Data Networks

Introduction to Networking

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ISOTDAQ 2011, Rome

Outline

- Introduction
  - Networking basics
  - OSI reference model
- Technologies and protocols
  - Ethernet
  - Internet Protocol (IP)
  - Routers and routing
- Network monitoring
- Software defined networking

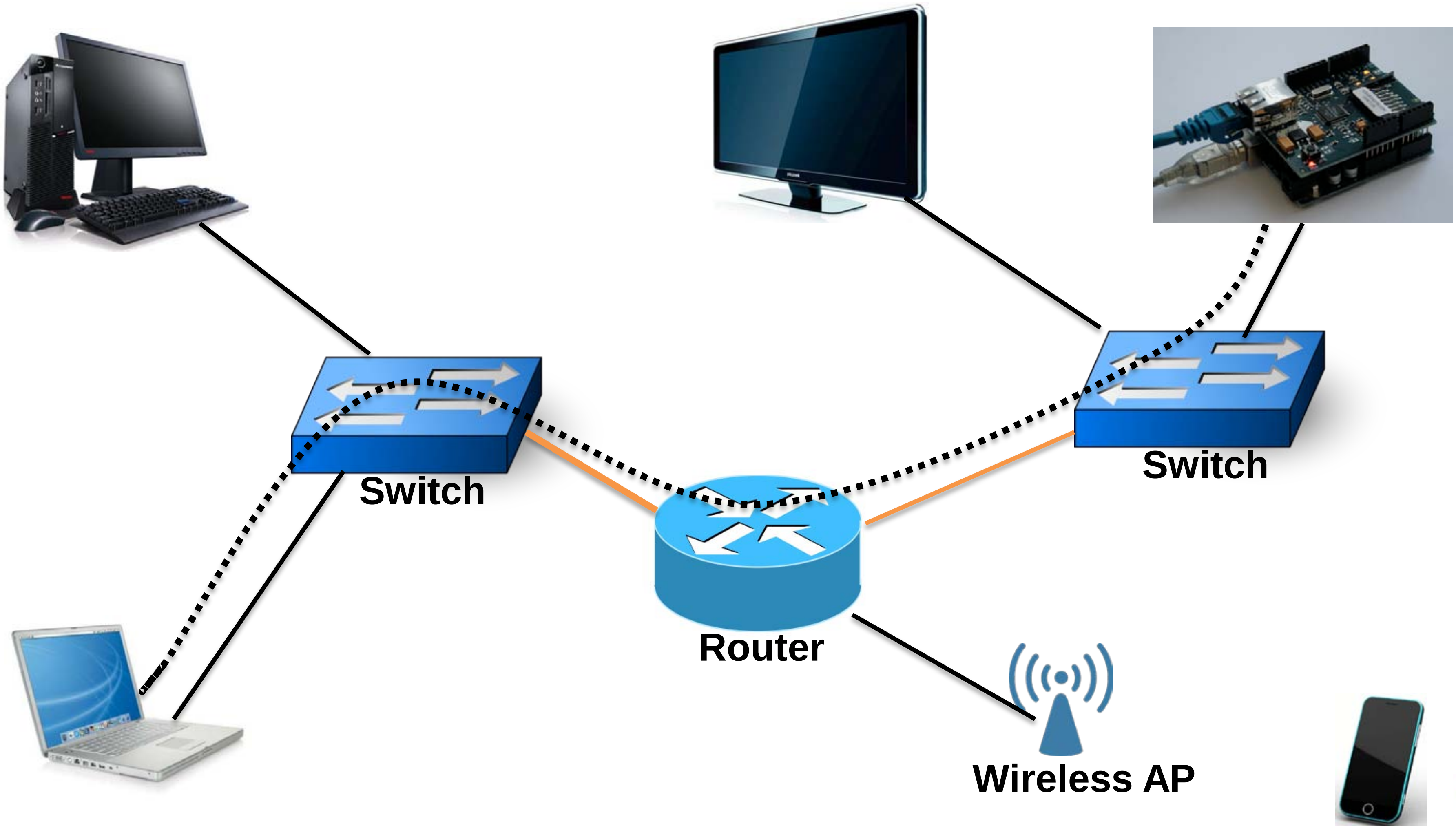
What is a network ?

- A ***network*** is simply two or more computers connected together so they can exchange information. At the same time it can be a complex interconnected system of objects and people (Internet)

- ***End-host devices*** are hosts attached to a network
- A ***source host*** is the place where the data originally comes from
- A ***destination host*** is the place where the data is being sent to
- ***Networking devices*** are waypoints along paths for data to travel along
- **Links** are direct data paths between adjacent devices

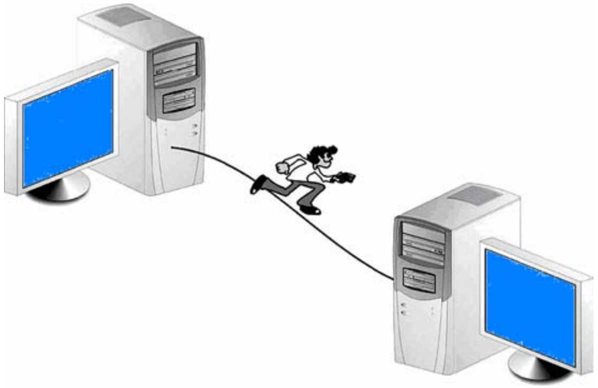
- A **route** is the path between any two network points

What is a network ?



Why do we need a network ?

- Sneaker Net
  - Inefficient data communication;
  - Many copies of the same file;
  - Reliability, scalability, flexibility… issues.



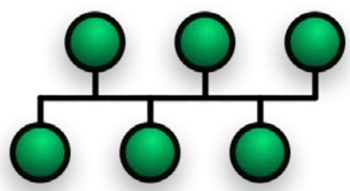
- (High speed) networks connecting all hosts help address slow transmission of information
- Interconnected datacenter servers help minimize redundant copy of files
- File sharing, resource sharing, communication & collaboration, group organization, remote access, data backups etc

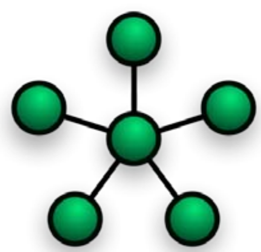
Network types

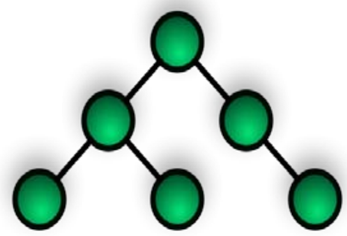
- Networks have different varieties to suit different purposes and needs
- **LAN** (small size, high speed, physical proximity)
- **WAN** (long distance, lower data transfer rates)
- **MAN** (metropolitan area network)
- **PAN** (immediate space around a person)
- **SAN** (connecting storage farms, high speed)
- **VPN** (private network extension across a shared or a public network)

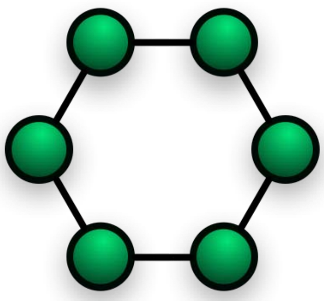
Network structure

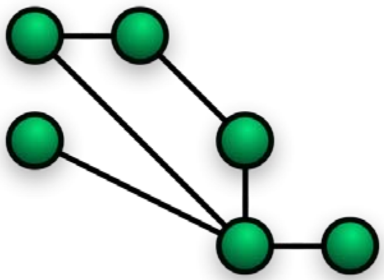
- The structure of a network is known as the ***topology***
  - **Physical** = The way the network is cabled
  - **Logical** = The way devices use the network to communicate

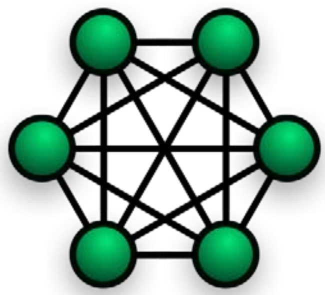

Bus Topology


Star Topology


Hierarchical Topology

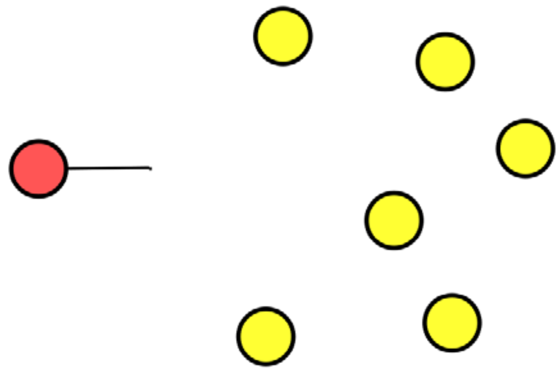

Ring Topology

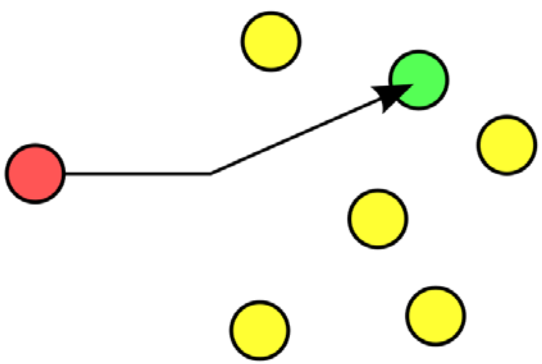

Partial Mesh Topology


Fully Mesh Topology

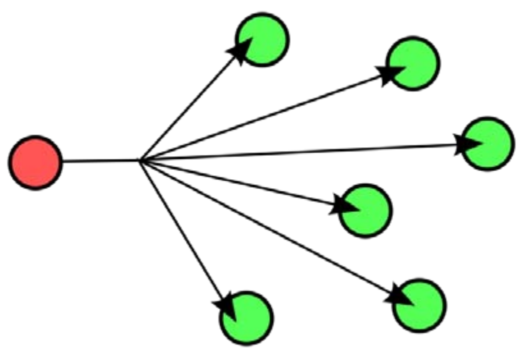
Network communication

- One-to-one
- One-to-all
- One-to-many

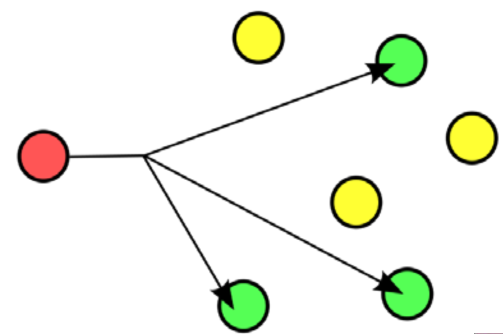




Unicast

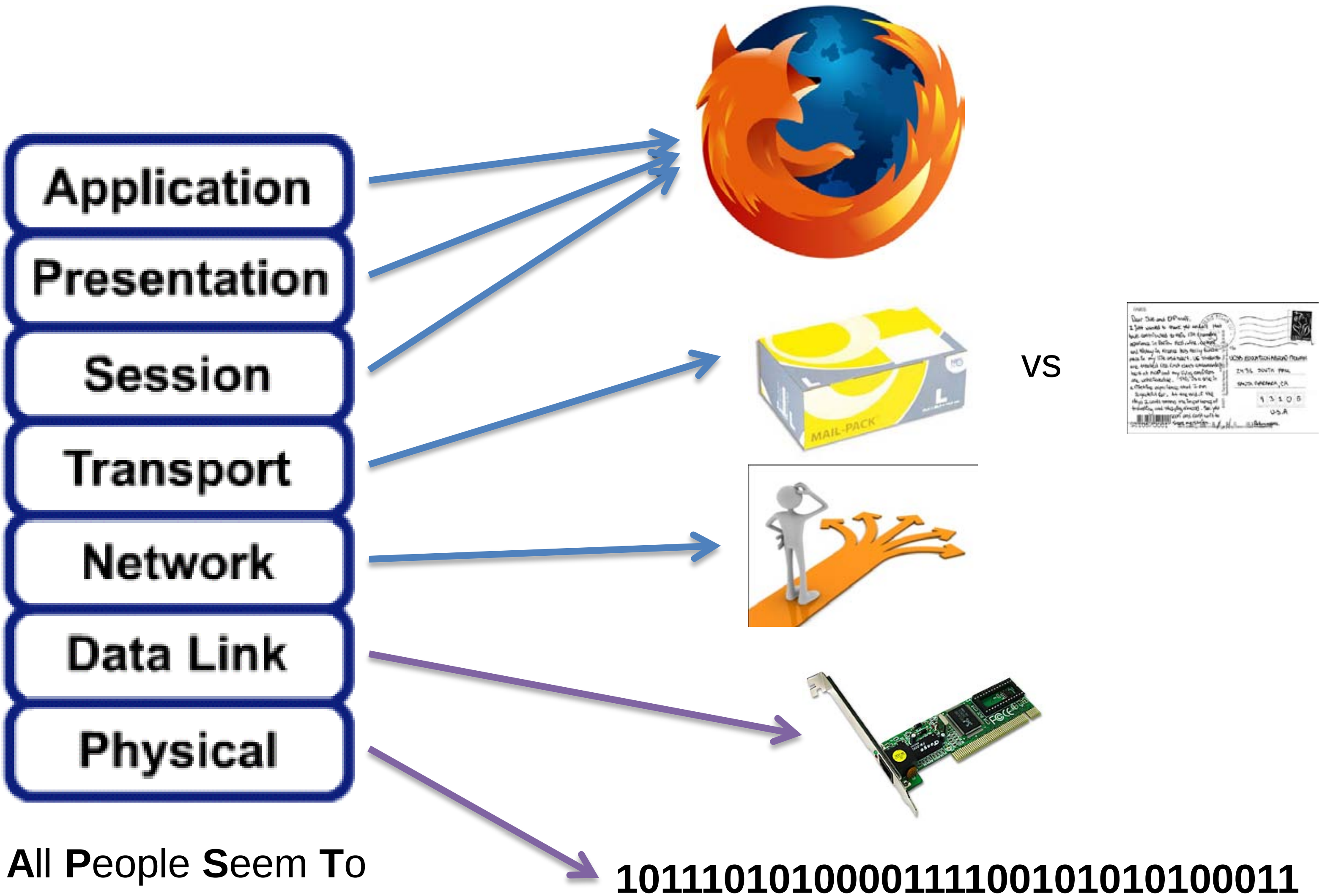


Broadcast



Multicast

OSI Model. Divide et impera.



All **P**eople **S**eem **T**o
Need **D**ata **P**rocessing

OSI Model. Divide et impera.

All **P**eople **S**eem **T**o **N**eed **D**ata **P**rocessing

Why layers in OSI ?

- Simplifies understanding of networking
- Breaks networking tasks into smaller, manageable, chunks
- Allows for platform independence
- Provides a standard for networking manufactures
- Easier to determine the correct networking protocol required to connect
- Problem investigation is easier and debugging time is shortened

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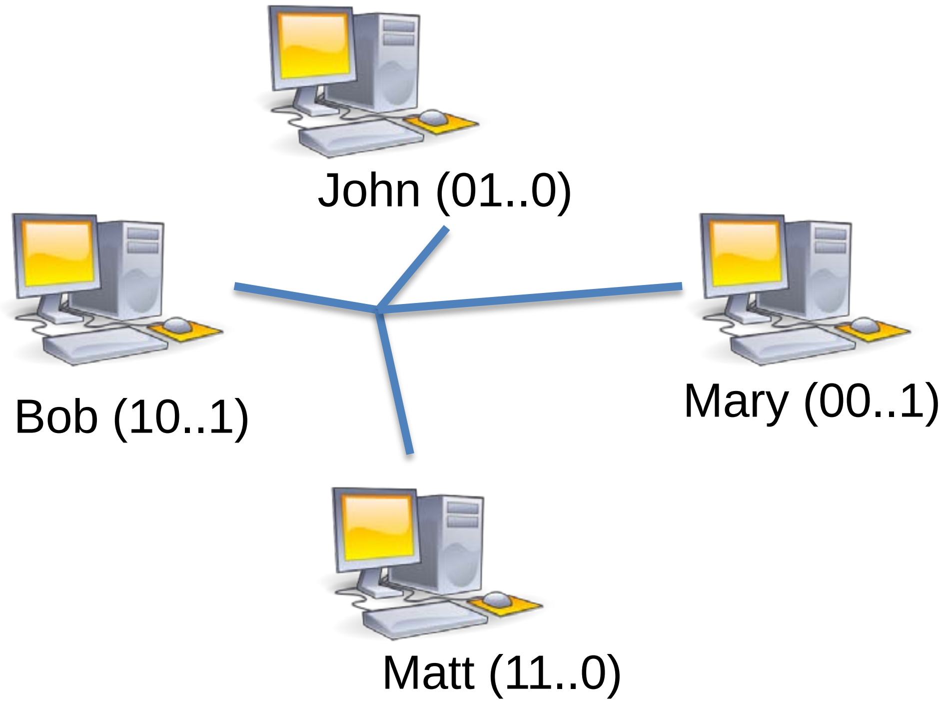
  - IP Protocol
  - Routers and routing
- Network monitoring
- Software defined networking

Ethernet. Reliable since 1973.

- Created at Xerox in 1973, released as an open standard in the early 80s
- Later modified to comply with the OSI model, ratified as IEEE 802.3 in 1985
- Ethernet has evolved significantly since then:
  - Proved flexible as a technology, able to upgrade to new media and faster data transmission speeds.
  - 10Gig Ethernet ratified as IEEE 802.3ae
  - Optical fiber has joined copper as media of choice for the IEEE 802.3 family
- Flexibility came through the simplicity of Ethernet’s structure
- Ease of installation and maintenance

Ethernet

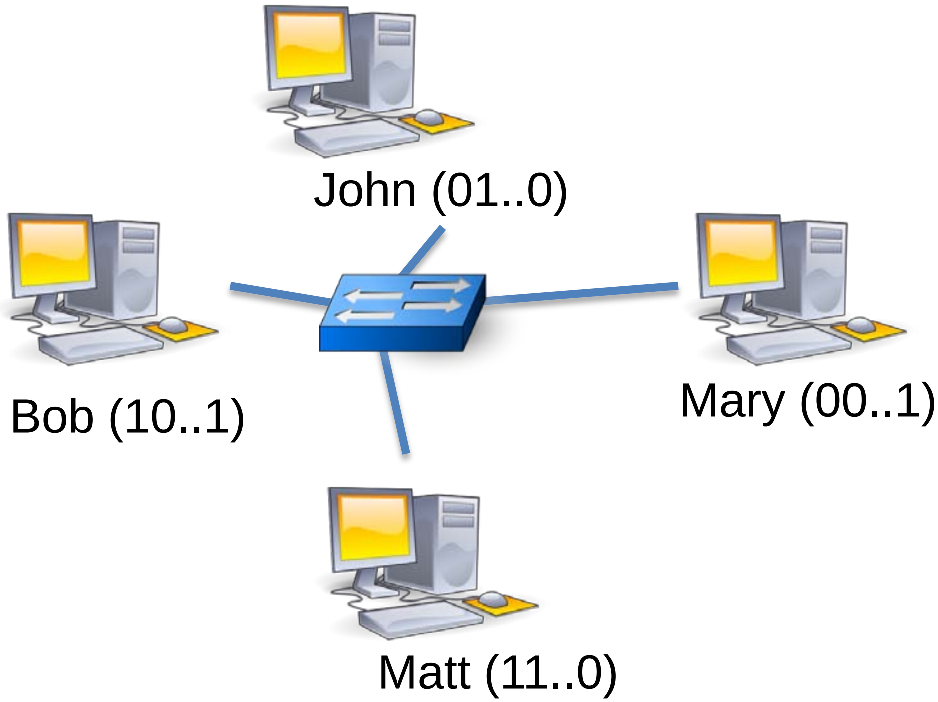


- Small to medium size group of computers
- Frame based technology
- Defines wiring and signaling standards (Layer1)
- Defines a flat addressing scheme with local visibility, called **MAC** (Layer 2)

8	6	6	2	46 ~ 1500 bytes	4
Pre-amble	Dest.	Source	Type/ Length	Data	Frame check

Basic Ethernet frame

Ethernet. Switch



- Analyses incoming frames and switches them to correct segment using MAC addresses (a process called switching)
- Simultaneous data transmissions without medium sharing
- Layer 2 device

8	6	6	2	46 ~ 1500 bytes	4
Pre-amble	Dest.	Source	Type/ Length	Data	Frame check

Basic Ethernet frame

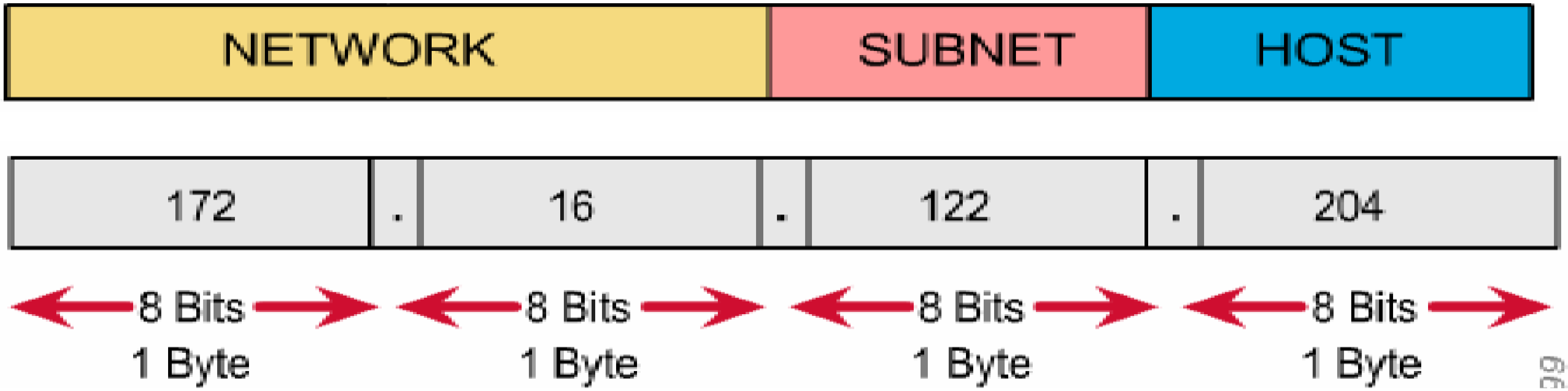
IP. (Un)reliable since 1974.

- Connectionless, best effort protocol
- Designed to be encapsulated into layer 2 protocols , such as Ethernet
- Initially created by Vint Cerf and Bob Kahn in 1974
- IPv4 described in RFC 791 (1981) hyperlink

- Defines a hierarchical (logical) addressing scheme capable of connecting all the hosts in the world (Layer 3)
- Routes packets towards destination using best available path, with the help of routing protocols (Layer 3)

IP (Addressing)

- 32bit address space (IPv4)
- Hierarchical addressing (similar to postal addressing)
- Global visibility
- ARP (Address Resolution Protocol) used to map an IP address with an Ethernet MAC address (layer 2, local visibility)



Routers

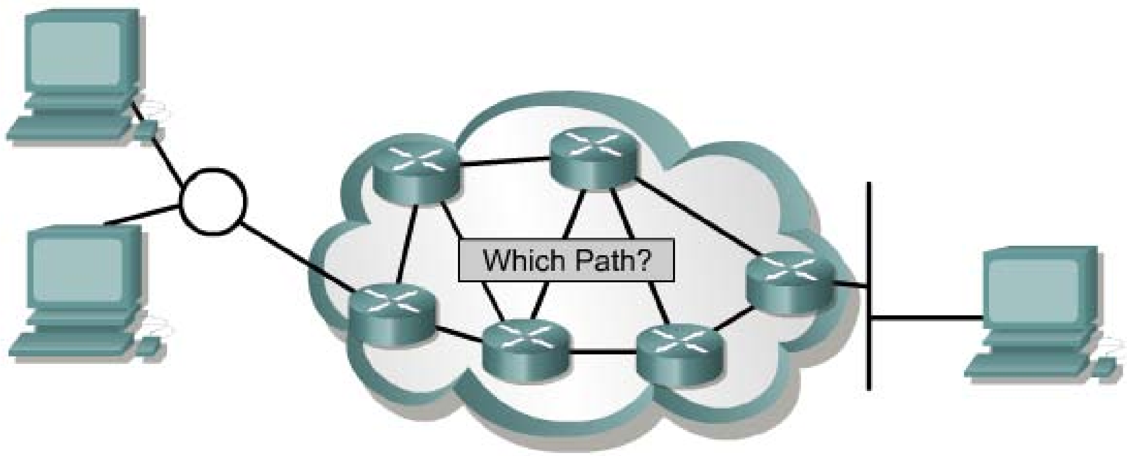
- **Connect** together **separate networks**, sometime of various networking technologies (ex: Ethernet and DSL)
- Make path determination decision based upon logical addresses (such as IP). The process is called **routing**.
- Layer 3 networking devices
- Routing and switching are similar concepts, but are in different layers:
  - Routing occurs in Layer 3, uses IP
    - Maintains routing tables (IP network addresses)
    - Maintains ARP tables (IP to MAC mappings)
  - Switching occurs in layer 2, uses MAC
    - Maintains switching tables (MAC addresses)

Routing

The **process of selecting paths** in a network along which to send network traffic, based upon logical addresses (such as IP).

A routing protocol allows one router to share information with other routers regarding known network paths as well as its proximity

- Static routing
- Dynamic routing
    - Distance Vector
    - Link State



Routing. Dynamic routing

Distance Vector Protocols

- Each router tell its neighbors about its view over the network
- Routes are advertised as a vector of distance and direction.
- Routers do not have knowledge of the entire path to a destination

Link State Protocols

- Each router tells the world about its neighbors
- Routes are computed based on the network connectivity map (topological database)
- Routers have knowledge of the entire path to a destination

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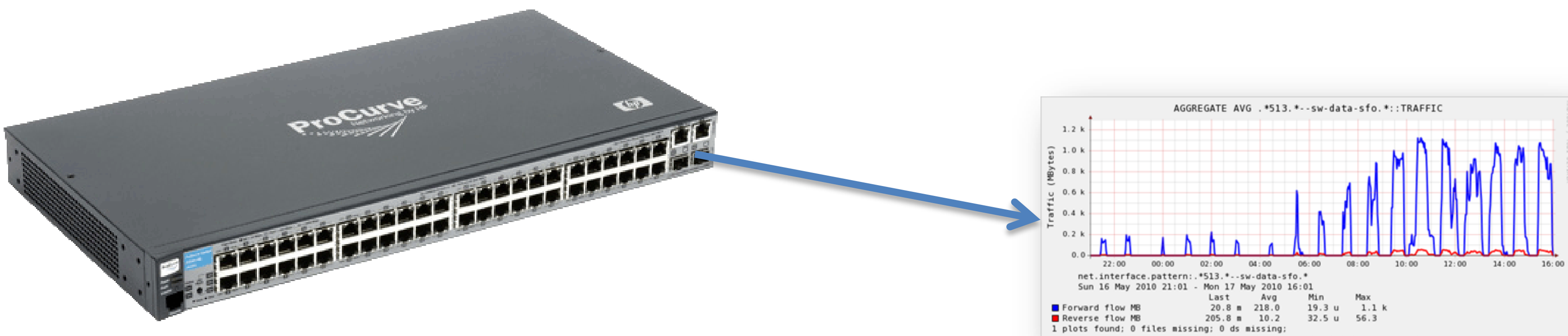
Network Monitoring. SNMP

- A standard protocol for managing devices on IP networks (switches, routers, computers etc);
- Exposes management data in the form of variables on the managed systems. These variables are then queried;
- Used to gather device-based or port-based statistics (traffic volume, errors, packets, discards, temperature etc);

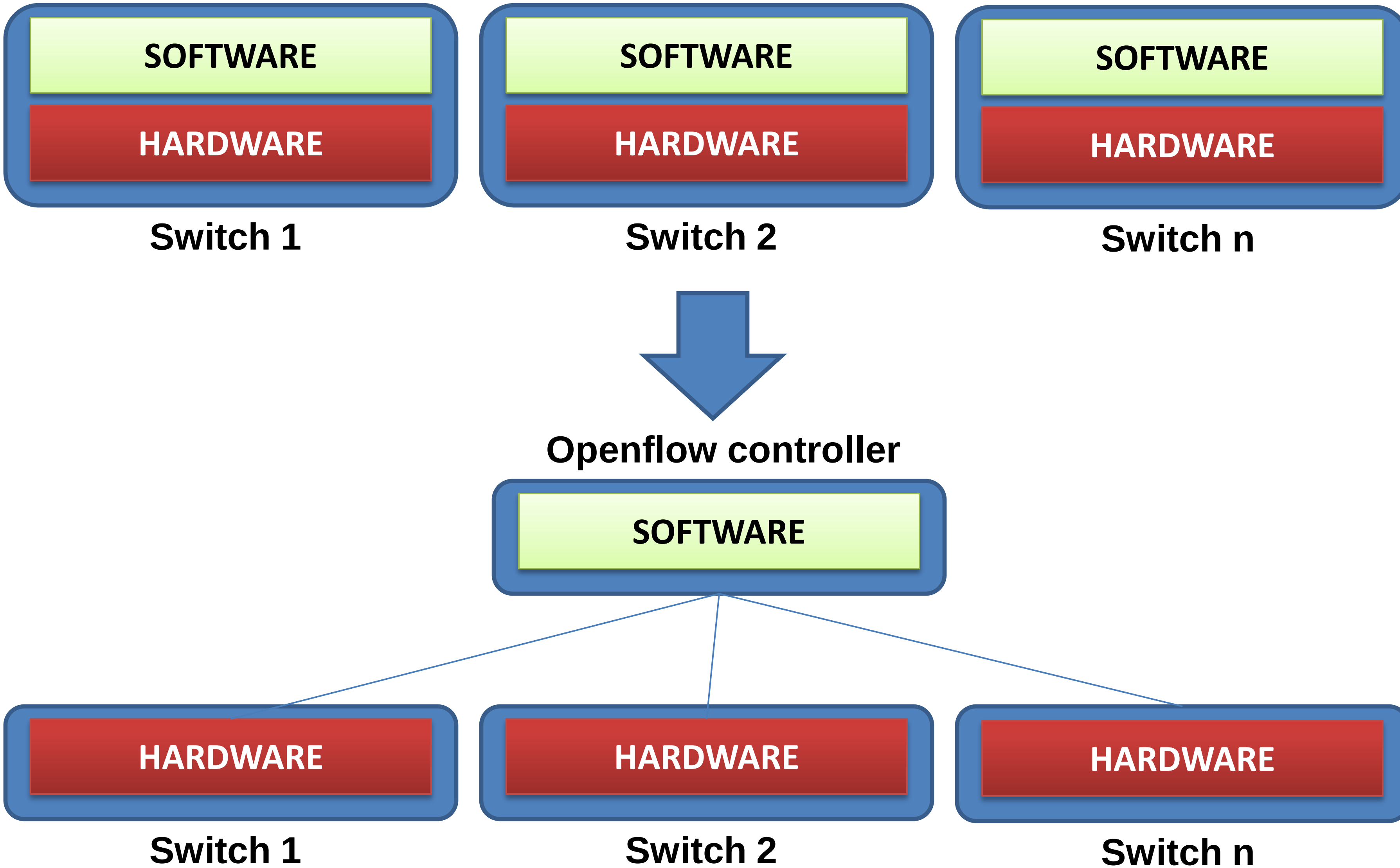


Network Monitoring. sFlow & NetFlow

- Network monitoring technology to gather flow-related statistics;
- Can track the source and destination for packets that passes through an interface;

- sFlow compute statistics based on a sampling mechanism;
- NetFlow keeps a record for every flow. If needed, it can also use sampling.

Software defined networking. OpenFlow



Software defined networking. OpenFlow

- An open protocol to remotely add/remove flow entries;
- Allows the path of network packets through a network to be determined by a software running on a separate server, called a **controller**
- The controller run a **NOS** (Network Operating System) that allows user applications to control network behavior.

- Allow researchers to run routing experiments in their network;
- Already supported on several routers (ex: HP Procurve)

The show must go on …

Data Networks

Networking for Data Acquisition

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Practical usage of networks for DAQ

- Network for data acquisition

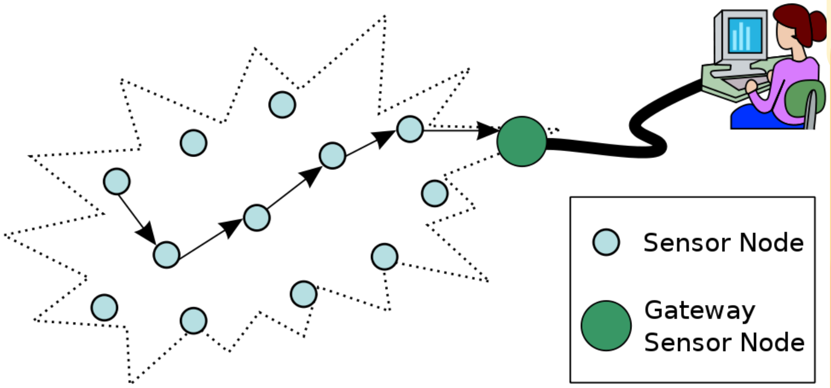
- Efficiency
  - Network
  - Hosts

- Architecture for large experiments

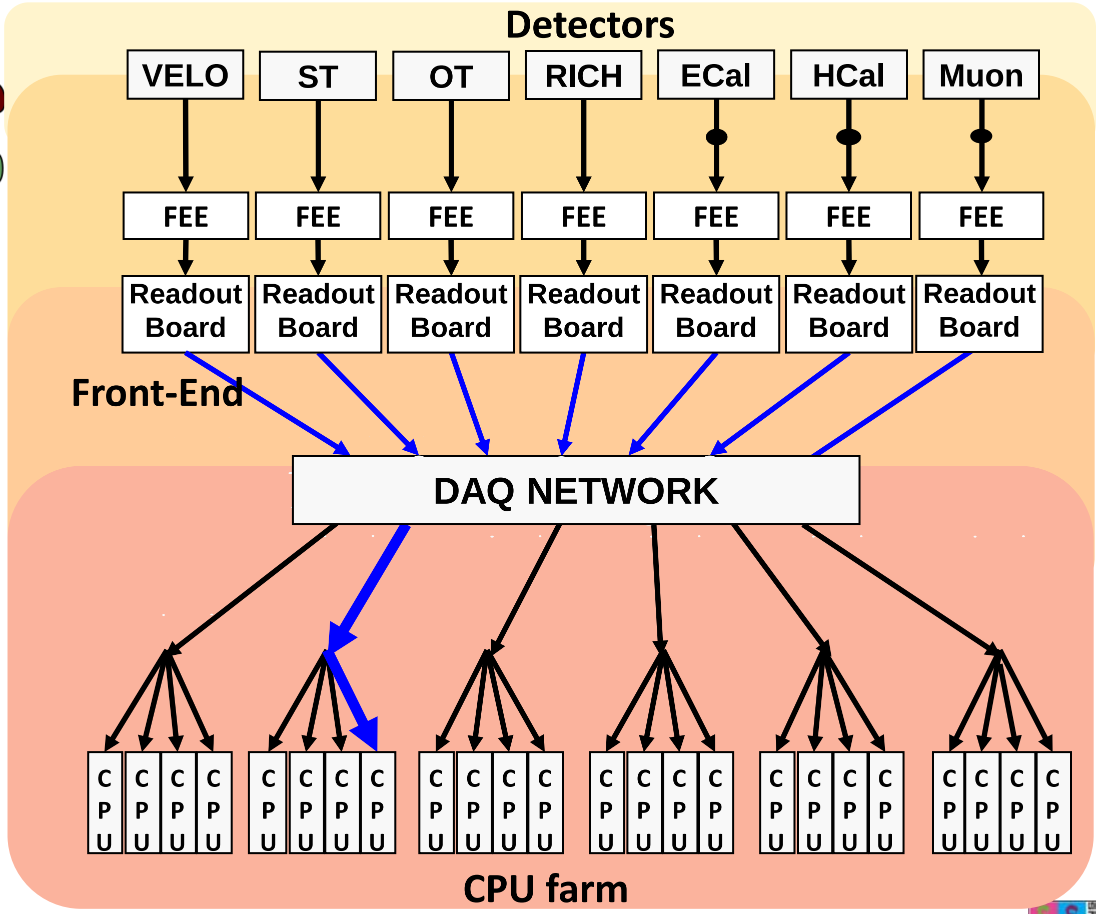
Network for Data Acquisition

- Data acquisition
  - Measure and digitize physical conditions
  - Typically from hardware devices
  - Manipulate data with computers
- Network
  - Interconnected devices sharing information
- Bring data from sources to analysis computers
  - Unidirectional useful data traffic
  - Monitoring and control traffic almost negligible

Examples

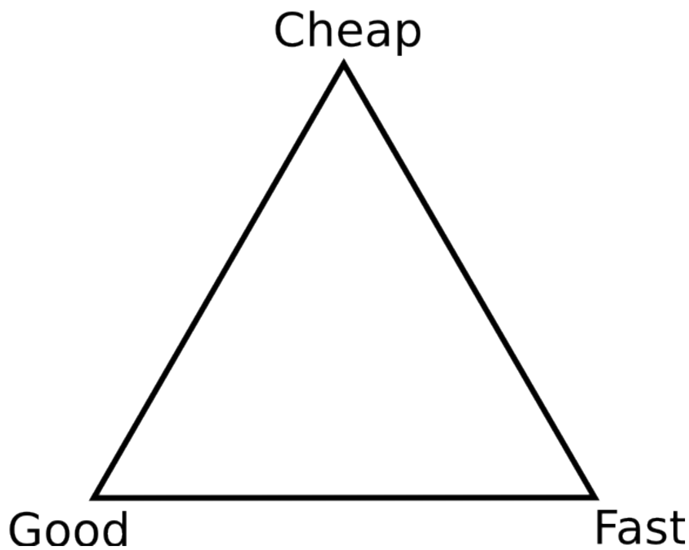


Wireless Sensor Network



LHCb DAQ Network

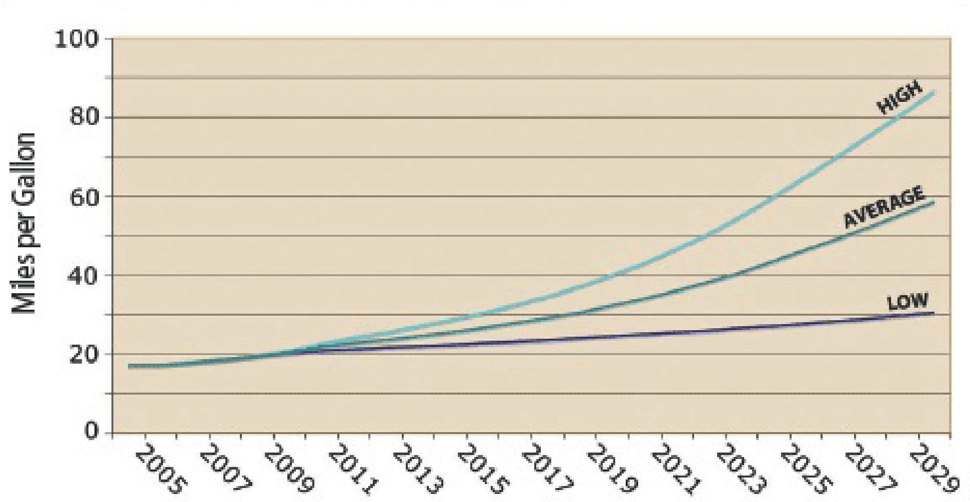
Choosing Technologies



- Requirements
  - Scalability
  - Reliability
  - Low cost
  - Expected life-time
  - Provider's health
- Ethernet is a de-facto standard
  - Largely used in the industry
  - Many providers
  - More and more used
    - Layering allows to put everything on top of it
- Others: Myrinet, InfiniBand

Efficiency

- Ratio of the useful output to the total input in any system
- In other terms, get the most out of your resources



- Networking concerns:
  - Bandwidth
  - CPU and memory on host computers

Useful data rate optimization

Ethernet	IP	TCP	Payload	Ethernet

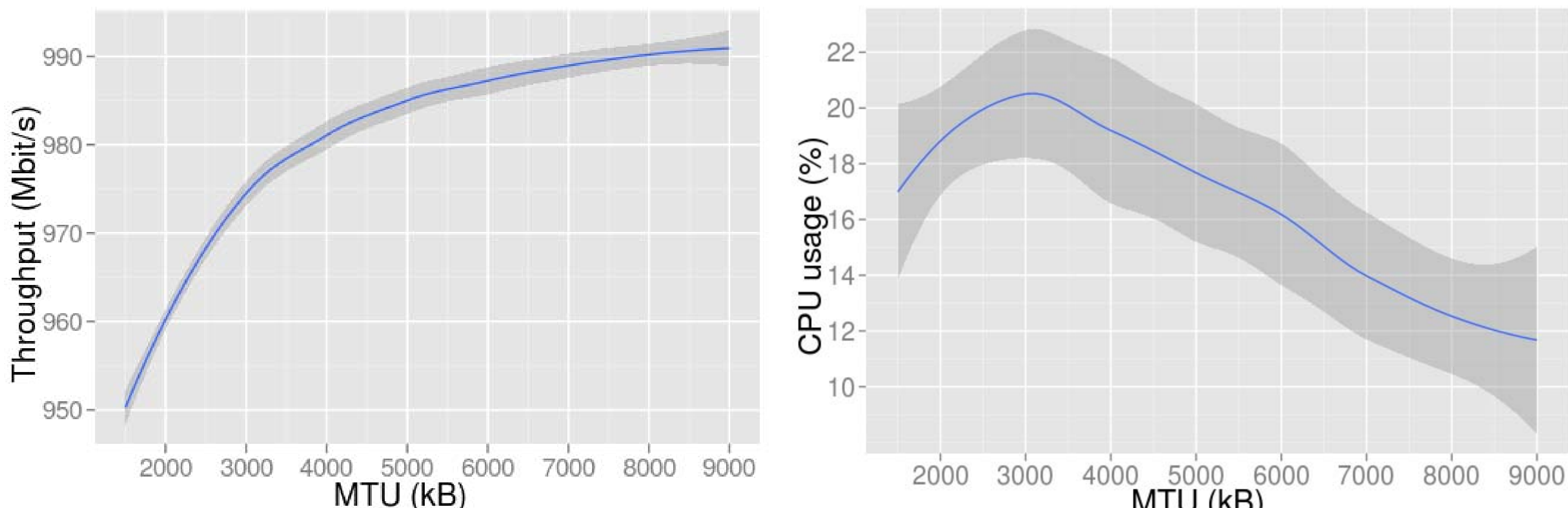
0 21–22 41–42 61-62 161-162 177

- Encapsulation adds overhead to your network
- Example : Sending 100 bytes of data using TCP/IP over Ethernet
  - Add 38 bytes for Ethernet (802.3) or 42 with optional 802.1Q
    - 8 bytes of preamble, 14 of header, 4 of CRC and 12 of interframe gap
  - Add 20 bytes for IP
  - Add 20 bytes for a minimal TCP header (no options)
  - 100 178 = 56%

- Only small data packets ? Use <u>coalescing</u>
  - Append numerous messages into the same datagram to increase your payload

Coalescing and Jumbo Frames

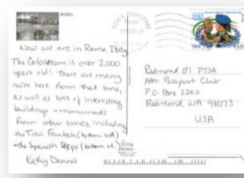
- Filling the payload up to the Maximum Transfer Unit (MTU):
  - Typically 1500 at IP layer: 1460 1538 = 94%
  - Non standard Jumbo frames: 8960 9038 = 99%
- Jumbo frames also improve
  - Data rate
  - CPU usage (both server and client sides)



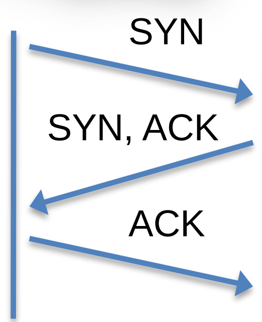
Tests performed on a Broadcom NIC and an 8 core Intel Xeon processor

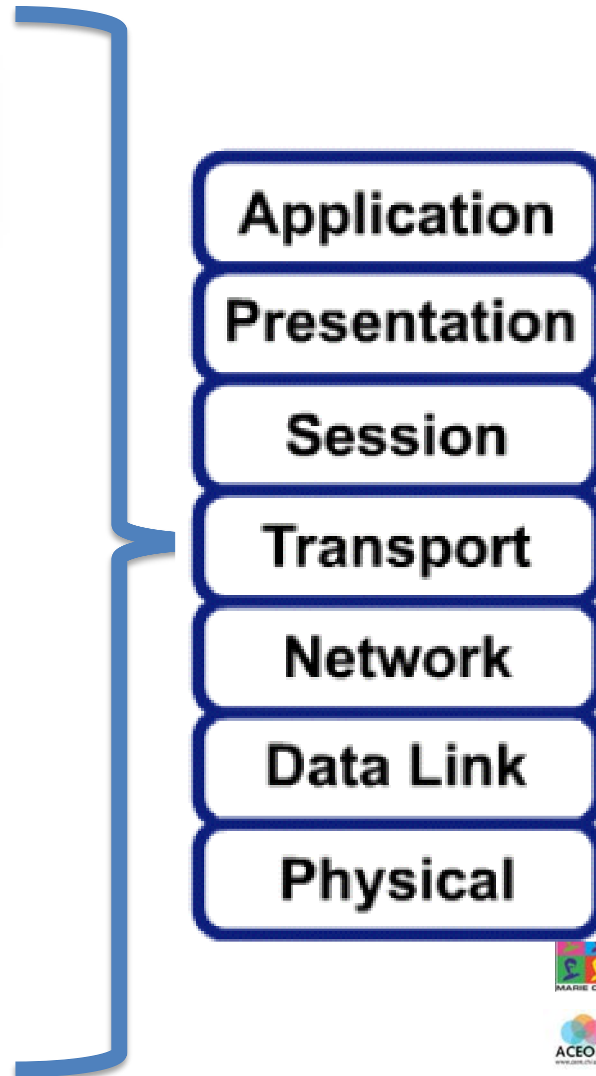
Major Transport Protocols: TCP and UDP

- Unreliable Datagram Protocol
  - Unreliable but simple
  - Connectionless
  - RFC 768
    - http://tools.ietf.org/html/rfc768

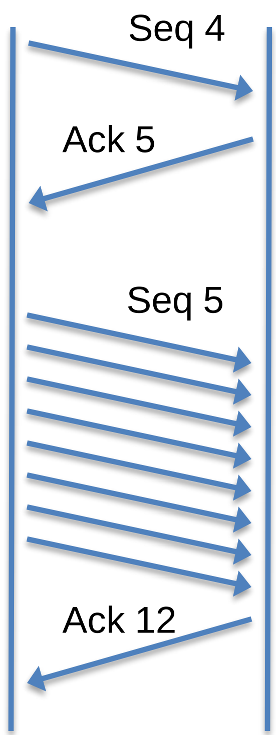


- Transport Control Protocol
  - Connection oriented protocol
  - Flow control
  - Lossless
  - RFC 793
    - http://tools.ietf.org/html/rfc793

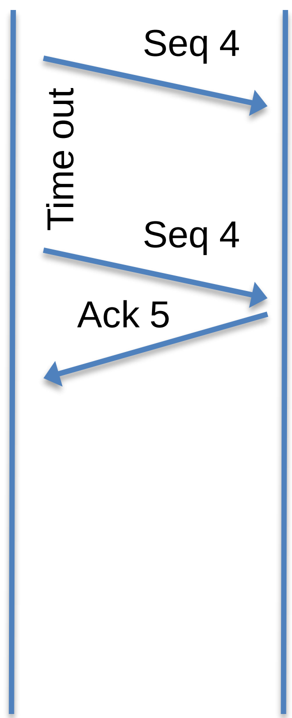




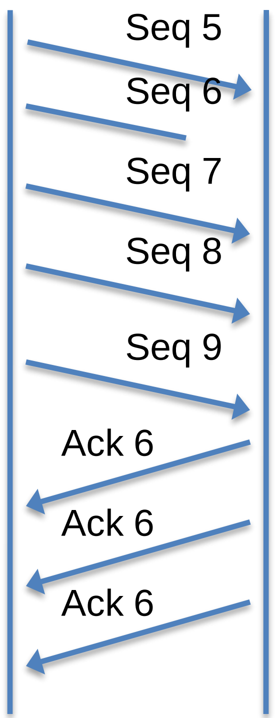
TCP: How it works



Normal transmission



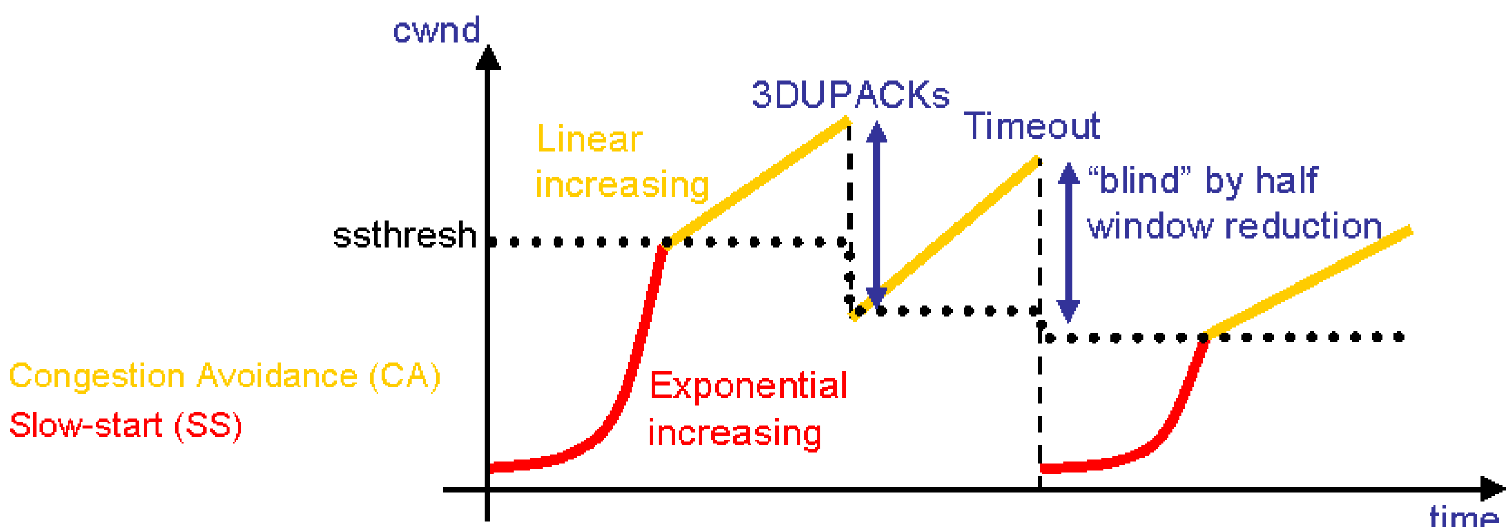
Packet never acknowledged
Time out



Packet lost
in a sequence
3 duplicated ACKS

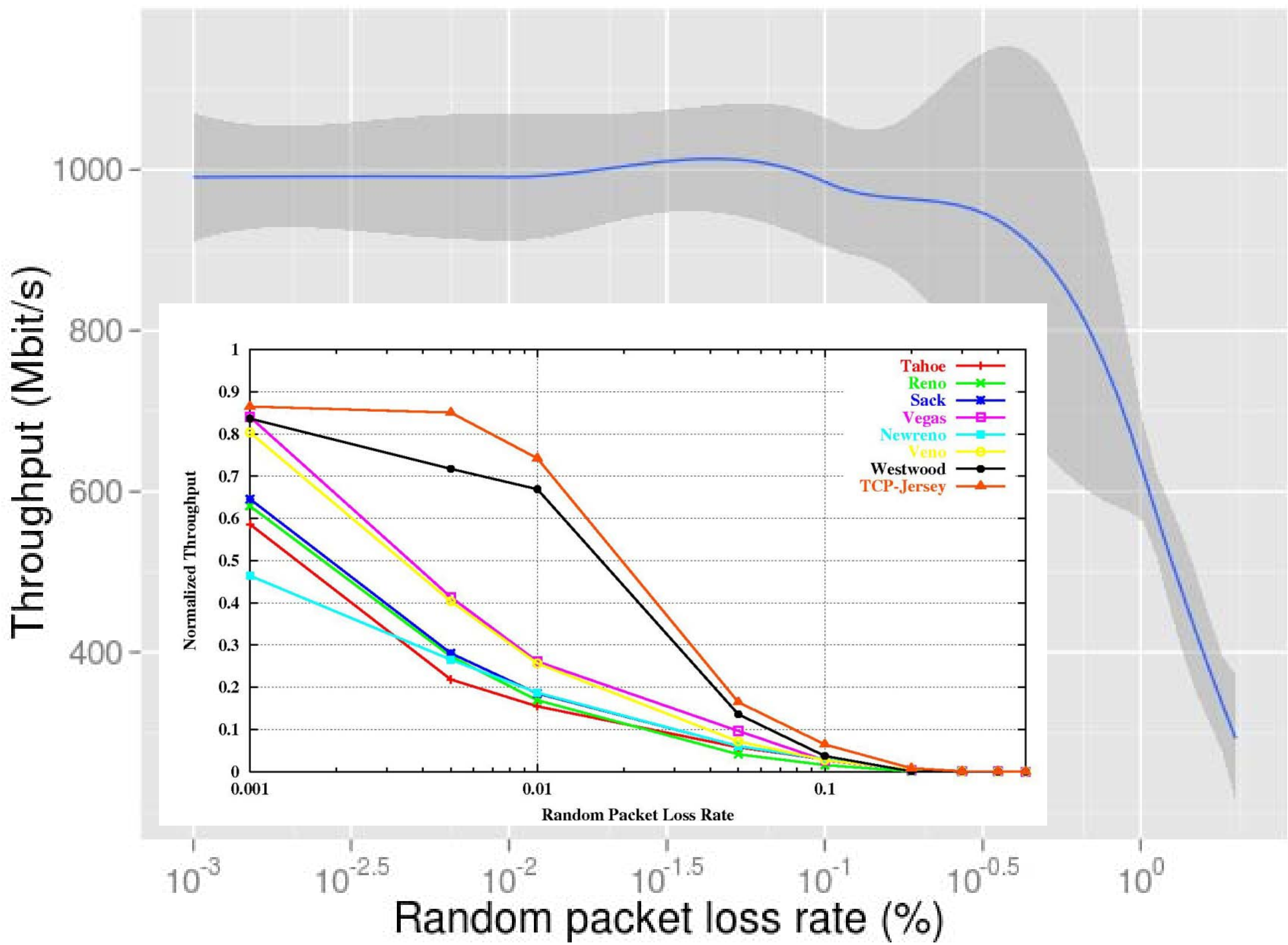
TCP: Reliability Vs Performance

- Cause of packet loss:
  - Congestion
  - Discards and errors
  - Faulty hardware or drivers
  - Quality of service
- Congestion is detected
  - If time out happens while no ACK received
  - If multiple ACKs received
- Congestion avoidance: adapt data rate to the traffic conditions



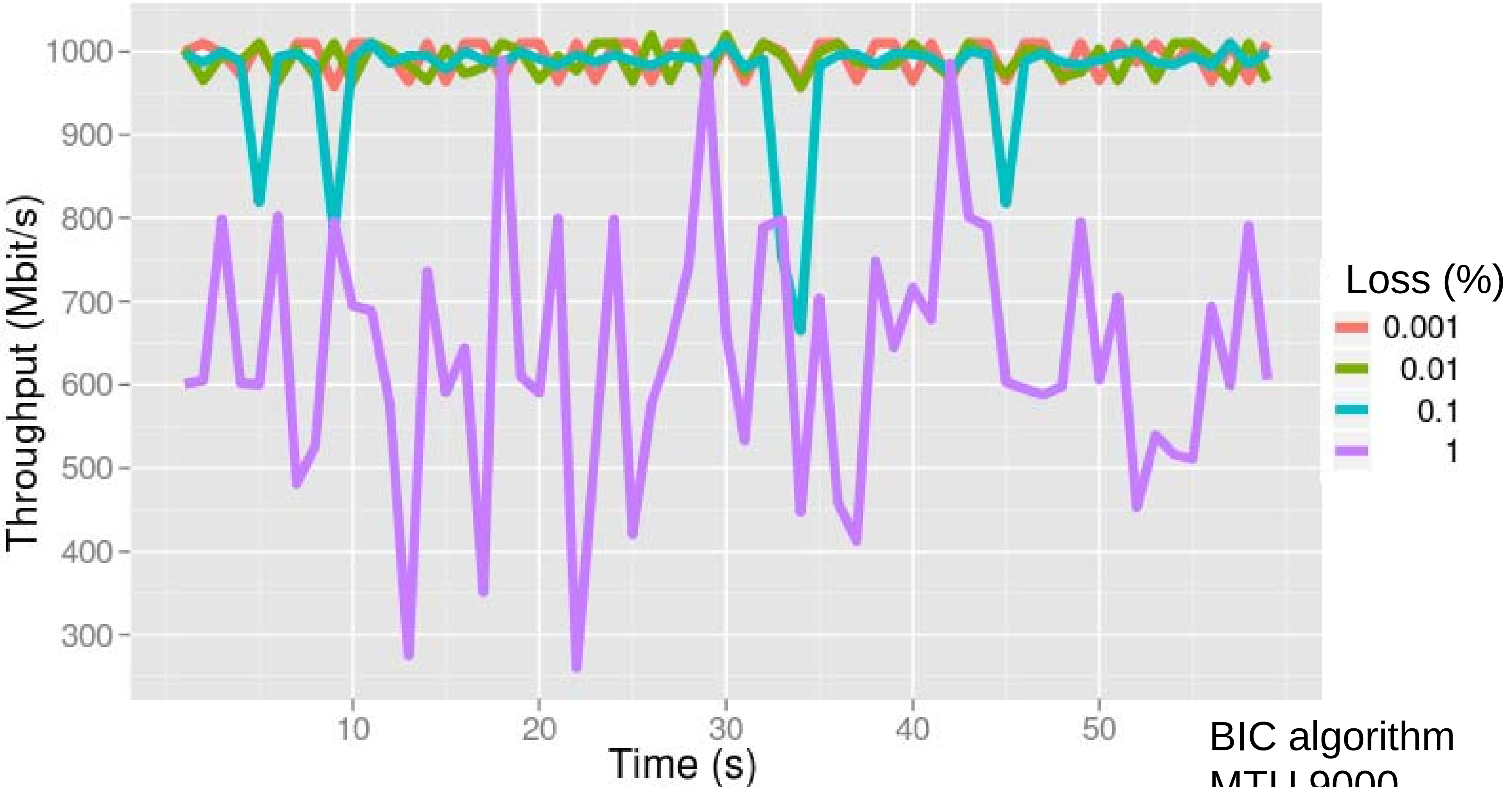
TCP Westwood

TCP Performance with Packet loss



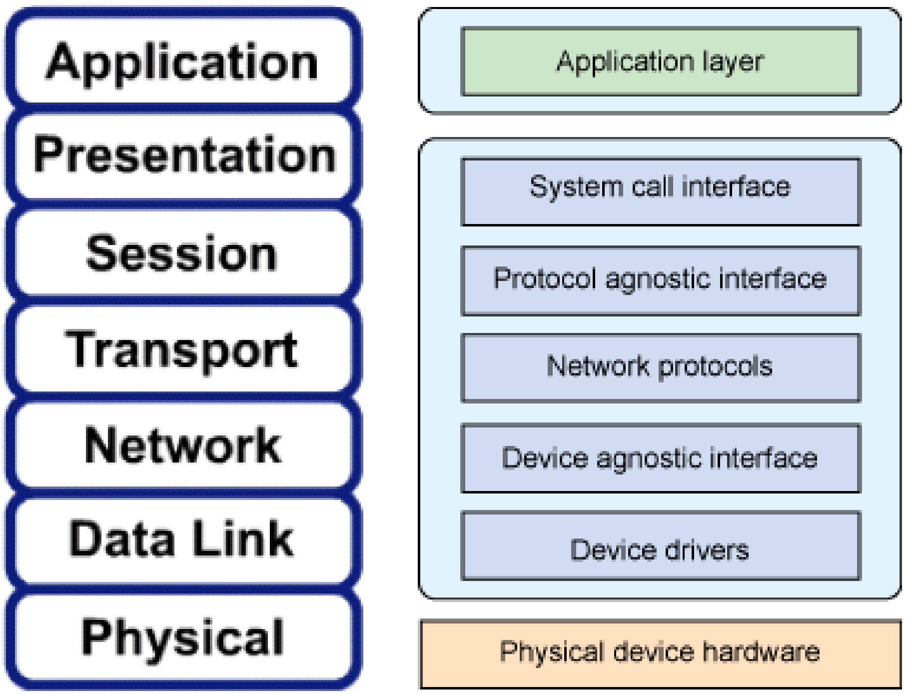
MTU = 9000 bytes
Tools: netem and iperf
1 GbE link
Binary Increase Congestion control algorithm

TCP Throughput over time



BIC algorithm
MTU 9000
1 GbE link
Netem and iperf

From network to software

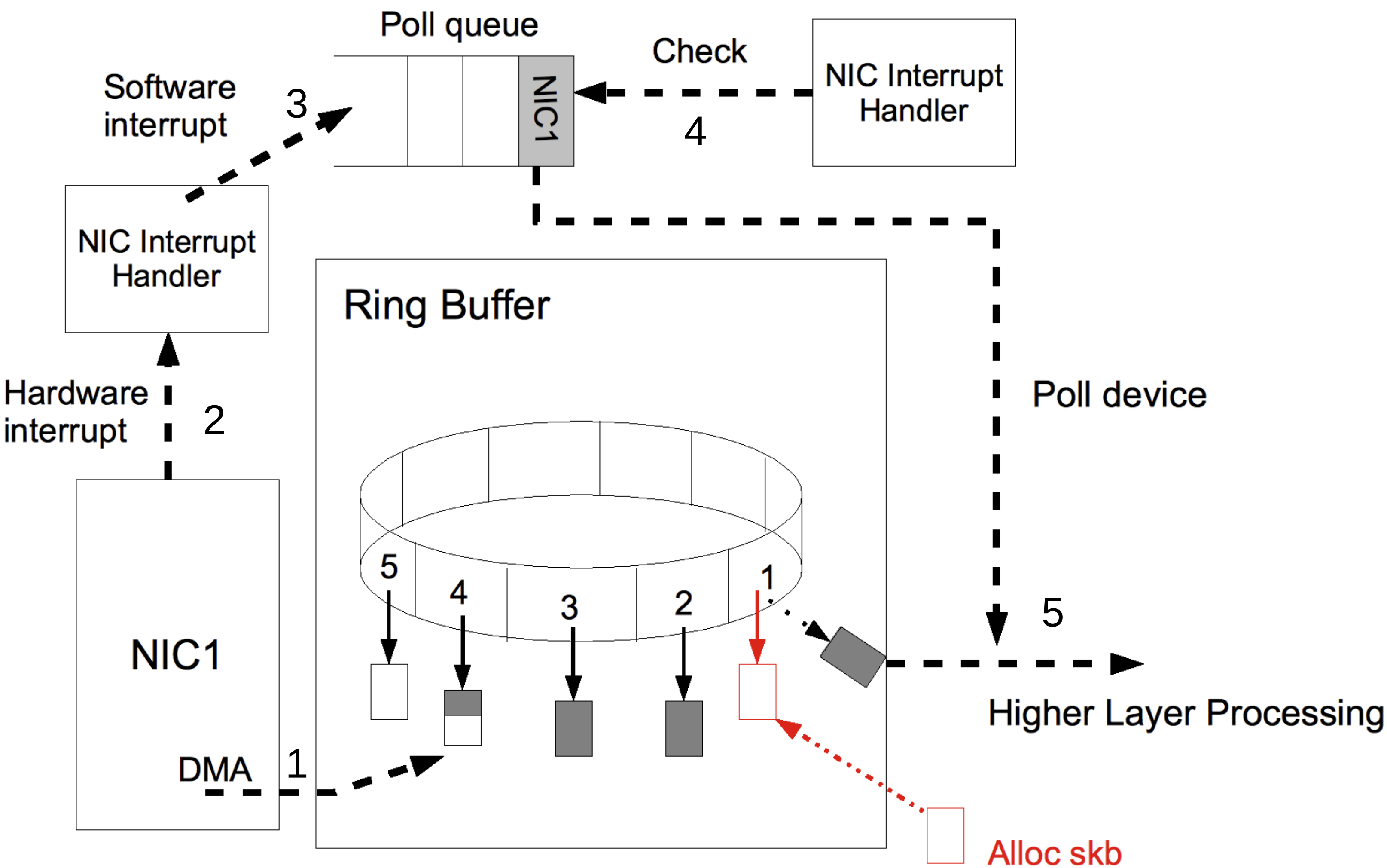


The OSI model and the Linux network stack
(Similar on Windows and other OS)

Numerous bottlenecks

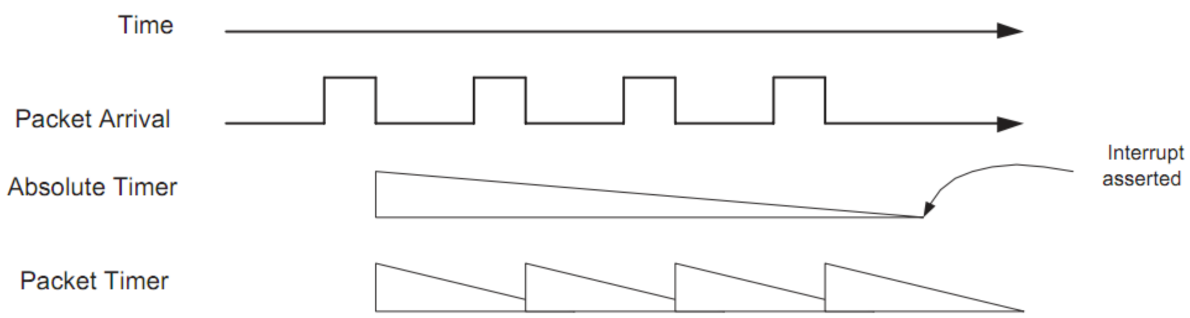
- Mapping with OSI reference model !
- No 1 to 1 mapping
- Unique data structure, sk_buff, moves packets between layers
- System calls = application access to the network stack
- Layering provides:
  - a common interface to many transport protocols
  - a common interface to many devices

From the device to the Kernel



Interrupts

- Hardware interrupt has a cost
  - Context switch of a CPU
    - Saving and loading registers and memory maps, updating various tables and list
  - Happens every time an Ethernet frame is received ?
    - 1538 bytes -> 12304 bits -> 1 frame every 12.3 µs
  - Around 100.000 frames per seconds at full speed
- Lower the rate with interrupt coalescing
  - 1 interrupt for several frames
  - Do not add too much latency in case of low traffic

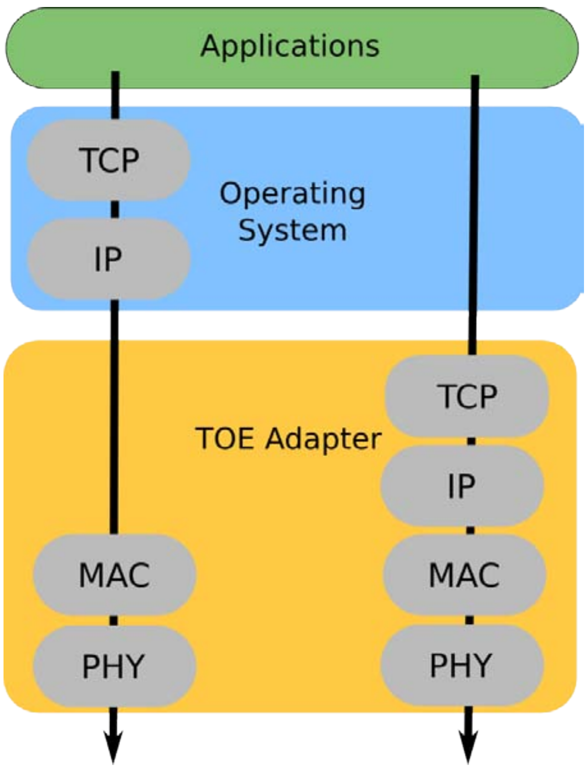


  - Careful to the ring buffer size, if the buffer is full, new packets will be discarded

Considering efficiency at all stages

- Higher Layer Processing consists of numerous tasks:
  - Checksum calculations
  - Data copies
  - Header stripping or adding
  - Protocol logic implementation
  - Reordering
  - Reassembling
  - ….
- High bandwidth impact on CPU consumption
  - 100% of one 2.33 GHz core for a bandwidth of about 5 Gb/s (without any tuning ☺)
- Trying to outsource these to hardware controllers

Offloads



TOE: export processing to hardware controllers

- Purpose: free host CPU cycles
- TCP Offload Engine
  - TCP/IP stack processed by the network device
    - Checksum computing
    - Transport protocol segmentation
  - Not supported by standard Linux Kernel
    - Vendors provide patches
- Large Segment Offload
  - Ask the socket to send a large buffer, and let the NIC split them into smaller packets
    - Reminder: sk_buff size = MTU
- Large Receive Offload
  - Aggregate multiple incoming packets into a large buffer before they are passed to the higher network stack

Basic optimizations

- Hosts
  - Mainly for reception side
    - Its task is much harder (c.f. Enrico Pasqualucci lecture)
  - Provide large kernel buffers and large socket buffer for the application
    - Machines can easily cope
  - Tune IRQ moderation

- Network devices
  - Usually clean network with an unidirectional dataflow
  - Enable jumbo frames on all port to improve bandwidth
    - as demonstrated earlier
  - Reduce the amount of output queues to maximize the buffer size of each queue

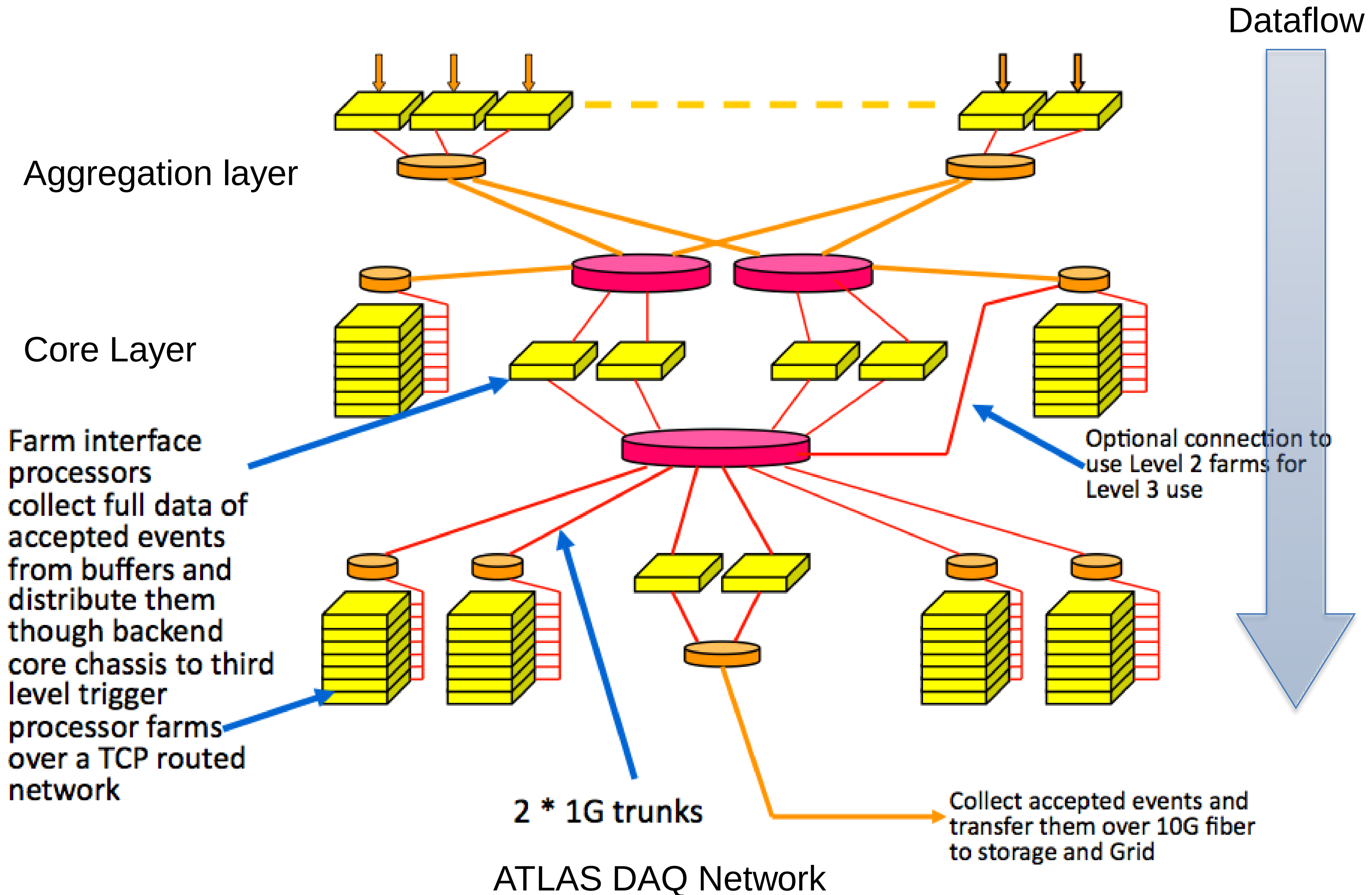
Network devices for DAQ

Core router

Edge switch

- LHC data acquisition systems uses O(1000) ports -> too large for a single device
- Typical architecture
  - Aggregation layer
  - Core layer
  - De-aggregation / fan-out / edge
- Top-down dataflow relies on static routing and layer 2 switching

Overview


Dataflow
Aggregation layer
Core Layer
Farm interface processors collect full data of accepted events from buffers and distribute them though backend core chassis to third level trigger processor farms over a TCP routed network
Optional connection to use Level 2 farms for Level 3 use
2 * 1G trunks
Collect accepted events and transfer them over 10G fiber to storage and Grid
ATLAS DAQ Network

Conclusion

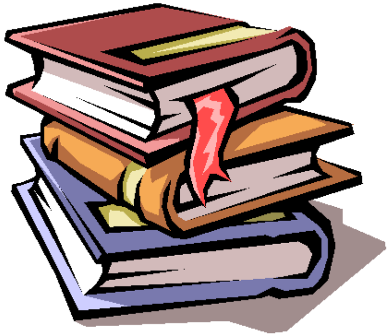
- Networking basics
  - OSI Model is your friend !
  - Ethernet is used to connect hosts together
  - TCP/IP is used to connected networks together
  - SNMP and sFlow/netFlow will monitor everything (for you)

- Only scratched the surface of a few standard or new technologies
  - Many other protocols, less known than TCP and UDP but very interesting for DAQ
  - Numerous other optimizations

- New investigation
  - Other network topologies
  - 10 GbE
  - InfiniBand

References

- **Wikipedia**
- **IETF RFCs**
- **« man » pages**
- **Conference proceedings and journals**



A few noticeable:

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