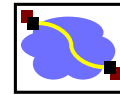


## 15-441 Computer Networking

### Lecture 18 – Datalink and LANs

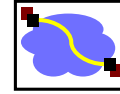
#### Goals



- 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



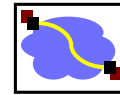
- **Physical Layer Recap.**
- Link Layer Overview.
- Multiple Access Protocols.
- Ethernet.
- Bridges and Switches.

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Link layer

3

## Physical layer recap



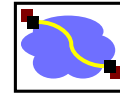
- Modulation.
  - Put bits on the wire, i.e. convert bits into either a digital or analog signal.
- Bit encoding.
- Framing (Link layer).
- Errors.
  - Detection.
  - Correction.

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Link layer

4

# Link Taxonomy



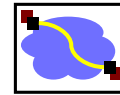
Point to point	Broadcast	Switched
Single wire; e.g., phone line, PPP, SLIP.	Shared wire or medium; e.g., Ethernet, air (radio waves).	e.g., switched Ethernet, ATM.

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Link layer

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# Link Speed



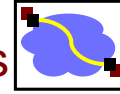
Point to point	Broadcast	Switched
Dedicated. Half duplex or full duplex	Shared, resource contention.	Similar to point to point.

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Link layer

8

## 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.

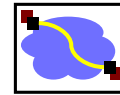
Goal: efficient, fair, simple, decentralized.

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Link layer

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## Channel Partitioning MAC Protocols



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

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Link layer

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## Outline



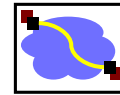
- Physical Layer Recap.
- Link Layer.
  - Overview.
  - Services.
- Multiple Access Protocols.
- Ethernet.
- Bridges and Switches.

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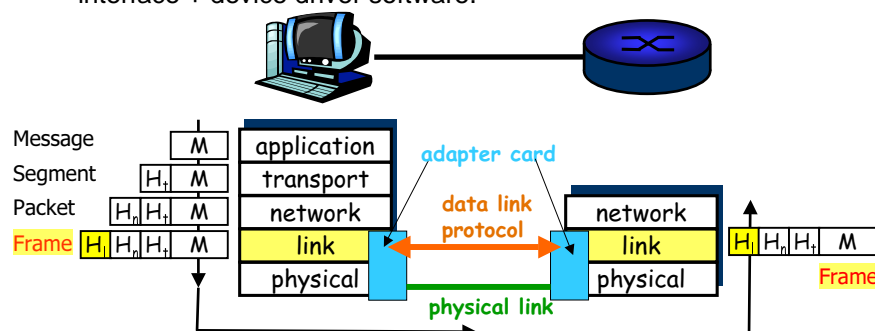
Link layer

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## 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.



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Link layer

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## Link Layer Services



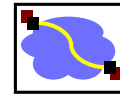
- Framing and addressing. ( ✓ )
- **Link access.** (this lecture)
- Reliable delivery. ( ✓ )
- Flow control. ( ✓ )
- Error detection. ( ✓ )
- Error correction. ( ✓ )

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Link layer

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## Outline



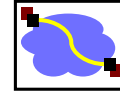
- Physical Layer Recap.
- Link Layer.
- **Multiple Access Protocols.**
  - “Taking Turns” (Token ring).
  - Random Access Protocol -- Ethernet CSMA/CD.
- Ethernet.
- Bridges and Switches.

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Link layer

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## Multiple Access Protocols



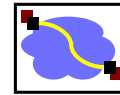
- Single shared communication channel.
- Two or more simultaneous transmissions → interference.
  - Only one node can send *successfully* at a time.
- *Multiple Access Protocol*:
  - Distributed algorithm that determines how stations share channel, i.e., determine when station can transmit.
  - Communication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

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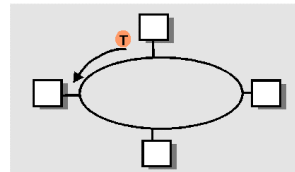
Link layer

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## “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).



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Link layer

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## Outline



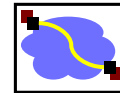
- Physical Layer Recap.
- Link Layer.
- **Multiple Access Protocols.**
  - “Taking Turns” MAC and Other LANs.
  - **Random Access Protocol - Ethernet CSMA/CD.**
- Ethernet.
- Bridges and Switches.

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Link layer

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## Random Access Protocols



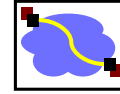
- When node has packet to send:
  - Transmit at full channel data rate  $R$ .
  - No *a priori* coordination among nodes.
- Two or more transmitting nodes → “collision”.
- Random access MAC protocol specifies:
  - How to detect collisions.
  - How to recover from collisions (e.g., via delayed retransmissions).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

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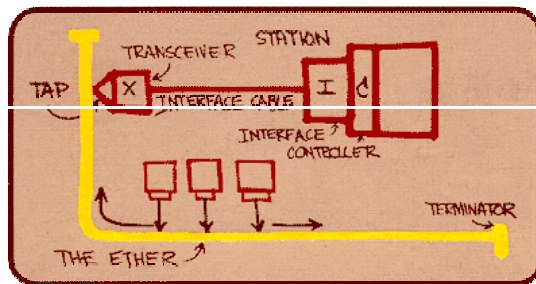
Link layer

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## 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 .



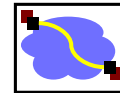
Metcalfe's Ethernet sketch.

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Link layer

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## Ethernet MAC – Carrier Sense



Basic idea:

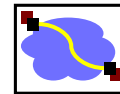
- Listen to wire before transmission.
- Avoid collision with active transmission.

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Link layer

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## CSMA Collisions



### Collisions *can* occur:

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

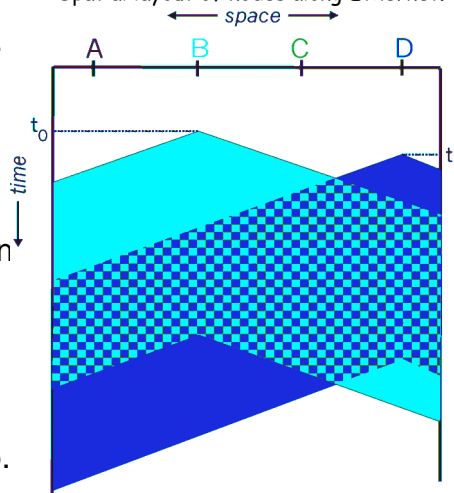
### Collision:

Entire packet transmission time wasted.

### Note:

Role of distance and propagation delay in determining collision prob.

Spatial layout of nodes along Ethernet.

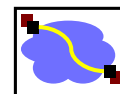


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Link layer

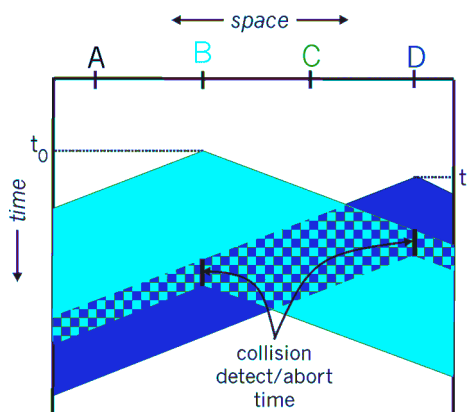
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## Ethernet MAC – Collision Detection



### Basic idea:

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



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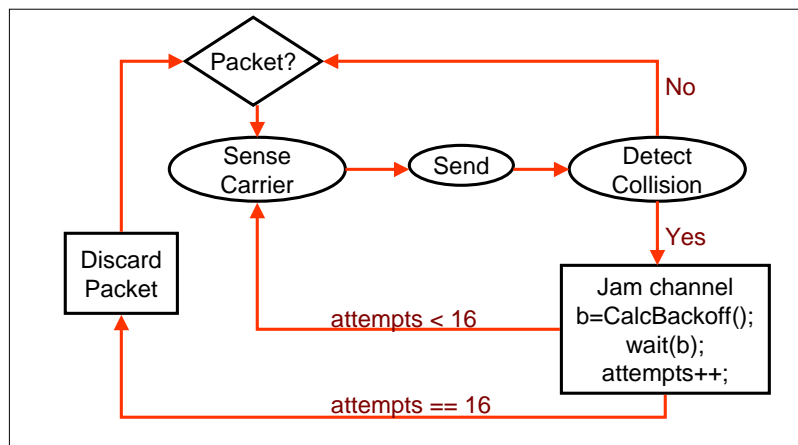
Link layer

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## Ethernet MAC – CSMA/CD



- Carrier Sense Multiple Access/Collision Detection.

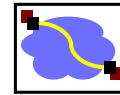


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Link layer

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## 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.

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Link layer

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## Ethernet Backoff Calculation



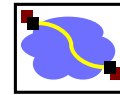
- Exponentially increasing random delay:
  - Infer senders from # of collisions.
  - More senders → increase wait time.
- First collision: choose K from {0,1}; delay is K x 512 bit transmission times.
- After second collision: choose K from {0,1,2,3}.
- After  $n \leq 10$  collisions: choose K from {0,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

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Link layer

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## Outline



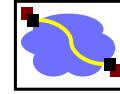
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  - Fast Ethernet and Gigabit Ethernet.
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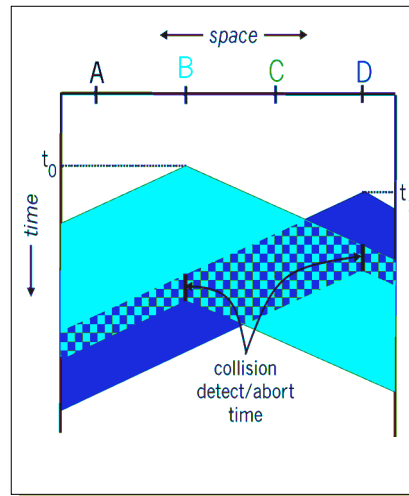
Link layer

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## 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.

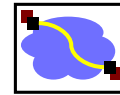


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Link layer

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## Ethernet Collision Detect



- Min packet length  $> 2 \times$  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.

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Link layer

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## End to End Delay



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

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Link layer

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## Packet Size



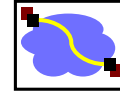
- What about scaling? 3Mbit, 100Mbit, 1Gbit, ...
  - Original 3Mbit Ethernet did not have minimum packet size.
    - 1Km  $\rightarrow 1000/1.8 \times 10^8 \approx 5 \times 10^{-6} = 5\mu\text{s}$ .
    - $5\mu\text{s} * 3\text{Mbps} =$  only 15bits in flight! < header size.
  - For higher speeds must 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.

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Link layer

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## Outline



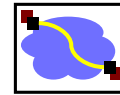
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  - Minimum Packet Size.
  - **Ethernet Technologies.**
  - Fast Ethernet and Gigabit Ethernet.
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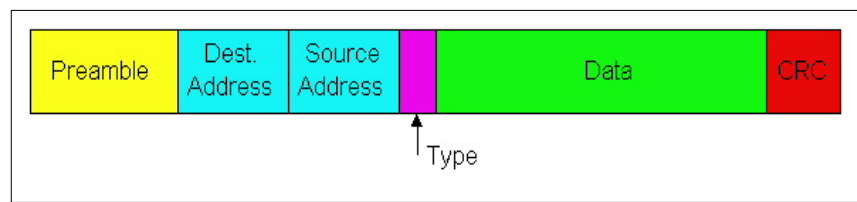
Link layer

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## 802.3 Ethernet Frame Structure



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

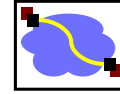


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Link layer

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## Ethernet Frame Structure (cont.)



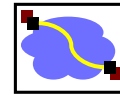
- **Preamble:** 8 bytes.
  - 101010...1011.
  - Used to synchronize receiver, sender clock rates.
- **CRC:** 4 bytes.
  - Checked at receiver, if error is detected, the frame is simply dropped.

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Link layer

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## Ethernet Frame Structure (cont.)



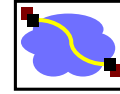
- Each protocol layer needs to provide some hooks to upper layer protocols.
  - Demultiplexing: identify which upper layer protocol packet belongs to.
  - E.g., port numbers allow TCP/UDP to identify target application.
  - Ethernet uses Type field.
- **Type:** 2 bytes.
  - Indicates the higher layer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

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Link layer

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## Ethernet Frame Structure (cont.)



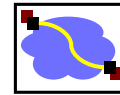
- **Addresses:** 6 bytes.
  - Each adapter is given a globally unique address at manufacturing time.
    - Address space is allocated to manufacturers.
      - 24 bits identify manufacturer.
      - E.g., 0:0:15:\* → 3com adapter.
    - Frame is received by all adapters on a LAN and dropped if address 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.


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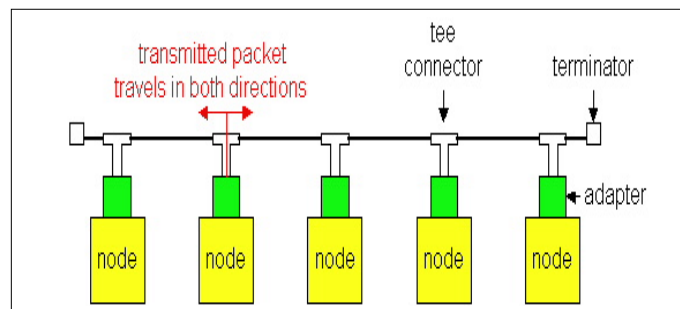
Link layer

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## 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!

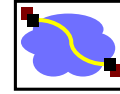



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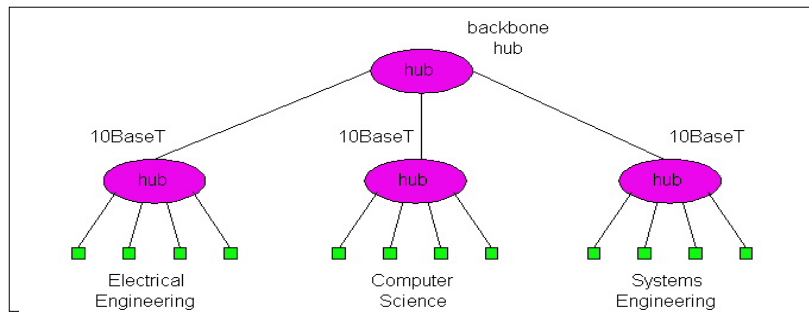
Link layer

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## 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.

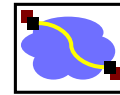


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Link layer

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## 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.

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Link layer

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## Outline



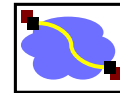
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Link layer

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## 802.3u Fast Ethernet (100BaseT)



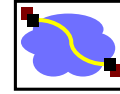
- Apply original CSMA/CD medium access protocol at 100 Mbps.
- Minimum packet size requirement.
  - Must change either minimum frame or maximum diameter.
  - Solution for 100BaseT: Make network smaller.
  - Max. distance from node to Hub is 100 meters.
  - No more “shared wire” connectivity: Hubs and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

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Link layer

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## 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.

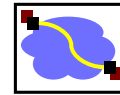


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Link layer

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## Gigabit Ethernet Frame Size



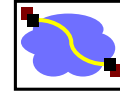
- Minimum frame size requirement
  - Make network smaller?
    - 512bits @ 1Gbps = 512ns.
    - $512\text{ns} * 1.8 * 10^8 = 92\text{meters} = \text{too small !}$
  - Make min frame time but not frame size larger.
    - Gigabit Ethernet uses collision extension for small frames and backward compatibility.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

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Link layer

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## Why Did Ethernet Win?



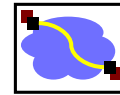
- Failure modes:
  - Token rings – network unusable.
  - Ethernet – node detached.
- Good performance in common case.
- Volume → lower cost → higher volume ...
- Adaptable:
  - To higher bandwidths (vs. FDDI).
  - To switching (vs. ATM).
- Completely distributed, easy to maintain/administer.
- Easy incremental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

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Link layer

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## Outline



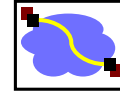
- Physical Layer Recap.
- Link Layer.
- Multiple Access Protocols.
- Ethernet.
- **Bridges and Switches.**

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Link layer

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## Interconnecting LANs



### Q: Why not just one big LAN?

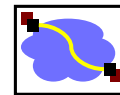
- Limited amount of supportable traffic: on single LAN, all stations must share bandwidth .
- Limited length: 802.3 specifies maximum cable length.
- Large “collision domain” (can collide with many stations).
- Limited number of stations.

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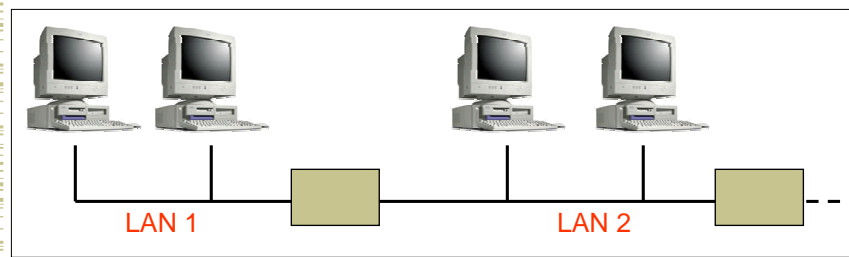
Link layer

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## 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.

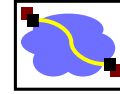


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Link layer

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## Switched Network Advantages



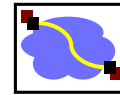
- Higher link bandwidth.
  - Point to point electrically simpler than bus.
- Much greater aggregate bandwidth.
  - Separate segments can send at once.
- Improved fault tolerance.
  - Redundant paths.
- Challenge.
  - Learning which packets to copy across links.
  - Avoiding forwarding loops.

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## 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.

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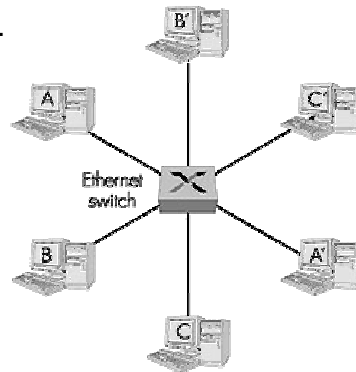
Link layer

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## 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.

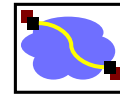


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Link layer

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## 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.

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Link layer

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