Pushing the Limits of Kernel Networking

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Agenda

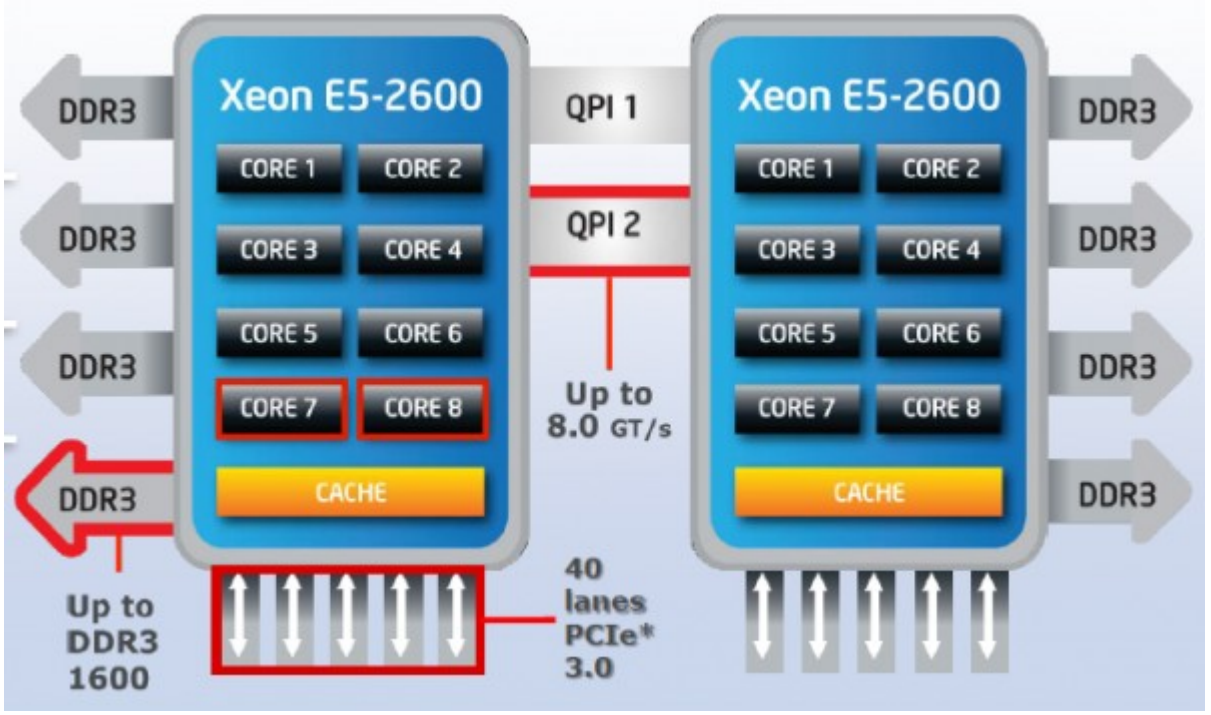
- Identifying the Limits
  - Memory Locality Effect
  - Death by Interrupts
  - Flow Control and Buffer Bloat
  - DMA Delay
- Performance
  - Synchornization Slow Down
  - The Cost of MMIO
  - Memory Alignment, Memcpy, and Memset
  - How the FIB Can Hurt Performance
- What more can be done?

Identifying the Limits

- With 60B frames achieving line rate is difficult
  - Only 24B of additional overhead per frame
  - 10Gb/s / 125MB/Gb / 84Bpp = 14.88Mpps, 67.2nspp
- L3 cache latency on Ivy Bridge is about 30 cycles
  - Each nanosecond an E5-2690 will process 2.6 cycles
  - 30 cycles / 2.6 cycles/ns = 12ns
- To achieve line rate at 10G we need to do two things
  - Lower processing time
  - Improve scalability

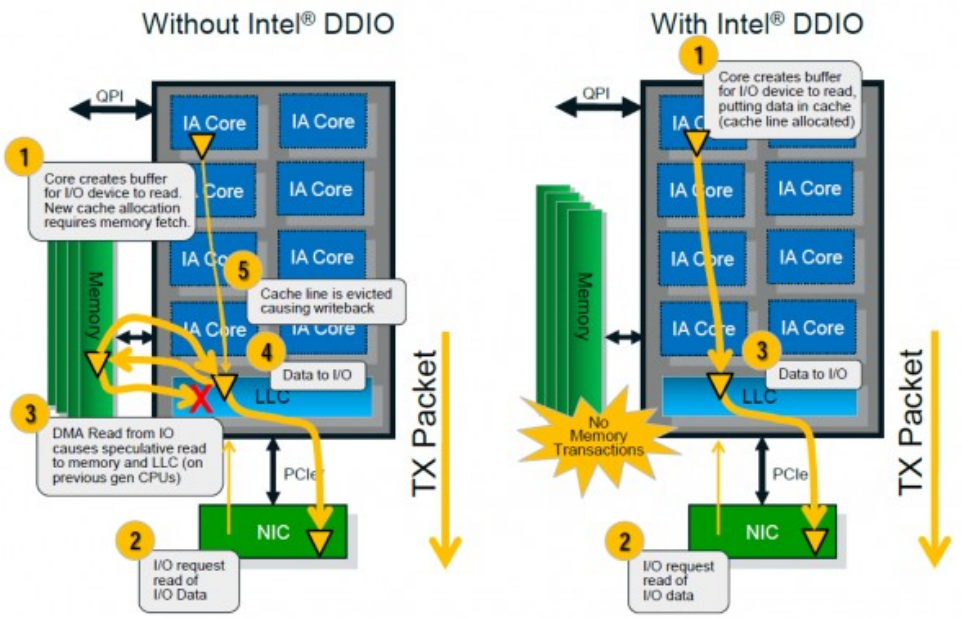
Memory Locality Effect

- NUMA – Non-uniform memory access



Memory Locality Effect

- DDIO - Data Direct I/O
  - Xeon E5 26XX Feature
  - Local socket only
  - No need for memory access



- XPS – Transmit Packet Steering
  - Transmit packets on local CPU

```
echo 01 > /sys/class/net/enp5s0f0/queues/tx-0/xps_cpus
echo 02 > /sys/class/net/enp5s0f0/queues/tx-1/xps_cpus
echo 04 > /sys/class/net/enp5s0f0/queues/tx-2/xps_cpus
echo 08 > /sys/class/net/enp5s0f0/queues/tx-3/xps_cpus
```


Death by Interrupts

- Interrupts can change location based on irqbalance
- Too low of an interrupt rate
  - Overrun ring buffers on device
  - Add unnecessary latency
  - Overrun socket memory if NAPI shares CPU
- Too high of an interrupt rate
  - Frequent context switches
  - Frequent wake-ups
- Interrupt moderation schemes often tuned for benchmarks instead of real workloads

Flow Control and Buffer Bloat

- Flow control can siginficantly harm performance
  - Adds additional buffering, adding extra latency
  - Creates head-of-line blocking which limits throughput
    - Faster queues drop packets waiting on slowest CPU
- Some NICs implement per-queue drop when disabled
- Disabling it requires just one line in ethtool

```
ethtool -A enp5s0f0 tx off rx off autoneg off
```


DMA Delay

- IOMMU can add security but at significant overhead
  - Resource allocation/free requires lock
  - Hardware access required to add/remove resources
- If you don't need it you can turn it off

  ```
  intel_iommu=off
  ```

- If you need it for virualization (KVM/XEN)

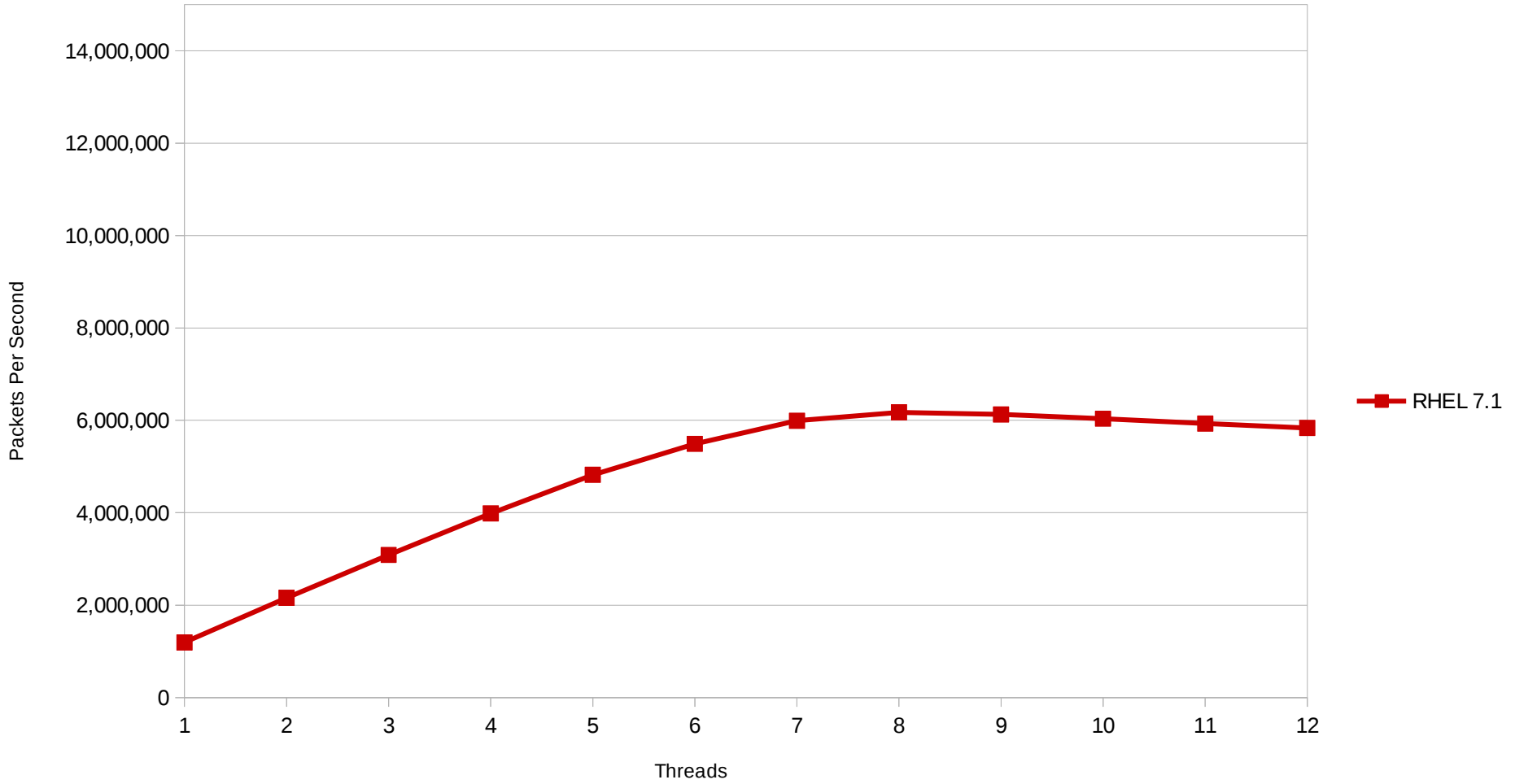
  ```
  iommu=pt
  ```

- Some drivers include mitigation strategies
  - Page reuse

Performance Data Ahead!!!

- Single socket Xeon E5-2690v3
- Dual port 82599ES
  - Assigned addresses 192.168.100.64 & 192.168.101.64
  - Disabled flow control
  - Pinned IRQs 1:1
  - Used ntuple filter to force flows to specific queues
- CPU C states disabled via cpu /dev/cpu_dma_latency
- Traffic generator sent IP data w/ RR source address
  - Each frame sent 4 times before moving to next address
- Your Experience May Vary

Routing Performance



Synchronization Slow Down

- Synchronization primitives come at a heavy cost
  - local_irq_save/resore costs 10s of ns
    - Not needed when all requests are in same context
  - rmb/wmb flush pipelines which adds delay
    - Needed for some architectures but not others
- Updated kernel to remove unecessary bits in 3.19
  - NAPI allocator for page fragments and skb
  - dma_rmb/wmb for DMA memory ordering

The Cost of MMIO

- MMIO write to notify device can cost hundreds of ns
- Latency shows up as either Qdisc lock, or Tx queue unlock overhead
- xmit_more was added to 3.18 kernel to address this
  - Reduces MMIO writes to device
  - Reduces locking overhead per packet
  - Reduces interrupt rates as packets are coalesced
  - Allows for 10Gbps line rate 60B packets w/ pktgen

Memory Alignment, Memcpy, and Memset

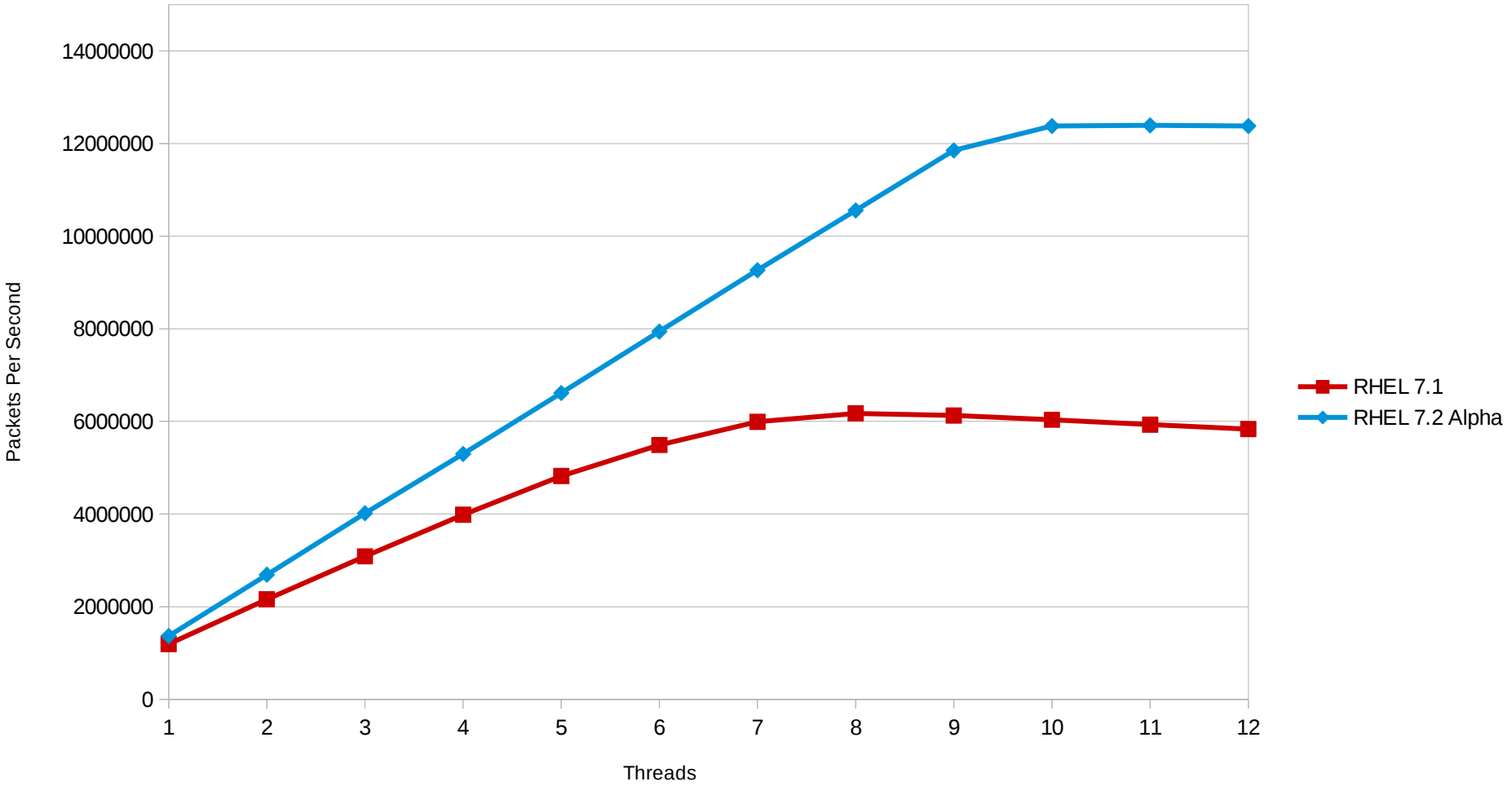
- Partial cache-line writes come at a cost
  - Most architectures now start with NET_IP_ALIGN = 0
  - On x86 partial writes trigger a read, modify, write cycle
- String ops change implementation based on CPU flags
  - erms and rep_good can have impact on performance
  - KVM doesn't copy CPU flags by default
- tx-nocache-copy
  - Enabled use of movntq for user to kernel space copy
  - Enabled by default for kernels 3.0 – 3.13
  - Prevents use of features such as DDIO

```
ethtool -K enp5s0f0 tx-nocache-copy off
```


How the FIB Can Hurt Performance

- Starting w/ version 4.0 of kernel fib_trie was rewritten
  - FIB statistics were made per CPU and not global
  - Penalty for trie depth significantly reduced
  - Kernel 4.1 merged local and main trie for further gains
- Recommendations for kernels prior to 4.0
  - Disable CONFIG_IP_FIB_TRIE_STATS in kernel config
  - Avoid assigning addresses such as 192.168.122.1
    - IPs in the range 192.168.122.64 – 191 can reduce depth by 1
  - Use class A reserved addresses to reduce trie walk
    - 10.x.x.x likely will contain fewer bits than 192.168.x.x

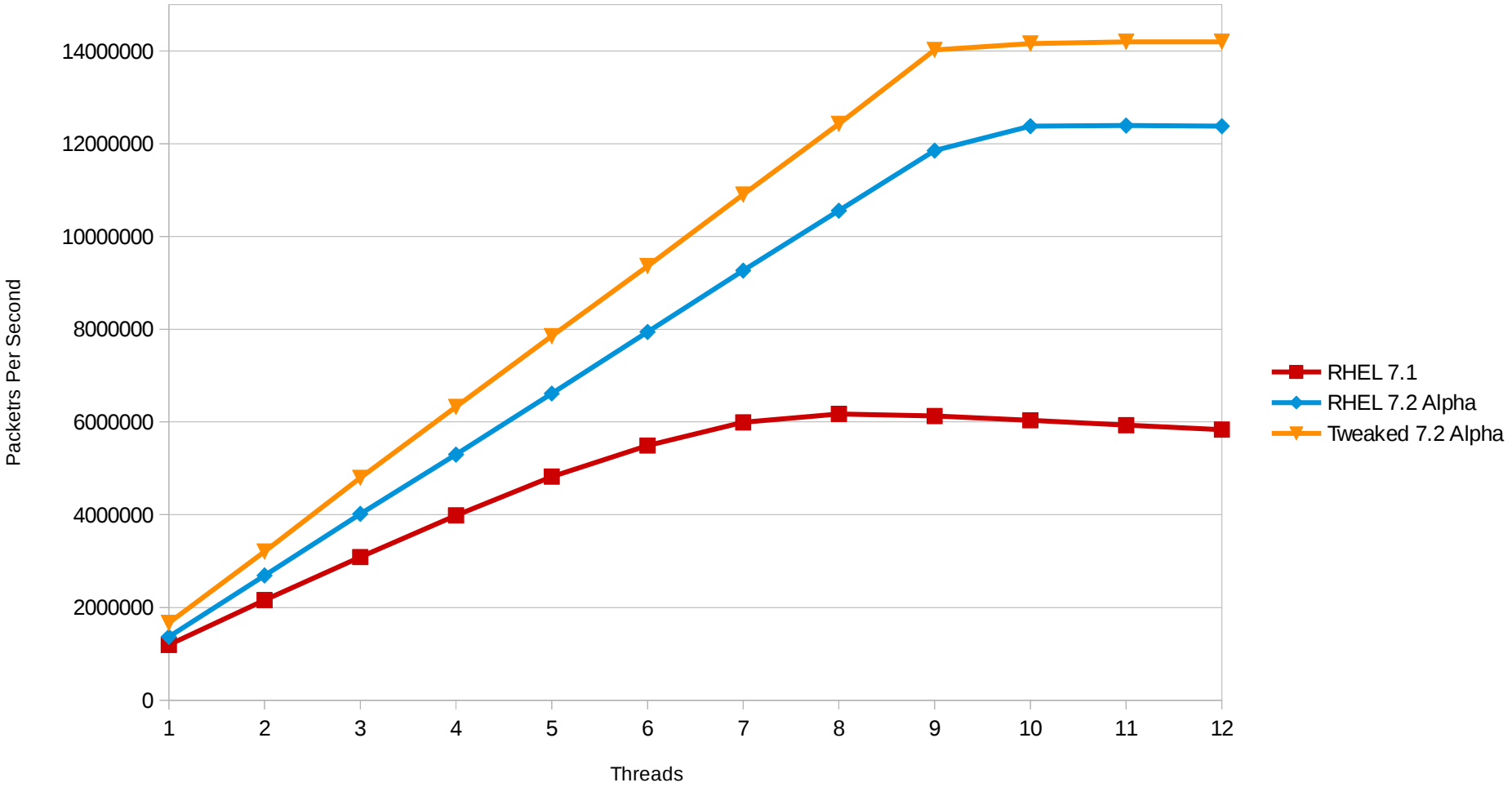
Routing Performance



What More Can be Done?

- SLAB/SLUB bulk allocation
  - https://lwn.net/Articles/648211/
- Tuning interrupt moderation to work in more cases
  - Pktgen with 60B packets
- Explore optimizing users for memset/memcpy()
  - build_skb()
- Find a way to better use xmit_more on small packets
- Explore shortening Tx/Rx queue lengths

Routing Performance



Questions?

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