The World Needs a New NIC (and it needs to run Homa)

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Overview

- **New transport protocol: Homa**
- **How to replace TCP in the datacenter?**
- **Datacenters will require new NICs**
  - Time to remove transport protocols from the OS
  - Implement Homa on the NIC

Mission: Low Latency RPC

- **Ultimate goal: 2-3 µs round-trips in datacenters**
  - Assumptions:
    - 3-layer switching structure (10 switch traversals in round-trip)
    - 1 µs speed-of-light delay round-trip
  - Minimal degradation for short messages (2-3x) at high network loads
- **Deployed today:**
  - 35 µs best-case (unloaded)
  - > 1 ms tail latency under load

- **Impediments to low latency:**
  - Operating system kernel
  - TCP
  - Virtualization/management
  - PCIe interconnect
  - Dispatching/load-balancing

Impediment #1: OS Kernel

- **Linux adds about 10 µs overhead:**
  - Homa RPC via Linux kernel: 14.6 µs
  - Homa RPC w. kernel bypass (RAMCloud): 4.0 µs

  (2 servers attached to same TOR)
- **Kernel bypass is essential, but:**
  - Today must implement protocols in applications
  - Other issues, such as dispatching

Impediment #2: TCP Protocol

- **4-5 µs extra round-trip overhead:**

	TCP	Homa
CloudLab xl170	28 µs	23 µs
CloudLab m510	32 µs	28 µs
CloudLab c220gl	41 µs	37 µs

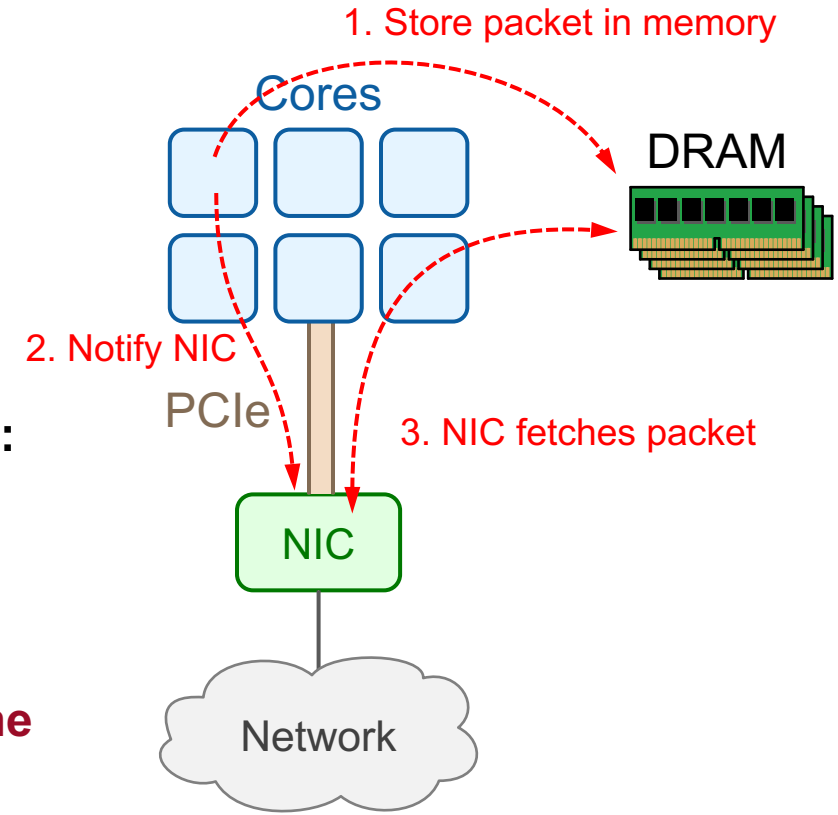
- **100-1000x slowdown under load:**
  - Congestion control requires buffer occupancy
- **Problematic features:**
  - Connection-oriented (large amounts of state)
  - Stream-oriented

Impediment #3: Virtualization/Mgmt

- **Features such as:**
  - Virtual host addresses
  - Performance isolation (rate limiting)
  - Live migration
- **Current implementations in software:**
  - VMware Open vSwitch
  - Google Andromeda
- **Significant latency penalty: > 10 µs round-trip?**

Impediment #4: PCIe Bus

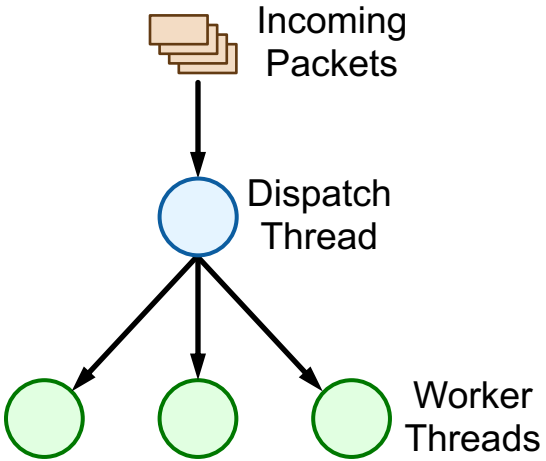
- **PCIe bus has high latency: 100s of ns**
- **Multiple transits for each host-NIC exchange**
- **Synchronous: locks up CPU**
- **Overall cost of host-NIC communication:**
  - ~ 0.5 µs per packet sent or received
  - ~ 2 µs per round trip



PCIe bus accounts for half of total RPC time under kernel bypass!

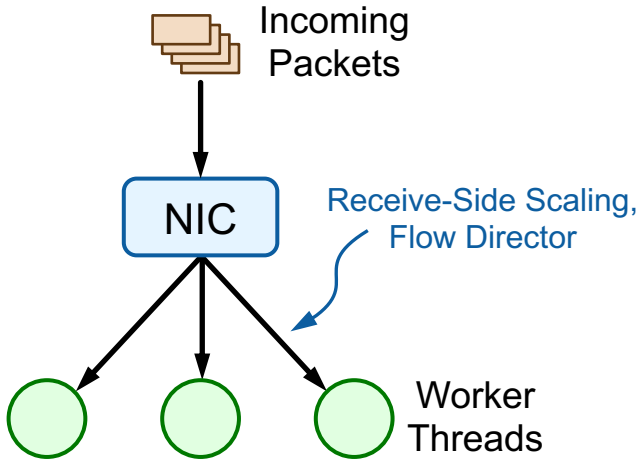
Impediment #5: Load Balancing

Choice #1: dispatch thread



- Extra latency for worker handoff
- Dispatch thread is throughput bottleneck

Choice #2: sharding



- NIC dispatches based on shard info provided by sender
- Prone to hot spots

Things Will Get Worse

- **The future:**
  - Faster networks (40 Gbps →100 Gbps → ??)
  - Extremely high packet rates for small messages
  - CPUs not getting faster
  - More and more cores generating/handling traffic
- **Software-based packet handlers increasingly problematic:**
  - Centralized handlers can't handle traffic
  - Distributed software approaches challenging
    - Load balancing
    - Synchronization hot spots

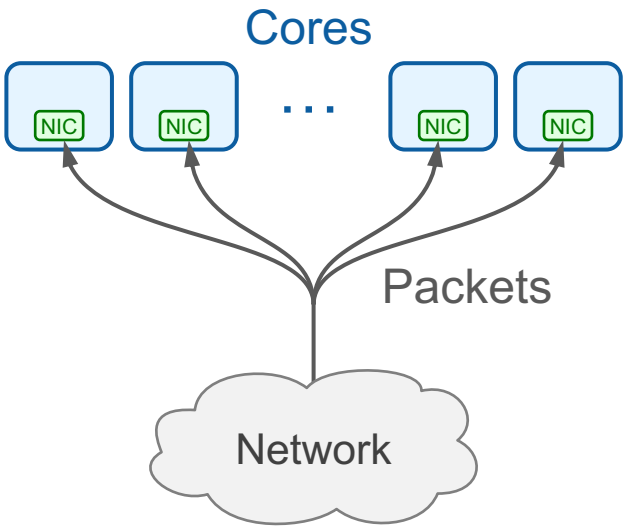
Homa Transport Protocol

- **Solves congestion problem**
  - Uses in-switch priority queues to prioritize short messages
  - Receiver-driven flow control
- **Other attractive features:**
  - Simpler than TCP
  - Message-oriented (not streaming)
  - Connectionless (state only for active RPCs)
- **Performance >> TCP**
  - Small RPCs: 5 µs (small networks, kernel bypass)
  - Tail latency slowdown ~ 3x at 80% bandwidth utilization

How to make Homa the standard for datacenter communication?

Bring the Network to the Cores?

- Distribute raw network on-chip
- Simple NIC for each core
- Special user-space instructions to send/receive packets
- Run Homa in apps on each core



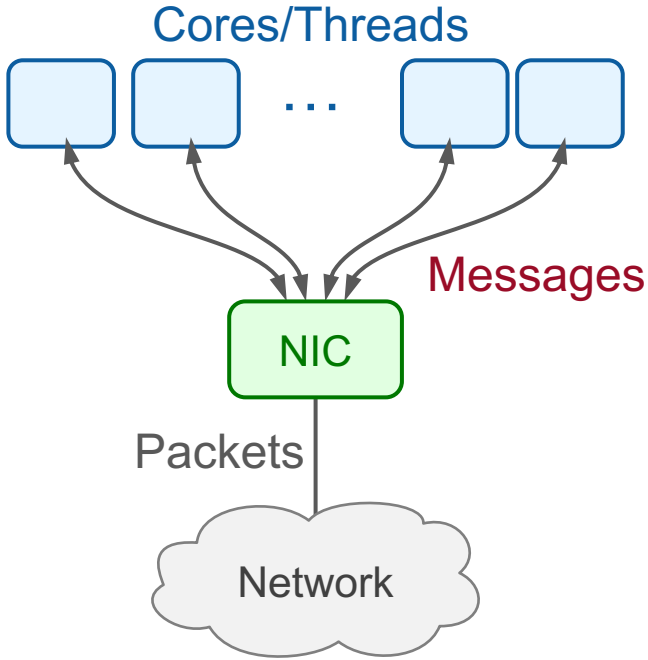
Problems:

- Requires processor modifications
- Homa needs centralized state for network link
- No solution for virtualization/mgmt

Better Solution: New NIC

NIC Features:

- **Transport protocol implemented by NIC**
- **Kernel bypass**
- **Message-based interface on host side (no packets!)**
- **Dispatching/load-balancing**
  - E.g., pick idle thread
- **Virtualization/mgmt (zero overhead)**
- **Encryption (and authentication?)**
- **Replace PCIe for NIC-app communication (eventually)**



Why Homa Instead of TCP?

- **100-1000x better tail latency for small messages**
  - Homa has better congestion control
- **Homa is simpler than TCP**
- **NIC can't do dispatching with TCP**
  - Dispatchable units (messages) must be visible
  - TCP: stream based (no message boundaries)
  - Homa: message based
- **TCP requires expensive state**
  - TCP: connection oriented (separate state for each source-destination pair)
  - Homa: no connections; state only for active RPCs
- **Kernel bypass awkward/expensive with TCP**
  - TCP: kernel (and hypervisor?) interaction for each new connection
  - Homa: kernel interaction once per application: single socket for all communication

How Do We Get There?

- **Today's "smart NICs" inadequate**
- **Too large a project for a university?**
  - But Nick McKeown has ideas…
- **Special-purpose Homa NIC unlikely to come from industry**
  - Companies unlikely to bet on Homa until it is more established
- **Best hope: a new programmable NIC**
  - Looks more like a switch than a traditional NIC?
  - High performance datapath
  - Customizable/programmable (> P4)
- **Risks:**
  - Proprietary protocol implementations
  - Special-purpose TCP implementation makes new protocols impossible

Conclusion

- **Trend towards special-purpose hardware**
- **Opportunity in the datacenter: new NIC**
  - As important as FPUs, GPUs, and TPUs
- **Should support complete transport protocol implementation(s)**
- **Homa is the right protocol**