Layer 1, 2 and 3 Refresher

Campus Network Design & Operations Workshop

UNIVERSITY OF OREGON

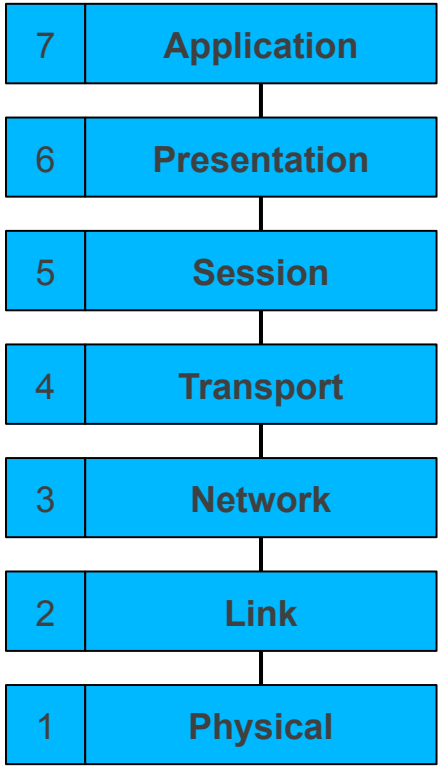
Last updated 30th September 2024

NSRC
Network Startup Resource Center

Objectives

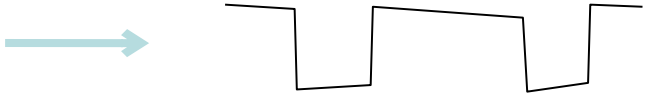
- To revise core networking concepts
- To ensure we are using the same terminology

What is this?


7
Application
6
Presentation
5
Session
4
Transport
3
Network
2
Link
1
Physical

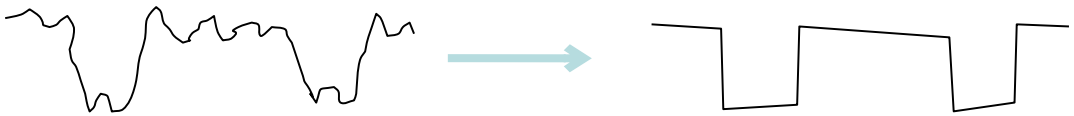
Layer 1: Physical Layer

- Transfers a stream of bits
- Defines physical characteristics
  - Connectors, pinouts
  - Cable types, voltages, modulation
  - Fibre types, lambdas
  - Transmission rate (bps)
- No knowledge of bytes or frames

101101 

Types of equipment

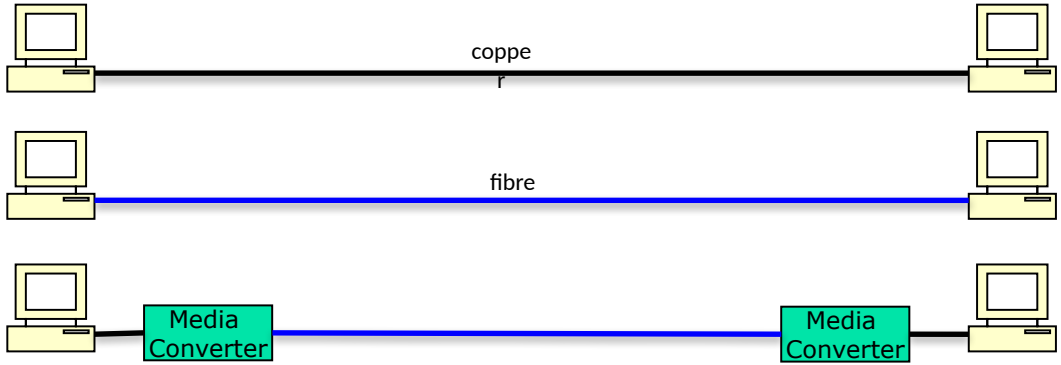
- Layer 1: Hub, Repeater, SFP, Media Converter
  - Hubs are not used any more!
- Works at the level of individual bits



- All data sent out of all ports
  - Hence data may end up where it is not needed
- Transmission errors can occur
  - BER (Bit Error Rate), SNR (Signal to Noise Ratio)

Building networks at Layer 1

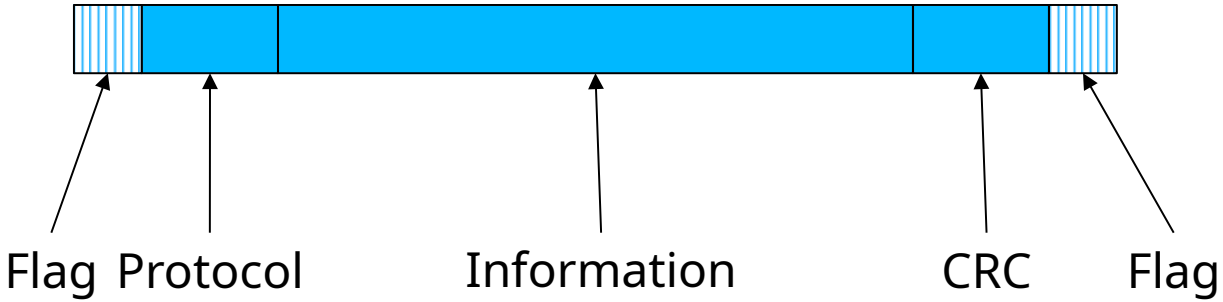
- What limits do we hit?
  - Cat5E/Cat6A cable length?
  - Fibre length?
  - Fibre type?
  - Media converters?
  - Wireless limits?



Layer 2: (Data) Link Layer

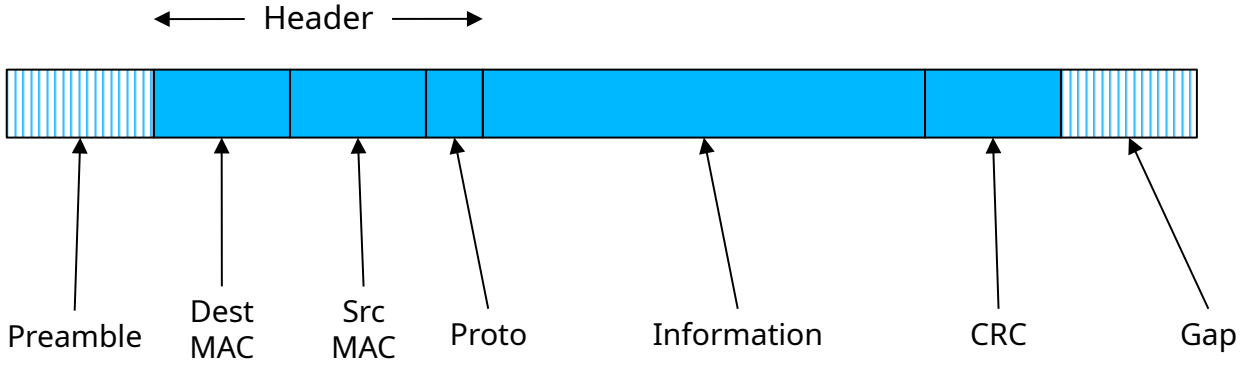
- Organises data into *frames*
- May detect transmission errors (corrupt frames)
- May support shared media
  - Addressing (unicast, multicast) – who should receive this frame
  - Access control, collision detection
- Usually identifies the L3 protocol carried

Example Layer 2: PPP



- Also includes link setup and negotiation
  - Agree link parameters (LCP)
  - Authentication (PAP/CHAP)
  - Layer 3 settings (IPCP)

Example Layer 2: Ethernet



- MAC addresses
- Protocol: 2 bytes
  - e.g. 0800 = IPv4, 0806 = ARP, 86DD = IPv6
- Preamble: carrier sense, collision detection

Types of equipment (contd)

- Layer 2: **Switch, Bridge**
- Receives whole layer 2 frames and selectively retransmits them
- Learns which MAC address is on which port
- If it knows the destination MAC address, will send it out only on that port
  - Otherwise, it sends it out on all ports
- **Broadcast** frames must be sent out of all ports, just like a hub
- Doesn't look any further than L2 header

Address Learning

- MAC addresses learned by each switch

S1

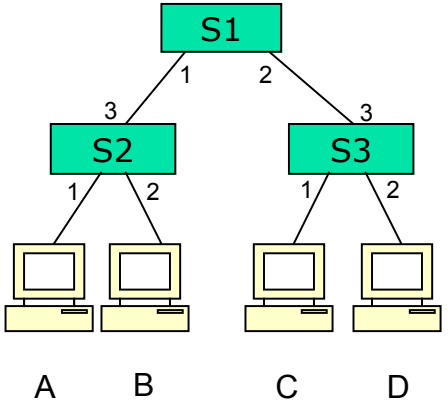
MAC	Port
A	1
B	1
C	2
D	2

S2

MAC	Port
A	1
B	2
C	3
D	3

S3

MAC	Port
C	1
D	2
A	3
B	3



How Address Learning Works

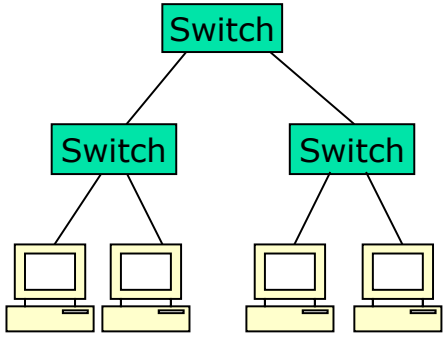
- After receiving a frame with the source MAC address X on port Y, it “learns” that X is connected to port Y
- Learned MAC address and the corresponding port are added to the MAC Address Table ("bridge forwarding table")
- Later, when it receives a frame with destination MAC address = X, it can send it out only on port Y, and not on other ports
- If the destination MAC address of a received frame is not in the MAC Address Table, it must be sent out on all ports (like a hub)

Address Learning (contd)

- If a switch port is connected to a single computer, then only its Ethernet address will be associated with that port
- If a switch port is connected to another switch (or hub or AP), then a number of Ethernet addresses may be associated with that port
- Entries in the forwarding table may expire, or be forced out if it runs out of space
- A managed switch will let you inspect its forwarding table

Building networks at Layer 2

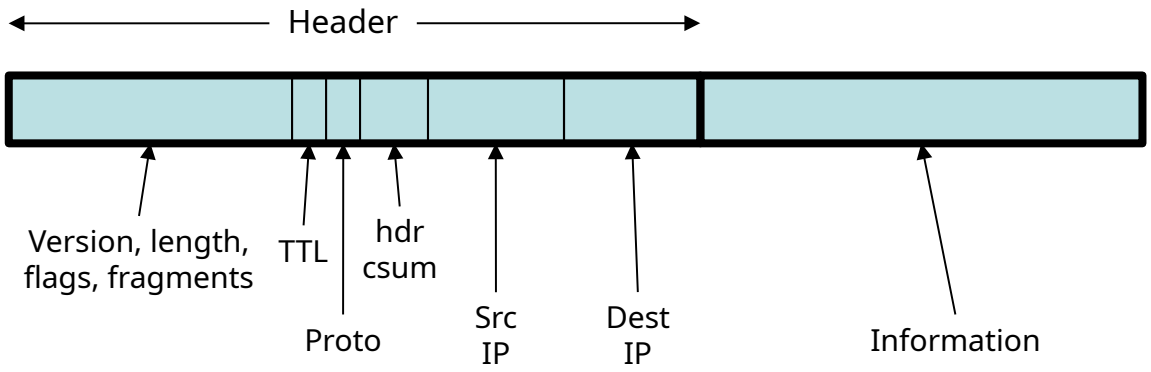
- What limits do we hit?
  - Why can't we just keep adding more and more switches and devices indefinitely? What problems occur?



Layer 3: (Inter)Network Layer

- Connects Layer 2 networks together
  - Forwarding data from one network to another
  - These different networks are called subnets (short for sub-network)
- Universal datagram (Layer 3 data unit) format
- Unified addressing scheme
  - Independent of the underlying L2 network(s)
  - Addresses organised so that it can scale globally (aggregation)
- Identifies the layer 4 protocol being carried
- Fragmentation and reassembly

Example Layer 3: IPv4 Datagram

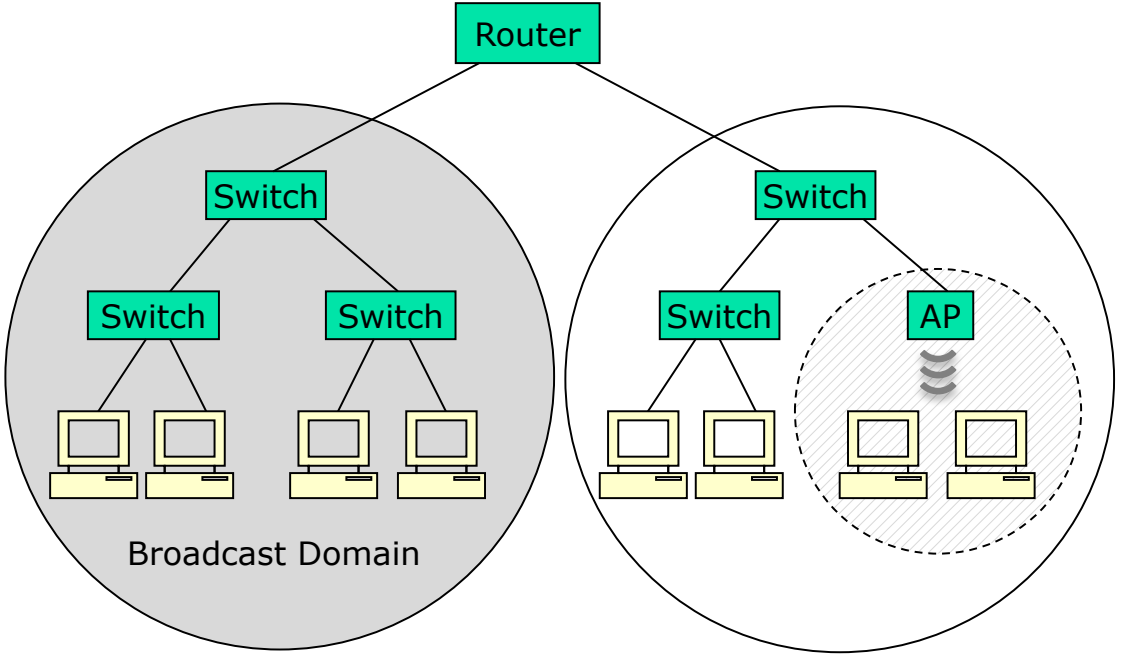


- Src, Dest: IPv4 addresses
- Protocol: 1 byte
  - e.g. 6 = TCP, 17 = UDP (see /etc/protocols)

Types of equipment (contd)

- Layer 3: **Router**
- Looks at the destination IP in its Forwarding Table to decide where to send next
- Collection of routers managed together is called an “Autonomous System”
- The forwarding table can be built by hand (static routes) or dynamically
  - Within an AS: IGP (e.g. OSPF, IS-IS)
  - Between ASes: EGP (e.g. BGP)

Traffic Domains



Collision Domain: where several devices share one communication medium (e.g. wireless networks)

Broadcast Domain: all devices on the same sub-network

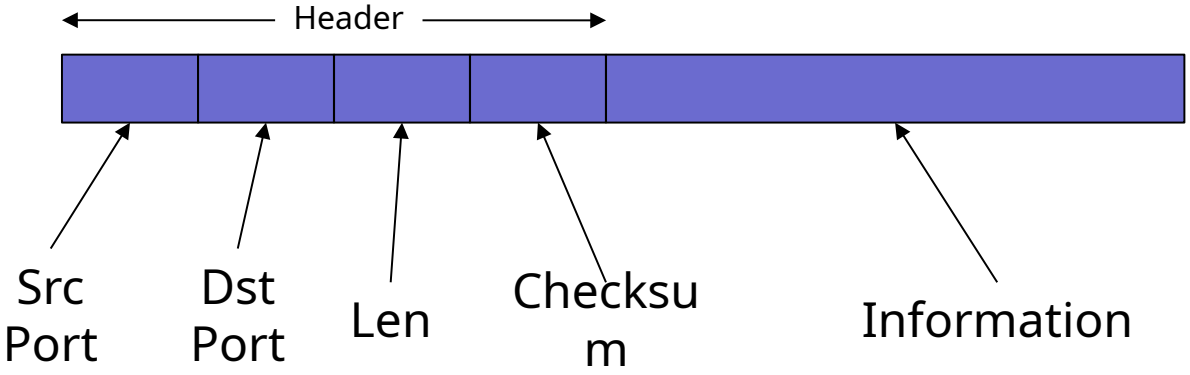
Network design guidelines

- No more than ~250 hosts on one subnet
  - Implies: subnets no larger than an IPv4 /24
  - Maybe bigger if a lot of address churn (e.g. roaming wireless devices)
- Campus guideline
  - At least one subnet per building
  - More than one subnet will usually be required for larger buildings
- Wireless
  - many APs, each covering a small area, are better than one AP covering a large area
  - neighboring APs should be on non-overlapping radio channels

Layer 4: Transport Layer

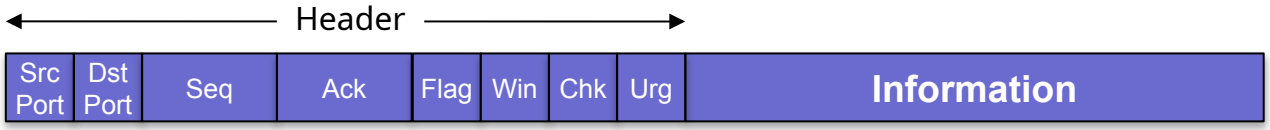
- Identifies the *endpoint* process
  - Another level of addressing (port number)
- May provide reliable delivery
  - Streams of unlimited size
  - Error correction and retransmission
  - In-sequence delivery
  - Flow control
- Might just be unreliable datagram transport

Example Layer 4: UDP



- Port numbers: 16 bits each
  - Well-known ports: e.g. 53 = DNS
  - Ephemeral ports: ≥1024, chosen dynamically by client

Example Layer 4: TCP



- Port numbers: 16 bits each
  - Well-known ports: e.g. 80 = HTTP
  - Ephemeral ports: ≥1024, chosen dynamically by client
- Reliable transmission: Sequence and Acknowledgement numbers
- Flow control: Window
- Session flags including SYN, ACK, FIN, RST
- Extensible via Options

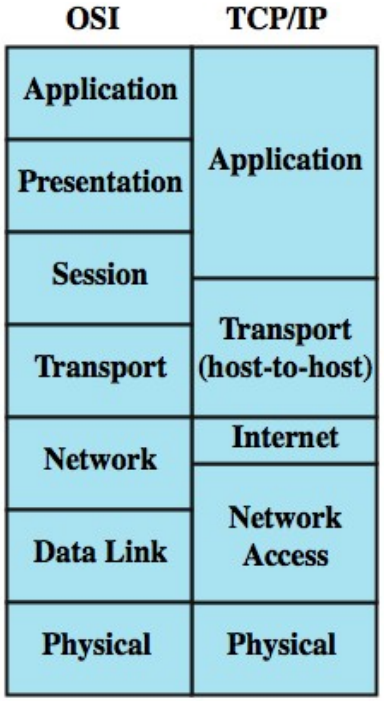
Layers 5 and 6

- Session Layer: long-lived sessions
  - Re-establish transport connection if it fails
  - Multiplex data across multiple transport connections
- Presentation Layer: data reformatting
  - Character set translation
- Neither exist in the TCP/IP suite: the application is responsible for these functions

Layer 7: Application layer

- The actual work you want to do
- Protocols specific to each application
- *Give some examples*

OSI vs TCP/IP

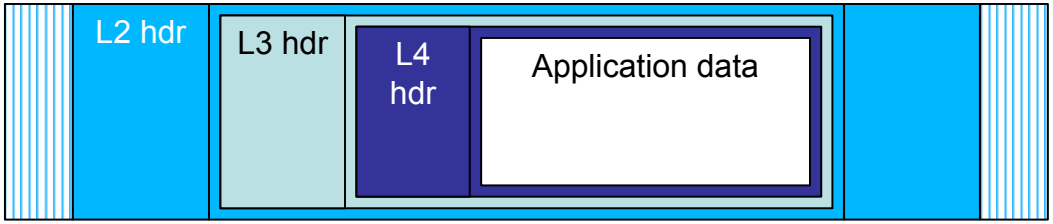


Source: William Stallings
"Data and Computer Communications"

Encapsulation

- Each layer provides services to the layer above
- Each layer makes use of the layer below
- Data from one layer is *encapsulated* in frames of the layer below

Encapsulation in action



- L4 segment contains part of stream of application protocol
- L3 datagram contains L4 segment
- L2 frame has L3 datagram in data portion

For discussion

- Can you give examples of equipment which interconnects two networks and operates at layer 4? At layer 7?
- At what layer does a wireless access point work?
- What is a “Layer 3 switch”?

Debugging Tools

- What other tools can you use to debug your network
  - At layer 1?
  - At layer 2?
  - At layer 3?
  - Higher layers?

Questions?

Extra Slides

Example layer 7 protocol: HTTP

⇨ **GET / HTTP/1.0**
Host: nsrc.org

⇦ *HTTP/1.1 200 OK*
Server: nginx/1.14.0 (Ubuntu)
Date: Mon, 22 Feb 2021 11:16:16 GMT
Content-Type: text/html; charset=UTF-8
Connection: close
Cache-Control: max-age=21600, public
...

<!DOCTYPE html>
<html lang="en" dir="ltr" ...

Example layer 7 protocol: SMTP

⇦ *220 smtp.nsrc.org ESMTP Postfix (Ubuntu)*
⇨ **EHLO remote.server**
⇦ *250-smtp.nsrc.org*
250-PIPELINING
...
250 DSN
⇨ **MAIL FROM:<xxxxxxxx@gmail.com>**
⇦ *250 2.1.0 OK*
⇨ **RCPT TO:<xxxxxxxx@nsrc.org>**
⇦ *550 5.1.1 <xxxxxxxx@nsrc.org>: Recipient address rejected: User unknown in virtual mailbox table*