Large Scale Systems
CS 410 / 510

Lecture 18:
Streamlined Consensus

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Assignment 4 is Out!

- Assignment 4 is due on **June 2, 2025** at **11:59pm PST**.
- Please start working with your groups.

Presentations

- Each group will present their MiniSpanner on **June 4, 2025 in class**.
- The class will start **10min earlier** on **8:20am** to accommodate all the groups.
- Each group will get **25-30min** to present their progress.

Reading Material

- Online reading

Last Class

- Last class we looked at:

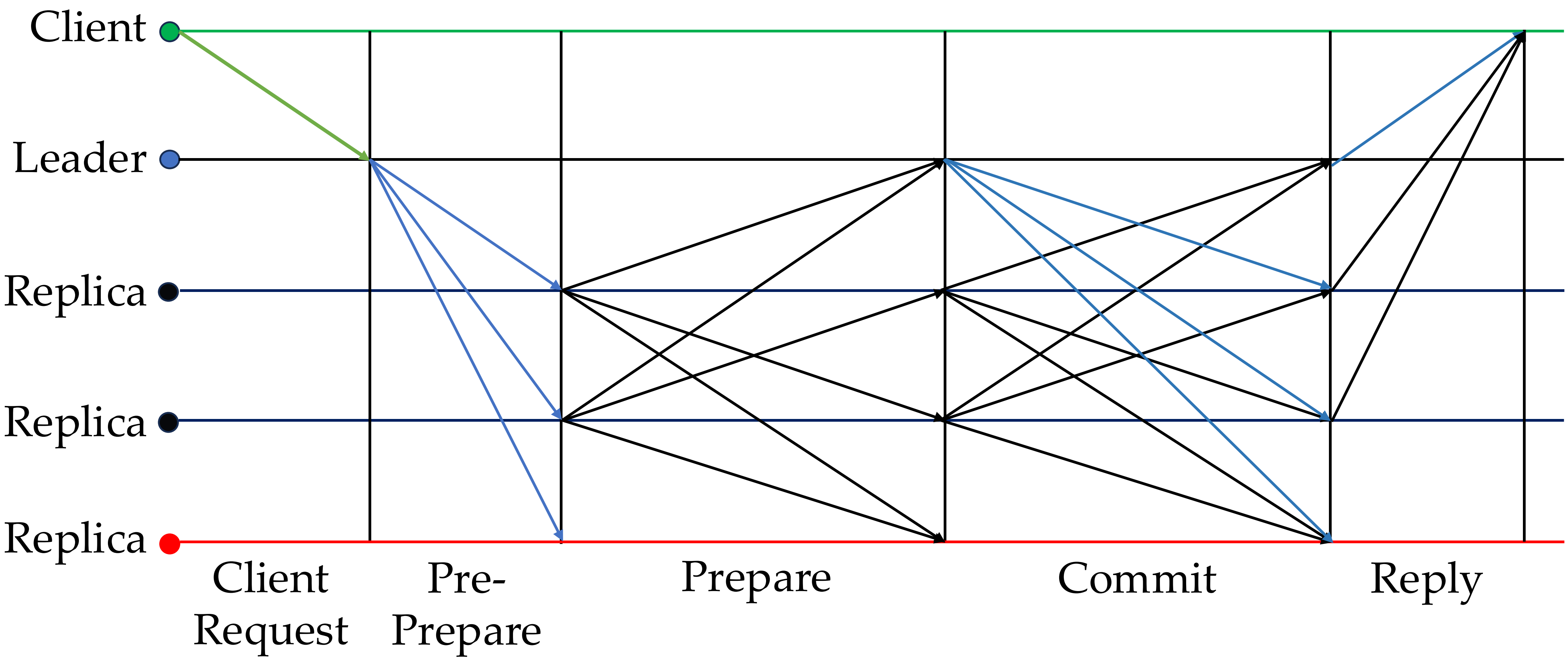
- Scaling Consensus across Globe
- GeoBFT
- RingBFT

Optimizing PBFT

- Today, our goal is to continue optimizing PBFT.

- Until now, we added to PBFT:
    - Pipelining
    - Out-of-Order Message Processing
    - Speculation
    - Parallelism
    - Geo-scaling
    - Sharding

PBFT Protocol



What can we do next?

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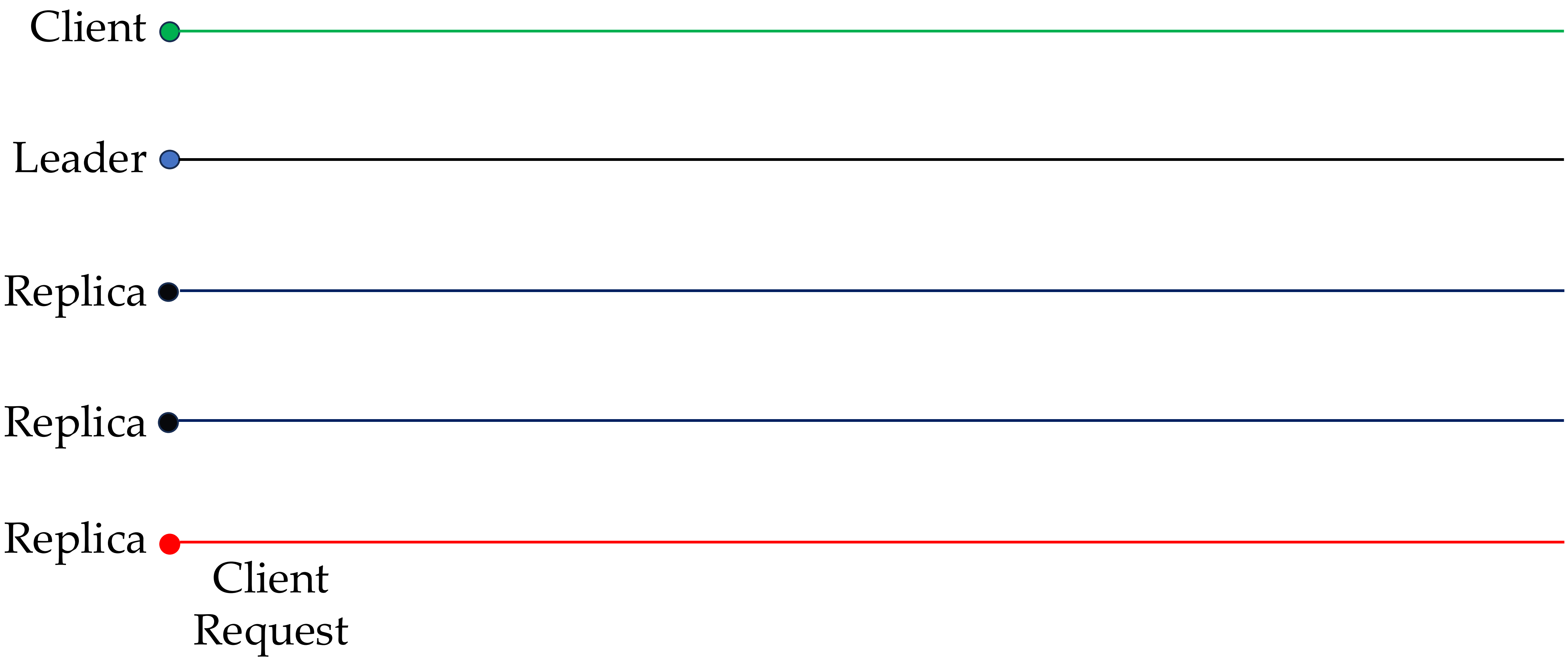
- We can **linearize** the phases of PBFT.

- Split each phase with quadratic communication complexity into 2 phases of linear complexity.

- Instead of All-to-All → All-to-One + One-to-All.

PBFT Linearized



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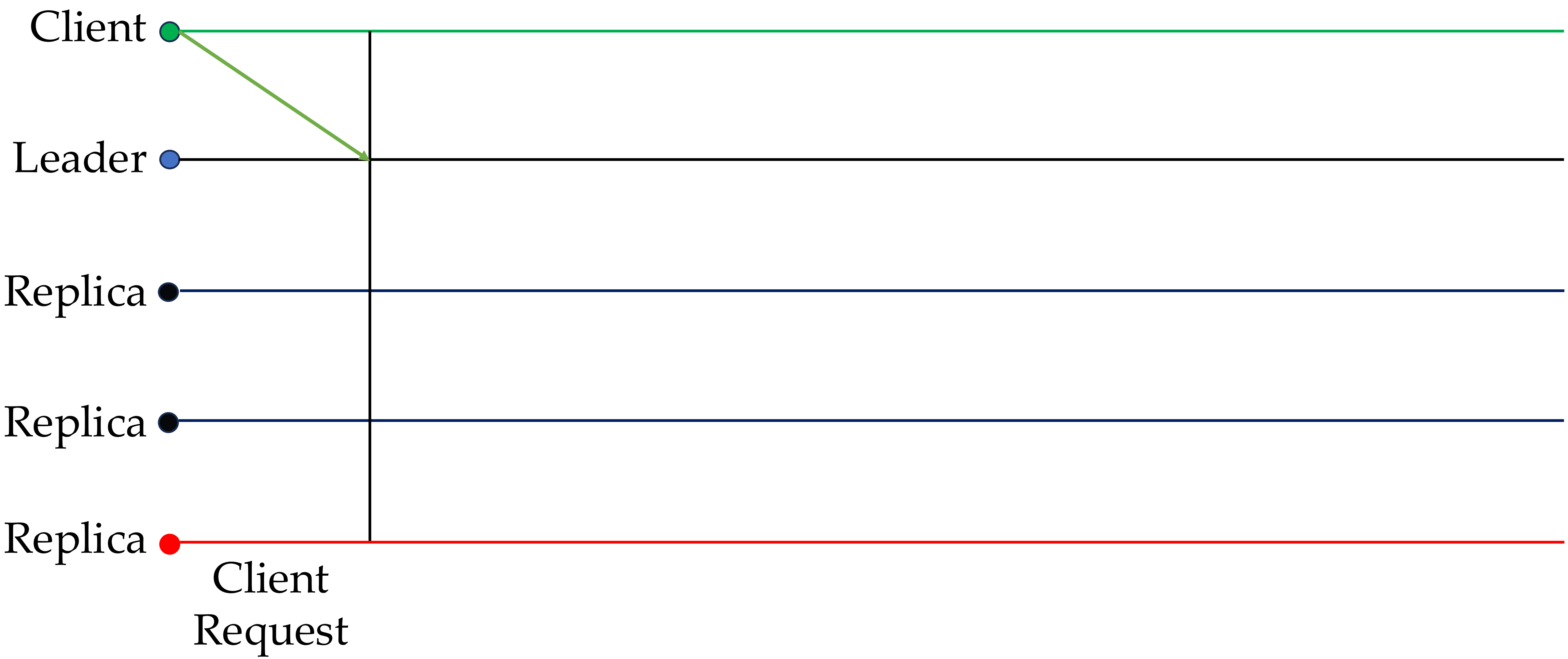

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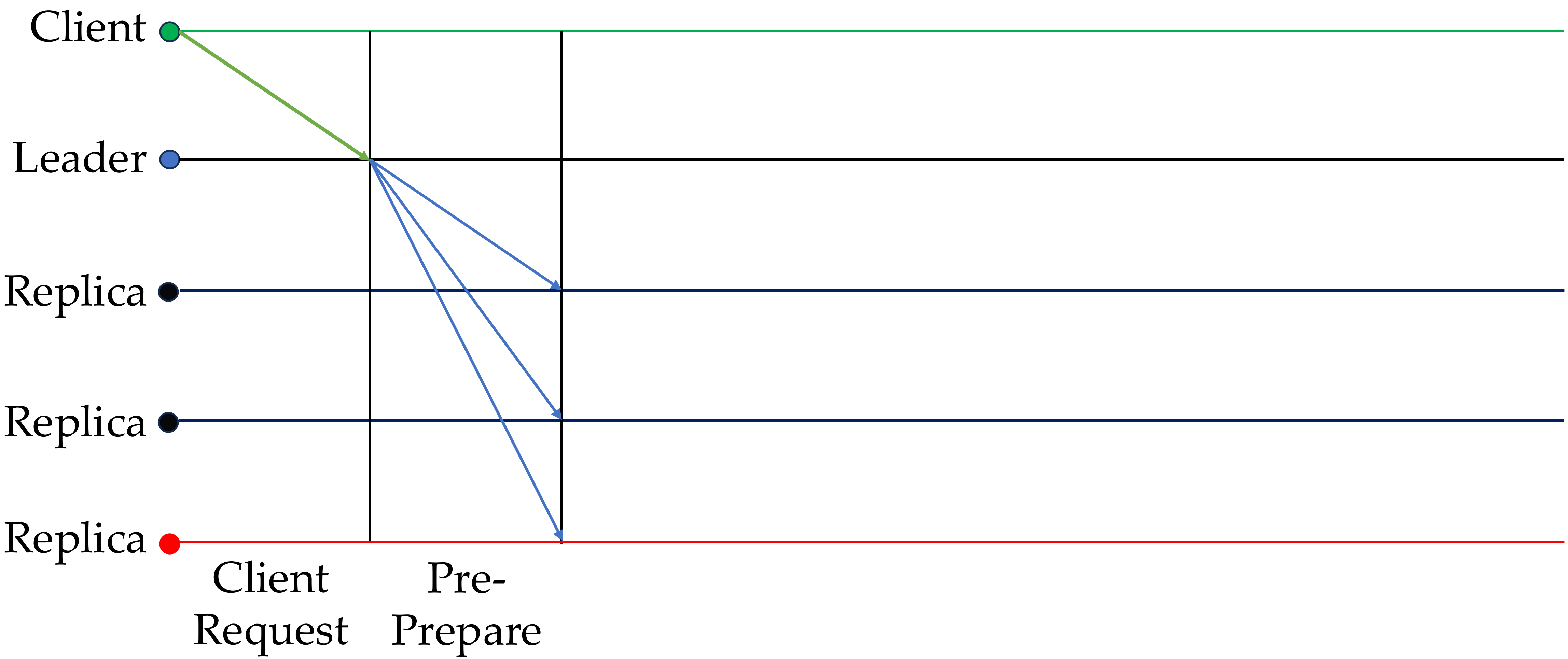

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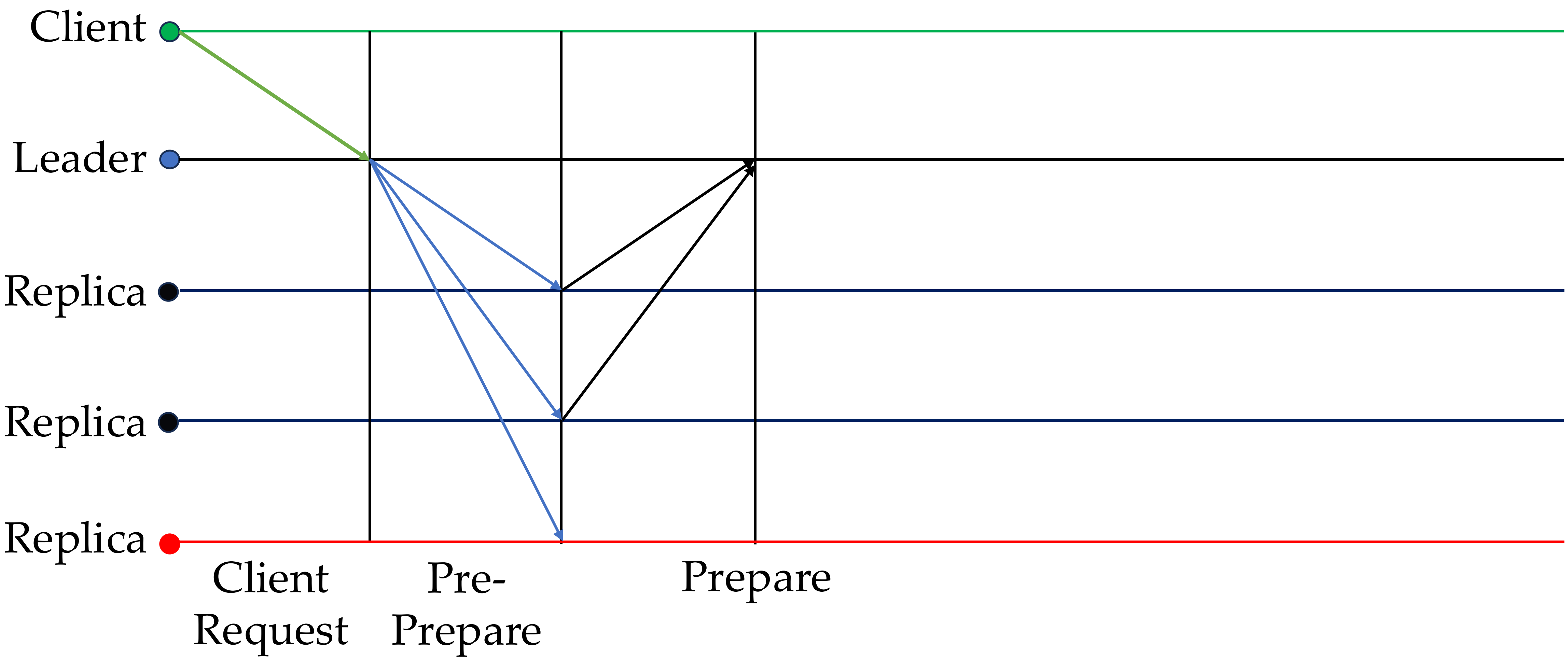

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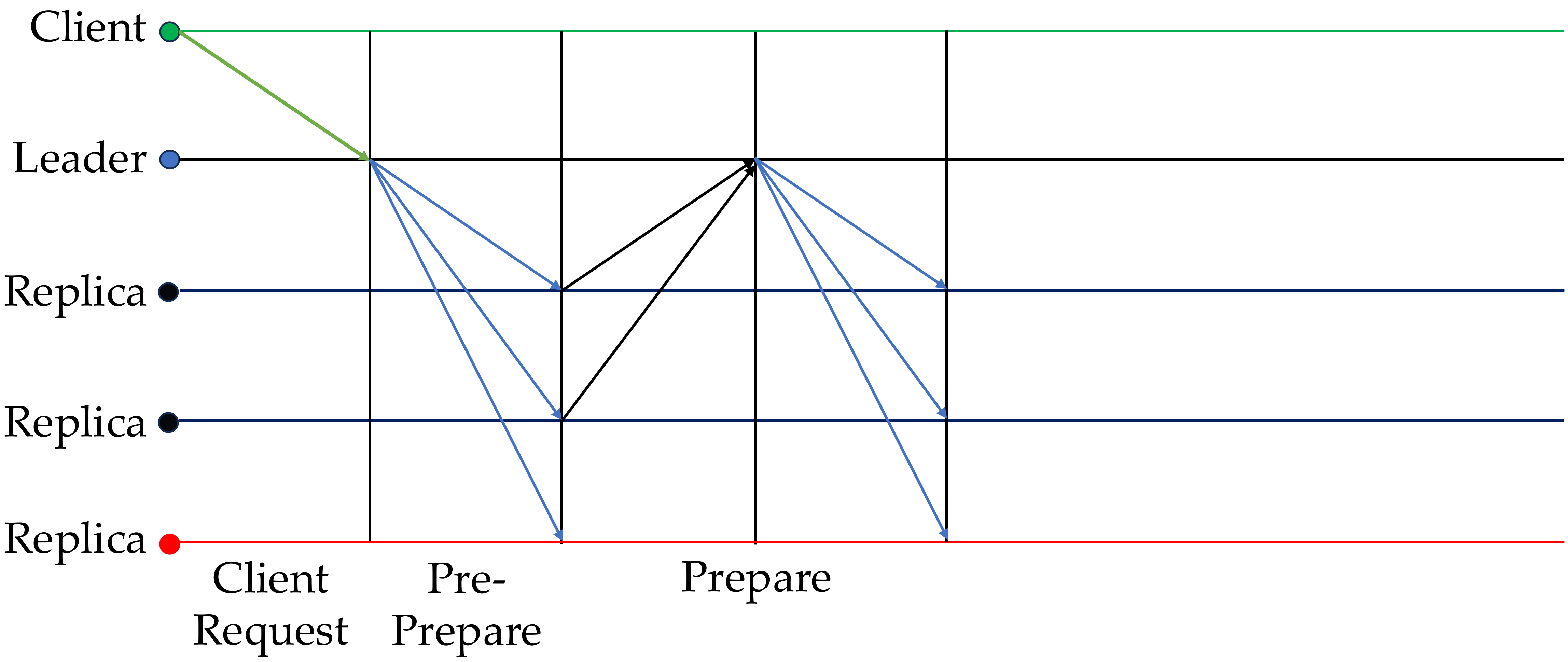

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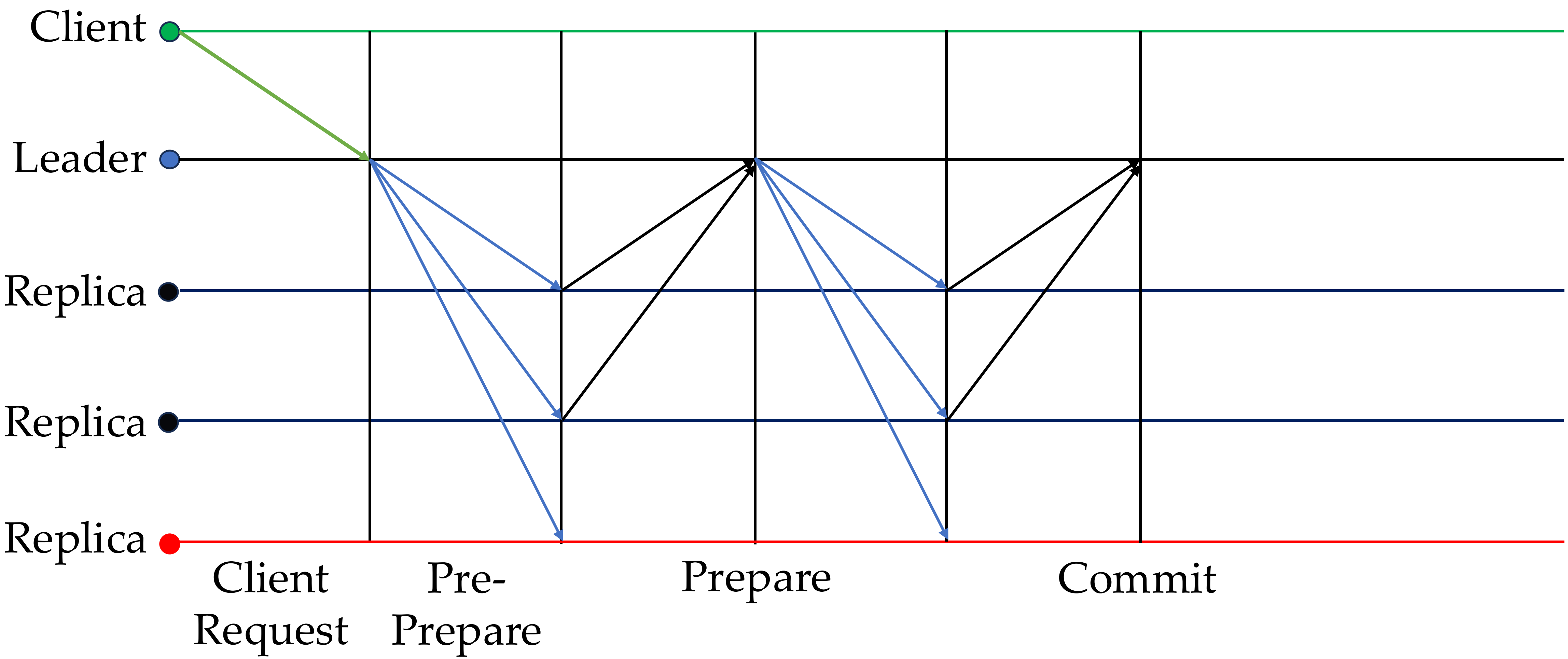

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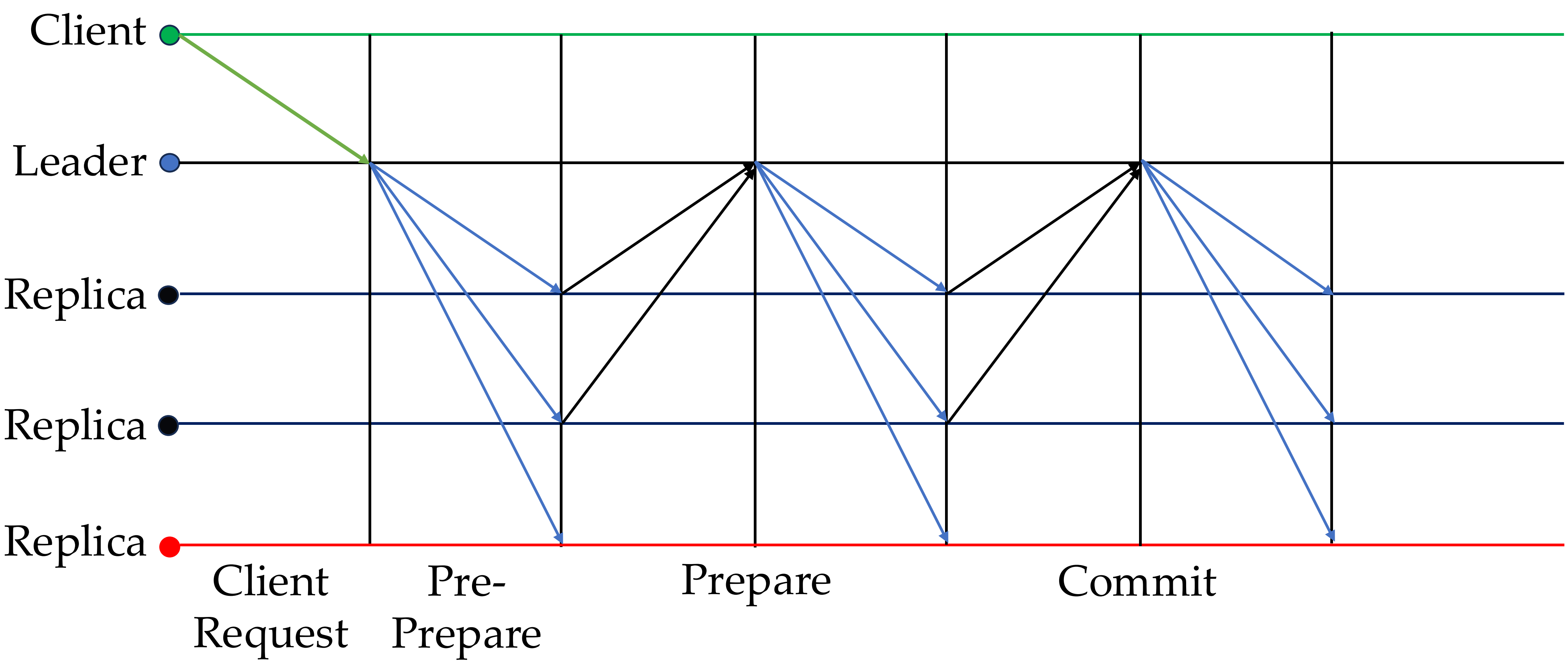

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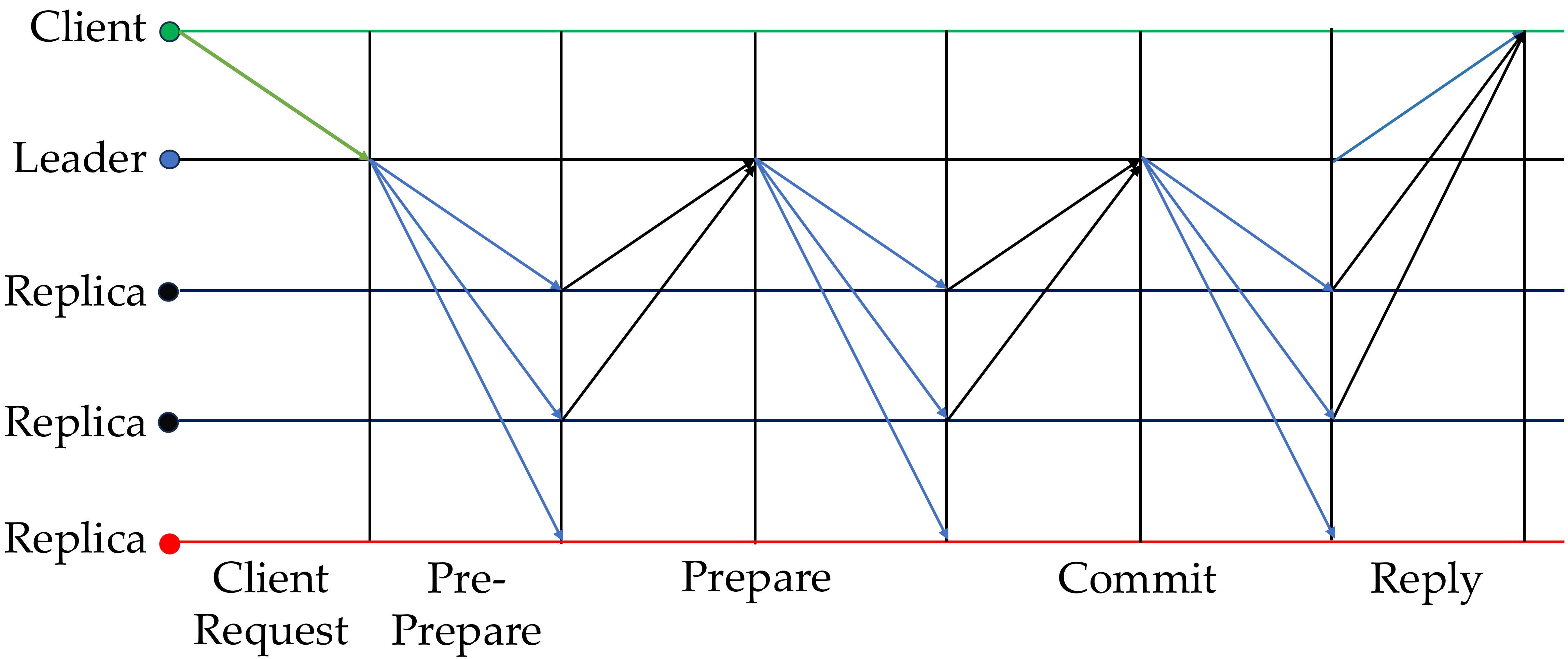

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    - A certificate comprises of n-f Prepare or Commit messages.

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- Can we do something better?

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- This whole idea is enabled using threshold cryptographic schemes that allow creating keys that support aggregation.

Linearized PBFT with Threshold Cryptography

- With threshold cryptography, linearization of PBFT is complete.
- Now, we have reduced communication cost from quadratic to linear.
- However, the design is now more computationally expensive as threshold cryptography is expensive.
- This idea was introduced in a protocol → **HotStuff [PODC'19].**
- The **n-f** threshold signature is often referred to as **QC** → **Quorum Certificate**.

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- Any other remaining challenges?
    - Yes!

- HotStuff also discussed about the challenges of having one leader:
    - Censorship of Clients.
    - Leader Slowness.
    - Expensive view change.

Client Censorship

- A single fixed leader can censor clients → silently drop their requests.

- May avoid proposing requests of specific clients unless forced.

Leader Slowness

- A clever Byzantine leader may propose client requests slowly.
- If the leader knows that it will not be replaced if it proposes a minimum number of requests within a specific time period, then it will not propose any extra requests.

View Change Costs

- We know that view change is expensive.

- During view change, no consensus can take place.

HotStuff’s Solution

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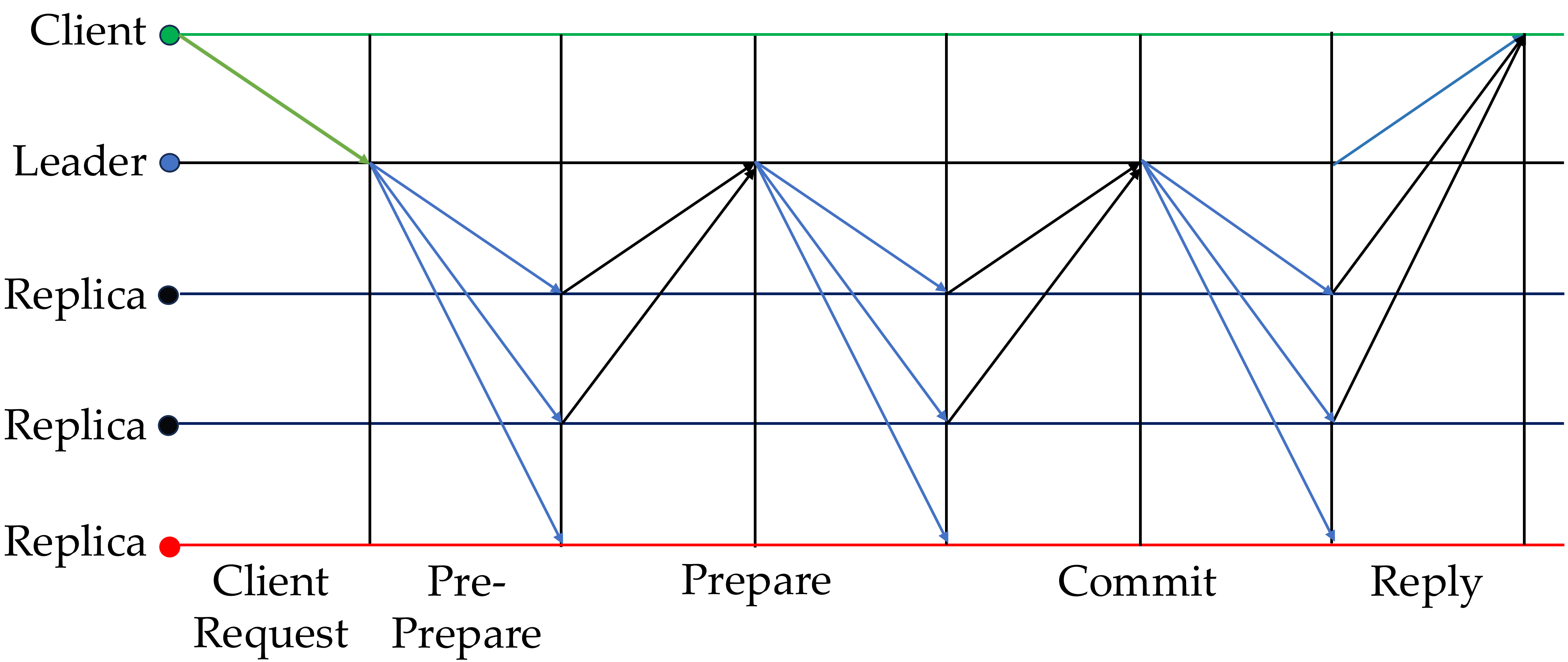
- Switch leader after every consensus!

- Each leader lasts for only one round of consensus.

HotStuff-2 (a faster variant of HotStuff)



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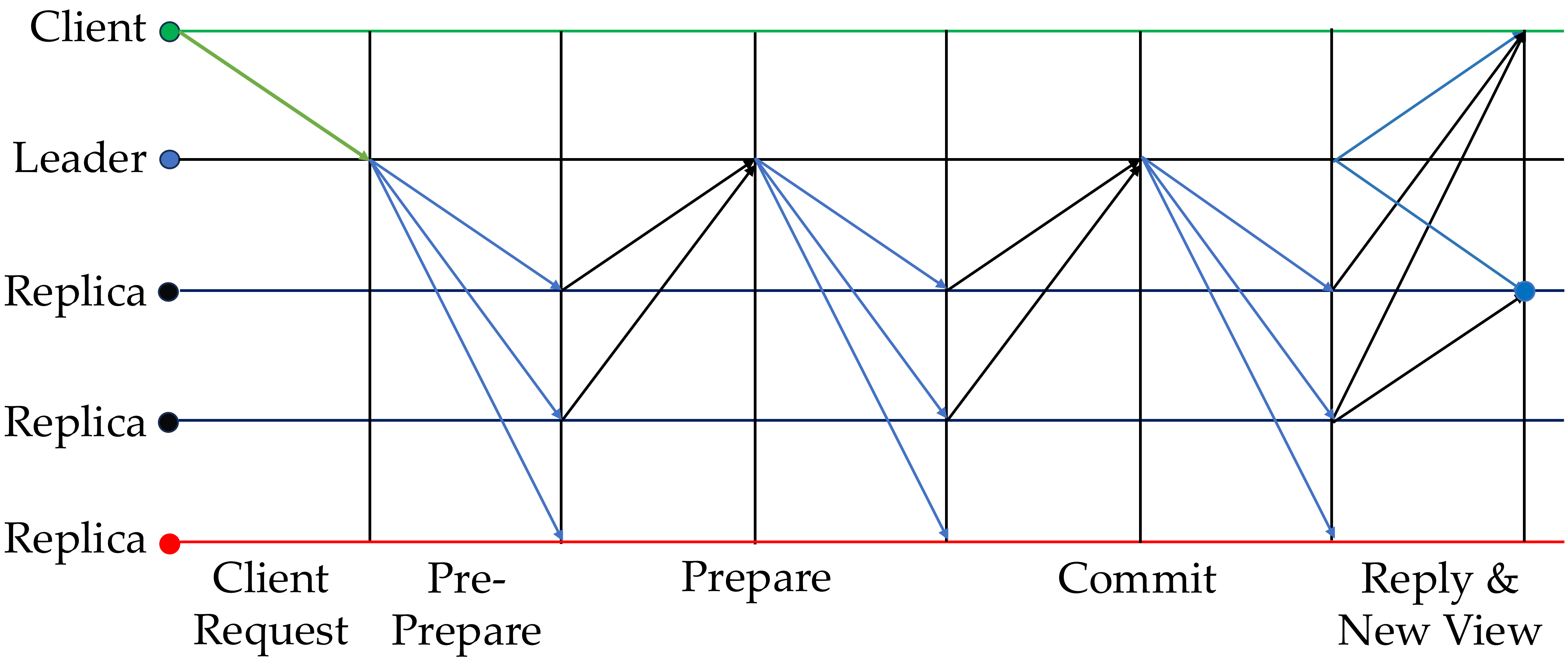


Challenges with HotStuff-2

Challenges with HotStuff-2

- Changing leader at the end of each consensus enforces that each leader can propose only one batch.

- Propose one batch → Switch.

- No possibility for applying out-of-order message processing!

- Extreme drop in throughput.

How can we increase HotStuff-2's throughput?

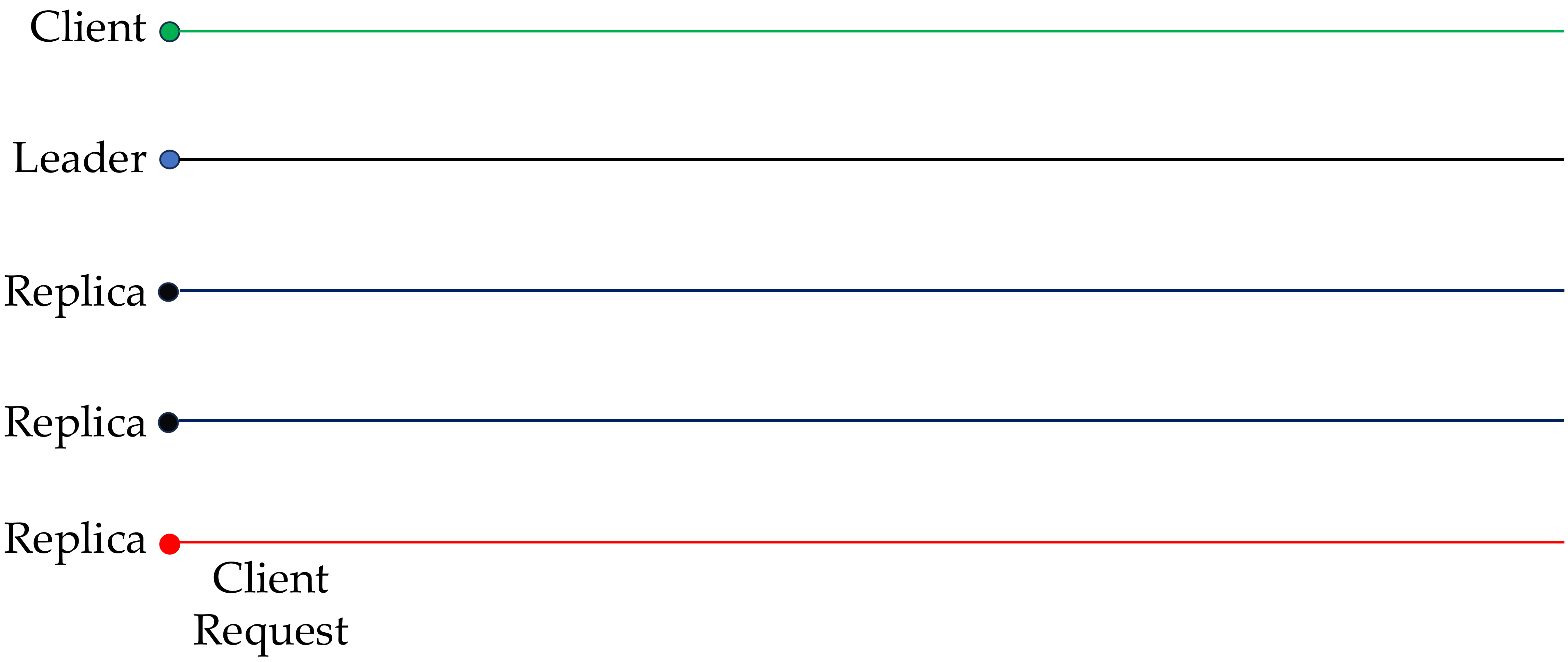
Streamlined HotStuff-2

- Allow switching leader in every alternate phase.
    - Essentially pipelining

- Twice the throughput.

- No change in the number of phases necessary to commit a transaction.

Streamlined HotStuff-2



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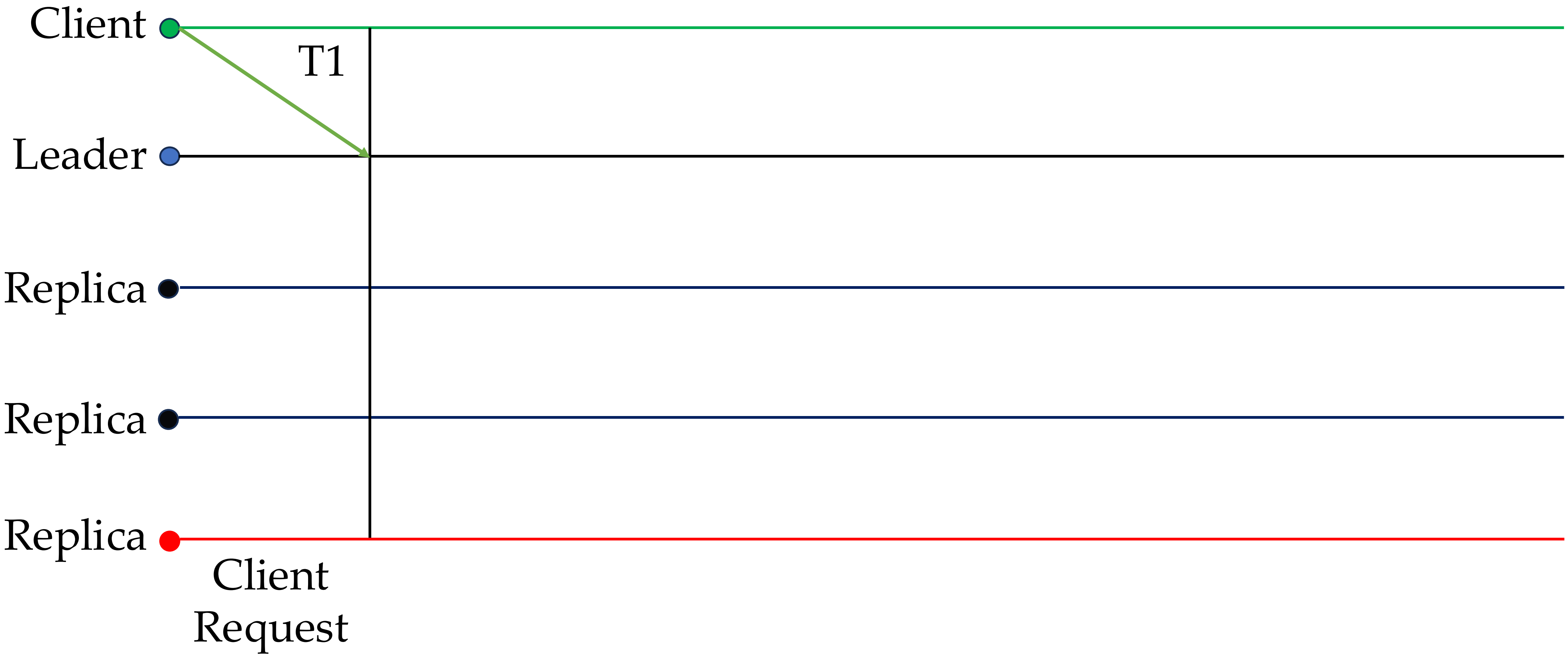

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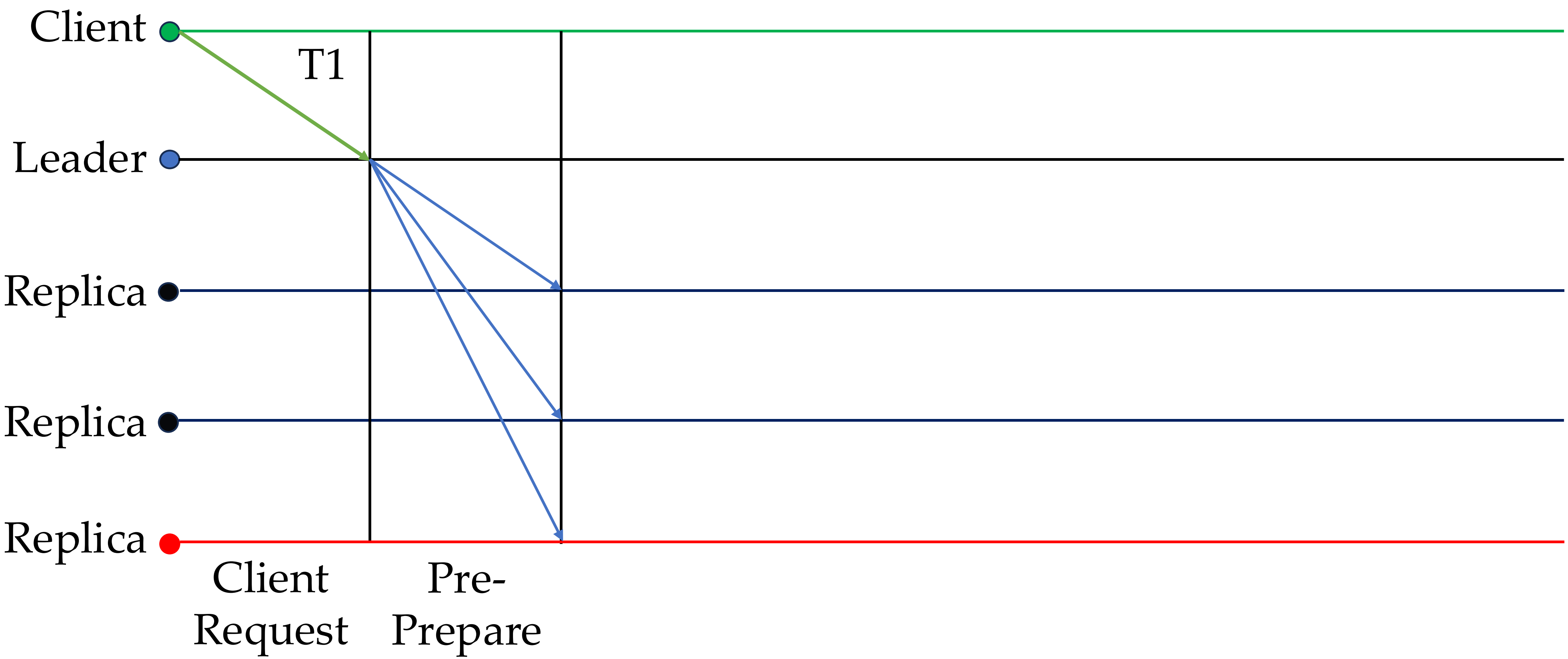

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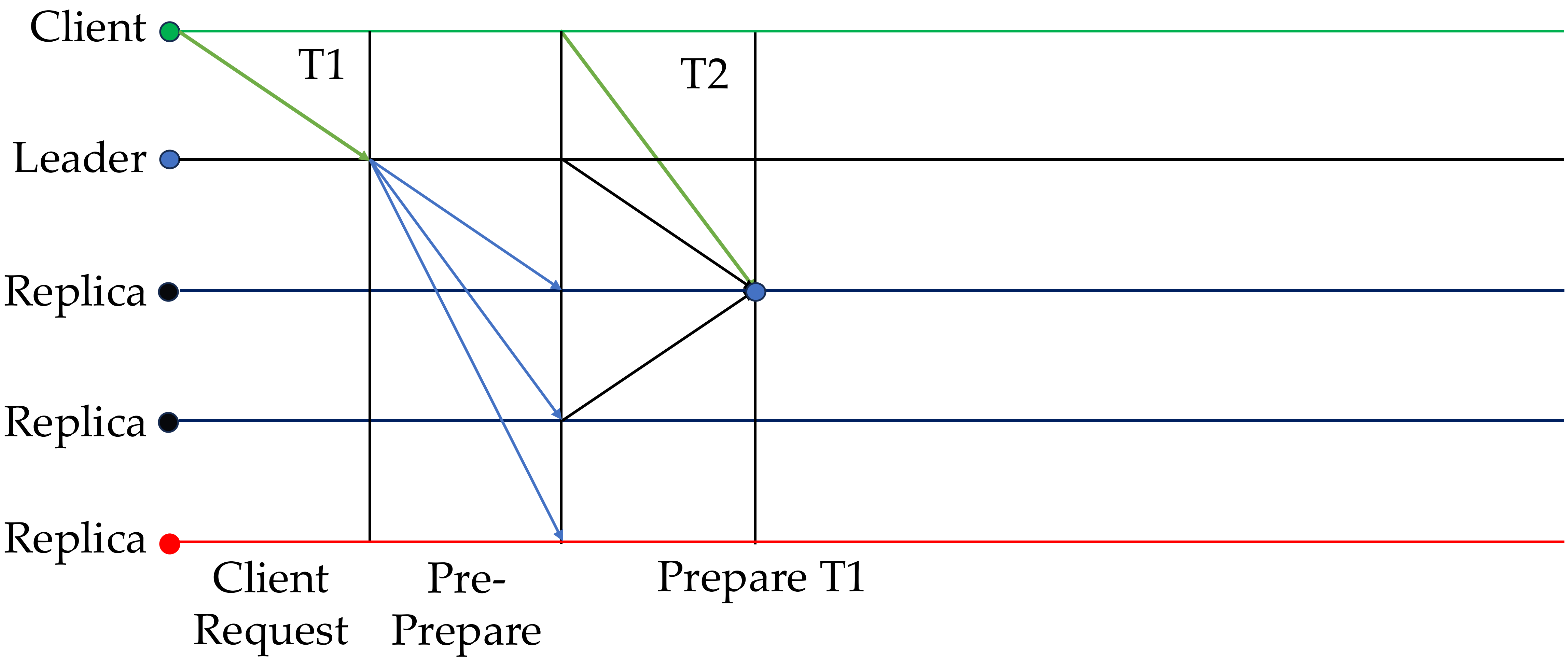

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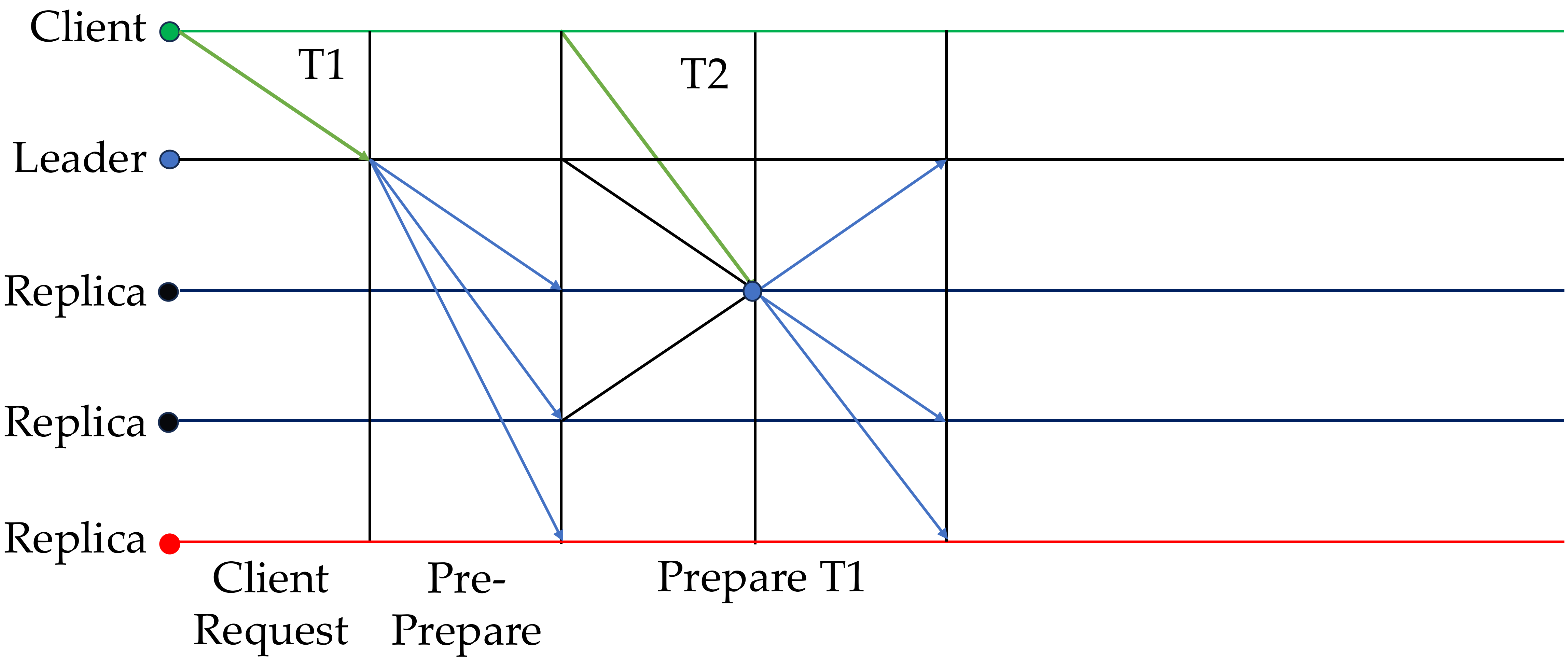

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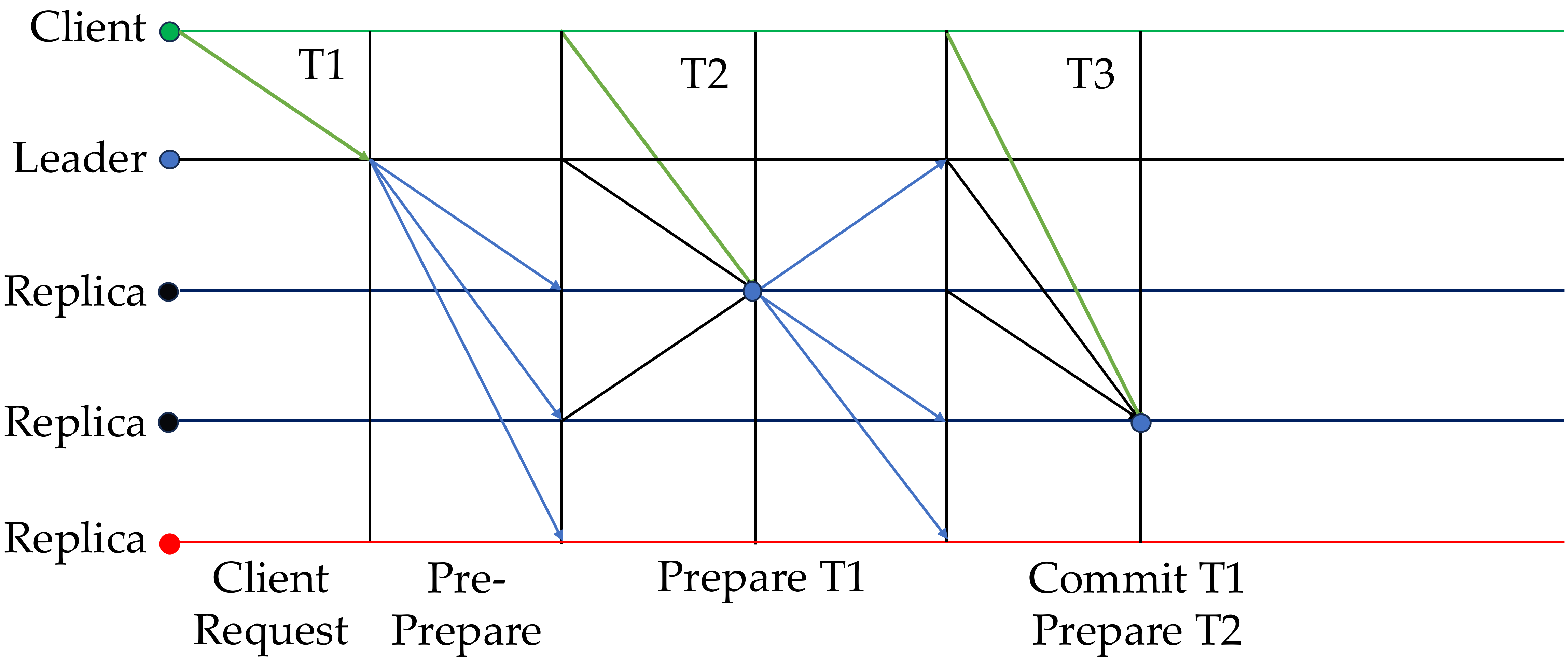

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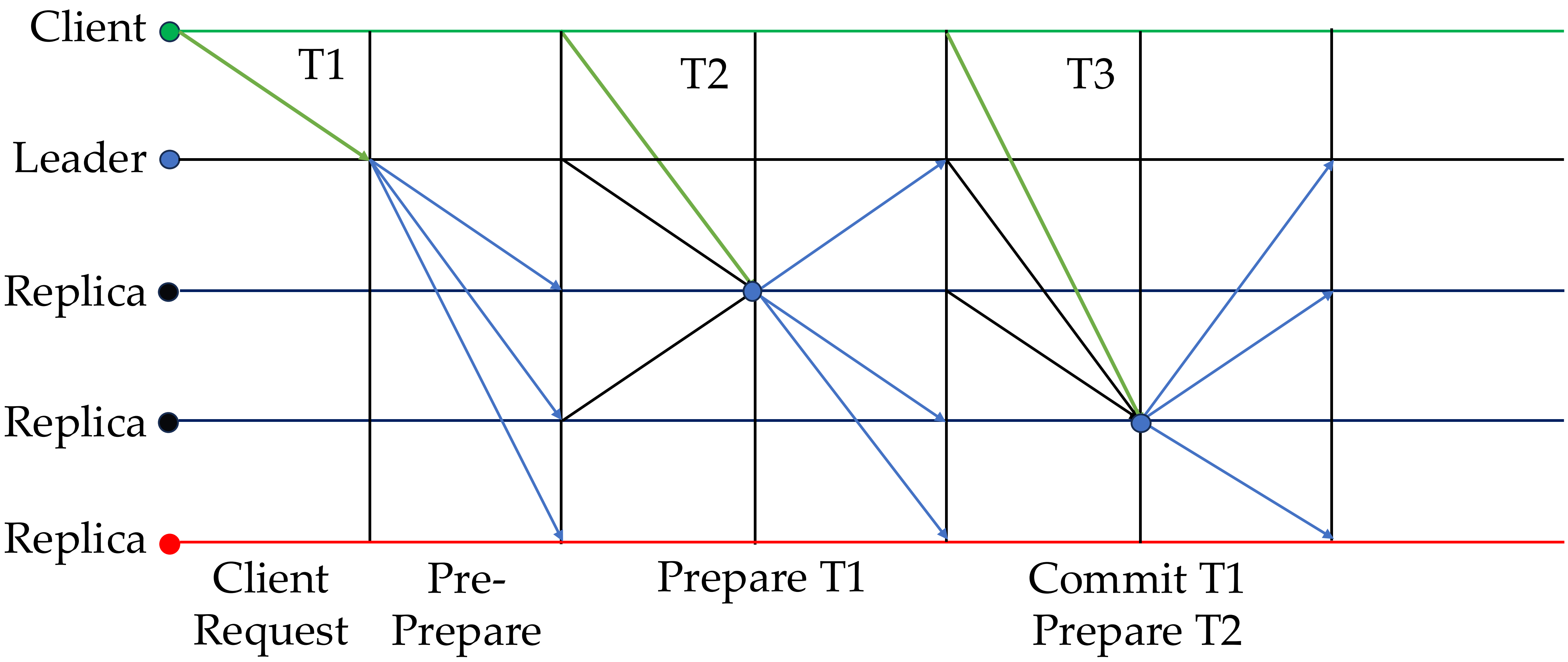

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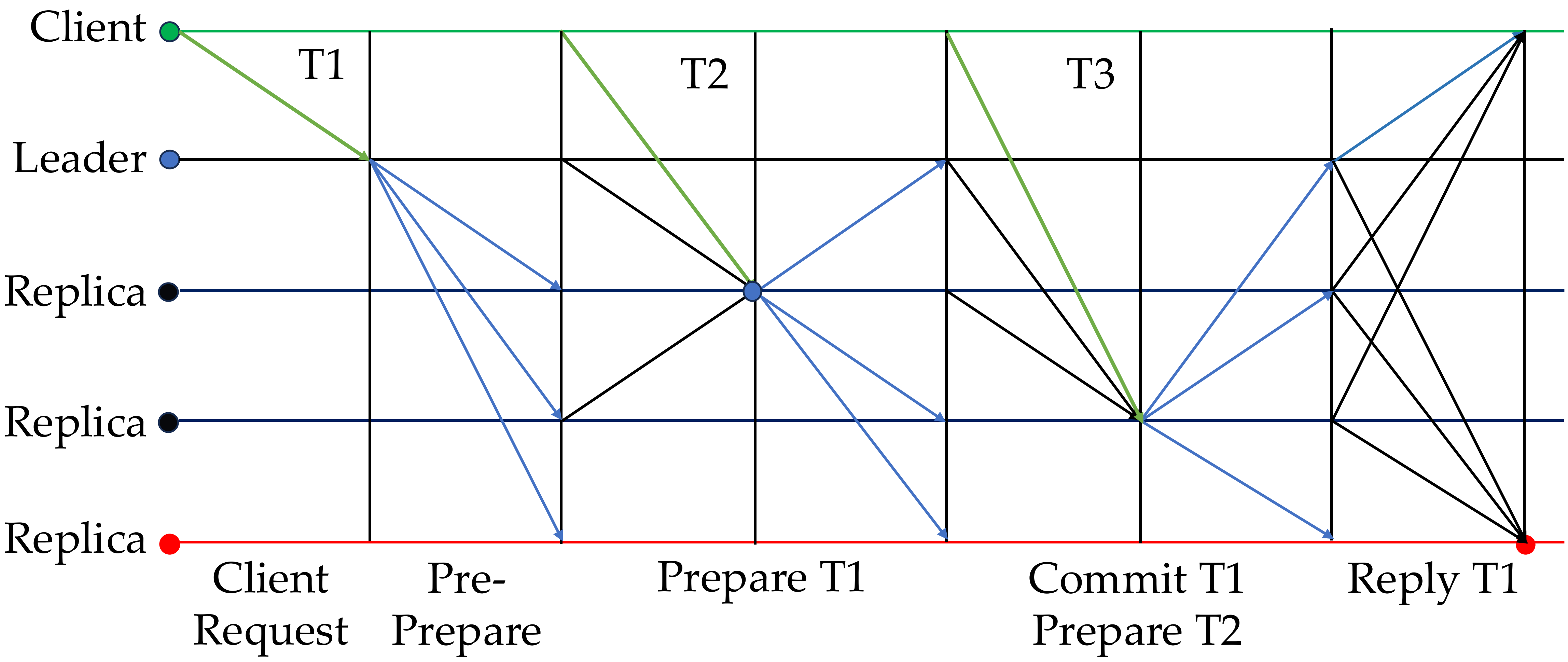

Streamlined HotStuff-2

- The first QC is formed and stored by each replica at the end of Prepare phase.

- The second QC → at the end of Commit phase.

- Storing QC is same as locking the QC.
  - Essentially a guarantee by the replica that it will not support any QC formed at a lower view.

Can we do better?

HotStuff-1

- **HotStuff-1 [SIGMOD’2025]** → Speculation + HotStuff-2.
  - More challenging than PoE as regular view changes!

- HotStuff-1 + Slotting:
  - Increases throughput by giving leaders multiple proposal slots.