Birds of a Feather Flock Together: Scaling RDMA RPCs with Flock

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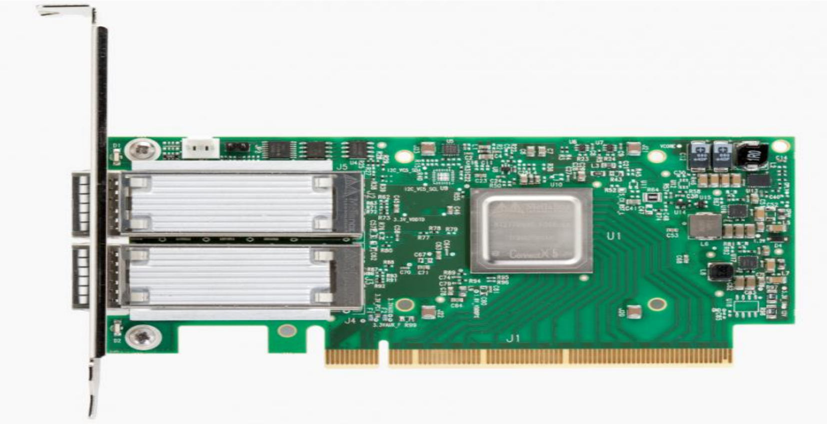
Datacenters adopting RDMA

To achieve good performance, datacenter applications require the network to deliver

- high throughput
- low latency



Within datacenters RDMA deployment ⬆

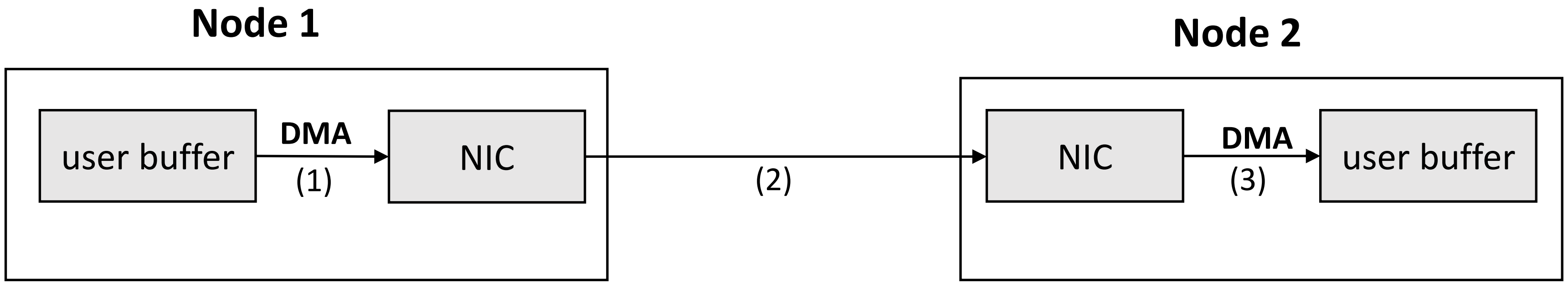
- ✓ high throughput and low latency
- ✓ drop in RDMA hardware prices

[1] https://www.datacenterknowledge.com/archives/2015/06/17/rdma-replaces-tcpip-in-linbits-data-replication-tool

[2] https://www.nextplatform.com/2018/03/27/in-modern-datacenters-the-latency-tail-wags-the-network-dog/

Remote direct memory access (RDMA)

- enables direct access to memory of a remote machine
- low latency (1 μs)
- kernel bypass + CPU bypass



RDMA background

Transport Types

- Reliable Connection (RC)
- Unreliable Connection (UC)
- Unreliable Datagram (UD)

Queue Pair : hosts establish queue pairs (QP) to communicate with each other

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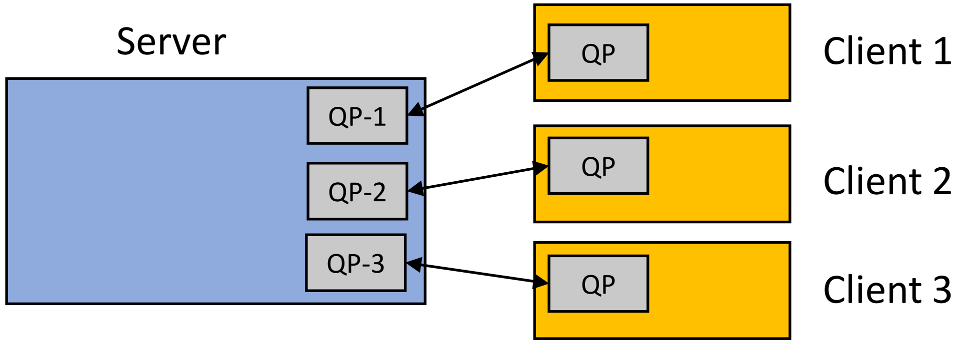
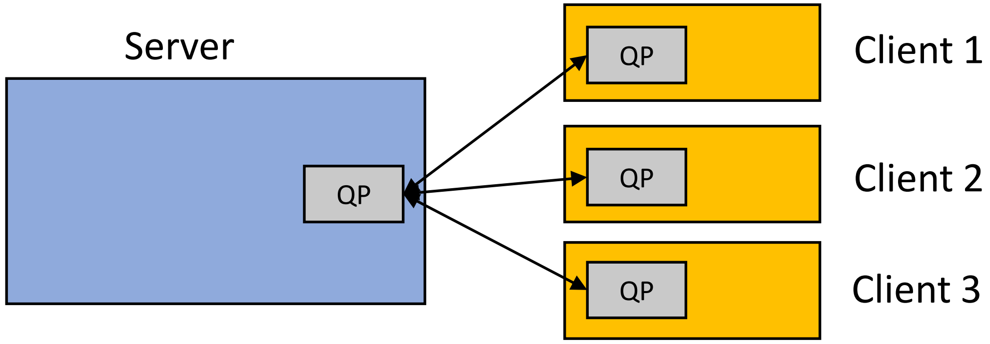


Connected transport (RC, UC)



Datagram transport (UD)

RDMA background

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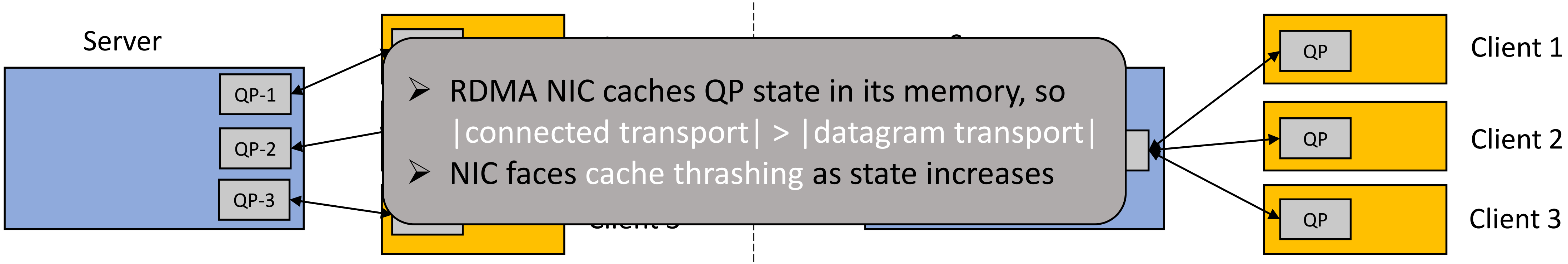

- RDMA NIC caches QP state in its memory, so |connected transport| > |datagram transport|
- NIC faces cache thrashing as state increases

Connected transport (RC, UC) **Datagram transport (UD)**

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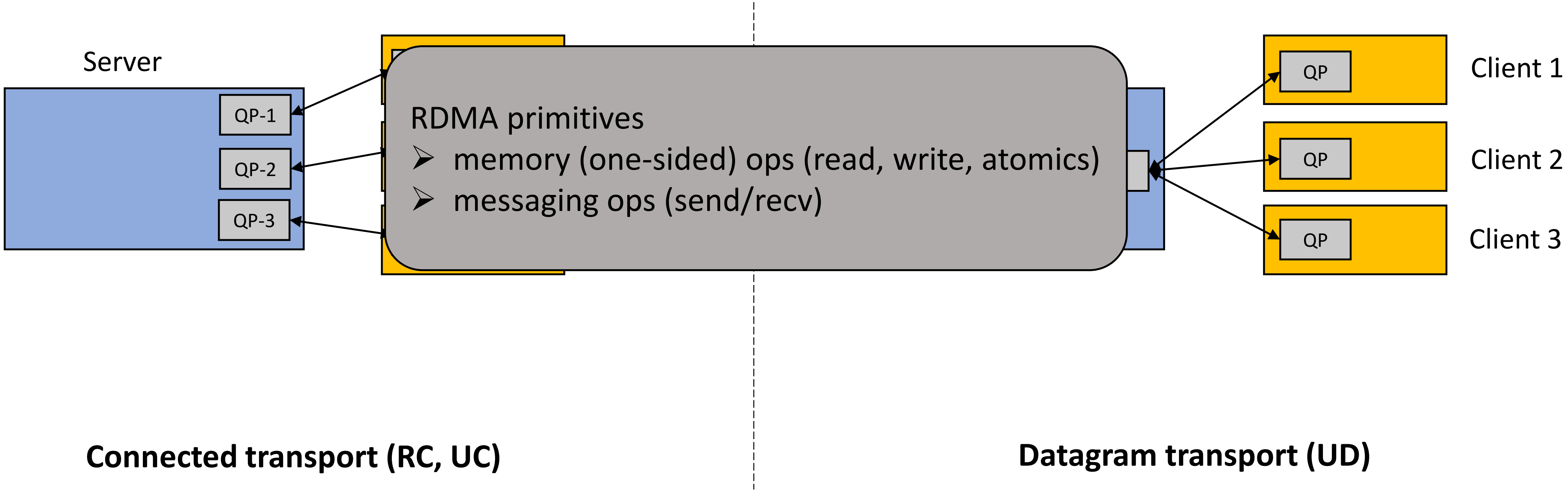

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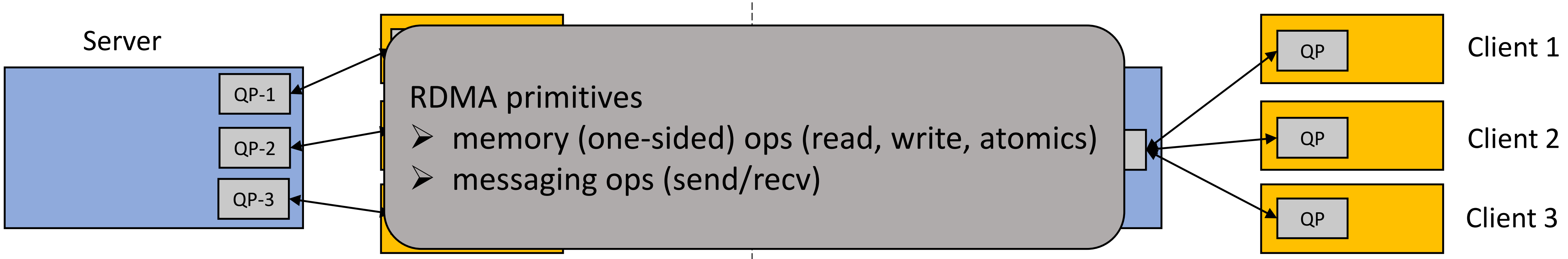

RC supports all RDMA primitives

UD supports only send/recv

Connected transport (RC, UC)

Datagram transport (UD)

Large cluster RDMA scalability challenges

- Non-scalable RC
  - + Provides one-sided ops
  - - Limited on-chip memory on the RDMA NIC
- Limited UD functionality:
  - + Enables one-to-many communication
  - - Lacks CPU-efficient one-sided ops

Which RDMA transport to use for scalable communication ?

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Only RC	Only UD	Hybrid
FaRM [NSDI 14, SOSP 15] Storm [SYSTOR 19] ScaleRPC [EuroSys 19]	FaSST [OSDI 16] eRPC [NSDI 19]	HERD [SIGCOMM 14] (UC + UD) DrTM+H [OSDI 18] (RC + UD)

Scalability comparison of RC vs UD

Benchmark setup: 1 server with increasing clients

Each client issues

- a 16B one-sided read from server memory (RC)
- a 16B RPC with server (UD)

* each machine has a Mellanox ConnectX-5 100 Gbps NIC

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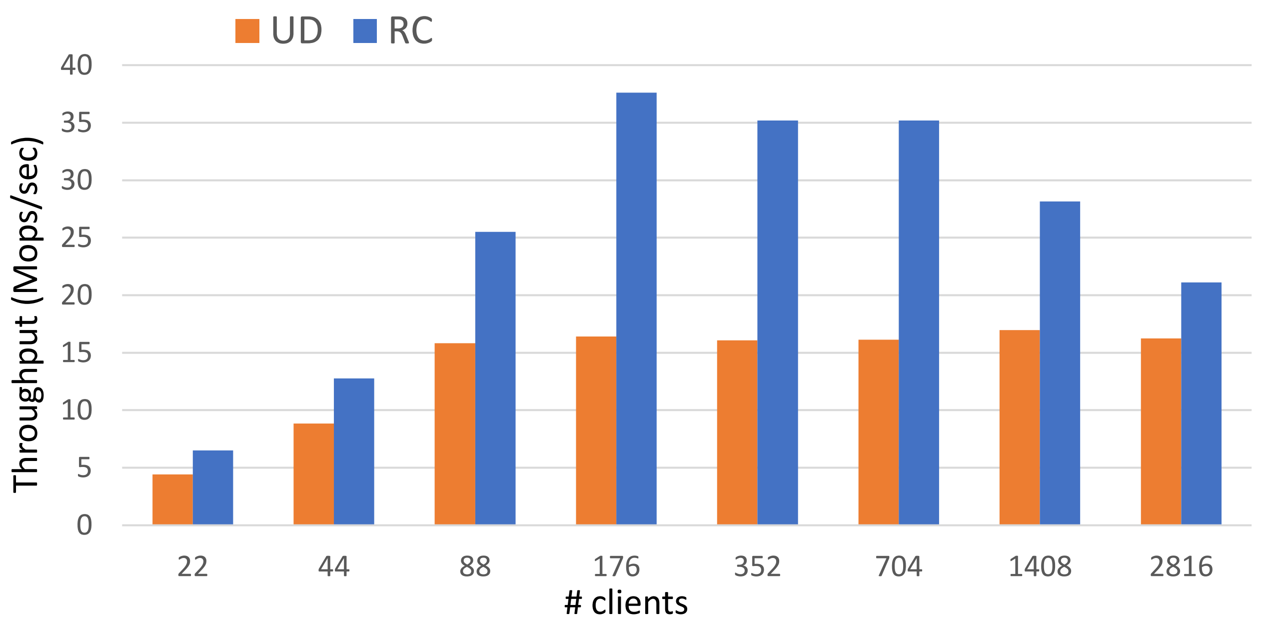

- NIC's cache thrashing after 700 clients
- UD:
  - Lower throughput and saturates earlier than RC
  - Server CPU cycles are used

* each machine has a Mellanox ConnectX-5 100 Gbps NIC

Connection scalability with RDMA full flexibility?

Goals:

- Maintain **connection scalability**
- Expose all RDMA features, i.e., **versatility**
- Minimal **software-induced overheads**

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FLOCK: An RDMA communication library

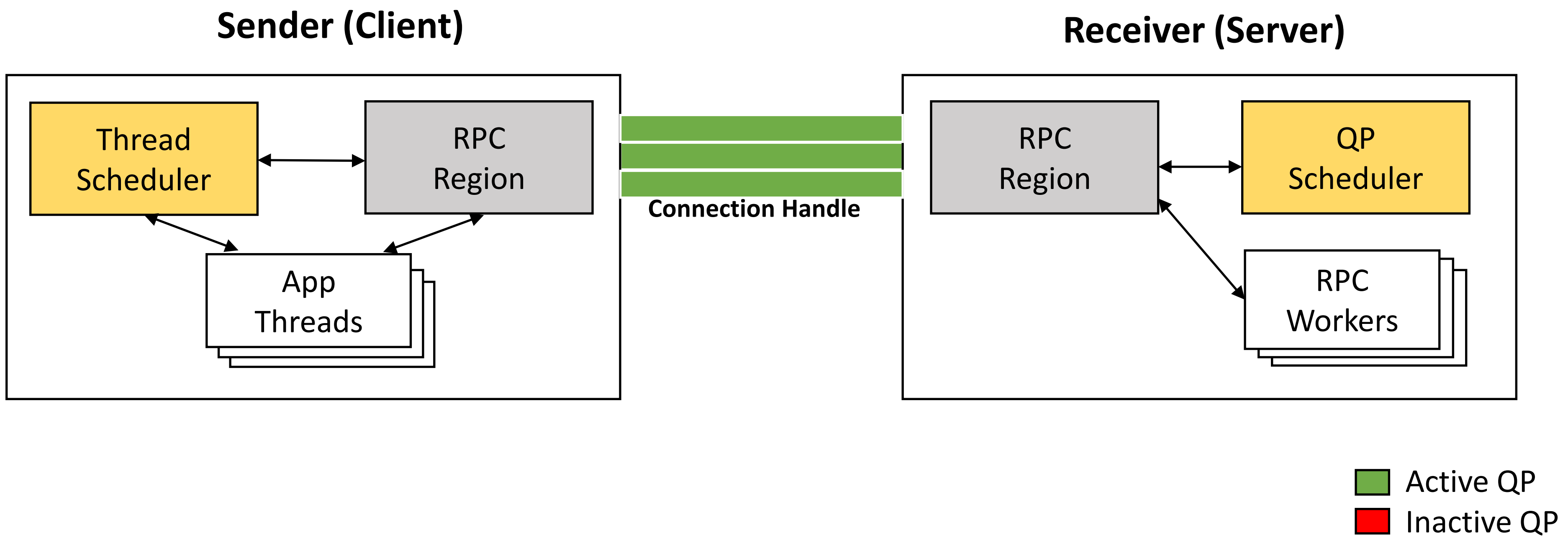
FLOCK

- Uses RC
  - + Exposes all RDMA capabilities
- Uses QP sharing among threads[1,2]
  - + Uses FLOCK synchronization for connection scalability
- Introduces **symbiotic send-recv scheduling**
  - + A cooperative scheduling policy between sender and receiver
  - + Enables efficient network resource allocation and utilization at the end-hosts

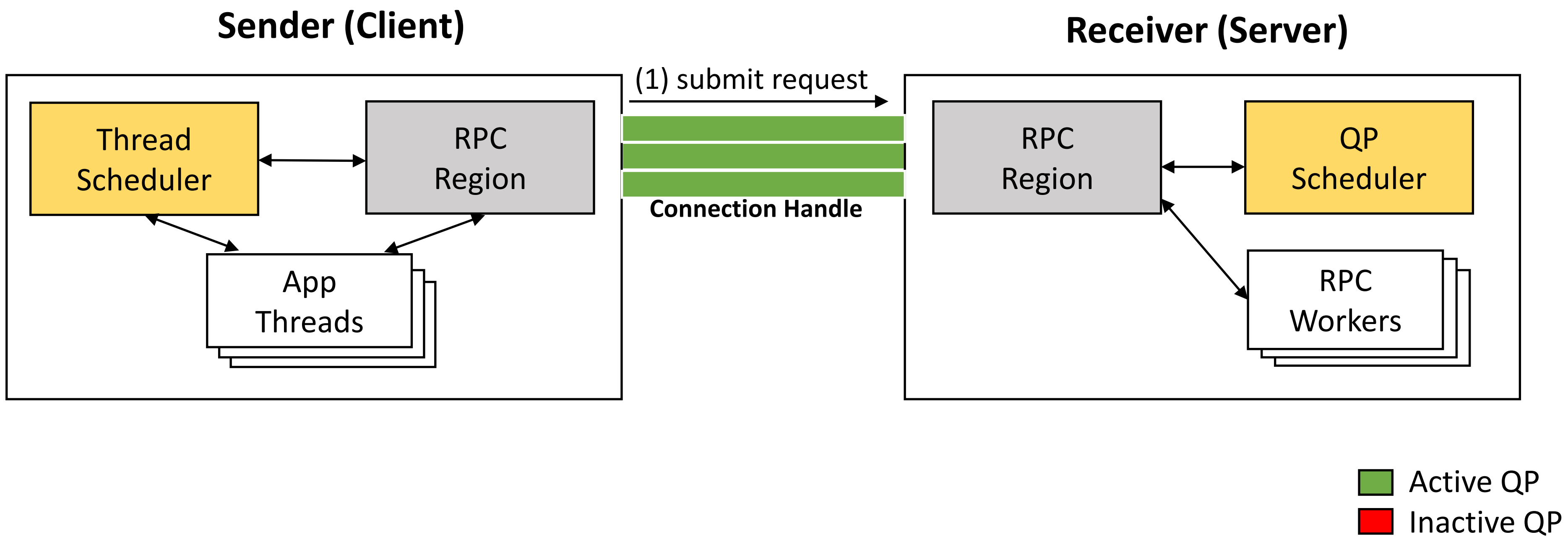
[1] FaRM : Fast remote memory, NSDI 2014

[2] No compromises : distributed transactions with consistency, availability, and performance, SOSP 2015

FLOCK Architecture

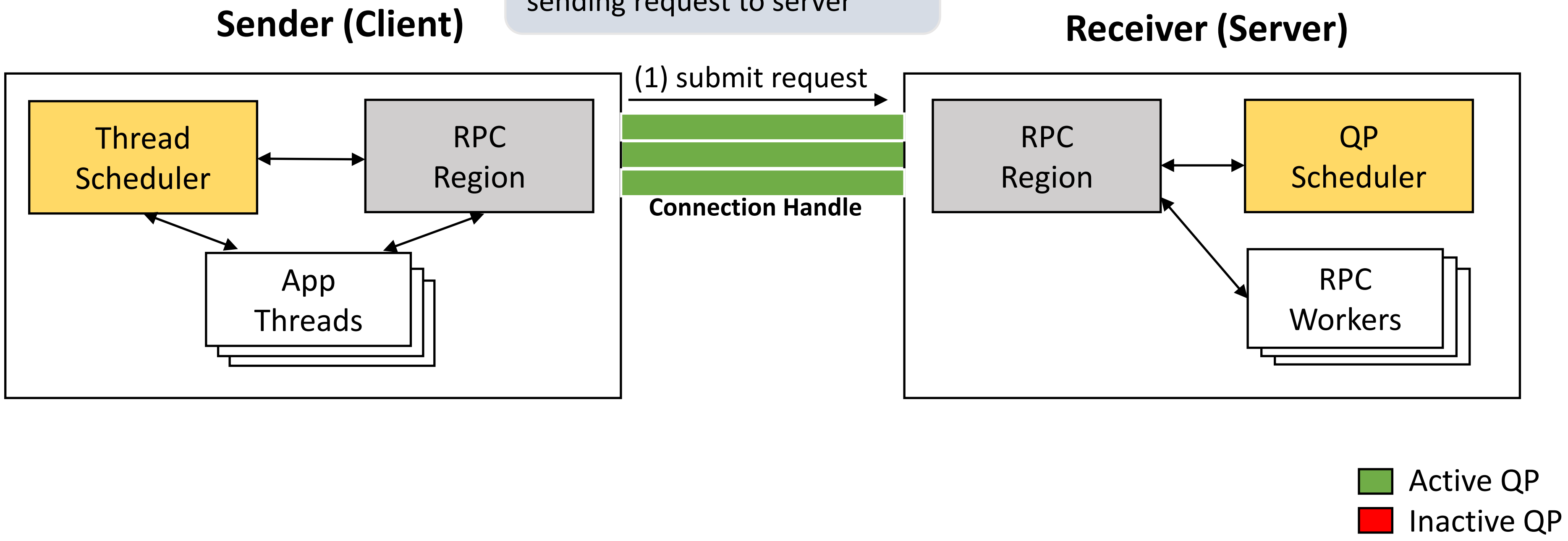


FLOCK Architecture



FLOCK Architecture

(1) client asks for credit while sending request to server



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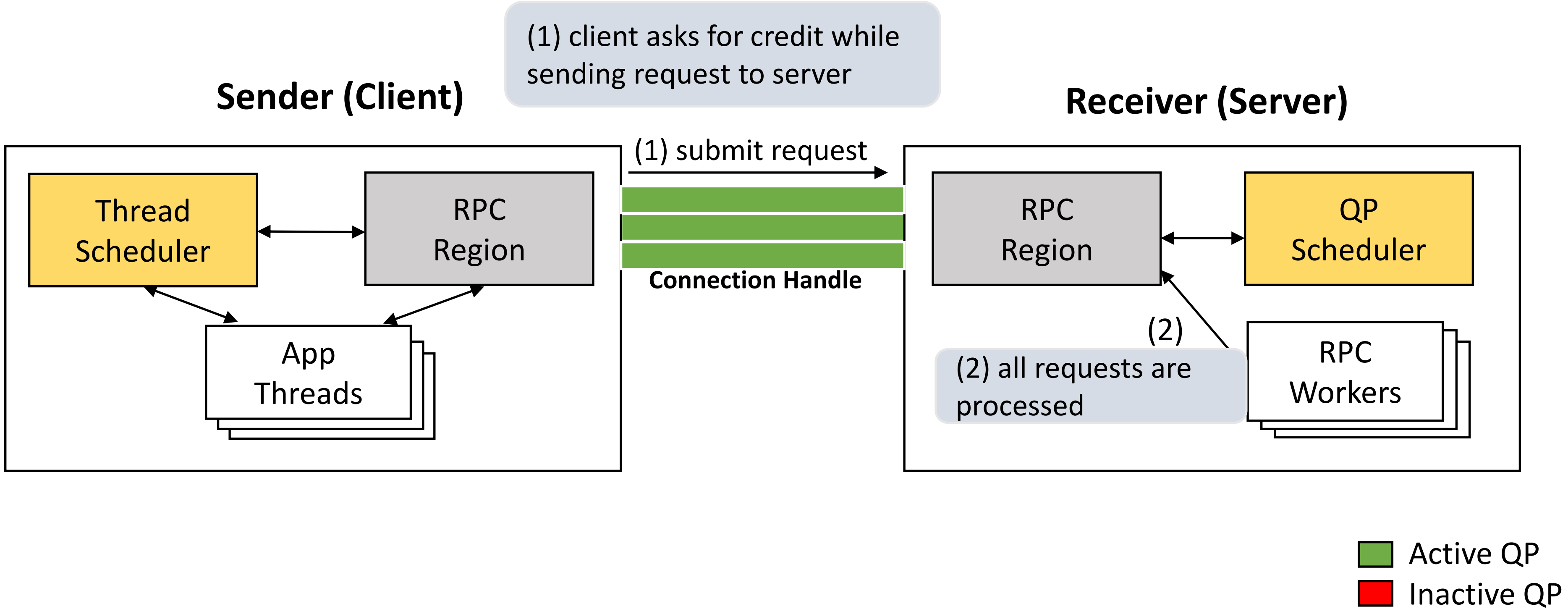

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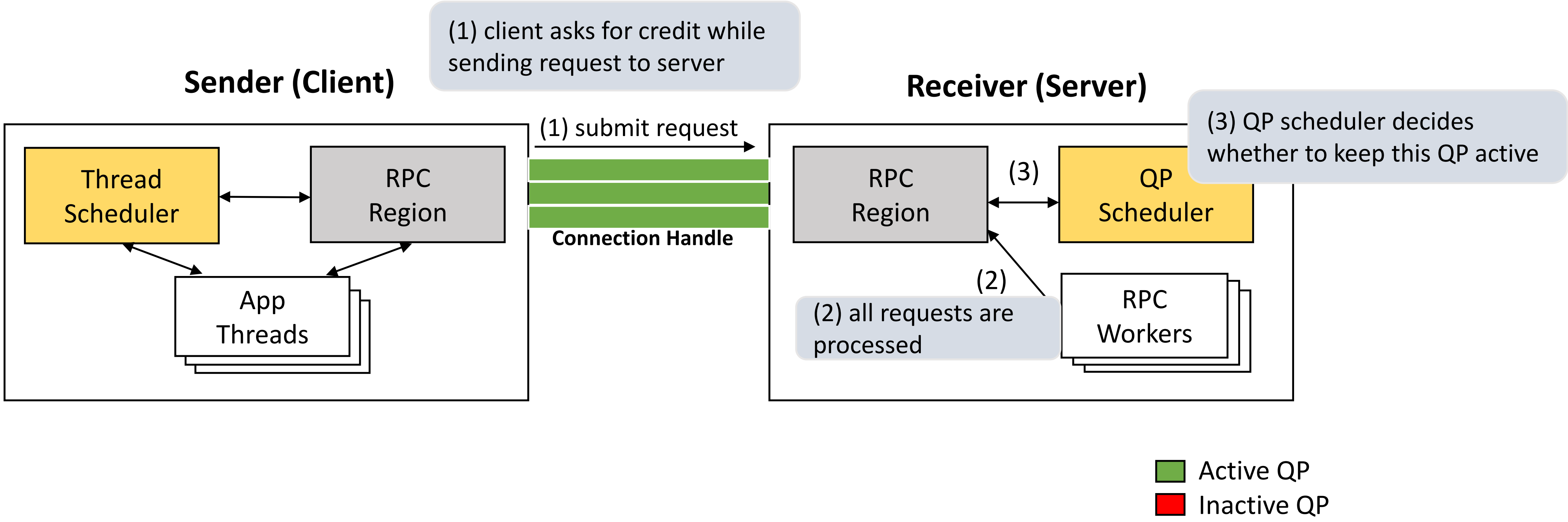

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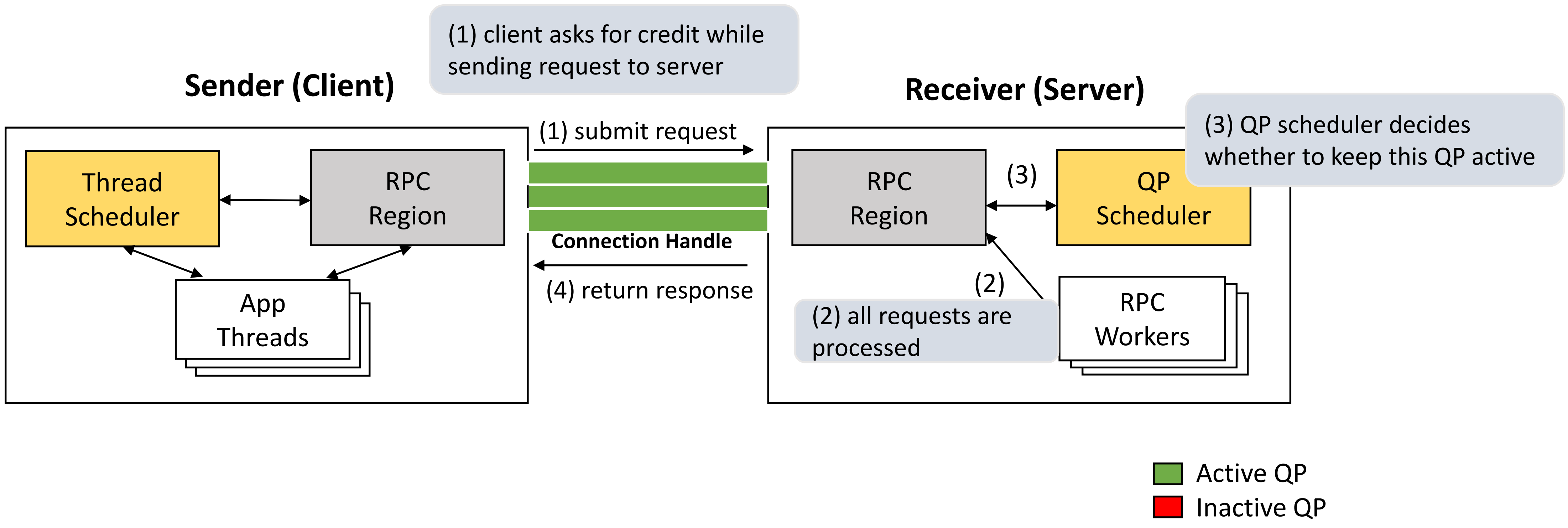

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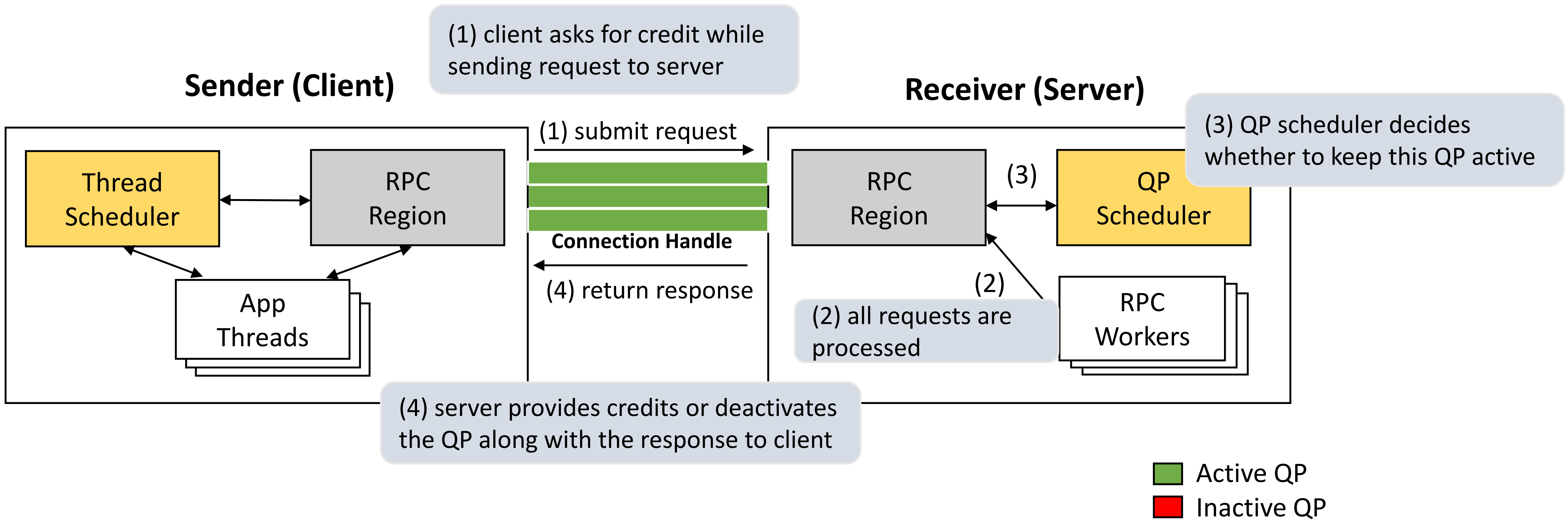

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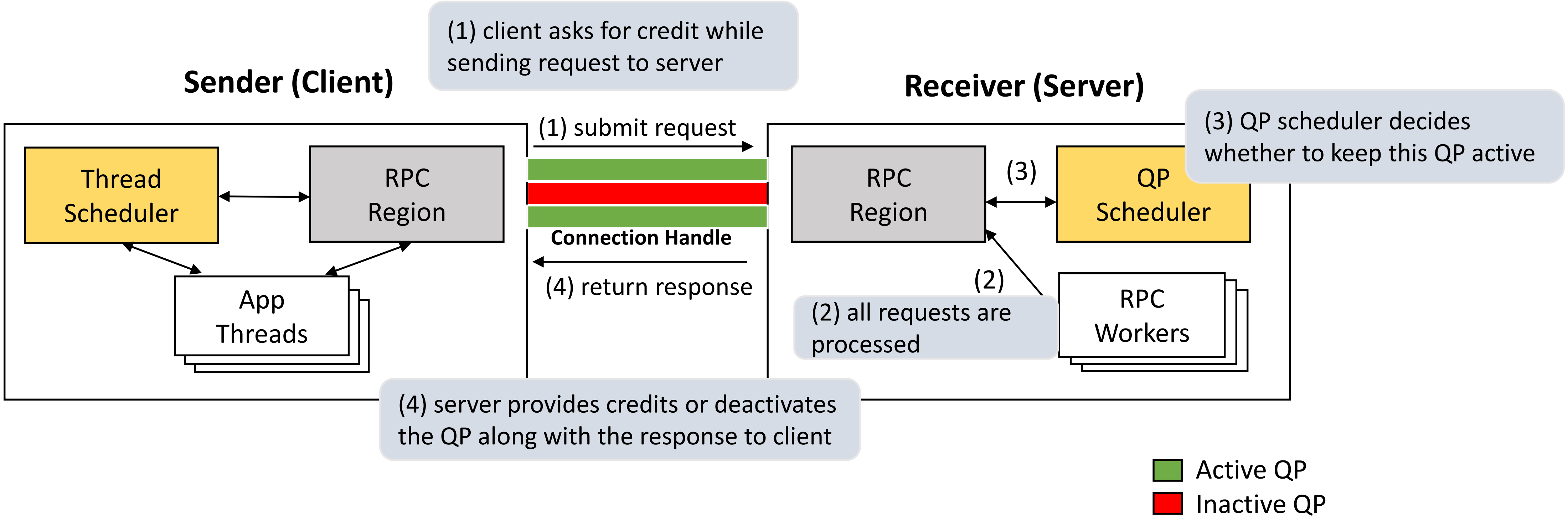

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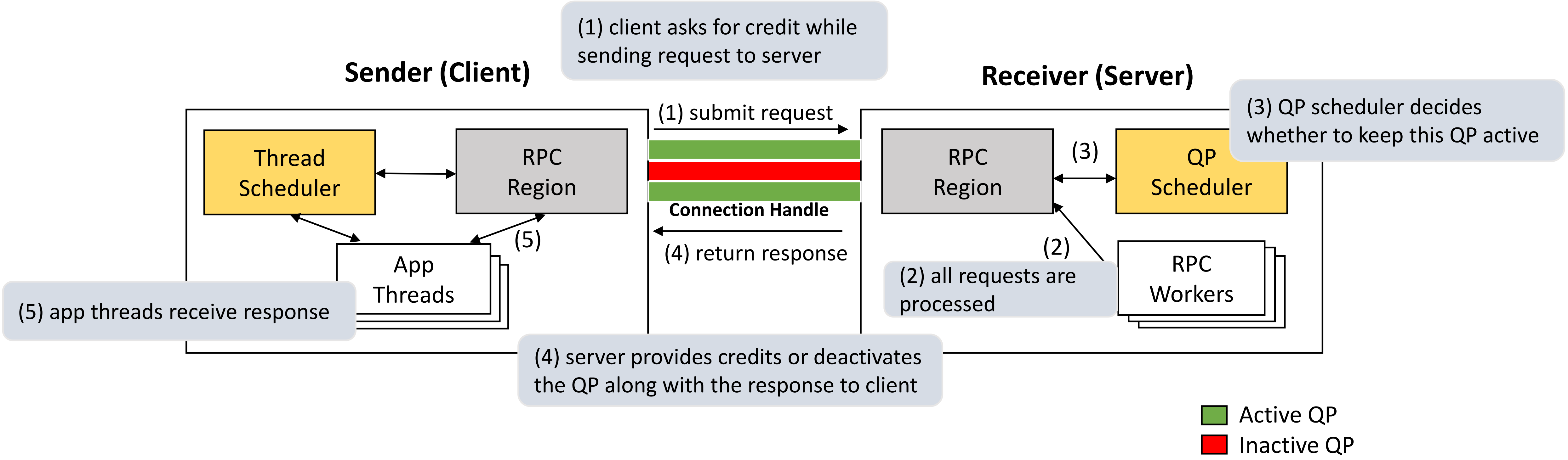

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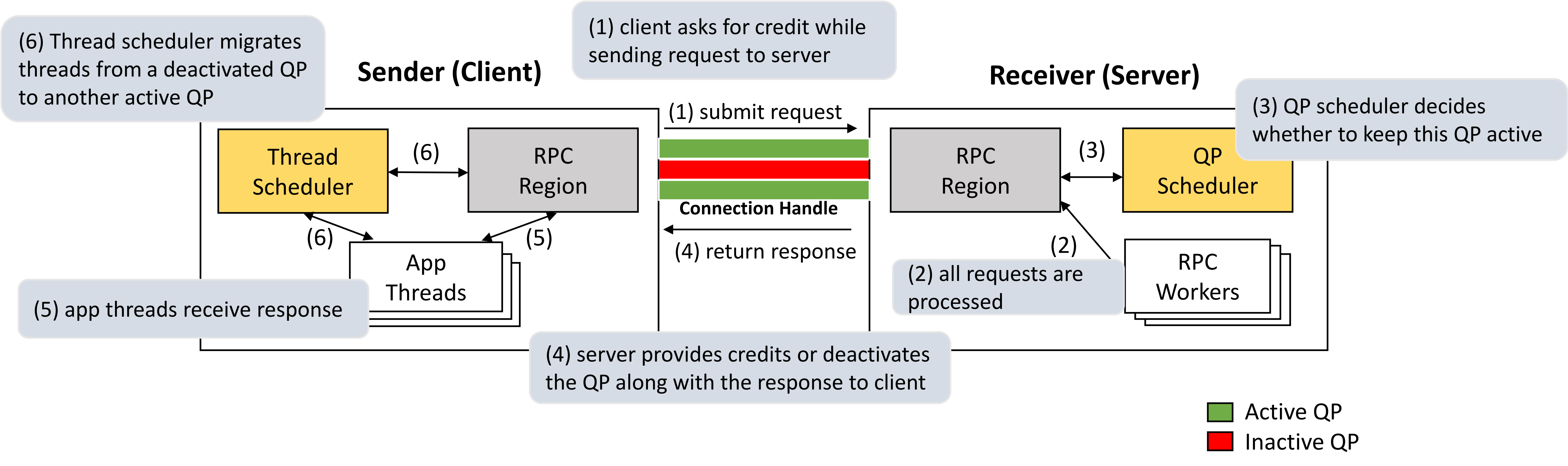

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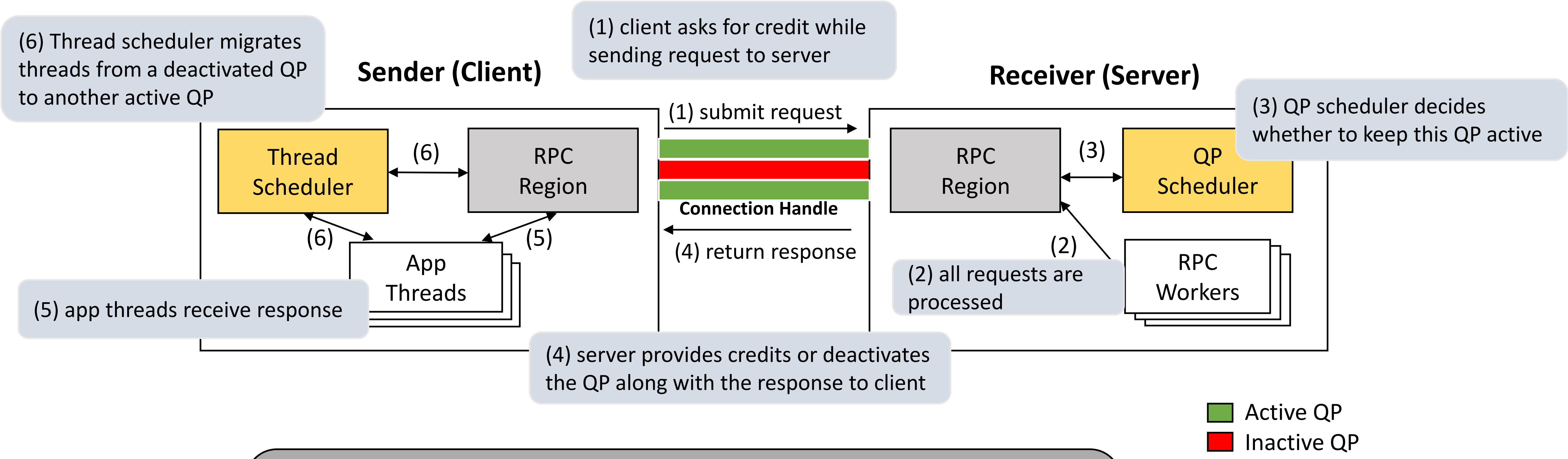


- Receiver-side QP Scheduler dynamically activates/deactivates QPs on a per-sender basis to avoid NIC cache pressure
- Sender-side Thread scheduler multiplexes active QPs among application threads

But isn’t QP sharing bad for performance

QP sharing among threads is detrimental to performance[1,2]

- Low parallelism
- High synchronization overheads

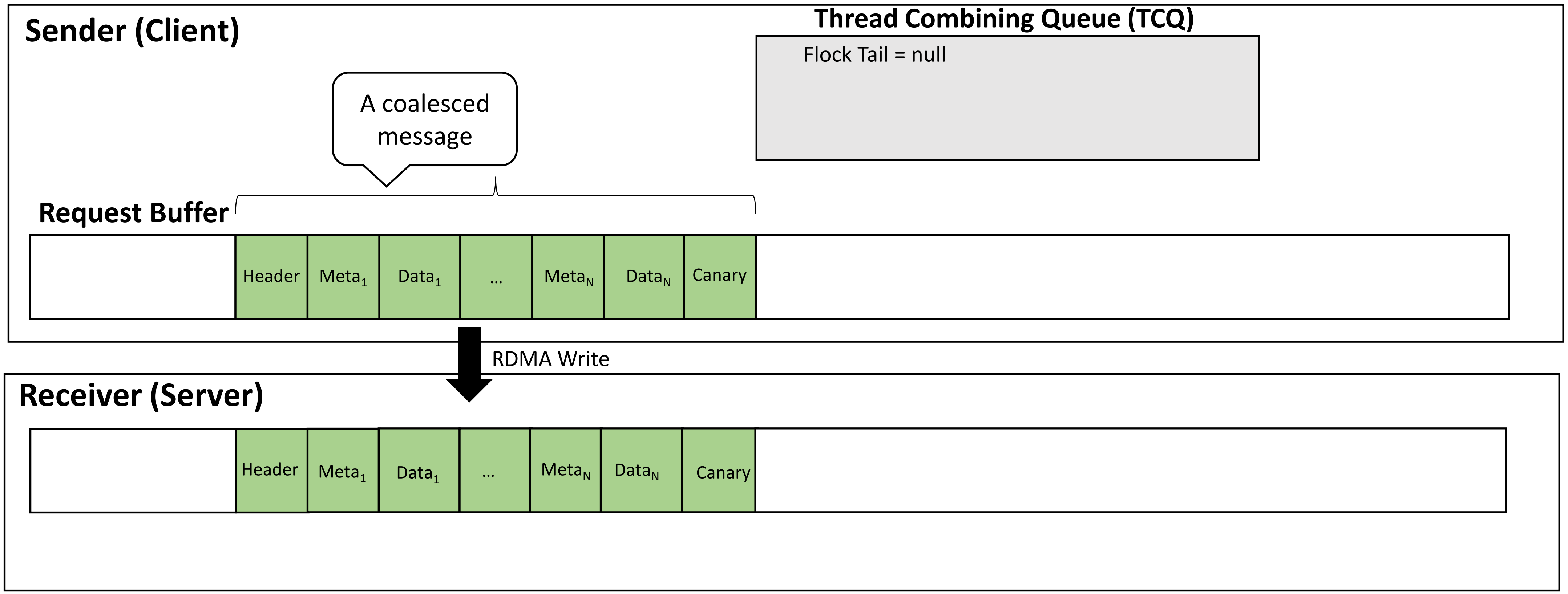
FLOCK synchronization overcomes these challenges

- Threads sharing a QP progress concurrently with minimal synchronization
- Coalesces smaller messages utilizing network bandwidth + CPU efficiently

[1] FaRM : Fast remote memory, NSDI 2014

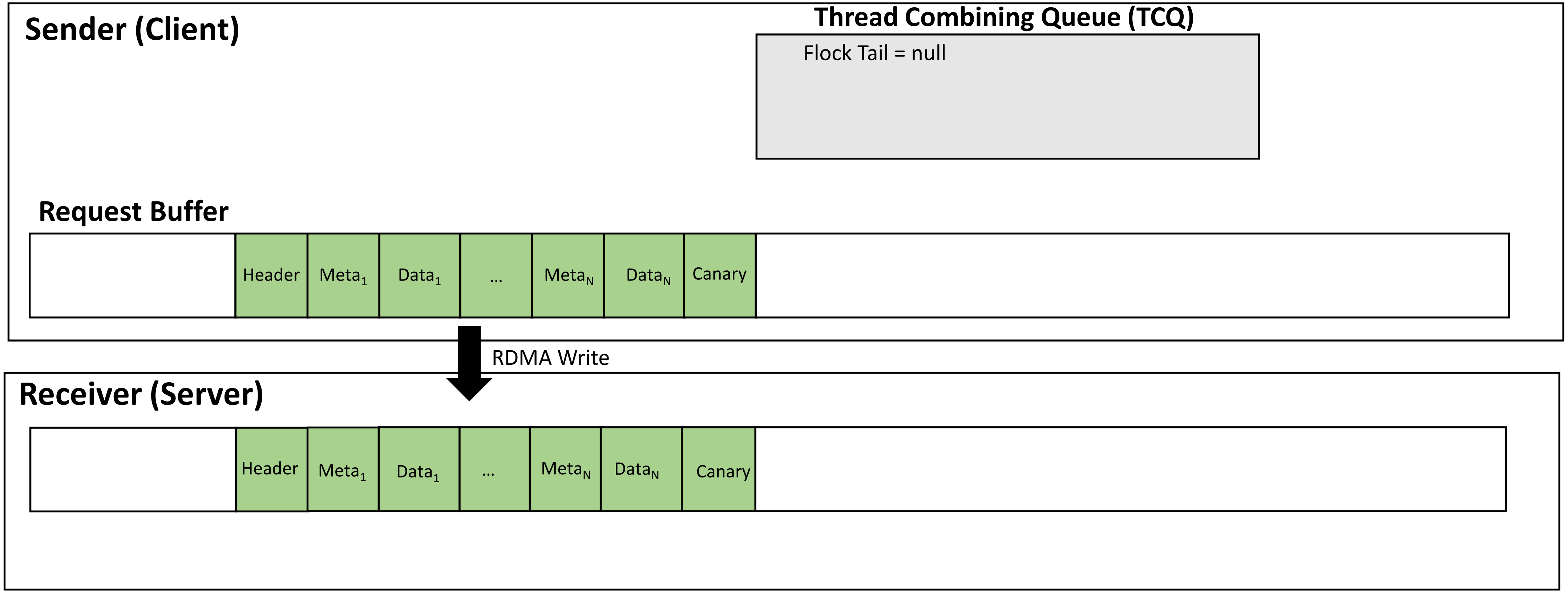
[2] FaSST : Fast, Scalable and Simple Distributed Transactions with Two-Sided RDMA Datagram RPCs, OSDI 2016

FLOCK Synchronization



FLOCK Synchronization

- QP sharing using leader-follower coordination
- leader coalesces requests from followers



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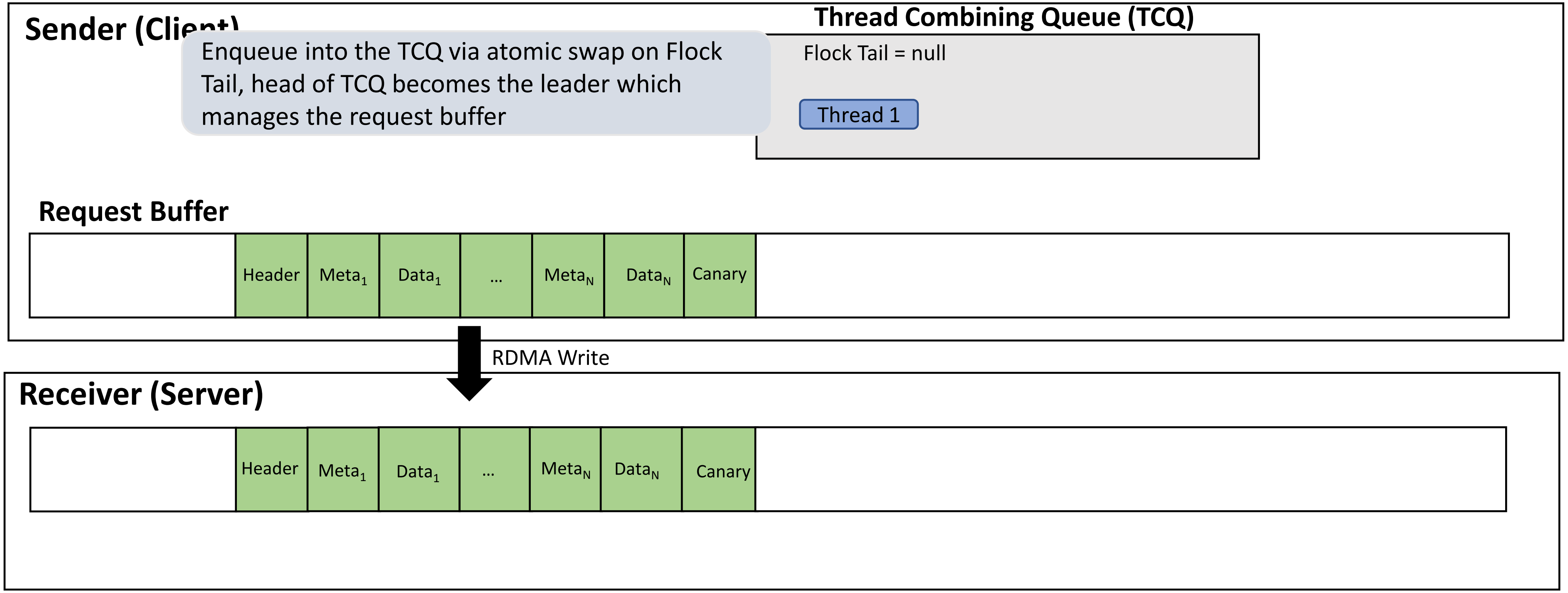

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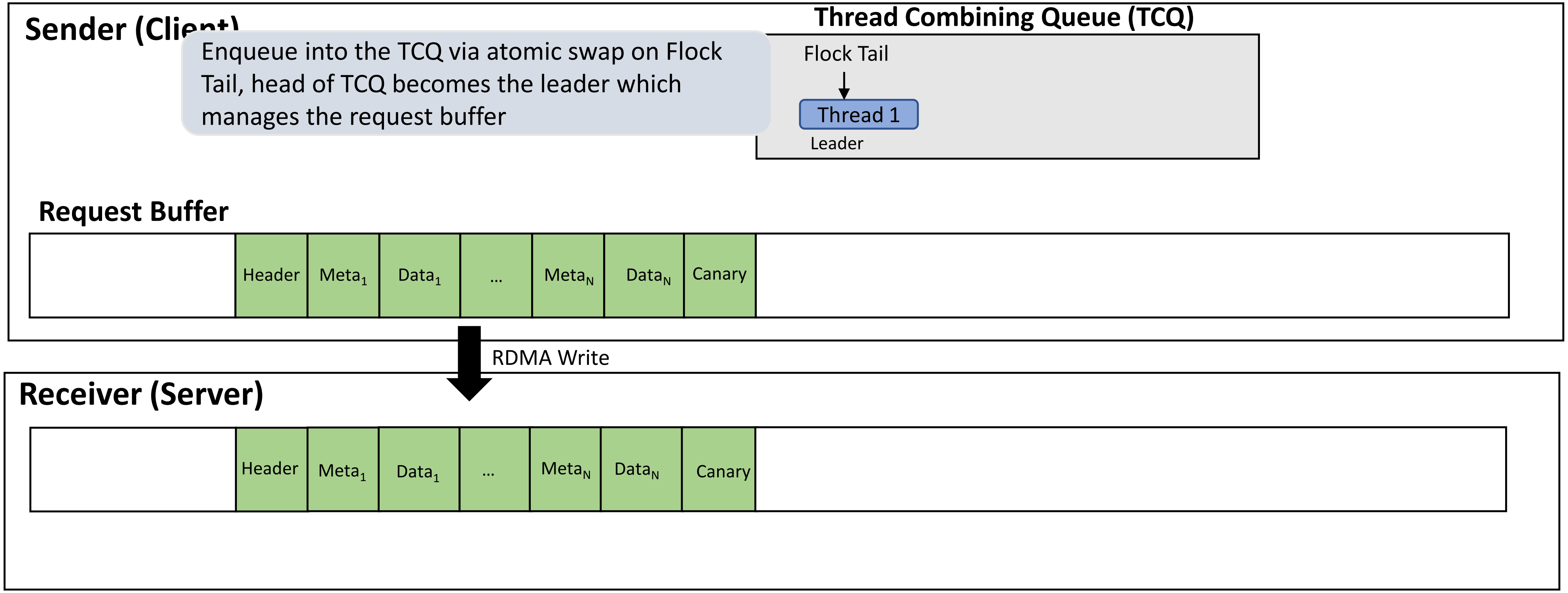

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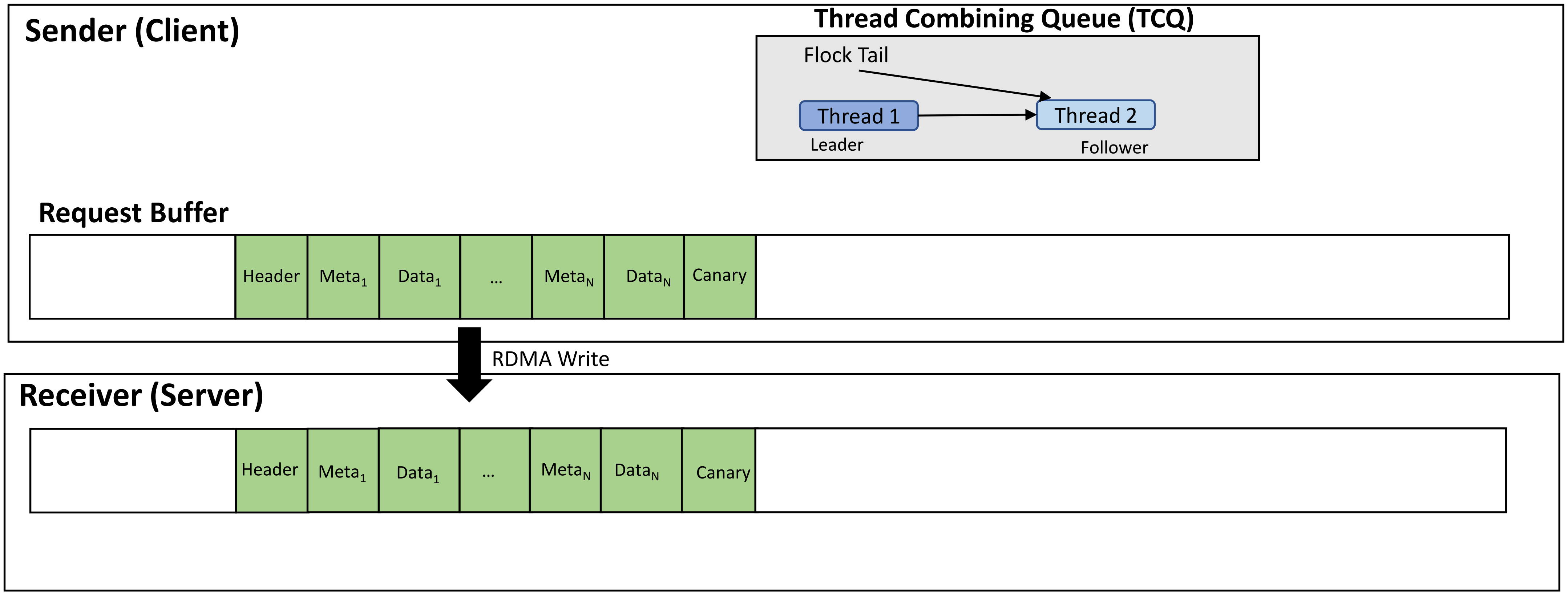

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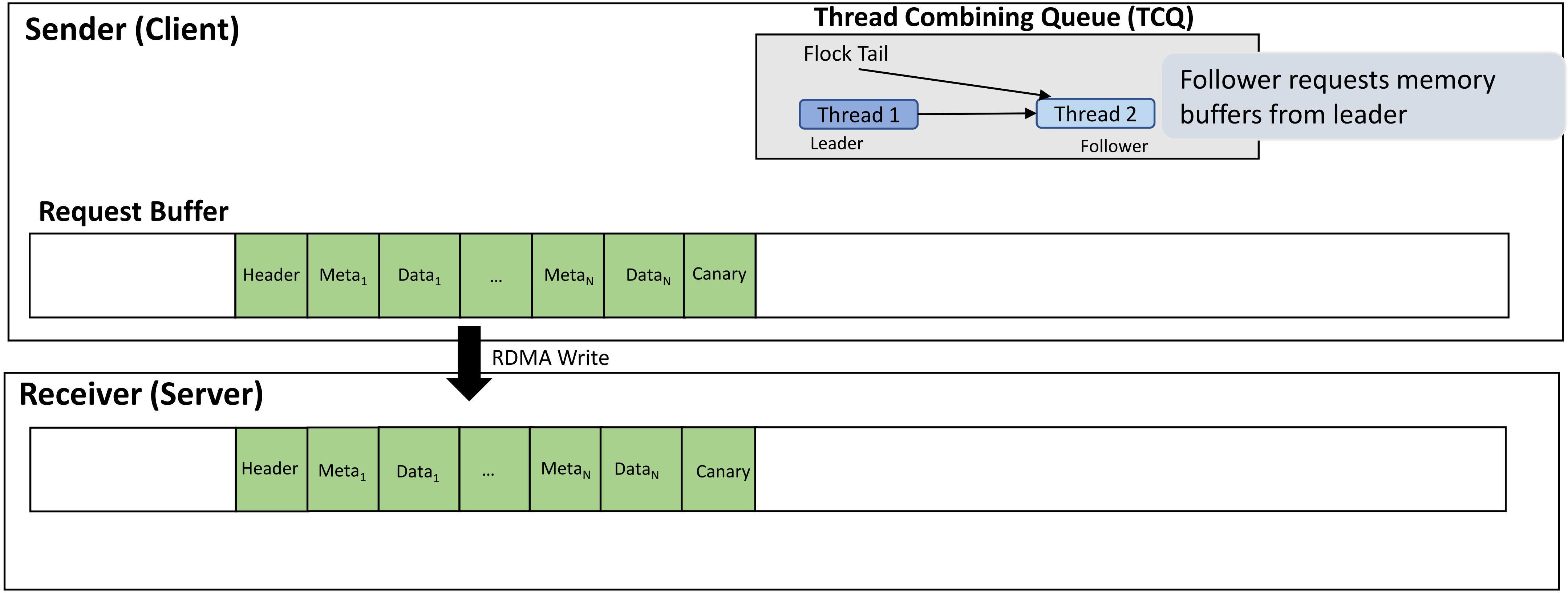

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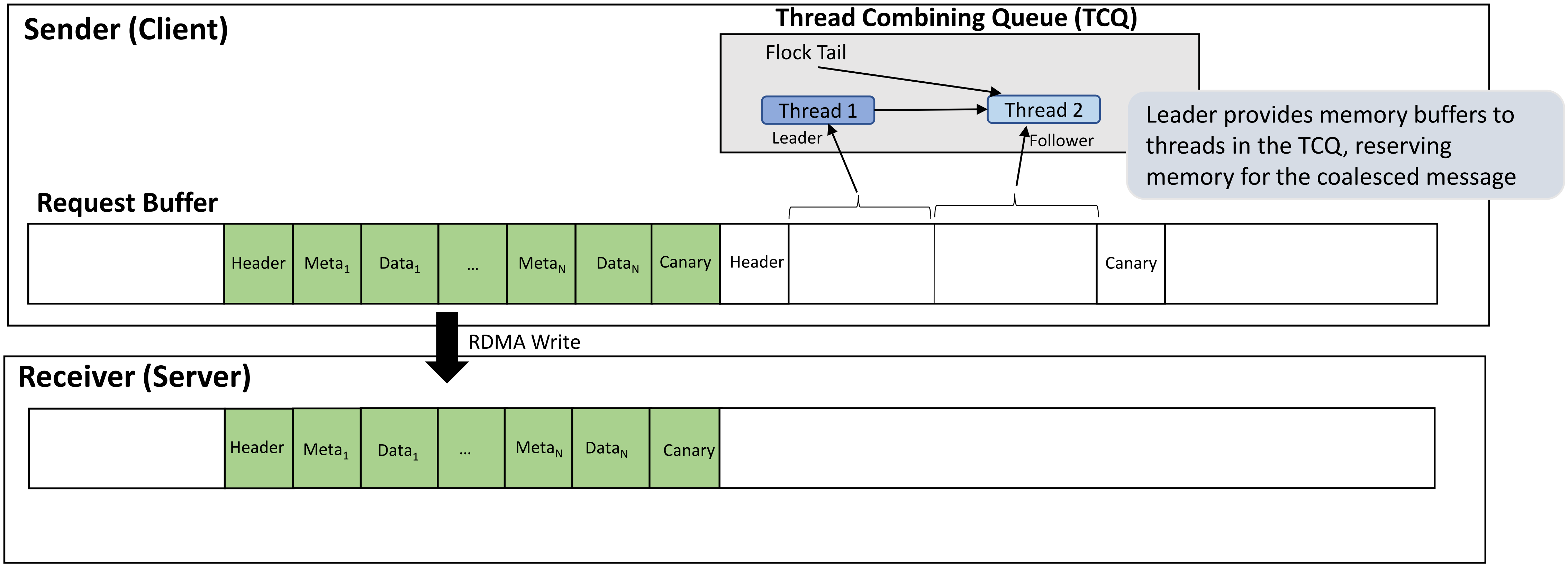

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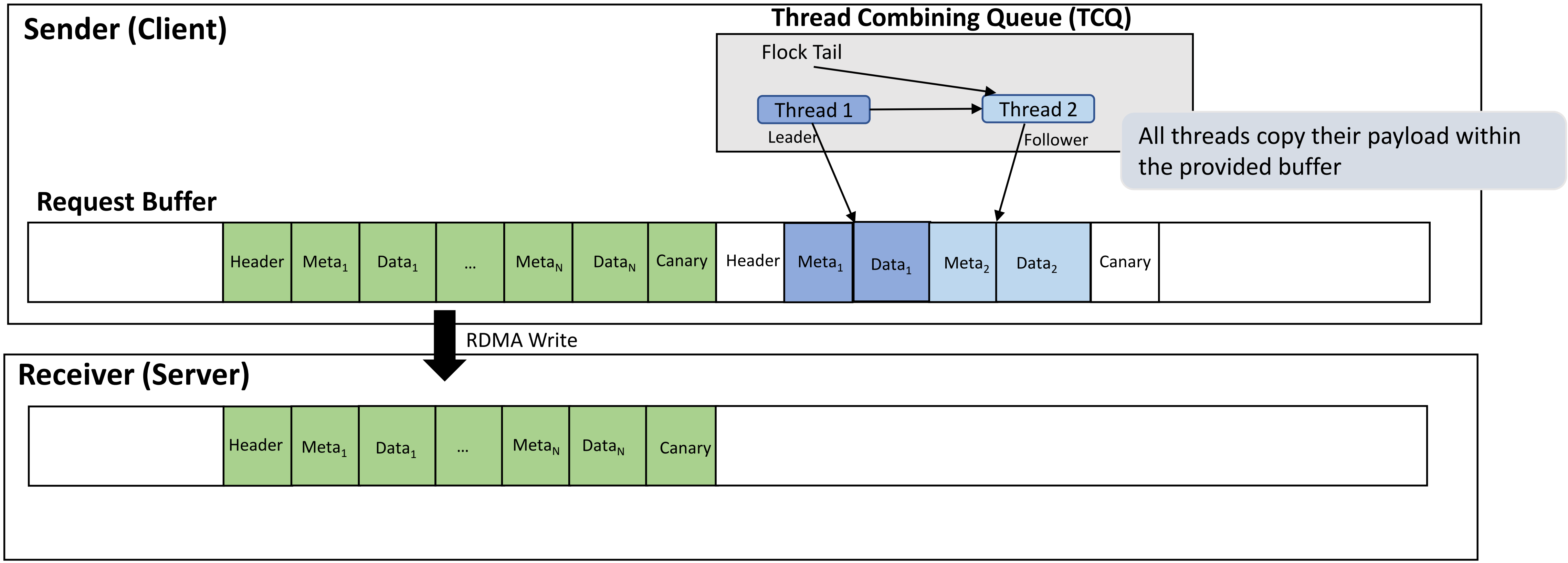

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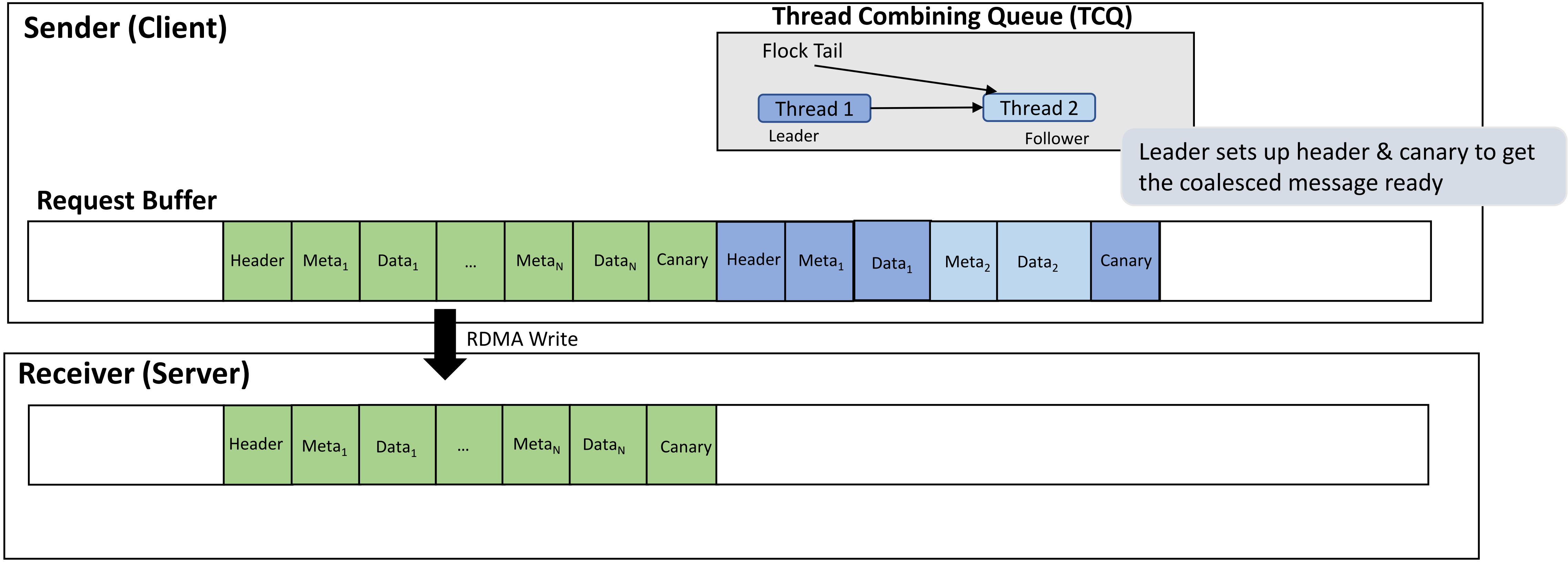

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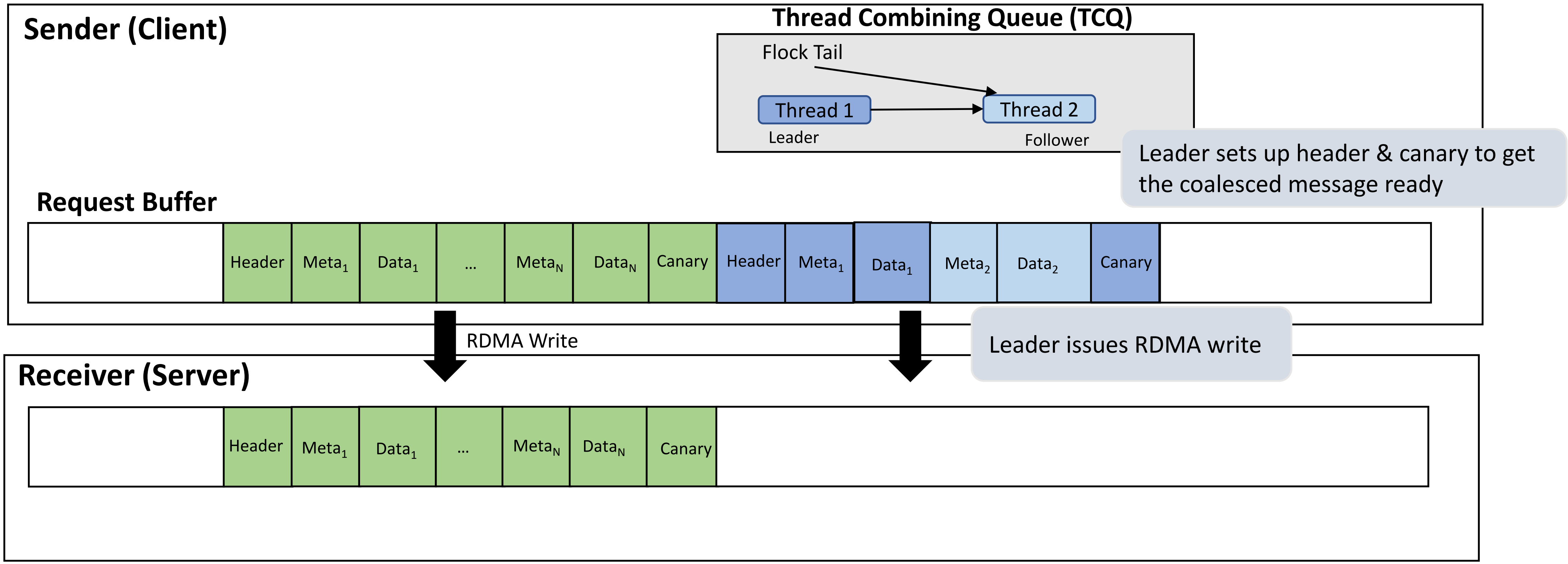

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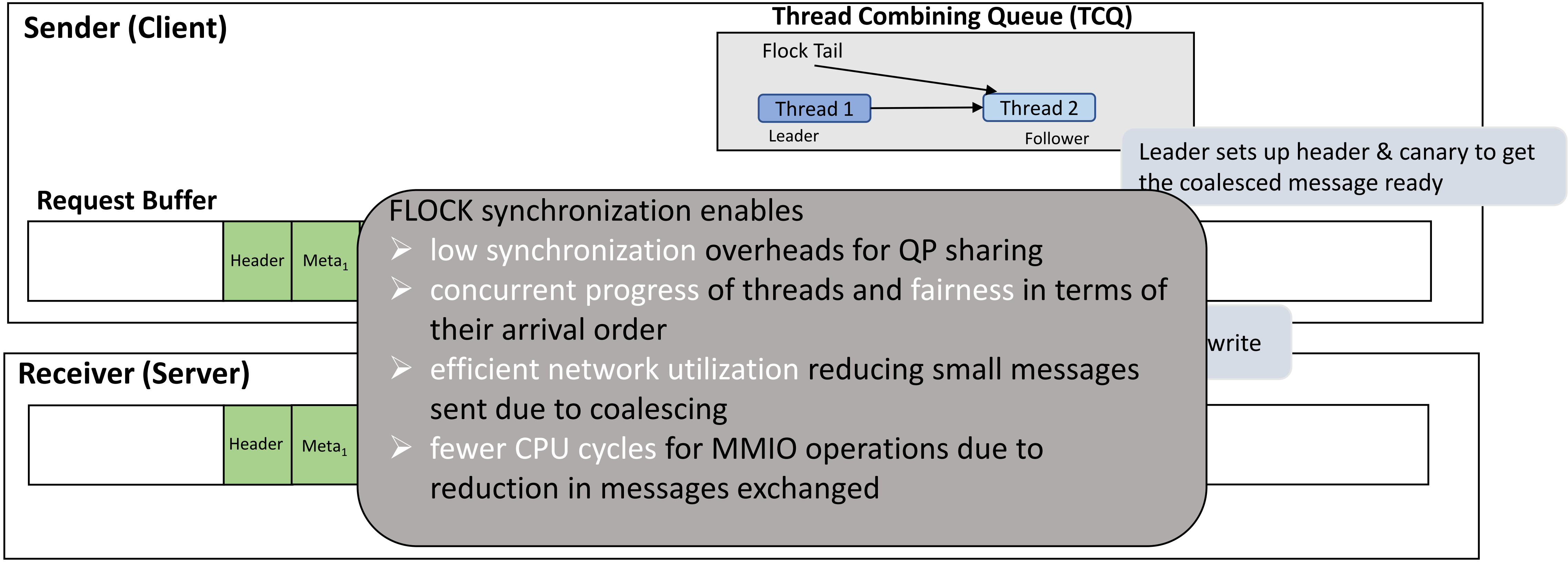

FLOCK synchronization enables

- low synchronization overheads for QP sharing
- concurrent progress of threads and fairness in terms of their arrival order
- efficient network utilization reducing small messages sent due to coalescing
- fewer CPU cycles for MMIO operations due to reduction in messages exchanged

Performance-Scalability Tradeoff

RDMA networks face a tradeoff between performance and scalability

Configuration	Performance	Scalability
Threads using dedicated QPs	✓ More parallelism within RDMA NIC	✘ Limited NIC cache
Threads sharing QP	✘ Hampers performance due to synchronization overheads	✓ Fewer NIC cache misses

FLOCK aims to resolve this tradeoff using **symbiotic send-recv scheduling**

Receiver-side QP Scheduling

- Limit active QP count to bound NIC state and prevent CPU overload
- Allocate fewer QPs to dormant clients and more to active clients

Clients categorized as active or dormant based on their utilization metrics

- **Credit renewal**: credits for future requests
- **Coalescing degree**: indicates the number of requests coalesced within a message. Higher values imply *QP contention*

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Clients receive active QPs in proportion to their utilization

Evaluation Questions

- FLOCK vs state-of-the-art RDMA RPC systems
- Scalability with symbiotic scheduling
- Impact on a real-world application

Evaluation Environment

- 24 machines from CloudLab d6515 cluster
  - 32-core AMD 7452 2.5 GHz CPU
  - Mellanox ConnectX-5 100 Gbps NIC
- 100 Gbps switch connecting the machines
- Maximum active QP count at the server is 256

FLOCK vs eRPC

Configuration : 1 server, 23 clients

Workload : 64B request and 64B response

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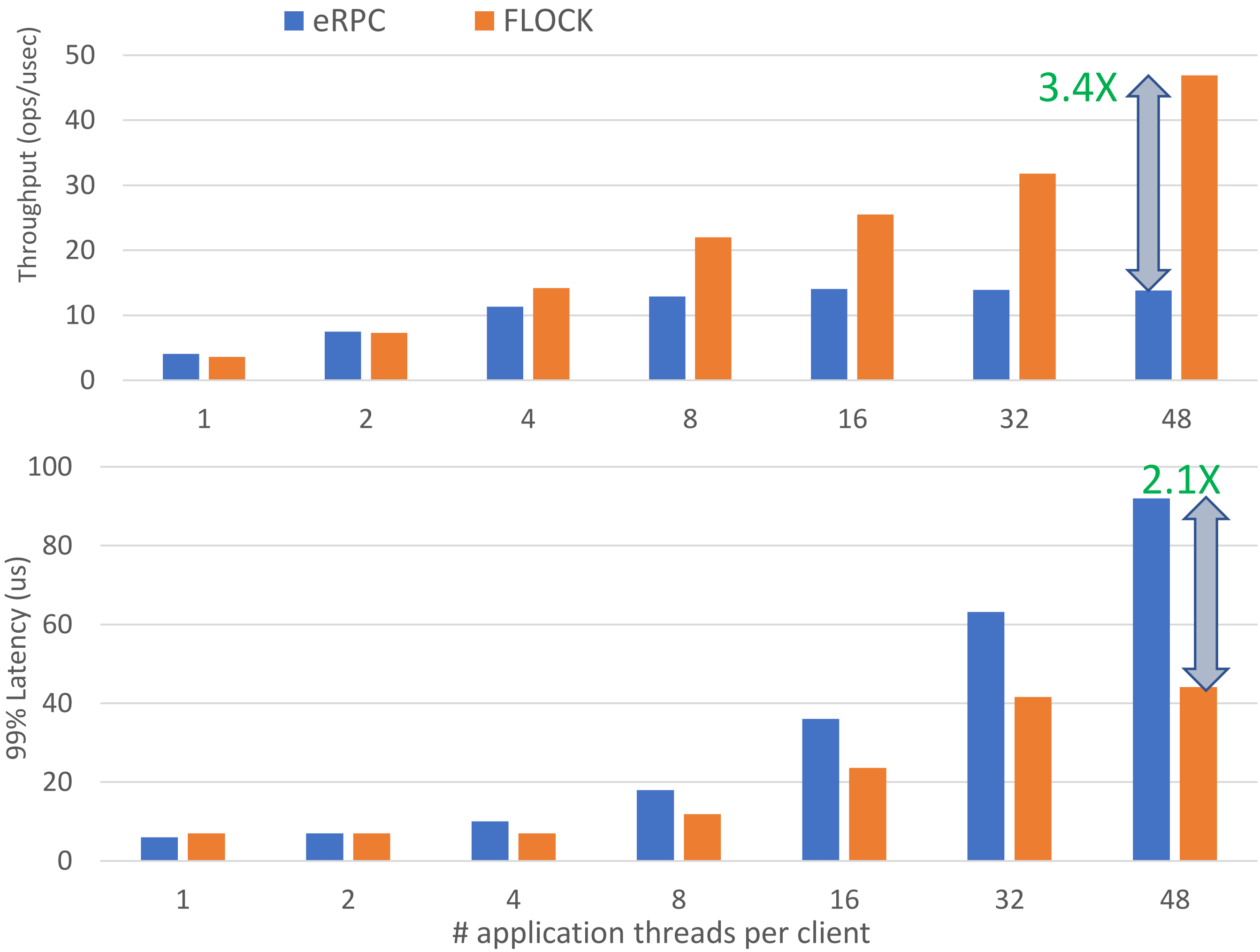
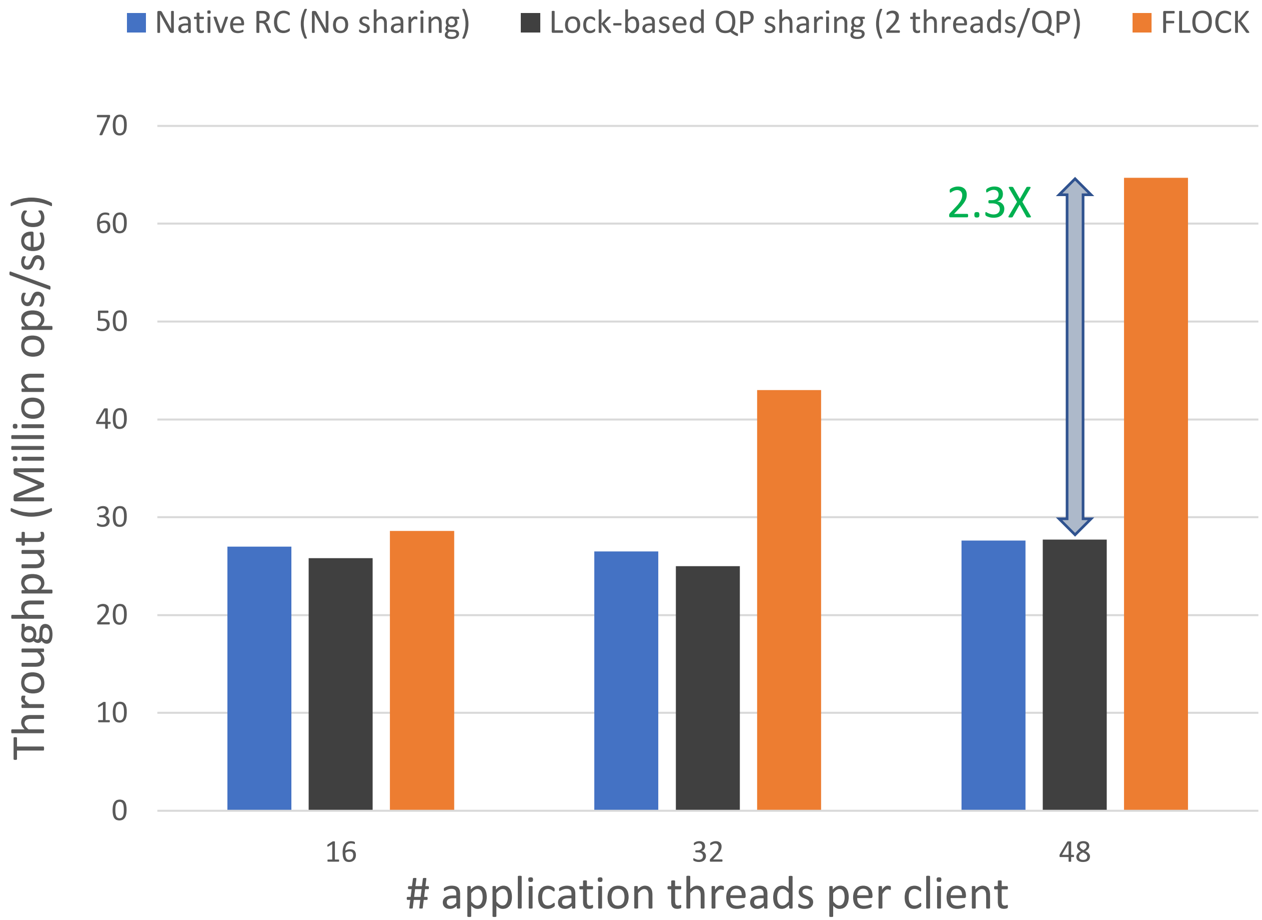


- ❑ FLOCK throughput up to 3.4X against eRPC
- ❑ Tail latency lower by up to a factor of 2

+ Coalescing enables more concurrency at the clients & scheduling limits active QP count

- UD-based RPCs have higher CPU overheads

Scalability with Symbiotic Scheduling



- ❑ Similar performance up to 16 threads
- ❑ FLOCK outperforms others by up to 133% at higher thread counts
- ❑ Sharing using spinlock serializes threads working on the same QP
- ❑ Coalescing in FLOCK enables concurrent request submission by threads sharing a QP, reducing messages transferred by client as well as server

Distributed Transaction Processing

Configuration

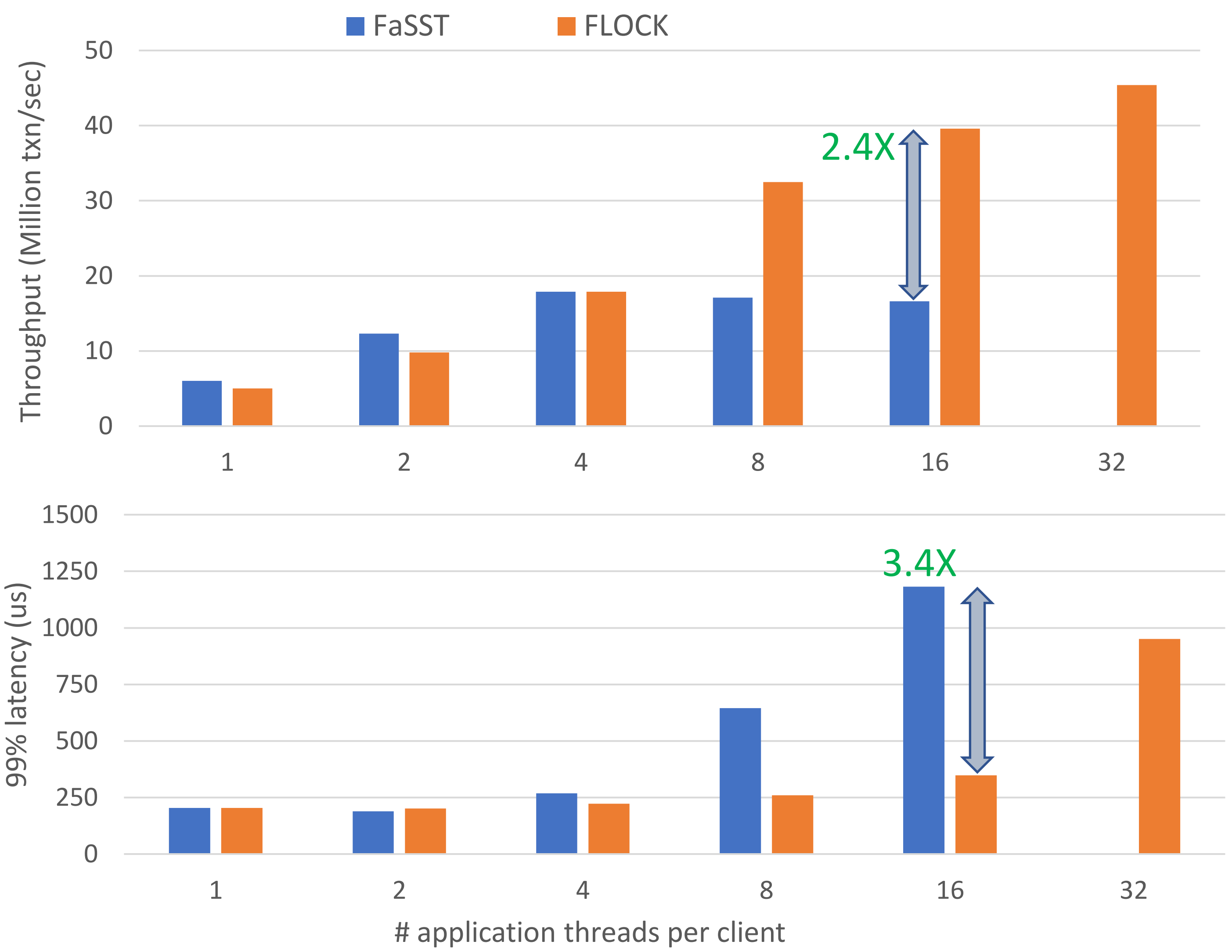
- comparison against FaSST, an RDMA-based transaction processing system
- Transaction protocol like FaSST : OCC[1] and 2-phase commit to provide serializable transactions
- 3 servers and 20 clients

Workloads

- TATP (read-intensive)
- Smallbank (write-intensive)

[1] Optimistic Concurrency Control

FLOCK vs FaSST for TATP



- ❑ FaSST performs better up to 2 threads, but its performance saturates at 4 threads
- ❑ Throughput in FLOCK up to 2.4X FaSST with lower median and tail latency
- ❑ FLOCK's performance improves with higher thread counts due to better coalescing and efficient network utilization

* FaSST suffers packet loss at 32 threads

Other evaluations

- Performance under increasing node counts
- Impact of coalescing on network and CPU utilization
- Head-of-line blocking mitigation using symbiotic scheduling
- Comparison with eRPC using in-memory index structure (HydraList)

Conclusion

FLOCK

- targets balancing the performance-scalability tradeoff in vanilla RDMA hardware
- offers low overhead QP sharing using leader-follower synchronization
- a cooperative scheduling mechanism between client and server to limit the maximum load at the server
- superior performance with efficient network utilization and reduced CPU usage

Thank you!