Performance Tuning of Gigabit Network Interfaces

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Outline

- The problem
- The network testbed
- The workload
- The results
- The model
- Conclusions

The Problem

- A standard DIX Ethernet frame consists of
  - Physical and link layer headers: 22 bytes
  - Network layer PDU: 1500 bytes
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  - and the maximum arrival rate is $81,324 frames/sec$

- At this frame rate the CPU can become a bottleneck leading to
  - Degraded system performance,
  - Poor network throughput, or in the worst case
  - Receive livelock

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  - Kernel buffer and buffer queue management
- Per byte overhead
  - Copying data from kernel to user space buffers.
  - Software checksumming (if required)

Overhead mitigation

- Coalesce interrupts
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  - If a new arrival commences during the delay, the NIC defers the IRQ until frame completes
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- Use zero copy protocols in which NIC transfers data directly to user space buffers with DMA

Complicating factors

- Coalescing of interrupts
  - Not all NIC's support interrupt coalescing
  - Even if the NIC does the device driver may not
  - Even if the device driver does support it configuring it may be an adventure.
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  - Some switches will not pass large frames at all
- Use of zero copy protocols
  - Requires replacement of complete protocol stack

Testbed

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- Extreme Black Diamond 6804 Switch provides two VLANs
  - Management VLAN: (rlogin, NFS, etc)
  - Graphics VLAN: (used in the tests reported here)

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  - 1.6 MHz Pentium 4 processor
  - 512 MB RAM
  - 2 NICs operating on separate VLANs
  - 24 Nodes have Intel Pro 1000 NICs on the Graphics VLAN
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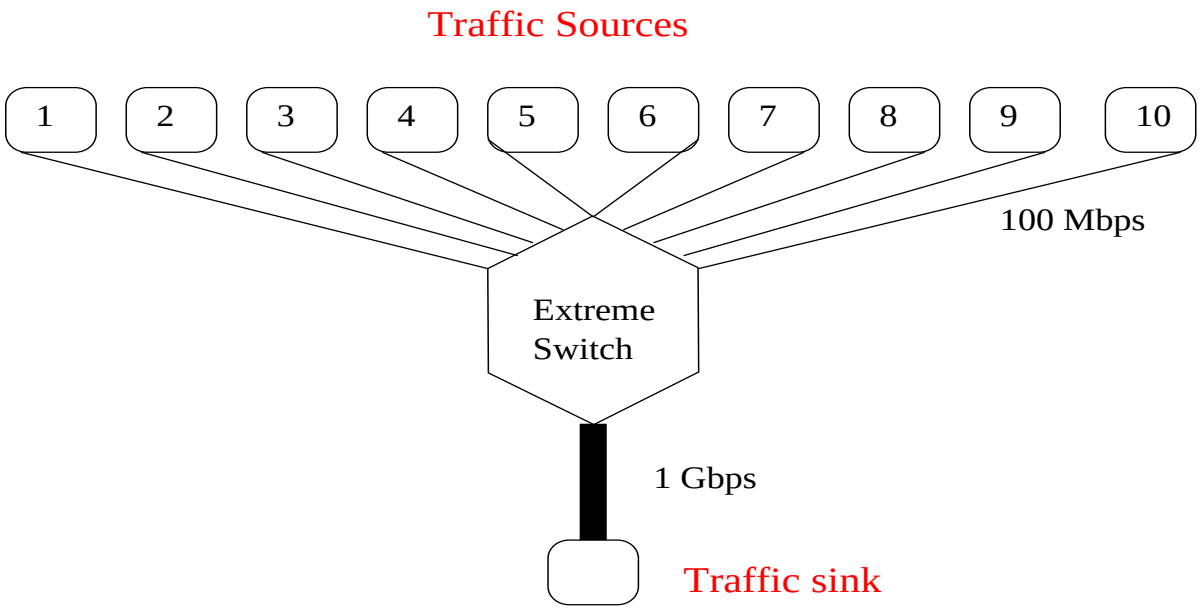
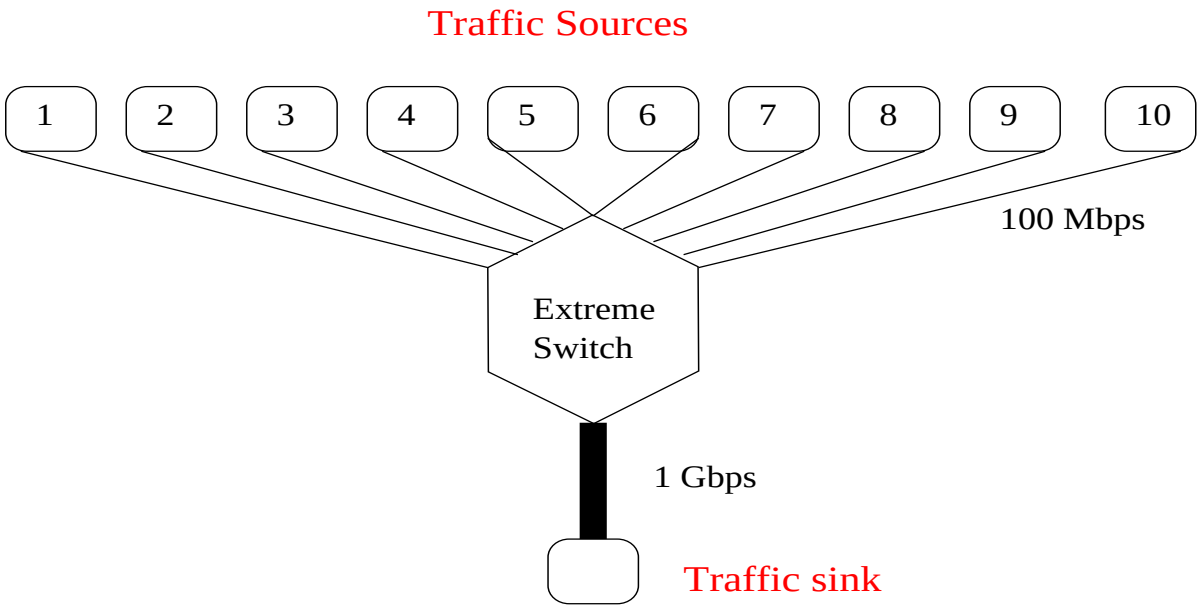
- Node software
  - RedHat 7.1 Linux
  - Linux kernel version 2.4.7

UDP Workload



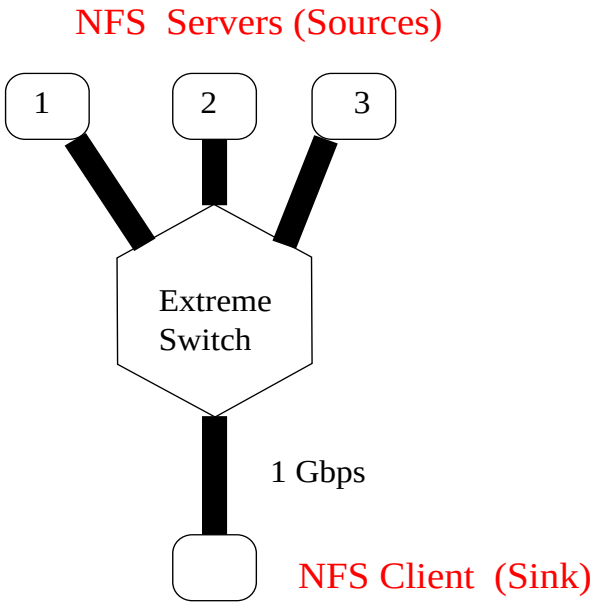
- Simplex flow
- Each sender sends approximately 1.5 GB
- No observed loss
- APDU size is max supported by path MTU

TCP Workload



- Simplex flow
- Each sender sends approximately 1.5 GB
- No observed loss
- APDU size fixed at 16000 bytes

NFS Workload



- Clients and servers all use 1 Gbps NICs
- 3 client processes run on NFS Client
- Each process reads the entire 1.67 GB /usr tree on one server
- Unlike UDP and TCP workloads disk speed *is* a factor

Operational parameters

Two parameters were varied during the testing

- MTU (NPDU size) $\in \{1500, 3000, 4500, 6000\}$
- RxAbsIntDelay $\in \{10, 20, 40, 80, 160, 240, 320, 480, 640\}$
- Interrupt coalescing delays are in units of 1.024μ seconds

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Other parameters were set to ensure

- Interrupt coalescing would occur
- Tx interrupts would *not* occur
- RxAbsIntDelay would determine packets per interrupt

TxIntDelay	1400
TxAbsIntDelay	65000
RxDescriptors	256
TxDescriptors	256
RxIntDelay	1200

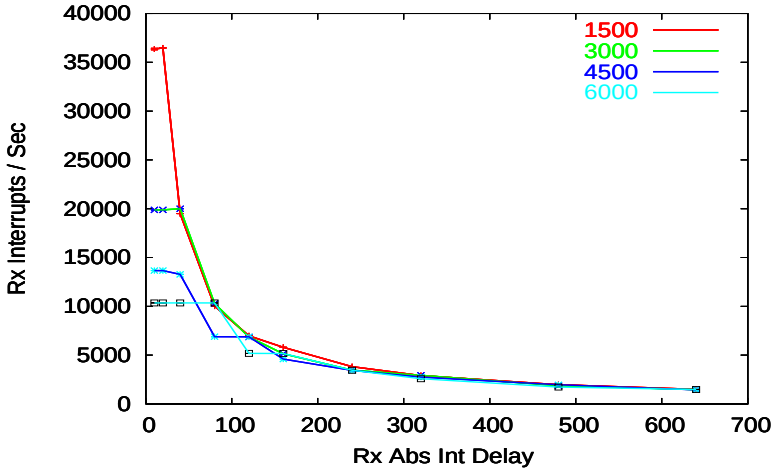
Metrics

Metrics were captured by a customized version 5.2.39 of Intel's e1000 device driver. Metrics reported in the paper include:

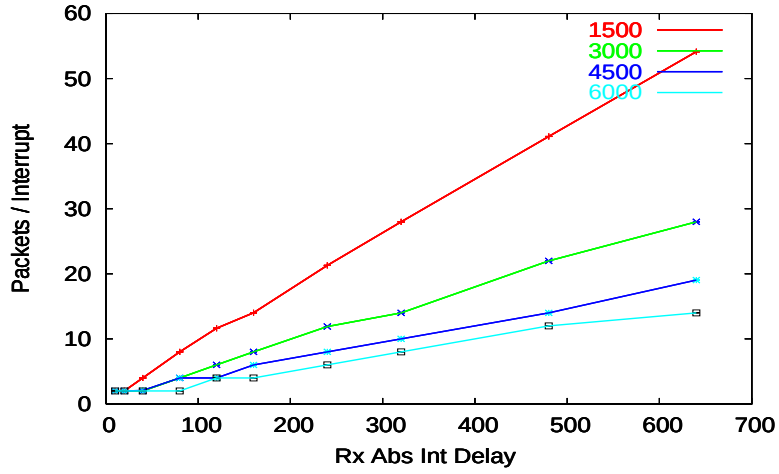
- Interrupts per second
- Packets processed per interrupt
- Throughput in Mbps
- System mode (supervisor state) CPU utilization
- System mode (supervisor state) CPU time

The NFS workload shows that CPU utilization can be a misleading indicator of system performance.

UDP Results



Interrupt Rate



Packets per Interrupt

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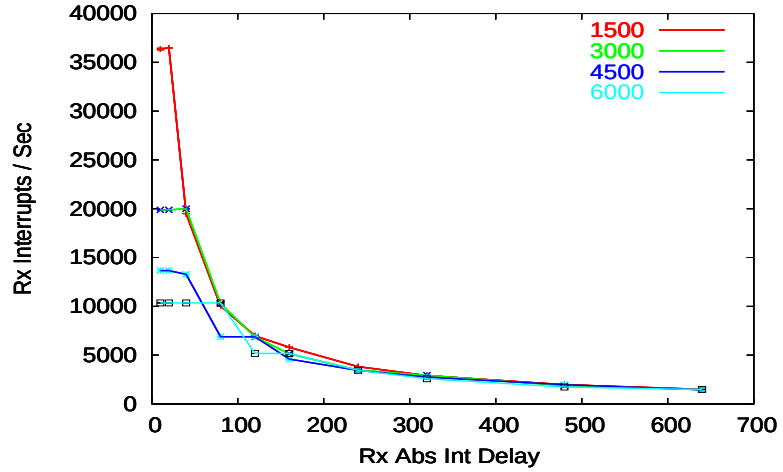

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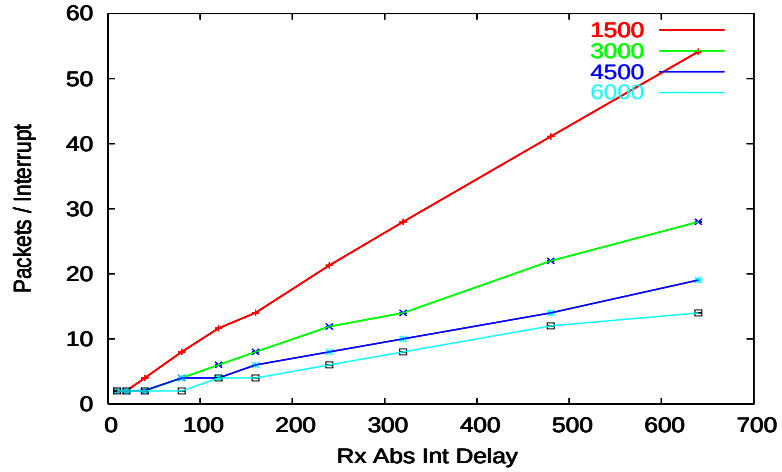

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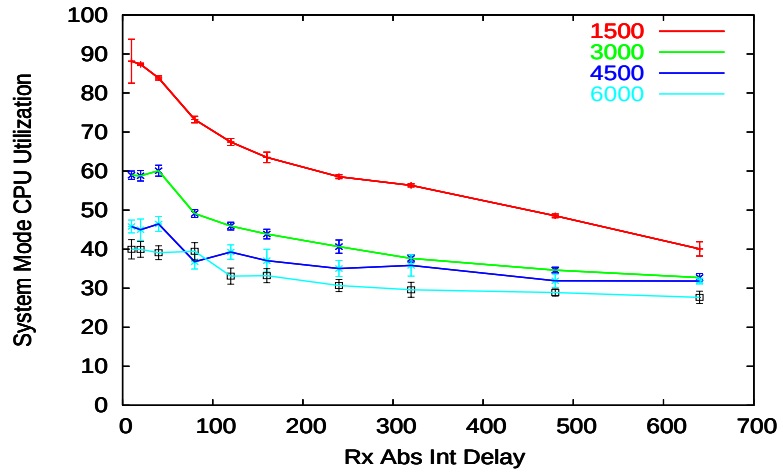
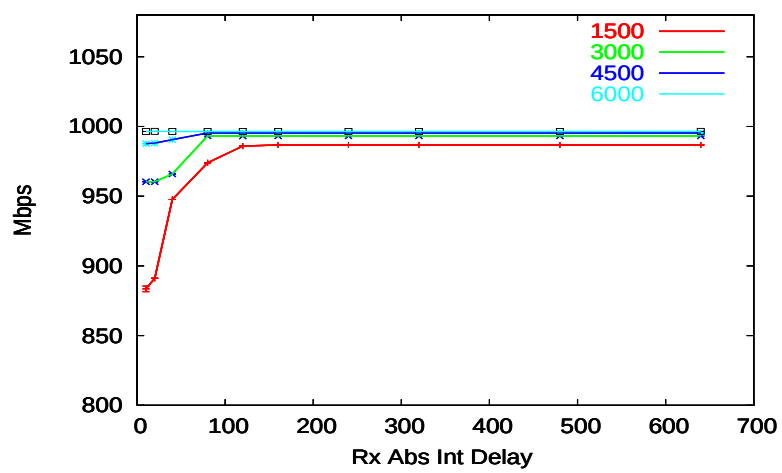


System Mode CPU utilization



MAC Throughput in Mbps

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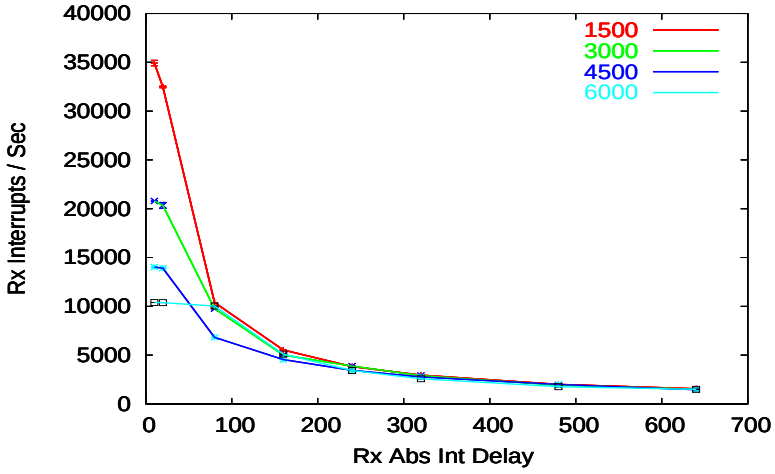
- Maximum throughput is reached with RxAbsIntDelay <= 160.
- Reduction in CPU util can be seen for RxAbsIntDelay <= 2000.
- Increasing RxAbsIntDelay can never harm the throughput of an unacknowledged packet flow.

TCP Results



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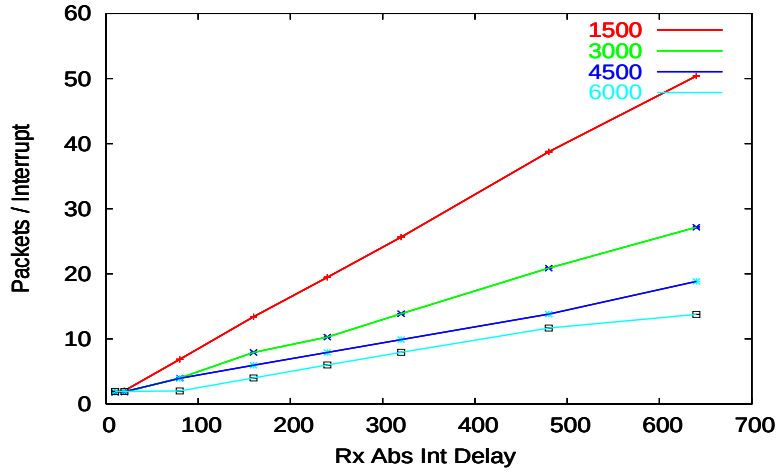

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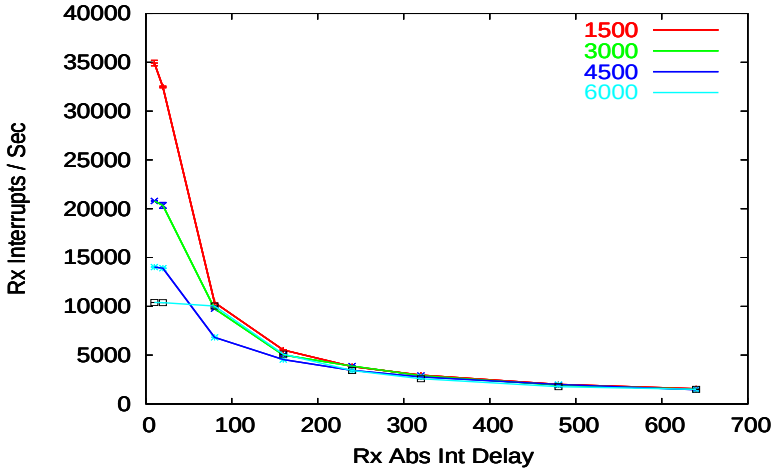

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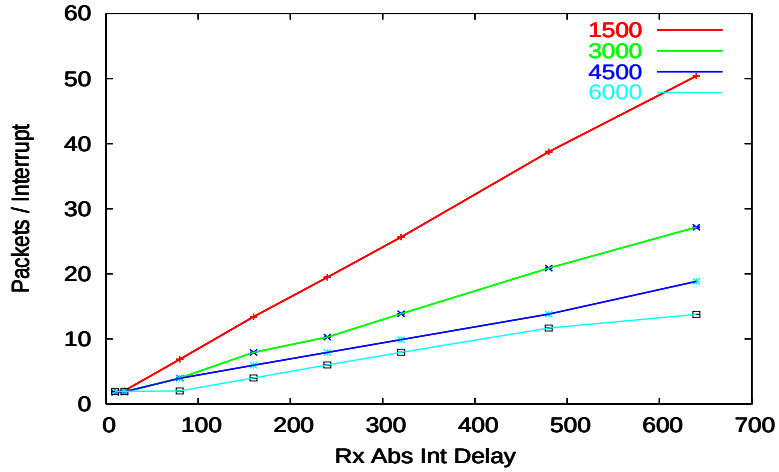

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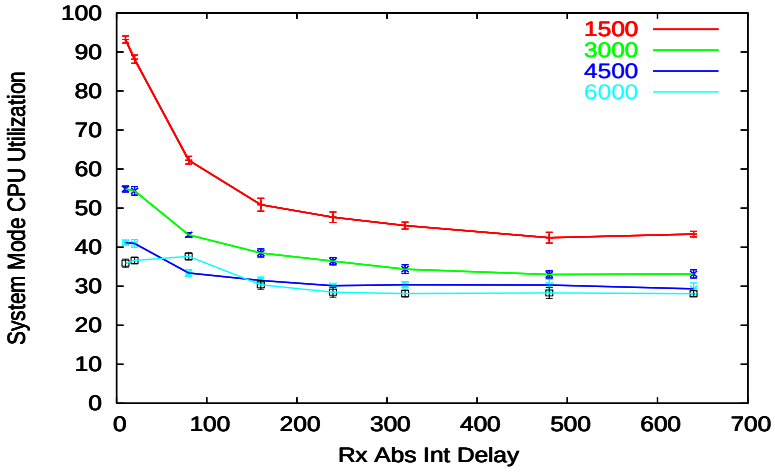
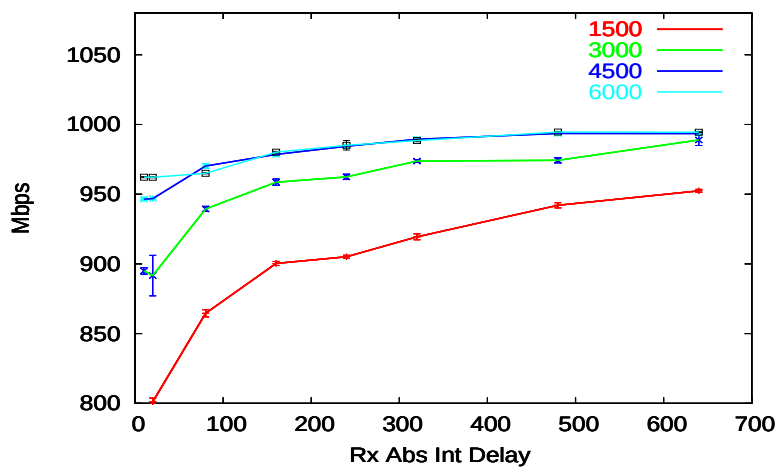


System Mode CPU utilization



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- Maximum link layer throughput
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- Maximum throughput is achieved with
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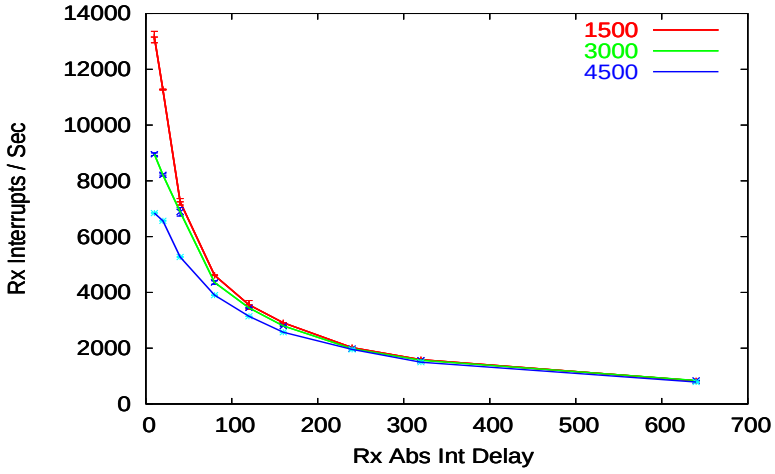
For the both the 10 sender UDP and TCP workloads near maximal throughput and minimum CPU usage can be obtained with $RxAbsIntDelay \approx 640$

NFS Results



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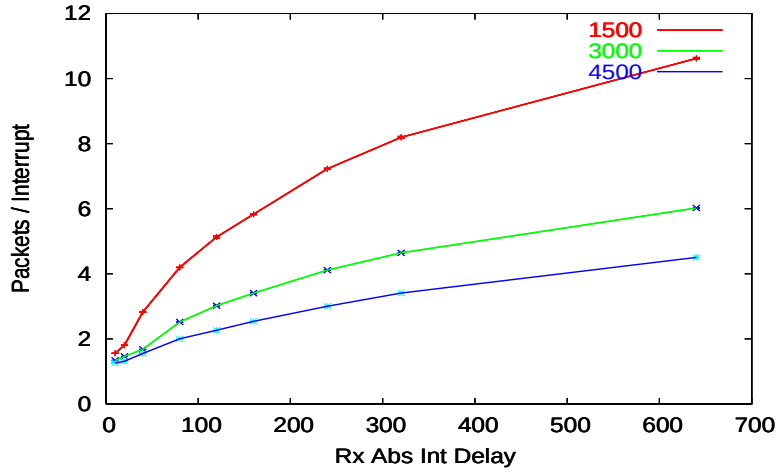

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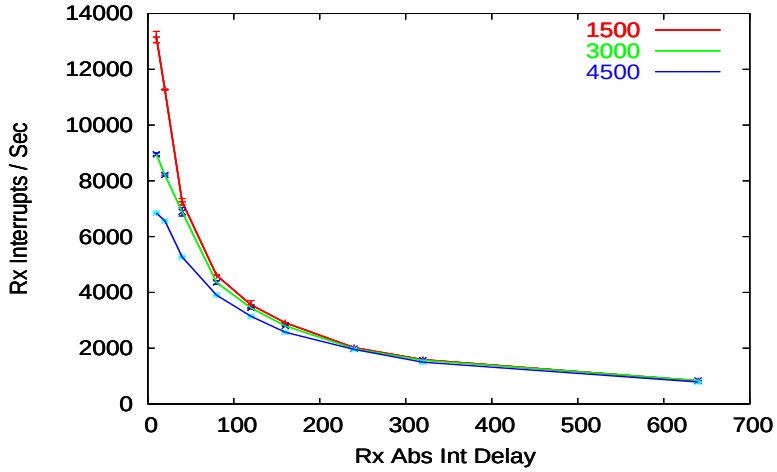

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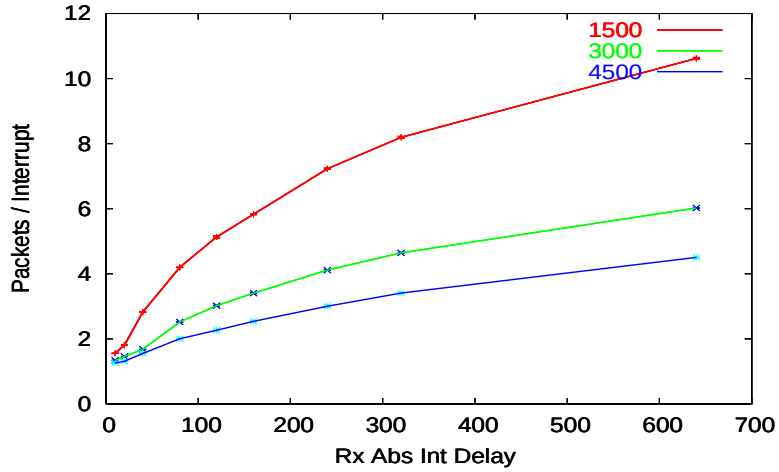

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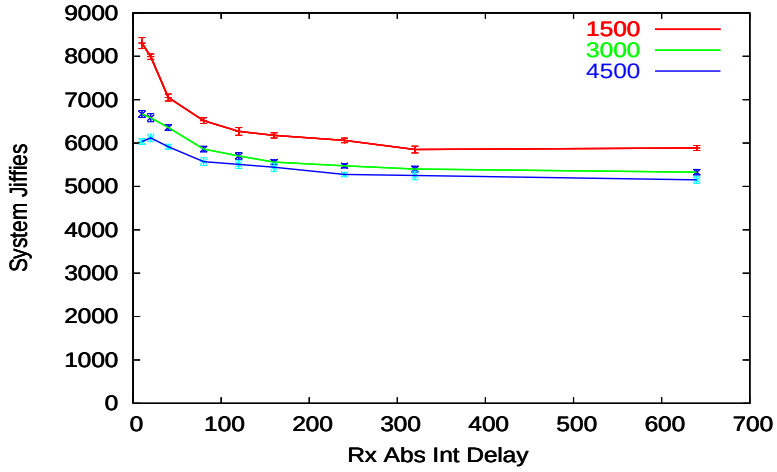
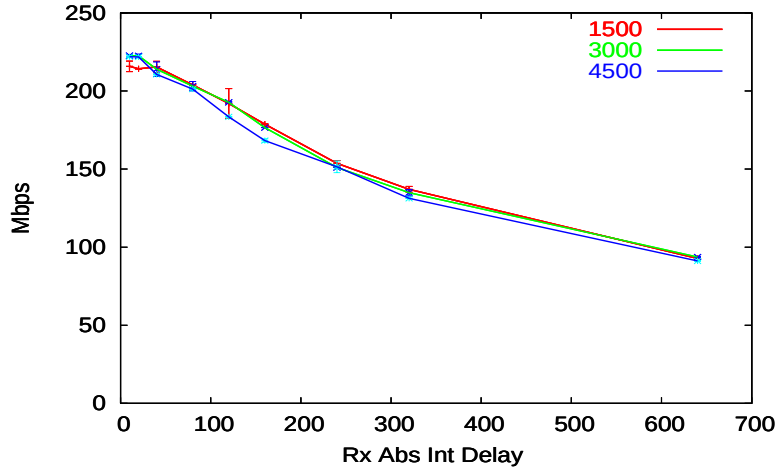


System Mode CPU consumption



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  - $RxAbsIntDelay \approx 20$ for small MTUs.
  - Rapid throughput decay occurs for $RxAbsIntDelay > 80$
- CPU utilization decays with increasing RxAbsIntDelay because the throughput decay is causing less work per unit time to be done.
- Minimal system mode CPU usage is achieved for $RxAbsIntDelay \approx 320$.
- Unlike the UDP and TCP workloads, there is no sweet spot in which both throughput and CPU usage are near optimal.

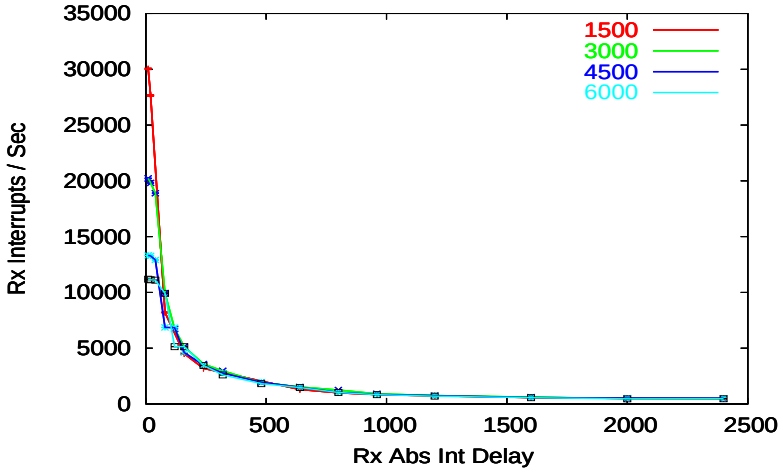
The wrong conclusions to draw

- For UDP and TCP use relatively large RxAbsIntDelay
- For request/response protocols use minimal RxAbsIntDelay

The actual situation is considerably more complex. Even when all nodes reside on a Gigabit LAN the optimal configuration is a function of:

- the number of active senders;
- the rate at which they are sending;
- for TCP senders, min(cwin, offered window).

Three TCP Senders on Gigabit links



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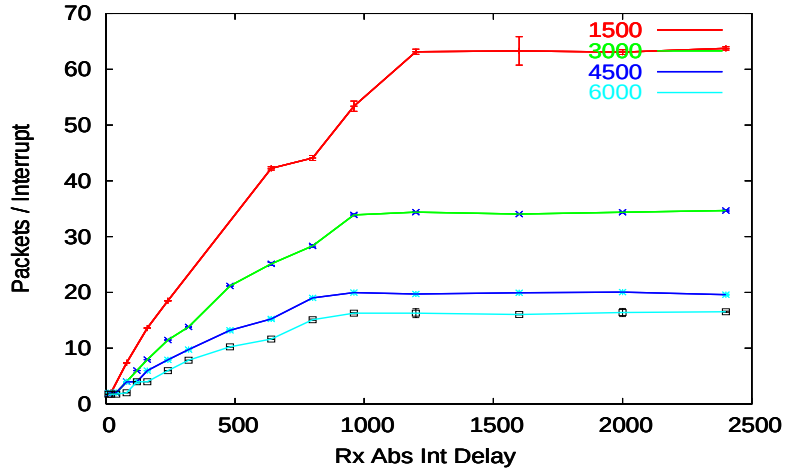

Packets per Interrupt

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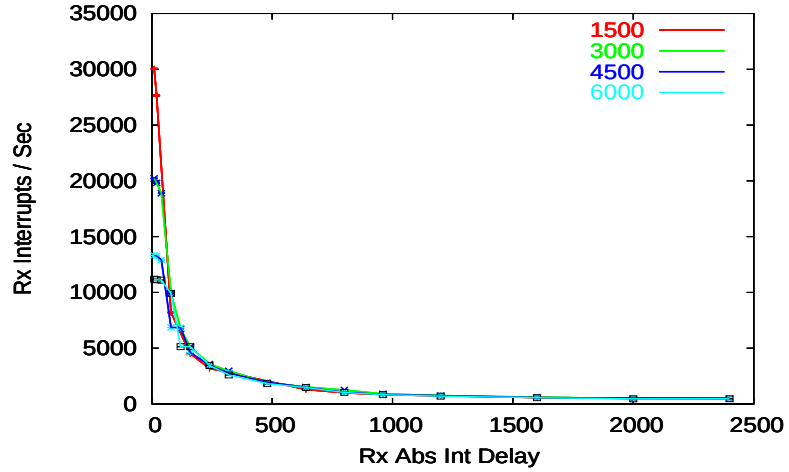

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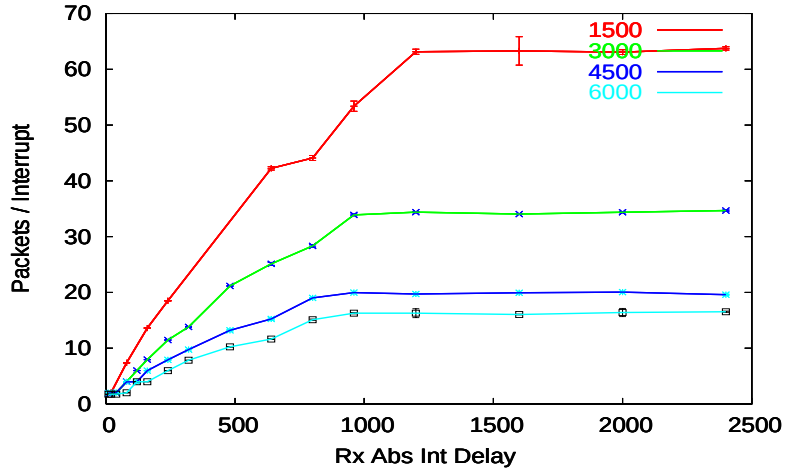

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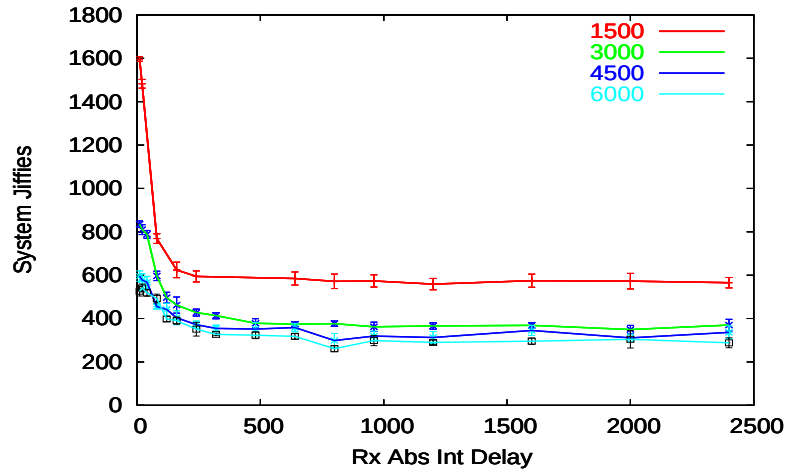
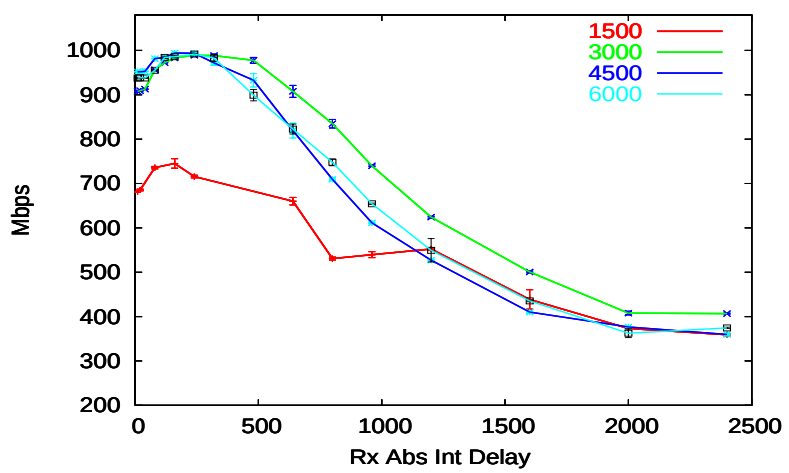


System Mode CPU consumption



MAC Throughput in Mbps

Observations on the 3 sender TCP workload

- High thoughput sweetspot much narrower than with 10 senders
- Throughput decay occurs:
  - for $RxAbsIntDelay > 320$ in 3 sender workload
  - for $RxAbsIntDelay > 2000$ in 10 sender workload

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- Good CPU util is achieved with $RxAbsIntDelay \approx 480$.
- But unlike the NFS workload 480 provides an operating point at which good throughput and CPU usage can be obtained.

TCP in a Gigabit Ethernet Environment

- For good TCP performance TCP senders must not block on full *ownd* or *cwnd*.
- If *acks* are excessively delayed senders will block.
- Interrupt coalescing does delay packet delivery and thus also *acks*.

TCP in a Gigabit Ethernet Environment

Therefore,

- Having a large number of senders is good.
- Having large sender buffer space (large *ownd*) is good but,
- an offered load that exceeds receiver link capacity results in a small *cwnd* which is bad.

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Therefore,

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Furthermore,

- Interrupt coalescing can lead to both
  - ack compression
  - ack rate reductions (e.g. 1 ack per 5 or 6 packets)
- These are known to be bad in a WAN but
- produce no apparent ill effects in a LAN.

A model for CPU usage

$$T = \alpha N_{MB} + \beta N_{KP} + \gamma N_{KI}$$

- α = Per megabyte cost of checksumming and copying
- β = Per thousand packet cost of protocol operations
- γ = Per thousand interrupt cost of context switching
- For TCP $\alpha \approx 0.1, \beta \approx 0.4, \gamma \approx 1.4$ jiffies

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Suppose one MB of data is to be transfered using application payload per packet = MTU and packets per interrupt = PPI.

Then $T = \alpha + \frac{1000}{MTU}\beta + \frac{1000}{MTU \times PPI}\gamma$

- $PPI << MTU$
- PPI impacts only the last term
- MTU plays a much more significant role in reducing CPU usage

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- but it provided lower throughput and higher CPU usage for all MTUs on the 10 TCP sender workload.
- More research is needed ... especially as 10 Gbit NICs become common.