TCP offload is a dumb idea whose time has come

Jeffrey Mogul

JeffMogul@acm.org

Large Scale Systems Group

HP Labs, Palo Alto

One-slide summary

What is TCP Offload?

- Moving IP and TCP processing to the Network Interface (NIC)

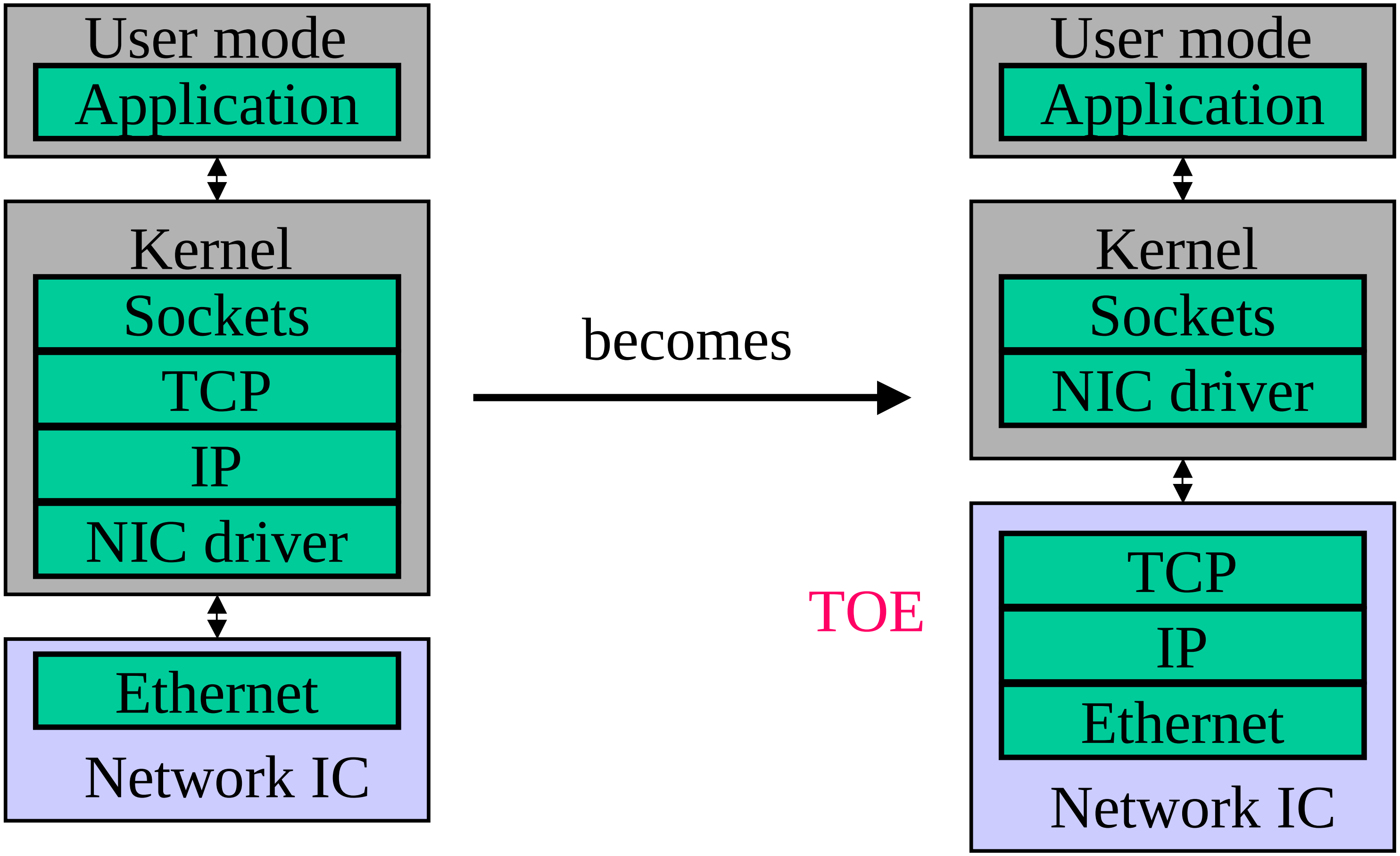
Why is it a dumb idea?

- Fundamental performance issues
- Practical deployment issues
- Poor justification (wrong applications)

Why has its time come?

- So we can offload higher-level protocols

TCP Offload Engines (TOEs)



Typical justifications for TCP offload

- Reduction of host CPU cycles for protocol header processing, checksumming
- Fewer CPU interrupts
- Fewer bytes copied over the memory bus
- Potential to offload expensive features such as encryption

Why TCP offload is dumb: Performance (part 1: technology issues)

- TCP/IP headers don’t take many CPU cycles
  - Cf. Jacobson’s “Header prediction” code
- Moore’s Law works against “smart” NICs
  - Complexity increases time-to-market
  - CPUs keep getting faster & benefit from large volumes
- TOEs impose complex interfaces
  - Protocol *between* TOE & CPU can be worse than TCP
  - Could require passing more context info

Why TCP offload is dumb:
Performance (part 2: management)

- Suboptimal buffer management
  - Very hard to avoid buffer copy (esp. on receive)
  - But buffer copies are the real performance issue
- Connection management overhead
  - For short connections, overwhelms any savings
- Ditto for event management overhead
- Resource management
  - Virtual resources (e.g., ports) must be managed
  - Coordination with host OS adds overhead

Why TCP offload is dumb:
Performance (part 3: alternatives)

- Much simpler NIC extensions can be effective
- For example:
  - TCP checksum offload (can avoid CPU data-touching)
  - Afterburner (Dalton *et al*. 1995) for single-copy TCP
- Sometimes the OS implementation just sucks

Why TCP offload is dumb:
Deployment issues (part 1: using TOEs)

- Scaling is harder for TOEs than for host CPUs
  - Large systems have large buffer pools, routing tables
  - TOEs reduce allocation flexibility
- Programmable NICs: more vulnerable to hackers?
  - Programmability is always a potential hole
  - But: many modern NICs are already programmable
- More system management interfaces to deal with
  - Or, seams showing between “integrated” interfaces
  - TOEs may lack state visibility available in host OS

Why TCP offload is dumb:
Deployment issues (part 2: maintenance)

- TOEs likely to have more bugs than simple NICs
  - IP/TCP implementations often need fixes/upgrades
  - Doubles the number of code bases to manage
- More code bases means QA is harder, slower
- Problem isolation becomes harder
  - Finger-pointing between OS and TOE vendors
- Exposes customers to risk of TOE vendor failure
  - Lack of support worse for TOEs than for simple NICs

Why TCP offload is dumb: Mismatched applications

- Traditional applications for TCP:
  - WAN applications (email, FTP, Web, IM, USENET)
  - Short connections, and many of them at once
  - IP/TCP packet processing costs do not dominate
- Problem areas for TCP offload:
  - High network delay (obviates low-delay NIC tricks)
  - Lots of connections, lots of connection management
  - Low ratio of packet processing costs to other costs
- So: traditional TCP apps don’t need offload

Insights

- Sweet spot for TCP offload might be apps with:
  - Very high bandwidth
  - Relatively low end-to-end latency network paths
  - Long connection durations
  - Relatively few connections
- Typical examples of these might be:
  - Storage-server access
  - Graphics
  - Cluster interconnect

Network-I/O convergence?

- Promising aspects:
  - Replace special-purpose hw w/ cheap commodity parts
    - 1Gbit or 10Gbit Ethernet
  - Only one fabric to provision, connect, and manage
    - More scalable and interoperable
- Challenges:
  - Data copy costs dominate (busses are too slow)
  - Zero-copy and single-copy seem too hard to adopt

What’s so hard about zero-copy TCP?

- On receive: headers interspersed with data
  - Page-remapping tricks often fail to help
- On transmit: buffer ownership issues
  - Application can’t touch buffer before it’s ACKed
- Some techniques force new APIs on applications
- Changing commercial OS stacks is a nightmare
- Lots of people have tried to make this work
  - Has anyone really succeeded?

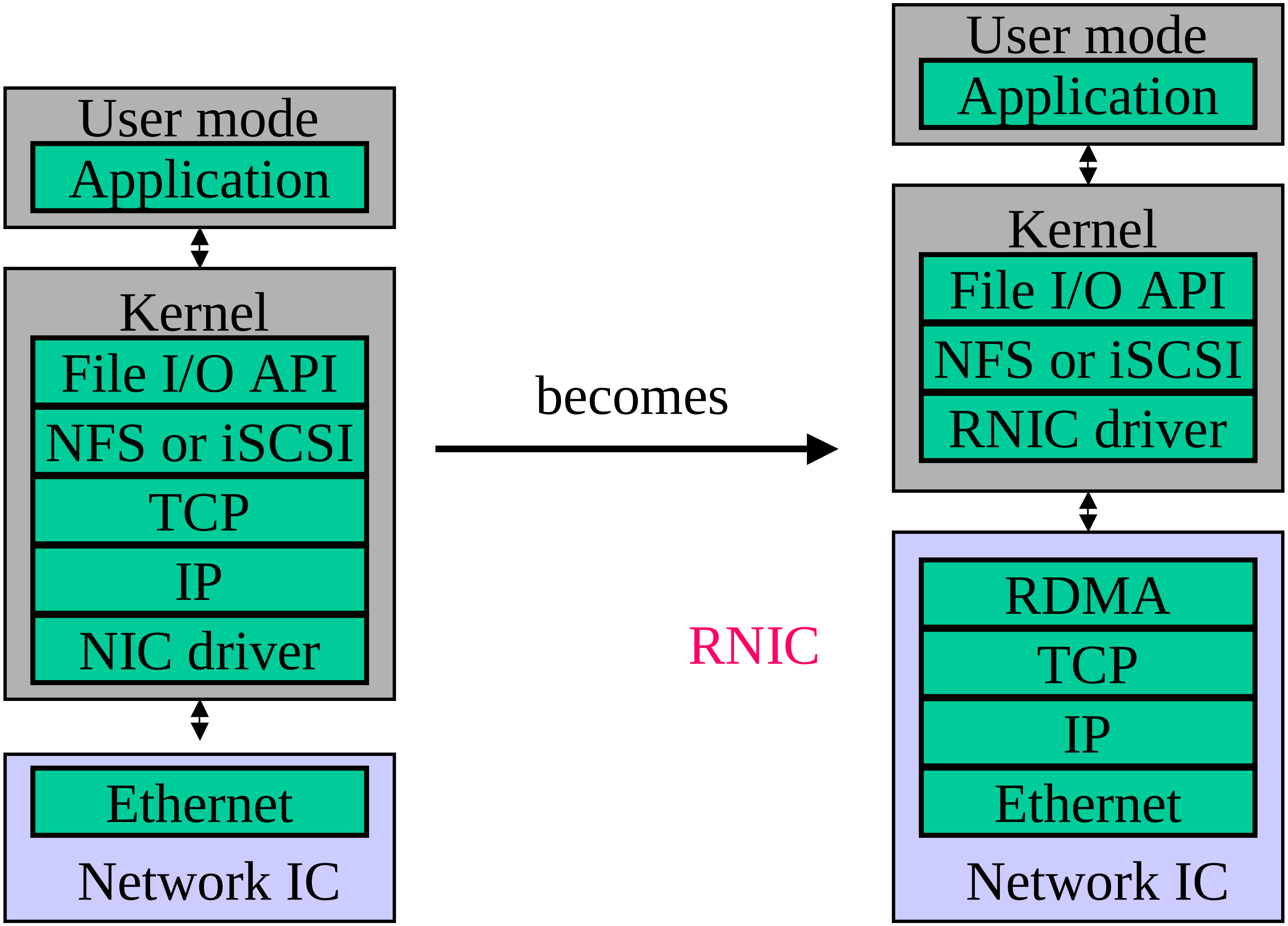
Side-stepping the problems: RDMA

- Remote Direct Memory Access
- New protocol layer *between* transport and apps
  - App @ host X registers buffer regions w/ local RDMA
  - Region IDs are sent (somehow) to App @ host Y
  - App @ Y reads/writes data buffers in X's memory
  - RDMA layer knows what is data, what is header
- Intended for hardware implementation (RNIC)
  - Allowing zero-copy for many (not all) applications

Aha!: RDMA *requires* transport offload

- Must offload transport in order to offload RDMA
  - Transport could be (e.g.) TCP+MPA shim, or SCTP
- RDMA well matched to storage access
  - Fits easily below NFSv4, DAFS, iSCSI
- The right characteristics for transport offload
  - Data-center networks, long connections
- Simplifies many problems w/generic TCP offload
  - Explicit protocol-visible separation of data & headers

RDMA NICs (RNICs)



Why should we believe that this will fly?

- NIC vendors want to ship RNICs in volume
  - They need to raise the price point over current NICs
  - RDMA allows generic solution (vs. iSCSI NICs)
  - InfiniBand isn’t a high-volume market (yet?)
- System, OS, and storage vendors want it
  - Cheaper hardware, simpler data centers
  - Willing to deal with a new protocol layer
- Upper-Level Protocols (ULPs) ready & waiting(?)
  - NFSv4, DAFS, iSCSI extensions for RDMA (iSER)

What could go wrong?

- Many problems of TOEs still apply
  - E.g., multiple code bases, resource allocation
- So far, the benefits have been “elusive”
  - cf. Sarkar *et al.* 2003, Shivam & Chase 2003
  - May need well-integrated NIC + 10 Gbit LANs
- Extension to user-level networking is tricky
  - New API; transmit buffer-pinning still a problem
- Standardization not quite done
  - SCTP vs. TCP; MPA concerns; security questions

Summary

- Generic TCP offload seems like a bad idea
  - “solution in search of a problem”
  - Cure is usually worse than the disease
- RDMA offload justifies transport offload
  - OK, jury is still out on that
- New networking model might change OS APIs
  - Are read() and write() really the only way to go?
- RDMA requires “OS thinking” in new places

Odds and ends

- SCTP: an alternative to TCP
  - Doesn’t require MPA shim to get message boundaries
  - Not ready to ship in silicon, yet
- RDMA or DDP (Direct Data Placement)?
  - DDP: remote-write only; should be simpler
  - Are remote reads & other RDMA verbs necessary?
- Security: not a simple issue
  - Implementations of a secure protocol may have bugs
  - Consequences of exploited bug: free access to memory