Aalto University
School of Chemical Technology

Ethernet, IP & TCP/UDP

CHEM-E7215 - Special Course in Process Systems Engineering

Jukka Kortela

Learning outcomes

- Student knows the network topology of and automation system
- Student will understand the basic principles of an Ethernet based system

Contents

- Introduction
- OSI model
- Ethernet
  - Physical layer
  - Data link layer
- IP
  - Network layer
- TCP & UDP

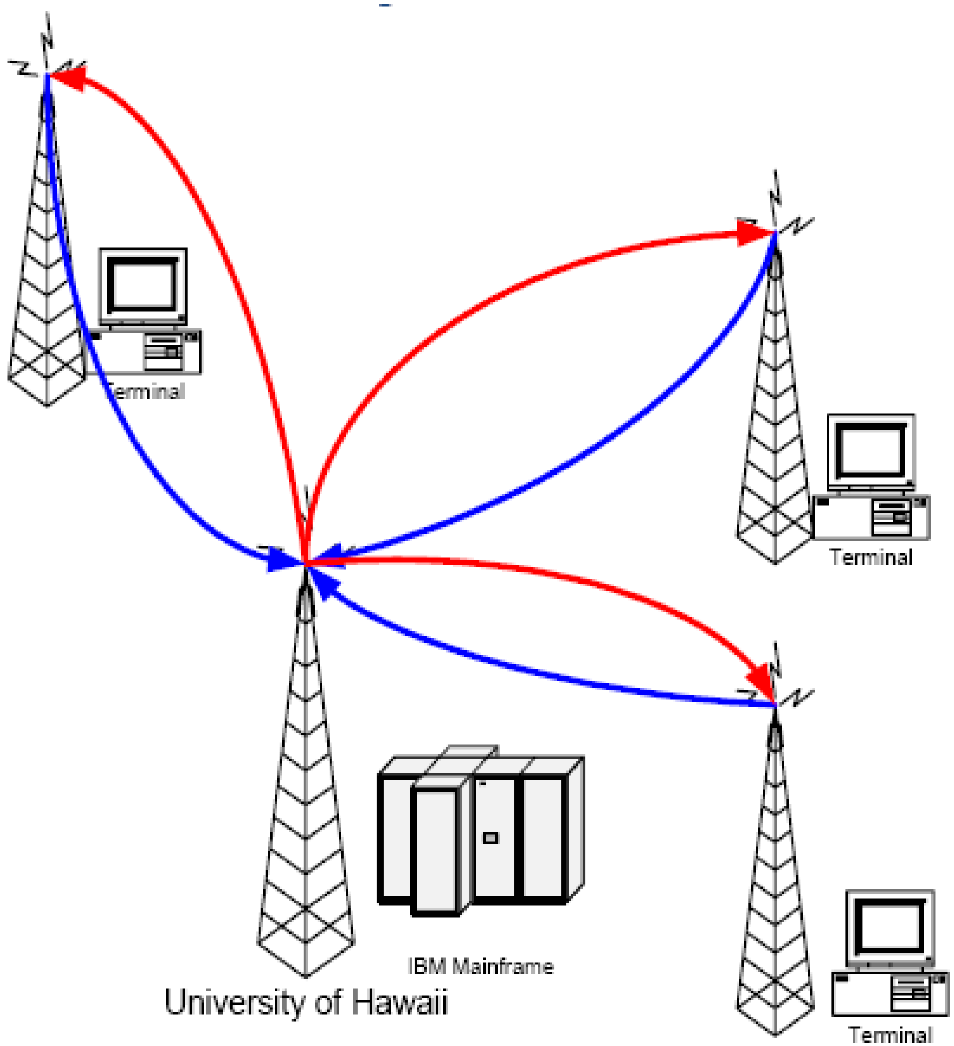
What is Ethernet?

- Ethernet is a way of transmitting a signal between two or more devices over a shared medium.
- It is purely concerned with the medium used, the way the signal is put onto that medium, and what form that signal takes.

What is Ethernet?

- A type of network cabling and signalling developed by Digital, Intel and Xerox in the 1970’s. Ethernet became a IEEE standard in 1985
- The most common type of LAN used today.

Ethernet History –
The ALOHA network (1971)



- Pioneered the concept of a shared transmission channel, or the CSMA/CD model.
- Developed to link the IBM 360 mainframe to the other islands of Hawaii

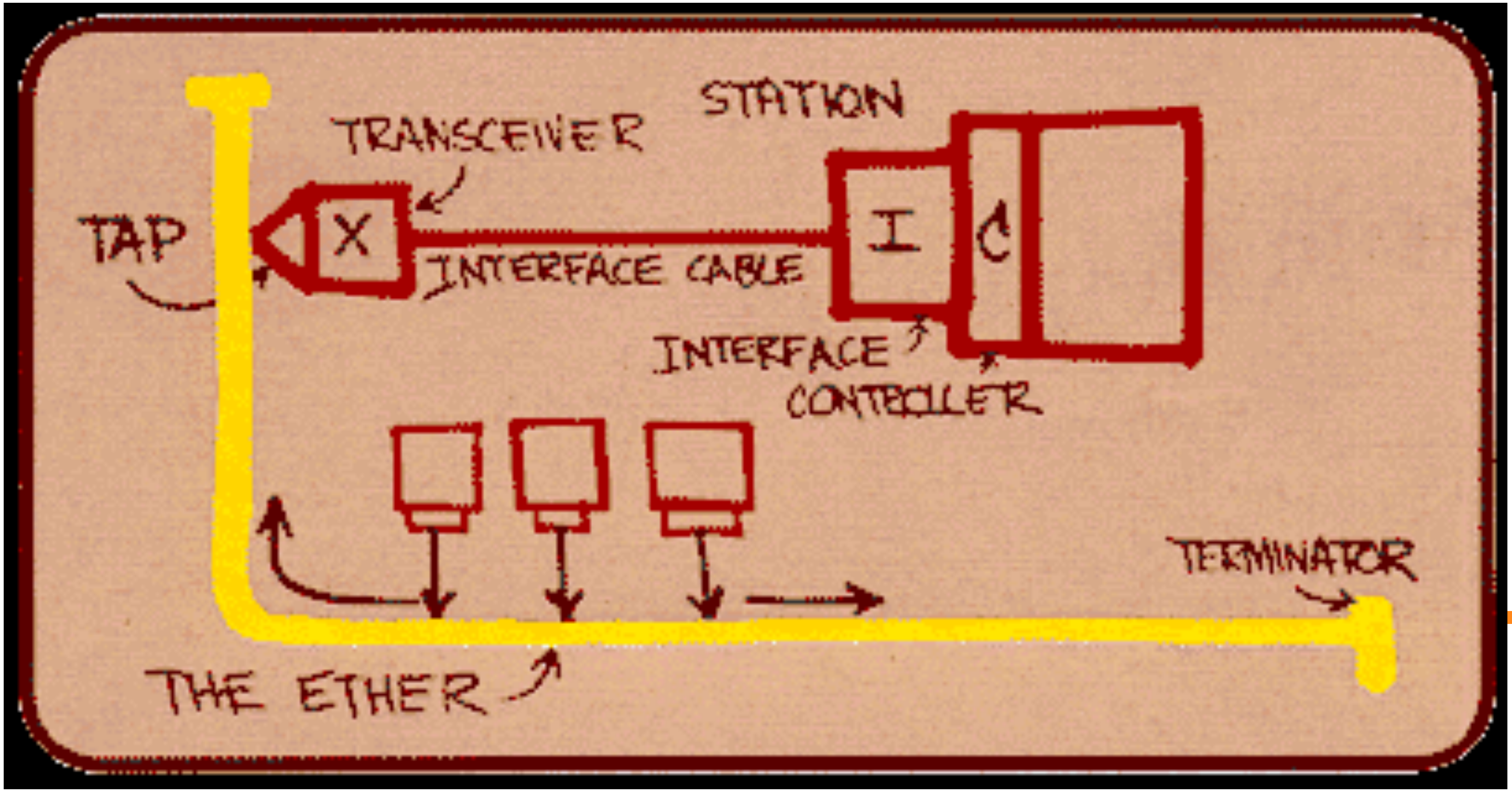
Outbound channel uses one-to-many transmission

All inbound transmissions use same channel frequency with possible contention

Acknowledgements sent to everyone simultaneously

Ethernet History – The First Ethernet

- Designed by Bob Metcalf at PARC in 1972/3



Standards Organisations – IEEE

Institute of Electrical and Electronic Engineers

- US engineering society
- Project 802 (1980 February)
- ANSI delegated lower speed (<50Mbps) LAN standardisation to IEEE
- Now responsible for 100Mb and 1Gbps Ethernet
- Focuses on Physical and Link levels

Standards Organisations – IEEE

- IEEE develops a standard and - in the past - submitted it to ANSI. ANSI approved the standard and submitted it to ISO
  - ISO-8802
- Today IEEE sets the standard. There is no need for an other agreement or standardization.

Project 802 Overview

- 802.1 Overview including higher layers and internetworking
- 802.2 Logical Link Control
- 802.3 Carrier Sense Multiple Access with Collision Detect - Ethernet
- 802.4 Token Bus
- 802.5 Token Ring
- ...
- 802.11 Wireless LAN
- 802.15 Bluetooth
- 802.16 Wireless MAN
- 802.17 Resilient Packet Ring
- More information available at http://www.ieee.org

Internet Engineering Task Force

- The IETF is an open international community of network designers, operators, vendors, and researchers concerned with the evolution of the Internet architecture and the smooth operation of the Internet. It is open to any interested individual.
- Based in the US, but international, as most work is done by email.
- The IETF publishes Requests For Comments (RFCs)

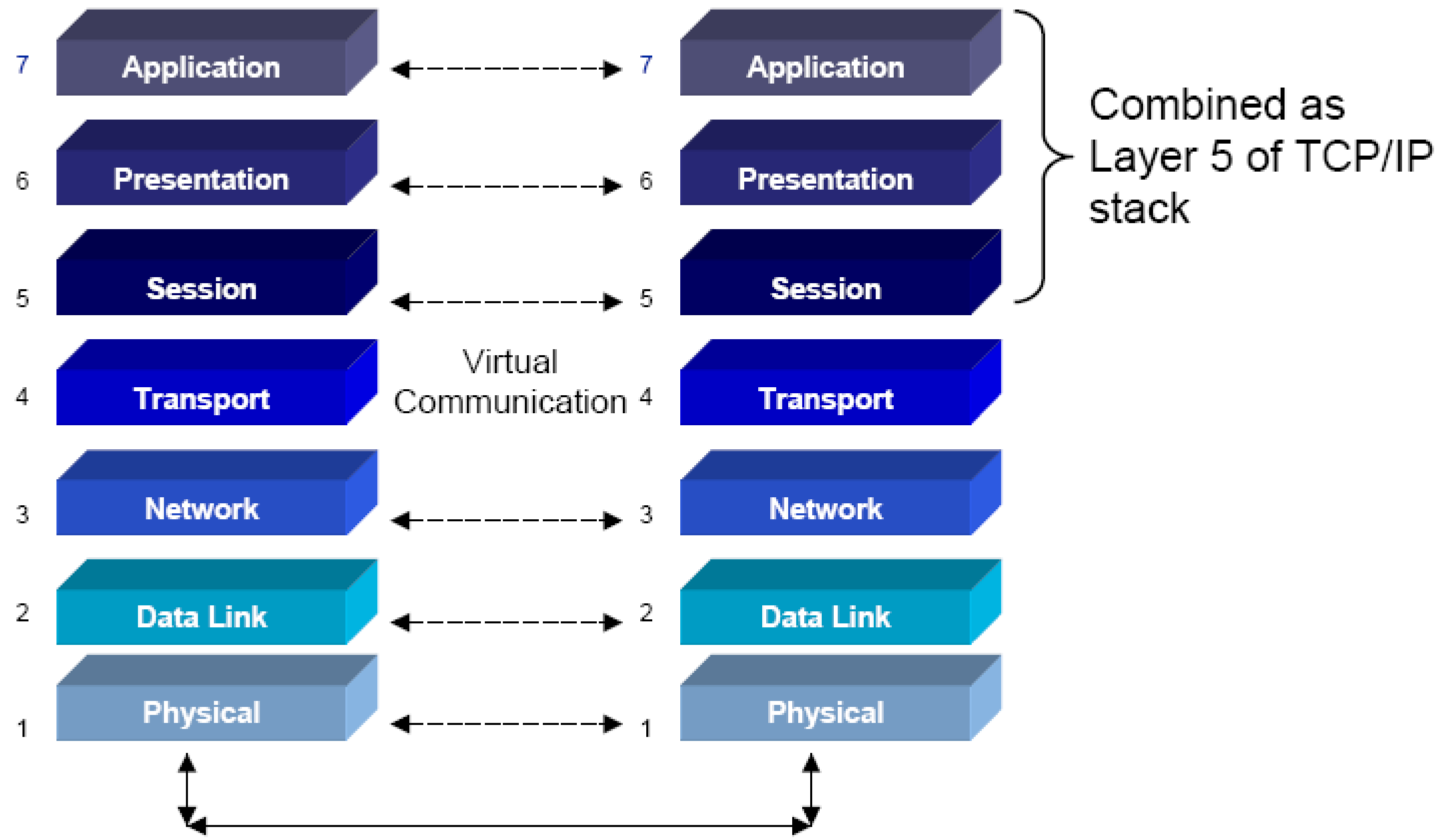
Internet Engineering Task Force

- There are draft RFCs and approved RFCs
- Drafts are circulated for discussion
- Approved RFCs become internet routing standards
- The IETF is the governing body for everything from layer 3 of the 7 layer model up.

Contents

Introducing The 7 Layer Model

- OSI Reference Model



OSI Reference Model

- Physical
  - The Physical Layer defines the physics of getting a message from one device to another. Is responsible for an error free transmission
  - converts bits into signals for outgoing messages and signals into bits for incoming ones
  - This is the most important area in terms of troubleshooting and operations

OSI Reference Model

- Data Link
  - The Data Link Layer provides the rules for converting electrical signals to data, error checking, physical addressing and media access control.
  - Handles the delivery of frames from sender to receiver through the physical layer.

OSI Reference Model

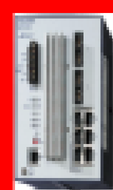
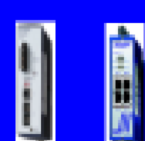
- Transport
  - The Transport Layer establishes a dependable “end-to-end” connection between two devices.
  - It ensures that datagrams delivered can be accepted by its recipient and that data received matches the data sent.
  - This is a “virtual” connection, the transport layer believes it is the “actual” connection between devices

Layer	Name	Message Name	Addressing	Physical Connections	Connects	Tasks
7	Application					Resource sharing, device redirection, remote file access, remote printer access, inter-process communication, network management, directory services, electronic messaging, network virtual terminals, identification, authorisation.
6	Presentation					Character code translation, data conversion, data compression, data encryption.
5	Session		Socket number			Session establishment, session support.
4	Transport	Datagram	Port address		End Devices	Message segmentation, message acknowledgement, message traffic control, session multiplexing.
3	Network	Packet	IP address	Routers 	Subnets	Routing, subnet traffic control, frame fragmentation, logical to physical address mapping, subnet usage accounting.
2	Data Link	Frame	MAC address	Switches 	Collision Domains	Link establishment and termination, frame traffic control, frame sequencing, frame acknowledgement, frame delimiting, frame error checking, media access management.
1	Physical	Wire	Physical port	Hubs/Media Converters  	Nodes	Data encoding, physical medium attachment, tranmission technique, physical medium transmission.

OSI Reference Model

So where does Ethernet fit?

- Ethernet is purely the lowest two layers of the 7 layer model

Layer	Name	Message Name	Addressing	Physical Connections	Connects	Tasks
2	Data Link	Frame	MAC address	Switches 	Collision Domains	Link establishment and termination, frame traffic control, frame sequencing, frame acknowledgement, frame delimiting, frame error checking, media access management.
1	Physical	Wire	Physical port	Hubs/Media Converters 	Nodes	Data encoding, physical medium attachment, tranmission technique, physical medium transmission.

Contents

The Physical Layer

- The physical layer defines the electrical signalling, symbols, line states, clocking requirements, encoding of data and connectors for data transmission.
- All higher layers talk to the physical layer through a predefined interface.
  - 10Mbps – Attachment Unit Interface (AUI)
  - 100Mbps – Media Independent Interface (MII)
  - 1Gbps – Gigabit Media Independent Interface (GMII)
- Layer 1 interfaces to the actual cable by using a medium dependent interface (MDI)

The Physical Layer

Types of Ethernet

- 10 Mbits per second (Mbps) - Ethernet
  - 10BASE-T Twisted pair (cat. 3)
  - 10BASE-FL Fibre optic
  - 10BASE5 Thick Ethernet (yellow cable, 50 Ohm)
  - 10BASE2 Thin Ethernet (cheapernet, 50 Ohm coax)
- 100 Mbps – Fast Ethernet
  - 100BASE-TX Twisted pair (cat. 5)
  - 100BASE-FX Fibre optic
- 1000 Mbps – Gigabit Ethernet
  - 1000BASE-TX Twisted pair (4 pair cat. 5)
  - 1000BASE-SX Fibre optic (multi-mode)
  - 1000BASE-LX Fibre optic (single-mode)
- 10 Gbps – 10 Gigabit Ethernet, 25GBASE-T, 40GBASE-T

The Physical Layer

- Cabling
  - Cabling accounts for more downtime and disruptions than anything else.
  - Cabling is normally less than 10 % of the project budget but causes >50 % of the problems.
  - Cabling equipment is measured in terms of megahertz (MHz) and respective their transmission quality divided into categories.

The Physical Layer

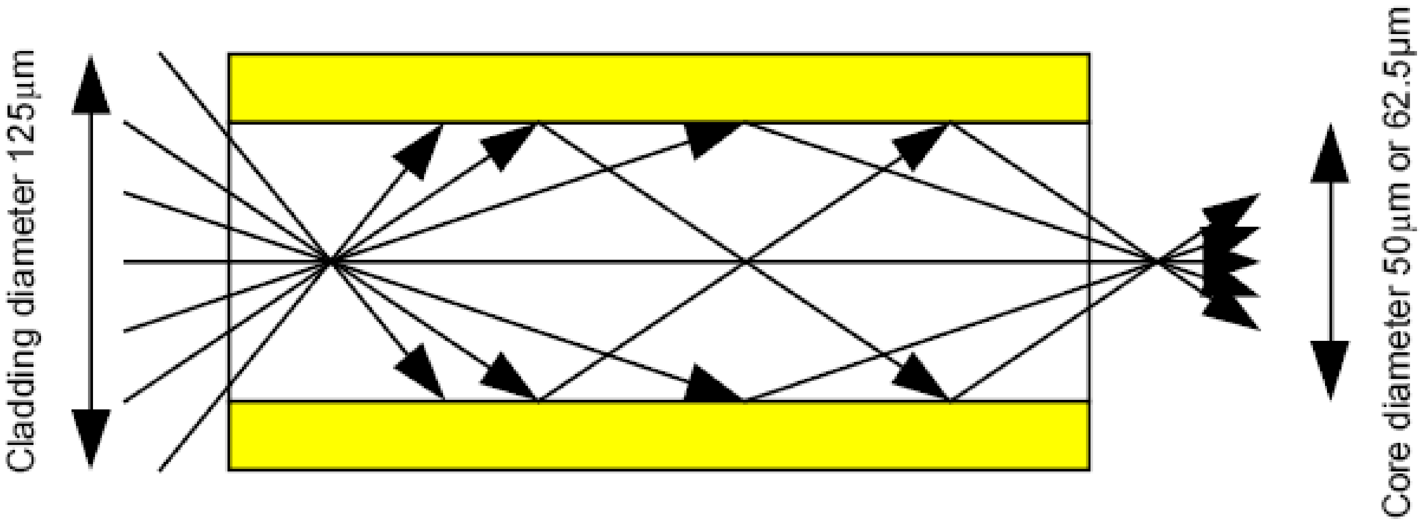
- Cabling
  - Copper cabling
    - Traditionally Ethernet was run on coax cable.
    - There have been two standards
      - Thick Ethernet
      - Thin Ethernet
    - Most modern installations are moving to S/UTP.
      - Category 3 (Cat 3) - maximum frequency of 16 MHz
      - Category 5 (Cat 5) - maximum frequency of 100 MHz
      - Category 6 cable (Cat 6) is a standardized twisted pair cable for Ethernet (250 MHz)
      - Category 6A cable is characterized to 500 MHz and has improved alien crosstalk characteristics, allowing 10GBASE-T to be run for the same 100-metre (330 ft) maximum distance as previous Ethernet variants

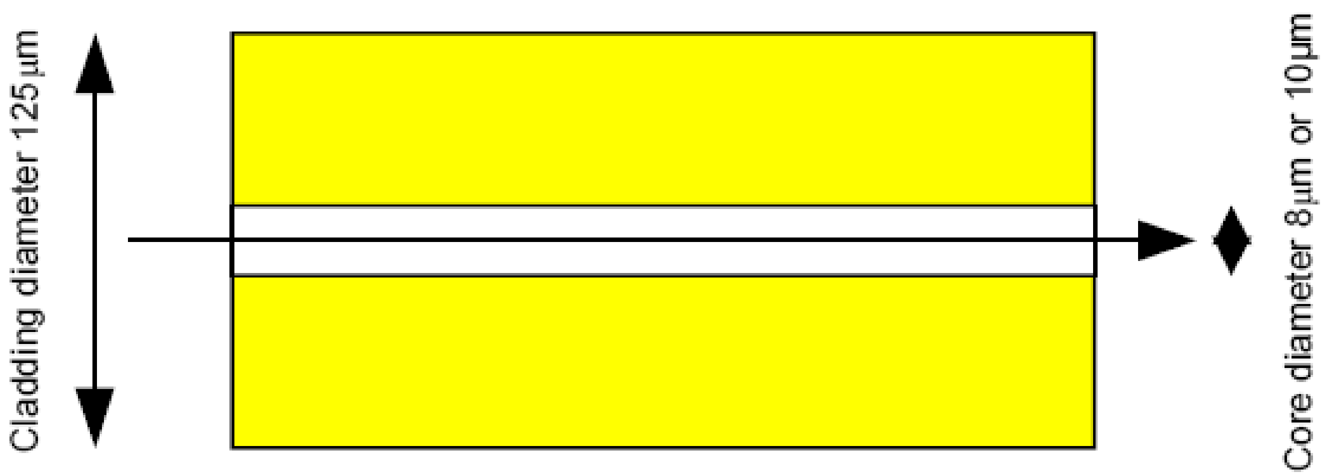
The Physical Layer

- Currently no industrially suitable connector standardized by IEEE
  - Demands: mechanical stability, IP protection (IP64 or IP67) , stable against vibrations
- Crossover
  - A NIC requires that it's transmit is connected to the opposing receive.
  - As most NICs connect to hubs or switches, the hub or switch manufacturer usually swaps the transmit and receive around so everything lines up correctly.

The Physical Layer

- Cabling
  - Fiber Optic Cable
    - advantages over copper
      - It's immune to Electromagnetic Interference
      - Support of long distances
    - There are 2 basic types
      - Multi-mode Fiber (MMF), used for short distances
      - Single-mode Fiber (SMF), used for long distances
    - There are 3 basic light sources
      - LED – low cost, used for MMF
      - ELED - medium cost, used for SMF, cheaper than LDs, no Laser protection measures needed
      - Laser, Laser Diodes LD – used with SMF over long distances


Cladding diameter 125µm
Core diameter 50µm or 62.5µm


Cladding diameter 125µm
Core diameter 8µm or 10µm

The Physical Layer

- NIC
  - Network Interface Card is the interface between the computer or device and the network.
  - You can have more than one per computer, in which case the computer is said to be “multi-homed”
  - Each NIC will have its own MAC and IP address.

The Physical Layer

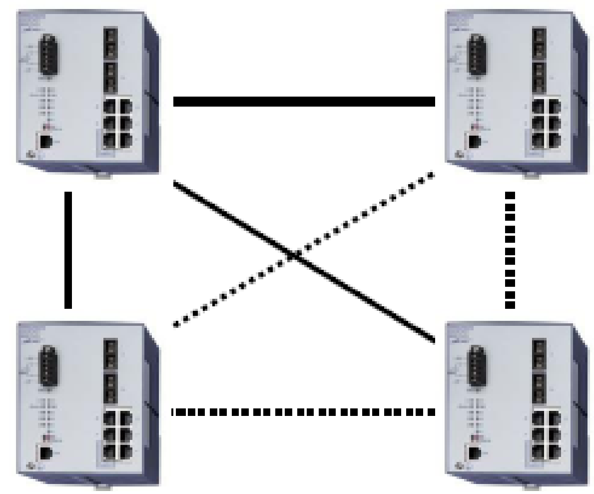
- Media Converters
  - Transparent conversion between media types
  - Half / Full Duplex
  - Used to extend maximum distance
  - E.g. Hubs, Switches

The Physical Layer

- Hubs
  - Connects multiple devices to a single collision domain
  - Half Duplex only
  - All frames sent out of all ports
- Switches (Layer 1 part)
  - Each port is a collision domain
  - Half / Full Duplex
  - Learned Address Table / Forwarding Database

The Physical Layer

- Topologies
  - Bus Topology
  - Star Topology
  - Ring Topology
  - Mesh Topology
- Layer 2 Redundancy
  - (Fast) Spanning Tree
  - Link Aggregation (“Trunking”)
  - Link Redundancy (proprietary)
  - Etc.



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Data Link (Layer 2)

- The Data Link Layer provides the rules for converting electrical signals to data, error checking, physical addressing and media access control.
- Handles the delivery of frames from sender to receiver through the physical layer.

Data Link - physical addressing

- Types of Addresses
  - Broadcast
    - Sent to all devices
    - Forwarded by switch and hub to all ports
    - Must be examined by all devices
  - Multicast
    - Sent to a group of devices
    - forwarded by switch, hub and router to all ports
    - Only examined by device in group
  - Unicast
    - Sent to individual devices
    - Exceptions – Unknown / Promiscuous mode
    - Unknown Unicast: sent to individual device - because address unknown - flooded by switch to all of its ports

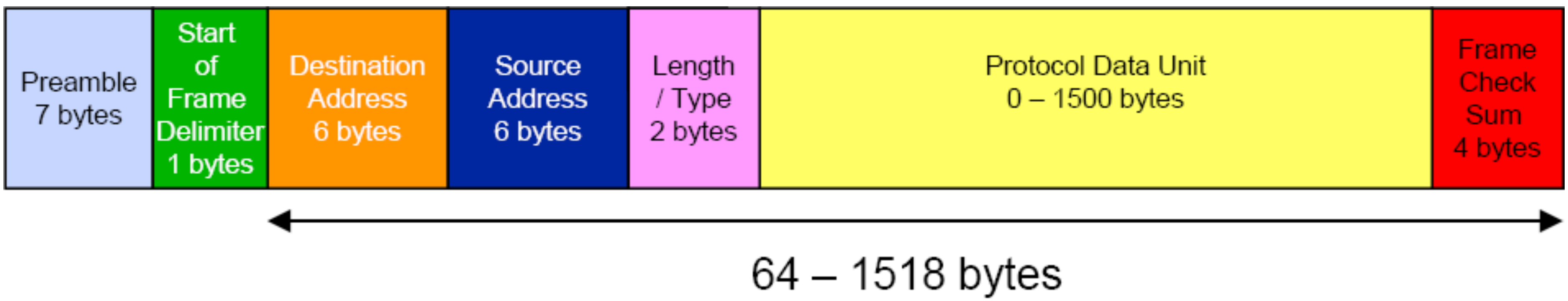
Data Link
physical addressing

- MAC address (Ethernet address)
  - allocated by manufacturer
  - worldwide unique
  - Layer 2
  - 6 byte (48 bit)
  - 256^{6} or 2.81×10^{14} different addresses
  - manufacturer : component part

    aa:bb:cc:xx:yy:zz

Data Link - Packets

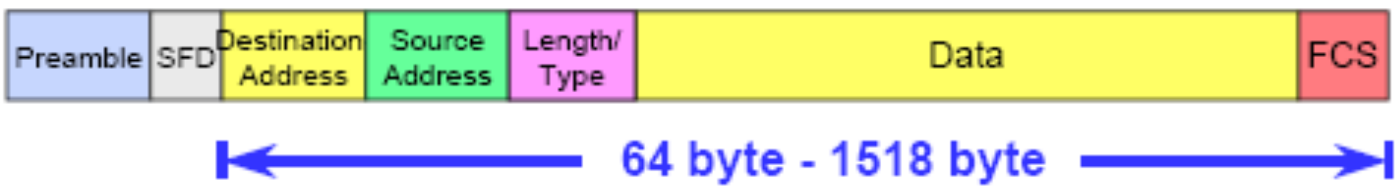
- Ethernet Frames



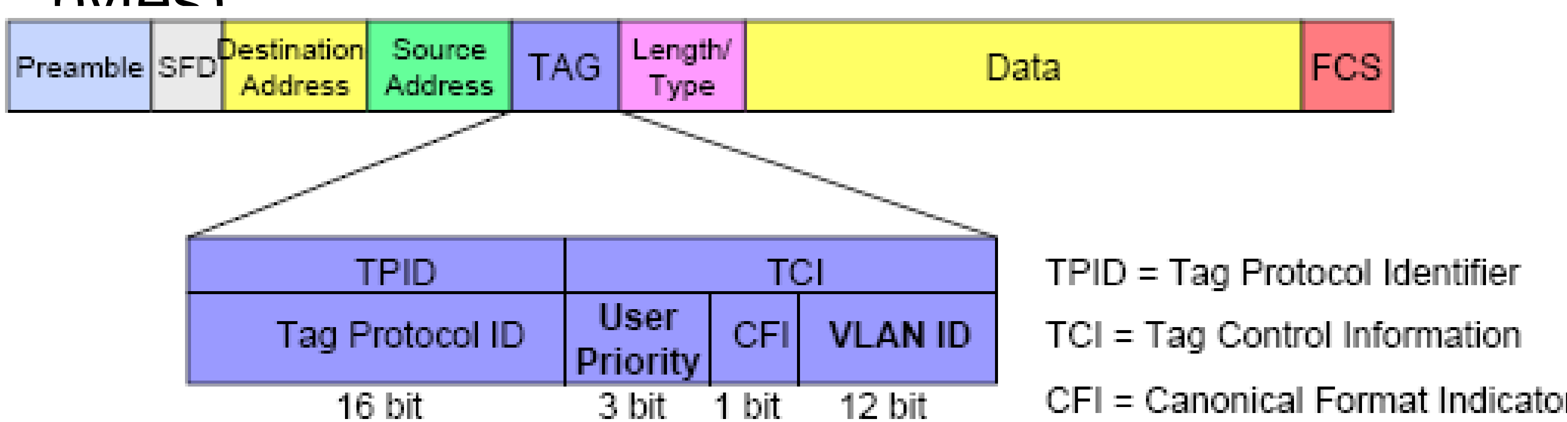
  – If the PDU field is less than 46, then it is padded out so that the frame is the minimum size of 64 bytes.

Data Link - Packet Prioritization (QoS)

- Original Ethernet standards (Max 1518 bytes)



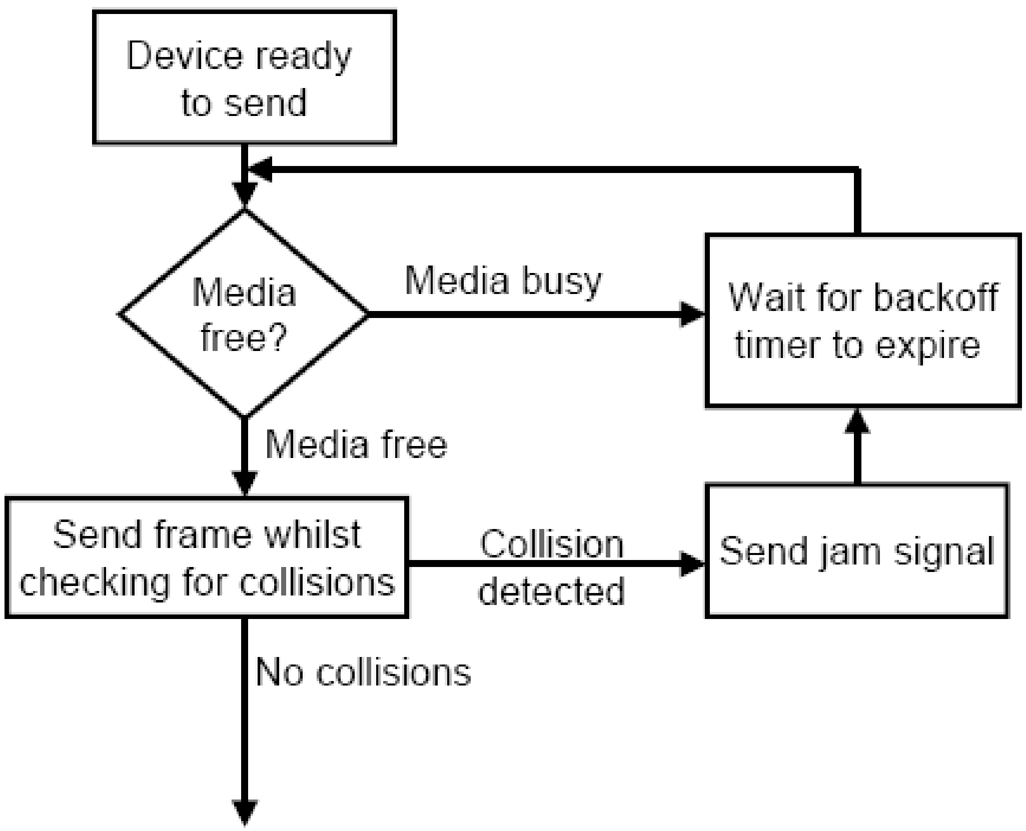
- Change to allow Prioritizations
  - Maximum frame size – 1522 bytes (increase of 4 bytes)



Data Link - Collision Domains

- CSMA-CD (Half Duplex)
  - **Carrier Sense**: Network members check to see if the transmission medium is free.
  - **Multiple Access**: If the transmission medium is free, any network member can start transmitting data.
  - **Collision Detection**: If more than one member of the network start transmitting data simultaneously, a data collision will result. The transmitting members will detect the collision and terminate transmission. A back-off strategy determines when the members can retry the data transmissions.

Access Method IEEE 802.3 CSMA/CD

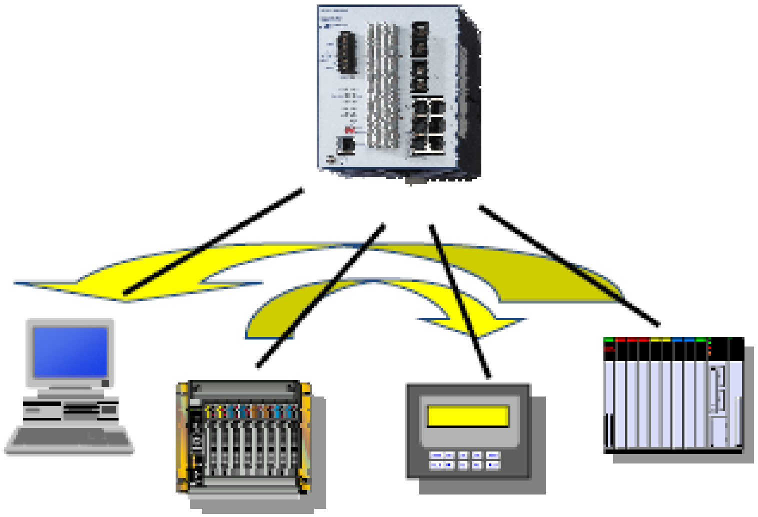


CSMA/CD

Carrier Sense
Multiple Access
Collision Detection

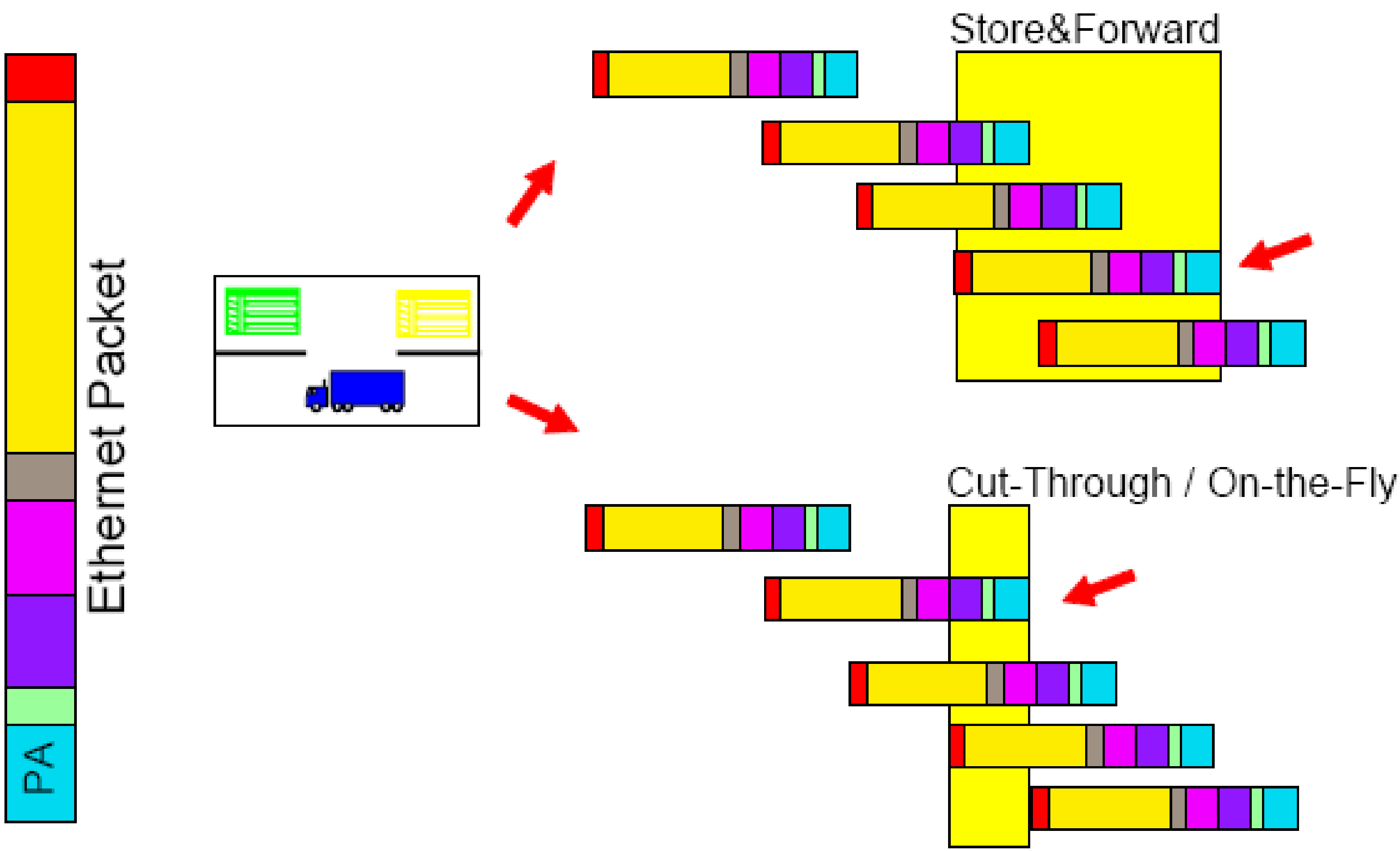
Data Link Layer

- Switch (cont.)
  - Switched Ethernet with full duplex communication
    - Now there are no collision domains and hence no collisions!
    - Each port has a buffer to store overflow



Data Link - Switching

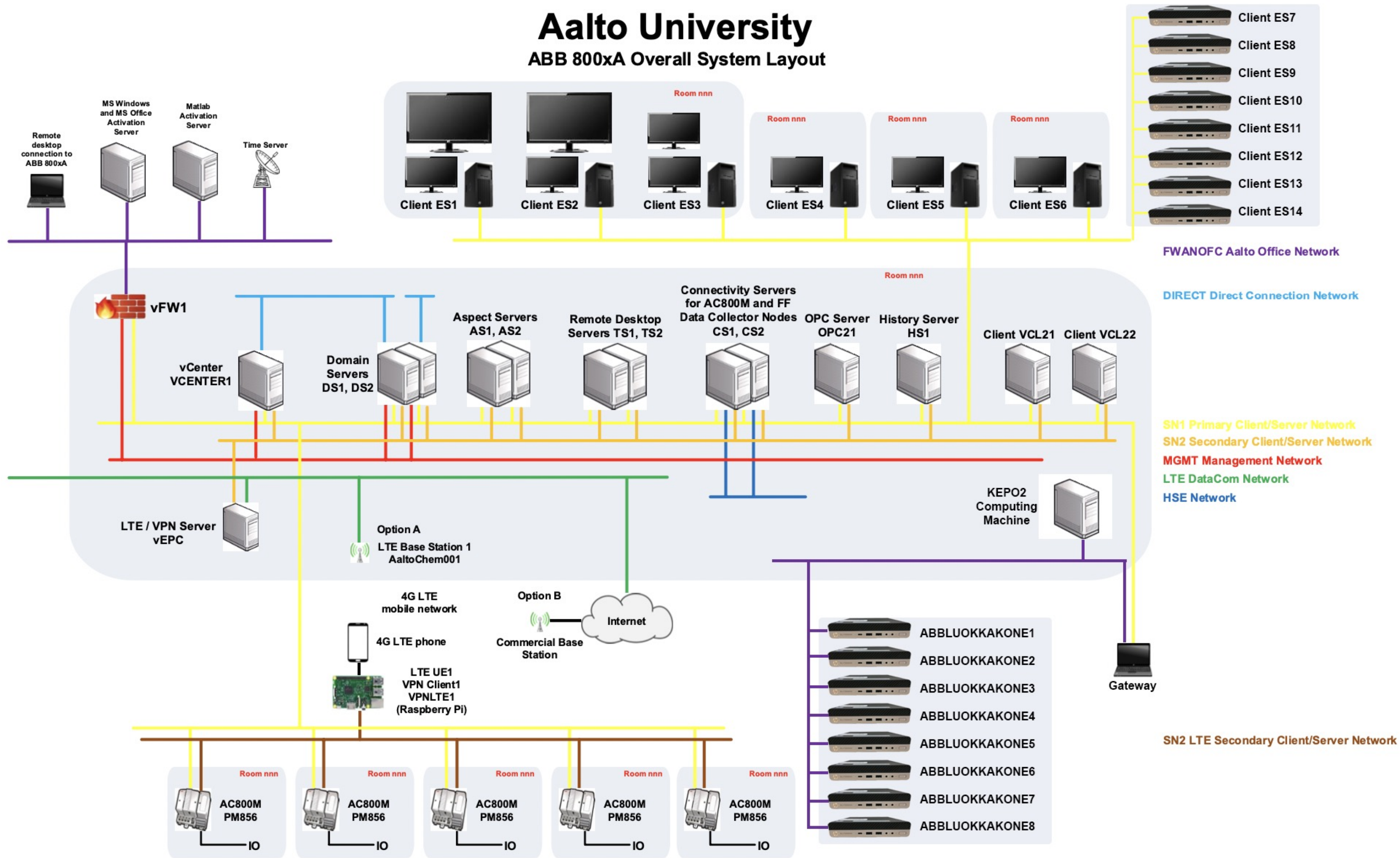
- Store & Forward vs. Cut-Through



Task

- Draw a network topology of an ABB automation used in ABIO Centre

Familiarization with the ABB automation system



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Network (Layer 3)

- MAC and IP : Are they related?
  - Every device will have a MAC address and an IP address
    - MAC address is fixed
    - IP address is user configurable
  - IP address stays constant between end devices
    - MAC address may change as frame goes through routers

Network (Layer 3)

– What if you know one but not the other?
  - ARP – Address Resolution Protocol
    IP address -> MAC address
    ARP delivers to a given IP address the matching MAC address. Therefore the MAC address is asked via ARP request (MAC broadcast with IP unicast).
  - RARP – Reverse Address Resolution Protocol
    MAC address -> IP address
  - Every host has a ARP cache that stores IP addresses and their related MAC addresses
    – The one on your PC can be seen by typing: *arp –a*

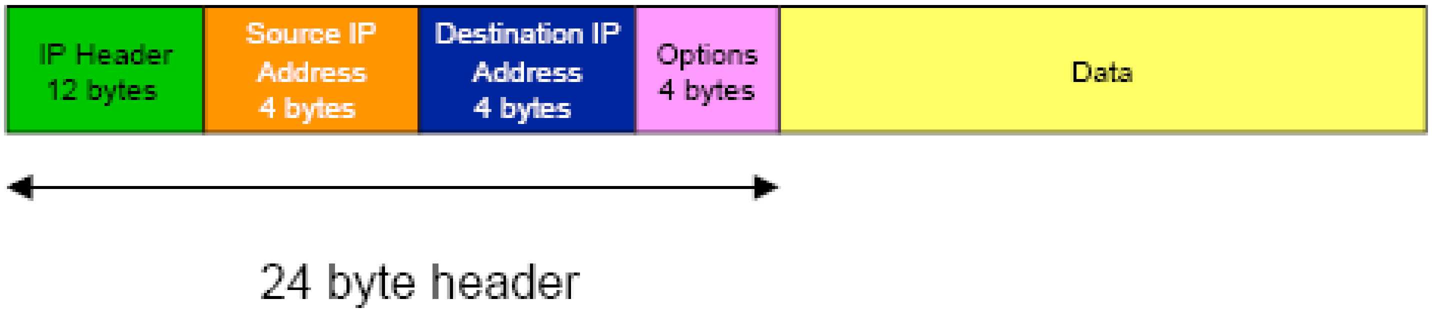
Network (Layer 3)

- Devices: Router
- Connect: subnets
- Task:
  - Routing
  - Subnet traffic control
  - Packet fragmentation
  - Logical to physical address mapping
  - Subnet usage accounting

Network (Layer 3)

- Ethernet is defined only for layers 1 and 2.
- Layers 3 and upwards commonly use a suite of protocols known as the **TCP/IP** suite.
- There are other protocols
  - IPX (Novell), SNA (IBM), NetBIOS, NetBEUI, AppleTalk (Apple), DECnet (Digital Equipment)
  - Profibus, ControlNet, DeviceNet

The IP Packet



- IP Addresses
  - Not unique (but should be), user assigned
  - Layer 3
  - 4 byte (32 bit)
  - Network part + host part
  - 256^4 or 4,290 million different addresses

The IP Packet

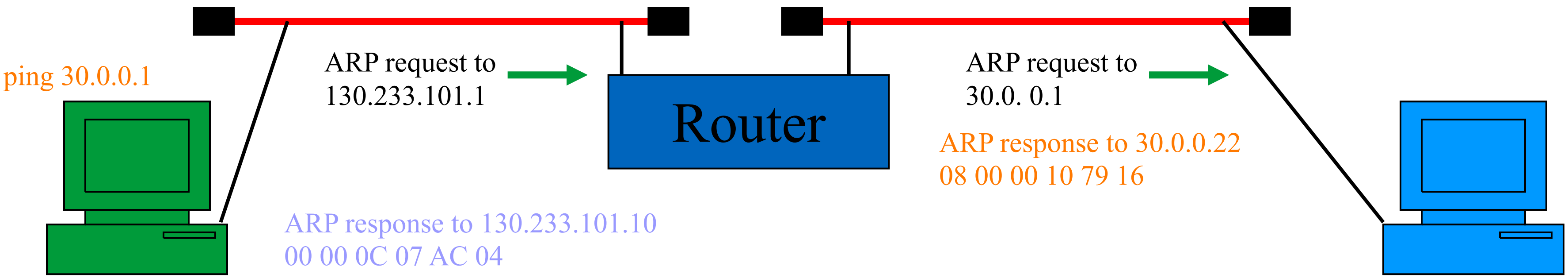
- Always accompanied by a subnet mask
  - IP Address : 192.168.0.1
  - Subnet Mask : 255.255.255.0
- In addition to the subnet mask a default gateway is also added. This is the device that the host should talk to if it cannot find any
- particular IP address or MAC address on the connected network.
- Most common name for this device is Router

Broadcast Addresses and Valid Host Ranges

- Each subnet will have an IP address that is used for broadcasts
  - Always the highest address in the subnet
  - Example
    IP address 149.218.19.90
    Subnet mask 255.255.255.0
    Subnet 149.218.19.0
    Broadcast Address 149.218.19.255
  - The Valid Host Range is everything in between
    - VHR 149.218.19.1 to 149.218.19.254
- Private Address Ranges

This means the first 3 bytes form the network part

IP Communication



TO	From
30.0.0.1	130.233.101.10
00000C07AC04	0002B39B877D

TO	From
30.0.0.1	130.233.101.10
080000107916	080000102174

TO	From
130.233.101.10	30.0.0.1
0002B39B877D	00000C07AC04

TO	From
130.233.101.10	30.0.0.1
080000102174	080000107916

IP address	130.233.101.10	130.233.101.1	30.0.0.22	30.0.0.1
MAC address	00:02:B3:9B:87:7D	00:00:0C:07:AC:04	08:00:00:10:21:74	08:00:00:10:79:16
Default Gateway	130.233.101.1	255.255.0.0		30.0. 0.22
Netmask	255.255.0.0			255.255.0.0

Network Layer

- Routers
  - Protocol dependent
  - Connects different networks
  - Routing
  - Filtering
  - Division into subnets
  - Limitation of broadcasts
  - Load sharing
  - Plug & Call Hotline

Comparison

Switch

- OSI Layer 2
- Coupling of networks of same topology
- Independent of transport protocols
- Separates networks physically, not logically
- Load separation by MAC addresses
- Creation of Collision Domains
- Short delay times
- Static transmission paths

- Switch with routing function
  - Function like switch, additionally
  - Coupling of different network topologies, e.g. Ethernet/FDDI

Router

- OSI Layer 3
- Coupling of different network topologies
- Dependent of transport protocols
- Separates networks physically and logically
- Load separation by network addresses
- Creation of Broadcast Domains
- High delay times
- Dynamic routing
- Optimum use of bandwidth possible
- Reduced transmission costs in WAN (LAN/ISDN router)

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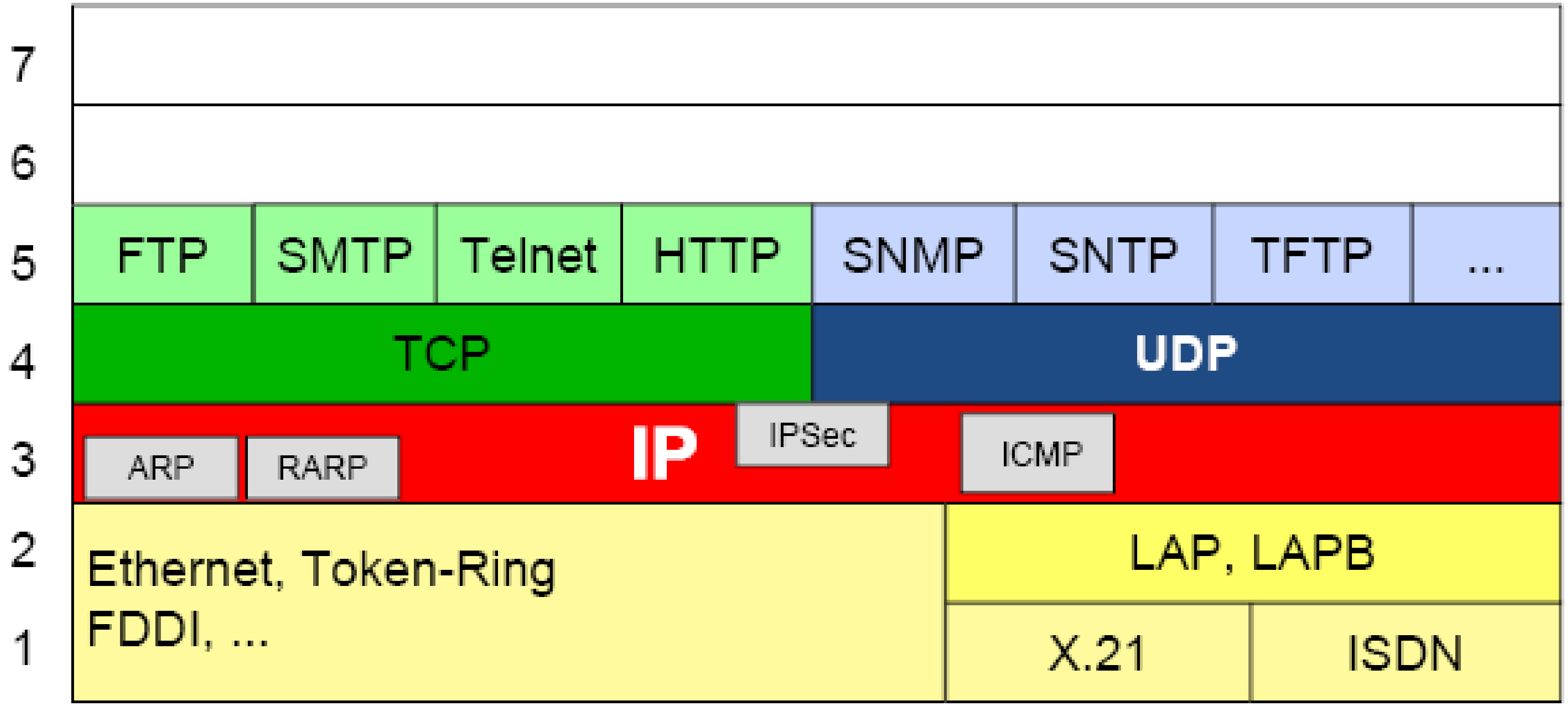
TCP and UDP

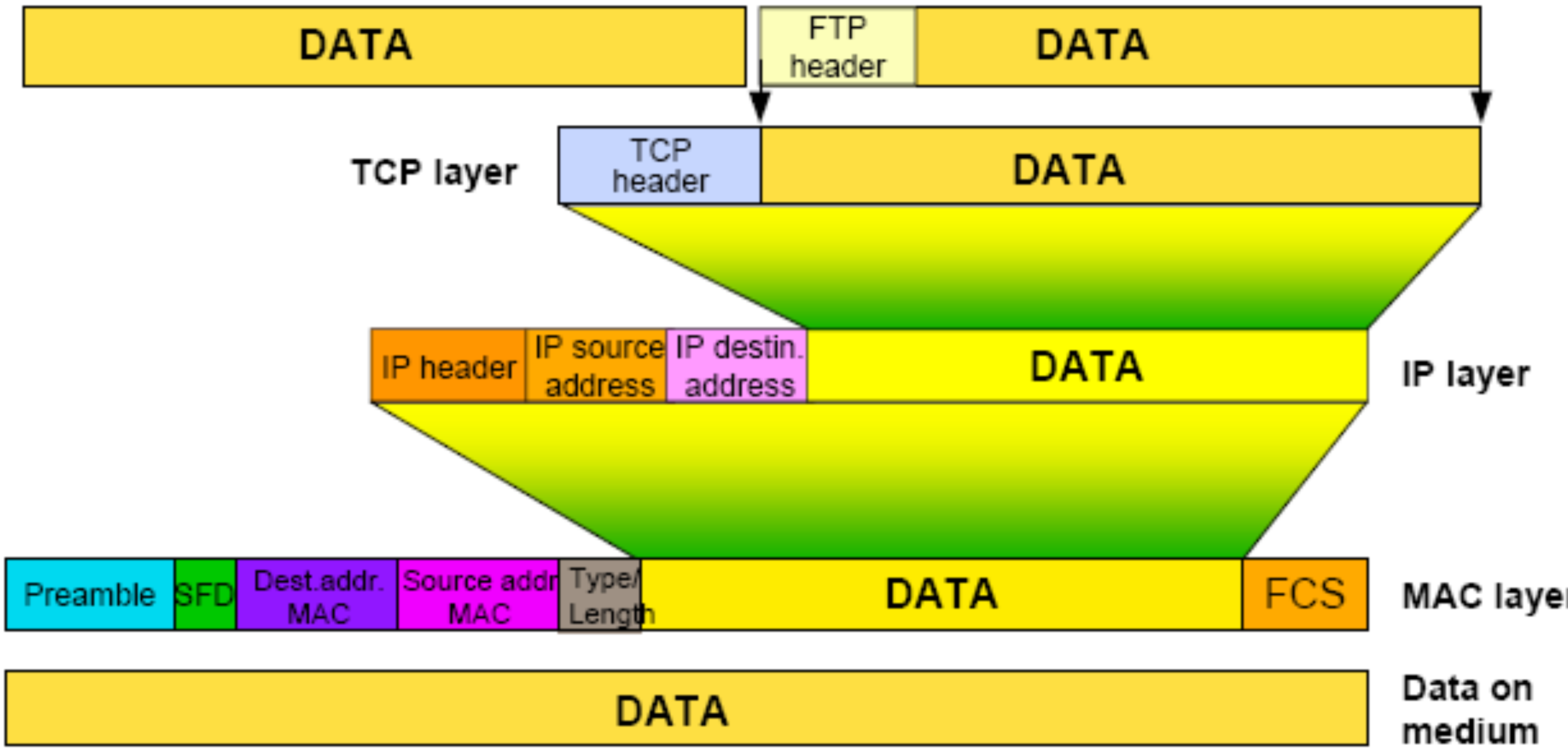


The TCP/IP stack consists of 5 layers.

Layer 5 offers all functions of layer 5-7 of the ISO/OSI model

Data transmission with TCP/IP and Ethernet

Frames encapsulated into each other



TCP header: Dest.port no., Source port no., Sequence no., Window size, Check sum, etc.

IP header: Source-IP address, Dest.-IP address, Protocol no., Checksum, etc.

TCP/IP
Well-known Ports and Services

IP Address + Port = Socket

to address the upper protocol/service

Protocol	Port number
FTP	20 (Data); 21 (Control)
SSH	22
Telnet	23
SMTP	25
TFTP	69
HTTP	80
SNTP	123
SNMP	161
SNMP Traps	162
HTTPS	443

UDP - An Unreliable Protocol

... Why use it?

- Simplicity
- No need to establish connections
- When an application has data to send, it sends it
- Less delay in communications
- Some simple systems cannot implement TCP, for example UPS
- There is no value to retransmitting time critical data (video / process control)
- Lost data should not prevent more recent data being processed (video / process control)

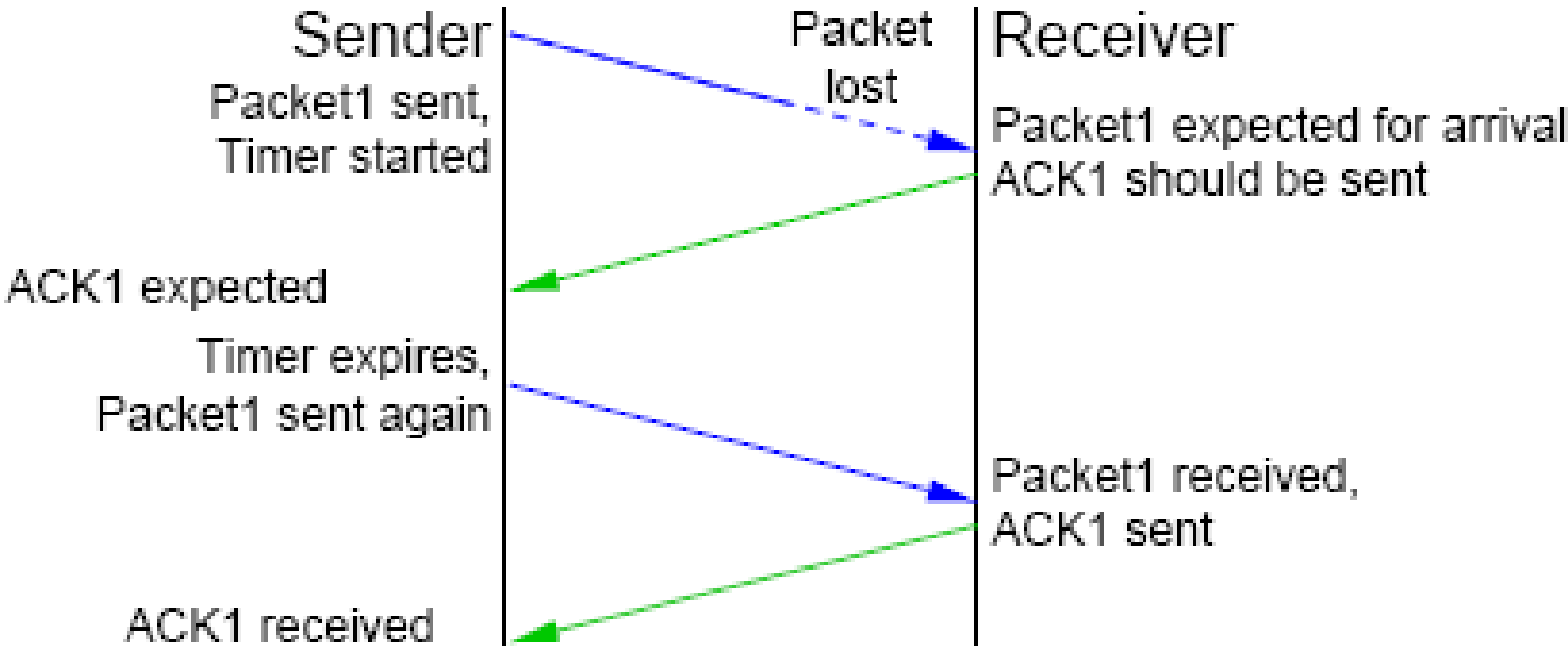
TCP - What is reliable delivery?

- Error free
  - TCP is a “nearly error free” protocol
- Assured delivery
  - If TCP cannot deliver the data, it will notify the sender
- In sequence
  - “Copy old file to new file”
  - “Delete old file”
- No duplication
  - “Pay this bill”
- End to end
  - TCP only operates at the communication endpoints

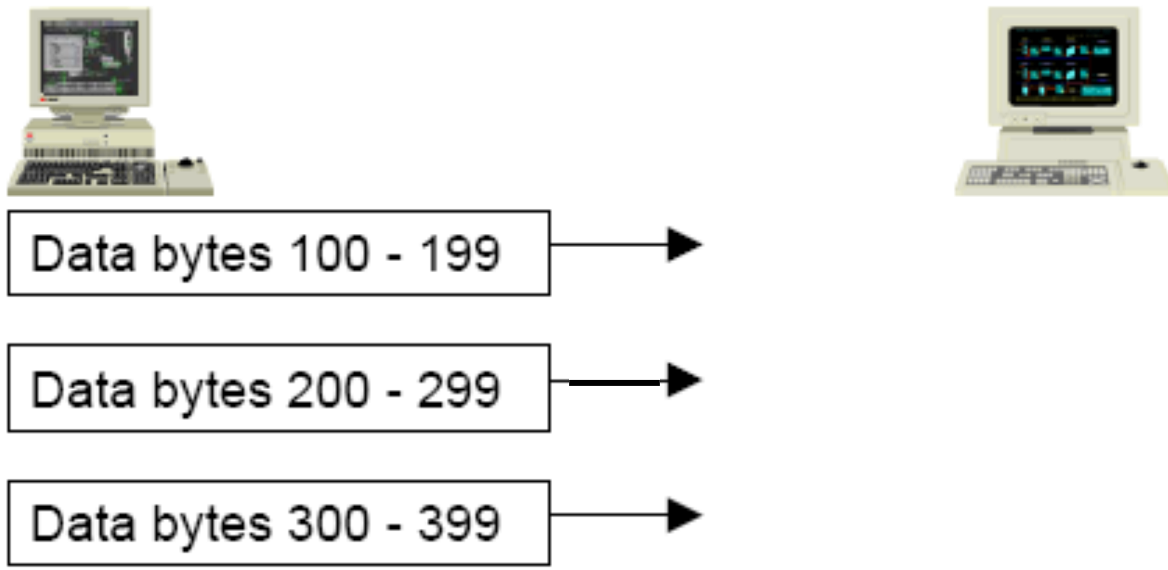
TCP

- Transmission Control Protocol
  - Connection (logical, not physical) oriented establishes and terminates a connection
    - guaranteed order of packets
  - Buffer: TCP waits (Push flag), till a sufficient amount of data is delivered by the application, thus using the packet size best.
  - Continuous supervision of connection

TCP


Sender
Packet lost
Receiver
Packet1 sent,
Timer started
Packet1 expected for arrival,
ACK1 should be sent
ACK1 expected
Timer expires,
Packet1 sent again
Packet1 received,
ACK1 sent
ACK1 received

TCP - Retransmissions



QUESTIONS?