Hydra:
Serialization-Free Network Ordering for Strongly Consistent Distributed Applications

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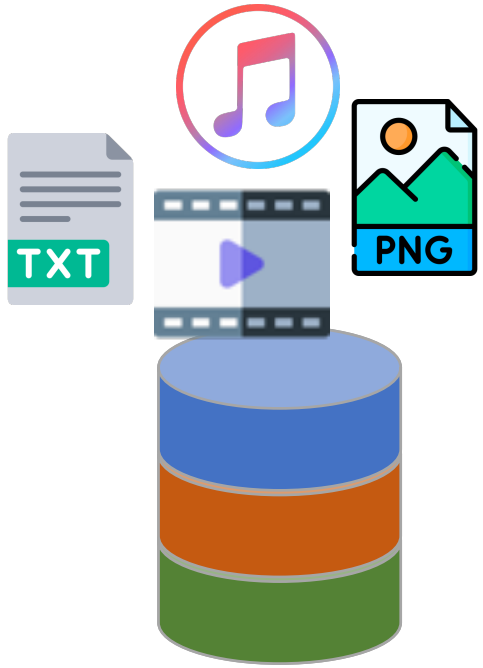
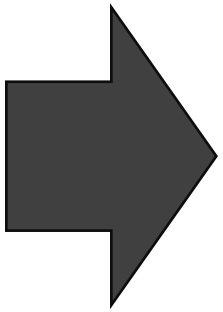
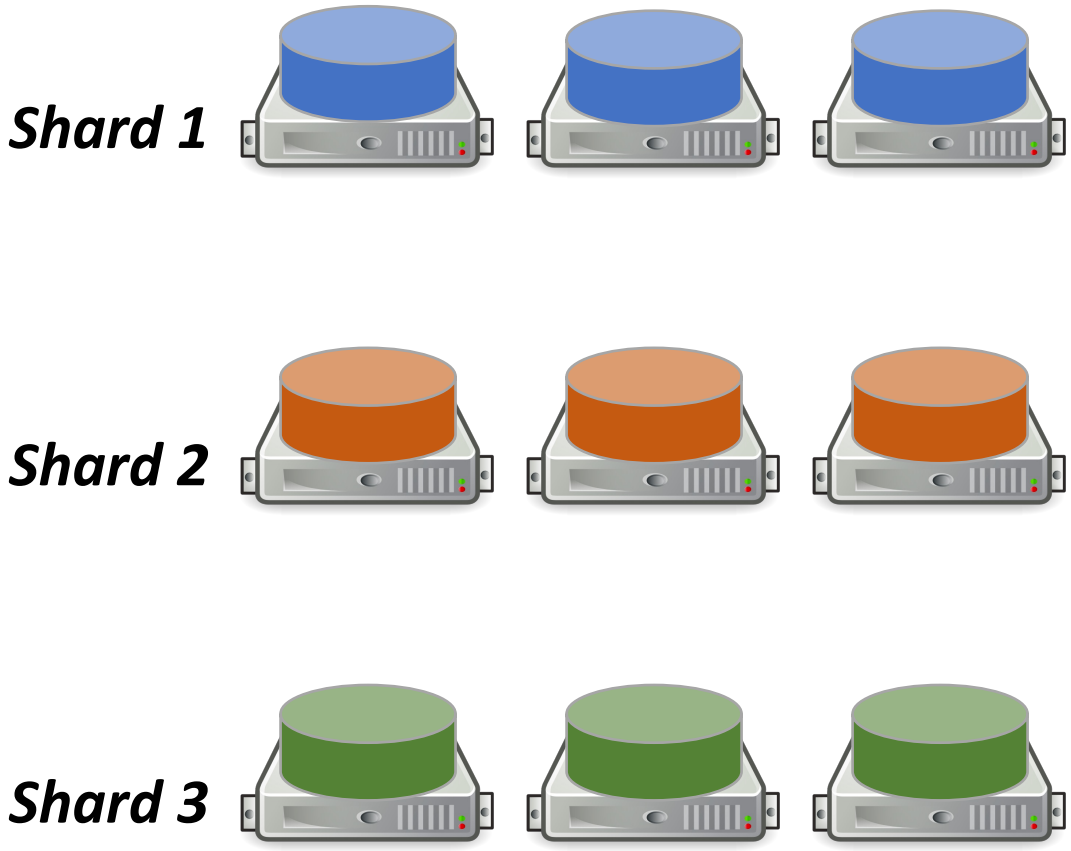
[1]*National University of Singapore,* [2]*University of Washington,* [3]*Microsoft Research*

Scalability by *Sharding*
Fault Tolerance by *Replication*



Sharding
Replication





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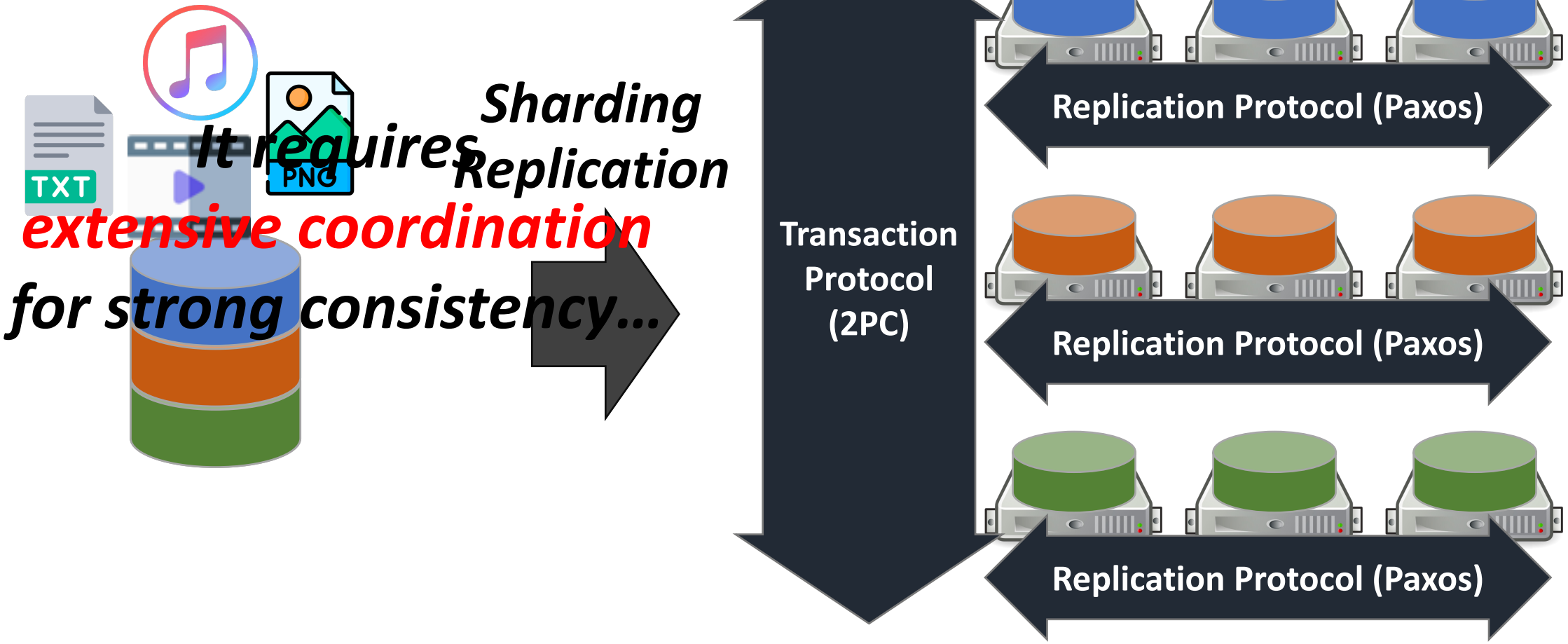


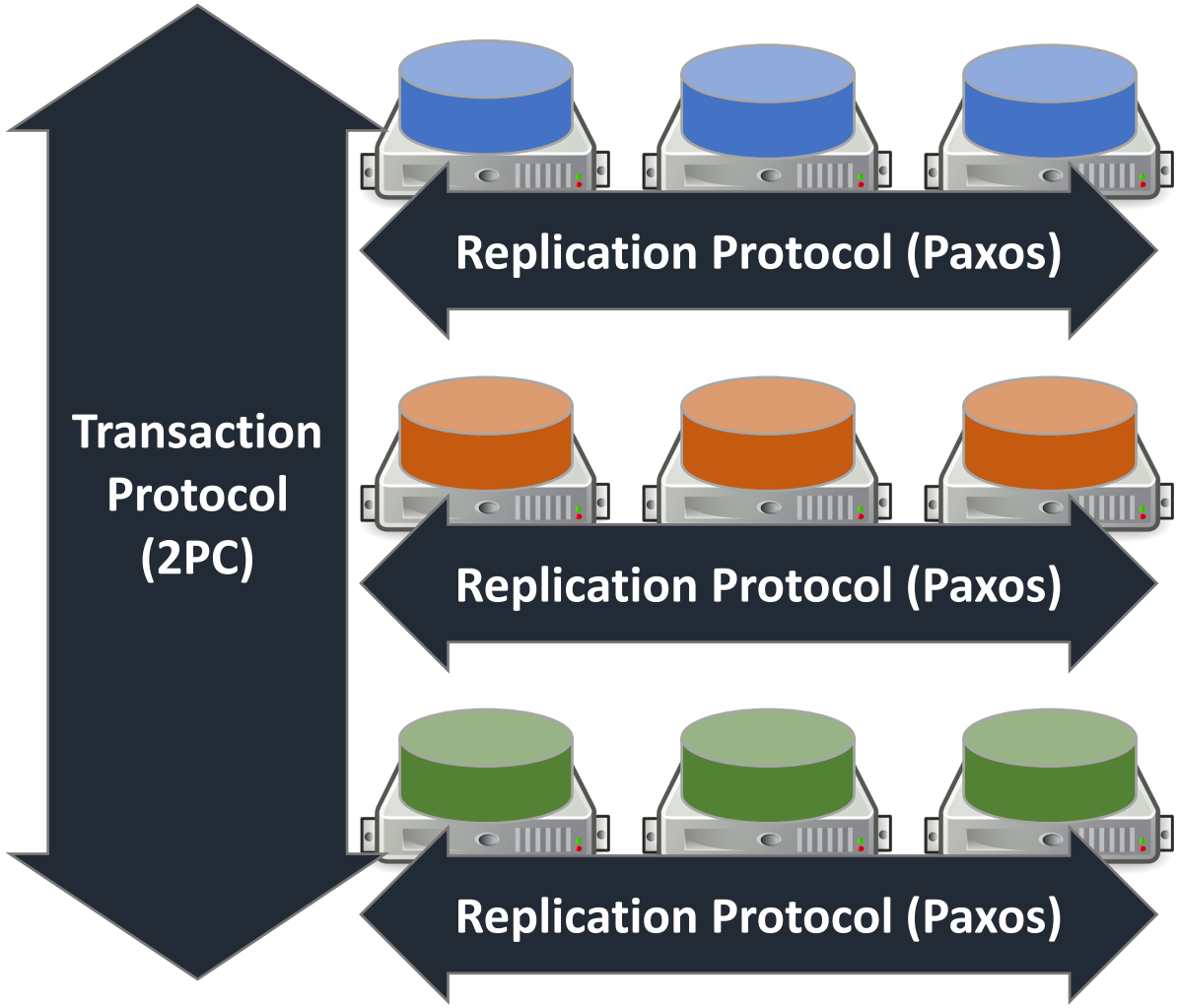
Network Ordering to Eliminate Coordination

Network

Sequencer
(e.g., Programmable Switch)

Consistent Ordering

Related Works:
NOPaxos [OSDI '16], **Eris** [SOSP '17]



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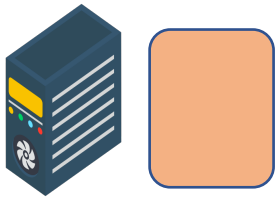
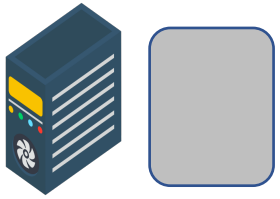
Senders

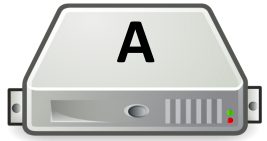


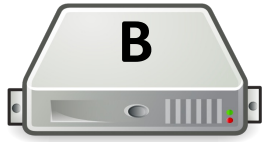


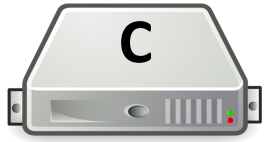
Sequencer

Counter
0

Receivers







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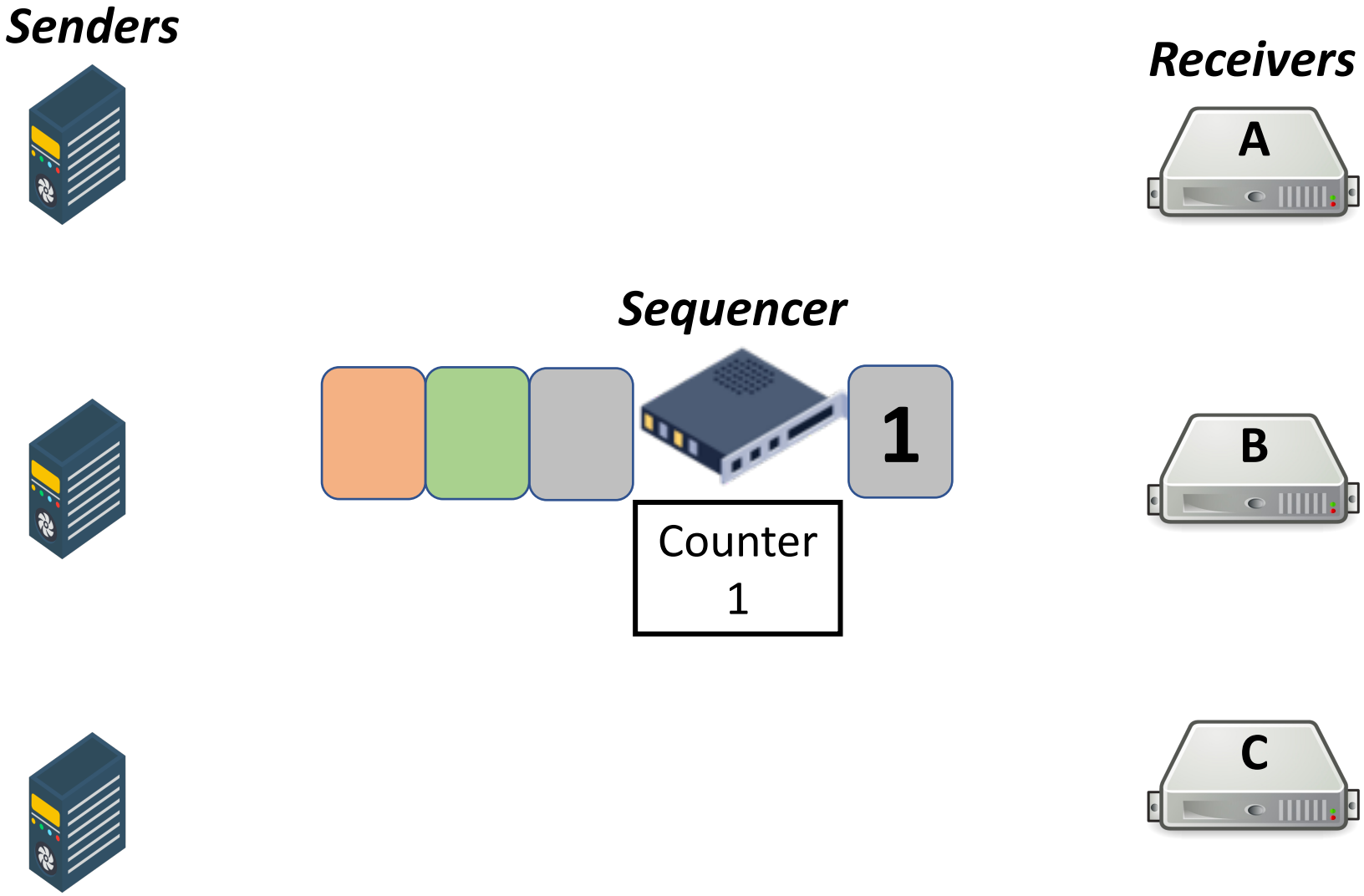

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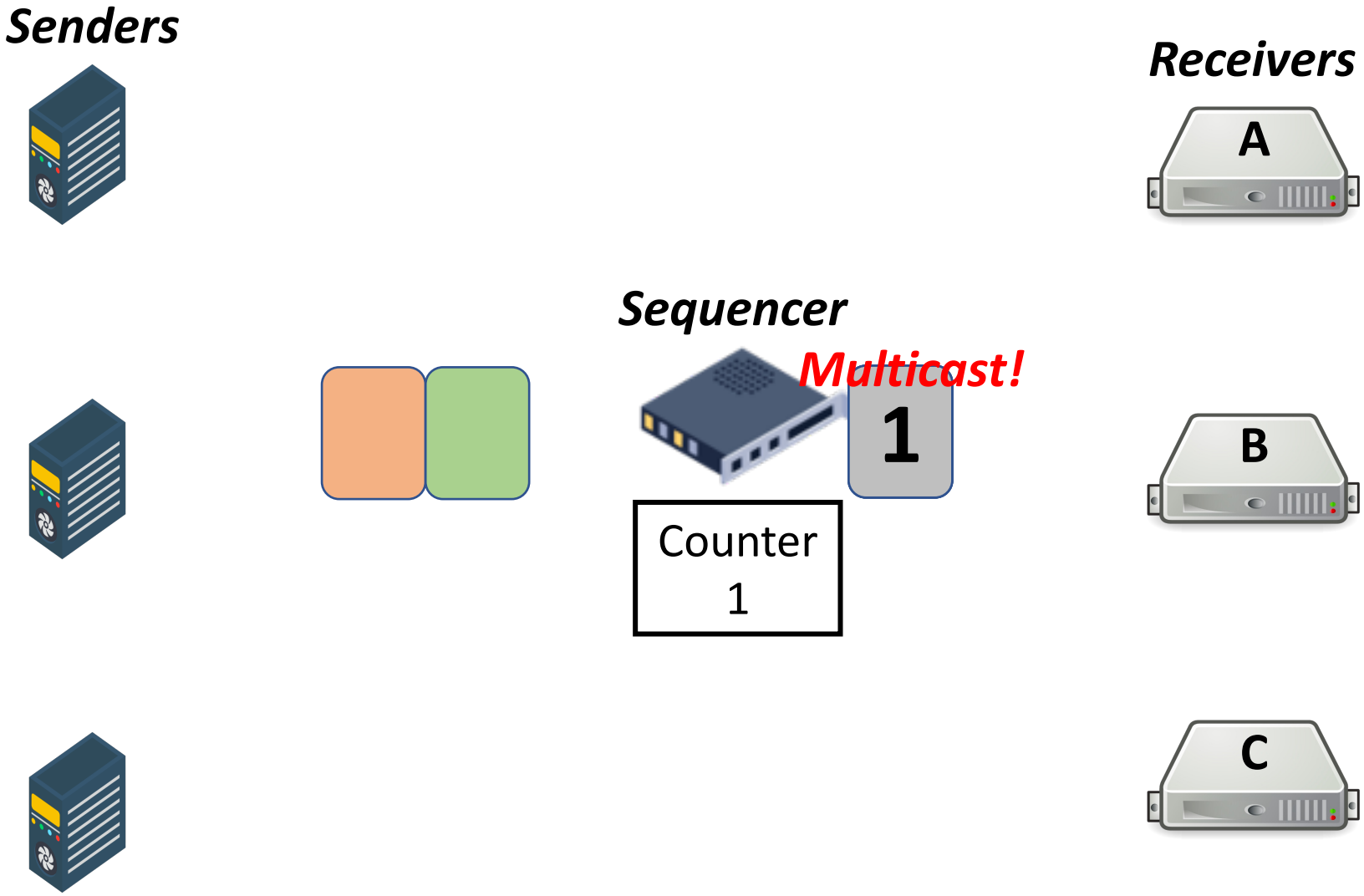

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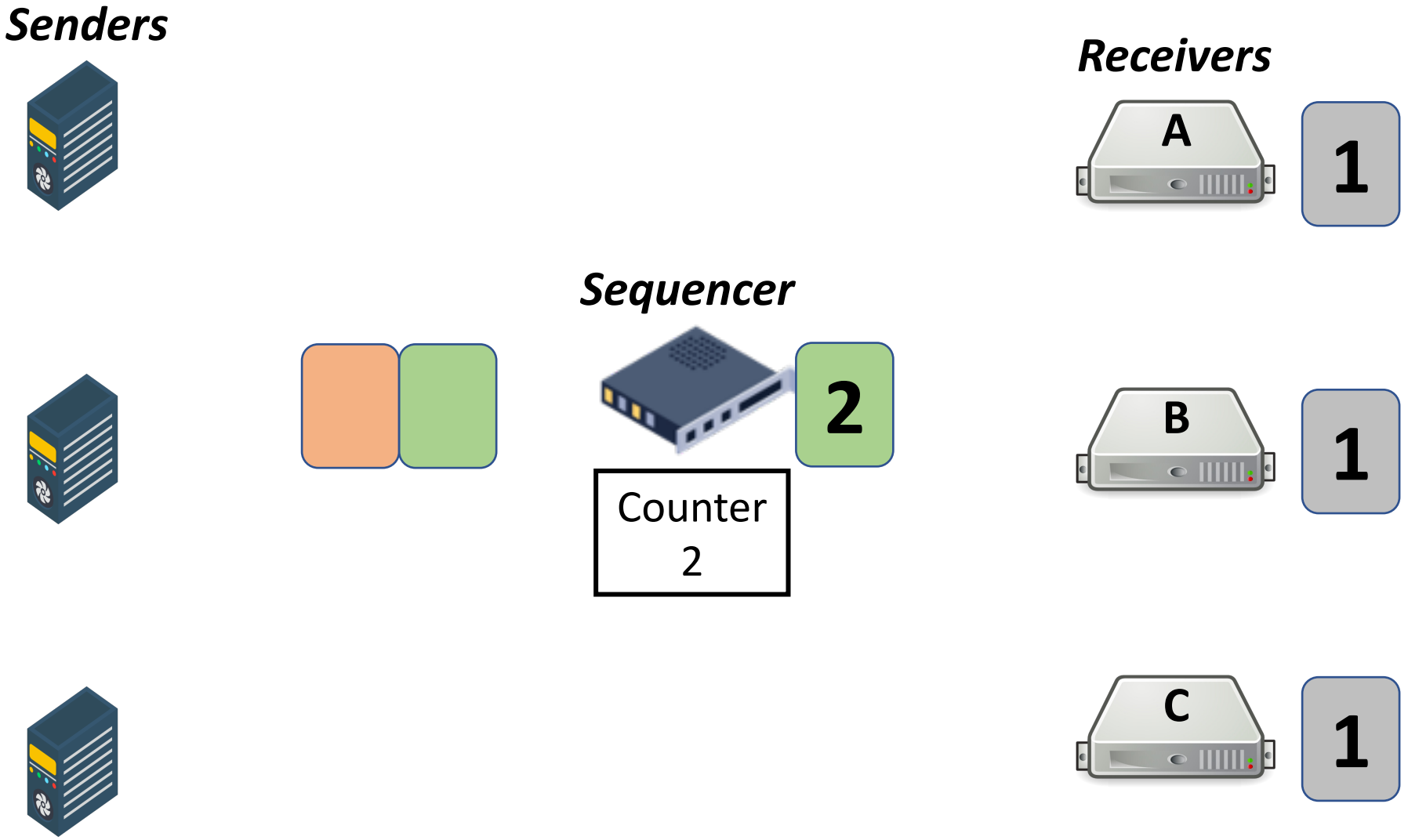

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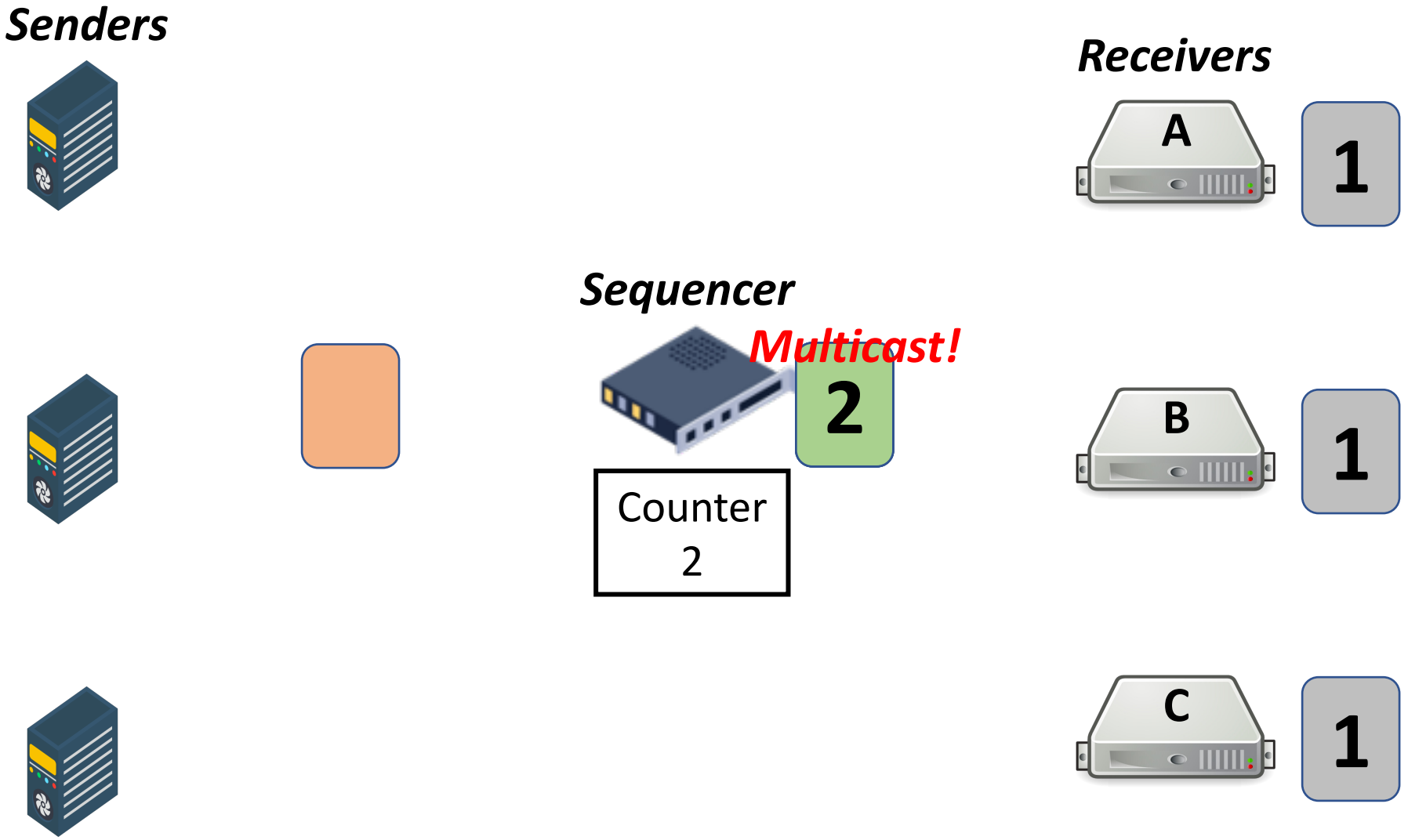

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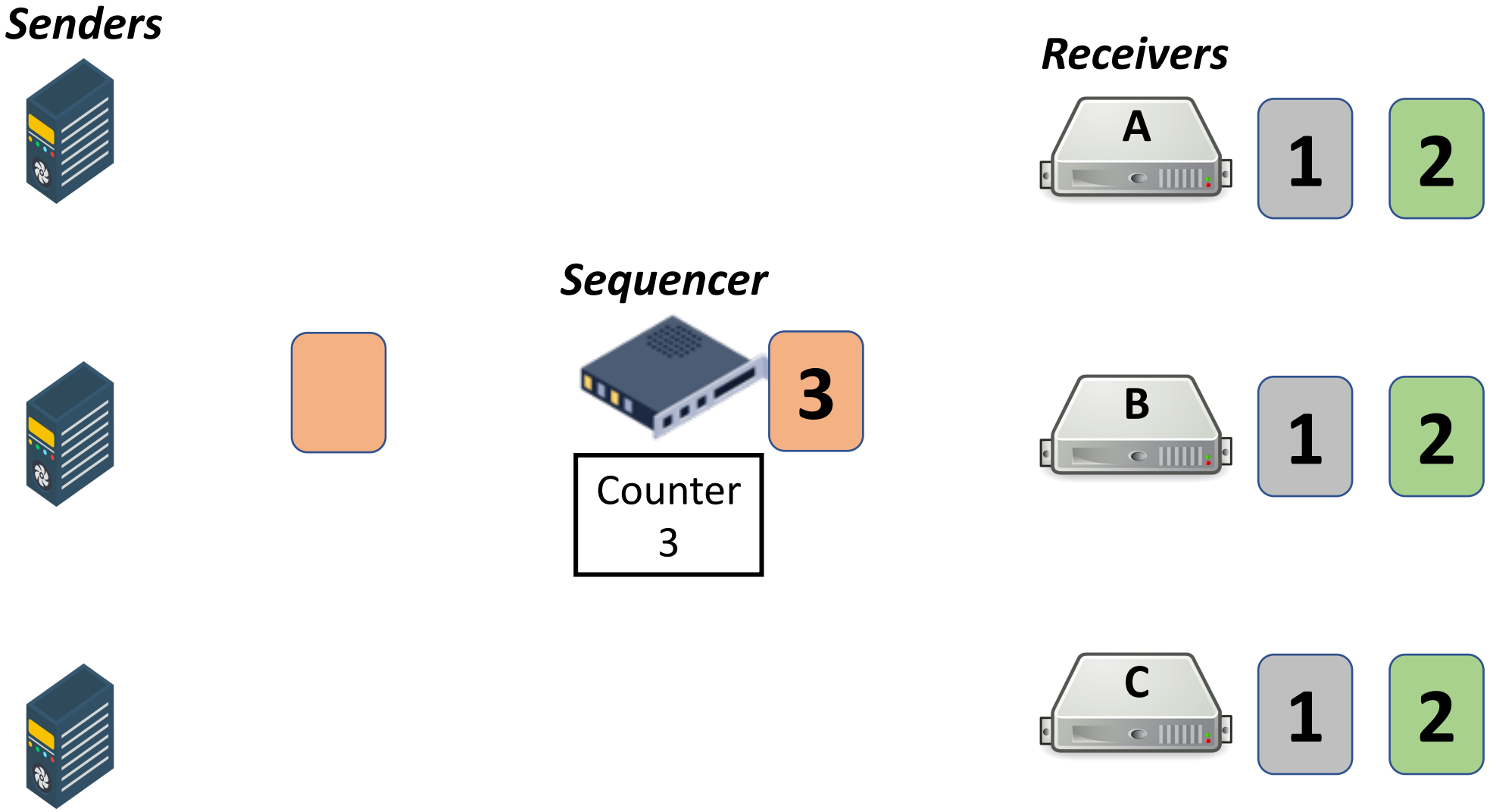

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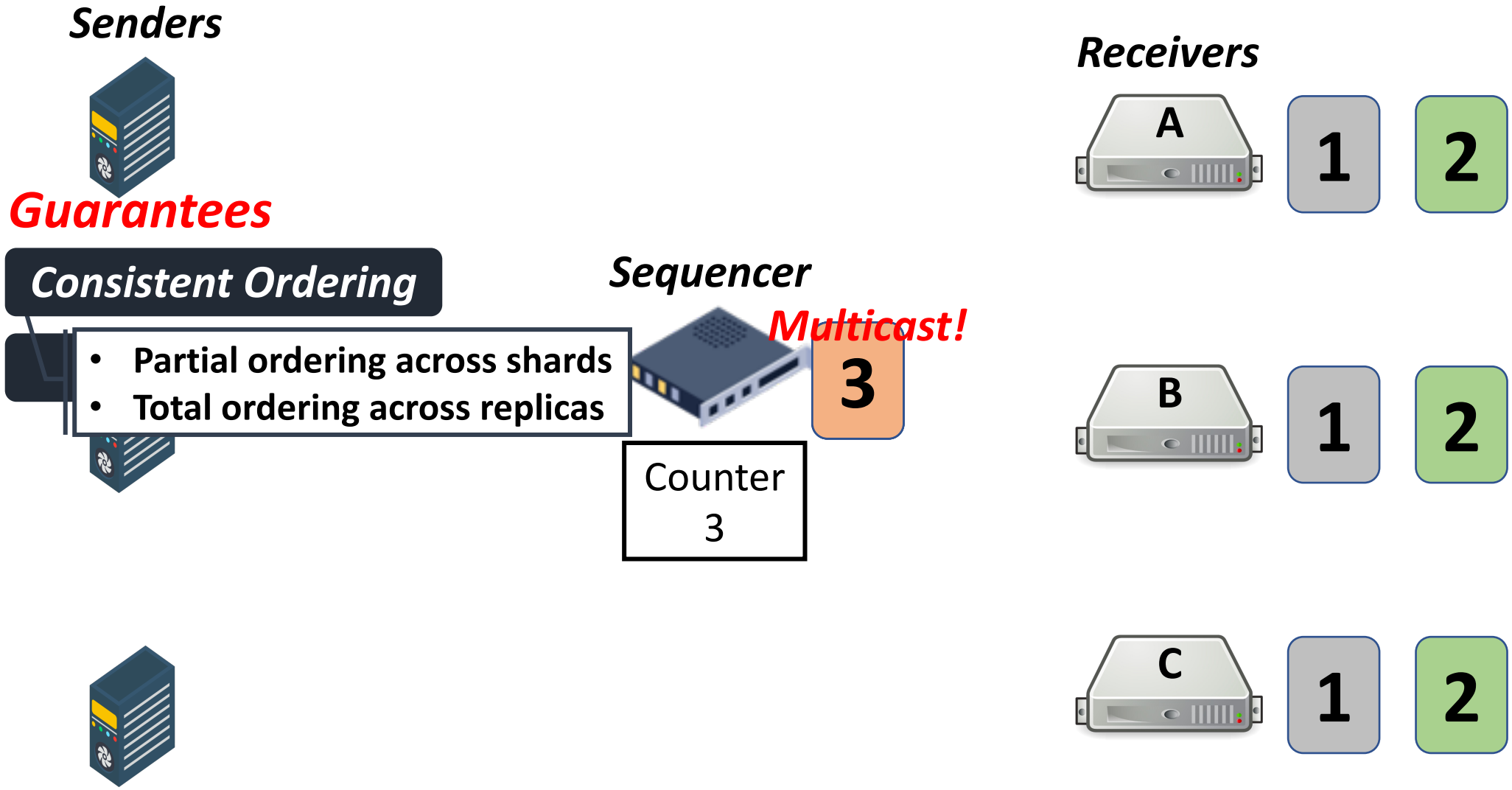


Network Ordering to Eliminate Coordination

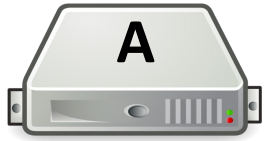
Guarantees

Consistent Ordering

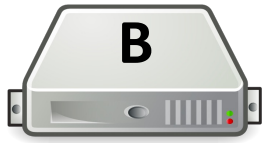
Drop Detection

Sequencer

Receivers



1 2 3



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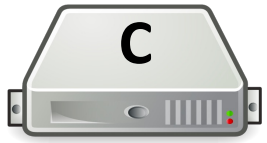
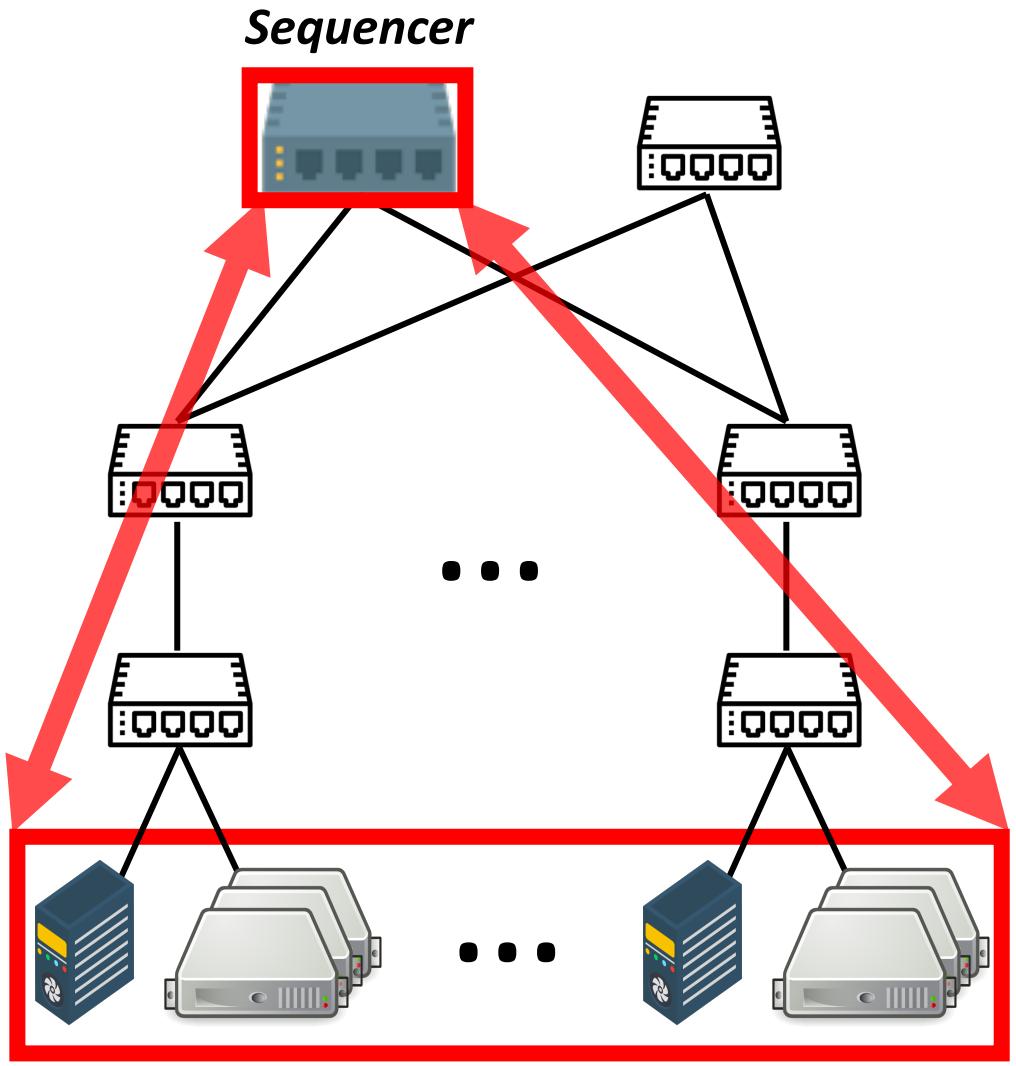


1 2 3

Drawbacks due to the Single Sequencer



All request traffic
must go through the *single sequencer*
(Network Serialization)

☒ ***Network load imbalance ⇒ high latency***
☒ ***Sequencer scalability bottleneck***
☒ ***Prolonged sequencer failover***

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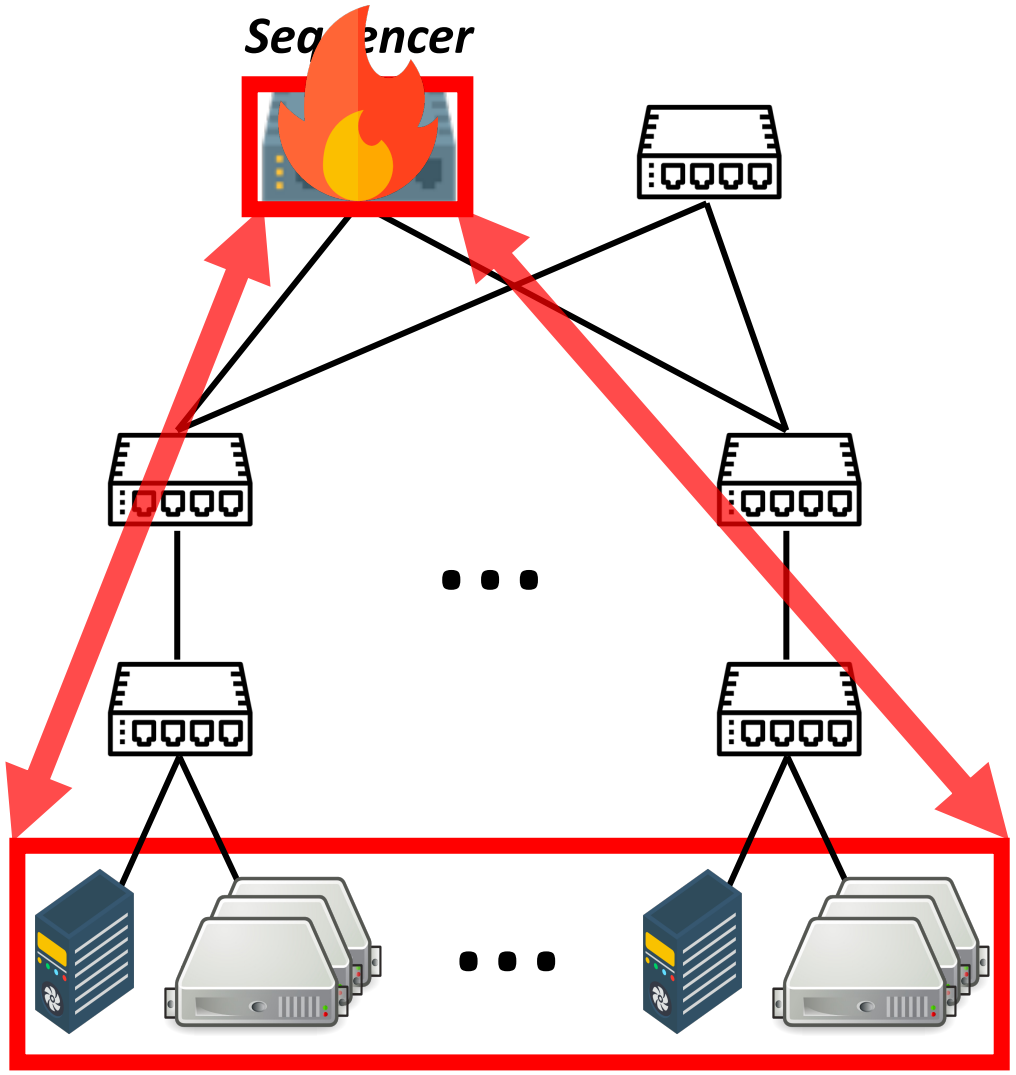

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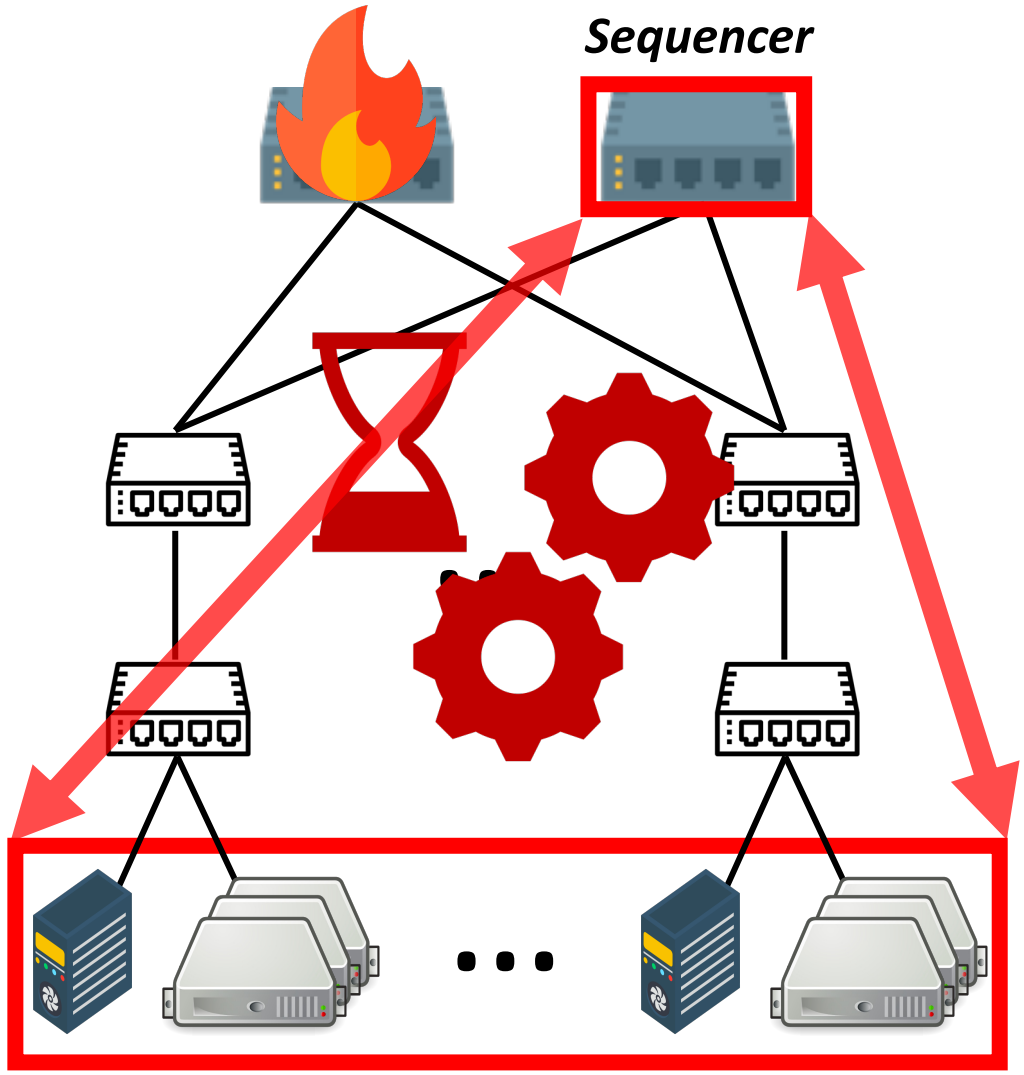

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☒ ***Network load imbalance ⇒ high latency***
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Can we achieve network ordering ***without serialization***?

All request traffic must go through the *single sequencer*

(*Network Serialization*)

☒ *Network load imbalance ⇒ high latency*

☒ *Sequencer scalability bottleneck*

☒ *Prolonged sequencer failover*

Hydra

Use multiple sequencers concurrently

(*Serialization-Free*)

✅ *Network load balancing ⇒ low latency* (e.g., 13x)

✅ *Higher scalability beyond a single sequencer*

✅ *Faster sequencer failover* (e.g., 5x)

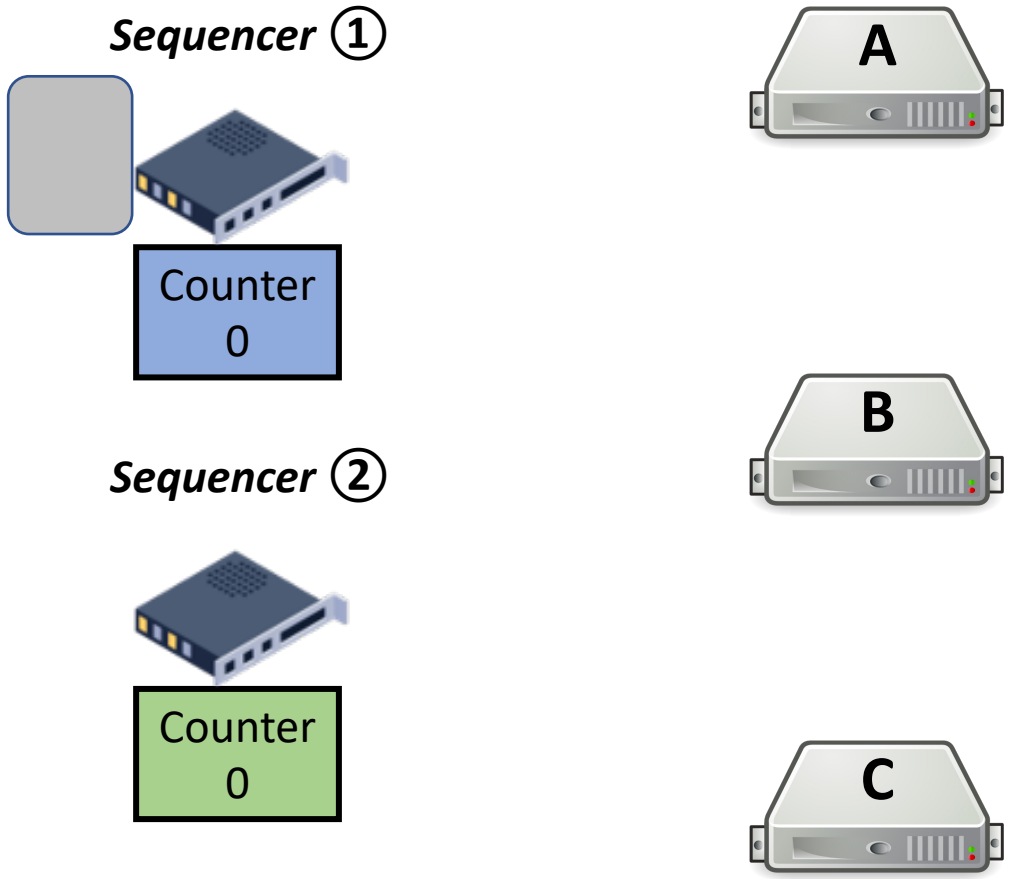
Outline

1. Introduction
2. Hydra Network Primitive
3. Handling Network Anomalies
4. Evaluation

Multi-Sequencer Challenge:
Provide the same guarantees

Guarantees

- ***Consistent Ordering***
- ***Drop Detection***



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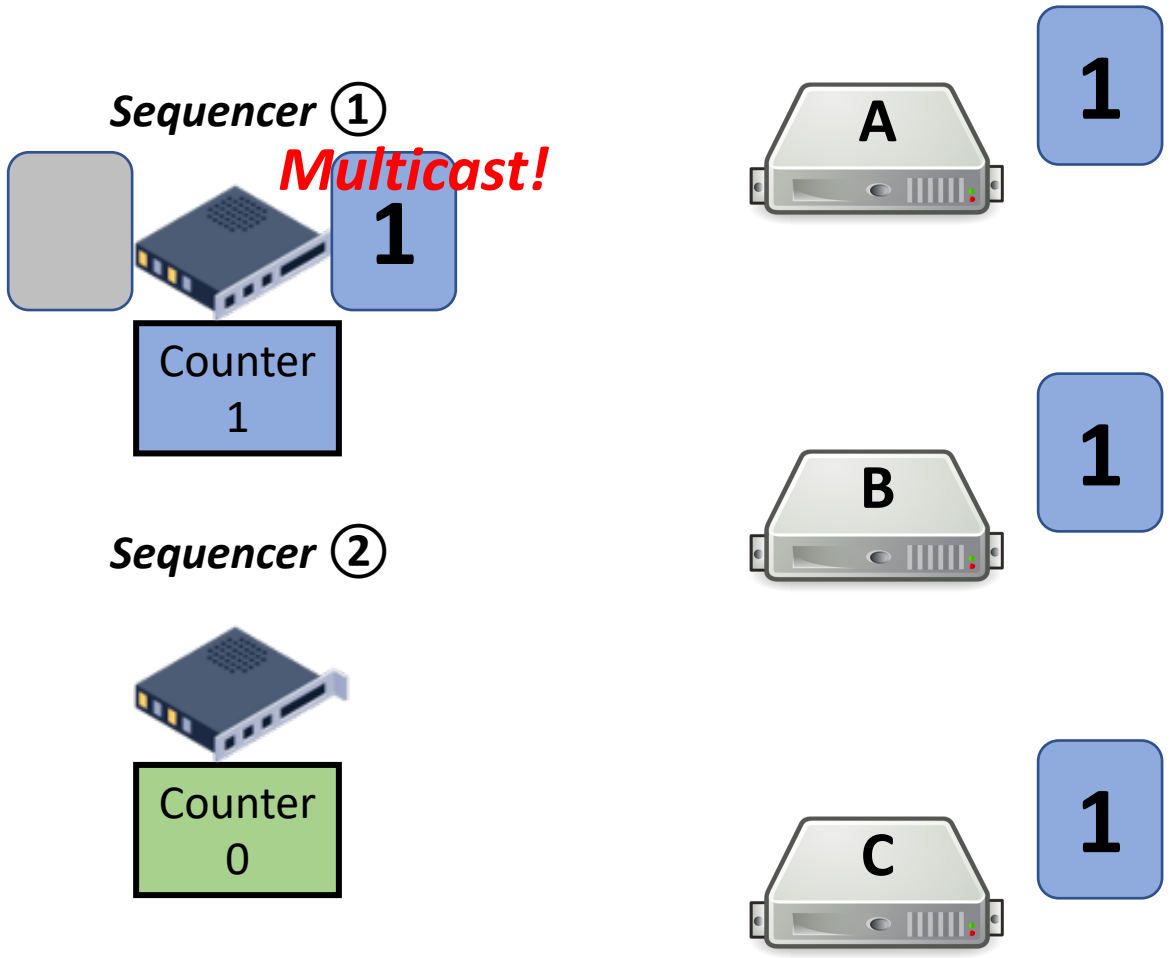

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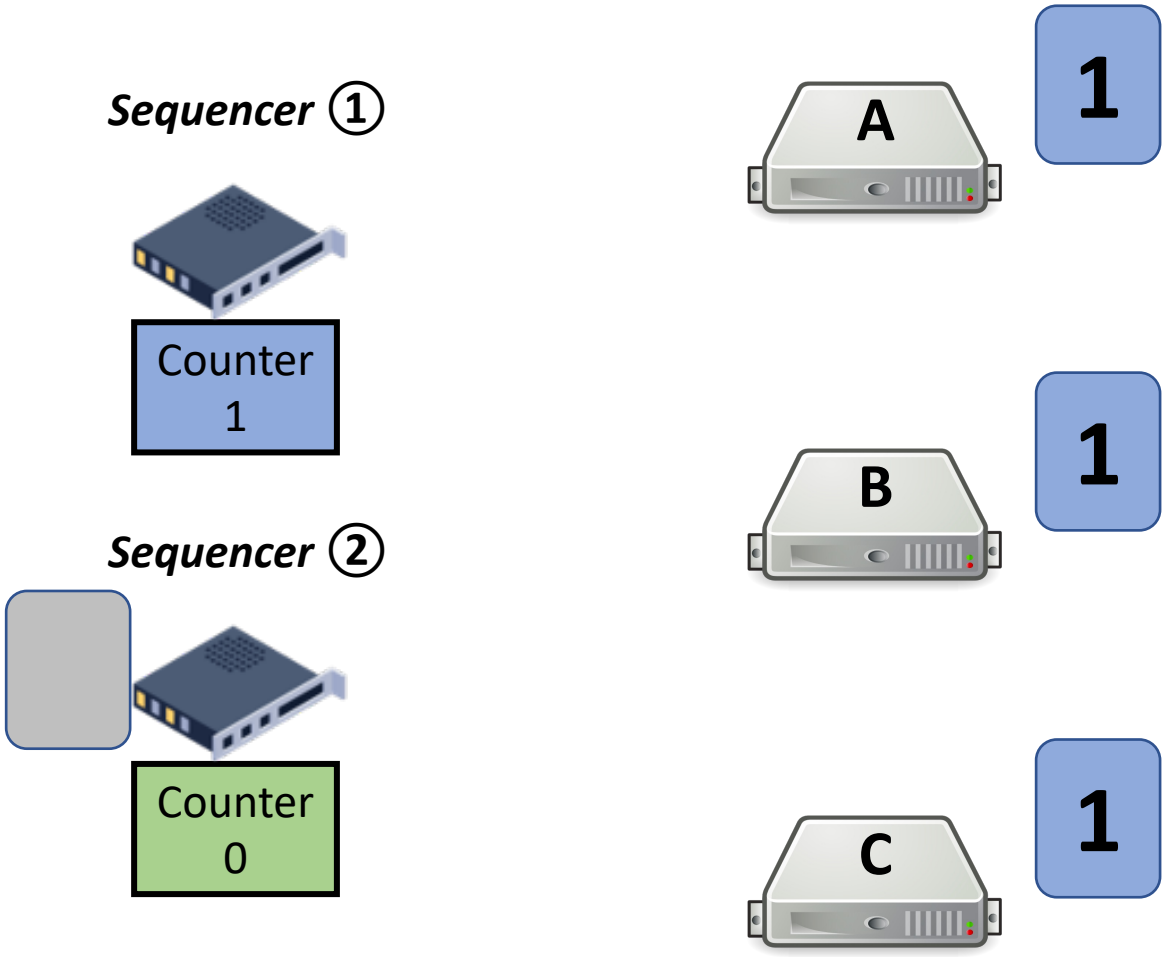
Consistent Ordering

Drop Detection



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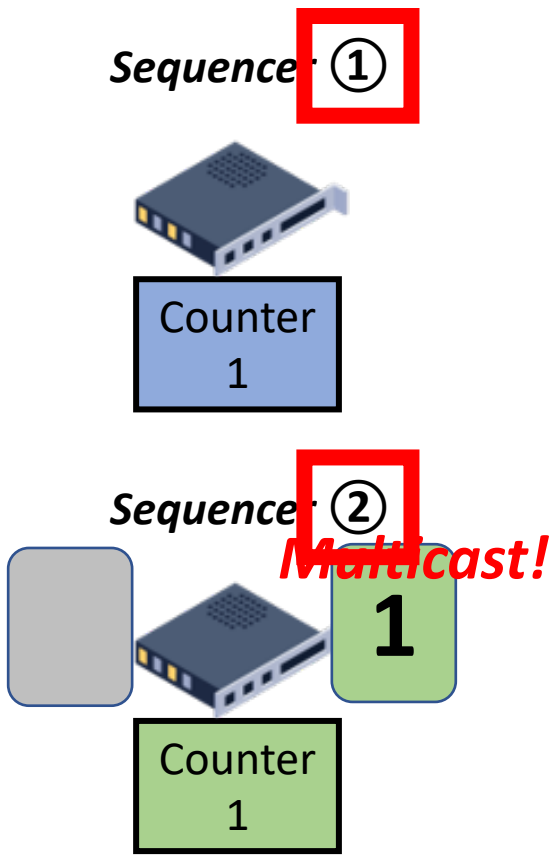
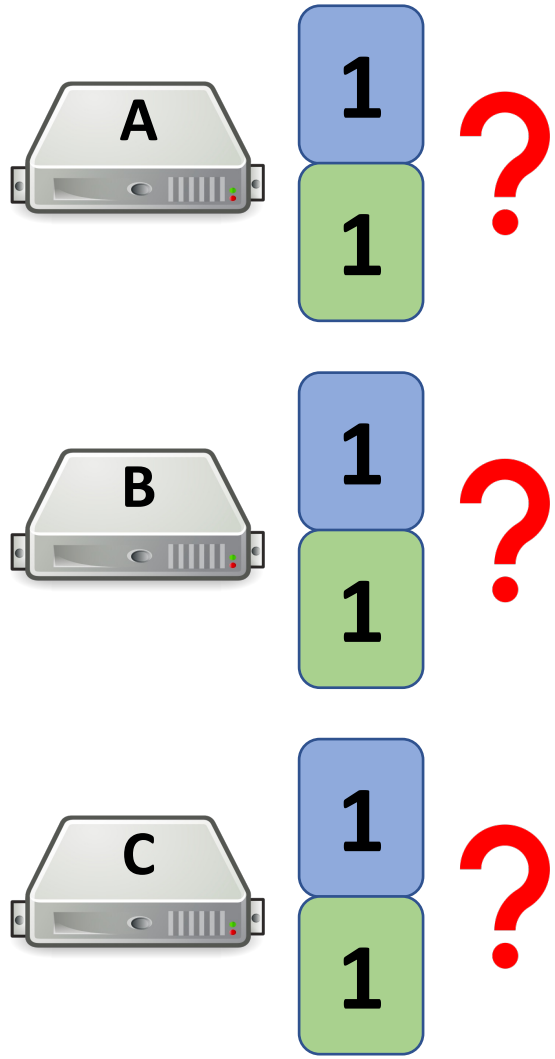
~~***Consistent Ordering***~~

Drop Detection





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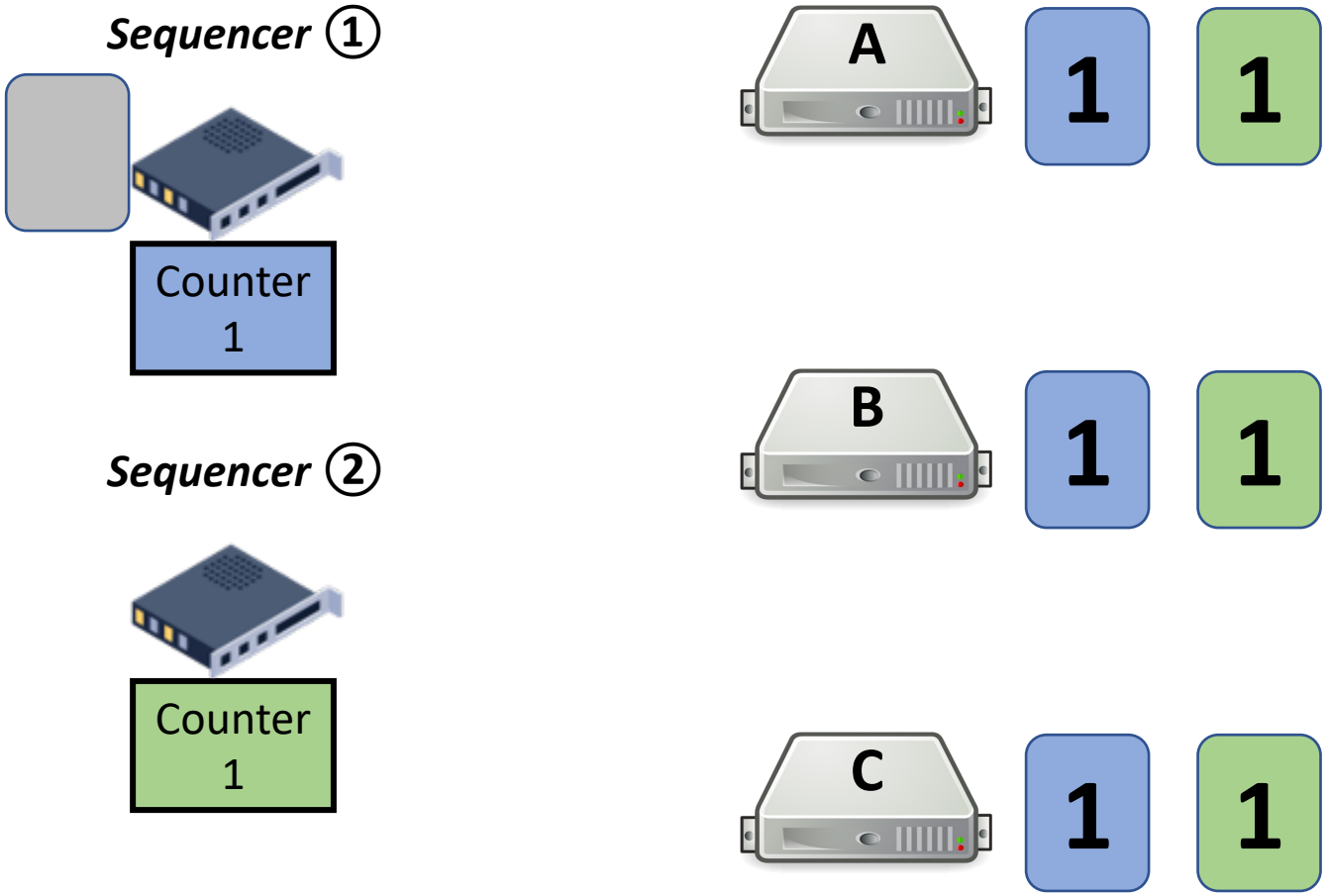

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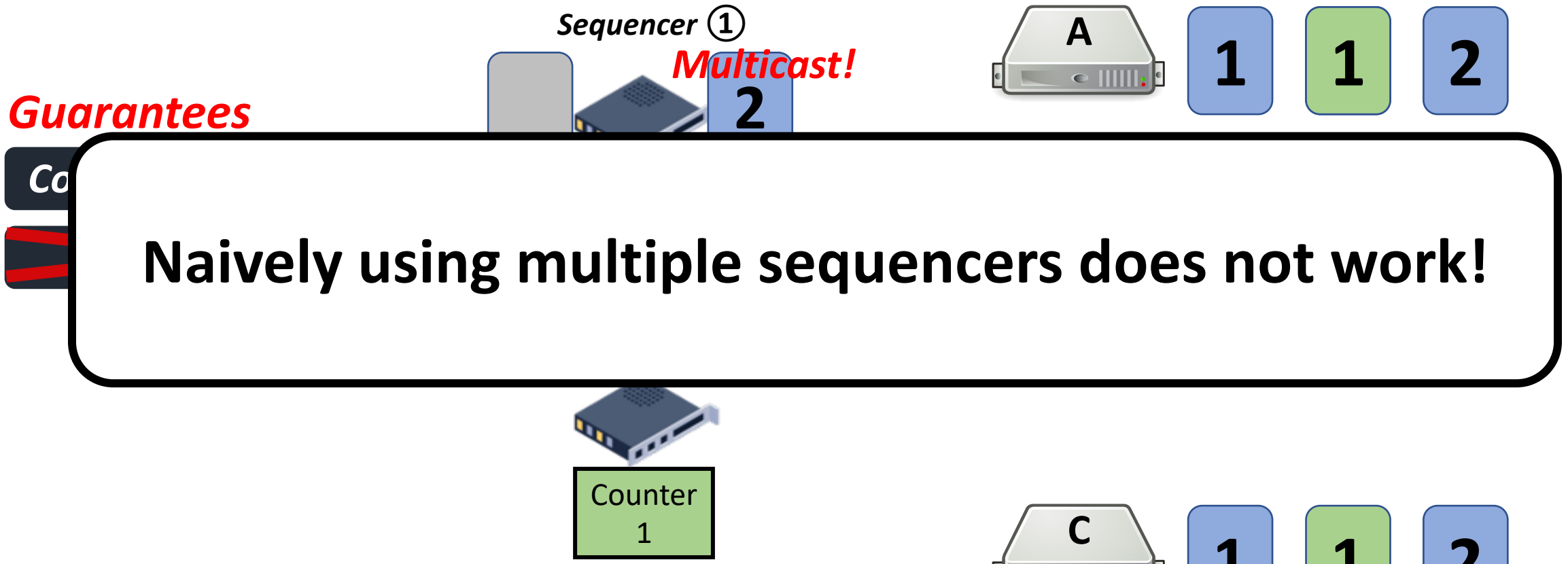
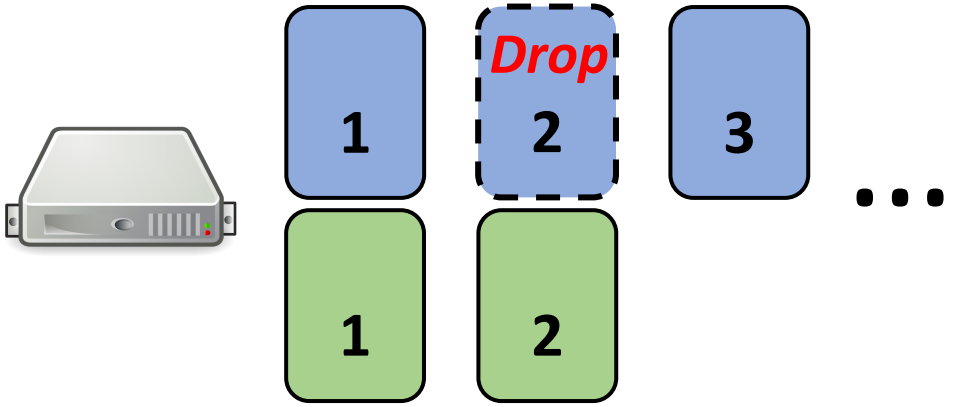


Solution: Combine sequence number with *physical clock*



Sequence Number → ***Drop Detection***

Physical Clock Timestamp → ***Consistent Ordering***

- Consistent across receivers
- Strictly monotonically increasing
- Physical clocks can be (loosely) synchronized across sequencers

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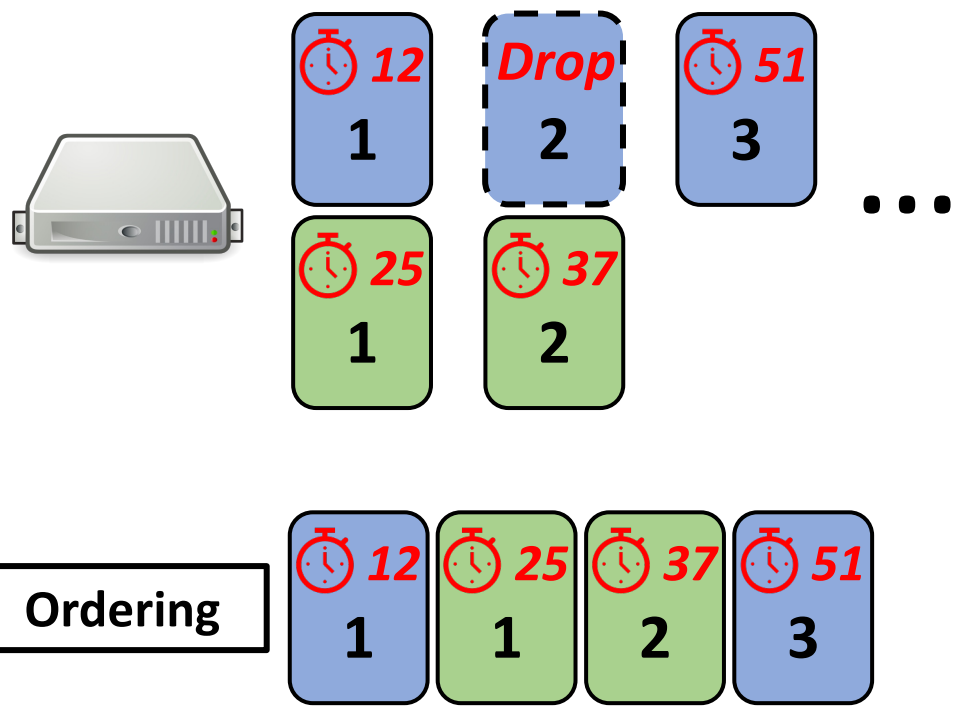

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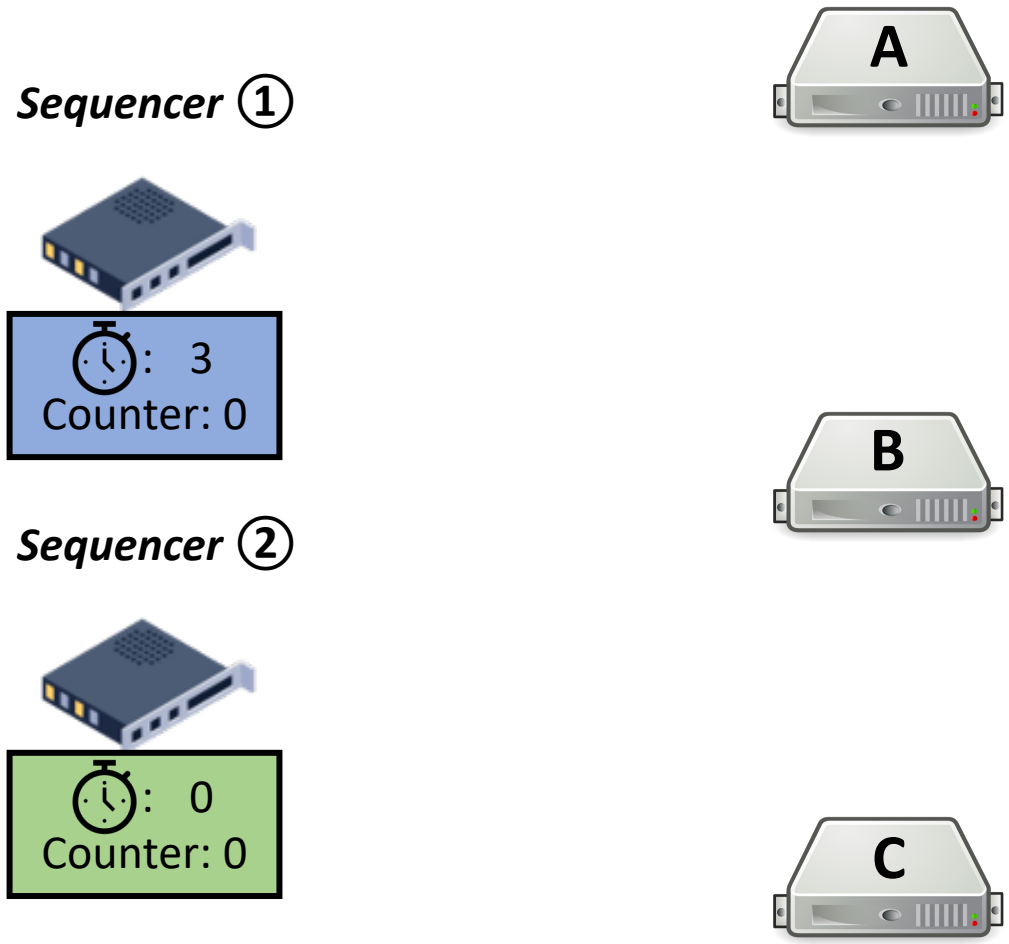
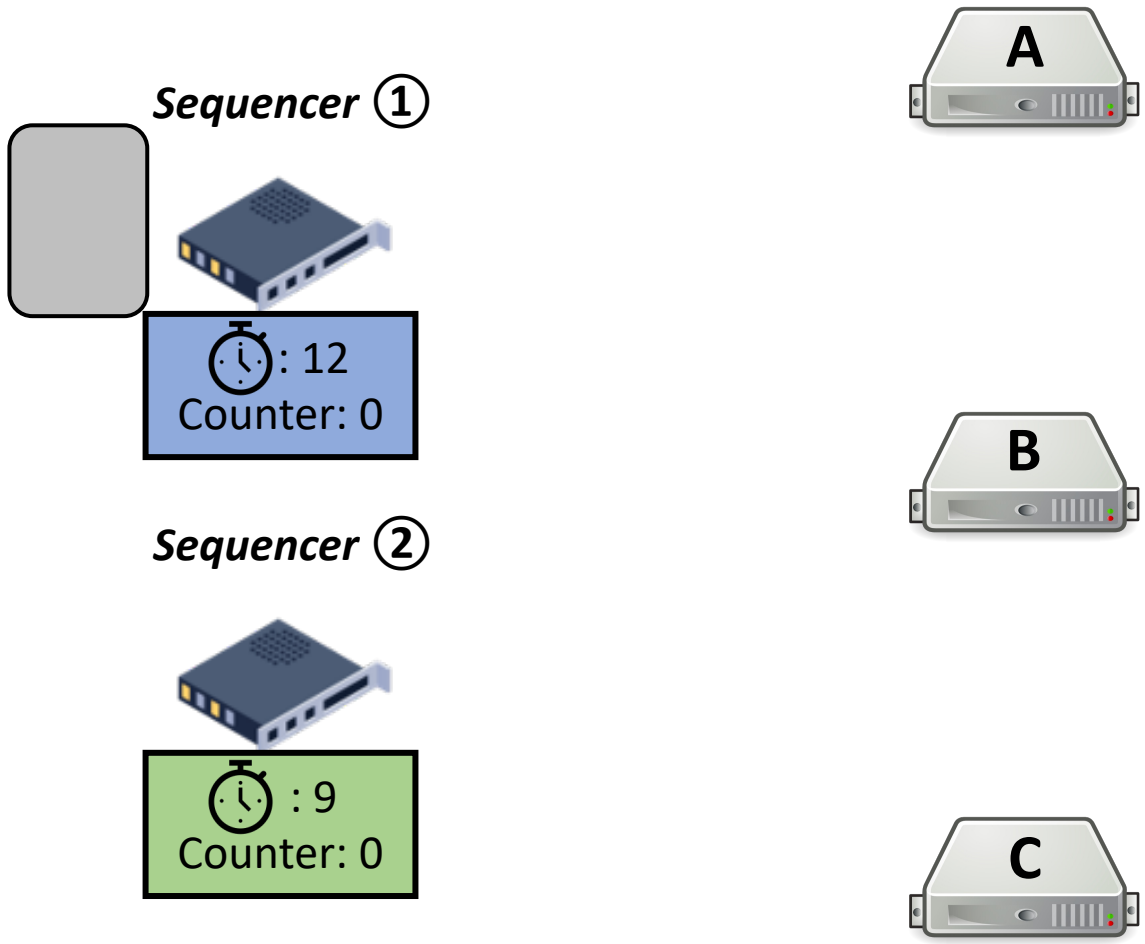
Hydra Network Primitive



Hydra Network Primitive - Sequencers



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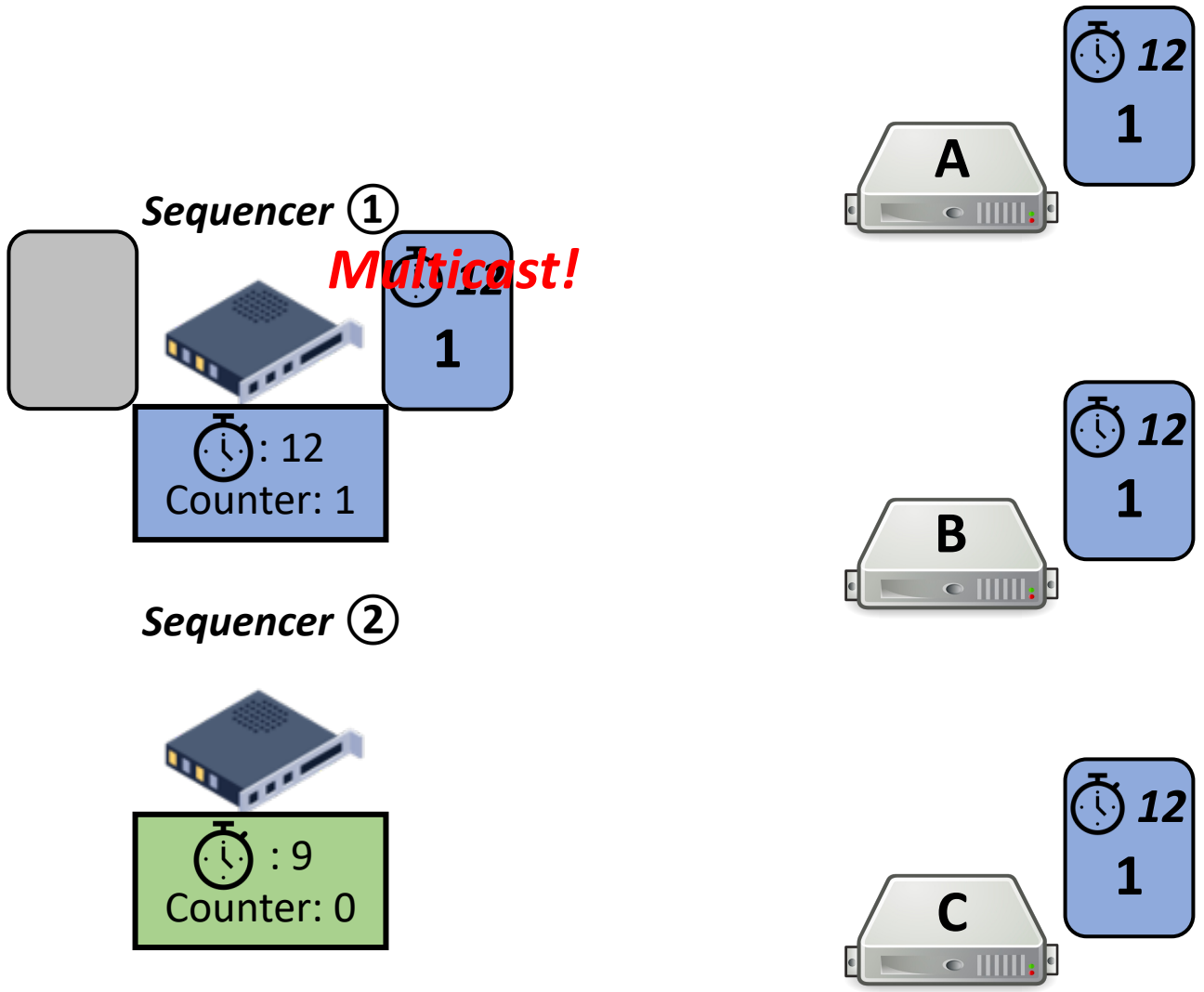

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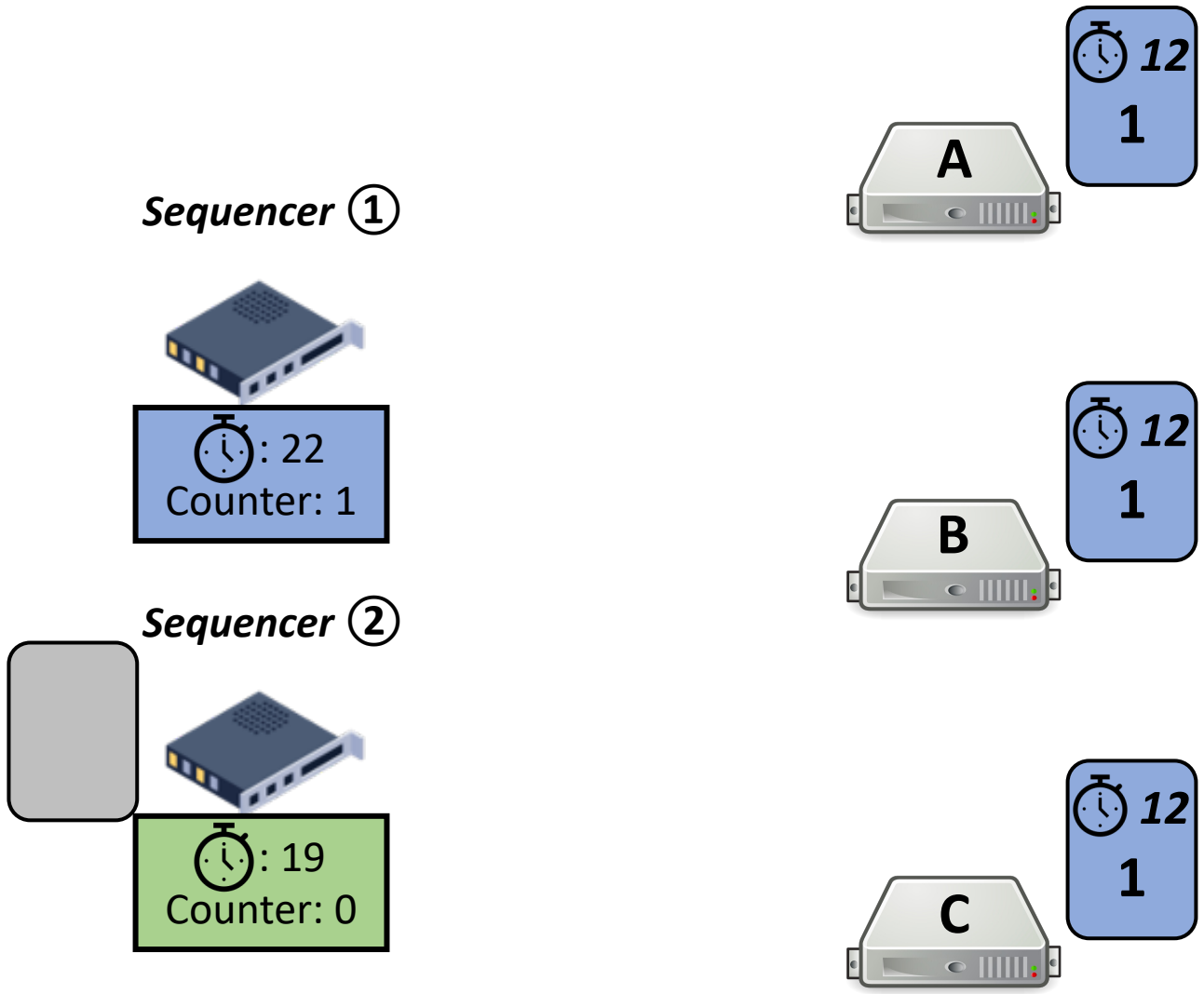

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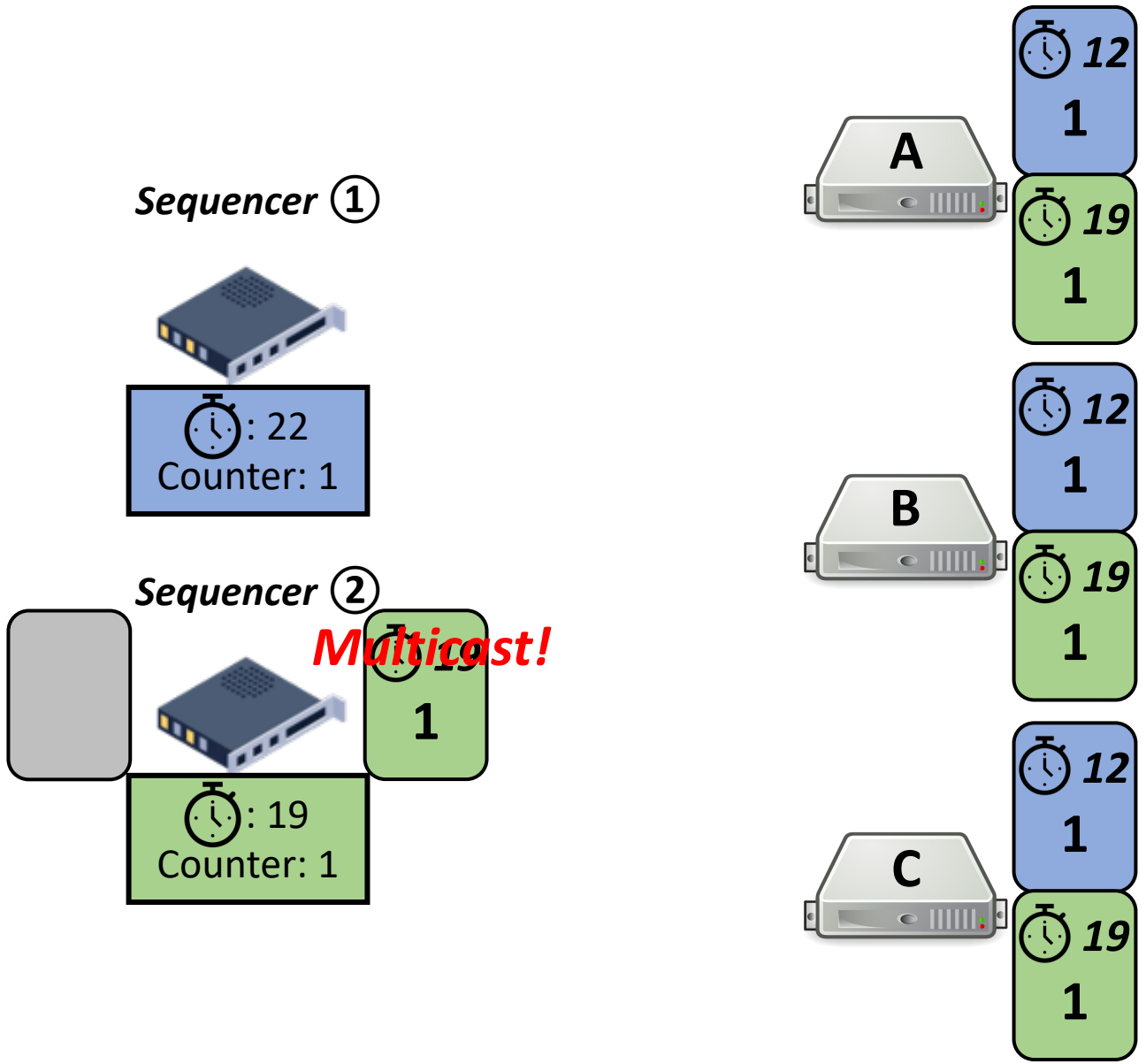
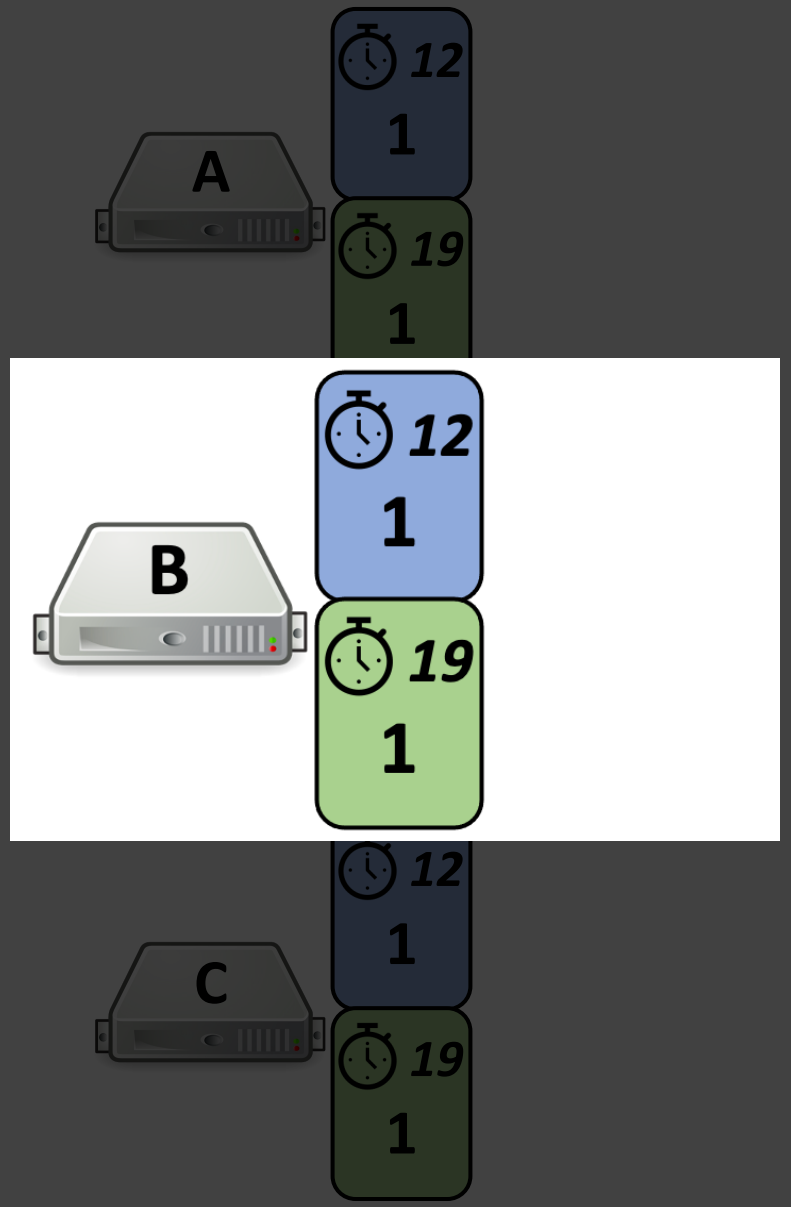


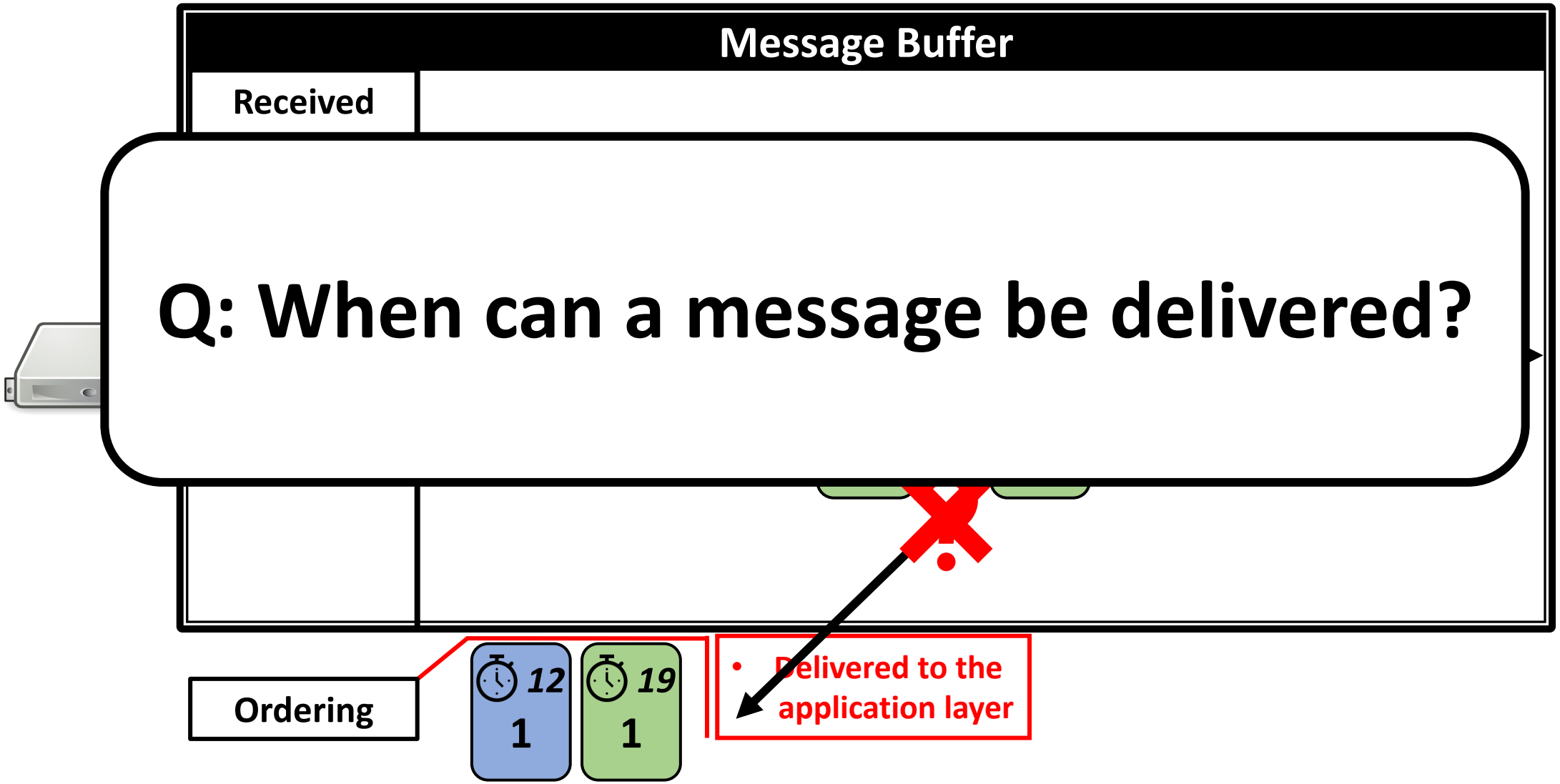
Hydra Network Primitive - Sequencers

Sequencer ①

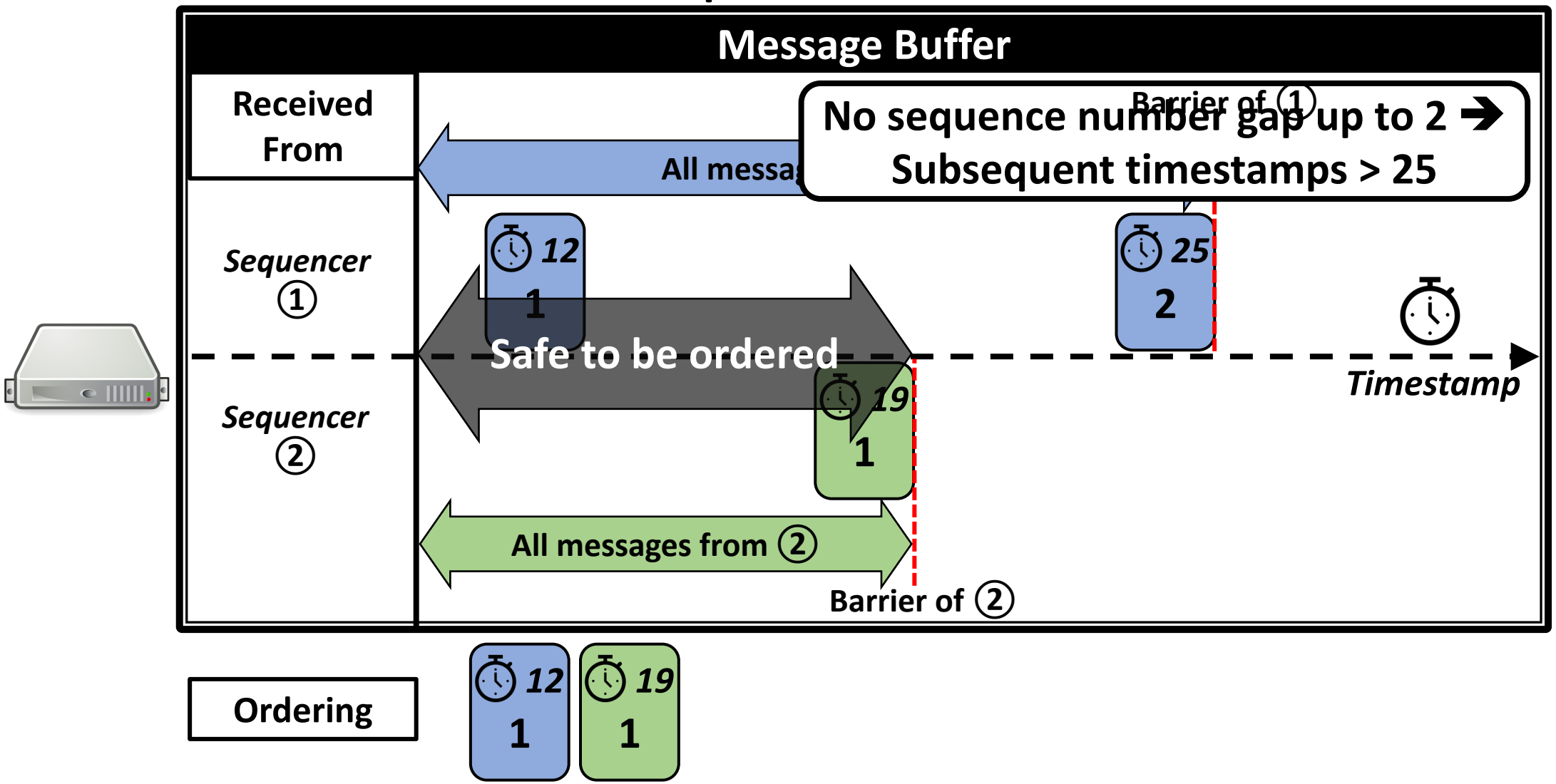
Sequencer ②



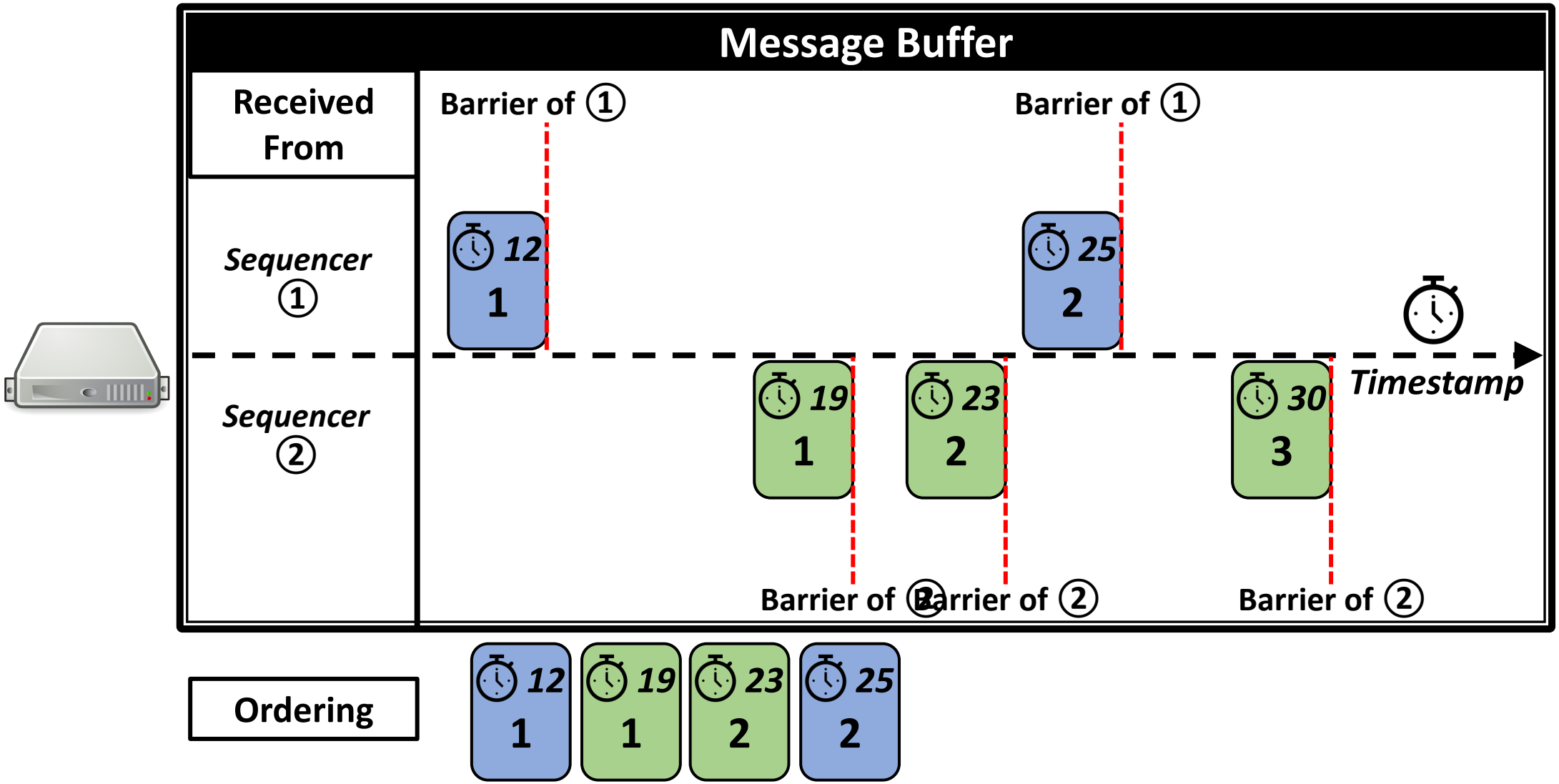
Hydra Network Primitive - Receivers



A: Once ALL messages with lower timestamp have been received



Deliver messages up to *the minimum barrier*



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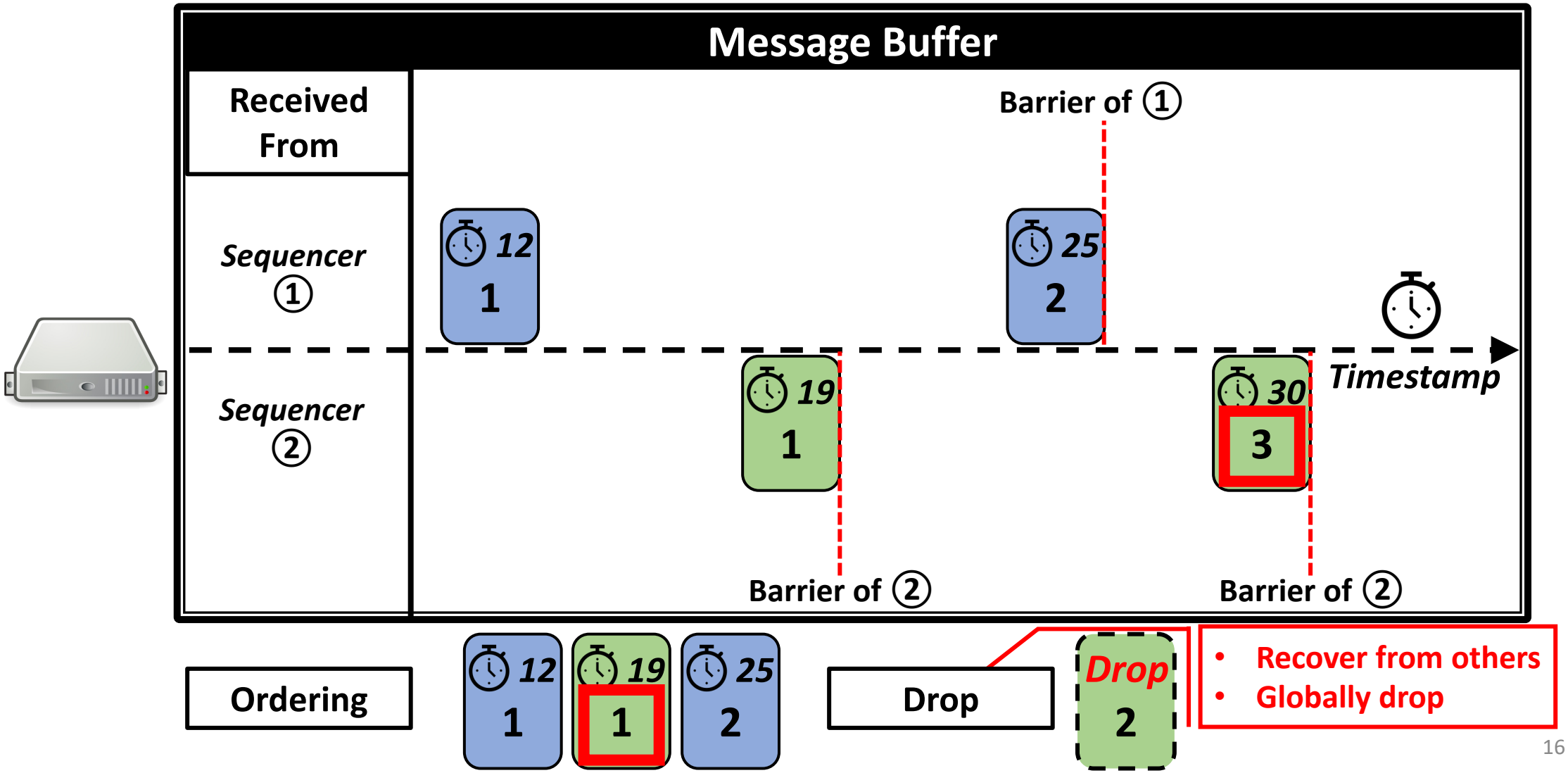
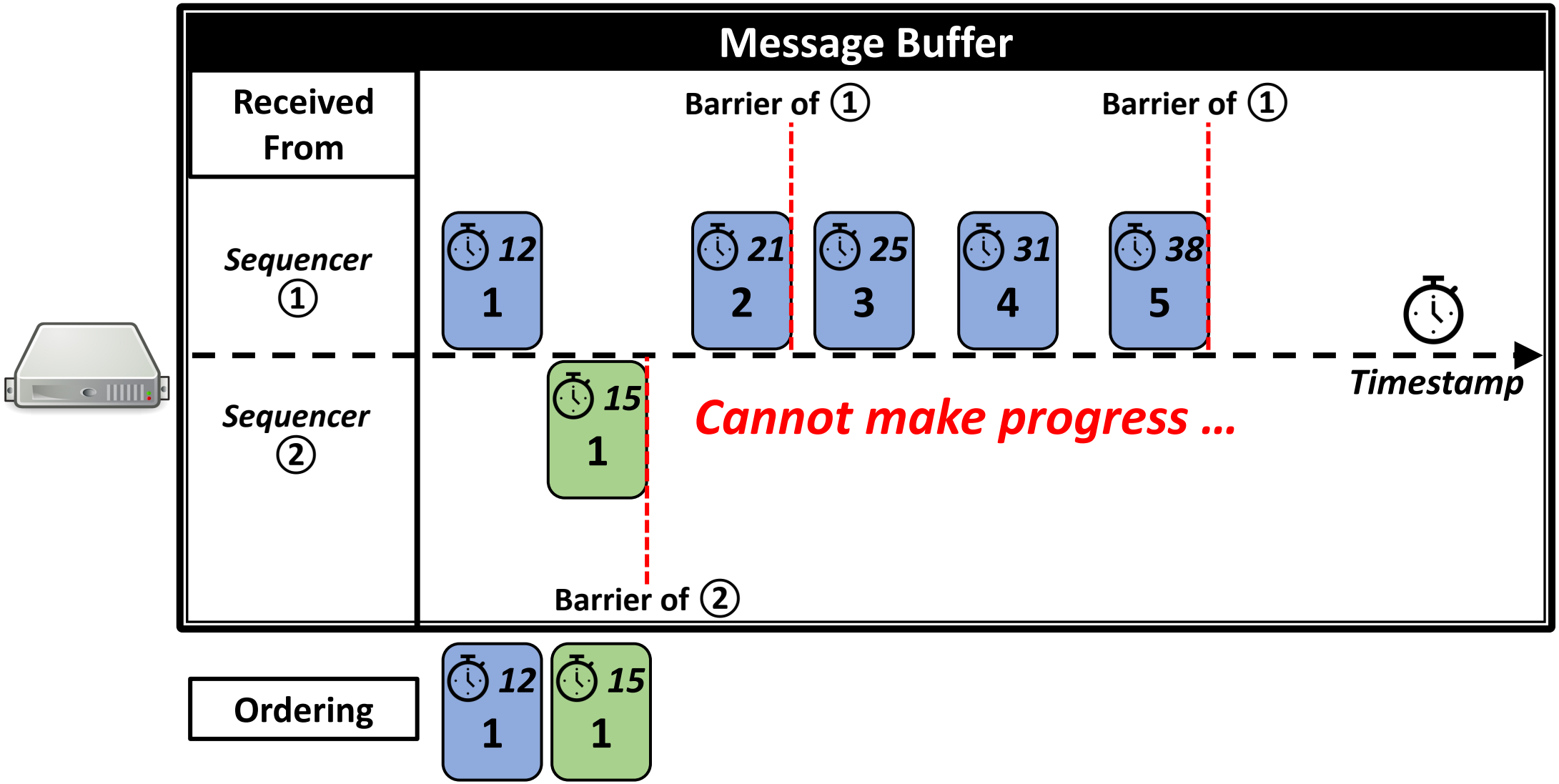
How to handle messages drops?

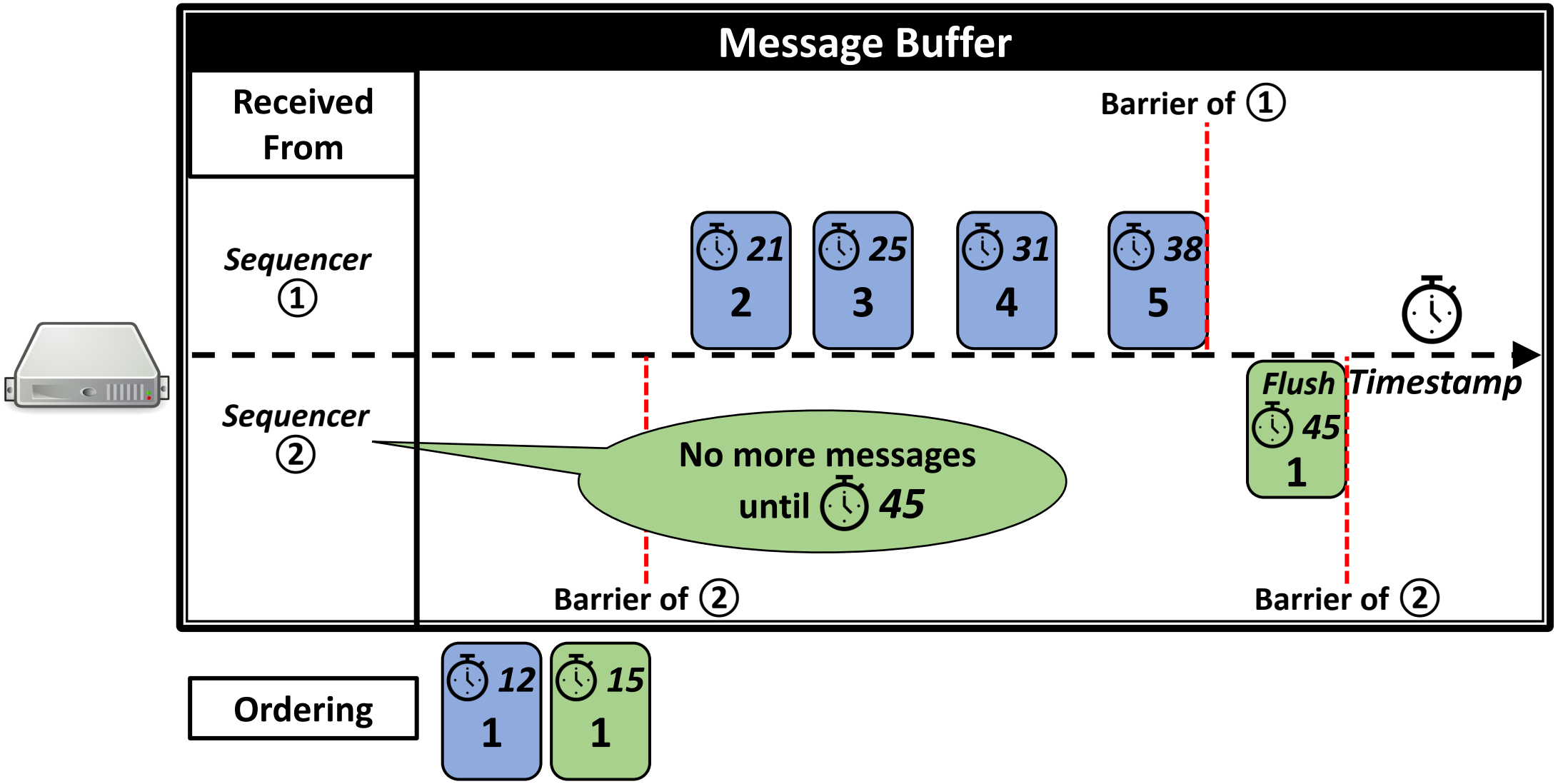


What happens if a sequencer is idle?

Does not receive any messages for a while



Flush Message from Sequencers



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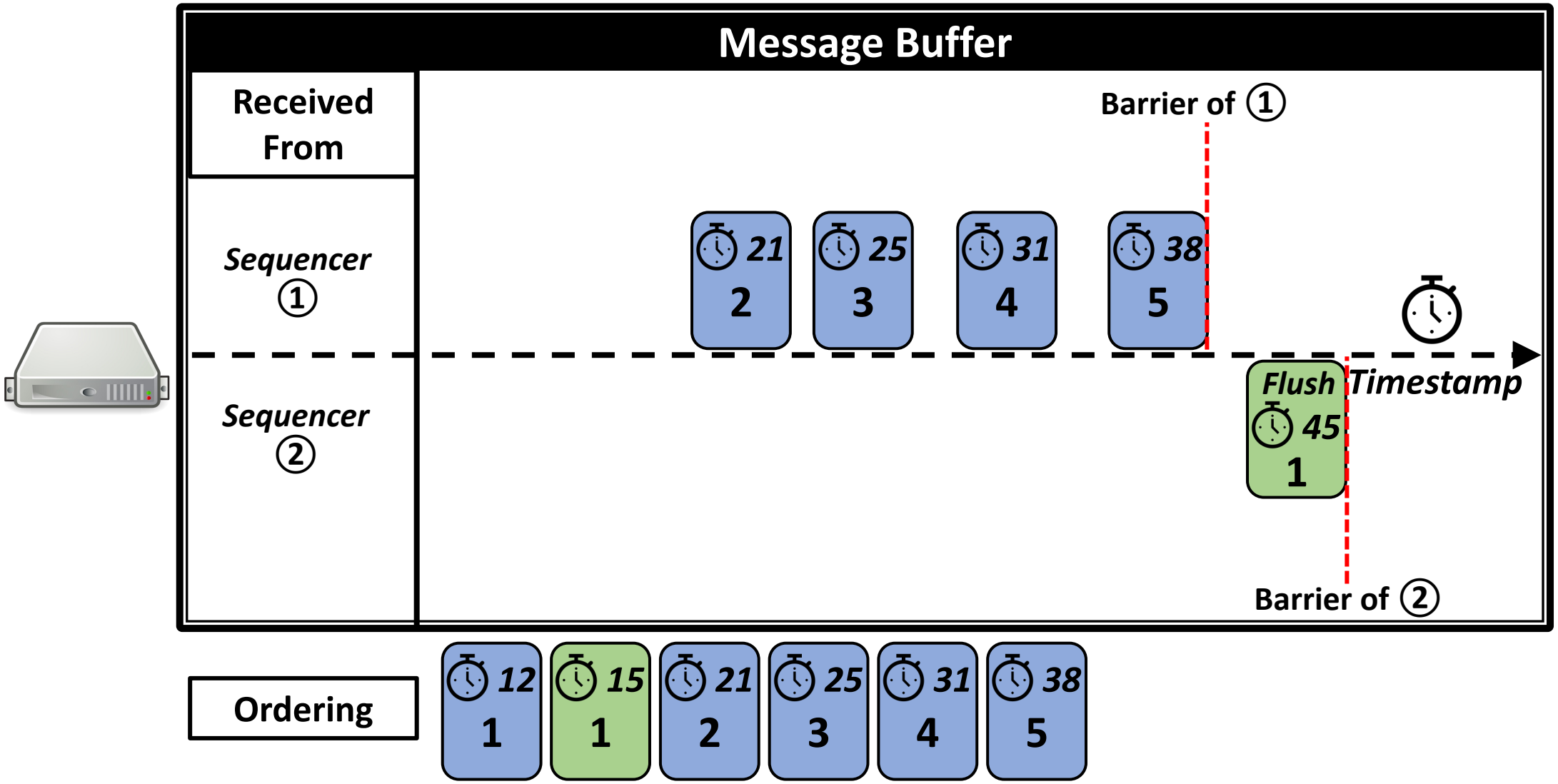

More Discussions

Flush message optimizations

- Receiver-side solicitation
- In-network aggregation

Adding or removing sequencers

Congestion-aware routing

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Low Latency through Network Load Balancing

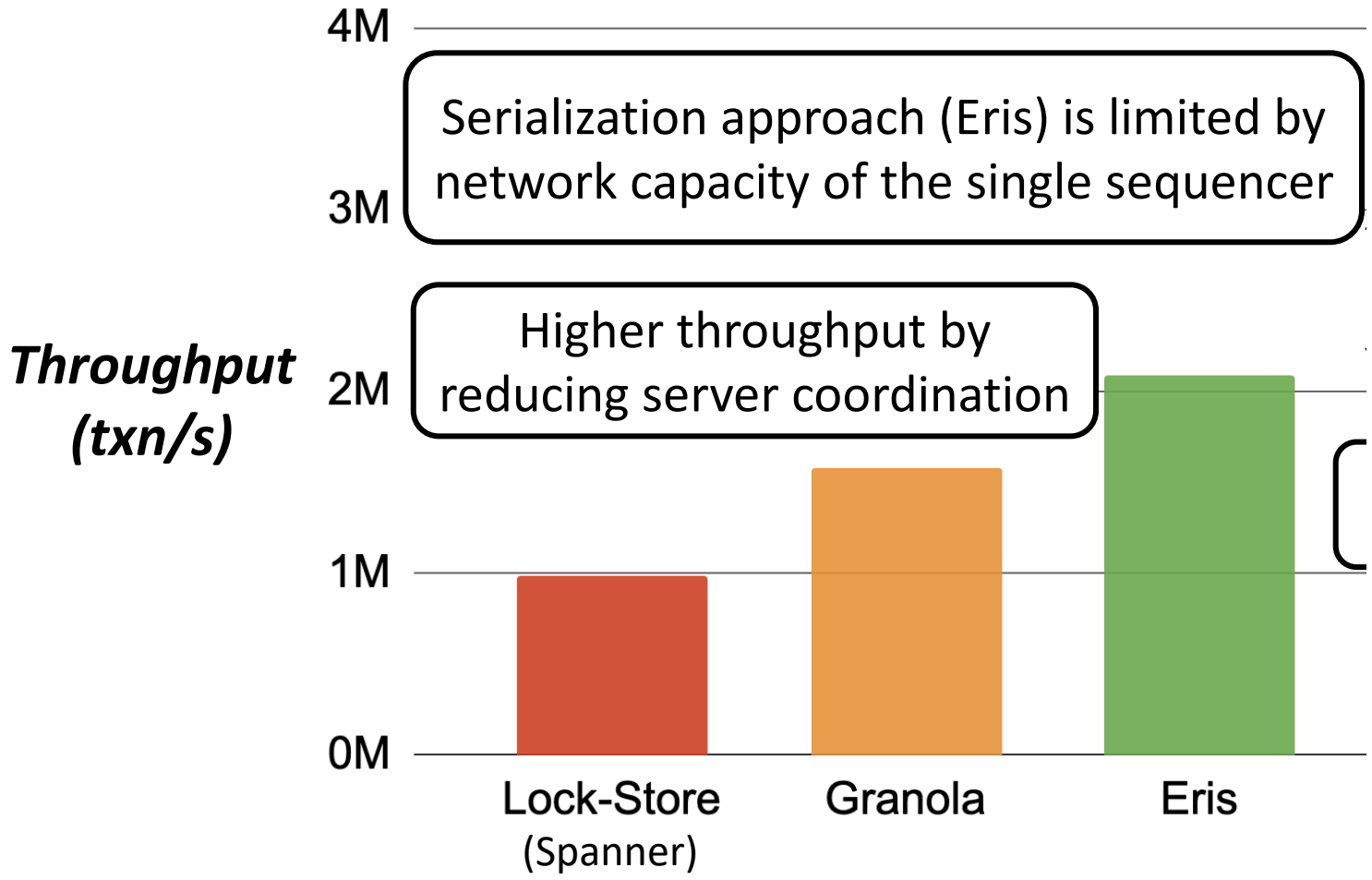
Transactional Database Performance

Experimental Setup

- **HydraTxn**: transactional key-value store using Hydra
- 15 physical shards (3 replicas per shard), virtual shards
- Limited sequencer switch capacity (details in the paper)
- Workload: YCSB+T *

* *Benchmarking cloud serving systems with YCSB* [SoCC '10]

Scales beyond a single sequencer



Spanner: Google's Globally-Distributed Database [OSDI '12]
Granola: Low-Overhead Distributed Transaction Coordination [ATC '12]
Eris: CoordinationFree Consistent Transactions Using In-Network Concurrency Control [SOSP '17]

More Evaluations

- Throughput of Hydra ***scales linearly with the number of sequencers***
- Hydra ***reduces sequencer failover time by 5x***
- Performance of Hydra is ***resilient to moderate levels of packet drops or clock skews*** across sequencers

  Do not affect system correctness
- Hydra ***significantly reduces flush message overhead*** using various optimizations

Summary

- Existing network ordering approaches pose serious drawbacks, due to ***in-network serialization***

- Hydra combines ***sequence number and physical clock*** of sequencers

- Result: ***serialization-free*** network ordering with significantly
  - ✅ ***Better network-level load balancing***
  - ✅ ***Higher sequencer scalability***
  - ✅ ***Faster sequencer failover***

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