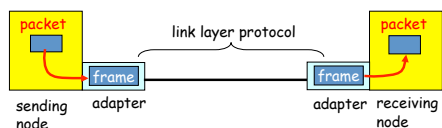


Adaptors Communicating



- **Sending side**
 - Encapsulates packet in a frame
 - Adds error checking bits, flow control, etc.
- **Receiving side**
 - Looks for errors, flow control, etc.
 - Extracts datagram and passes to receiving node

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Link-Layer Services

- **Encoding**
 - Represent the 0s and 1s
- **Framing**
 - Encapsulate packet into frame, adding header/trailer
- **Error detection**
 - Receiver detecting errors with checksums
- **Error correction**
 - Receiver optionally correcting errors
- **Flow control**
 - Pacing between sending and receiving nodes

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Addresses

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Medium Access Control Address



- **Identify the sending and receiving adapter**
 - Unique identifier for each network adapter
 - Identifies the intended receiver(s) of the frame
 - ... and the sender who sent the frame

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Medium Access Control Address

- **MAC address (e.g., 00-15-C5-49-04-A9)**
 - Numerical address used within a link
 - Unique, hard-coded in the adapter when it is built
 - Flat name space of 48 bits
- **Hierarchical allocation: Global uniqueness!**
 - **Blocks:** assigned to vendors (e.g., Dell) by the IEEE
 - **Adapters:** assigned by the vendor from its block
- **Broadcast address (i.e., FF-FF-FF-FF-FF-FF)**
 - Send the frame to *all* adapters

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As an Aside: Promiscuous Mode

- **Normal adapter: receives frames sent to**
 - The local MAC address
 - Broadcast address FF-FF-FF-FF-FF-FF
- **Promiscuous mode**
 - Receive *everything*, independent of destination MAC
- **Useful for packet sniffing**
 - Network monitoring
 - E.g., wireshark, tcpdump



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Why Not Just Use IP Addresses?

- Links can support *any* network protocol
 - Not just for IP (e.g., IPX, Appletalk, X.25, ...)
 - Different addresses on different kinds of links
- An adapter may move to a new location
 - So, cannot simply assign a static IP address
 - Instead, must reconfigure the adapter's IP address
- Must identify the adapter during bootstrap
 - Need to talk to the adapter to assign it an IP address

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Who Am I: Acquiring an IP Address



- Dynamic Host Configuration Protocol (DHCP)
 - Broadcast “I need an IP address, please!”
 - Response “You can have IP address 1.2.3.4.”

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Who Are You: Discovering the Receiver



- Address Resolution Protocol (ARP)
 - Broadcast “who has IP address 1.2.3.6?”
 - Response “OC-C4-11-6F-E3-98 has 1.2.3.6!”

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Sharing the Medium

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Collisions



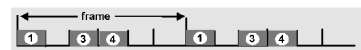
- Single shared broadcast channel
 - Avoid having multiple nodes speaking at once
 - Otherwise, collisions lead to garbled data

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Multi-Access Protocol

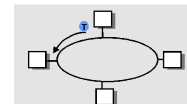
- Divide the channel into pieces

- In time
- In frequency



- Take turns

- Pass a token for the right to transmit



- Punt

- Let collisions happen
- ... and detect and recover from them

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Like Human Conversation...

- **Carrier sense**
 - Listen before speaking
 - ...and don't interrupt!
- **Collision detection**
 - Detect simultaneous talking
 - ... and shut up!
- **Random access**
 - Wait for a random period of time
 - ... before trying to talk again!

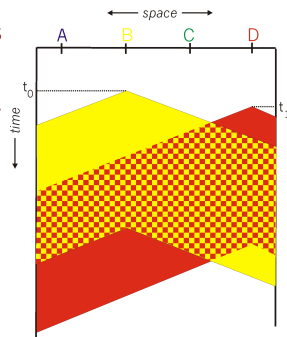


Please Wait...

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Carrier Sense Multiple Access

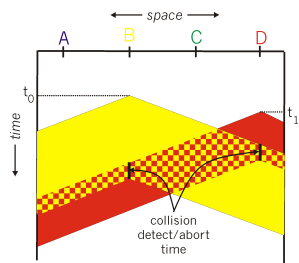
- **Listen for other senders**
 - Then transmit your data
- **Collisions can still occur**
 - Propagation delay
 - Wasted transmission



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CSMA/CD Collision Detection

- **Detect collision**
 - Abort transmission
 - Jam the link
- **Wait random time**
 - Transmit again
- **Hard in wireless**
 - Must receive data while transmitting



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Comparing the Three Approaches

- **Channel partitioning is**
 - (a) Efficient/fair at high load, inefficient at low load
 - (b) Inefficient at high load, efficient/fair at low load
- **“Taking turns”**
 - (a) Inefficient at high load
 - (b) Efficient at all loads
 - (c) Robust to failures
- **Random access**
 - (a) Inefficient at low load
 - (b) Efficient at all load
 - (c) Robust to failures

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Comparing the Three Approaches

- **Channel partitioning is**
 - (a) Efficient/fair at high load, inefficient at low load
 - (b) Inefficient at high load, efficient/fair at low load
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- **Random access**
 - (a) Inefficient at low load
 - (b) Efficient at all load
 - (c) Robust to failures

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Comparing the Three Approaches

- **Channel partitioning**
 - Efficient and fair at high load
 - Inefficient at low load
- **“Taking turns”**
 - Eliminates empty slots without collisions
 - Vulnerable to failures (e.g. lost token)
- **Random access**
 - Efficient at low load
 - Collision overhead at high load

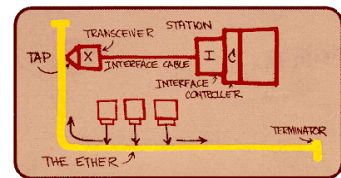
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Ethernet

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Ethernet

- Dominant wired LAN technology
- First widely used LAN technology
- Kept up with speed race: 10 Mbps – 40 Gbps



Metcalfe's Ethernet sketch

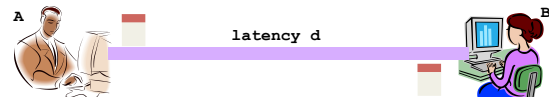
26

Ethernet Uses CSMA/CD

- **Carrier Sense:** wait for link to be idle
 - Channel idle: start transmitting
 - Channel busy: wait until idle
- **Collision Detection:** listen while transmitting
 - No collision: transmission is complete
 - Collision: abort transmission, and send jam signal
- **Random Access:** exponential back-off
 - After collision, wait random time before trying again
 - After m^{th} collision, choose K randomly from $\{0, \dots, 2^m - 1\}$
 - ... and wait for $K * 512$ bit times before trying again

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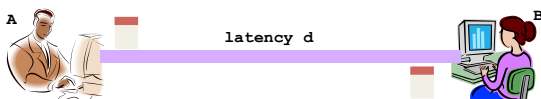
Limitations on Ethernet Length



- Latency depends on physical length of link
 - Time to propagate a packet from one end to other
- Suppose A sends a packet at time t
 - And B sees an idle line at a time just before $t+d$
 - ... so B happily starts transmitting a packet
- B detects a collision, and sends jamming signal
 - But A doesn't see collision till $t+2d$

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Limitations on Ethernet Length

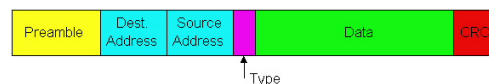


- A needs to wait for time $2d$ to detect collision
 - So, A should keep transmitting during this period
 - ... and keep an eye out for a possible collision
- Imposes restrictions on Ethernet
 - Maximum length of the wire: 2500 meters
 - Minimum length of the packet: 512 bits (64 bytes)

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Ethernet Frame Structure

- Sending adapter encapsulates packet in frame

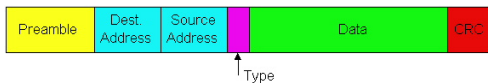


- **Preamble:** synchronization
 - Seven bytes with pattern 10101010, followed by one byte with pattern 10101011
 - Used to synchronize receiver, sender clock rates

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Ethernet Frame Structure

- **Addresses: source and destination MAC addresses**
 - Adaptor passes frame to network-level protocol
 - If destination is local MAC address or broadcast address
 - Otherwise, adapter discards frame
- **Type: indicates the higher layer protocol**
 - Usually IP
 - But also Novell IPX, AppleTalk, ...
- **CRC: cyclic redundancy check**



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Unreliable, Connectionless Service

- **Connectionless**
 - No handshaking between send and receive adapter
- **Unreliable**
 - Receiving adapter doesn't send ACKs or NACKs
 - Packets passed to network layer can have gaps
 - Gaps can be filled by transport protocol (e.g., TCP)
 - Otherwise, the application will see the gaps

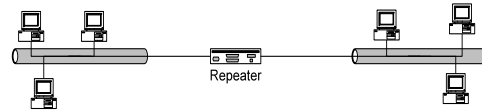
32

Hubs and Switches

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Physical Layer: Repeaters

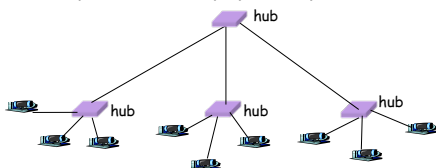
- **Distance limitation in local-area networks**
 - Electrical signal becomes weaker as it travels
 - Imposes a limit on the length of a LAN
- **Repeaters join LANs together**
 - Analog electronic device
 - Continuously monitors electrical signals
 - Transmits an amplified copy



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Physical Layer: Hubs

- **Joins multiple input lines electrically**
 - Designed to hold multiple line cards
 - Do not necessarily amplify the signal
- **Very similar to repeaters**
 - Also operates at the physical layer



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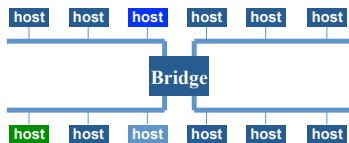
Limitations of Repeaters and Hubs

- **One large shared link**
 - Each bit is sent everywhere
 - So, aggregate throughput is limited
- **Cannot support multiple LAN technologies**
 - Does not buffer or interpret frames
 - Can't interconnect between different rates/formats
- **Limitations on maximum nodes and distances**
 - Shared medium imposes length limits
 - E.g., cannot go beyond 2500 meters on Ethernet

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Link Layer: Bridges

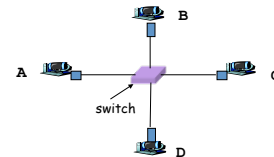
- Connects two or more LANs at the link layer
 - Extracts destination address from the frame
 - Looks up the destination in a table
 - Forwards the frame to the appropriate segment
- Each segment can carry its own traffic



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Link Layer: Switches

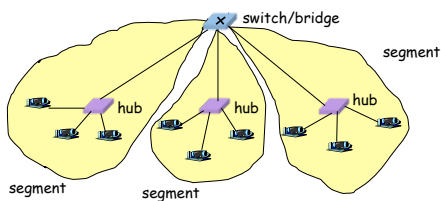
- Typically connects individual computers
 - A switch is essentially the same as a bridge
 - ... though typically used to connect hosts
- Supports concurrent communication
 - Host A can talk to C, while B talks to D



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Bridges/Switches: Traffic Isolation

- Switch filters packets
 - Frame only forwarded to the necessary segments
 - Segments can support separate transmissions



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Switches vs. Hubs

- Compared to hubs, Ethernet switches support
 - (a) Larger geographic span
 - (b) Similar span
 - (c) Smaller span
- Compared to hubs, switches provides
 - (a) Higher load on links
 - (b) Less privacy
 - (c) Heterogenous communication technologies

40

Switches vs. Hubs

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41

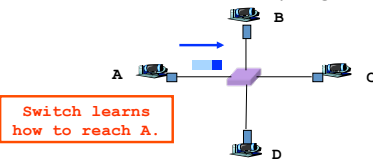
Advantages Over Hubs/Repeaters

- Only forwards frames as needed
 - Avoid unnecessary load on segments
- Wider geographic span
 - Separate segments allow longer distances
- Improves privacy
 - Hosts can "snoop" traffic traversing their segment
 - ... but not all the rest of the traffic
- Can join segments using different technologies

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Self Learning: Building the Table

- When a frame arrives
 - Inspect the *source* MAC address
 - Associate the address with the *incoming* interface
 - Store the mapping in the switch table
 - Use a timer to eventually forget the mapping

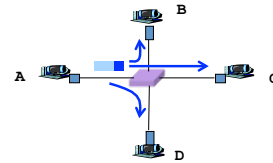


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Self Learning: Handling Misses

- When frame arrives with unfamiliar destination
 - Forward the frame out all of the interfaces
 - ... except for the one where the frame arrived
 - Hopefully, this case won't happen very often!

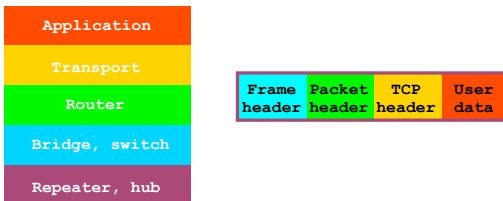
When in doubt, shout!



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Summary: Multiple Layers

- Different devices switch different things
 - Network layer: packets (routers)
 - Link layer: frames (bridges and switches)
 - Physical layer: electrical signals (repeaters and hubs)



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Conclusion

- Links
 - Connect two or more network adapters
 - ... each with a unique address
 - ... over a shared communication medium
- Coming next
 - Friday: Socket Programming “How To”
 - Monday: Network layer (IP)
- Get started
 - On assignment #1 on socket programming

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