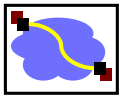
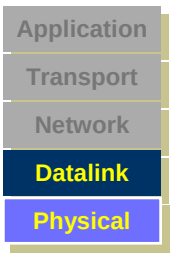
15-441 Computer Networking

Lecture 18 – Datalink and LANs

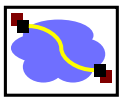
Goals



- Understand and services provided by the datalink layer and the the principles used to implement them.
- Understand the design principles and tradeoffs of various implementations of link layer technologies.

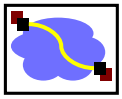


Outline



- **Physical Layer Recap.**
- Link Layer Overview.
- Multiple Access Protocols.
- Ethernet.
- Bridges and Switches.

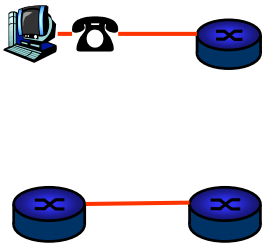
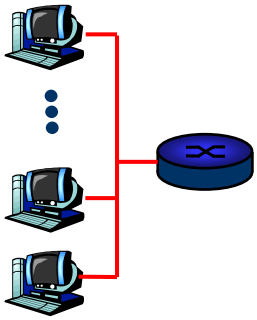
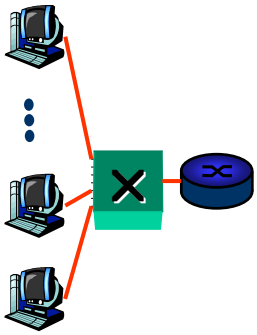
Physical layer recap



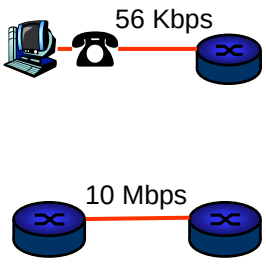
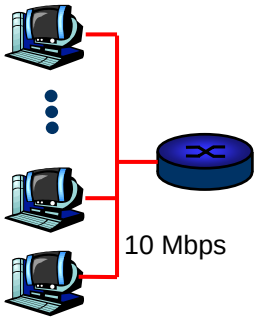
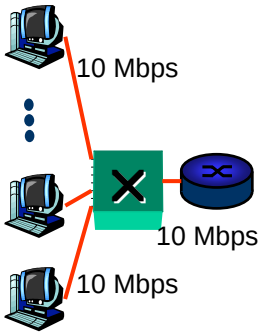
- Modulation.

  Put bits on the wire, i.e. convert bits into either a digital or analog signal.
- Bit encoding.
- Framing (Link layer).
- Errors.
  - Detection.
  - Correction.

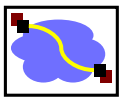
Link Taxonomy

Point to point	Broadcast	Switched
		
Single wire; e.g., phone line, PPP, SLIP.	Shared wire or medium; e.g., Ethernet, air (radio waves).	e.g., switched Ethernet, ATM.

Link Speed

Point to point	Broadcast	Switched
		
Dedicated. Half duplex or full duplex	Shared, resource contention.	Similar to point to point.

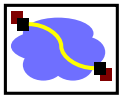
Sharing the media: MAC Protocols

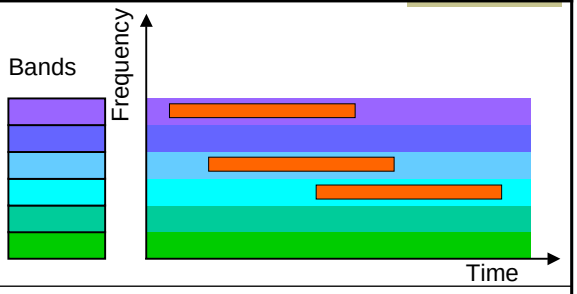
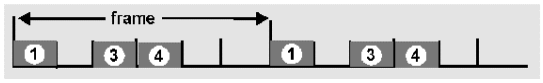


- Channel partitioning.
  - Divide channel into smaller “pieces” (frequency, time slots).
  - Allocate piece to node for exclusive use.
- “Taking turns”.
  - Tightly coordinate shared access to avoid collisions.
- Random access.
  - Allow collisions.
  - “Recover” from collisions.

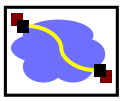
Goal: efficient, fair, simple, decentralized.

Channel Partitioning MAC Protocols



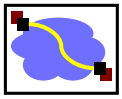
FDMA	Frequency Division Multiple Access	
WDMA	Wavelength Division Multiple Access	
TDMA	Time Division Multiple Access	

Outline

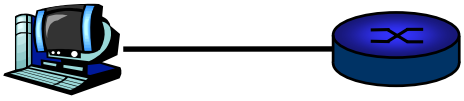


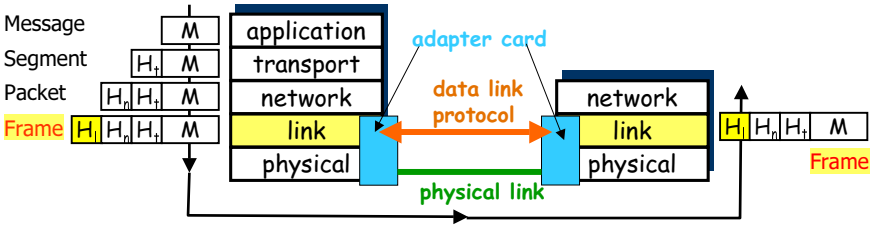
- Physical Layer Recap.
- Link Layer.
  - Overview.
  - Services.
- Multiple Access Protocols.
- Ethernet.
- Bridges and Switches.

Link Layer: Overview

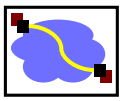


- Two or more *physically connected* devices.
- Implemented in the “adapter”.
  - E.g., Ethernet card, PCMCIA card.
  - Typically includes: RAM, DSP chips, host bus interface, and link interface + device driver software.



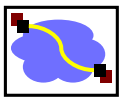


Link Layer Services



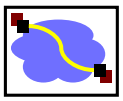
- Framing and addressing. (✓)
- Link access. (this lecture)
- Reliable delivery. (✓)
- Flow control. (✓)
- Error detection. (✓)
- Error correction. (✓)

Outline



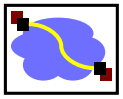
- Physical Layer Recap.
- Link Layer.
- **Multiple Access Protocols.**
  - **"Taking Turns" (Token ring).**
  - Random Access Protocol -- Ethernet CSMA/CD.
- Ethernet.
- Bridges and Switches.

Multiple Access Protocols

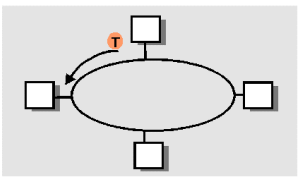


- Single shared communication channel.
- Two or more simultaneous transmissions → interference.
  - Only one node can send *successfully* at a time.
- *Multiple Access Protocol:*
  - Distributed algorithm that determines how stations share channel, i.e., determine when station can transmit.
  - Communication about channel sharing must use channel itself!

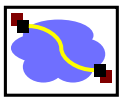
"Taking Turns": Token Rings



- Packets broadcast around ring.
- Token "right to send" rotates around ring.
- Every host holds token for limited time.
  - Fair, real-time bandwidth allocation.
  - Higher latency when only one sender.
  - High utilization: > 98%.
- Higher bandwidth: Point to point links electrically simpler than bus.
- Concerns:
  - Token overhead.
  - Latency.
  - Single point of failure (token).



Outline



- Physical Layer Recap.
- Link Layer.
- **Multiple Access Protocols.**
  - "Taking Turns" MAC and Other LANs.
  - **Random Access Protocol -** Ethernet CSMA/CD.
- Ethernet.
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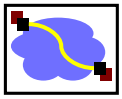
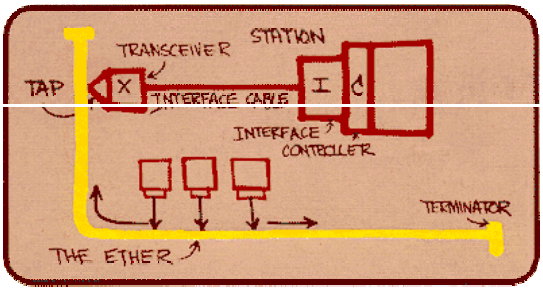
Random Access Protocols



- When node has packet to send:
  - Transmit at full channel data rate R.
  - No *a priori* coordination among nodes.
- Two or more transmitting nodes → "collision".
- Random access MAC protocol specifies:
  - How to detect collisions.
  - How to recover from collisions (e.g., via delayed retransmissions).
- Examples of random access MAC protocols:
  - Slotted ALOHA.
  - ALOHA.
  - CSMA and CSMA/CD.

Ethernet

- First practical local area network, built at Xerox PARC in 70's.
- "Dominant" LAN technology:
  - Cheap $20 for 100Mbs!
  - Kept up with speed race: 10, 100, 1000 Mbps .



Metcalfe's Ethernet sketch.

Ethernet MAC – Carrier Sense

Basic idea:

- Listen to wire before transmission.
- Avoid collision with active transmission.

CSMA Collisions

Collisions *can* occur:

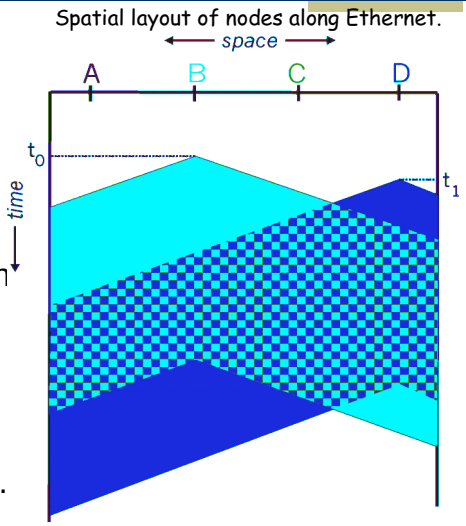
Propagation delay means two nodes may not yet hear each other's transmission.

Collision:

Entire packet transmission time wasted.

Note:

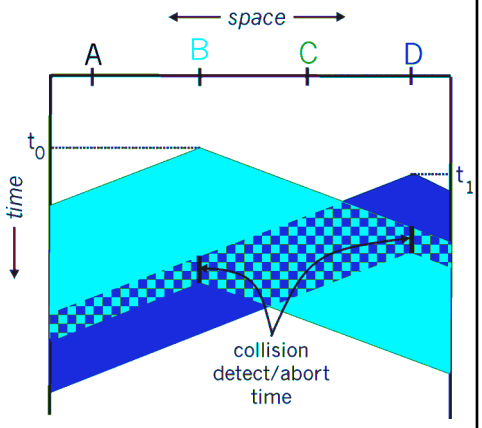
Role of distance and propagation delay in determining collision prob.



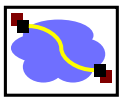
Ethernet MAC – Collision Detection

Basic idea:

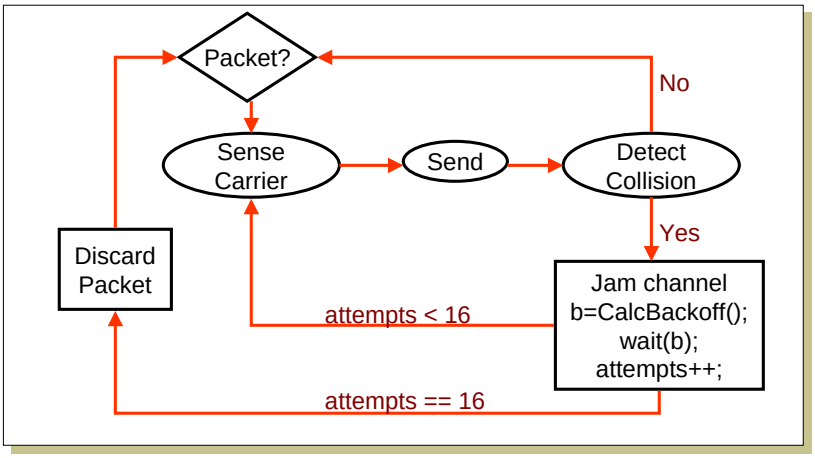
- Listen while transmitting.
- If you notice interference then assume collision.



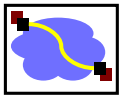
Ethernet MAC – CSMA/CD



- Carrier Sense Multiple Access/Collision Detection.



Ethernet's CSMA/CD (more)

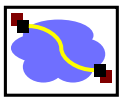


Jam Signal: Make sure all other transmitters are aware of collision; 48 bits.

Exponential Backoff:

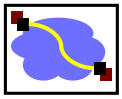
- If deterministic delay after collision, collision will occur again in lockstep.
- If random delay with fixed mean:
  - Few senders → needless waiting.
  - Too many senders → too many collisions.
- *Goal*: Adapt retransmission attempts to estimated current load.
  - Under heavy load the random wait is longer.

Ethernet Backoff Calculation



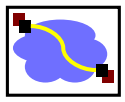
- Exponentially increasing random delay:
  - Infer senders from # of collisions.
  - More senders → increase wait time.
- First collision: choose K from {0,1}; delay is K x 512 bit transmission times.
- After second collision: choose K from {0,1,2,3}.
- After n <= 10 collisions: choose K from {0, …, 2^n}.
- After ten or more collisions, choose K from {0,1,2,3,4,…,1023}.

Outline

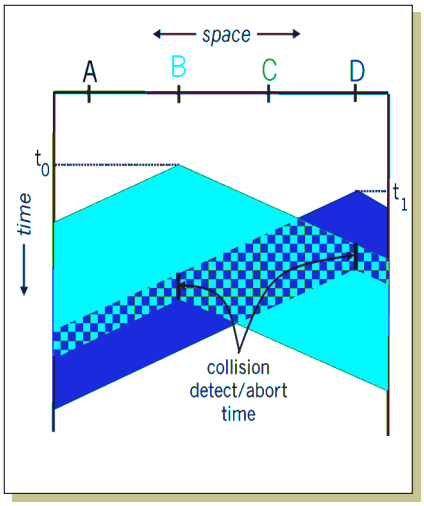


- Physical Layer Recap.
- Link Layer.
- Multiple Access Protocols.
- **Ethernet.**
  - **Minimum Packet Size.**
  - Ethernet Technologies.
  - Fast Ethernet and Gigabit Ethernet.
- Bridges and Switches.

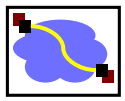
Minimum Packet Size



- What if two people sent really small packets?
  - How do you find collision?
  - All nodes should detect the collision, most critically senders.
- Implication:
  - Short wires.
  - Long packets.
  - Or a combination of both.

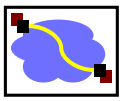


Ethernet Collision Detect



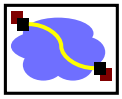
- Min packet length > 2 x max. prop. delay.
  - If A, B are at opposite sides of link, and B starts one link prop delay after A.
- Jam network for 48 bits after collision, then stop sending.
  - Ensures that everyone notices collision.

End to End Delay



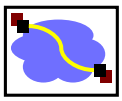
- c in cable = 60% * c in vacuum = 1.8 x 10^8 m/s
- Modern 10Mb Ethernet:
  - Maximum cable length is 2.5 km then ~= 12.5us delay.
  - + introduced repeaters delay (max 5 segments).
  - Worst case: 51.2us round trip time!
  - 10 Mbps, bit time is 0.1 μseconds.
- Slot time = 51.2us = 512bits = 64 bytes in flight.
  - After this amount, sender is guaranteed sole access to link.
  - 51.2us = slot time for backoff.

Packet Size



- What about scaling? 3Mbit, 100Mbit, 1Gbit, …
  - Original 3Mbit Ethernet did not have minimum packet size.
    - 1Km → 1000/1.8 x 10^8 ~= 5 x 10^-6 = 5us.
    - 5us * 3Mbps = only 15bits in flight! < header size.
  - For higher speeds must make network smaller, minimum packet size larger or both.
- What about a maximum packet size?
  - Needed to prevent node from hogging the network.
  - 1500 bytes in Ethernet.

Outline



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  - Minimum Packet Size.
  - **Ethernet Technologies.**
  - Fast Ethernet and Gigabit Ethernet.
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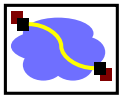
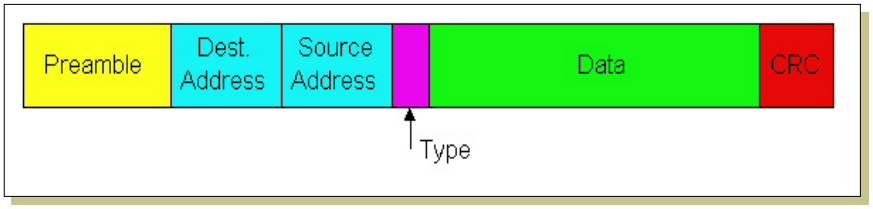
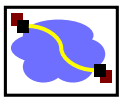
802.3 Ethernet Frame Structure



- Sending adapter encapsulates IP datagram (or other network layer protocol packet) in Ethernet frame.

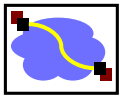


Ethernet Frame Structure (cont.)



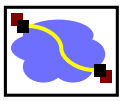
- Preamble: 8 bytes.
  - 101010…1011.
  - Used to synchronize receiver, sender clock rates.
- CRC: 4 bytes.
  - Checked at receiver, if error is detected, the frame is simply dropped.

Ethernet Frame Structure (cont.)



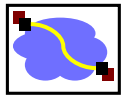
- Each protocol layer needs to provide some hooks to upper layer protocols.
  - Demultiplexing: identify which upper layer protocol packet belongs to.
  - E.g., port numbers allow TCP/UDP to identify target application.
  - Ethernet uses Type field.
- Type: 2 bytes.
  - Indicates the higher layer protocol, mostly IP but others may be supported such as Novell IPX and AppleTalk).

Ethernet Frame Structure (cont.)

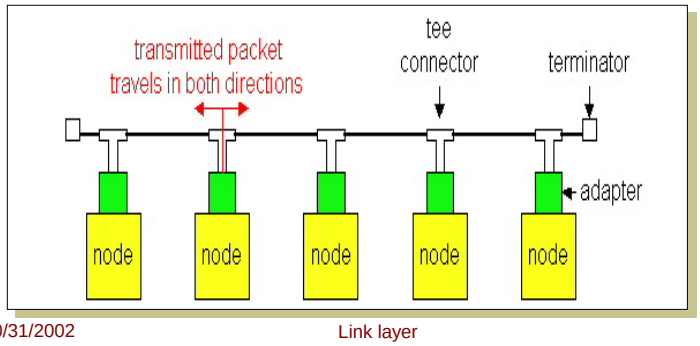


- Addresses: 6 bytes.
  - Each adapter is given a globally unique address at manufacturing time.
    - Address space is allocated to manufacturers.
      - 24 bits identify manufacturer.
      - E.g., 0:0:15:* → 3com adapter.
    - Frame is received by all adapters on a LAN and dropped if address does not match.
  - Special addresses.
    - Broadcast – FF:FF:FF:FF:FF:FF is “everybody”.
    - Range of addresses allocated to multicast.
      - Adapter maintains list of multicast groups node is interested in.

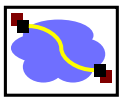
Ethernet Technologies: 10Base2



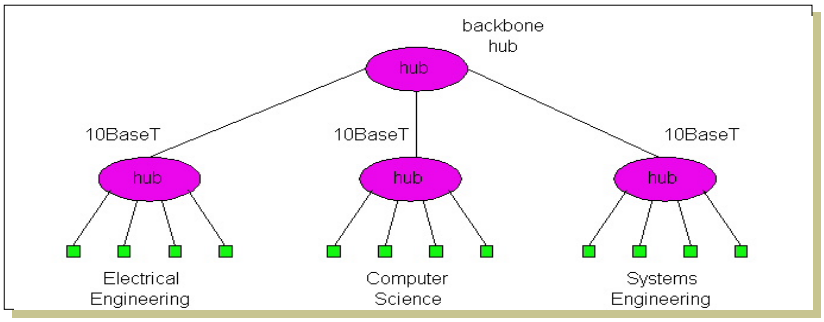
- 10: 10Mbps; 2: under 185 (~200) meters cable length.
- Thin coaxial cable in a bus topology.
- Repeaters used to connect up to multiple segments.
- Repeater repeats bits it hears on one interface to its other interfaces: physical layer device only!



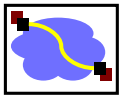
Ethernet: 10BaseT and 100BaseT



- 10/100 Mbps rate; latter called “Fast ethernet”.
- T stands for Twisted Pair.
- Hosts connected to hub by twisted pair, thus “star topology”. Hubs can be arranged in a hierarchy.

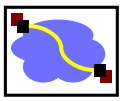


Ethernet Hubs



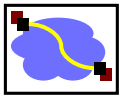
- Physical Layer devices, i.e., repeaters.
  - + Simple, inexpensive device
  - + Hierarchy: graceful degradation.
  - + Extends maximum distance between node pairs (100m per Hub).
  - + Disconnect “jabbering” adapter.
  - - Hubs do not isolate collision domains.
  - - Cannot connect different Ethernet types (e.g., 10BaseT and 100baseT).
- Gather monitoring information and statistics.

Outline



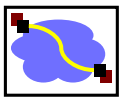
- Physical Layer Recap.
- Link Layer.
- Multiple Access Protocols.
- **Ethernet.**
  - Minimum Packet Size.
  - Ethernet Technologies.
  - **Fast Ethernet and Gigabit Ethernet.**
- Bridges and Switches.

802.3u Fast Ethernet (100BaseT)



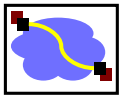
- Apply original CSMA/CD medium access protocol at 100 Mbps.
- Minimum packet size requirement.
  - Must change either minimum frame or maximum diameter.
  - Solution for 100BaseT: Make network smaller.
  - Max. distance from node to Hub is 100 meters.
  - No more “shared wire” connectivity: Hubs and switches only.
- Relatively cheap.

802.3z Gigabit Ethernet



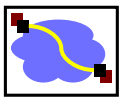
- Standard Ethernet frame format.
- Point-to-point links and shared broadcast channels.
  - 1 Gbps full-Duplex point-to-point links (backbone).
  - In shared mode, CSMA/CD is used; short distances between nodes to be efficient.
- Uses hubs, called here “Buffered Distributors”.
- Flow control to deal with congestion.
- Fiber and copper transmission media.

Gigabit Ethernet Frame Size



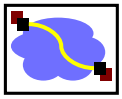
- Minimum frame size requirement
  - Make network smaller?
    - 512bits @ 1Gbps = 512ns.
    - 512ns * 1.8 * 10^8 = 92meters = too small !
  - Make min frame time but not frame size larger.
    - Gigabit Ethernet uses collision extension for small frames and backward compatibility.
- Maximum frame size requirement
  - 1500 bytes is not really “hogging” the network.
  - Defines “jumbo frames” (9000 bytes) for higher efficiency.

Why Did Ethernet Win?



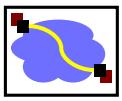
- Failure modes:
  - Token rings – network unusable.
  - Ethernet – node detached.
- Good performance in common case.
- Volume → lower cost → higher volume …
- Adaptable:
  - To higher bandwidths (vs. FDDI).
  - To switching (vs. ATM).
- Completely distributed, easy to maintain/administer.
- Easy incremental deployment.
- Cheap cabling.

Outline



- Physical Layer Recap.
- Link Layer.
- Multiple Access Protocols.
- Ethernet.
- **Bridges and Switches.**

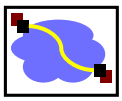
Interconnecting LANs



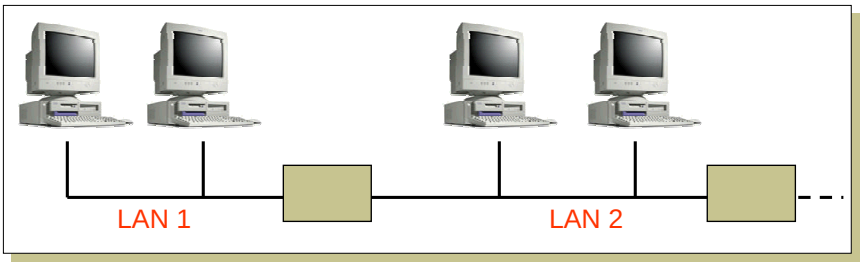
Q: Why not just one big LAN?

- Limited amount of supportable traffic: on single LAN, all stations must share bandwidth .
- Limited length: 802.3 specifies maximum cable length.
- Large “collision domain” (can collide with many stations).
- Limited number of stations.

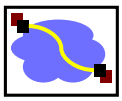
LAN Switching



- Extend reach of a single shared medium
- Connect two or more “segments” by copying data frames between them
  - Switches only copy data when needed → key difference from repeaters.

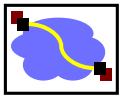


Switched Network Advantages



- Higher link bandwidth.
  - Point to point electrically simpler than bus.
- Much greater aggregate bandwidth.
  - Separate segments can send at once.
- Improved fault tolerance.
  - Redundant paths.
- Challenge.
  - Learning which packets to copy across links.
  - Avoiding forwarding loops.

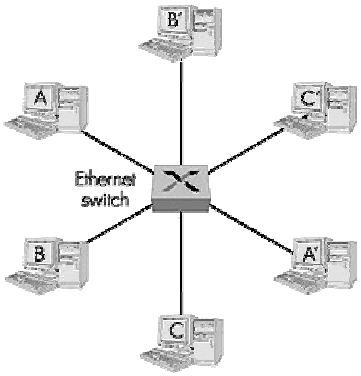
Ethernet Bridges and Switches



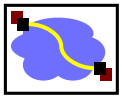
- Bridges make it possible to increase LAN capacity.
  - Link Layer devices: operate on Ethernet frames.
  - Filtering: Packets are no longer broadcasted - they are only forwarded on selected links, isolates collision domains.
  - Forwarding: CSMA/CD to access destination link and transmit.
  - Higher total max throughput and no limit the number of nodes nor geographical coverage.
  - Can connect different types of Ethernet.
  - Transparent: no need for any change to hosts LAN adapters.
- Ethernet switch is a special case of a bridge: often each port is connected to a single host.

Ethernet Switches

- High-speed internal switch fabric.
  - Unlike hubs, store-and-forward or alternatively cut-through switching.
- Large number of interfaces (ports).
  - Ports can be dedicated or shared.
  - Different port speeds on the same switch 10/100/1000 Mbps.
  - Simplifies the protocol and hardware used (only two stations on the link).
  - Can make the link full-duplex.



Summary



- Link layer.
- Multiple Access Protocols.
  - "Taking turns": Token Ring.
  - Ethernet's CSMA/CD.
- Effects of bandwidth, propagation delay and distance on minimum frame size.