August 28

KEYSPACE

Amsterdam

Demystifying Valkey Clustering: Architecture, Fault Tolerance, and Scalability

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Valkey

Agenda

- Overview
- Operation mode
- Cluster mode components
- Cluster coordination mechanisms
- Recent improvements
- Benchmark
- Future work

Valkey

Introducing the Valkey project

- In-memory key value store
- Supports over 200 commands and multiple data structures like hashes, sets, sorted sets
- Used for caching, session management, leaderboard, message broker

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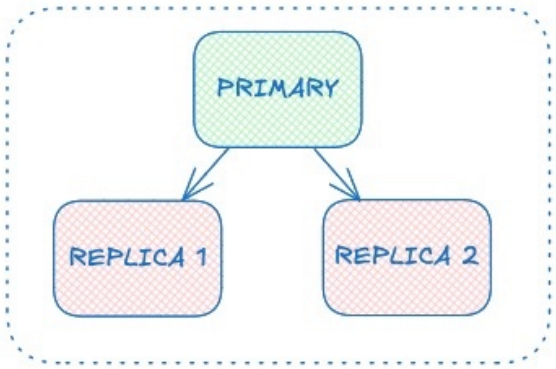
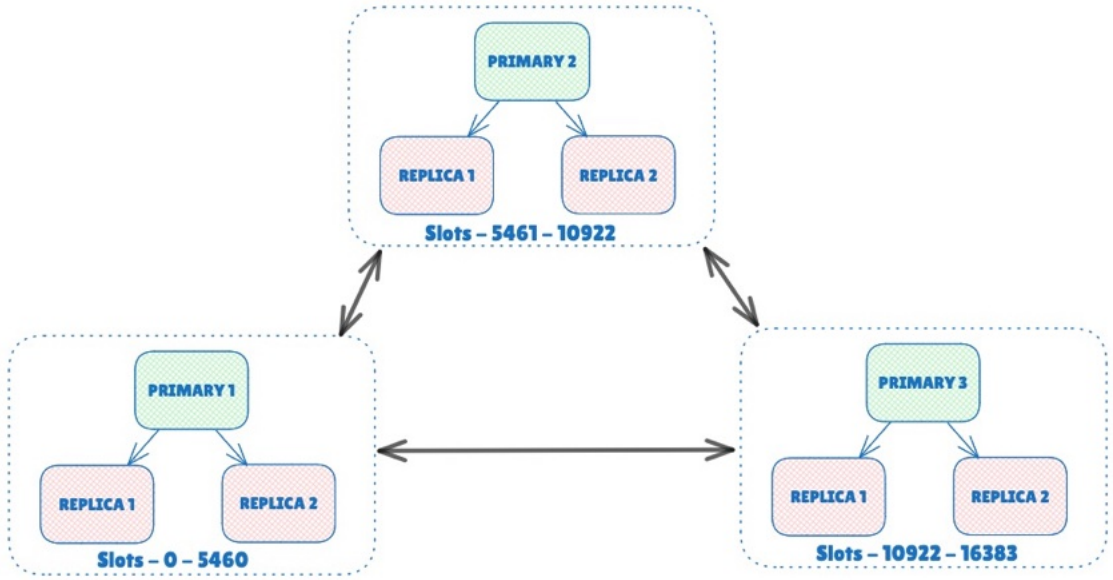
Operation mode



STANDALONE



CLUSTER

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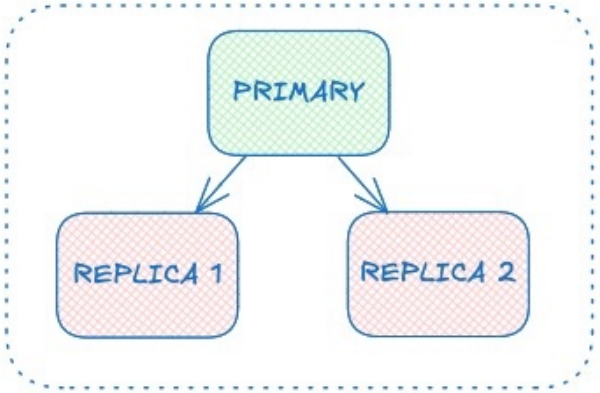
Valkey Standalone Overview

- Single keyspace
- Asynchronous replication
- Scalable reads



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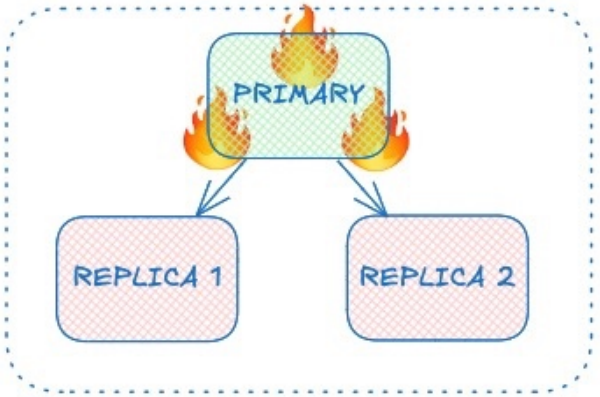
Valkey Standalone - Summary

- Easy to setup
- Lack of fault tolerance
- Memory and write throughput bottleneck



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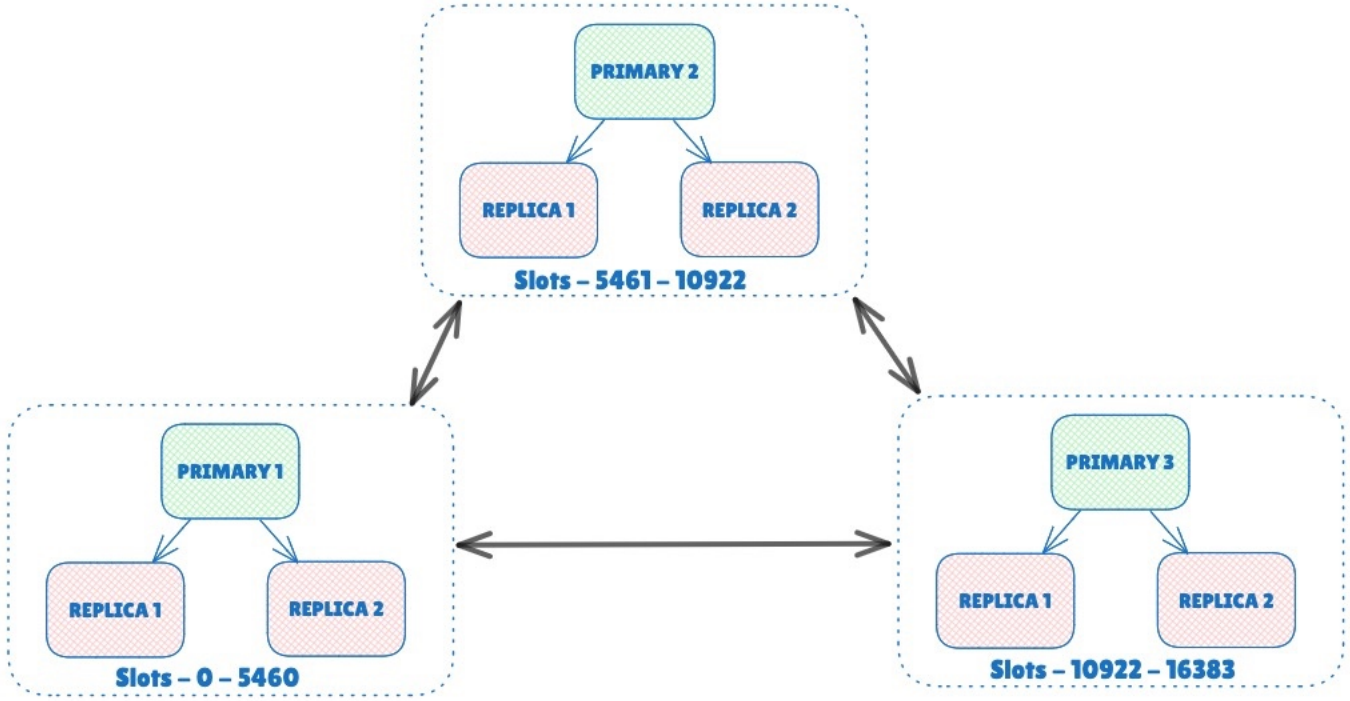
Valkey Cluster Overview

- Horizontally scalable
- Homogenous setup
- Server enabled data sharding
- Automatic client redirection
- In-built fault tolerance



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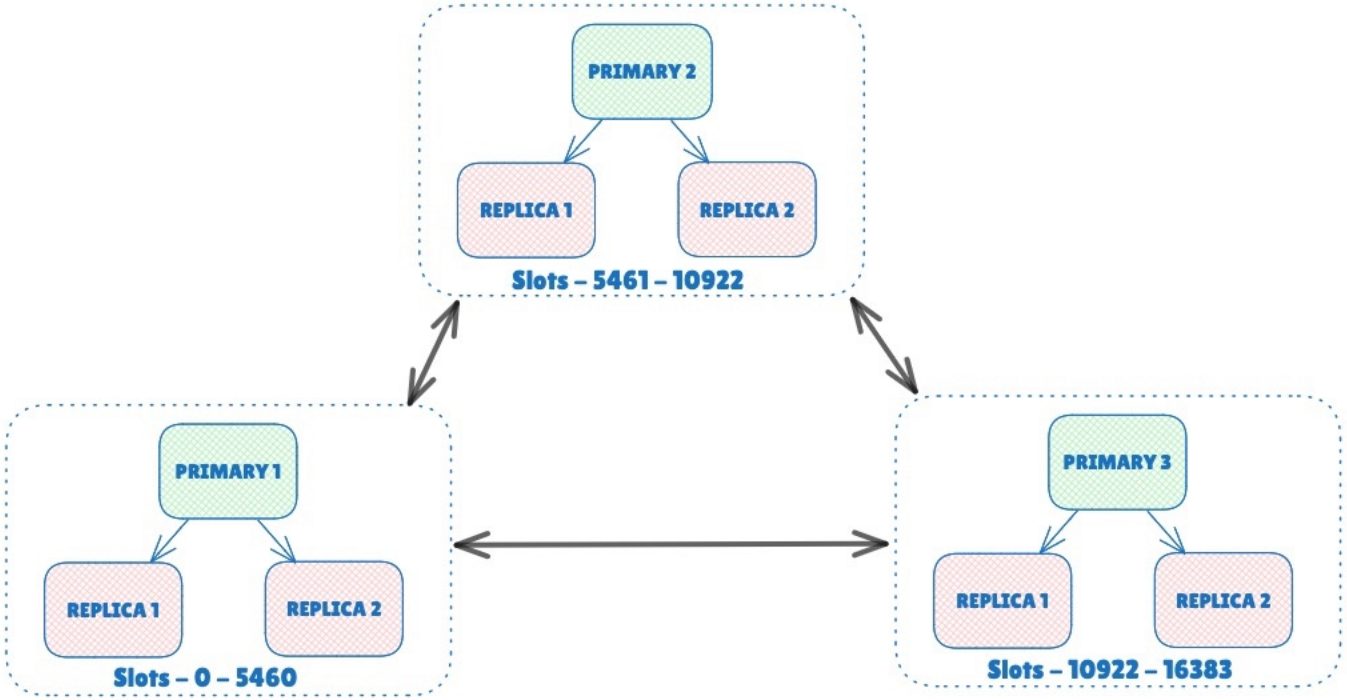
Cluster Mode Components

- Cluster Node
- Cluster Slots
- Cluster Bus



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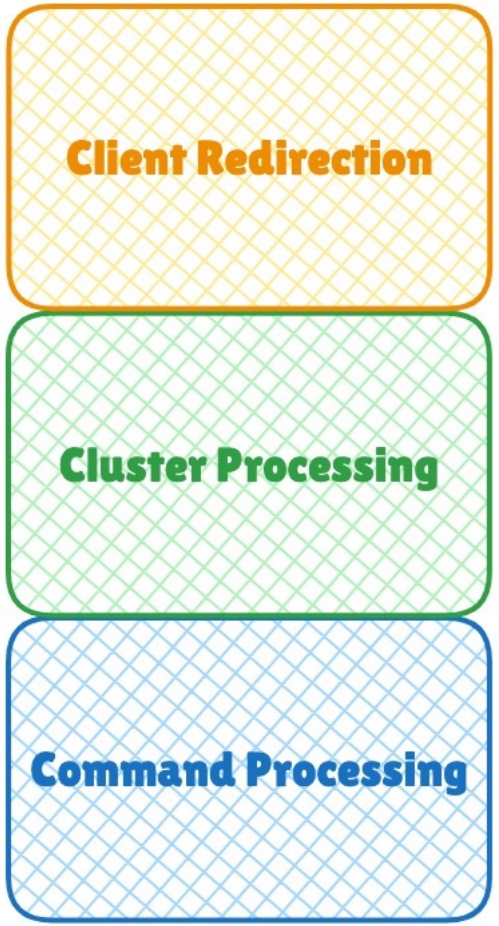
Cluster Node

- Serves data
- Health detection
- Serves topology information



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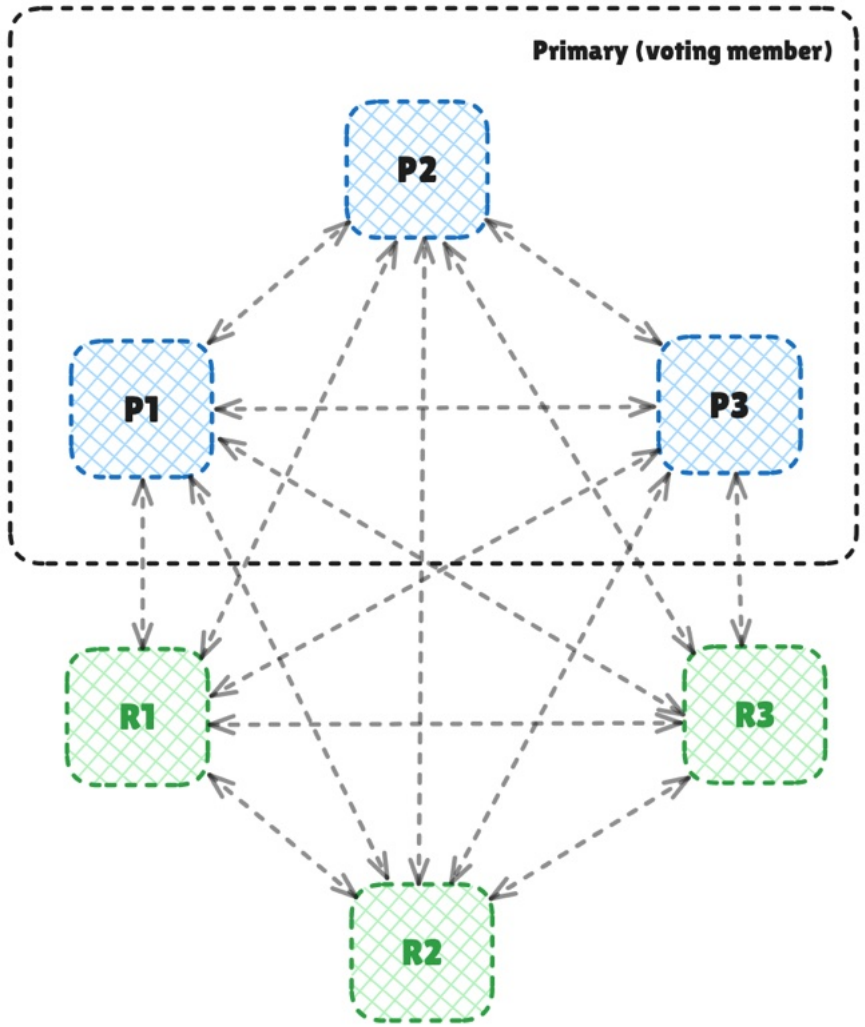
Cluster Node (Contd.)

- Primary
  - Quorum - Voting member
- Replica
  - Election candidate



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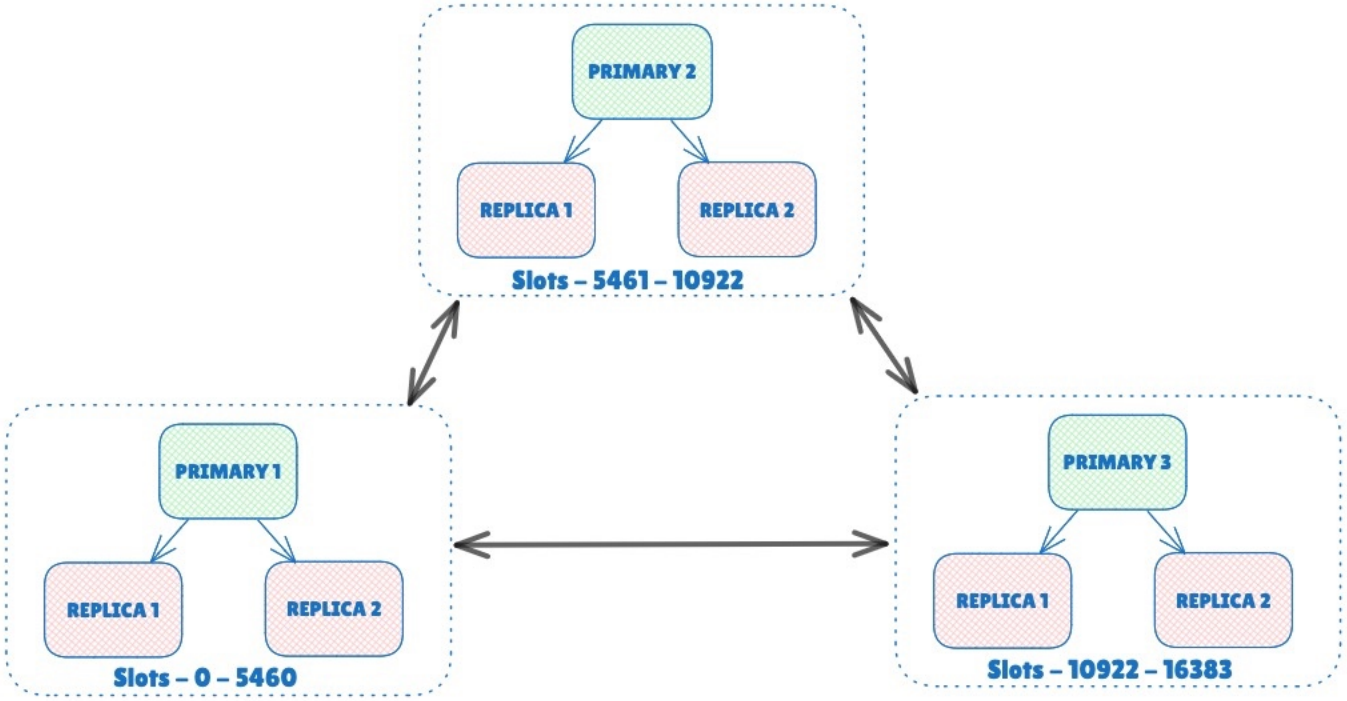
Cluster Slots

- Hashes key to a slot
- Slot to a node
- Key distribution – 16384 slots
- Algorithm - CRC16(key) % 16384
- Primary – one or more slots



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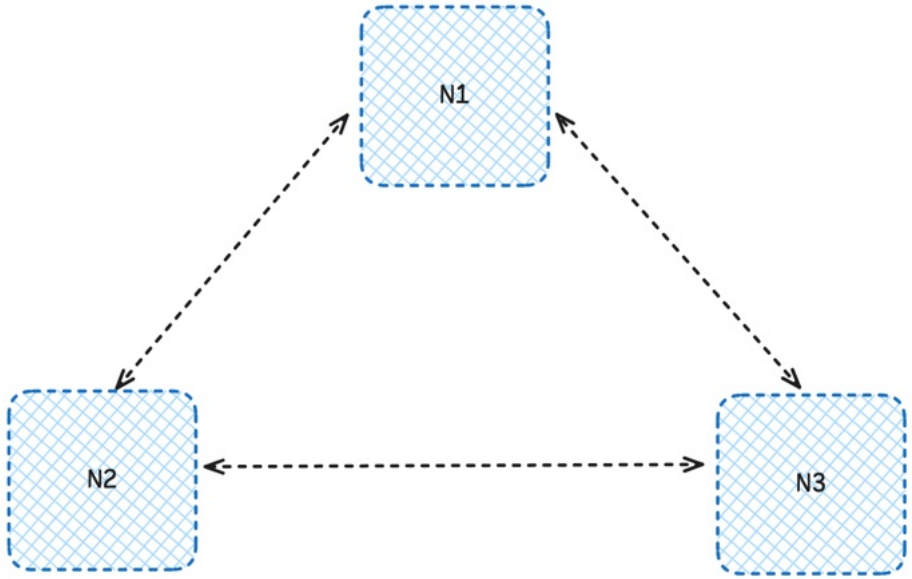
Cluster Bus

- Bidirectional persistent TCP connection between nodes
- Mesh topology
- Custom message protocol
- Gossip – piggyback information
- Supports Pub/Sub traffic



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Cluster Bus – Message Type

- New node discovery - MEET
- Heart beat – PING / PONG
- Node failure – FAIL / UPDATE
- PubSub – PUBSUB / PUBSUBSHARD

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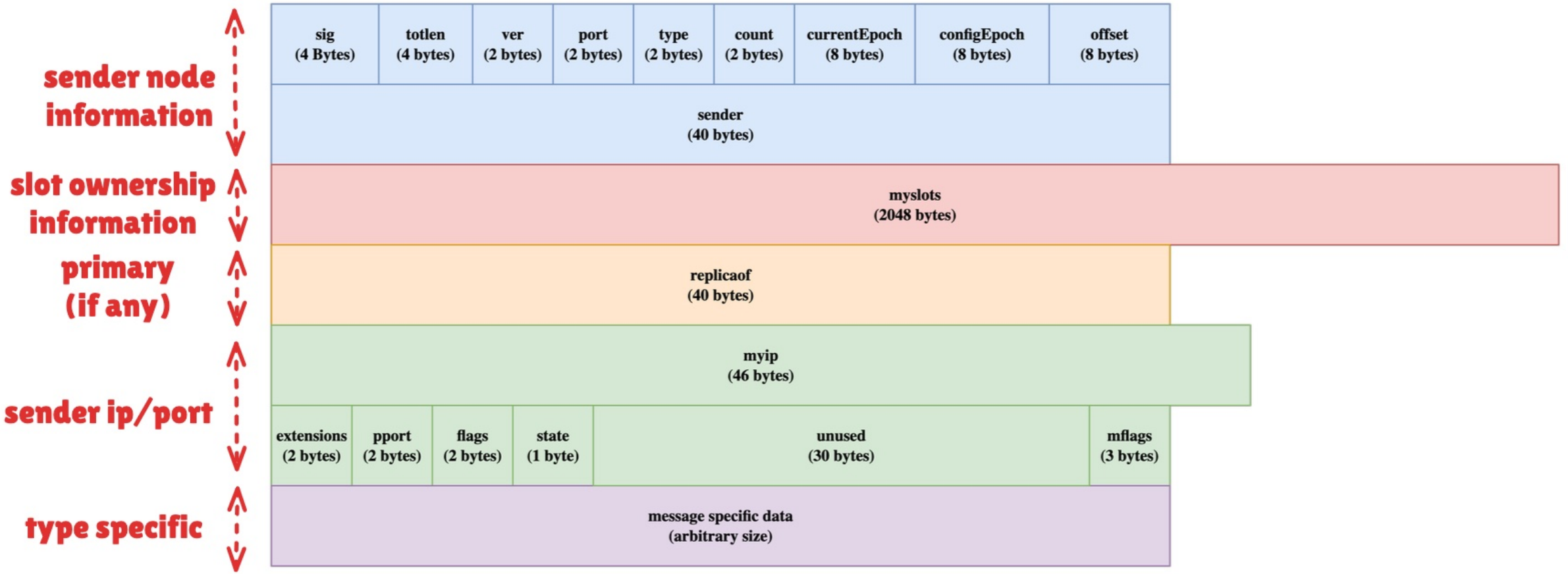
Cluster Bus - Message Header Format



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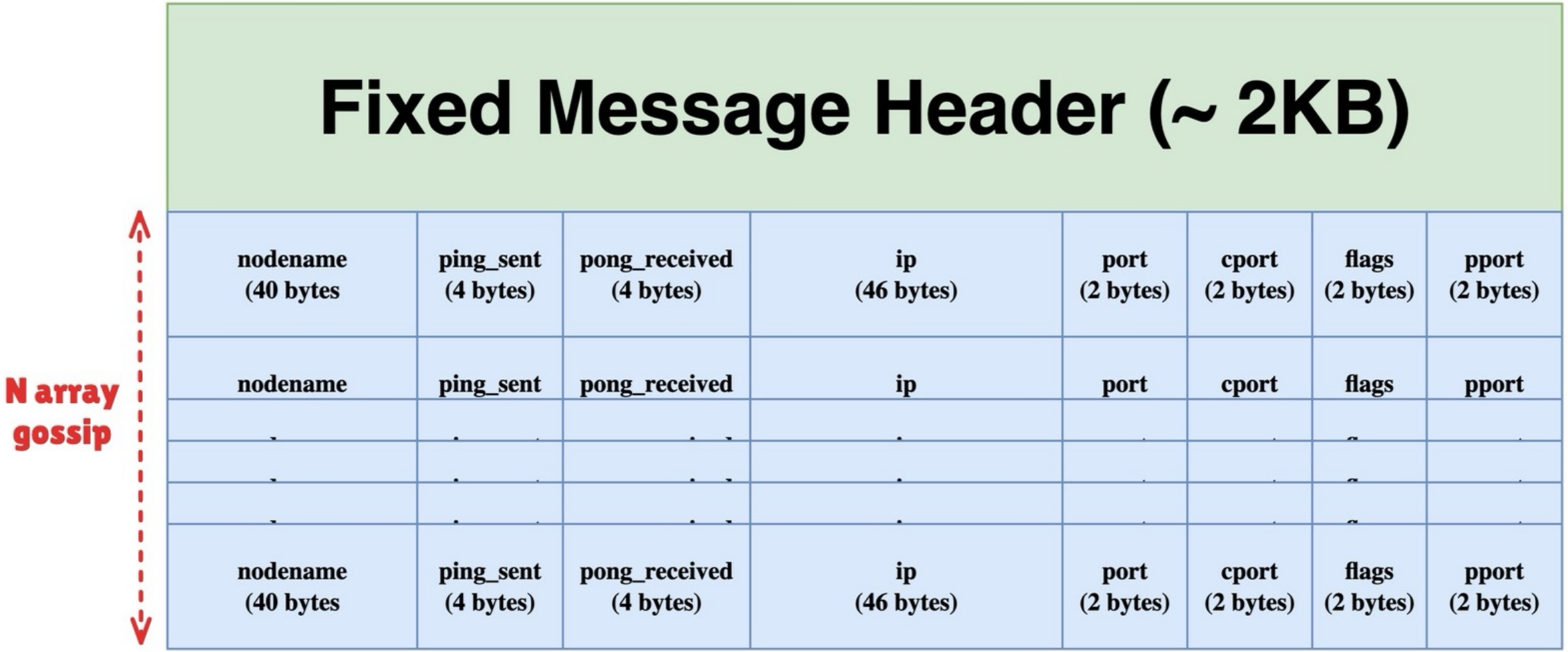
Cluster Bus - Message Header (PING/PONG/MEET)



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Cluster Coordination Mechanism

- Membership
- Redirection - Client
- Failure detection
- Failover
- Versioning – Conflict Resolution

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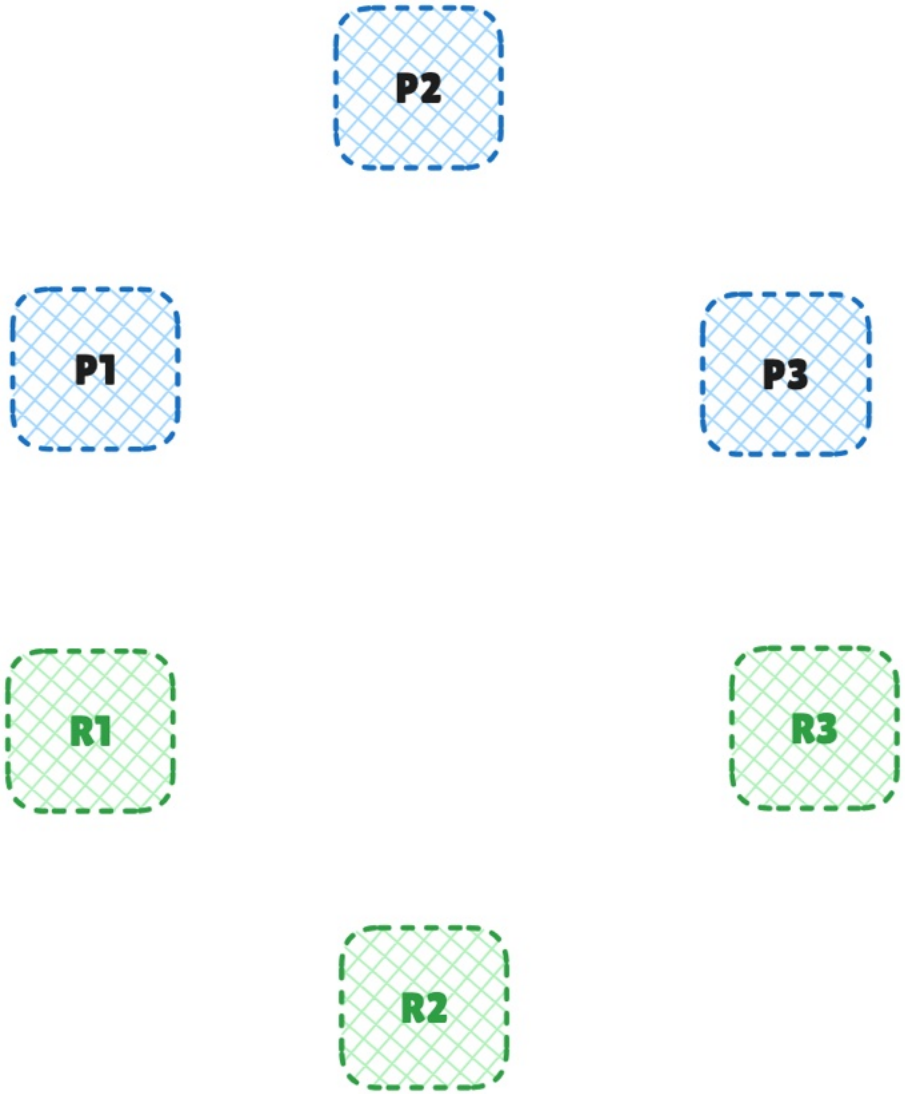
Cluster Node Membership



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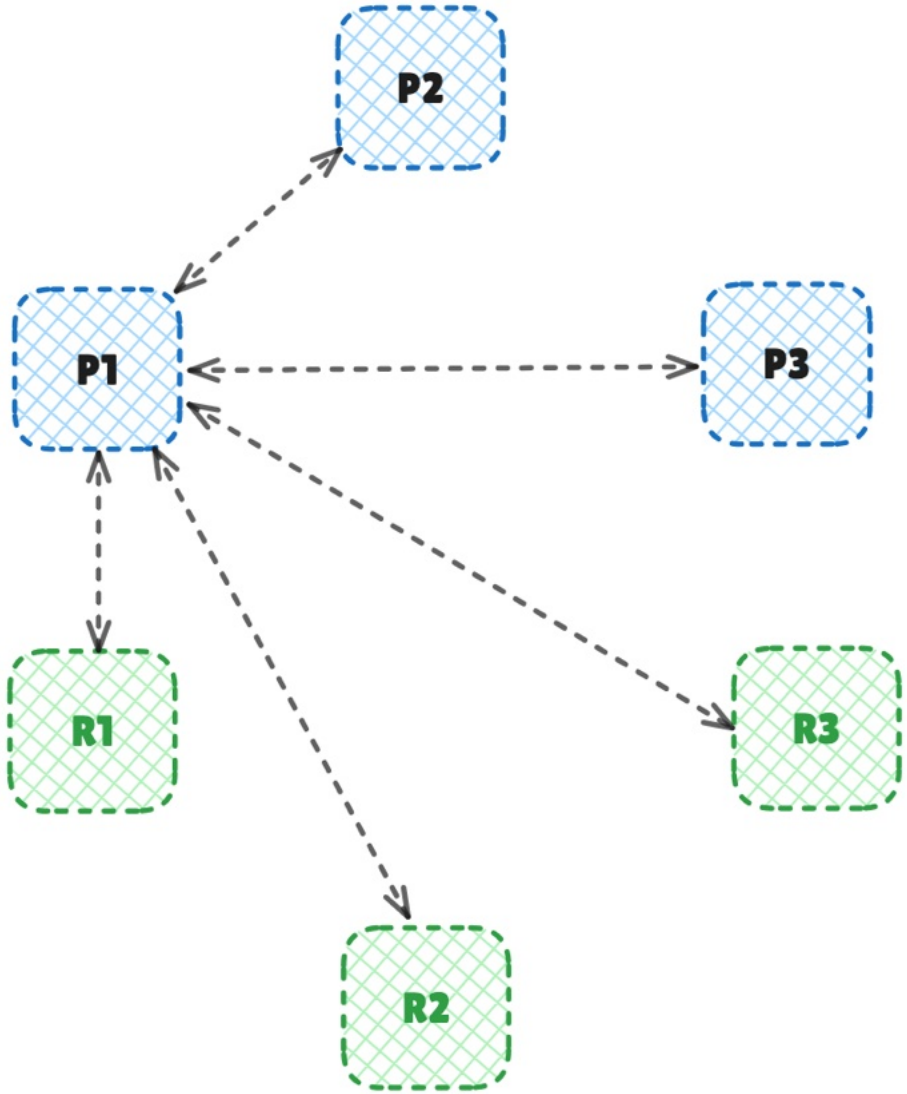
Node Membership – Seed node discovery



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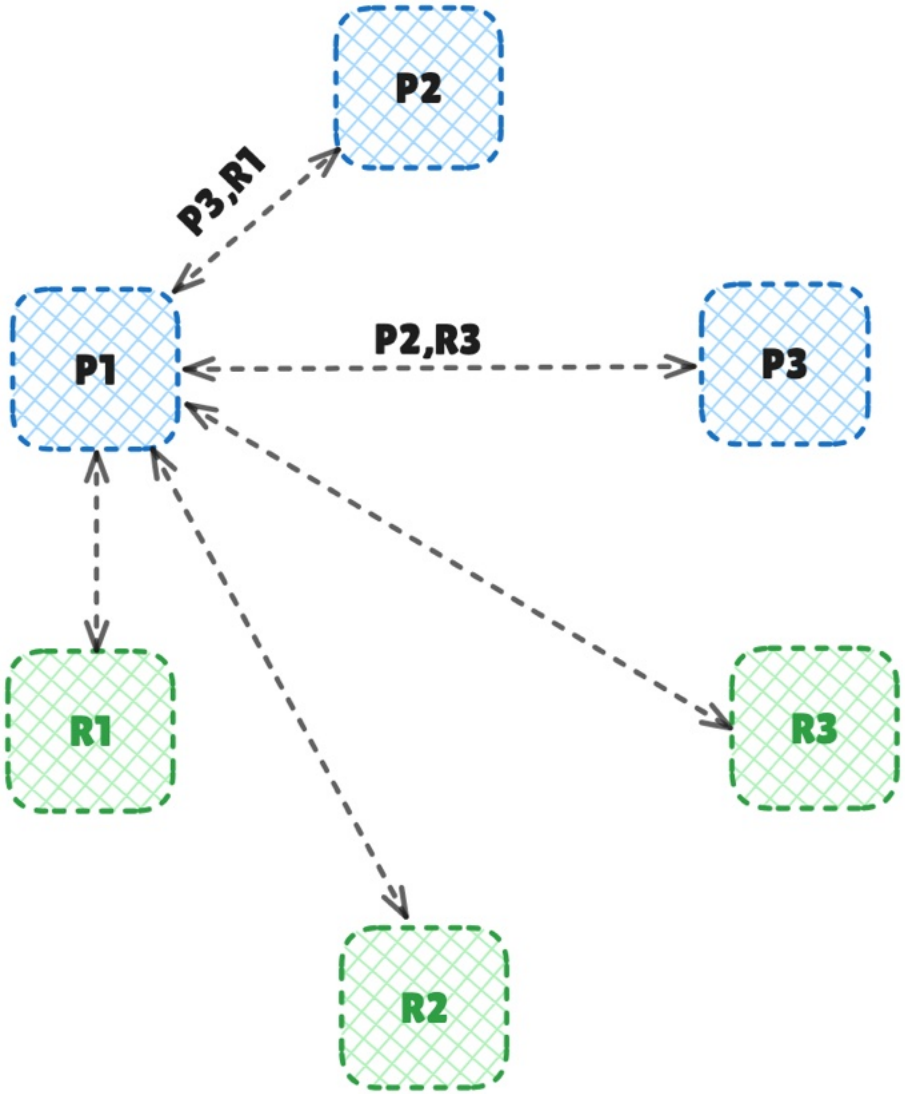
Node Membership – Gossip



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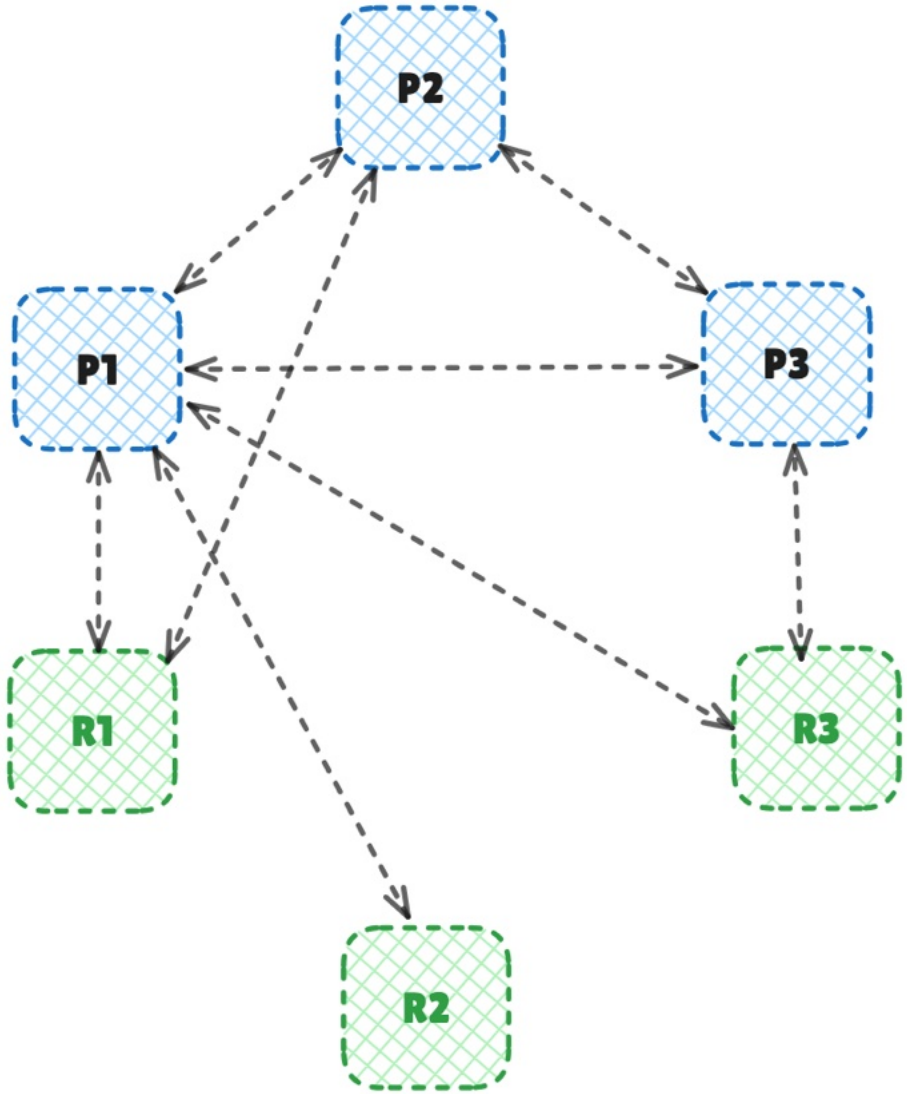
Node Membership– Discovery via gossip



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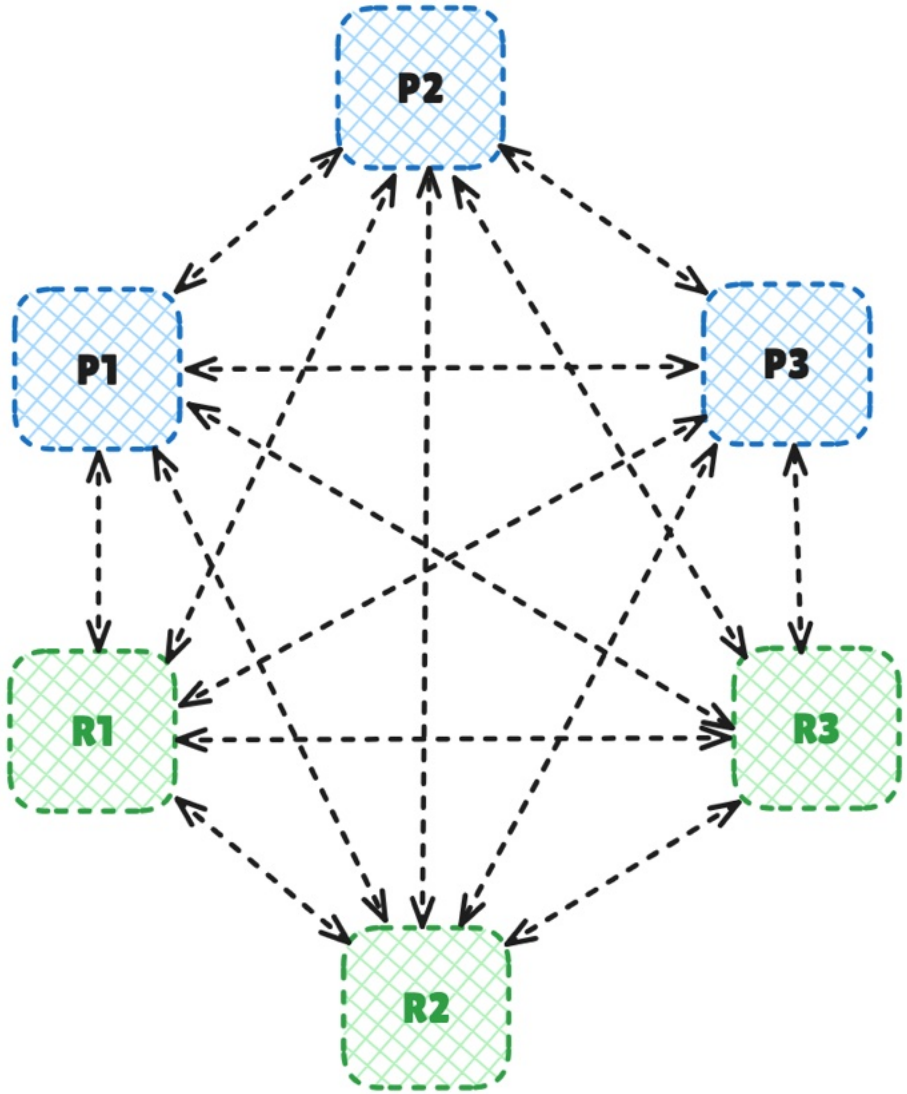
Node Membership – Fully connected



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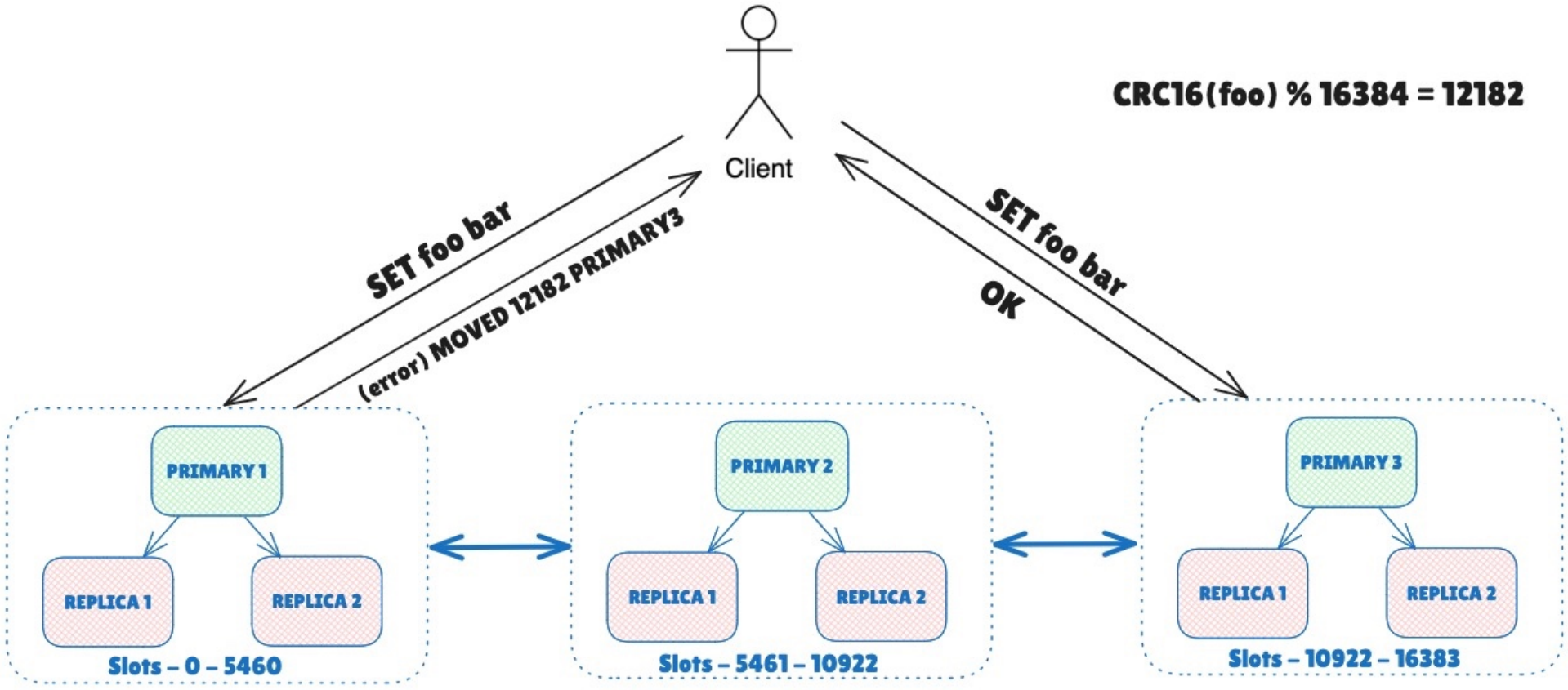
Node Redirection - Client



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Failure Detection – PING/PONG

- ping-sent
- pong-received
- Partial failure – node-timeout / 2
- Complete failure (Quorum) – node-timeout
- node-timeout is configurable

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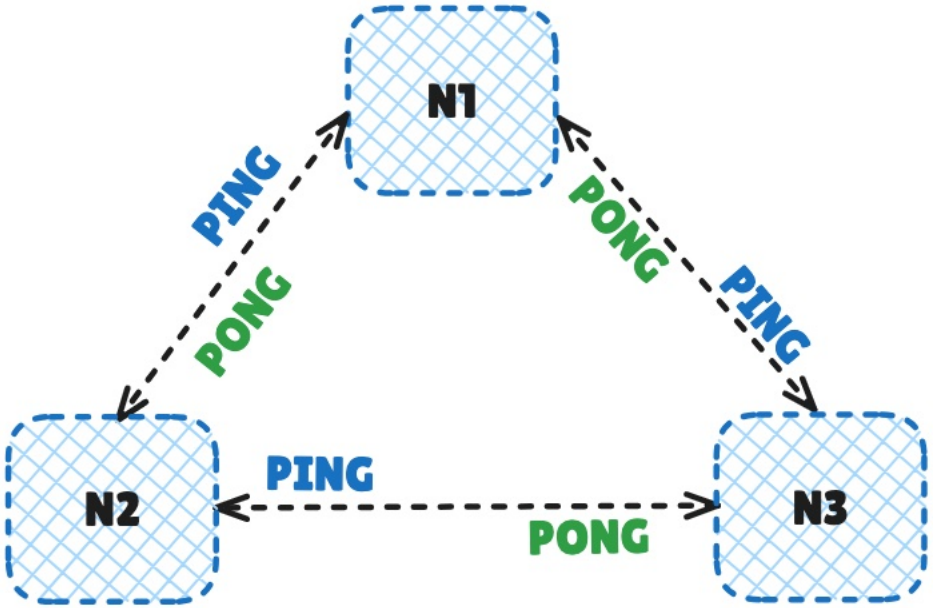
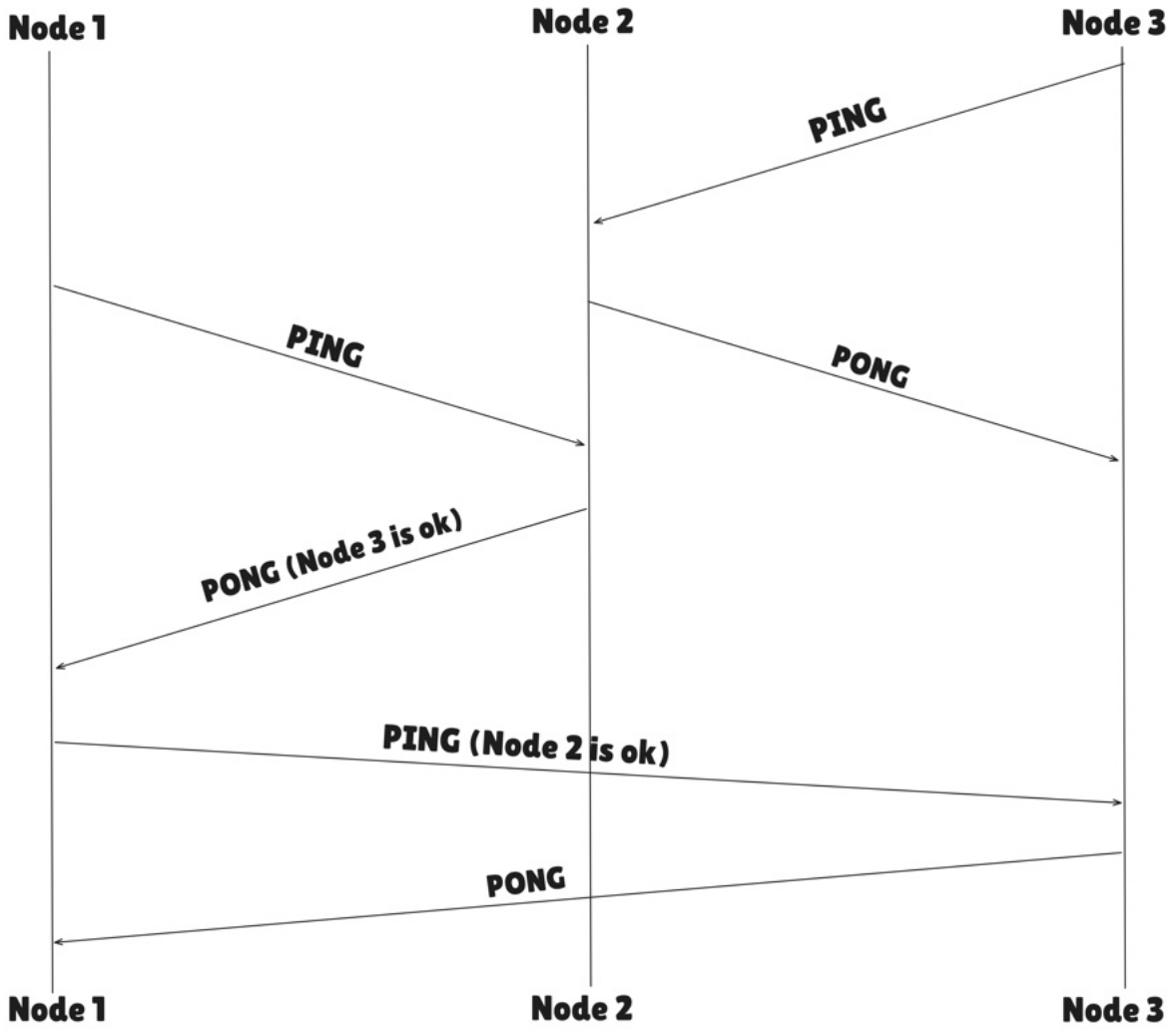
Failure Detection – Healthy State





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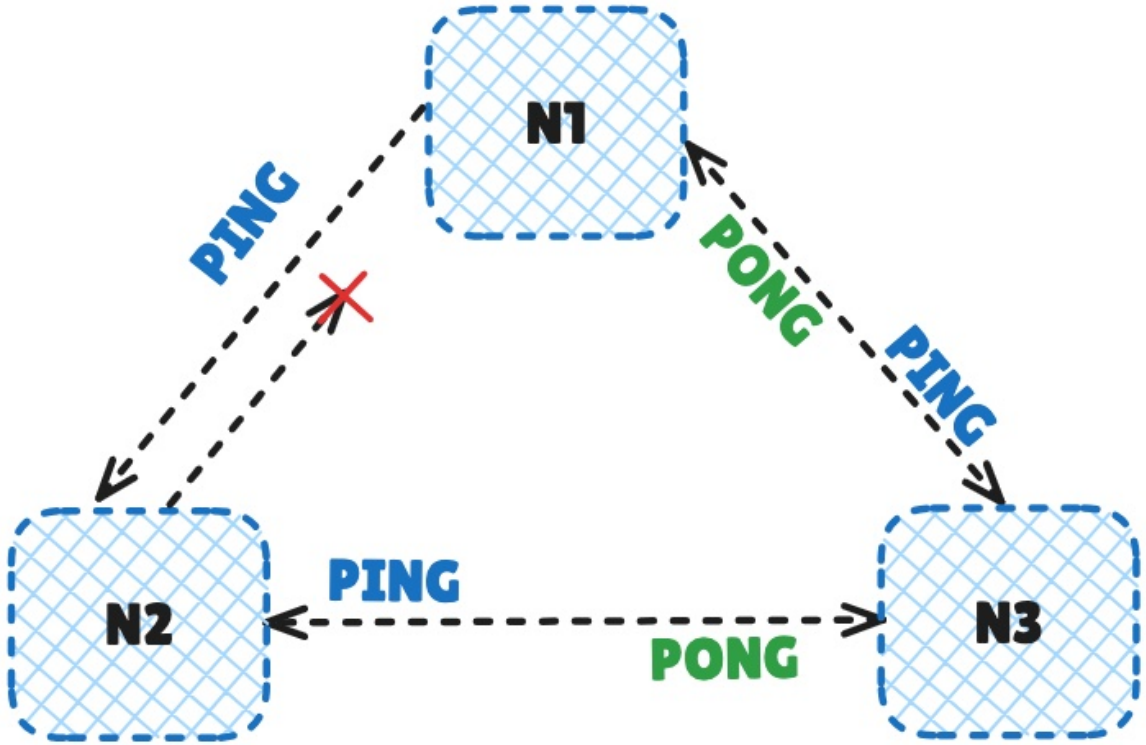
Failure Detection – Partial failure



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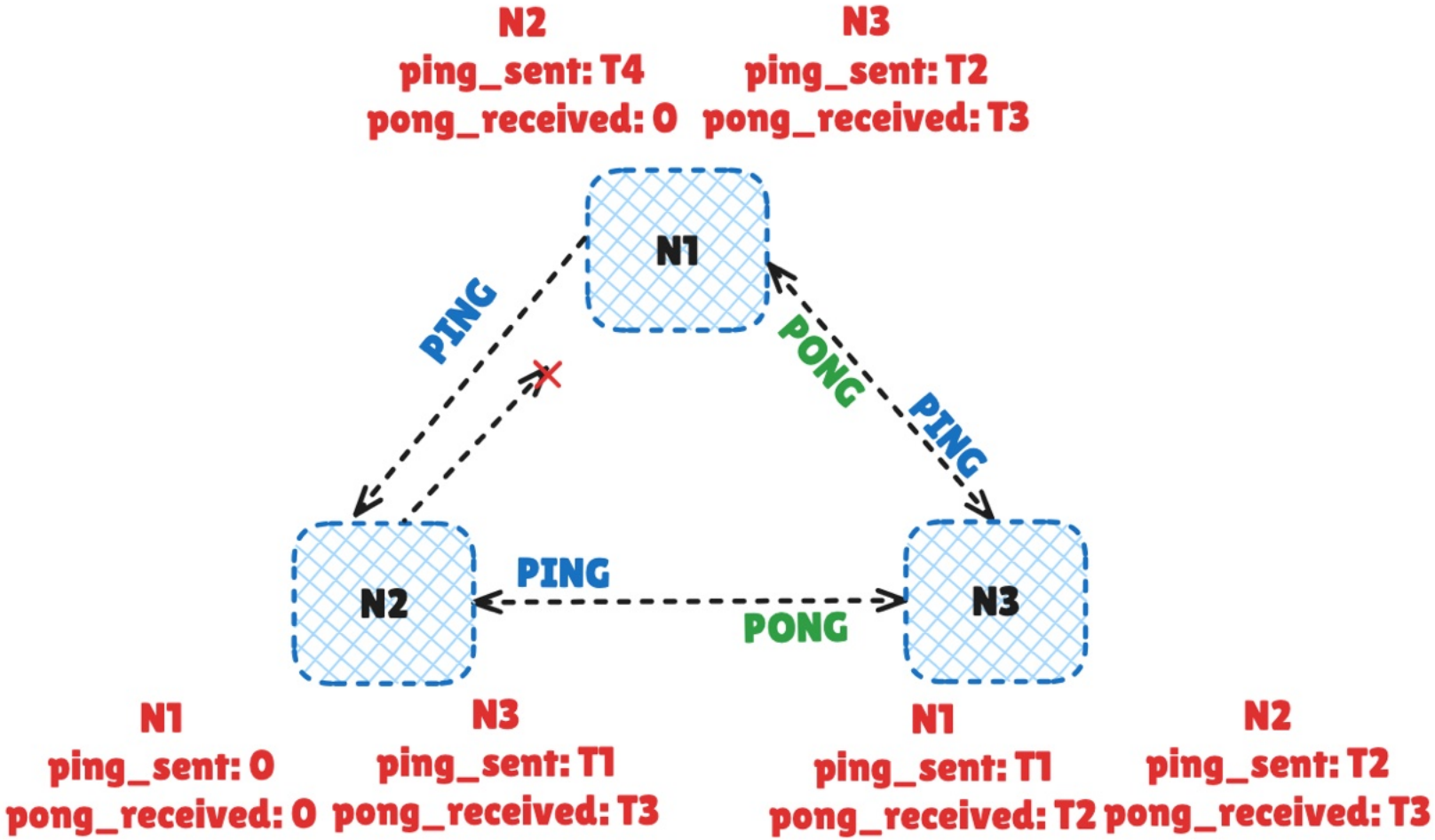
Failure Detection – Partial failure



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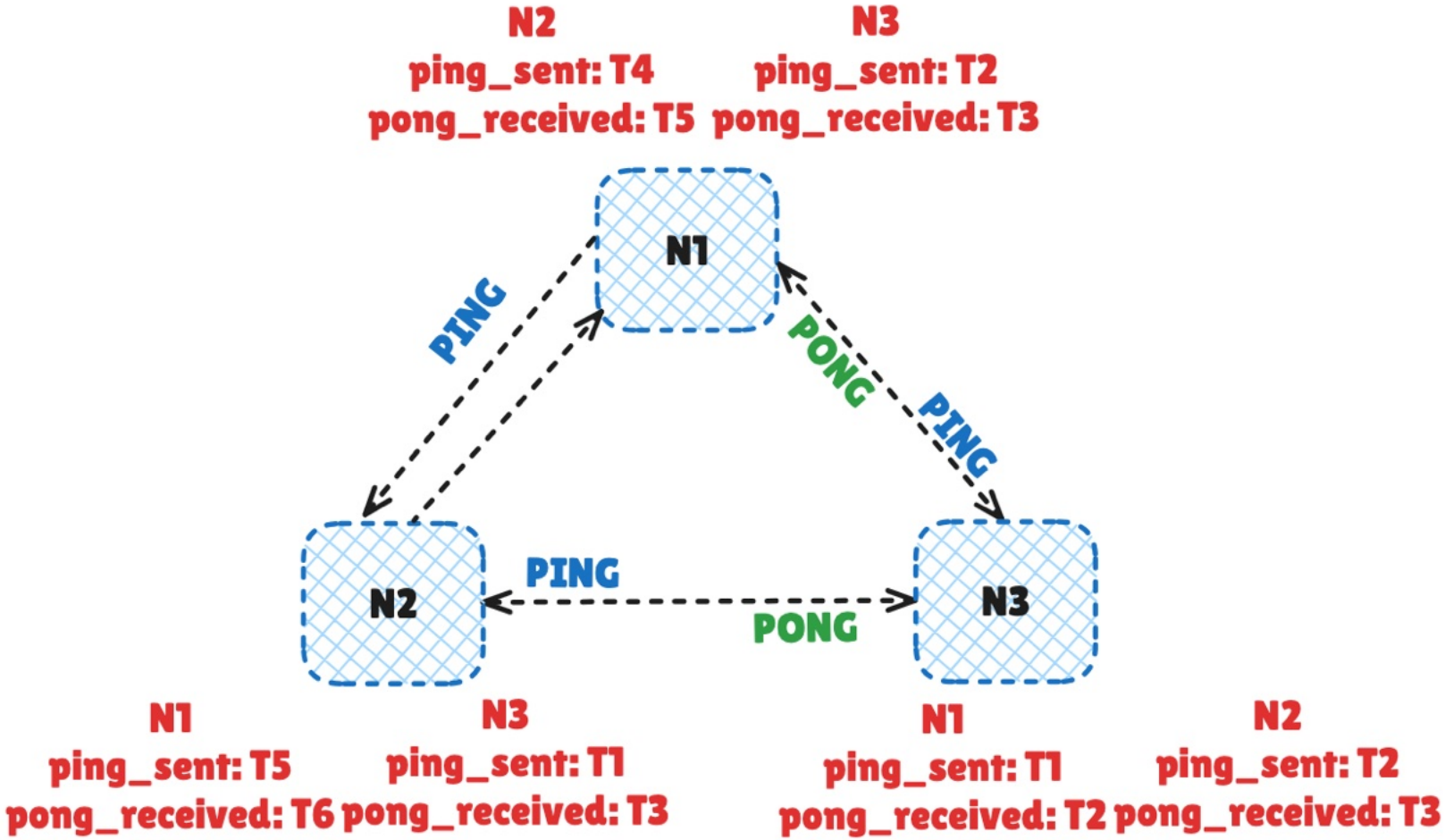
Failure Detection – Healthy



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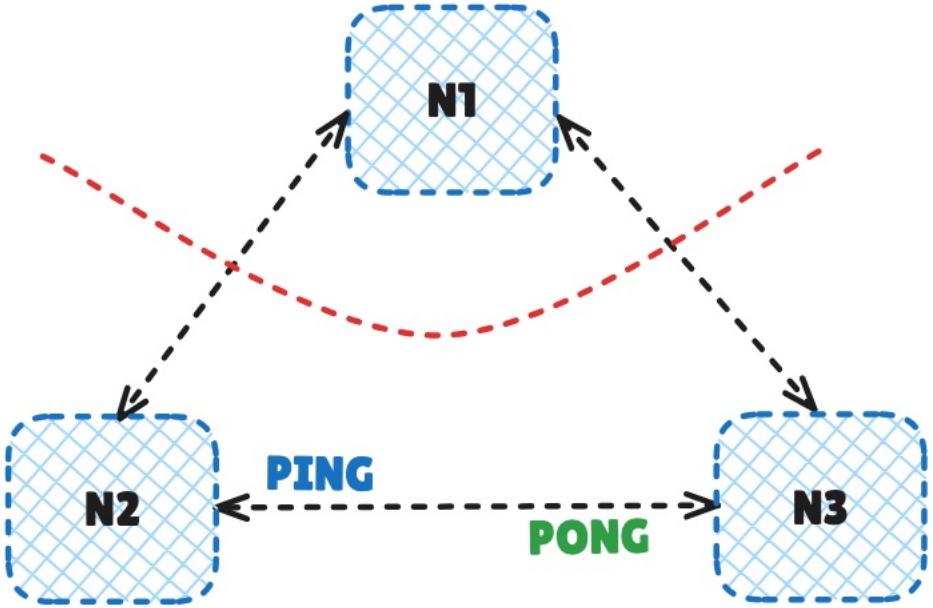
Failure Detection - Partition



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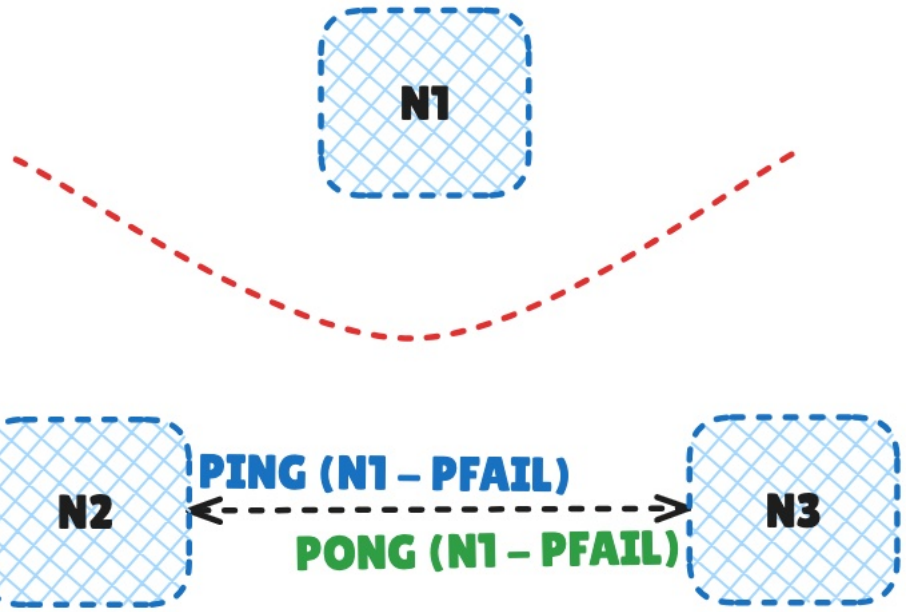
Failure Detection – Time out gossip



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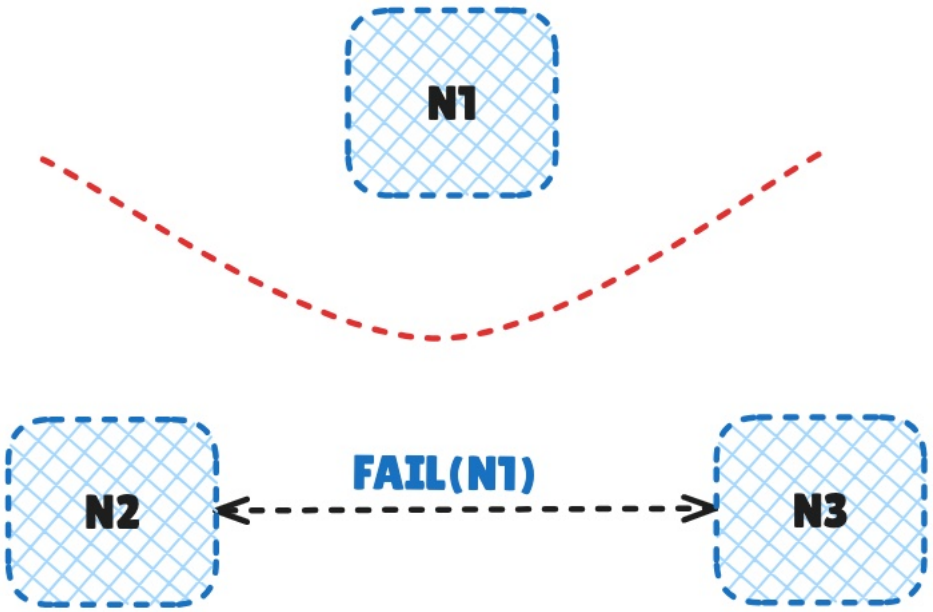
Failure Detection - Broadcast



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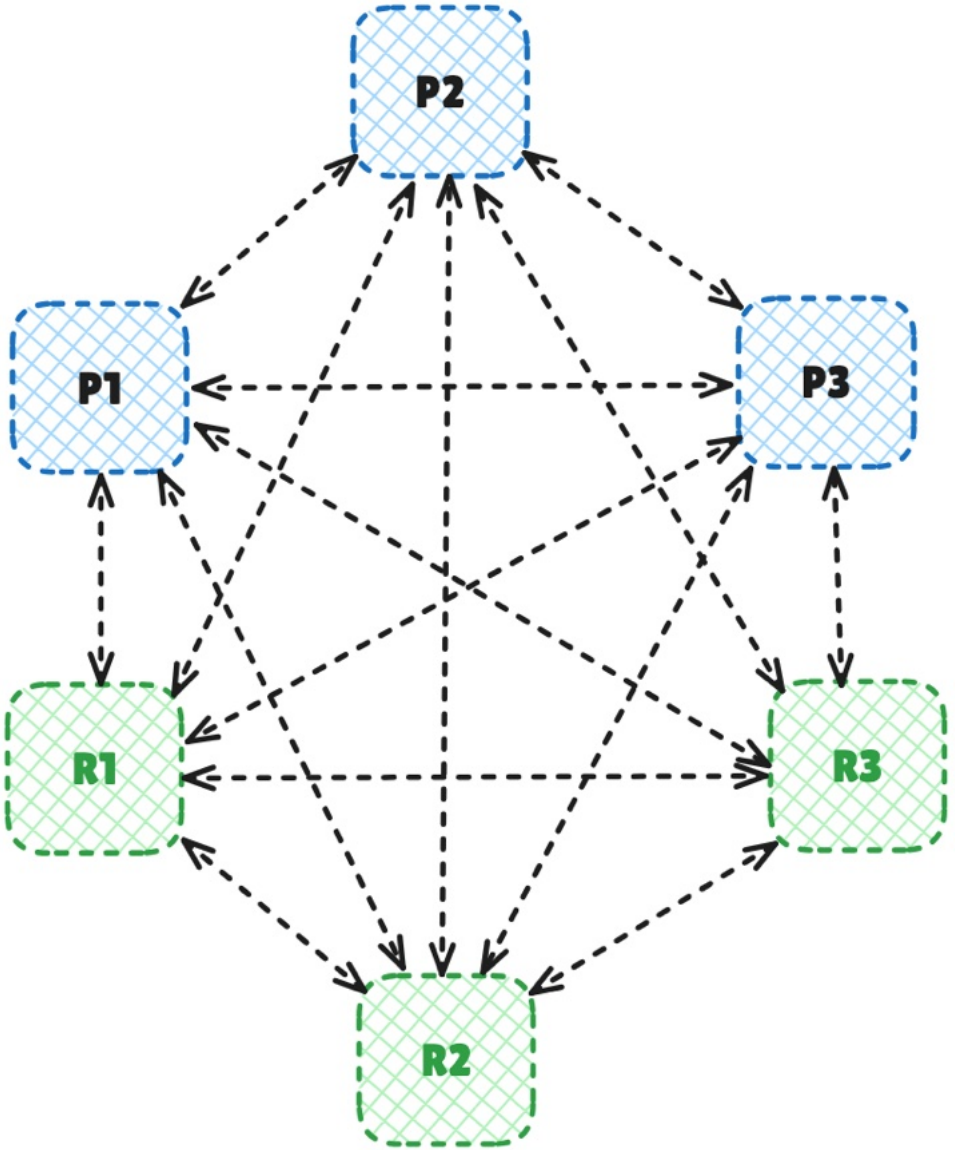
Failover



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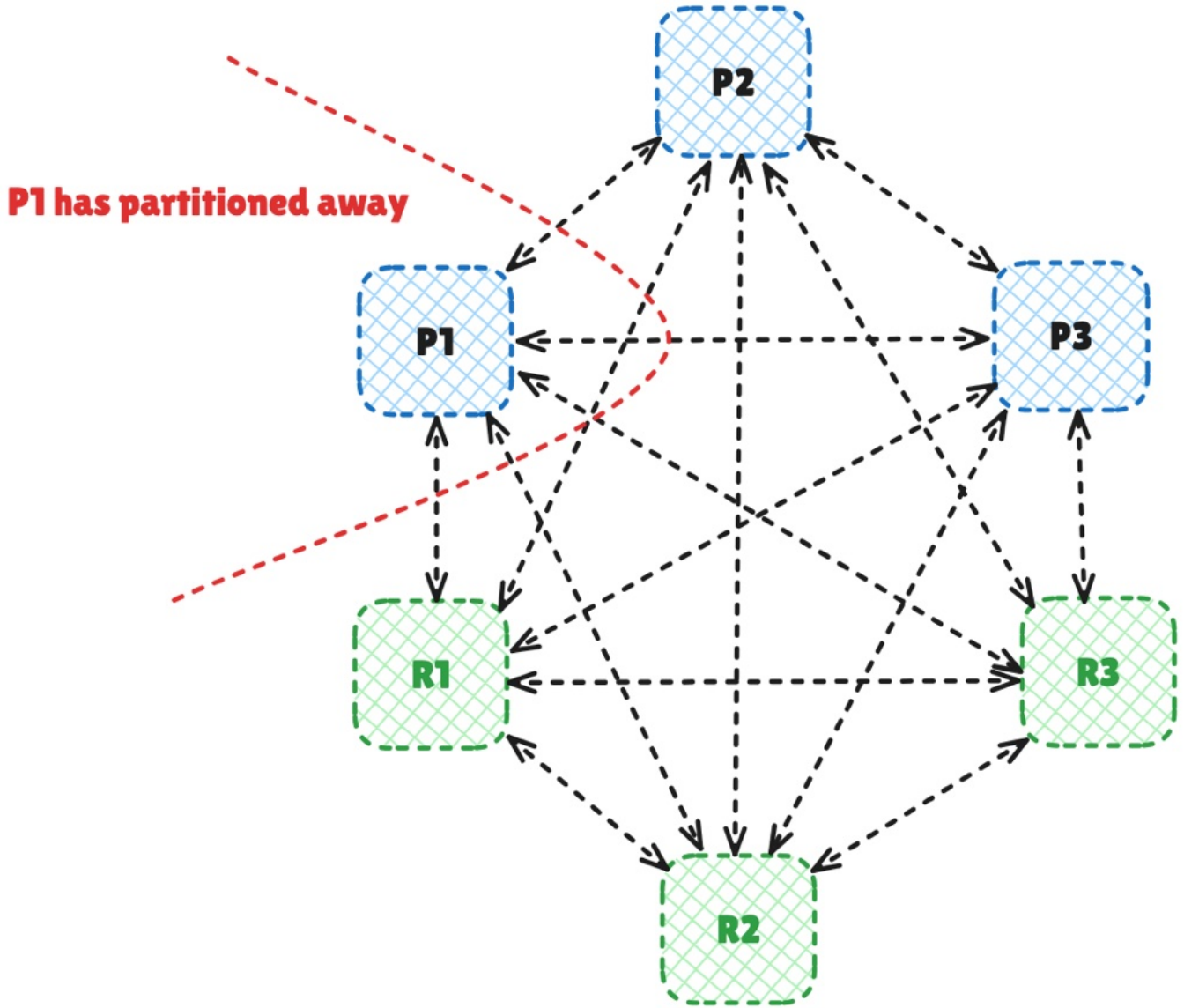
Failover – Failure detection



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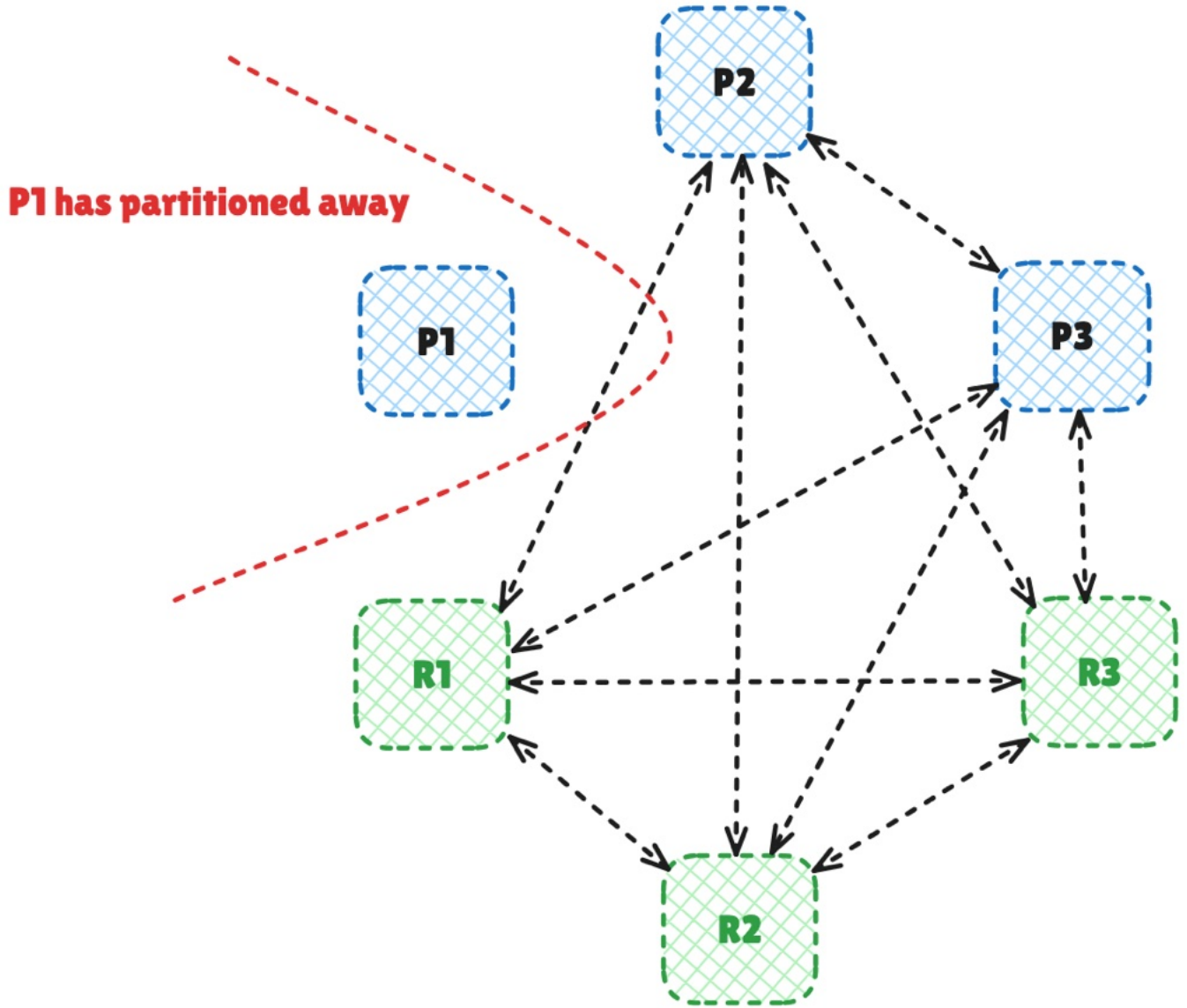
Failover – Link disconnection



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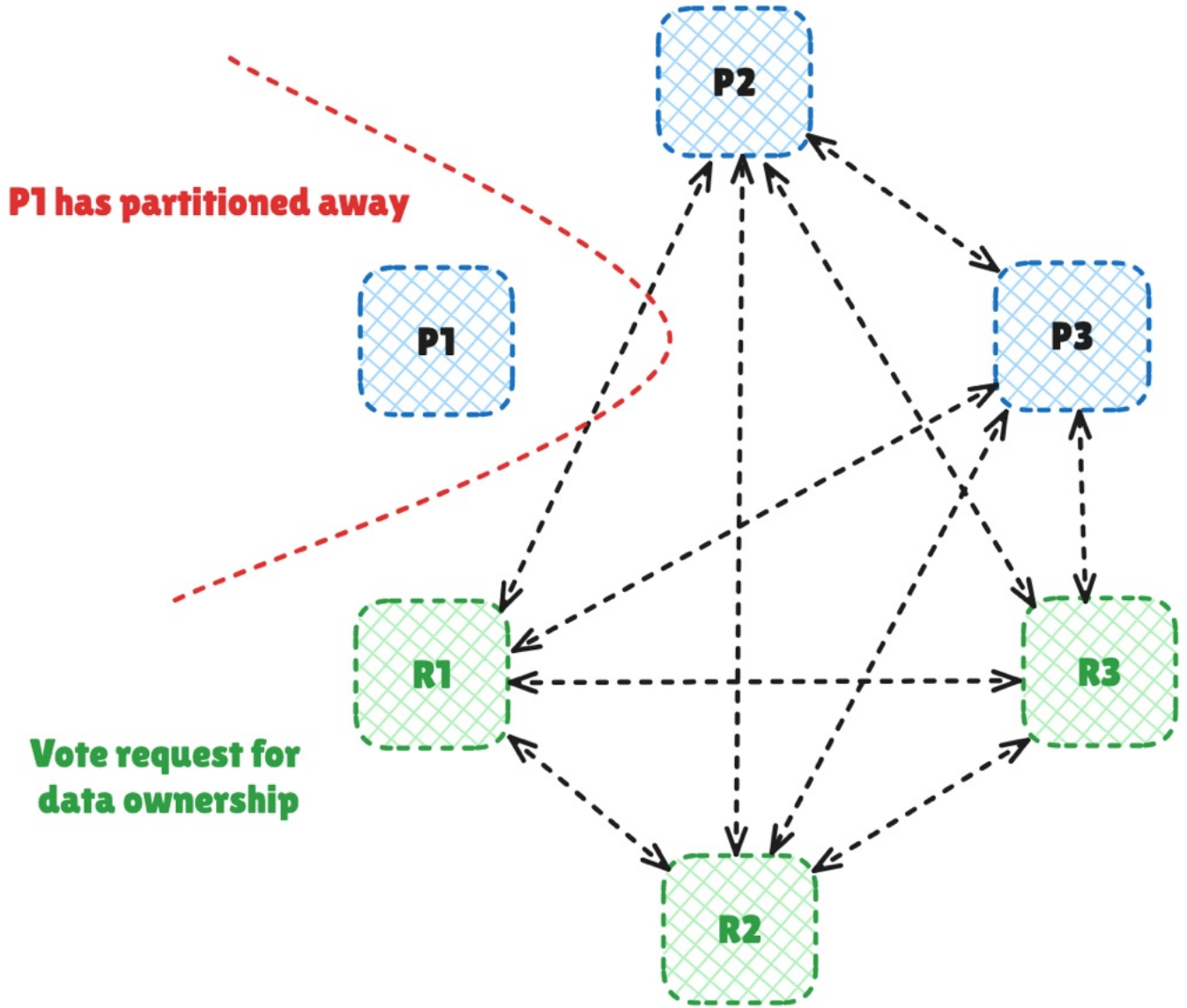
Failover – Replica promotion request



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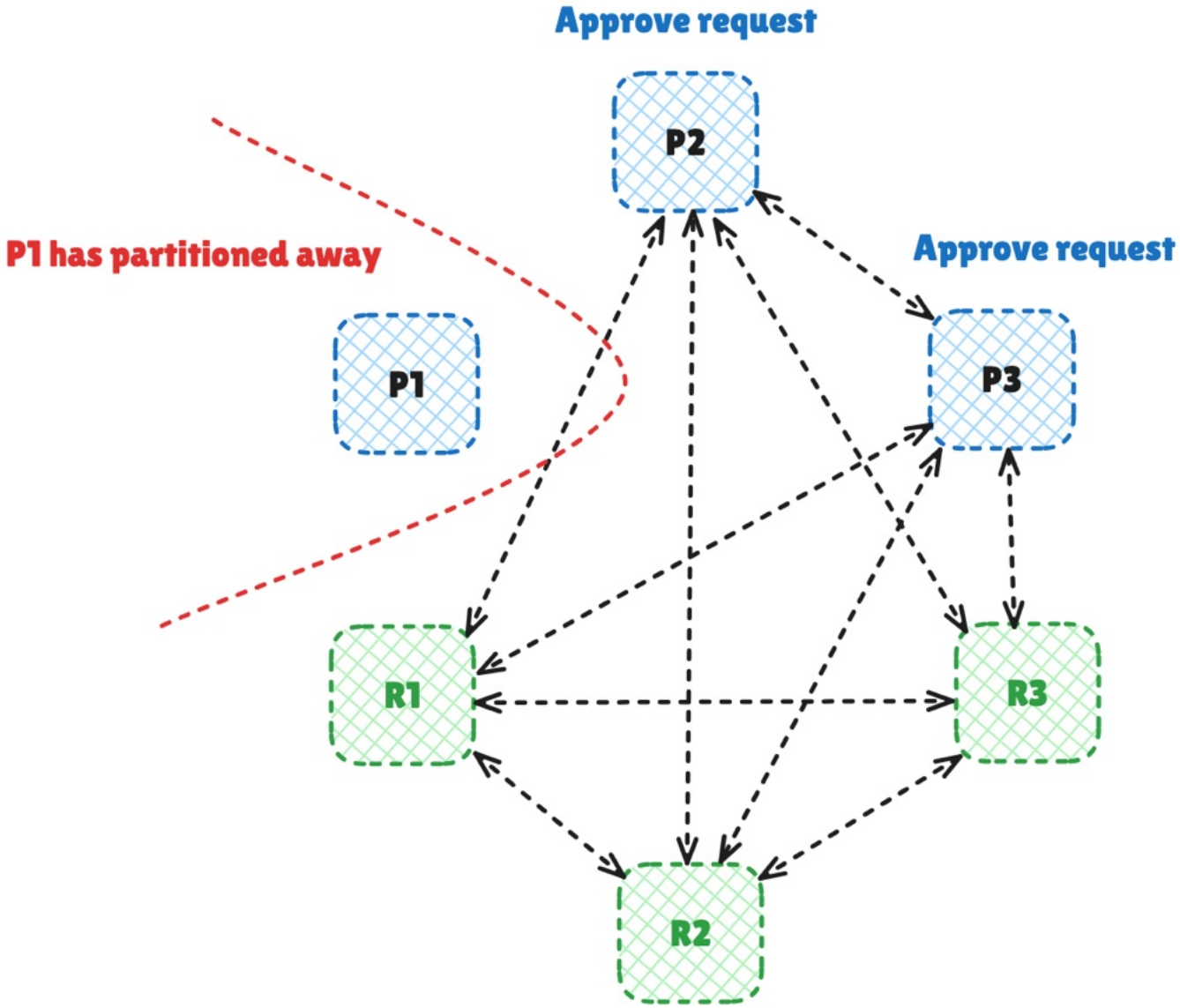
Failover – Replica promotion request



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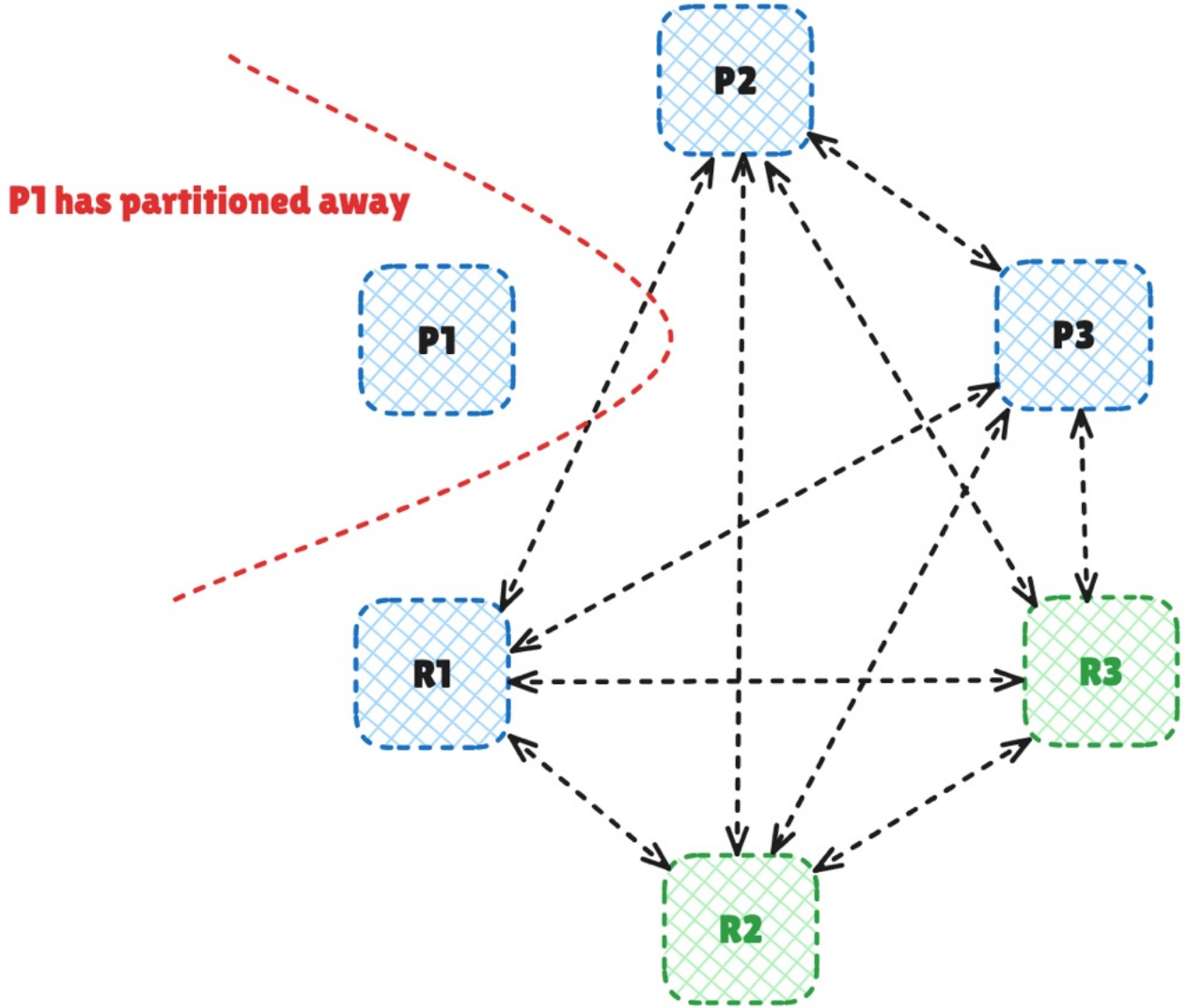
Failover – Replica promoted



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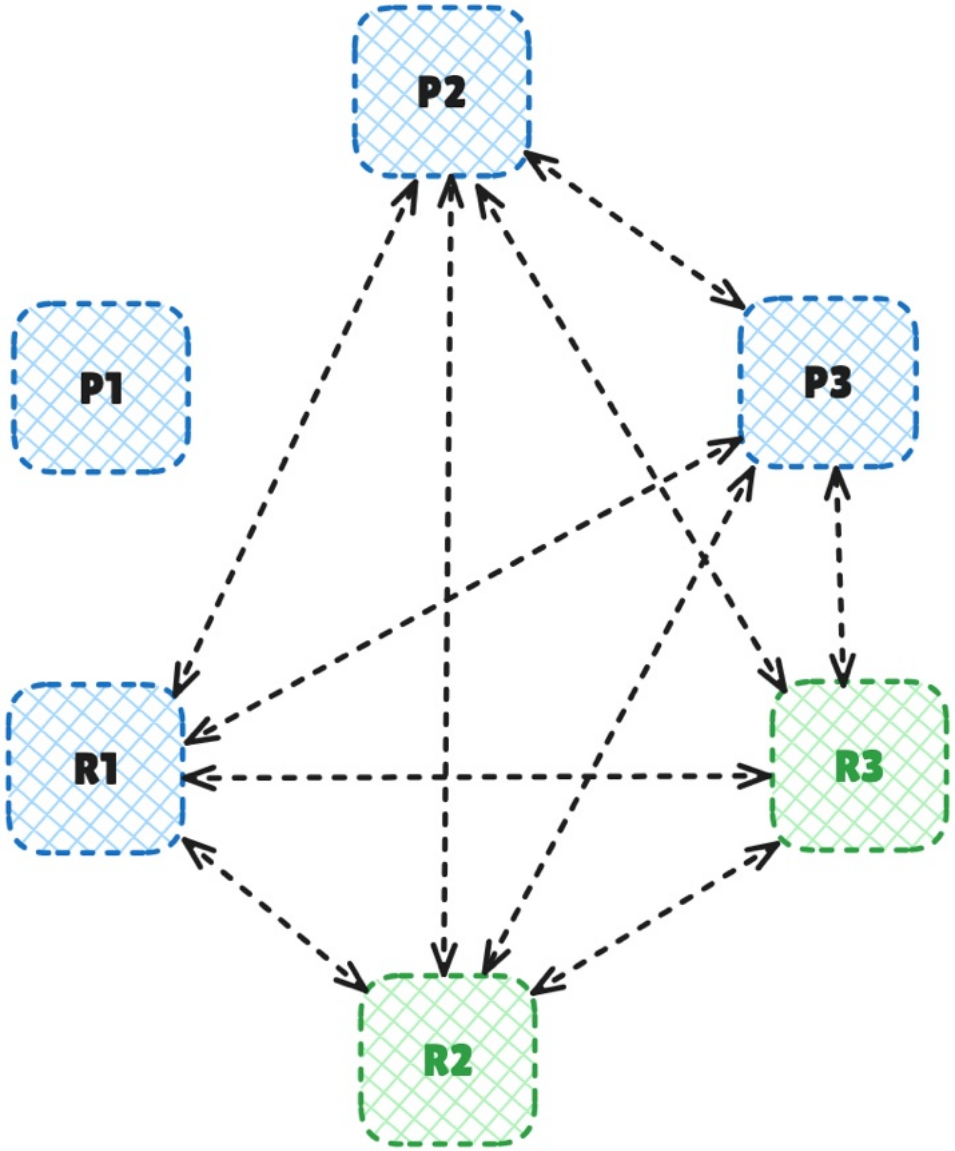
Failover – Partition heal start



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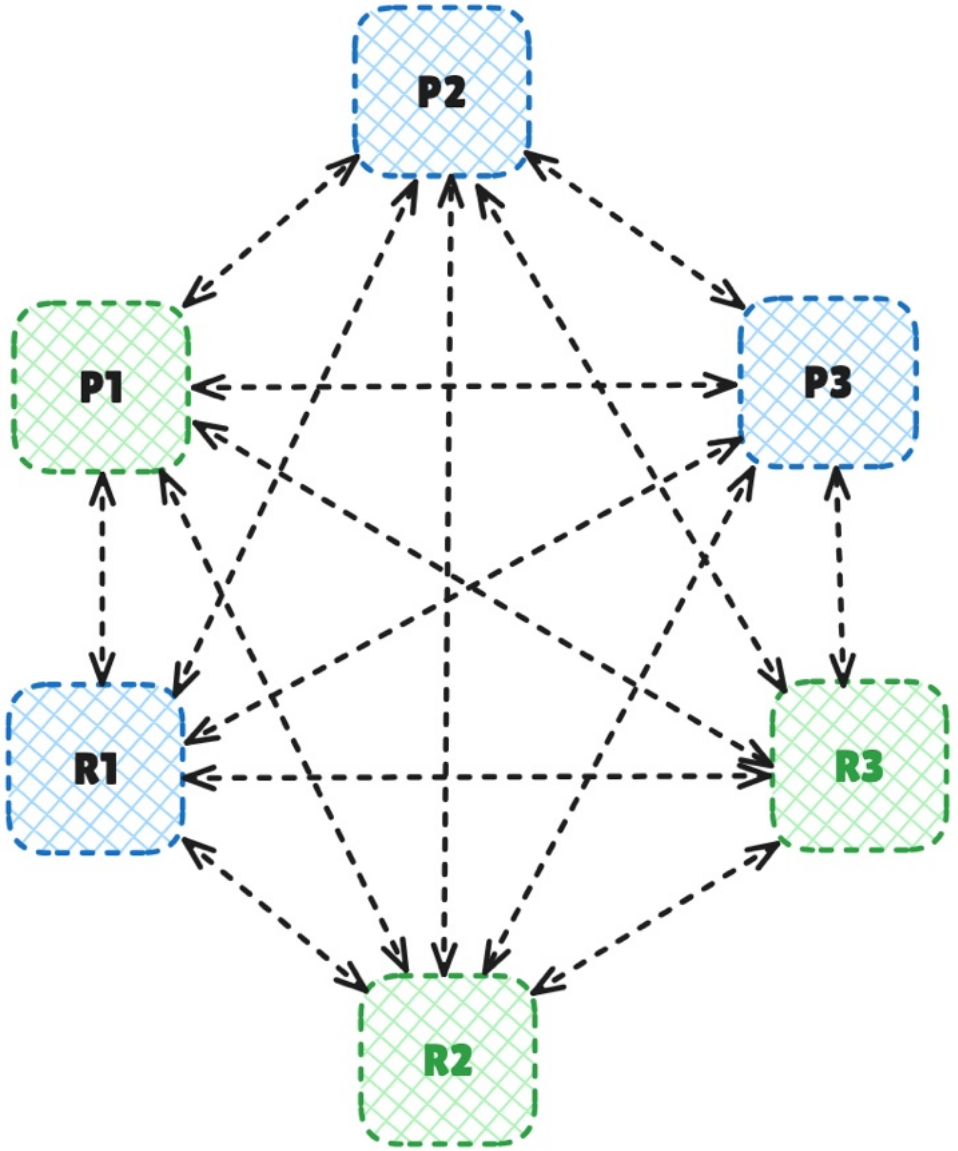
Failover – New topology



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Conflict Resolution - Epoch

- Decentralized cluster – no single source of truth
- Monotonically increasing counter
- Conflict resolution
  - config epoch, node id to break ties safely

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Conflict Resolution – Epoch Types

- Node level epoch – config epoch
  - Per node epoch indicating **authority over slots**
- Cluster wide epoch – cluster epoch
  - Global for the **entire cluster**
  - Incremented during failovers to assign unique epochs

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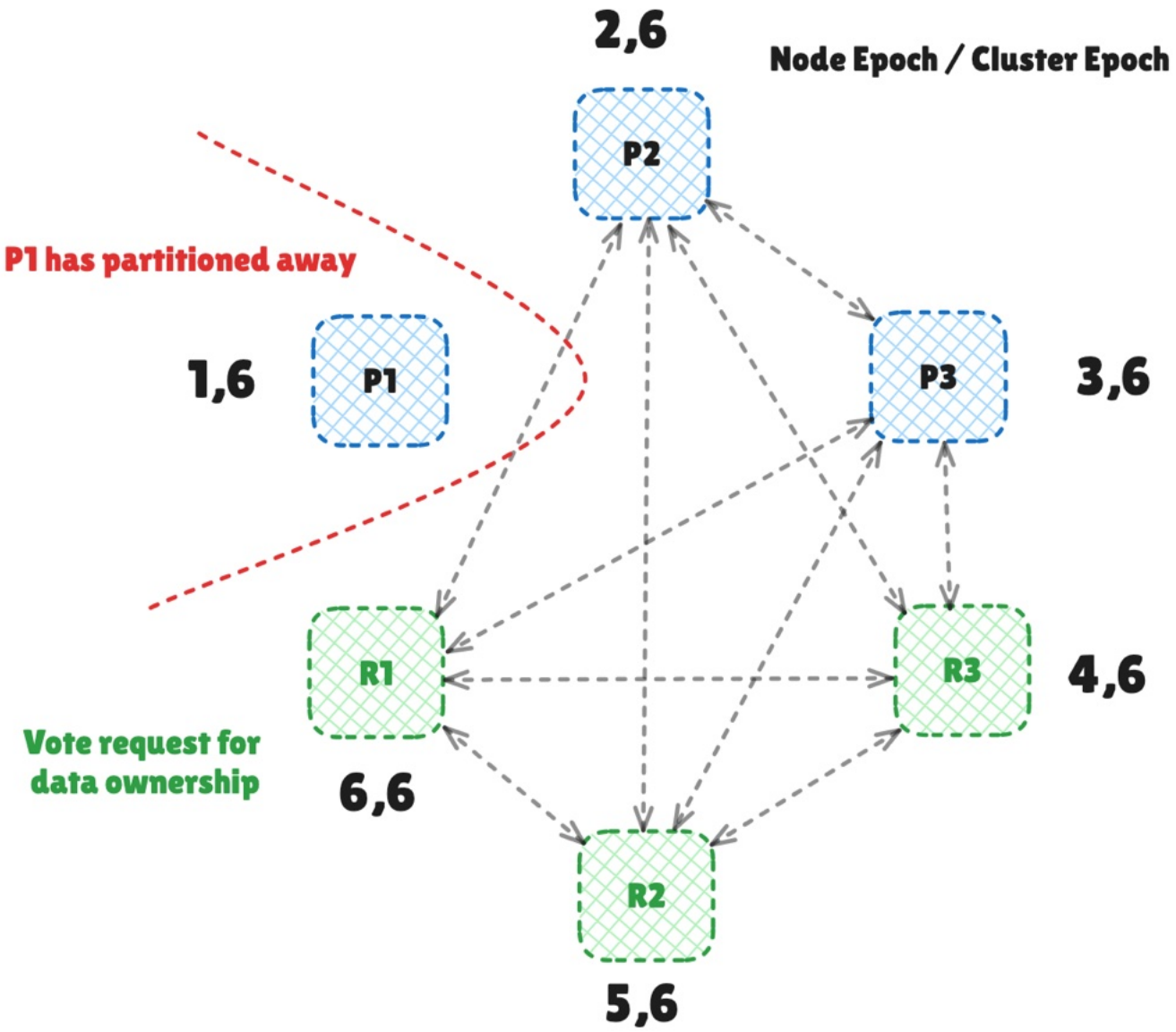
Conflict Resolution - Epoch



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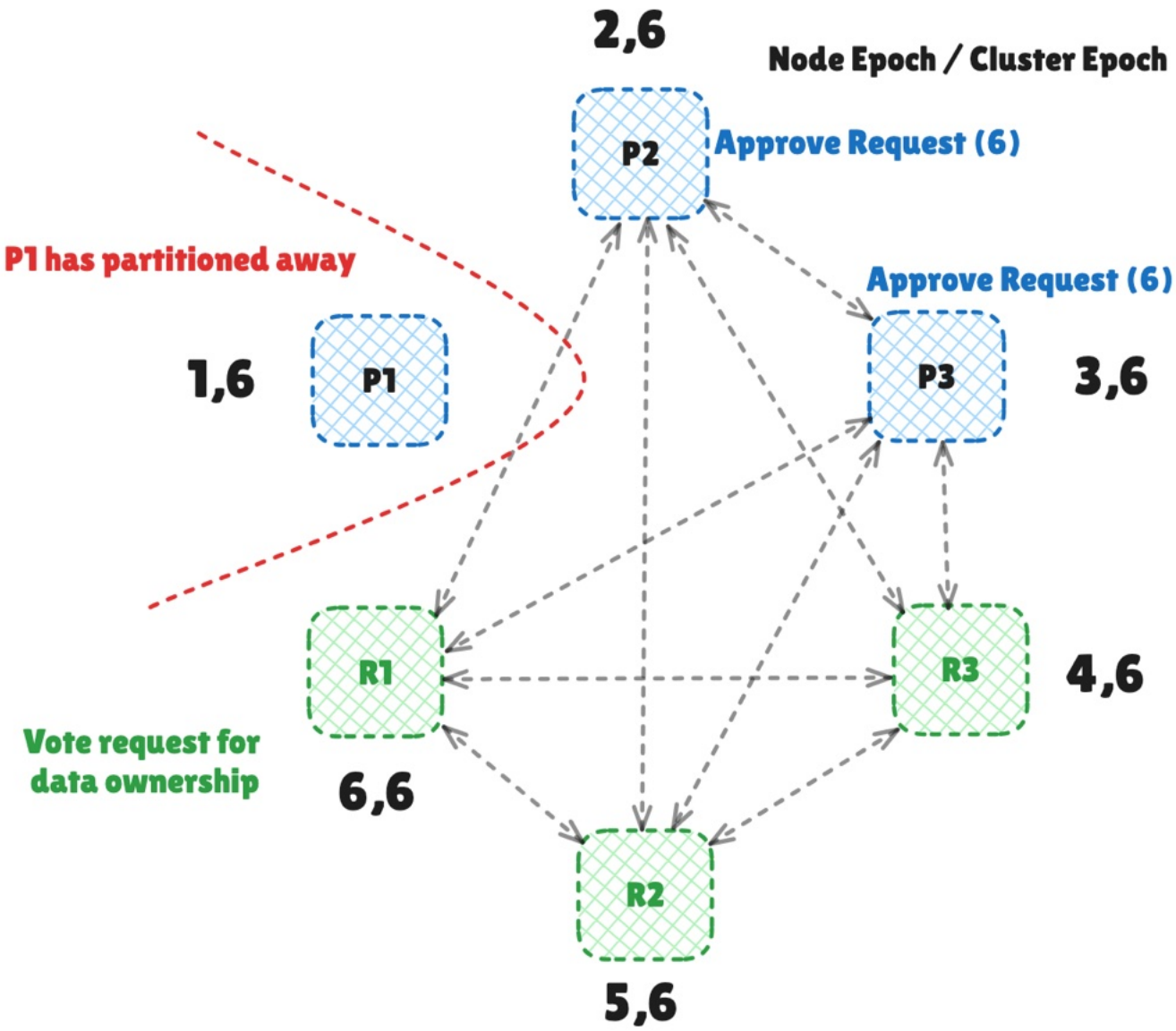
Epoch – Vote Request



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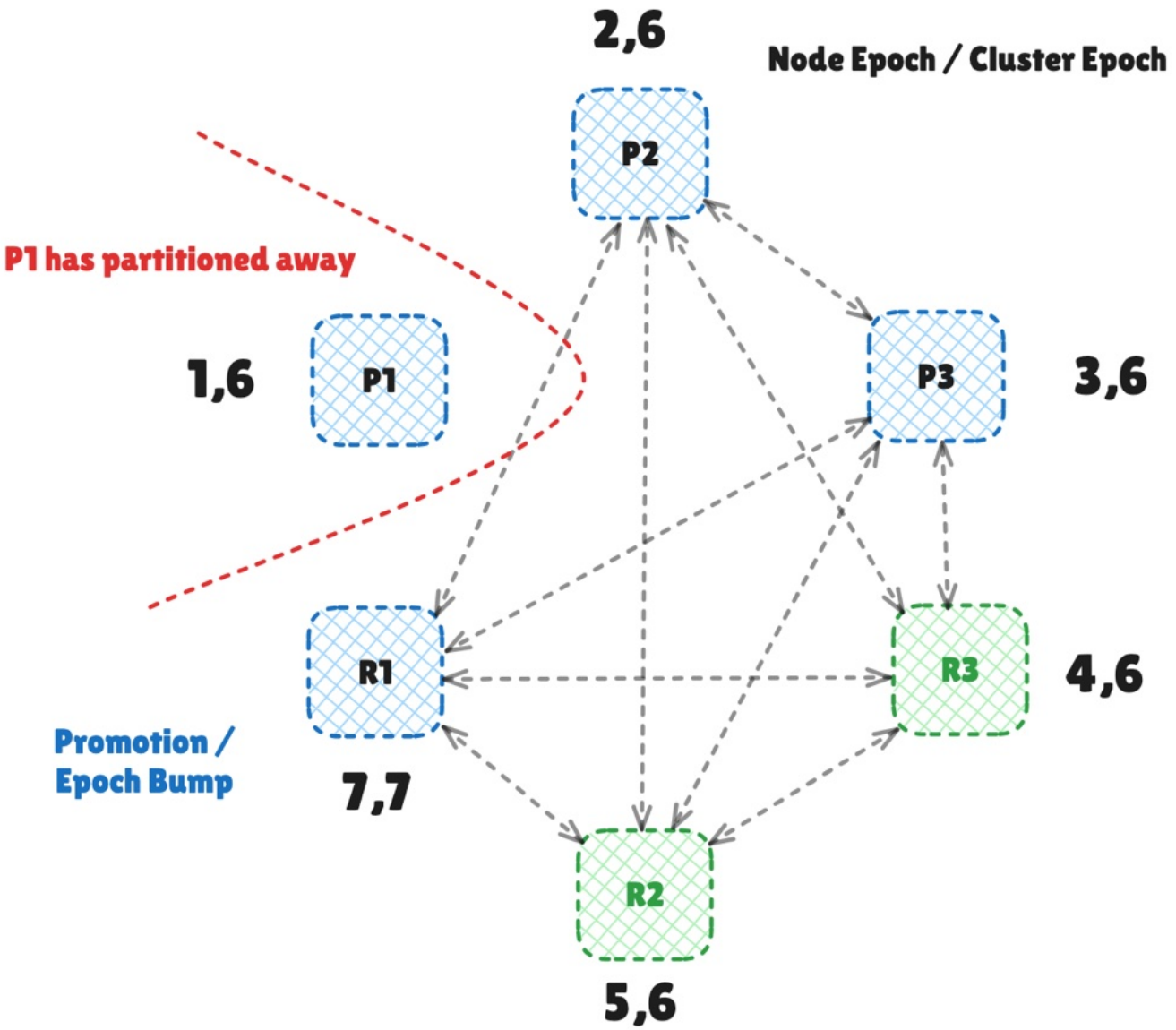
Epoch Bump



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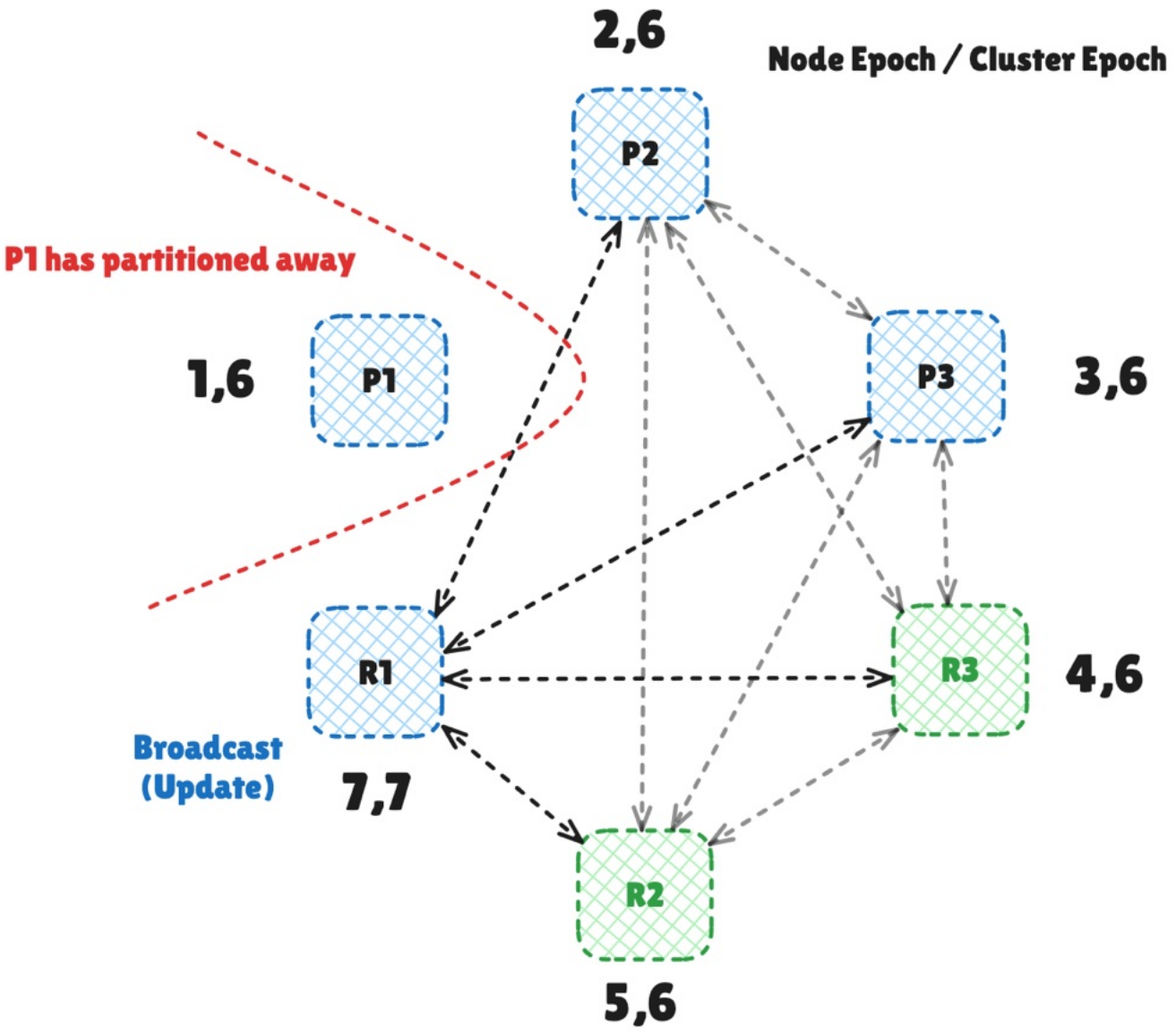
Epoch Bump - Broadcast



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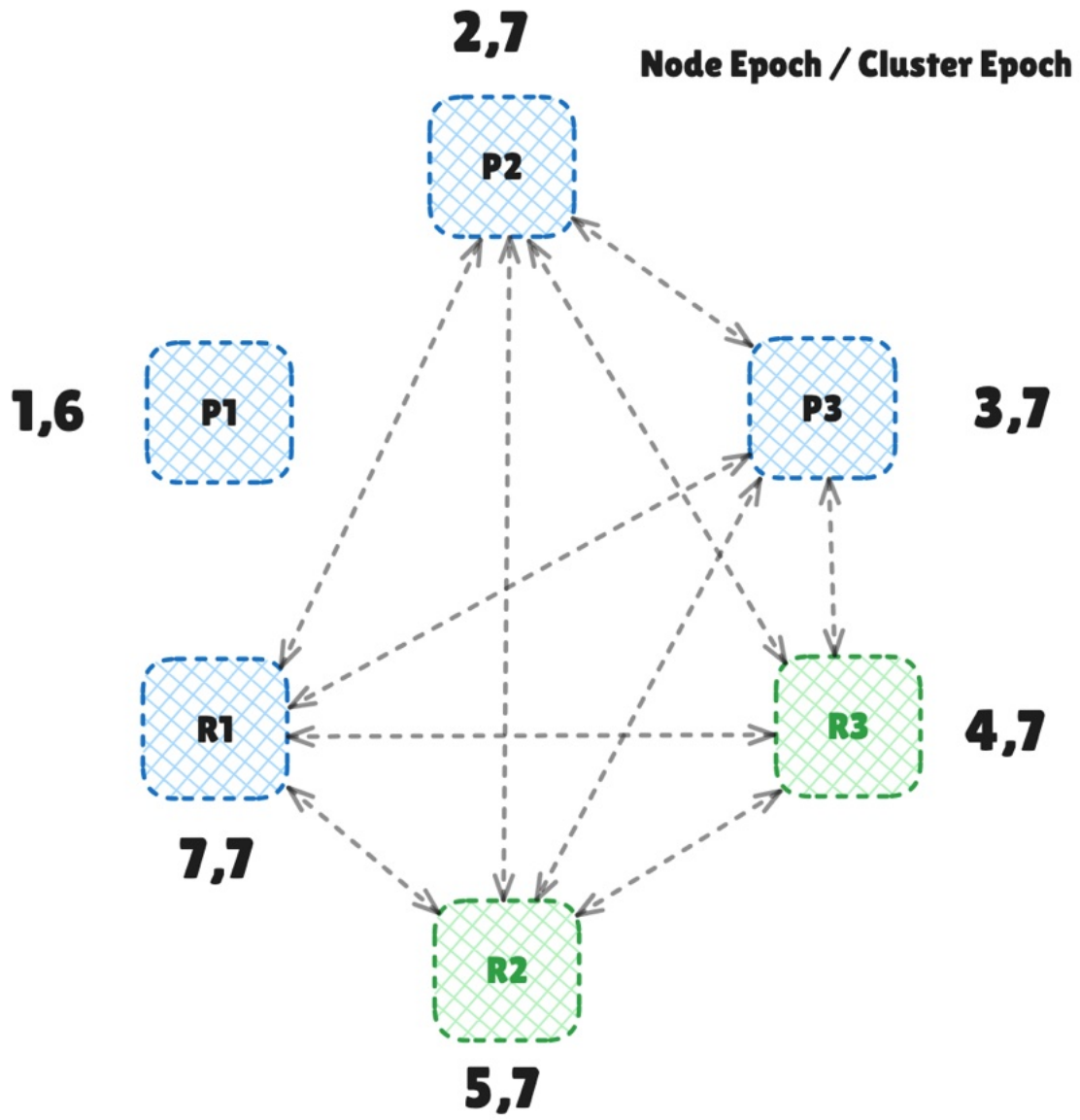
Epoch Bump – New Topology



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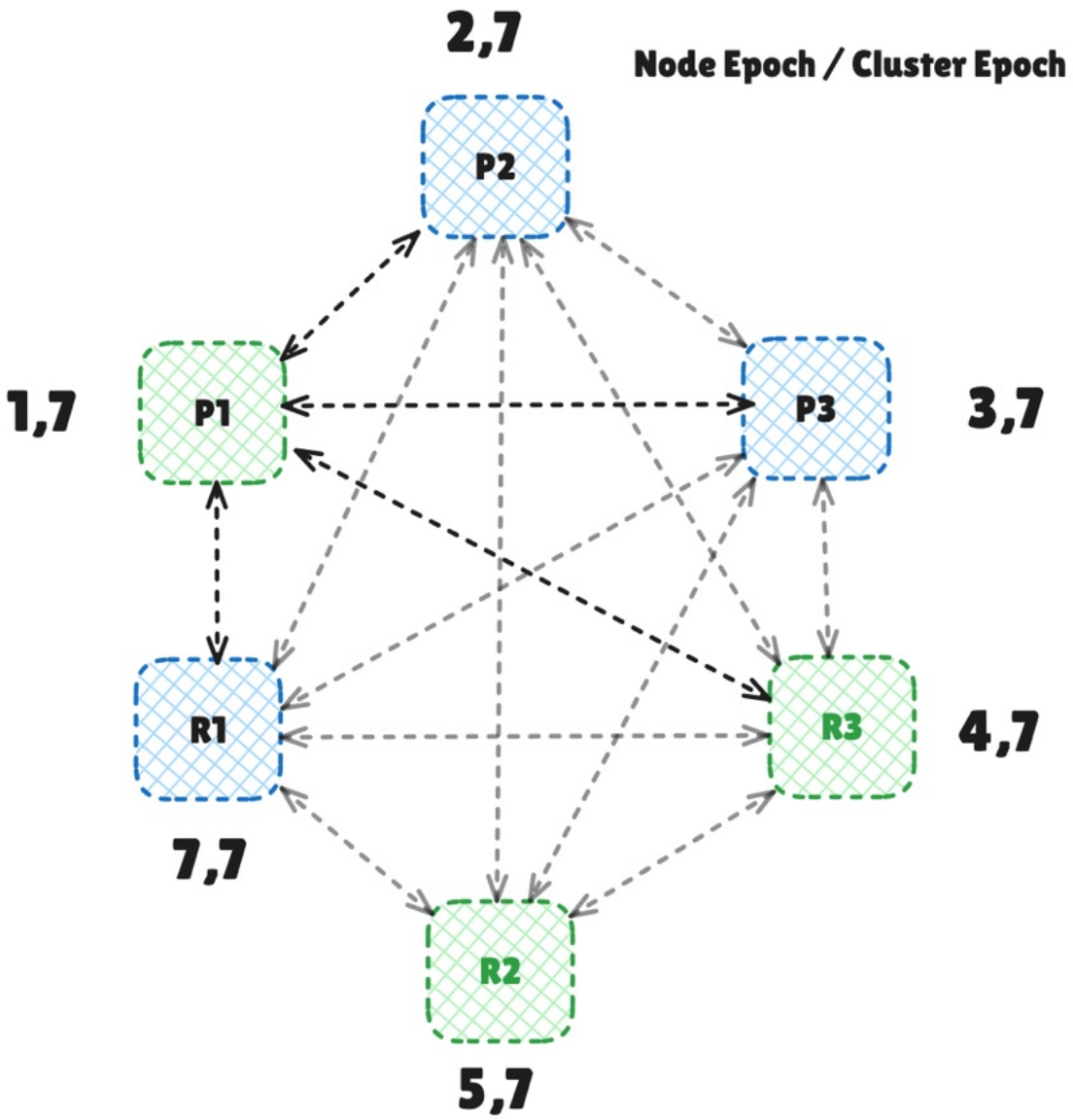
Epoch Bump – Conflict Resolution



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Valkey Clustering improvements

- Fast failover with multiple primary failures
- Light message header type (~30 bytes)
- Connection rate limiting

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Can it scale?

- Peer to peer health detection, does it scale?
- Message transfer rate is high during ideal state ?
- Too many votes (quorum of primaries) for failover ?

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Benchmark - Results

- Scales well upto 2000 nodes cluster
- Node timeout - 15 seconds
- 10% node failure detection and failover time ~ 20 seconds

```
127.0.0.1:6379> CLUSTER INFO
cluster_state:ok
cluster_slots_assigned:16384
cluster_slots_ok:16384
cluster_slots_pfail:0
cluster_slots_fail:0
cluster_nodes_pfail:0
cluster_nodes_fail:0
cluster_voting_nodes_pfail:0
cluster_voting_nodes_fail:0
cluster_known_nodes:1998
cluster_size:666
cluster_current_epoch:1997
cluster_my_epoch:180
cluster_stats_messages_ping_sent:1442617
cluster_stats_messages_pong_sent:1461312
cluster_stats_messages_meet_sent:671
cluster_stats_messages_sent:2904600
cluster_stats_messages_ping_received:1457438
cluster_stats_messages_pong_received:1448050
cluster_stats_messages_meet_received:934
cluster_stats_messages_received:2906422
total_cluster_links_buffer_limit_exceeded:0
127.0.0.1:6379>
```

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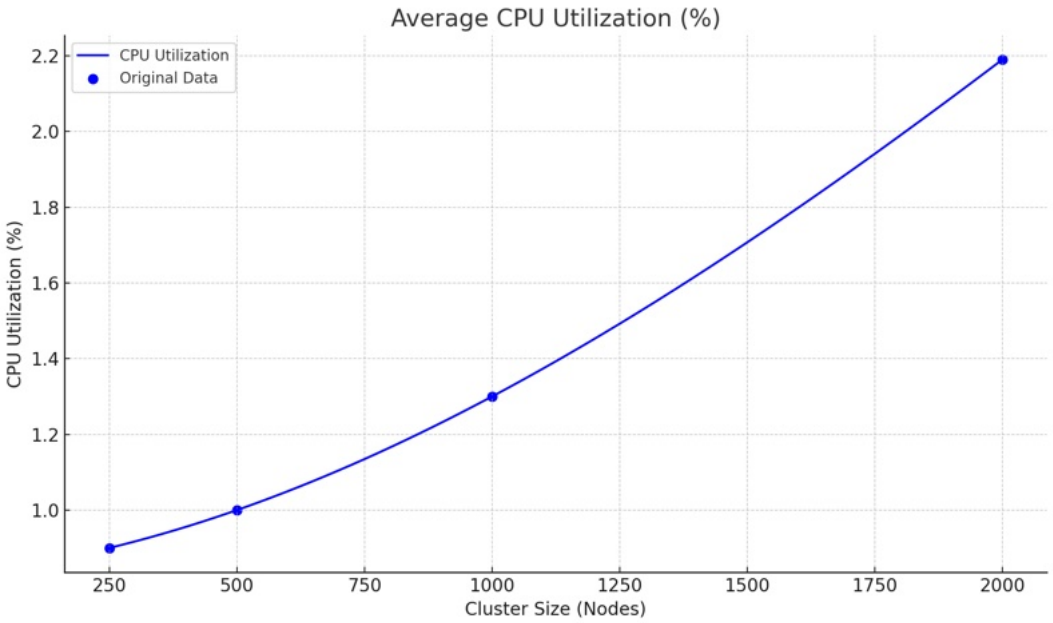
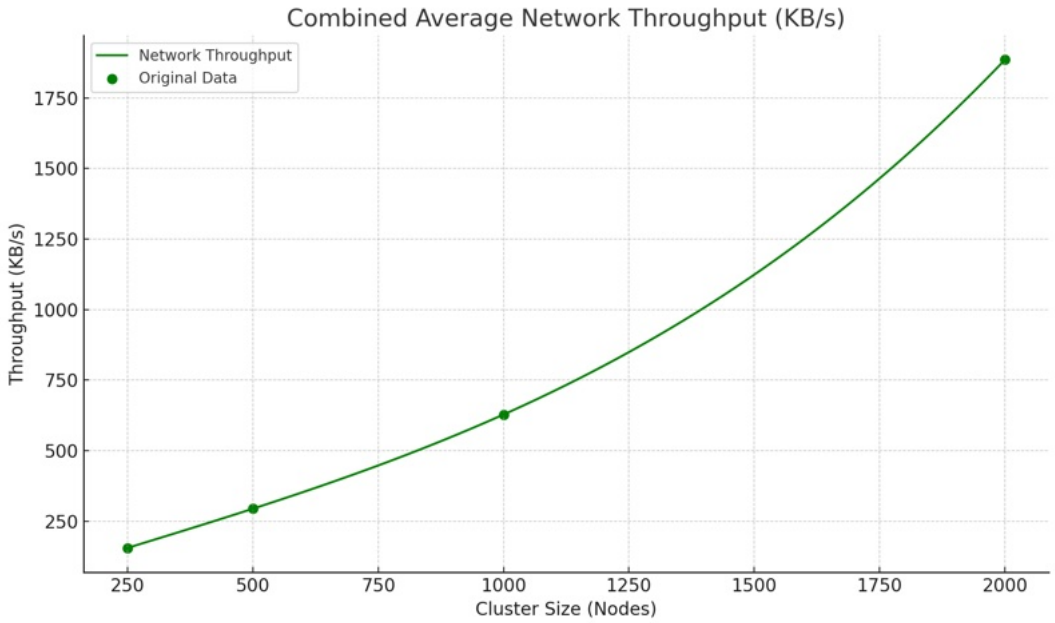
Benchmark - Results





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What’s next?

- Reduce steady state CPU utilization
- Offload cluster message processing
- Additional observability information
- Fuzzy testing

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Get involved in the project

valkey.io

valkey/valkey

github.com/valkey-io

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Thank you!

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linkedin.com/in/harkrishn-patro