Homa

Data Center Transport Protocol

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What is Homa?

- Data Center transport protocol
- Goal: Provide lowest possible latency for short msgs at high network load
- Focus is on reducing tail latency for short messages
- Needed due to inefficiencies of TCP and designed to overcome all of them
- Not API-compatible with TCP, but can be deployed with no hardware changes

General Data Center Topology

Data Center

↓

Clusters

↓

Racks (each one having a Top of Rack Switch)

↓

Machines/Hosts

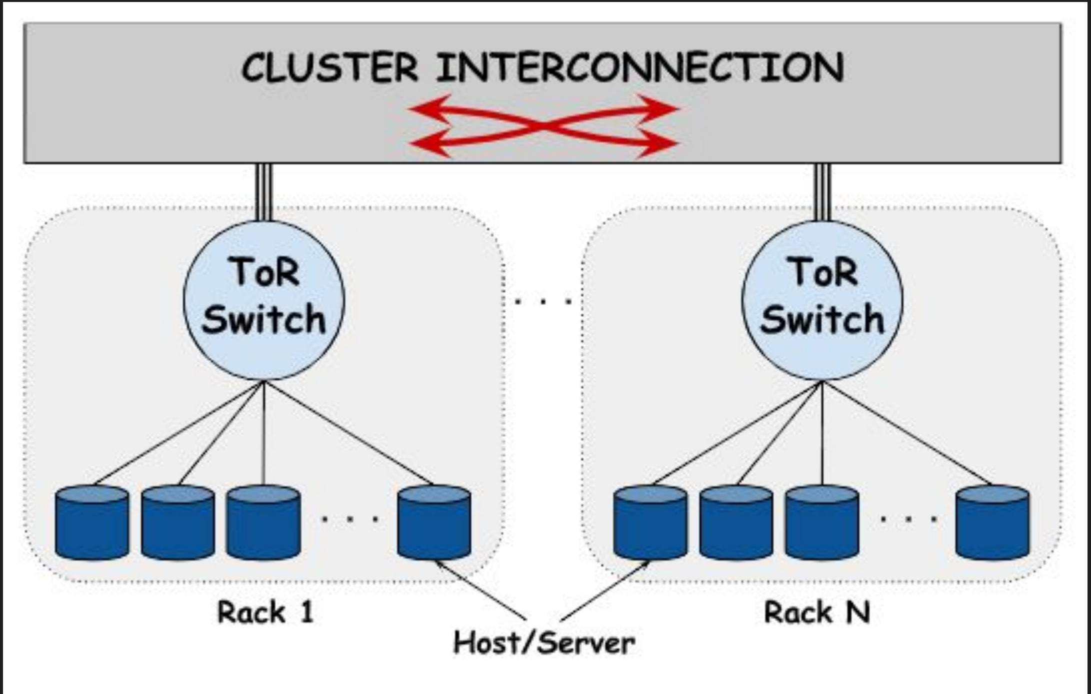
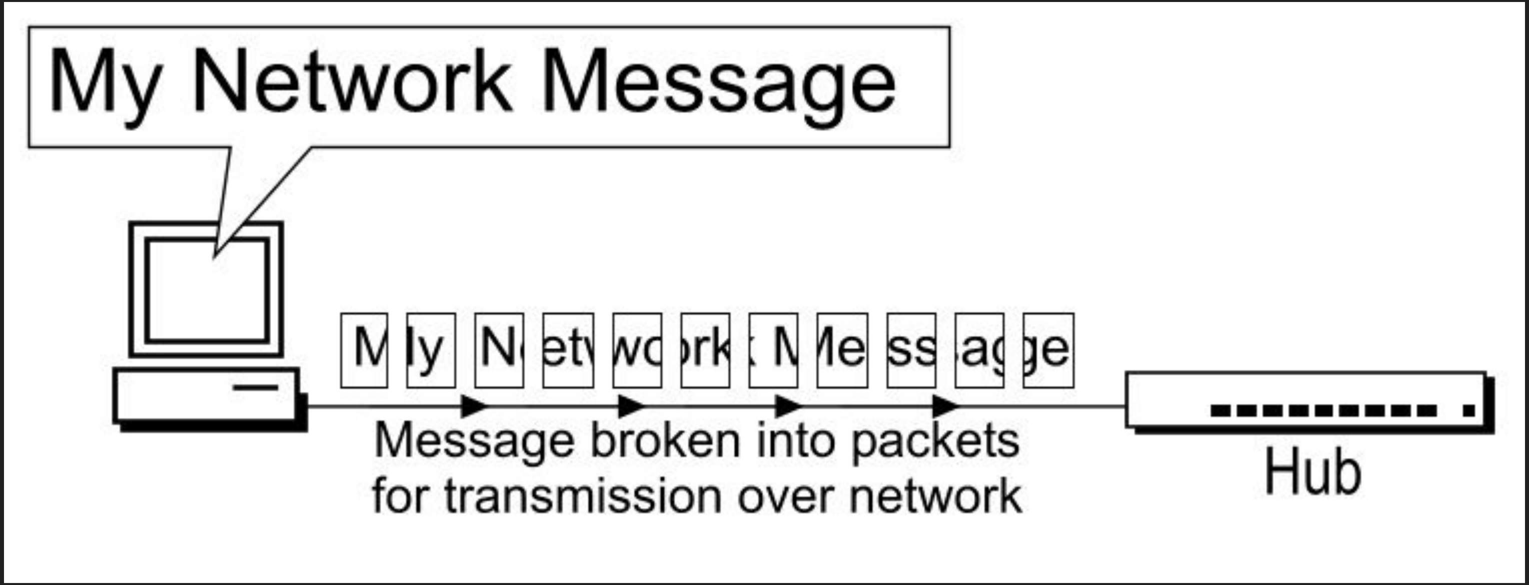


Fig. 1. A typical datacenter cluster.

Data Center Transport Protocol Requirements

- Low latency
  - Low processing overheads
  - Tail latency should be low
- High throughput
  - Both Data and Message Throughput should be high
- Reliable delivery
- Good Congestion Control
  - Needs to be low to keep latency low
  - Buffering leads to increase in latency
- Efficient Load Balancing
  - Hot spots need to be avoided
  - It causes overheads
  - Contributor to tail latency
- NIC offload
  - NIC hardware can be modified to handle part of the protocol

Message vs Packet


My Network Message
M y N et w o rk M e ss a g e
Message broken into packets for transmission over network
Hub

Problems with TCP in the Data Center

- Stream orientation
- Connection orientation
- Bandwidth sharing (Fair Scheduling)
- Sender-driven Congestion Control
- In-order packet delivery

TCP Problem: Stream Orientation

- TCP only aware of current packet length, not message size
- TCP just breaks up data into ‘MSS bytes’ and sends
- Causes Buffering and Packet Re-ordering at receiver
- Receiver has no knowledge of how much data it is going to receive and when to start processing
- Sender responsible for Congestion and Flow Control
- TCP Head of Line Blocking (HoLB) problem
  - Multiple TCP connections from the sender to counter this causes connection explosion issue
- Load Balancing difficulties due to Flow-Consistent Routing and hot spots

TCP Problem: Connection Orientation

- Connections cause overheads in terms of storage and processing time
- Connection setup takes up 1 RTT
- For TCP, keeping packet buffers and application level state aside, 2000 bytes of state data maintained per connection in Linux

TCP Problem: Bandwidth Sharing

- TCP uses Fair Scheduling
- TCP HoLB causes short messages to have high RTTs
- Under high load, all streams share bandwidth, which collectively slows down everyone

TCP Problem: Sender-Driven Congestion Control

- Congestion detected (assumed) through dropped packets or duplicate ACKs
    - Not the most accurate parameters
- ECN helps in congestion detection, but is a late indicator
- Congestion implies buffer occupancy and queueing
    - Increases latency
    - Causes HoLB
- Doesn’t make use of priority queues in modern switches
- Sender responsible for managing congestion, when receiver is more aware of its state

TCP Problem: In-Order Packet Delivery

- Flow-Consistent Routing
  - Doesn’t allow Packet Spraying
  - Load Balancing issues increase tail latency
    - Causes hot spot links
    - Causes hot spot cores
- Not tolerant to high levels of re-ordering

Recap: Problems with TCP in the Data Center

- Stream orientation
- Connection orientation
- Bandwidth sharing (Fair Scheduling)
- Sender-driven Congestion Control
- In-order packet delivery

Sender vs Receiver

- Client → Server
  - Sender: Client
  - Receiver: Server
- Server → Receiver
  - Sender: Server
  - Receiver: Client

Homa Packet Types

- `DATA`
  - Sender → Receiver
  - Contains a range of bytes within a message, defined by an offset and a length
  - Also indicates the total message length
- `GRANT`
  - Receiver → Sender
  - Indicates that the sender may now transmit all bytes in the message up to a given offset
  - Specifies the priority level to use
- `RESEND`
  - Receiver → Sender
  - Indicates that the sender should re-transmit a given range of bytes within a message
- `BUSY`
  - Sender → Receiver
  - Indicates that a response to `RESEND` will be delayed
  - Used to prevent timeouts.

Homa Features

- Message-oriented (RPCs)
- Connectionless
- Shortest Remaining Processing Time (SRPT) Scheduling
- Receiver-driven Congestion Control
- Out-of-order packets

Homa Feature: Message-Orientation

- Uses RPC messages rather than streams
  - Buffering and Packet Re-ordering still exists at receiver
- Every message split into
  - Unscheduled `DATA` packets (Blindly sent)
  - Scheduled `DATA` packets (`GRANT` authorised sending)
- Msgs have priorities, with shorter msgs having higher priorities than longer msgs
  - Makes use of priority queues in switches and on sender and receiver
  - Implementing SRPT becomes easier
  - Prevents queuing
  - Improves (tail) latency
  - HoLB prevented
  - Better Load Balancing
- Message size sent in unscheduled `DATA` packets
  - Receiver can calculate total bandwidth requirement for message
  - Receiver can check buffer occupancy, load and other metrics to allow or deny further communication
  - Puts power of Congestion and Flow control in the hands of more aware receiver than sender

Homa Feature: Connectionless

- RPC message-oriented protocol
- Avoids connection setup and management overhead
- State data stored: 200 bytes per host vs TCP’s 2000 bytes per connection
- Each RPC is handled independently

Homa Feature: SRPT Scheduling

- Homa approximates to Shortest Remaining Processing Time Scheduling
- Both sender and receiver have to implement
- Prevents short messages from starving (HoLB prevention)
- Messages have dynamic priorities and make use of priority queues in switches to prevent starvation
  - Aids approximating to SRPT Scheduling
- Improves tail latency
- Also allocates 5-10% of bandwidth to oldest (longest) message to prevent complete starvation.

Homa Feature: Receiver-Driven Congestion Control

- Receiver has better understanding of its state
    - Buffer occupancy
    - RPCs active vs inactive
    - Observed RTTs
    - Expected and current load
- After every `DATA` packet, **if transmission allowed**, receiver sends `GRANT` for next ‘`RTT` bytes’ with message priority.
    - Receiver can vary ‘`RTT` bytes’ and priority dynamically
- Can set flag in `GRANT` packets to signal issues to reduce sending capacity
    - Helps in handling Incast
- More cognizant receiver thus signals and drives congestion rather than using sender assumptions

Homa Feature: Out-of-Order Packets

- High tolerance threshold for out-of-order packets
- Aids Packet Spraying, which reduces latency, hot spots and buffering

Recap: Homa Features

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Homa Design Principles

- Transmitting short messages blindly
- Using in-network priorities
- Allocating priorities dynamically at receivers in conjunction with receiver-driven rate control
- Controlled over-commitment of receiver downlinks

Homa Working Overview

- On receiving message from top layer, sender blindly sends unscheduled portion
- Sender can send further scheduled `DATA` packets only if receiver authorises through `GRANT` packet
- `GRANT` usually requests for ‘`RTT` bytes’ worth outstanding data to keep transmission uninterrupted

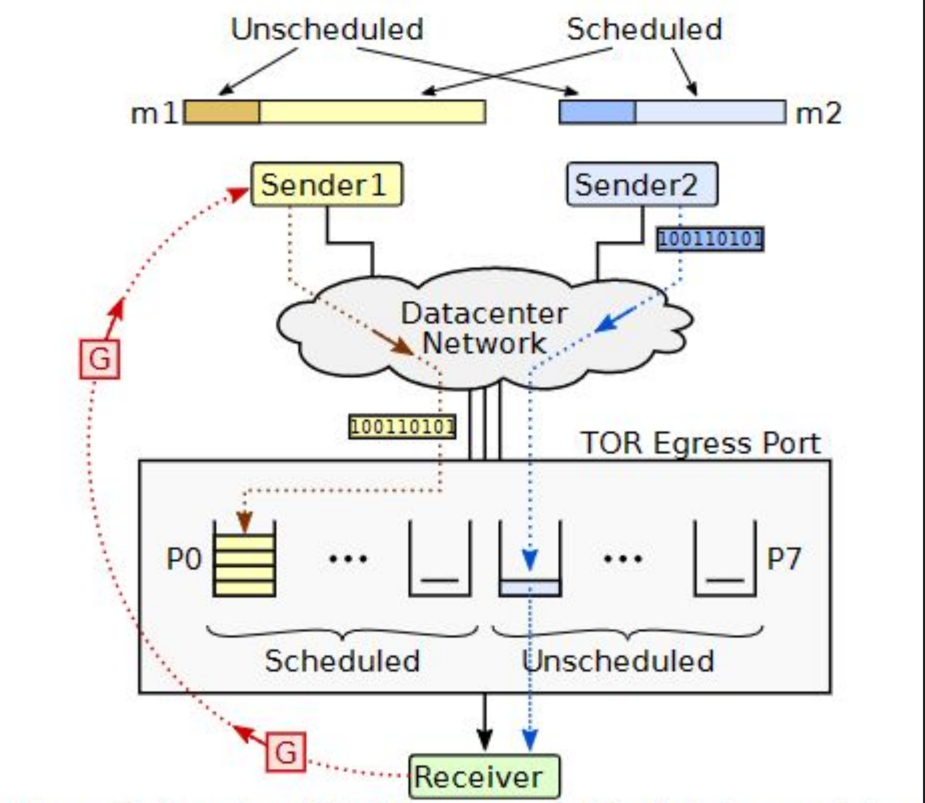
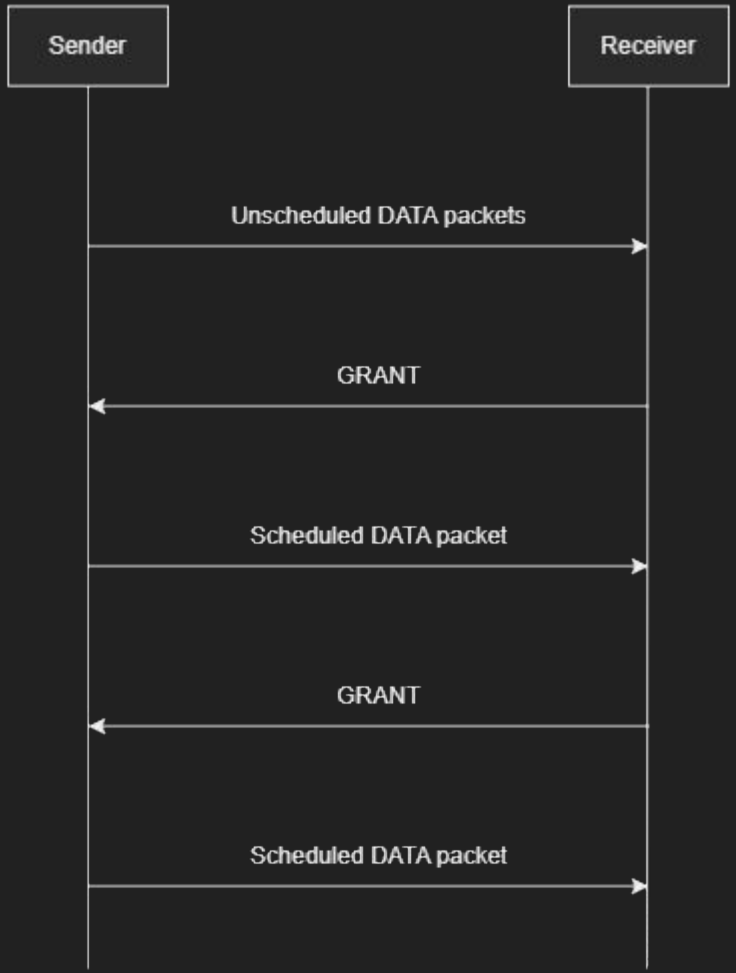
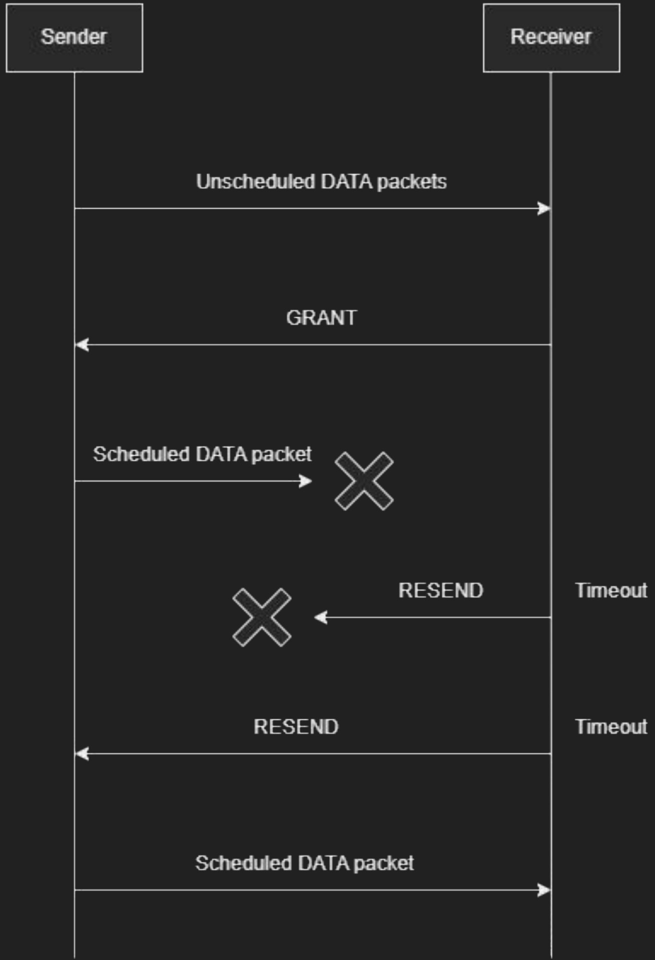


Figure 2: Overview of the Homa protocol. Sender1 is transmitting scheduled packets of message *m1*, while Sender2 is transmitting unscheduled packets of *m2*.

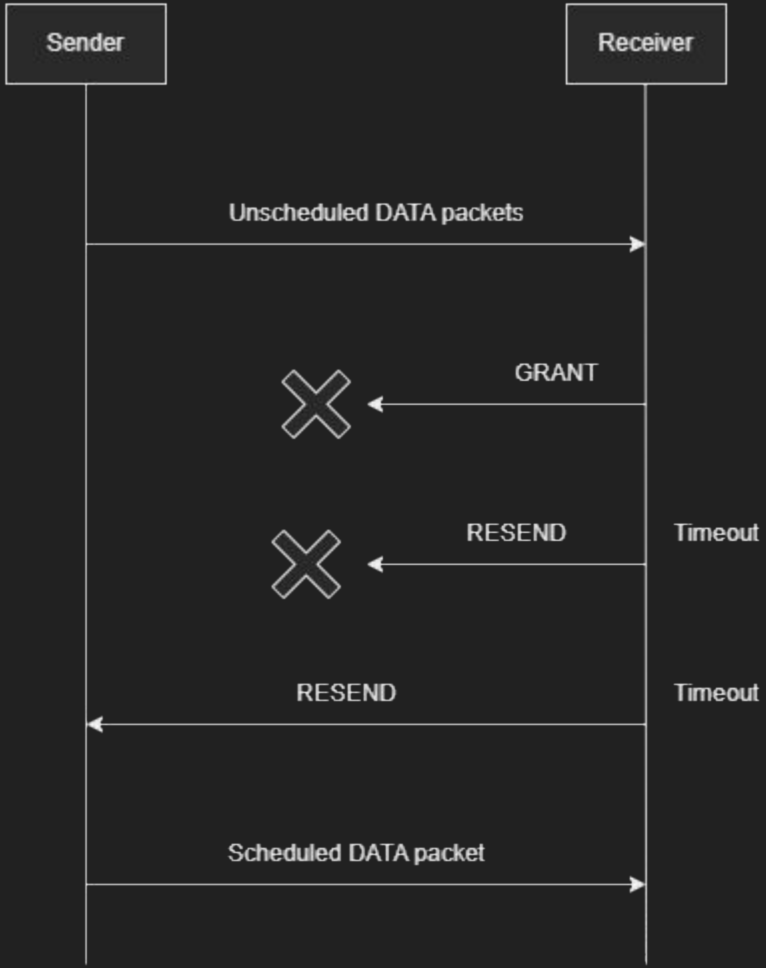
Homa Working



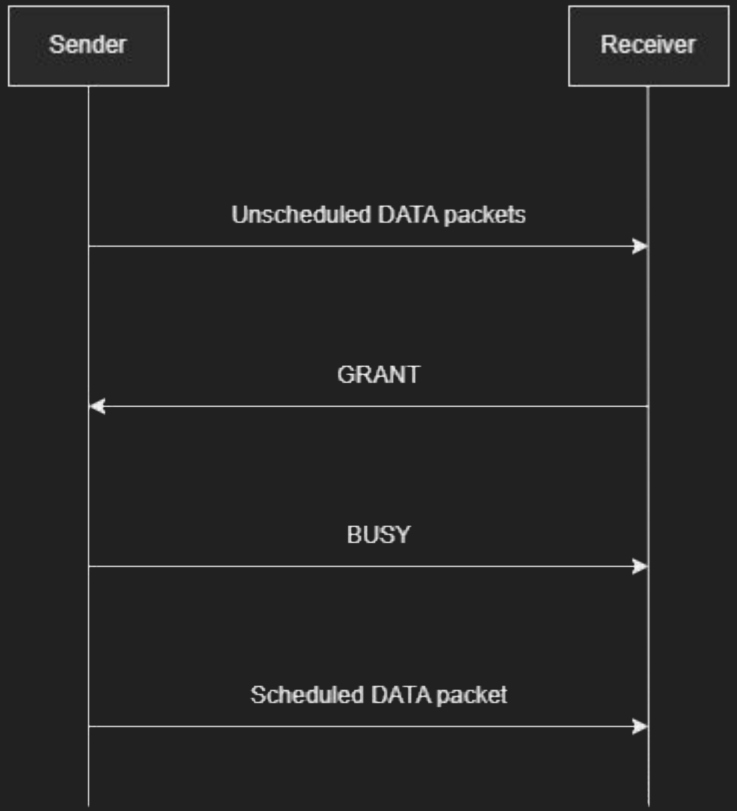
Homa Working



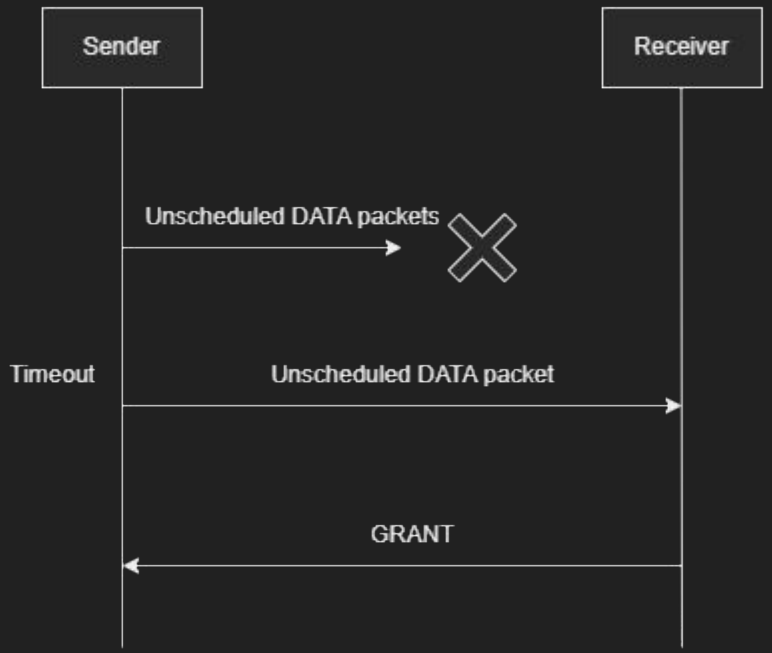
Homa Working



Homa Working



Homa Working



Homa Assumptions / Limitations

- Designed for Data Center environments; won't work well in WANs
- Assumes that congestion occurs primarily at host downlinks (ToR switches), not in core of network, due to Data Center designs
    - Congestion and buffer occupancy reducing mechanisms might make congestion lesser than TCP flows, but left open for future work.
- One Homa implementation per physical NIC recommended
    - Virtualizing NICs and sharing Homa state between them on one physical NIC left for future work.
- With faster networks, '`RTT` bytes' might increase, thus causing buffer occupancy issues and reducing Incast tolerance
- Incast above a certain threshold will cause packet loss and degraded perf

Tentative Future Plan

- Understand:
  - Homa Linux Implementation
  - Existing performance comparisons
  - DCTCP
- Carry out performance experiments
  - Try to look into future work
  - Try to plan and execute experiments along those lines
- Try to find improvements to protocol
  - Try to explore future work

Resources

- networking.harshkapadia.me/homa

Thank you!