Multi-Kilohertz Control of Multiple Robots via IEEE-1394 (***Firewire***)

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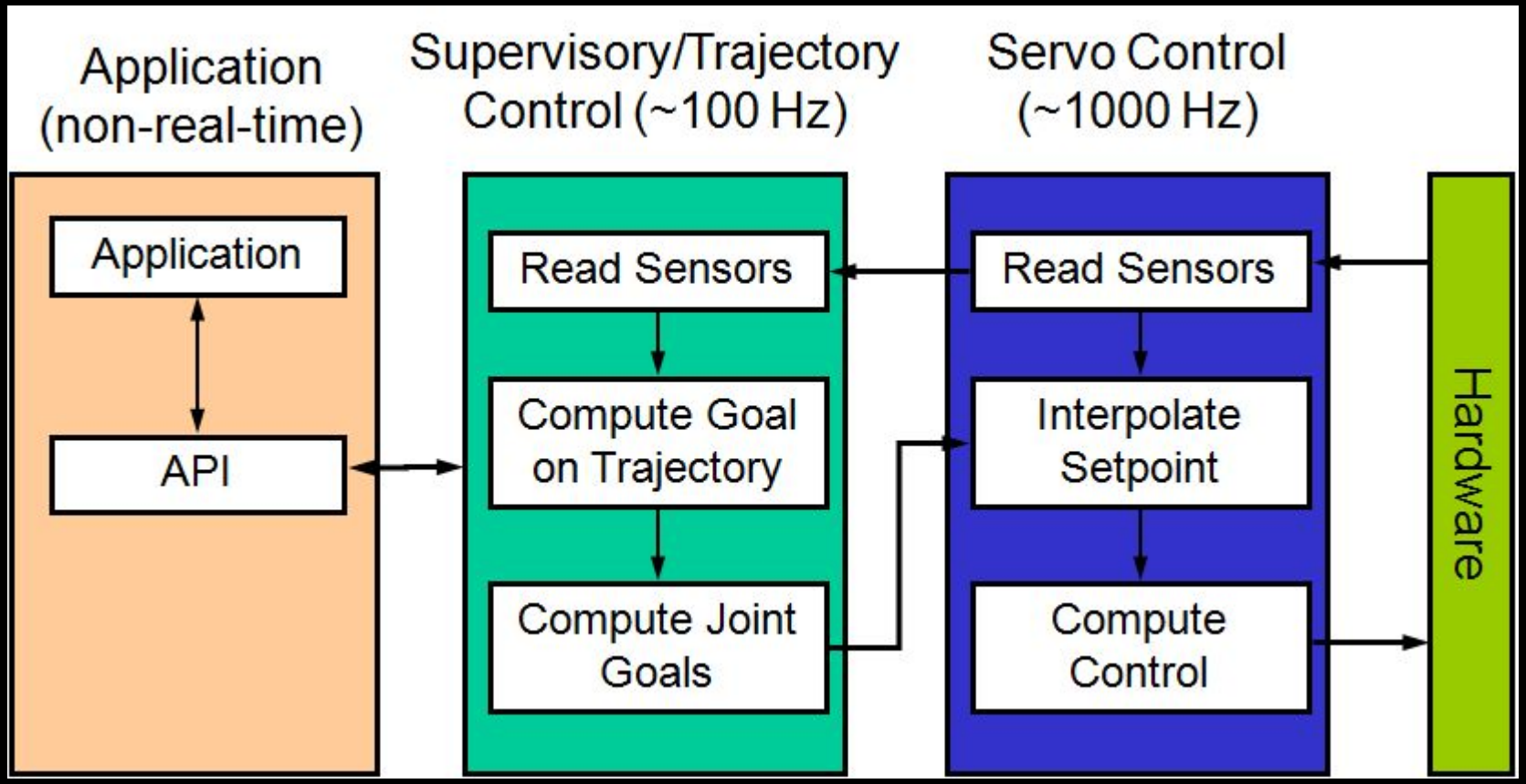
Outline

- Background
- Protocol
- Results
- Future work
- Summary

Background

Background: Centralized computation

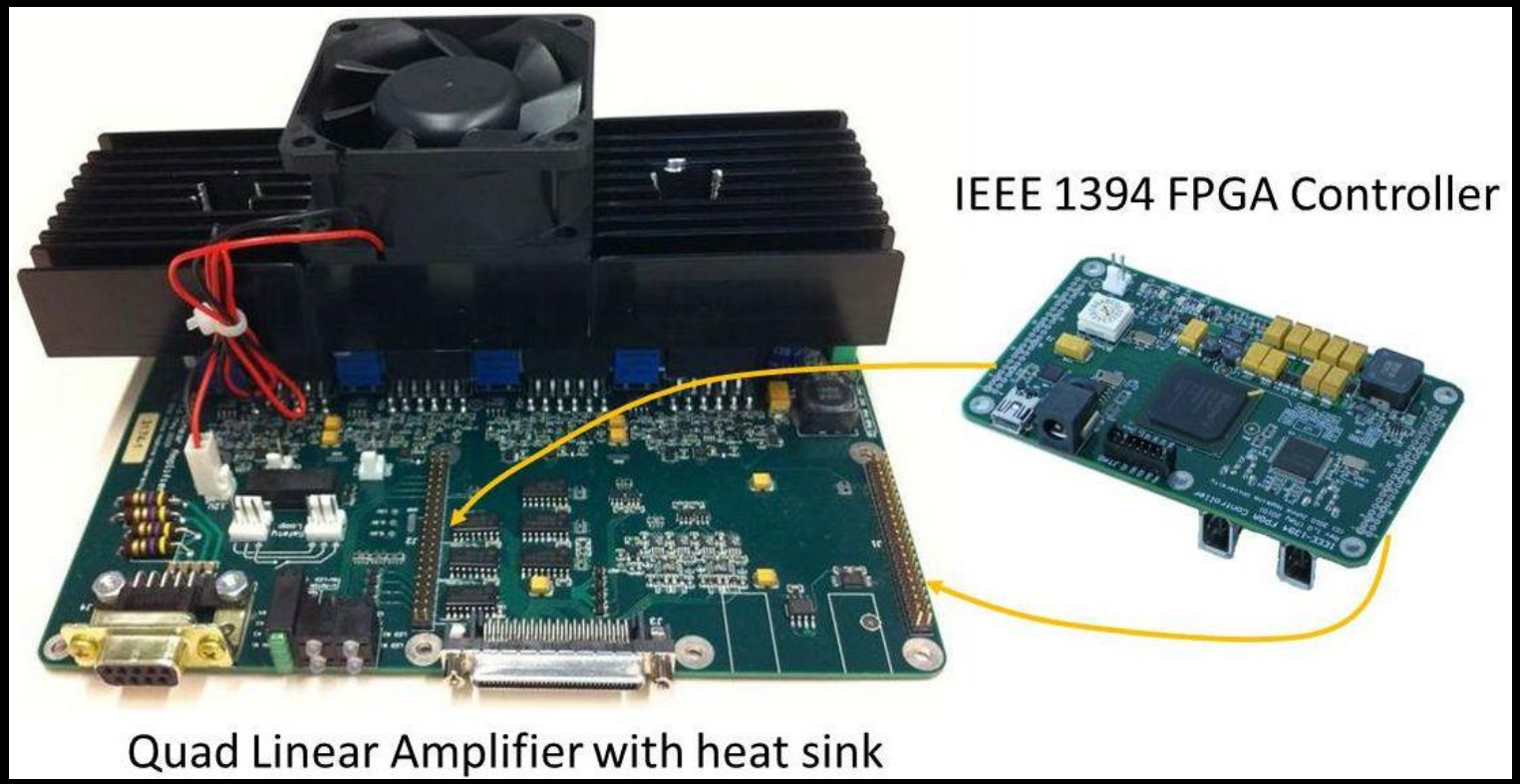


Background

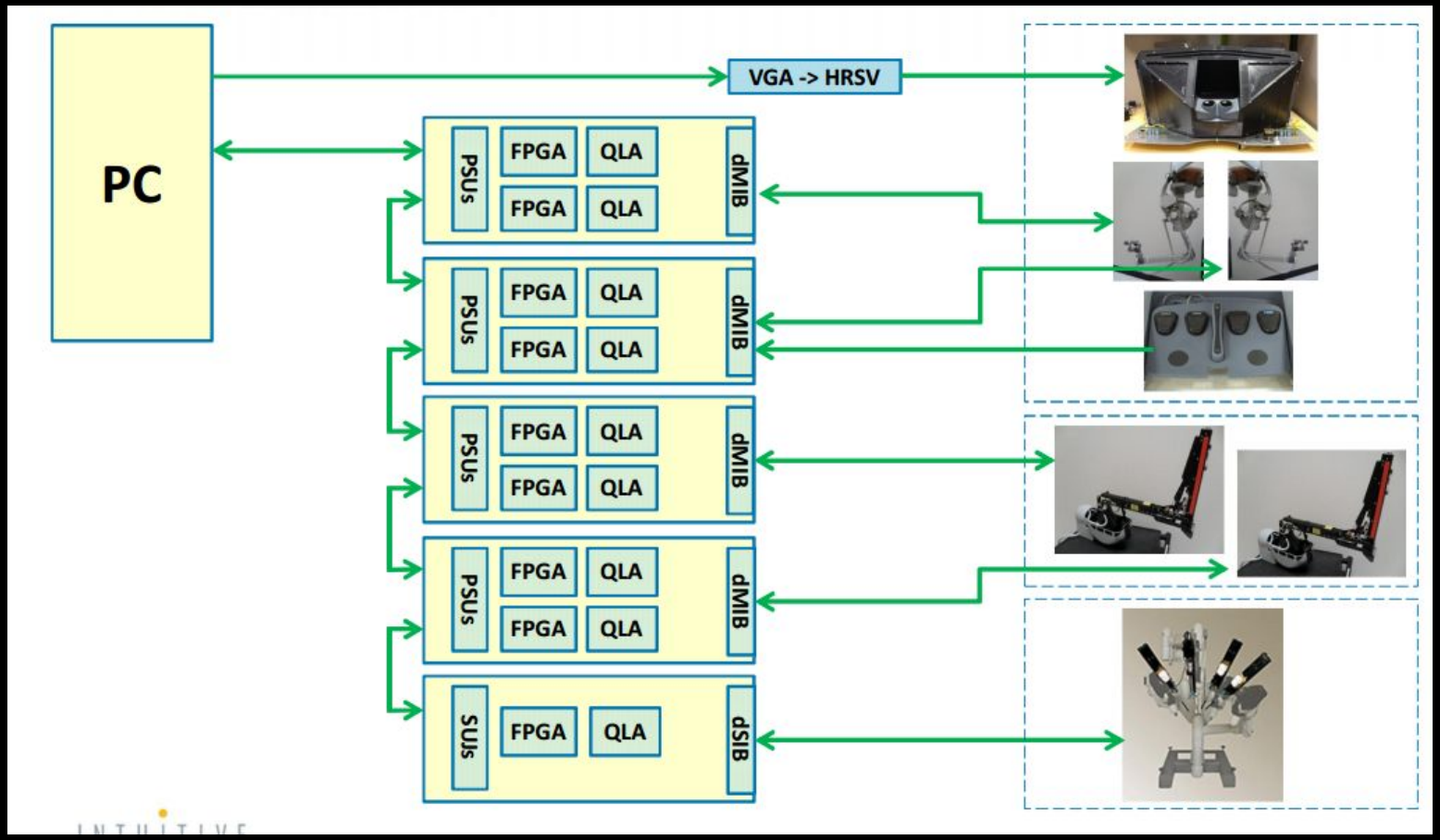
Centralized I/O

Distributed I/O

Background: Controller



Background: da Vinci Research Kit

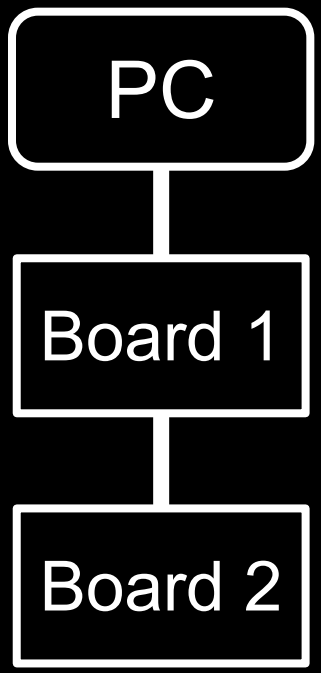


Credit: Simon DiMaio

Background: DVRK users (16 Groups)

Credit: Simon DiMaio

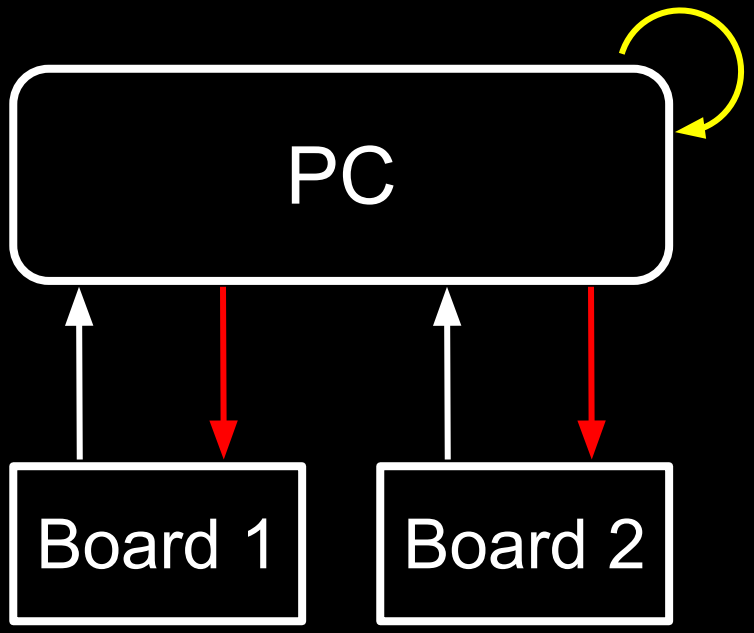
Background: Firewire



- 1394a (Firewire) 400 Mbps
- Peer-to-Peer
- Daisy-chain connection
- Multicast (broadcast)
- Isochronous + Asynchronous

Protocol

Naive Protocol



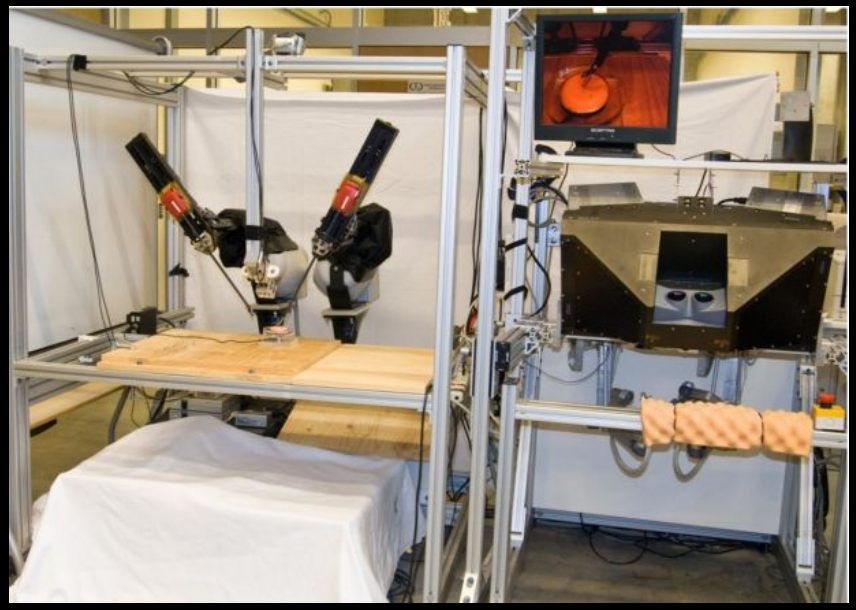
- 1 read + 1 write / per board
- T(Read) ~ 30 us
- T(Write) ~ 30 us
- T(I/O) ~ 60 us x N(Boards)

Read Compute Write

Issues

Case 1:

- da Vinci Classic
- 8 boards
- T(I/O) ~ 480 us
- **5 kHz** Servo Loop



Issues

Case 2:

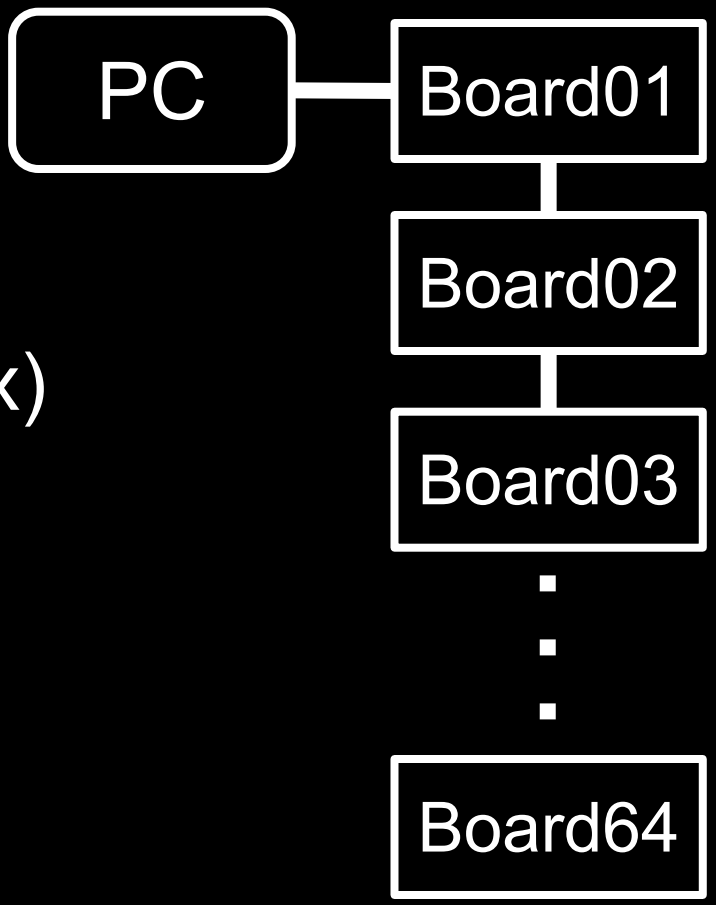
- da Vinci Si
- 16 boards
- T(I/O) ~ 960 us
- Freq ~ 1 kHz

Image from Intuitive Surgical

Issues

Case 3

- Hypothetical
- 64 boards (Firewire max)
- T(I/O) ~ 3840 us
- Freq ~ **250 Hz !!!**



How to make it FASTER?

1 Reduce number of transactions

2 Make transactions faster

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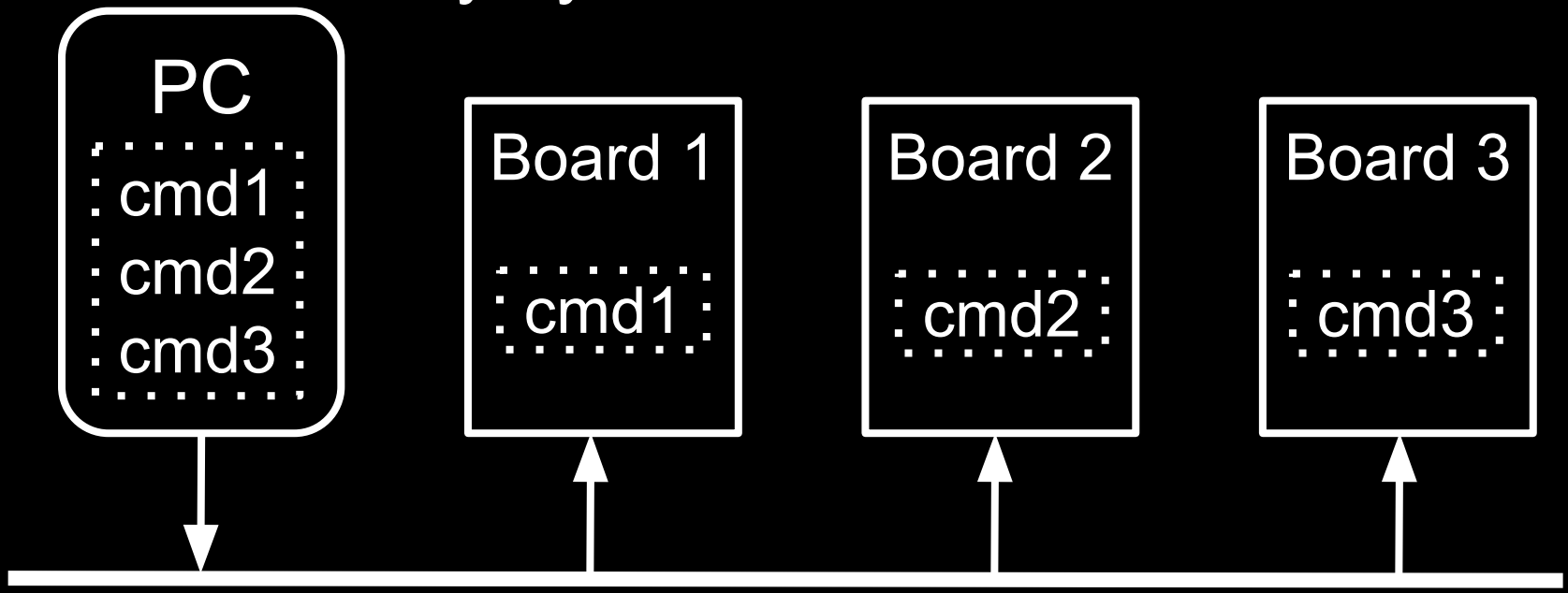
2 Make transactions faster

Write Transaction

One-to-Many by Nature



One Broadcast Write

Write Transaction

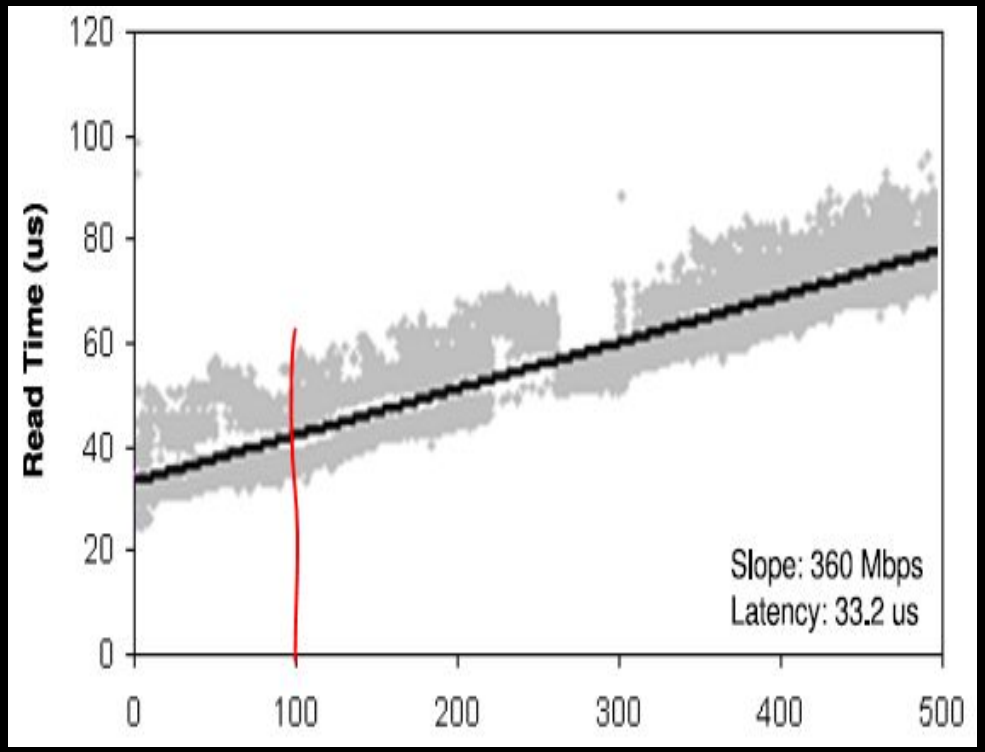
I/O Time ? **GOOD** but **NOT** enough

- Number of transaction = N + 1
- T(I/O) ~ (N + 1) x 30 us
- Cut I/O time by half when N is large

1 Reduce number of transactions

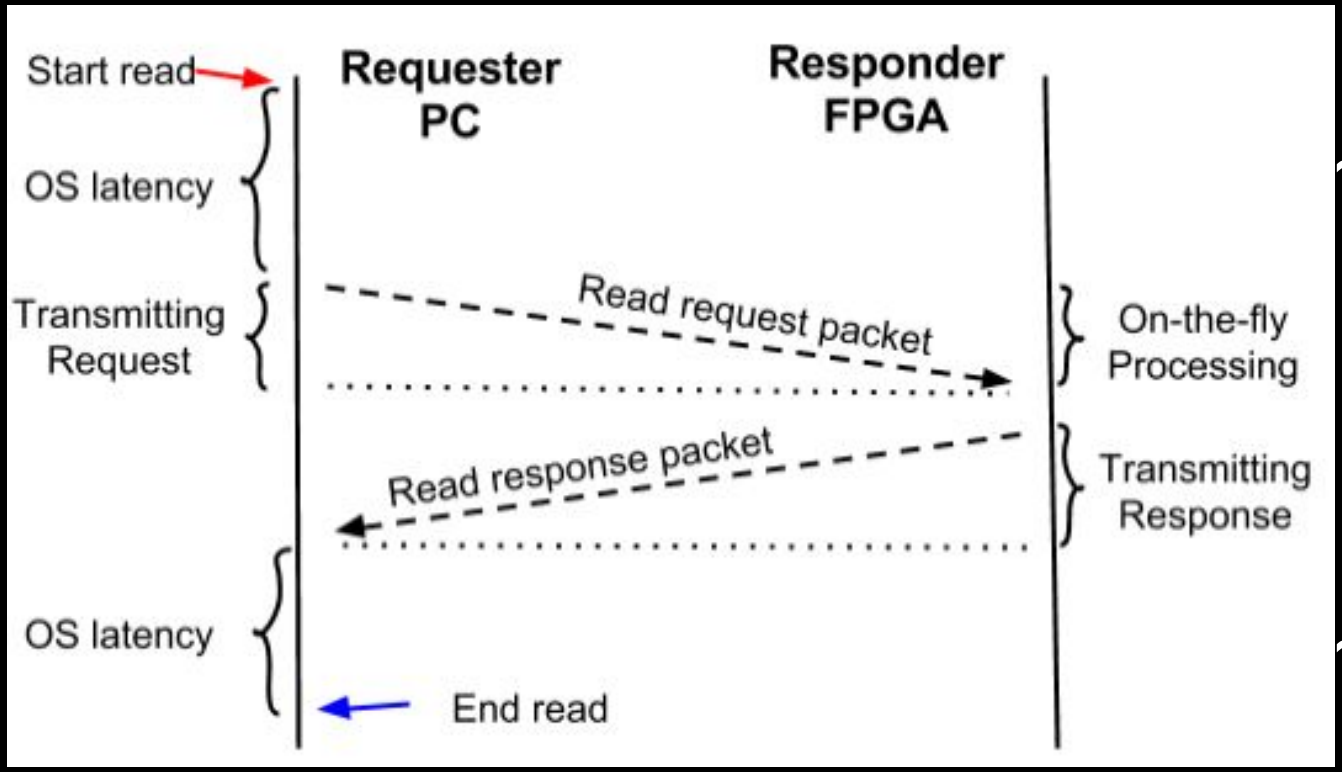
2 Make transactions faster

Read time vs Block size



- < 100 Quadlets
- Overhead is large

Asynchronous Firewire transaction



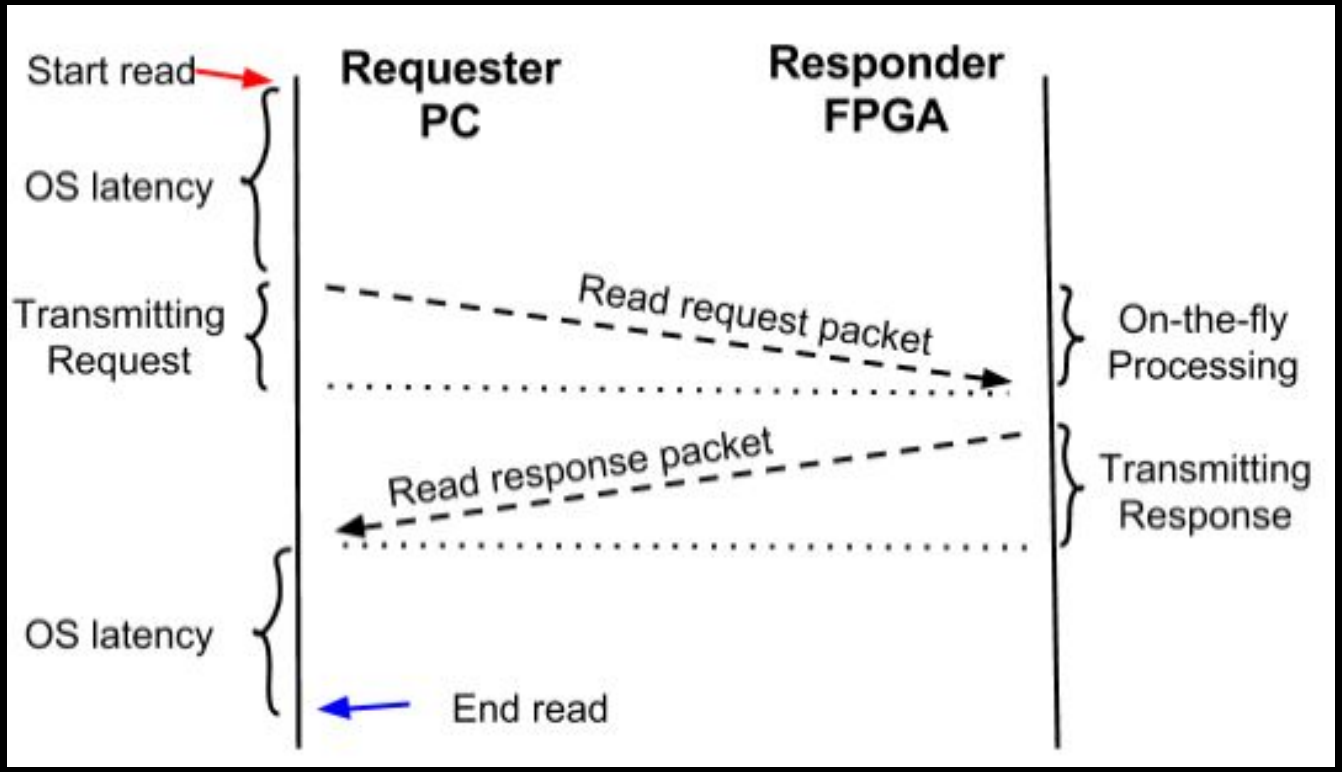
~10 us

~5 us

~5 us

~10 us

Timing Analysis

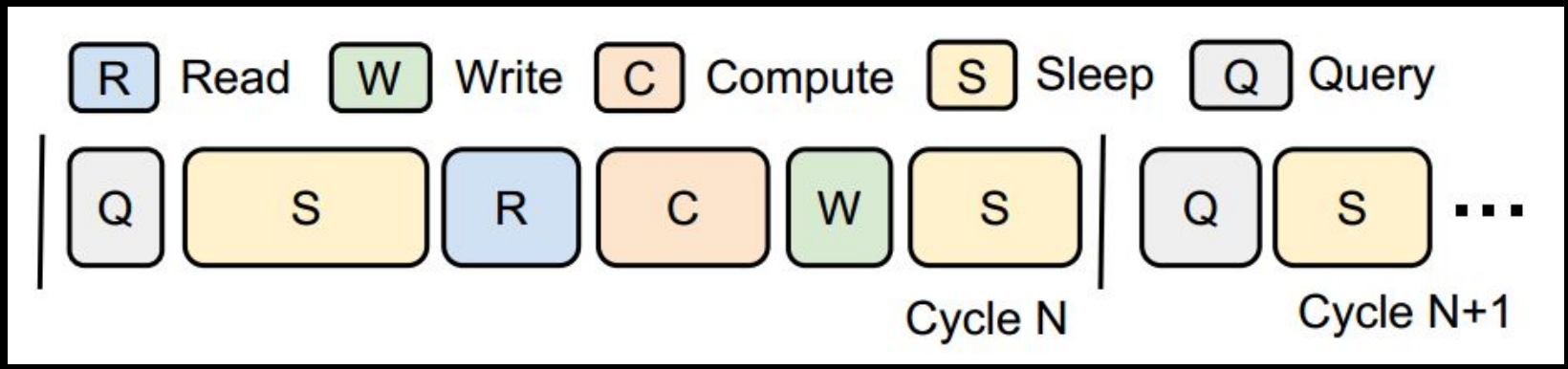


~5 us

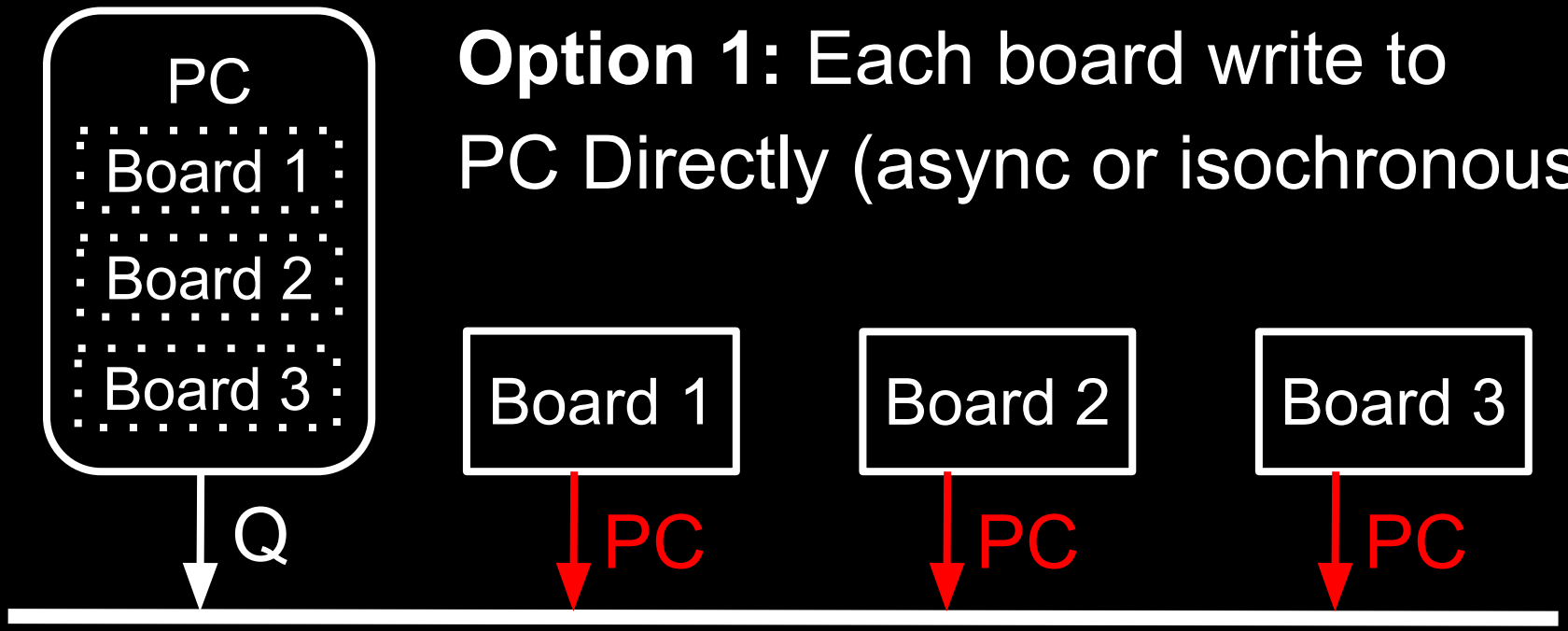
Strategy REDUCE

PC initiated Firewire transactions

Control Period



Read Option 1

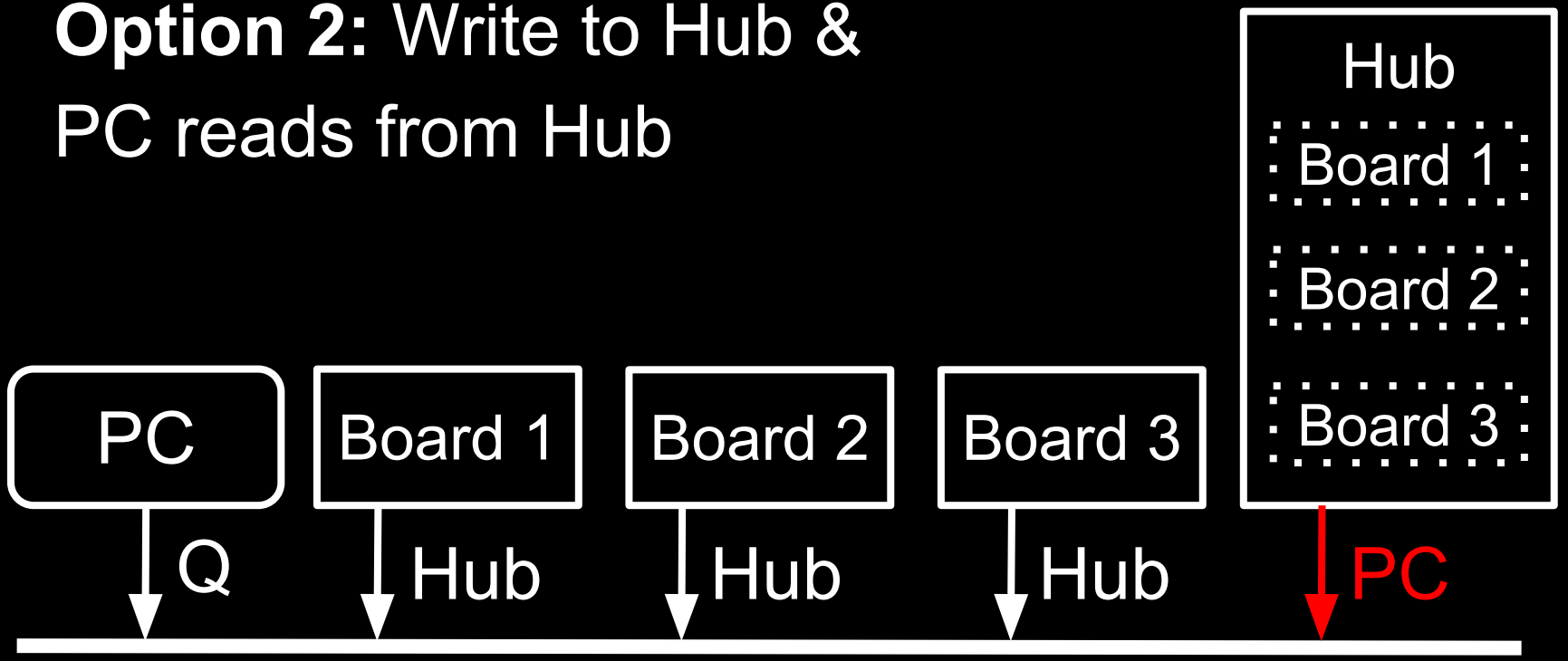


Option 1: Each board write to PC Directly (async or isochronous)

Issue: dropped packets (Relies on OS + Driver)

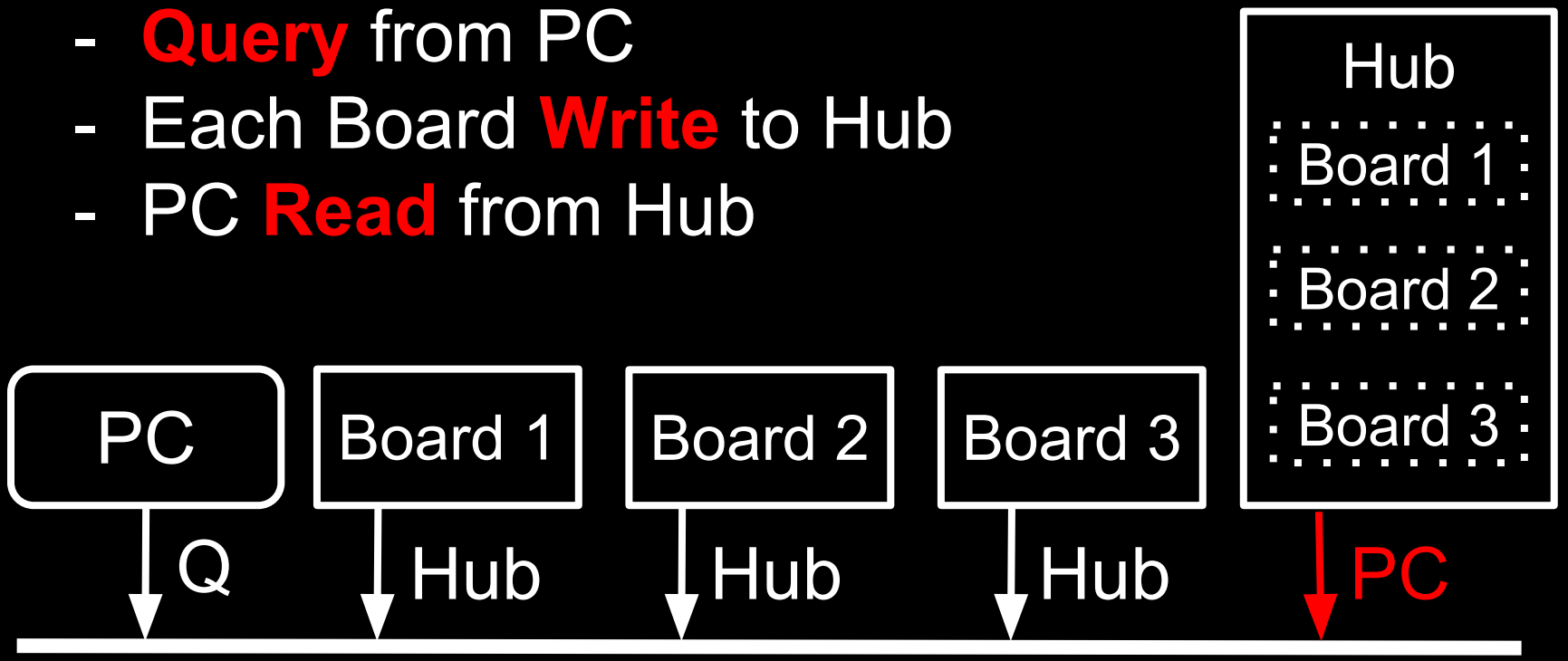
Read Option 1

Option 2: Write to Hub &
PC reads from Hub

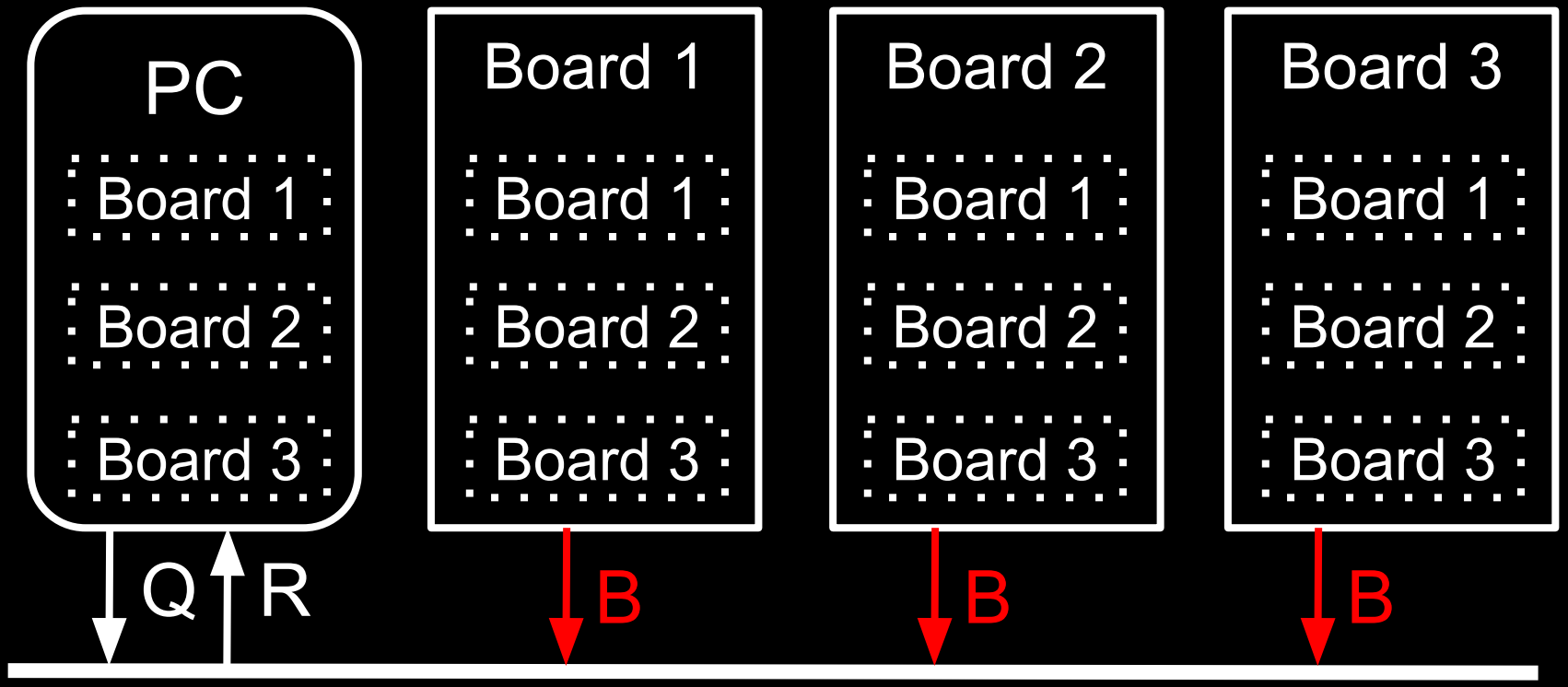


Read Option 1

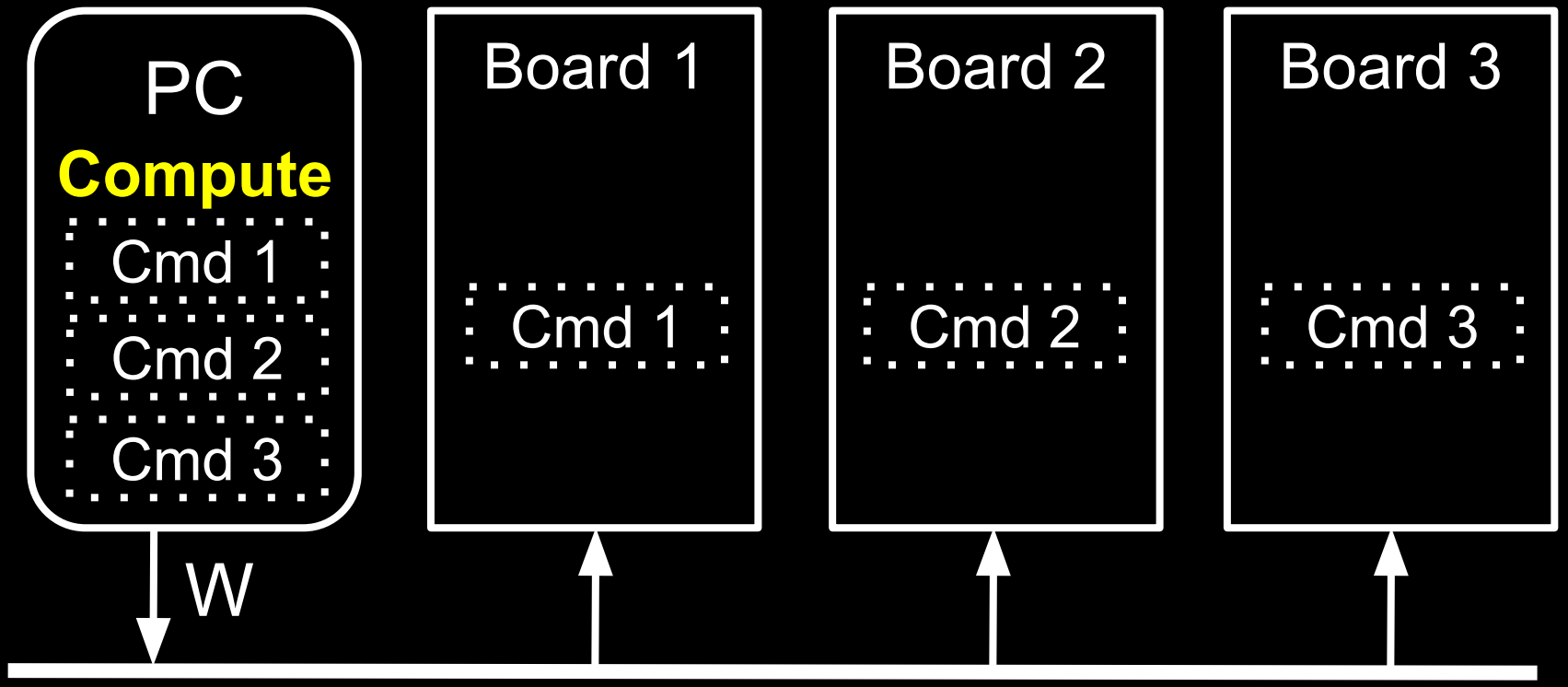
- **Query** from PC
- Each Board **Write** to Hub
- PC **Read** from Hub



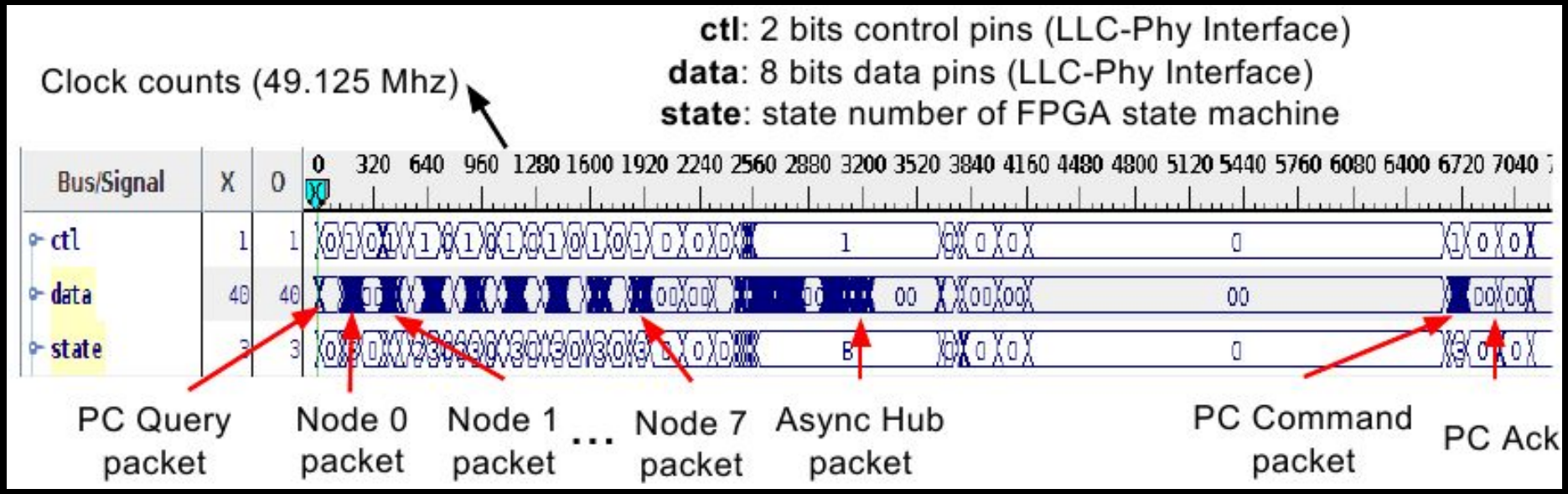
Broadcast Protocol



Broadcast Protocol



Control Scheme



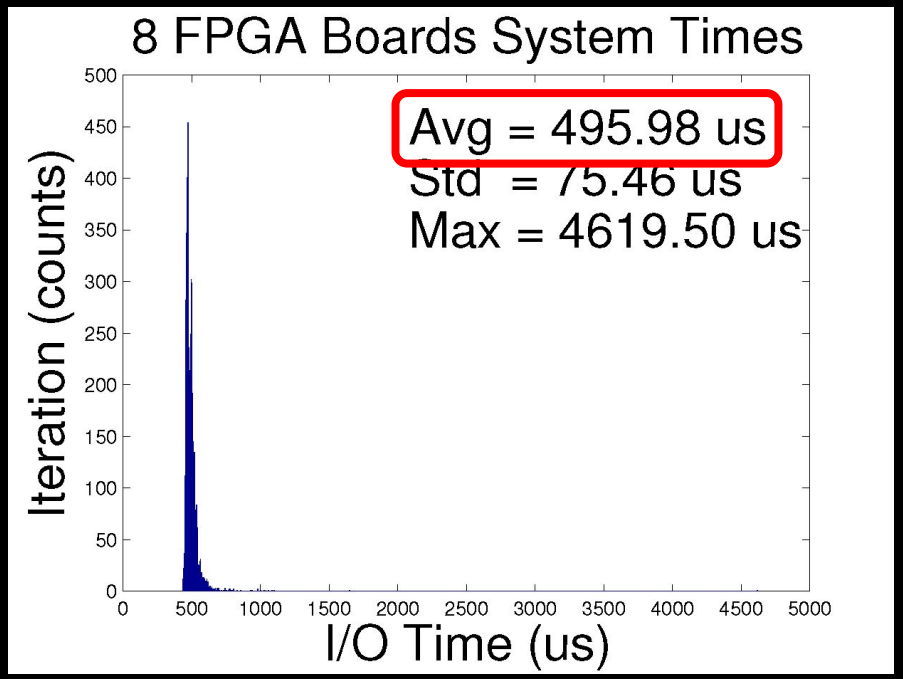
Other minor improvement

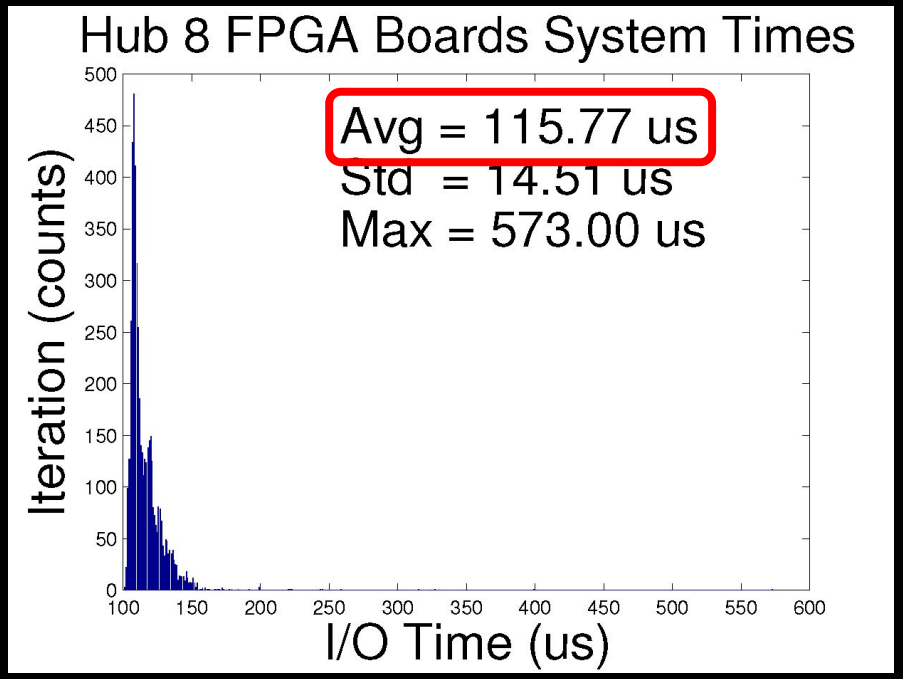
- Fixed FireWire root
- Disable cycle start clock
- Change broadcast default to 400 Mbps

Results

Results

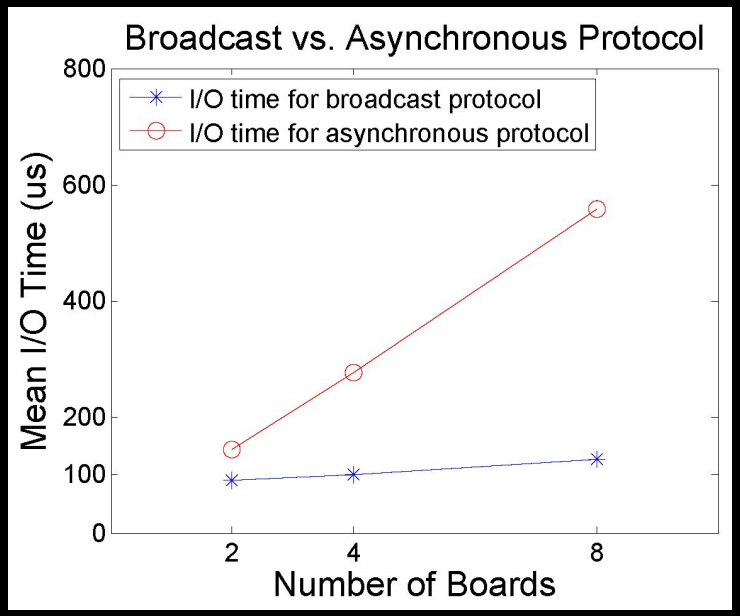
4x Faster





Results

$$T_{I/O\_bc} = T_Q + 5\mu s \times N_{boards} + T_R + T_W$$



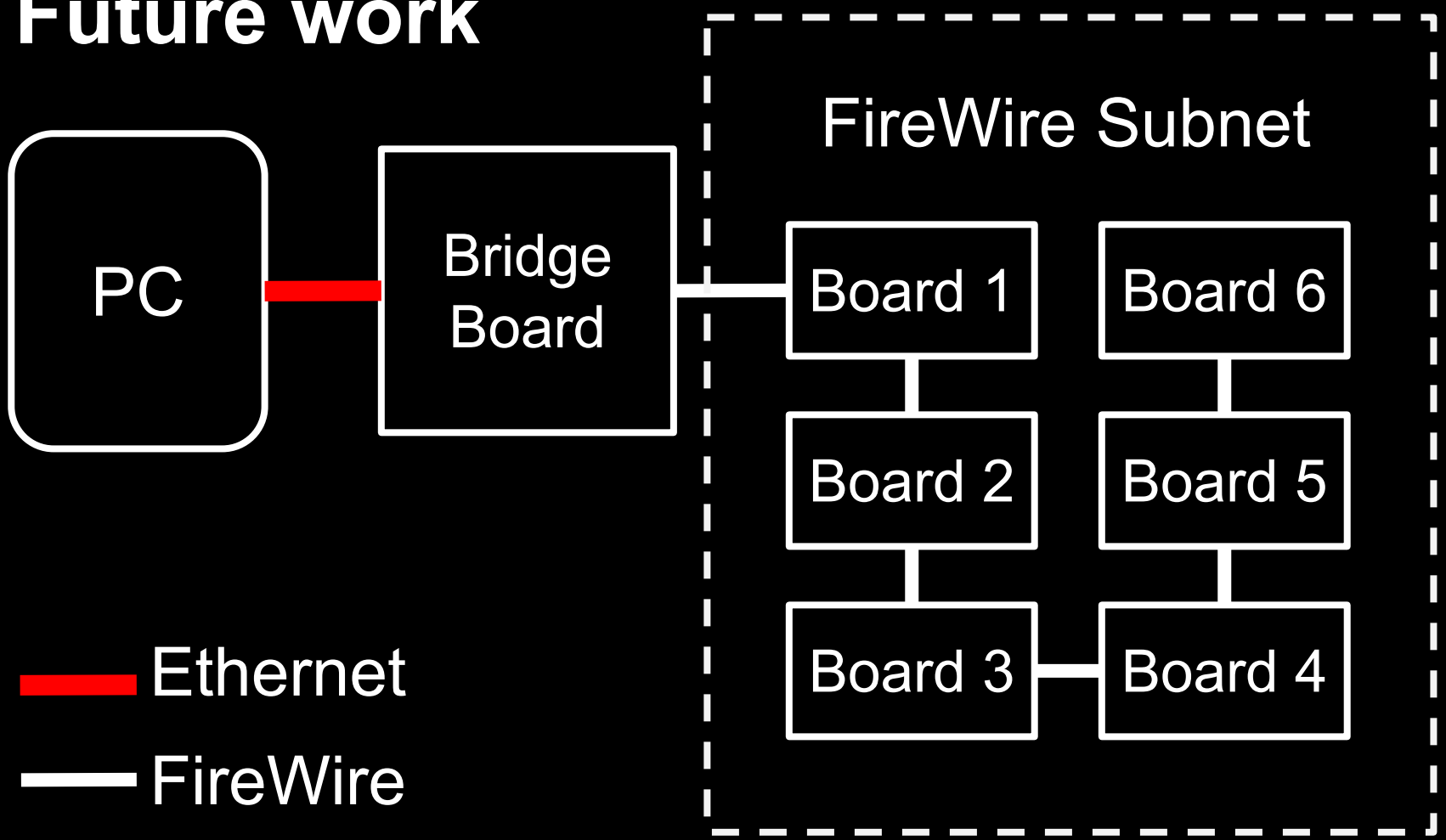
- Scales well
- 6 kHz (8 boards)
- T(I/O) = 395 us (64 boards)

Results: EtherCAT

- EtherCAT
  - Sufficient performance
  - Ubiquitous hardware
  - Easier cabling
- Firewire
  - Easier to reconfigure
  - Completely open

Future work

Future work


FireWire Subnet
PC
Bridge Board
Board 1
Board 2
Board 3
Board 4
Board 5
Board 6
Ethernet
FireWire

Summary

Summary

- Broadcast protocol
- All boards hub capable
- Scales well for large systems
- 4x Faster for 8 boards system
- 6 kHz control for 8 boards system

Thank You !

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