Impact of Network Topologies on Blockchains Performance

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- Flexibility and adaptability of blockchain solutions to diverse industries **(e.g., Finance, Supply Chain, Healtcare)**.

- Assessing and comparing the performance of different blockchain systems.

- Presence of several tool and suite for evaluating blockchain performance.

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Blockchain benchmark tools comparison

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Table 1: Comparison of several blockchain benchmark tools (◌ = not found; ○ = no match; ● = match; ◑ = partial match; Centr. = Centralized; Distr. = Distributed; Simul. = Simulation; Emul. = Emulation; SC = Smart Contract; TT = Transfer Transactions).

Tool	Year	Network settings	Orchestration	Mode	Reproducibility	Versatility	Observability	Portability	Ease to run	Workload
Shadow-Bitcoin [54]	2015	◌	Centr.	Simul.	○	○	○	○– Bitcoin	○	TT
HIVE [14]	2016	◌	Distr.	Simul.	○	○	○	○– Ethereum	○	◌
Simcoin [3]	2016	◌	Centr.	Simul.	○	○	●	○– Bitcoin	○	TT
Bitcoin-Simulator [39]	2016	◑	Centr.	Simul.	○	○	○	●– Bitcoin-like	○	TT
BlockBench [30]	2017	◌	◌	Simul.	○	●	○	●– Private	○	SC
Caliper [45]	2018	◑	Distr.	Emul.	○	○	●	●– Ethereum,Hyperledger	○	SC
Minichain [75]	2019	◑	Centr.	Emul.	○	○	○	●	○	◌
BlockLite [73]	2019	◌	Centr.	Emul.	○	○	○	●– PoW-public	○	◌
BlockSim-f [34]	2019	◑	Centr.	Simul.	○	○	○	●	○	◌
SimBlock [20]	2019	◑	Centr.	Simul.	○	○	○	●	○	TT
BlockSim-m [16]	2020	◑	Centr.	Simul.	○	○	○	●	○	TT
Core-Bit-Netw-Simul. [17]	2020	◑	Centr.	Simul.	○	○	○	●	○	◌
BBB [60]	2020	◑	Centr.	Emul.	○	○	○	●– Private	○	◌
SIMBA [35]	2020	◑	Centr.	Simul.	○	○	○	●	○	◌
BCTMark [65]	2020	◑	Distr.	Emul.	○	○	●	●	○	TT
BlockPerf [62]	2021	○	Distr.	Both	○	○	○	○– Bitcoin	○	TT
DLPS [36]	2021	◑	Distr.	Emul.	○	○	●	●	○	TT
Gromit [56]	2022	◑	Distr.	Emul.	○	○	●	●	○	SC
Diablo v2 [42]	2022	○	Distr.	Emul.	●	●	●	●	●	TT,SC
JABS [77]	2023	◑	Centr.	Simul.	○	○	○	●	○	TT
COCONUT [40]	2023	◌	Distr.	Emul.	●	●	○	●	●	TT,SC
GFBE [50]	2024	○	Distr.	Emul.	●	●	●	●	●	SC
STABL [43]	2024	◑	Distr.	Emul.	○	●	●	●	●	TT,SC
Lilith	2024	●	Distr.	Emul.	●	●	●	●	●	TT,SC

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- Lilith stands out as the tool that serve all the features and respect the criteria for blockchain benchmark.

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- Resource management and transaction handling.
- Steep learning curve.

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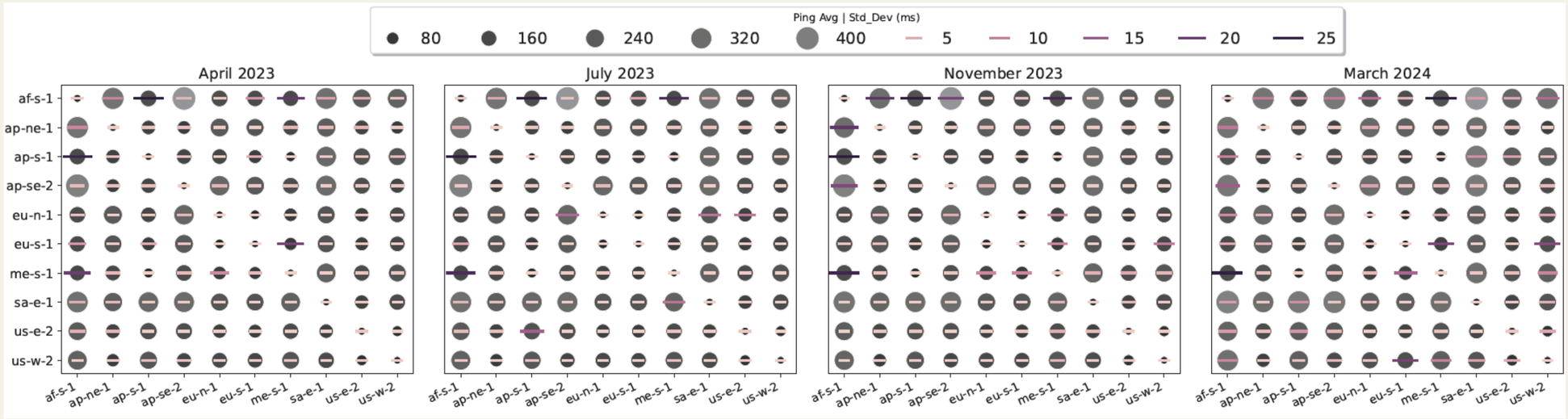
- Network links between the data centers changes throughout the day (e.g., infrastructure updates, contention on links, etc.).



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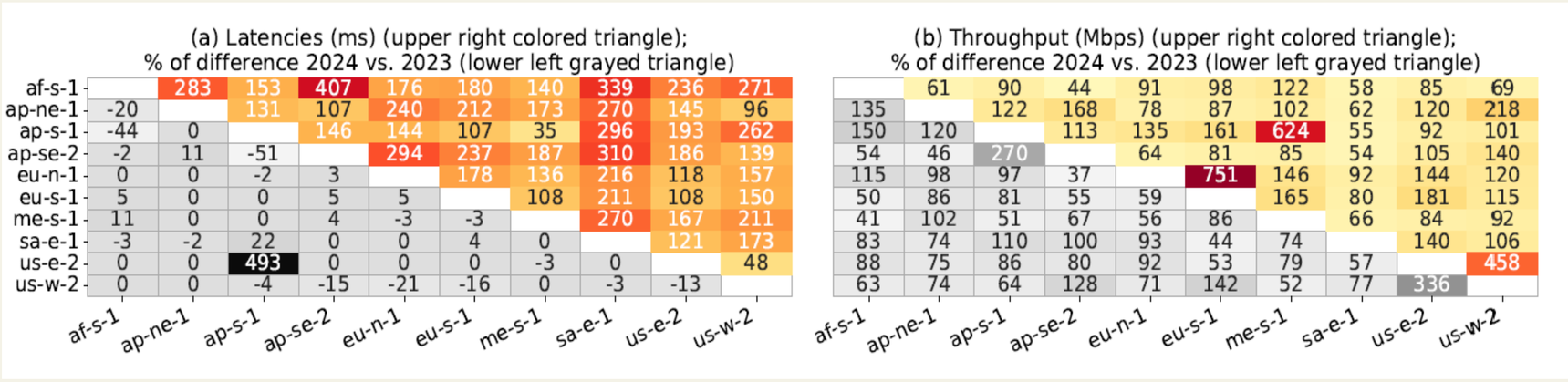

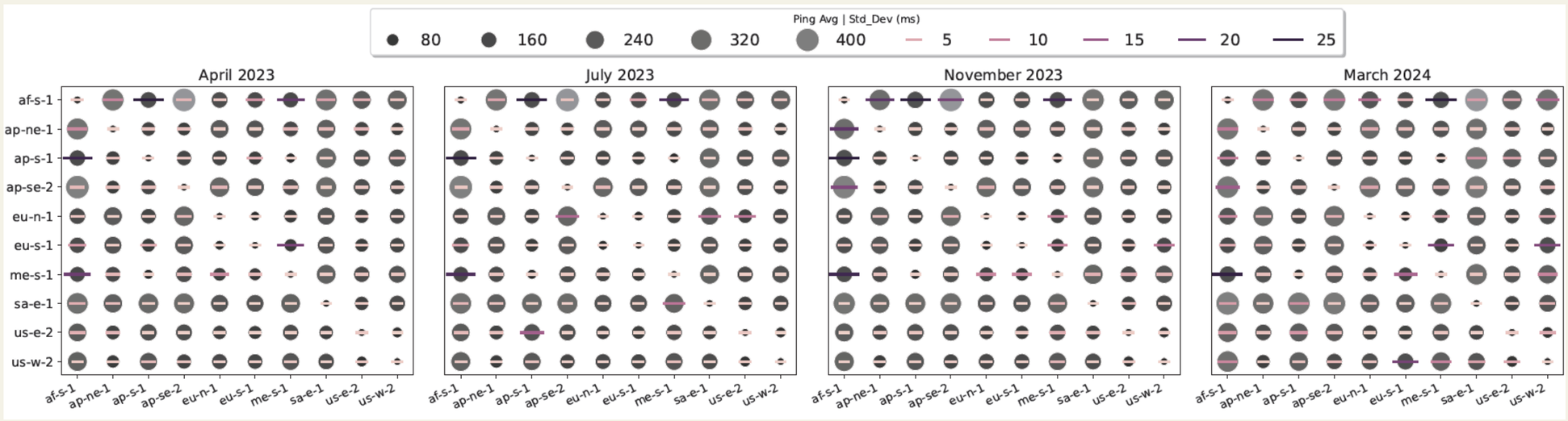

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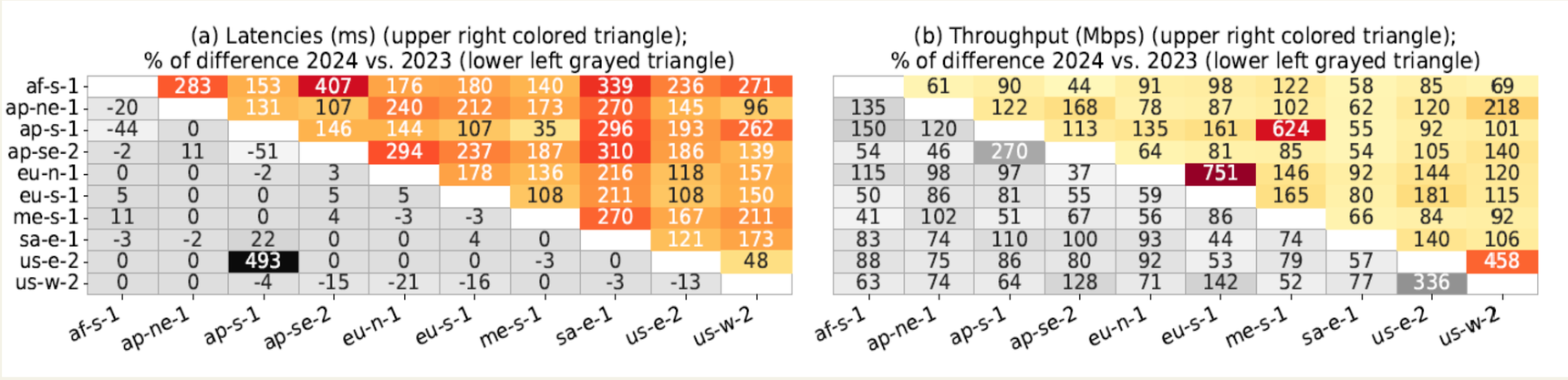

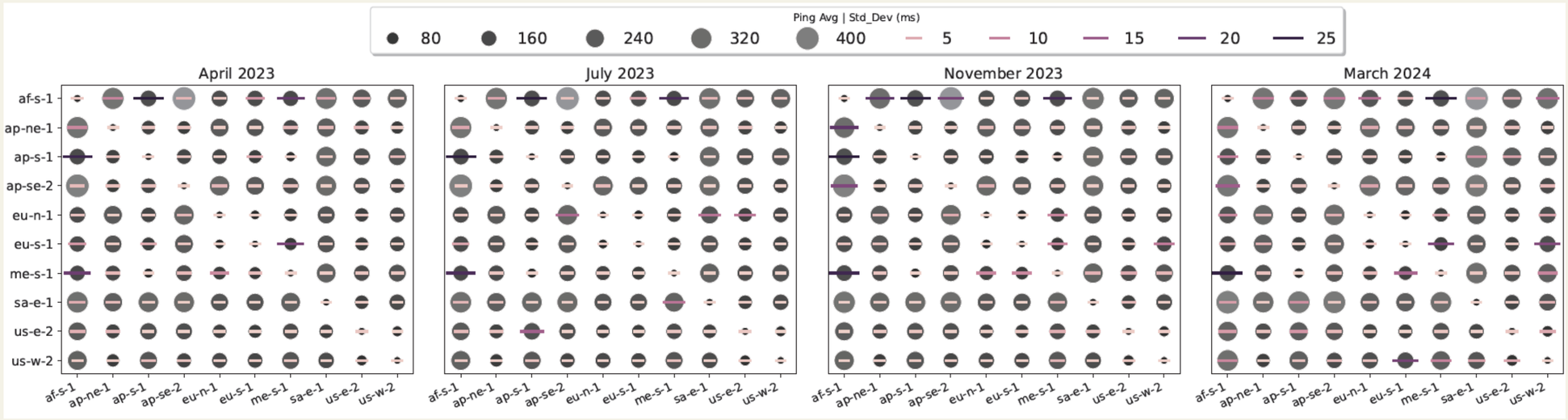

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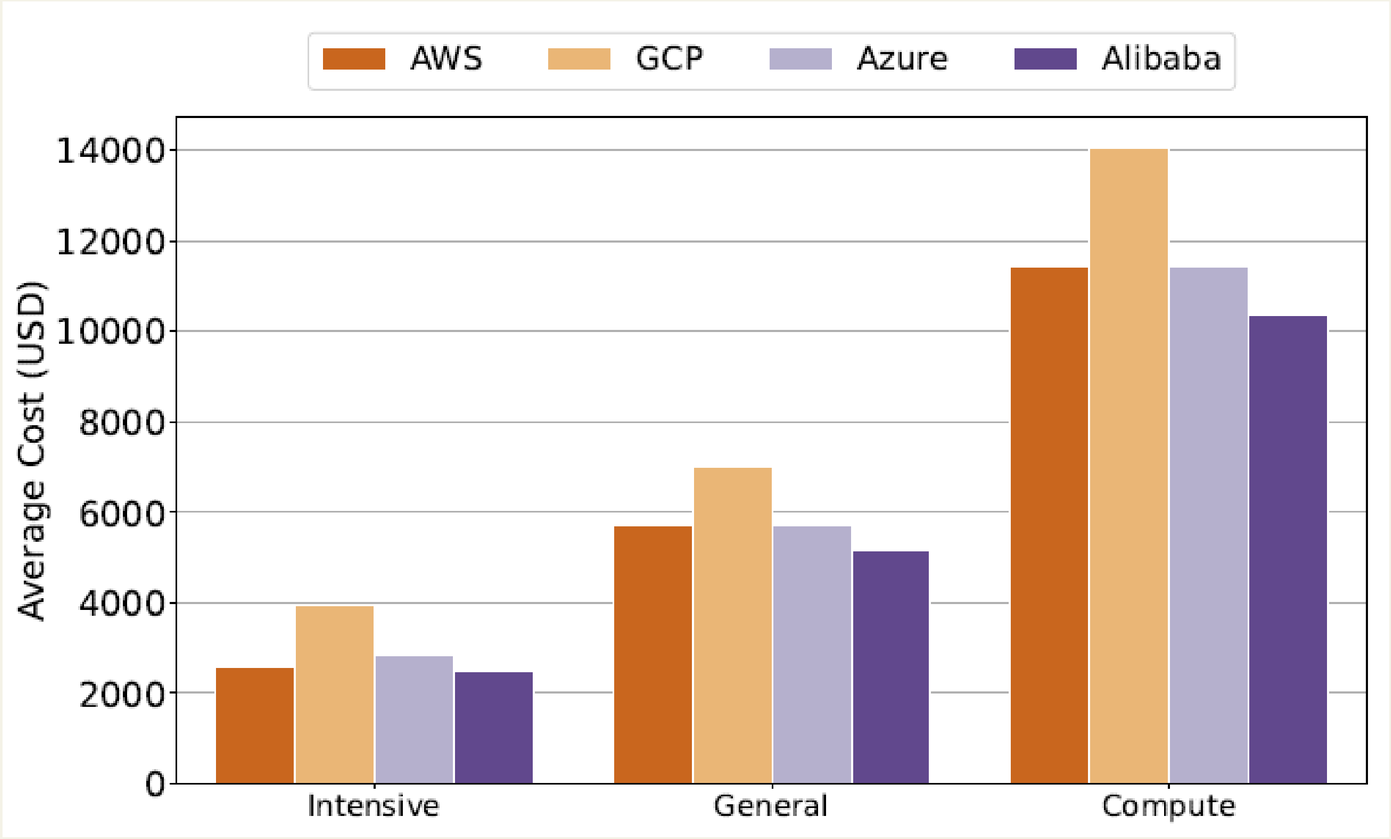

Intensive, 30/60 vCPU, 64/120 GiB RAM, 10 nodes

General, 4 vCPU, 8 GiB RAM, 200 nodes

Compute, 8 vCPU, 16 GiB RAM, 200 nodes

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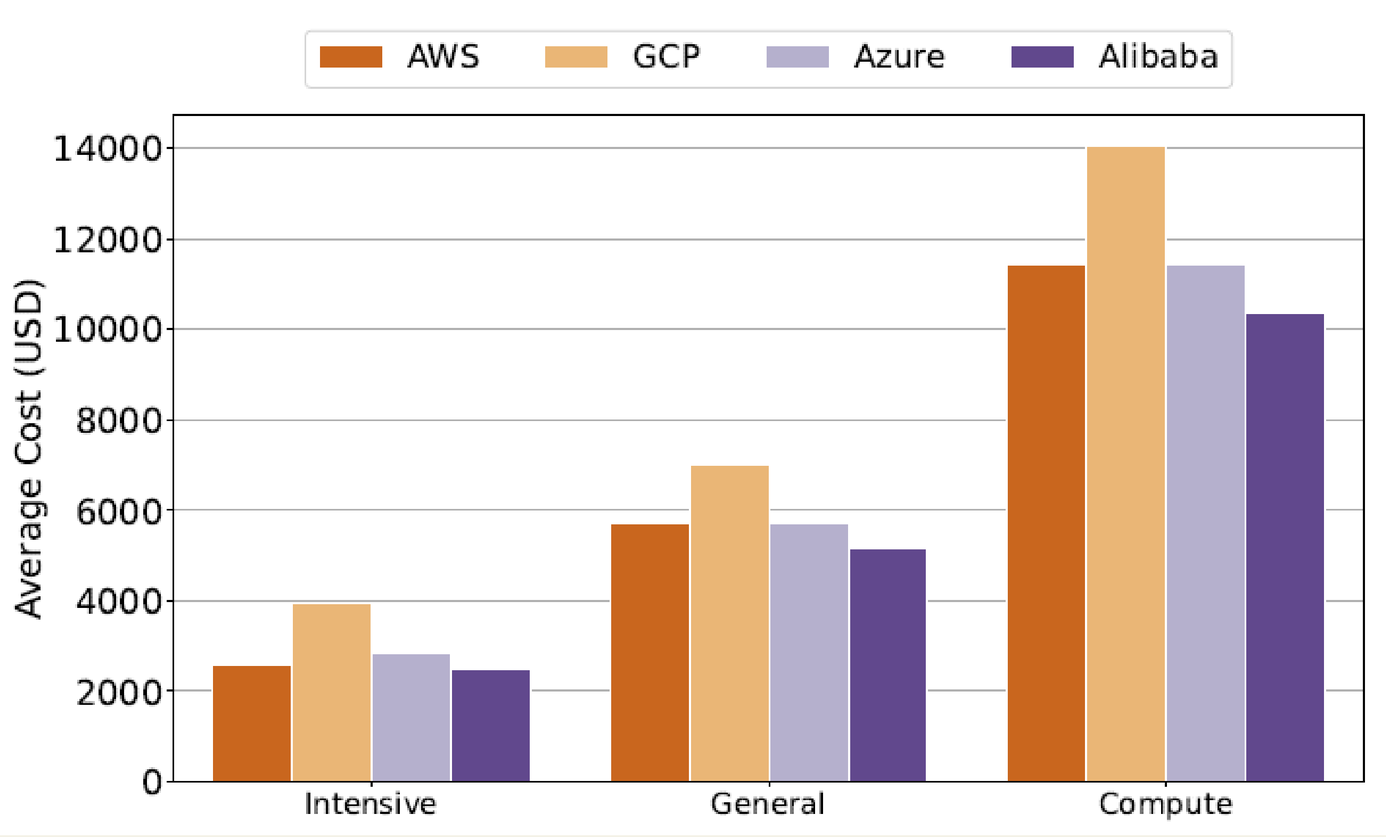
- Network modeling/malleability.



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3. Serving a controlled environment.
4. Assessing the feasibility of achieving comparable performance in a cost-effective cluster setup.

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Research Questions

- **RQ1 -** How do topologies affect blockchain performance, and which is optimal for each?

- **RQ2 -** What is the impact on performance of network perturbations, such as packet loss, congestion, node failures, and increased latency, and which blockchain is most affected?

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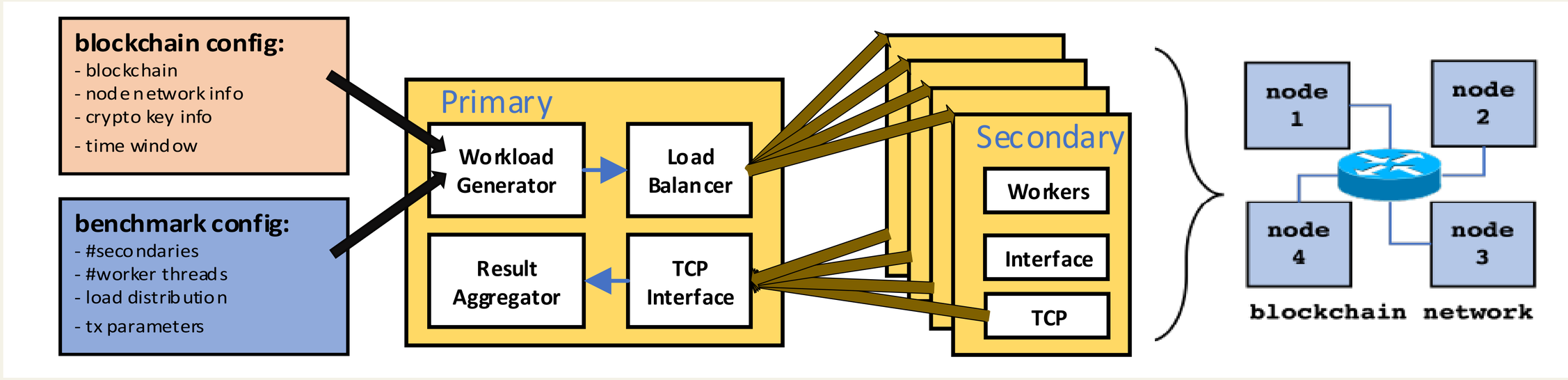
- Define, evaluate and compare different blockchains under realistic and tunable workloads/**Dapps (e.g., Exchange, Web Service)**.
- Enhanced distributed workload generation.



- **Primary** element transmits a description of the transactions to Secondaries elements, waits for all of them to be ready and informs when to start the benchmark.
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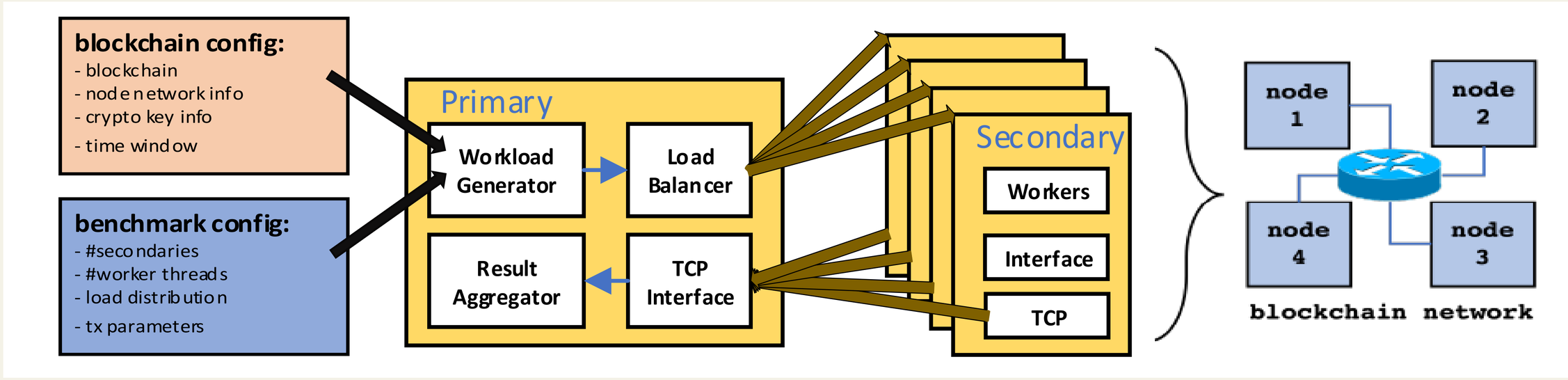

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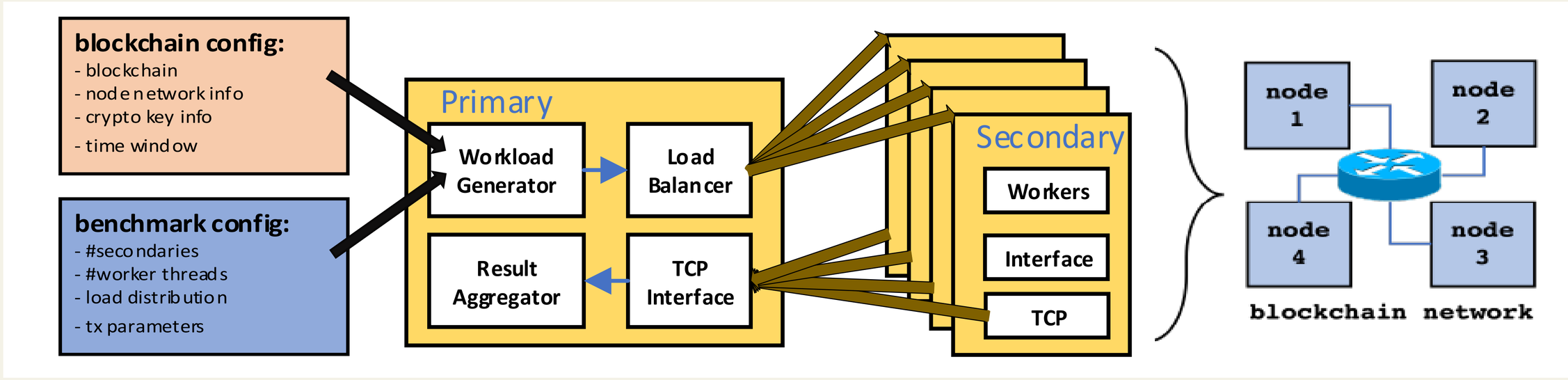

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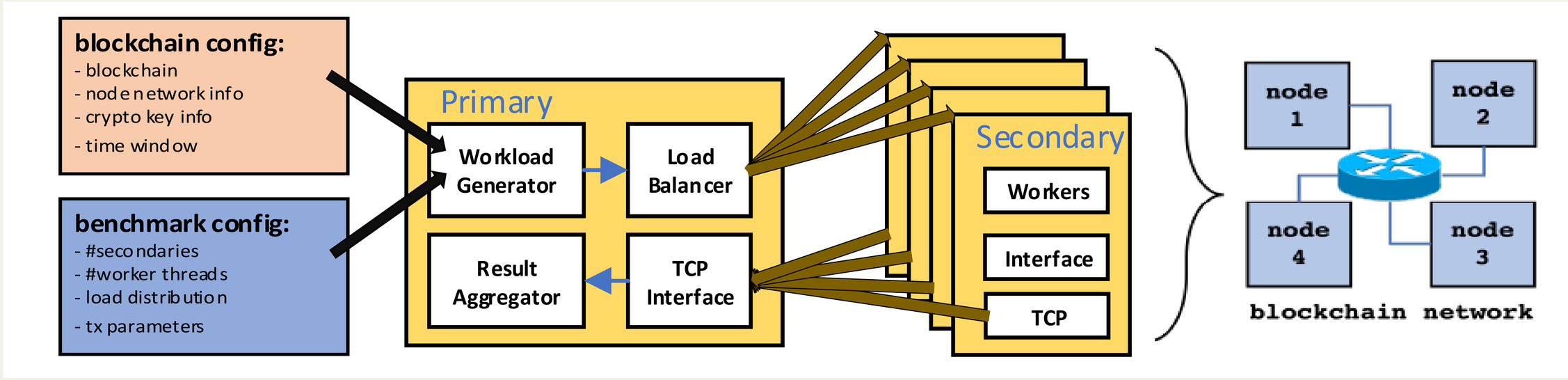

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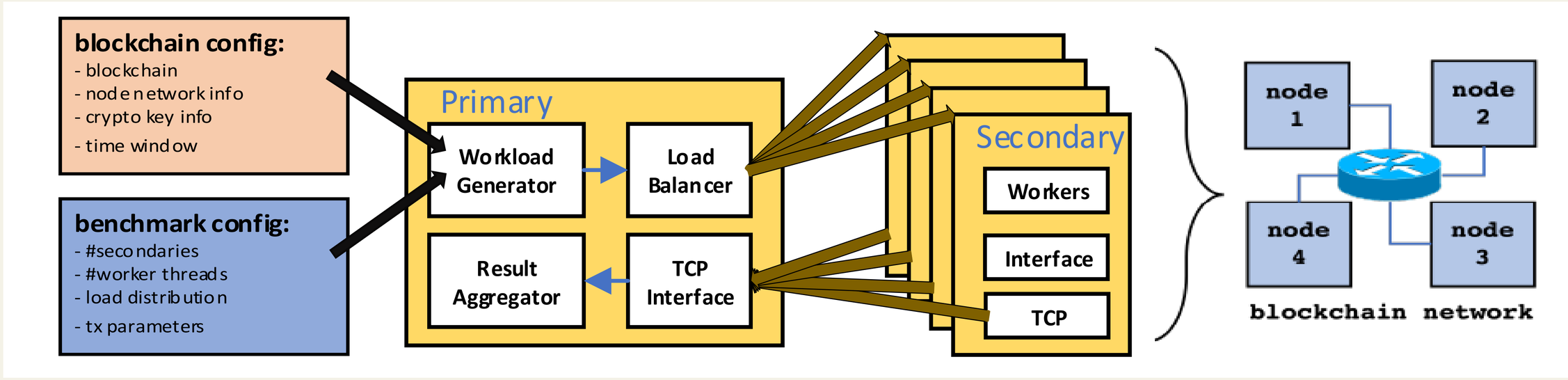

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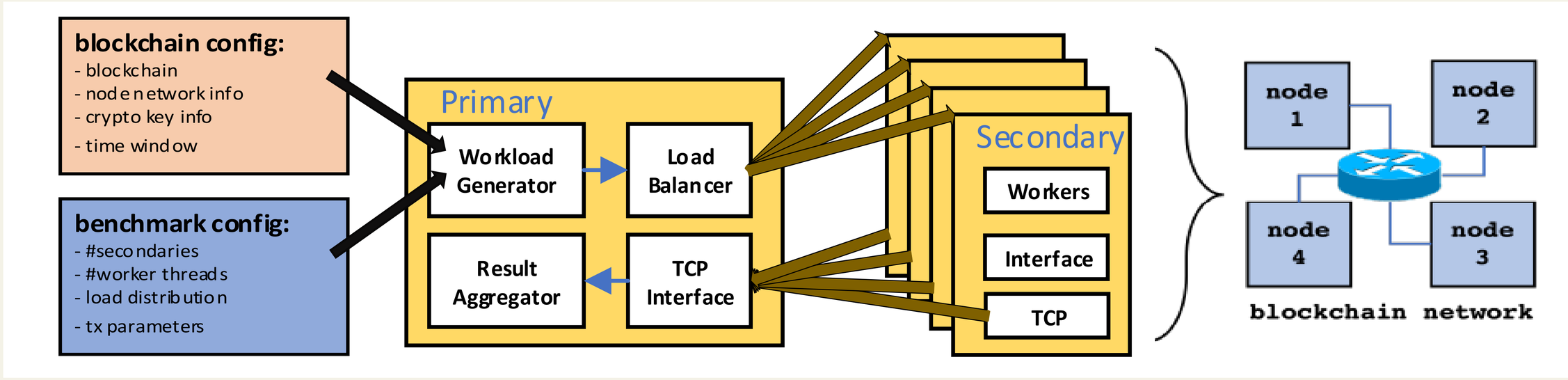

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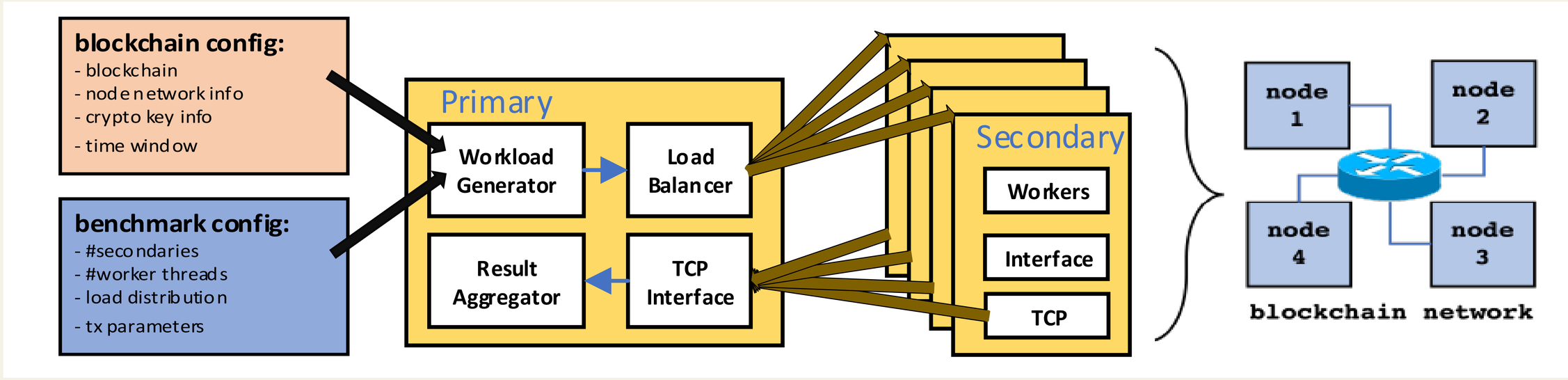

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- Prior to starting the benchmark, the workload generator parses 2 configuration files:

- **benchmark** configuration file, defining the distribution of DIABLO Secondaries, transaction information, function calls, data types and variants of what data is passed into the transaction;

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Paper Experimental Settings

- 6 blockchains: *Algorand*, *Avalanche*, *Diem*, *Quorum*, *Ethereum*, *Solana*.

- 5 configurations on up to 200 machines distributed in 10 countries around the world.

- Diablo emulate clients sending either native or smart-contract transactions to the blockchain during the duration of the workload, e.g., 120 seconds at a constant rate of 1000 TPS **(order of magnitude as the average load of the VISA system)**.

- If the measured throughput is close to 1000 TPS, the blockchain handles the simple payment use case for the configuration.

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NETWORK EMULATION

Name	Year	Orchestration	Concurrent deployments	Path congestions	Topology dynamics	Depl. Unit
DelayLine	1994	Centralized	✗	✗	✗	P
ModelNet	2002	Centralized	✗	✓	✓	P
Nist NET	2003	Centralized	✗	✗	✗	P
NetEm	2005	*note1	*note1	*note1	✗	P
Trickle	2005	*note1	*note1	*note1	✗	P
EmuSocket	2006	*note1	*note1	*note1	✗	P
ACIM/FlexLab	2007	Centralized	✗	✓	✓	V
NCTUns	2007	Centralized	✗	✓	✗	P
Emulab	2008	Centralized	✗	✓	✓	V
IMUNES	2008	Centralized	✗	✗	✗	P
MyP2P-World	2008	Centralized	✗	✗	✗	P
P2PLab	2008	Centralized	✗	✗	✗	P
Netkit	2008	Centralized	✗	✓	✗	V
DFS	2009	Centralized	✓	✗	✓	P
Dummynet	2010	Centralized	✗	✗	✗	P
Mininet	2010	Centralized	✗	✓	✓	P
SliceTime	2011	Centralized	✗	✓	✓	V
Mininet-HiFi	2012	Centralized	✗	✗	✓	C
SPLAYNET	2013	Decentralized	✓	✓	✓	P
MaxiNet	2014	Centralized	✗	✓	✓	P
EvalBox	2015	Centralized	✗	✗	✓	P
ContainerNet	2016	Centralized	✗	✓	✓	VC
Kathará	2018	Centralized	✗	✓	✗	C
Dockemu 2.0	2019	Centralized	✗	✗	✗	C
NEeaaS	2020	Decentralized	✗	✗	✗	VC
DockSDN	2021	Decentralized	✗	✗	✗	VC
Testground	2022	Centralized	✓	✗	✓	PC
KOLLAPS	2023	Decentralized	✓	✓	✓	PVC

*P=process, V=virtual machine, C=container

*note1:(N/A: single link emulation only)

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- Decentralized network emulator for large-scale applications.
- Observable end-to-end properties (latency, jitter, bandwidth and packet loss) without emulating the full-state of network elements (routers, switches).
- Fully-distributed emulation model allowing to scale without sacrificing accuracy.
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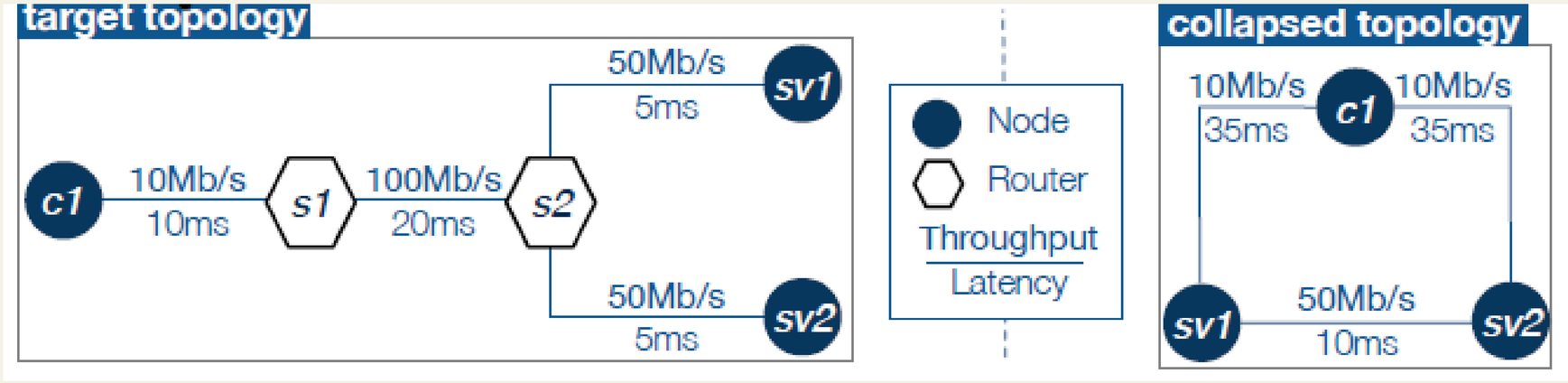

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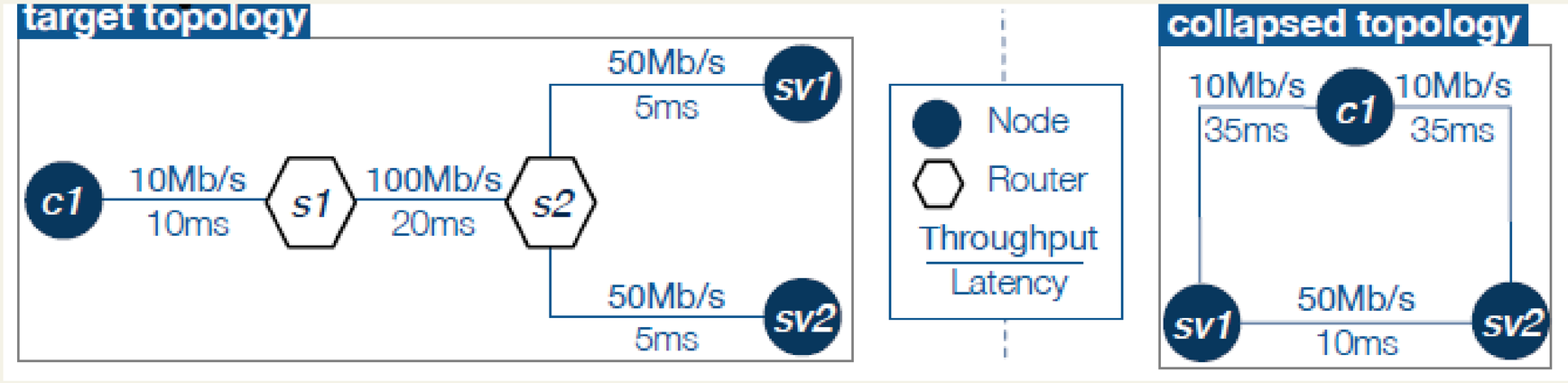

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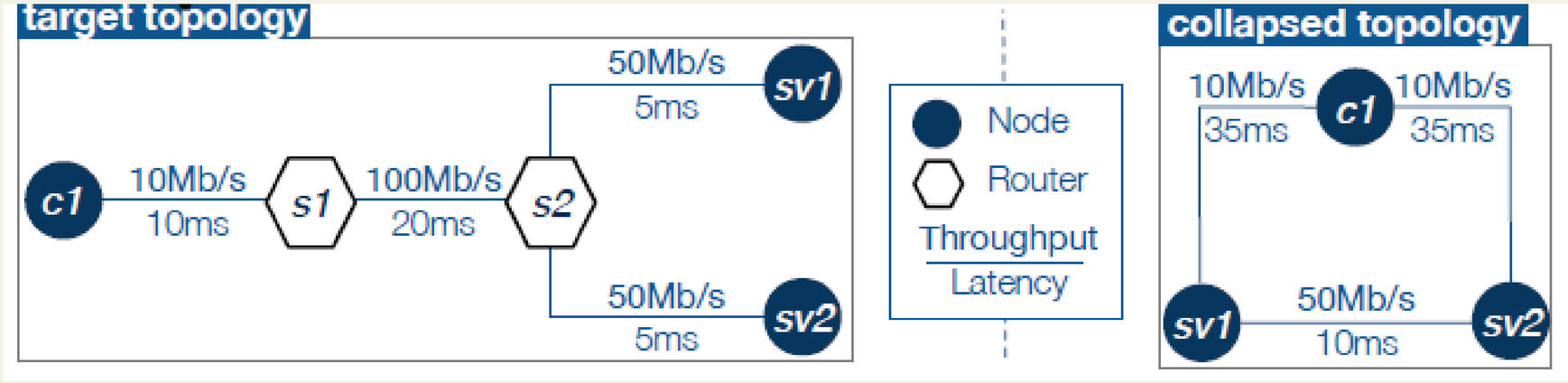

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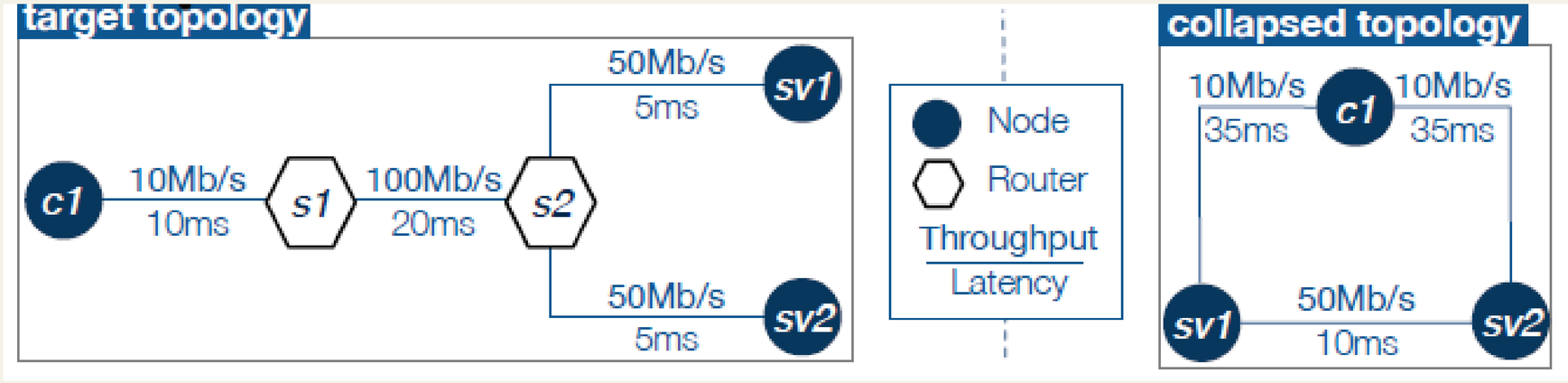

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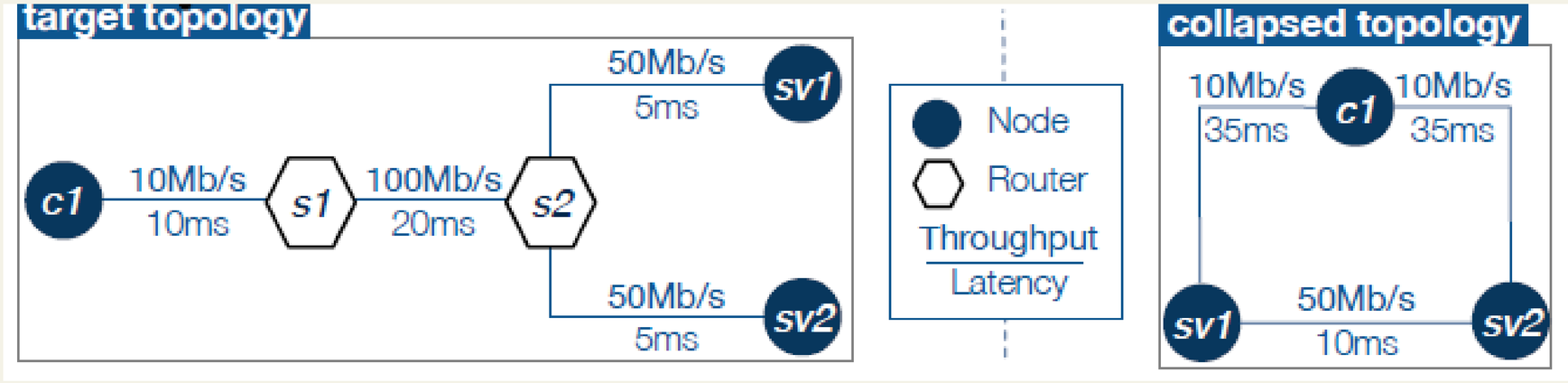

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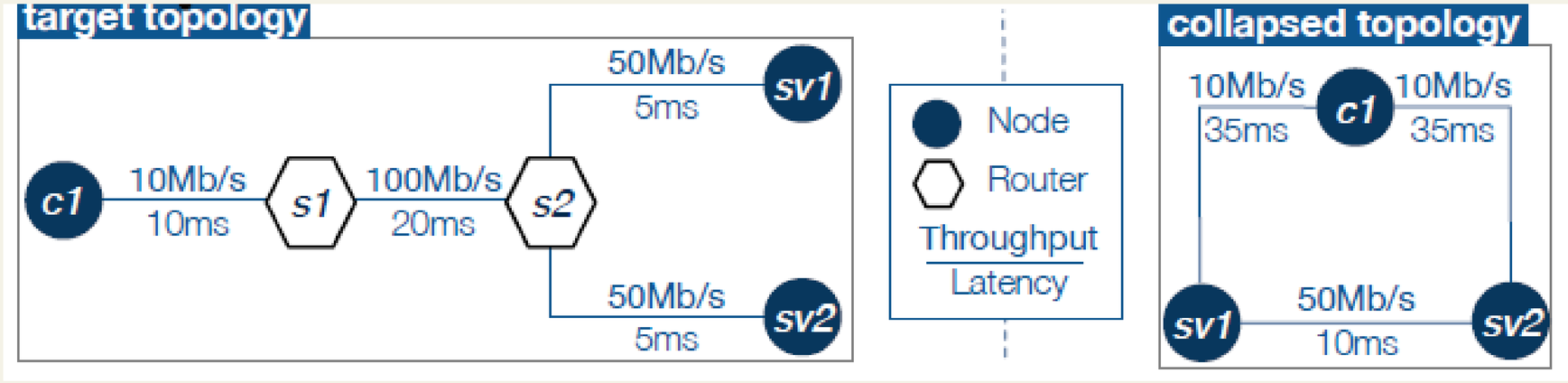

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- **Emulation Manager,** a single instance per physical machine responsible for maintaining the emulation model.

- **TC Abstraction Layer** (TCAL), once per application container, it retrieves and sets the link properties.

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- Integration with container images and orchestration tools (e.g., Docker Swarm, Kubernetes) need to configure:

  1. orchestrator APIs (used at runtime for name resolution);
  2. topology descriptor file (read by each Em instance to setup the initial network state and compute the graph of the dynamic changes);
  3. setup of multiple virtual networks.

- Similar results by running applications with Kollaps in a cluster or in Amazon EC2, scaling and having constant cost regardless of the emulated bandwidth usage.

- Emulation accuracy comparable with full network state emulator (Mininet).

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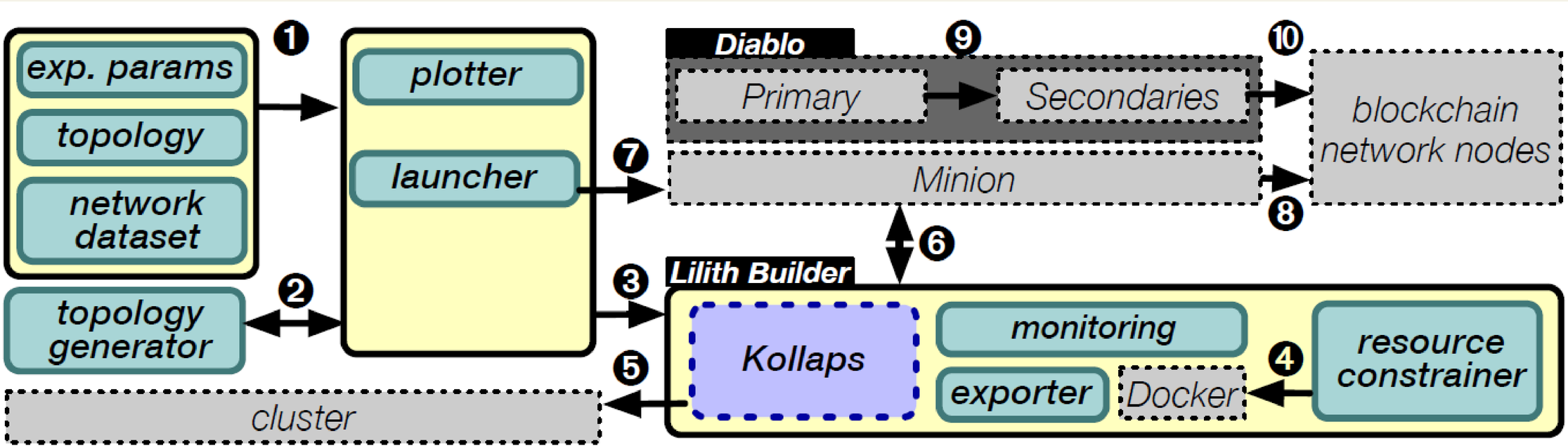
Benchmarking process



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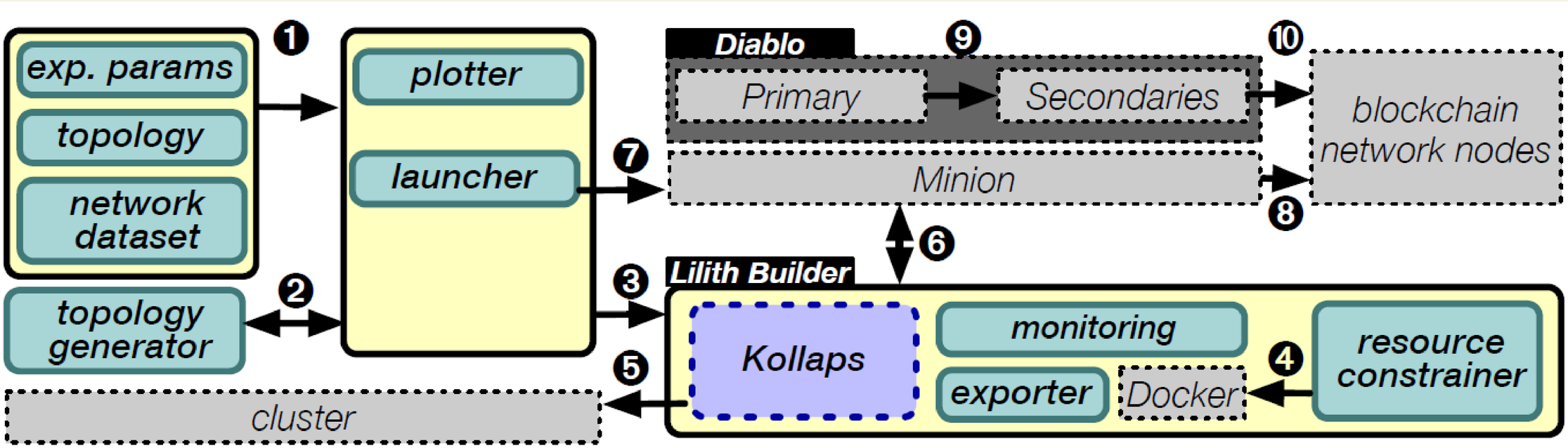

TESTING SCENARIO

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Workflow Evolution

amazon web services™ | EC2

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- Obtain a cost-effective infrastructure to benchmark blockchain solutions.
- Integration of multiple blockchain systems.
- Improved result analytics alongside blockchain node log files.
- Transitioning from cloud to cluster, resulting in cost reduction.
- Facilitate real-world benchmarking scenarios.
- Enabling network malleability, flexibility, and availability for configuration on a per-request basis.
- Enrich already existing documentation by providing both network datasets and execution traces.

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- ***Fat-tree***. A hierarchical topology consisting of core, aggregation, and edge layers.
- ***Full mesh***. Each node is connected to every other node, ensuring maximum connectivity.
- ***Hypercube***. Each node is connected to its adjacent nodes in a binary-like fashion, forming a multidimensional cube.
- ***Scale-free***. A few nodes have significantly more connections than others.
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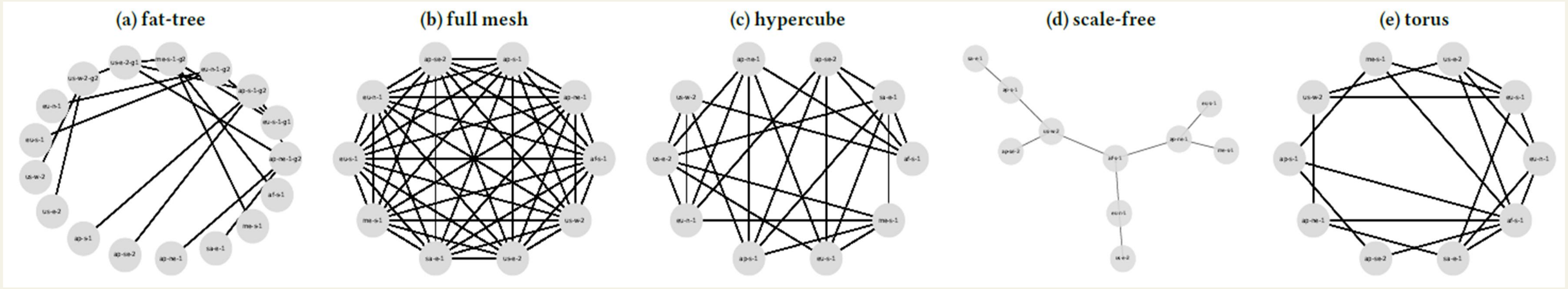

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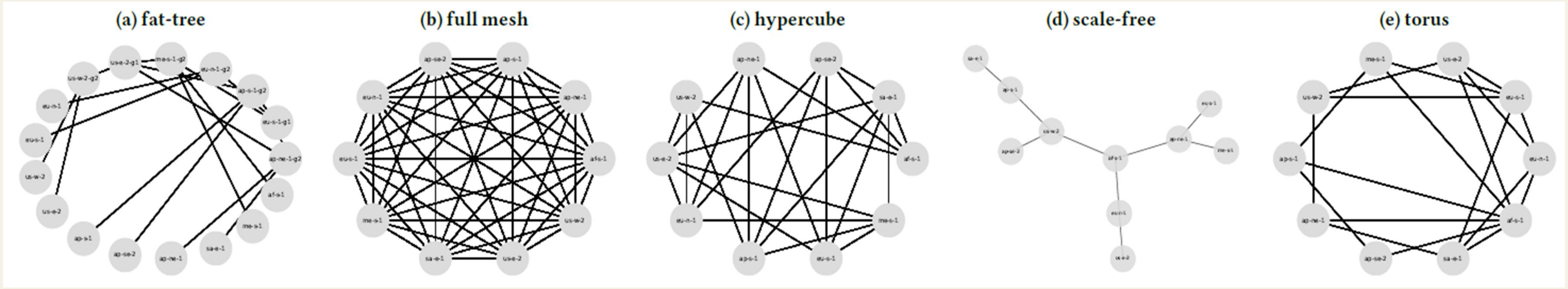

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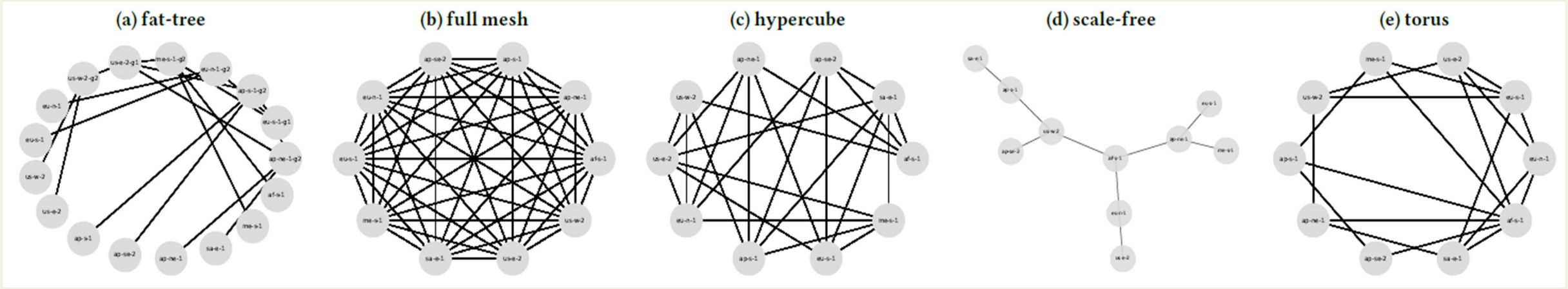

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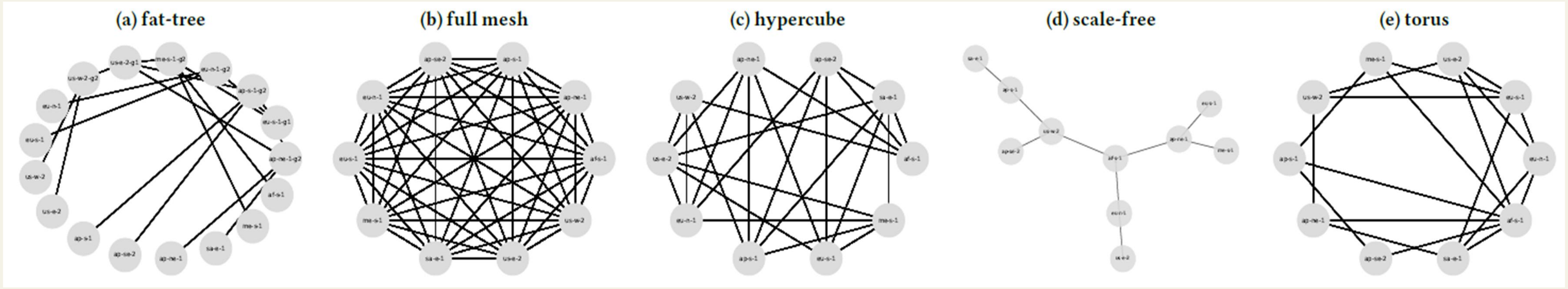

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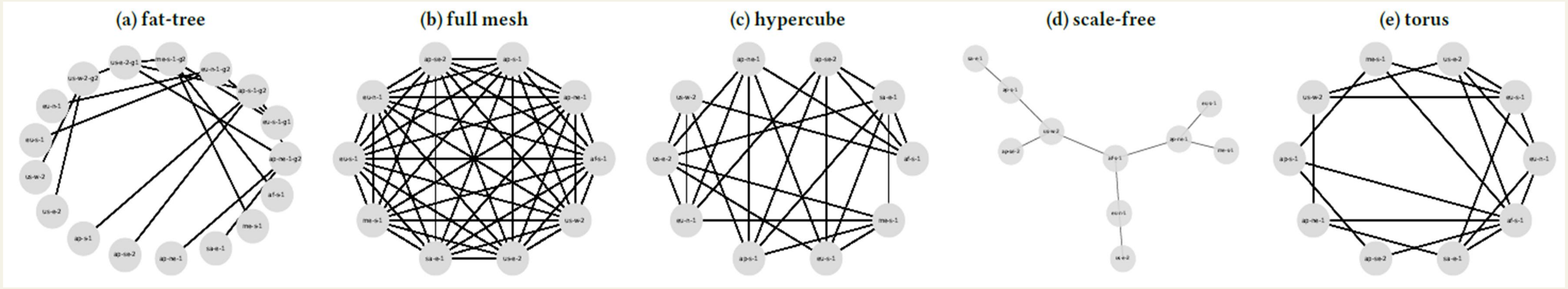

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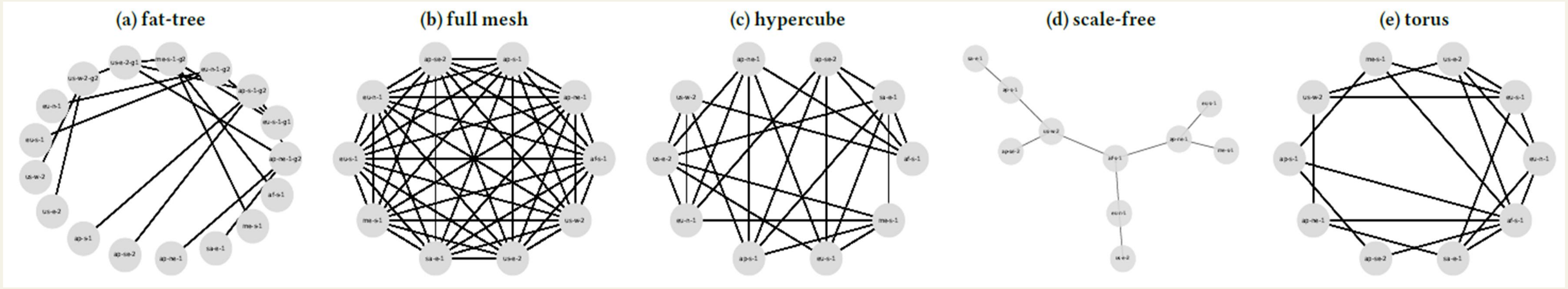

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Kollaps Network construction

- Network measurements in the cloud don't provide much insight into the underlying infrastructure.

- Having node with degree >= 2 in Kollaps, it is not possible to obtain the same network performance (Kollaps activates a best-route selection mechanism).

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fat-tree (k ports=4, l level=2)	k	$k^l/2$	102	712
full mesh (N nodes)	$N-1$	$N \times (N-1)/2$	194	600
hypercube (n dimensions=4)	n	$n \cdot 2^{(n-1)}$	208	560
scale-free (N nodes)	(Based on Power Law)		218	432
torus (N nodes/row=5, n dim.=2)	$2n$	$n \cdot N^n$	197	728

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- Based on both native transactions and smart contract requests.

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- ***PayPal and VISA***. To test their transactions capacity to a blockchain.

Workload	Type	Scenario	Duration (s)	Injected TPS
DDoS	Transfer Tx	Constant rate	120	10,000
FIFA	Smart contract	High sending rate	100	45,000
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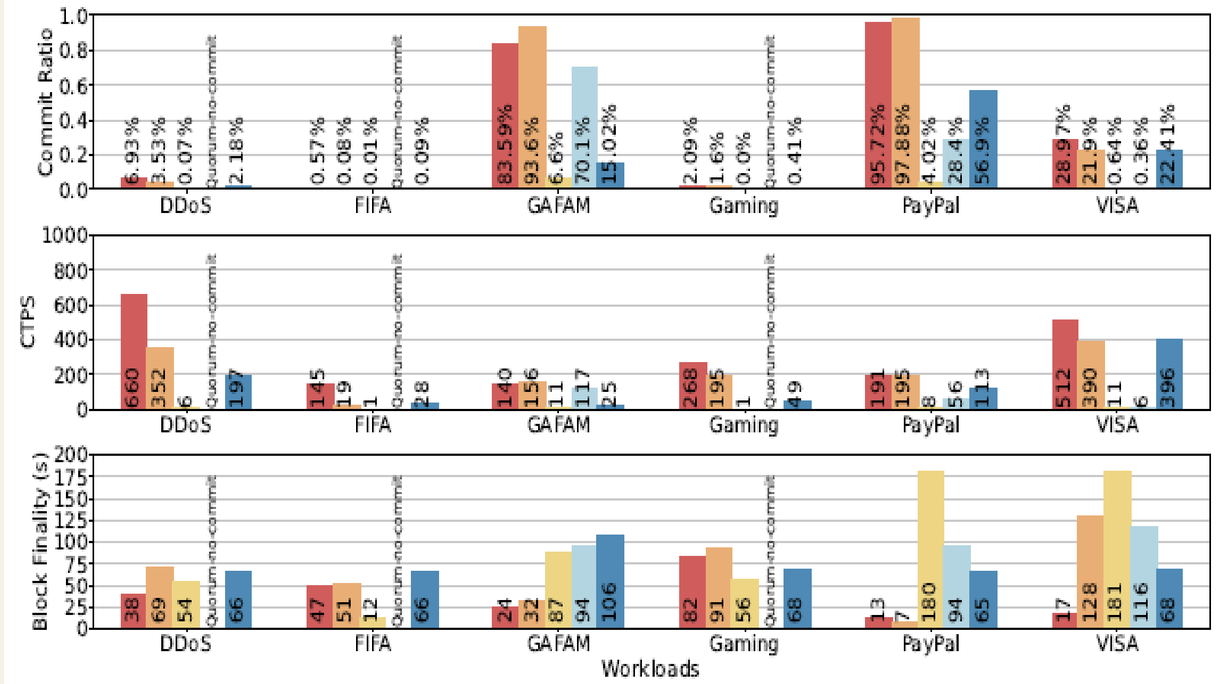
FINDINGS

RQ1 Torus allows generally for better results with more demanding workloads. We achieve the best overall results, across the five tested blockchains, atop full mesh and hypercube, due to their high degree and link capacity.

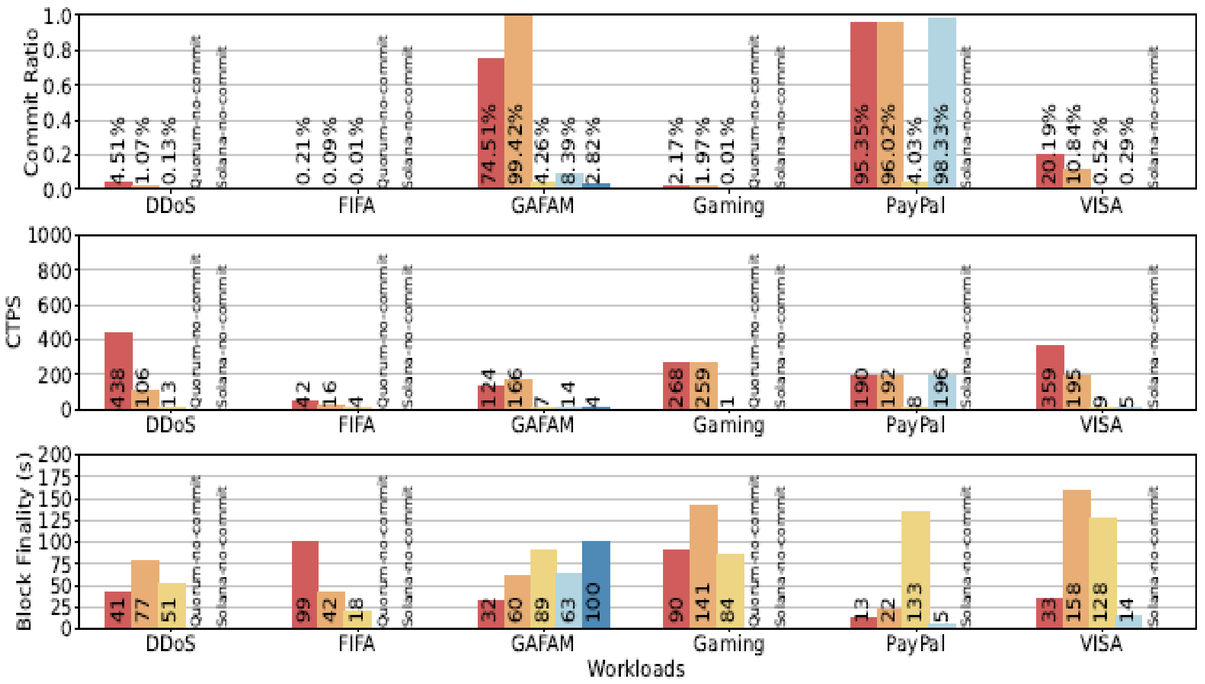
RQ2 Our results demonstrate that Diem and Solana are the most affected by packet loss, followed by Quorum and Algorand. Classical consensus mechanism, as in Quorum, are less reactive to increasing latencies. Despite consistently exhibiting lower CTPS compared to the others, Ethereum is the least affected by these dynamic network events.

RESULTS #1

Benchmark on a fat-tree topology with different blockchain network size



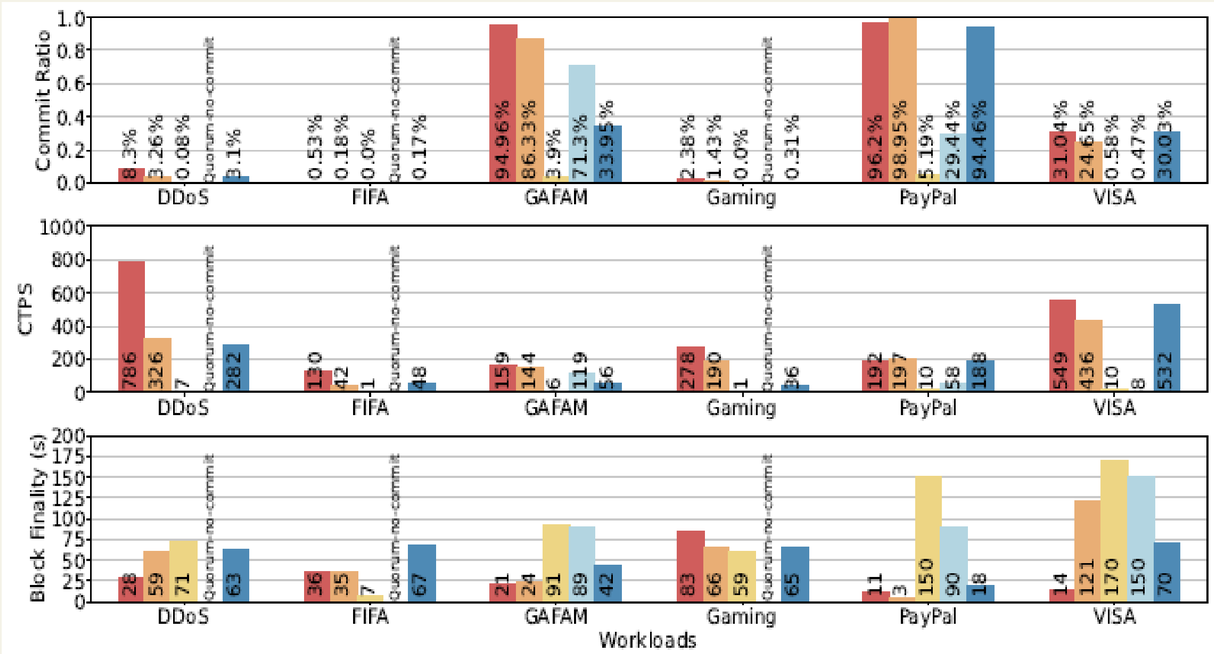
(a) Fat-tree, one node/region.



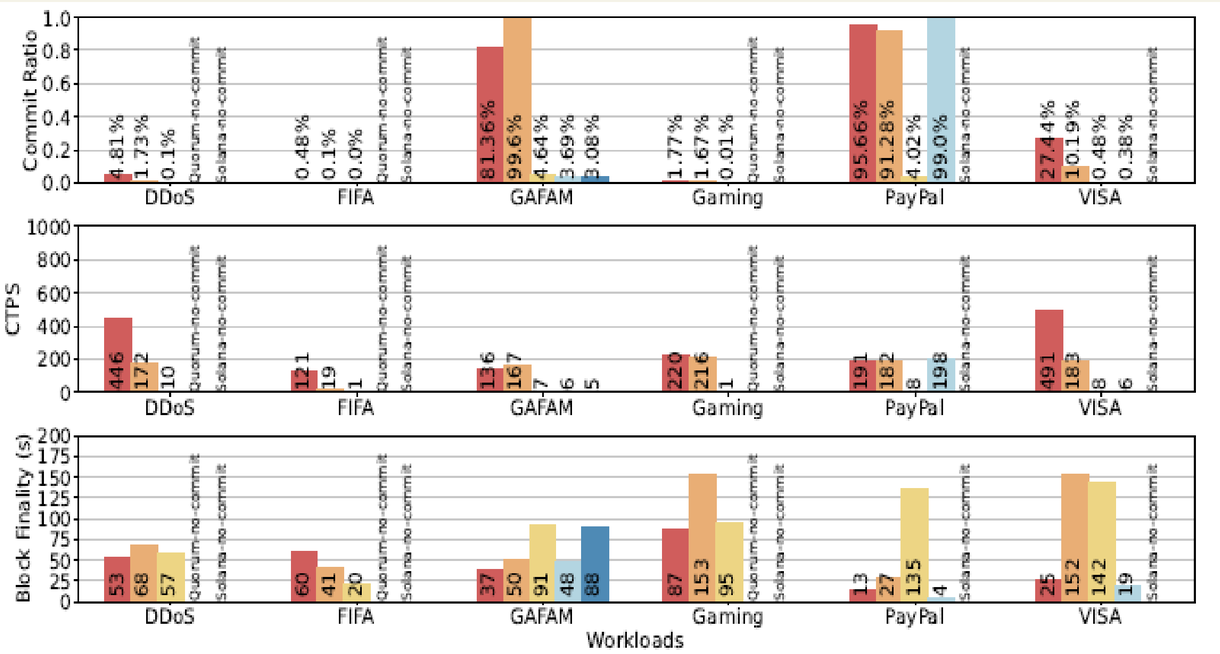
(b) Fat-tree, four nodes/region.

RESULTS #2

Benchmark on a full mesh topology with different blockchain network size



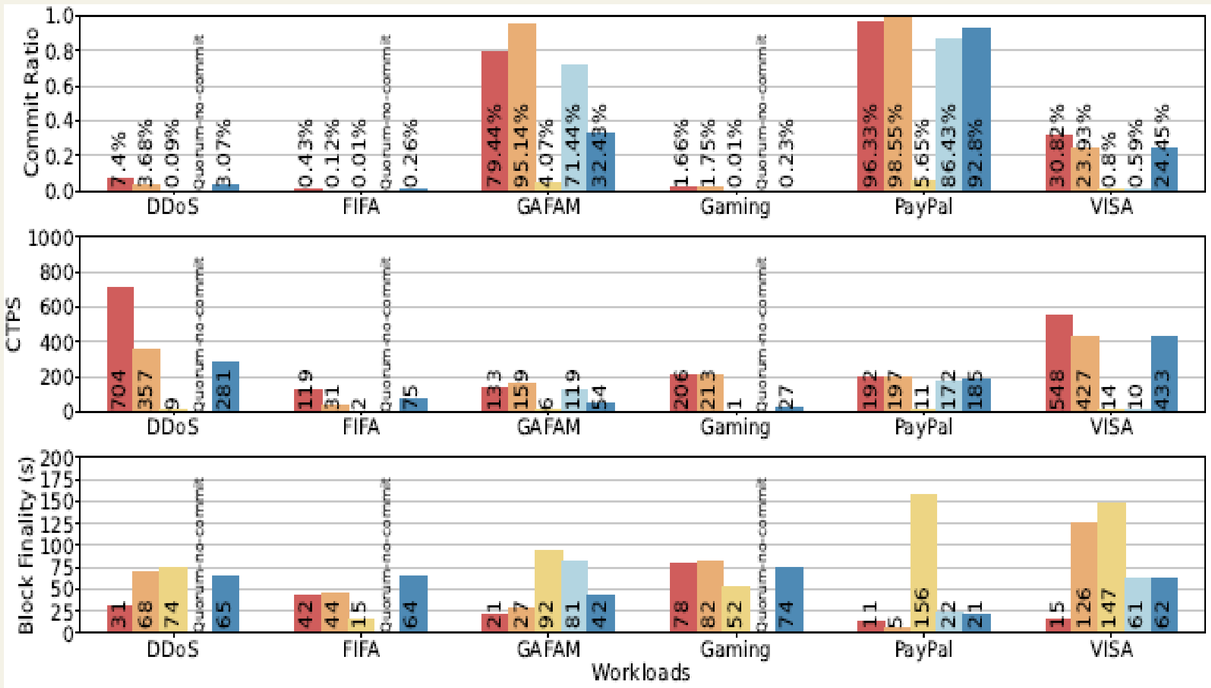
(c) Full mesh, one node/region.



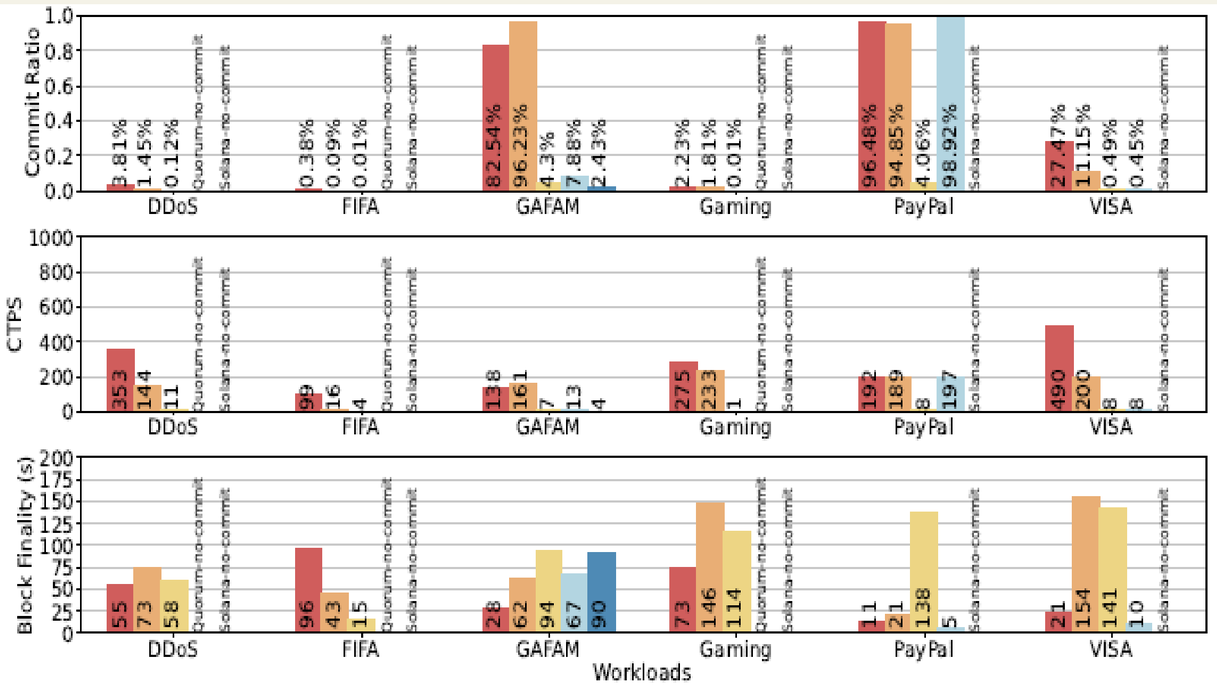
(d) Full mesh, four nodes/region.

RESULTS #3

Benchmark on a hypercube topology with different blockchain network size



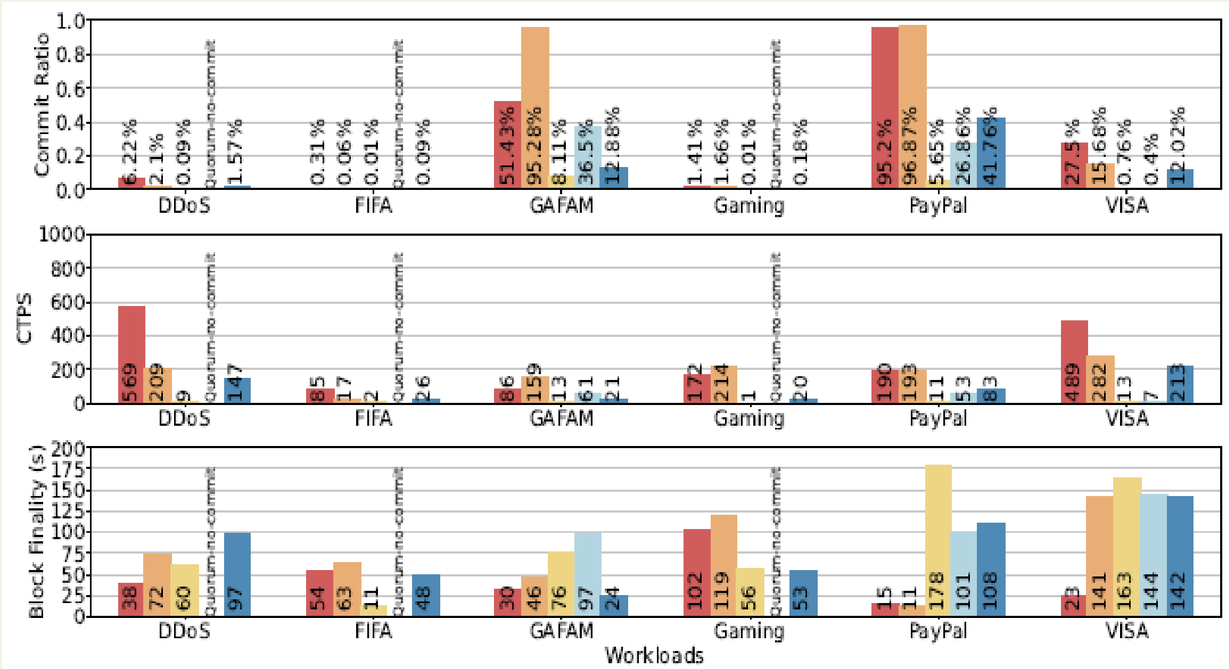
(e) Hypercube, one node/region.



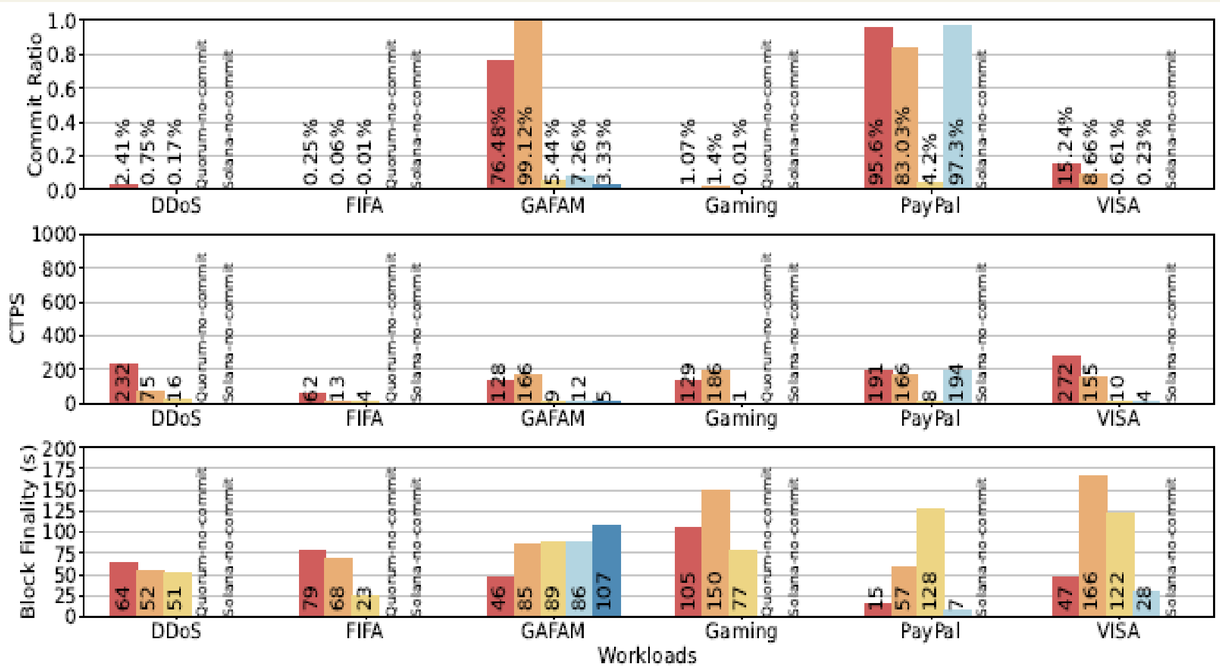
(f) Hypercube, four nodes/region.

RESULTS #4

Benchmark on a scale-free topology with different blockchain network size



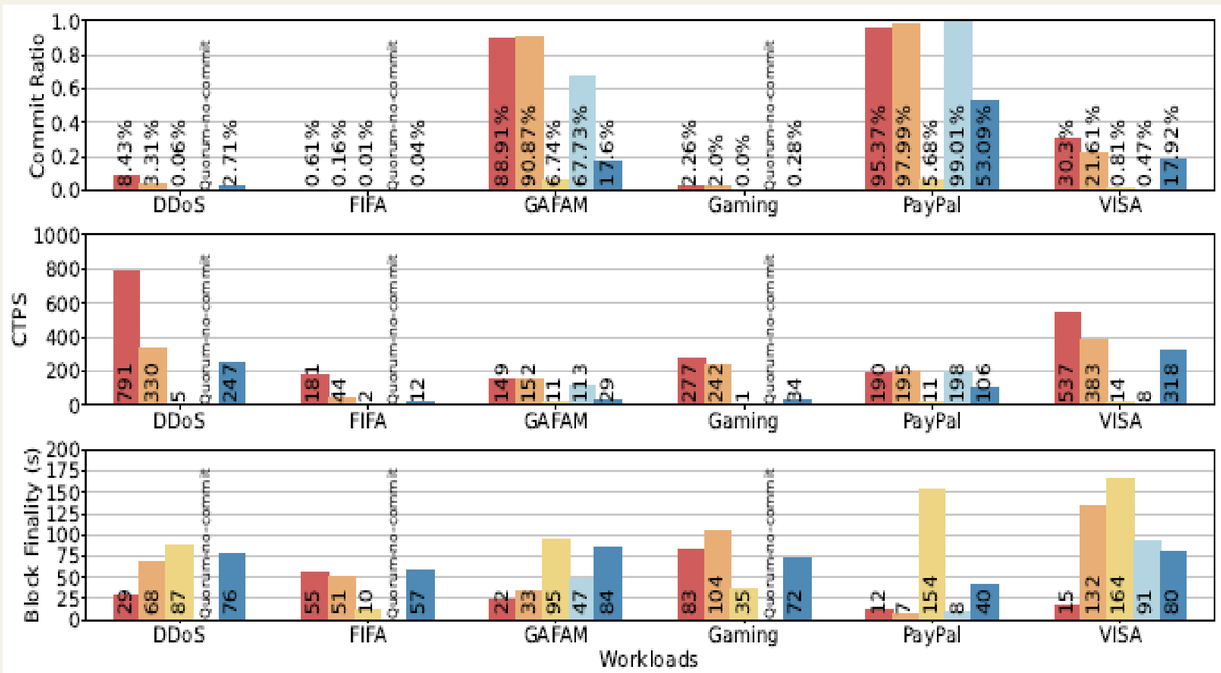
(g) Scale-free, one node/region.



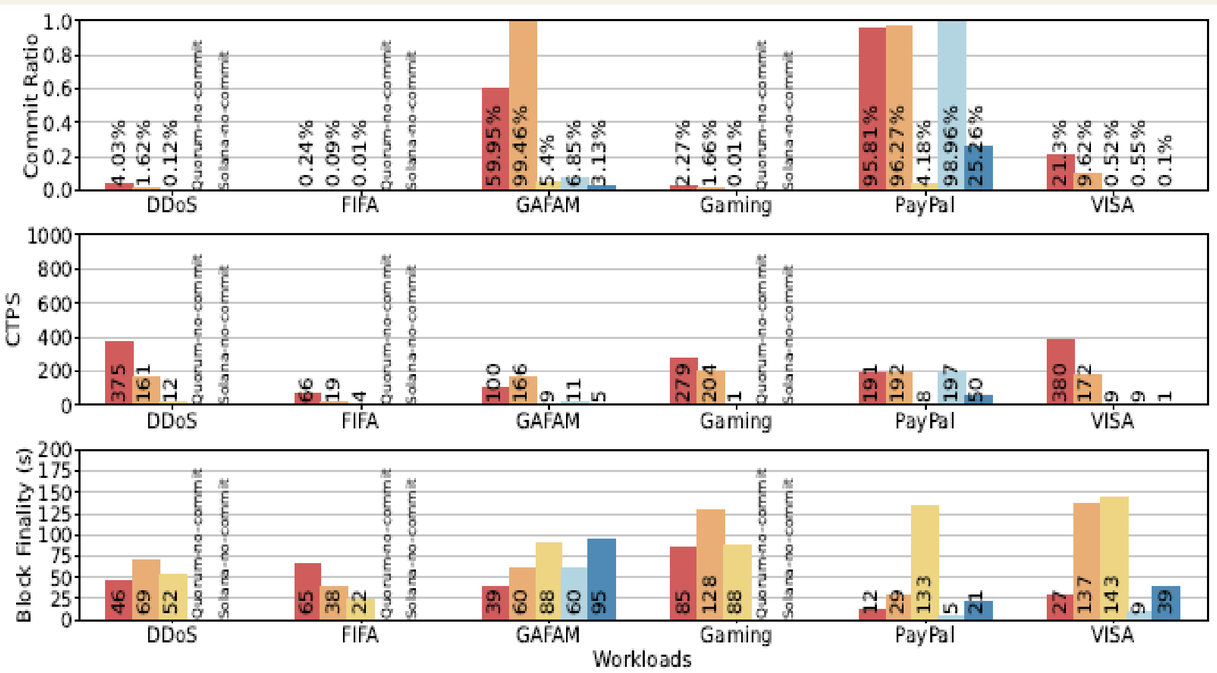
(h) Scale-free, four nodes/region.

RESULTS #5

Benchmark on a torus topology with different blockchain network size



(i) Torus, one node/region.



(j) Torus, four nodes/region.

RESULTS #6

Network load based on the different workload executed on the topologies set

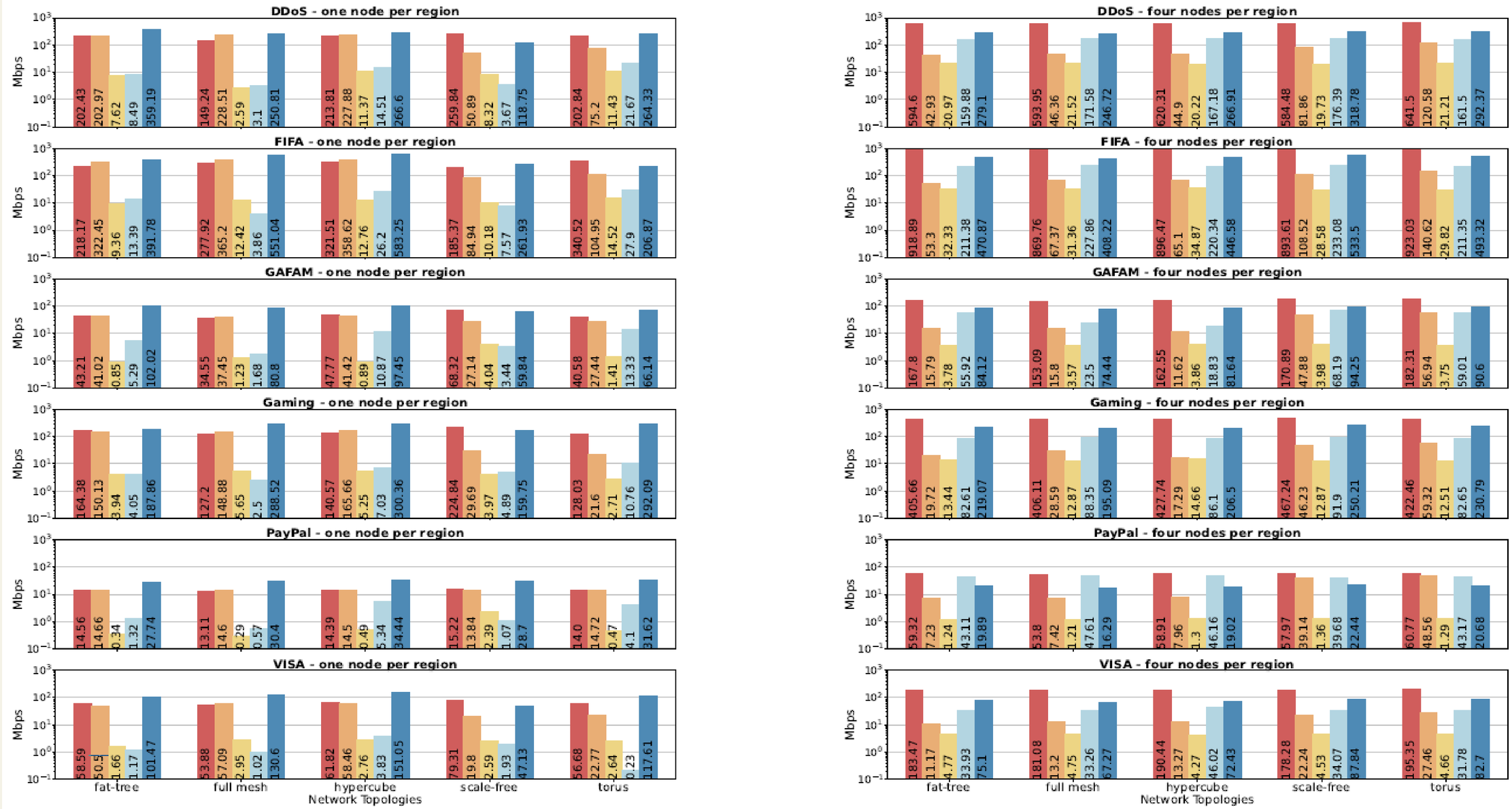
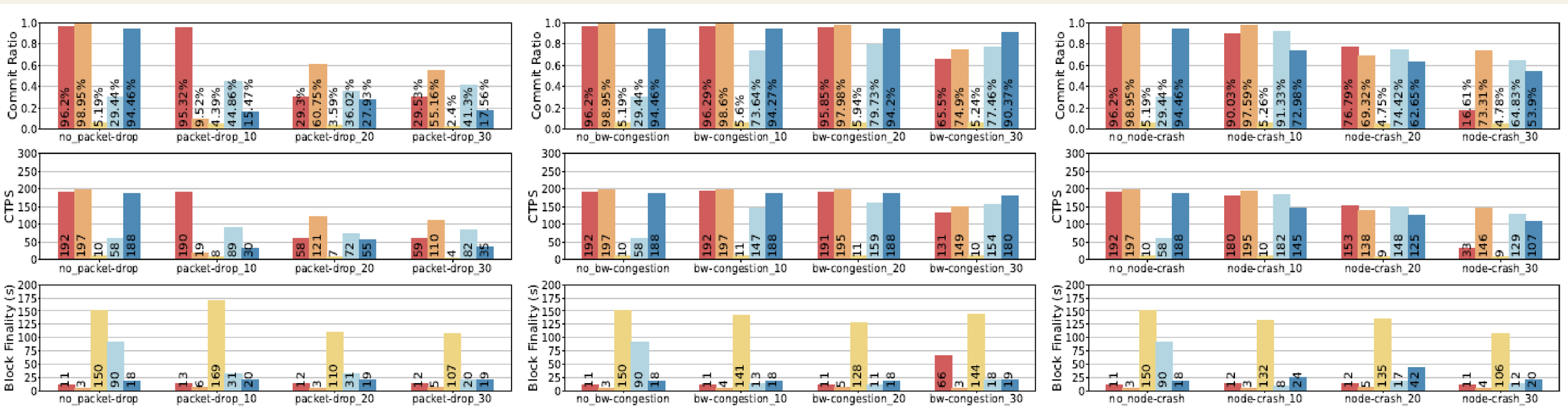


Figure 7: Network load (Mbps) during the workloads execution (Algorand, Diem, Ethereum, Quorum, Solana).

RESULTS #7

Benchmark on a full mesh topology with different packet drop percentage, link bandwidth congestion and node crash during the workload execution

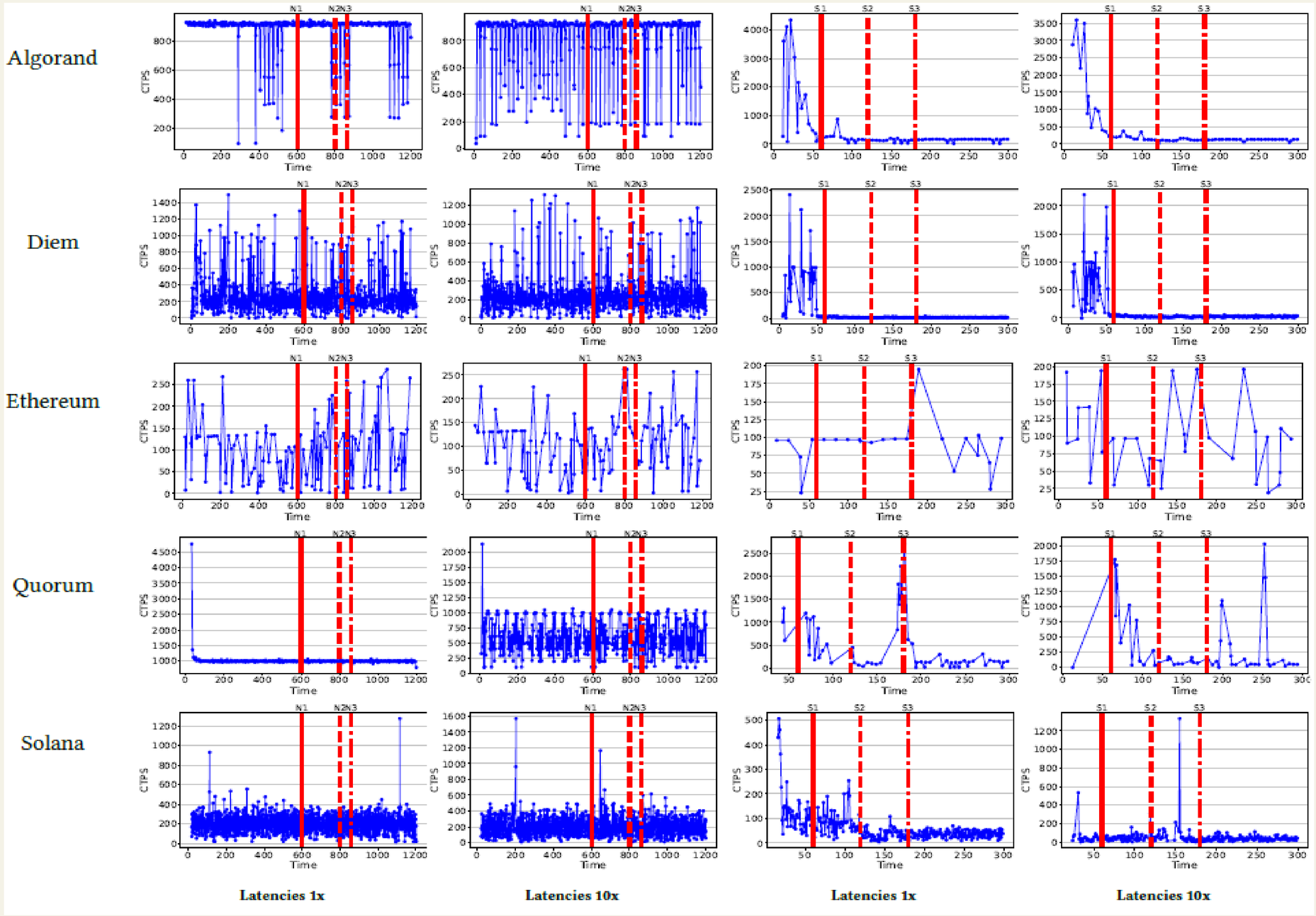


(a) Packet drop. (b) Link bandwidth congestion. (c) Node crash.

Figure 8: Network dynamics, one node per region, full mesh topology (Algorand, Diem, Ethereum, Quorum, Solana).

RESULTS #8

Benchmark on a full mesh topology with increasing latencies during the PayPal (left) and GAFAM (right) workloads execution



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Thanks for your attention

References

Vincent Gramoli, Rachid Guerraoui, Andrei Lebedev, Chris Natoli, and Gauthier Voron. 2023. *Diablo: A Benchmark Suite for Blockchains*. In *Proceedings of the Eighteenth European Conference on Computer Systems (EuroSys '23)*. Association for Computing Machinery, New York, NY, USA, 540–556. https://doi.org/10.1145/3552326.3567482

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