Understanding the Effects of Network Topologies on Blockchains Performance and Efficiency

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1506 UNIVERSITÀ DEGLI STUDI DI URBINO CARLO BO

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- 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 5. Comparison of several blockchain benchmarking tools. Legend: ◌ = not found; ○ = no-match; ● = match; ◐ = partial-no match; ◑ = partial-match; SC = Smart Contract; N = Native.

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

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- ***(C6)*** *Steep learning curve.*

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Cloud-based vs cluster benchmark

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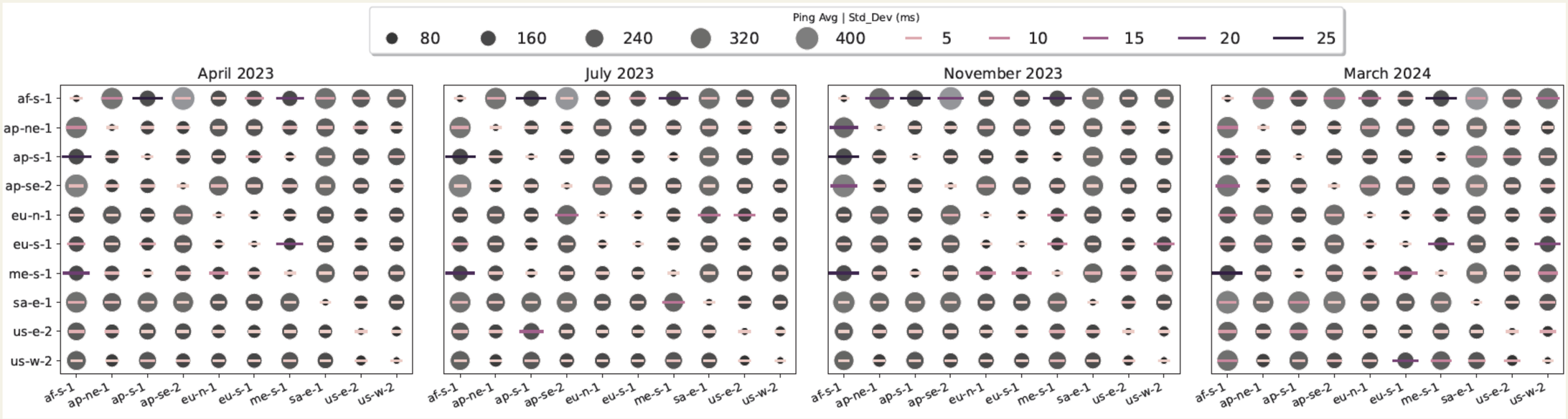
- Network links between the data centers changes throughout the day (e.g., infrastructure updates, contention on links, etc.).



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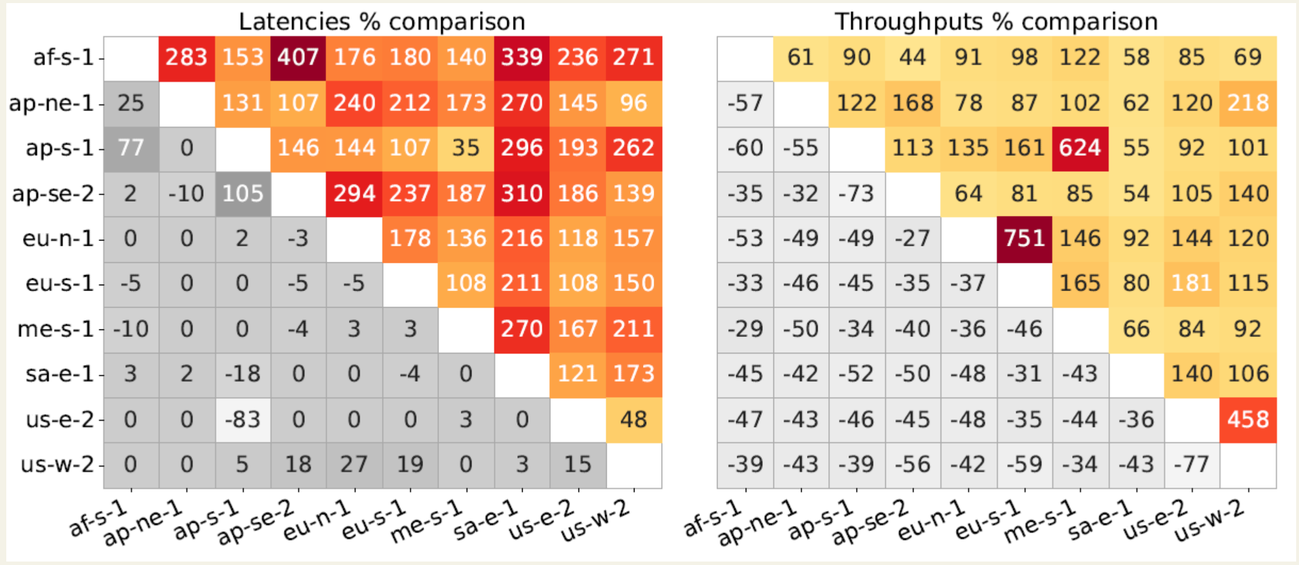

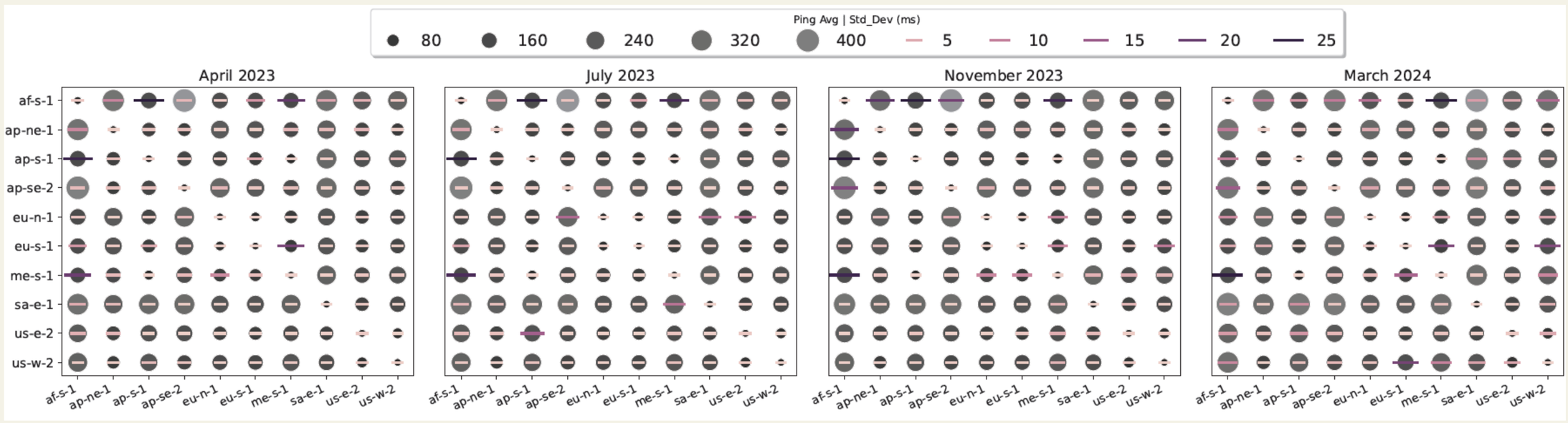

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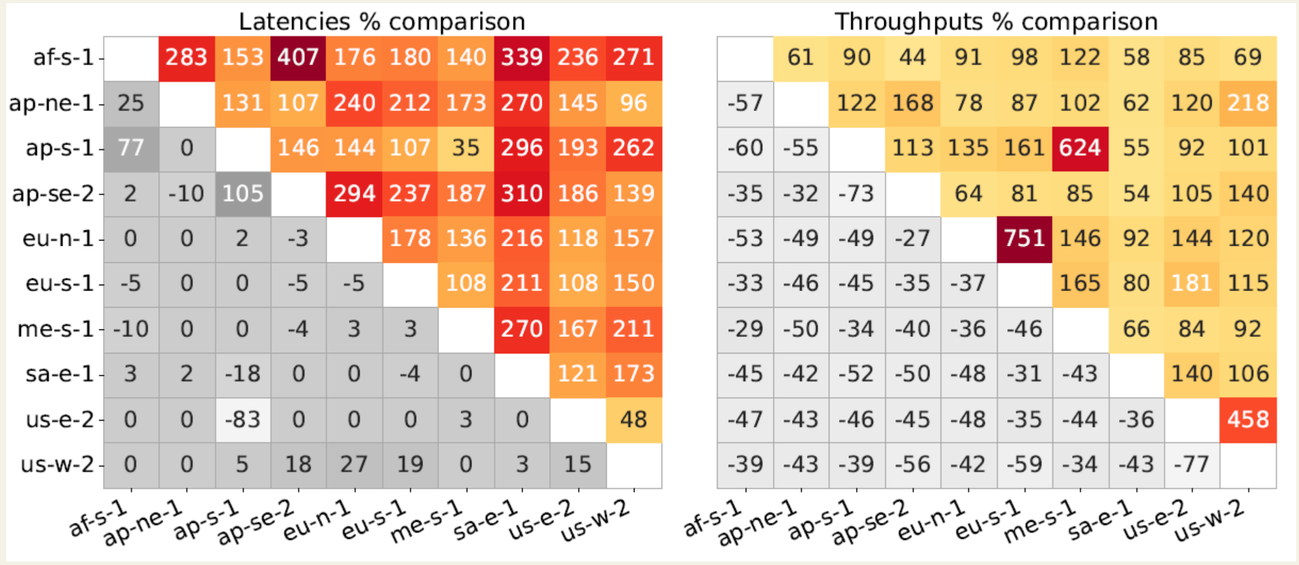
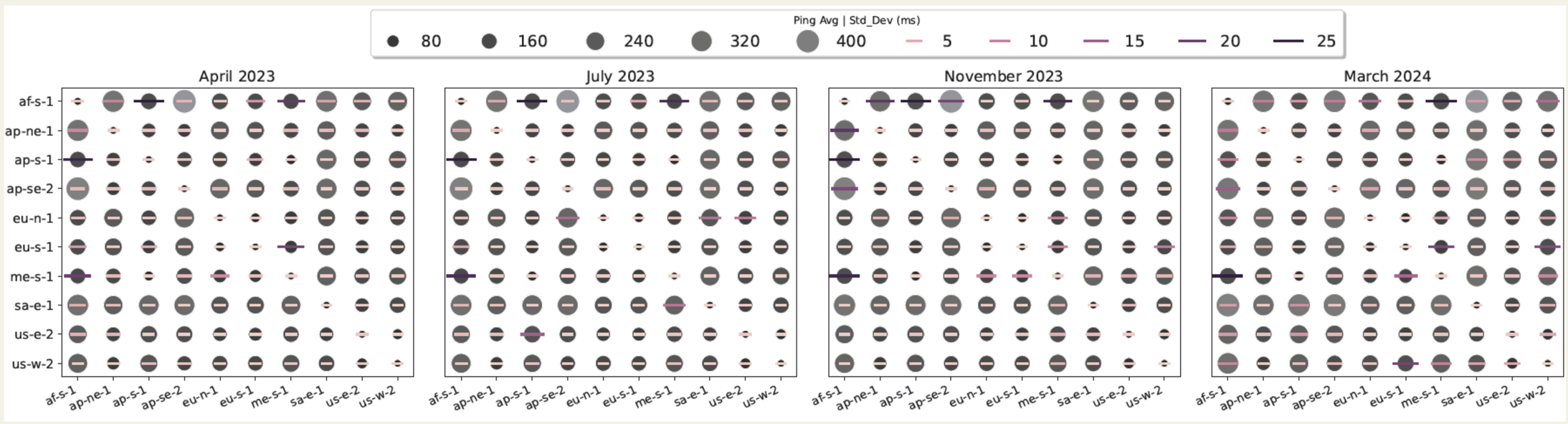
- Limited opportunities to adjust network properties.

	Latency	Costs	Network flexibility
Cloud	Physical	High	Not allowed
Cluster	None	(almost) None	Allowed





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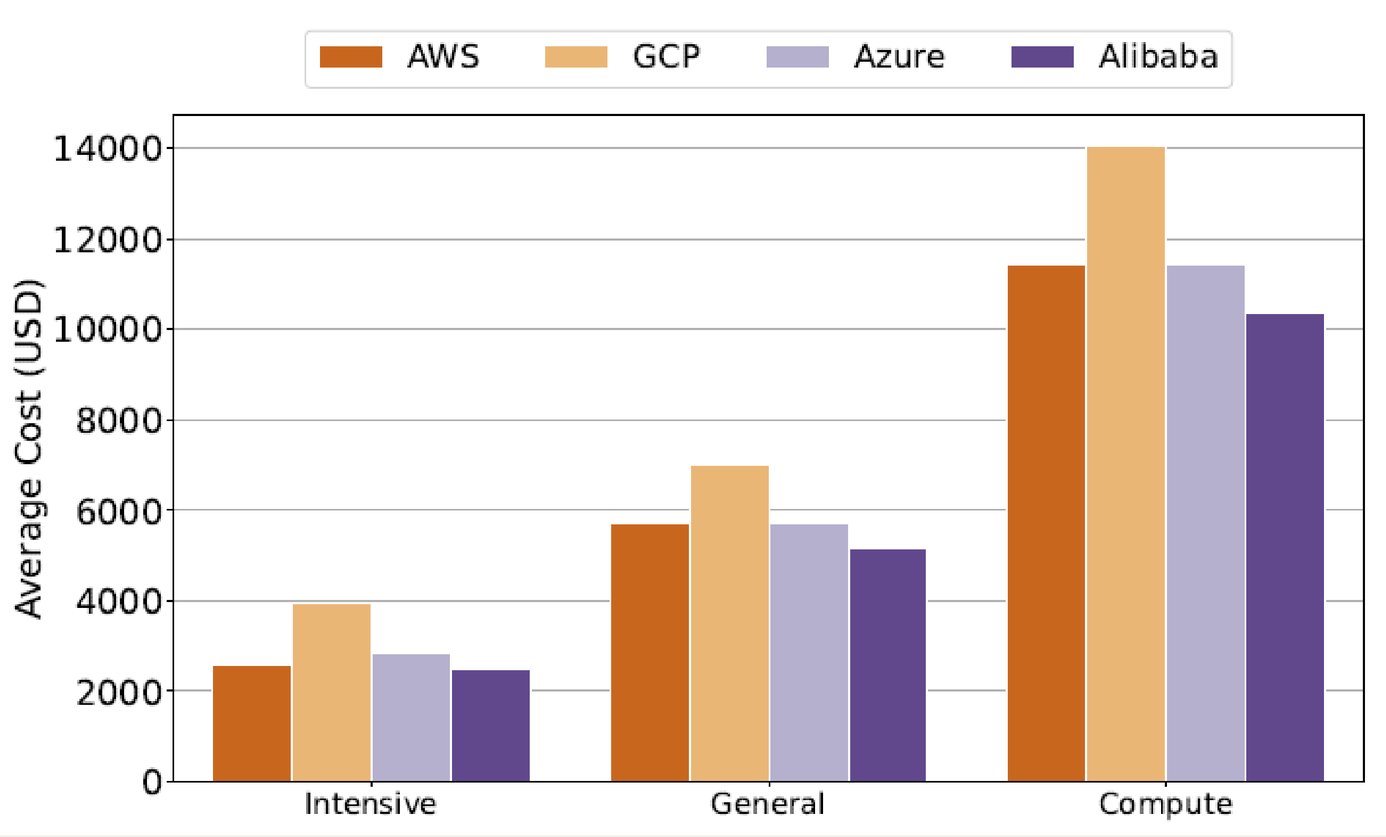

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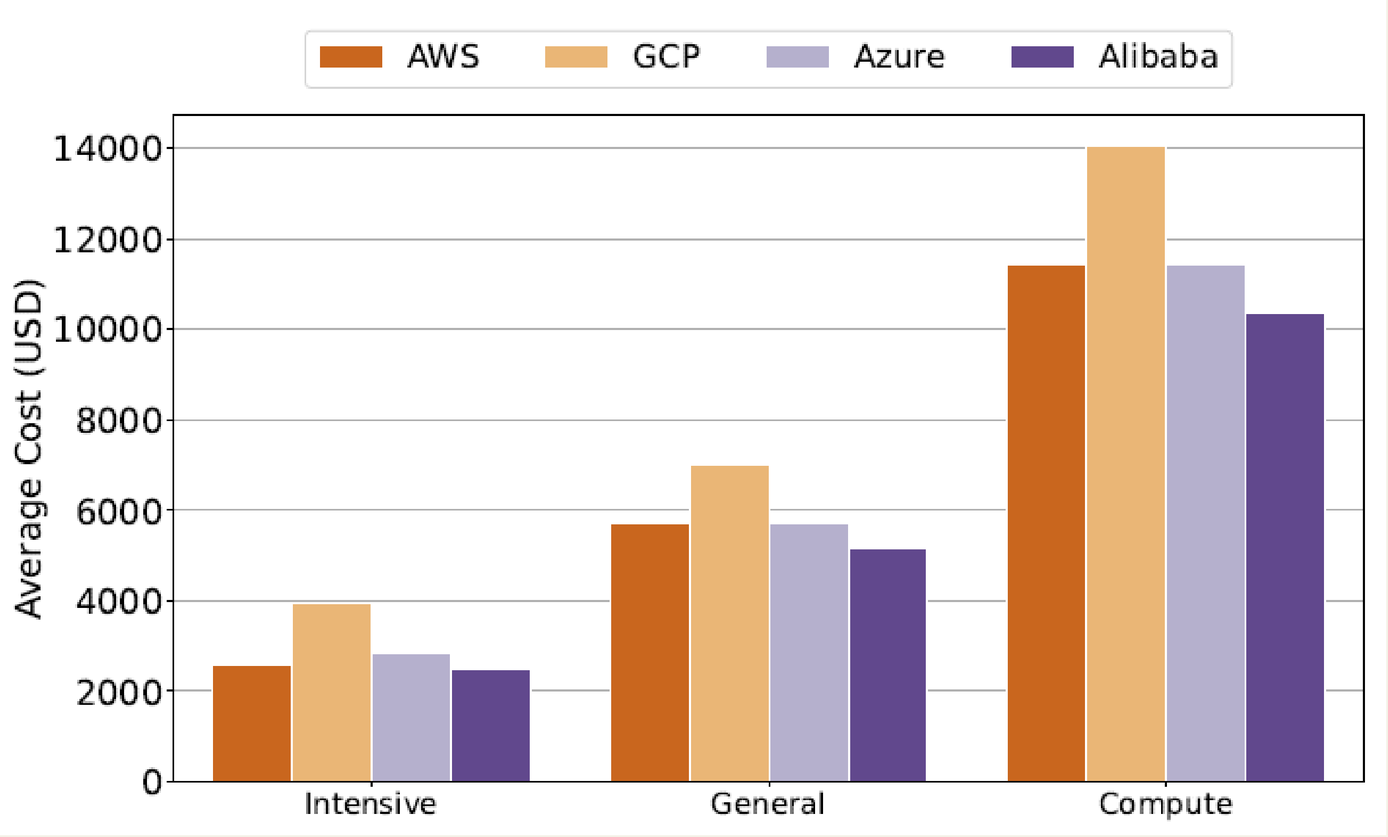

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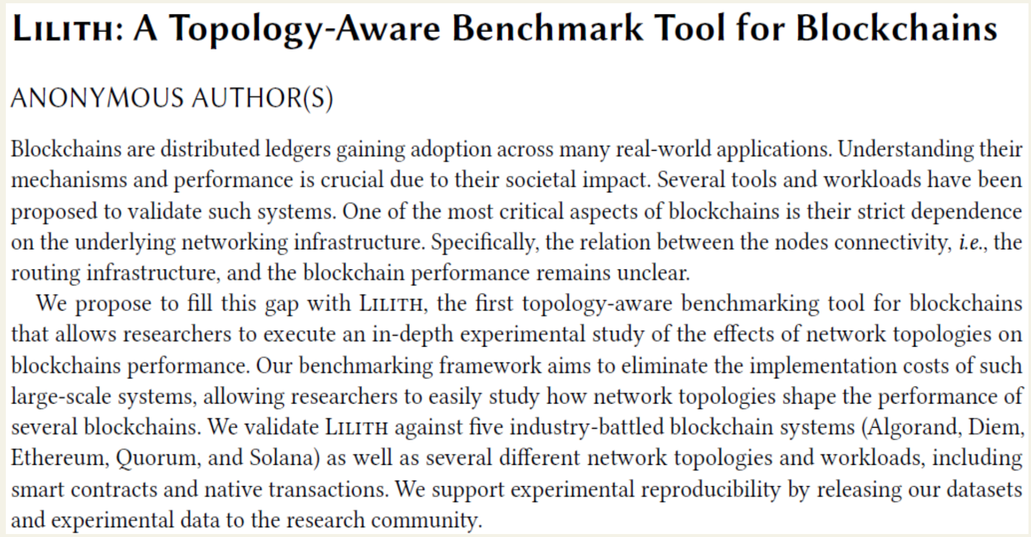
LILITH: A Topology-Aware Benchmark Tool for Blockchains



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ANONYMOUS AUTHOR(S)

Blockchains are distributed ledgers gaining adoption across many real-world applications. Understanding their mechanisms and performance is crucial due to their societal impact. Several tools and workloads have been proposed to validate such systems. One of the most critical aspects of blockchains is their strict dependence on the underlying networking infrastructure. Specifically, the relation between the nodes connectivity, *i.e.*, the routing infrastructure, and the blockchain performance remains unclear.

We propose to fill this gap with Lilith, the first topology-aware benchmarking tool for blockchains that allows researchers to execute an in-depth experimental study of the effects of network topologies on blockchains performance. Our benchmarking framework aims to eliminate the implementation costs of such large-scale systems, allowing researchers to easily study how network topologies shape the performance of several blockchains. We validate Lilith against five industry-battled blockchain systems (Algorand, Diem, Ethereum, Quorum, and Solana) as well as several different network topologies and workloads, including smart contracts and native transactions. We support experimental reproducibility by releasing our datasets and experimental data to the research community.

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- **RQ7 -** Regarding the results of the experiments executed using topology construction method 2, what can be inferred about the network configuration used (i.e., Scale-free, switches, links)?

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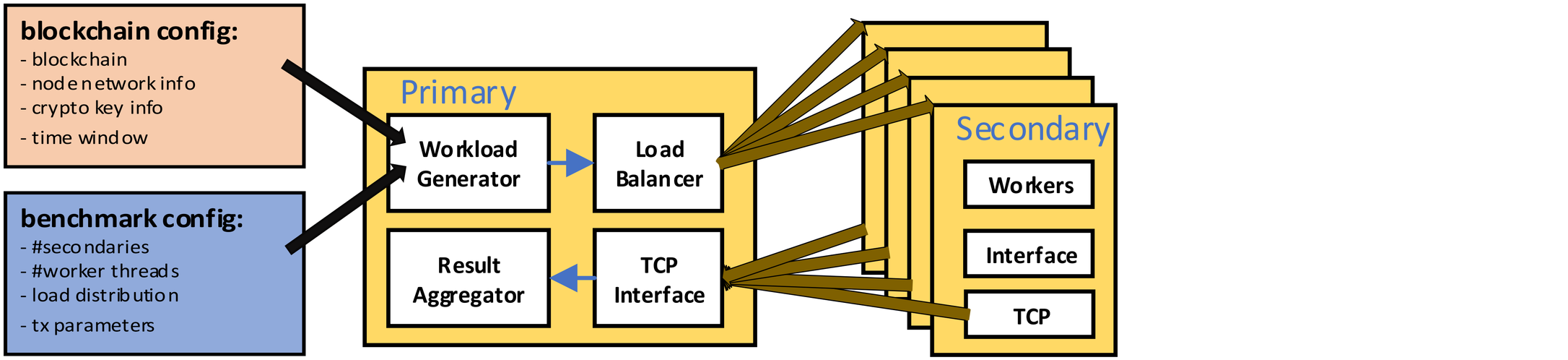
- Enhanced distributed workload generation.



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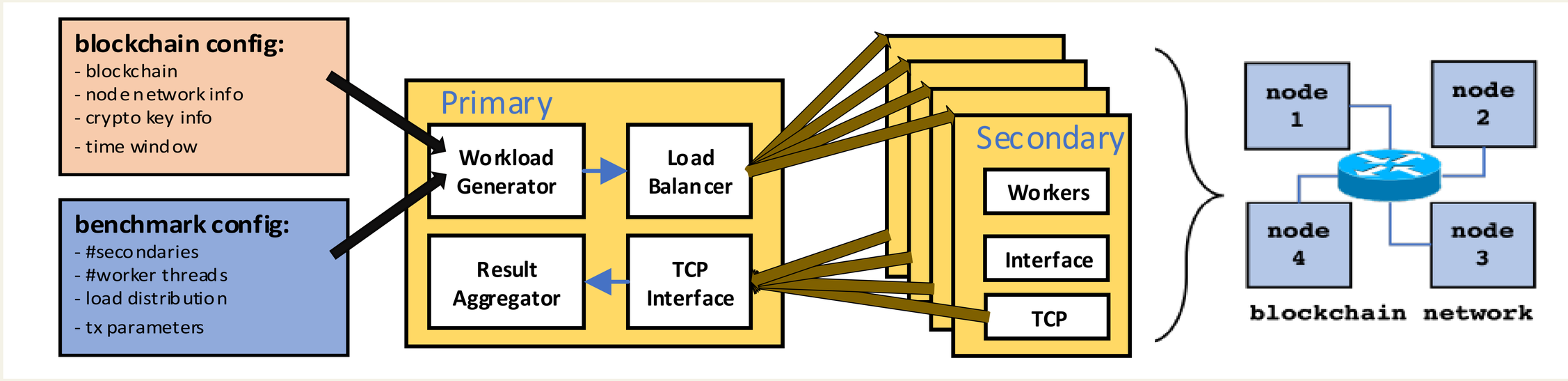

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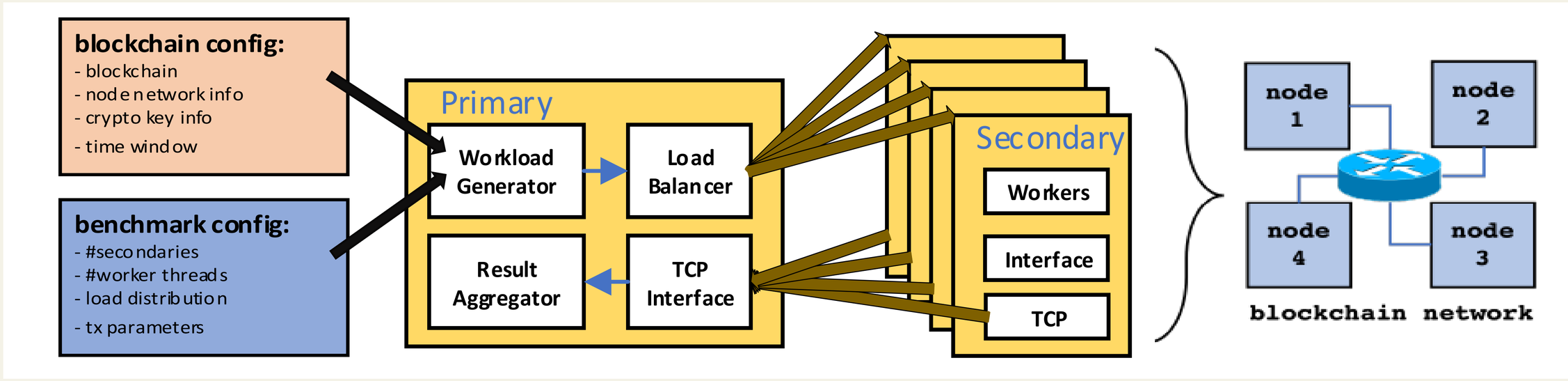

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- Each **Secondary** sends its results to the Primary and an aggregator collects them indicating the timestamps that can be used to generate time series, analyze latencies, etc.

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- **blockchain** configuration file, defining the experimental setup, denoting the configuration of machines to make the network of the blockchain.

DIABLO BENCHMARK #3

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

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
Katharà	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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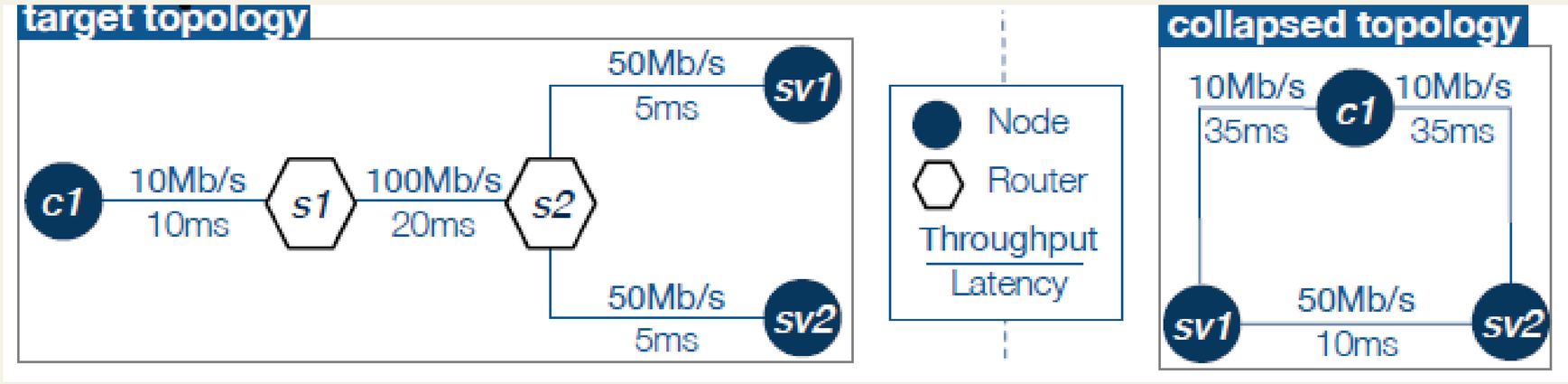

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- **Deployment Generator** converts an experiment description into a deployment plan.

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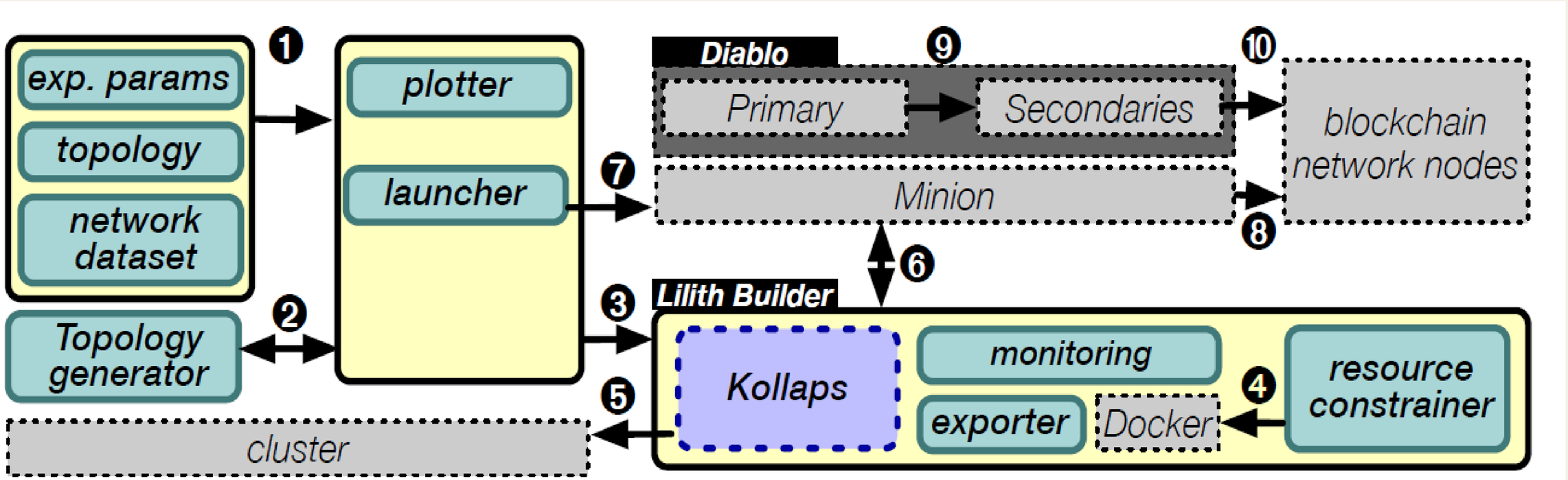

TESTING SCENARIO

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Workflow Evolution

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amazon web services™ | EC2

```
<experiment boot="kollaps:2.0">
  <services>
    <service name="dashboard" image="kollaps/dashboard:1.0" supervisor="true"
    <service name="client1" image="kollaps/iperf3-client:1.0" command="['serve
    <service name="server" image="kollaps/iperf3-server:1.0" command="['server
  </services>

  <bridges>
    <bridge name='b1' />
  </bridges>

  <links>
    <link origin="client1" dest="server" latency="0.001" upload="22Mbps" downl
  </links>

  <dynamic>
    <schedule name="client1" time="0.0" action="join">
    <schedule name="server" time="0.0" action="join">
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</experiment>
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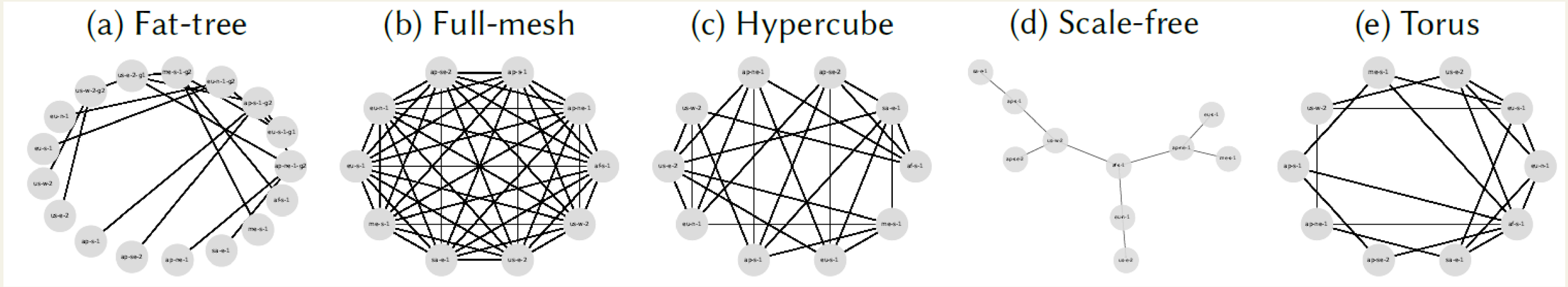

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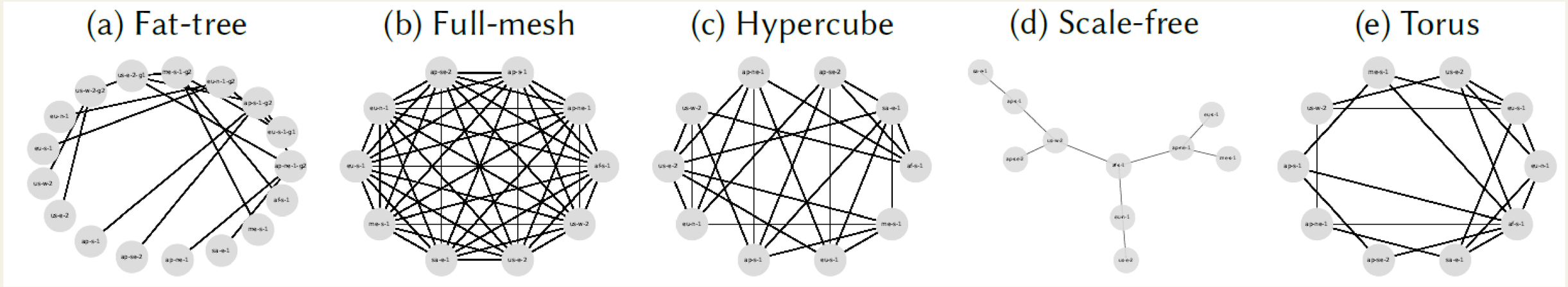

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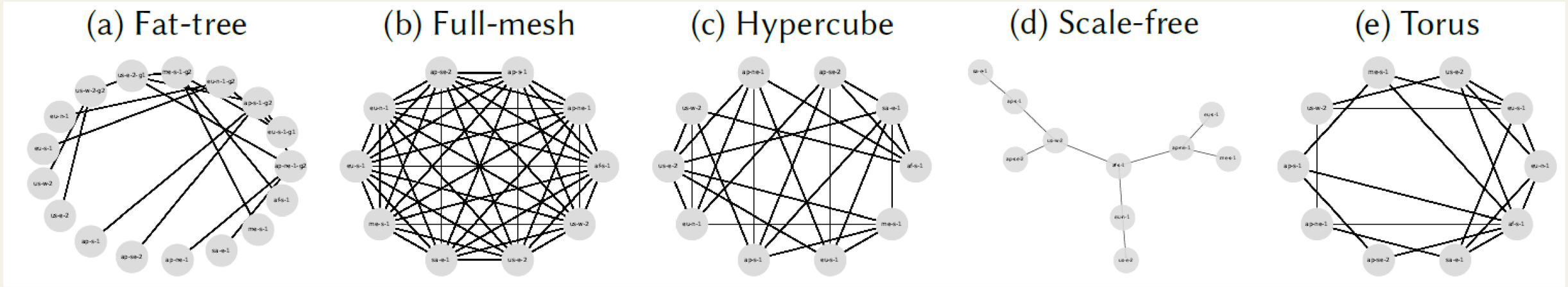

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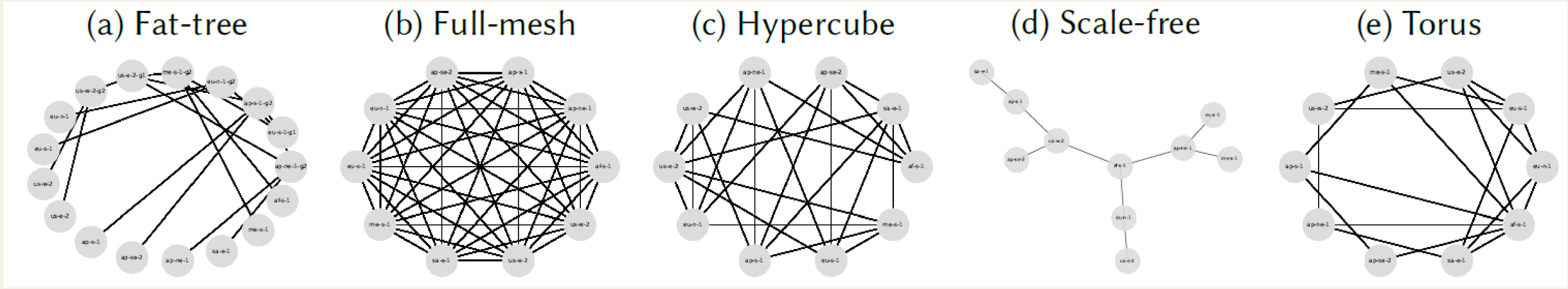

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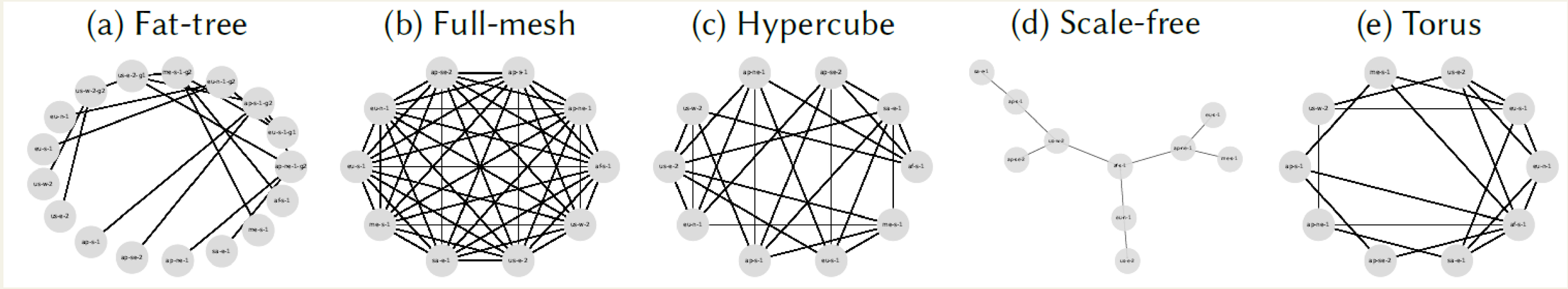
- ***Torus***. Resembling a grid where each node is connected to its adjacent nodes in a wrap-around fashion.



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Full-mesh (N nodes)	$N-1$	$\frac{N\times(N-1)}{2}$	193.88	–	$2.3(\sigma = 1)$	$-17.7(\sigma = 20.2)$
Hypercube (n dimensions=4)	n	$n \cdot 2^{(n-1)}$	207.64	–	$78(\sigma = 173.7)$	$-40.6(\sigma = 37.8)$
Scale-free (N nodes)	(Based on Power Law)		218.3	Latency-based	$380(\sigma = 540)$	$-79.7(\sigma = 28.5)$
Torus (N nodes per row=5, n dimensions=2)	$2n$	$n \cdot N^n$	196.80	Latency-based	$119(\sigma = 151.9)$	$-53.9(\sigma = 42.47)$
AWS-2024 (N nodes)	$N-1$	$\frac{N\times(N-1)}{2}$	188.15	–	$6.5(\sigma = 3.5)$	$-55.4(\sigma = 10.9)$

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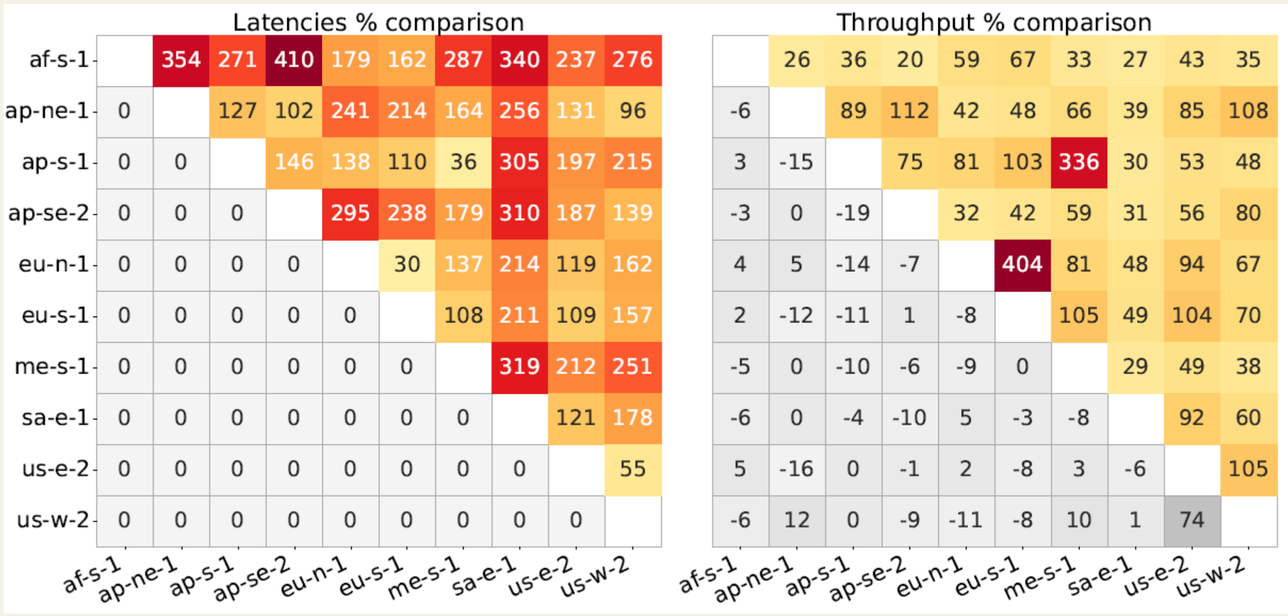

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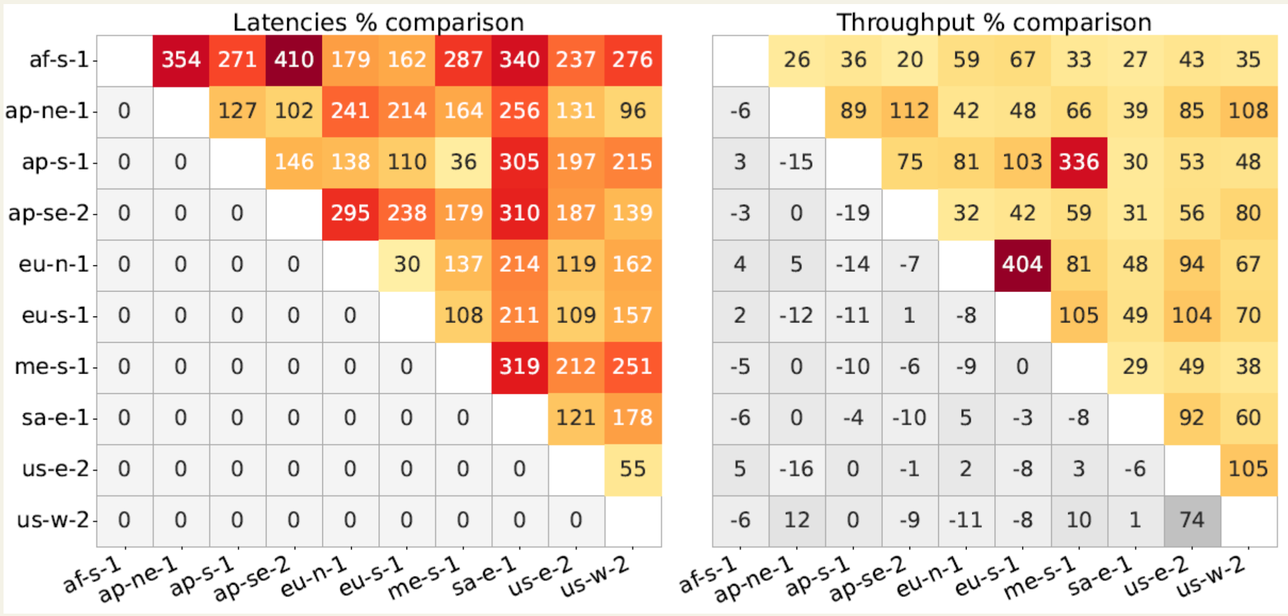
- This confirms that measurements in the cloud only show a part of its network infrastructure design.



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AWS-2024 (N nodes)	$N-1$	$\frac{N\times(N-1)}{2}$	188.15	–	$6.5(\sigma = 3.5)$	$-55.4(\sigma = 10.9)$

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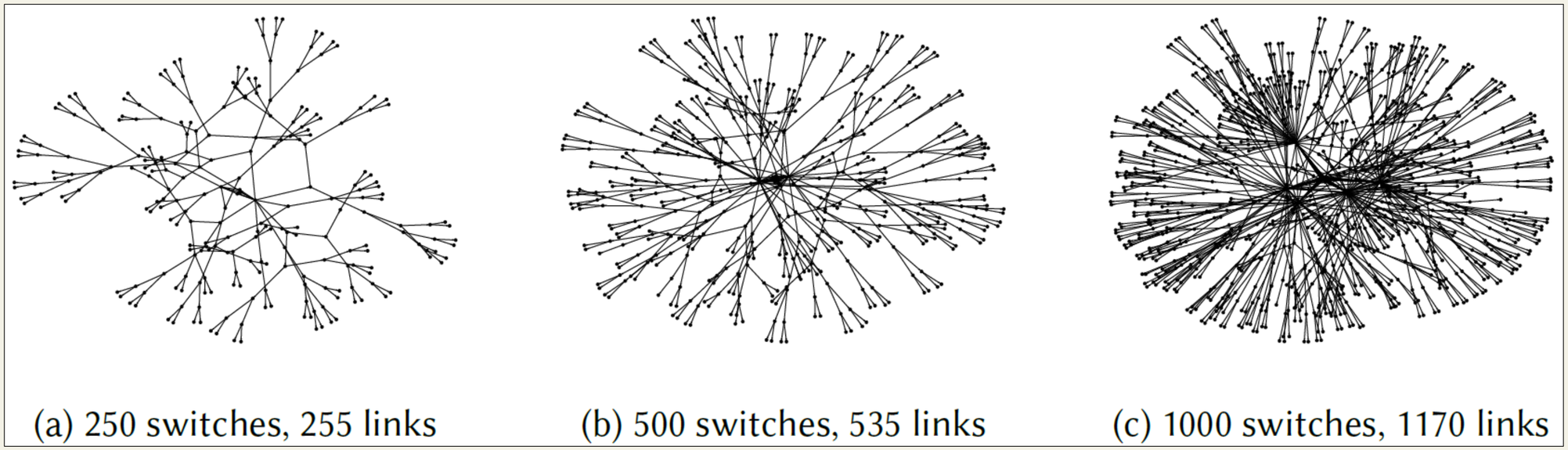
- We select the Scale-free topology, as it provides a high variation in linkages and degree among nodes.
- We use an increasing number of switches (250, 500, and 1000) with an increasing latency value (25, 50, 100) on the links.



BLOCKCHAINS

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- ***Ethereum Clique (Proof-of-Authority).*** Validates transactions in a round-robin fashion through approved validators with a minimum block interval.

	Throughput assertion (TPS)	Latency Block Finality (s)	Consensus	VM	DApp language
Ethereum	10−15 [96]	10−20 [61]	Clique	geth	Solidity
Quorum	0.7K−2.5K [5]	2−15 [70]	IBFT	geth	Solidity
Solana	65K [16]	12 [17]	TowerBFT	eBPF	Solang
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- ***PayPal and VISA.*** To test their transactions capacity to a blockchain.

Workload	Type	Duration (s)	Scenario	TPS
PayPal*	Native Tx	300	Constant Rate	200
VISA*	Native Tx	300	Constant Rate	1.8 K
DDoS	Native Tx	120	Constant Rate	10 K
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FINDINGS

Answer to RQ1: *Although Diablo's team states it uses configurations with this network setup in [72], it doesn't display the corresponding results (except for native transactions workloads) or explain any deployment errors, if present. Therefore, we can only partially answer this question if we consider that, for instance, Quorum fails to commit under heavier workloads also in [72], or that Ethereum's performance is low in [72] as well.*

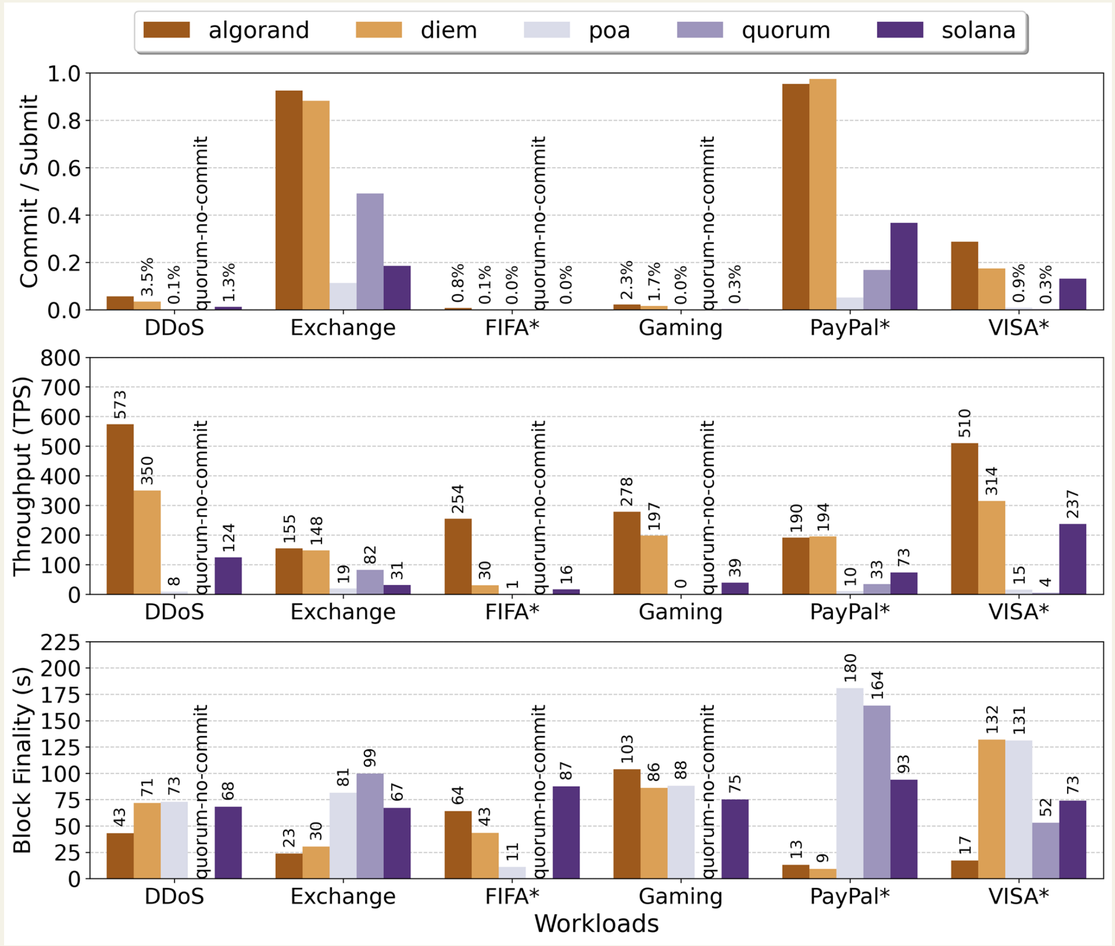
Answer to RQ2: *We report that Diem and Algorand exhibit more consistent results across different topologies, with Algorand performing better under more demanding workloads. Following them are Quorum and Solana. Finally, Ethereum, while showing consistent results, has the lowest performance among the blockchains tested.*

Answer to RQ3: *Considering the characteristics in Table 1 for each topology used in the experiments, we observe that Torus performs quite well with higher workloads, likely due to its high number of links and low number of switches, which ensure lower congestion. The topologies that perform best appear to be Full-mesh and Hypercube, due to their high degree and link capacity.*

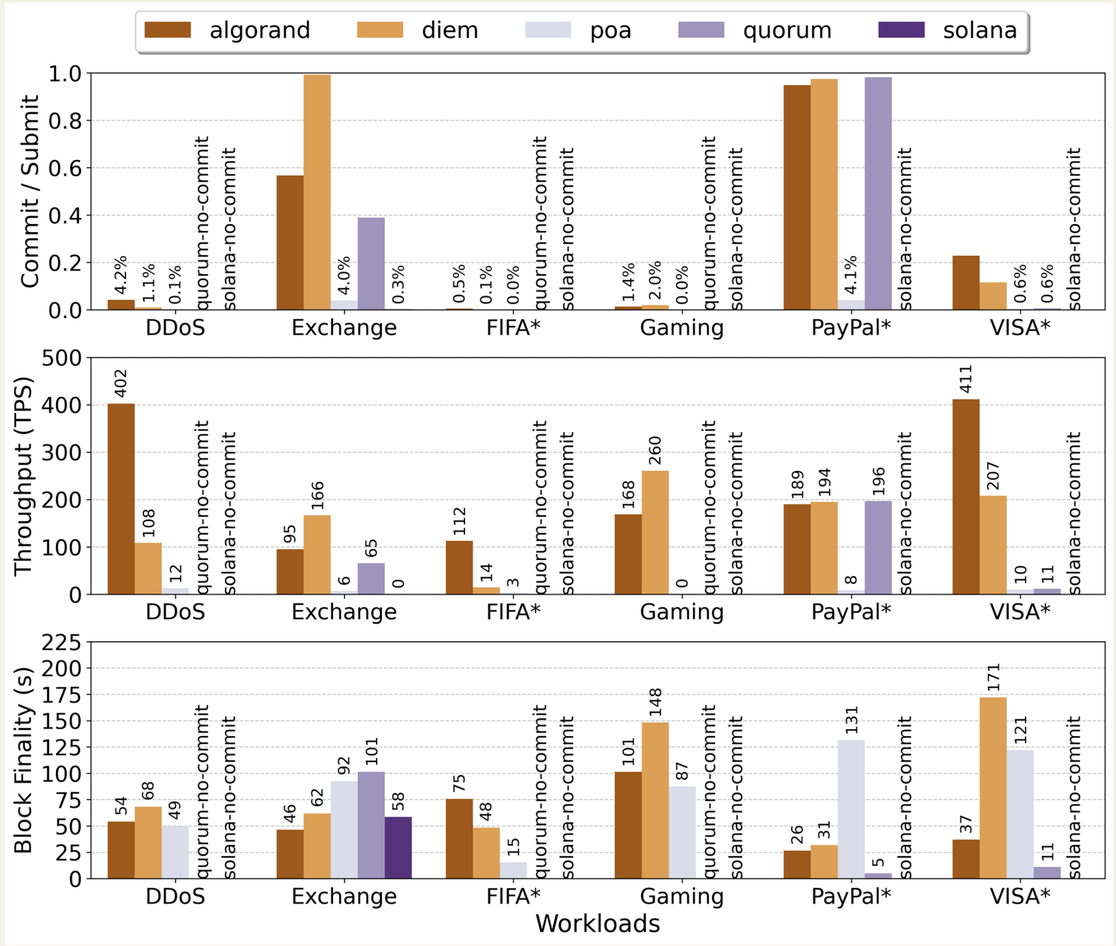
Answer to RQ4: *We observe that increasing the nodes per region the commit rate decreases and the average block latency increases.*

RESULTS #1

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



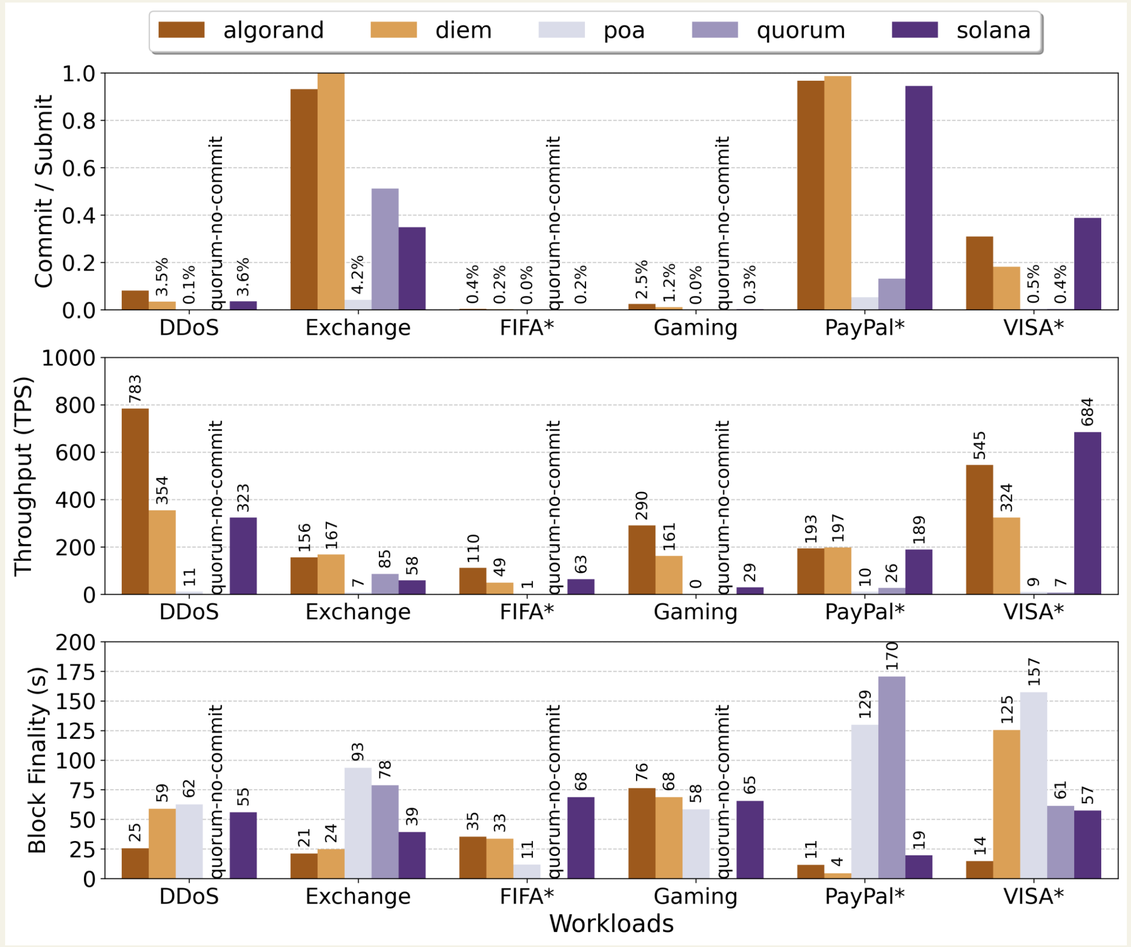
1-node per region



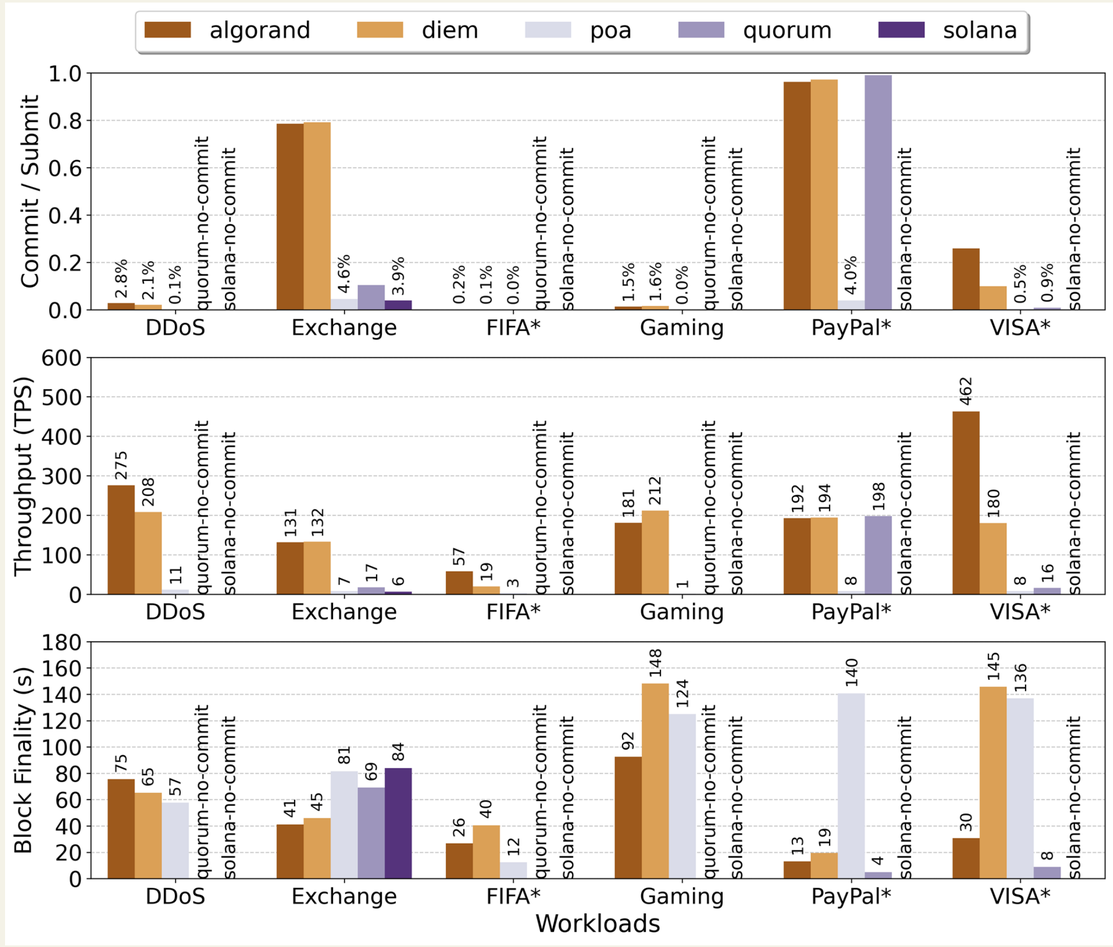
4-nodes per region

RESULTS #2

Benchmark on a Full-mesh topology with different blockchain network size



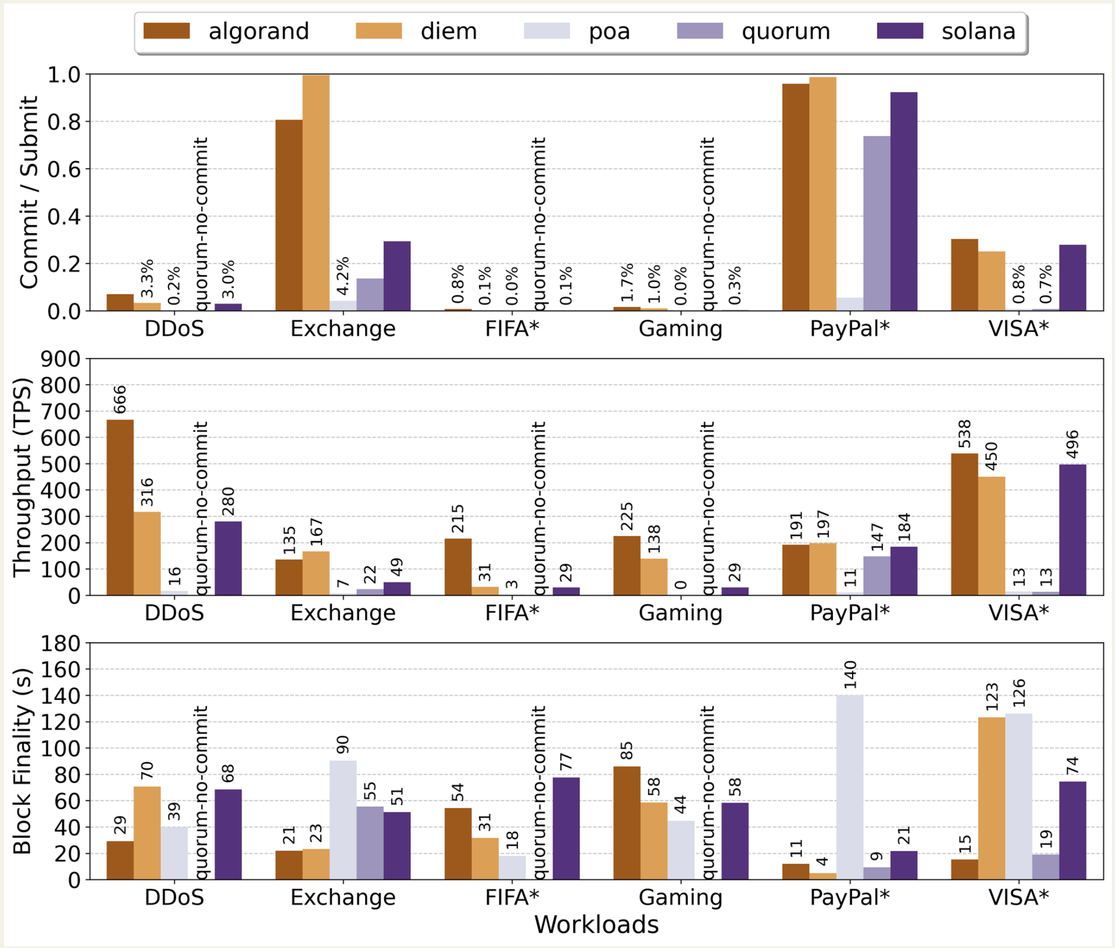
1-node per region



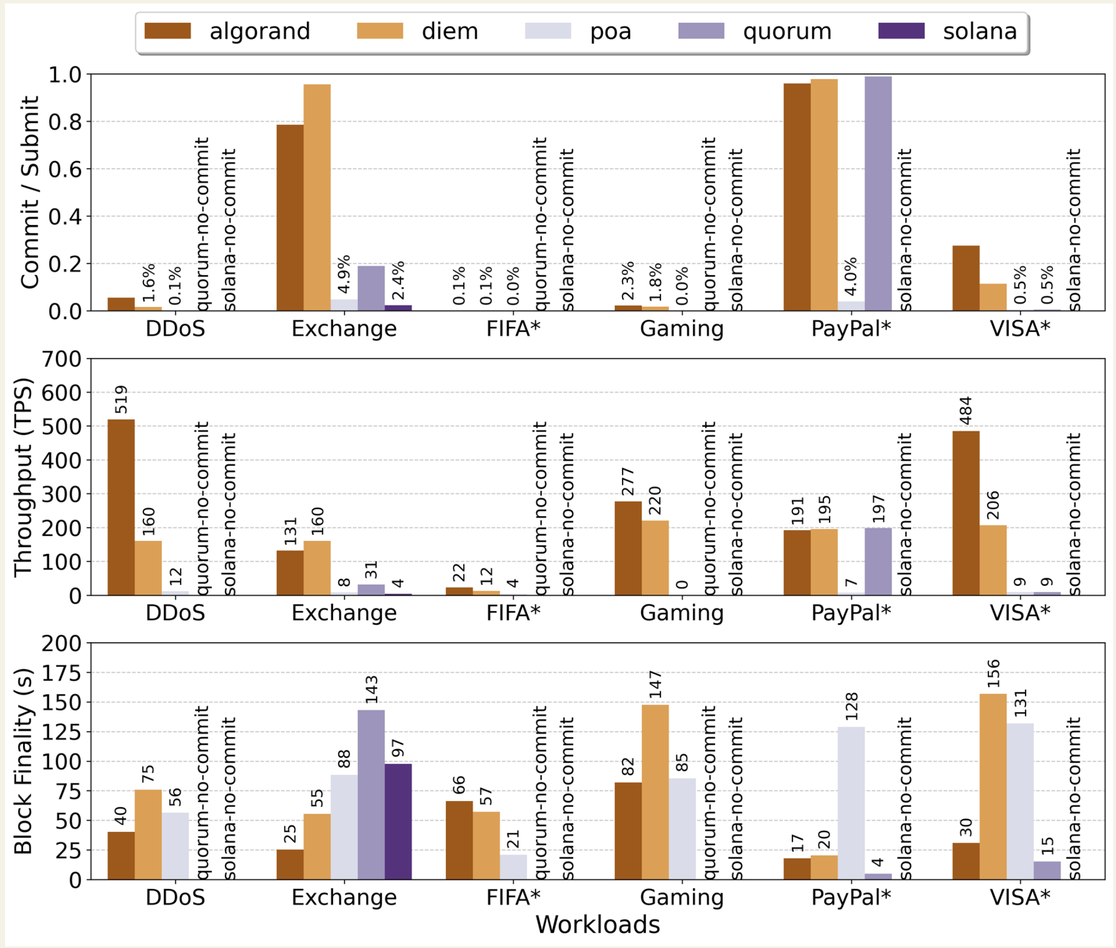
4-nodes per region

RESULTS #3

Benchmark on a Hypercube topology with different blockchain network size



1-node per region



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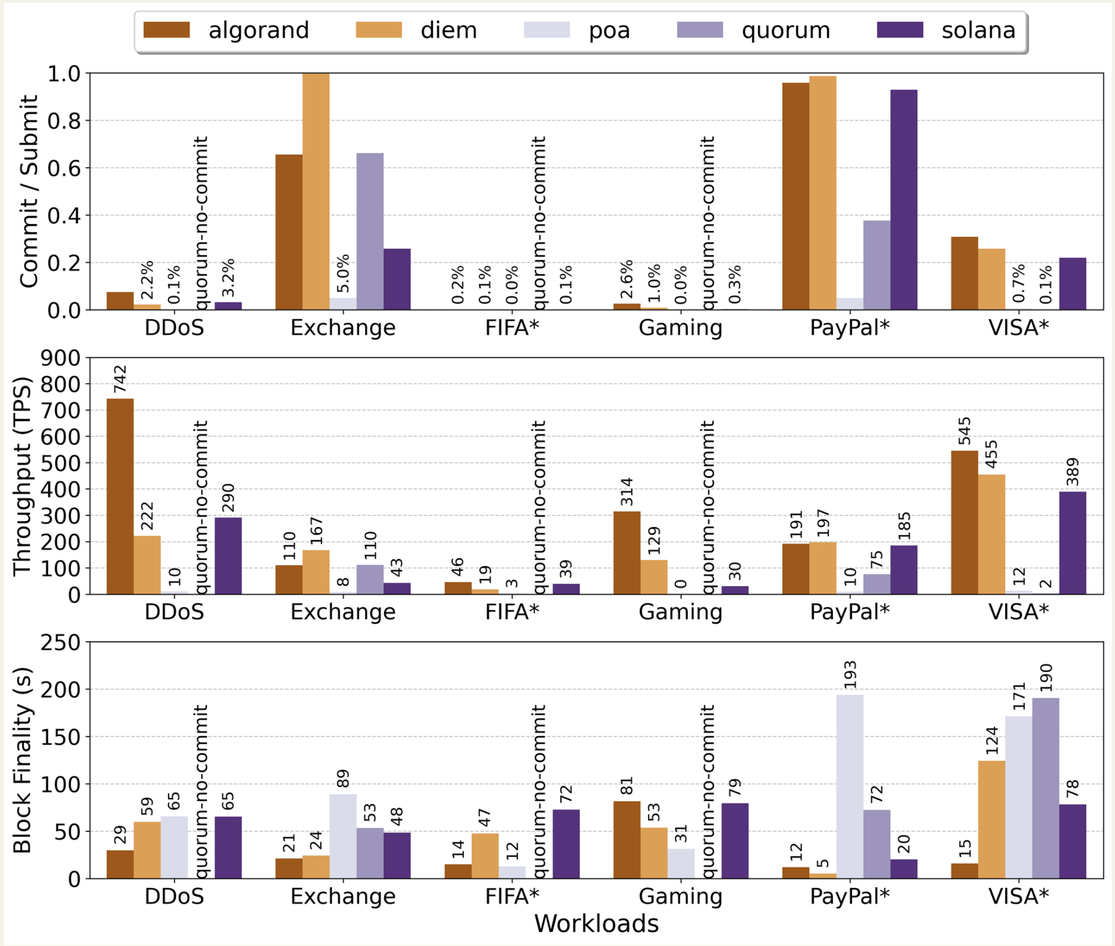
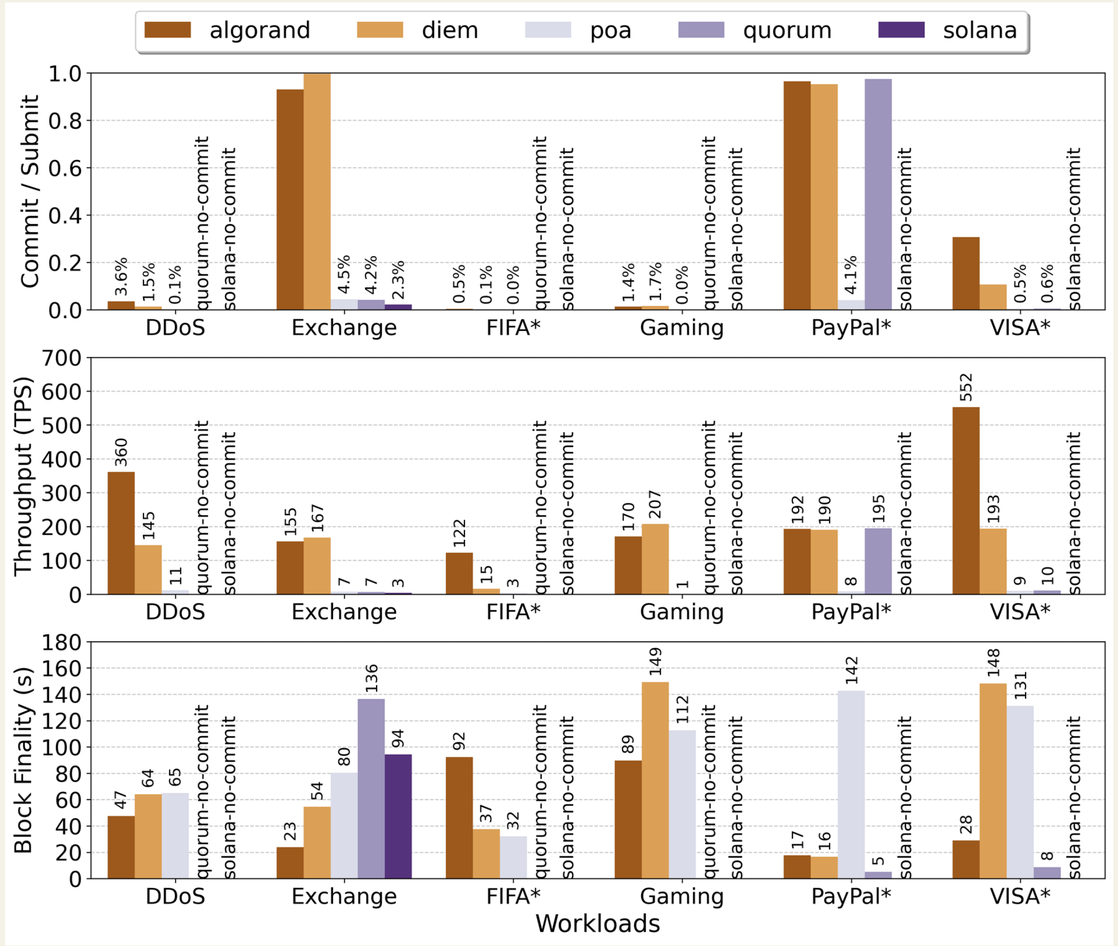
RESULTS #4

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



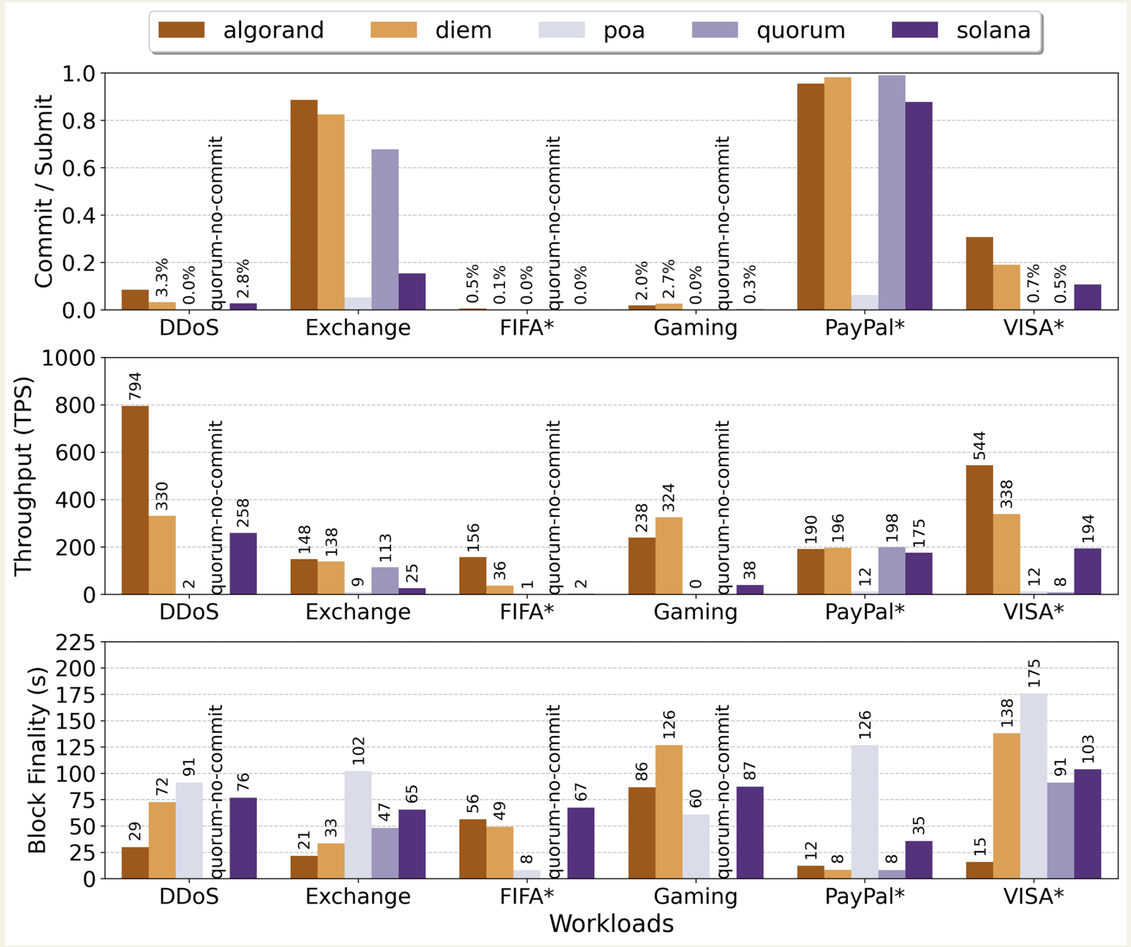
1-node per region



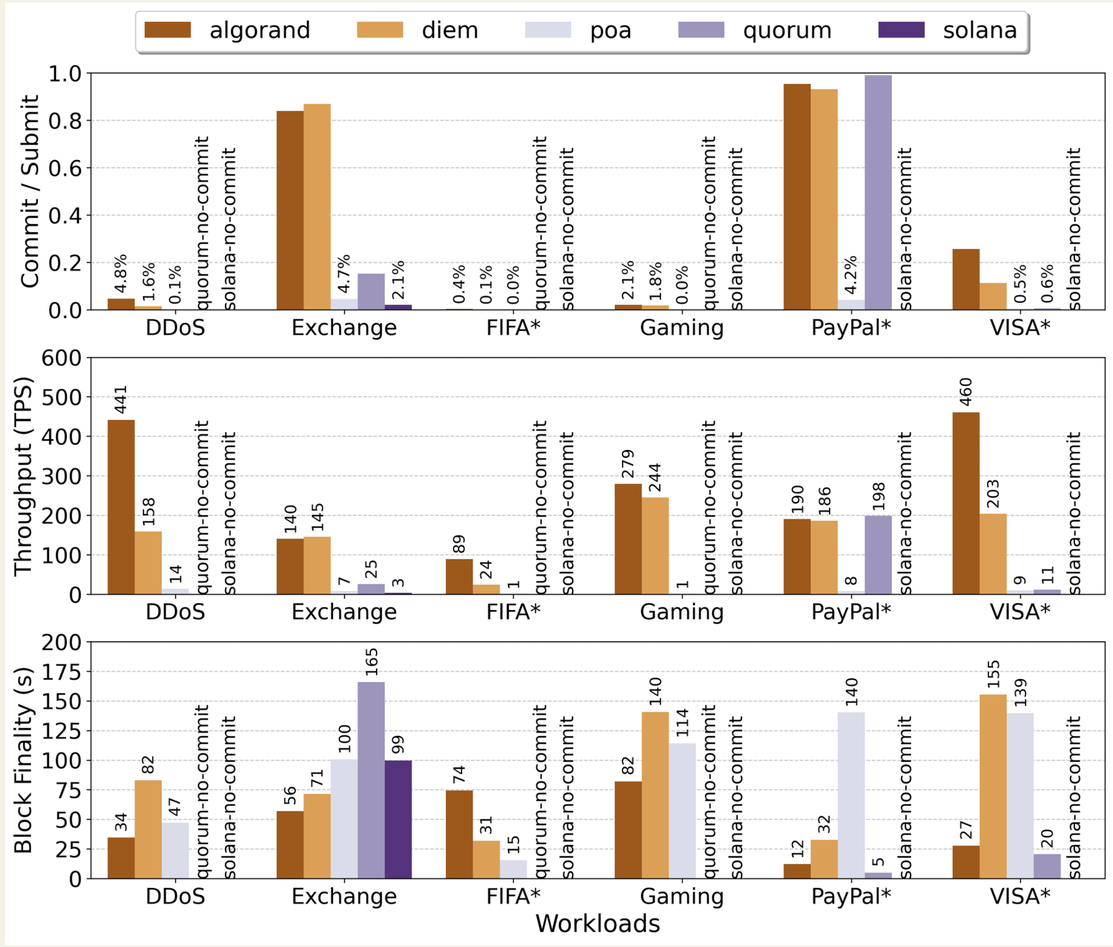
4-nodes per region

RESULTS #5

Benchmark on a Torus topology with different blockchain network size



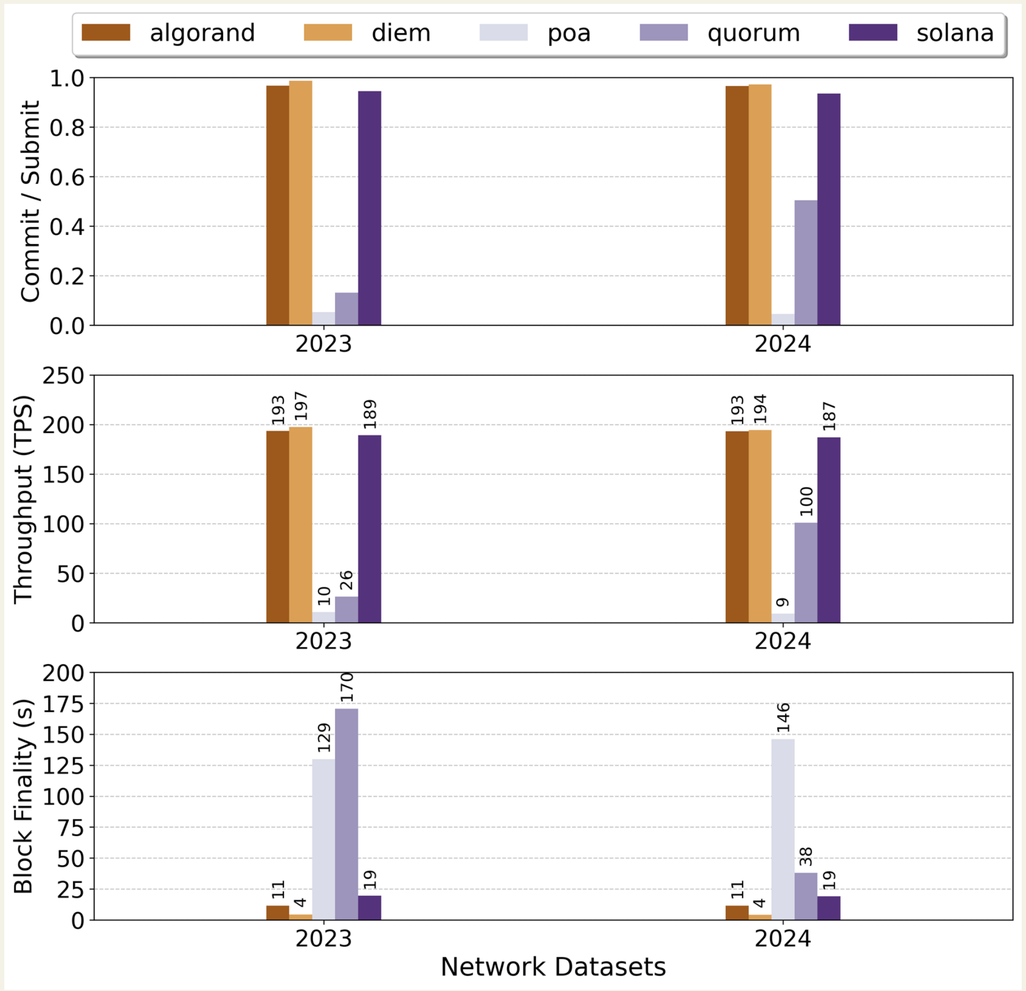
1-node per region



4-nodes per region

RESULTS #6

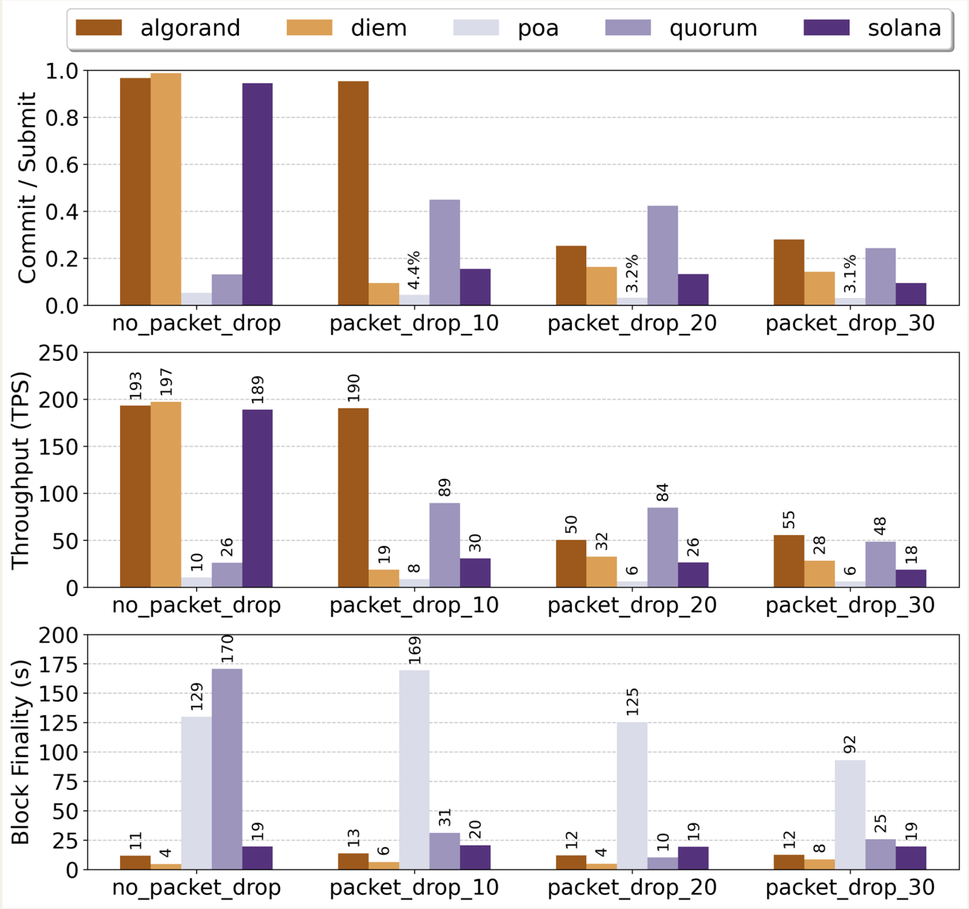
Benchmark on a Full-mesh topology with different network datasets



Answer to RQ5: *We can confirm that emulating two different moments taken from AWS in two separate measurements (2023 and 2024) shows different results for the benchmark. Referring specifically to Fig. 12, the most significant variation impacts Quorum.*

RESULTS #7

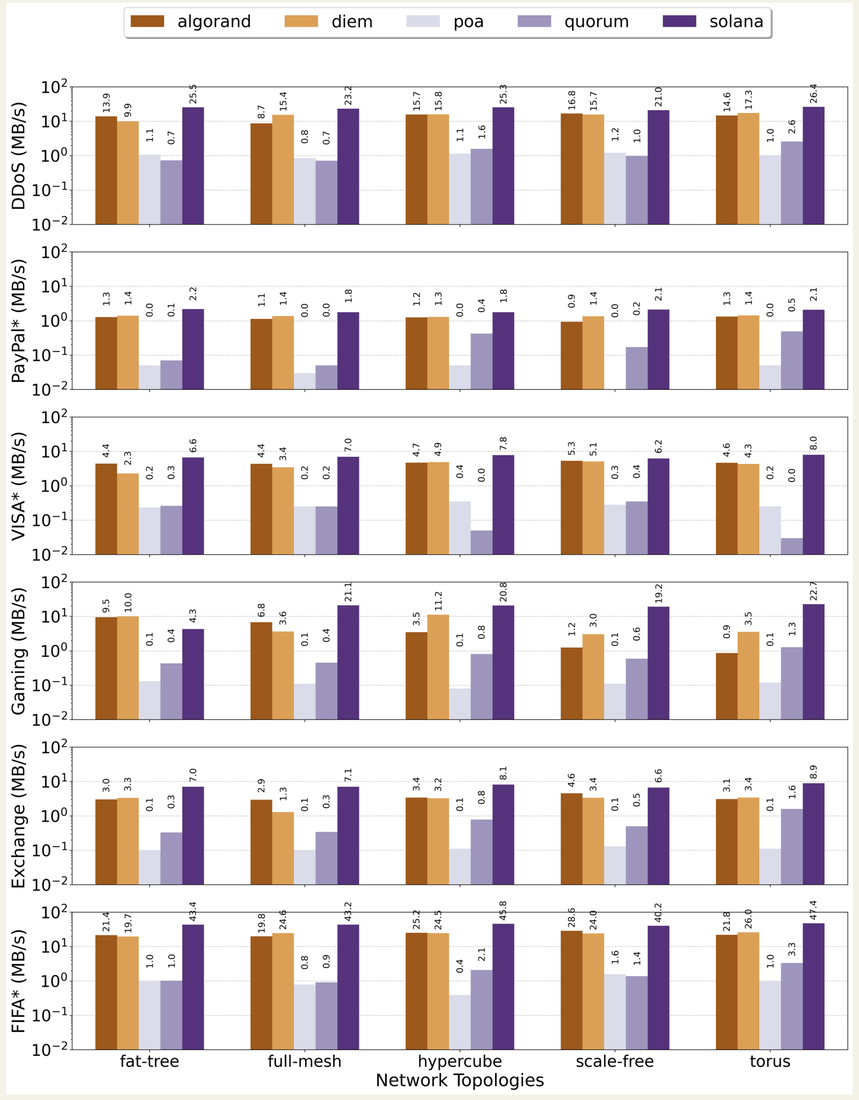
Benchmark on a Full-mesh topology with different packet drop percentage during the workload execution



Answer to RQ6: *Regarding throughput, the blockchains that show the most performance degradation as the packet drop rate increases are Diem and Solana, followed by Quorum and Algorand. Although Ethereum consistently has a much lower TPS compared to the others, it is the least affected by the packet drop rate.*

RESULTS #8

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



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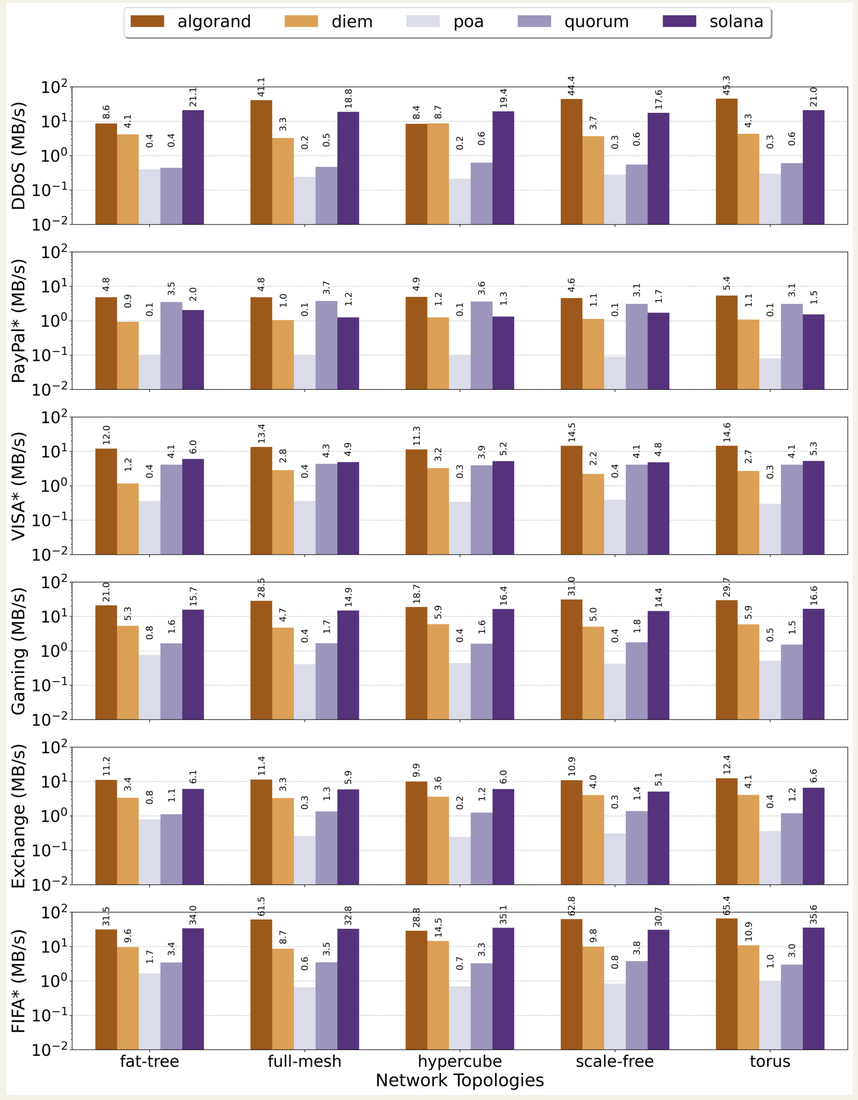

4-nodes per region

RESULTS #9

Experiments with Scale-free and increasing number of switches-link

Table 4. Results for experiments executed using the topology construction method 2 on Scale-free shape with increasing number of switches-links (250-255, 500-535, 1000-1170) and latencies (25, 50, 100 ms). On the left 0.1 Gbps, while on the right side 1 Gbps.

		Algorand			Diem			PoA			Solana		
		250	500	1000	250	500	1000	250	500	1000	250	500	1000
Throughput (TPS)	25	31.7	46.0	62.0	15.7	19.6	46.1	4.2	3.0	2.9	43.4	54.3	72.4
	50	204.9	90.7	171.5	13.1	21.9	8.9	1.8	1.1	2.2	–	97.2	36.6
	100	40.7	116.8	128.1	40.3	14.4	15.9	1.1	2.1	4.2	–	–	–
Block Finality (s)	25	17.2	37.8	53.1	60.8	54.2	36.4	9.1	12.8	8.4	65.5	60.6	61.8
	50	58.6	58.9	68.0	35.6	51.7	38.3	6.6	3.4	8.2	–	56.8	66.9
	100	66.6	80.5	61.3	79.2	33.9	61.2	11.1	13.7	8.2	–	–	–

		Algorand			Diem			PoA			Solana		
		250	500	1000	250	500	1000	250	500	1000	250	500	1000
Throughput (TPS)	25	27.4	338.2	13.0	20.5	40.0	48.3	5.3	3.4	1.4	10.9	70.2	42.4
	50	25.8	104.3	72.0	10.6	59.4	13.9	0.9	3.7	2.1	–	66.2	49.9
	100	111.0	77.0	111.9	15.4	1.2	35.2	2.1	0.8	4.2	–	–	–
Block Finality (s)	25	20.3	58.4	13.0	41.3	58.5	31.9	16.2	7.1	11.0	75.1	59.9	68.3
	50	19.8	58.7	58.3	30.1	57.3	50.3	3.3	16.8	8.0	–	74.9	67.7
	100	79.5	67.1	57.5	66.7	74.1	36.1	2.4	10.5	7.1	–	–	–

Answer to RQ7: *We observe that: (i) increasing the available bandwidth does not always improve Block Finality; (ii) adding more switches amplifies the dispersive effect of messages in the network for some blockchains (e.g., Diem); (iii) with the same number of switches, increased latency does not always lead to performance degradation.*

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- Use temporal data to simulate dynamic network events
- Implement and compare other (potentially new) blockchain protocol

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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