A way towards Lower Latency and Jitter

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Intel® Ethernet

BIO

- Jesse Brandeburg <jesse.brandeburg@intel.com>
  - A senior Linux developer in the Intel LAN Access Division, producing the Intel Ethernet product lines
  - Has been with Intel since 1994, and has worked on the Linux e100, e1000, e1000e, igb, ixgb, ixgbe drivers since 2002
  - Jesse splits his time between solving customer issues, performance tuning Intel's drivers, and bleeding edge development for the Linux networking stack

Acknowledgements

- Contributors
  - Anil Vasudevan, Eric Geisler, Mike Polehn, Jason Neighbors, Alexander Duyck, Arun Ilango, Yadong Li, Eliezer Tamir

“The speed of light sucks.”

- John Carmack

Current State

- NAPI is pretty good, but optimized for throughput
- Certain customers want extremely low end to end latency
  - Cloud providers
  - High Performance Computing (HPC)
  - Financial Services Industry (FSI)
- The race to the lowest latency has sparked user-space stacks
  - Most bypass the kernel stack
  - Examples include OpenOnload® application acceleration, Mellanox Messaging Accelerator (VMA), RoCEE/IBoE, RDMA/iWarp, and others [1]

[1] see notes for links to above products

Problem Statement

- Latency is high by default (especially for Ethernet)
- Jitter is unpredictable by default

Software Causes	Hardware Causes
• Scheduling/context switching of the process • Interrupt balancing algorithms • Interrupt rate settings • Path length from receive to transmit	• # of fetches from memory • Latency inside the network controller • Interrupt propagation • Power Management (NIC, PCIe, CPU)

Latency and Jitter Contributors

Key sources today	Solutions
Raw Hardware Latency	New Hardware
Software Execution Latency	Opportunity
Scheduling / Context Switching	Opportunity
Interrupt Rebalancing	Interrupt-to-core mapping
Interrupt Moderation/Limiting	Minimize/Disable throttling (ITR=0)
Power Management	Disable (or limit) CPU power management, PCIe power management
Bus Utilization (jitter)	Isolate device

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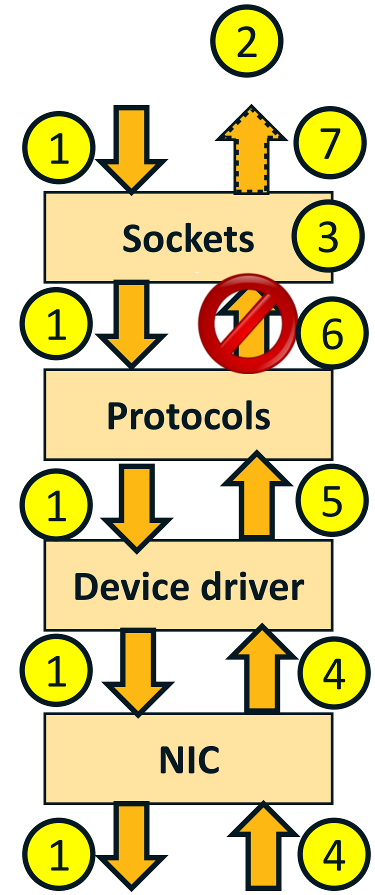
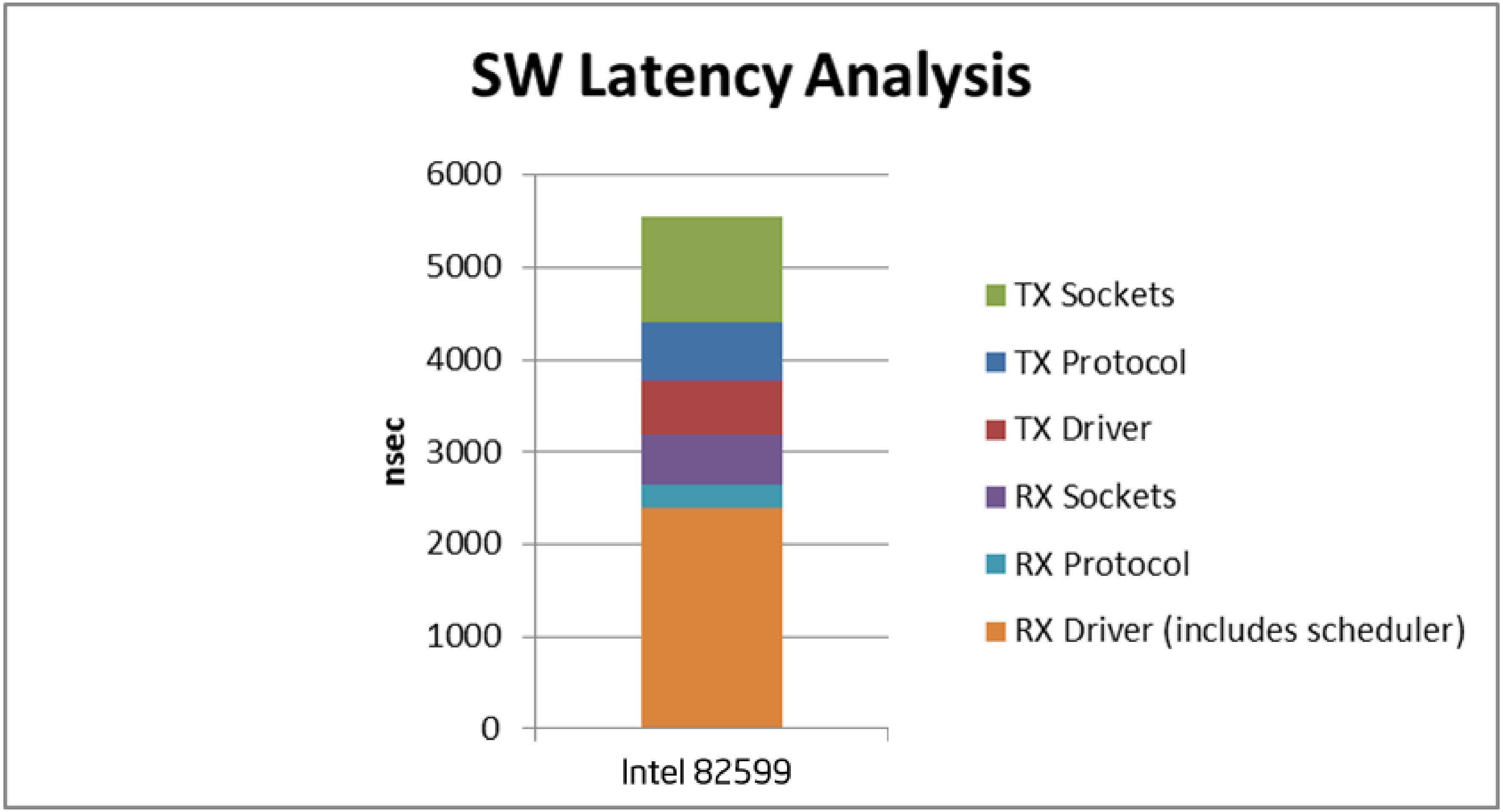
Traditional Transaction Flow

1. App transmits thru sockets API
   - Passed down to driver and h/w unblocked
   - TX is “Fire and Forget”
2. App checks for receive
3. No immediate receive – thus block
4. Packet received & Interrupt generated
   - Interrupt subject to Int Rate & Int Balancing
5. Driver passes to Protocol
6. Protocol/Sockets wakes App
7. App received data thru sockets API
8. Repeat

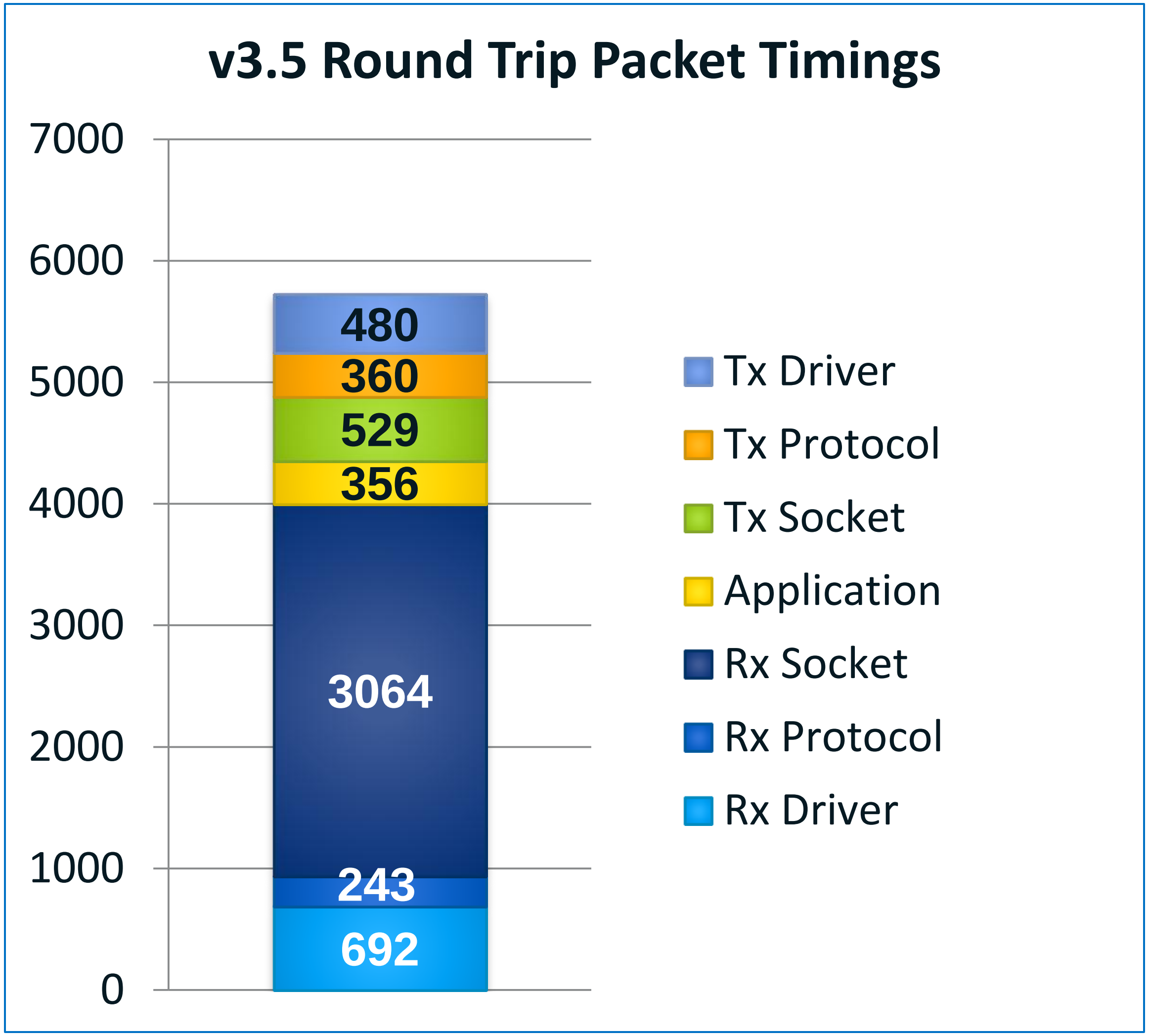


Very inefficient for low-latency traffic

Latency Breakdown 2.6.36

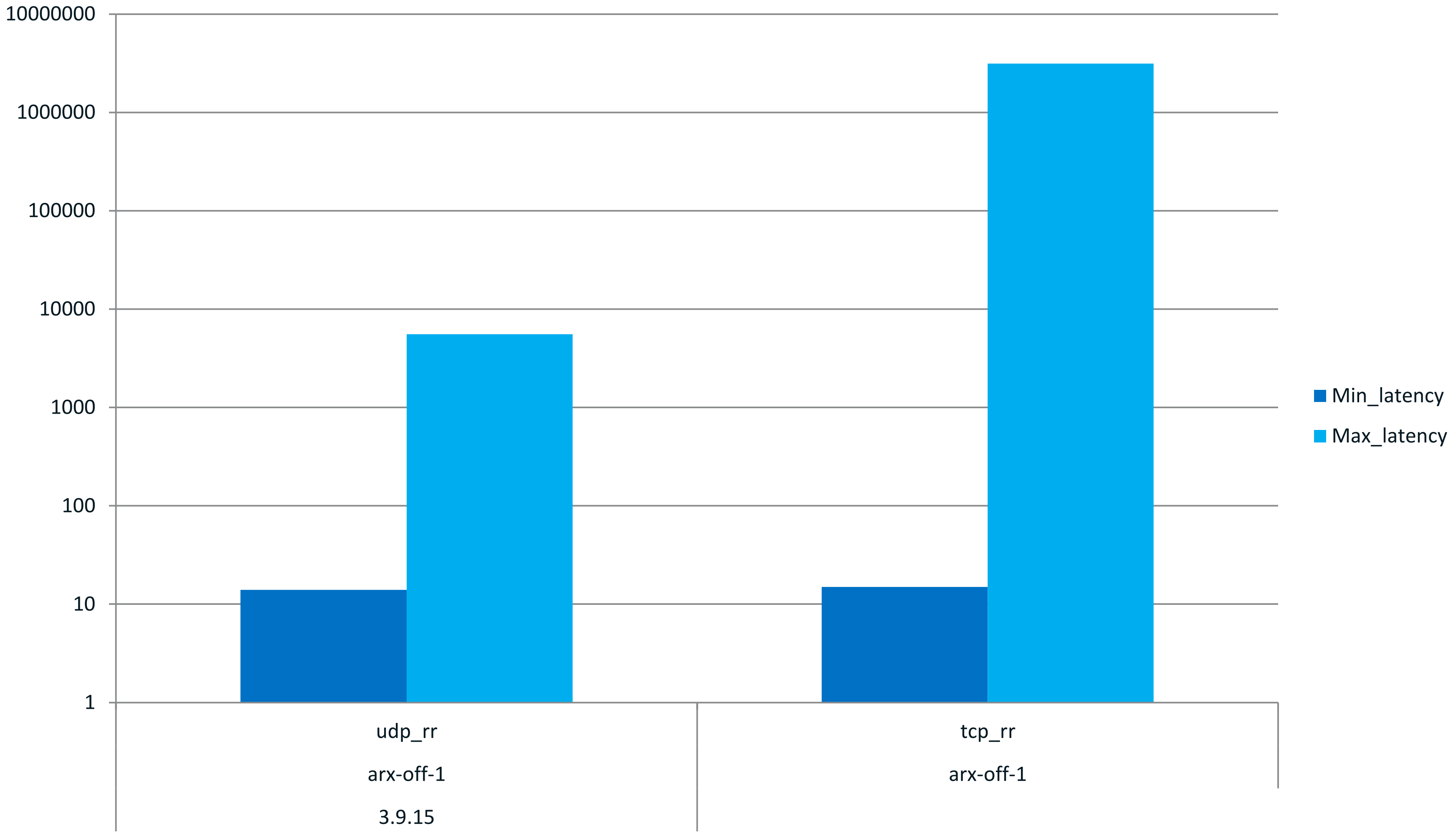


Latency Breakdown kernel v3.5

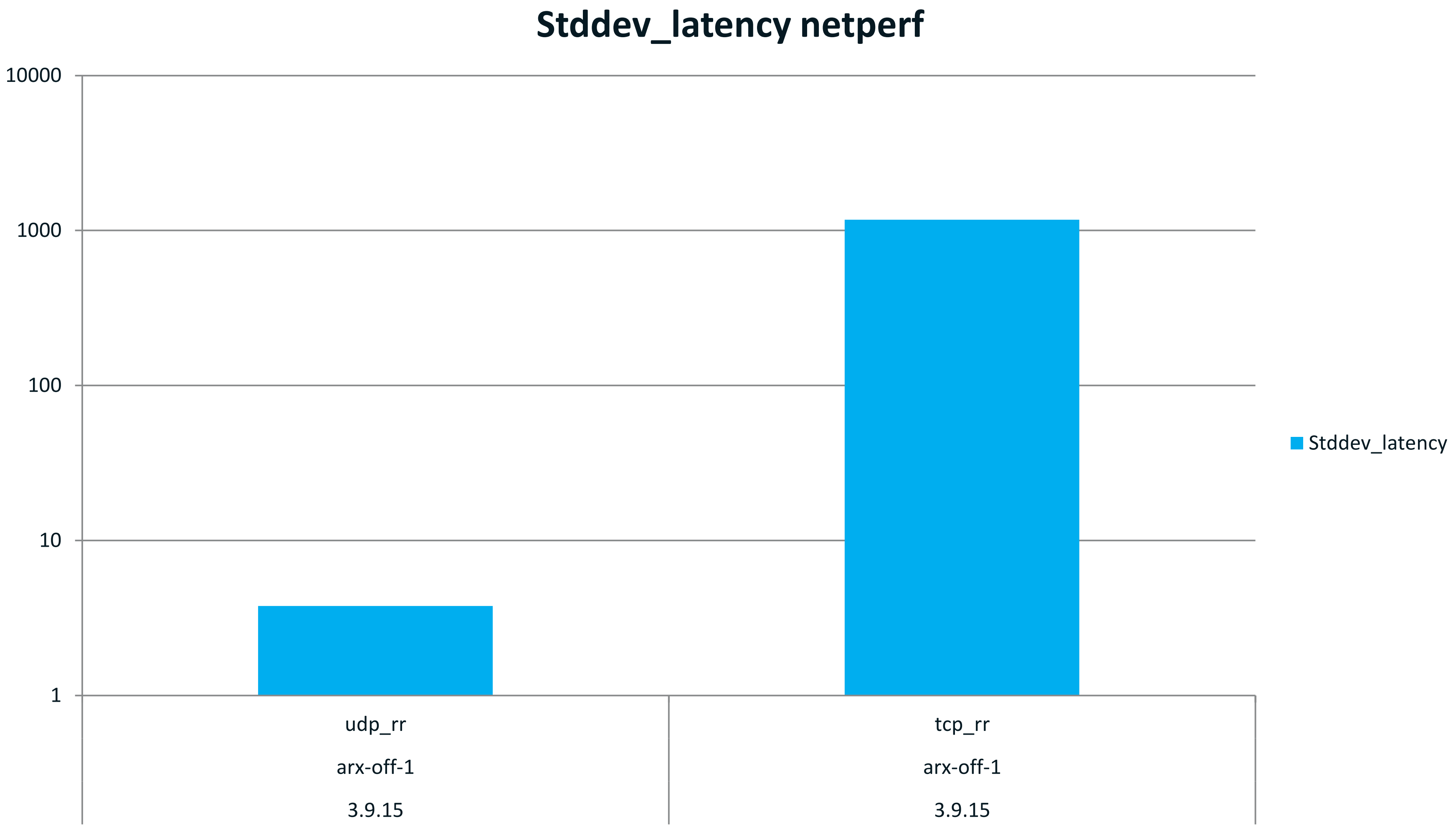


- Total: 5722 ns

Jitter Measurements
min/max in us measured by netperf



Jitter Measurements
standard deviation measured by netperf



Proposed Solution

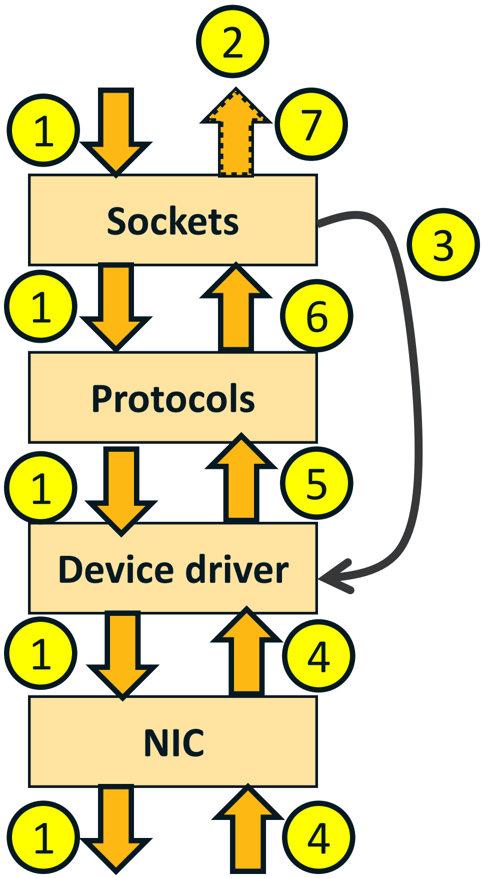
- Improve the software latency and jitter by driving the receive from user context
- Result
  - The Low Latency Sockets proof of concept

Low Latency Sockets (LLS)

- LLS is a software initiative to reduce networking latency and jitter within the kernel
- Native protocol stack is enhanced with a low latency path in conjunction with packet classification (queue picking) by the NIC
- Transparent to applications and benefits those sensitive to unpredictable latency
- Top down busy-wait polling replaces interrupts for incoming packets

New Low-Latency Transaction Flow

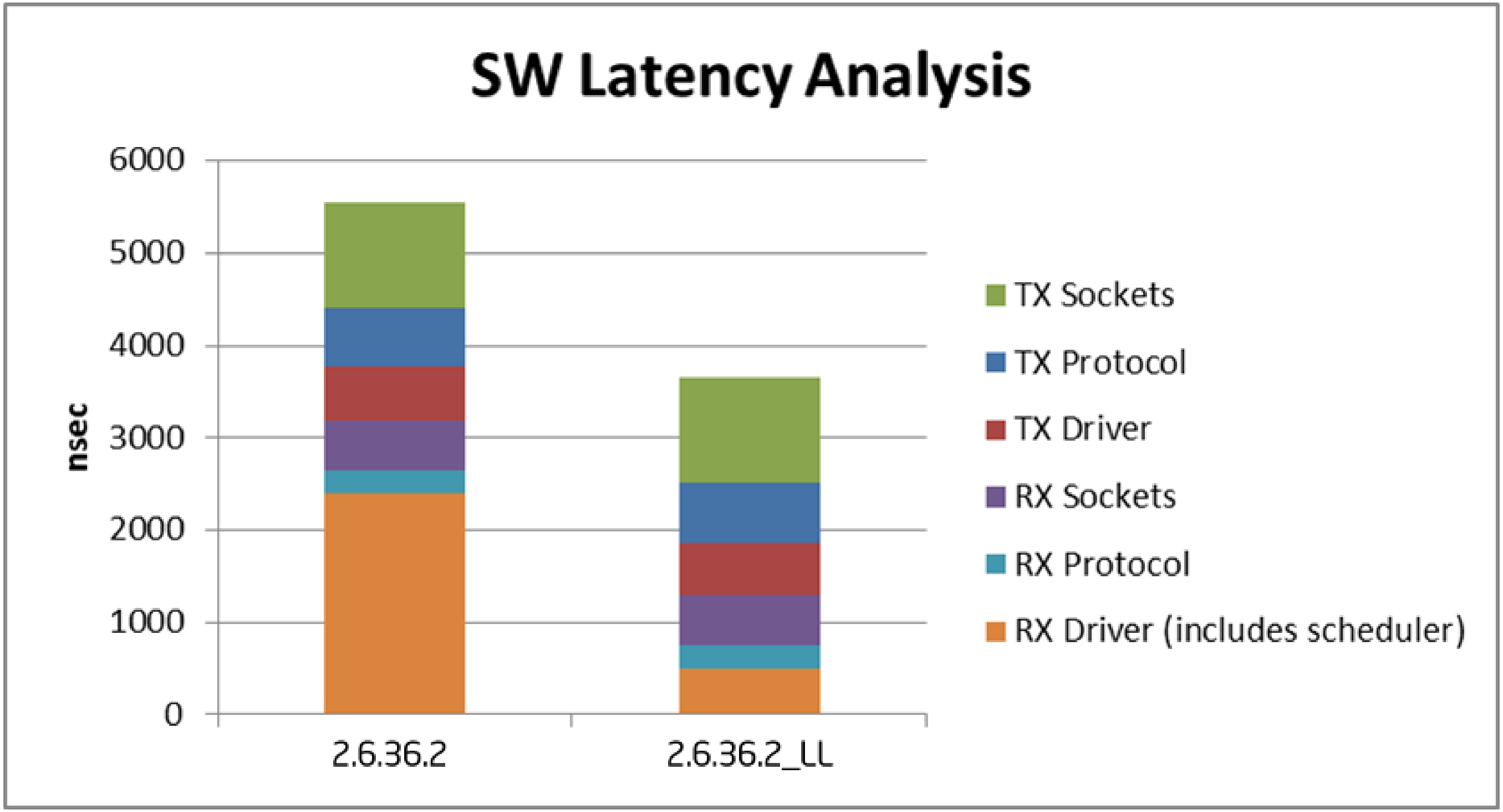
1. App transmits thru sockets API
   - Passed down to driver and h/w unblocked
   - TX is “Fire and Forget”
2. App checks for data (receive)
3. Check device driver for pending packet (poll starts)
4. Meanwhile, packet received to NIC
5. Driver processes pending packet
   - Bypasses context switch & interrupt
6. Driver passes to Protocol
7. App receives data through sockets API
8. Repeat



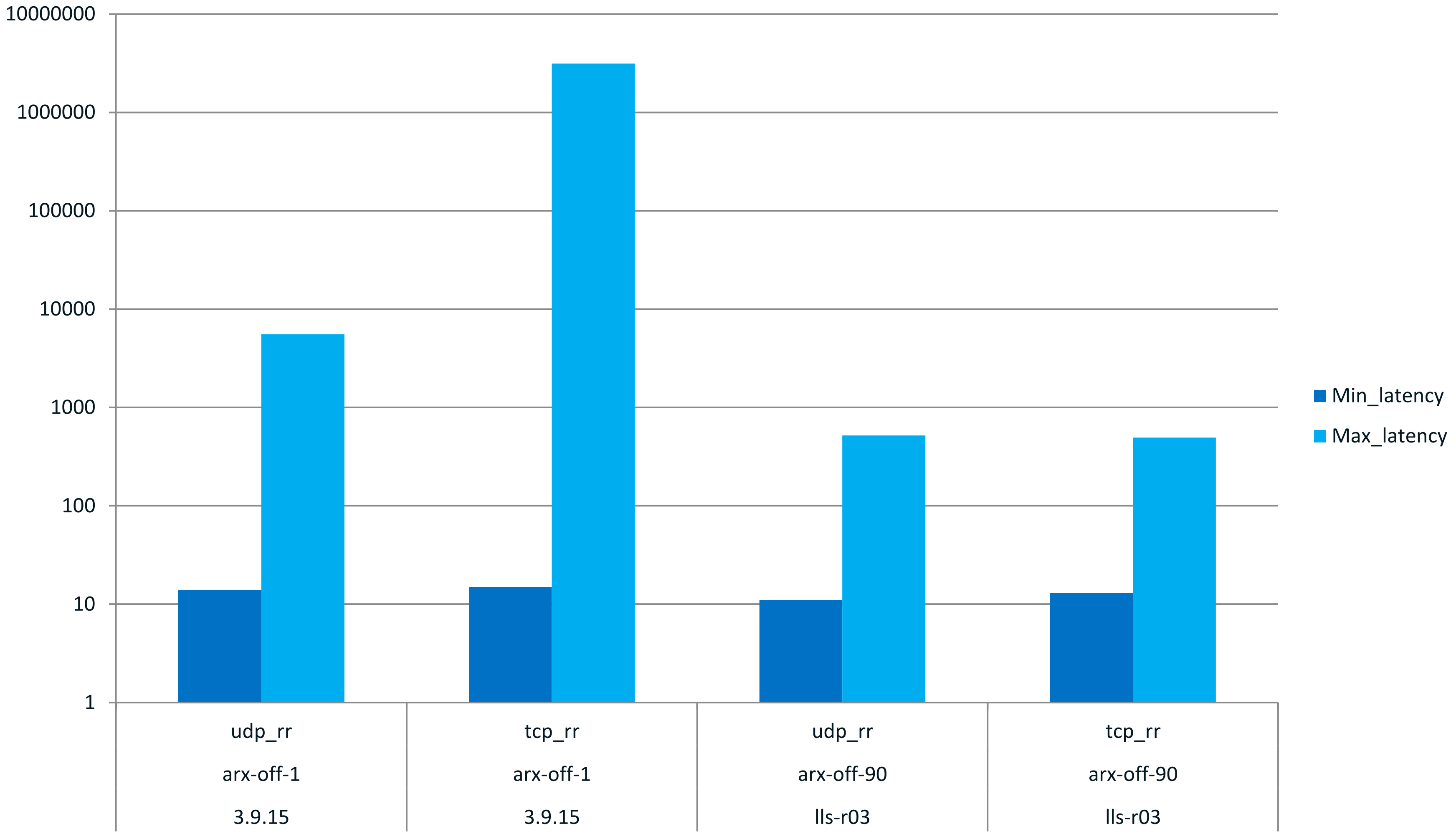
Proof of Concept

- Code developed on 2.6.36.2 kernel
- Initial numbers done with ixgbe driver from out of tree
- Includes lots of timing and debug code
- Currently reliant upon
  - hardware flow steering
  - one queue pair (Tx/Rx) per CPU
  - Interrupt affinity configured

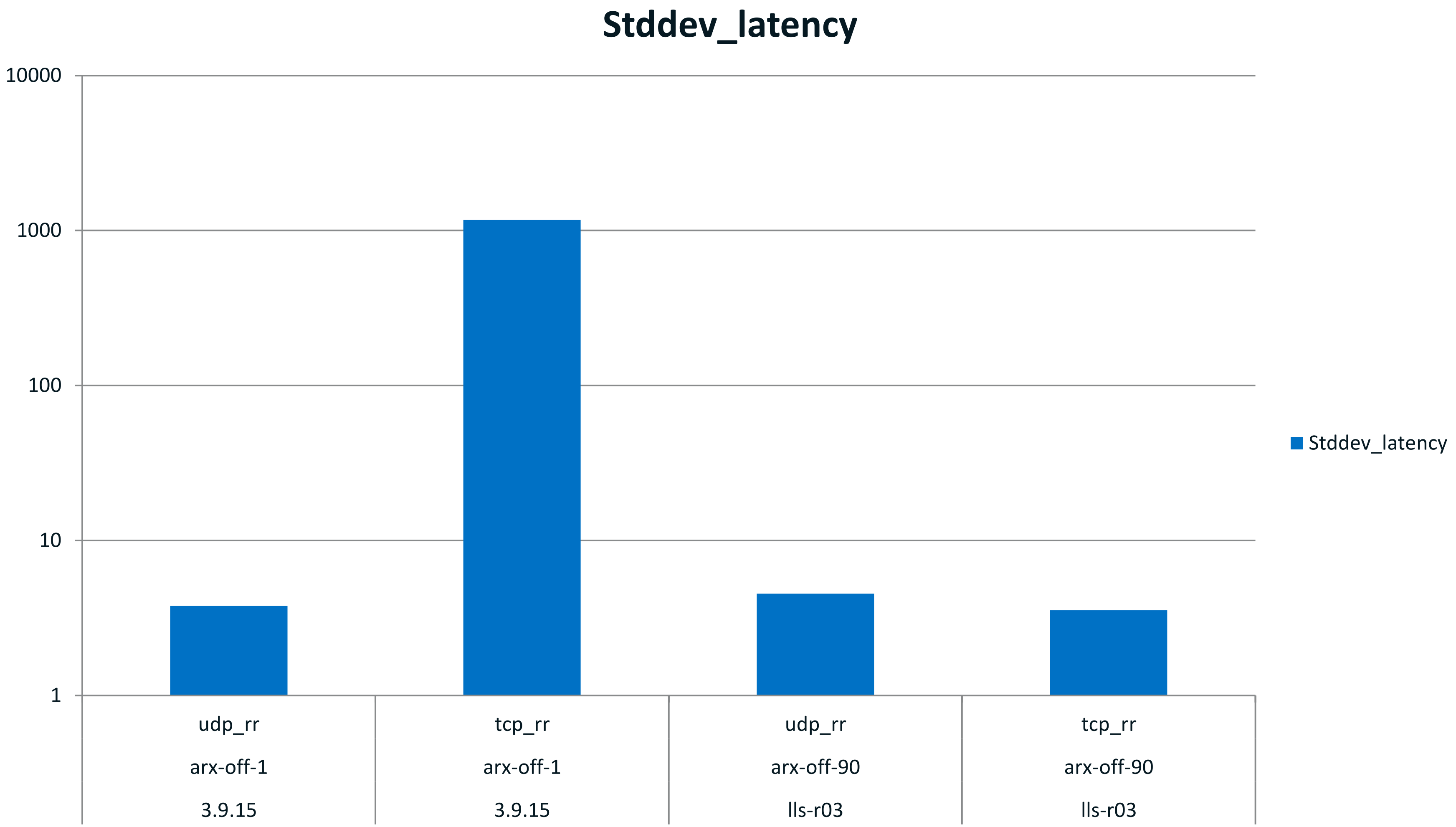
Proof of Concept Results (2.6.36.2)



Jitter Results
min/max latency in us, as measured by netperf



Jitter Results
standard deviation as measured by netperf



Possible Issues

- Unpalatable structure modifications
  - struct sk_buff
  - struct sk
- Dependency on driver or kernel implemented flow steering
- Current amount of driver code to implement
  - Current work already in progress on a much simpler version
- Default enabled?
  - How can we turn this on and off
    - Don't want a socket option – defeats the purpose
- Security issues?
  - Application can now force hardware/memory reads – unlikely to be an issue
  - The new poll runs in syscall context, which should be safe but we need to be careful to not create a new vulnerability
  - does this new implementation create other problems?

Current work

- Work in progress includes
  - Further simplified driver using a polling thread
  - Port of the current code to v3.5
- Future work
  - Post current v3.5 code to netdev (Q4 – 2012)
  - Design and refactor based on comments
  - Make sure new flow is measurable and debuggable

Code

- Git tree posted at:
  - https://github.com/jbrandeb/lls.git
- Branches
  - v2.6.36.2_lls
    - Original 2.6.36.2 based prototype
  - v3.5.1_lls
    - Port of code to v3.5.1 stable (all features may not work yet)

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Summary

- Customers want a low latency and low jitter solution
  - We can make one native to the kernel
- LLS prototype shows a possible way forward
  - Achieved lower latency and jitter

- Discussion
  - What would you do differently?
  - Do you want to help?

Backup

Abstract

- Development-in-progress of a new in-kernel interface to allow applications to achieve lower network latency and jitter
- Creates a new driver interface to allow an application to drive a poll through the socket layer all the way down to the device driver
- Benefits are
  - applications do not have to change
  - Linux networking stack is not bypassed in any way
  - Minimized latency of data to the application
  - Much more predictable jitter
- The design, implementation and results from an early prototype will be shown, and current efforts to refine, refactor, and upstream the design will be discussed
- Affected areas include the core networking stack, and network drivers