SPANIDS

A Parallel High-bandwidth Network Intrusion Detection Platform

Lambert Schaelicke

&

SPANIDS Group
University of Notre Dame

Outline

- Network Intrusion Detection Overview
- Performance Requirements
- Parallel NIDS: Spanids
- Prototype Development

1. Network Intrusion Detection Overview

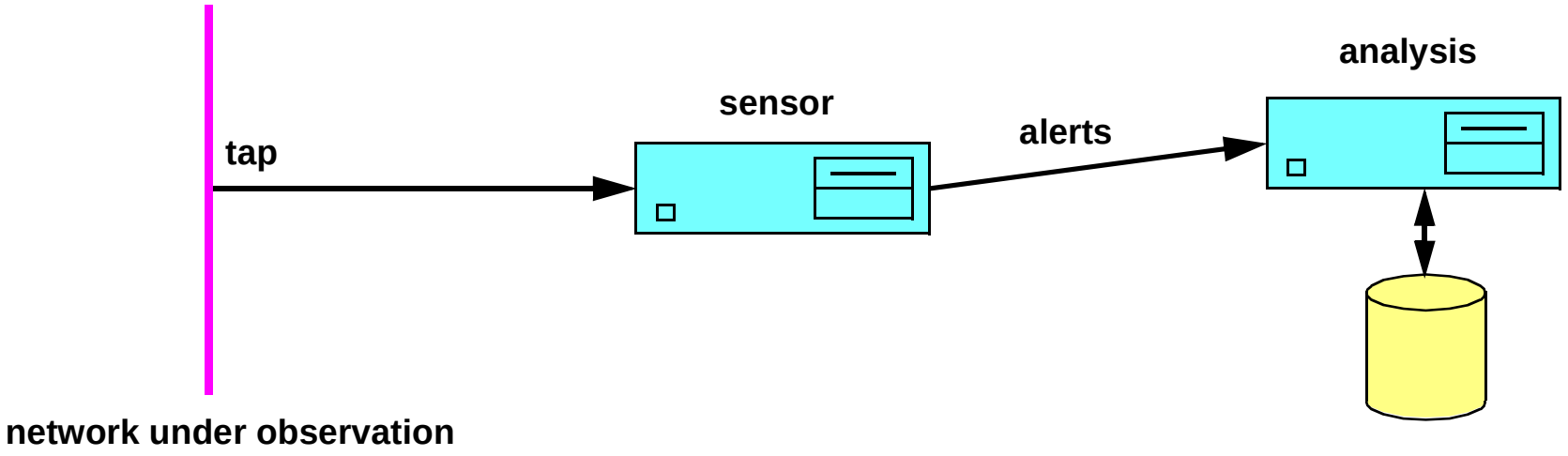
Network Intrusion Detection

Data security and integrity has become a major concern.

- prevent: firewalls, encryption, anti-virus tools, patches etc.
  - first line of defense
  - always catching up with attackers
- detect: alert administrator of attack or intrusion
  - allows reaction to unpreventable attacks
  - network & host-based intrusion detection

Network IDS complements other defense mechanisms.

General-purpose NIDS Architecture



- sensor analyzes all network packets
  - real-time detection of attacks
  - filters out packets of interest
- ‘database’ back-end for long-term storage and alert correlation

NIDS Approaches

Rule-based

- apply set of rules to each packet
- issue alert upon match
- limited to known attacks

Anomaly-based

- establish normal network behavior
- issue alert upon deviation from norm
- can potentially detect previously unknown attacks

Snort NIDS

Open-source Intrusion Detection

- popular NIDS software with large user base
- frequently updated rule set

Rule-based

- inspect packet header and/or payload
- covers ICMP, TCP, UDP, ... and all popular application protocols
- specific attacks and policy violations
- over 2000 default rules

Snort Rule Example

MS SQL Buffer Overflow Attack

```
alert udp $EXTERNAL_NET any -> $SQL_SERVERS any
  (msg:"MS-SQL probe response overflow attempt";
   content:"|05|"; depth:1; byte_test:2,>,512,1;
   content:"|3b|"; distance:0; isdataat:512,relative;
   content:!"|3b|"; within:512;
   classtype:attempted-user;
   sid:2329; rev:2;)
```

Bro NIDS

Rule-based, stateful analysis

- keeps track of connections
- applies scripted policies to connections and/or payload
- kernel-level packet filter may reduce analysis load
- open-source, but less well-supported than Snort

Alternative: Anomaly Detection

Establish Normal Behavior

- track high-level traffic statistics
  - packet rates, sizes, ports ...
- in most cases automatically extracted during learning phase

Alert upon Deviation from Norm

- so far successful mostly for DOS attacks
- too many false positives in general scenarios
- difficult to adjust to changing baseline behavior

Attacking & Avoiding the NIDS

Rule-based

- overwhelm NIDS with high-intensity traffic
- deviate from known attack patterns

Anomaly-based

- minimize perturbation of normal traffic
  - e.g. slow ramp-up of DOS attack, slow port scan
- insert attacks during learning period

Noise: Generate Large Number of non-critical Alerts

2. NIDS Performance

NIDS Performance

1. Qualitative = Sophistication

- detect all true attacks and intrusions
- minimize false alerts

2. Quantitative = Speed

- inspect all packets under all network conditions
- packet loss degrades quality

Both factors are important!

Snort Performance Requirements

1. Header Inspection

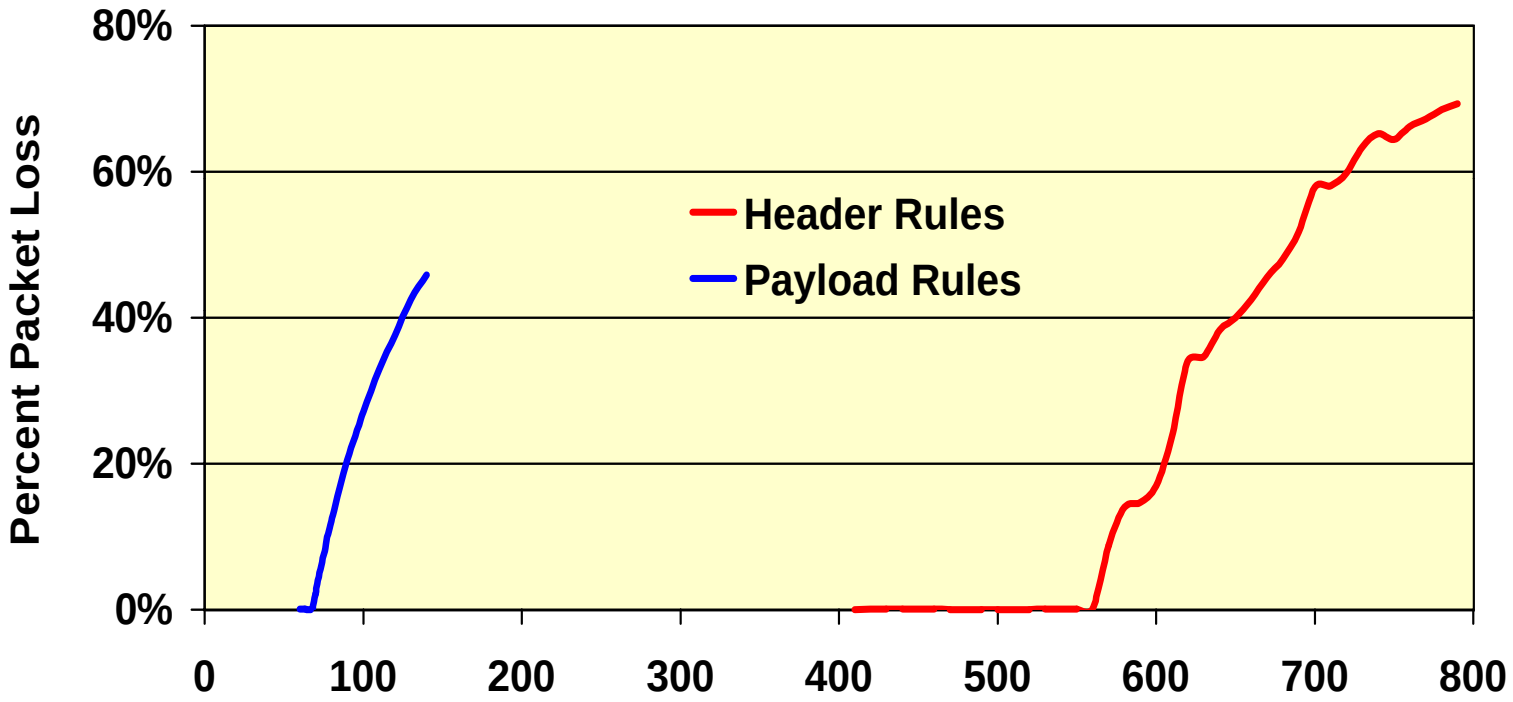
- constant per-packet cost
- limited by interrupt handling and protocol processing overhead

2. Payload Analysis

- scales with payload size
- limited by main memory bandwidth

Most rules combine both types of analysis.

Snort Performance Characteristics



- 1.2 Ghz P-3, saturated 100 Mbit Ethernet, 512-byte frames
- standard Snort distribution includes over 2000 rules

Measurement Approach

Constant network traffic

- *ttcp* session over 100 Mbit Ethernet between Linux hosts
- fixed data and packet rate – nearly 100% saturation
- passive tap forwards traffic to test system

Increase number of Snort rules

- observe packet loss
- record number of rules when exceeding 2.5 % loss
- separate header and payload rules

Experimental Setup

Six Different NIDS Platforms

- x86 Intel & AMD, 180 to 2400 Mhz, single and dual processor
- Linux and FreeBSD
- gauge architectural and OS sensitivity

Traffic Scenarios

- 64 – 512 – 1000 – 1452 byte packets
- cover complete spectrum of packet sizes

Results Normalization

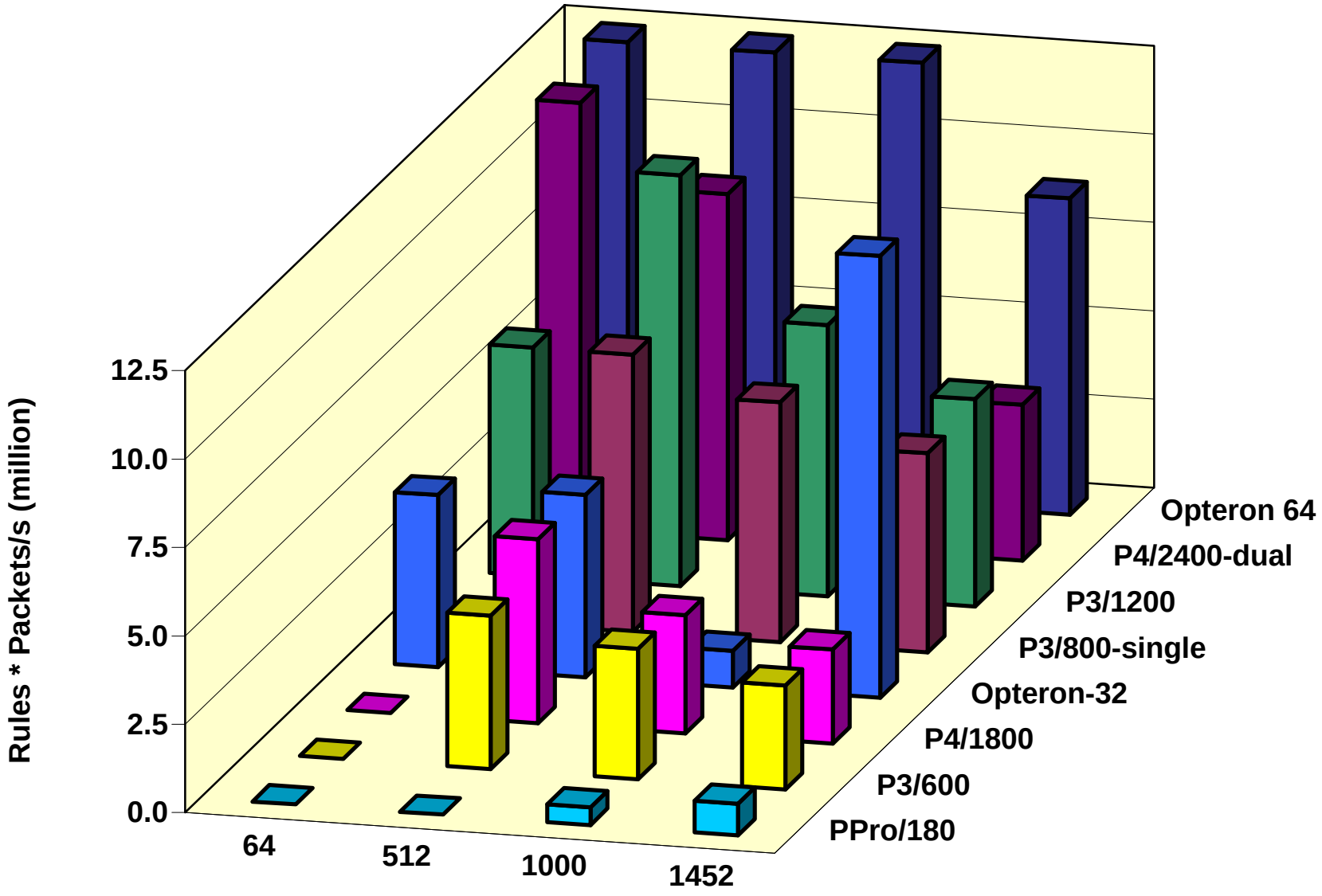
Header Rules * Packets / Second

- approximately constant cost per packet
- account for varying packet rates in tests

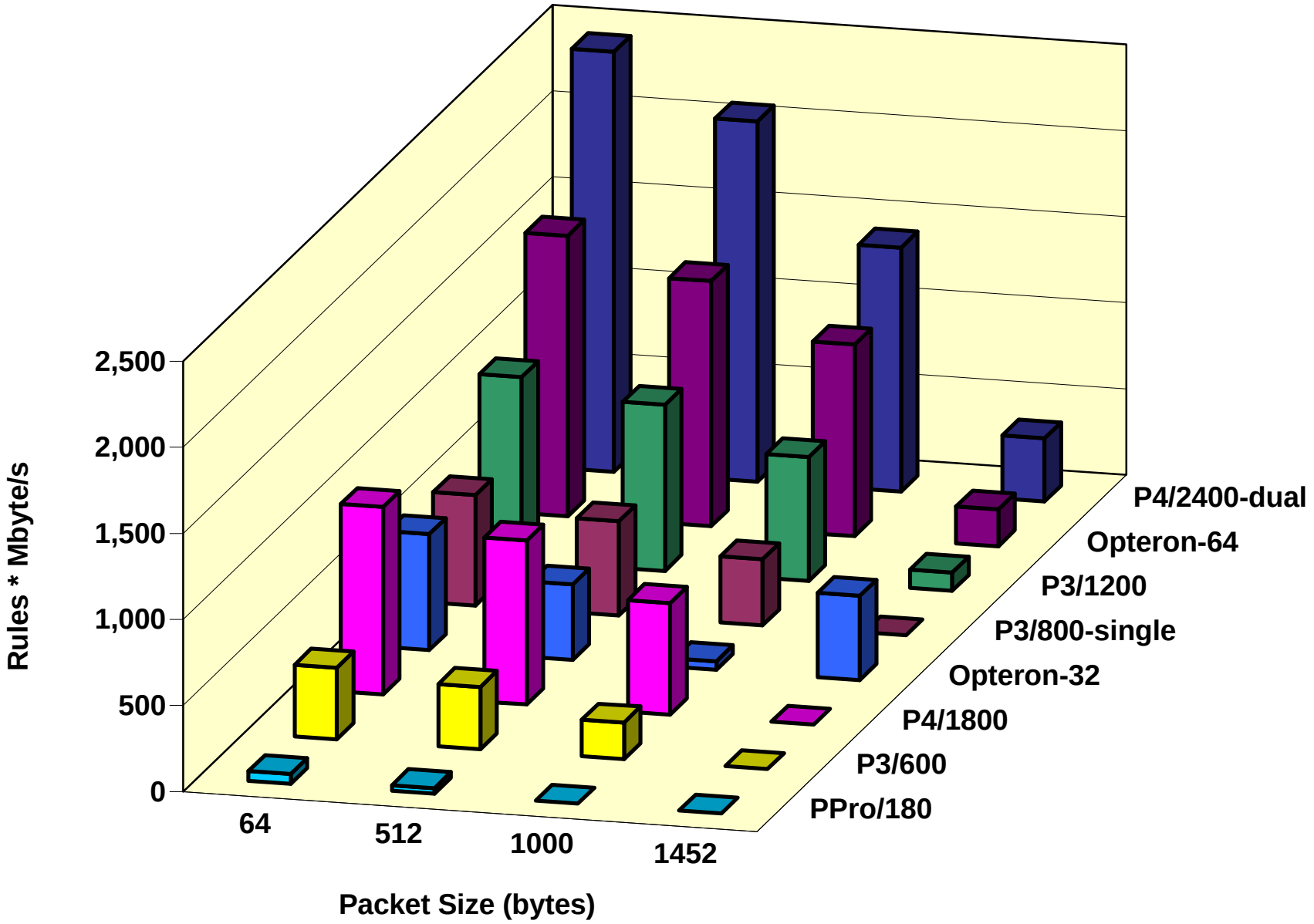
Payload Rules * Mbytes / Second

- approximately constant per-byte cost
- account for varying effective bandwidth

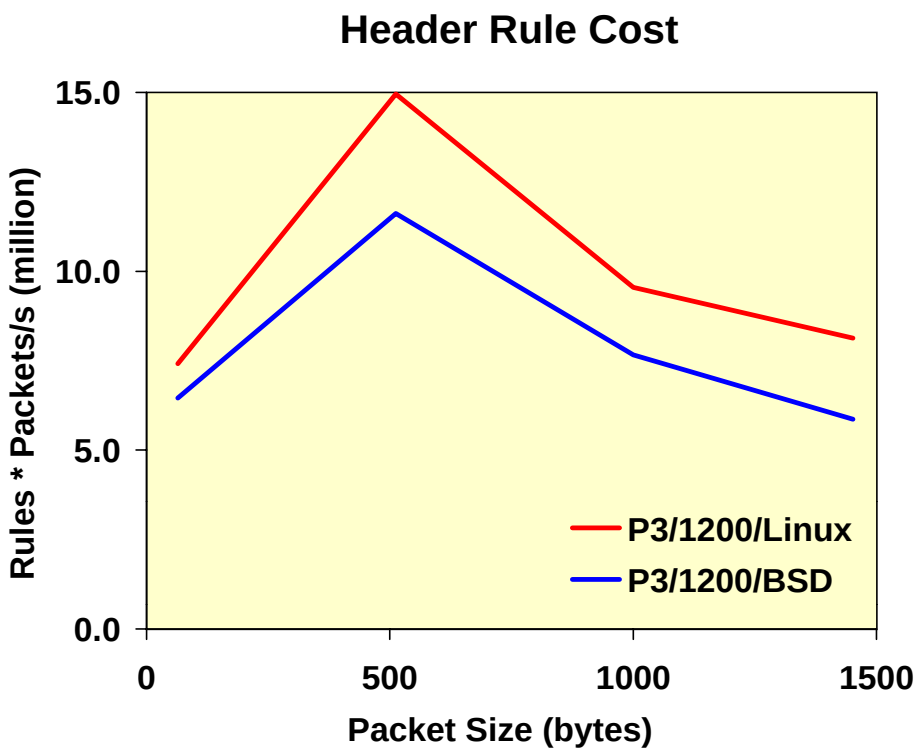
Header Rule Performance

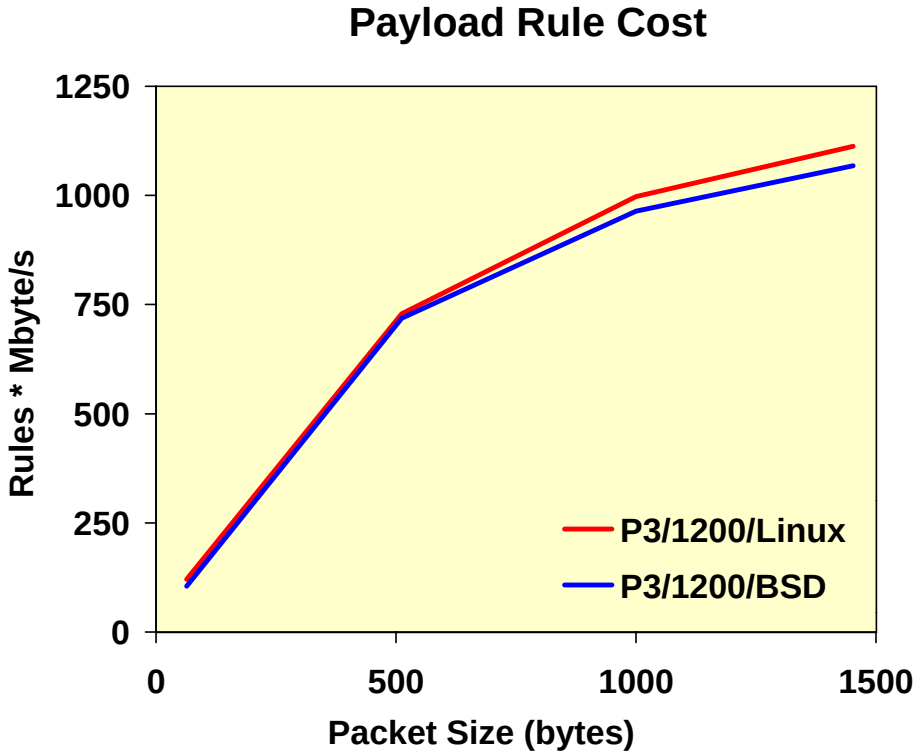


Payload Rule Performance



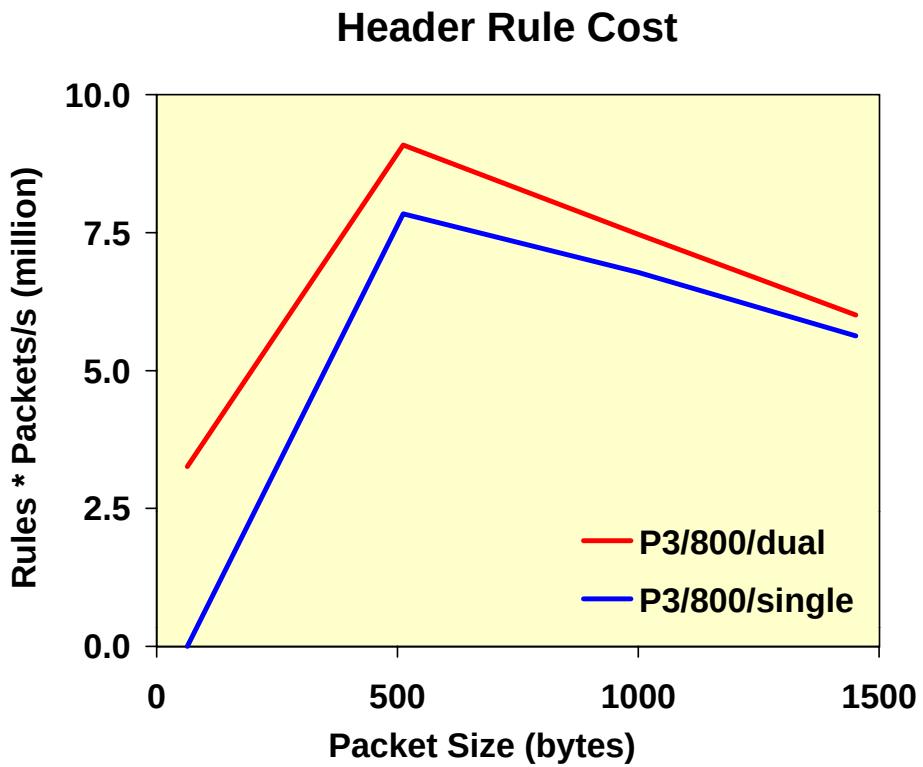
OS Sensitivity

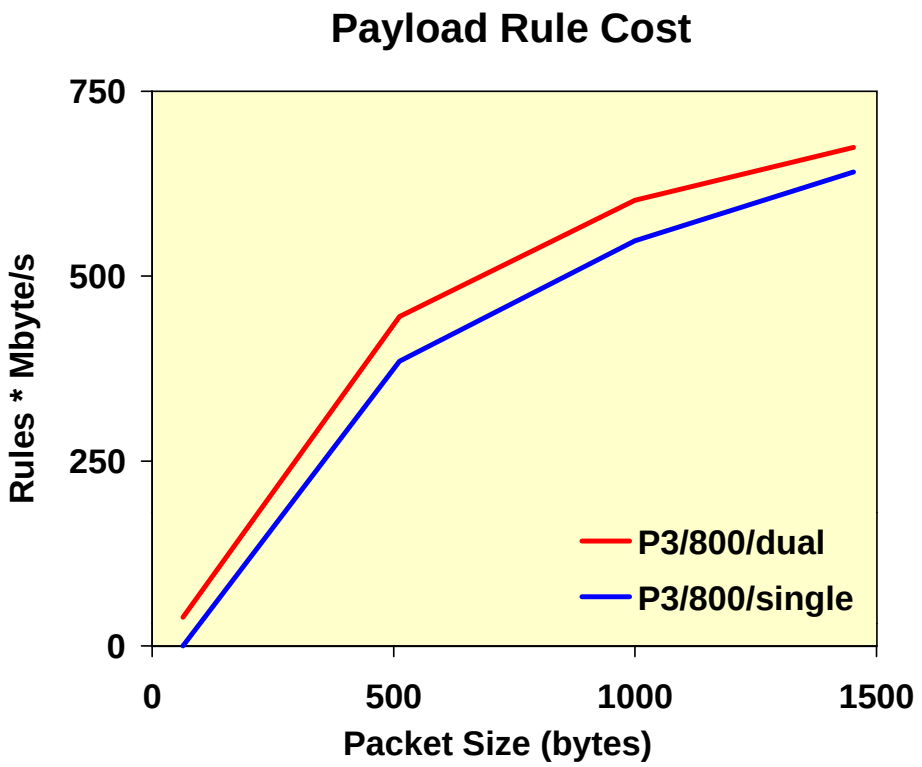




- Linux outperforms BSD for header rules
- small per-packet cost – interrupt handling dominates

Multiprocessor Sensitivity





- some benefit from offloading interrupts
- minor impact on payload analysis

Performance: Conclusions

CPU Speed Not a Good Indicator of NIDS Capabilities

- main memory bandwidth critical
- deep pipelines hurt NIDS performance
- some difference between kernels
- little benefit from multiprocessing
  - but server-class memory subsystems helps

3. Parallel NIDS: Spanids

The Sensor Bottleneck

Single-stream Design Limits Performance

- general-purpose system overwhelmed by interrupts
  - GigE: up to 1.5 million packets per second
  - > 1 µs per interrupt: CPU is saturated
- limited bandwidth
  - 125 Mbyte/s saturates 32-bit PCI bus
  - 3 data transfers: DMA, kernel read, user write

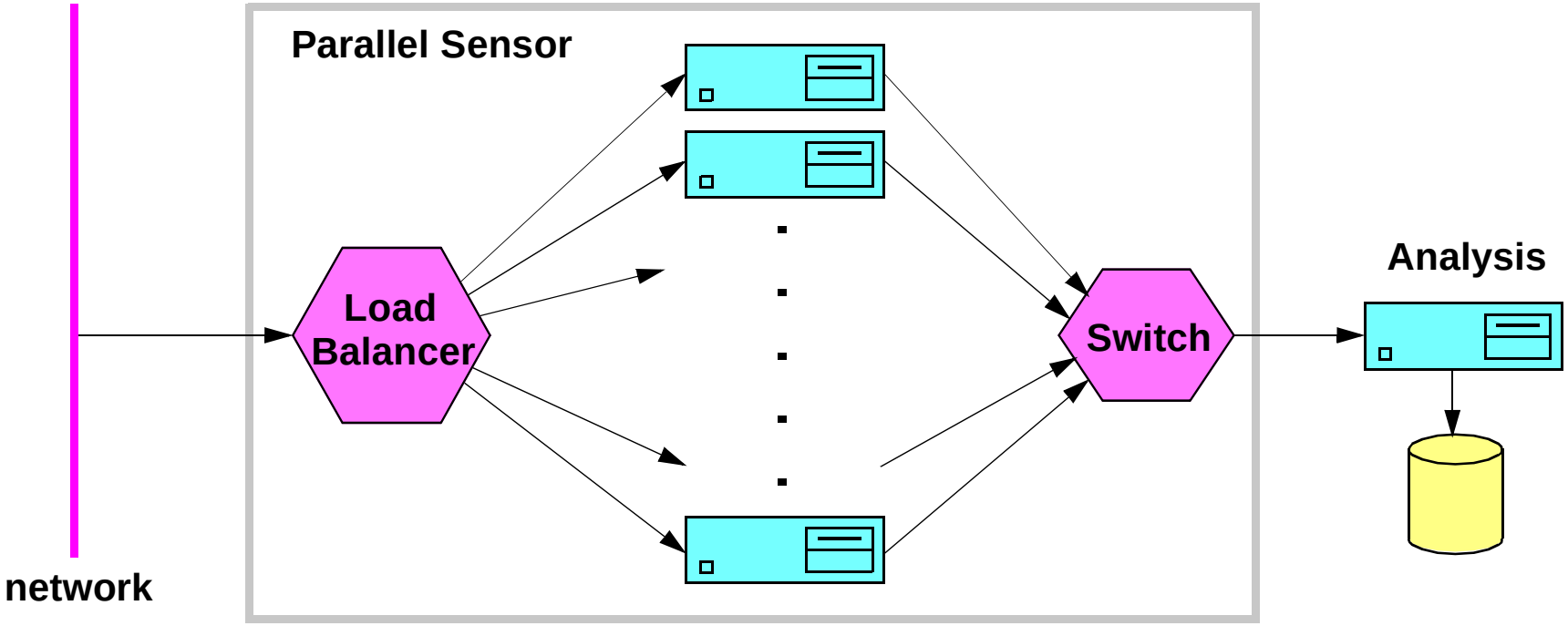
PC/Workstation incapable of receiving Gb/s traffic – unsuitable as high-bandwidth NIDS platform.

Parallel NIDS

Distribute traffic over multiple sensors.

- exploit concurrency in network traffic
- greater aggregate performance
- retains benefit of commodity hardware & software
  - cost-effective & flexible
  - rides desktop performance curve
  - benefits from software improvements
- scalable: just add sensors

Parallel Architecture



- custom load balancer distributes packets across sensor array
- off-the-shelf sensors running standard NIDS software
- aggregate and forward alerts to analysis engine

Parallel NIDS Challenges

Effective Distribution of Work

- (nearly) equal load for all sensors

Scalability

- scale with offered network load
- load balancing must not become bottleneck
- avoid maintaining per-connection or per-packet state

Minimize Vulnerabilities

Throughput & Scalability

- must keep up with peak network load
- adapt to load changes

Limited View of Each Sensor

- potential loss of precision
- avoid distributing connections over multiple sensors
- current NIDS software keeps limited state anyway

Parallel NIDS Approaches

Flow Balancing: TopLayer

- round-robin distribution of connections
- based on Cisco router
- stateful: keeps track of active connections

Parallel Routing

- round-robin scatter to array of routers
- forward flows to sensor array

Other High-speed NIDS Approaches

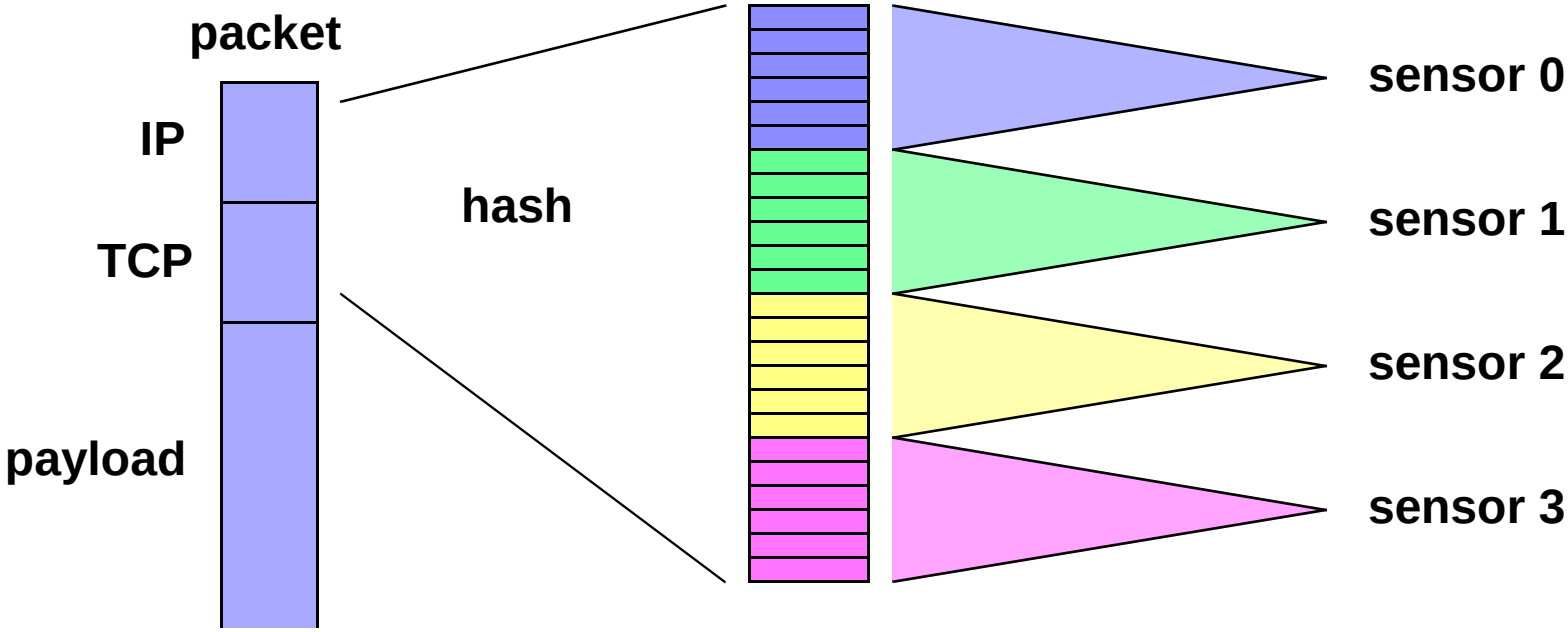
Pre-Filtering

- analyze only ‘interesting’ packets
- software (Bro) or hardware filter
- which packets?

High-end System & Optimized Driver

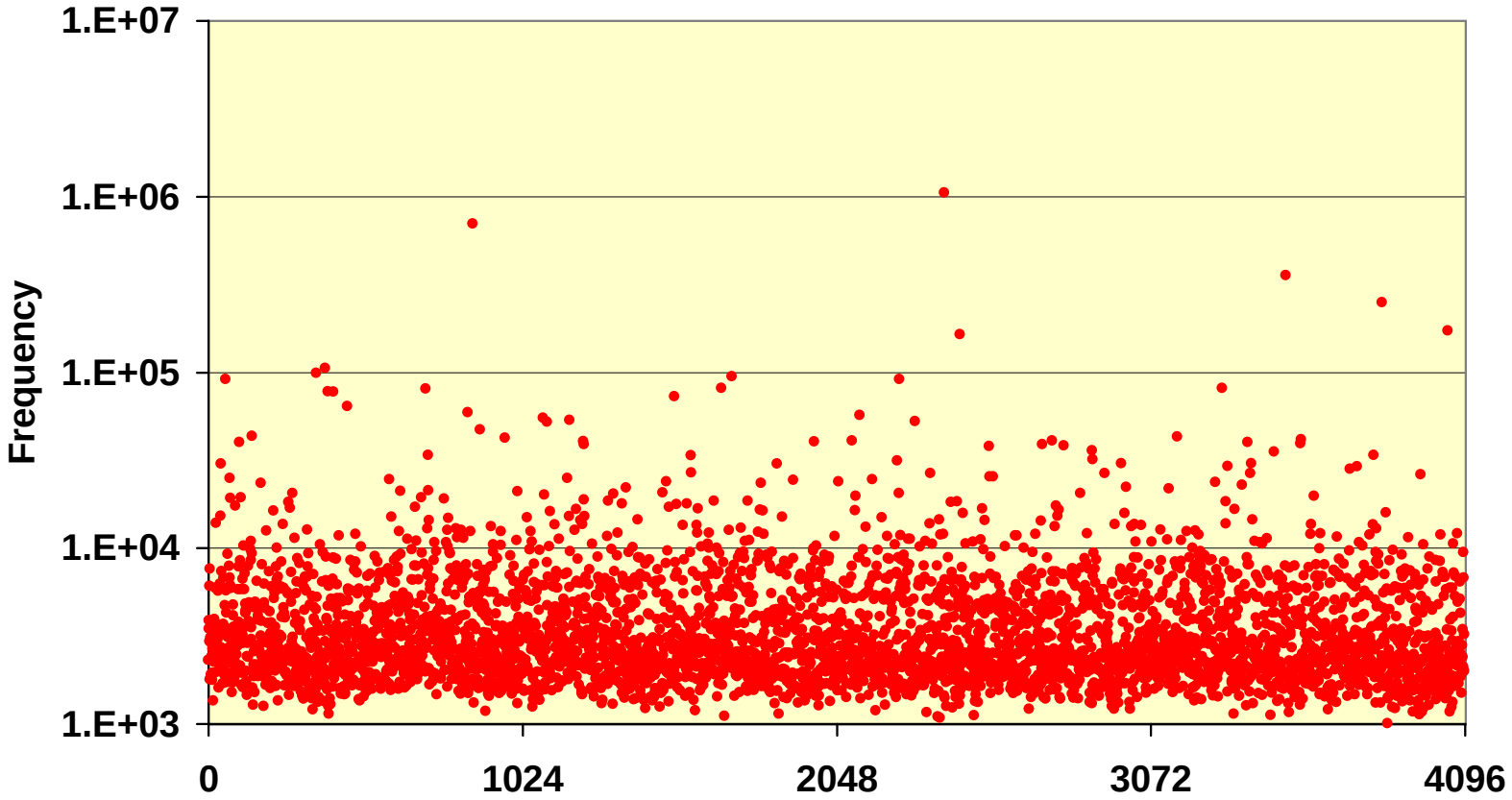
- may support very light-weight NIDS processing
- does not scale to next generation networks

The SPANIDS Approach



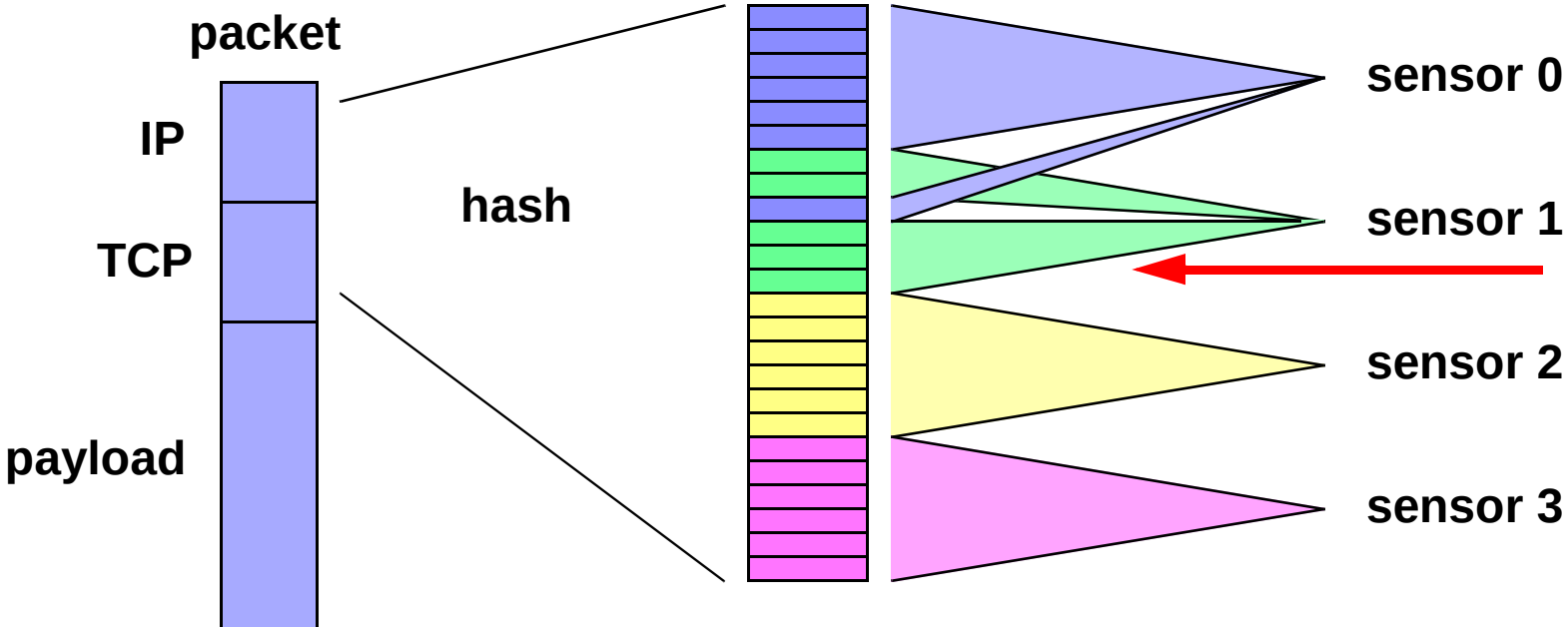
- hash connection ID to large number of buckets: fixed-size state
  - src/dest IP, src/dest port
  - avoid breaking up network flow
- assign buckets to sensors

Hash Example



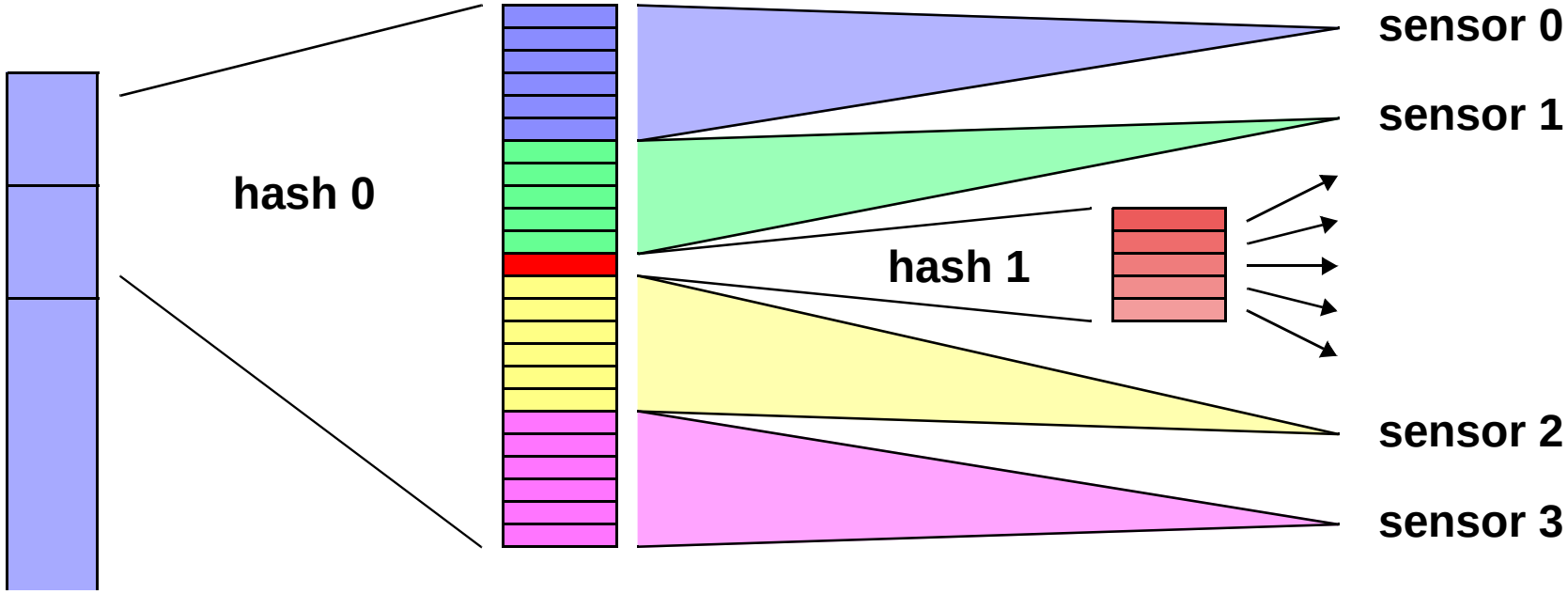
- 60 minute trace of ND Campus feed
- 12 bit XOR hash of source/destination IP address, port numbers

Dynamic Loadbalancing



- reassign hash buckets when sensor load exceeds threshold
  - which bucket ?
- in initiated by flow control feedback from sensor
  - based on packet buffer utilization

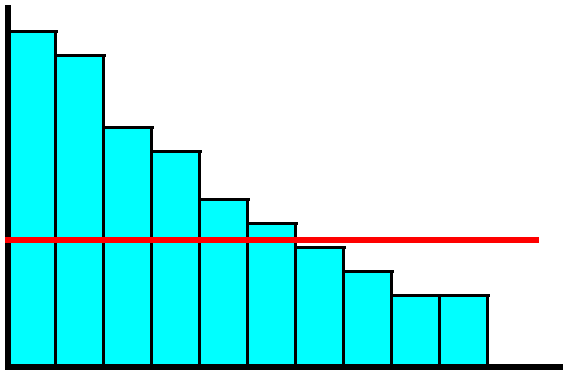
Hot Buckets



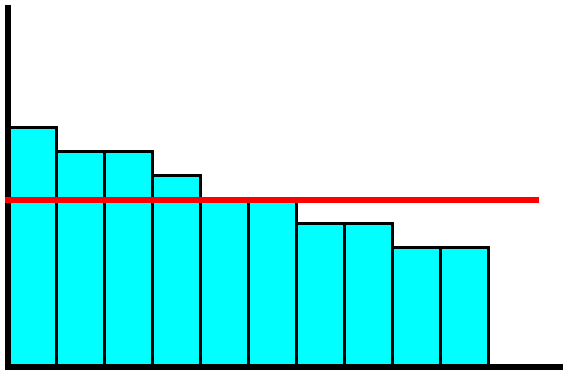
- observe bucket load: packet and/or data rate
- rehash when exceeding threshold
- potentially multiple levels of hashing

Bucket Move vs. Promote

- per-sensor list of N hot buckets
- table of sensor packet rates



promote



move

- compare hottest buckets with average sensor rate
  - above certain percentage: promote to rehash

Evaluation

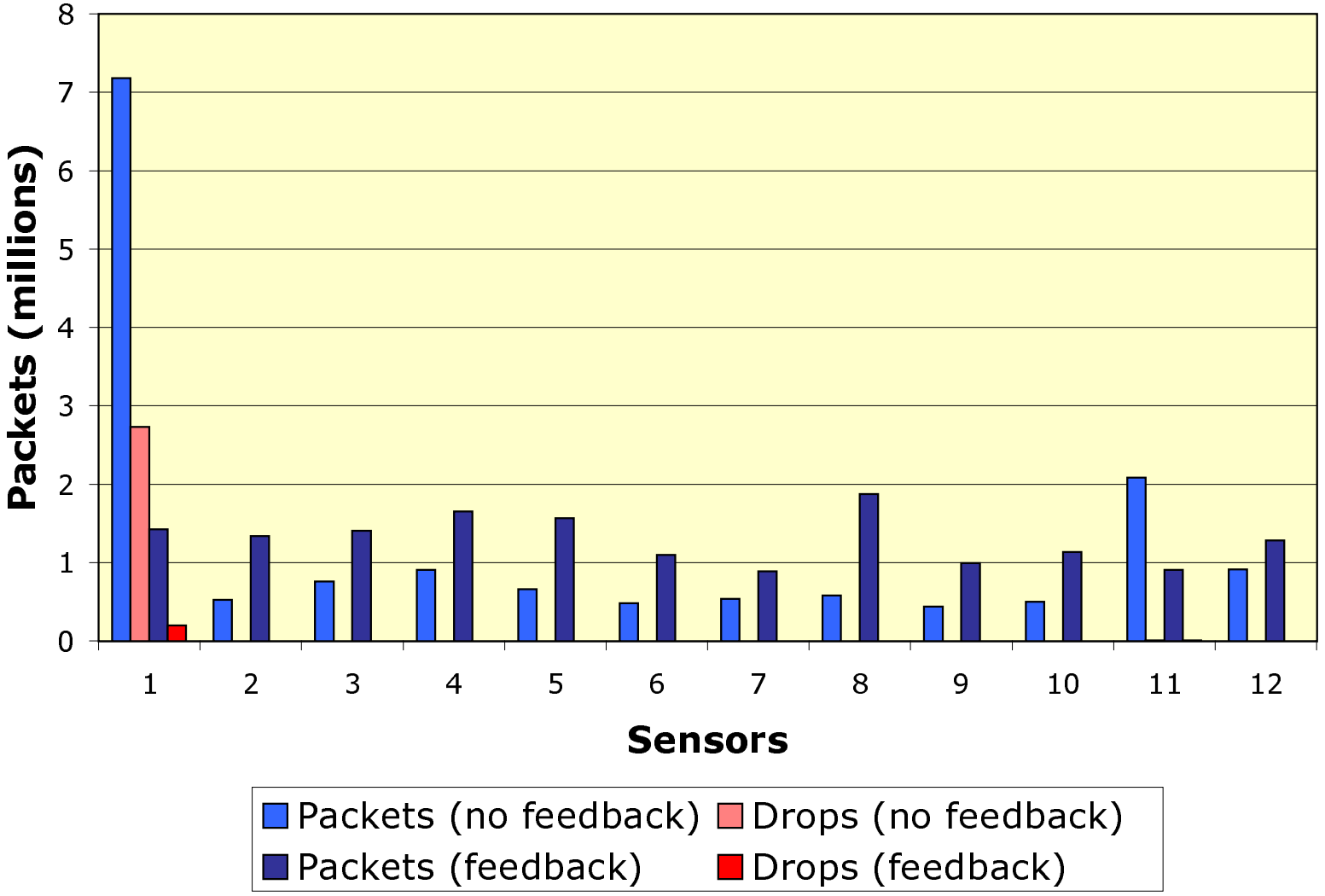
Trace-driven Simulation

- event-driven models of load balancer and sensors
- approximate sensor performance & issue flow control messages
- functionally accurate model of load balancer operation

The Trace Challenge

- real-life traces are benign & don't stress the load balancer
- must design for, and test worst-case
- solution: synthetic traces

Preliminary Results



- recover from imbalance, move-only

4. Spanids Prototype

Prototype Overview

Low-cost Sensors

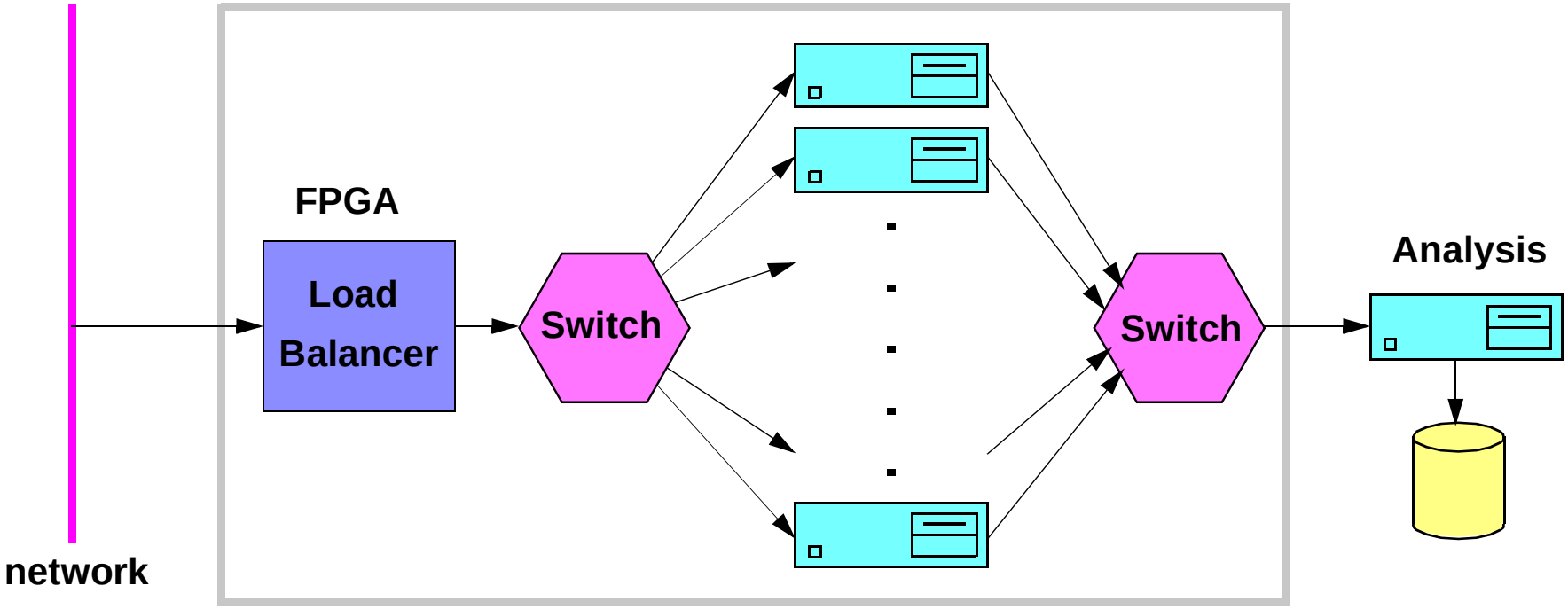
- general-purpose rack-mount Opteron servers
- Linux running Snort

Scalable Loadbalancing

- FPGA-based custom hardware combined with commodity switch
- evaluate variety of distribution schemes

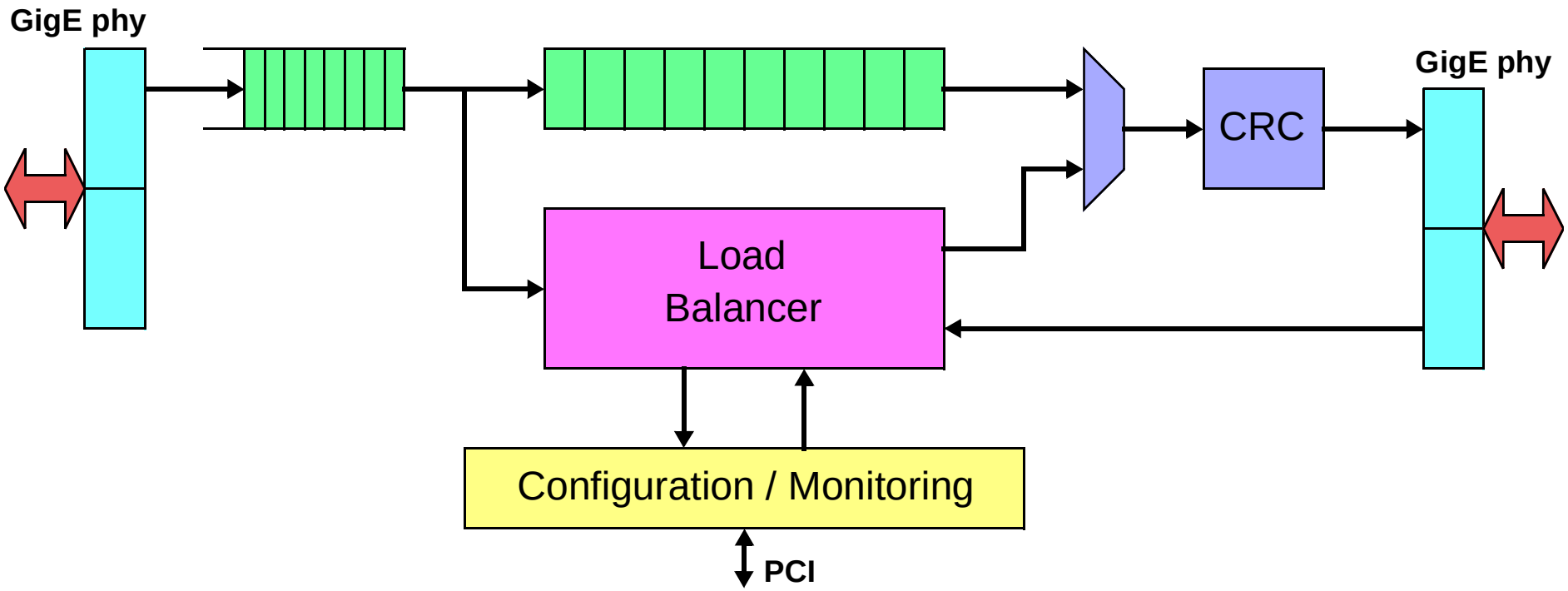
Handle Gigabit/s traffic with precision of single-stream design.

Prototype Architecture



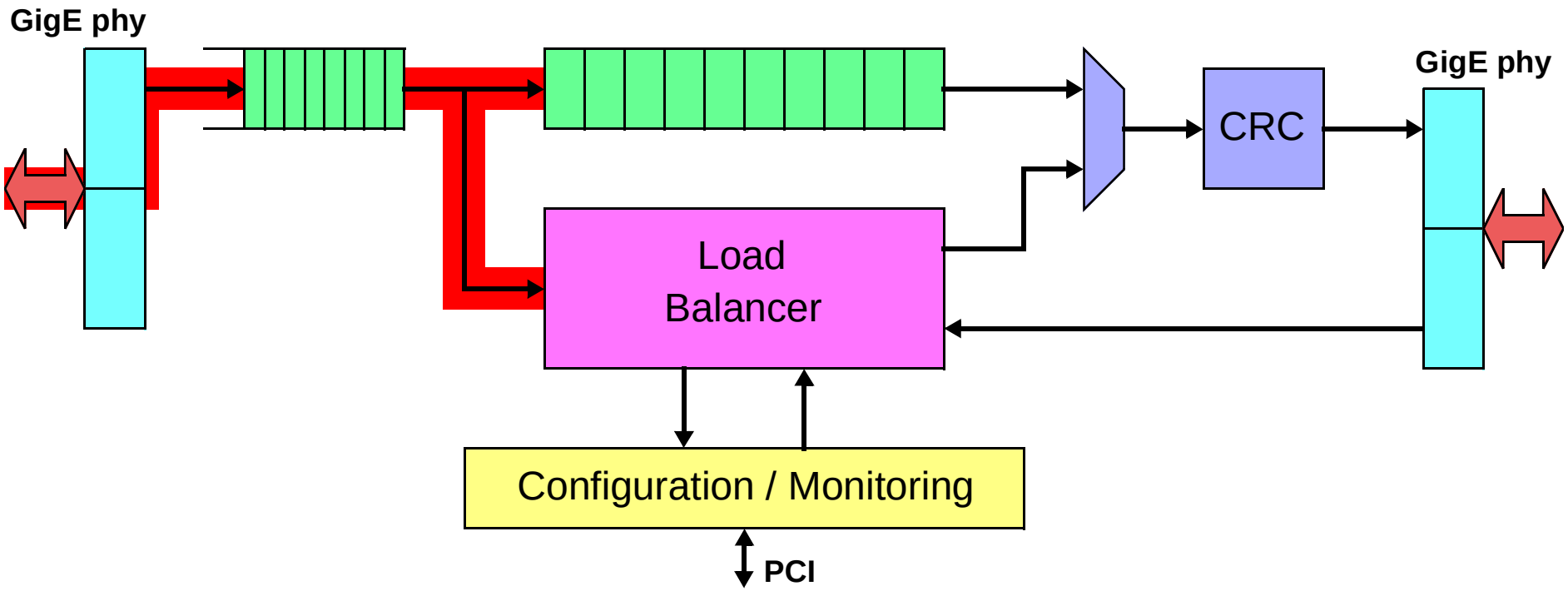
- FPGA-based loadbalancer rewrites Ethernet MAC address
- external commodity switch forwards packets
- two GigE ports on FPGA, off-the-shelf platforms available

Loadbalancer Architecture



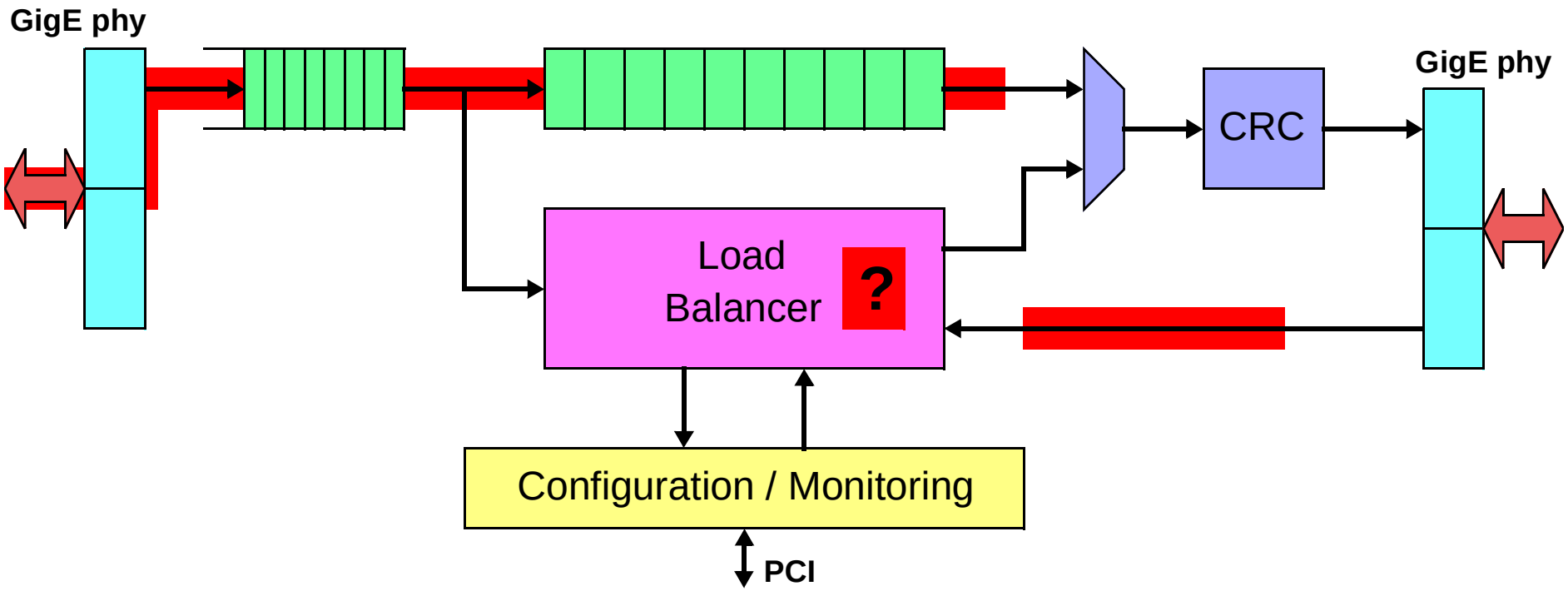
- two full-duplex GigE interfaces
- PCI target
- hash-based loadbalancer

Loadbalancer Packet Flow (1)



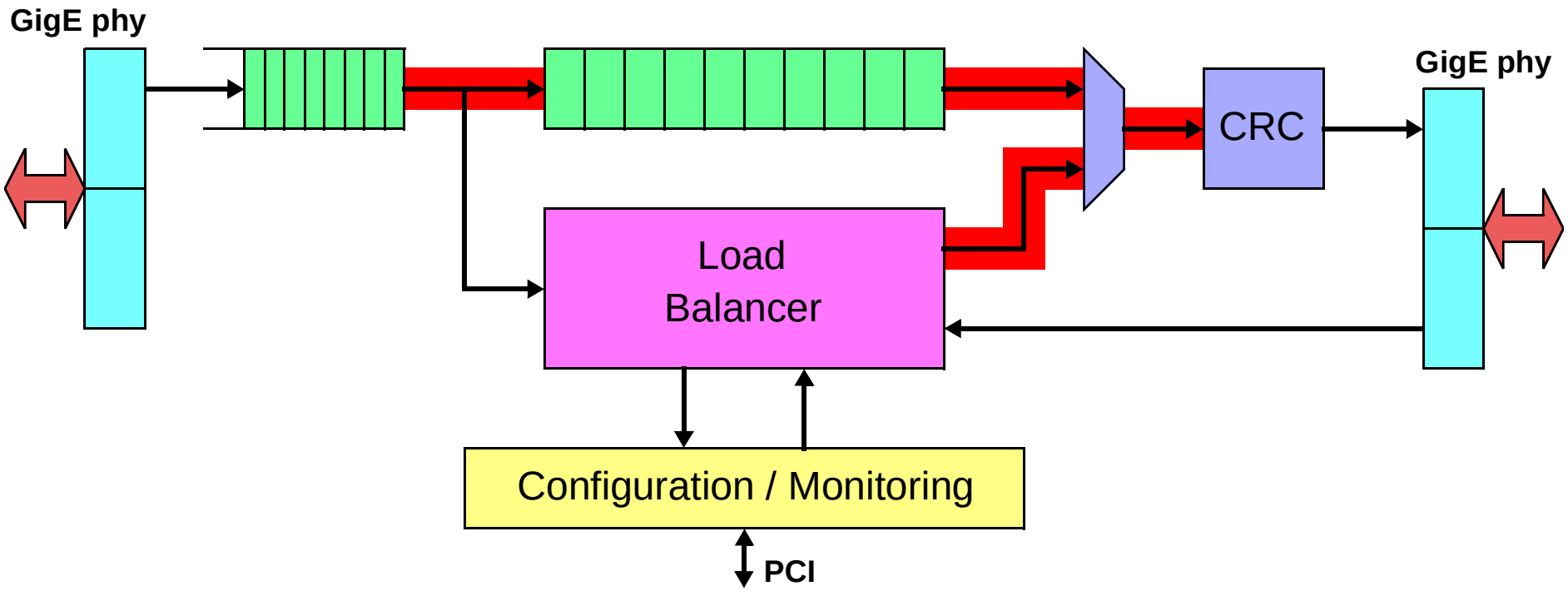
- input FIFO synchronizes GigE clock domains
- forward packet to router and delay pipeline

Loadbalancer Packet Flow (2)



- hash packet header & determine target sensor
- delay packet to compensate for routing delay
- process flow control information

Loadbalancer Packet Flow (3)



- rewrite destination MAC address
- recalculate CRC and forward packet
- update performance monitors in PCI subsystem

Configuration and Monitoring

Initialization

- hardware requests sign-on via broadcast UDP packet
- sensors reply with MAC address
- load balancer builds initial hash tables

Monitoring

- through host PCI bus
- status & global statistics
- per-sensor statistics with snapshot capability

Evaluation

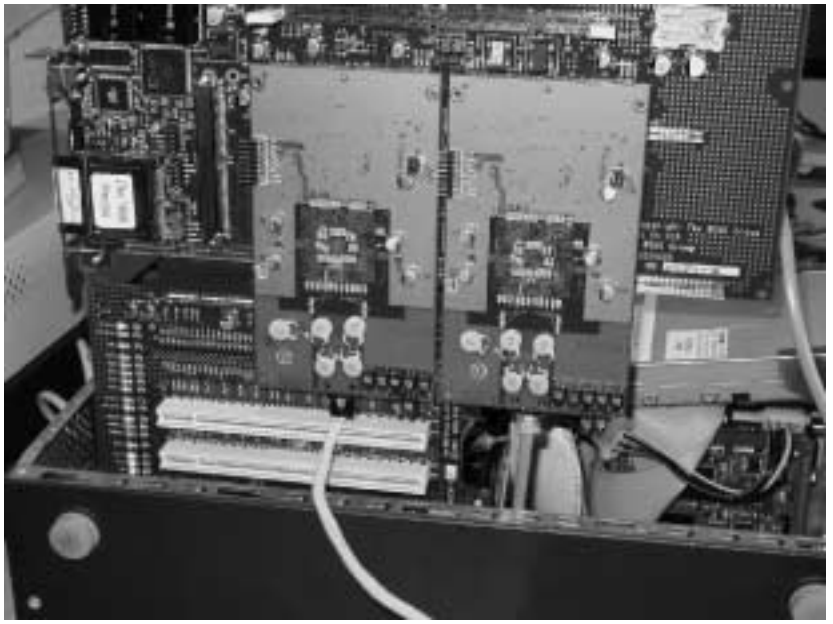
Trace-based

- synthetic traffic for systematic testing
- replay traces from ND campus and other sources
- aggregate sender/receiver to saturate GigE link

Life Traffic

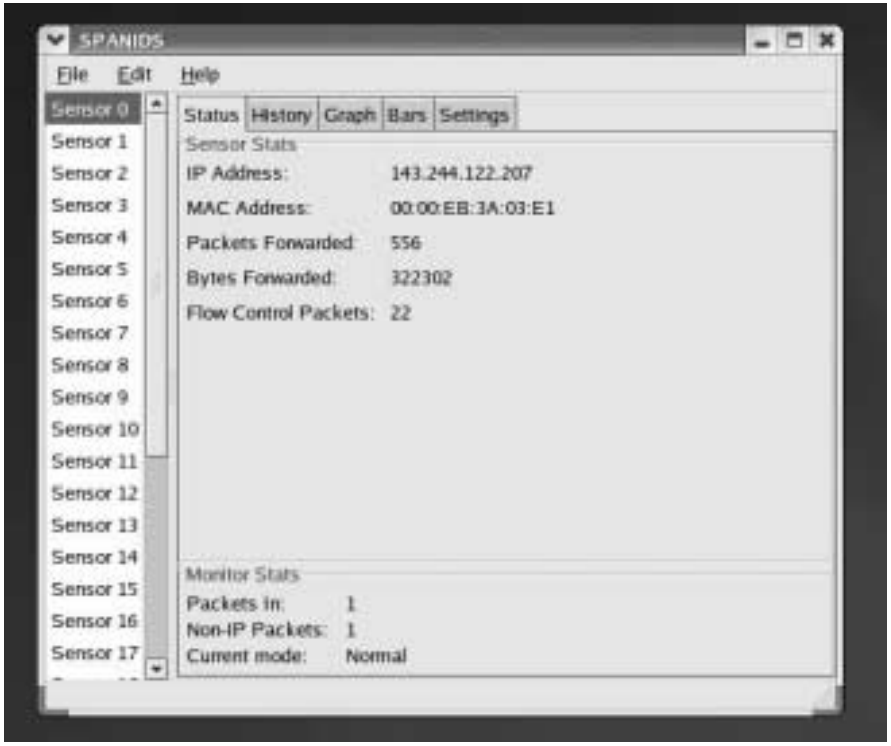
- access to ND campus internet link

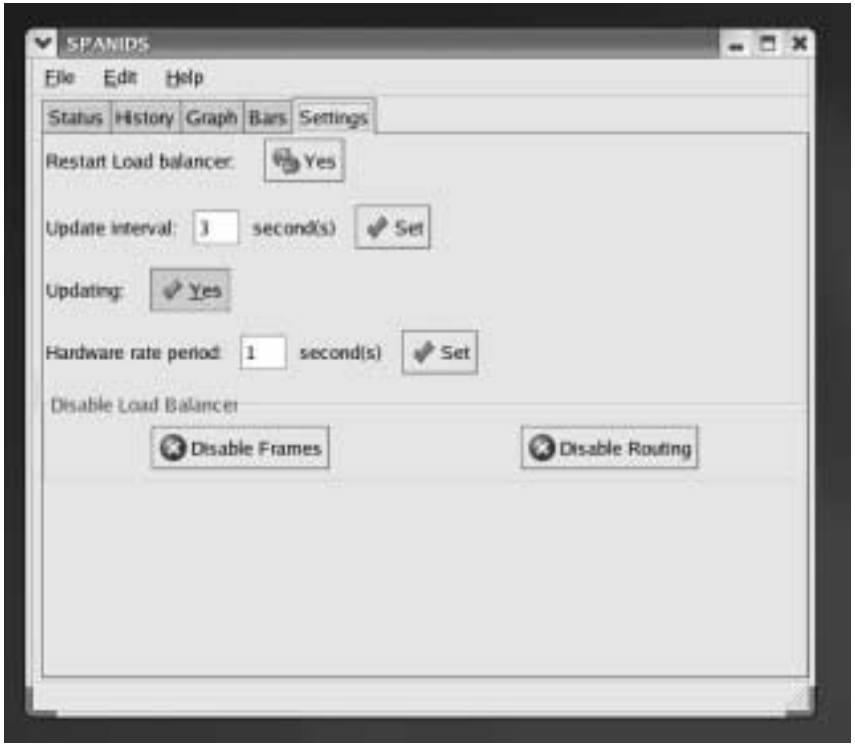
Prototype Hardware



- Virtex-II FPGA board with PCI interface (Dini Group)
- dual GigE daughtercards (Metanetworks)
- PCI riser card to fit in host PCI slot

Control Software





- configures load balancer hardware
- monitors performance
- not involved in actual load balancing

Status

- NIDS performance requirements established
- trace-based simulator completed
- initial version of synthetic trace generator completed
- currently 15% of FPGA resources utilized
  - Gigabit Ethernet & PCI Interface
  - preformance monitor
  - packet decoder & hash functions
- flow control module added to Linux packet socket

Acknowledgements

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