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THE U-NET USER-LEVEL NETWORK ARCHITECTURE

A Case for User-Level Network Protocols

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Joint work with Werner Vogels, Anindya Basu, and Vineet Buch

U-Net Goal

Improve Communication in Networks of Workstations

- key for running parallel and tightly coupled distributed programs

Proposed solution: user-level network access

- overcome bottlenecks in current centralized networking layers

Motivation 1: Performance

- fully utilize high speed network fabrics
- support parallel processing
- tighter application-network coupling

Motivation 2: Flexibility

- variants of standard protocols
- new communication semantics
- different types of communication paradigms

Inspiration: Massively Parallel Machines

Key idea: allow user-level access to network interface device

- Examples: TMC CM-5, IBM SP-2, Meiko CS-2
- Advantages
  - bypasses the kernel for send/receive
  - no copy: DMA in/out of user memory
  - application-specific protocols
- Shortcomings
  - custom network interface, custom reliable network
  - assumes homogeneous nodes
  - restricts multi-user capabilities

Related Work

User-level protocol implementations

- Mach 3.0
- HP Jetstream
- AN1 TCP

Kernel bypass

- UW remote read/write instructions
- Active Messages over ATM
- Arizona ADCs
- Shrimp

Packet filter in the network interface

- Arizona Pathfinder
- HP Jetstream

The U-Net Approach

Targets

- Performance: 10x bandwidth *and* 0.1x latency
- Flexibility: TCP&Co. as well as parallel computations

Techniques

- use parallel machine technology
  - protected user-level access to the network
- build user-level protocols
  - thin networking software layers

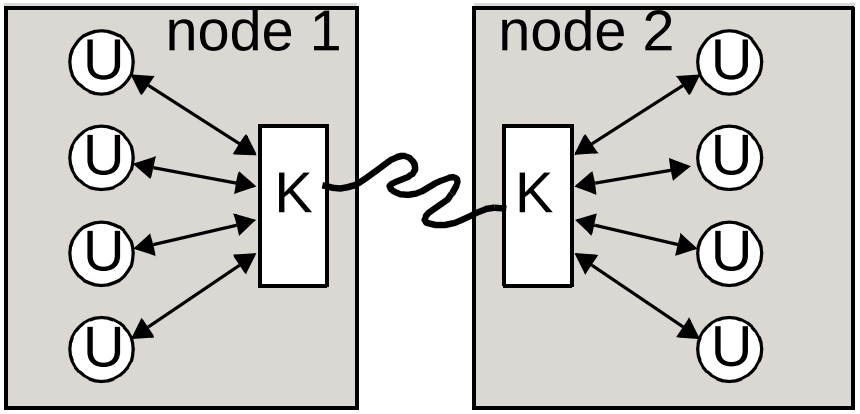
Invariants

- off-the-shelf hardware and software
  - workstations, operating system, and network
- no compromise on protection
  - process A cannot inspect or corrupt process B's messages
  - process A cannot impersonate process B

U-Net: Basic Idea

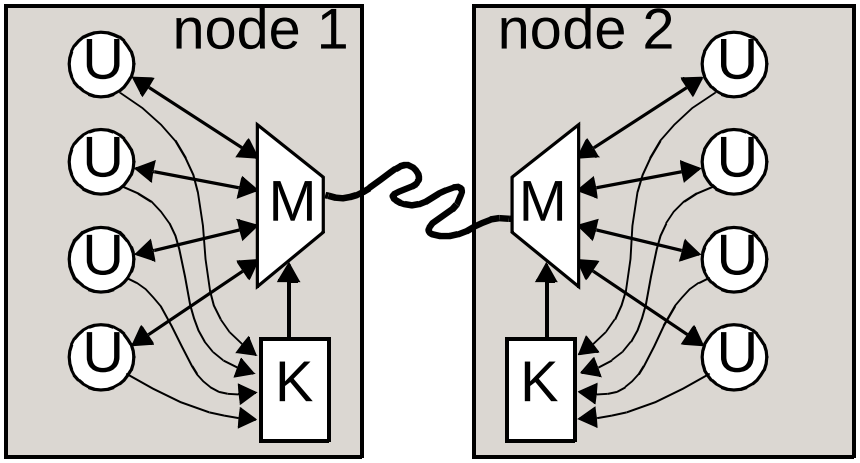
Traditional:

- kernel controls the network
- all communication goes via kernel



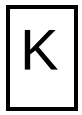
U-Net:

- applications send and receive directly via simple mux in NI
- kernel only involved in route set-up



Legend:

User application

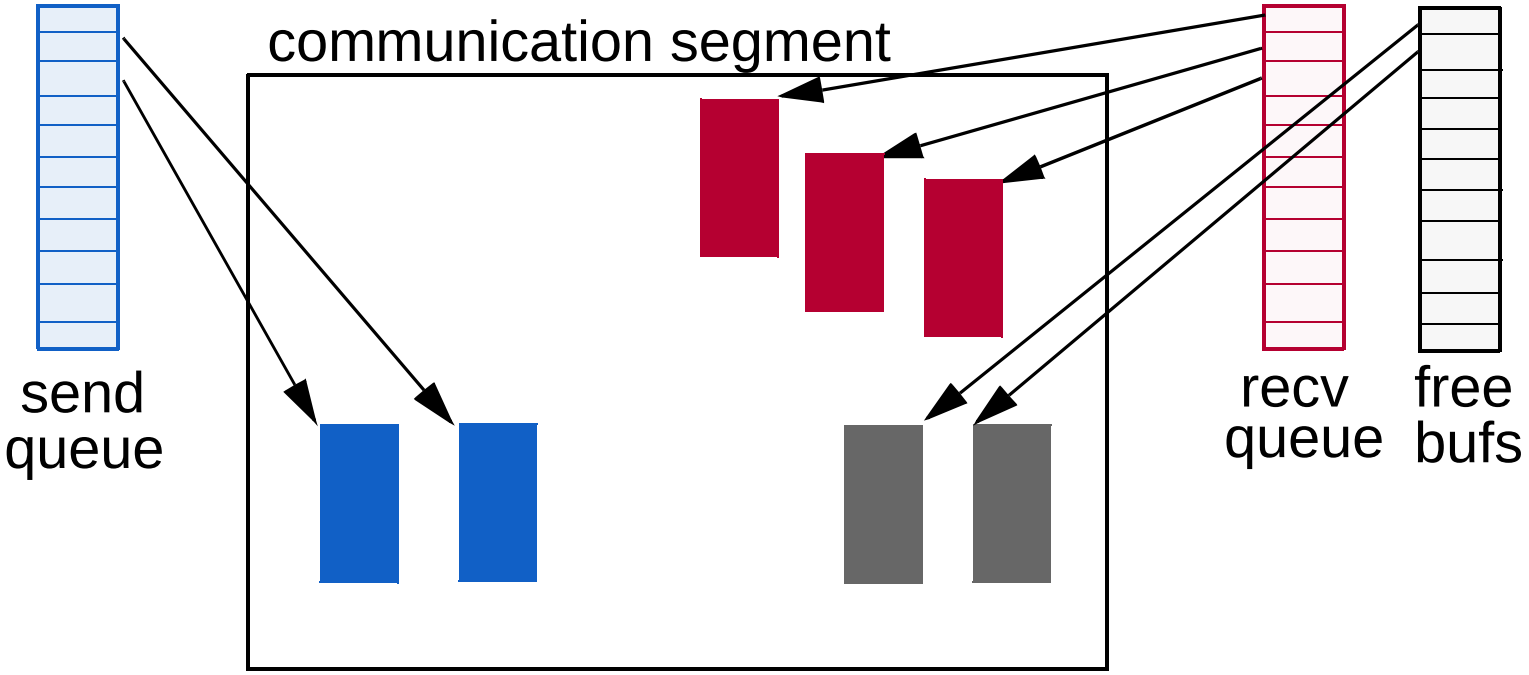


Operating system kernel

Message mux/demux

The U-Net Interface

- virtual device-like interface
  - buffers, queues, interrupts
- U-Net Endpoint: virtual device data structure



Sending & Receiving Messages

Sending a message

- allocate buffer in communication segment
- assemble message in buffer
- push message descriptor onto send queue

Waiting for a message to arrive

- a) poll receive queue
- b) block until message arrival — select()
- c) asynchronous notification — signal()

Receiving a message

- pop message descriptor from receive queue
- consume message
- push (free) buffer descriptors onto free queue

U-Net implementation

Invariant 1: off-the-shelf hardware/OS

- Sun SPARCstations 10 and 20, SunOS 4.1.3
- Fore Systems SBA-200 ATM network interface (140Mbit/s)

U-Net software

- SBA-200 firmware
  - *on-board i960 processor + 256Kb RAM + DMA*
  - implements U-Net message mux/demux
- SunOS device driver
  - manages communication segments and queues (currently pinned)
  - controls application access to routes (ATM -> VCIs)

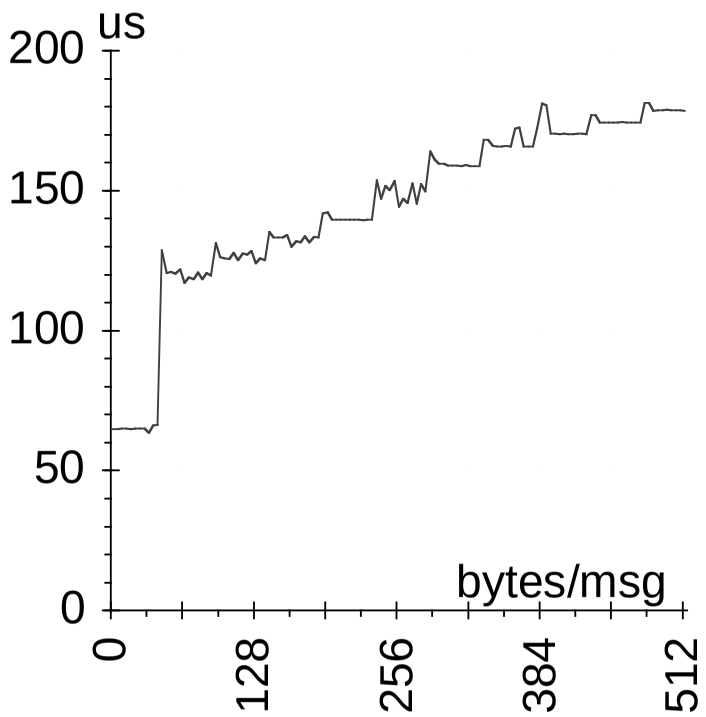
Invariant 2: protection

- VM system used to protect communication segments and queues
- table in NI maps between <endpt;channel> and VCIs

Raw U-Net Performance

Round-trip latency

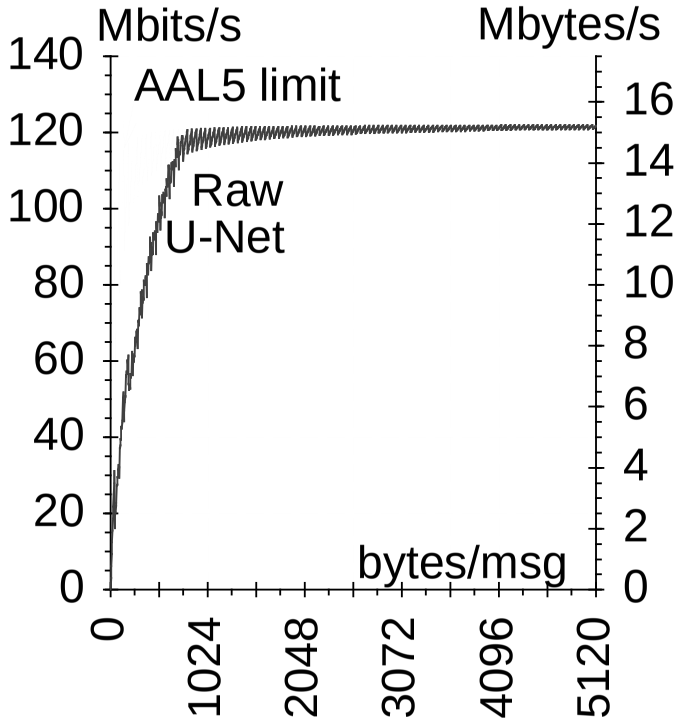
(application to application and back)



- Single-cell messages: 65µs round-trip
  - 20µs: ATM switch & fiber
  - 40µs: due to i960&DMA

Bandwidth

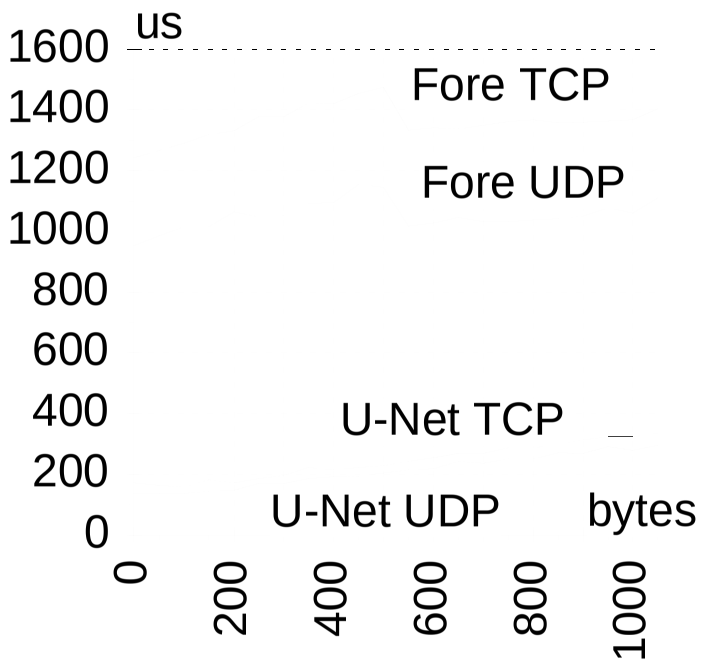
(comm segment to comm segment)



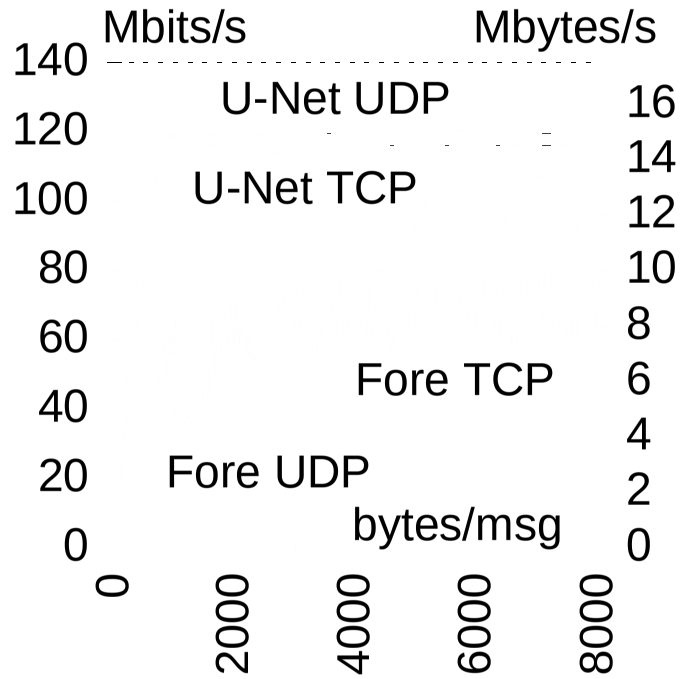
- Fiber saturated with <1Kbyte msgs

TCP and UDP Bandwidth

Round-trip latency



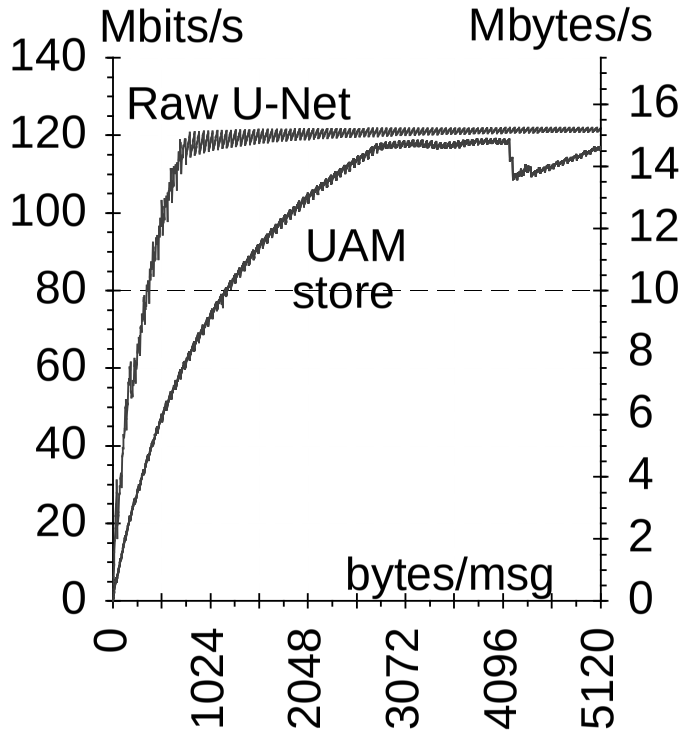
Bandwidth



- U-Net TCP
  - proof-of-concept user-level implem. (IP hdr, chksum, ~~ICMP~~, ~~IPoverATM~~)
  - 2Kbyte segments, 8Kbyte TCP window
- Kernel TCP
  - SunOS network stack, Fore ATM driver
  - 8Kbyte segments, 64Kbyte TCP window

U-Net Active Messages: Micro-benchmarks

- communication layer for parallel language implementations
- message = data + ptr to handler
- Active Message handler
  - small, custom code
  - moves data into data structures
    may send a reply back
- Small message latency
  - up to 32 bytes of data
  - 71µs round-trip
  - ~10µs CPU overhead
- Block transfer bandwidth
  - arbitrary source & dest virtual address
    invoke handler upon reception



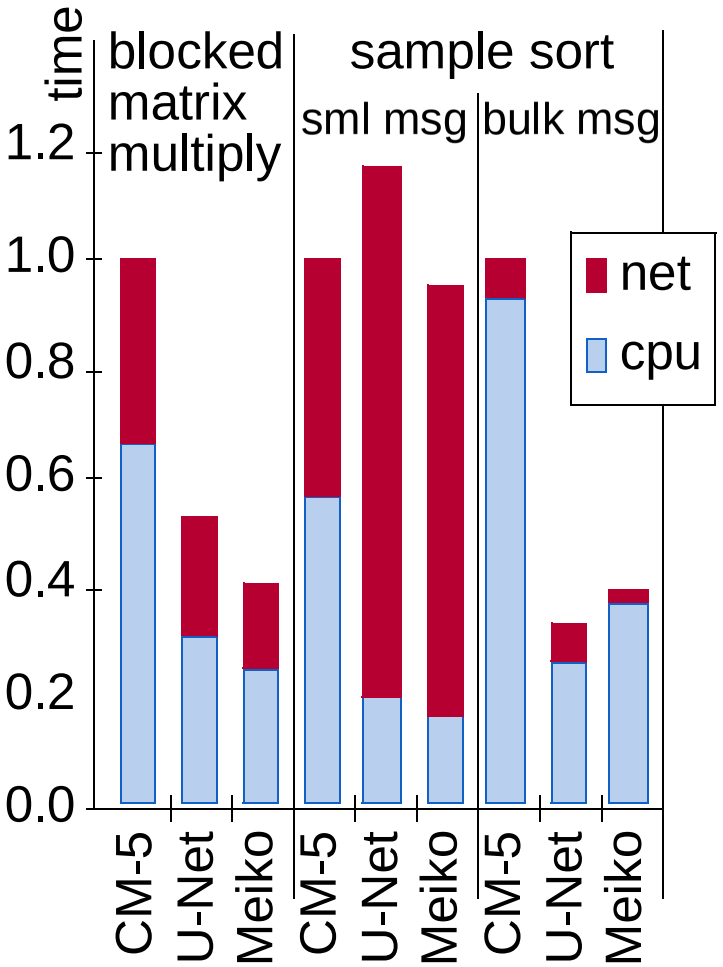
Split-C: Application benchmarks

Machines

Machine	CPU	Network	
		bandwidth	latency
CM-5	33Mhz sparc	80Mbits/s	12µs
CS-2	40Mhz supersparc	320Mbits/s	25µs
U-Net	50/60Mhz supersparc	120Mbits/s	70µs

Results

- on 8 processors
- normalized to the CM-5
- ATM cluster is comparable in performance to CM-5 and CS-2
- But: ATM cluster ≠ parallel machine



Work in progress

Complete U-Net implementation

- kernel endpoint, kernel networking stack over U-Net
- ATM signalling (connection set-up)

U-Net ports to new platforms

- 100MBit ethernet, x86/PCI, Linux
  - kernel traps/interrupts for message mux/demux
- ATM, SPARCstation, Solaris

Future plans

- couple message reception and process scheduling
- framework for developing user-level protocols
- parallel/distributed program manager

Conclusions

Target 1: performance

- 140Mbit/s fiber saturated using <1Kbyte messages
- 65µs round-trip latency for small messages
  - key to parallel computing
  - key to high bandwidth

Target 2: flexibility

- TCP: saturates fiber, offers low round-trip latency
- Active Messages & Split-C: comparable to parallel machines

Invariants:

- off-the-shelf components
  - U-Net firmware & driver are *simpler* than Fore's
- multi-user network access with protection

=> Proof that Network of Workstations can perform

U-Net TCP/IP modifications

- Simple connection mux/demux based on VCIs
- Custom buffering (not *mbufs* or *streams bufs*):
  - no buffer copy, no strange fragmentation, simple allocation, pre-aligned
- Straight-forward acks:
  - traditional TCP has “delayed ack” algorithm: delay every other ack by up to 200ms to try and piggy-back onto “reply” message
  - with U-Net/AAL5 an ack uses one cell — “no overhead, no bandwidth”
- Reasonable timers
  - kernel uses 200ms and 500ms timers (e.g. for retransmission)
- Small window and message sizes
  - large window = expensive retransmission
  - large messages = high probability of loss and of slow-start
  - TCP/IP over U-Net buffers: 8Kb window & 2Kb segments