sigcomm 2025 COIMBRA

iSingLab HKUST

MixNet: A Runtime Reconfigurable Optical-Electrical Fabric for Distributed Mixture-of-Experts Training

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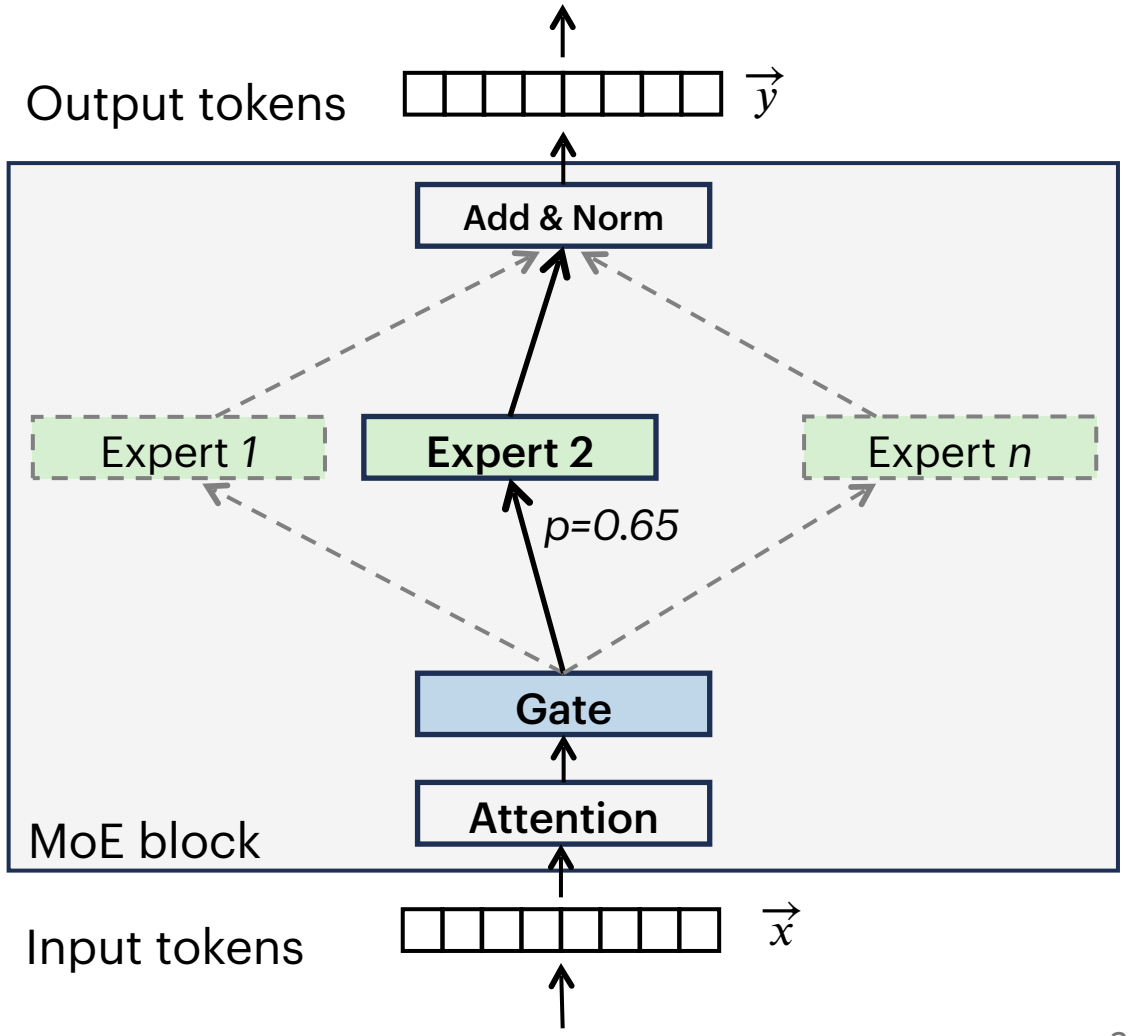
Meta

恒为科技 EmbedWay

Mixture-of-Experts Training

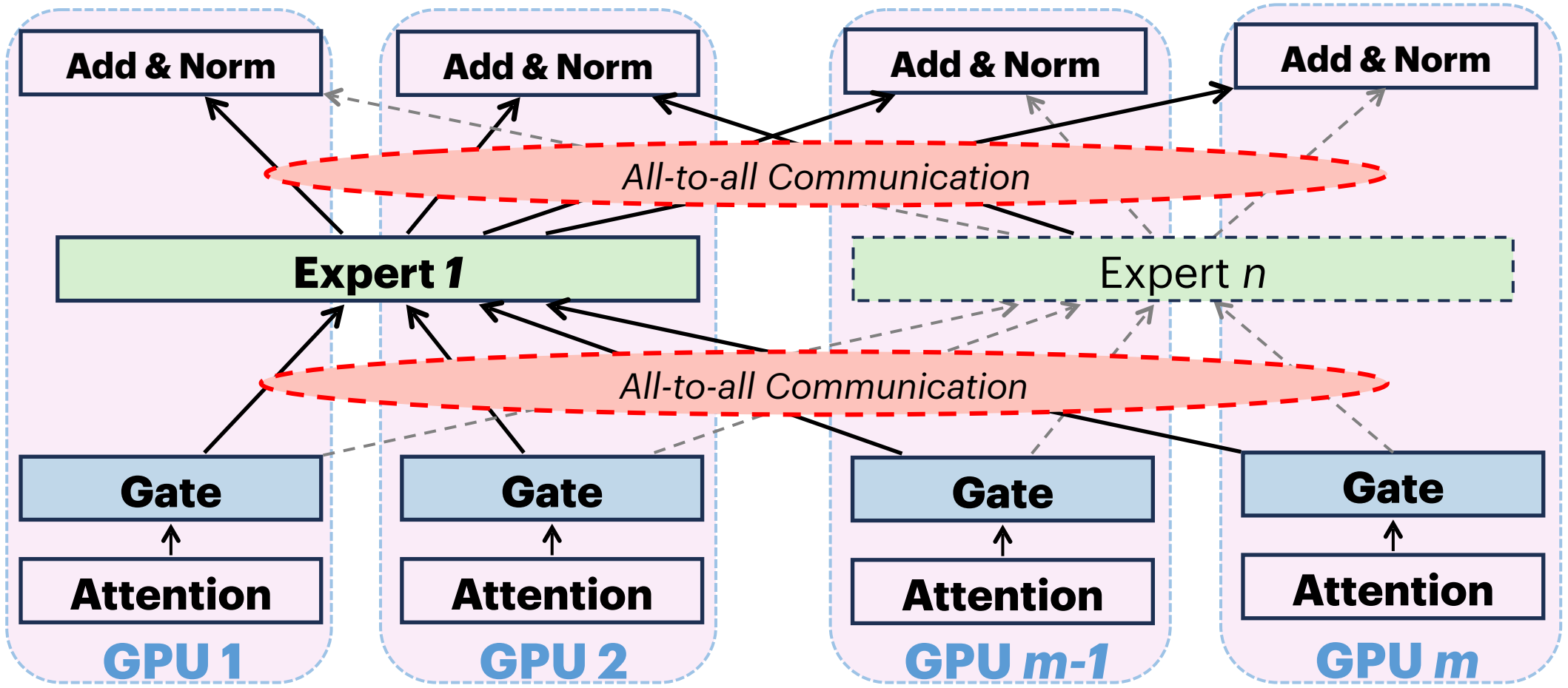
Mixture-of-Experts (MoE) models:

- ➢Sparse architecture with partially activated ***experts***
  - ➢Non-linearly increasing computation cost with increasing model size
- ➢Computation-based routing on each token
  - ➢Dynamic token trajectories at runtime



Parallelisms in MoE Training

Expert Parallel (EP) in ***Mixture-of-Experts*** (MoE) training



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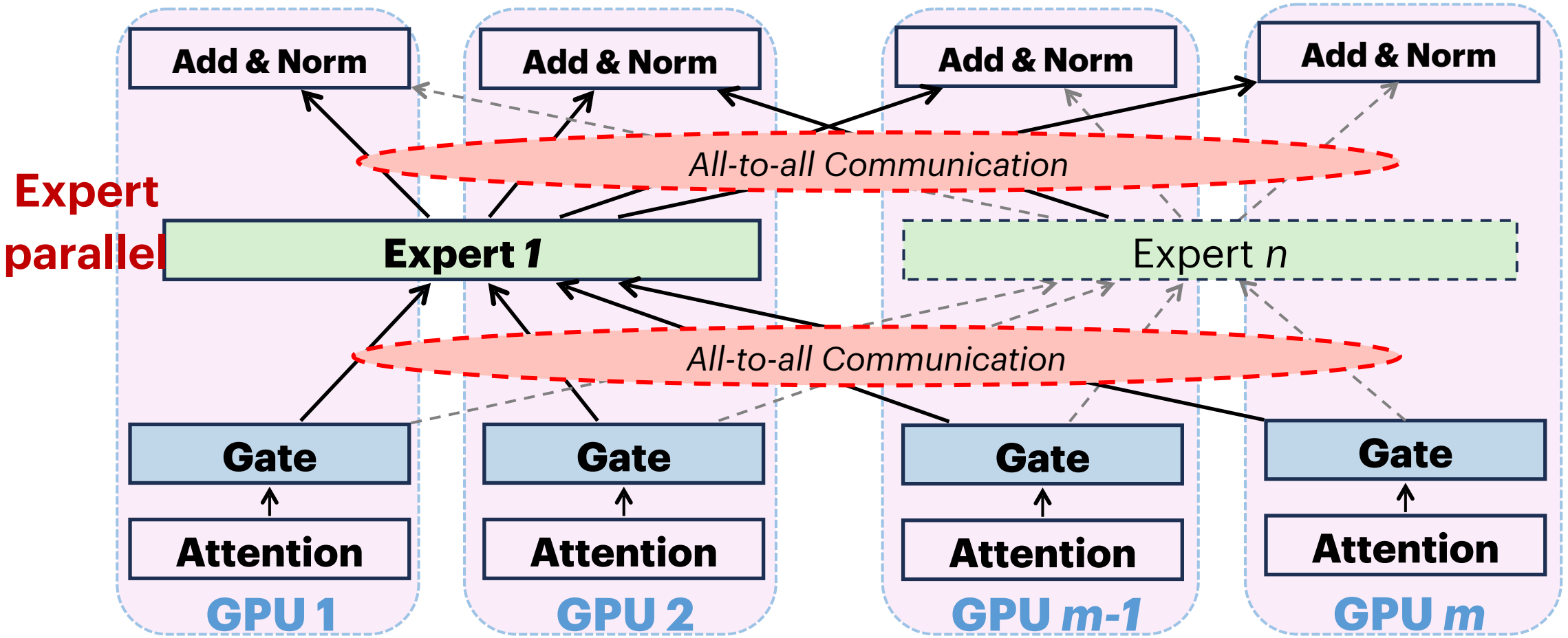

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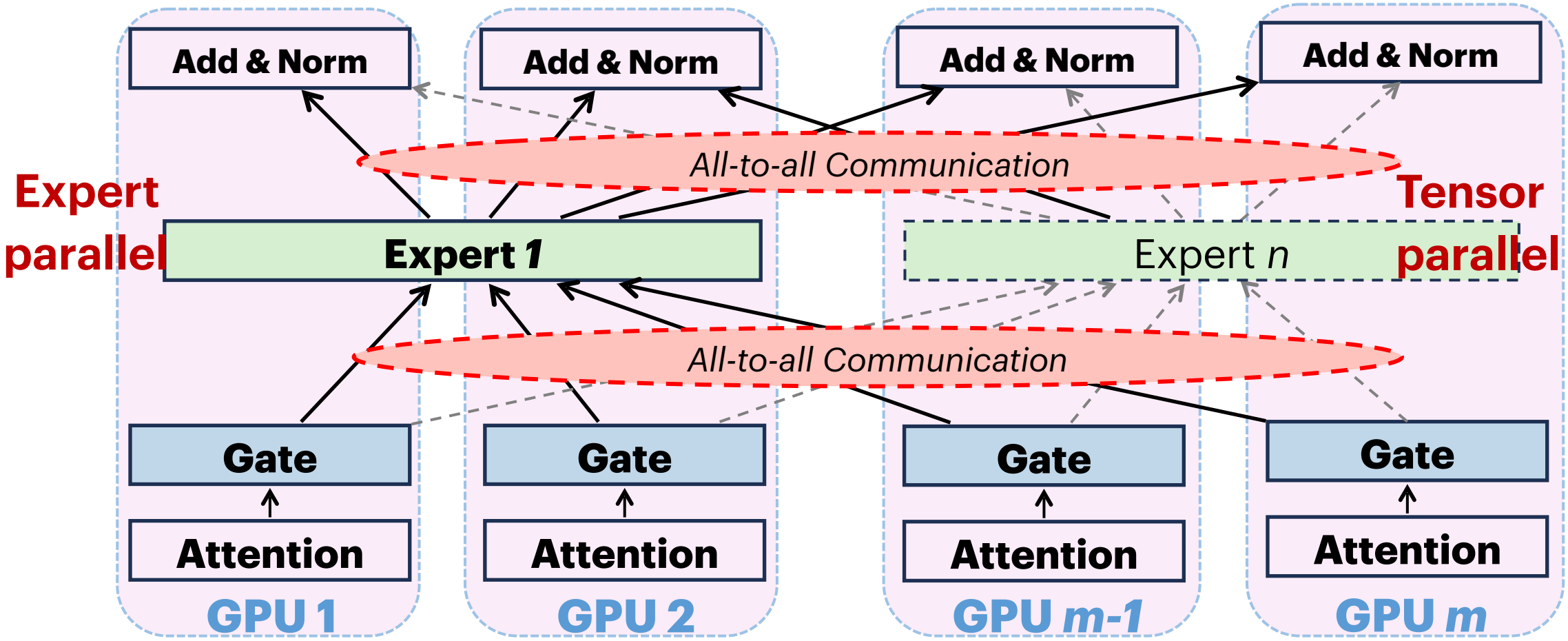
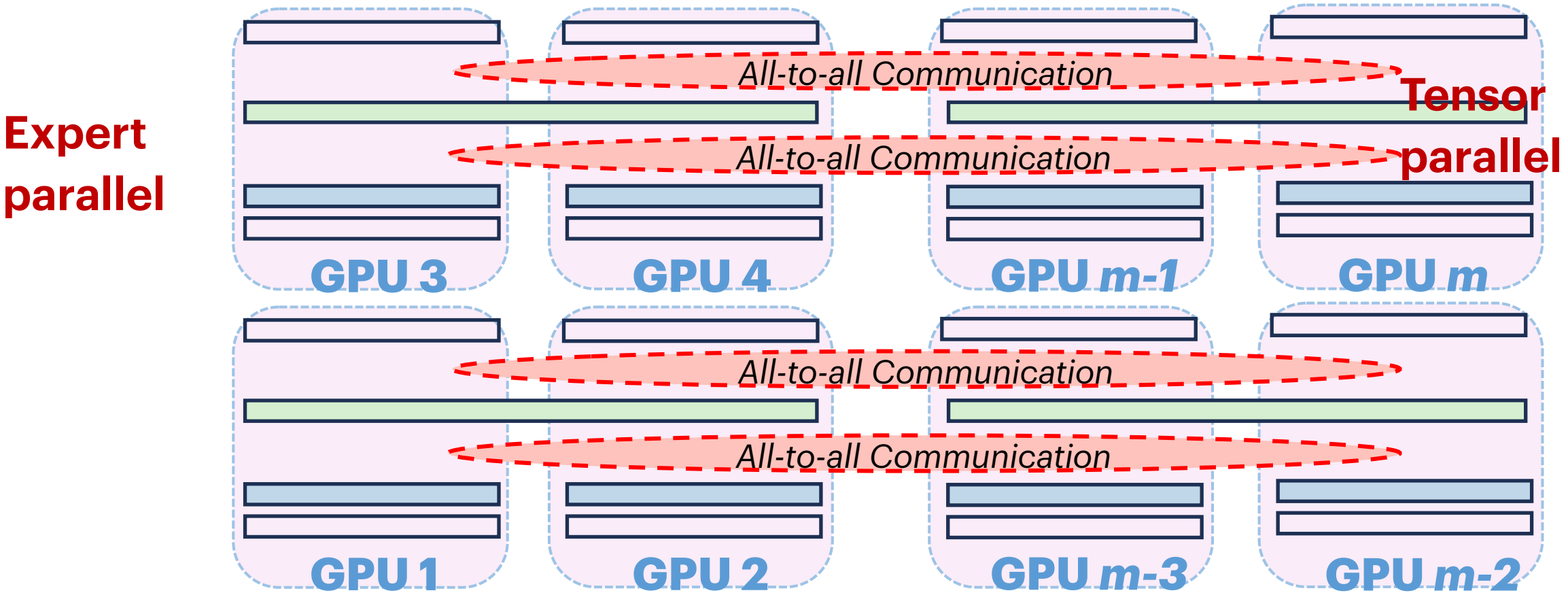


Parallelisms in MoE Training

State-of-the-art MoE training utilizes the ***hybrid parallelisms***: EP + TP + PP + DP



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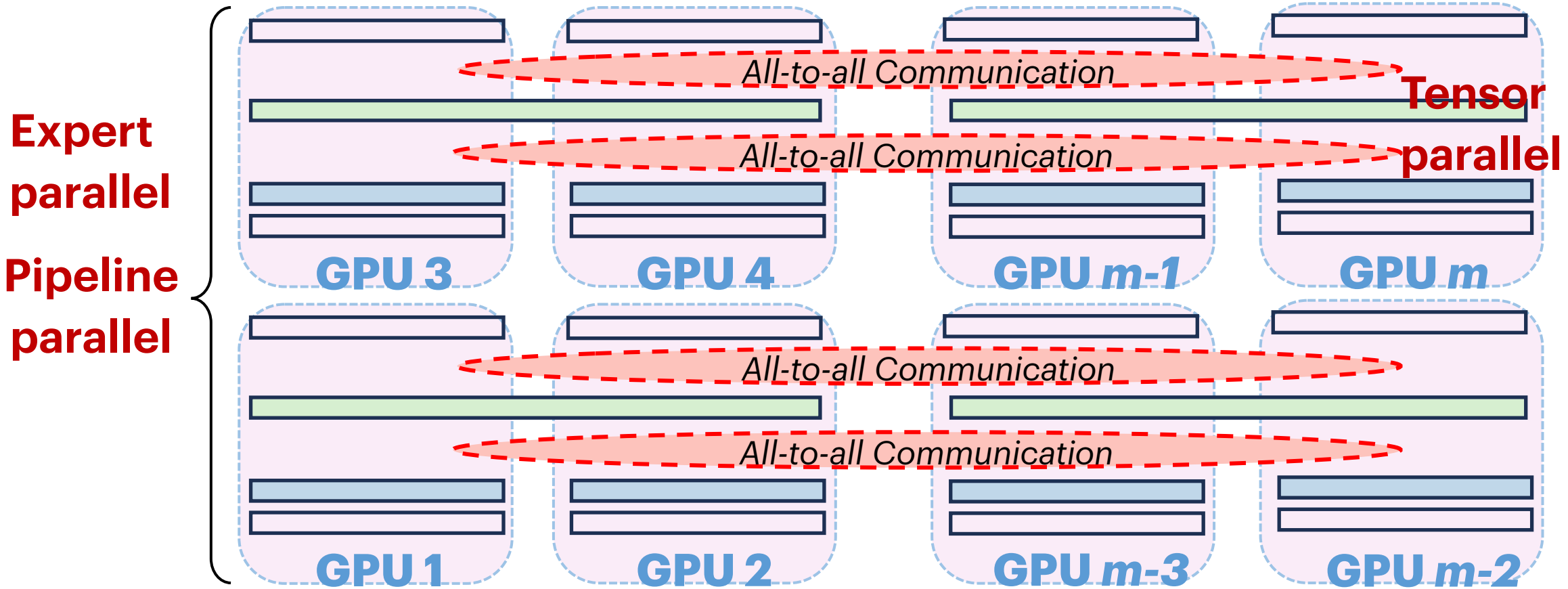

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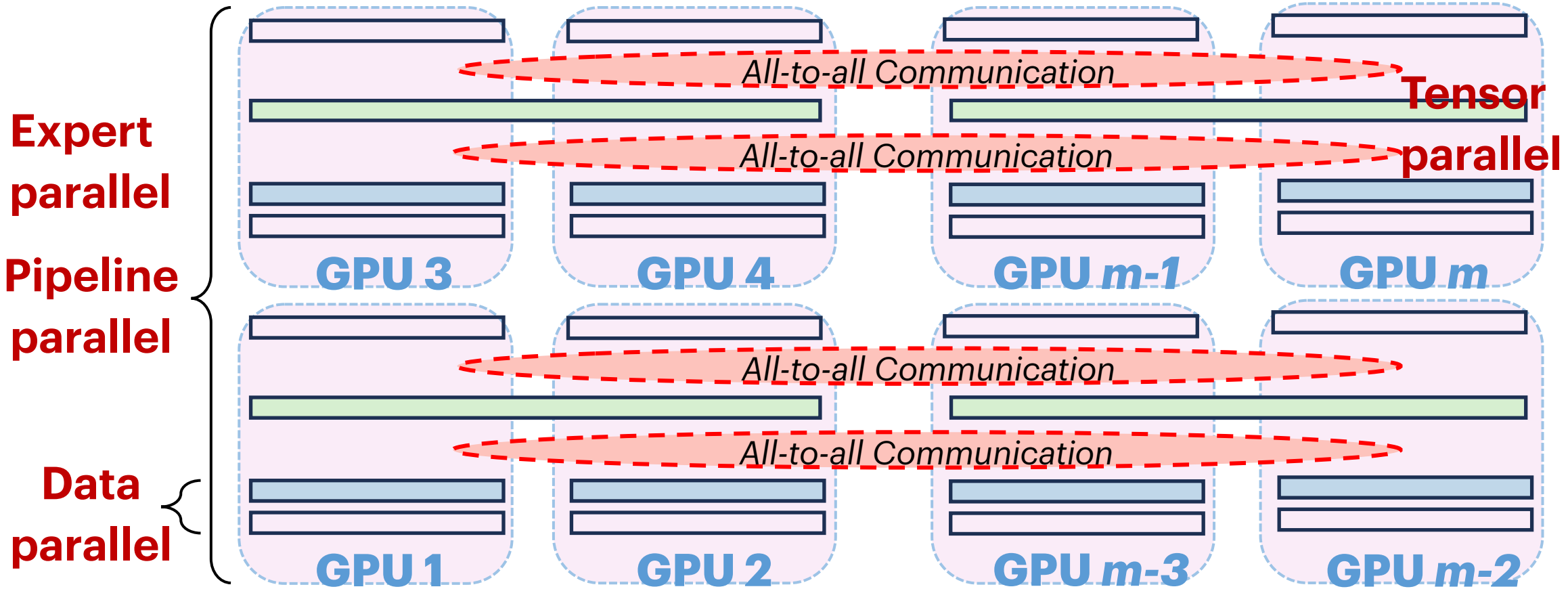
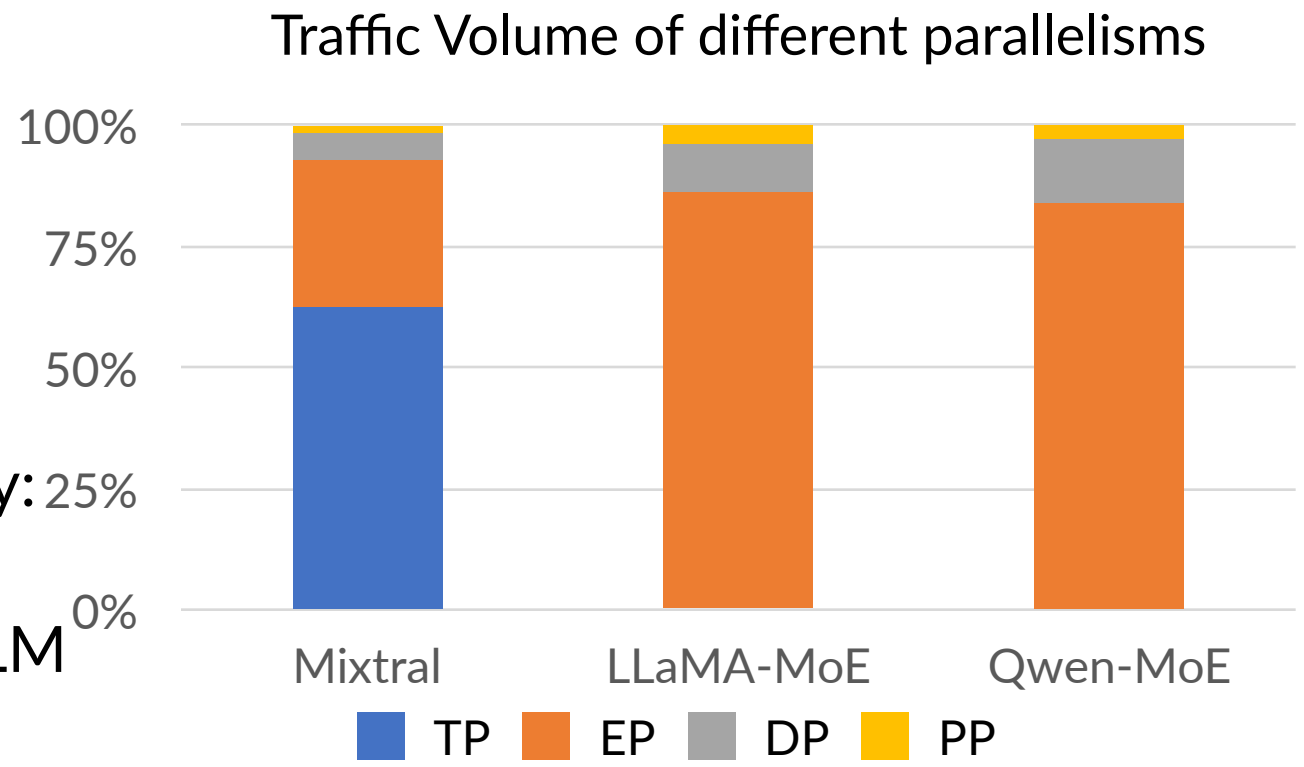


MoE Measurements in Production Cluster

Cluster setup:

- Hardware: 128 H800 GPU and 128 400 Gbps ConnectX-7 with Infiniband network
- Topology: rail-optimized
- Collective communication library: NCCL
- Training framework: Megatron-LM



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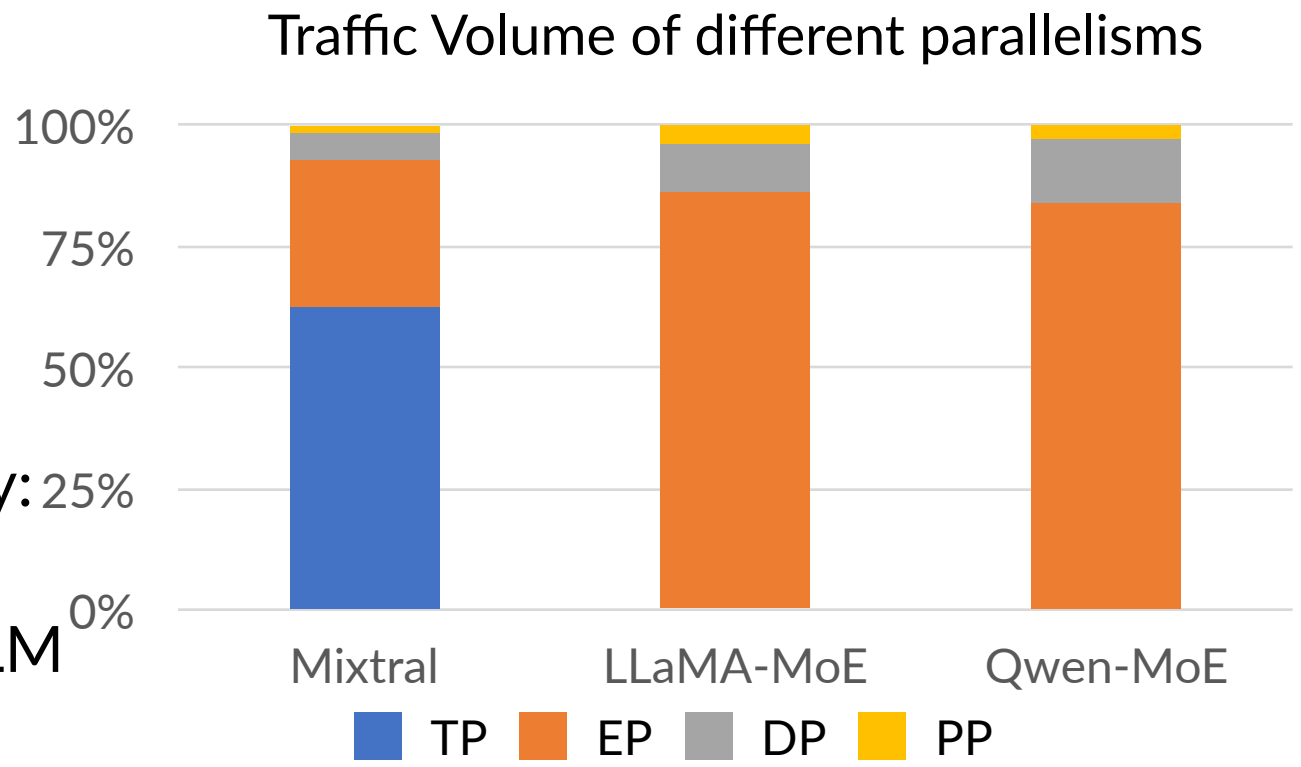
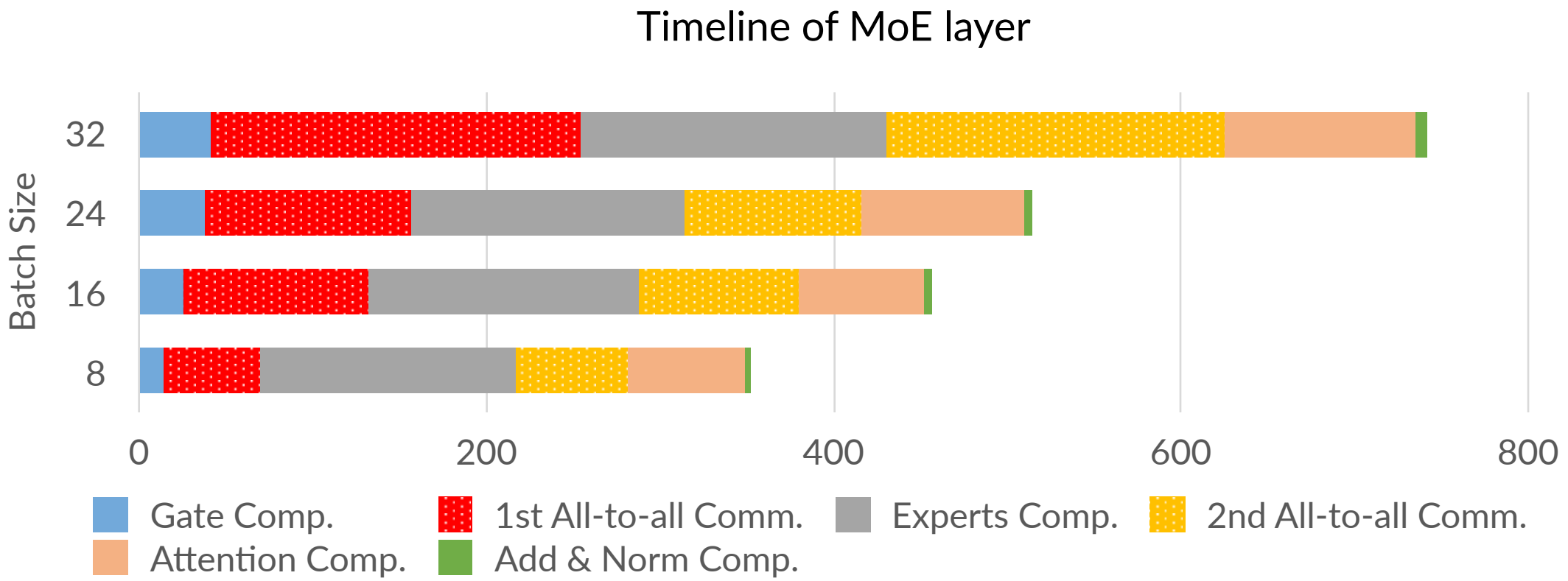


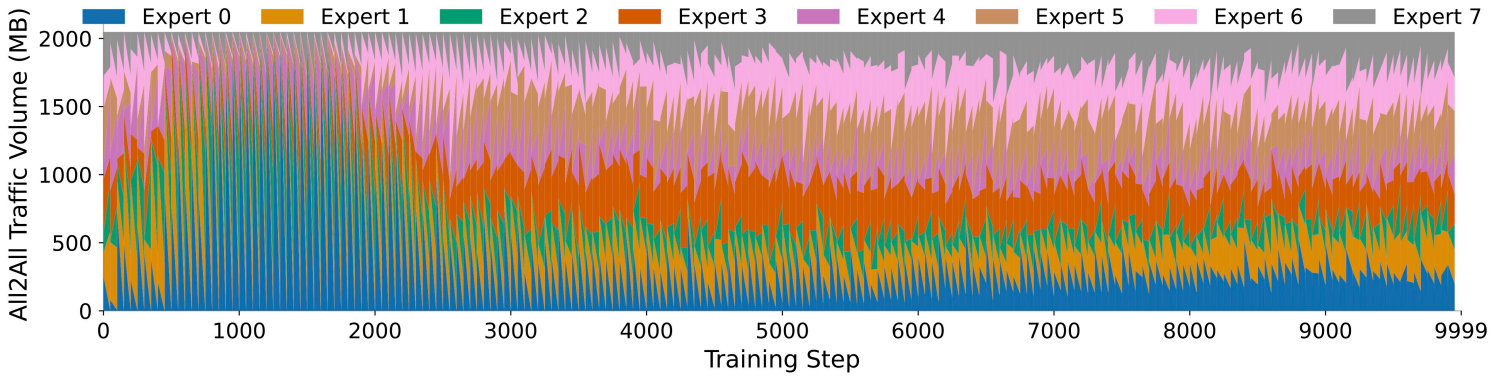
EP and TP are most ***communication-intensive.***

Communication Matters in MoE Training!



All-to-all communications account for ***35% - 55%*** training time in each MoE layer under a H800 SuperPod cluster with 400 Gbps Infiniband network.

Measurements: Temporal & Spatial Patterns



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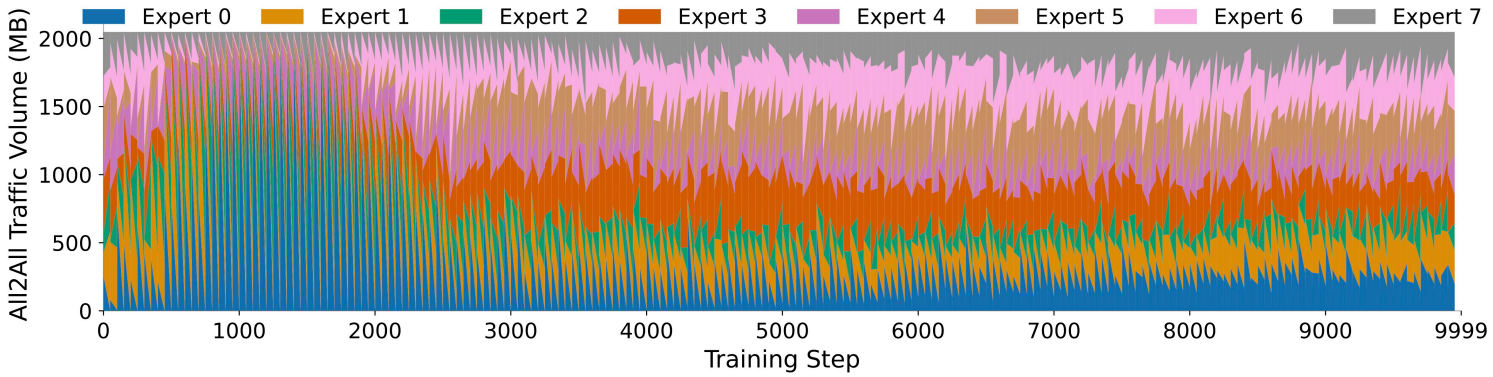

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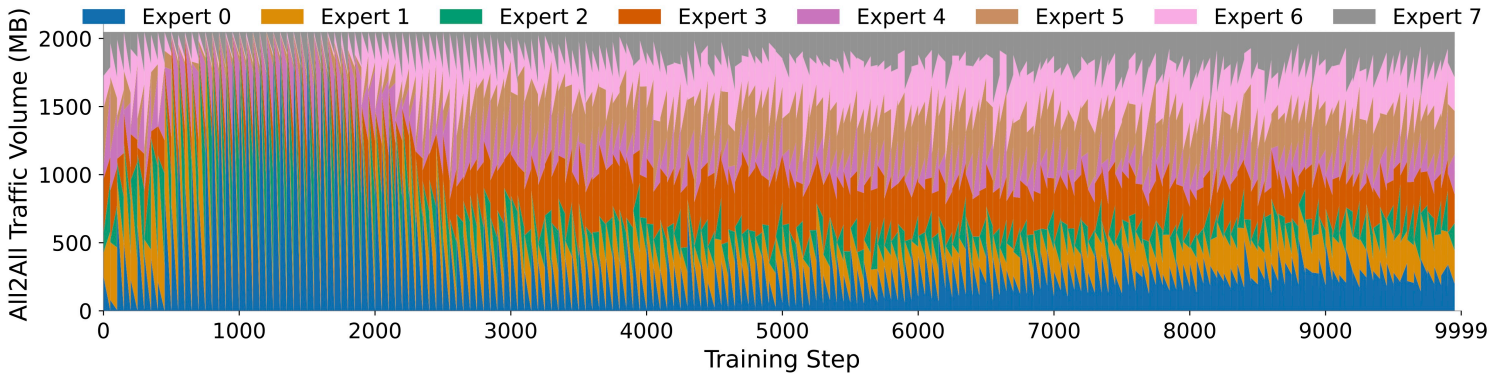

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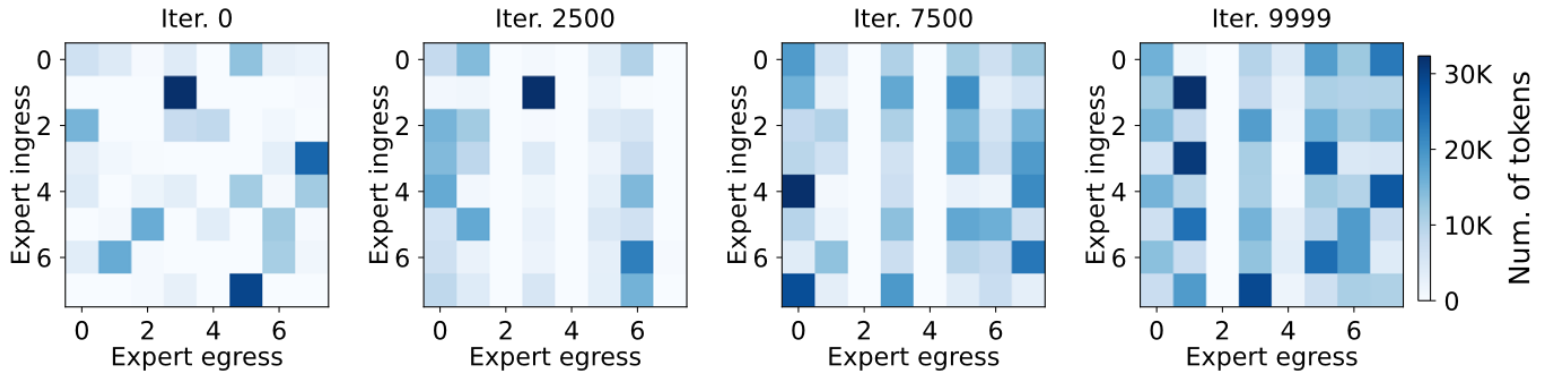

Non-uniform: heavy communications only occur between limited number of GPU pairs.

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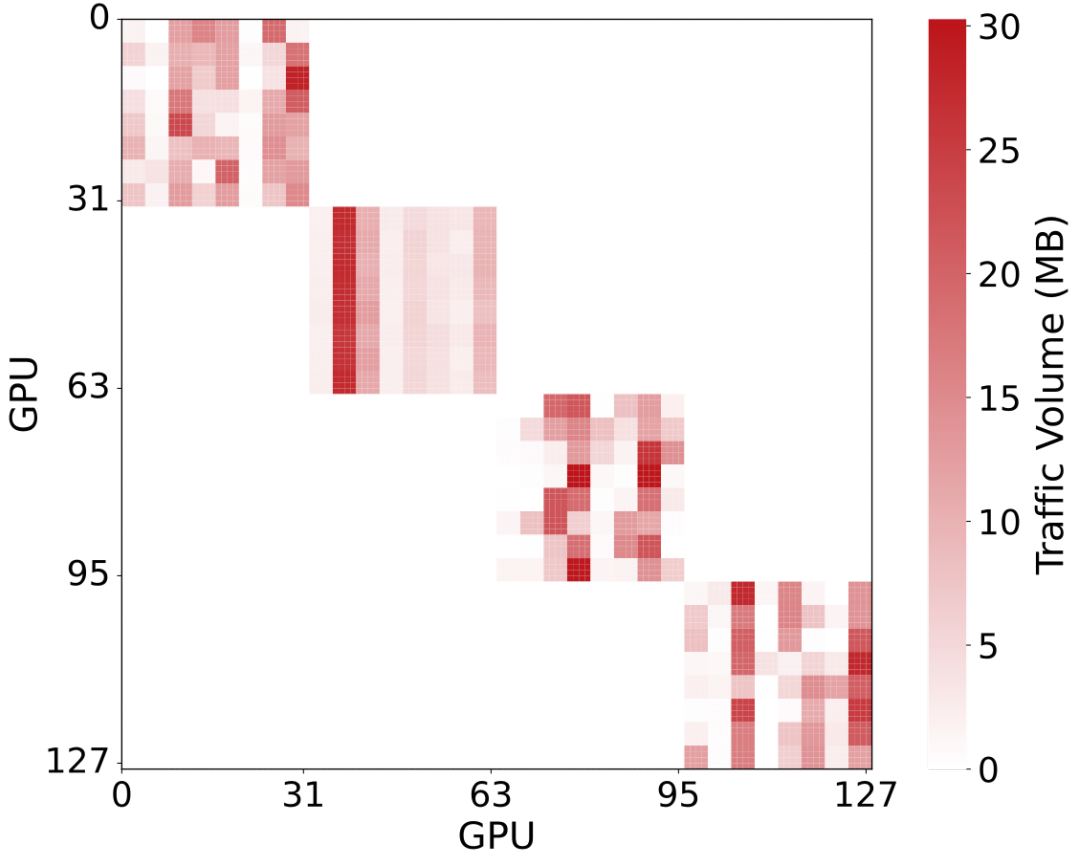

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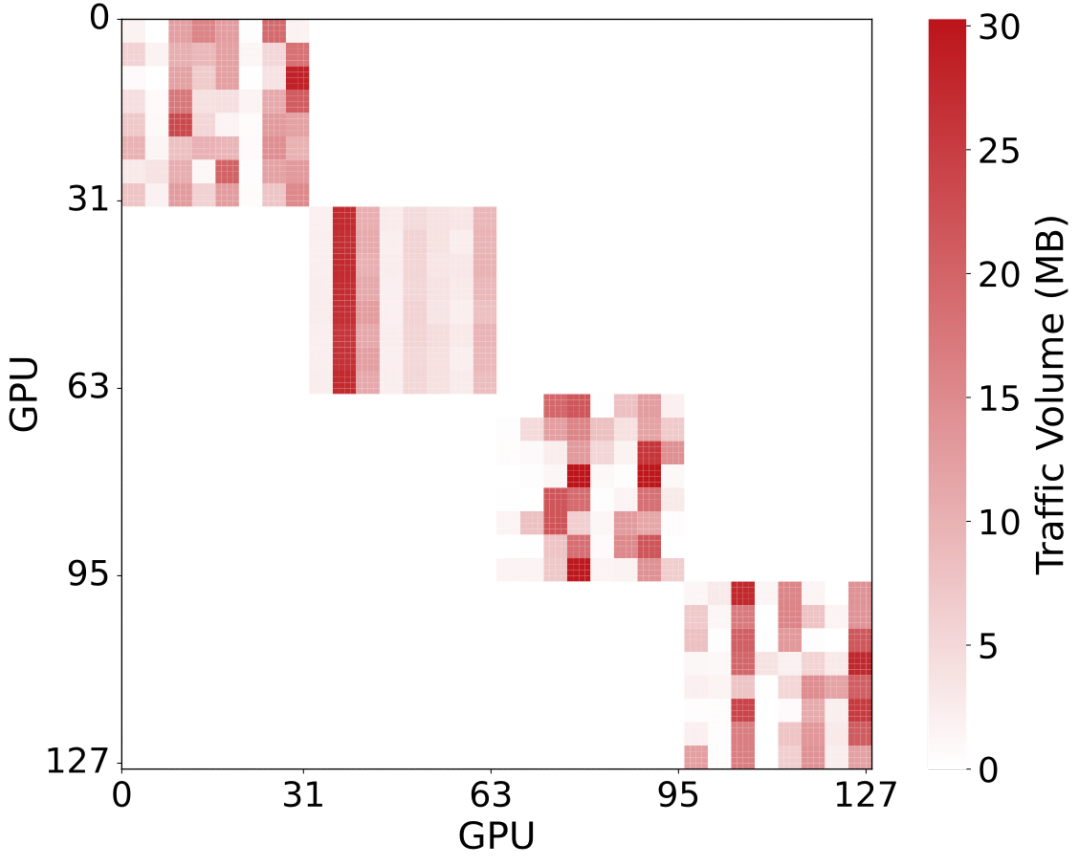
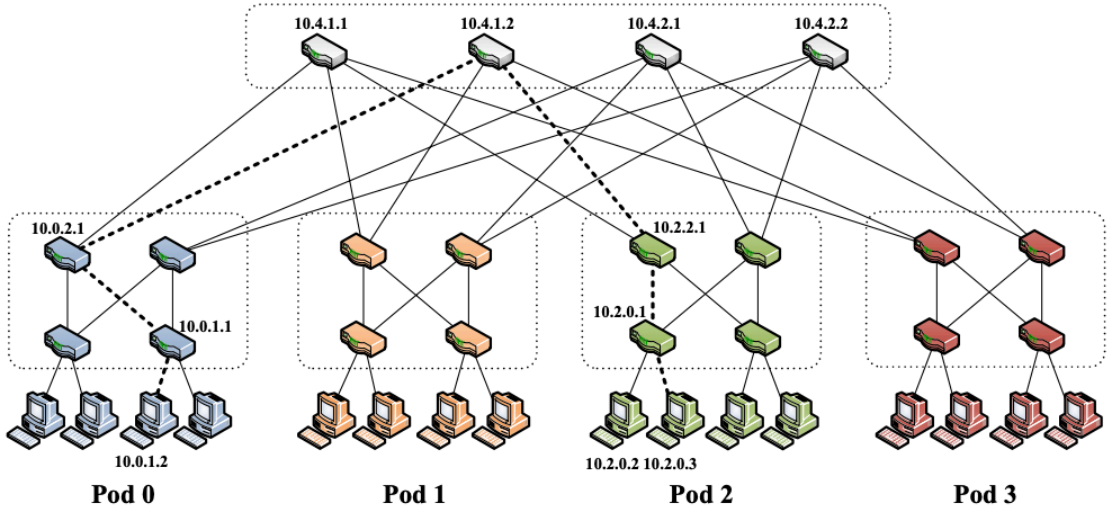


EP traffic has ***strong locality*** and is ***regional***: only the expert layers within the same MoE block need all-to-all communications

Motivation for a Cost-efficient Interconnect



Fat-tree

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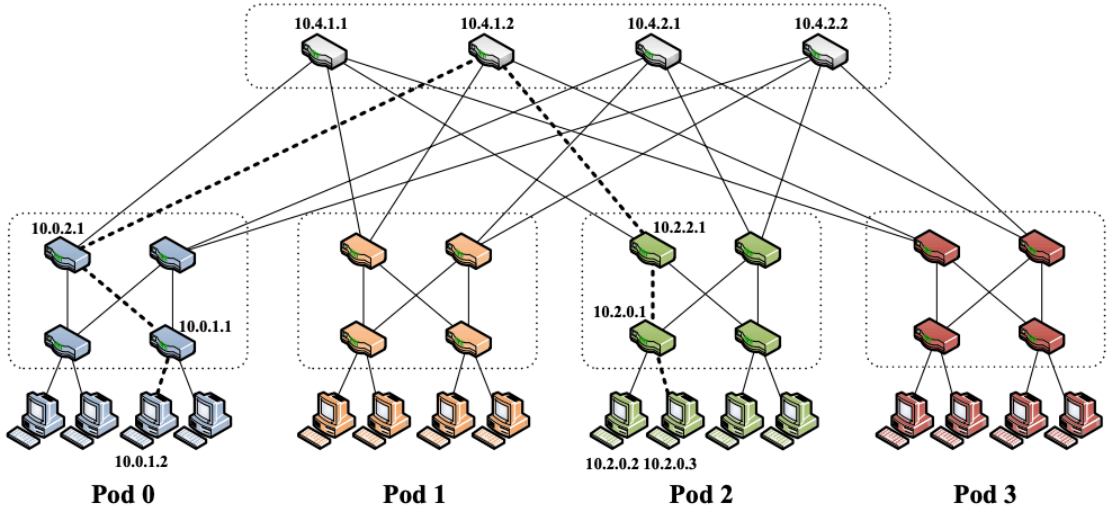

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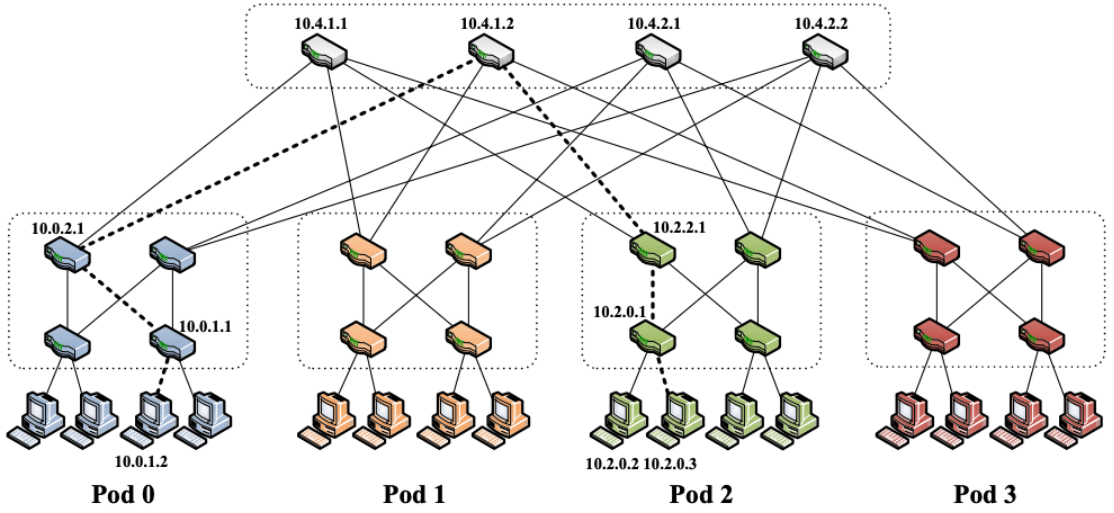

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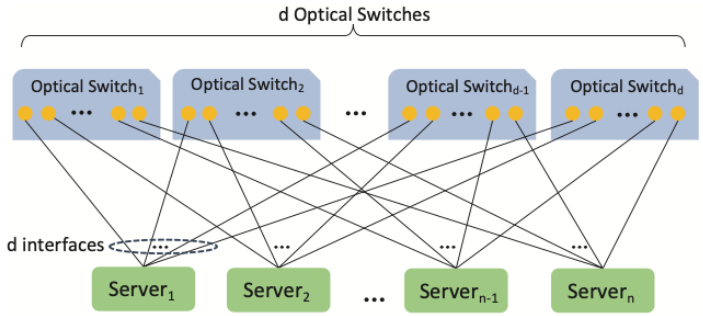

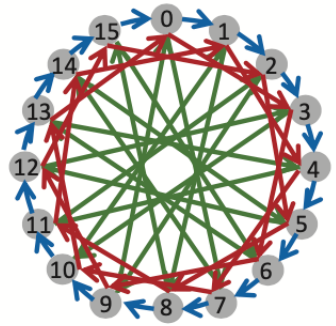

TopoOpt: model-wise one-off reconfiguration

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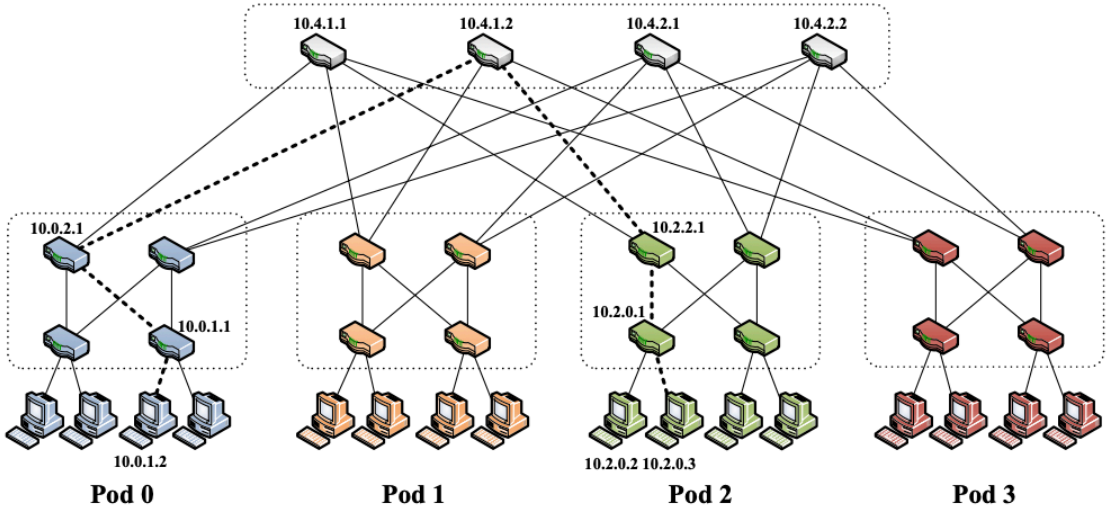

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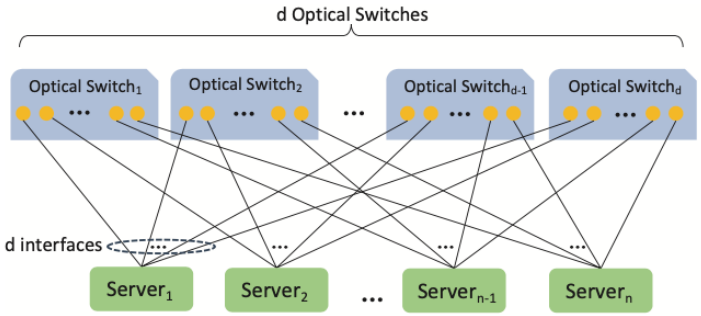

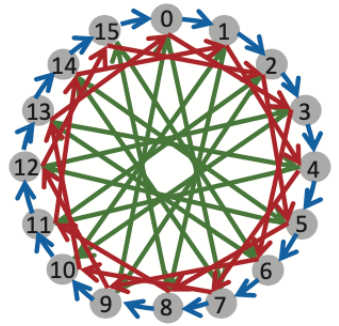

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How to ***architect*** GPU interconnects for large-scale MoE training?

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	Bandwidth	Predictability	Locality	Reconfigurability	Desired Fabric
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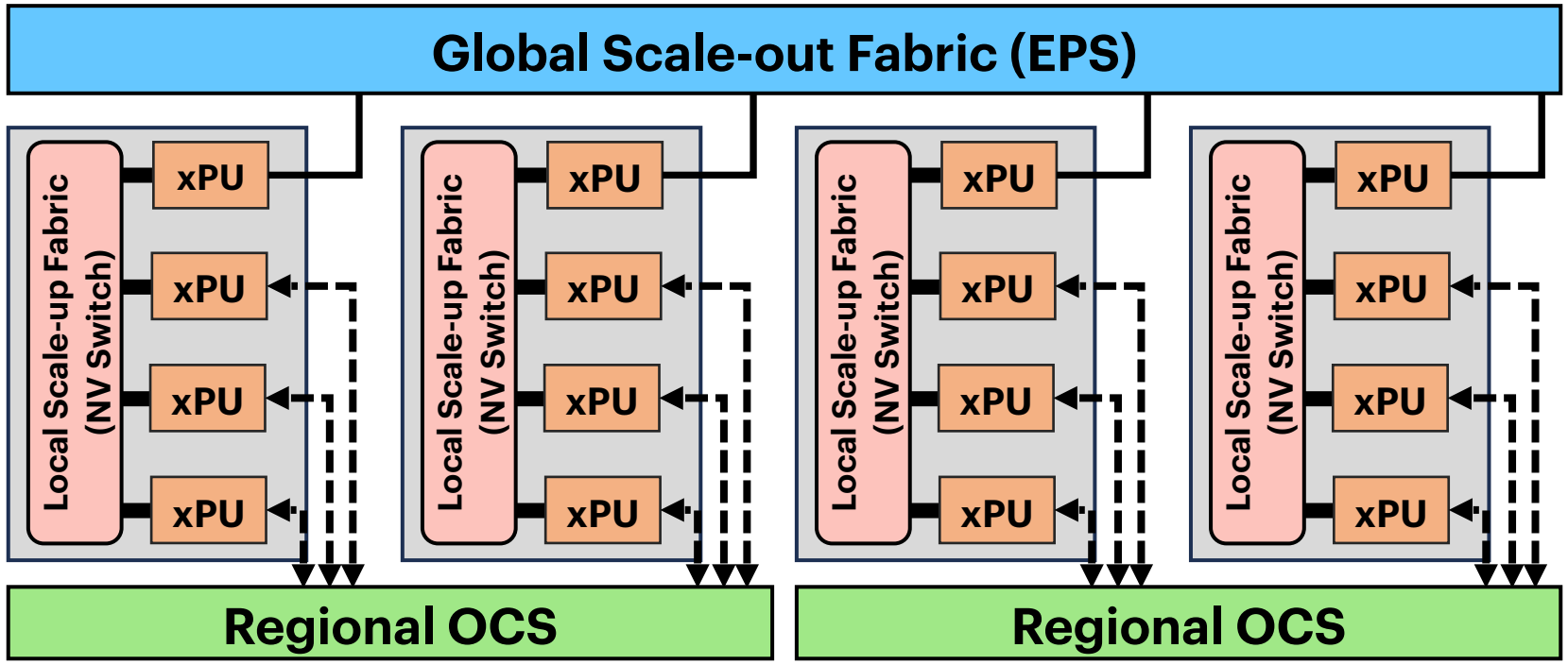
DP	Low	Deterministic	Large & All-reduce	N	Electrical Packet Switching (Ethernet)
PP	Low	Deterministic	Large & Point-to-point	N	Electrical Packet Switching (Ethernet)

MixNet Architecture: An Ideal yet Practical Fabric

Design philosophy: Find an ***ideal*** fabric that balances the bandwidth and scale for on-demand networking.



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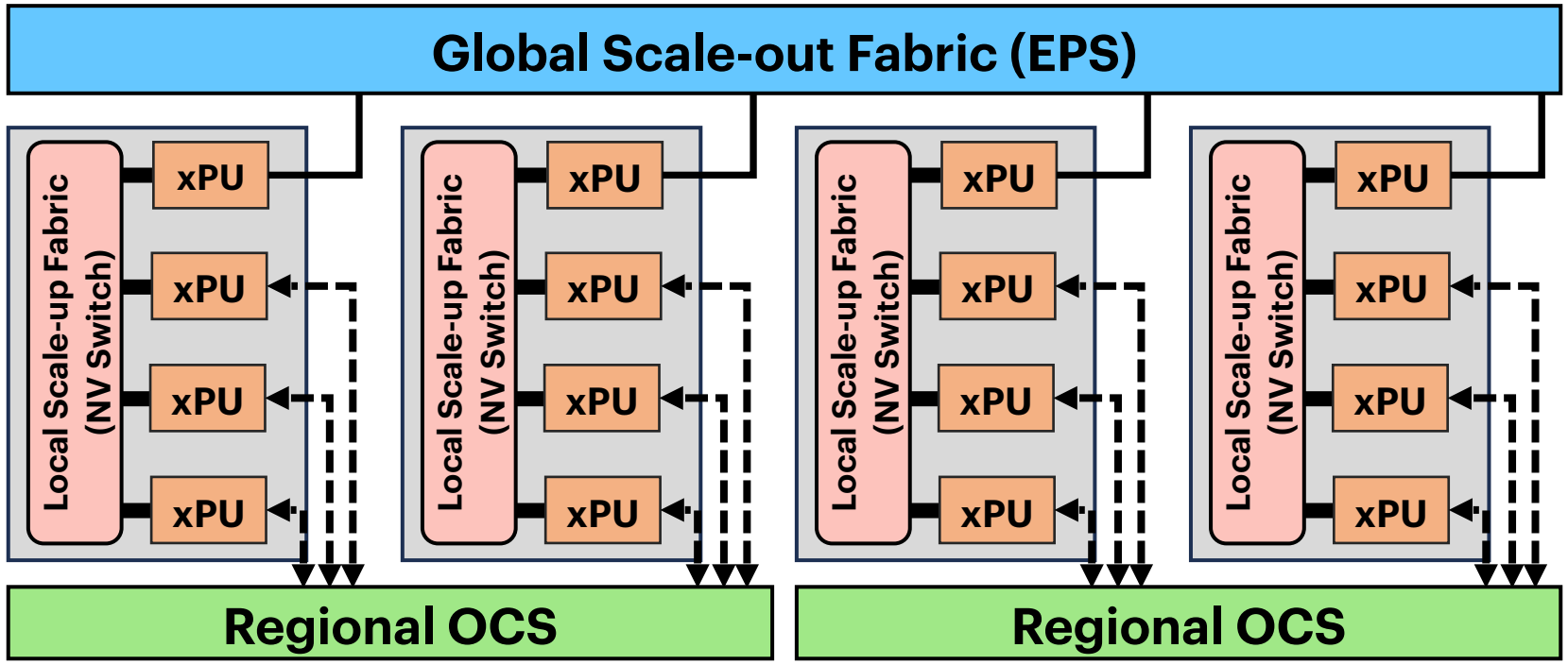

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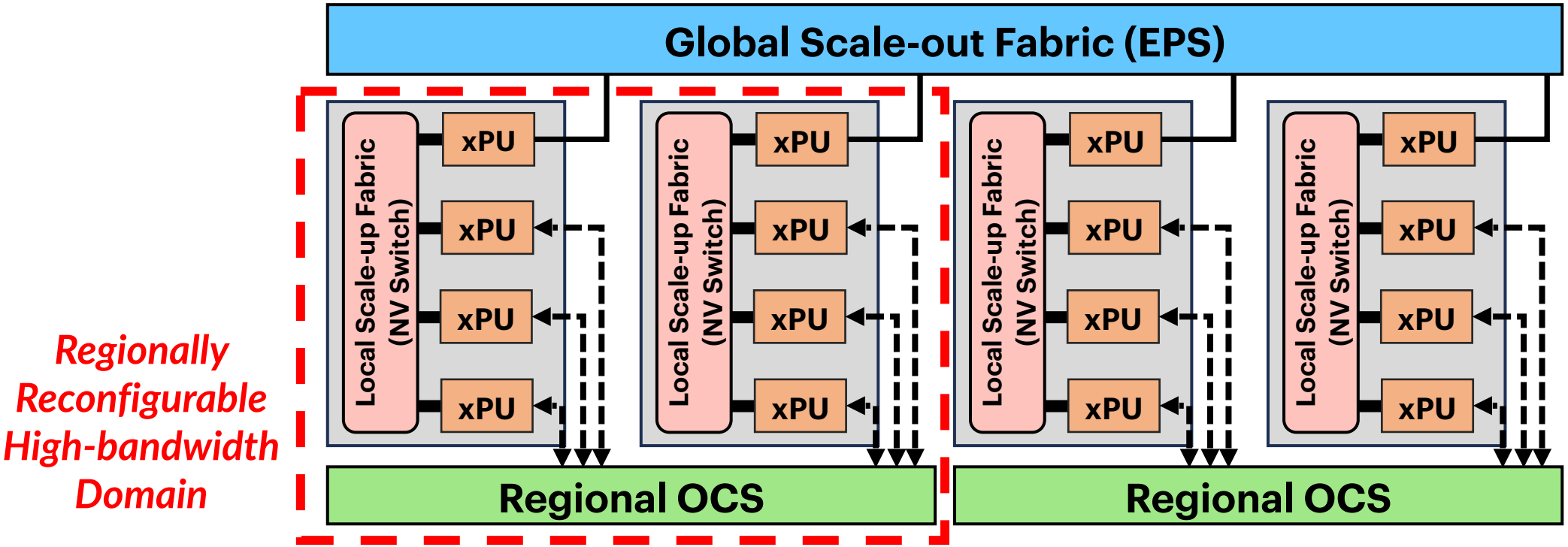
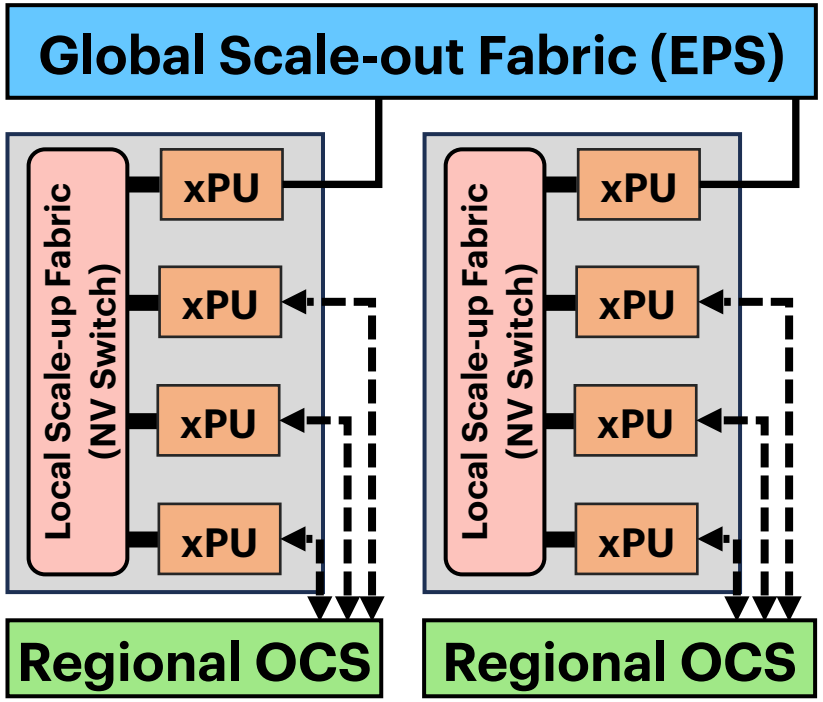


A Runtime Reconfigurable OCS-EPS Fabric



- NVSwitch handles the *intra-host TP* traffic
- Regional OCS handles *regionalized EP* traffic
  - MixNet reconfigures its topology based on runtime
- Global EPS handle both high-fanout *DP & PP* traffics

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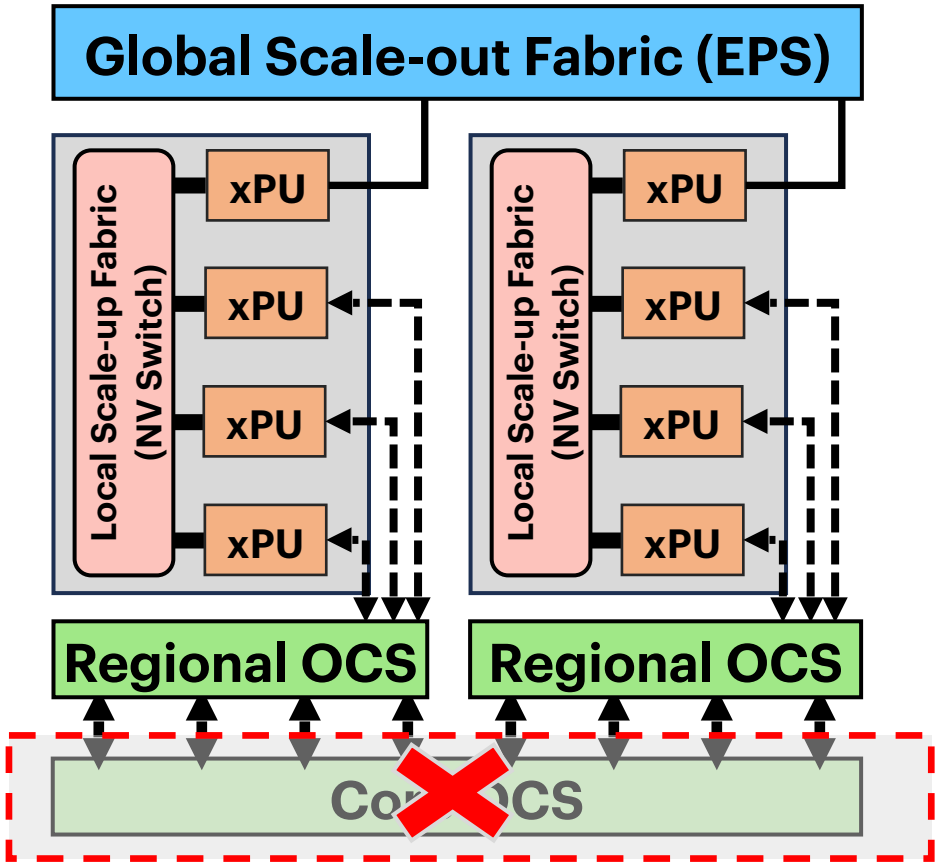

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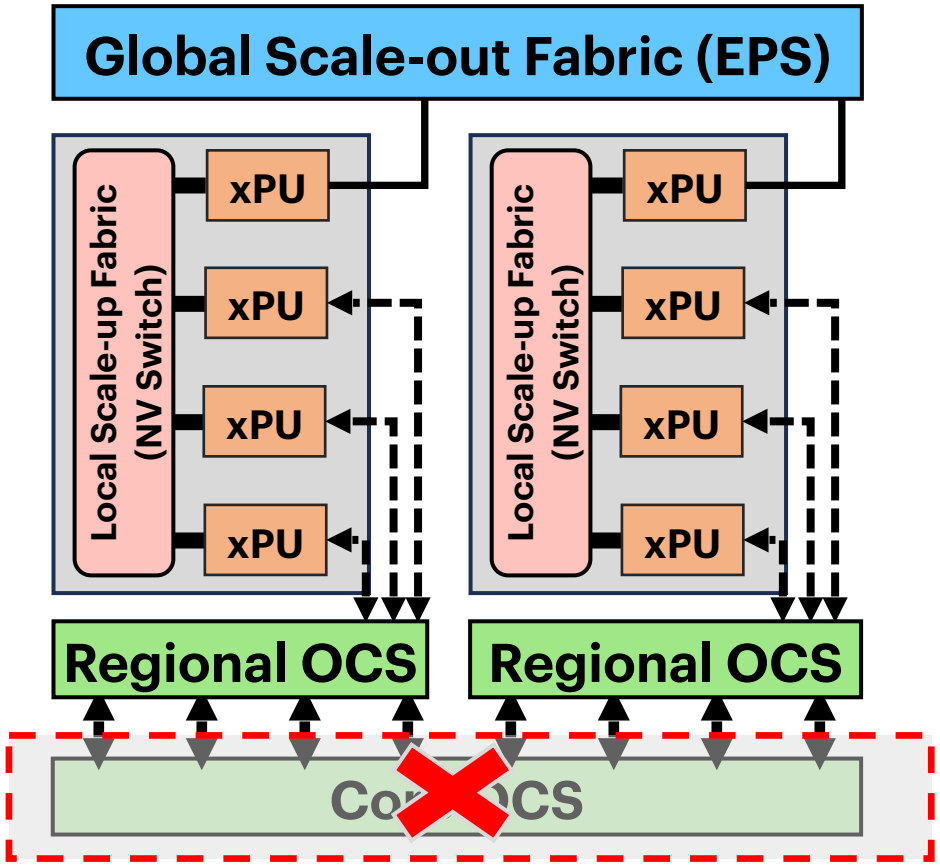

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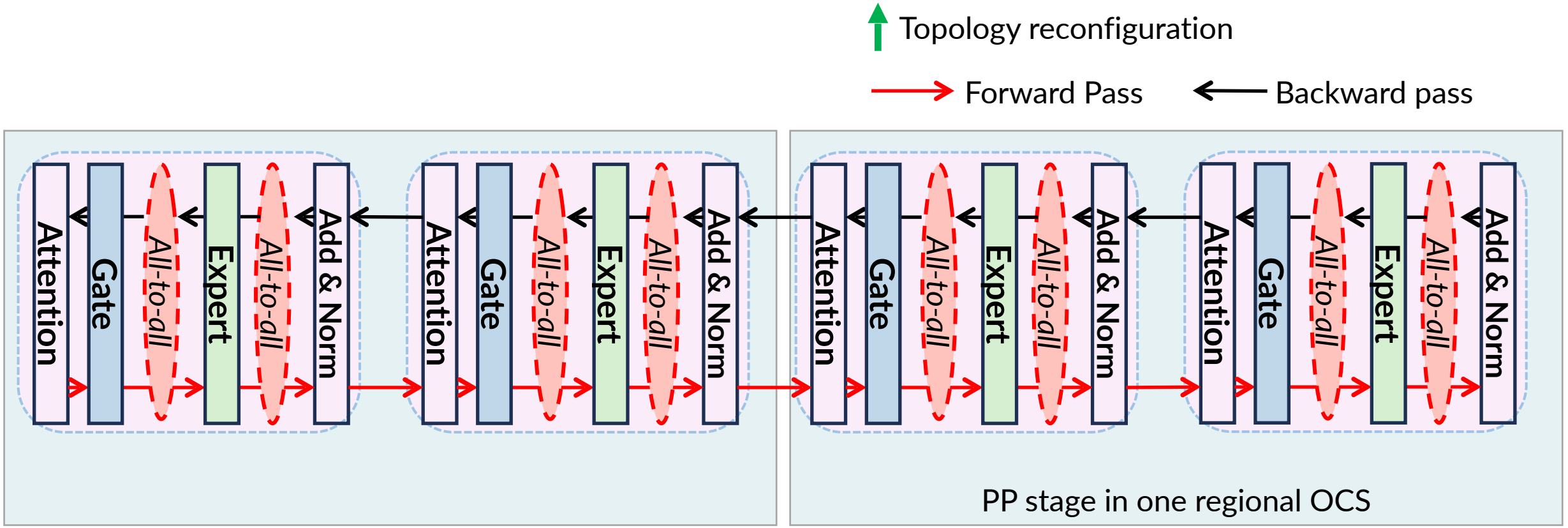
MixNet mitigates the tradeoff between ***OCS reconfigurable speed*** and ***port counts*** by designing the regional OCS.

MixNet Reconfiguration Timeline



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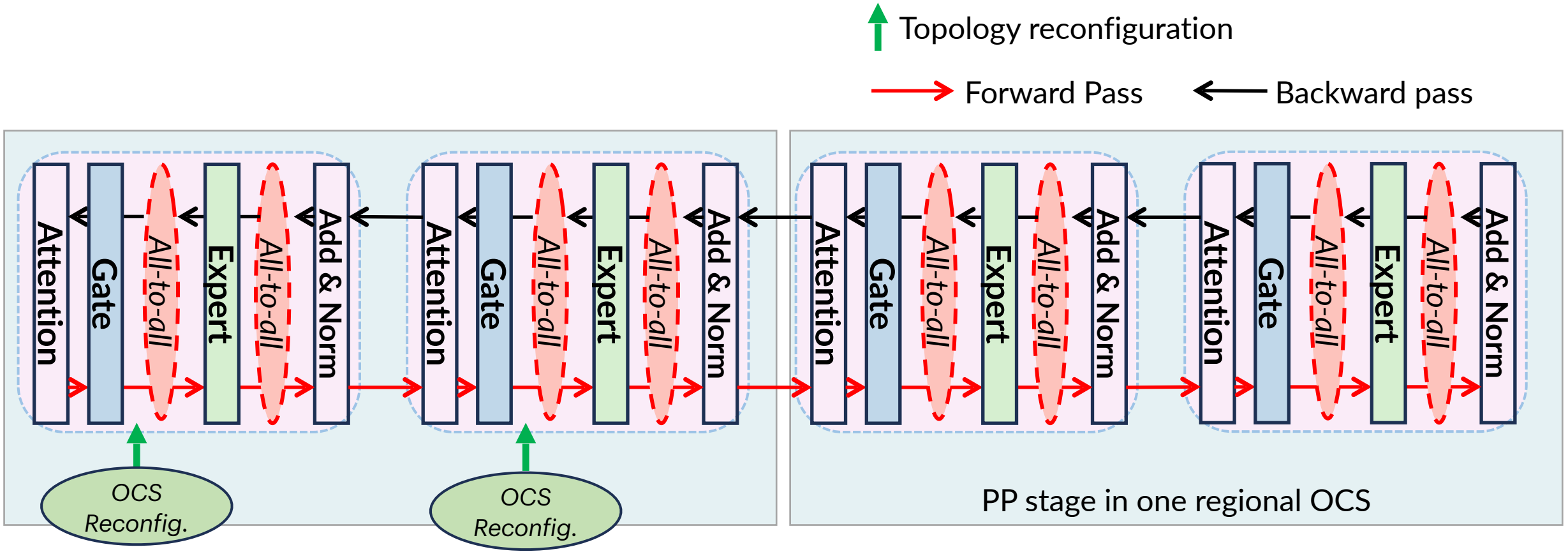

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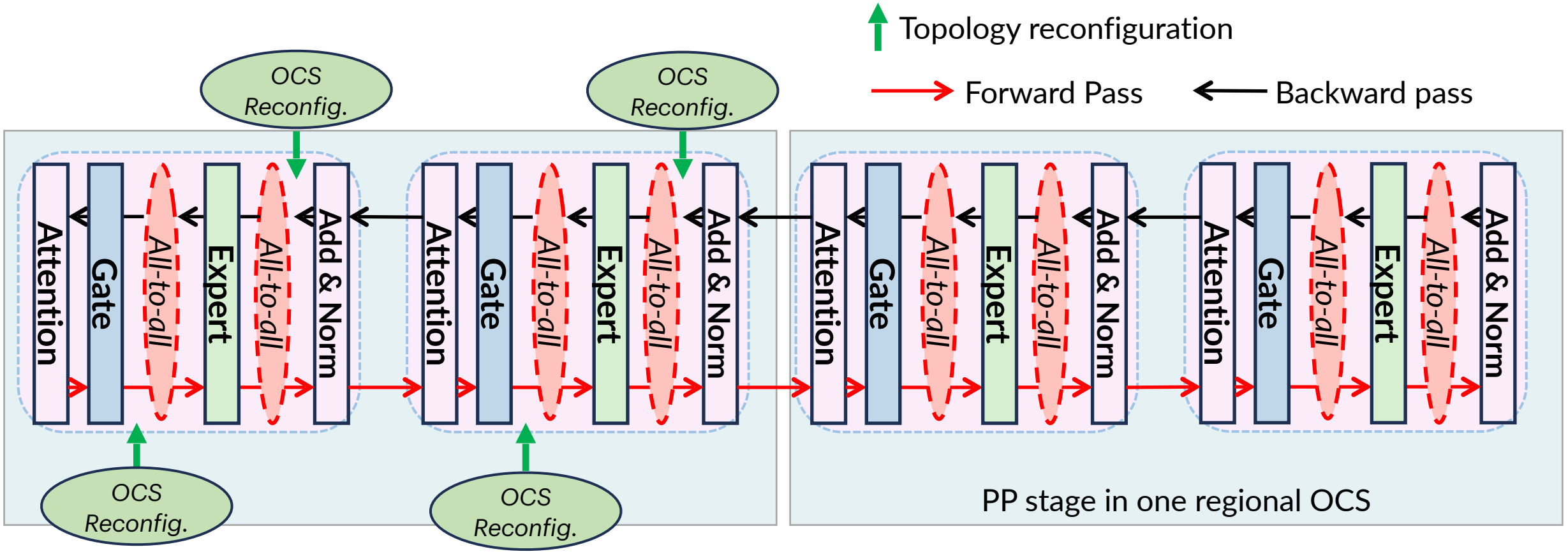

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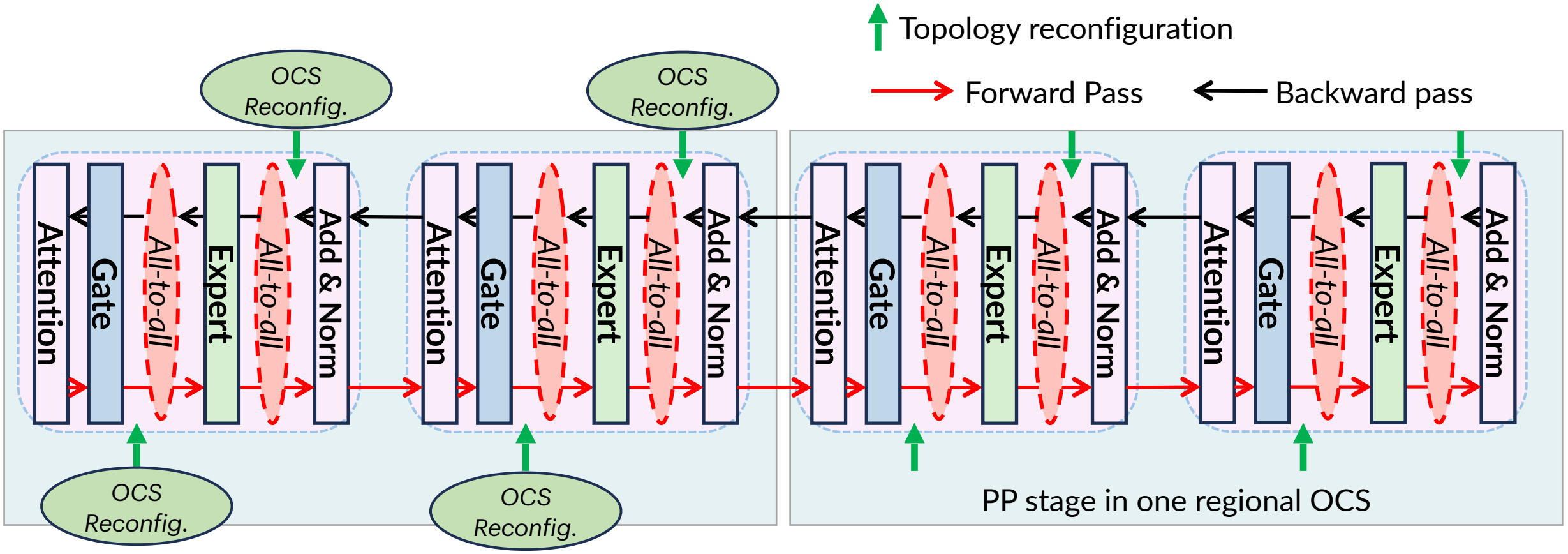

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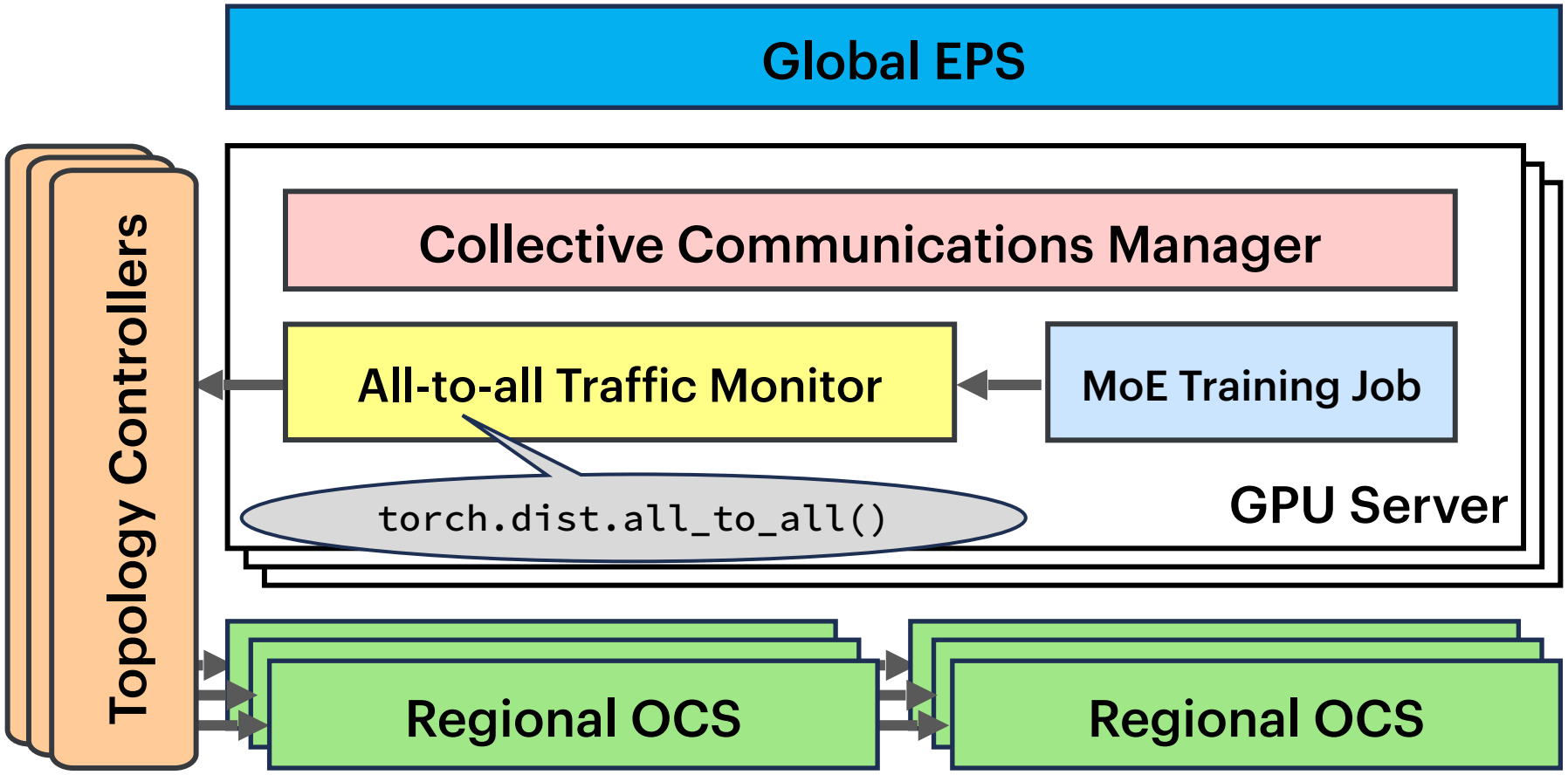

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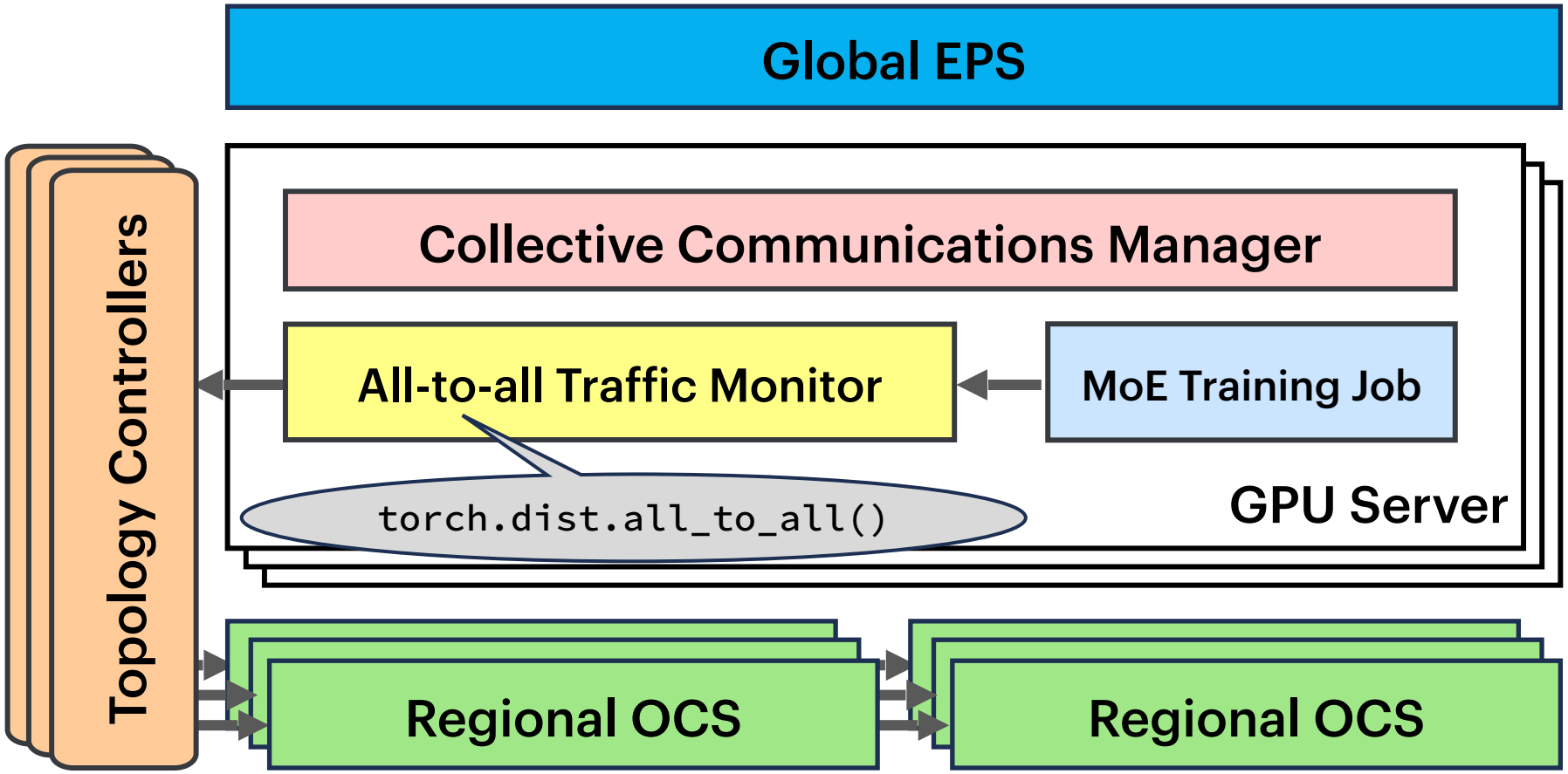

Fully localized control plane avoids the scalability limitation.

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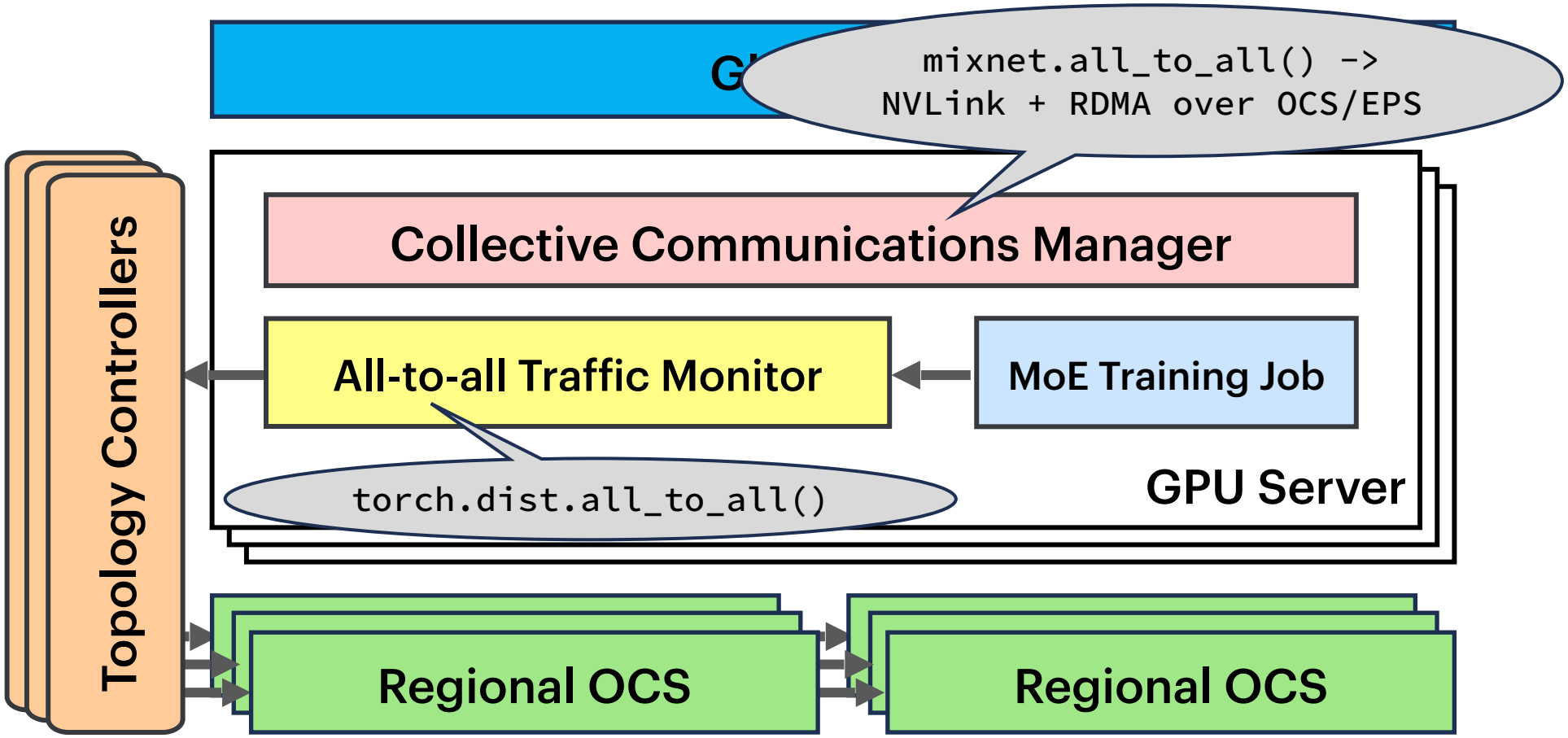

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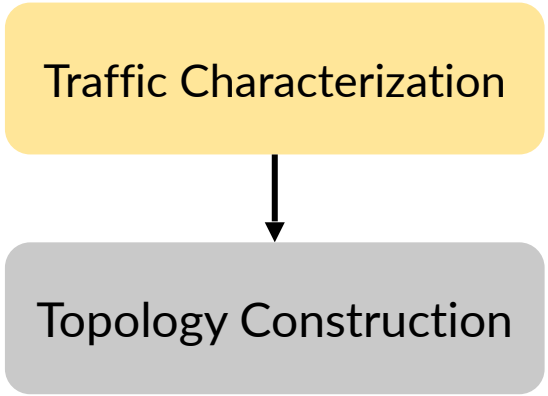

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Compute topology and reconfigure OCS to enforce it

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Intra-host

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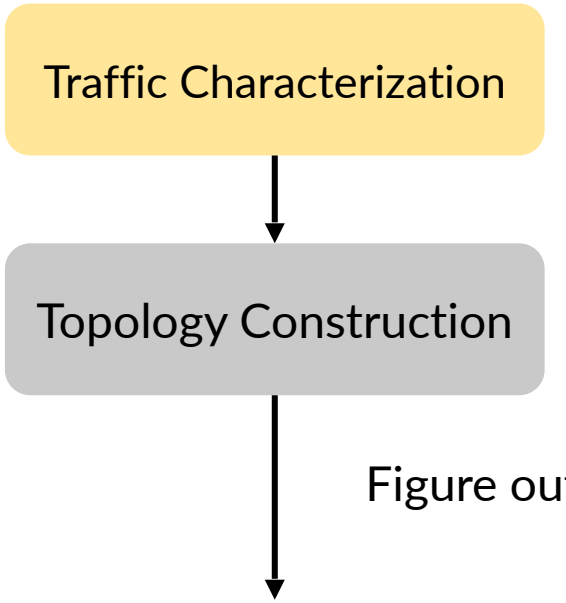

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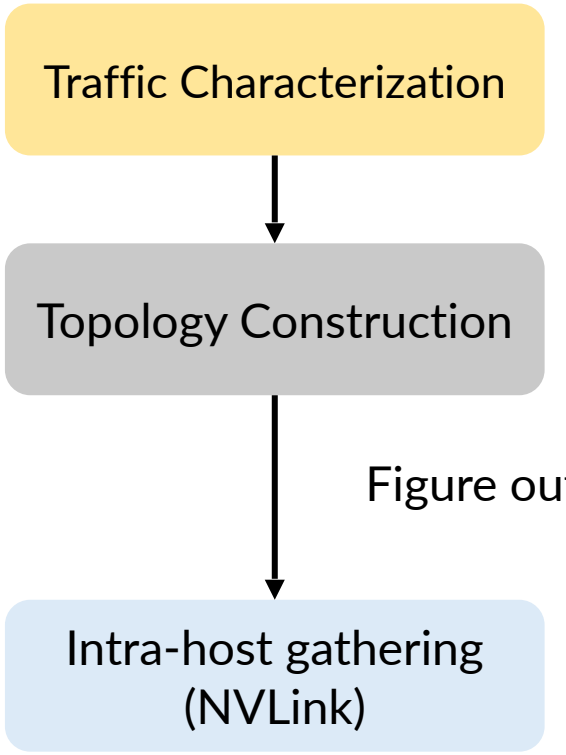

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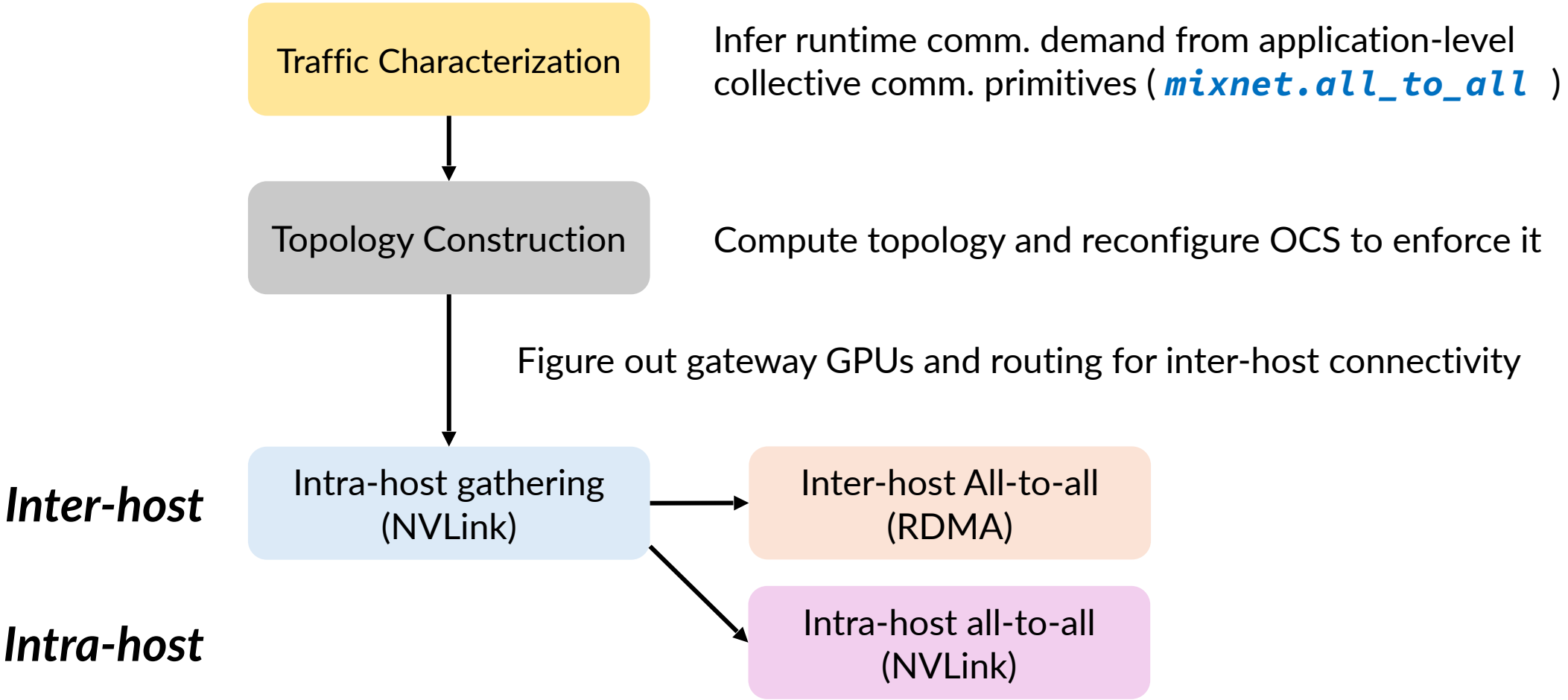

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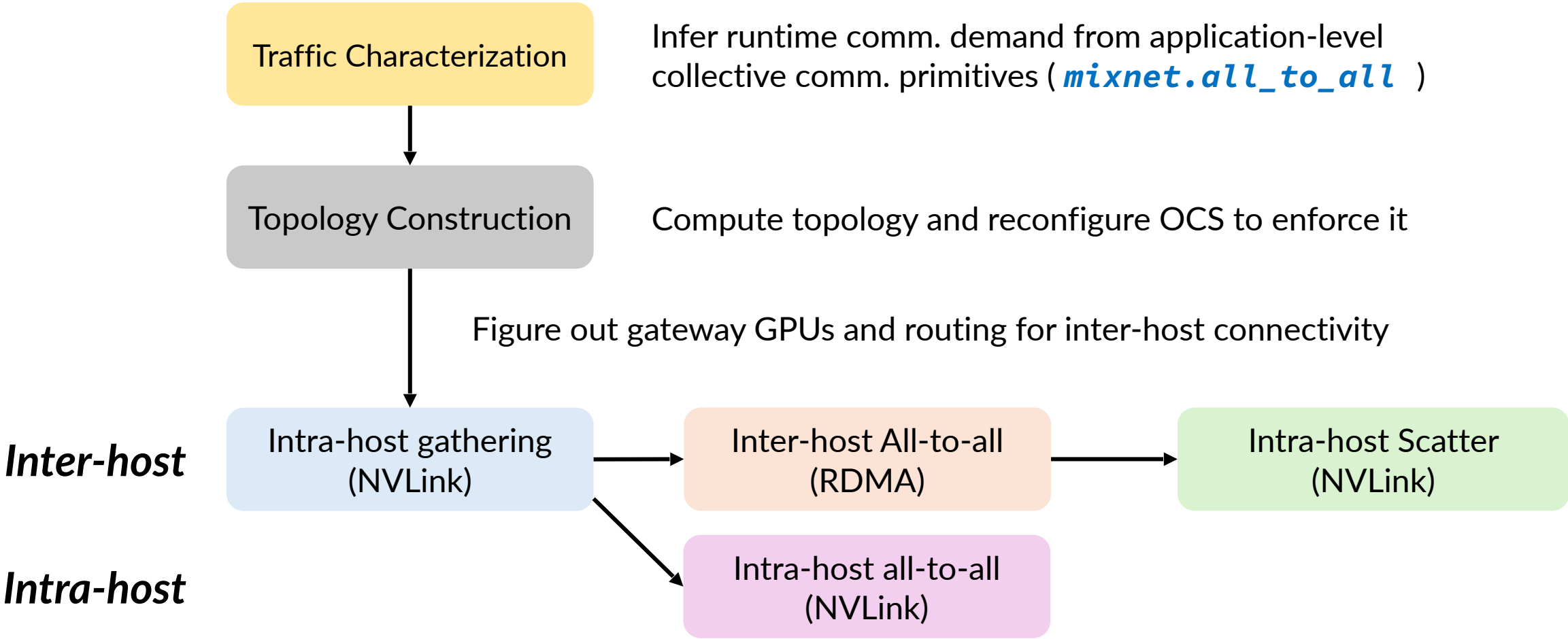
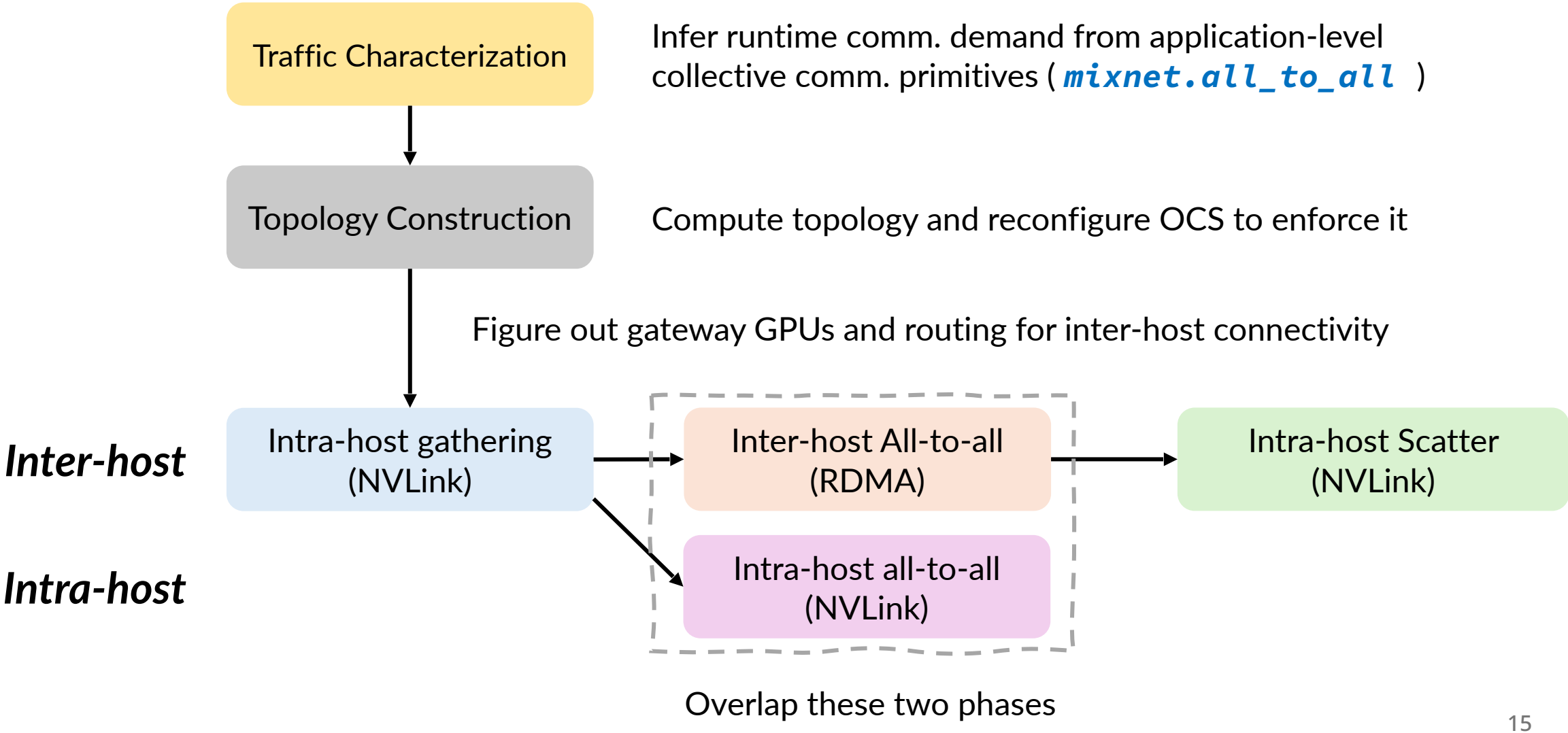
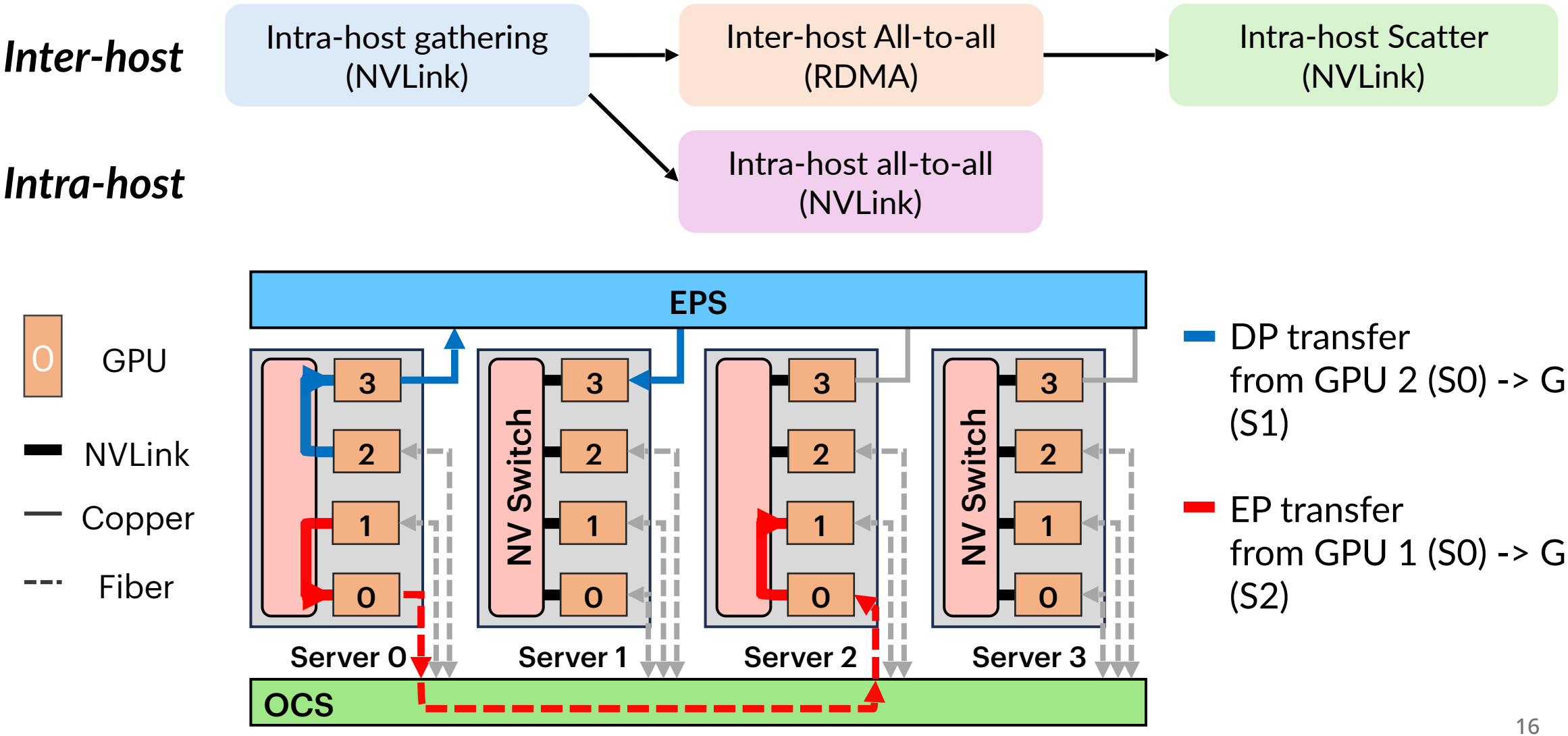


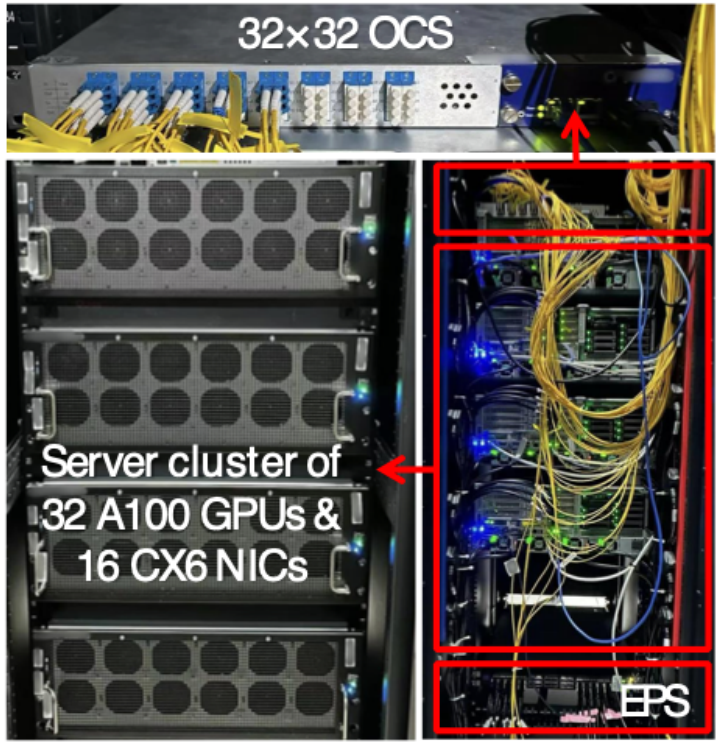
Collective Communication Schedule

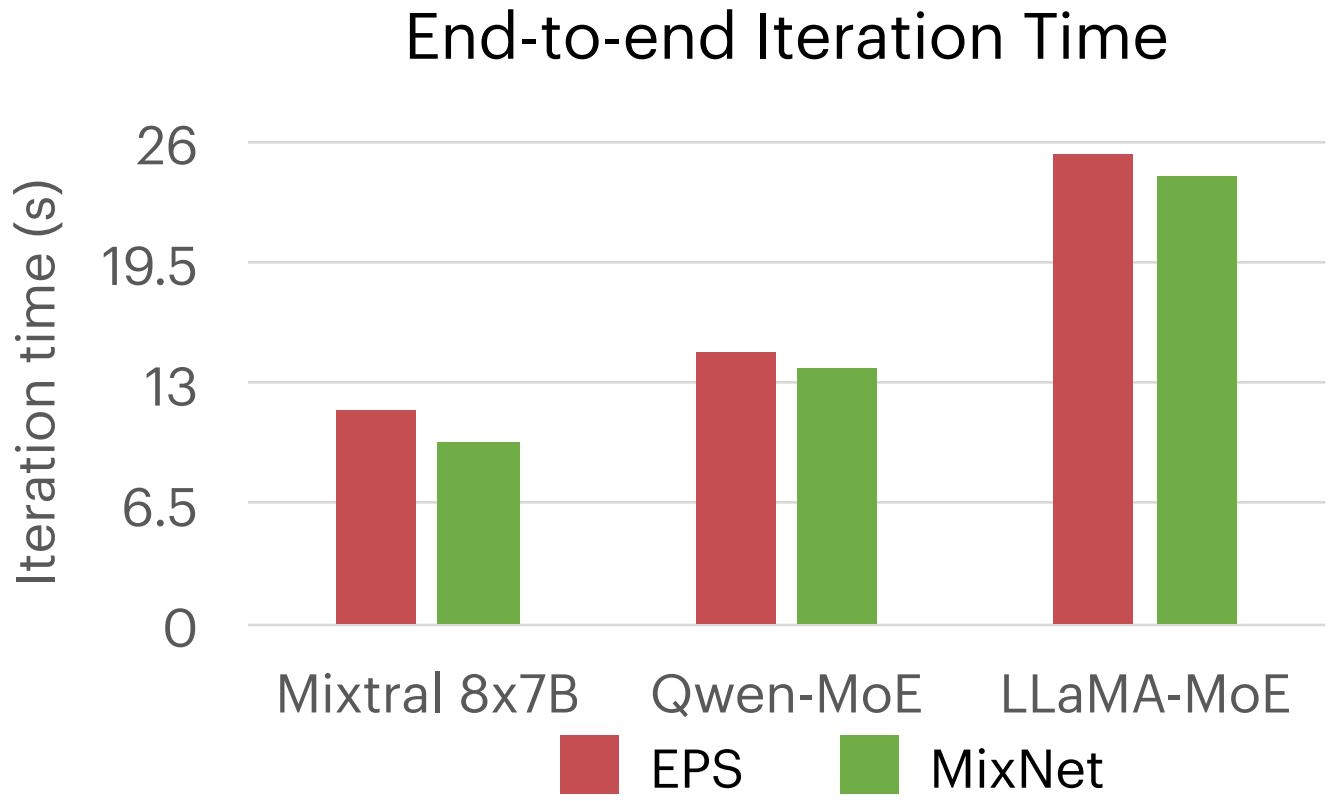


Collective Communication Schedule



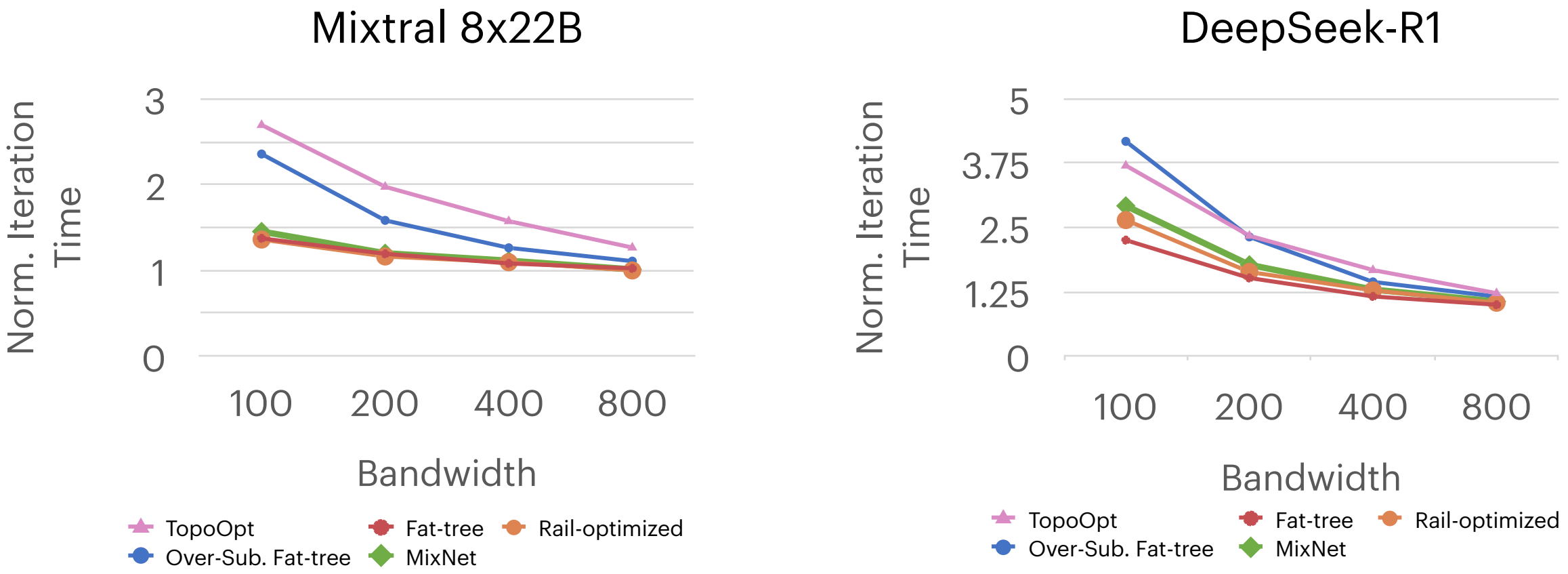
MixNet Prototype





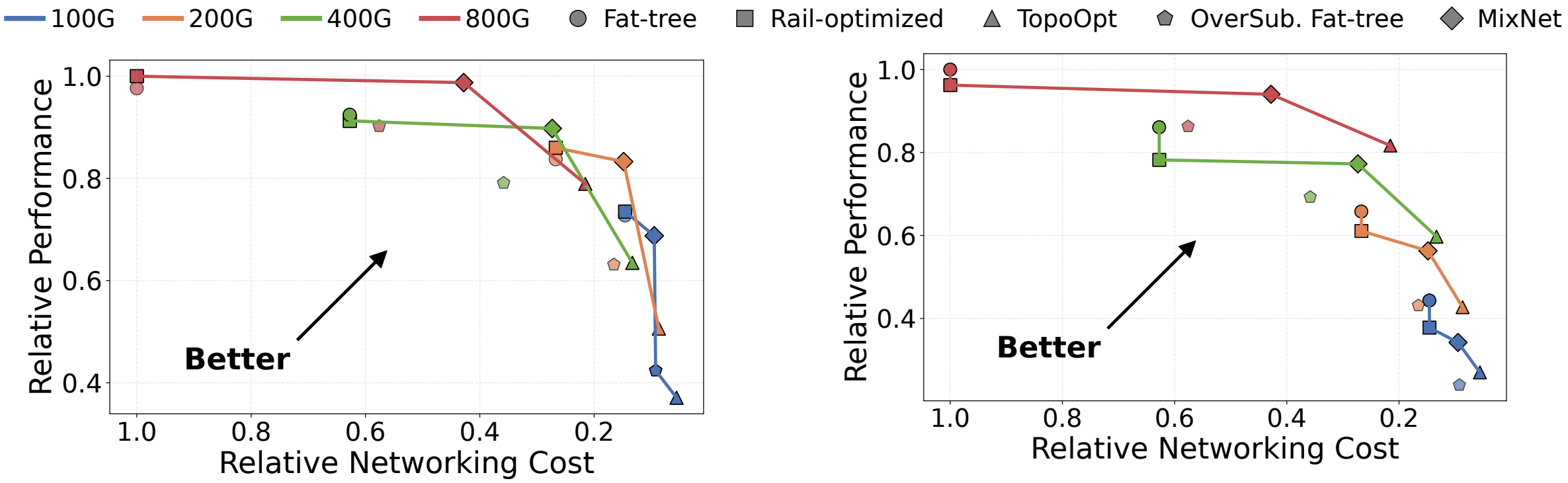
Feasibility: MixNet is able to train state-of-the-art MoE models and achieves comparable performance with bandwidth-equivalent EPS.

Large-scale Simulation



MixNet is comparable with 1:1 Fat-tree and outperforms TopoOpt by 2.5x.

Pareto Analysis on Performance vs. Cost

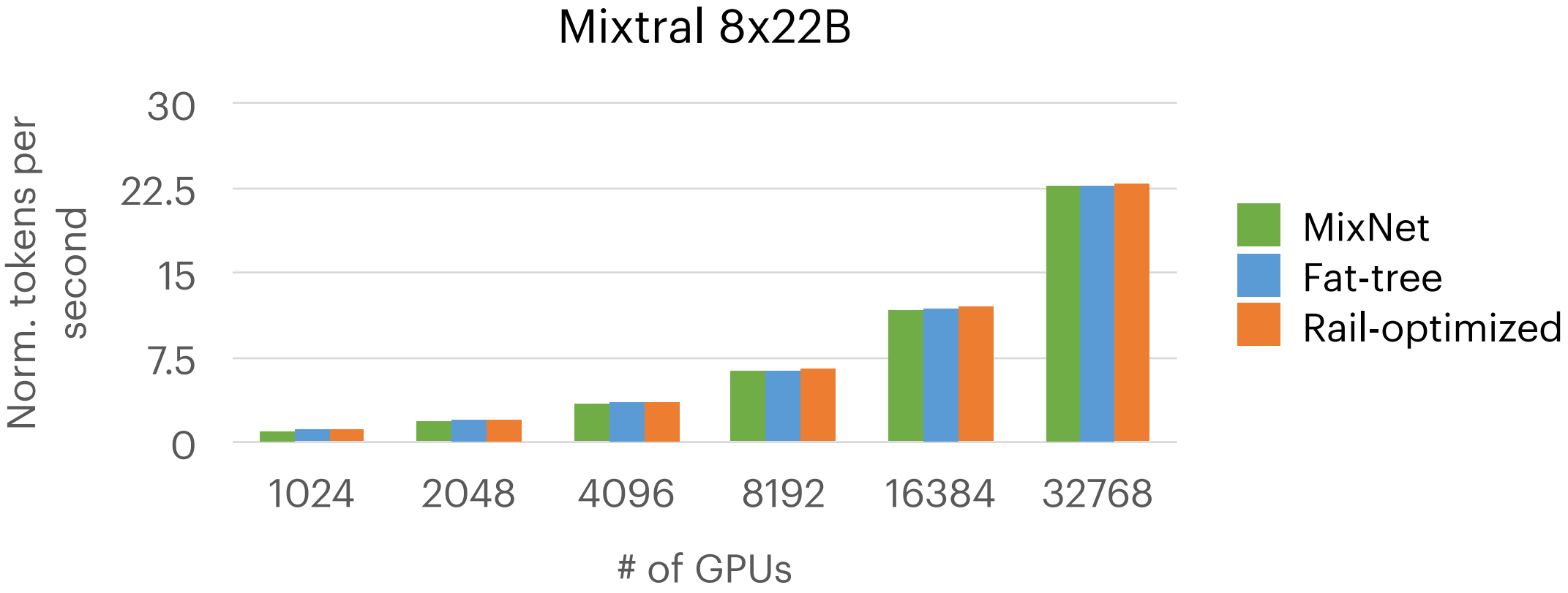


Mixtral 8*22B

DeepSeek-R1

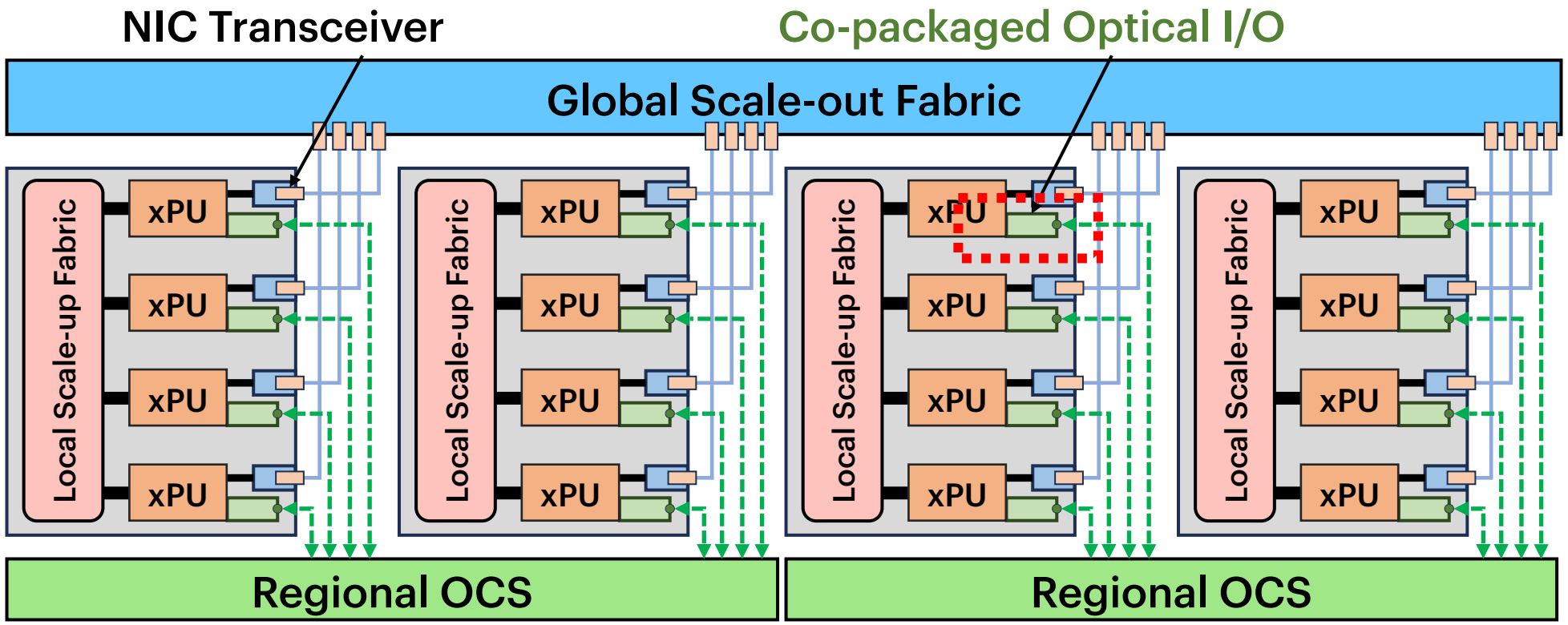
MixNet defines the ***Pareto Front*** among all interconnects and boosts the training cost efficiency by up to 2.3x at 400 Gbps network.

Scalability

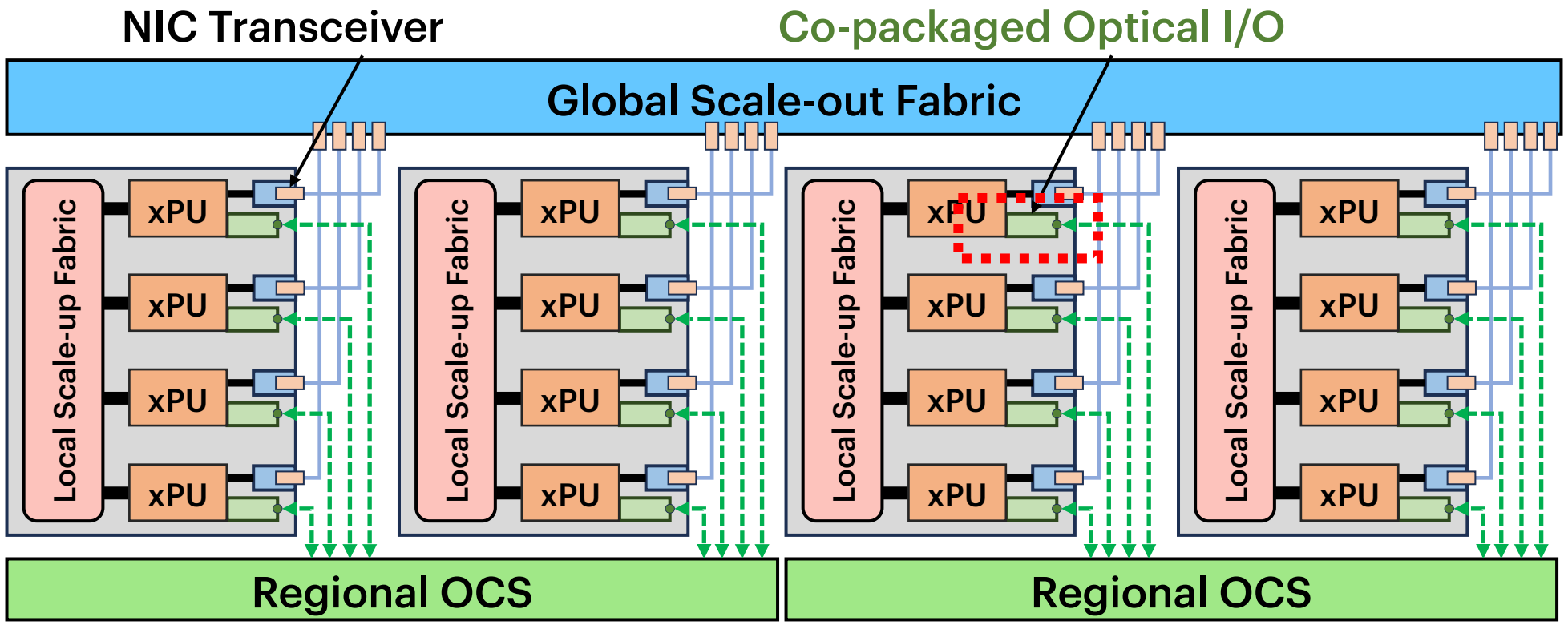


MixNet ***scales efficiently*** with an increasing number of GPUs, demonstrating strong scalability.

Look Forward: MixNet with Co-packaged Optical I/O

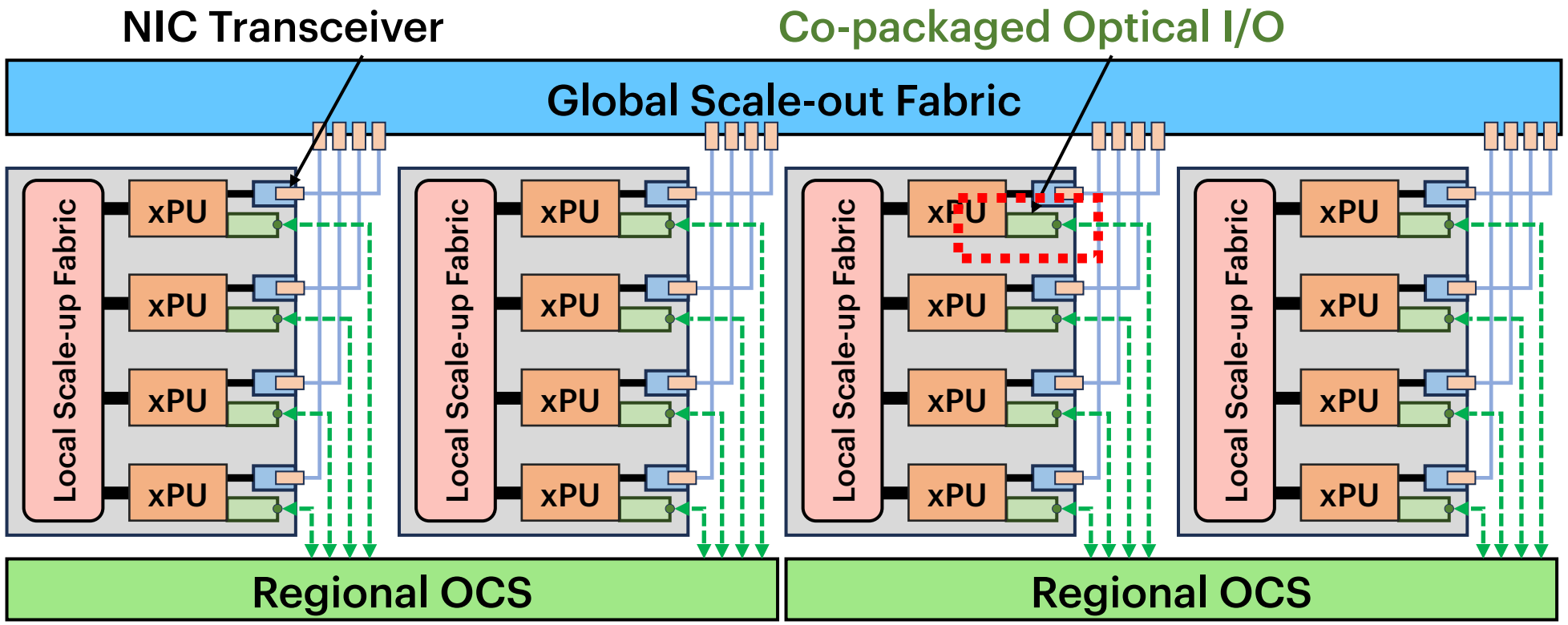


Look Forward: MixNet with Co-packaged Optical I/O



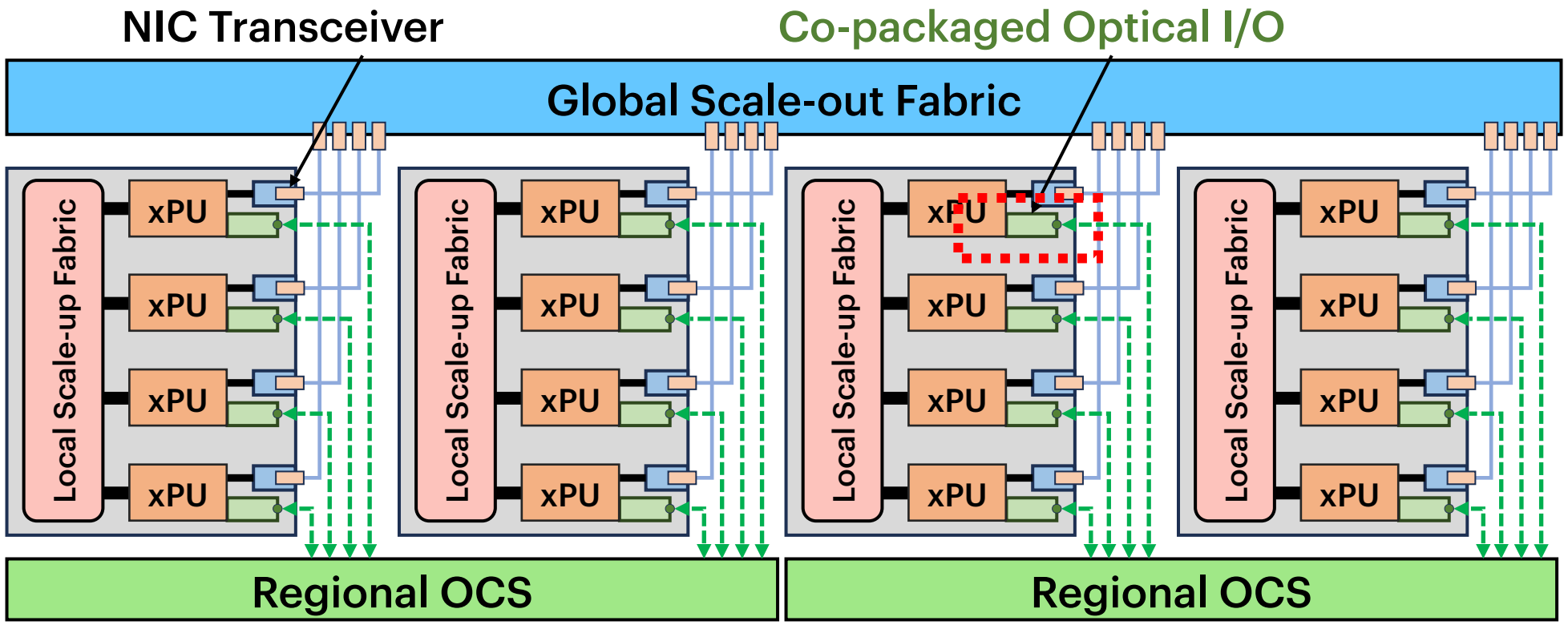
- ***Intra-node*** ultra-high speed scale-up electrical interconnect

Look Forward: MixNet with Co-packaged Optical I/O



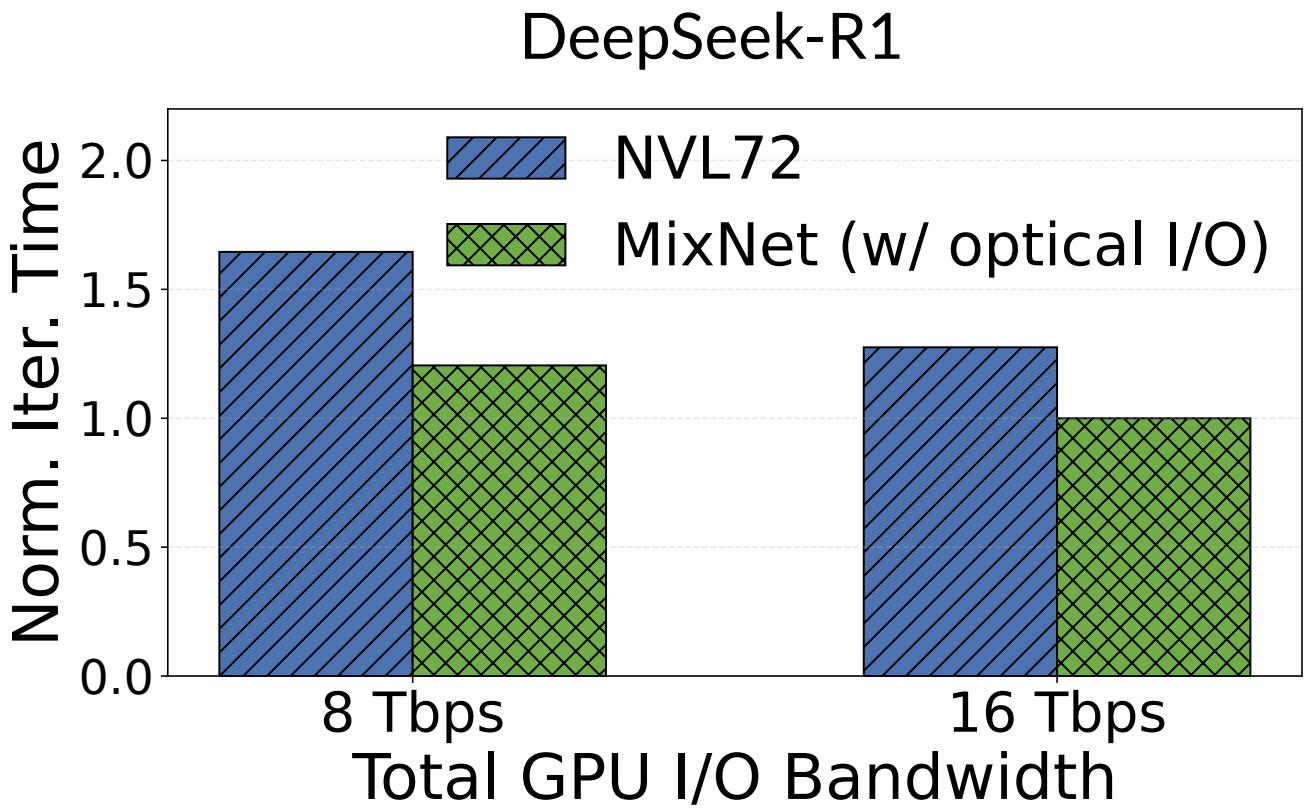
- ***Intra-node*** ultra-high speed scale-up electrical interconnect
- ***Regional*** medium-reach high-speed xPU-direct optical interconnect

Look Forward: MixNet with Co-packaged Optical I/O

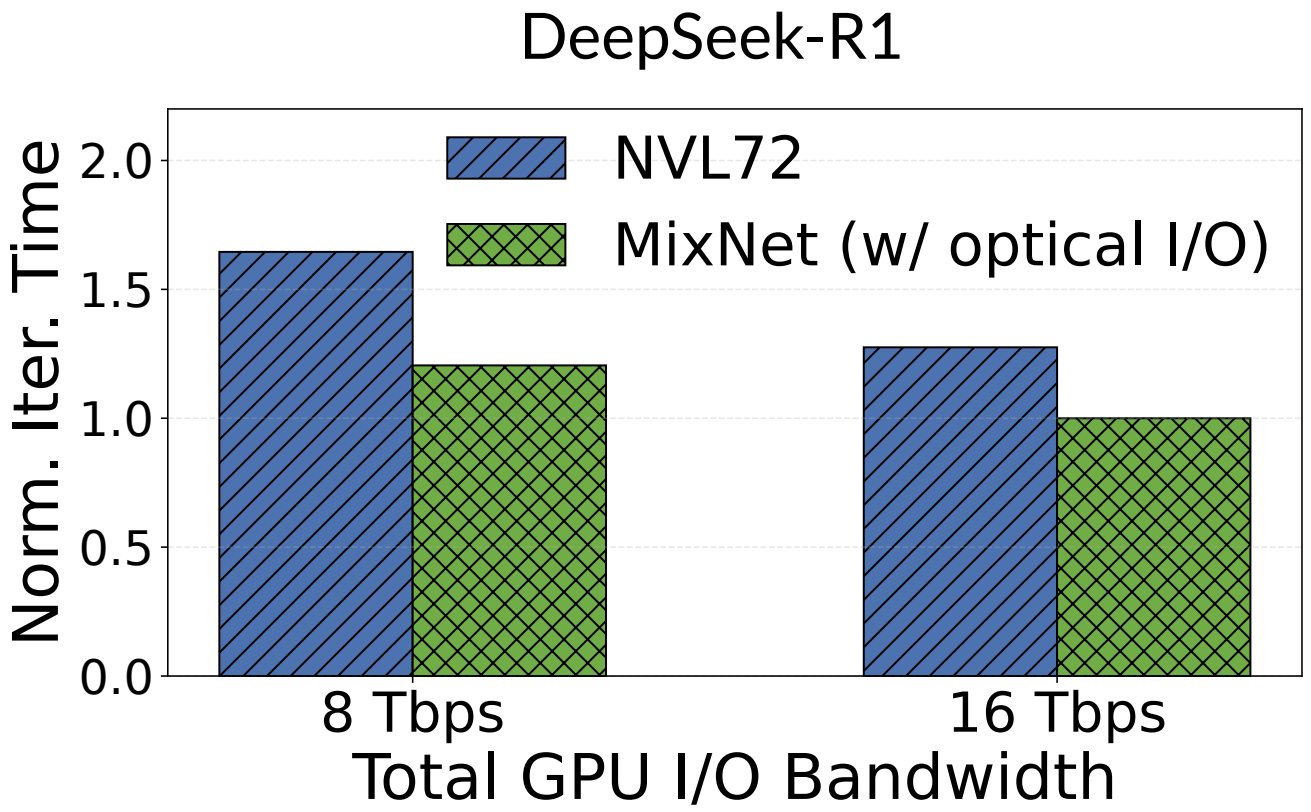


- ***Intra-node*** ultra-high speed scale-up electrical interconnect
- ***Regional*** medium-reach high-speed xPU-direct optical interconnect
- ***Cluster-scale*** electrical Ethernet interconnect

MixNet (w/ CPO) vs. NVL 72 System



MixNet (w/ CPO) vs. NVL 72 System



MixNet arguments the high-radix NVL72 system by 1.3x.

MixNet Recap

- MixNet is a ***first-of-its-kind*** system that designs mixed optical-electrical fabric for large-scale distributed MoE training, unlocking runtime topology reconfigurations.

- The core to MixNet is the design and implementation of ***regionally reconfigurable high-bandwidth domain***, making it flexible yet scalable.

- Forwarding-looking optical techniques can benefit from MixNet by arranging reconfigurable OCS within each EP group for providing massive bandwidth with intra-collective flexibility.

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