Local Area Networks (LAN)

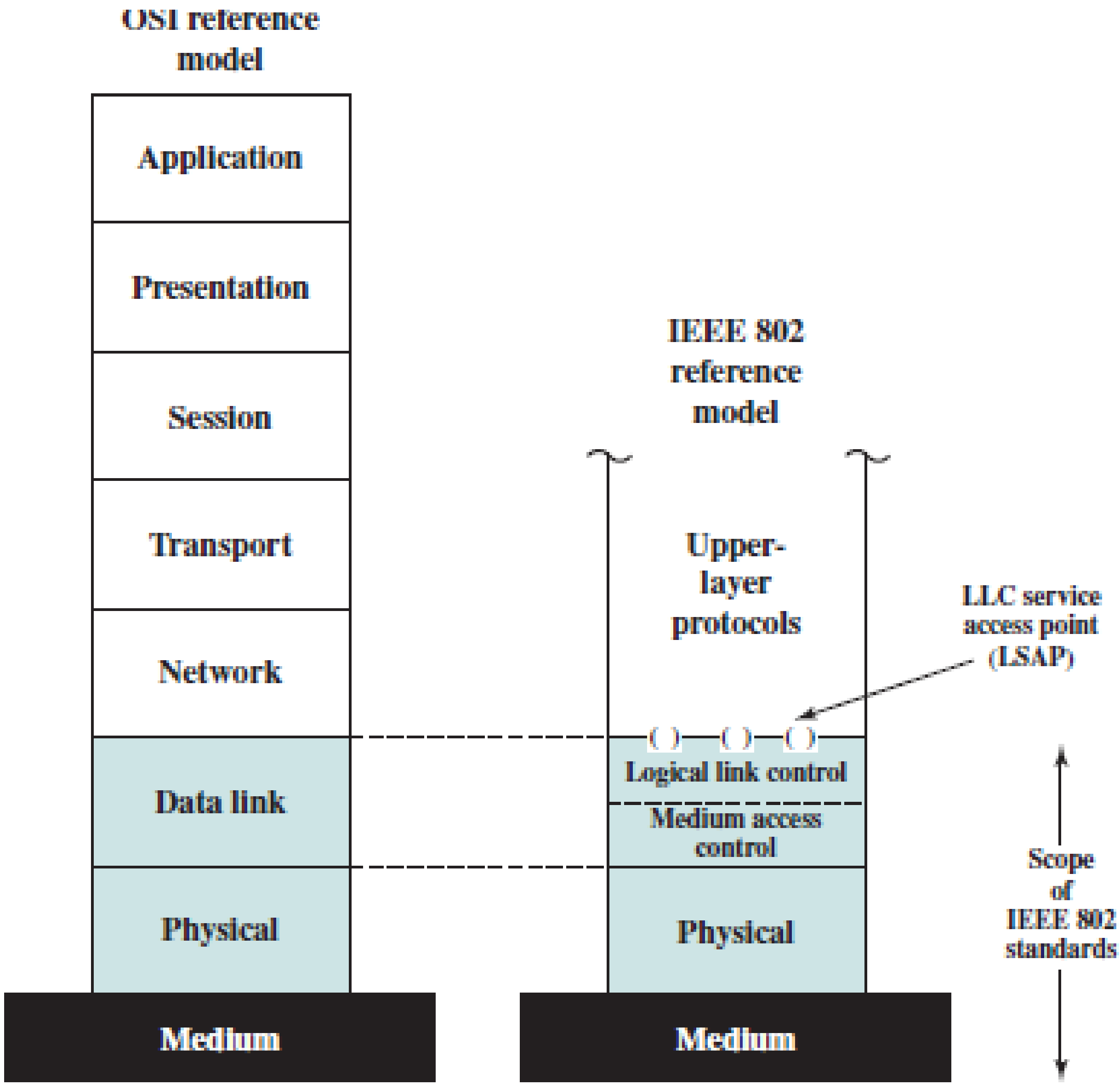
Local Area Network (LAN)

- Can be seen as a broadcast domain
  - The set of machines such that a broadcast message from any machine will reach all other machines
    - Machines are on the "same network"
  - That does not mean machines can only broadcast in LANs, a machine can send a message for another specific machine (unicast) or a group of machines (multicast)
- Characteristics
  - Usually (but not necessarily) spread over a small geographical area
  - Relatively high data rate
  - Single administrative management

- Topologies
  - Many specific physical topologies earlier: Bus, star, ring
  - Switched LANs nowadays for arbitrary physical topologies
- Specifications at physical and data link layer mostly
  - We have already seen most of the general issues there
  - We will study Ethernet, the de-facto standard protocol for LANs now

History of Ethernet

- Developed in early 70's in Xerox PARC by Metcalfe and Boggs
- DIX standard – Digital/Intel/Xerox standardized 10 Mbps Ethernet in early 80's (final one called Ethernet-2)
- IEEE 802 body – standardized various physical layer/MAC combinations, and a single Logical Link Control (LLC) on top of them (1985)
  - IEEE 802.2 : LLC
  - IEEE 802.3 : CSMA/CD
  - IEEE 802.4 : Token ring
  - Many others since then



OSI reference model
Application
Presentation
Session
Transport
Network
Data link
Physical
Medium
IEEE 802 reference model
Upper-layer protocols
LLC service access point (LSAP)
Logical link control
Medium access control
Physical
Medium
Scope of IEEE 802 standards

- Specifications at data link and physical layers
- Ethernet-2 specifies only MAC sublayer and physical layer
- IEEE 802.2 + one of IEEE 802.3/802.4 etc. specifies complete data link and physical layer
  - We will see what this means shortly

IEEE 802.3

- Working group of IEEE dealing with LANs
- A collection of standards defining various Ethernet types and related issues
- Multiple types depending on speed, media type etc.
  - 10Base-5 : 10Mbps, thickwire coaxial cable
  - 10Base-2 : 10Mbps, thinwire coax or cheapernet
  - 10Base-T : 10Mbps, UTP
  - 10Base-F : 10Mbps, optical fiber
  - 100Base-TX : 100Mbps, twisted pair
  - 100Base-FX : 100 Mbps, optical fiber
  - 1000Base-LX : 1 Gbps, optical fiber
  - 1000Base-T : 1 Gbps, UTP
  - 10GBASE-T : 10 Gbps, UTP
  - 10GBASE-SR : 10 Gbps, optical fiber
  - There are many other types not covered here

- All of them share the same basic frame format, difference is mostly in MAC and physical layer details like parameter values, encodings, media, connector etc.
- 802.3 primarily specify CSMA/CD for half duplex operations over shared media
- But modern day LANs are all switched LANs with full duplex operation, CSMA/CD is not needed mostly (why?)

Relation Between the Standards

- Standards now are from IEEE
  - "Ethernet LAN" and "IEEE 802.3 LAN" used interchangeably
- Frame format for both standards the same except for small difference
- TCP/IP implementations use original Ethernet-2 frame format, no LLC (network layer directly uses Ethernet frames)
- Both types can coexist on the same LAN (will discuss how later)

Minimum Frame Size

- A frame must take more than 2τ time to send (τ = max. one-way propagation delay) to detect collision
- An example scenario:
  - Two machines A and B located at the far ends of the cable
    - A starts sending a frame at time 0
    - Frame almost at B at time $\tau - \delta$
    - B starts sending a frame at time $\tau - \delta$
    - Collision occurs at time τ
    - Jam signal gets back to A at time 2τ
    - If A has finished transmitting the frame (before 2τ time), the collision is missed
- Minimum frame size of 10 Mbps Ethernet = 64 bytes
  - Slot time = time to transmit the minimum sized frame = 512bits/10Mbps = 51.2 microseconds for 10 Mbps Ethernet
  - If a station transmits for 1 slot time and does not detect any collision, it will be able to finish its transmission
- What about Fast Ethernet (100 Mbps) and Gigabit Ethernet (1 Gbps)?

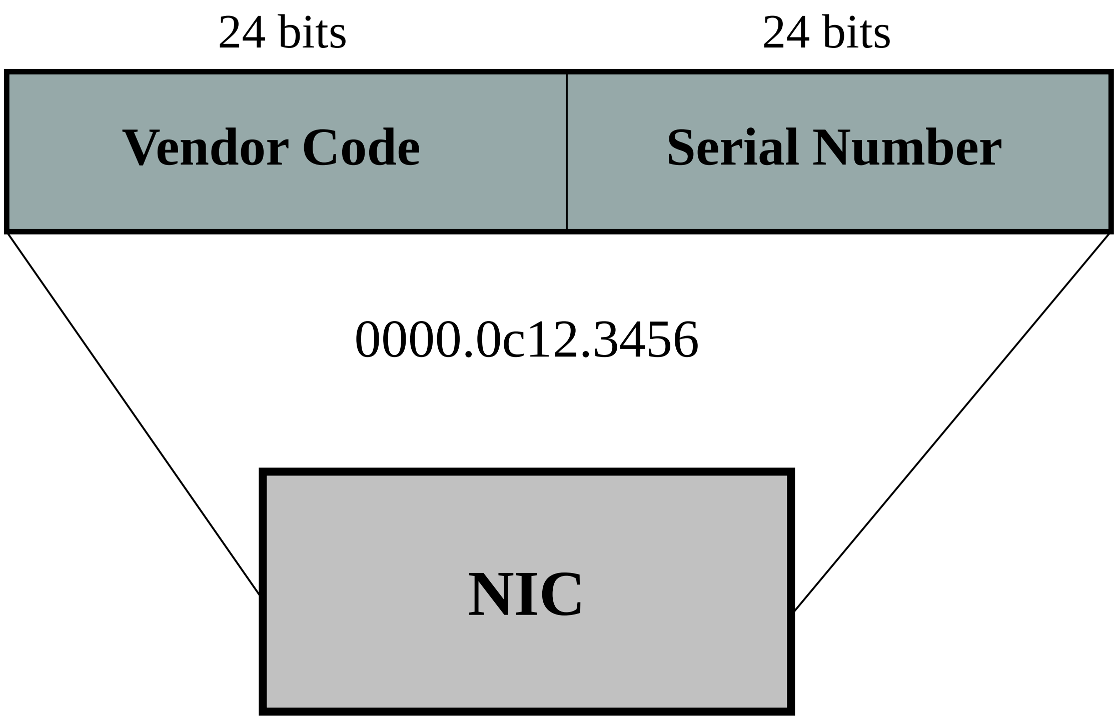
Ethernet Frame Format

7	1	6	6	2	46-1500		4	
PA	**SFD**	**DA**	**SA**	**LEN**	**LLC PDU**	**PAD**	**FCS**	**IEEE 802.3**

8	6	6	2	46-1500		4	
PA	**DA**	**SA**	**Type**	**DATA**	**PAD**	**FCS**	**Ethernet**

PA: Preamble --- 10101010s for synchronization
SFD: Start of frame delimiter --- 10101011 to start frame
DA: Destination MAC address
SA: Source MAC address
LEN: Length --- number of data bytes
Type: Identify the higher-level protocol
LLC PDU + Pad: minimum 46 bytes, maximum 1500
FCS: Frame Check Sequence --- CRC-32

MAC Address



ff.ff.ff.ff.ff.ff : Broadcast address

There are also multicast addresses

MAC Address (contd.)

- The MAC sublayer defines a hardware address which is unique for each LAN interface (NIC)
- The address is a 48-bit address, expressed as 12 hex digits
  - Vendor code given to NIC manufacturers by IEEE
  - Serial number given by vendor from its pool
  - Hierarchical address ensures uniqueness

Interoperation Between Ethernet and 802.3

- All protocols type values standardized have values greater than 1536
- Max. length field value in 802.3 frame = 1500
- If length/type field value ≤ 1500, it is a 802.3 frame, else it is a Ethernet-2 frame
- It is also possible to carry protocols using type field inside a 802.3 field (SNAP headers)
  - Not discussed in this course

Some Terminologies

- Segment
  - Part of medium without any repeater
  - One or more devices can connect to a segment
  - Segments can be connected using repeaters
- Collision domain
  - Set of devices such that simultaneous transmission by any two devices will cause a collision
  - One or more segments

IEEE 802.3i: 10Base-T

- 10 Mbps, Baseband, Unshielded Twisted Pair (two pairs), Cat 3 or better
- Max. segment length = 100m
- No. of machines/segment = 1
- Manchester encoding
- 1-persistent CSMA/CD for transmission
- 10 Mbps Ethernet is mostly not used for connecting computers now
  - But modified 10 Mbps Ethernet standards are being used in other network-enabled applications for connecting devices

	10BASE5	10BASE2	10BASE-T	10BASE-FP
Transmission Medium	Coaxial cable (50 Ω)	Coaxial cable (50 Ω)	Unshielded twisted pair	850-nm optical fiber pair
Signaling Technique	Baseband (Manchester)	Baseband (Manchester)	Baseband (Manchester)	Manchester/ on-off
Topology	Bus	Bus	Star	Star
Maximum Segment Length (m)	500	185	100	500
Nodes per Segment	100	30	—	33
Cable Diameter (mm)	10	5	0.4–0.6	62.5/125 μm

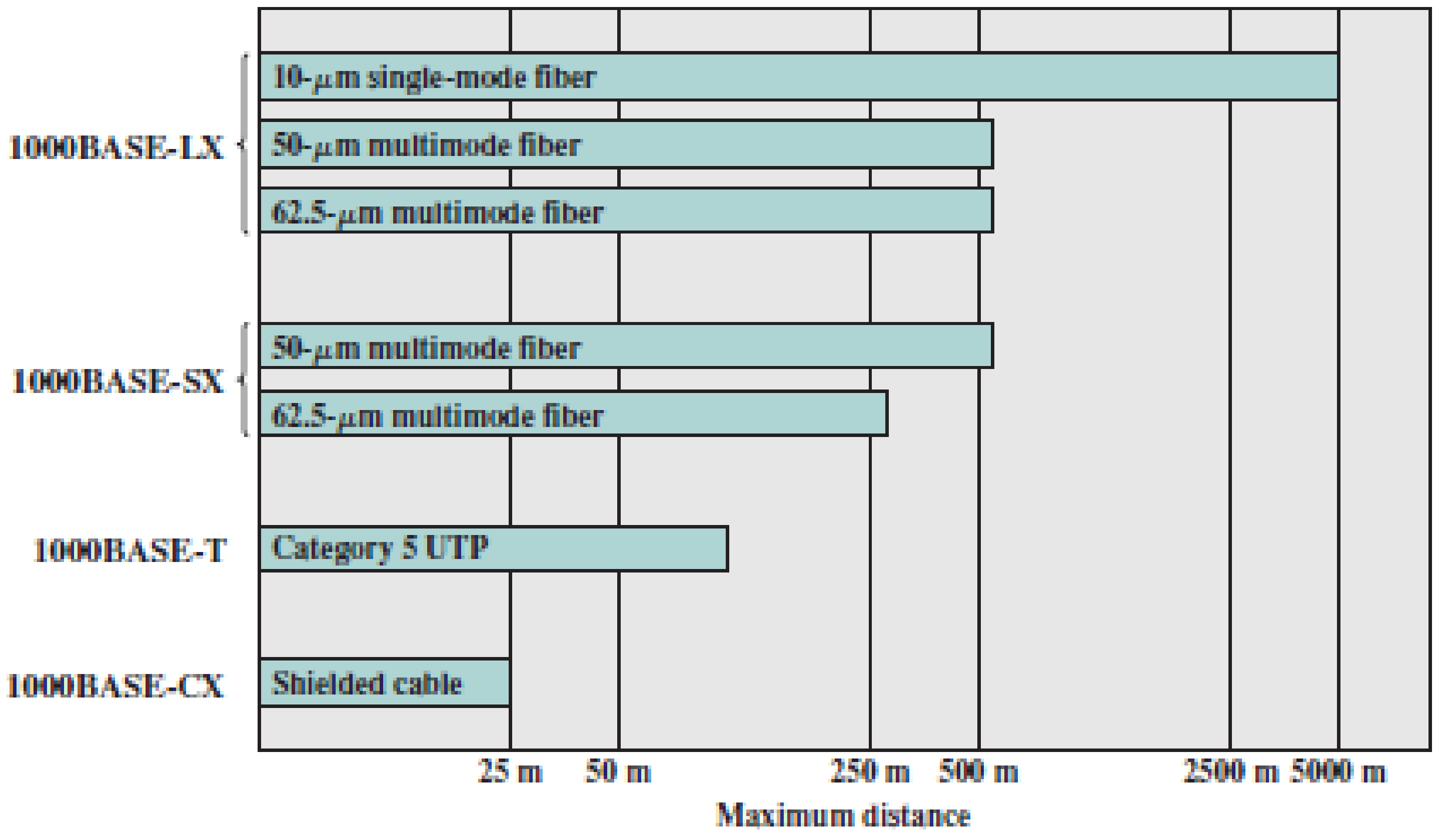
IEEE 802.3u: 100Base-TX

- Fast Ethernet (a group of 100 Mbps standards)
- 100 Mbps, Baseband, Unshielded Twisted Pair, Cat 5 or better, or Type 1 STP
- Max. segment length = 100 m
- 4B/5B+MLT-3 encoding
  - Other variations of Fast Ethernet also uses NRZI
- 1-persistent CSMA/CD for transmission

	100BASE-TX		100BASE-FX	100BASE-T4
Transmission Medium	2 pair, STP	2 pair, Category 5 UTP	2 optical fibers	4 pair, Category 3, 4, or 5 UTP
Signaling Technique	MLT-3	MLT-3	4B5B, NRZI	8B6T, NRZ
Data Rate	100 Mbps	100 Mbps	100 Mbps	100 Mbps
Maximum Segment Length	100 m	100 m	100 m	100 m
Network Span	200 m	200 m	400 m	200 m

IEEE 802.3 1 Gbps: 1000BaseLX

- 1 Gbps, Baseband, on single or multimode optical fiber
- Specified in IEEE802.3z
- Two strands of fiber – one for transmit, one for receive
- Max distance varies between 550 m and 5 Km depending on different factors
- 8B/10B Encoding
- CSMA/CD (with some changes) for half duplex

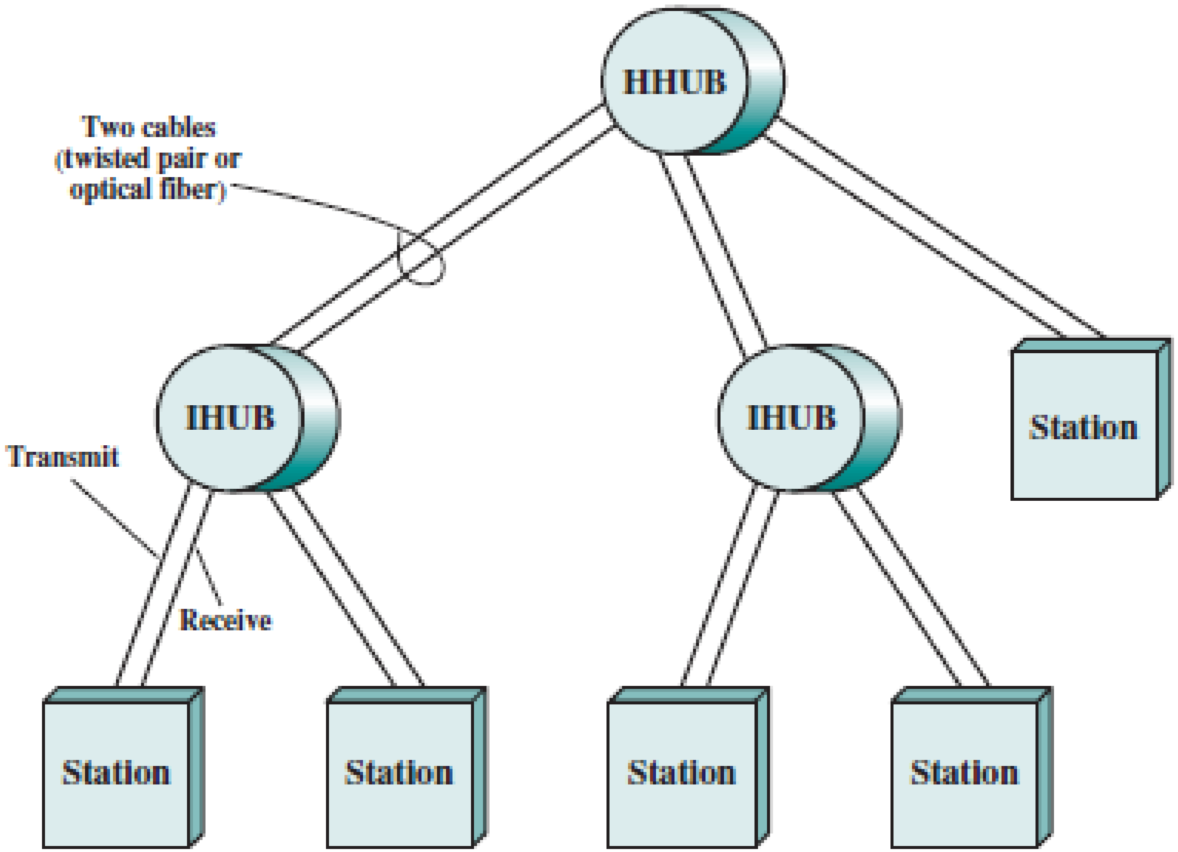


1000BASE-LX
10-µm single-mode fiber
50-µm multimode fiber
62.5-µm multimode fiber
1000BASE-SX
50-µm multimode fiber
62.5-µm multimode fiber
1000BASE-T
Category 5 UTP
1000BASE-CX
Shielded cable
25 m
50 m
250 m
500 m
2500 m
5000 m
Maximum distance

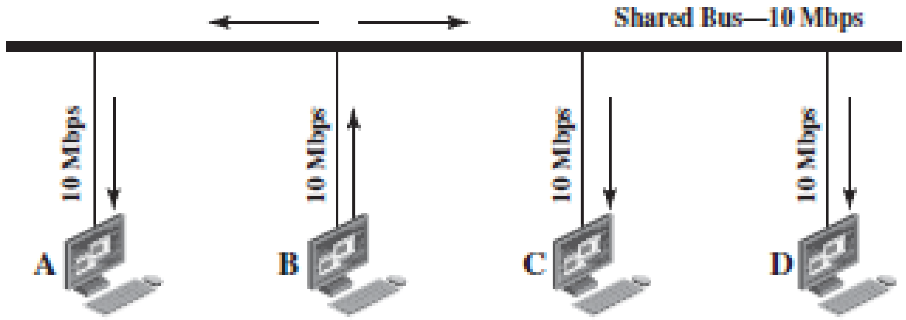
Physical Interconnection

- Bus topology with multidrop lines
  - One long connection with taps to connect machines
  - One machine's transmission can reach all machines
    - The destination machine accepts based on address in frame
  - Collision domain– all machines
  - Inflexible wiring, hard to extend
    - Think of a wiring already done and now you have to extend your network to one more room in the building

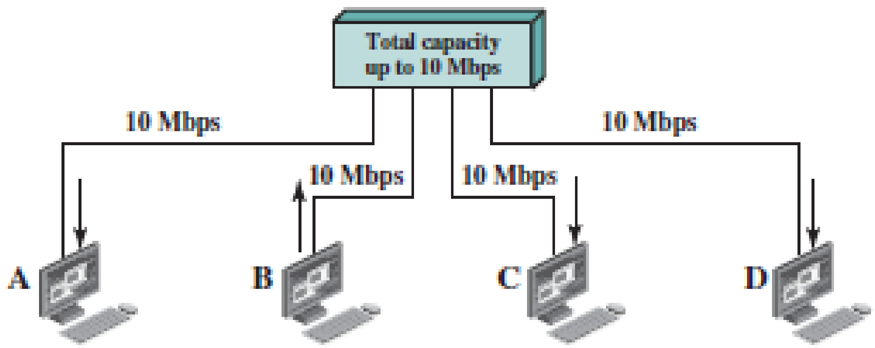
- Star/Tree topology with hubs
  - Hub: a central device with ports (4-port, 8-port, …)
  - One machine can be connected to each port
  - A frame received on one port is always broadcast to all ports (irrespective of the destination)
    - So logically still the same as a bus topology
    - Collision domain = all machines
  - Easy wiring, can extend easily by interconnecting hubs in tree topology
  - A hub just repeats the signal
    - Operates at physical layer


HHUB
Two cables
(twisted pair or
optical fiber)
IHUB
IHUB
Station
Transmit
Receive
Station
Station
Station
Station

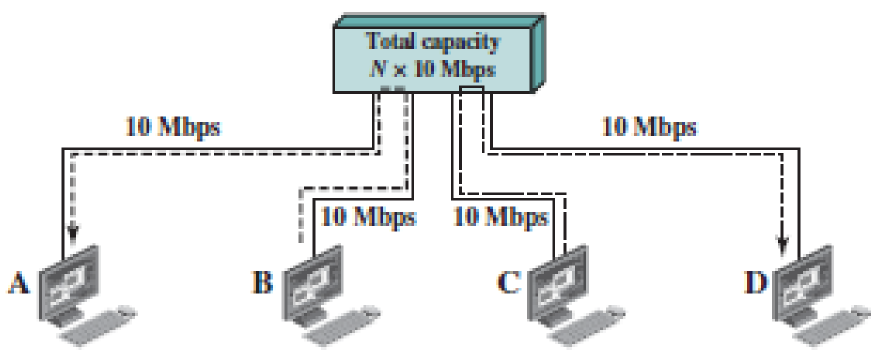
- Star/Tree topology with switches (Layer-2 switch)
  - Switch: similar to hub with ports
  - Difference: A frame received on one port is only sent on a port to which the destination is connected (how?)
  - So logically a point-to-point topology
    - Collision domain = 1 machine
  - Can extend easily by interconnecting switches in tree topology same as hubs
  - A switch also repeats the signal but looks at the MAC address
    - Operates at data link layer
- Almost all LANs are switched LANs now



(a) Shared medium bus



(b) Shared medium hub



(c) Layer 2 switch

Switched Ethernet

- Frames no longer broadcast always, sent to only port to which destination is connected
- Separates the single collision domain of hub-based Ethernet to multiple collision domains
  - Allows more than one pair to communicate simultaneously
- Increases bandwidth available to each machine
- How does the switch know which machine is connected to which port?
  - Use a forwarding table
    - Entries of the form <port, destination MAC addresses>
    - Looks up destination MAC address and forwards to appropriate port
  - How is the table built?

- Switch learns!
- Suppose m/c A sends frame to m/c B
  - Switch knows nothing initially, so broadcasts to all ports
  - But switch now knows which port m/c A is connected to!
  - If a frame comes for m/c A, it will be forwarded to only A's port
  - Internal table built up as more and more machines communicate, completely built up when every m/c has sent at least one frame

- What if we connect more switches?
  - Ex: You need to connect 16 machines (M1-M16), but you have only 8-port switches
    - Use 3 no. 8-port switches, S1, S2, S3
    - S1 connects 7 machines (M1-M7), S2 connects 7 machines (M8-M14)
    - One remaining port of S1 connected to one port of S3, same for S2
    - S3 connects 2 machines (M15 at Port 1, M16 at Port 2), plus have one connection each from S1 and S2 (say at Port 3 and Port 4)
    - S3's table will eventually map M15 to Port 1, M16 to Port 2, M1-M7 to Port 3, and M8-M14 to Port 4
    - A frame from say M15 to M6 will be forwarded by S3 to Port 3
    - S1 will then forward it to the port M6 is connected to (in local table of S1)
  - Learns the same way as for a single switch, just that entries in table are of the form <port, <list of destination MAC addresses>>

Spanning Tree Protocol

- For practical reasons, the interconnection between multiple switches may not be a tree
  - One switch's failure can cut off a large number of machines from each other
- So switches may be connected in an arbitrary physical topology
- So there can be more than one path between two switches
- Why can this be a problem?
  - A frame broadcast by a machine may go on circulating forever
- Solution:
  - Allow arbitrary physical topology of switches, but create a logical tree of switches out of it at any one time
  - Spanning Tree Protocol and its variations (IEEE802.1d/1w)

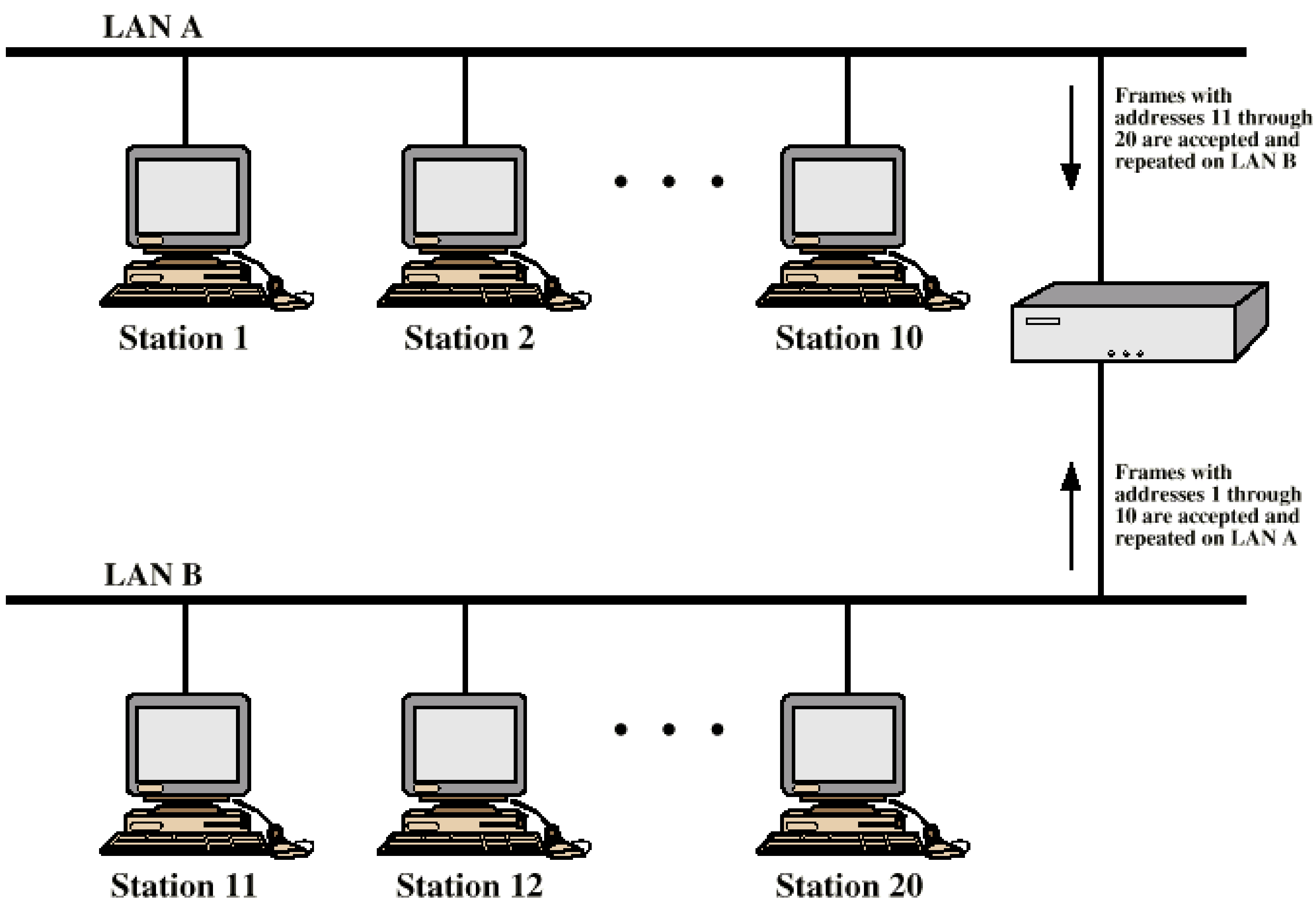
- Spanning Tree Protocol (STP)
  - Switches broadcast their switch ids to elect one switch as the root switch (root bridge)
    - By default the switch with the lowest MAC address
    - Can be configured by the administrator also (why needed?)
  - Each switch then finds the shortest "cost" path to the root bridge
    - The selected links form a rooted spanning tree
  - Only the switch ports on the links in the tree are used for forwarding packets (the port is in "forwarding" state)
  - All other ports are put in "blocked" state, not used for forwarding
  - Control packets (Bridge Protocol Data Units (BPDU)) exchanged on all ports periodically to monitor the topology
    - Reconfigure the links if a path is broken

Types of Switches

- Ethernet switches are commonly called L2 switches
  - since they switch based on L2 address (MAC address)
- Unmanaged switch
  - Can not be monitored or configured remotely
  - Low cost
- Managed switch
  - Can be monitored and configured remotely using network management protocols
  - Higher cost, but easier to maintain
- 10/100 Mbps switches are still available, but most switches from common OEMs are now gigabit switches
  - Each port is of speed 1 Gbps (or higher for backend switches)
  - Downward compatible usually to 10/100 Mbps cards

Bridges

- Connects more than one LAN segment
- LANs can be of same type (Transparent Bridging)
  - No modification to content or format of frame
  - No encapsulation
  - Exact bitwise copy of frame
  - MAC frames relayed, so does not need LLC
  - May have buffering to meet peak demand
- LANs can be of different types (Non-Transparent Bridging)
  - Frames may have different formats
  - Needs to transform frames before sending to other LAN
- We consider Transparent Bridging only


LAN A
Frames with addresses 11 through 20 are accepted and repeated on LAN B
Station 1
Station 2
Station 10
Frames with addresses 1 through 10 are accepted and repeated on LAN A
LAN B
Station 11
Station 12
Station 20

Bridge Routing

- How does a bridge know which frame should go to which LAN?
  - Has a routing table similar to switches
    - Entries of the form <port, <list of destination MAC addresses>>
    - Looks up destination MAC address and forwards to appropriate port
  - How is the routing table built?
    - Fixed and manually built – ok for small LANs
    - Automatic: same concepts as address learning and STP for switches
- A transparent bridge looks very similar to a switch! Are they the same?

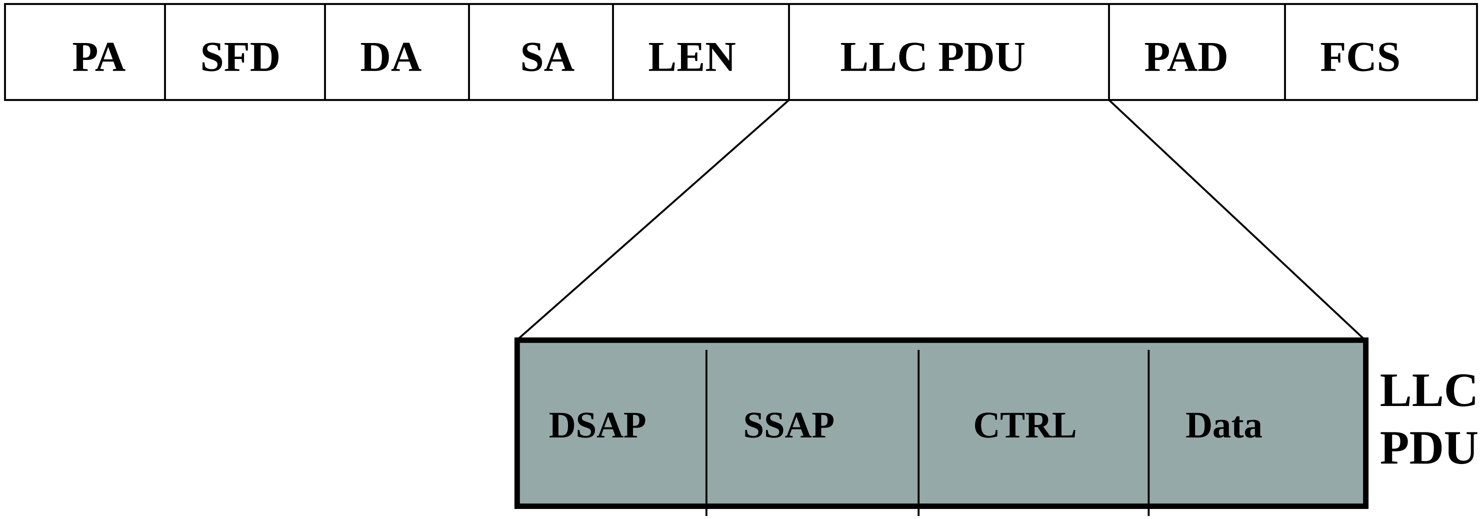
Auto-negotiation

- Allows two network devices to negotiate speed and other parameters
  - A 1000 Mbps network card connected to a 100 Mbps port of a switch
  - A half-duplex capable card connected to a full-duplex capable switch
- Can be turned on or off
- Protocol allows devices to exchange their abilities, the highest common abilities of the two devices is chosen usually
- Mostly relevant for network devices connected with copper (UTP/STP) wires.

LLC (Logical Link Control)

- IEEE 802.2
- Provides a common interface to higher layers for data transmission
- Provides optional link control functionalities (error control, flow control etc.) over MAC layers
- Common protocol over all IEEE 802.x MAC layers

MAC Frame Format for 802.3



LLC Header Fields

- SSAP - 8-bit address to identify *Source Service Access Point* (protocol) above data link layer whose data is carried by the LLC PDU
- DSAP – 8-bit address to identify *Destination Service Access Point* (protocol) above data link layer to whom the data in LLC PDU will be given
- Control – 1 or 2 bytes
- Data – Actual data, variable sized (but multiples of bytes)

Example

<table>
<tr><td>Network</td><td>Unix IP
SAP: 80</td><td>IBM Netbios
SAP: F0</td><td>Novell IPX
SAP: E0</td></tr>
<tr><td rowspan="2">Data Link</td><td colspan="3">IEEE 802.2 Logical Link Control Layer (LLC)</td></tr>
<tr><td colspan="3">IEEE 802.3 CSMA/CD
Medium Access Control Layer</td></tr>
<tr><td>Physical</td><td>802.3 - 10Base5</td><td>802.3a - 10Base2</td><td>802.3i - 10BaseT</td></tr>
</table>

Modes of Operation

- Unacknowledged connectionless (Type 1)
  - no acknowledgment, flow or error control; error detection and discard at MAC level
- Connection-oriented (Type 2)
  - Supports explicit connection establishment/reset/termination, flow control, sequencing, error control
- Acknowledged connectionless (Type 3)
  - No connection establishment, but acknowledgements are sent by receiver and retransmissions done by sender

- Frame formats to support Go-back-N or Selective Reject ARQ
- 7 bit sequence no. (frames numbered modulo 128)
- Exact frame formats skipped here
- IEEE 802.2 not used for IP networks
  - Can use using something called SNAP header (will not discuss), but not done
  - IP networks work on Ethernet-II directly