AccelTCP: Accelerating Network Applications with Stateful TCP Offloading

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TCP is widely adopted in modern networks

- Used by 95+% of WAN traffic and 50+% of datacenter traffic [1][2]
- The gap between network bandwidth and CPU capacity widens

2009

1GbE

100x

2019

100GbE

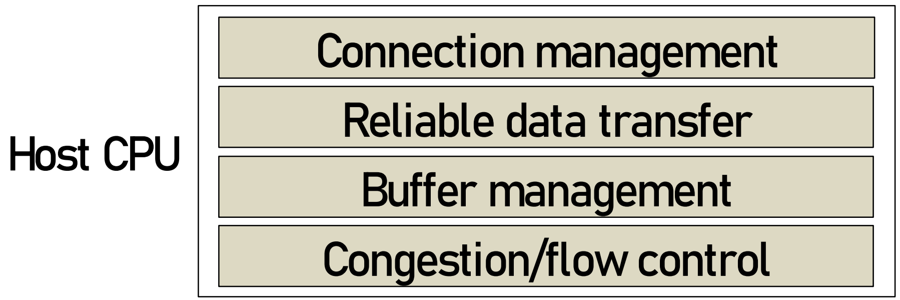
CPU efficiency of TCP stack becoming increasingly important

[1] Comparison of Caching Strategies in Modern Cellular Backhaul Networks (MobiSys '13)
[2] RDMA over Commodity Ethernet at Scale (SIGCOMM '16)

Suboptimal CPU efficiency in TCP stacks

- Recent TCP stacks adopt numerous optimization techniques
  - e.g., optimized packet I/O, kernel-bypassing, zero-copying

- Unfortunately, fundamentally limited by TCP conformance overhead



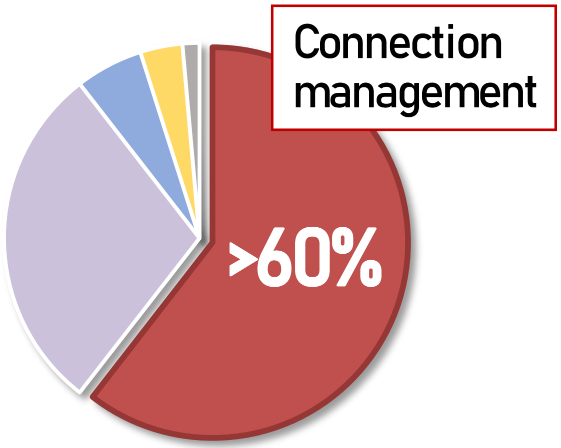
TCP overhead in short-lived connections

- Short TCP flows dominates the Internet
  - 80% of cellular network traffic is smaller than 8KB [1]

- Connection management overhead in short TCP flows

CPU breakdown of mTCP + Redis

- A single key-value lookup per connection

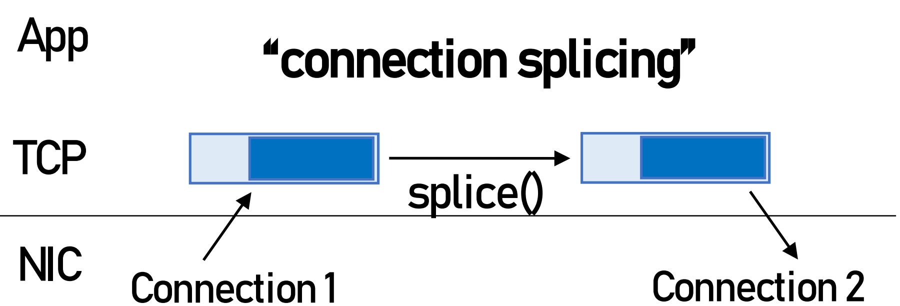


[1] Comparison of Caching Strategies in Modern Cellular Backhaul Networks (MobiSys '13)

TCP overhead in Layer-7 (L7) proxying

- L7 proxies are widely adopted (e.g., load balancer, API gateway)

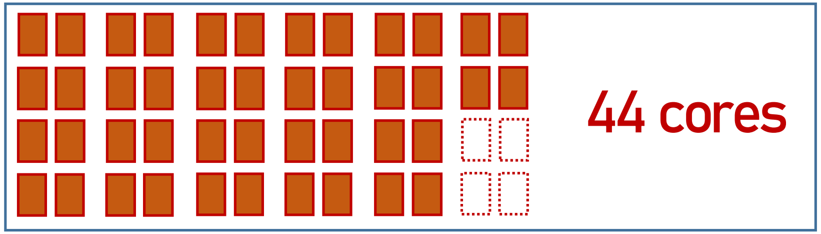
- Payload relaying overhead in L7 proxies



Overheads

- ~~Memcpy from/to app~~
- TCP processing
- DMA overhead

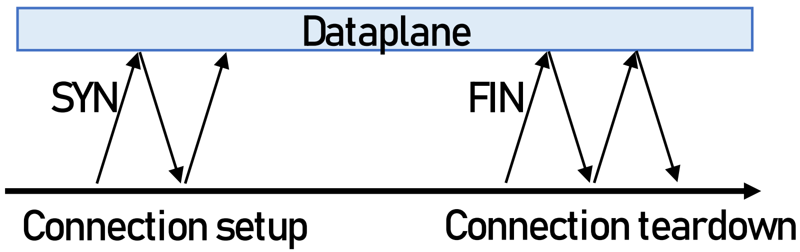
L7 load balancer
100GbE =



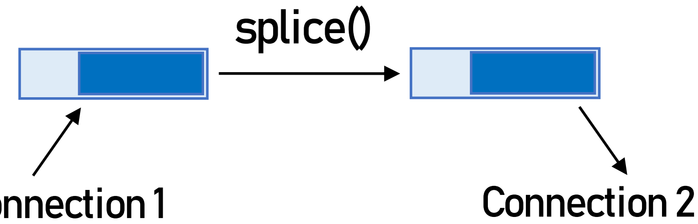
Our work: AccelTCP

NIC offload of mechanical operations for TCP conformance

Connection management



Connection splicing



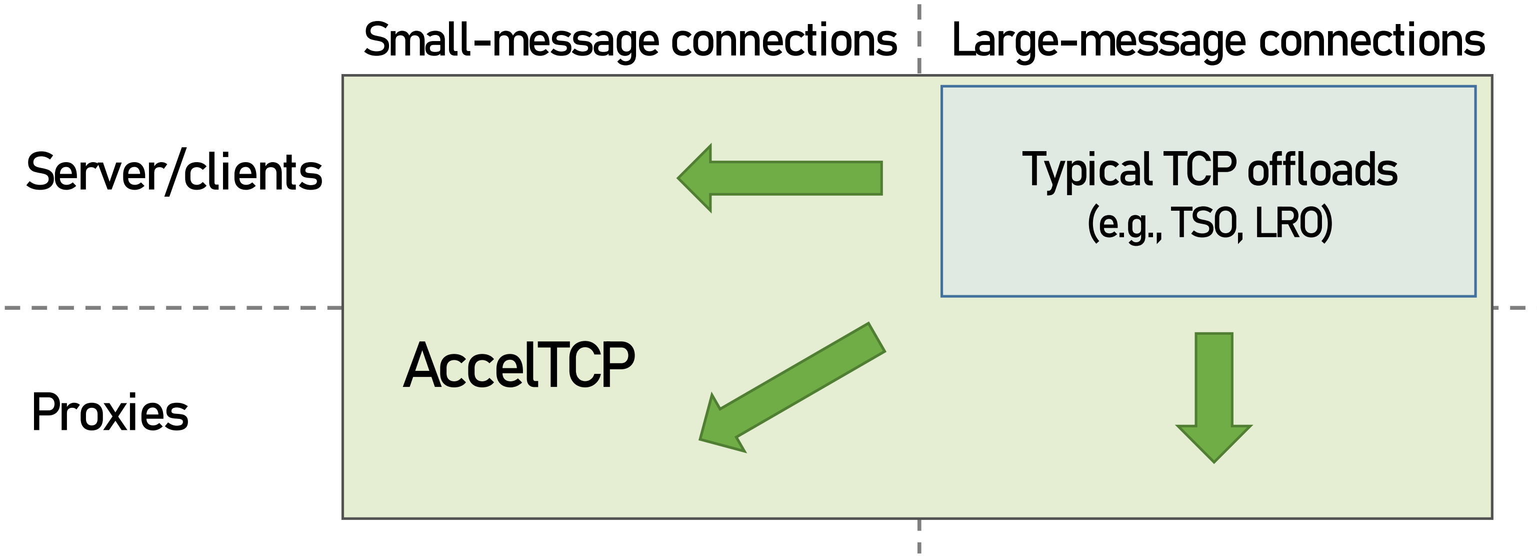
Existing TCP NIC offloads

- Full-stack TCP offload engine (TOE)
  - Poor connection scalability
  - Difficult to extend (e.g., adding a new congestion control algorithm)

- TCP Segmentation Offload (TSO) and Large Receive Offload (LRO)
  - Saves significant CPU cycles for processing ***large*** messages

Our work: AccelTCP

Extend the benefit of NIC offload to general TCP applications



AccelTCP design overview

- A dual-stack TCP architecture with stateful TCP offloading
  - Selectively offloads peripheral TCP operations to NICs

Host stack

Host stack
Reliable data transfer
Buffer management
Congestion/flow control

Central TCP operations
→ Required for data transfer

NIC stack

NIC stack
Segmentation/checksum
Connection setup/teardown
Connection splicing

Peripheral TCP operations
→ Required for protocol conformance

AccelTCP design overview

- A dual-stack TCP architecture with stateful TCP offloading
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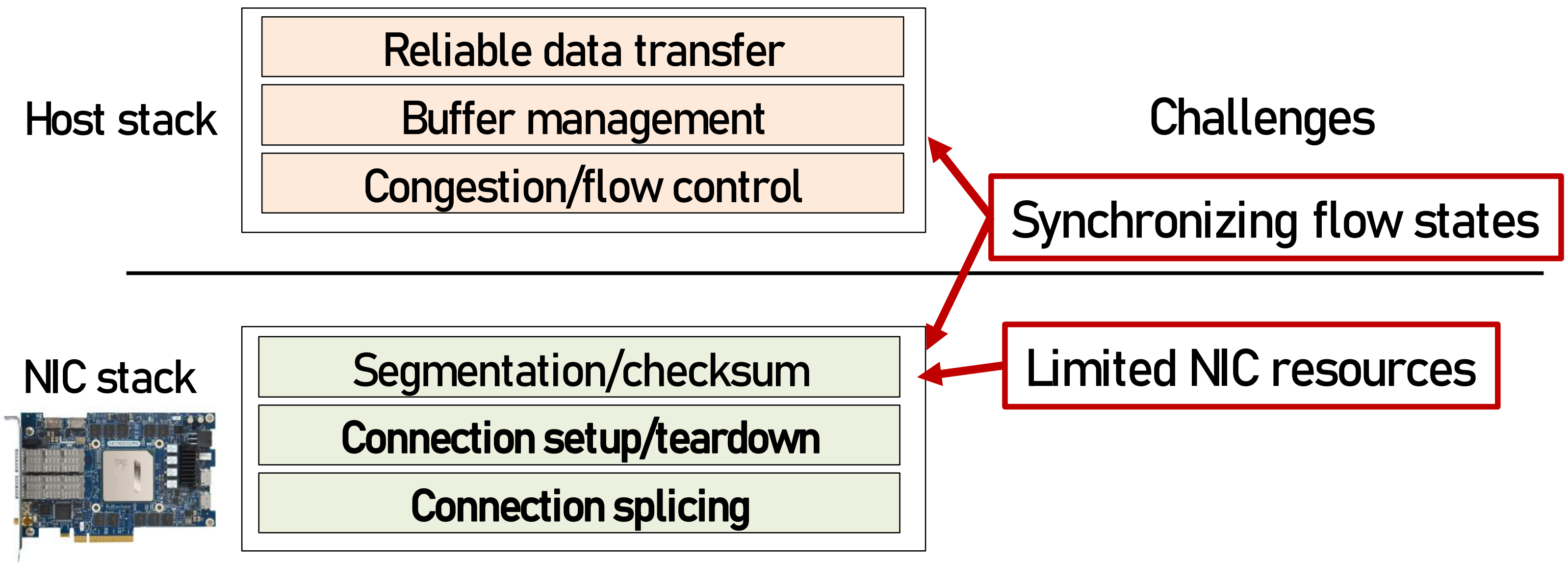
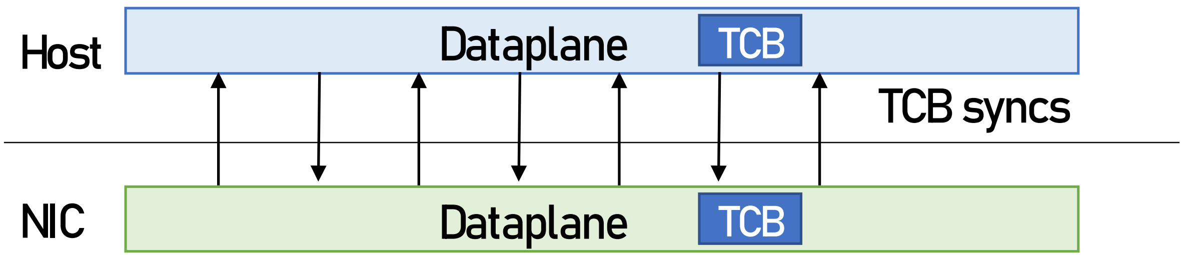


Challenge #1. Synchronizing flow states

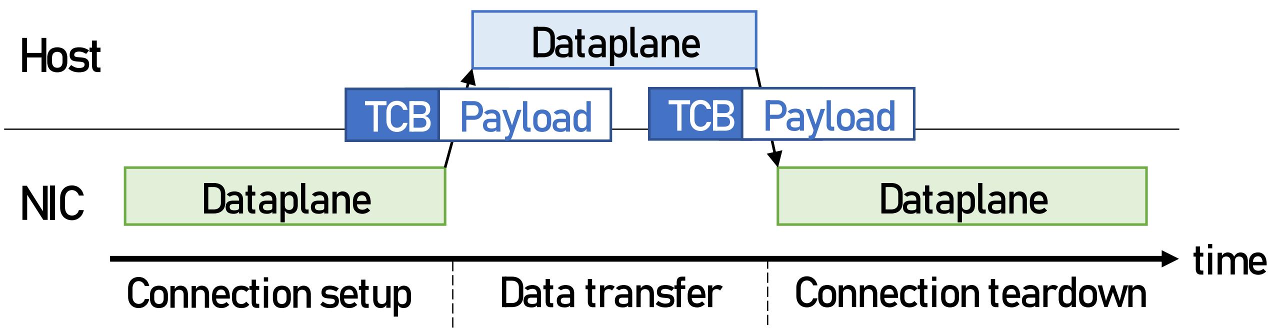
- Connection management and splicing are stateful TCP operations
  - Transmission control block (TCB) needs to be updated

- Challenging to maintain flow state consistency across two stacks
  - Huge DMA cost to deliver sync messages



Challenge #1. Synchronizing flow states

- Our approach: Single ownership of a TCP flow and its TCB
- Key ideas:
  - TCB sync occurs only in between the different phases
  - TCB sync messages are piggybacked with payload packets



Challenge #2. Limited NIC resources

- Limited fast memory size
  - For holding program instructions and connection states
  - e.g., 8MB SRAM in Netronome Agilio LX

- Limited compute capacity
  - Typical TCP stacks: 1000 - 3000 cycles/packet

  → Performance drop by 30 - 80% in Agilio LX

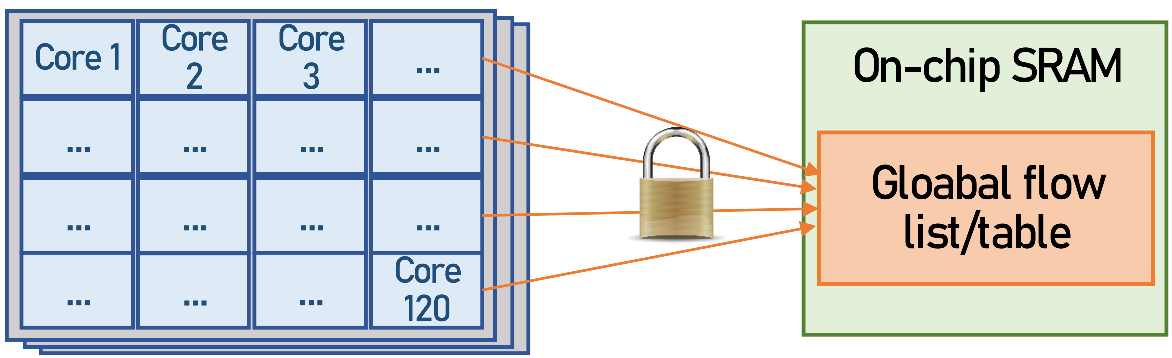
Challenge #2. Limited NIC resources

Our approach: Minimize NIC dataplane complexity

	Limited memory	Limited CPU capacity
Connection setup	Use SYN cookie → stateless operation	Use fast hashing (in hardware)
Connection splicing	Minimize TCB on NIC # of concurrent flows: 10k → 256k	Differential checksum update
Connection teardown		Timer bitmap wheel this talk

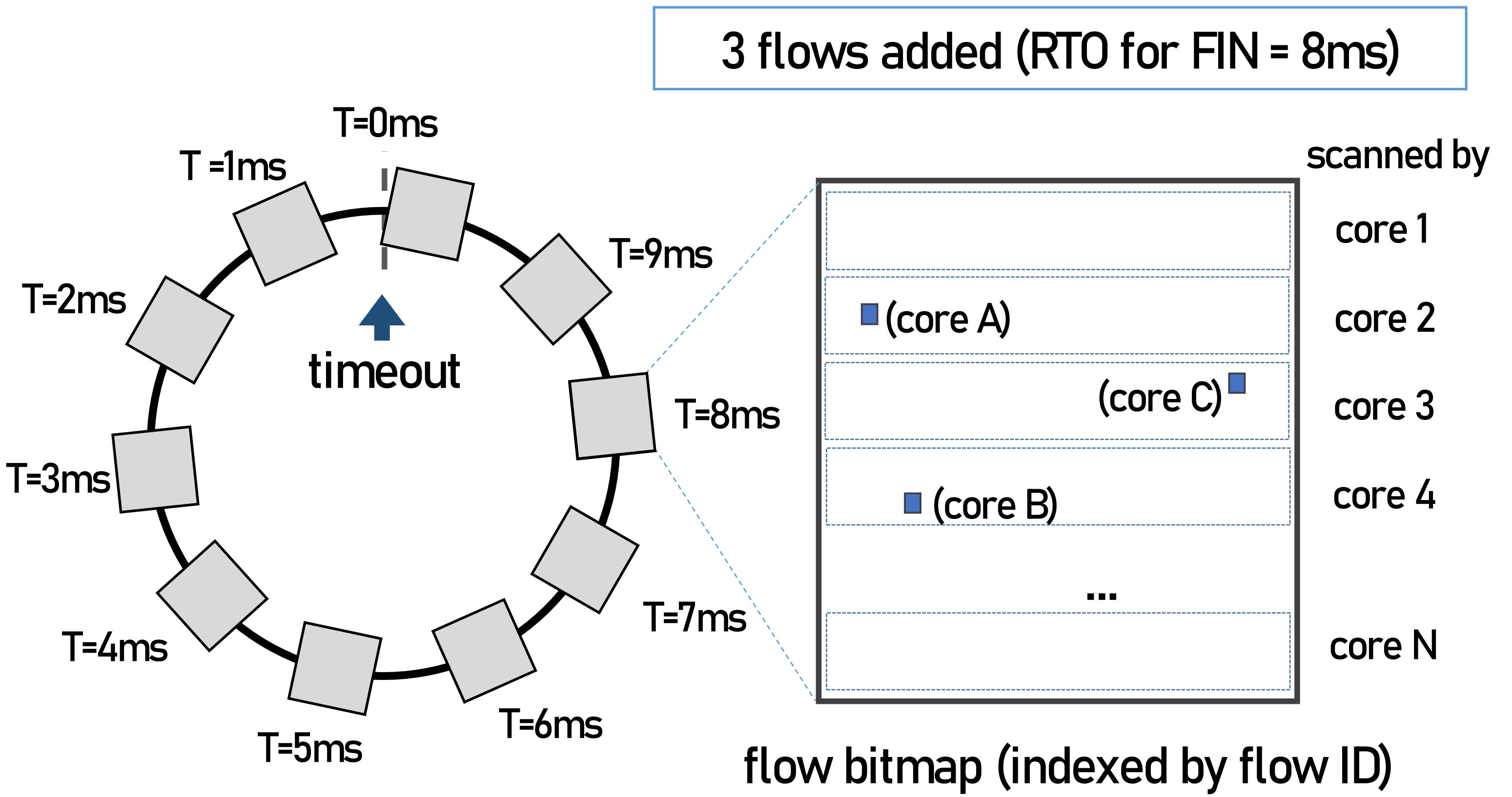
Tracking timeouts on NIC

- Required for TCP retransmission or last ACK timeout, TIME_WAIT
- No flow-to-core affinity → A global data structure for tracking timeout
  - Frequent timer registration incurs a huge lock contention



Timer bitmap wheel

- Efficient timer registration & invocation in NIC dataplane



Host stack optimizations

1. User-level threading
   - Avoid heavy context switching overhead between TCP stack and app

2. Opportunistic zero-copy
   - Avoid socket buffer copy if packets can be delivered directly from/to app

3. Lazy TCB Creation
   - Many fields of TCB (up to 700 bytes) are unused in single transaction case
   - ➢ Our approach: Create a quasi-TCB (40 bytes) for a new connection

Check out our paper for more details ☺

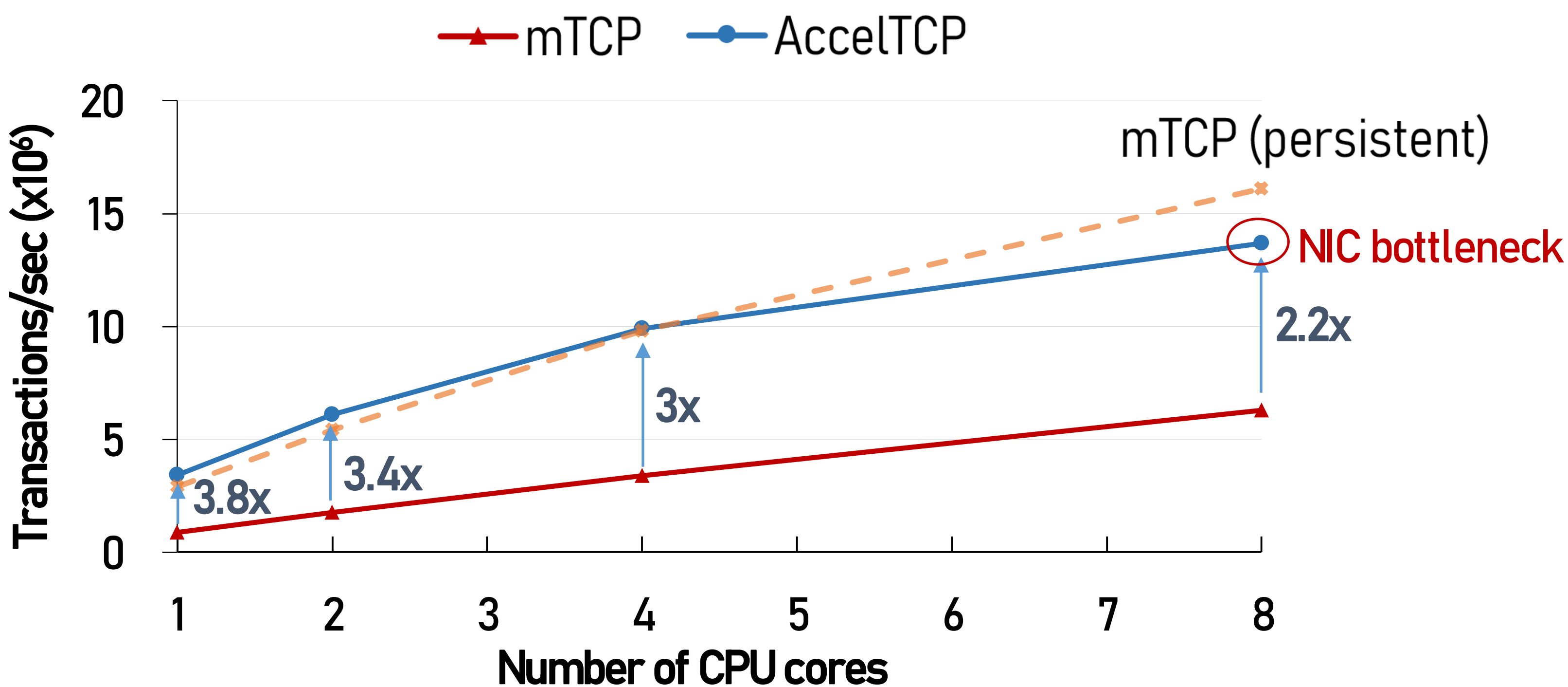
Implementation and experiment setup

- NIC stack: running on Netronome Agilio NICs
  - 1,501 lines of C code and 195 lines of P4 code
- Host stack: extended mTCP to support NIC offloads
  - Easy to port existing apps (connect() → mtcp_connect())

- Experiment setup
  - CPU: Xeon Gold 6142 (16-cores @ 2.6GHz)
  - NIC: Netronome Agilio LX 40GbE x2
  - Memory: 128GB DDR4 RAM
  - Use up to 8 client machines (Xeon E5-2640 v3) to generate workload

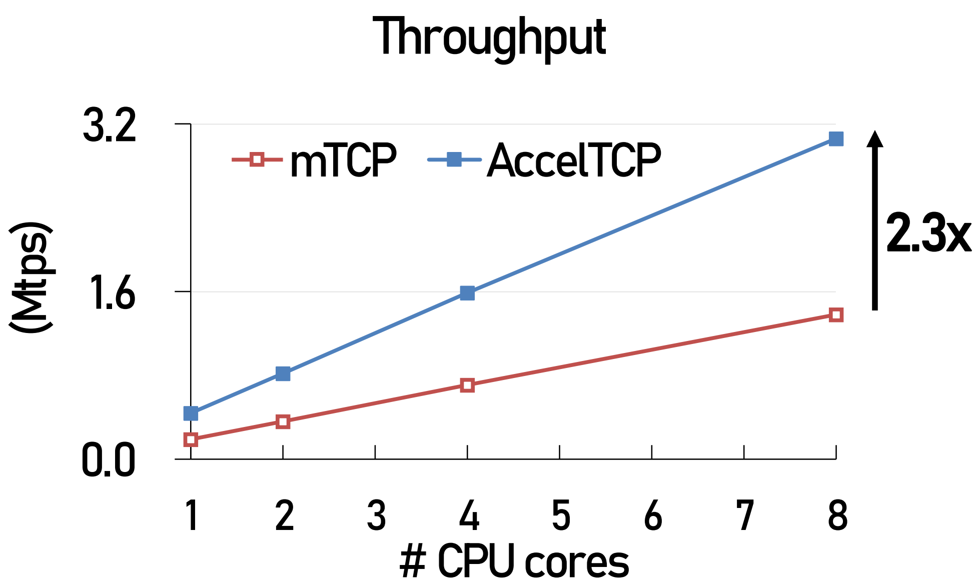
Does AccelTCP support high connection rate?

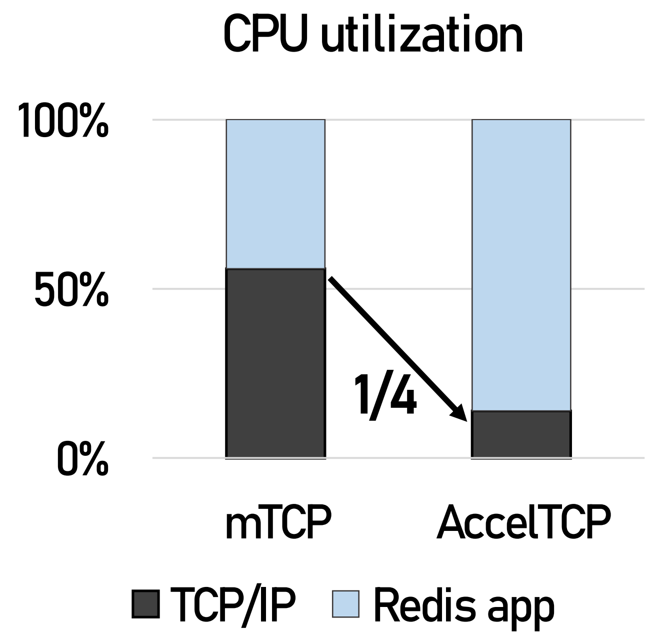
- Throughput performance of a TCP server
  - A single 64B packet transaction per connection



Do applications benefit from AccelTCP?

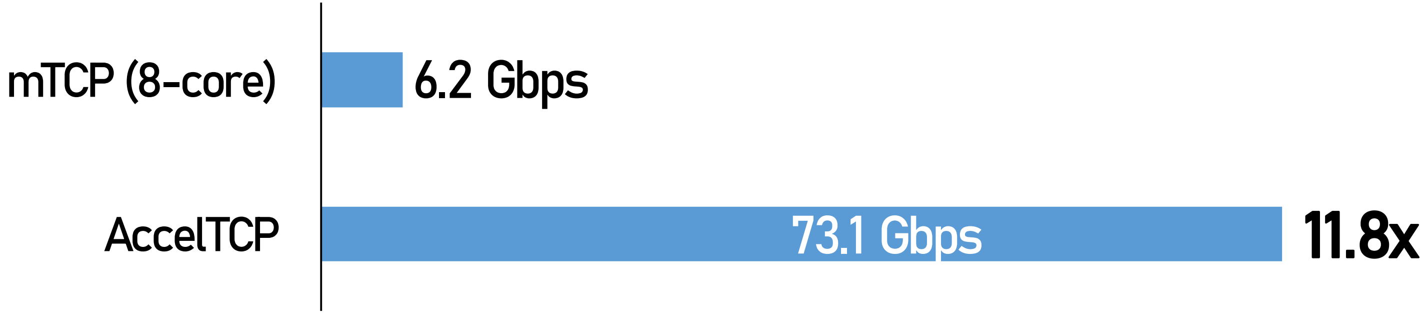
Redis under Facebook USR workload (flow size: < 20B)





Do applications benefit from AccelTCP?

HAProxy under SpecWeb2009-like workload



Summary

- TCP performance limited by protocol conformance overhead
  - Short-lived flows and L7 proxies cannot benefit from existing TCP offloads
- AccelTCP explores a new design space of NIC-assisted TCP stack
  - Connection management and splicing can be offloaded to NIC
- AccelTCP significantly improves CPU efficiency of real-world apps
  - 2.3x improvement with Redis, 12x improvement with HAproxy

Source code available:

shader.kaist.edu/acceltcp

github.com/acceltcp