Shoal: Improving DAG-BFT Latency and Robustness

FC'24

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1 Context: DAG-based BFT Consensus

- N = 3f+1 validators in total
- At most f validators are faulty

Goal

Global agreement on an infinitely growing sequence of some values.

New way to form consensus

- Historically we have a bunch of protocols which were optimized in the way of reducing communication compexity.
  - PBFT
  - Jolteon
  - …
  - Hotstuff - 3500 TPS
- Now we have new generation of protocols
  - 160kTPS - 600kTPS

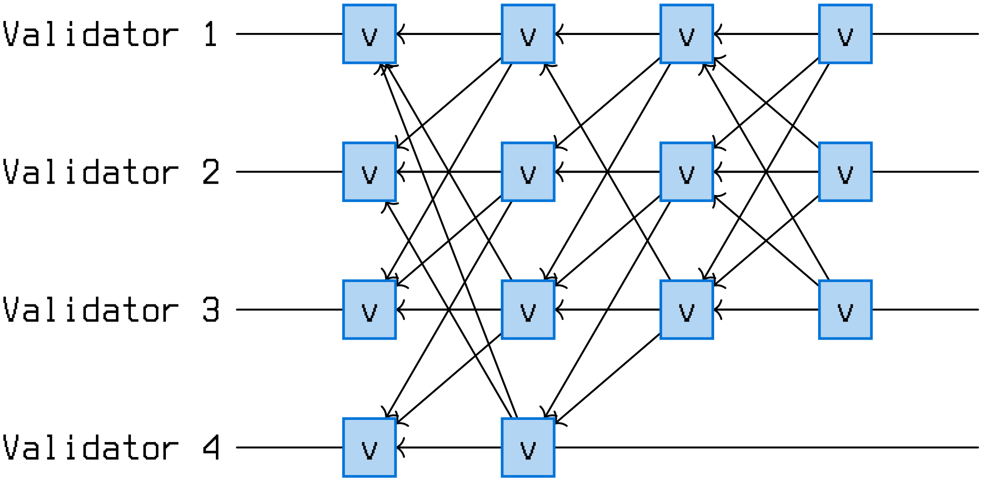
DAG purpose

Idea

Separate the network communication layer from the consensus logic.

- Each message contains a set of transactions, and a set of references to previous messages.
- Together, all the messages form a DAG that keeps growing - a message is a vertex and its references are edges.

DAG Example



Vertices dissemination

Common abstraction

Reliable BFT broadcast (Narwhal based protocols)

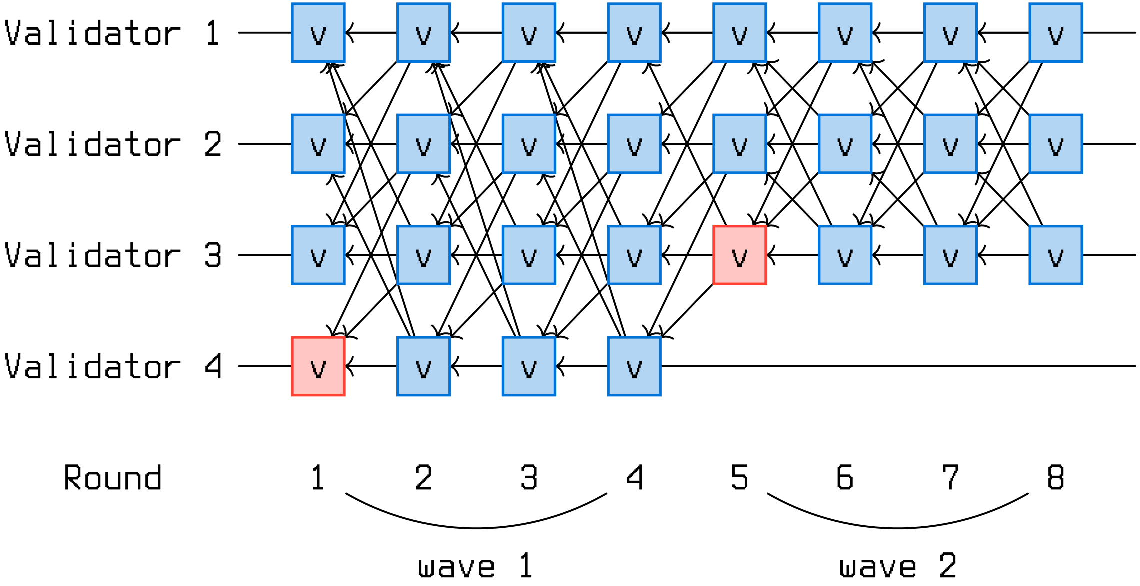
Result:

- All honest validators eventually deliver the same vertices and all vertices by honest validators are eventually delivered.
- Causal history of any vertex in both local views is exactly the same.
- All validators eventually see the same DAG

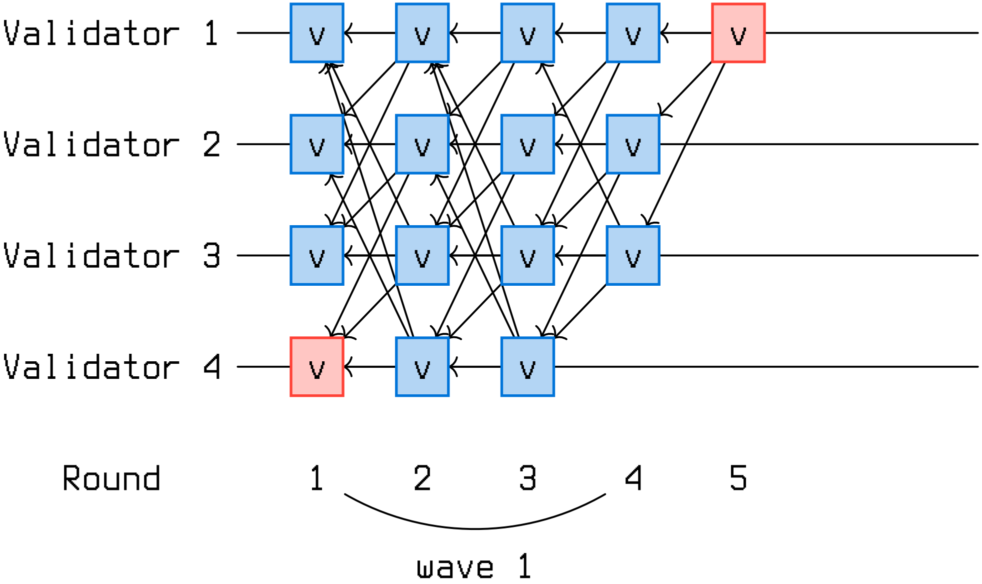
Consensus Structure

- Interpreting DAG structure as the consensus logic
  - Outcome - local solving
  - No need of any extra communication.
- Consensus divided into rounds
- Rounds groups waves
- Each wave contains predefined leader (Simplified)

DAG Waves example [DAG-Rider]

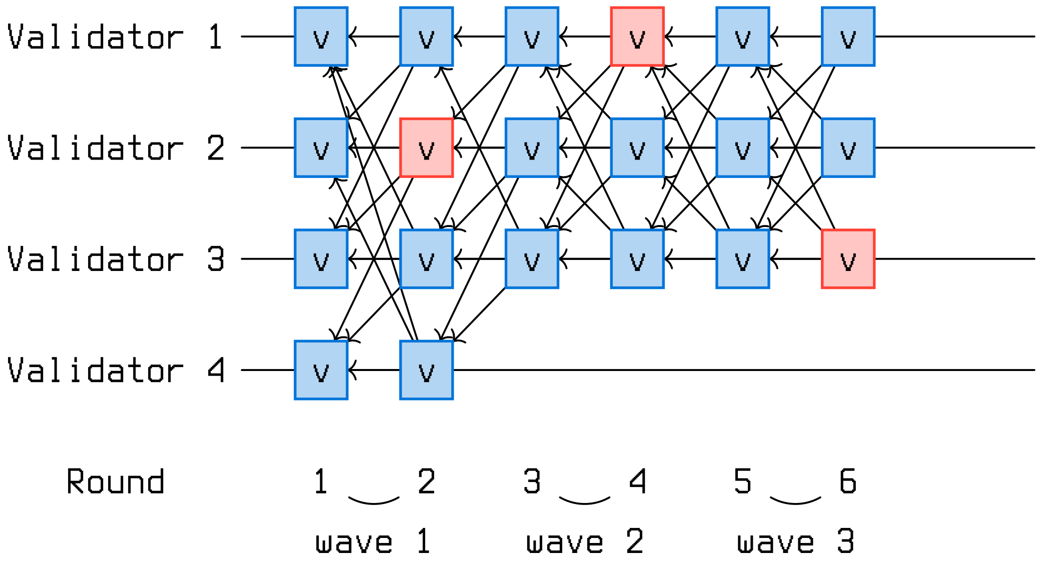


Casual history



Ordering

- Consists of two phases:
  1. Each validator determines which leader's vertices to order.
  2. Sequentially traverse these vertices backwards ordering the rest of vertices.
- Ordering happens with roughly linear dependency on wave size
- Larger waves size -> larger latency


Validator 1
Validator 2
Validator 3
Validator 4
v
Round
1 2 3 4 5 6
wave 1
wave 2
wave 3

2 Problem

Wave size

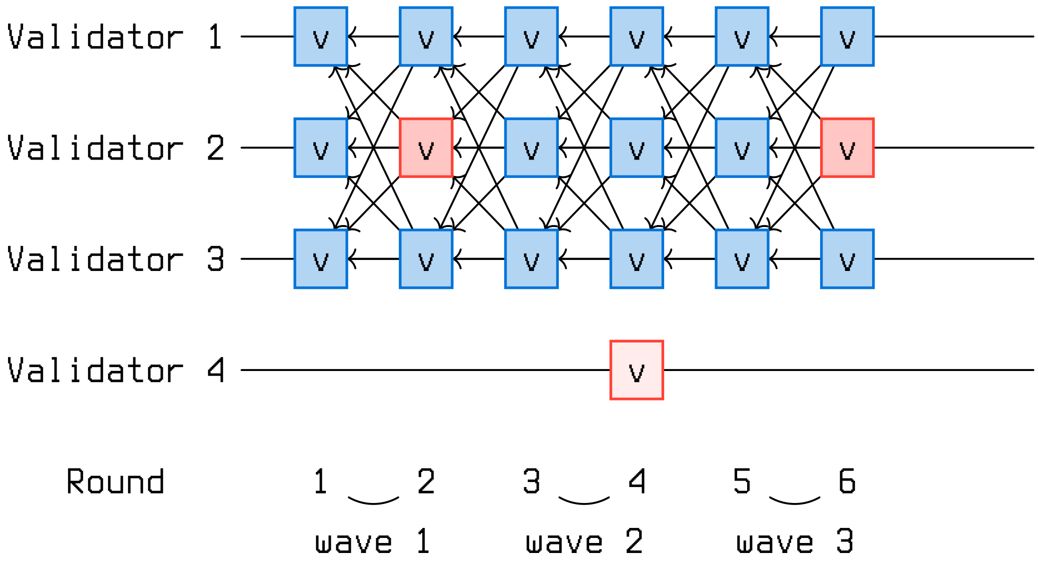
Problem №1

Sparse leader's vertices.

Protocol	Common case round latency	Async round latency
DAG-Rider	4	E(6)
Tusk	3	E(7)
Bullshark	2	E(6)

- Ideally we want to commit something each round.

Slow leaders



3 Solution

Common protocol structure

1. Pre-determined leaders each k rounds.
2. Order leaders. Same local ordering on honest validators.
3. Order casual histories.

Abstract property

Given a Narwhal-based protocol $\mathbb{P}$, if all honest validators agree on the mapping from rounds to leaders before the beginning of instance $\mathbb{P}$, then they will agree on the first leader each of them orders during execution of $\mathbb{P}$.

Introducing “Shoal”

- Protocol agnostic framework
- Suitable for all Narwhal-based protocols

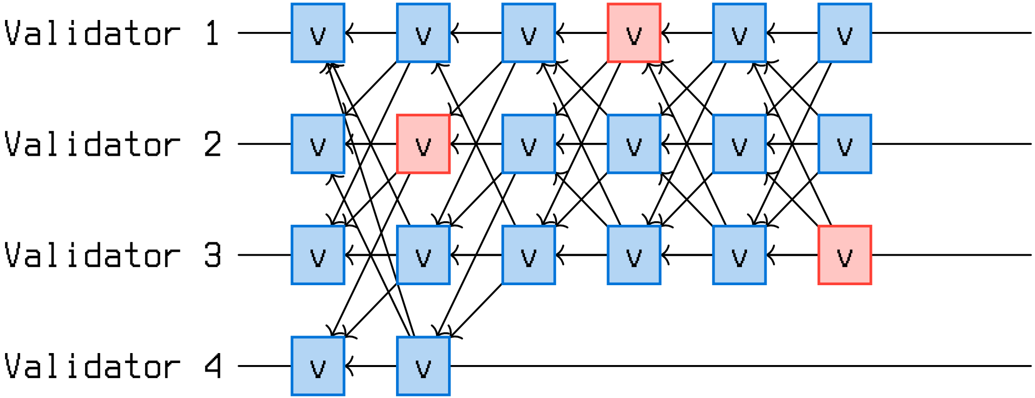
Idea

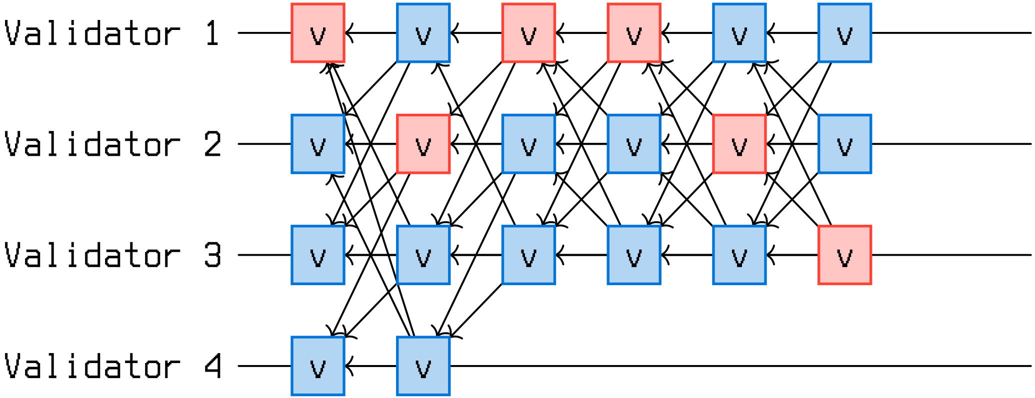
Combine batch of protocols instance in black-box manner.

Pipelining algorithm

current_round $\leftarrow$ 0
F: $\mathbb{R} \rightarrow \mathbb{L}$
while true do
    Execute $\mathbb{P}$, select leaders by F, starting from current_round until the first ordered (not skipped) leader is determined.
    let L be the first ordered leader in round r
    order L's casual history according to $\mathbb{P}$
    current_round $\leftarrow$ r+1

Recall Bullshark

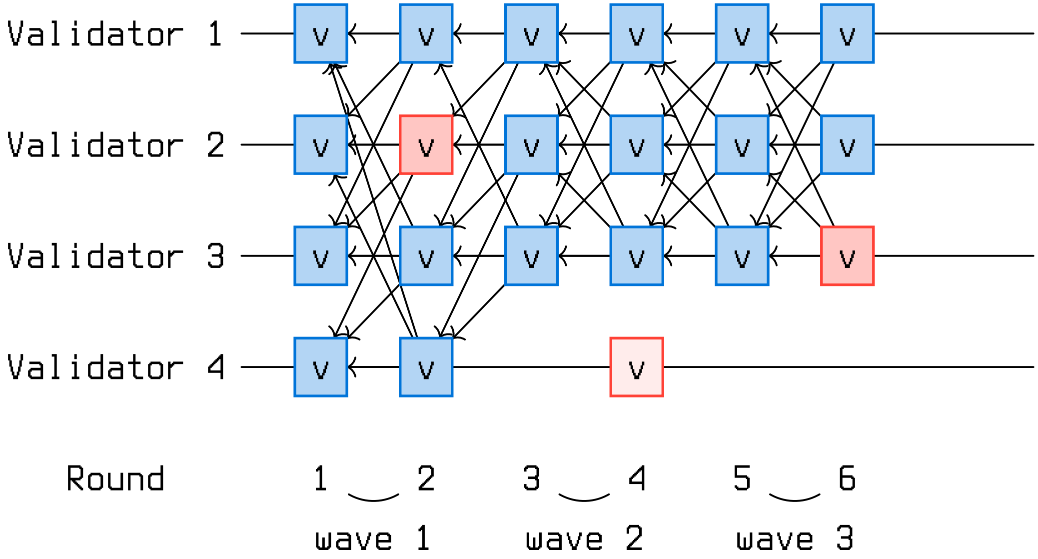



Validator 1
Validator 2
Validator 3
Validator 4
v

Leader reputation

- Byzantine systems are design to tolerate worst-case guarantees.
- However most common problem is slow leaders.

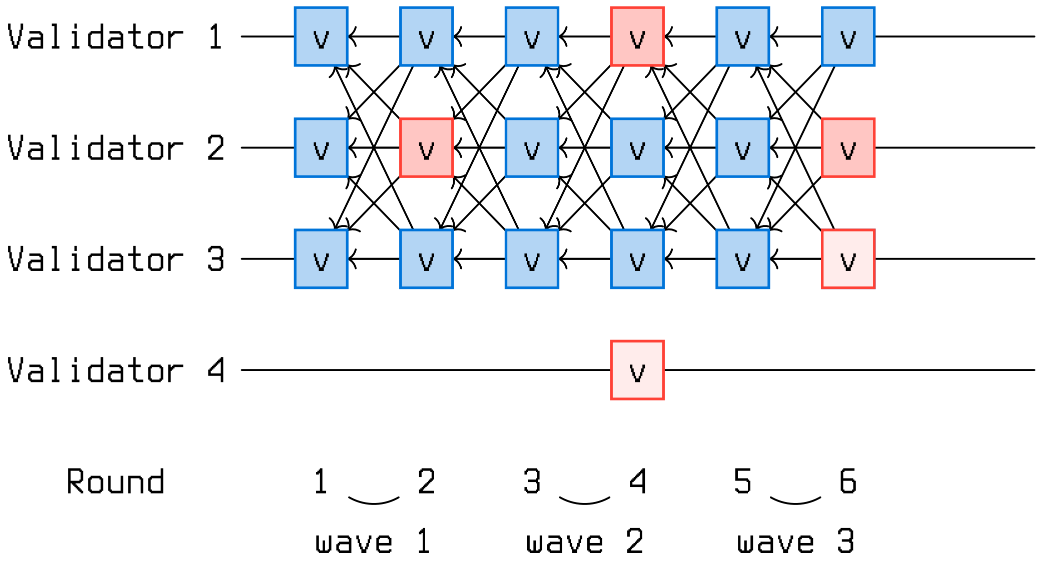
Example of missing leader



Reputation integration

current_round $\leftarrow$ 0
F: $\mathbb{R} \rightarrow \mathbb{L}$
while true do
    Execute $\mathbb{P}$, select leaders by F, starting from current_round until the first ordered (not skipped) leader is determined.
    let L be the first ordered leader in round r
    order L's casual history according to $\mathbb{P}$
    current_round $\leftarrow$ r+1
    Update F according to L's causal story

Leader change in action



4 Evaluation

Machine Setup

- Machines:
  - t2d-standard-32 type virtual machine
  - 32 vCPUs, 128GB of memory, up to 10Gbps of network bandwidth.
- Cluster:
  - Google Cloud
  - Machines spread equally across regions: us-west1, europe-west4, asia-east1.
  - Latencies: us-west1 asia-east1 [118ms]; europe-west4 asia-east1 [251ms]; us-west1 europe-west4 [133ms]
  - Cluster size (N): 10 (f <= 3); 20 (f <= 6); 50 (f <= 16)
- Data:

Machine Setup (ii)

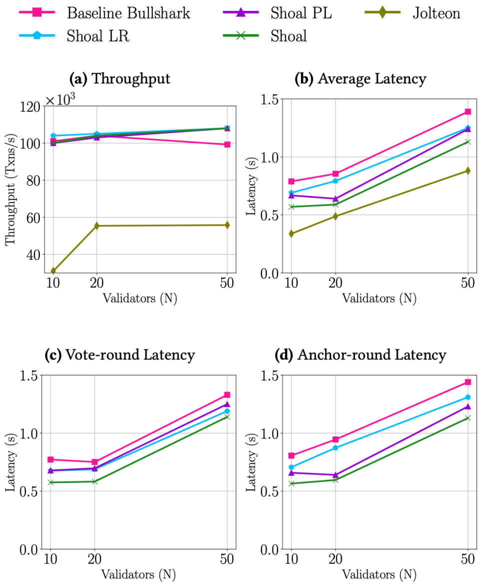
- Transactions ~270B in size
- Maximum batch size of 5000 transactions

Latency definition

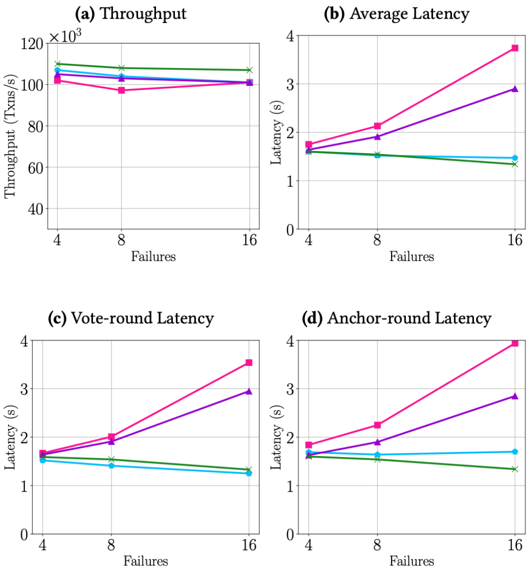
Latency

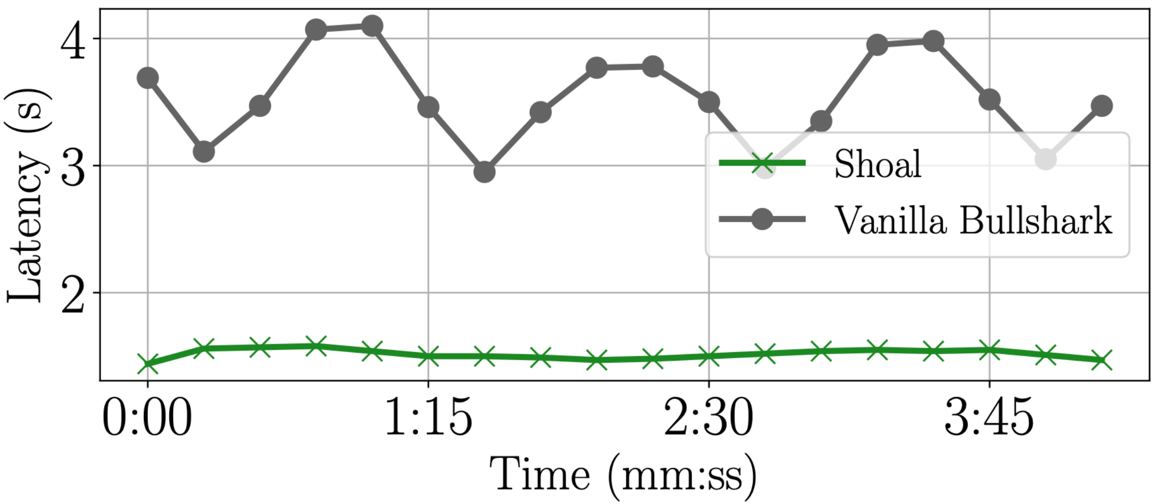
Time elapsed from when a vertex is created from a batch of client transactions to when it is ordered by a validator

Results: No failures



Results: With failures




Latency (s)
4
3
2
0:00
1:15
2:30
3:45
Time (mm:ss)
Shoal
Vanilla Bullshark

Results: total

- Up to 40% latency reduction in failure-free executions
- Up to 80% reduction in executions with failures agains vanilla Bullshark