10Gbit/s Bi-Directional Routing on standard hardware running Linux

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by
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ComX Networks A/S

Who am I

- Name: Jesper Dangaard Brouer
  - Edu: Computer Science for Uni. Copenhagen
    - Focus on Network, Dist. sys and OS
  - Linux user since 1996, professional since 1998
    - Sysadm, Developer, Embedded
  - OpenSource projects
    - Author of
      - ADSL-optimizer
      - CPAN IPTables::libiptc
    - Patches accepted into
      - Kernel, iproute2, iptables and wireshark

Presentation overview

- When you leave this presentation, you will know:
  - The Linux Network stack scales with the number of CPUs
  - About PCI-express overhead and bandwidth
  - Know what hardware to choose
  - If its possible to do 10Gbit/s bidirectional routing on Linux?

How many think is possible to do:
10Gbit/s bidirectional routing on Linux?

ComX Networks A/S

- I work for ComX Networks A/S
  - Danish Fiber Broadband Provider (TV, IPTV, VoIP, Internet)
- This talk is about
  - our experiments with 10GbE routing on Linux.
- Our **motivation**:
  - Primary budget/money (in these finance crisis times)
    - **Linux solution: factor 10 cheaper**!
      - (60K USD -> 6K USD)
  - Need to upgrade capacity in backbone edges
  - Personal: Annoyed with bug on Foundry and tech support

Performance Target

- Usage "normal" Internet router
  - 2 port 10 Gbit/s router
    - Bidirectional traffic
    - Implying:
      - 40Gbit/s through the interfaces (5000 MB/s)
  - Internet packet size distribution
    - No jumbo frame "cheats"
    - Not only max MTU (1500 bytes)
  - Stability and robustness
    - Must survive DoS attack with small packet

Compete: 10Gbit/s routing level

- Enabling hardware factors
  - PCI-express: Is a key enabling factor!
    - Giving us enormous “backplane” capacity
    - PCIe x16 gen.2 marketing numbers 160 Gbit/s
      - one-way 80Gbit/s → encoding 64Gbit/s → overhead ~54 Gbit/s
  - Scaling: NICs with multiple RX/TX queues in hardware
    - Makes us scale beyond one CPU
    - Large effort in software network stack (thanks DaveM!)
  - Memory bandwidth
    - Target 40Gbit/s → 5000 MBytes/s

PCI-express: Overhead

- Encoding overhead: 20% (8b/10b encoding)
  - PCIe gen 1. 2.5Gbit/s per lane → 2 Gbit/s
- Generation 1 vs. gen.2:
  - Double bandwidth, 2 Gbit/s → 4 Gbit/s
- Protocol overhead: Packet based
  - Overhead per packet: 20 Bytes (32-bit), 24 bytes (64-bit)
  - MaxPayload 128 bytes => 16 % additional overhead
    - PCIe x8 = 32 Gbit/s
    - MaxPayload 128 bytes => 26.88 Gbit/s
- Details see: http://download.intel.com/design/intarch/papers/321071.pdf

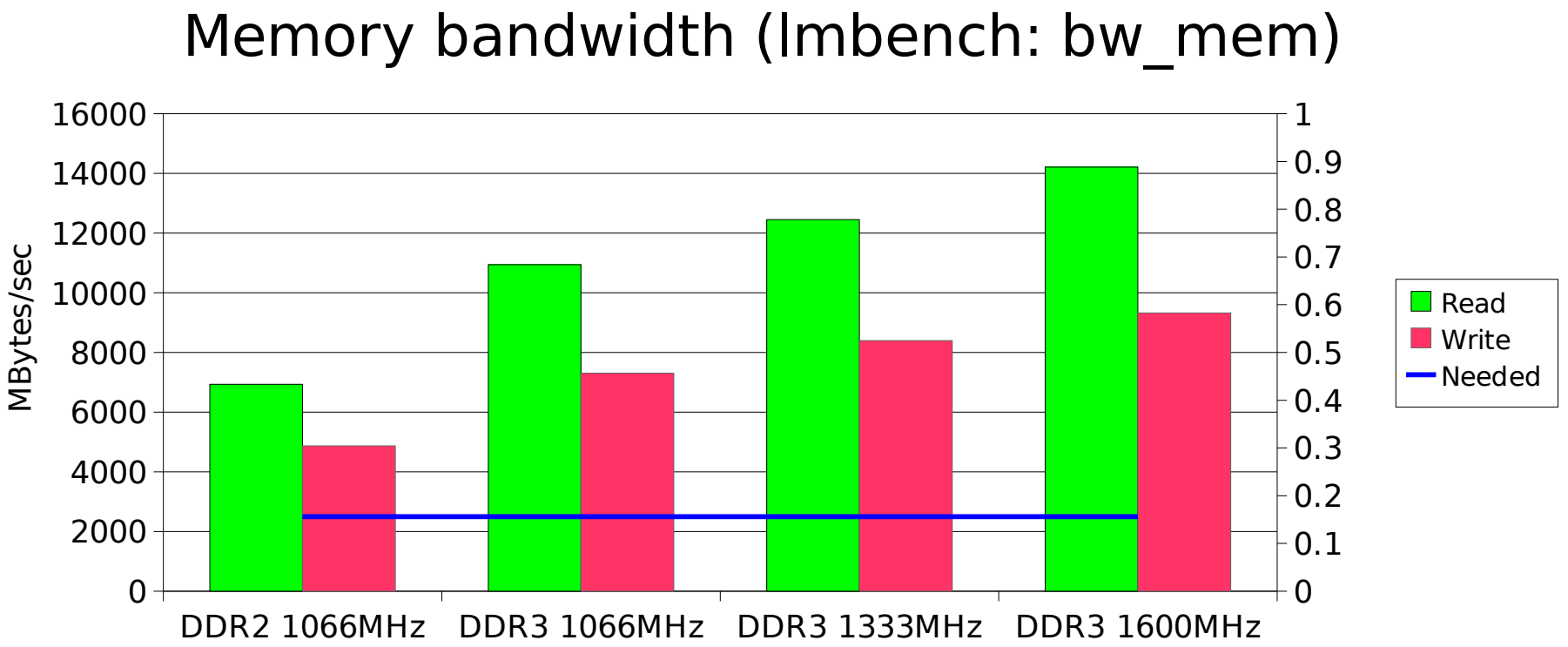
  Title: "Hardware Level IO Benchmarking of PCI express*"

Hardware: Device Under Test (DUT)

- Starting with cheap gaming style hardware
  - No budget, skeptics in the company
  - CPUs: Core i7 (920) vs. Phenom II X4 (940)
  - RAM: DDR3 vs DDR2
- Several PCI-express slots Generation 2.0
  - Motherboards
    - Core i7 – Chipset X58: Asus P6T6 WS Revolution
    - AMD – Chipset 790GX: Gigabyte MA790GP-DS4H

What can we expect from this hardware...

DUT: Memory Bandwidth



- Raw memory bandwidth enough?
  - Memory types: DDR2: Phenom II / DDR3: Core i7
- Target 5000 MBytes/s (40Gbit/s) (2500 MB/s write and 2500MB/s reads)
  - HW should be capable of doing several 10GbE

10Gbit/s Network Interface Cards

- Network Interface Cards (NICs) under test:
  - Sun Neptune (niu): 10GbE Dual port NIC PCIe x8 gen.1 (XFP)
    - PCIe x8 = 16Gbit/s (overhead 16% = 13.44 Gbit/s)
  - SMC Networks (sfc): 10GbE NIC, Solarflare chip (XFP)
    - hardware queue issues, not default enabled
    - only one TX queue, thus cannot parallelize
  - Intel (ixgbe): newest Intel 82599 chip NIC
    - Fastest 10GbE NIC I have ever seen!!!
    - Engineering samples from:
      - Intel: Dual port SFP+ based NIC (PCIe x8 Gen.2)
      - Hotlava Systems Inc.: 6 port SFP+ based NIC (PCIe x16 Gen.2)

Preliminary: Bulk throughput

- Establish: enough PCIe and Memory bandwidth?
  - Target: 2 port 10GbE bidir routing
    - collective 40Gbit/s
  - with packet size 1500 bytes (MTU)

Answer: **Yes**, but only with special hardware:

CPU Core i7
Intel 82599 based NIC
DDR3 Memory minimum at 1333 MHz
QuickPath Interconnect (QPI) tuned to 6.4GT/s (default 4.8GT/s)

Observations: AMD: Phenom II

- AMD Phenom(tm) II X4 940 (AM2+)
  - Can do 10Gbit/s one-way routing
  - Cannot do bidirectional 10Gbit/s
- Memory bandwidth should be enough
  - Write 20Gbit/s and Read 20Gbit/s (2500MB/s)
- 1800 Mhz HyperTransport seems too slow
  - HT 1800Mhz ~ bandwidth 57.6 Gbit/s
  - "Under-clocking" HT: performance followed
  - Theory: Latency issue
    - PCIe to memory latency too high, outstanding packets

Scaling with the number of CPUs

- To achieve these results
  - distribute the load across CPUs
  - A single CPU cannot handle 10GbE
- Enabling factor: “multiqueue”
  - NICs with multiple hardware RX/TX queues
  - **Seperate IRQ per queue** (both RX and TX)
    - Lots of IRQs used
      - look in /proc/interrupts eg. ethX-rx-2

Linux Multiqueue Networking

- RX path: NIC computes hash
  - Also known as RSS (Receive-Side Scaling)
  - Bind flows to queue, avoid out-of-order packets
- Large effort in software network stack
  - TX qdisc API "hack", backward compatible
    - http://vger.kernel.org/~davem/davem_nyc09.pdf
  - Beware: Bandwidth shapers break CPU scaling!

Linux Network stack scales with the number of CPUs

Practical: Assign HW queue to CPUs

- Each HW (RX or TX) queue has individual IRQ
  - Look in /proc/interrupts
  - A naming scheme: ethXX-rx-0
- Assign via "smp_affinity" mask
  - In `/proc/irq/nn/smp_affinity`
  - Trick: `/proc/irq/*/eth31-rx-0/../smp_affinity`
  - Trick: "`grep . /proc/irq/*/eth31-*x-*/../smp_affinity`"
- Use tool: `'mpstat -A -P ALL'`
  - see if the interrupts are equally shared across CPUs

Binding RX to TX: Stay on same CPU

- RX to TX queue mapping: tied to the same CPU
  - Avoid/minimize cache misses, consider NUMA
- 3 use-cases for staying on the same CPU:
  - Forwarding (main focus) (RX to TX other NIC)
    - How: Record queue number at RX and use it at TX
    - Kernel 2.6.30 for proper RX to TX mapping
  - Server (RX to TX)
    - Caching of socket info (Credit to: Eric Dumazet)
  - Client (TX to RX)
    - Hard, Flow "director" in 10GbE Intel 82599 NIC

Start on results

- Lets start to look at the results...
  - Have revealed
    - Large frames: 10GbE bidirectional was possible!
    - What about smaller frames? (you should ask...)
  - First need to look at:
    - Equipment
    - Tuning
    - NICs and wiring

Test setup: Equipment

- Router: Core i7 920 (default 2.66 GHz)
  - RAM: DDR3 (PC3-12800) 1600MHz X.M.P settings
    - Patriot: DDR3 Viper Series Tri-Channel
      - Low Latency CAS 8-8-8-24
  - QPI at 6.4 GT/s (due to X.M.P)
- Generator#1: AMD Phenom 9950 quad
- Generator#2: AMD Phenom II X4 940

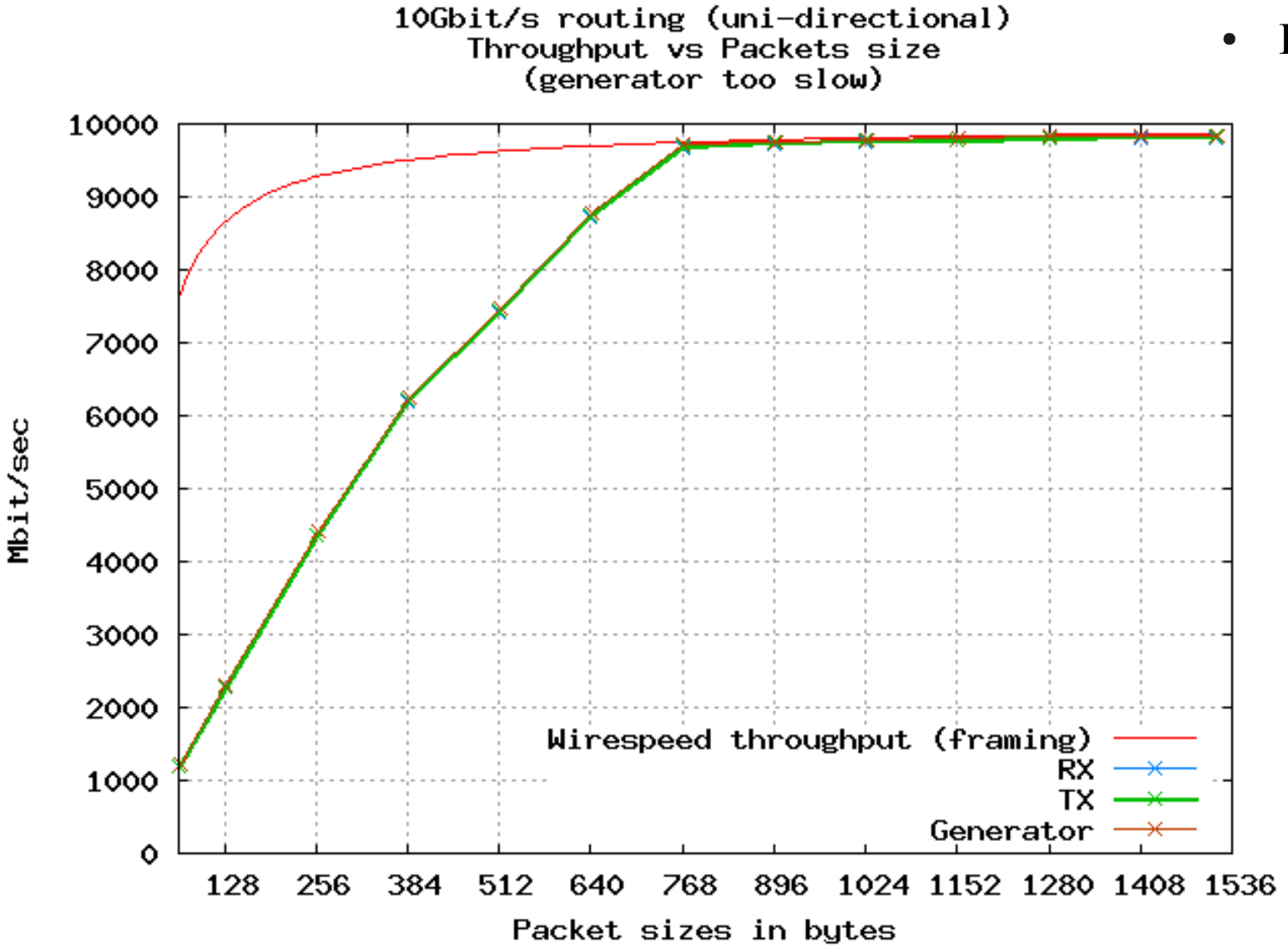
Test setup: Tuning

- Binding RX to TX queues
- Intel NIC tuning
  - Adjust interrupt mitigation parameters `rx-usecs` to 512
    - Avoiding interrupt storms (at small packet sizes)
      - 'ethtool -C eth31 rx-usecs 512'
  - Ethernet flow control (pause frames)
    - Turn-off during tests:
      - To see effects of overloading the system
      - 'ethtool -A eth31 rx off tx off'
    - Recommend turning on for production usage

NIC test setup #1

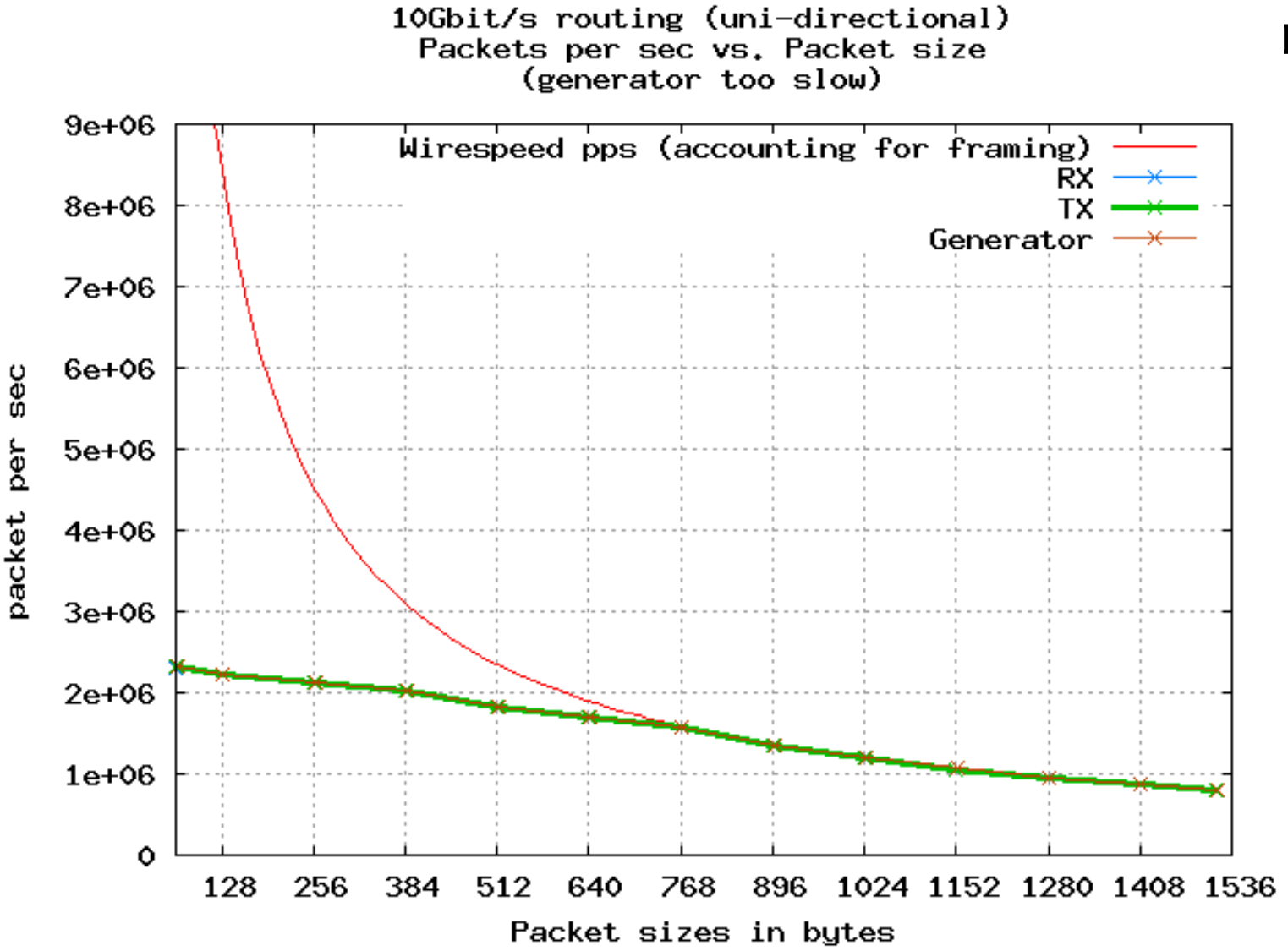
- Router
  - Equipped with: Intel 82599 Dual port NICs
  - Kernel: 2.6.31-rc1 (net-next-2.6 tree 8e321c4)
- Generators
  - Equipped with NICs connected to router
    - Sun Neptune (niu)
    - SMC (10GPCIe-XFP) solarflare (sfc)
  - Using: pktgen
    - UDP packets
    - Randomize dst port number – utilize multiple RX queue

Setup #1: 10GbE uni-directional



- Be skeptic
  - Packet generator
    - Too slow!
    - Sun NICs

Setup #1: Packet Per Sec



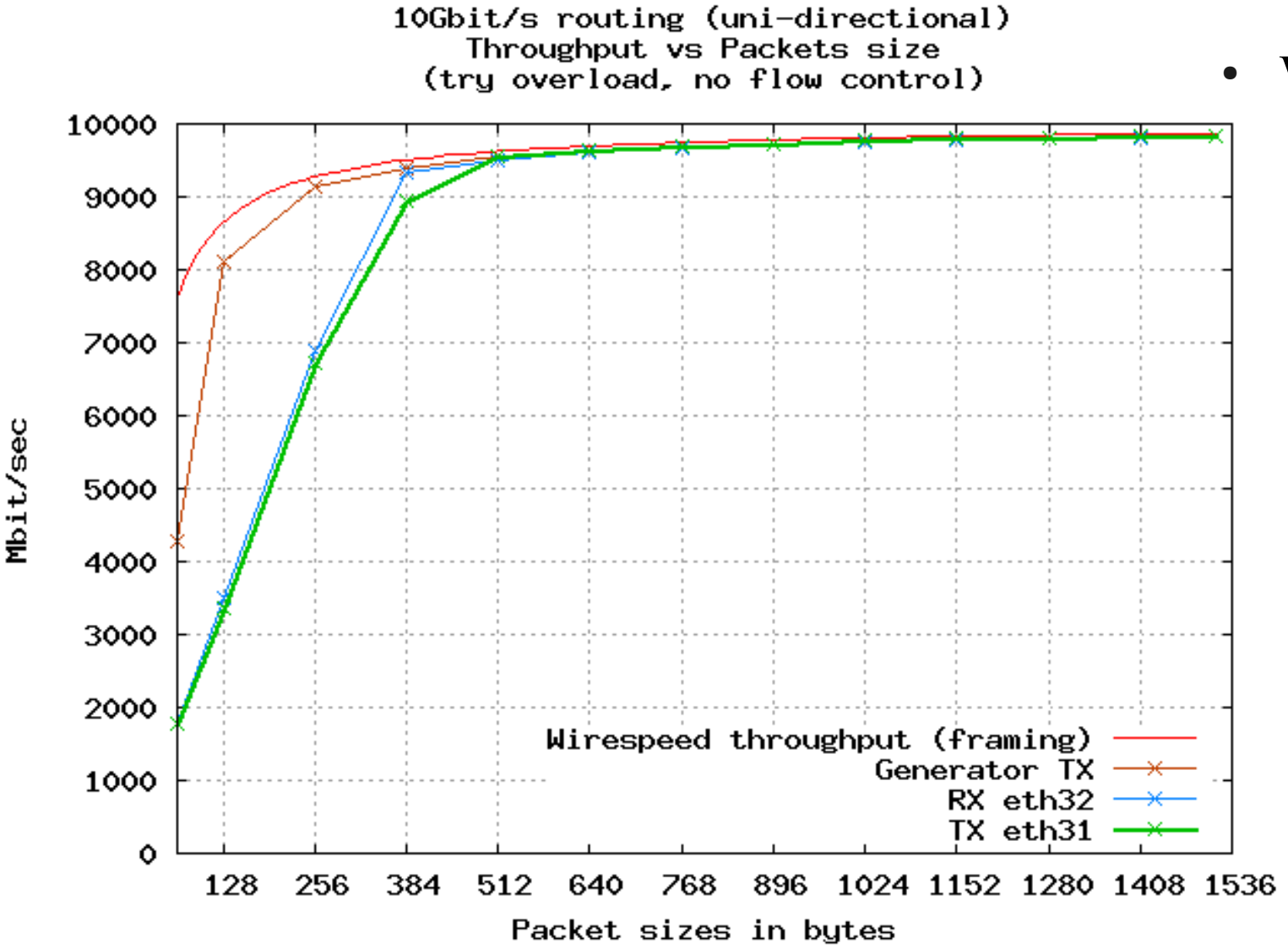
Be skeptic

- Packet generator
  - Too slow!
  - Sun NICs
  - PPS limit

NIC test setup #2

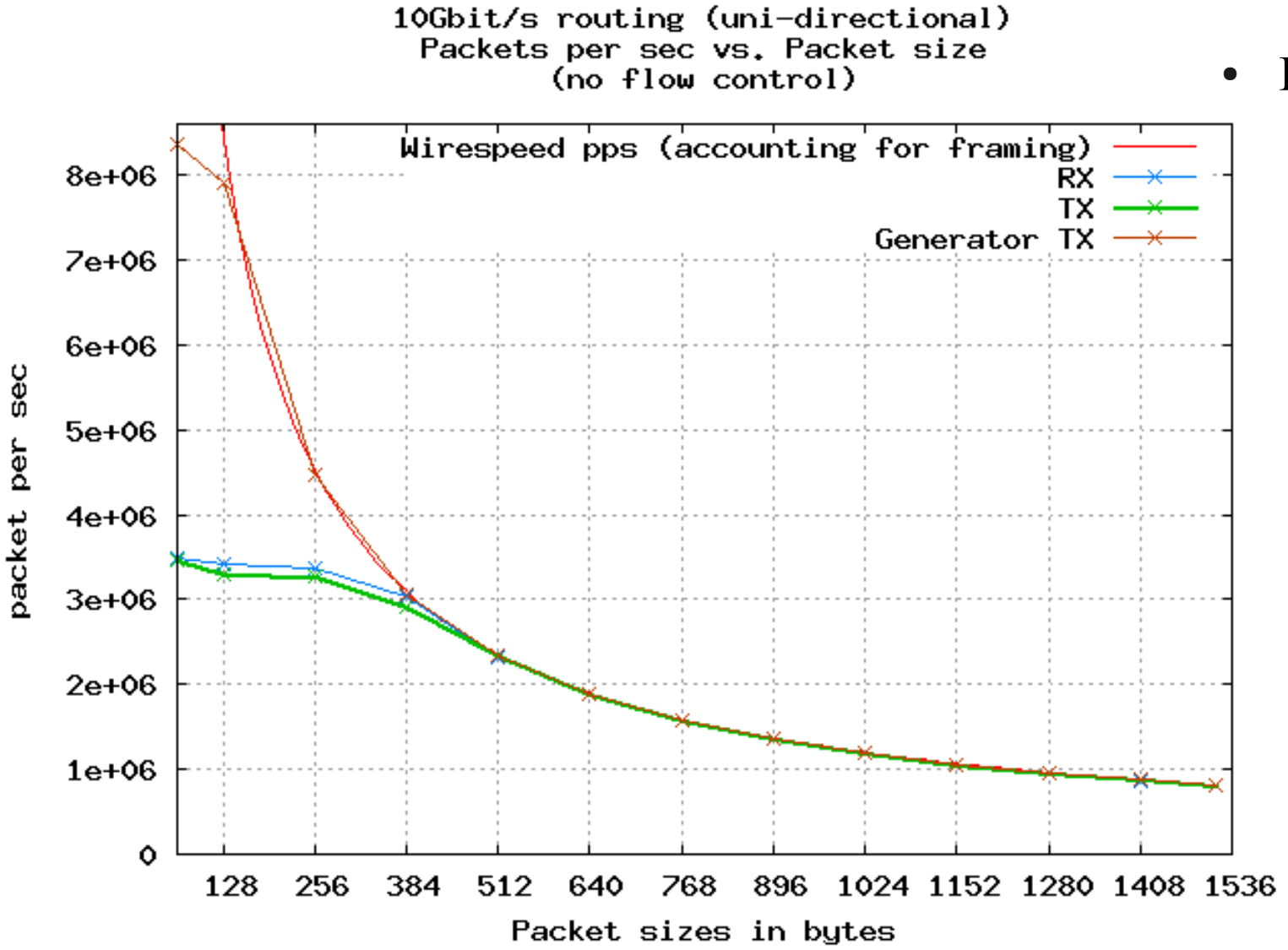
- Router and Generators
  - All equipped with:
    - Intel 82599 based NICs
- Pktgen limits
  - Sun NICs max at 2.5 Mpps
  - Intel 82599 NIC (at packet size 64 byte)
    - 8.4 Mpps with AMD CPU
    - 11 Mpps with Core i7 CPU as generator

Setup #2: 10GbE uni-dir throughput



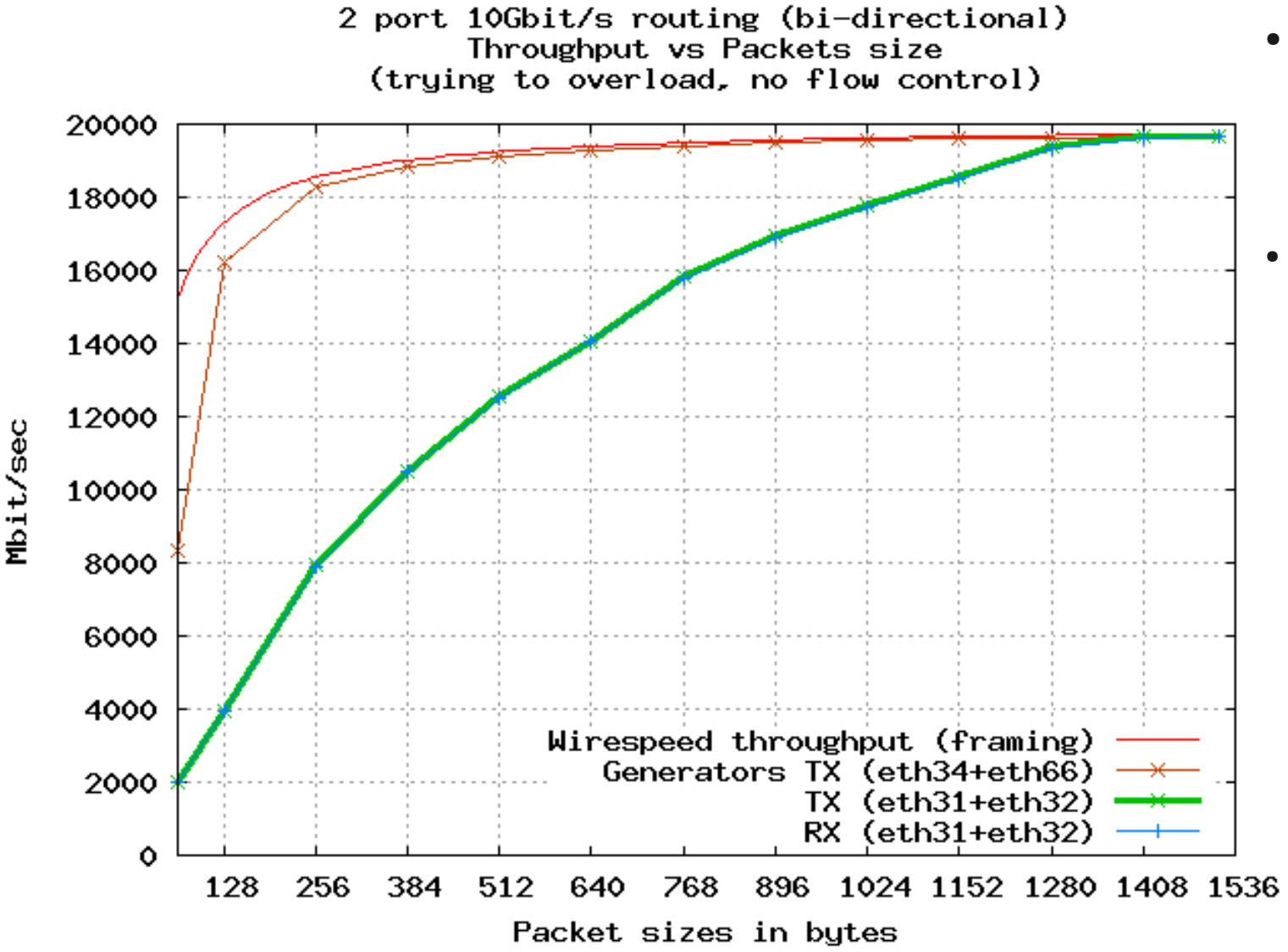
- Wirespeed 10GbE
  - uni-dir routing
  - pktsize 420

Setup #2: 10GbE uni-dir PPS



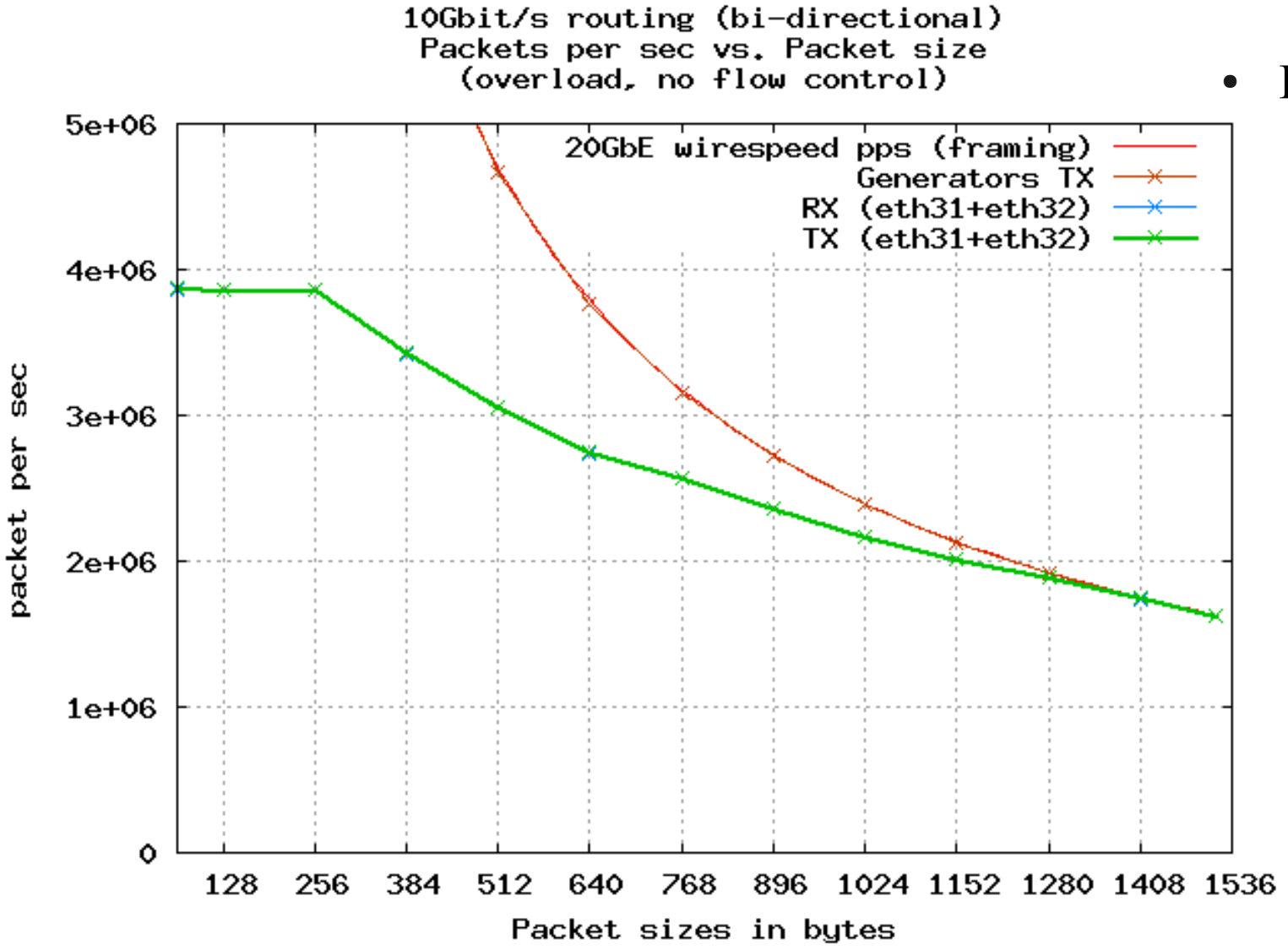
- Limits
  - Packet Per Sec
  - 3.5 Mpps
    - at 64bytes

10GbE Bi-directional routing



- Wirespeed at
  - 1514 and 1408
  - 1280 almost
- Fast generators
  - can survive load!

10GbE Bi-dir: Packets Per Sec



- Limited
  - by PPS rate
  - Max at
    - 3.8 Mpps

Simulate: Internet traffic pattern

- Target: Internet router
  - Simulate Internet traffic with pktgen
    - Based on Robert Olssons Article:
      - "Open-source routing at 10Gb/s"
  - Packet size distribution

pktsize	distribution	approximate
64	45.00%	50.00%
576	25.00%	25.00%
1514	30.00%	25.00%
avg. size	**627 bytes**	**554 bytes**

  - Large number of flows
    - 8192 flows, duration 30 pkts, destinations /8 prefix (16M)
    - watch out for:
      - slow-path route lookups/sec
      - size of route cache

Uni-dir: Internet traffic pattern

- Simulate Internet Traffic
  - 10GbE uni-directional

	Gbit/s	Mpps
Generator	9.5	2.17
RX-router	9.4	2.14
TX-router	9.4	2.14

New route lookups/s: 68k/sec

  - Route Cache is scaling
    - 900k entries in route cache
    - very little performance impact
    - almost same as const size packet forwarding

Bi-Dir: Internet traffic pattern

- 10GbE bi-directional

	Gbit/s	Mpps	avg. pkt
Generator	19.0 Gbit/s	4.3	554
RX	11.6 Gbit/s	3.4	423
TX	11.6 Gbit/s	3.4	423

New route lookups/s: 140k/sec

Comparing with constant size packet tests

Size 423	11.4 Gbit/s	3.3	423
Size 554	15.6 Gbit/s	3.5	554

  - Strange: Average packet size in test
    - Generators: 554 bytes vs. Receive size: 423 bytes
  - Route Cache seems to scale (1.2M entries)
    - when comparing to const size packet tests

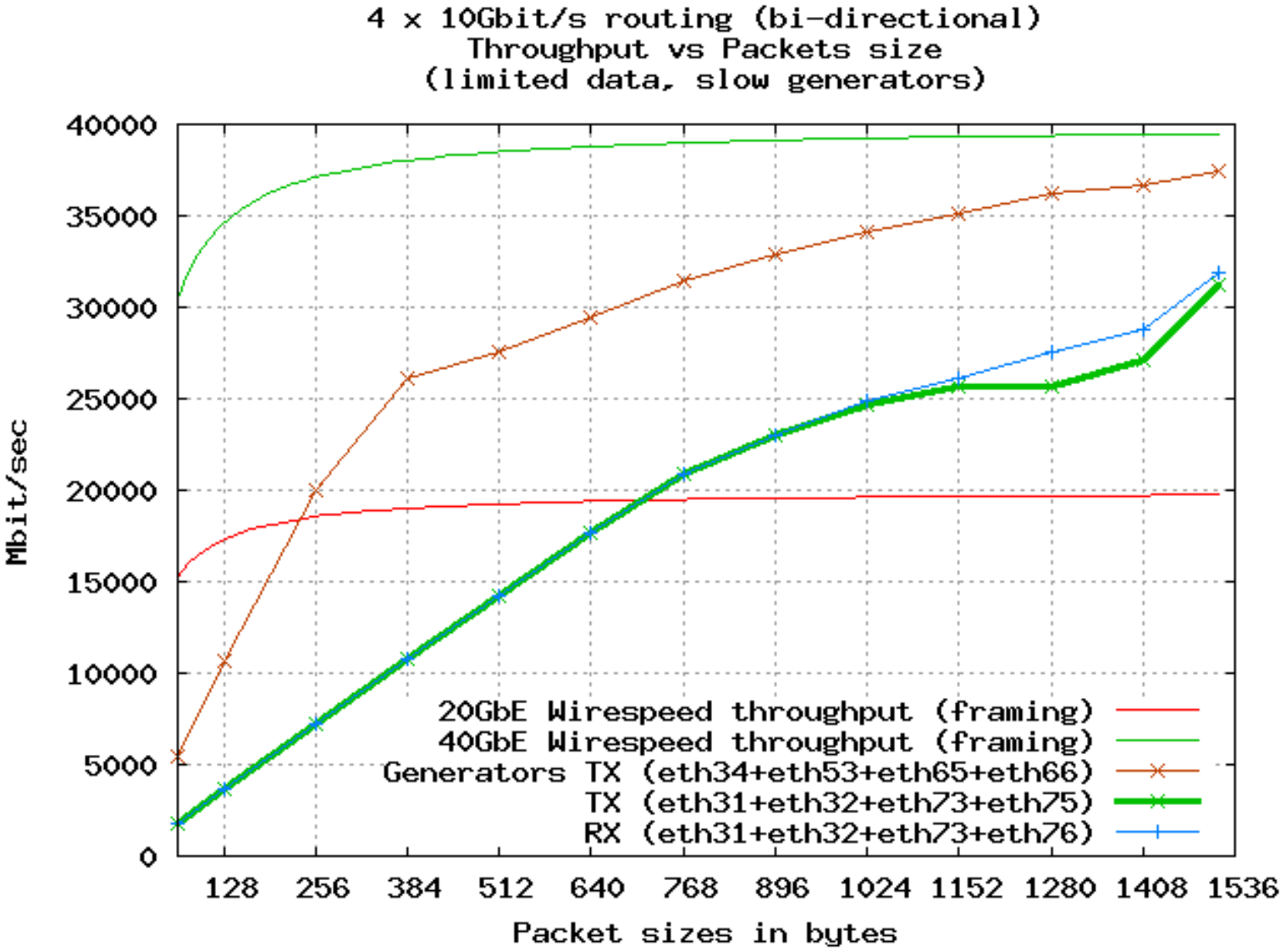
Summary: Target goal reached?

- 2 port 10GbE “Internet” router
  - Uni-Dir: Very impressive, Wirespeed with small pkts
  - Bi-dir: Wirespeed for 3 largest packet sizes
    - Good curve, no choking
    - Bandwidth: Well within our expected traffic load
  - Internet type traffic
    - Uni-dir: Impressive
    - Bi-dir: Follow pkt size graph, route cache scales
  - Traffic Overloading / semi-DoS
    - Nice graphs, doesn't choke with small pkts

Yes! - It *is* possible to do:

10Gbit/s bidirectional routing on Linux

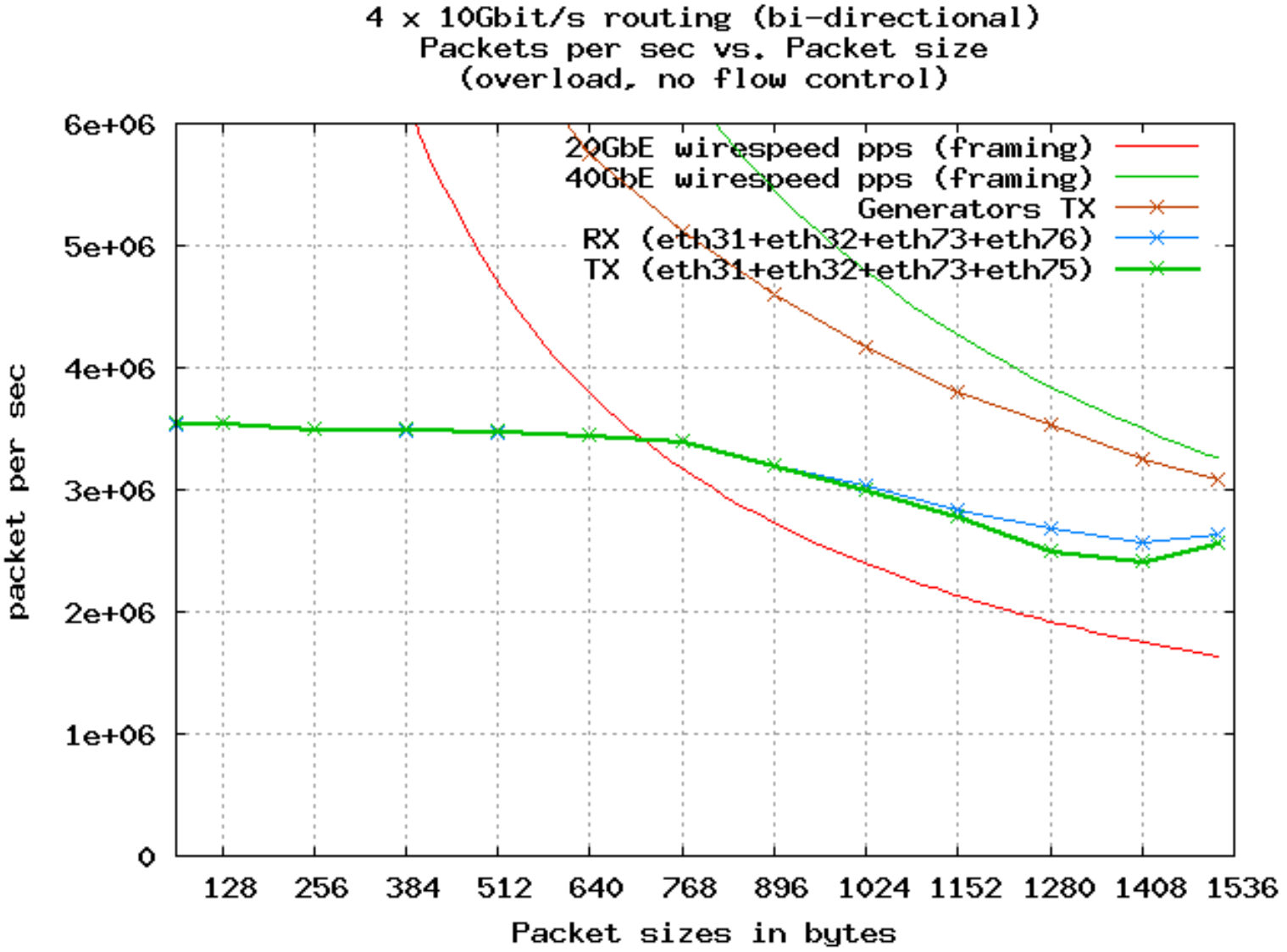
Bandwidth for 4 x 10GbE bidir ?



Beyond 20GbE

- Pktsize: 1514
  - Tx: 31.2 Gb/s
  - Rx: 31.9 Gb/s
- Enough mem bandwidth
- > 2x 10GbE bidir
- Real limit: PPS

4 x 10GbE bidir: Packets Per Sec



Real limit

- PPS limits

Summary: Lessons learned

- Linux Network stack scales
  - “multiqueue” framework works!
- Hardware
  - Choosing the right hardware essential
- PCI-express latency is important
  - Choose the right chipset
  - Watch out for interconnecting of PCIe switches
- Packets Per Second
  - is *the real limit*, not bandwidth

Future

- Buy server grade hardware
  - CPU Core i7 → Xeon 55xx
    - Need min Xeon 5550 (QPI 6.4GT/s, RAM 1333Mhz)
    - Two physical CPUs, NUMA challenges
- Smarter usage of HW queues
  - Assure QoS by assigning Real-time traffic to HW queue
    - ComX example: IPTV multicast streaming
- Features affecting performance?
    - Title: “How Fast Is Linux Networking”
      - Stephen Hemminger, Vyatta
        - Japan Linux Symposium, Tokyo (22/10-2009)

The End

Thanks!

Engineering samples:

- Intel Corporation
- Hotlava Systems Inc.
- SMC Networks Inc.

Famous Top Linux Kernel Comitter
David S. Miller

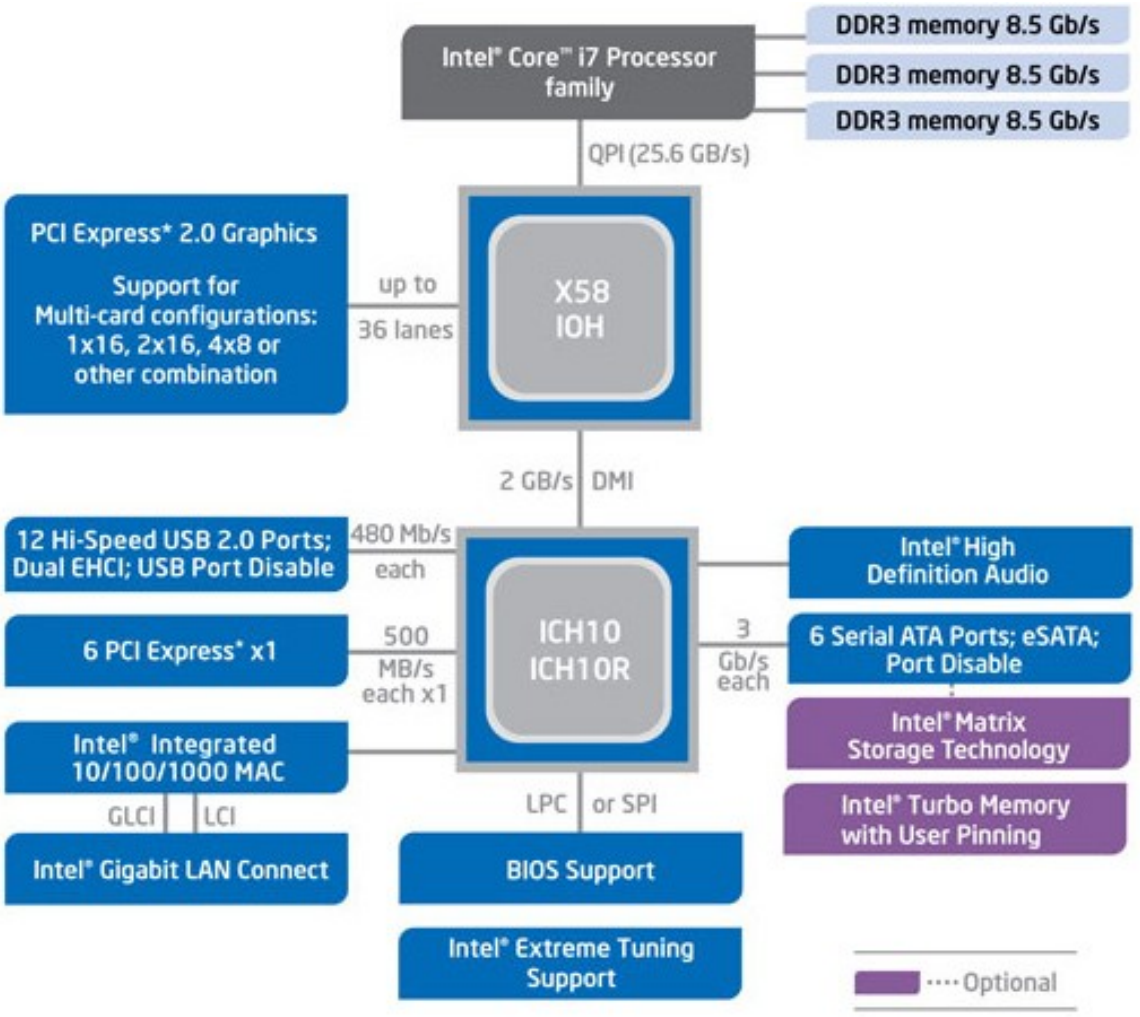
10G optics too expensive!

- 10GbE SFP+ and XFP optics very expensive
  - *There is a cheaper alternative!*
  - Direct Attached Cables
    - SFP+ LR optics price: 450 USD (need two)
    - SFP+ Copper cable price: 40 USD
  - Tested cable from:
    - Methode dataMate
      - http://www.methodedatamate.com

Pitfalls: Bad motherboard PCIe design

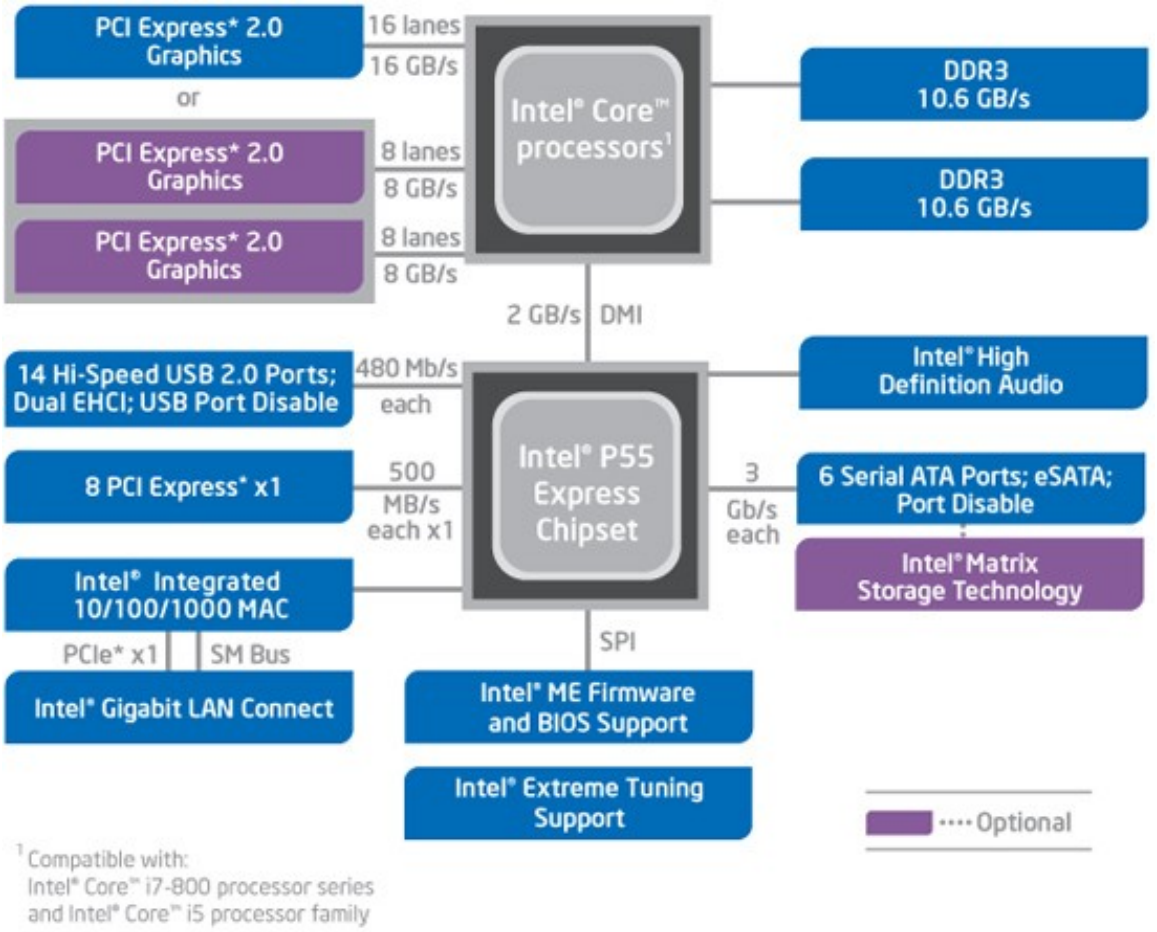
- Reason: Could not get beyond 2x 10GbE
- Motherboard: Asus P6T6 WS revolution
  - Two PCIe switches
    - X58 plus NVIDIA's NF200
    - NF200 connected via PCIe gen.1 x16
      - 32 Gbit/s -> overhead 26.88 Gbit/s
  - Avoid using the NF200 slots
    - scaling again...

Chipset X58: Core i7



- Bloomfield, Nehalem
- Socket: LGA-1366

Chipset P55: Core i5 and i7-800



- Lynnfield, Nehalem
- Socket: LGA-1156