Xen Network I/O

Performance Analysis and Opportunities for Improvement

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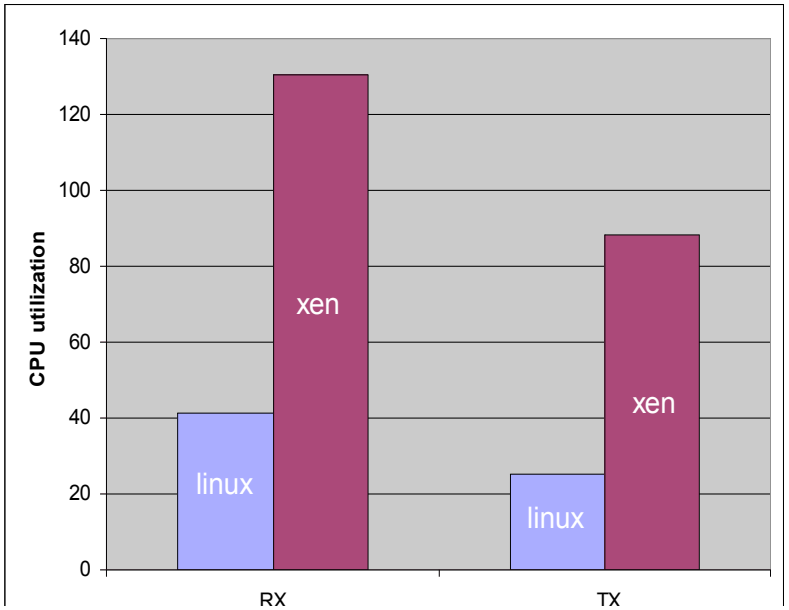
Motivation

CPU cost for TCP connection at 1 Gbps

(xen-unstable (03/16/2007) ; PV Linux guest; X86 - 32bit)



- Network I/O has high CPU cost
  - TX: **350%** cost of linux
  - RX: **310%** cost of linux

Outline

- Performance Analysis for network I/O RX path (netfront/netback)
- Network I/O RX optimizations
- Network I/O TX optimization

Performance Analysis

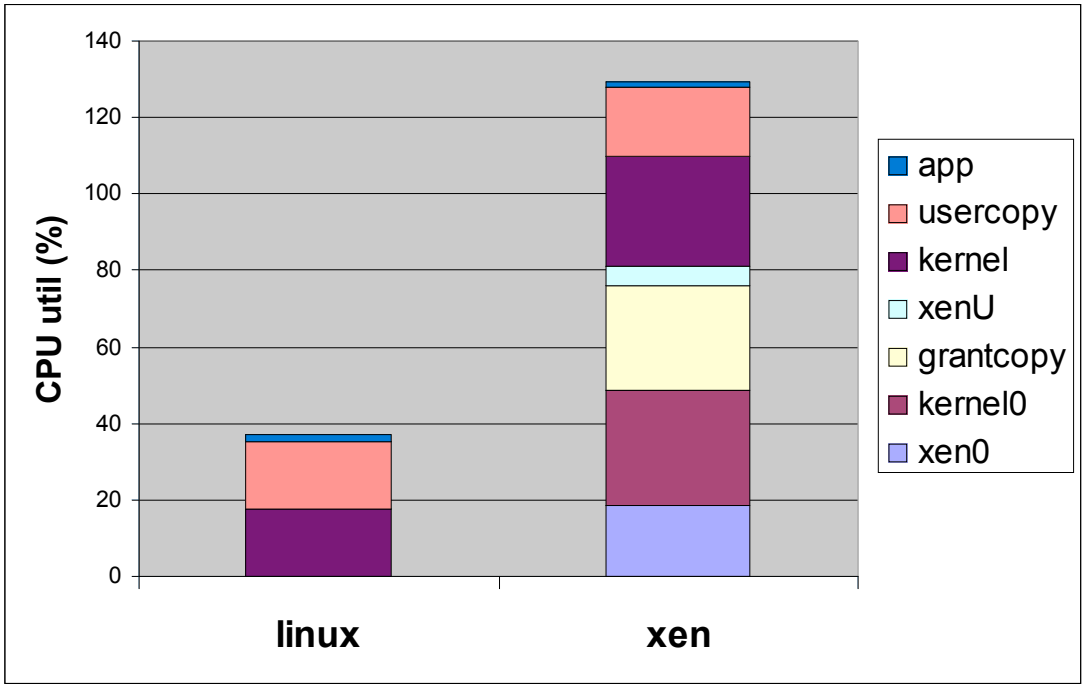
For Network I/O

RX Path

Experimental Setup

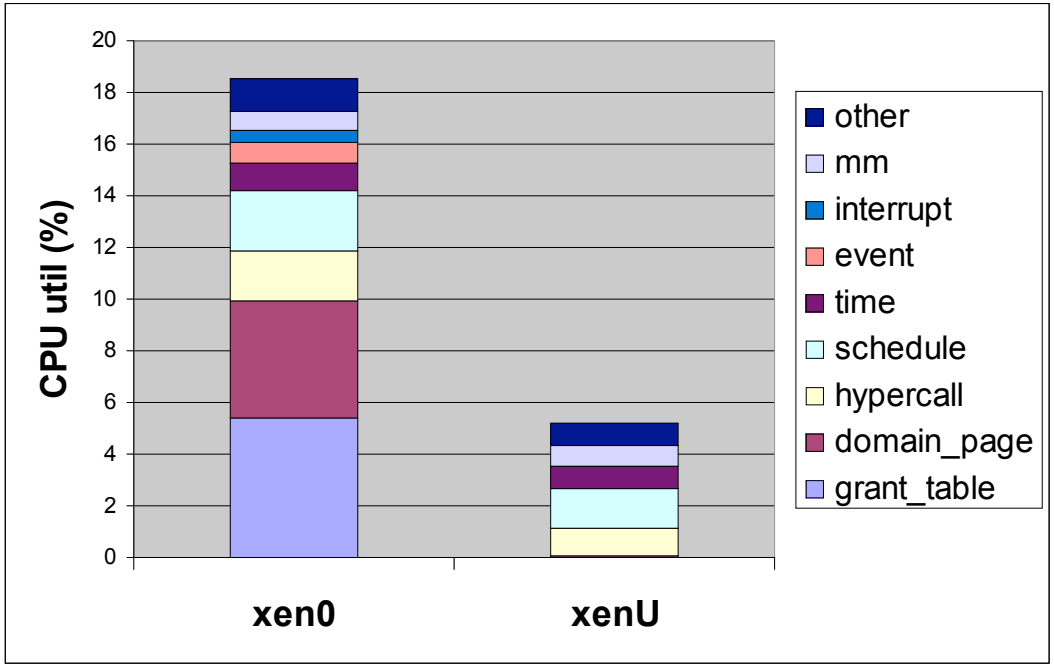
- Machines: HP Proliant DL580 (client and server)
  - P4 Xeon 2.8 Ghz, 4 CPU (MT disabled), 64 GB, 512 KB L2, 2MB L3
  - NIC: Intel E1000 (1 Gbps)
- Network configuration
  - Single switch connecting client and server
- Server configuration
  - Xen unstable (c.s.14415 – March 16, 2007) (default xen0/xenU configs)
  - Single guest (512MB), dom0 also with 512MB
- Benchmark
  - Simple UDP micro benchmark (1gbps, 1500 bytes packets)

CPU Profile for network RX path



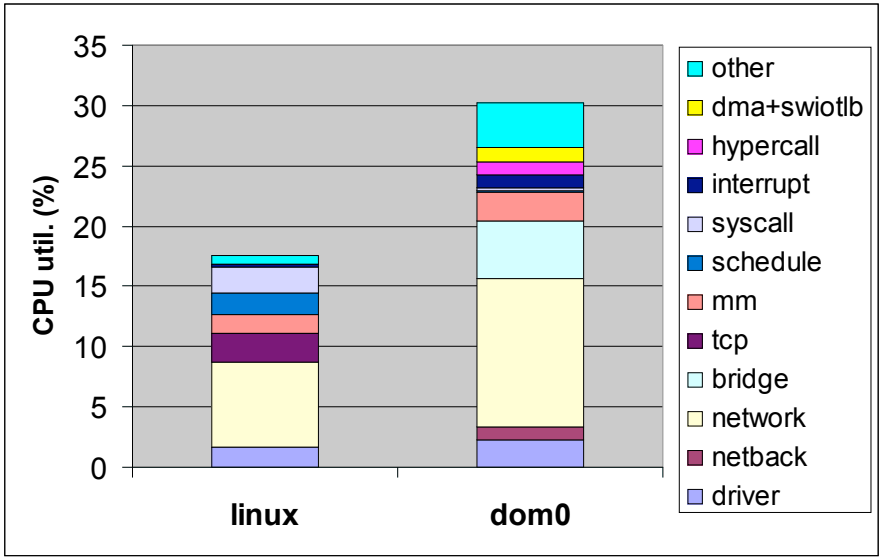
- Cost of data copy is significant both in Linux and Xen
  - Xen has the cost of an additional data copy
- Xen guest kernel alone uses more CPU than linux
- Most cost for Xen code is in dom0

Xen Code Cost



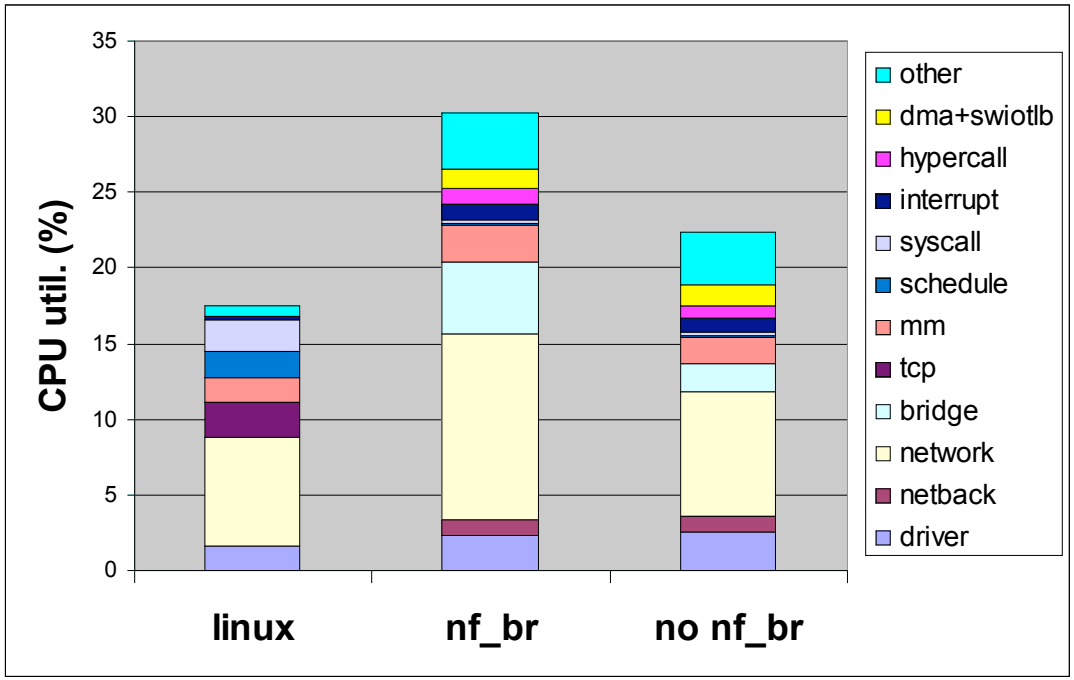
- Major Xen overhead is: grant table & dom page map/unmap
- Copy grant: several expensive atomic operations (lock instr.prefix):
  - Atomic cmpxchg operation for updating status field (grant in use)
  - Increment/decrement grant usage counters (multiple spinlock op)

Dom0 Kernel Cost



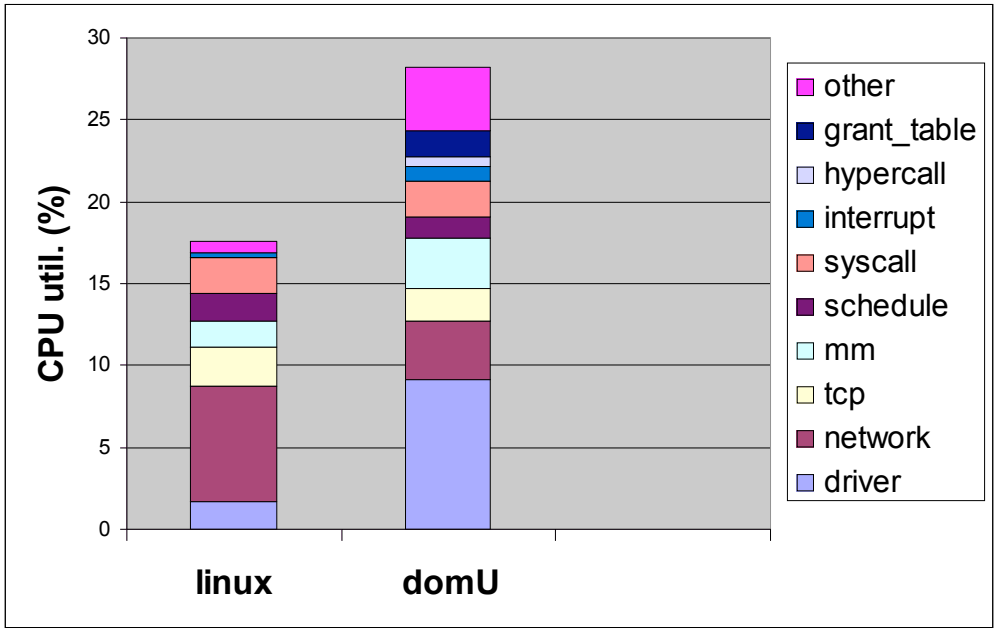
- Bridge/network is large component in dom0 cost (Xen summit 2006)
  - Can be reduced if netfilter bridge config option is disabled
- Xen new code: Netback, hypercall, swiotlb
- Higher interrupt overhead in Xen: extra code in evtchn.c
- Additional high cost functions in Xen (accounted in “other”)
  - spin_unlock_irqrestore(), spin_trylock()

Bridge netfilter cost



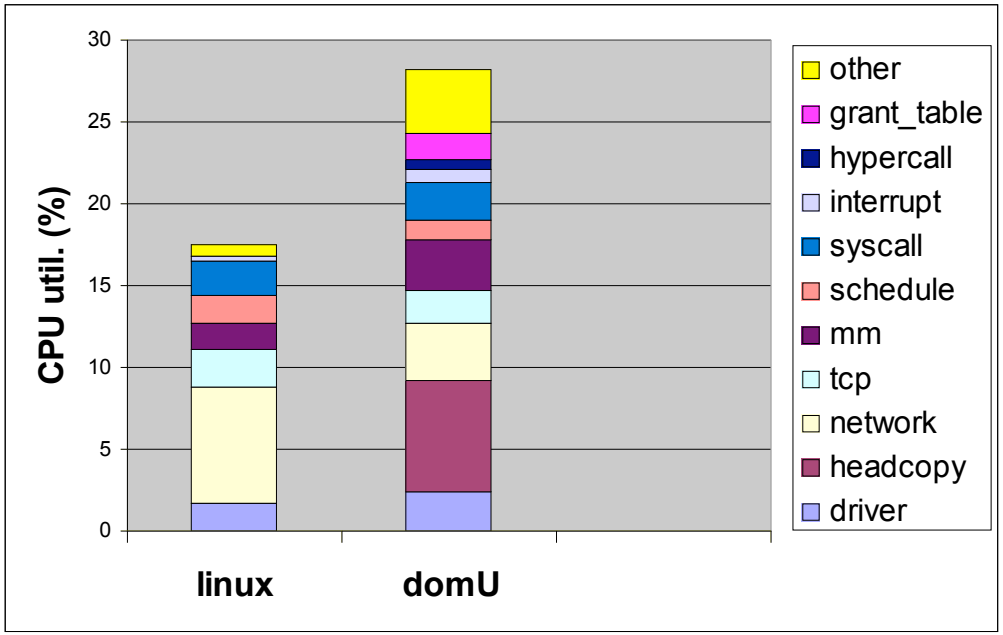
- What do we need to do to disable bridge netfilter by default?
  - Should we add a netfilter hook in netback?

Overhead in guest



- Netfront: 5 times more expensive than e1000 driver in Linux
- Memory op (mm): 2 times more expensive in Xen (?)
- grant table:
  - high cost of atomic cmpxchg operation to revoke grant access
- “Other”: spin_unlock_irqrestore(), spin_trylock() (same as dom0)

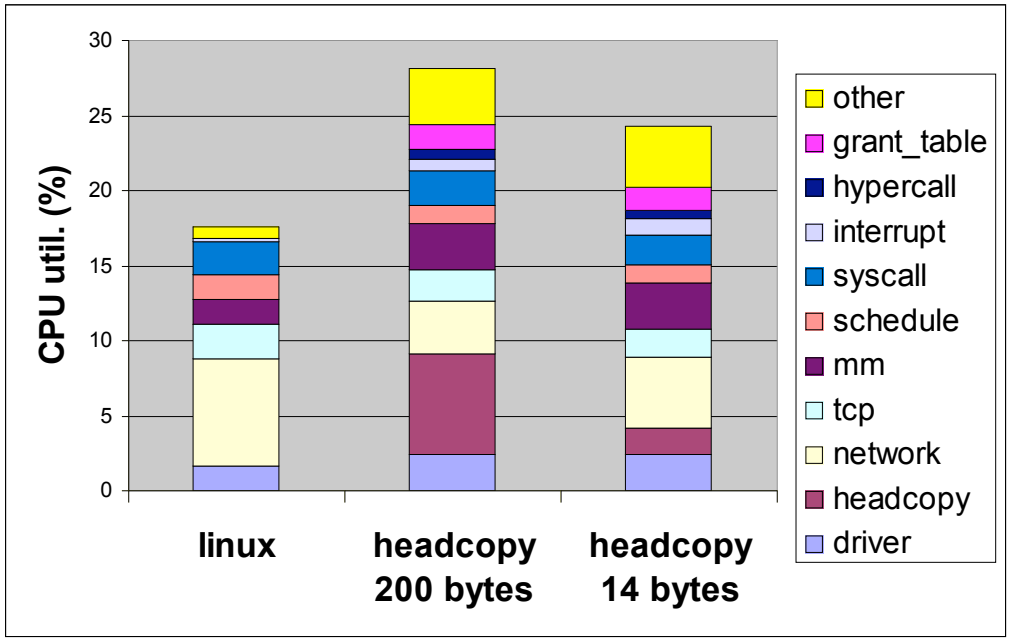
Source of Netfront Cost



- Netback copy packet data into netfront page fragments
- Netfront copies first 200 bytes of packet from fragment into main socket buffer data area
- Large netfront cost is due to this extra data copy

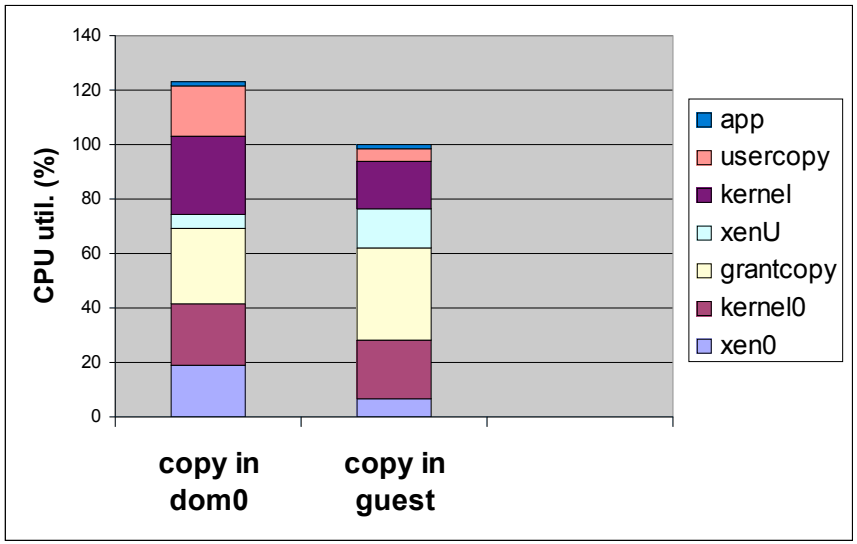
Opportunities for Improvement on RX path

Reduce RX head copy size



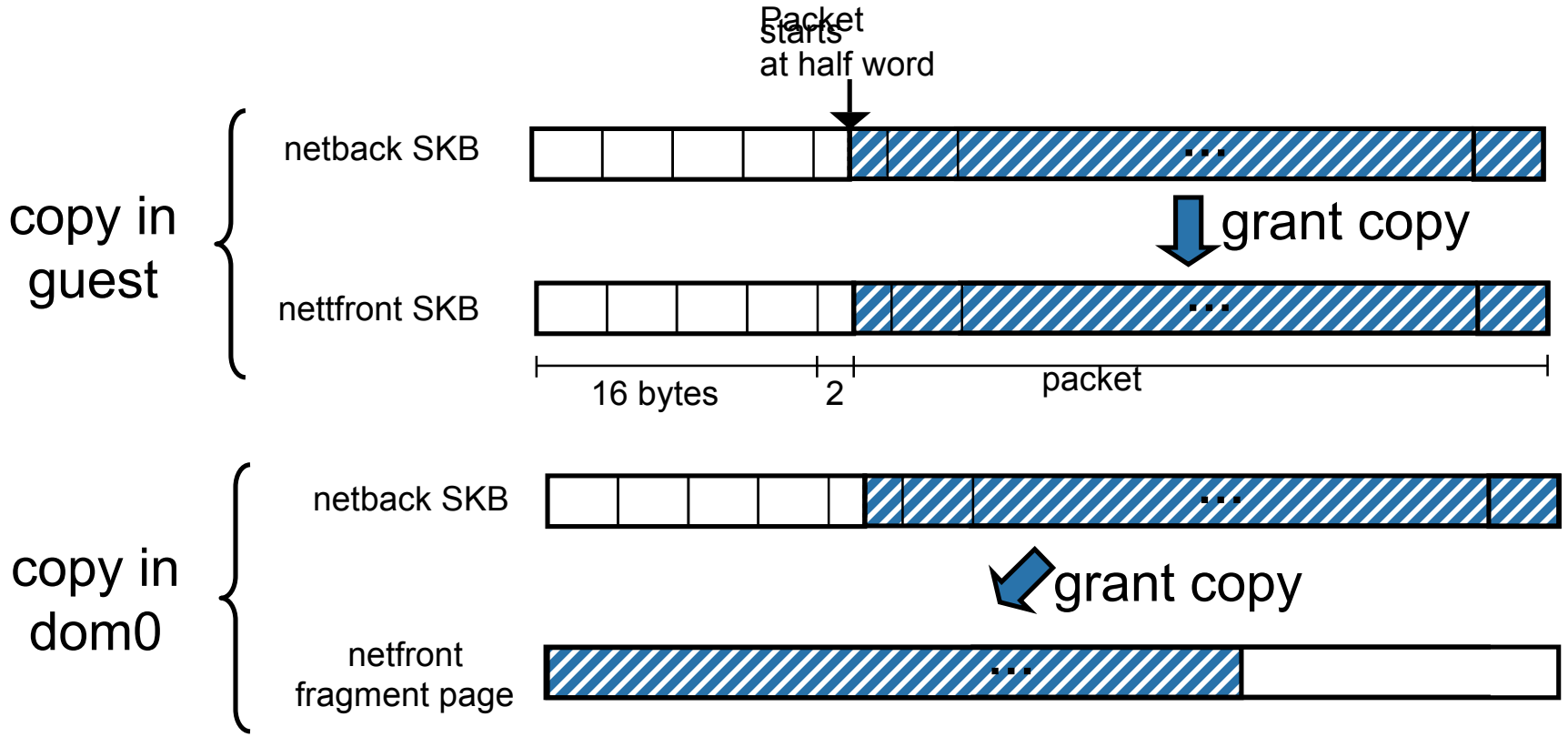
- No need to have all headers in main SKB data area
- Copy only Ethernet header (14 bytes)
- Network stack copies more data as needed

Move grant data copy into guest CPU



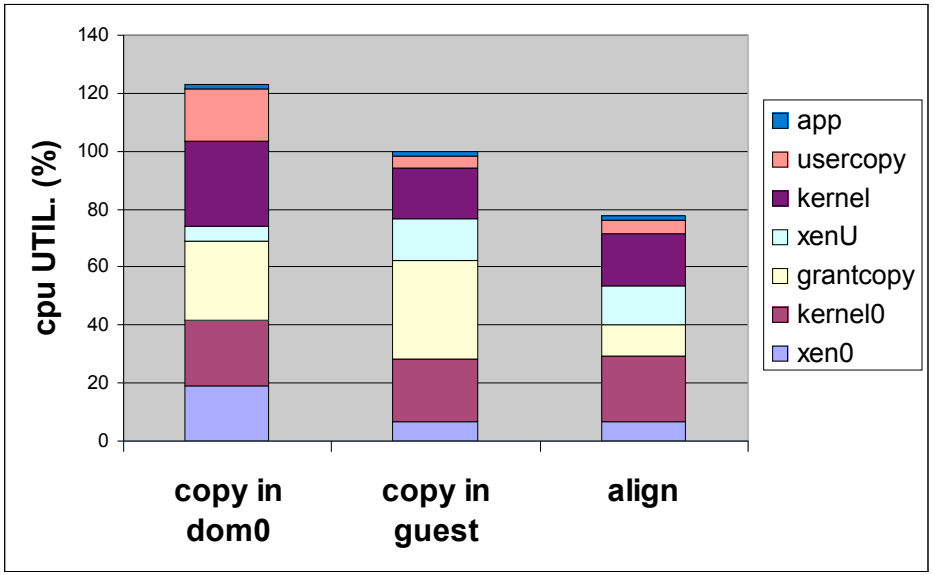
- Dom0 grant access to data and guest copy it using copy grant
- Cost of 2nd copy to user buffer is reduced as data is already in the guest CPU cache
  (assumes cache is not evicted due to user process delaying read)
- Additional benefit: Improves dom0 (driver domain) scalability as more work is done at the guest side
- Data copy is more expensive in guest (alignment problem)

Grant copy align problem



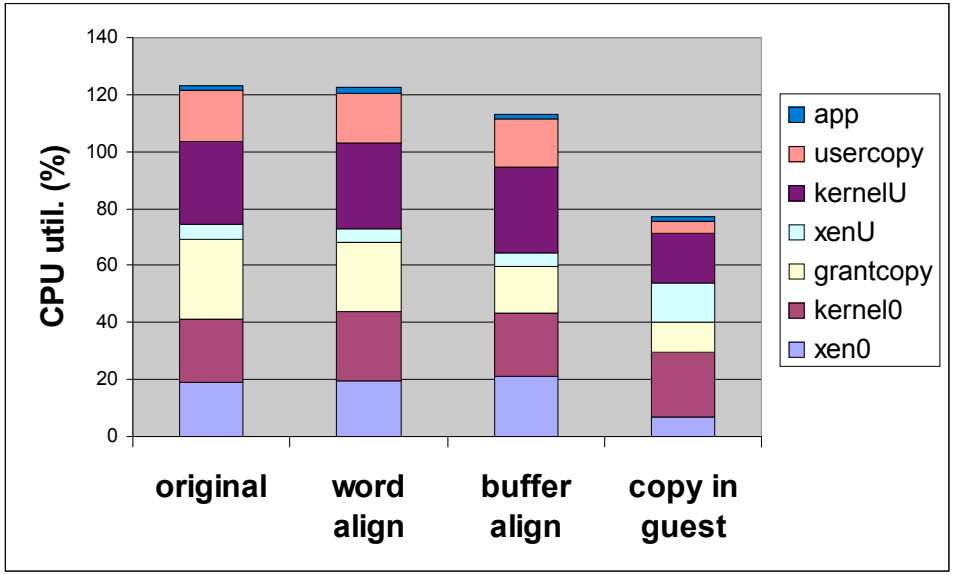
- copy is expensive when destination start is not at word boundary
- Fix: Copy also 2 prefix bytes → source and destination now aligned

Fixing grant copy alignment



- Grant copy in guest becomes more efficient than in current Xen
- Grant copy in dom0: destination is word aligned but
  - Source is not word aligned
  - Can also be improved by copying additional prefix data
    - Either 2 or (2+16) bytes

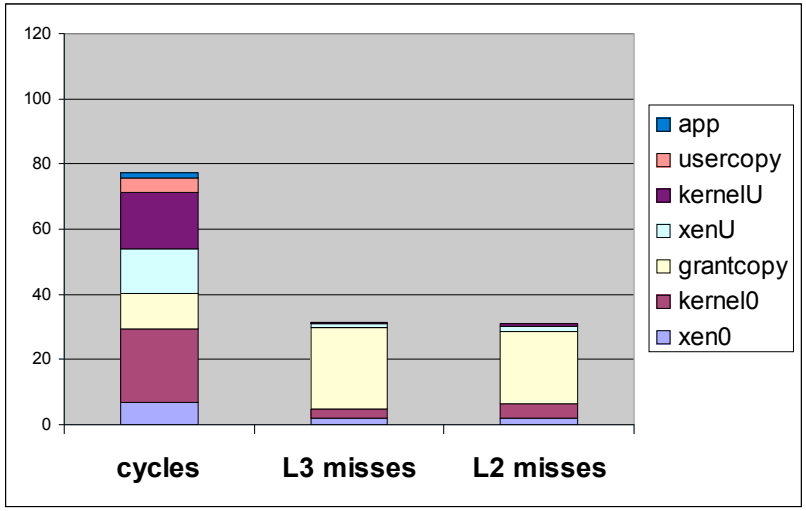
Fixing alignment in current Xen



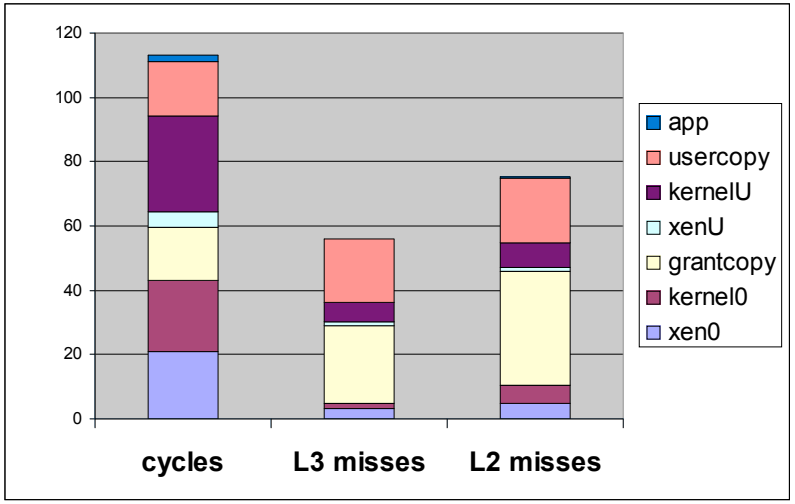
- Source alignment reduces copy cost
- Source and dest. at same buffer offset has better performance
  - Reason (?): maybe because same offset in cache?
- Copy cost in dom0 is still more expensive than copy in guest.
  - Different cache behavior

Copy in guest has better cache locality

grant copy in guest



grant copy in dom0

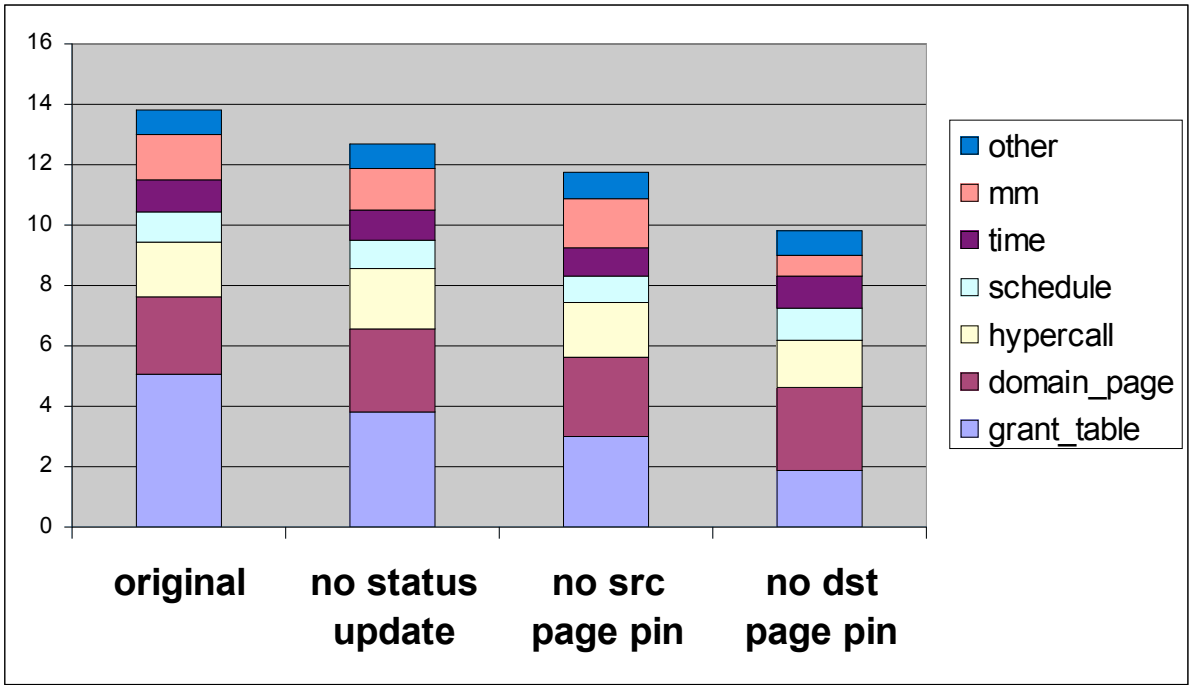


- Dom0 copy has more L2 cache misses than guest copy
  - Dom0 copy has lower cache locality
  - Guest post multiple pages on IO ring.
    - All pages in ring must be used before the same page can be reused
- For guest copy, pages are allocated on demand and reused more often improving cache locality

Possible grant optimizations

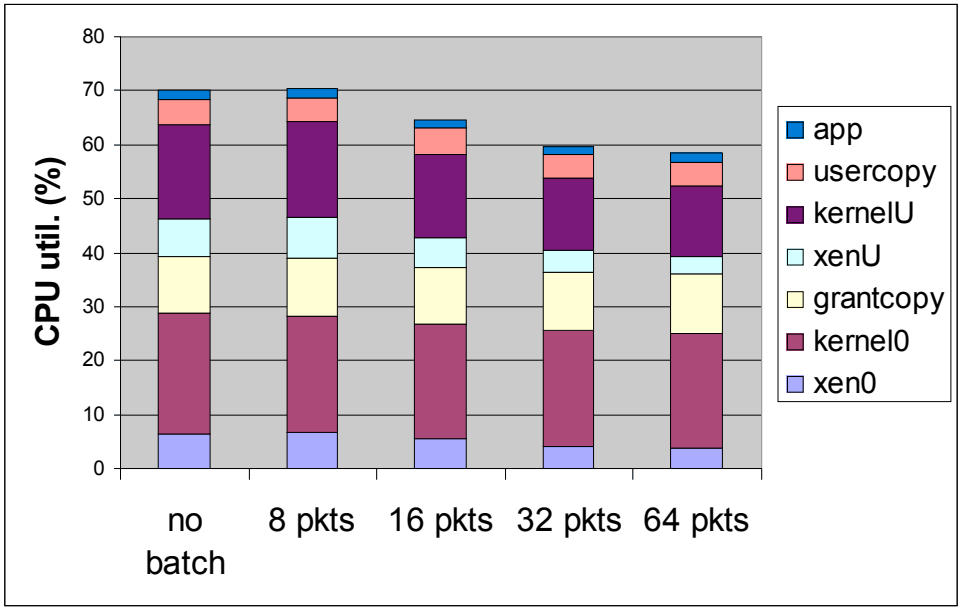
- Define new simple copy grant:
  - Allow only one copy operation at a time
  - No need to keep grant usage counters (remove lock)
- avoid cost of atomic cmpxchg operations
  - Separate fields used for enabling grant and usage status
- Avoid incrementing/decrementing page ref counters
  - Use an RCU scheme for page deallocation (lazy deallocation)

Potential savings in grant modifications



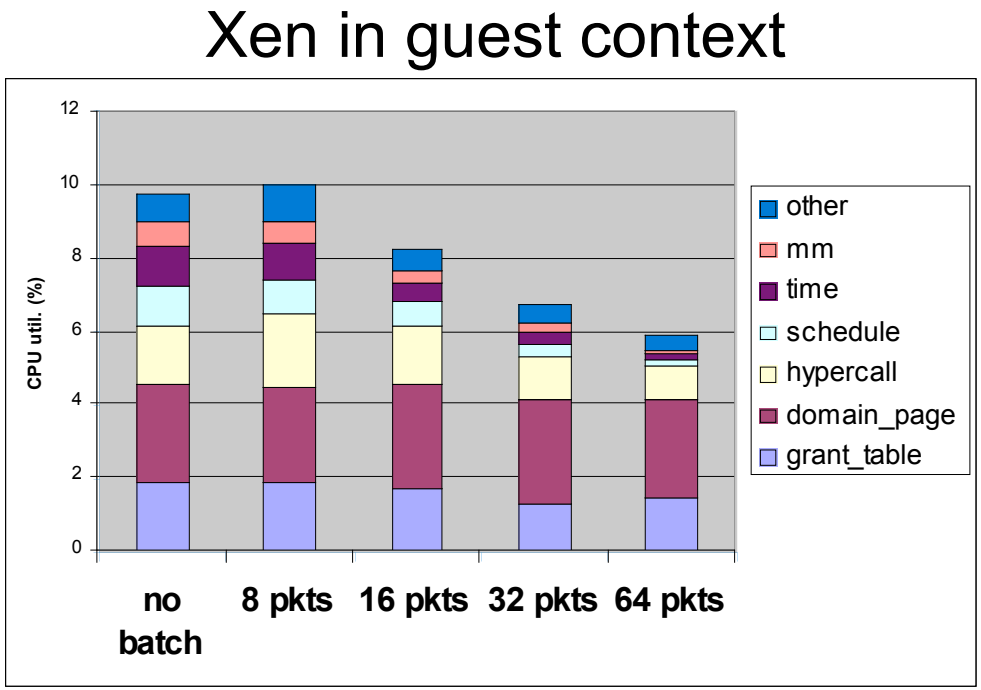
- Results are optimistic
  - Still need to implement grant modifications
  - Results are based on eliminating current operations

Coalescing netfront RX interrupts



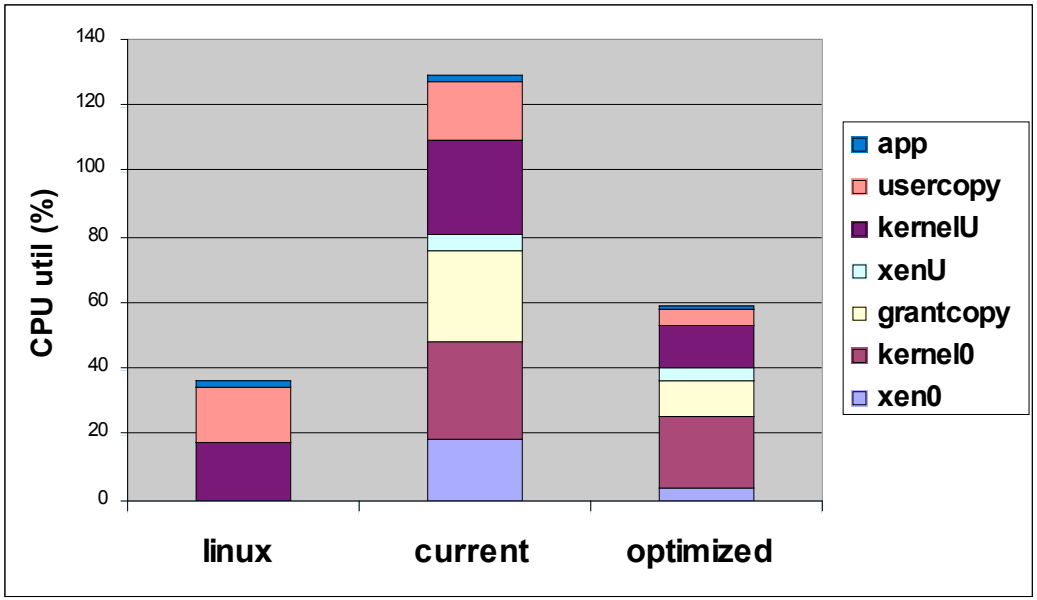
- NIC (e1000) already coalescing HW interrupts (~10 packets/int)
- Batching packets can provide additional benefit
  - 10% for 32 packets
  - But adds extra latency
  - Dynamic coalescing scheme should be beneficial

Coalescing effect on Xen cost



- Except grant and domain page map/unmap, all other Xen costs are amortized by larger batches
  - An additional reason for optimizing grant

Combining all RX optimizations



- Cost of network I/O for RX can be significantly reduced
  - From **~250%** to **~70%** ovehead (compared to linux)
- Largest improvement comes for moving grant copy to guest CPU

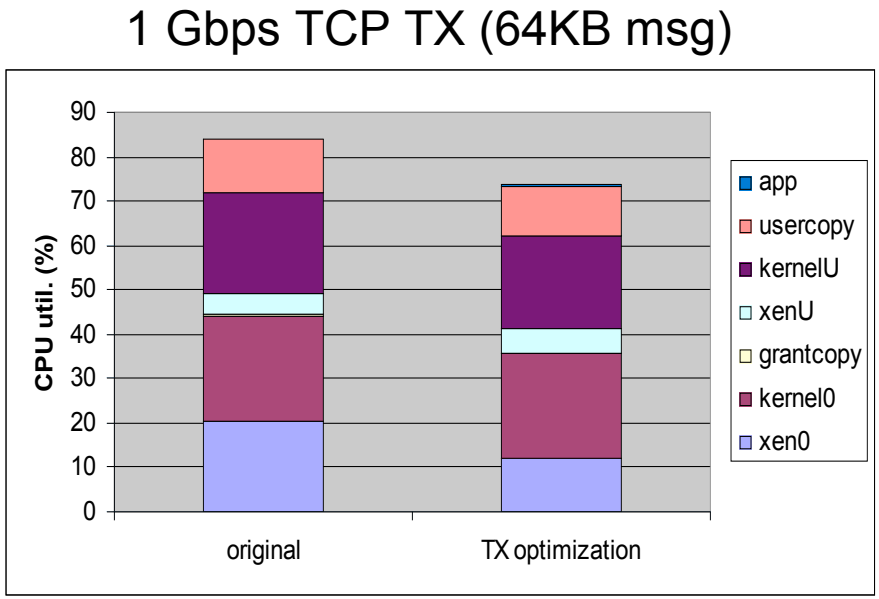
Optimization

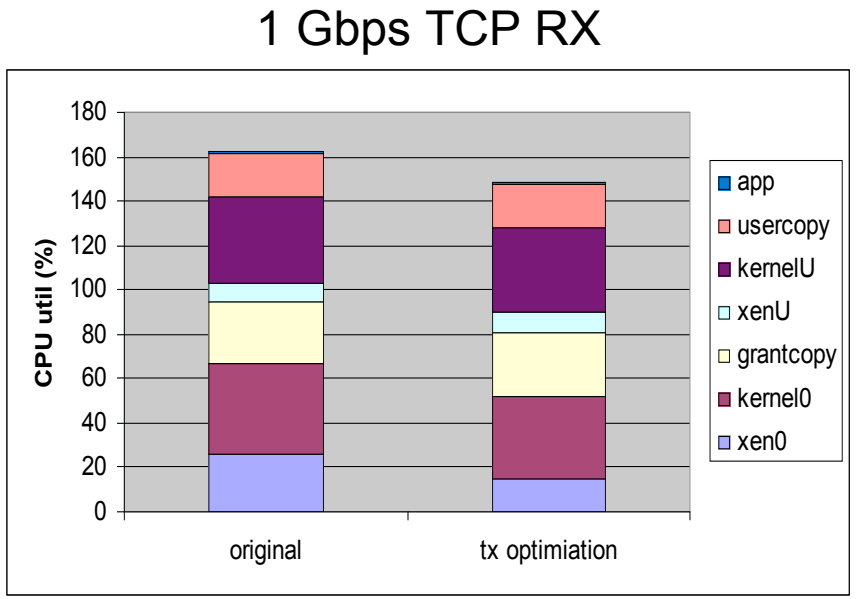
for TX path

Lazy page mapping on TX

- Dom0 only needs to access packet headers
- No need to map guest pages with packet payload
  - NIC device access memory directly through DMA
- Avoid mapping guest page on packet TX
  - Copy packet headers using I/O ring
  - Modified grant operation returns machine address (for DMA) but does not map page in dom0.
- Provide page fault handler to deal with cases in which dom0 needs to access payload
  - Packet to dom0/domU; netfilter rules

Benefit of lazy TX page mapping





- Performance improvement for TX optimization
  - ~10% for large TX
  - ~8% for TCP RX due to ACKs
- Some additional improvement may be possible with grant optimizations

Questions ?