AI Backend: Deploying SRv6 uSID and SONiC for Deterministic Load Balancing

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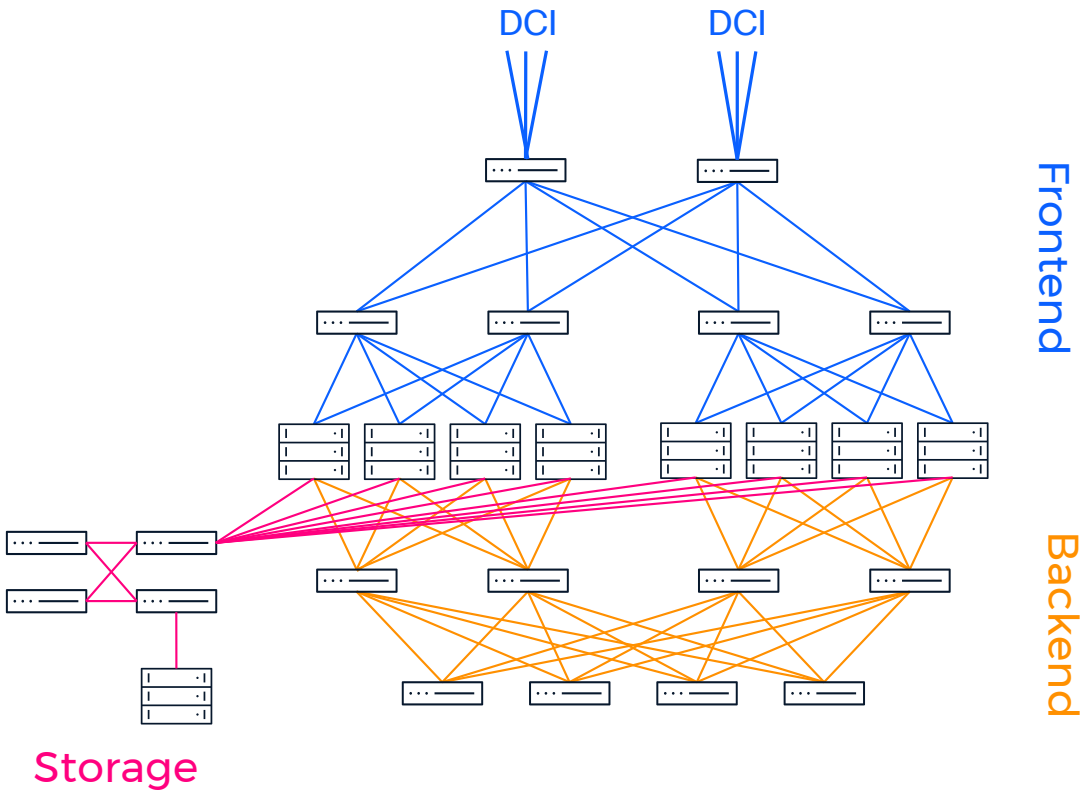
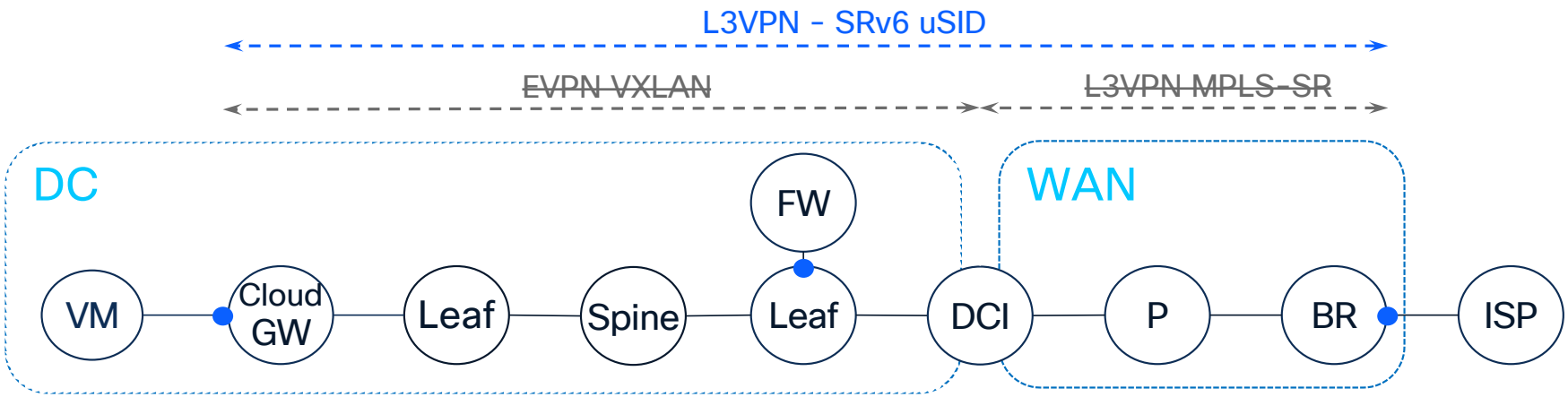
AI DC

- Frontend:
  - Compute
  - Inference
- Backend:
  - Inter-XPU
  - High-throughput (1:1 oversubscription)
  - Low jitter
- Storage:
  - Moves large datasets between storage systems and GPU servers
  - Load initial dataset for training jobs. Periodic Data Snapshots.



Frontend: SRv6 converged DC/WAN



- SRv6 uSID converged end-to-End design from the DC Front End, through the metro, up to the Peering
  - Including FW service insertion
- Replaces the legacy design with VXLAN in the DC and SR-MPLS in the metro network.
- Alexey Gorovoy from Nebius (recording)

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draft-filsfils-srv6ops-srv6-e2e-dc-frontend-wan

Backend: AI Training Traffic

- Long lasting (weeks)
- Highly synchronized
- Periodic
- Bursty, maximum link capacity
- Low Entropy
- Predictable!

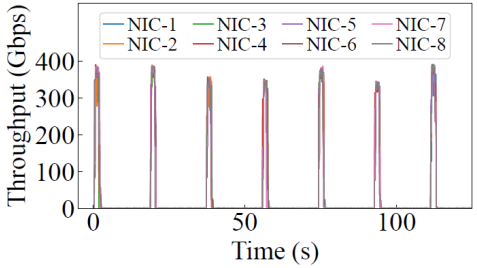


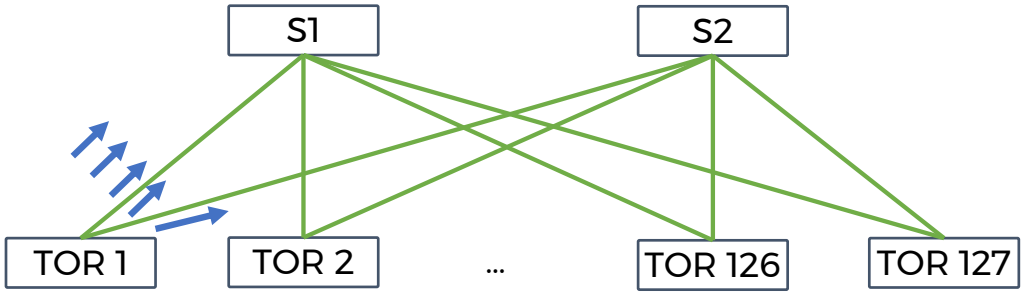
Figure 2: NIC egress traffic pattern during production model training.

Alibaba HPN, SIGCOMM 2024

- Failures of communications in LLM training are costly
  - An epoch of training is blocked until the synchronized collective communications of last epoch finishes
  - If an ongoing job crashes, all progress since the last checkpoint is lost (i.e., repeat last 15-30mins of computation)
  - META Llama3 (406B) training: 6k GPUs over 54 days; 419 unplanned interruptions *

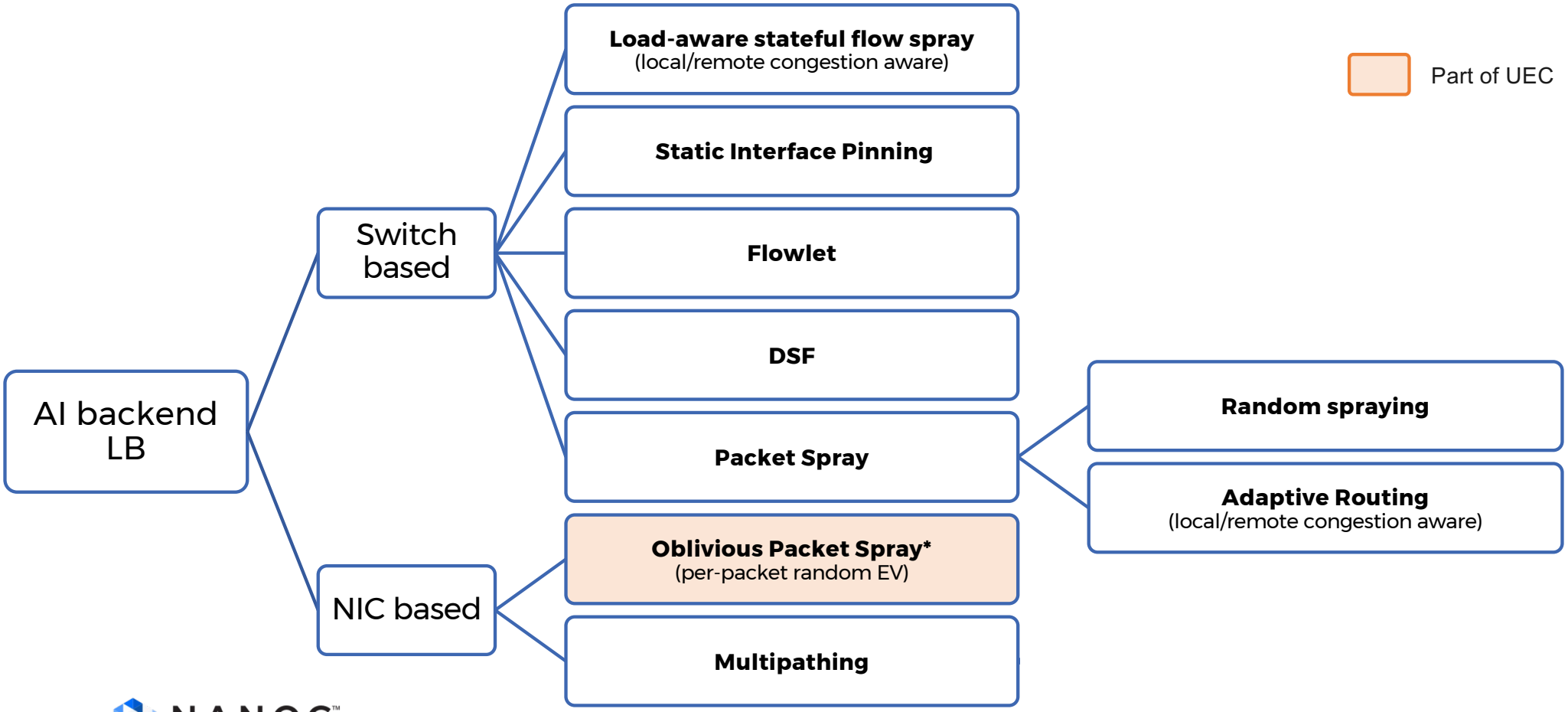
*** RDMA over Ethernet for Distributed Training at Meta Scale, SIGCOMM '24**

Load imbalance



- As number of QPs is small, traditional ECMP load-balancing results in load-imbalance (hash collision).
- Leading to congestion, packet loss, and GPU halted waiting for retransmission.
- Many different efforts to overcome it.

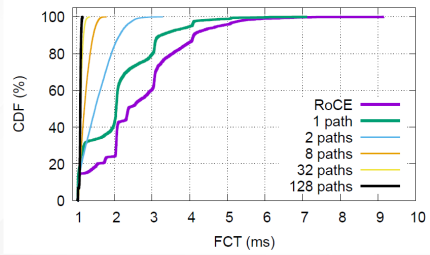
Many attempts to solve the LB problem



* Requires Packet Trimming from switch

The Need for Transport Multipathing

Ultra Ethernet Transport: a multipath replacement to RoCEv2.
Need multipath for pipeline parallelism



Takeaway: multipath is key to reduce tail FCT for ML training.
Flows start at line rate, but don't like PFC. Packet trimming being standardized.

Costin Raiciu, Load Balancing Approaches in AI/ML Networks, IETF123, July 2025

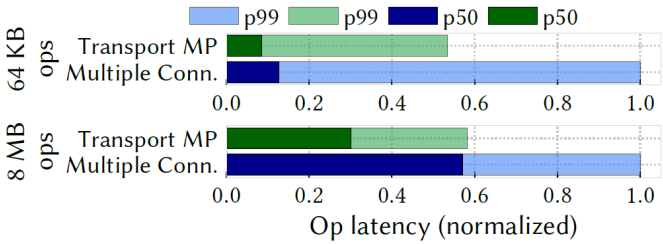


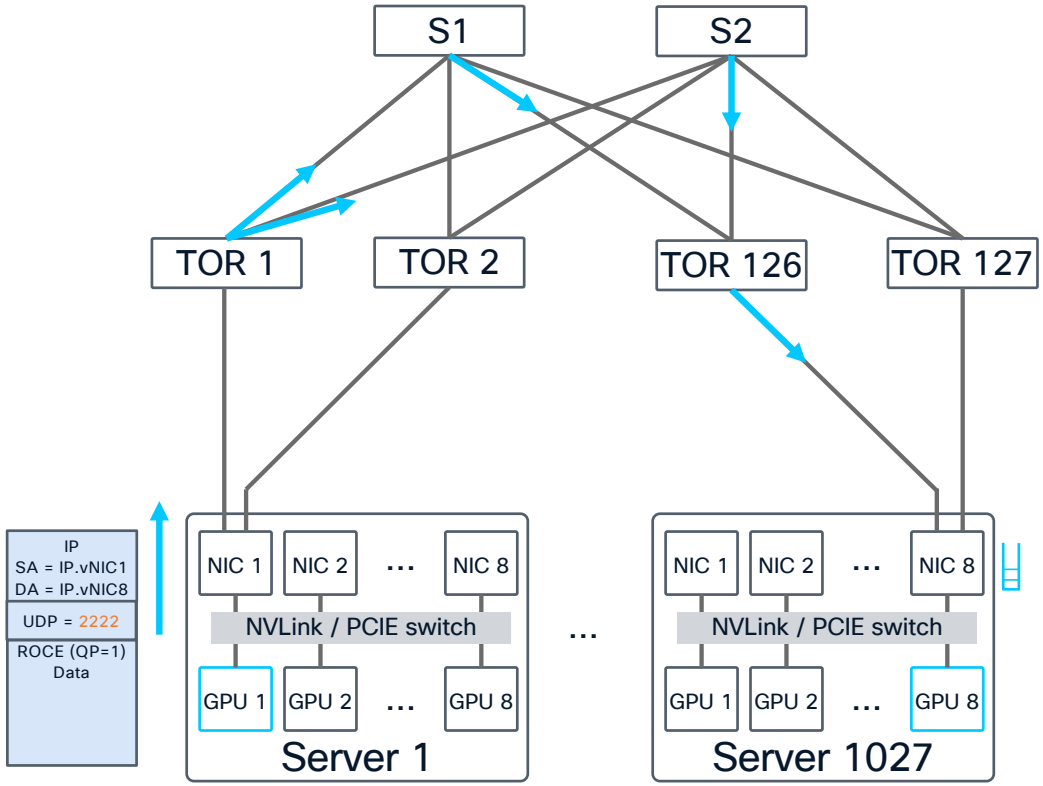
Figure 3: Multipathing benefits ML Workloads

Falcon: A Reliable Low Latency Transport, Google, SIGCOMM 2025

- Multipathing uses multiple paths for each QP
  - Host maintains state for each path.
  - Feedback loop and balancing done for each path.
- Typically, one single congestion window across all paths (to reduce RNIC overhead)
  - Some methods use a dedicated congestion window per path

A Probabilistic approach to Multipathing

- Select a few **random EV** (Entropy Value)
  - Transmit data
  - Monitor the performance of a QP (e.g., RTT, ECN, Packet Trimming)
- **IF there's a performance degradation** THEN **change the EV** randomly
  - …in hope to obtain a different path
- **Issue**: no guarantee that the new EV will be hashed through a different path in the fabric
- **A more refined version**: **predict** how EVs are hashed by intermediate switches
- **Issue**: Requires sticky load-balancing upon link failure (LB group change)



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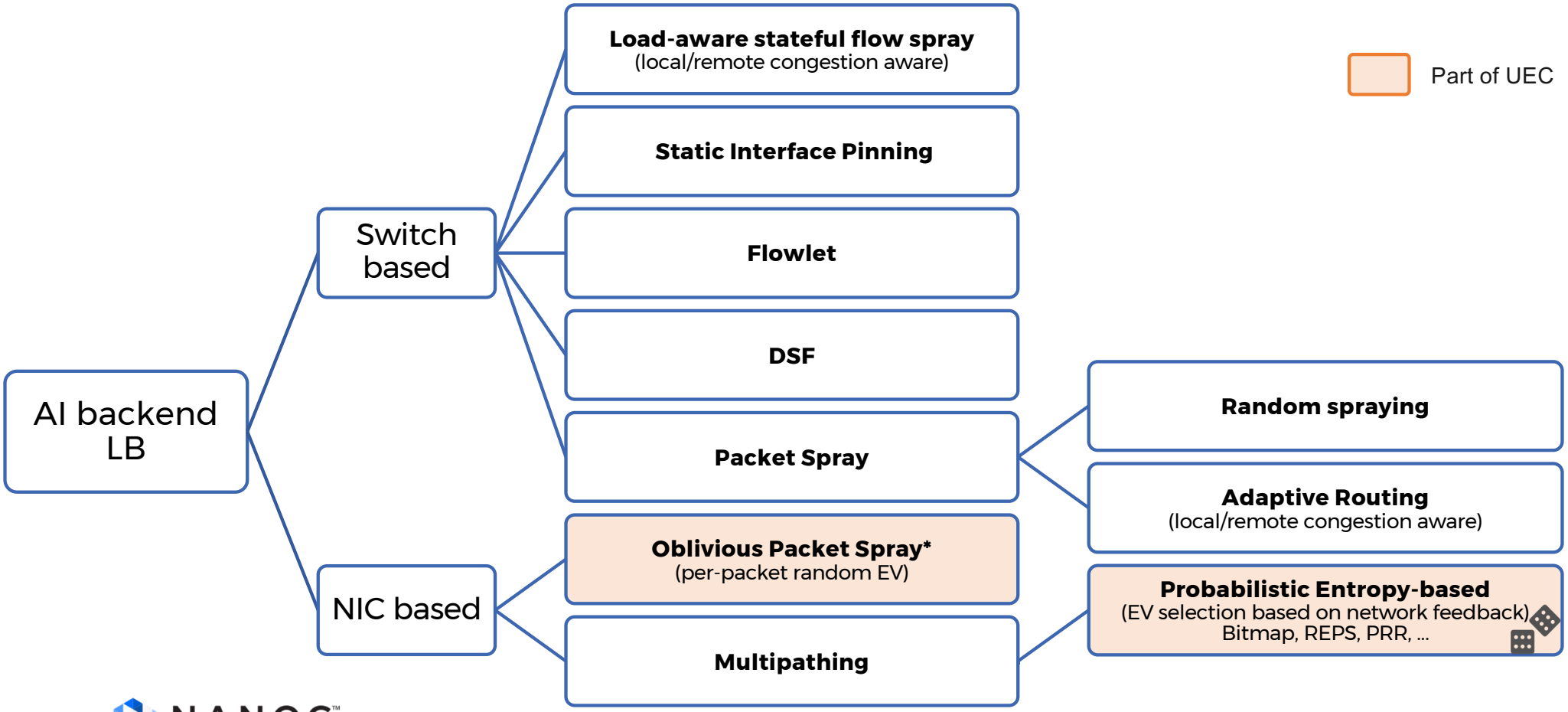
Many attempts to solve the LB problem



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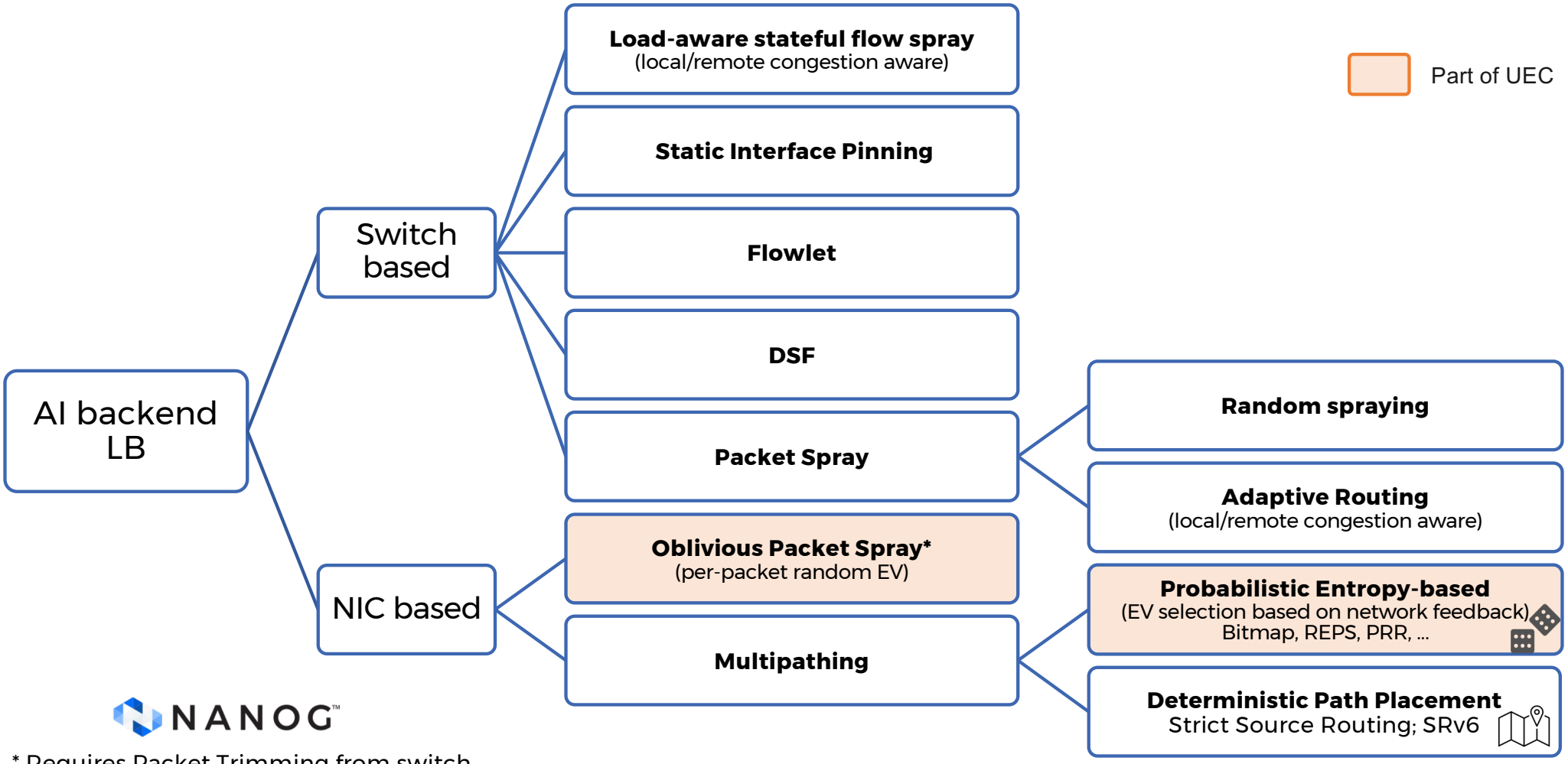
* Requires Packet Trimming from switch

Many attempts to solve the LB problem



* Requires Packet Trimming from switch

A deterministic approach: Source Routing

- GPU is in control of the end-to-end path
- Essence of SR: the application controls the end-to-end path as a network program in the packet header
- **Strict Source Routing**: full sequence of links the packet traverse
  - Traffic follows the explicit path step-by-step
  - Not exposed to ECMP
- Feedback loop is always faster at the NIC
  - Leverage of ECN and Packet Trimming (for congestion losses)
  - Change of path from is immediate (no state propagation through fabric)

SRv6 rich-ecosystem

Network Equipment Manufacturers

Cisco, Huawei, Nokia, Ciena, Juniper Networks, Arista, ZTE, Arrcus, Ericsson, H3C

Merchant Silicon

Access: A100 Edge: K100
Core: Q200, P100
Leaf/Spine: G100/200/300

Broadcom

DNX – Jericho
XGS – Tomahawk

Marvell, Nvidia

Open-Source Applications

Pyroute2, IPTABLES SERA, GoBGP, exaBGP, eBPF, cilium, Wireshark, FRRouting, Snort, BIRD, NANOG

SRv6 uSID

Open-Source Networking Stacks

SONiC, Linux, fd.io, P4, OPEN Compute Project, OvS Open vSwitch, VyOS

Smart NIC / DPU

Intel, Nvidia

Partners

kaloom, Trend Micro, ENEA Qosmos Division, NoviFlow, ixia A Keysight Business, Spirent, Red Hat, f5, 6WIND, Keysight Technologies

Failure resiliency

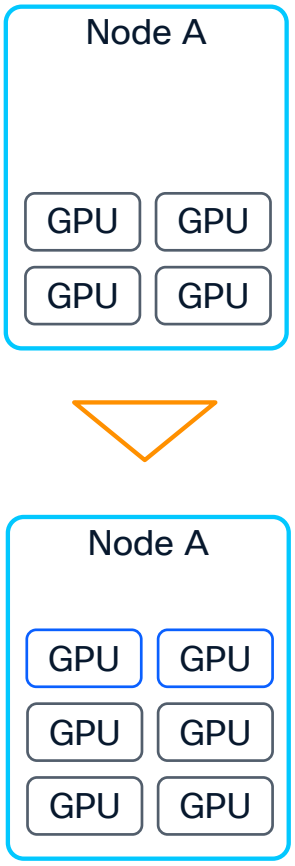
- An IP fabric with dynamic routing protocol is problematic for Backends
  - Assume 10ms to propagate a link flapping and ECMP group update in FIB
  - Assume 4KB MTU, 400Gbps link fully utilized
  - …over 120,000 packets (~0.5GB) lost plus all related congestion control

- **Strict Source Routing is not ECMP exposed**
- **SRv6 can be deployed on a statically provisioned fabric**
  - **No dependency on dynamic routing protocols**

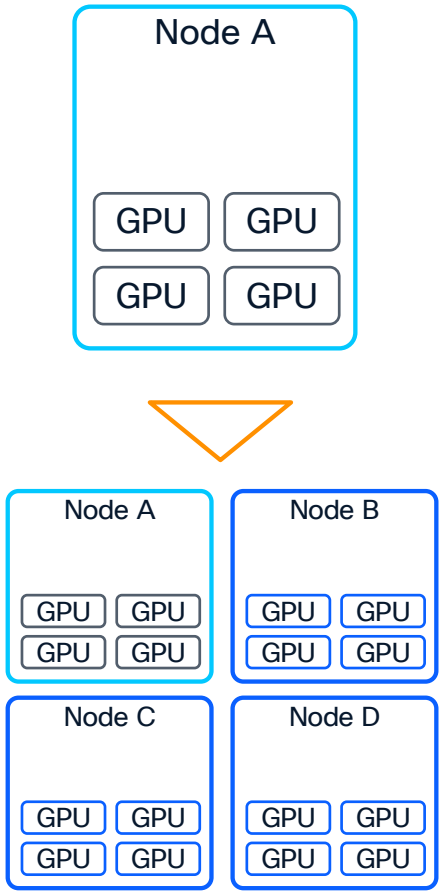
Virtualization

- SRv6 policy fulfills virtualization requirements in AI Backend:
- Efficient GPU Overlay/Tenancy separation
  - No MTU gain
  - No expensive DPU cycles
- Slicing of the backend
  - Multiple tenants in the same shared AI Backend
  - No impact by “noisy” neighbors

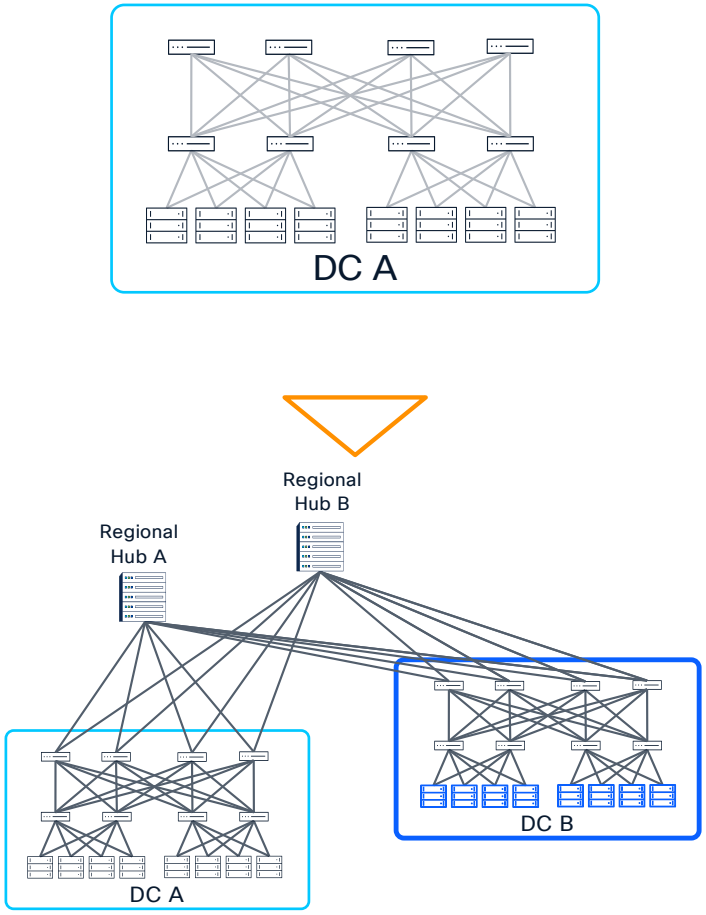
Scale Up



Scale Out

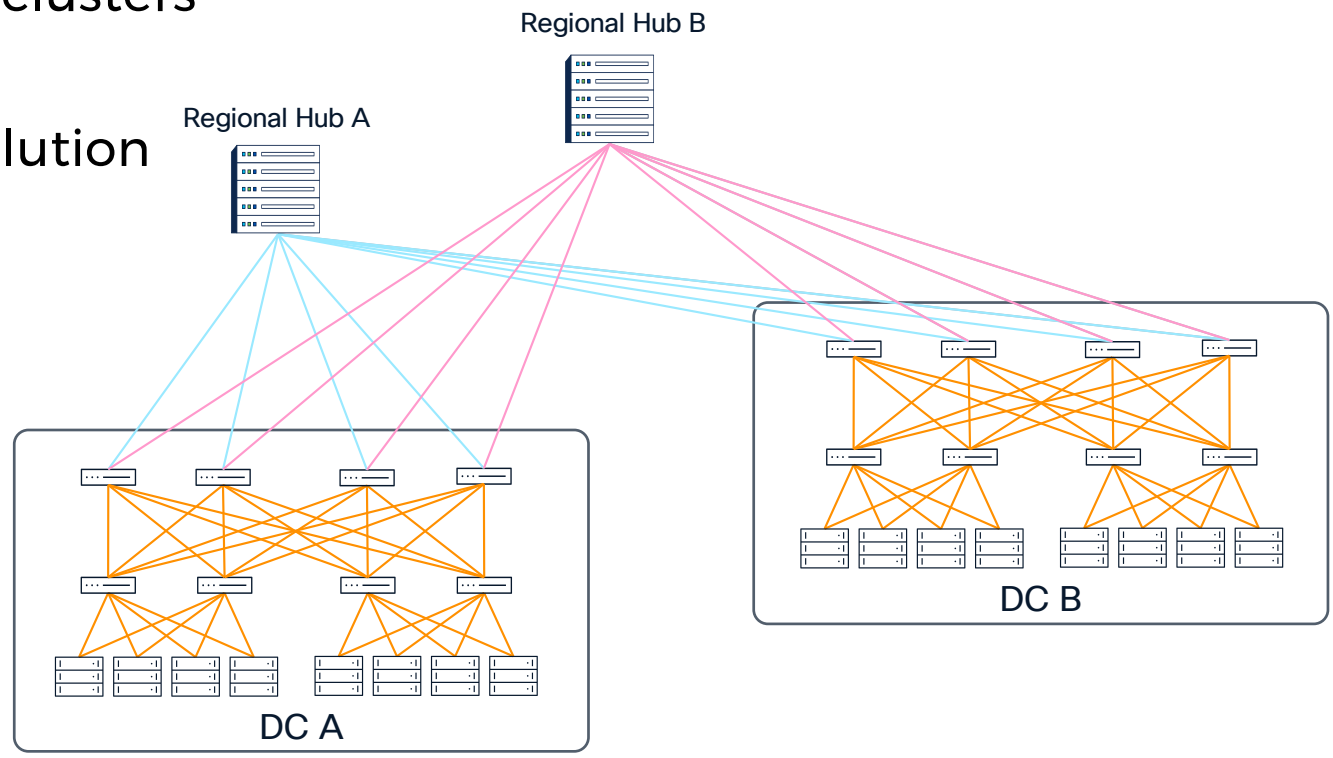


Scale Across



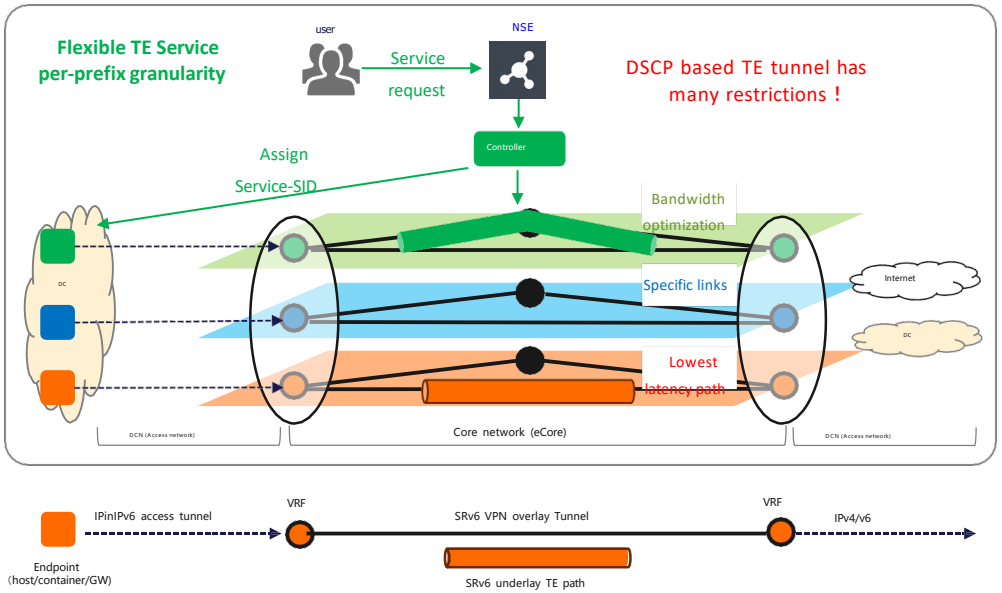
Scale Across: It's a TE Problem!

- The topology is less symmetric
- The capacity is more scarce
- Shortcuts between clusters
- SRLG's
- SR is the obvious solution



SRv6 DCI at Alibaba

- eCore = Alibaba's Data Center Interconnect
  - Whitebox running SONiC
  - Multi-plane (redundancy)
  - Multi-Space (capacity scaling)
  - Mult—Routing domain (failure isolation; small blast radius)
- Service Aware Traffic forwarding with SRv6
- BGP Underlay Routing + ISIS (per domain)
- Presented at OCP 2025 (link)



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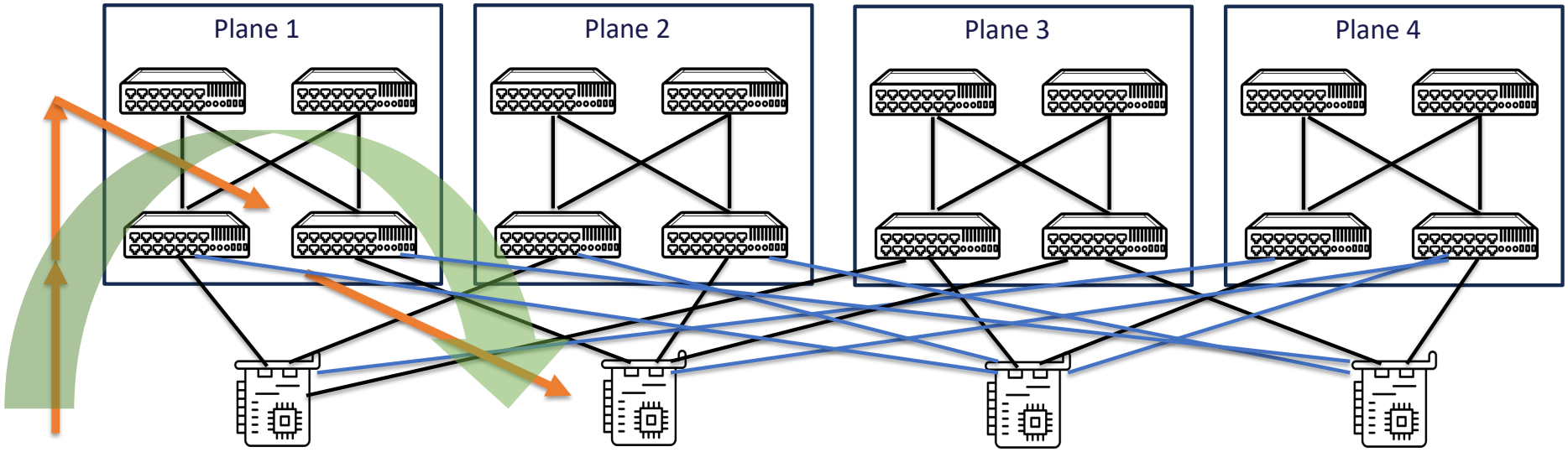
Microsoft: Backend Challenges

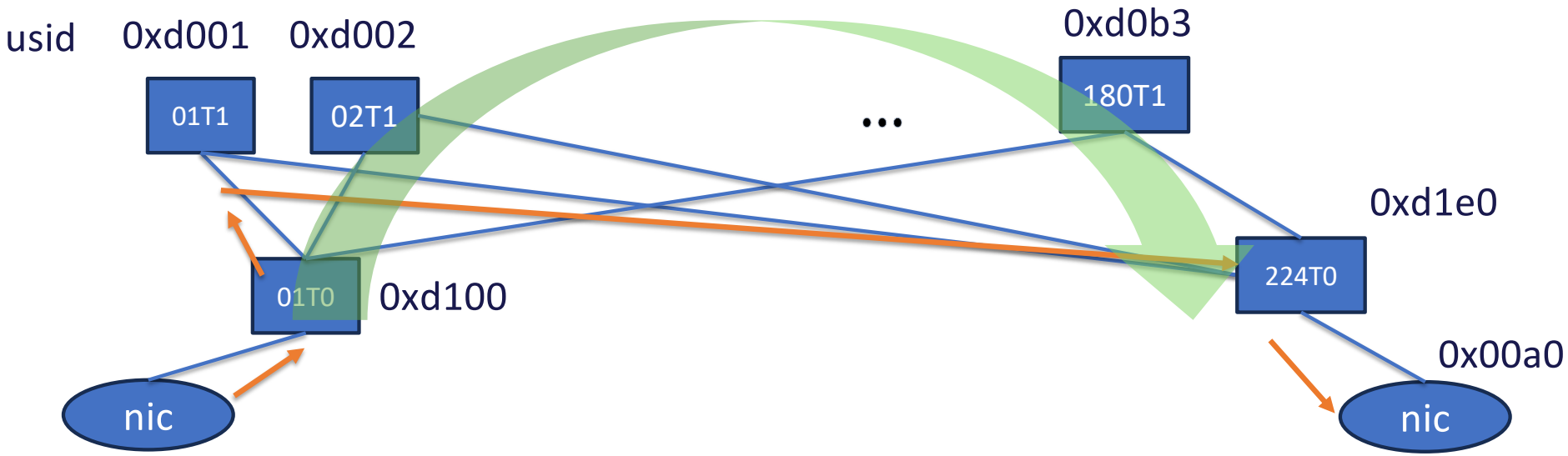
- The solution must be cost-effective and scalable
  → No Proprietary Technology
- Traditional passive hash-based load balancing mechanisms suffered from low entropy problem.
  → Need more active traffic engineering
- Failures is inevitable at this scale
  → Fast failover is necessary
- Multi-path transport is desired for efficient bandwidth utilization
  → Demand for fine-grained path control

SRv6 in AI Backend Network



- Provides fined-grained network control based on source routing
- Enables path enumeration for traffic management
- Integration with AI workloads flow scheduling provides optimal network performance
- Allow source to quickly reroute upon path failures or congestion

Failure handling with uSID

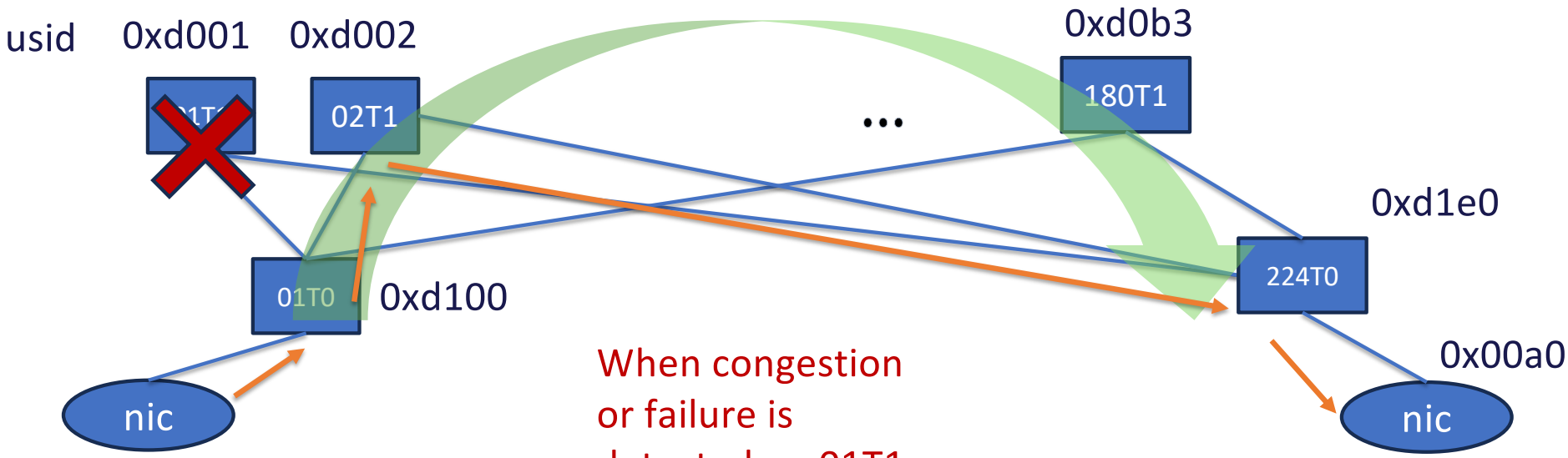


DstIPv6: *fcbb:bbbb:d100:d001:d1e0:00a0::*

NO SRH

1st hop 2nd hop 3rd hop 4th Hop

Failure handling with uSID



When congestion or failure is detected on 01T1

DstIPv6: *fcbb:bbbb:d100:d001:d1e0:00a0::*

NO SRH

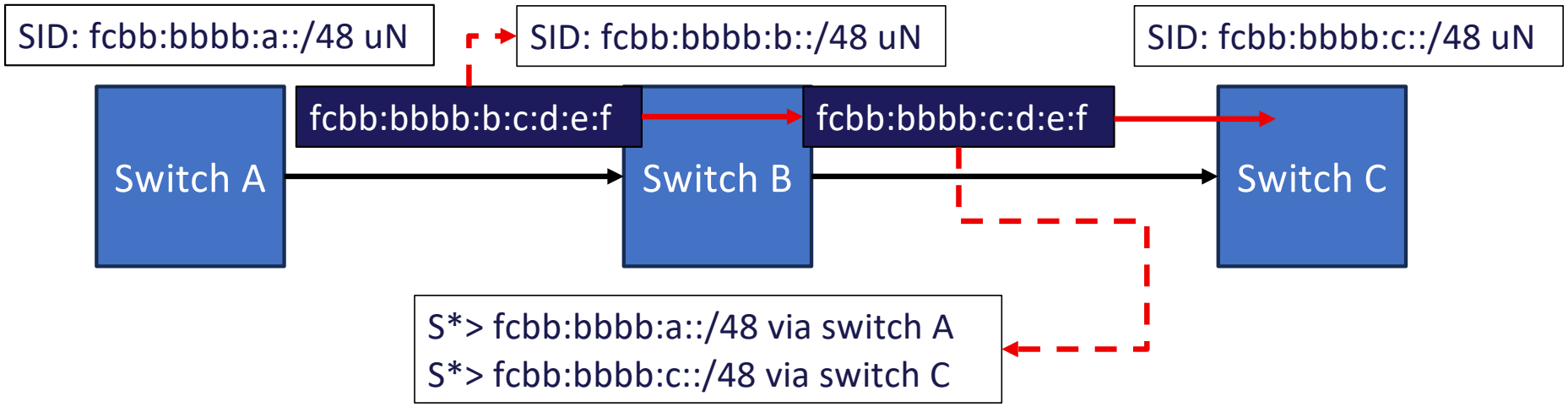
1st hop 2nd hop 3rd hop 4th Hop

fcbb:bbbb:d100:d002:d1e0:00a0::

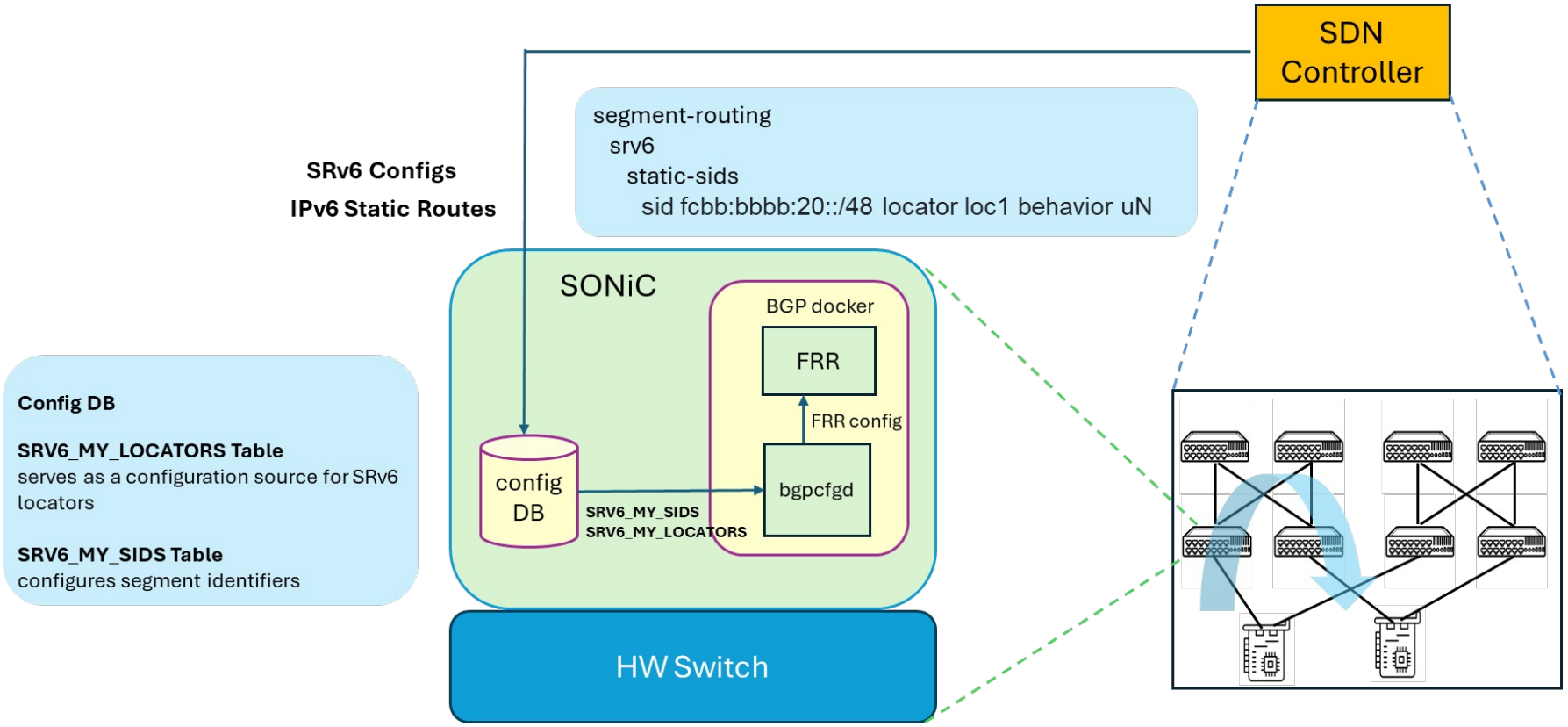
NIC switches to new path by change the uSIDs encoded in the packet header

Simplify SRv6 with Static Config

- Segment Identifiers(SIDs) are configured on switches statically.
- The switch has a static route configured for each of its neighbor's SIDs.
- Hosts get the list of SRv6 paths (encoded as a list of SIDs) that it should use from the central controller.



SRv6 with static uSID in SONiC



SRv6 Ecosystem in SONiC

- Mature Support
  - uN and uDT4/6/46 functions
  - Static SID allocation and provisioning
  - Static steering of traffic with SRv6 SID list
  - BGP-EVPN based L3VPN Services.
  - Evolving with FRR routing stack
- Rich community
  - Contributors: Microsoft, Cisco, Alibaba, Broadcom, Nvidia
  - Use cases: Telecom, Enterprise, Cloud Network

Acknowledgments

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- Mani Veerachamy

Thank you

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References

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- Ultra Ethernet's Design Principles and Architectural Innovations, Aug 2025 (link)
- @Scale 2025:
  - RDMA at Cloud Scale: The OCI Experience (link)
  - (META) Scaling AI Network with DSF (link)
- OCP 2025:
  - Microsoft: SRv6 for AI Backend Network (link)
  - Alibaba: eCore Architecture; Alibaba's Service-Oriented DCI network (link)

SRv6 - IETF

- SR Architecture – RFC 8402
- SR TE Policy Architecture - RFC 9256
- SRv6 Network Programming – RFC 8986
- IPv6 SR Header – RFC 8754
- Compressed SID Encoding – RFC 9800
- SRv6 BGP Services – RFC 9252
- SRv6 ISISI Extensions – RFC 9352
- SR Flex-Algo – RFC9350
- SRv6 OAM – RFC 9259
- Performance Management – RFC 5357