Shoal++

High Throughput DAG BFT Can Be Fast and Robust!

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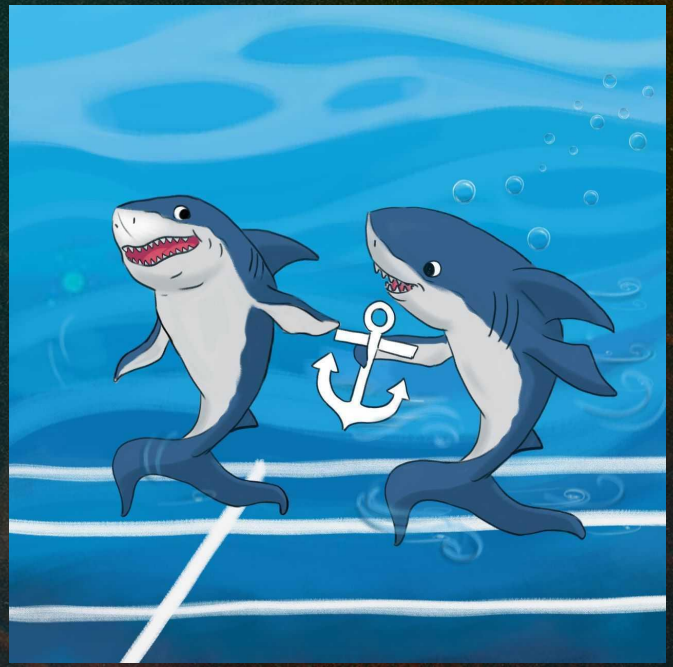


APRIL // 2025

Shoal++

Partially Synchronous BFT

- N = 3f+1

Certified DAG based for scalable throughput

4.5 message delays end-to-end latency

- Compared to 10.5 message delays in existing state-of-the-art

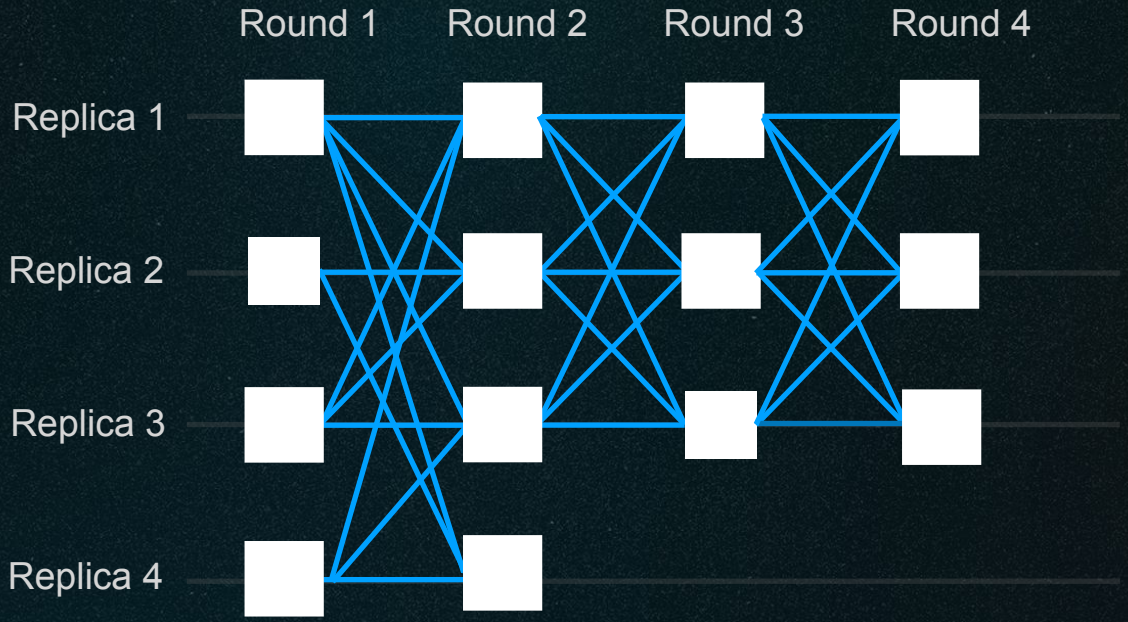
Robust under minor network glitches

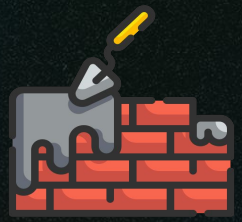
- Compared to Uncertified DAG approaches
- Minimal latency degradation under message drops

Background

Narwhal: Certified DAG [Eurosys'21]

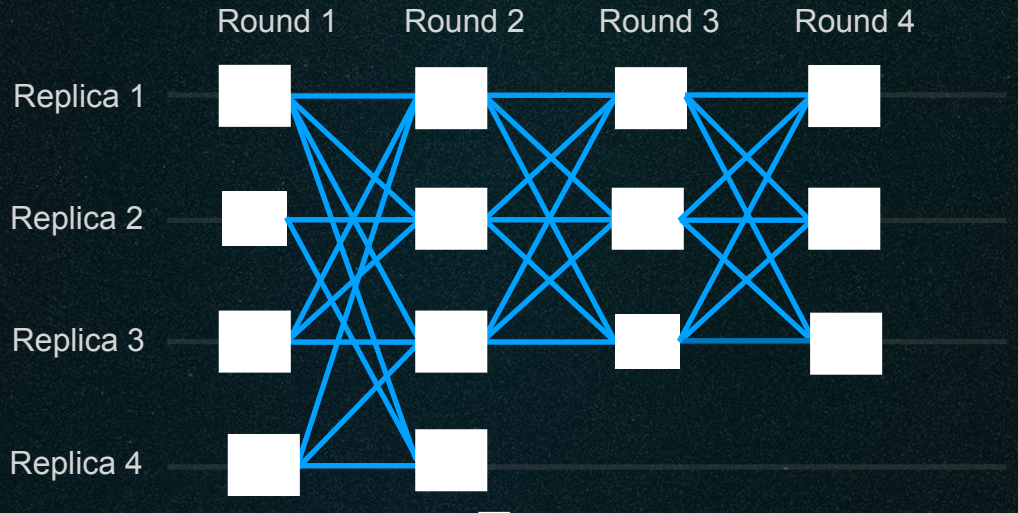
Decoupling data dissemination from total ordering is the key for performance





George Danezis, Lefteris Kokoris-Kogias, Alberto Sonnino, and Alexander Spiegelman. Eurosys 2022. Narwhal and Tusk: A DAG-based Mempool and Efficient BFT Consensus

Total Order with DAG



DAG-Rider[PODC'21]

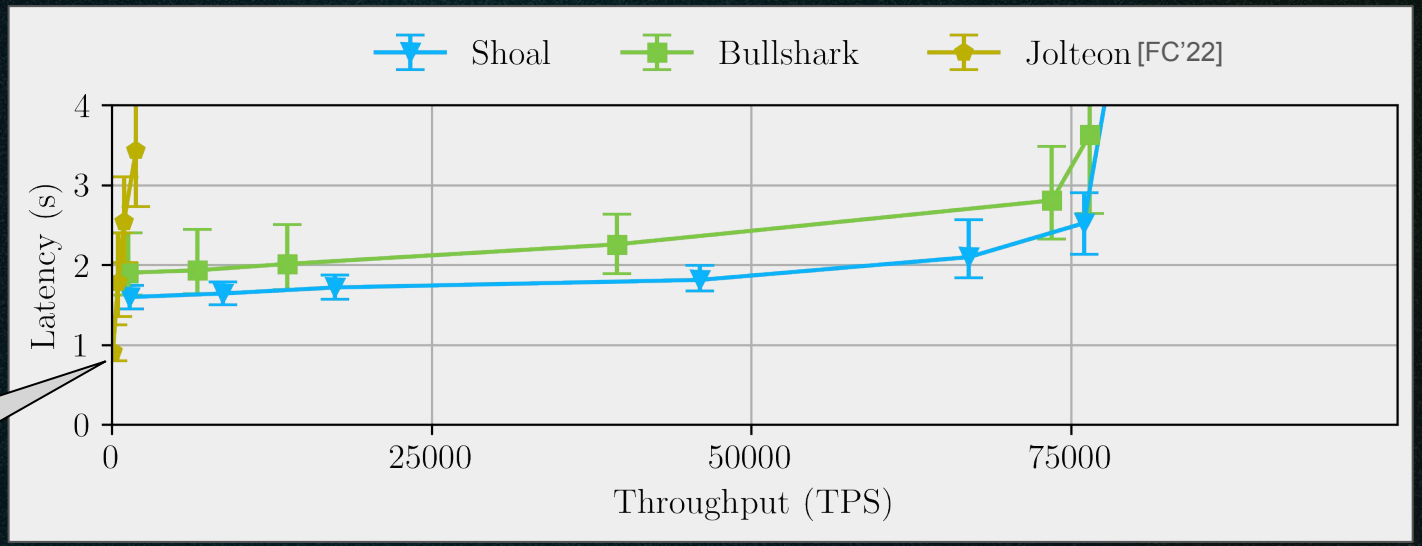
Tusk[Eurosys'21]

Bullshark[CCS'22]

Shoal[FC'24]

Total order with
zero communication overhead

Motivation: Reducing Latency



Leader based

Shoal++: Near-optimal Latency

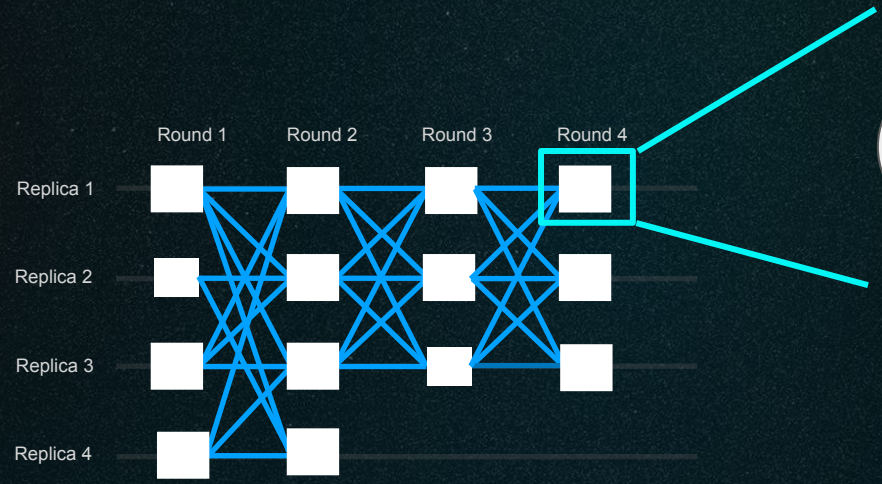
10.5 message delays (md) ⇒ 4.5 message delays (md)

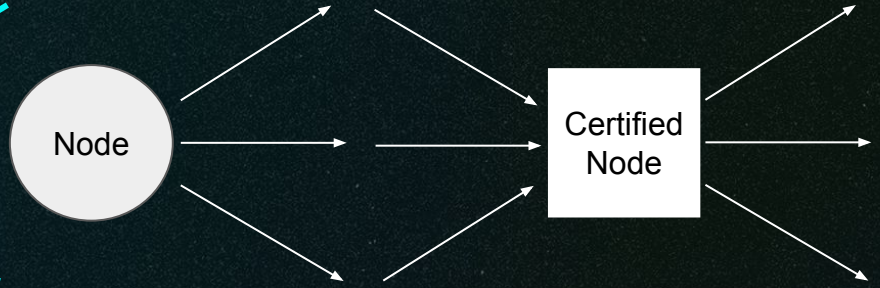
	Bullshark [CCS'22]	Shoal [FC'24]	Shoal++ (This Work)
Queuing Latency	1.5 md	1.5 md	0.5 md
Anchoring Latency	4.5 md	3 md	0 md
Anchor Commit Latency	6 md	6 md	4 md
	12 md	10.5 md	4.5 md

Queuing Latency

Queuing Latency	Anchoring Latency	Anchor Commit Latency

Queuing Latency on Certified DAGs



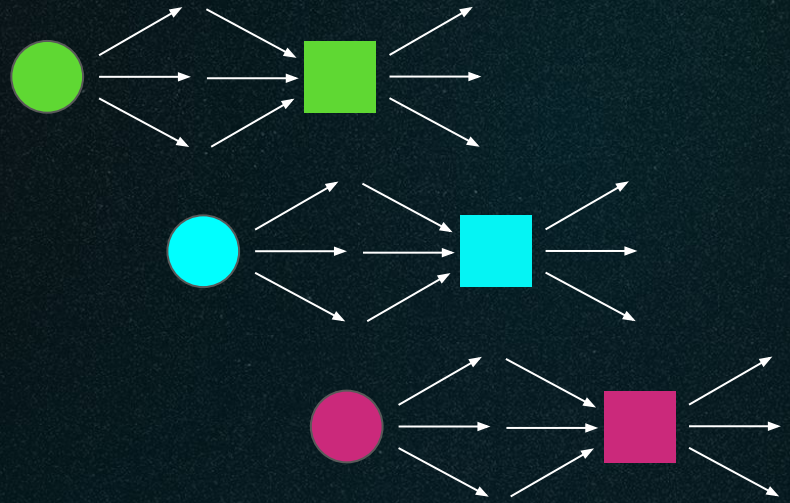


Reliable Broadcast based Certification (3md)

Queuing Delay: 1.5 md

Queuing Latency	Anchoring Latency	Anchor Commit Latency

Shoal++: More DAGs



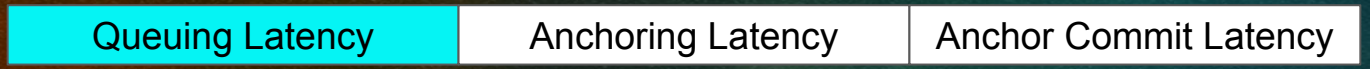
3 DAGs each offset by 1 md

Queuing: 1.5 md ⇒ 0.5 md

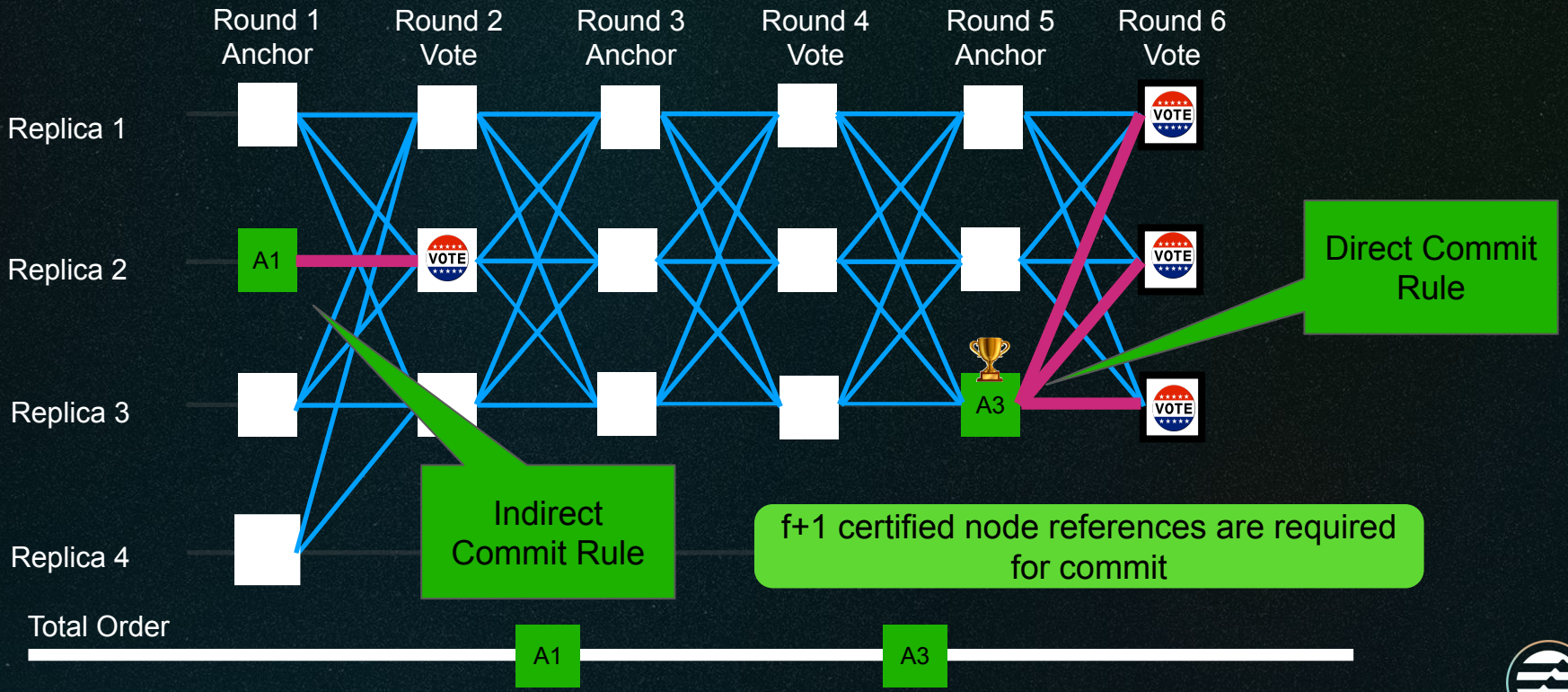
Total order: round robin order

Queuing Latency	Anchoring Latency	Anchor Commit Latency

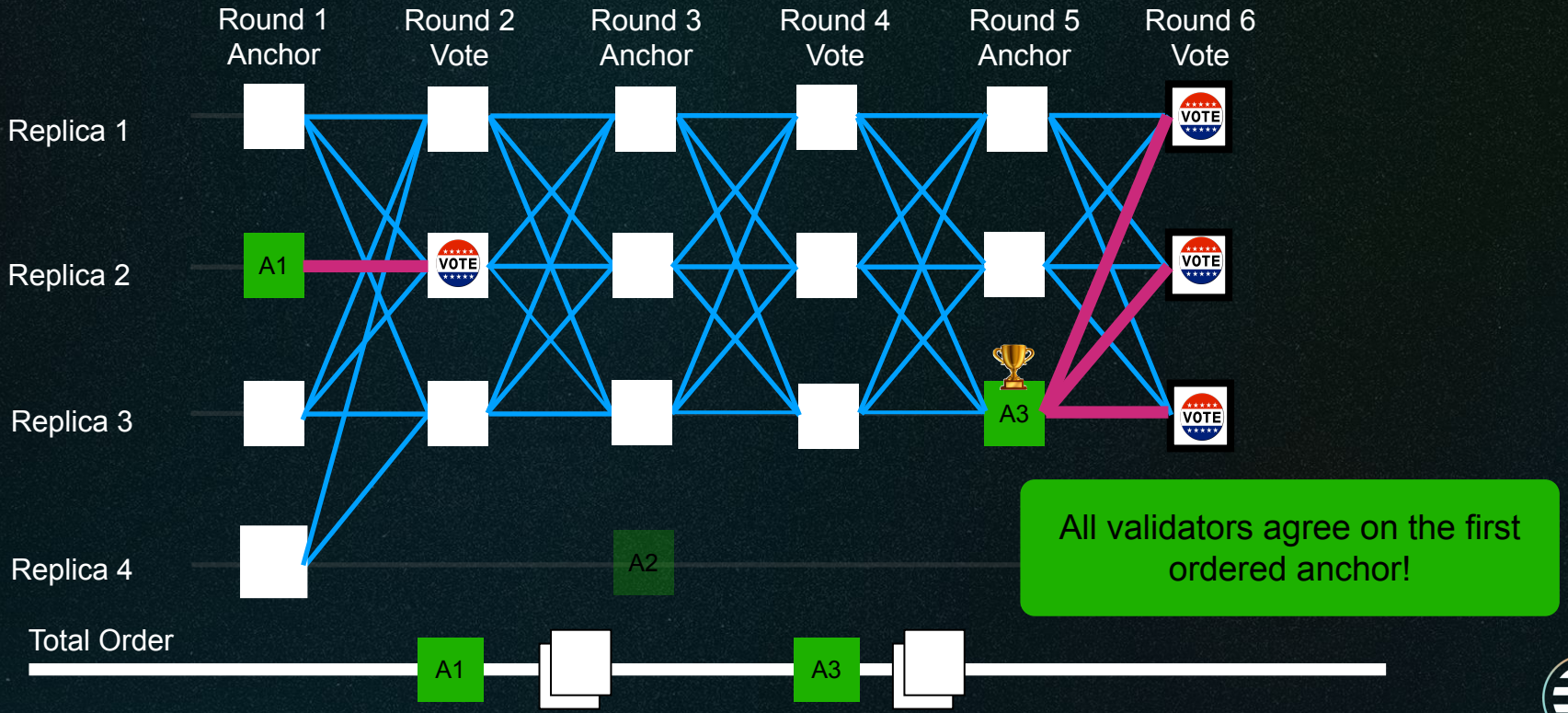
Ensuring Total Order between DAGs



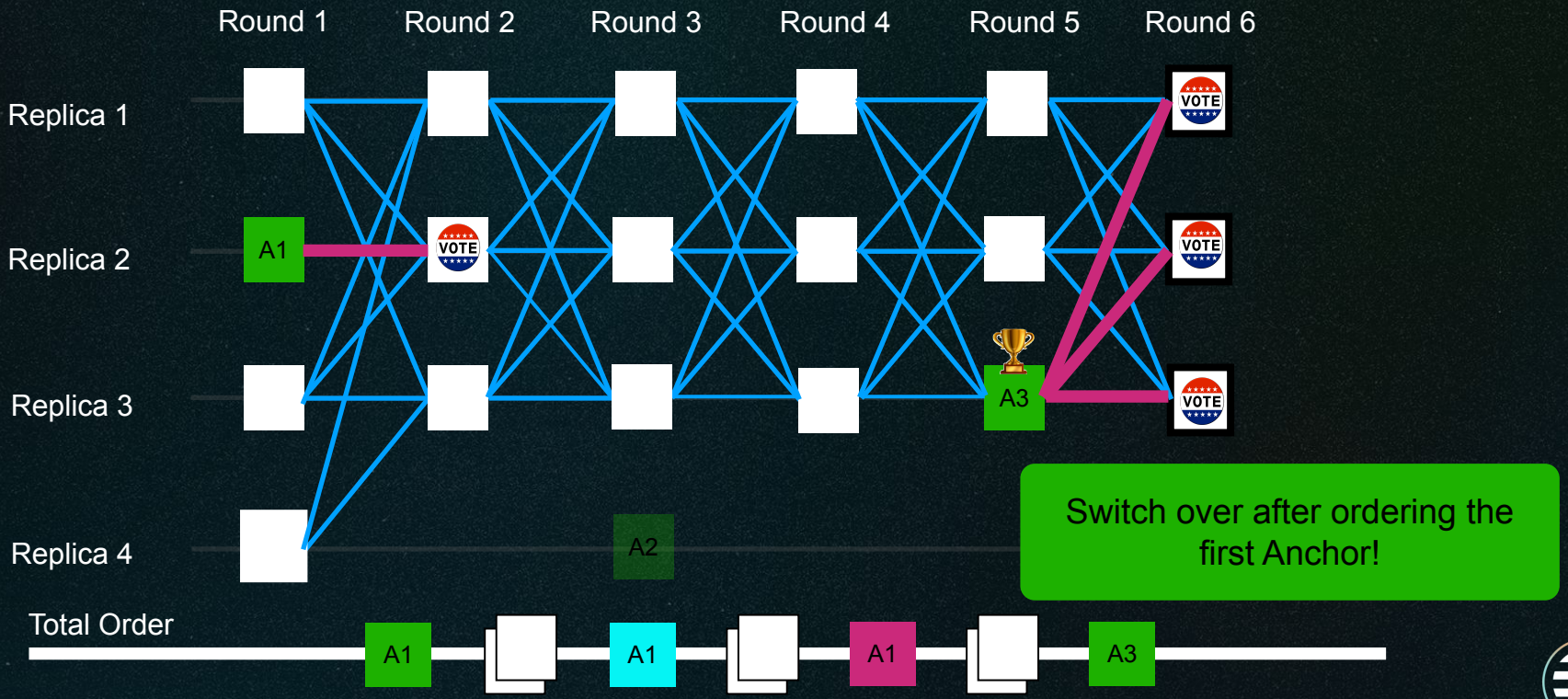
Revisiting Bullshark Order Rule



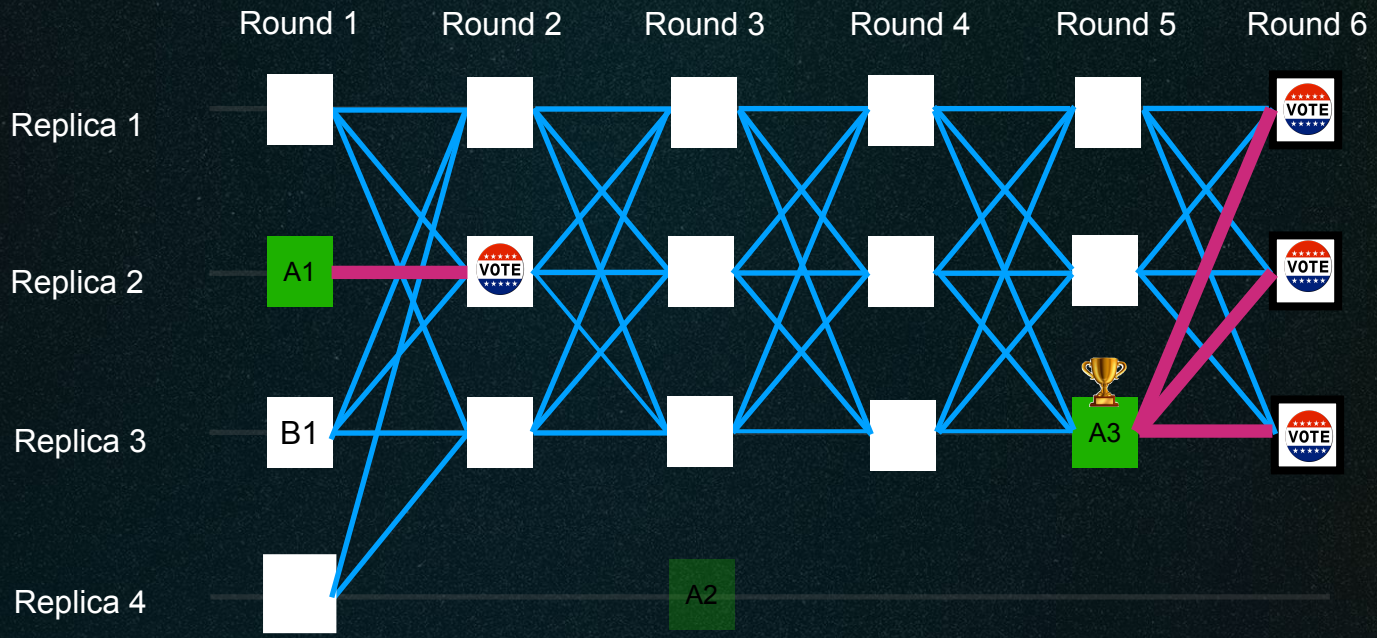
Revisiting Bullshark Order Rules



Total Order between DAGs

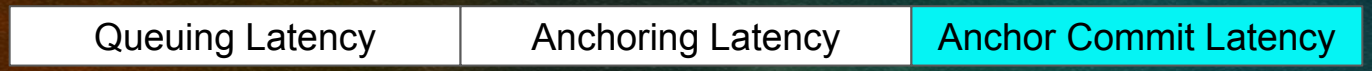


Anchoring Latency

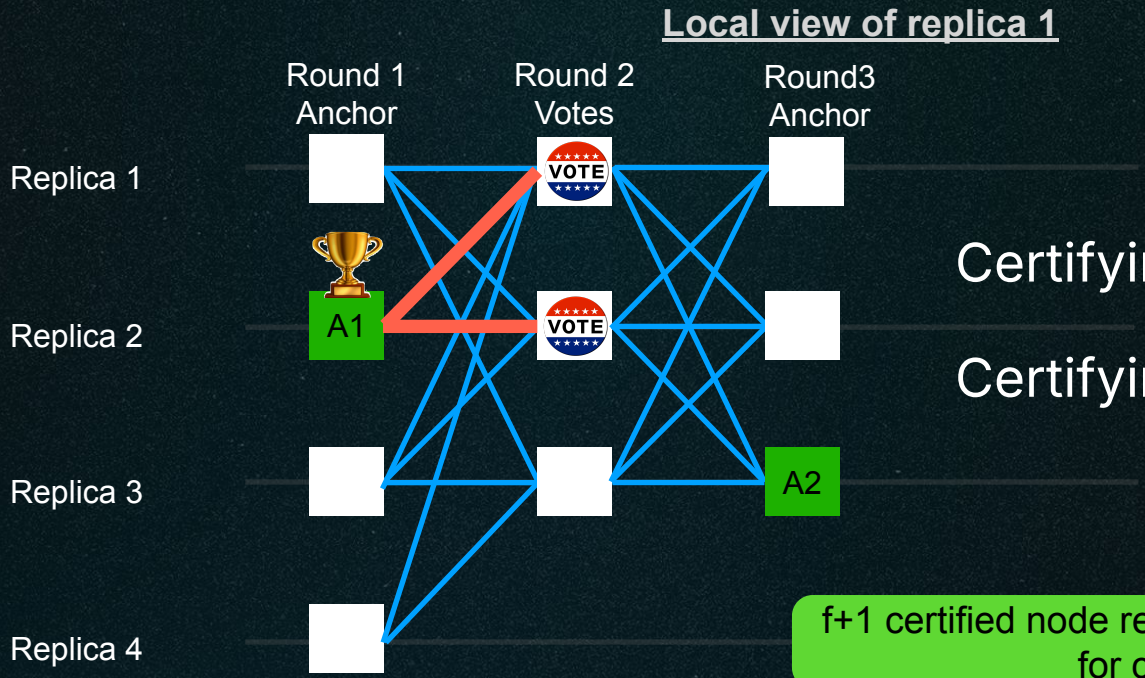


Queuing Latency	Anchoring Latency	Anchor Commit Latency

Anchor Commit Latency



Existing Direct Commit Rule



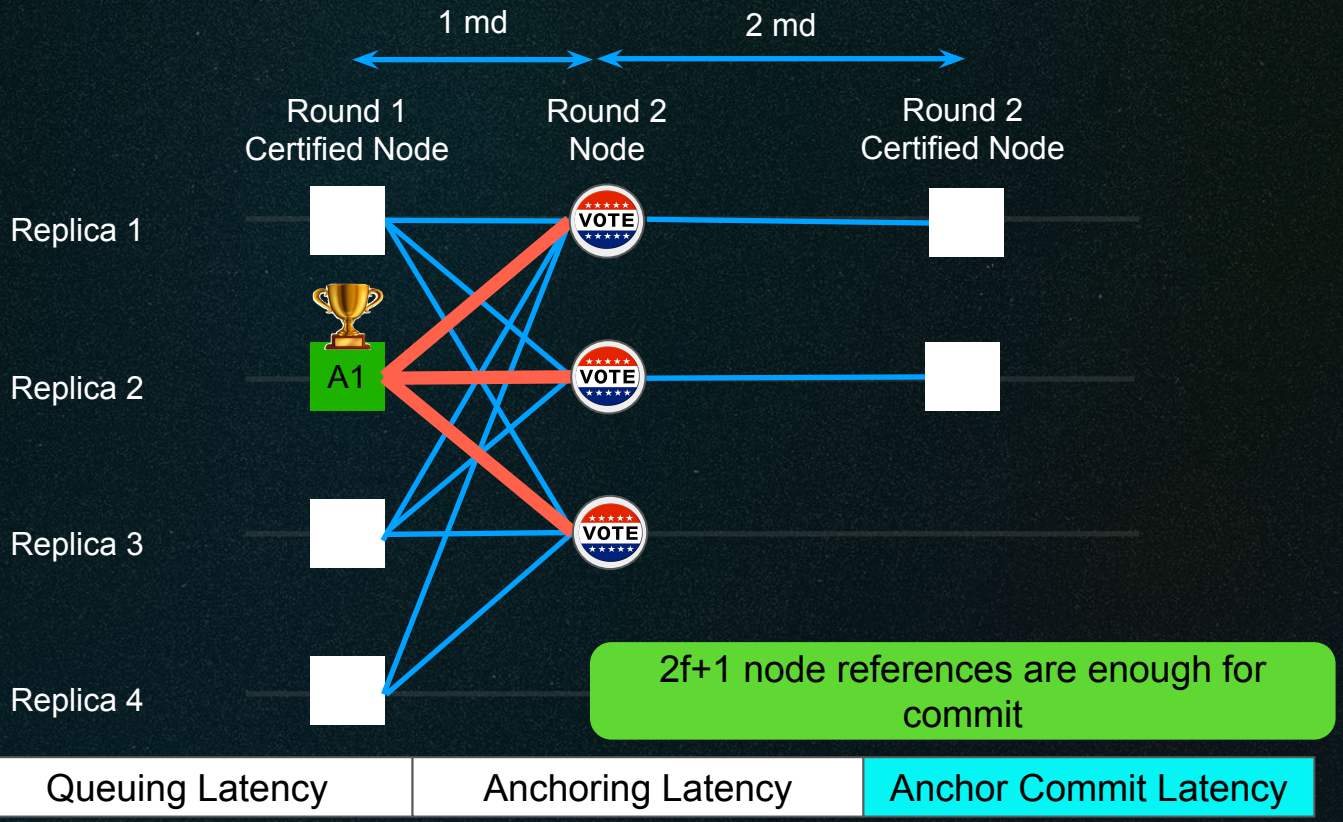
Certifying Anchor Node: 3md

Certifying Vote Nodes: 3md

f+1 certified node references are required for commit

Queuing Latency	Anchoring Latency	Anchor Commit Latency

New Fast Direct Commit Rule



Recap

10.5 message delays (md) ⇒ 4.5 message delays (md)

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	12 md	10.5 md	4.5 md

Evaluation

Geo-distributed Deployment

- 100 Replicas spread evenly
- 10 Regions in GCP
- Round trip latency 25ms to 317ms

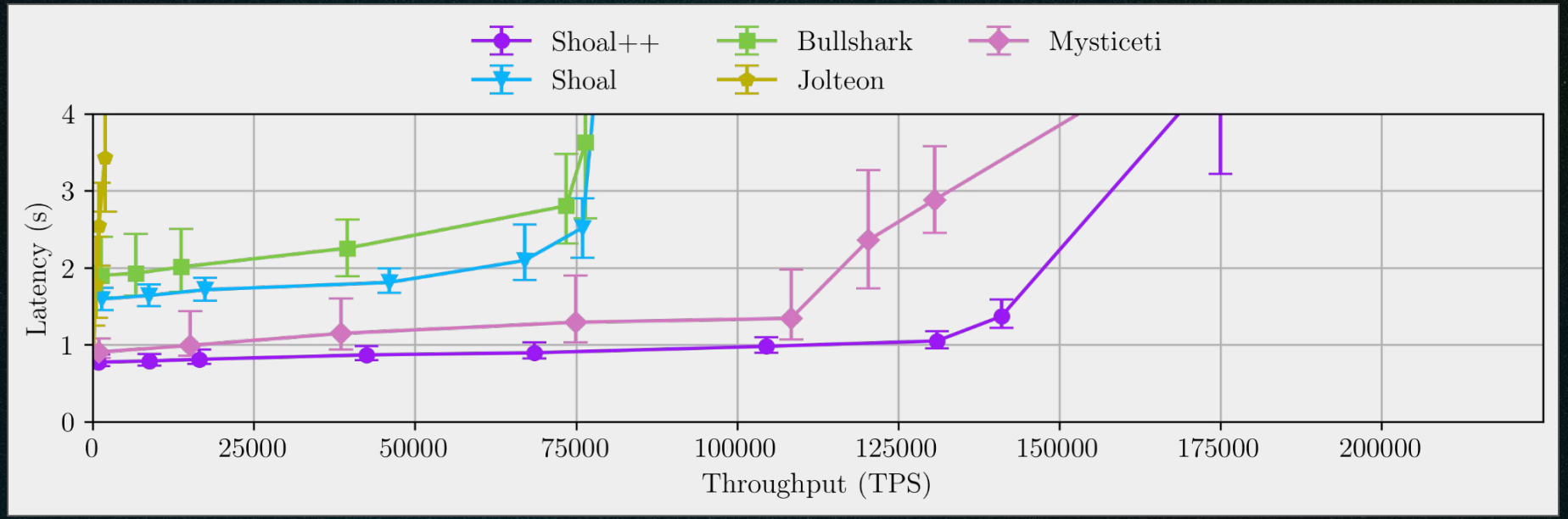
Protocols Under Test

- Rotating leader-based: Jolteon*
- Certified DAGs: Bullshark, Shoal
- Uncertified DAG: Mysticeti [NDSS'25]

Data

- 310 bytes per transaction
- Up to 500 transactions per DAG node

Evaluation Failure-free Performance

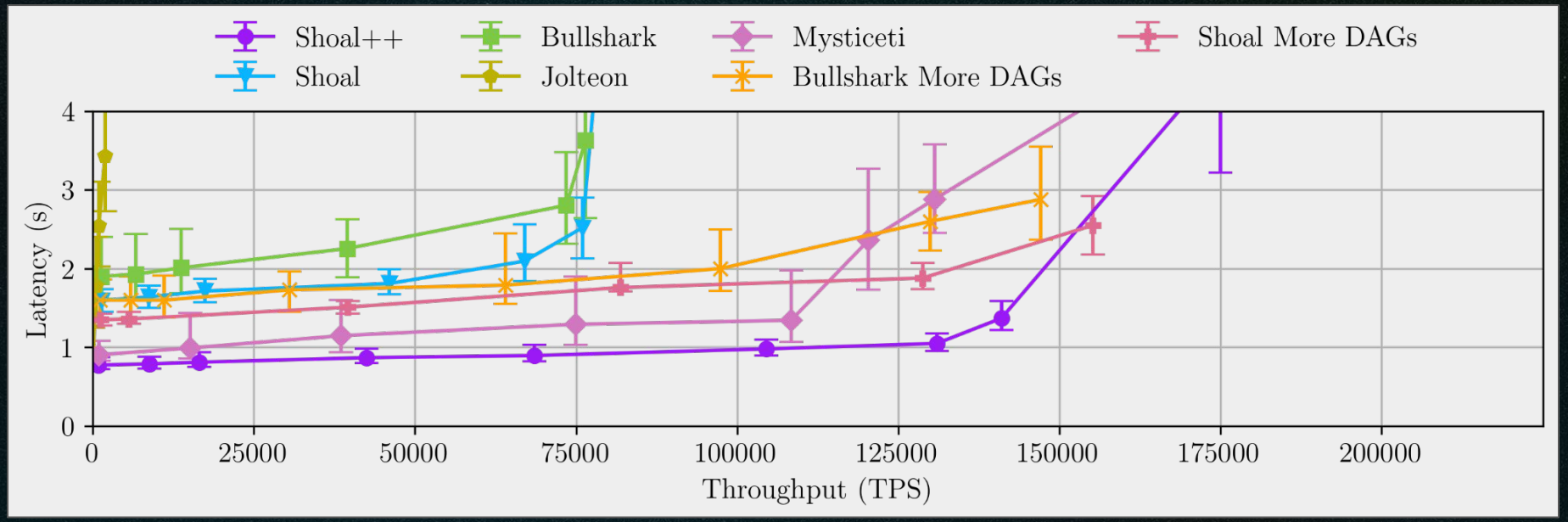


1.8x TPS vs other Certified DAGs

45% better latency than Shoal

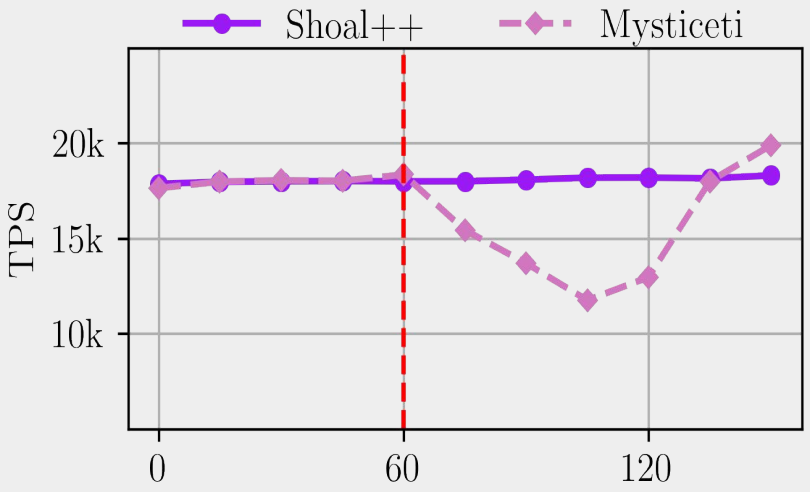
Sub-second latency up to 100,000 TPS

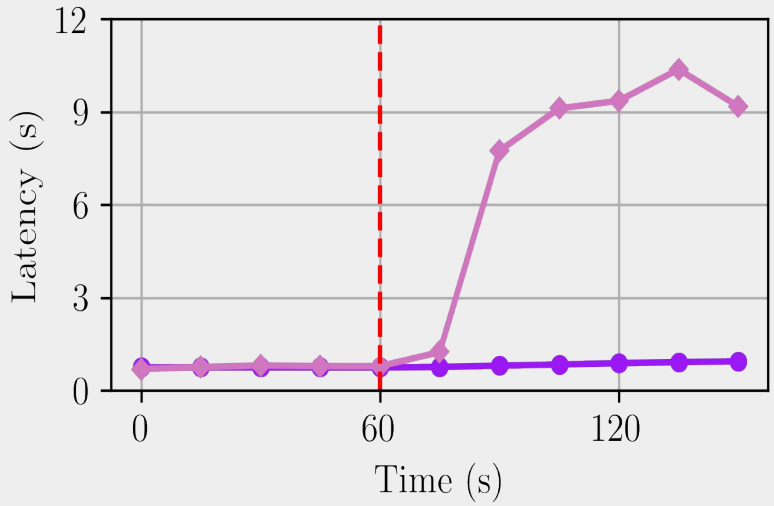
Evaluation Queuing Latency Optimization



All Certified DAG protocols benefit from 3 DAGs approach

Evaluation Network Glitch drops 0.05% messages





Drop 1% messages at 5% nodes

Uncertified DAGs diminish in performance

Summary

High Throughput

- Peak of 140,000 TPS

Low sub-second Latency

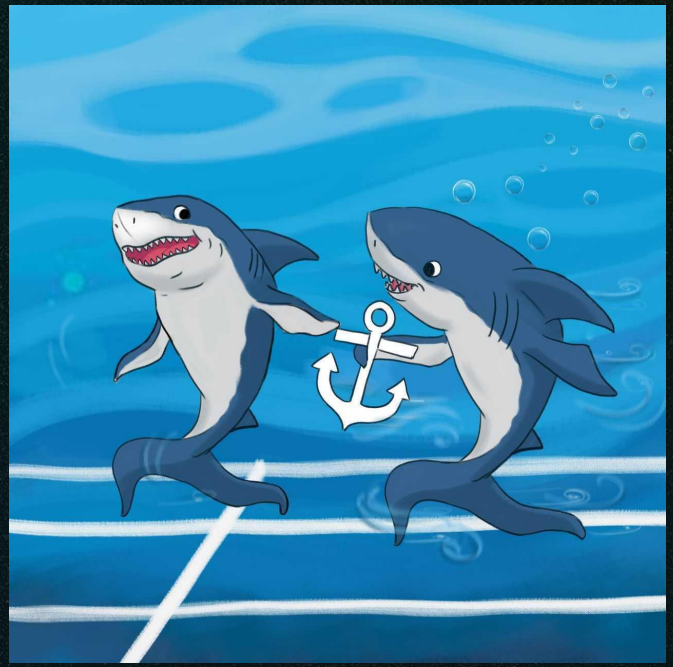
- 775 ms at 1000 TPS
- 980 ms at 104,000 TPS

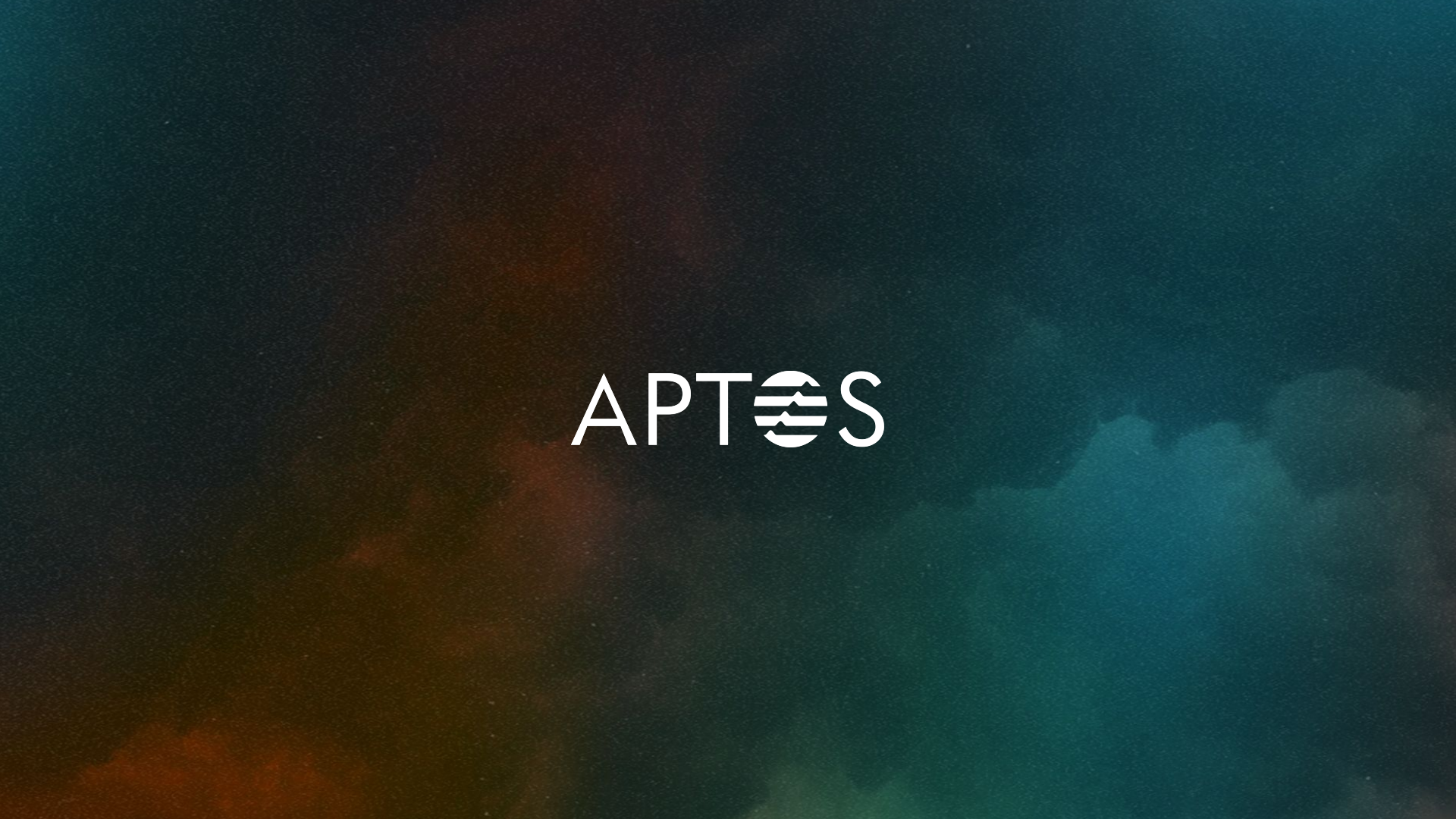
Robustness under network glitches

- 30% latency increase for Shoal++

vs.

- 10x latency increase for uncertified DAG protocols

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