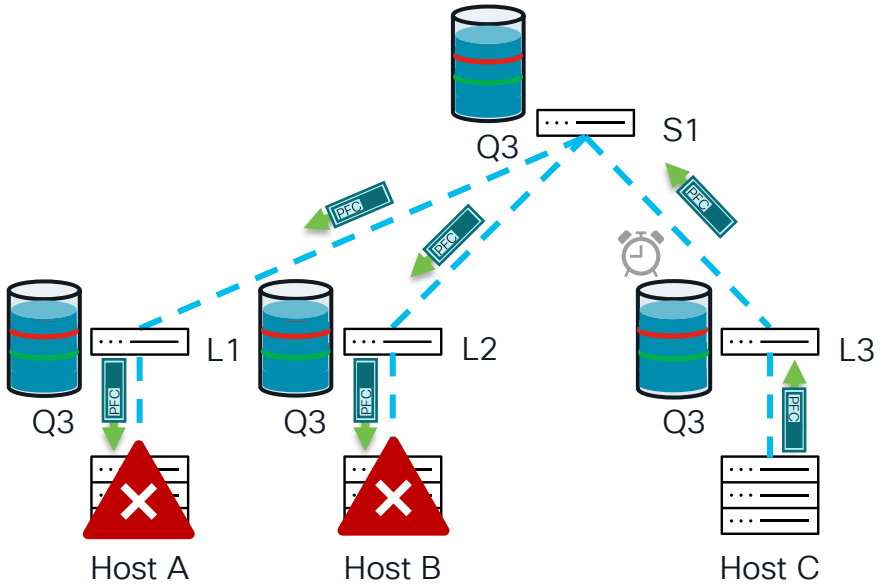
- In occasion of NIC or network malfunction, PFC storm can be triggered to send continues PFC frames in the network
- Network will propagate those frame to all senders
- PFC storm will stop traffic coming from sender
- PFC watchdog can drain the queue



https://www.microsoft.com/en-us/research/wp-content/uploads/2016/11/rdma_sigcomm2016.pdf

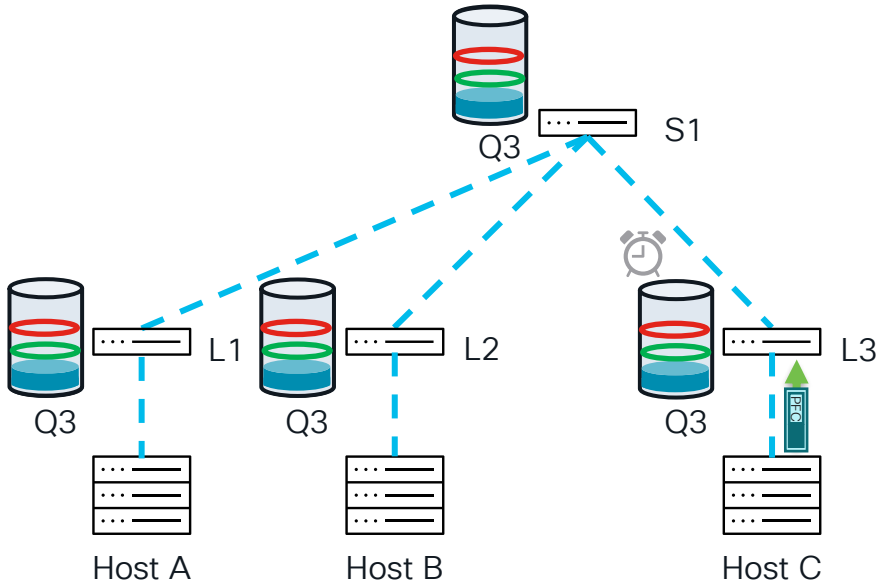
PFC watchdog

- PFC watchdog sets a timeout, if a packet exceeds time out, all packets from a queue will be cleared
- The watchdog prevents PFC frames propagating to sender and blocking it
- PFC Watchdog is supported on Cisco Nexus 9000 switches



PFC watchdog

- PFC watchdog sets a timeout, if a packet exceeds time out, all packets from a queue will be cleared
- The watchdog prevents PFC frames propagating to sender and blocking it
- PFC Watchdog is supported on Cisco Nexus 9000 switches



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Audience Q&A

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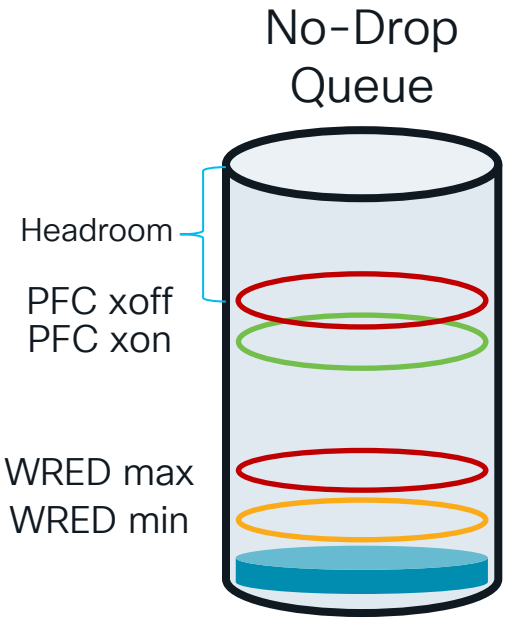
RoCEv2: PFC and ECN together

How does it work?

- WRED threshold are set low in no-drop queue
  - Signalize early for congestion, give enough time for end points to react
- PFC threshold are set higher than ECN
  - In case oversubscription buffers can be filled quickly without giving time to ECN to react
  - PFC will react and mitigate congestion



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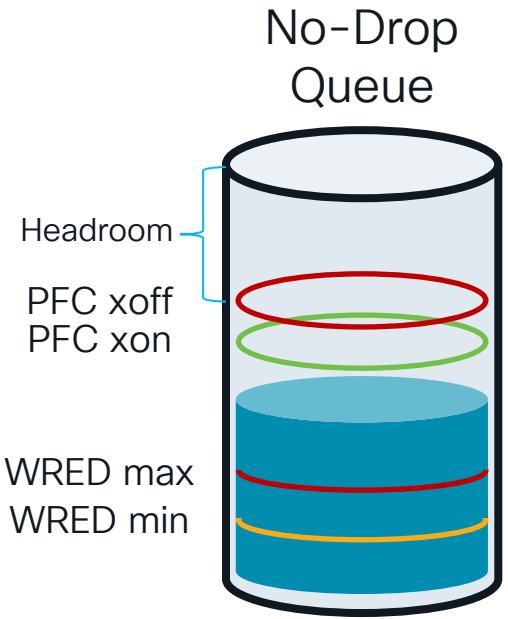

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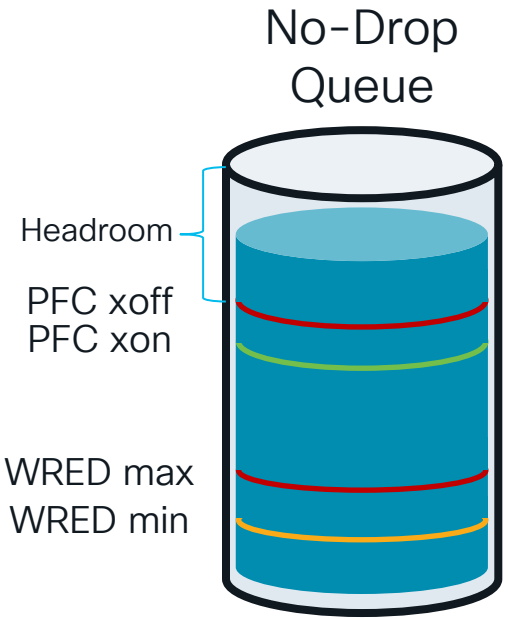
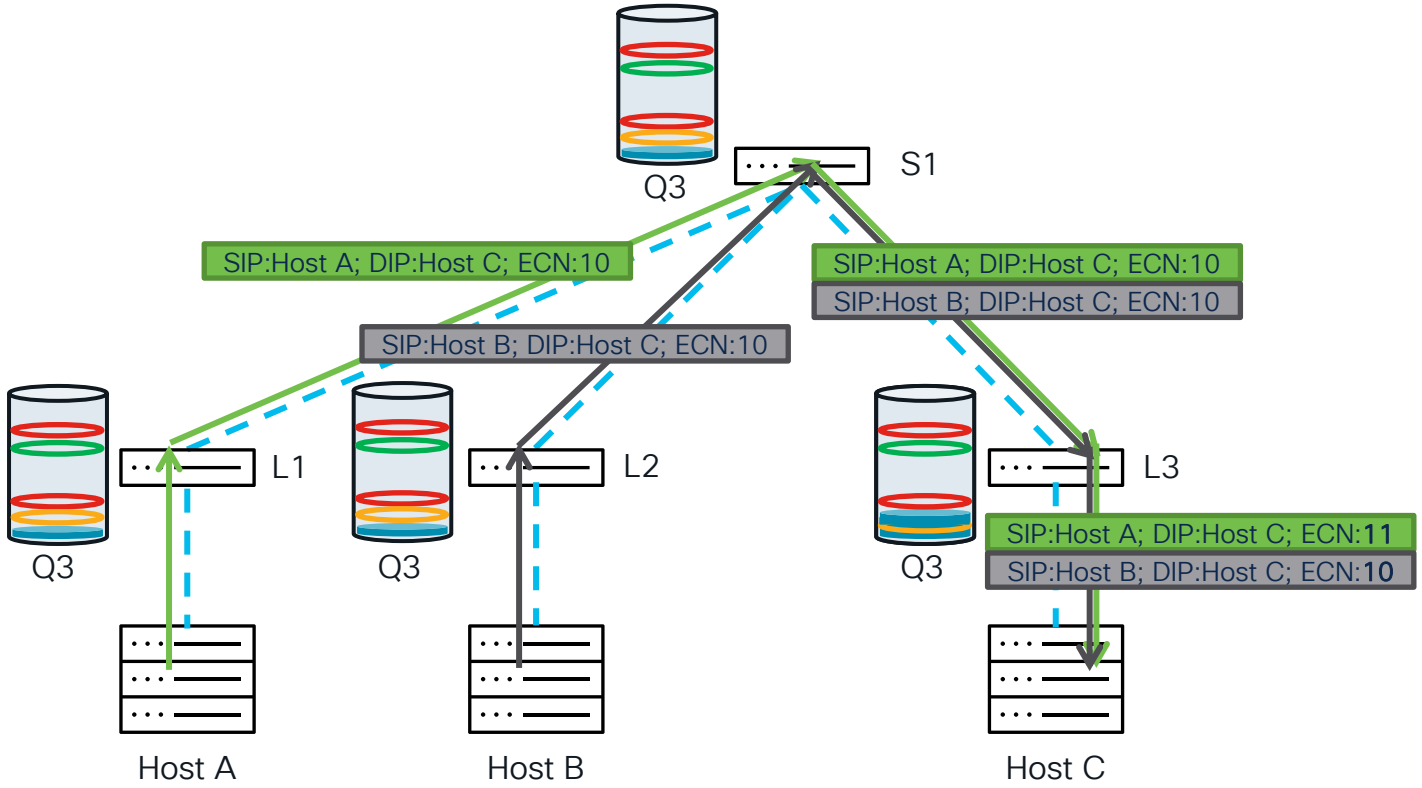


ECN and PFC make DCQCN



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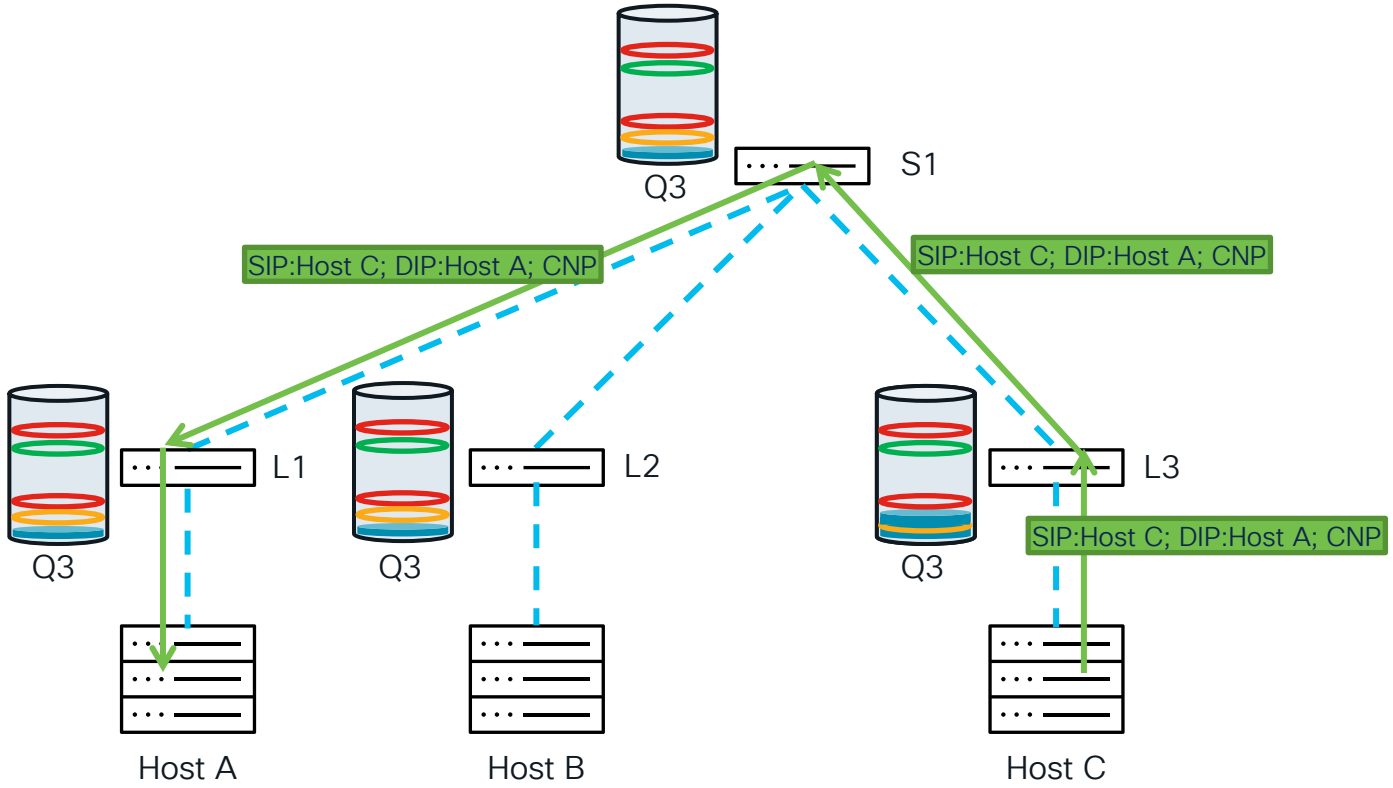

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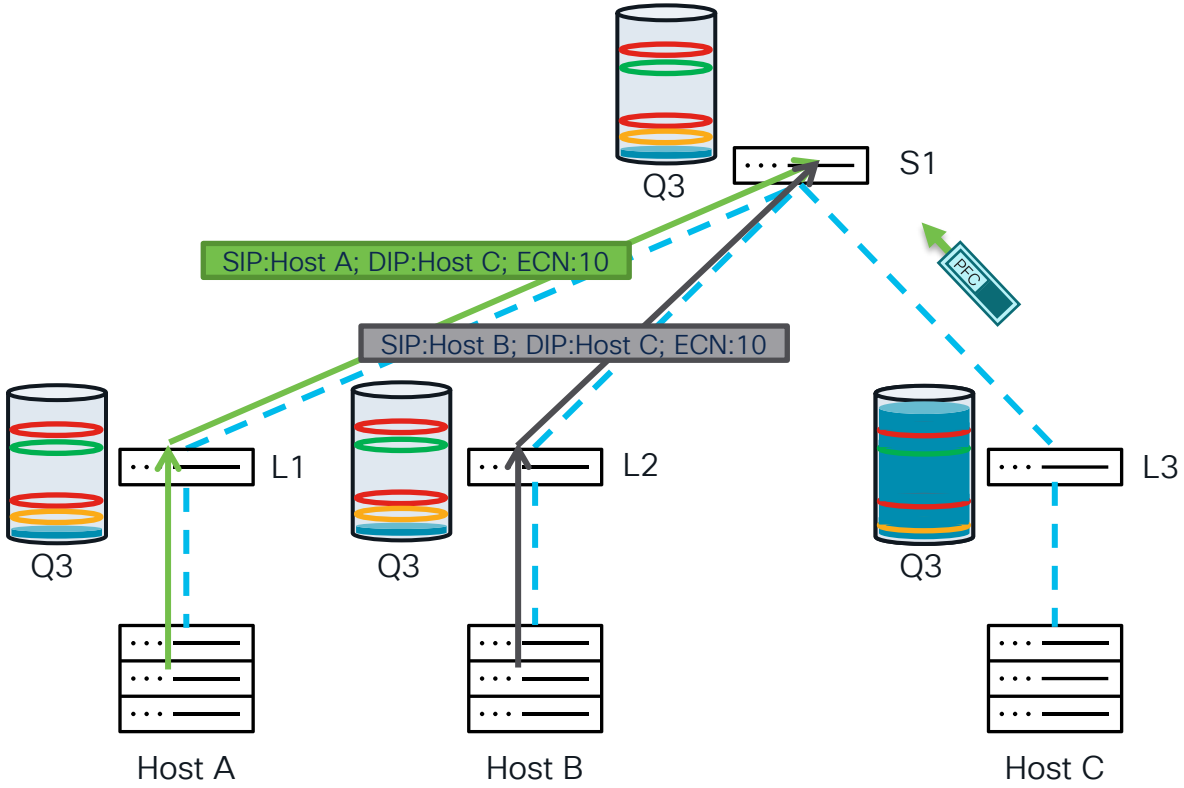
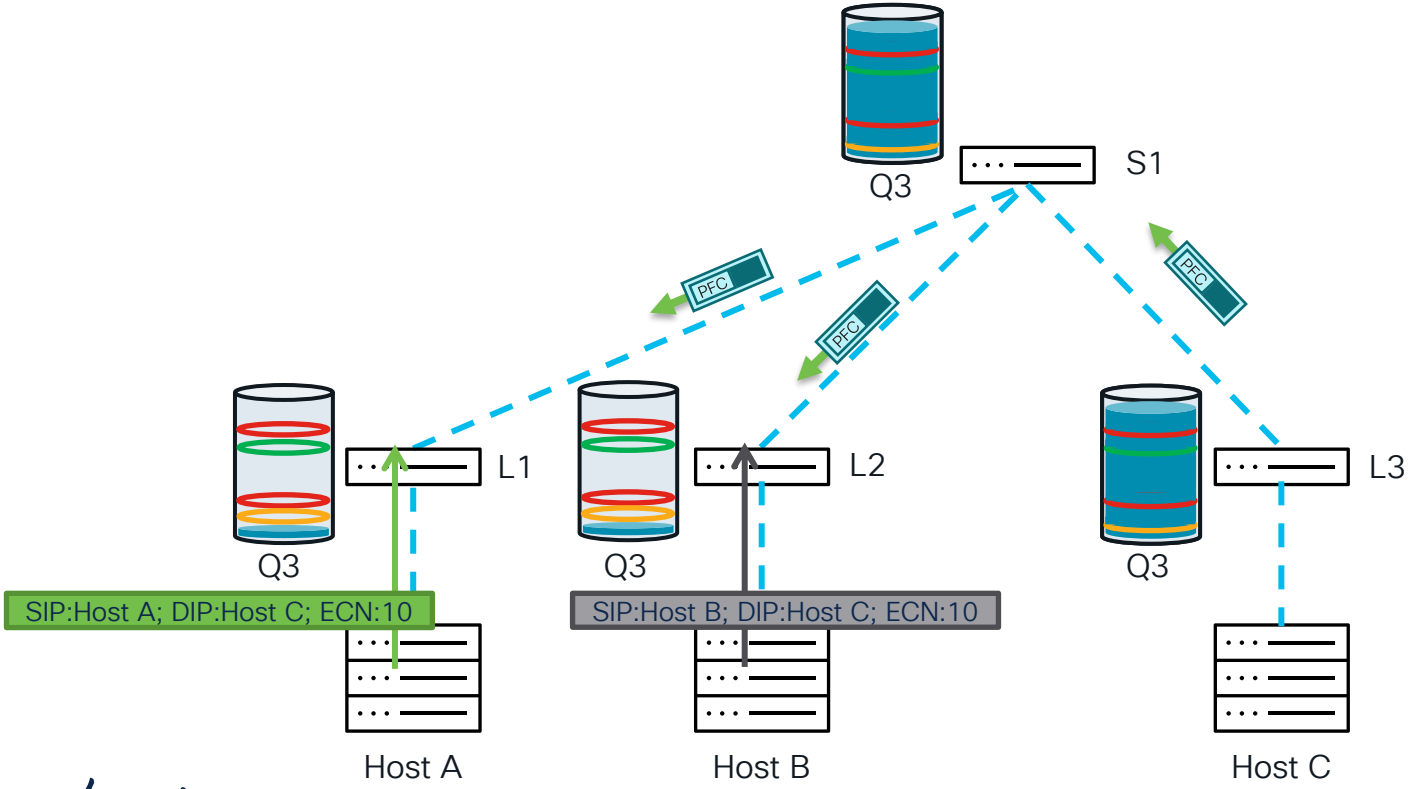


ECN and PFC make DCQCN



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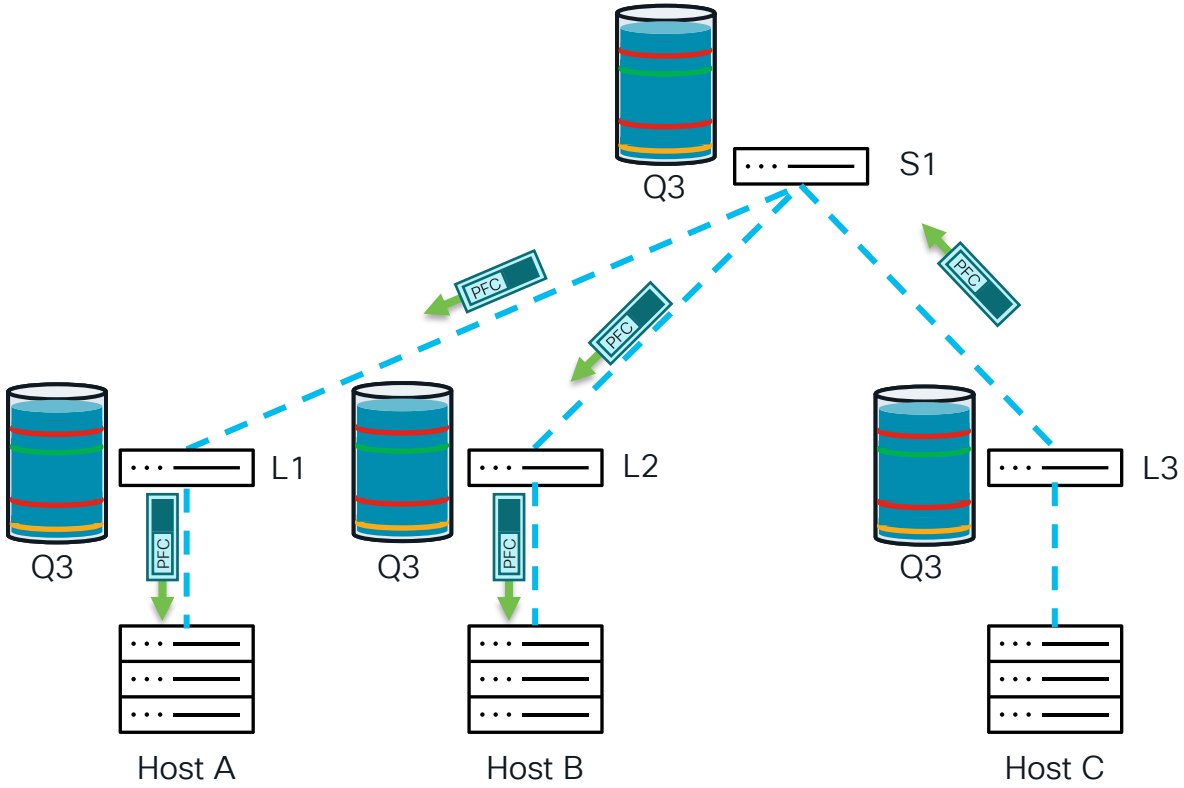
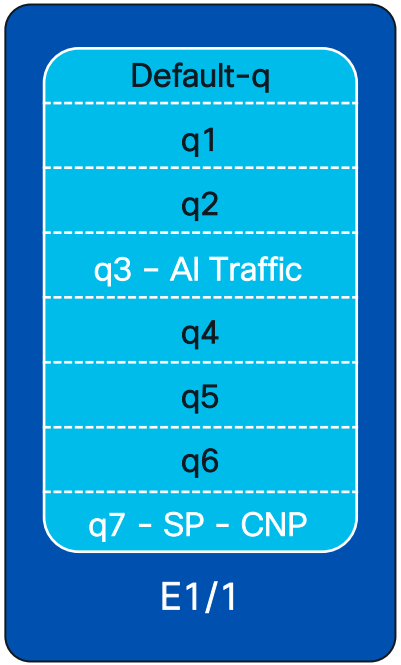


Quality of service

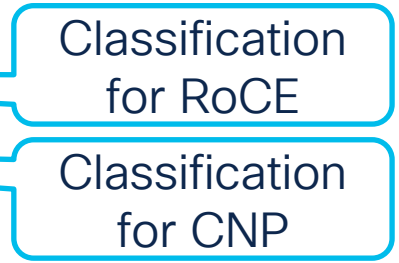
- Required separate queue for RoCEv2 traffic
  - Distinguished from other traffic in the port
  - Provide dedicated scheduling resources, to reduce latency
  - No contention for buffer resources with other traffic
  - RoCEv2 is not be part of strict priority queue, high volume of it might affect control plane
- RoCEv2 traffic requires ECN, PFC on the queue, while other traffic does not
- CNP traffic is part of strict priority queue, to deliver congestion signaling in time



Quality of service - Configuration

```
class-map type qos match-all class-roce
  match dscp 24
class-map type qos match-all class-cnp
  match dscp 48

policy-map type qos QOS_classification_policy
  class class-roce
    set qos-group 3
  class class-cnp
    set qos-group 7
  class class-default
    set qos-group 0
```



Quality of service - Configuration

```
policy-map type queuing custom-8q-out-policy
  class type queuing c-out-8q-q7
    priority level 1
<snip>
  class type queuing c-out-8q-q3
    bandwidth remaining percent 99
    random-detect minimum-threshold 150 kbytes maximum-threshold 3000 kbytes drop-probability 7
weight 0 ecn
<snip>
  class type queuing c-out-8q-q-default
    bandwidth remaining percent 1

policy-map type network-qos custom-8q-nq-policy
<snip>
  class type network-qos c-8q-nq3
    mtu 9216
    pause pfc-cos 3
<snip>
```

WRED min

WRED max

WRED random marked packets

Enable PFC*

*PFC default thresholds

Quality of service- Configuration

```
system qos
  service-policy type network-qos custom-8q-nq-policy
  service-policy type queuing output custom-8q-out-policy

interface Ethernet1/1
  service-policy type qos input QOS_classification_policy
  priority-flow-control mode on
  priority-flow-control watch-dog-interval on
```

Enable WRED ECN

Enable PFC per interface

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Audience Q&A

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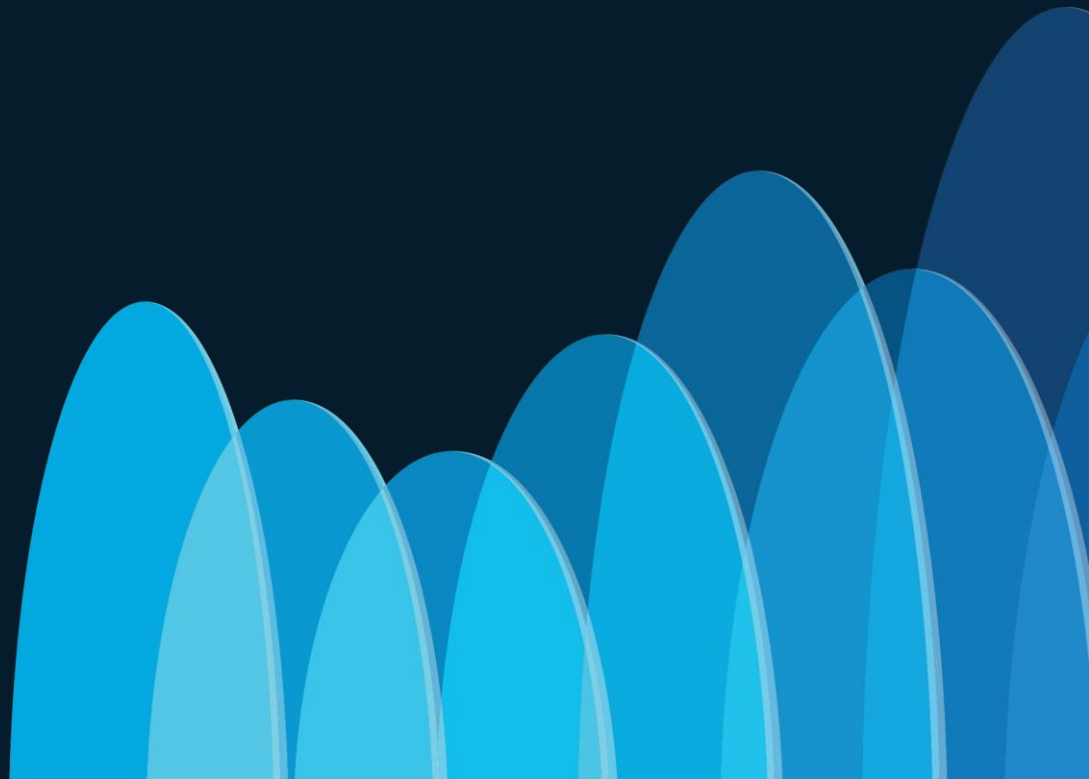
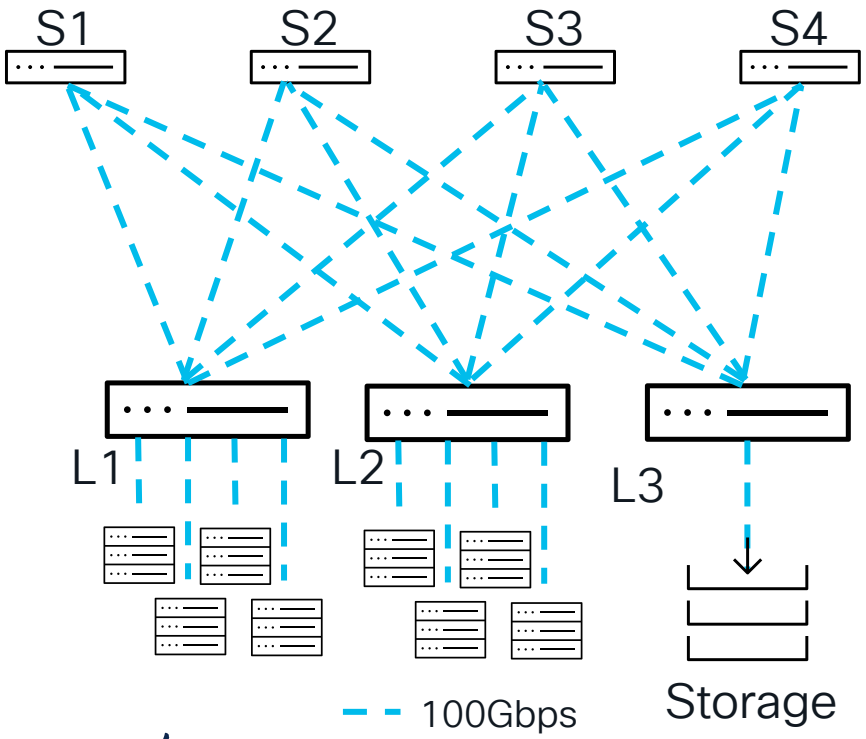
Traffic Load-balancing

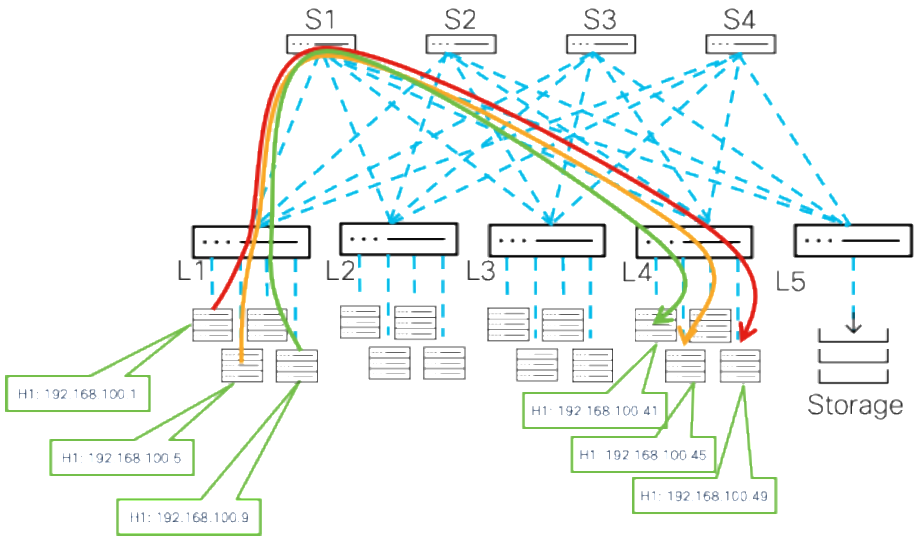


Non-blocking Network



- Non-Blocking Network, allow host to talk to other hosts at full bandwidth
- Leaf: Same bandwidth to the host as to the spine
- Reduces need for congestion management to increase performance

Traffic polarization on the uplinks – Problem



- Traffic does not provide enough entropy to ECMP
- Traffic is polarized to a spine S1 only
- Traffic polarization can affect application performance, triggering congestion management (PFC and ECN).

Default ECMP algorithm

- By default, ECMP looks at source and destination IP and Layer 4 ports
- Hosts in AI fabric may belong to uniform subnets
- Layer 4 ports, destination port is 4791 for RoCEv2
- Entropy comes from Layer 4 Source Port

```
N9K-switch# show ip load-sharing
IPv4/IPv6 ECMP load sharing:
Universal-id (Random Seed): 2467474893
Load-share mode : address source-destination port source-destination
Rotate: 32
```

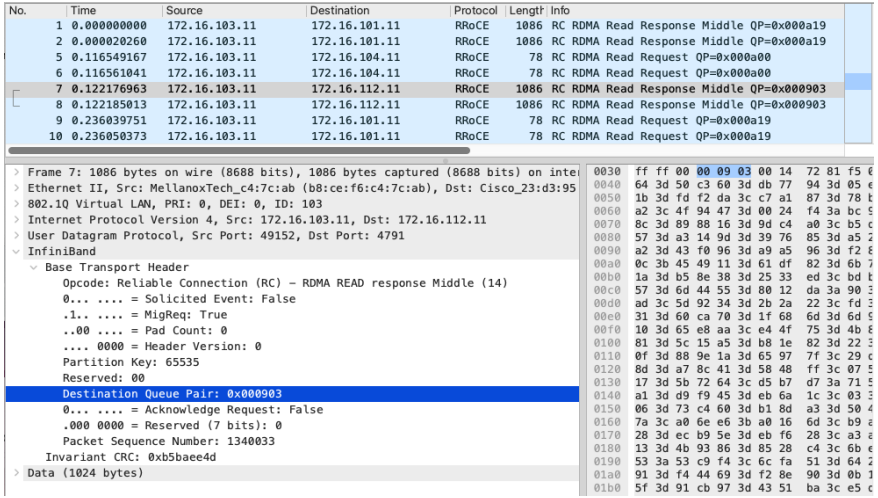
User Defined Field (UDF) ECMP algorithm

- UDF ECMP looks at source and destination IP and User Defined Field in a packet
- User can choose what field to look at to enhance entropy
- Every RoCE conversation is identified by Destinate Queue Pair, in IB header
- Destination Queue Pair is 3-byte field

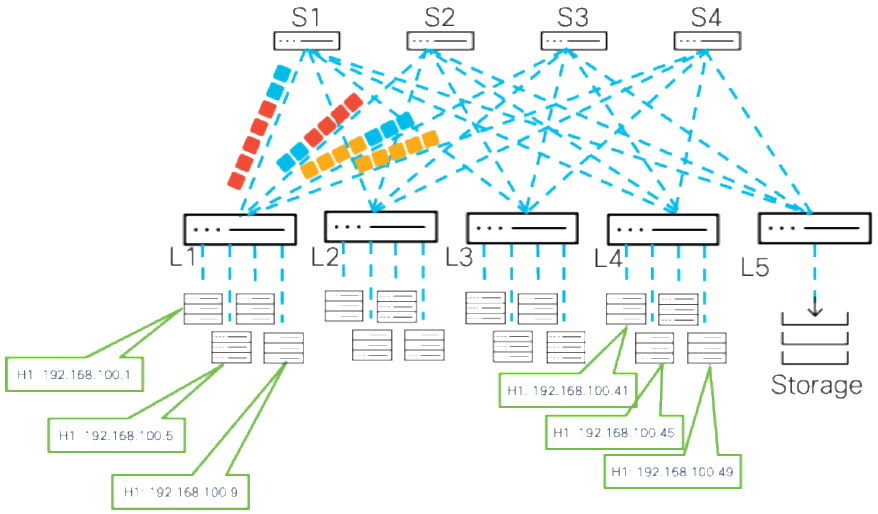
```
N9K-switch# show ip load-sharing
IPv4/IPv6 ECMP load sharing:
Universal-id (Random Seed): 908907021
Load-share mode : address source-destination udf offset 33 length 24
Rotate: 32
```

User Defined Field (UDF) – Destination Q Pair

- UDF offset of Nexus 9000 switches starts from first byte of IP header
- Destination Q Pair is 33 bytes from beginning of IP field (IP (20B) + UDP (8B) + IB (5B)) or 6th byte in InfiniBand header



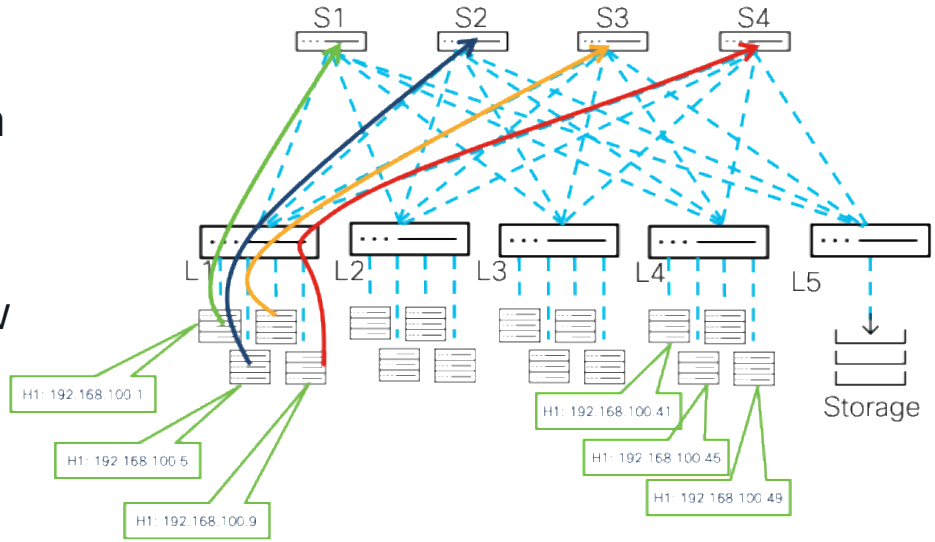
Dynamic Load Balancing – Flowlet Mode



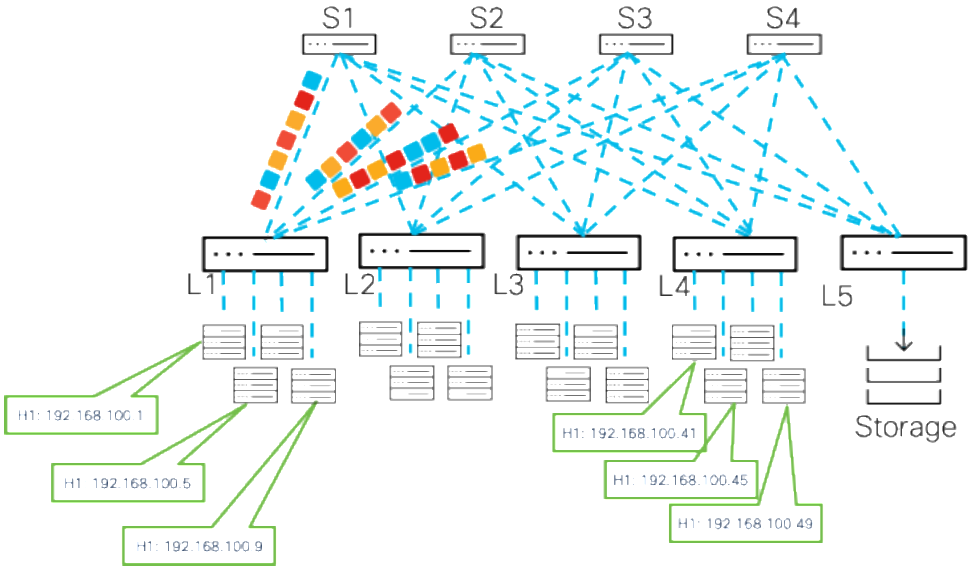
- Flowlets maintain the link, or dynamically change the link
- Least utilized link is chosen, for new flow, or at time flows are moved to different link
- Ageing time is used avoid out of order packets, it should be 2 x RTT
- AI workloads are balanced fairly and if flows are bursty they can dynamically change path

Dynamic Load Balancing – Static Pinning

- Allows static pinning between ingress and egress ports
- Valid only for multipath destination traffic
- Steady bit rate flows, or undersubscribed network, to allow fair distribution of the traffic
- Manual configuration, or API



Dynamic Load Balancing – Per-packet Mode



- Per packet mode load balancing, allows fair distribution of traffic
- Least utilized link is chosen per packet, delivering uniform usage of the links
- As packet of same flow, will take different path, may happen that they arrive at destination endpoints out of order
- Expected in deployments with per-packet load balancing for receiver to put packet in order (host needs to do packet reordering)

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Audience Q&A

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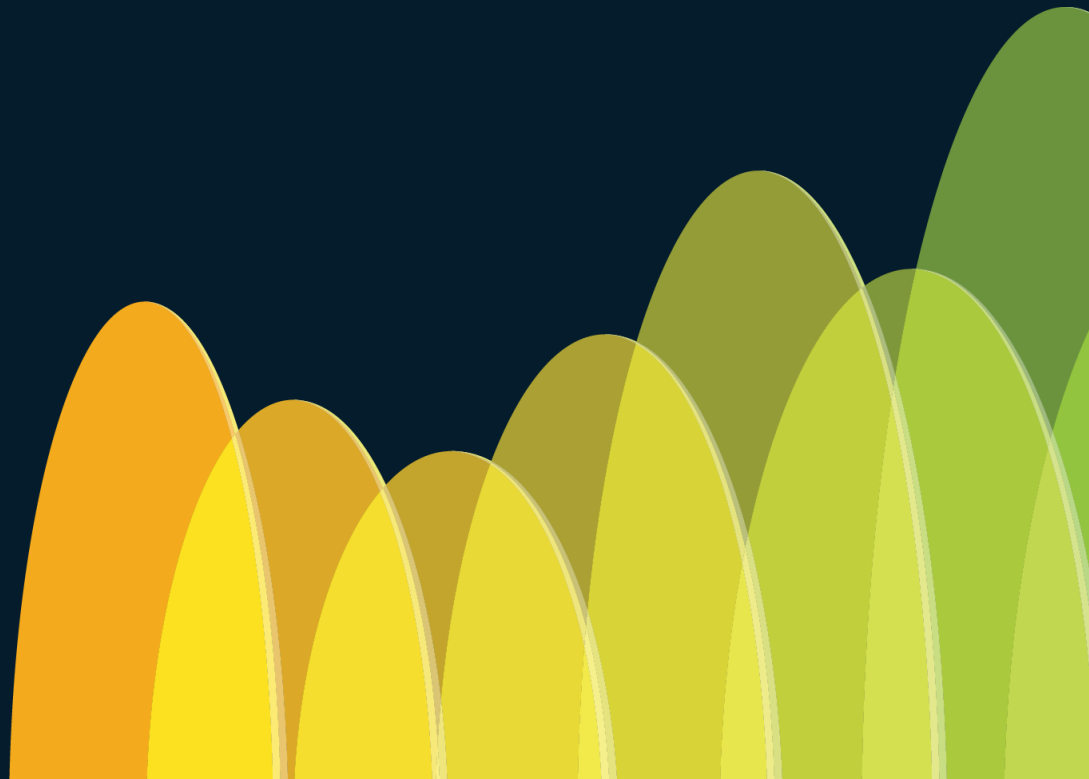
Automation and Visibility



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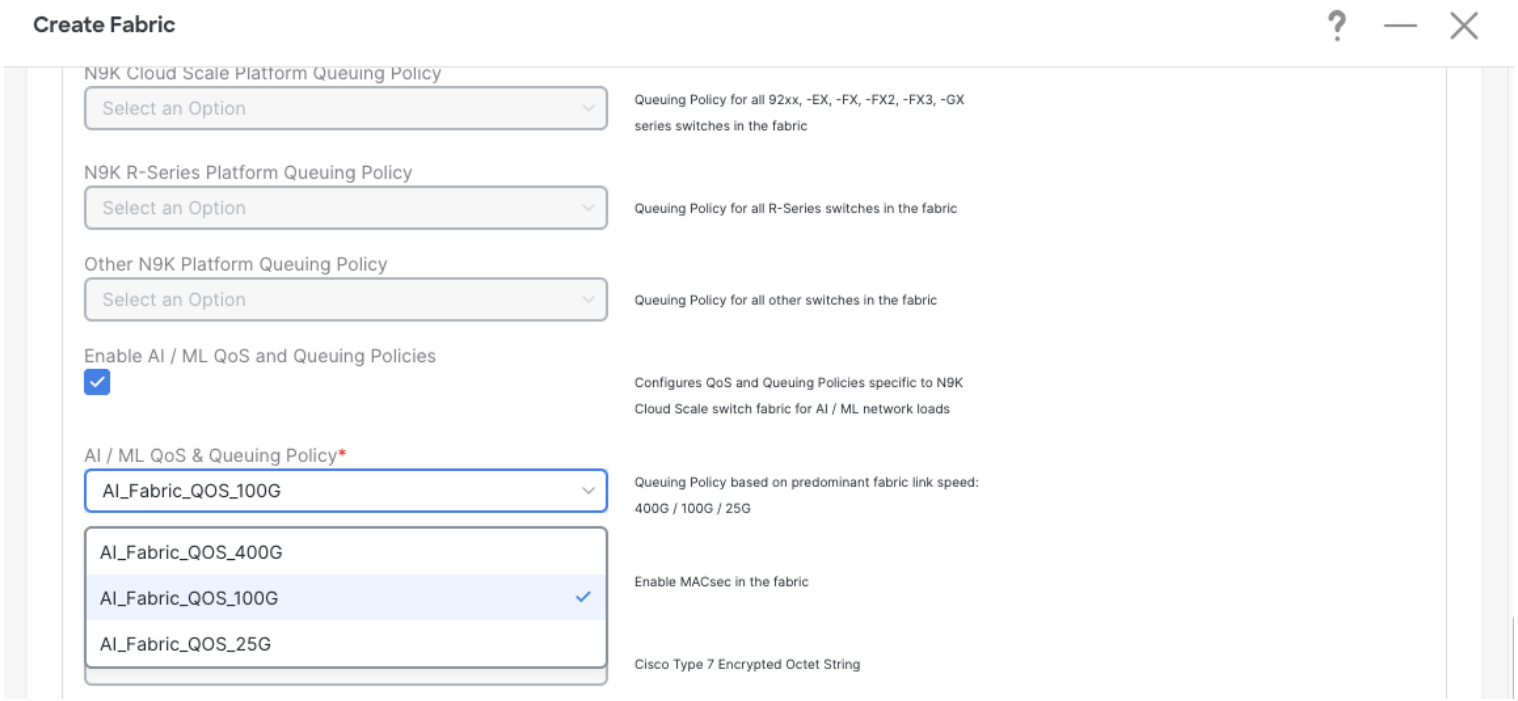
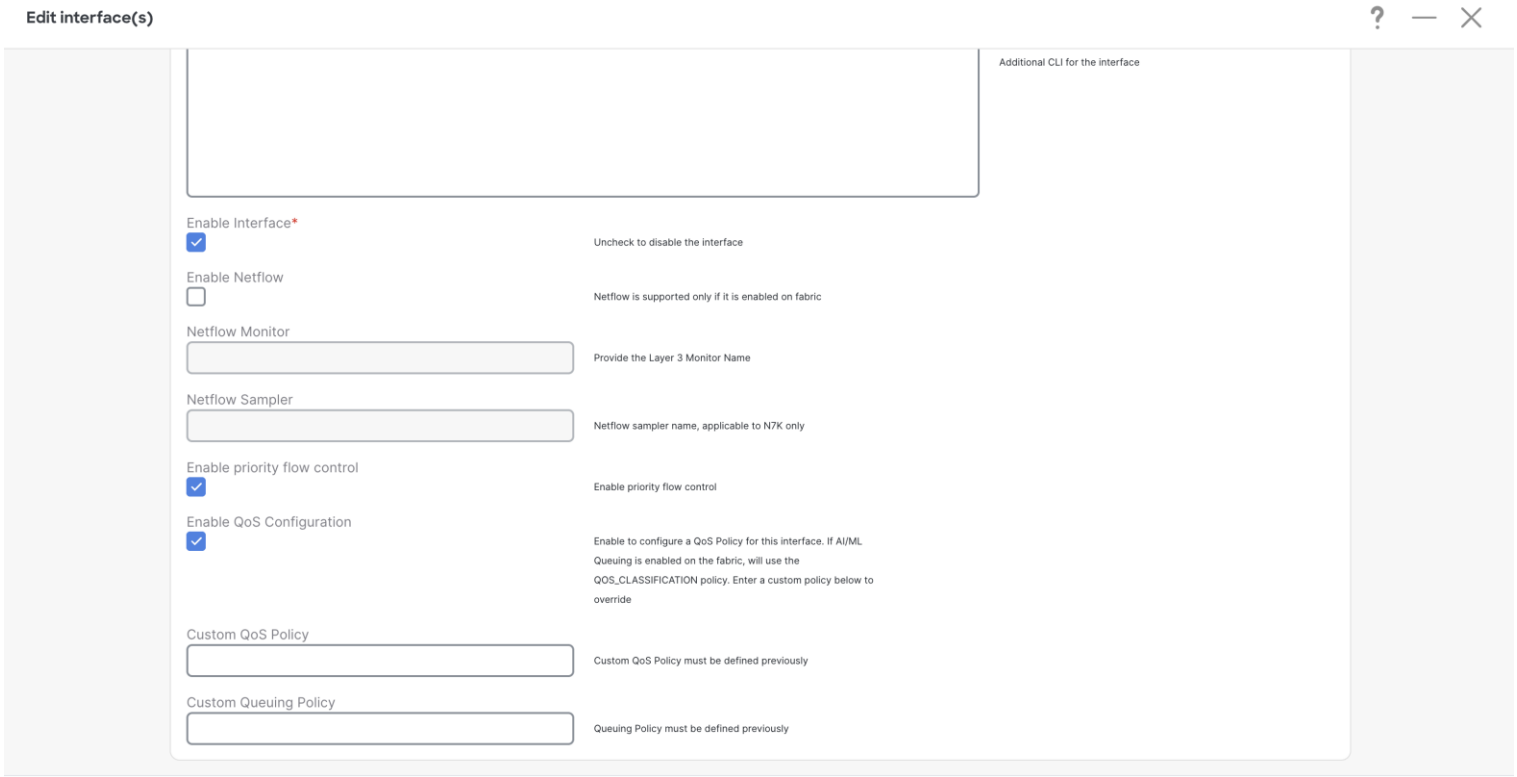
Nexus Dashboard Fabric Controller



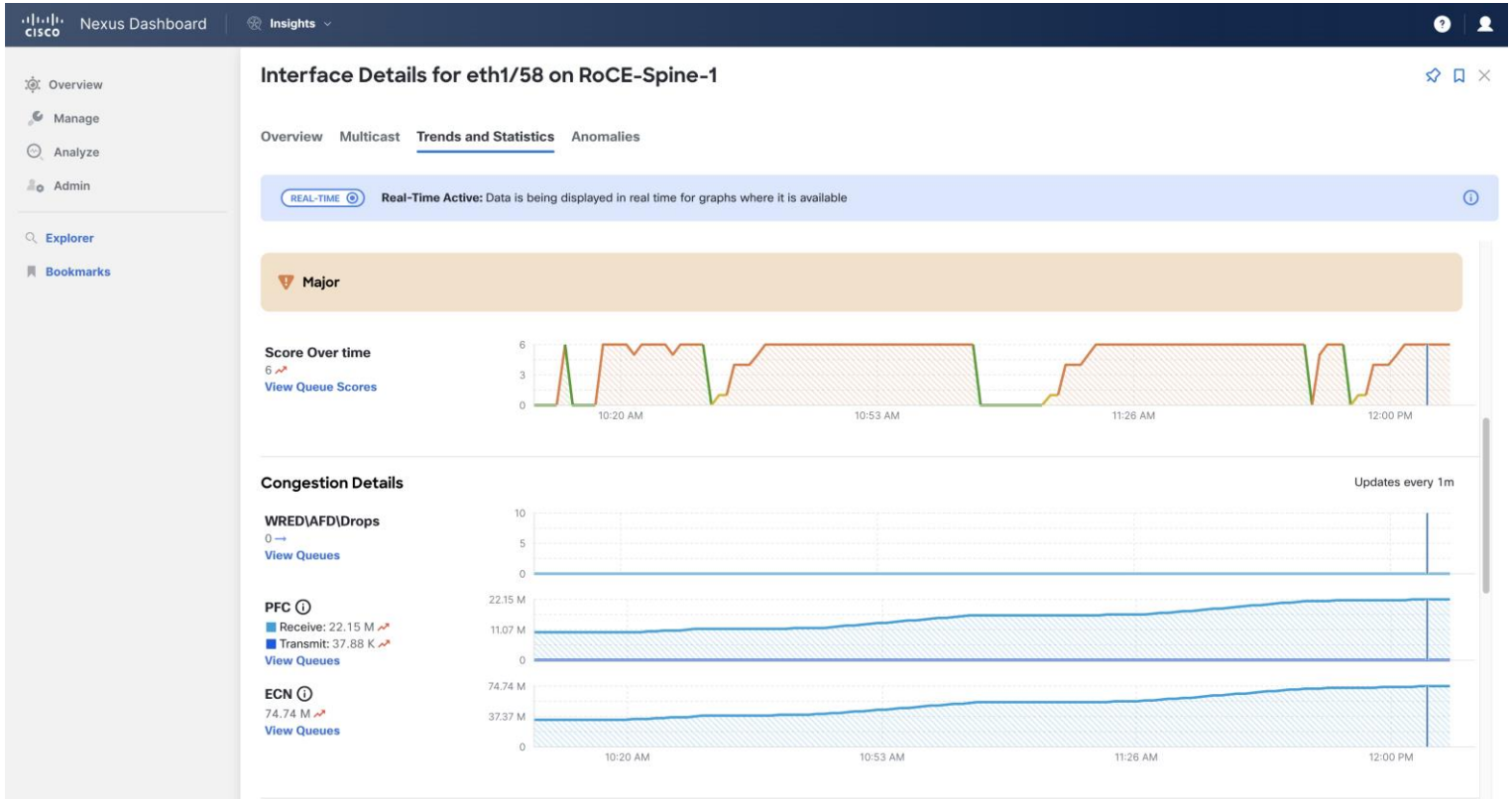
Nexus Dashboard Fabric Controller



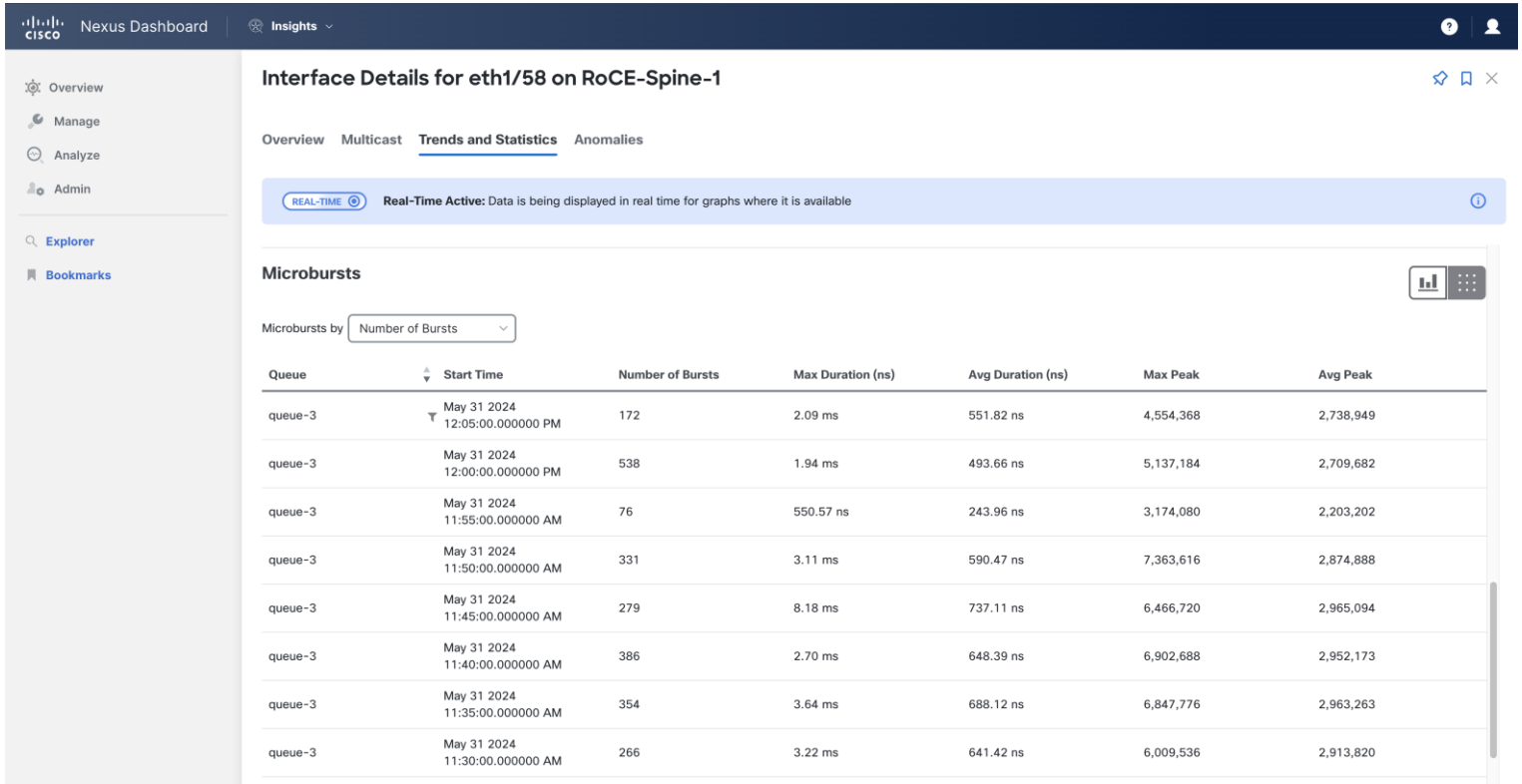
Visibility – Flow table

- Collects full flow information plus metadata
  - 5-tuple flow info
  - Interface/queue info
  - Flow start/stop time
  - Packet disposition (drop indicators)
  - Burst measurement
- Export date to collector
- Leveraged by Nexus Dashboard Insights

Nexus Dashboard Insights – Congestion visibility



Nexus Dashboard Insights – Congestion visibility



Queue	Start Time	Number of Bursts	Max Duration (ns)	Avg Duration (ns)	Max Peak	Avg Peak
queue-3	May 31 2024 12:05:00.000000 PM	172	2.09 ms	551.82 ns	4,554,368	2,738,949
queue-3	May 31 2024 12:00:00.000000 PM	538	1.94 ms	493.66 ns	5,137,184	2,709,682
queue-3	May 31 2024 11:55:00.000000 AM	76	550.57 ns	243.96 ns	3,174,080	2,203,202
queue-3	May 31 2024 11:50:00.000000 AM	331	3.11 ms	590.47 ns	7,363,616	2,874,888
queue-3	May 31 2024 11:45:00.000000 AM	279	8.18 ms	737.11 ns	6,466,720	2,965,094
queue-3	May 31 2024 11:40:00.000000 AM	386	2.70 ms	648.39 ns	6,902,688	2,952,173
queue-3	May 31 2024 11:35:00.000000 AM	354	3.64 ms	688.12 ns	6,847,776	2,963,263
queue-3	May 31 2024 11:30:00.000000 AM	266	3.22 ms	641.42 ns	6,009,536	2,913,820

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Audience Q&A

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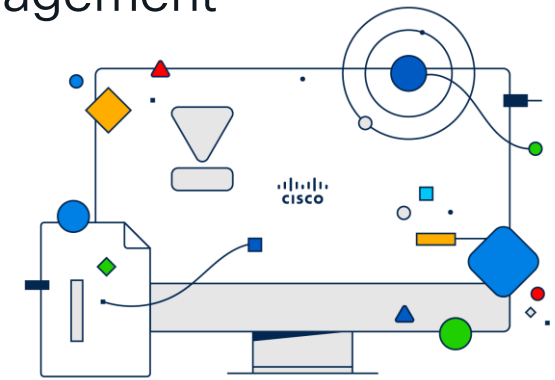
Blueprint of Today

Choosing the right infrastructure

- Build a Clos Fabric / Spine-Leaf
- Fixed Switches
  - Lower Latency, single AISC
  - Power Efficient
- Right Congestion management
- Routed Fabric
  - Use BGP for control plane
- Scalable design
  - Two tier design
  - Three tier design



Customer request #1

- Build Cluster of 260 GPUs
  - Use case: Inferencing for 100s of users, RAG, and fine tuning of a model
  - Cluster is bult with stand alone server (e.g. Cisco UCS-C240-M7)
- Build non-blocking network, for GPU communication
- Predictable and low latency for efficient training
- Host connectivity at dual 100Gbps
- Fabric at 400Gbps for efficient load-balancing

Networks – Why do I need them?

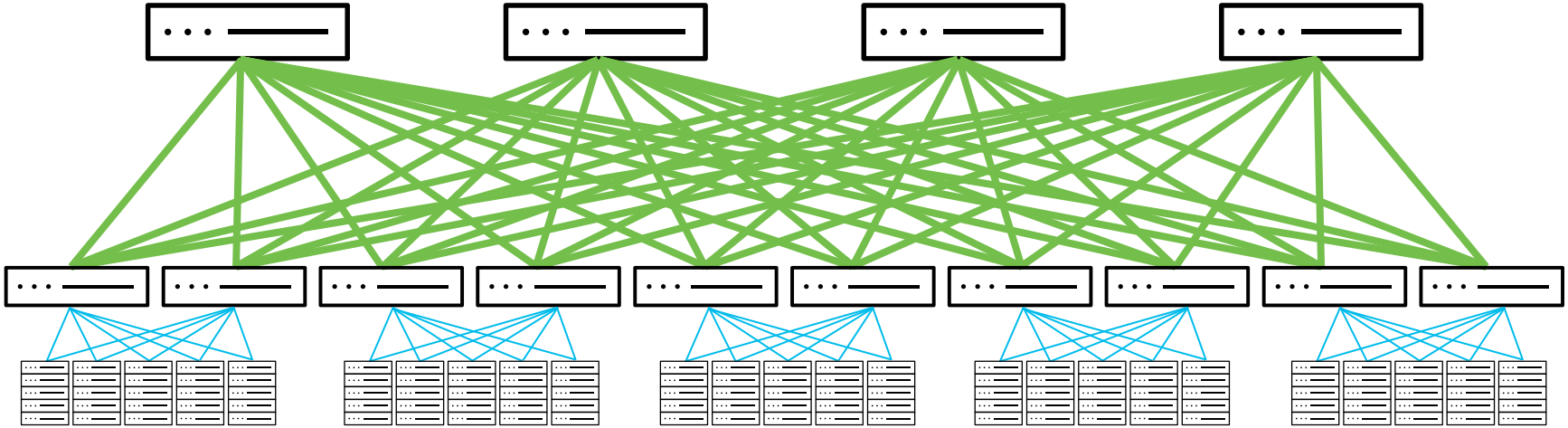
UCS C240 M7 Rack Server
Up to 2 GPUs

GPU to GPU, Front-end and Storage Network

Customer request #1 – Proposal

- Standalone server can have up to 2 GPUs
  - As required is 260 GPUs, 130 Stand alone servers are needed
  - Each standalone server is equipped with dual 100G port NIC
- 260 x 100G ports required for host connectivity in leaf layer
  - 26 x 100G host interfaces per leaf switch, for 10 leaf switches
  - Aggregate into 8 x 400G uplinks per switch for Spine connectivity
- Total of 4 spines 20 x 400G ports used per Spine
- Leave room for future expansion

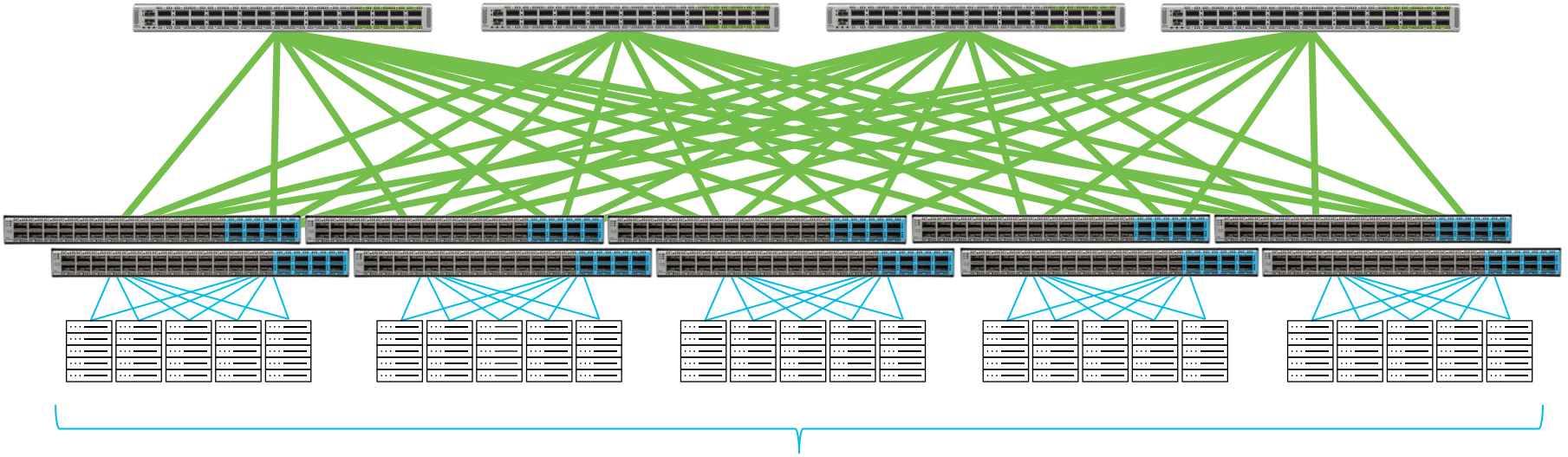
Customer request #1 – Design



130 Hosts each with 2 x GPU and 2 X100G NIC

100 Gbps
2 x 400Gbps

Customer request #1 – Design



130 Hosts each with 2 x GPU and 2 X100G NIC

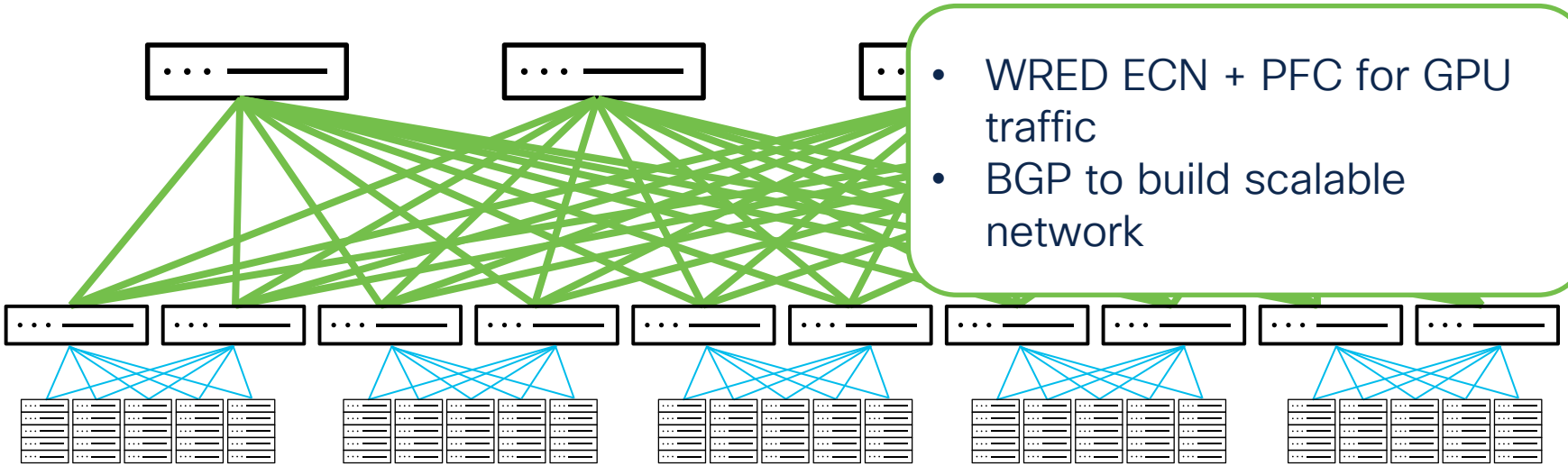
N9K-C93600CD-GX

N9K-C9332D-GX2B

100 Gbps

2 x 400Gbps

Customer request #1 – Design



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Audience Q&A

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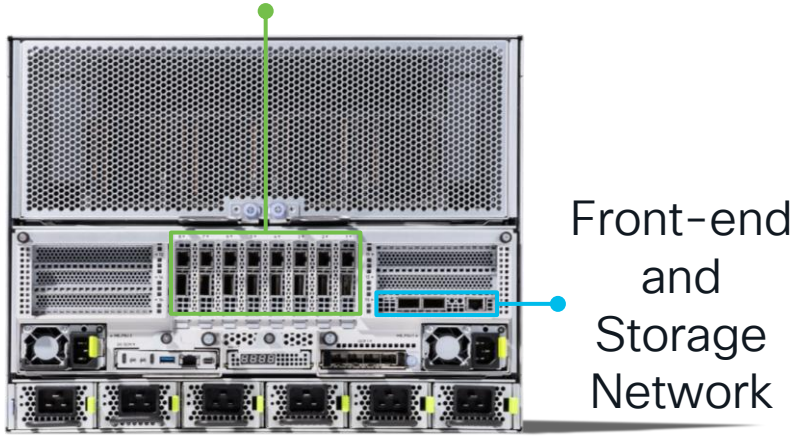
Customer request #2

- Build Powerful Cluster of 320 GPUs, for large training model use case
  - Cluster is bult with powerful accelerators (e.g. 8-way GPU server)
- Build non-blocking back-end network, for GPU communication
  - Predictable and low latency for efficient training
  - Host connectivity at 8 ports of 400Gbps
  - Fabric at 400Gbps for efficient load-balancing
- Build front-end network, for server-to-server interaction, and storage connectivity
  - 2 x 100Gbps ports for connectivity, non-blocking and future expansion

Networks – Why do I need them?

UCS C885A M8 Rack Server
8 GPUs

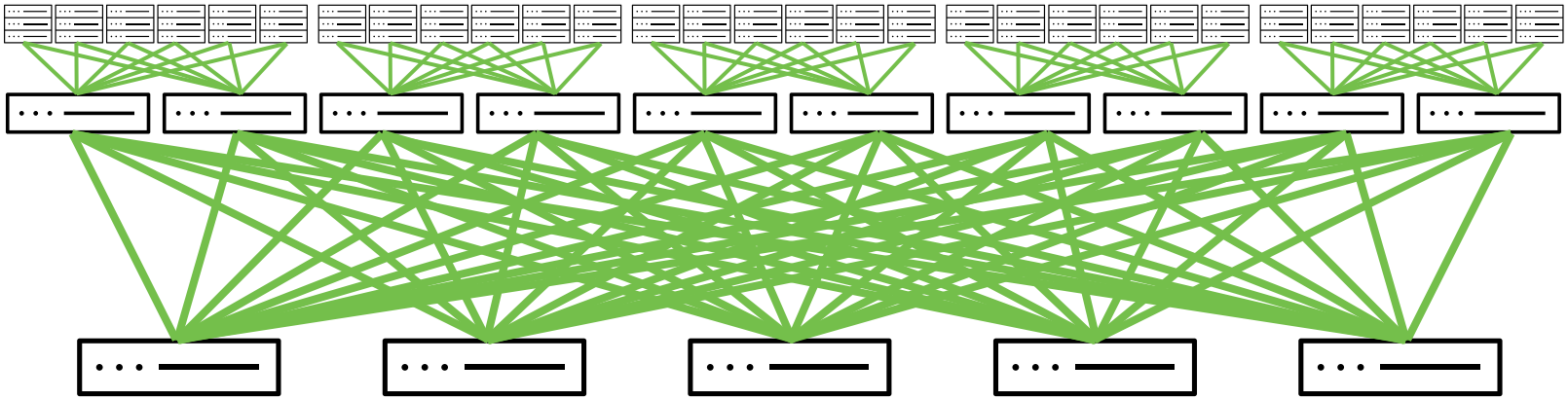


Customer request #2 – Proposal for Back-End

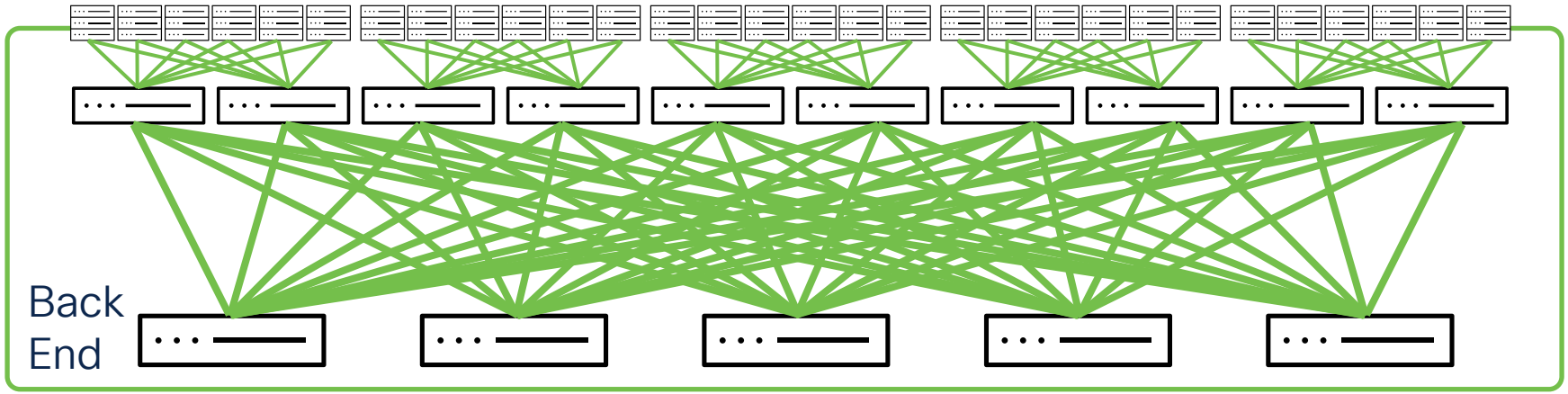
- Powerful AI training accelerator, has 8 GPUs per server
  - As required is 320 GPUs, 40 host are sufficient
  - Each host will connect with 8x 400G QSFP-DD ports
- 320 x 400G ports required for host connectivity in leaf layer
  - 32 x 400G host interfaces per leaf switch, for 10 leaf switches
  - Non-blocking network 32 x 400G uplinks per leaf for Spine connectivity
- Total of 5 spines 64 x 400G ports used per Spine

Front-End and Back-End Cluster Network

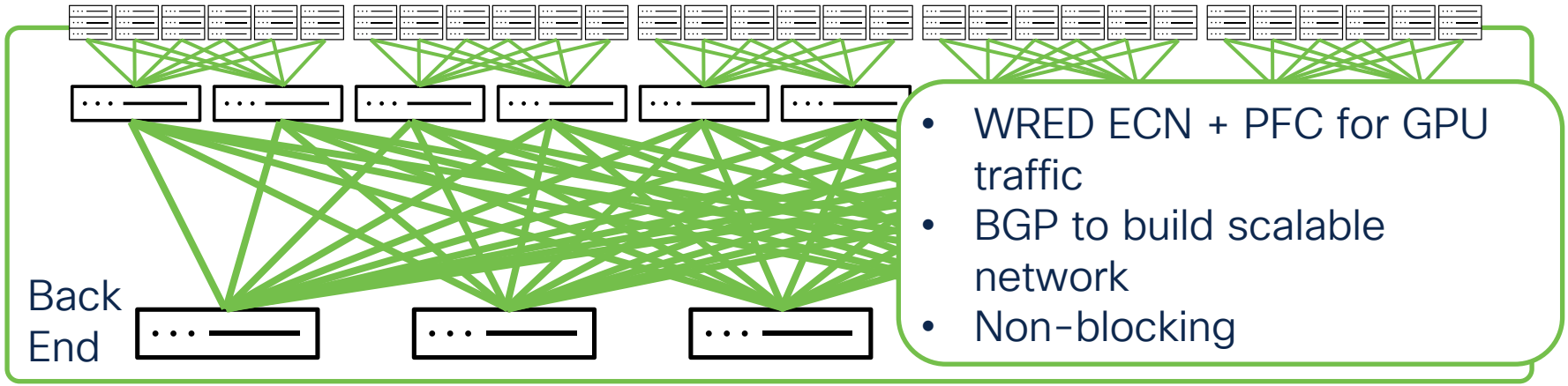
Back-End Cluster Network



Back-End Cluster Network

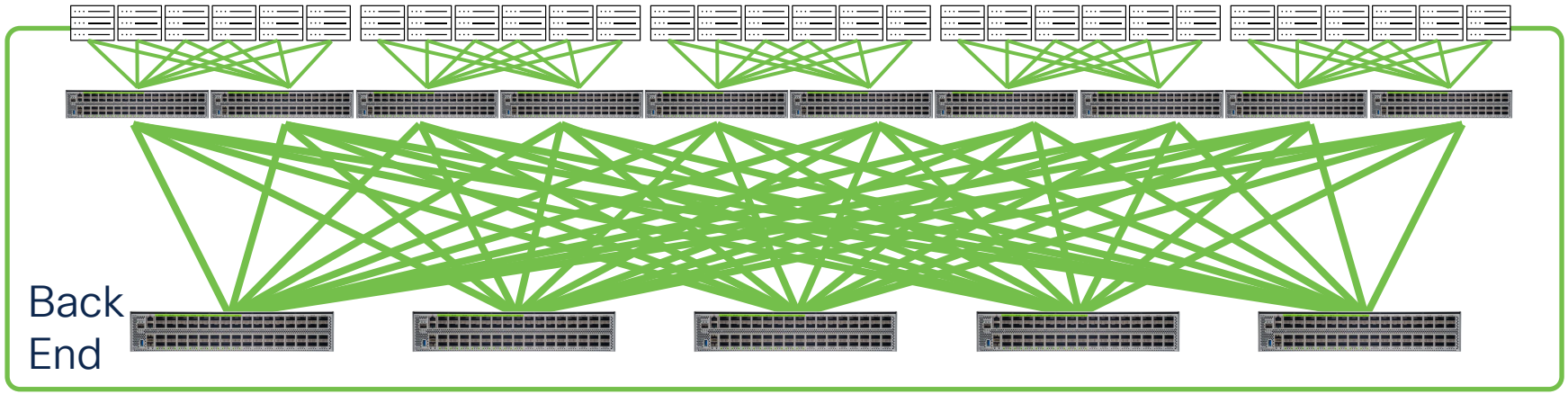


Back-End Cluster Network



Back-End Cluster Network

N9K-C9364D-GX2A

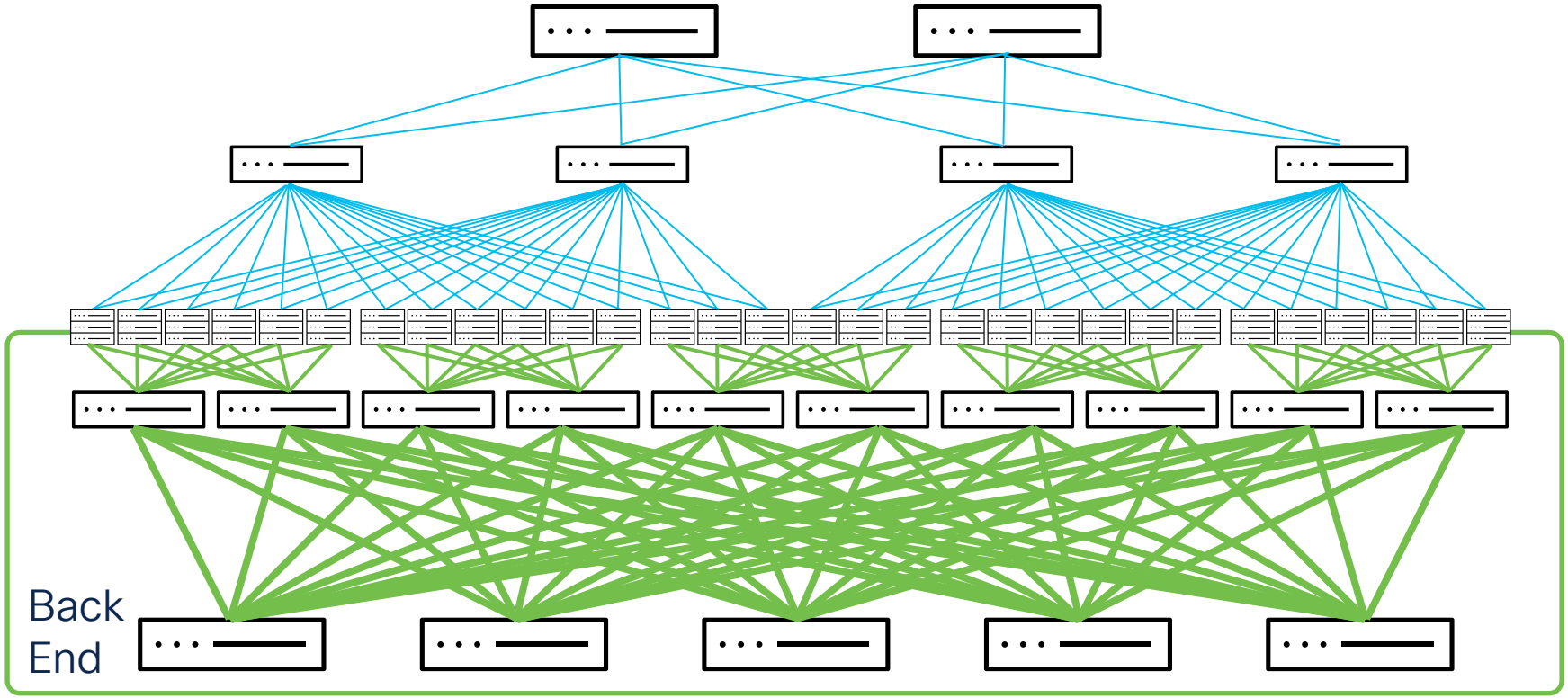


4 x 400 Gbps 6 x 400Gbps

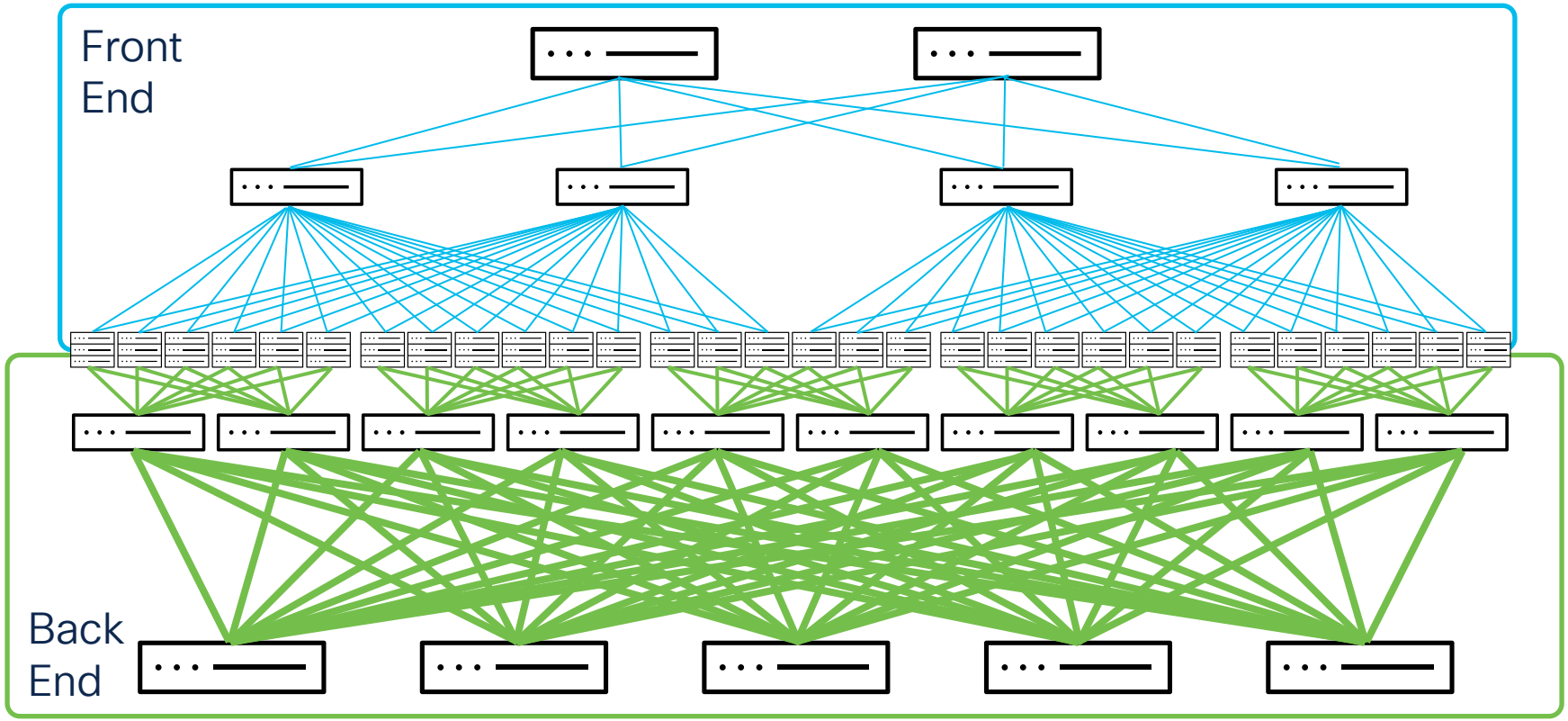
Customer request #2 – Proposal for Front-End

- Front End network for host communication, and storage
  - Each server has 2 x 100G ports
- 80 x 100G ports required for host connectivity in leaf layer
  - 20 x 100G host interfaces per leaf switch, for 4 leaf switches
  - Non-blocking network 20 x 100G uplinks per leaf for Spine connectivity
- Total of 2 spines 40 x 100G ports used per Spine
- Storage NFS network in Front End
  - 3 Storage array connected to leaf
  - RoCEv2 for storage networks

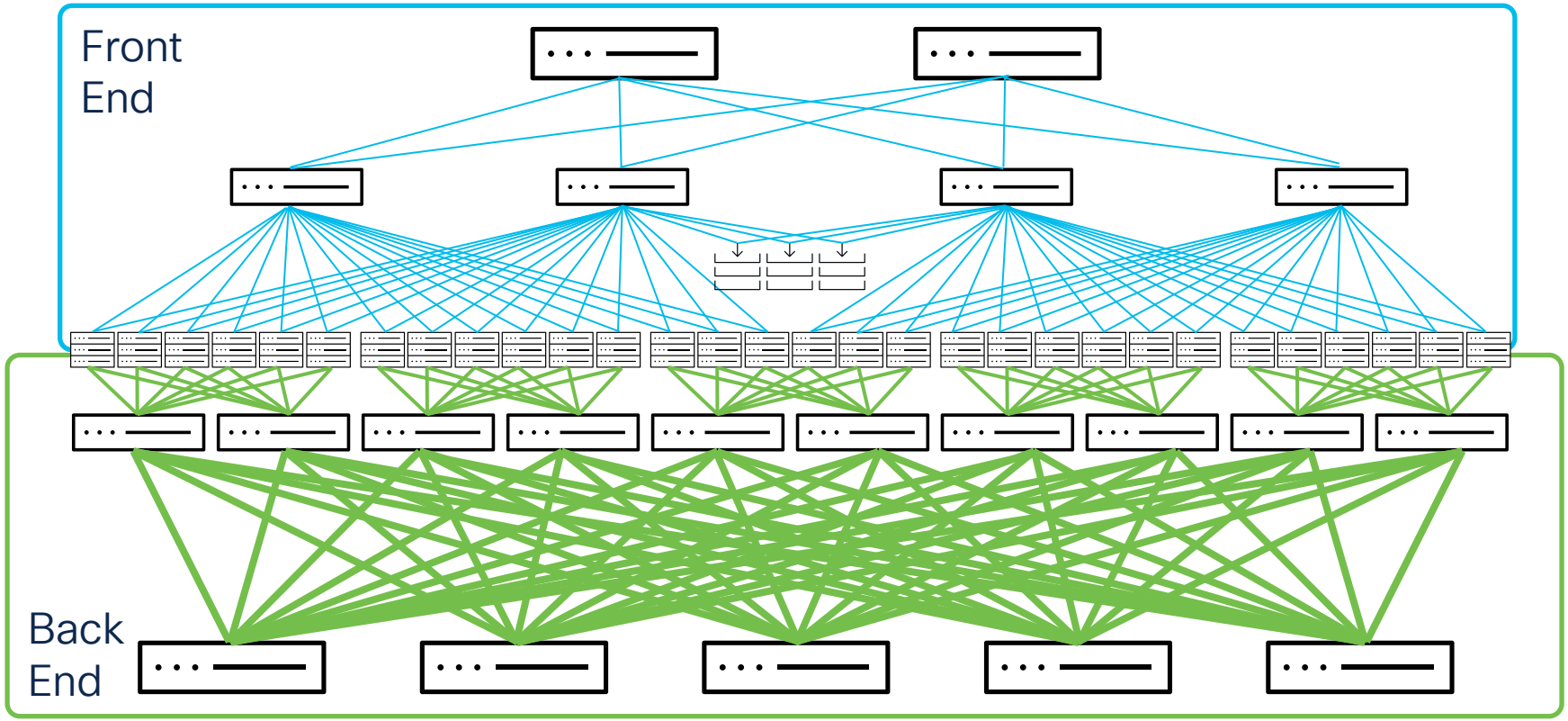
Front-End and Back-End Cluster Network



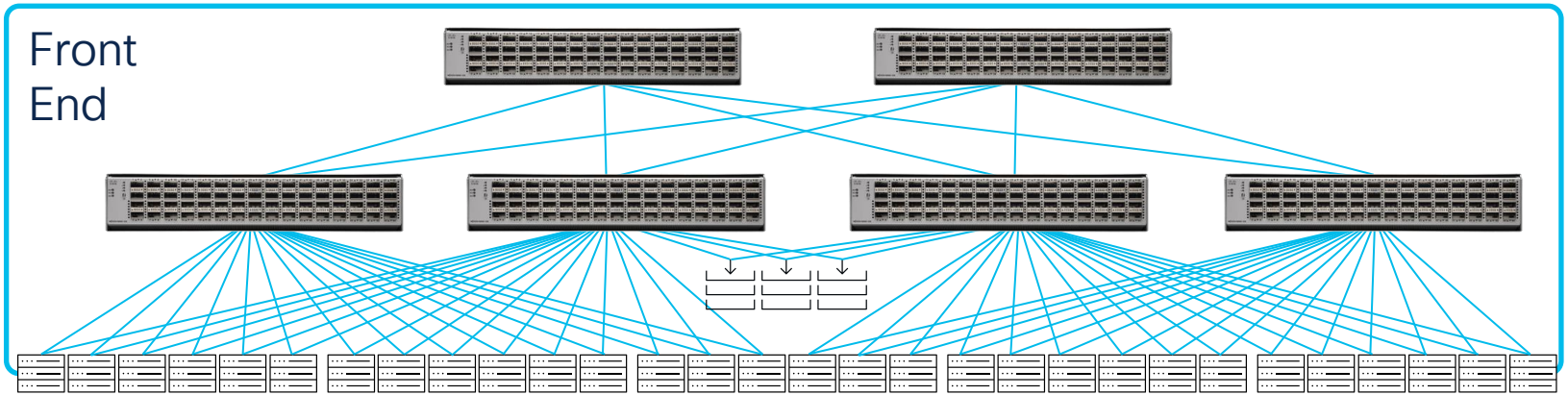
Front-End and Back-End Cluster Network



Front-End and Back-End Cluster Network



Front-End Cluster Network



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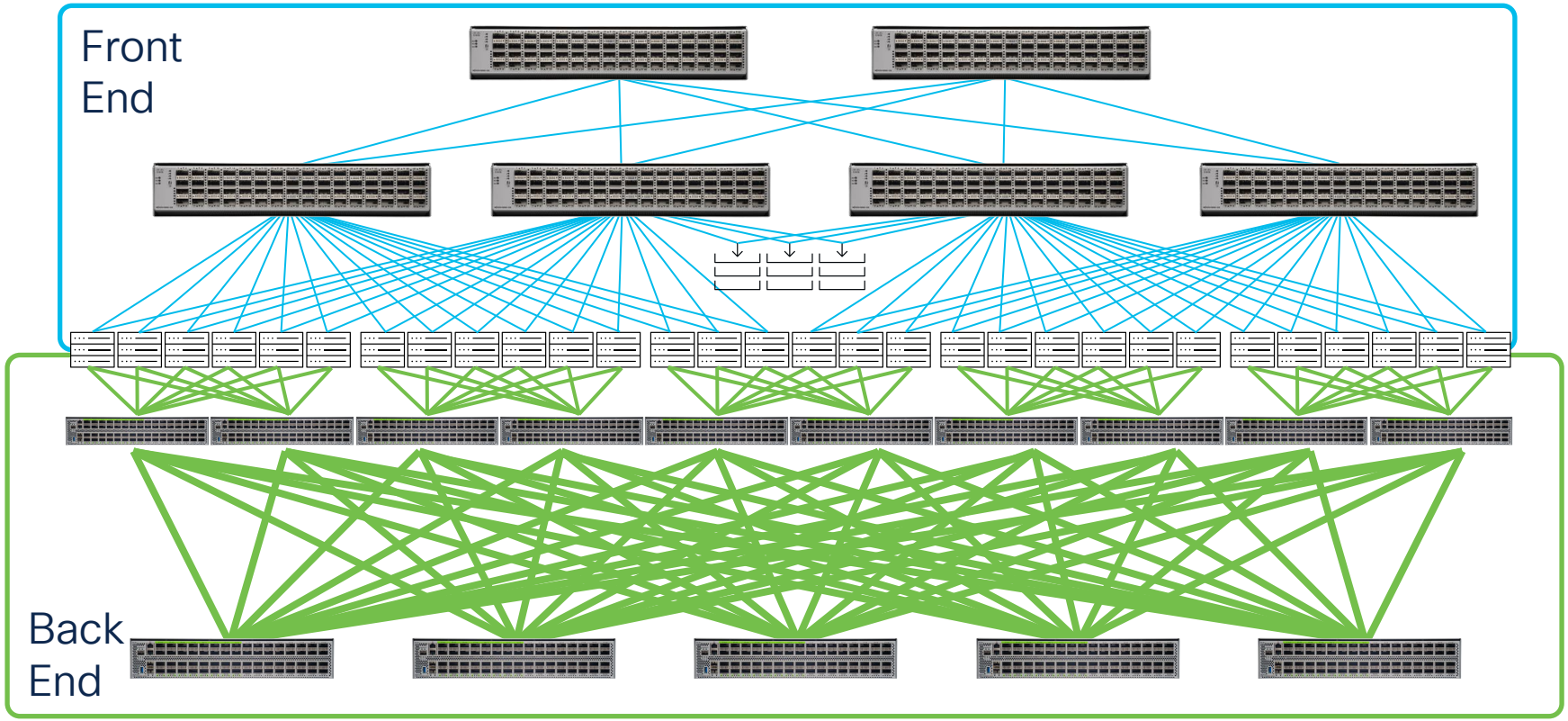
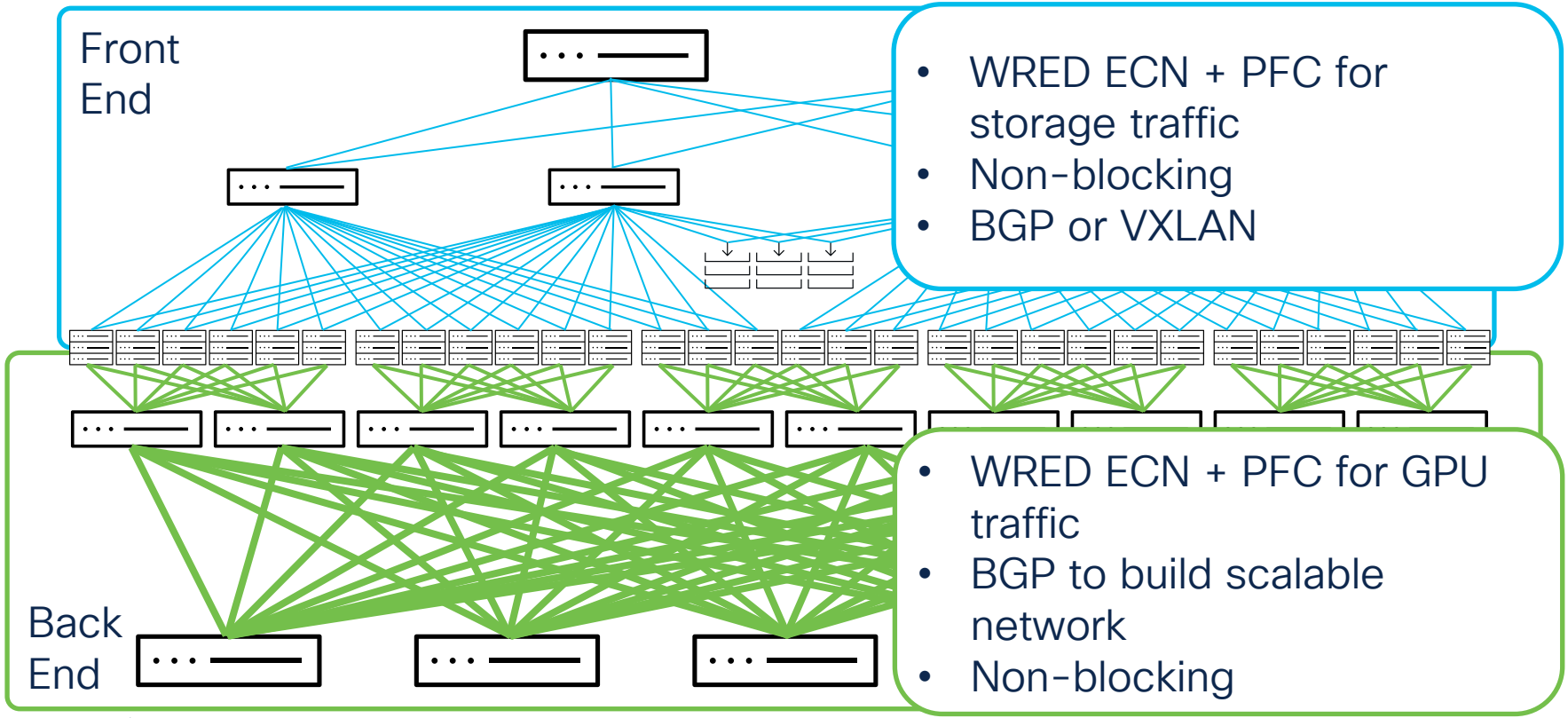
Front-End and Back-End Cluster Network



Front-End and Back-End Cluster Network



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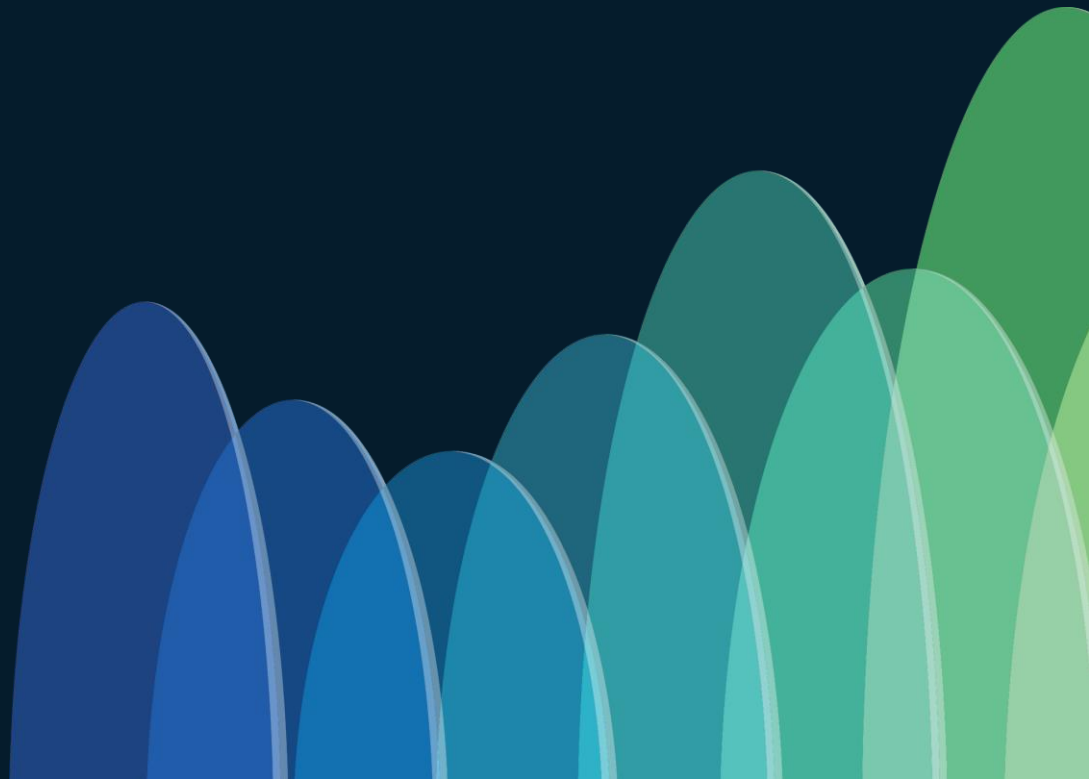
Audience Q&A

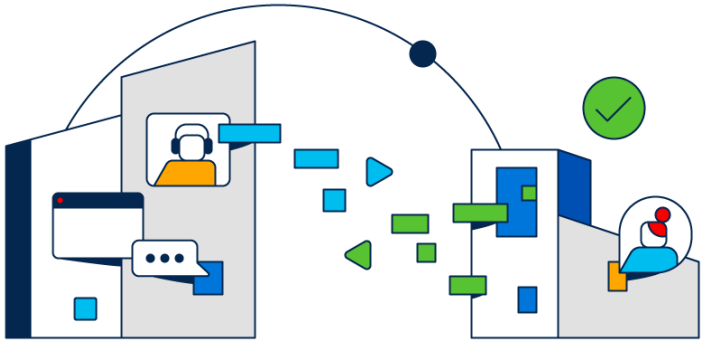
ⓘ Start presenting to display the audience questions on this slide.

Conclusion

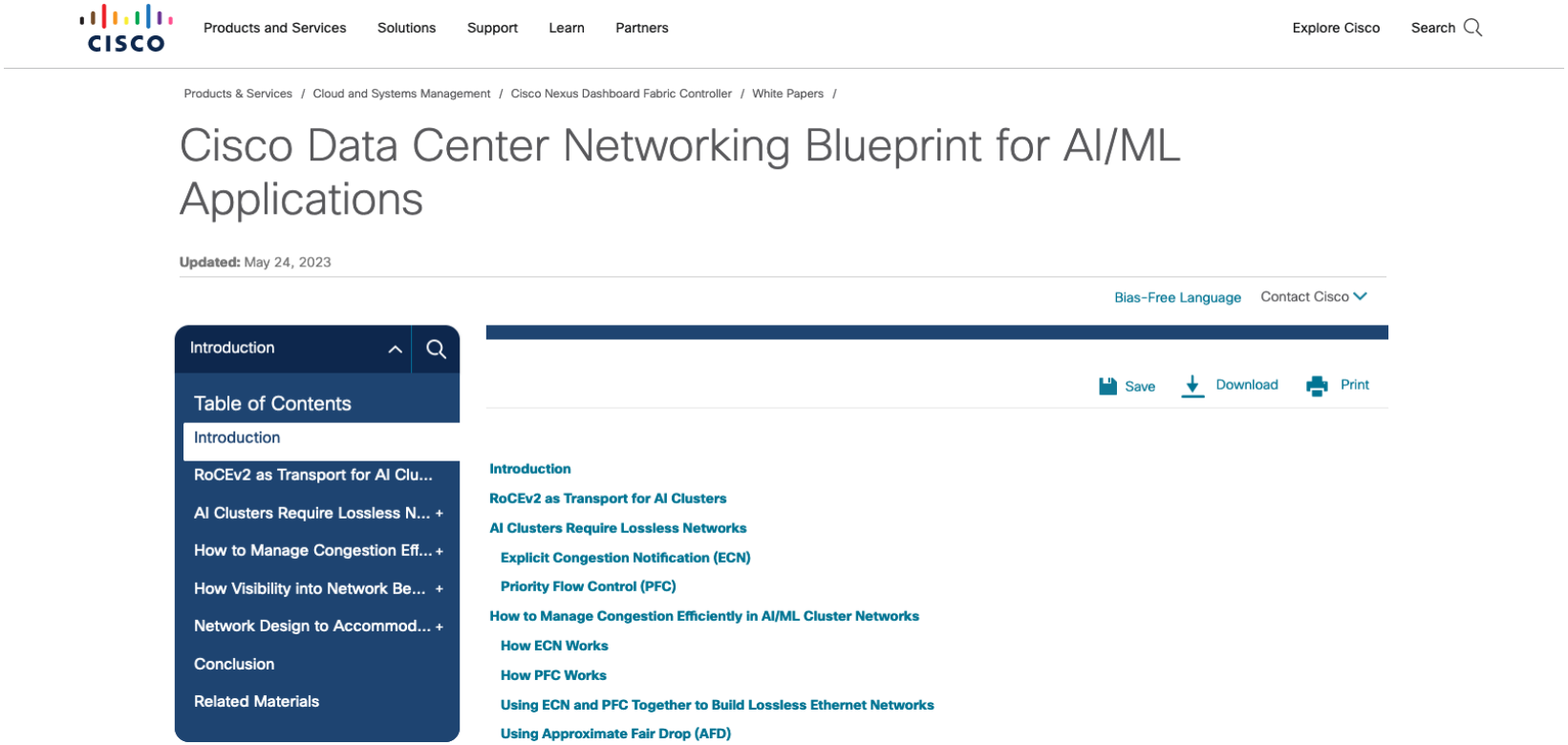


Takeaways

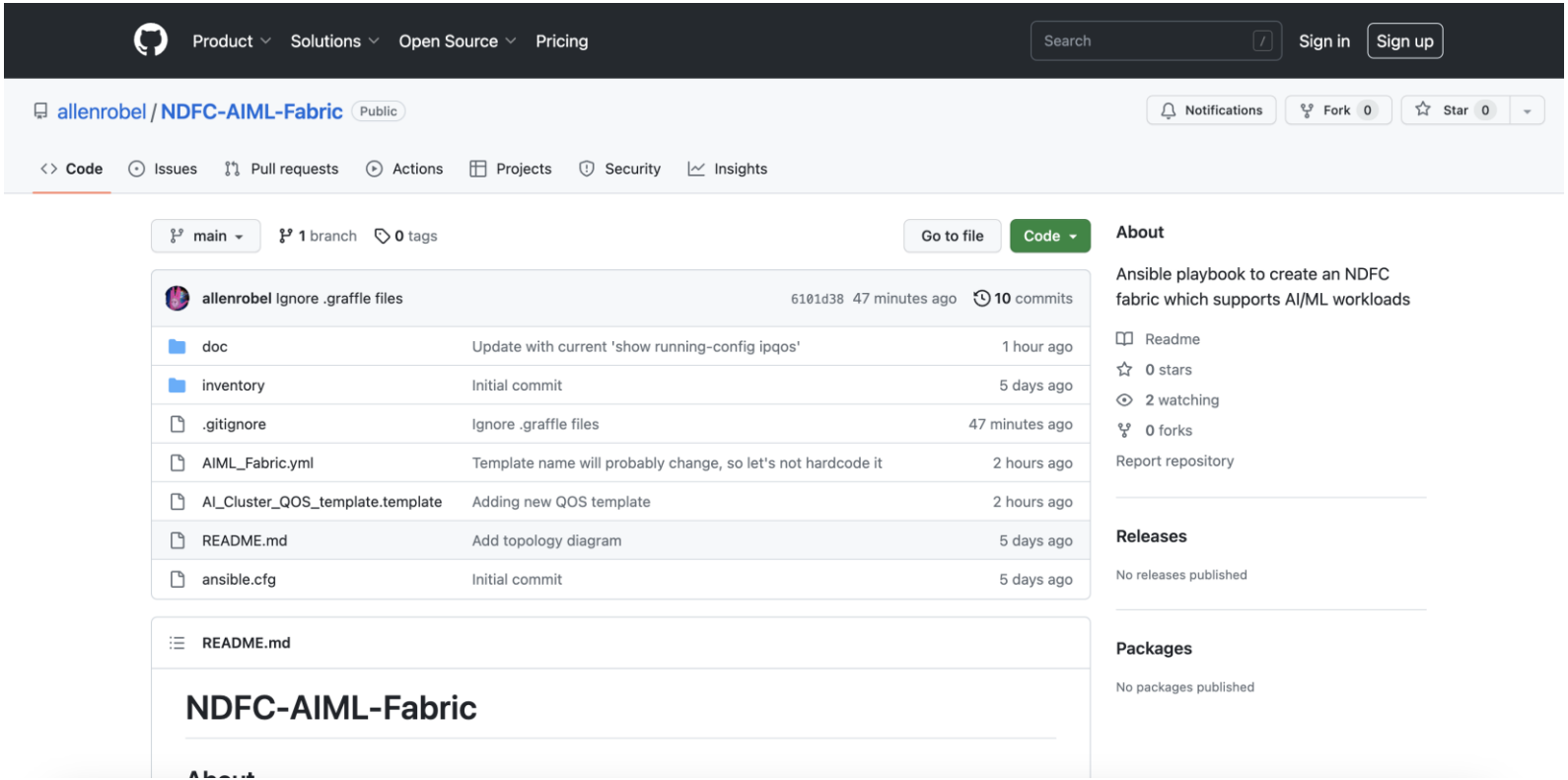
- Robust back-end network, and flexible front-end network
- Familiar data center fabric technologies, BGP or VXLAN
- Automate network for easier bring up and operation
- Visibility in network congestion, and bottleneck to troubleshoot and optimize



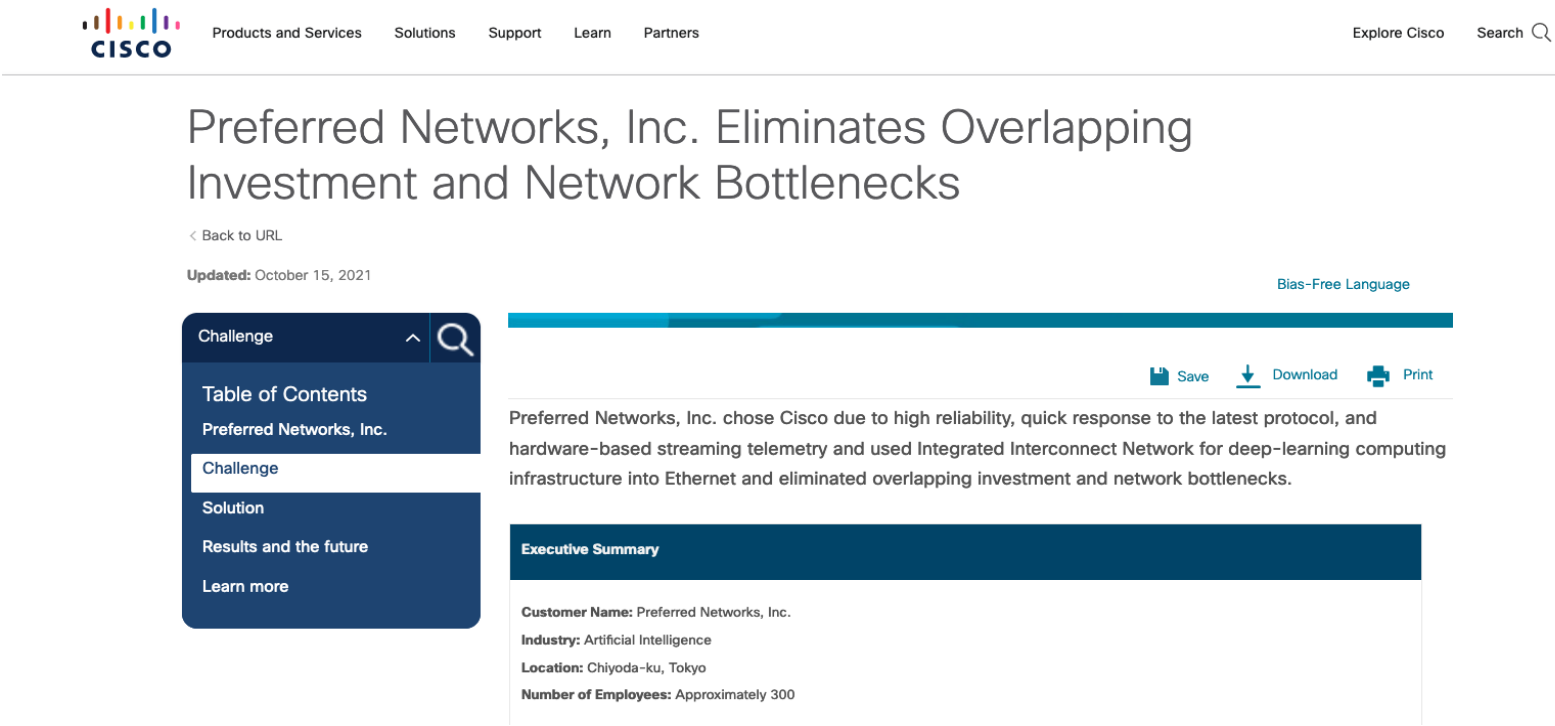
The Blueprint For Today



The Blueprint For Today



The Blueprint For Today



Related sessions

Session ID	Session Title	Day and Time
BRKDCN-2945	IP/Ethernet Storage Networking for AI Infrastructure	Thursday, Feb 13, 1:00 PM
BRKDCN-2999	Multi-Tier Fabric-Networks Designs for the Modern Data Center	Thursday, Feb 13, 3:15 PM

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Thank you

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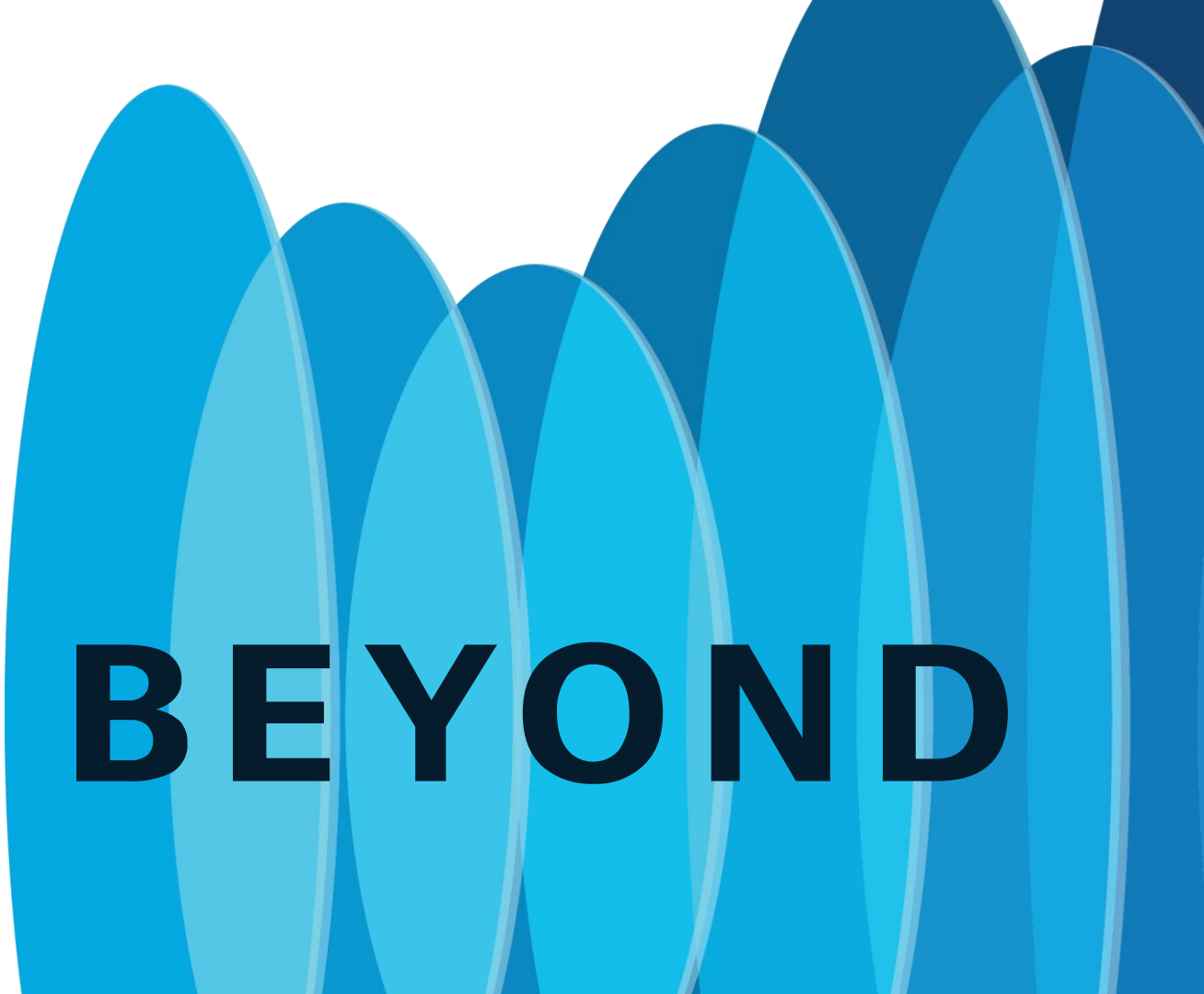

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