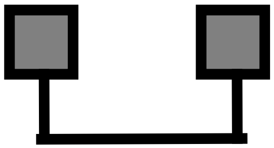
15-441 Computer Networking
Lecture 5
Data link Layer – Access Control

Based on slides by Peter Steenkiste

Datalink Functions

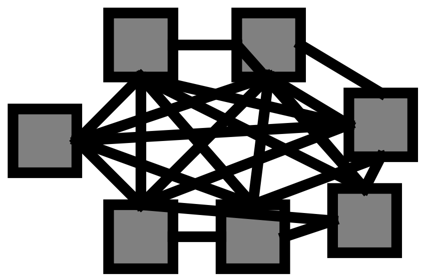
- Framing: encapsulating a network layer datagram into a bit stream.
  - Add header, mark and detect frame boundaries, …
- Error control: error detection and correction to deal with bit errors.
  - May also include other reliability support, e.g. retransmission
- Flow control: avoid sender overrunning receiver.
- Media access: controlling which frame should be sent over the link next.
  - Easy for point-to-point links
  - Harder for multi-access links: who gets to send?

So far …



Can connect two nodes

- … But what if we want more nodes?



Wires for everybody!

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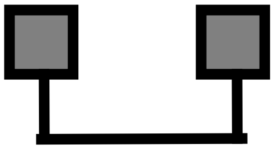

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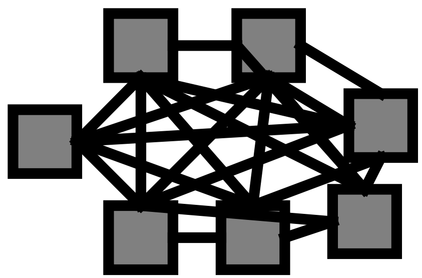

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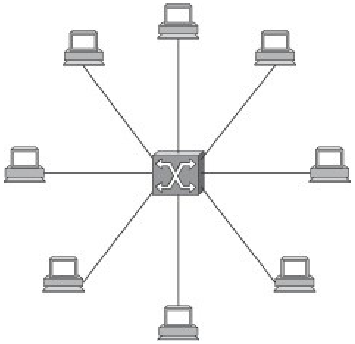
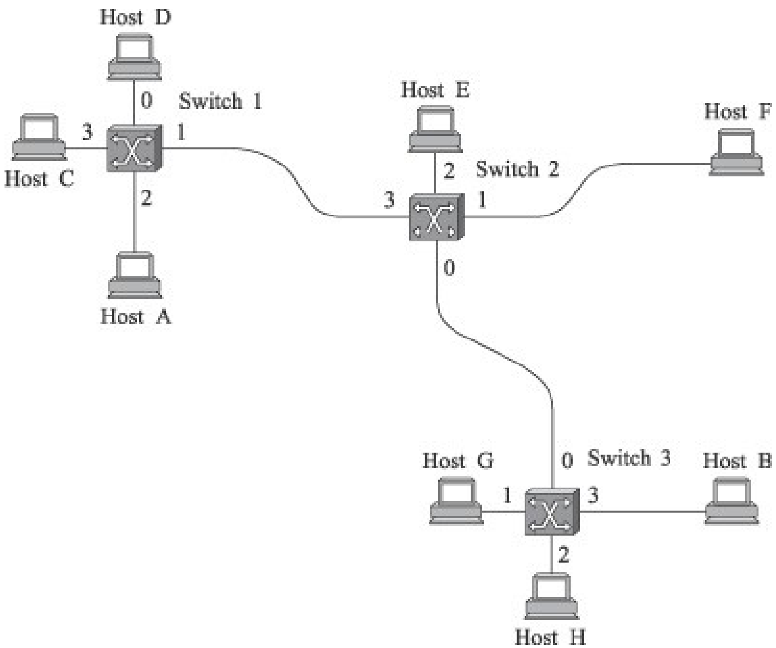
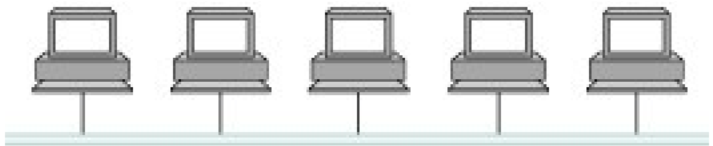


Datalink Architectures



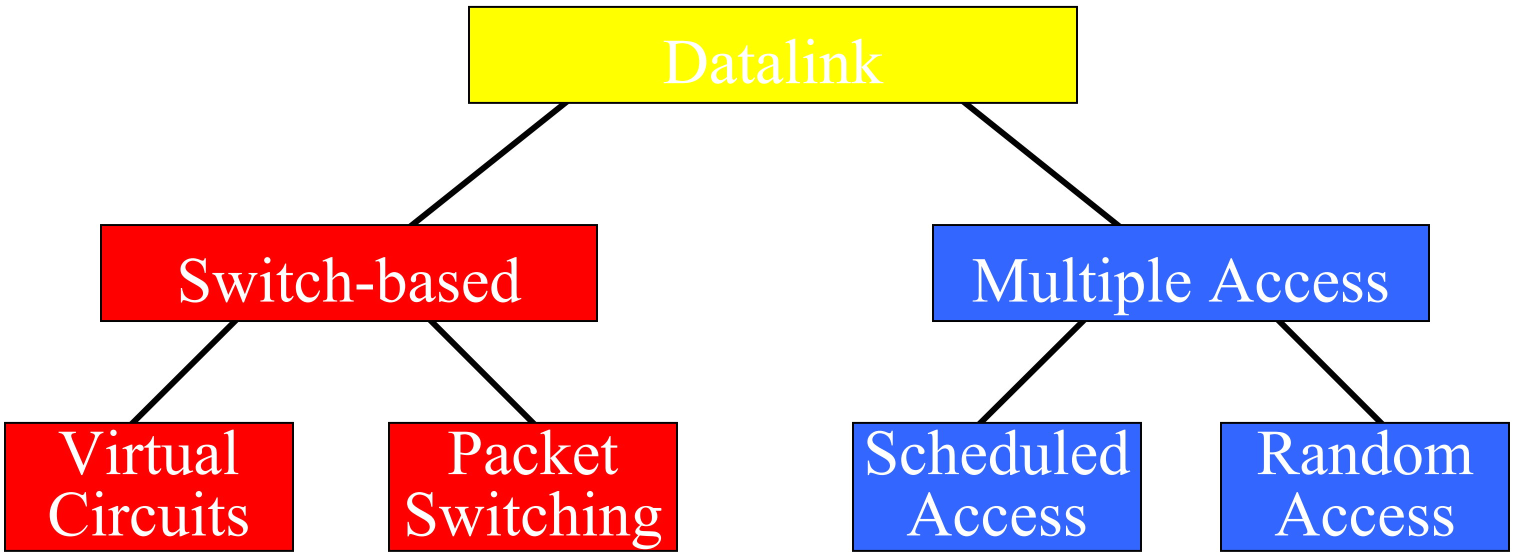


- Point-Point with switches
- Media access control.

Media Access Control

- How do we transfer packets between two hosts connected to the same network?
- Switches connected by point-to-point links -- store-and-forward.
  - Used in WAN, LAN, and for home connections
  - Conceptually similar to "routing"
    - But at the datalink layer instead of the network layer
- Multiple access networks -- contention based.
  - Multiple hosts are sharing the same transmission medium
  - Used in LANs and wireless
  - Need to control access to the medium

Datalink Classification

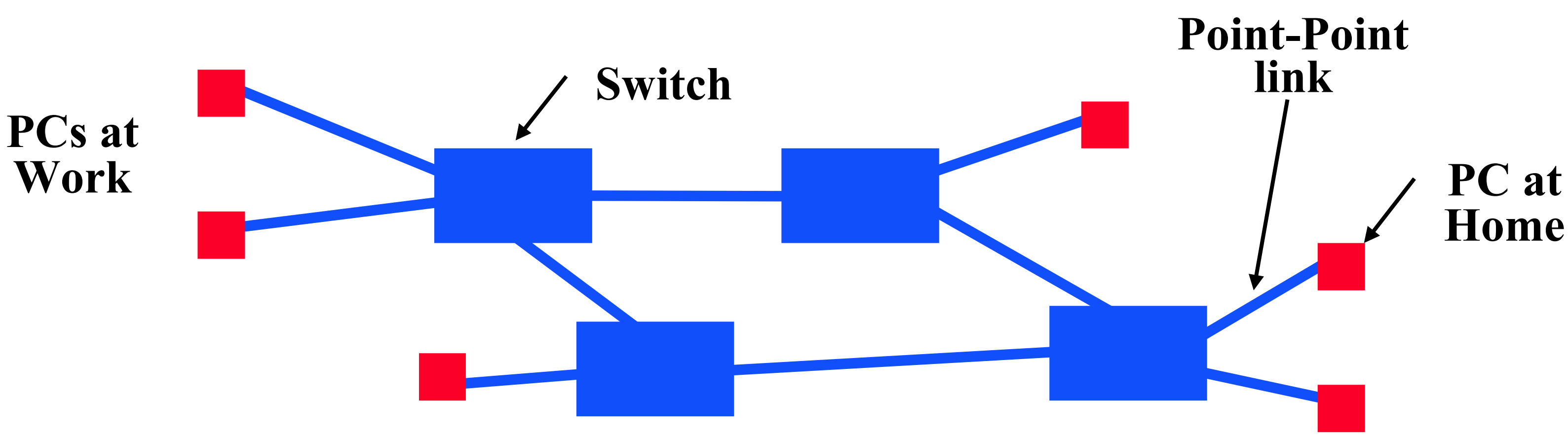


Switching

- Forward units of data based on address in header.
- Many data-link technologies use switching.
  - » Virtual circuits: Frame Relay, ATM, X.25, ..
  - » Packets: Ethernet, MPLS, …
- "Switching" also happens at the network layer.
  - » Layer 3: Internet protocol
  - » In this case, address is an IP address
  - » IP over SONET, IP over ATM, ...
  - » Otherwise, operation is very similar
- Switching is different from SONET mux/demux.
  - » SONET channels statically configured - no addresses

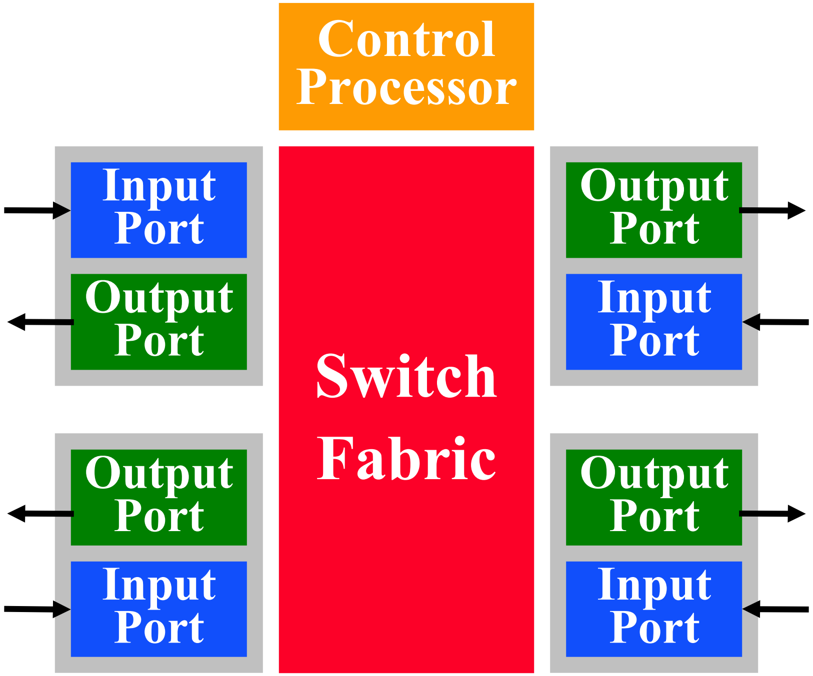
A Switch-based Network

- Switches are connected by point-point links.
- Packets are forwarded hop-by-hop by the switches towards the destination.
  - Forwarding is based on the address
- How does a switch work?
- How do nodes exchange packets over a link?
- How is the destination addressed?



Switch Architecture

- Packets come in one interface, forwarded to output interface based on address.
  - » Same idea for bridges, switches, routers: address look up differs
- Control processor manages the switch and executes higher level protocols.
  - » E.g. routing, management, ...
- The switch fabric directs the traffic to the right output port.
- The input and output ports deal with transmission and reception of packets.

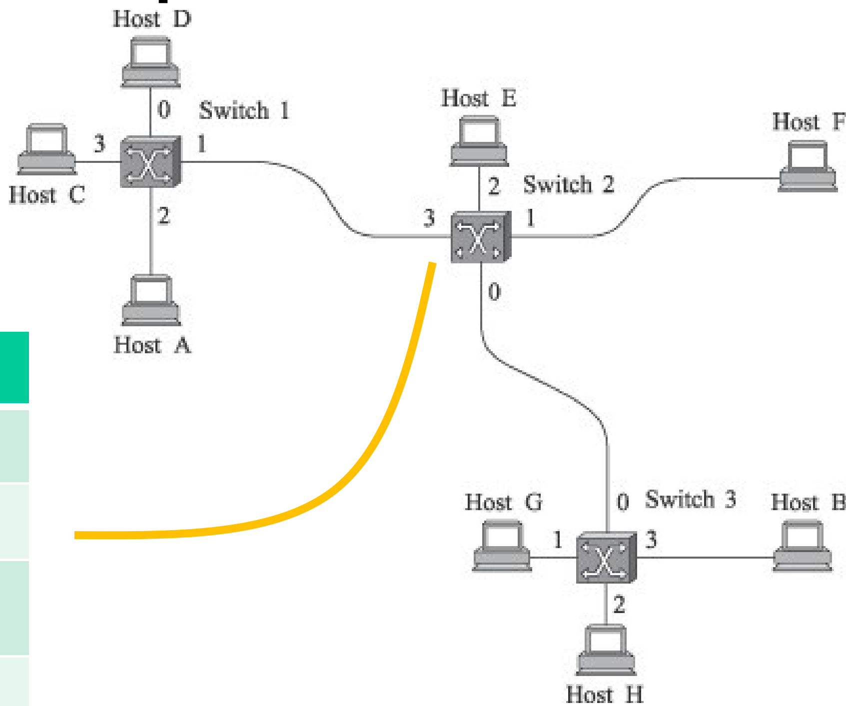


Connections or Not?

- Two basic approaches to packet forwarding
  - Connectionless
  - (virtual) Circuit switched
- When would you use?

Connectionless

- Host can send anytime anywhere
- No idea if resources are available to get to dest
- Forwarding is independent for each packet
- No setup time
- Fault tolerant



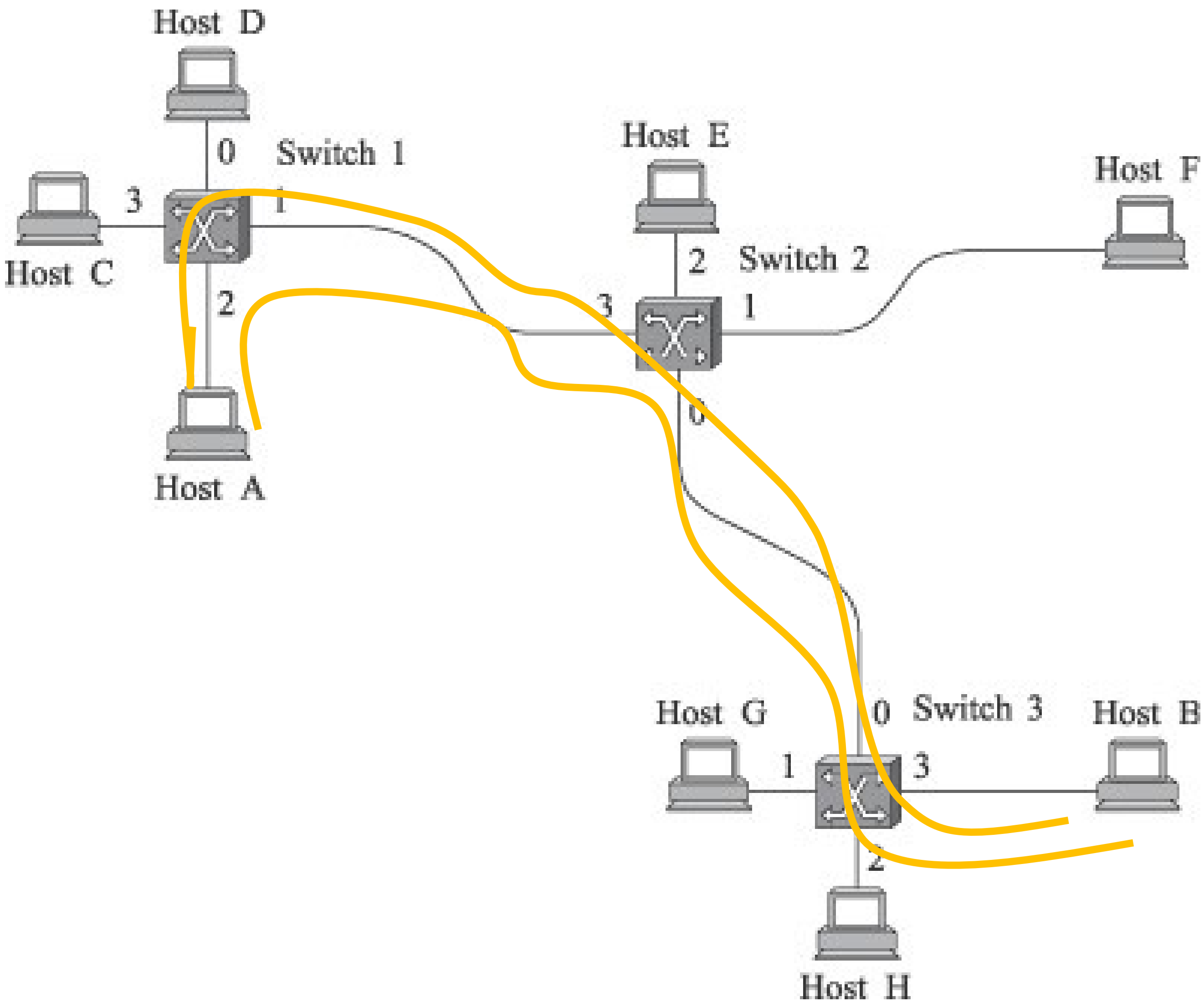
Destination	Port
A	3
B	0
C	
D	
E	

Virtual Circuit Switching

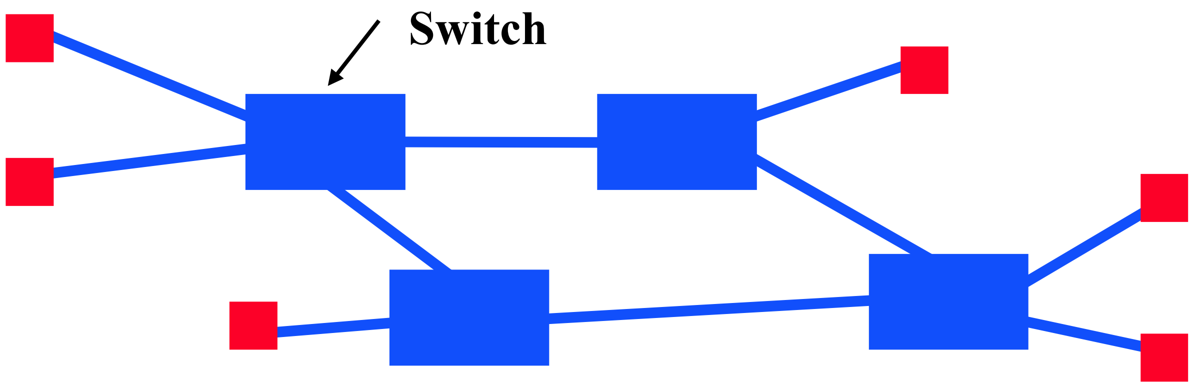
- Two stage process
  - » Setup connection (create VCIs)
  - » Send packets

- RTT introduced before any data is sent
- Per packet overhead can be smaller (VCI << adr)
- Switch failures are hard to deal with
- Reserves resources for connection

Setup, assign VCIs



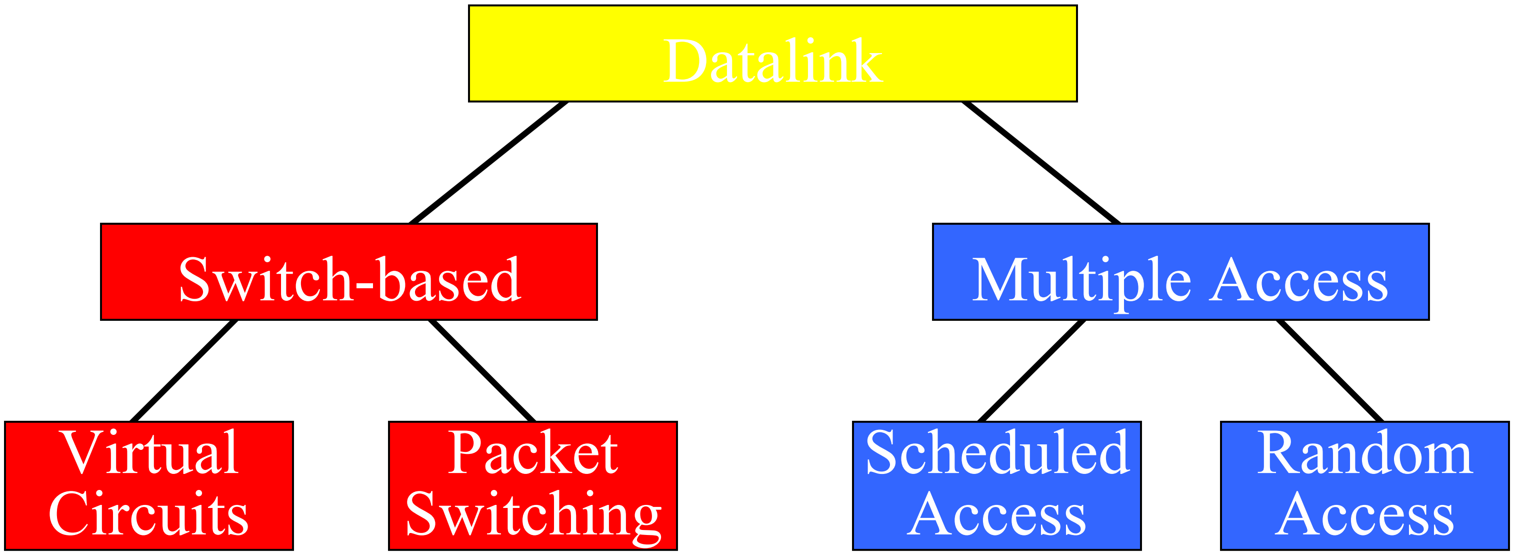
Packet Forwarding: Address Lookup



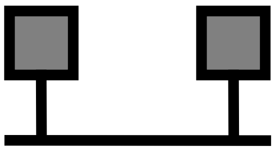
Address	Next Hop	Info
B31123812508	3	13
38913C3C2137	3	-
A21023C90590	0	-
128.2.15.	1	(2,34)

- Address from header.
  - Absolute address (e.g. Ethernet)
  - (IP address for routers)
  - (VC identifier, e.g. ATM))
- Next hop: output port for packet.
- Info: priority, VC id, ..
- Table is filled in by protocol.

Datalink Classification

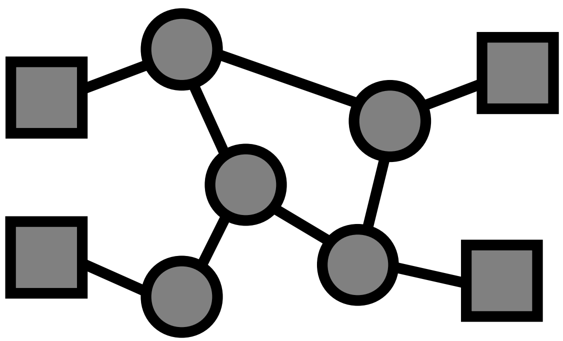


Problem: Sharing a Wire

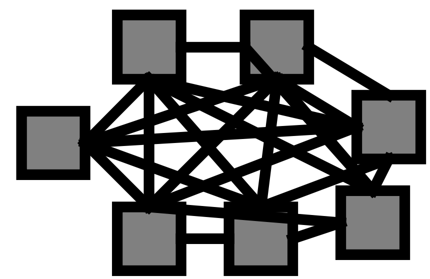


Learned how to connect hosts

- … But what if we want more hosts?

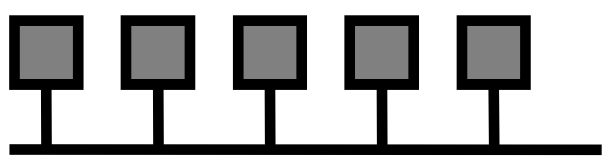


Switches



Wires for everybody!

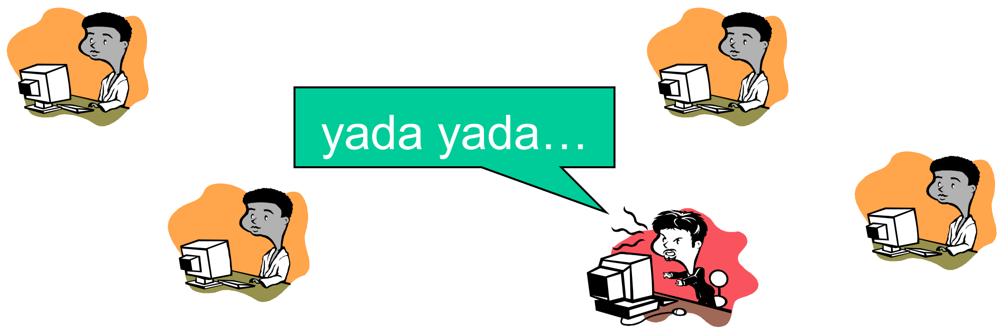
- Expensive! How can we share a wire?



Listen and Talk

- Natural scheme – listen before you talk…
  - Works well in practice

Listen and Talk



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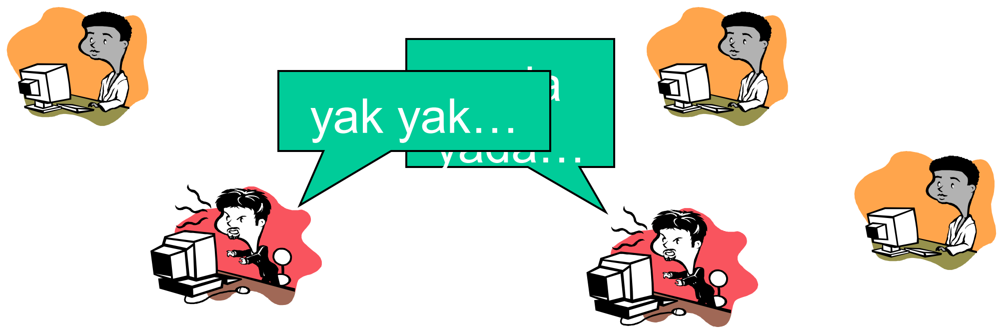
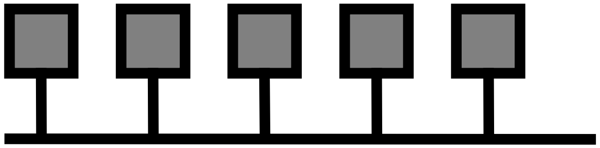
Listen and Talk



- Natural scheme – listen before you talk…
  - » Works well in practice
- But sometimes this breaks down
  - » Why? How do we fix/prevent this?

Problem: Who is this packet for?



- Need to put an address on the packet
- What should it look like?
- How do you determine your own address?
- How do you know what address you want to send it to?

Outline

- Aloha
- Ethernet MAC
- Collisions
- Ethernet Frames

Random Access Protocols

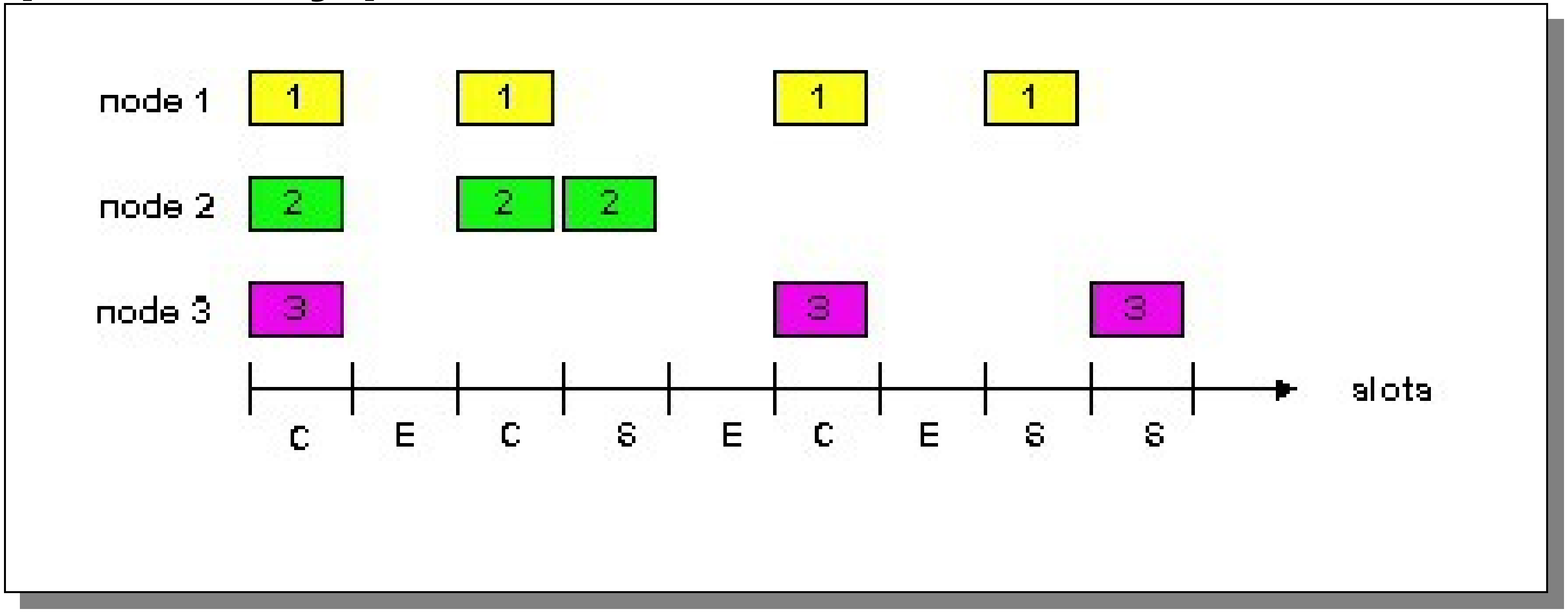
- When node has packet to send
  - Transmit at full channel data rate R
  - No *a priori* coordination among nodes
- Two or more transmitting nodes → "collision"
- Random access MAC protocol specifies:
  - How to detect collisions
  - How to recover from collisions (e.g., via delayed retransmissions)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

Aloha – Basic Technique

- First random MAC developed
  - For radio-based communication in Hawaii (1970)
- Basic idea:
  - When you are ready, transmit
  - Receivers send ACK for data
  - Detect collisions by timing out for ACK
  - Recover from collision by trying after random delay
    - Too short → large number of collisions
    - Too long → underutilization

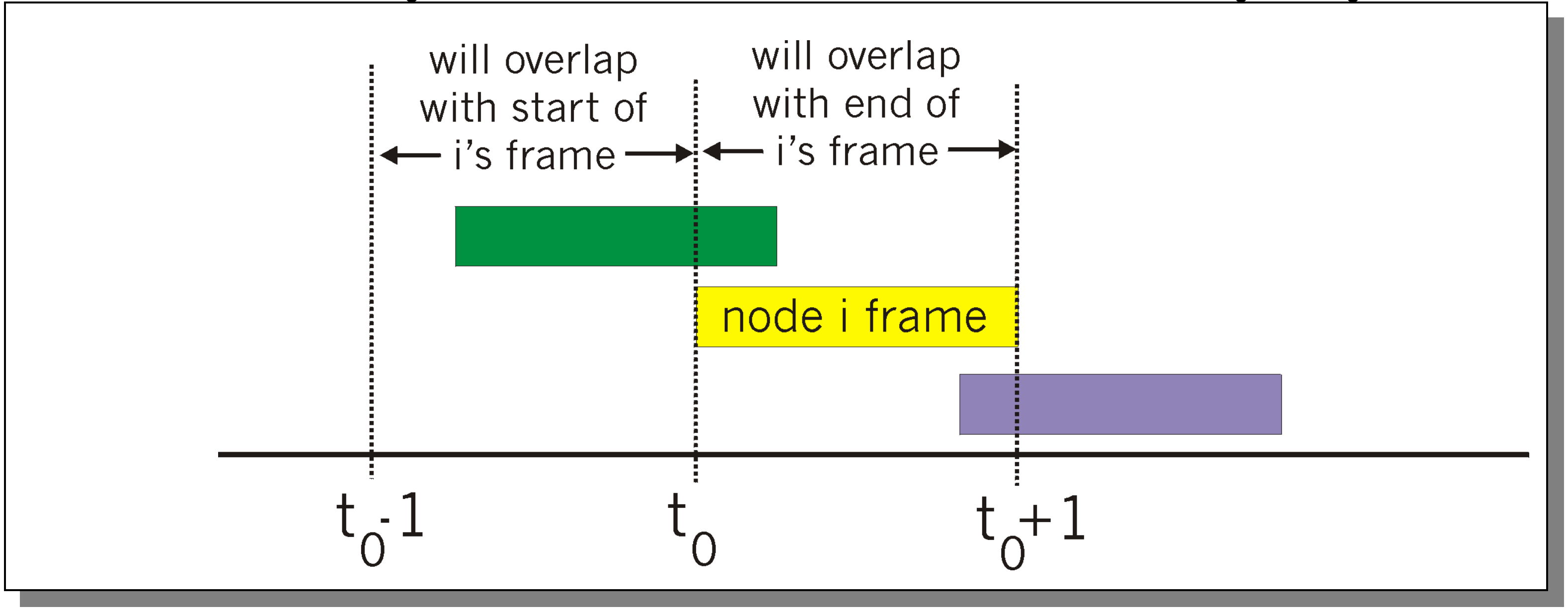
Slotted Aloha

- Time is divided into equal size slots
  - » Equal to packet transmission time
- Node (w/ packet) transmits at beginning of next slot
- If collision: retransmit pkt in future slots with probability p, until successful



Pure (Unslotted) ALOHA

- Unslotted Aloha: simpler, no synchronization
- Pkt needs transmission:
  - » Send without awaiting for beginning of slot
- Collision probability increases:
  - » Pkt sent at t_0 collide with other pkts sent in [t_0-1, t_0+1]



Slotted Aloha Efficiency

Q: What is max fraction slots successful?

A: Suppose N stations have packets to send

» Each transmits in slot with probability *p*

» Prob. successful transmission *S* is:

by single node: $S = p\,(1-p)^{(N-1)}$

by any of N nodes

S = Prob (only one transmits)

$= N\,p\,(1-p)^{(N-1)}$

… choosing optimum p as N -> infty …

… p = 1/N

$= 1/e = .37$ *as N -> infty*

At best:

Pure Aloha (cont.)

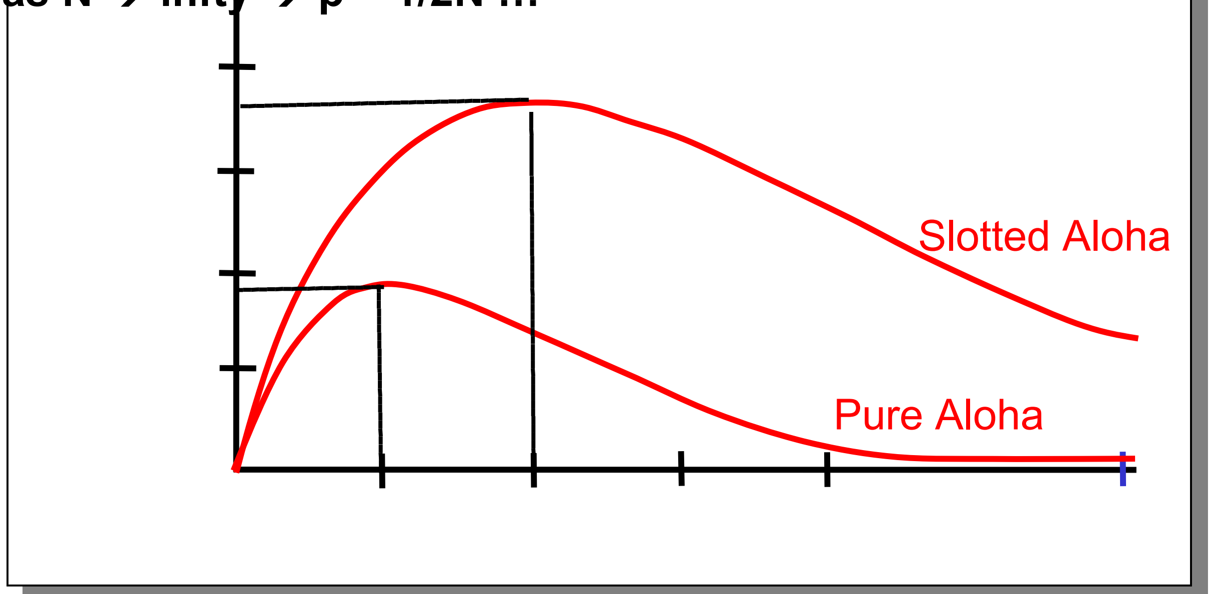
P(success by given node) = P(node transmits) X P(no other node transmits in $[p_0-1,p_0]$ X P(no other node transmits in $[p_0-1,p_0]$

$= p \times (1-p)^{(N-1)} \times (1-p)^{(N-1)}$

P(success by any of N nodes) = $N p \times (1-p)^{(N-1)} \times (1-p)^{(N-1)} = 1/(2e) = .18$

… choosing optimum p as N → infty → p = 1/2N …

protocol



Simple Analysis of Efficiency

- Key assumptions
  - » All packets are same, small size
    - – Packet size = size of contention slot
  - » All nodes always have pkt to send
  - » p is chosen carefully to be related to N
    - – p is actually chosen by exponential backoff
  - » Takes full slot to detect collision (I.e. no “fast collision detection”)

Outline

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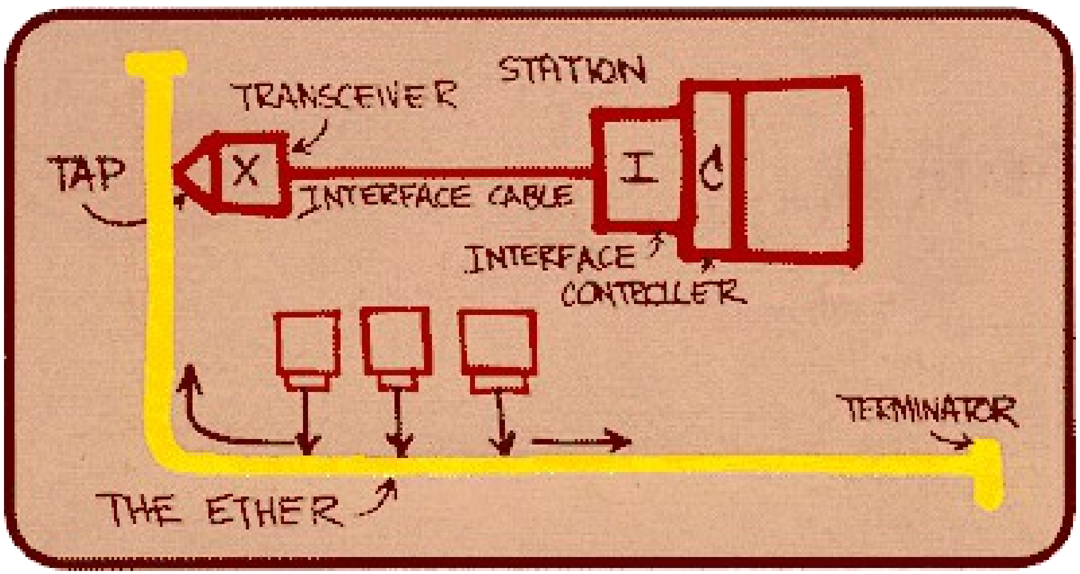
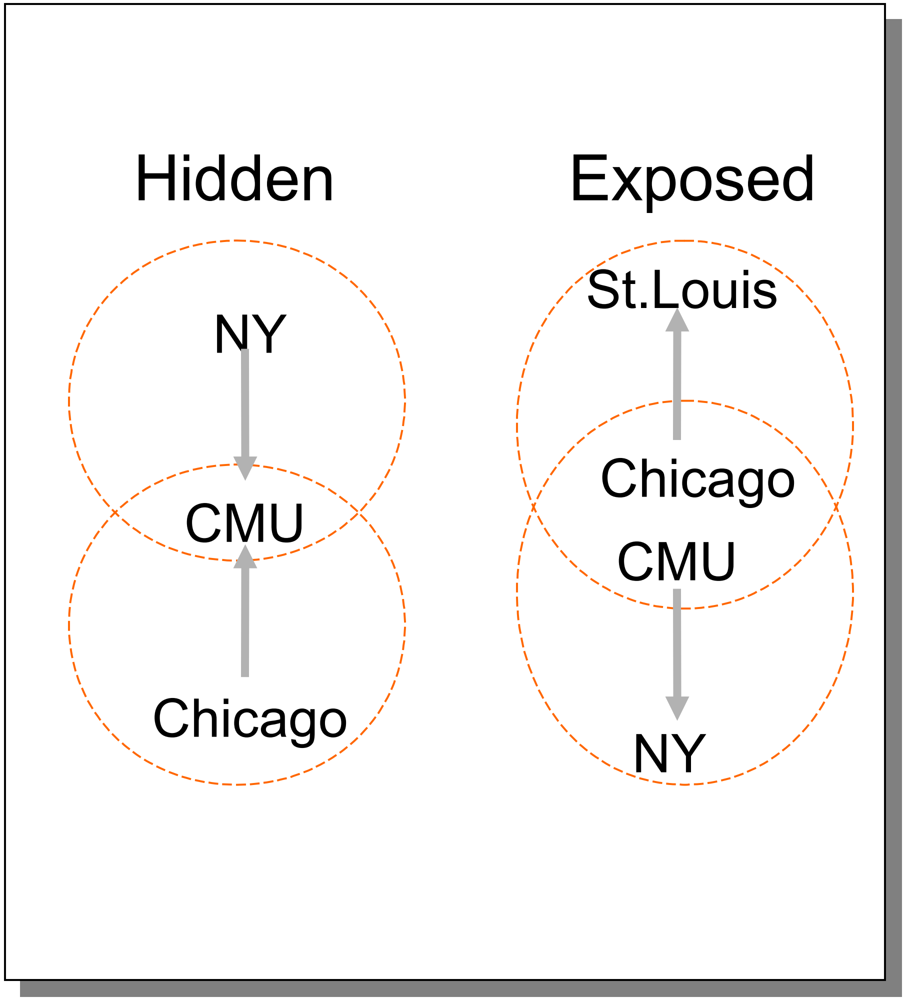
Ethernet

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



Ethernet MAC – Carrier Sense

- **Basic idea:**
  - » **Listen to wire before transmission**
  - » **Avoid collision with active transmission**
- **Why didn't ALOHA have this?**
  - » **In wireless, relevant contention at the receiver, not sender**
    - – **Hidden terminal**
    - – **Exposed terminal**

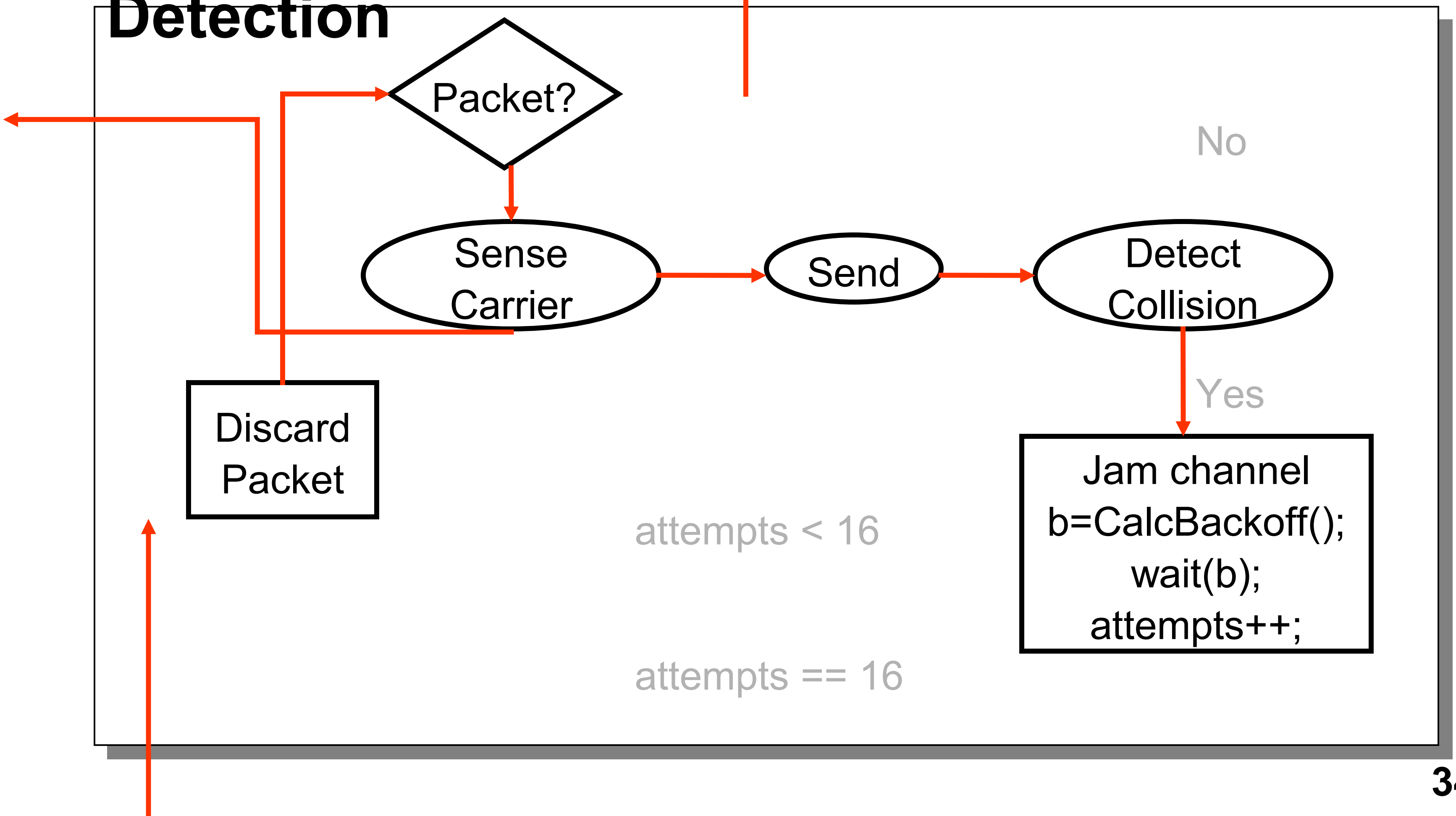


Ethernet MAC – Collision Detection

- But: ALOHA has collision detection also?
  - » That was very slow and inefficient
- Basic idea:
  - » Listen while transmitting
  - » If you notice interference → assume collision
- Why didn't ALOHA have this?
  - » Very difficult for radios to listen and transmit
  - » Signal strength is reduced by distance for radio
    - – Much easier to hear "local, powerful" radio station than one in NY
    - – You may not notice any "interference"

Ethernet MAC (CSMA/CD)

- **Carrier Sense Multiple Access/Collision Detection**



Ethernet CSMA/CD: Making it word

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
- Why not random delay with fixed mean?
  - » Few senders → needless waiting
  - » Too many senders → too many collisions
- ***Goal***: adapt retransmission attempts to estimated current load
  - » heavy load: random wait will be 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 ten or more collisions, choose K from {0,1,2,3,4,…,1023}

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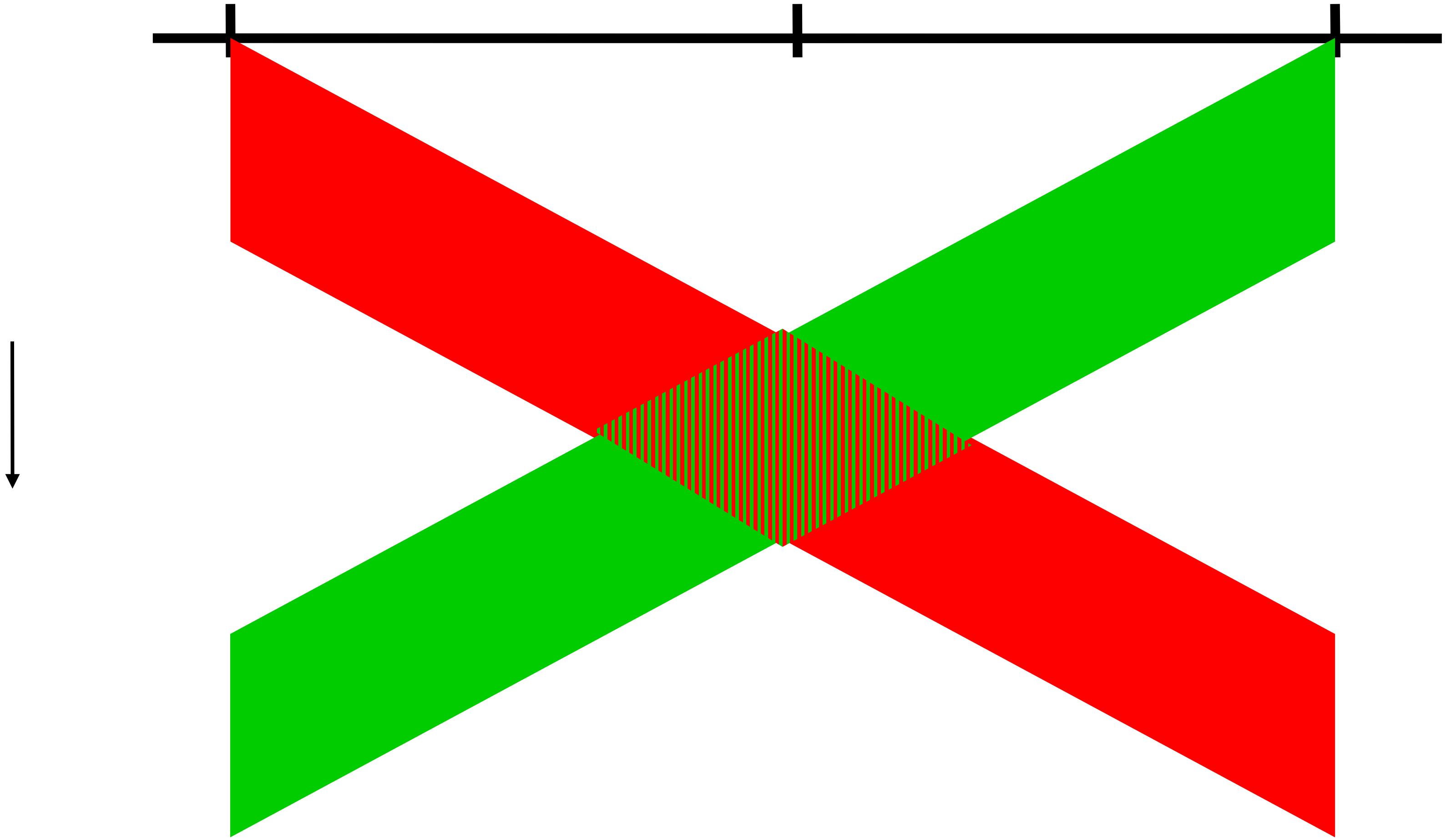
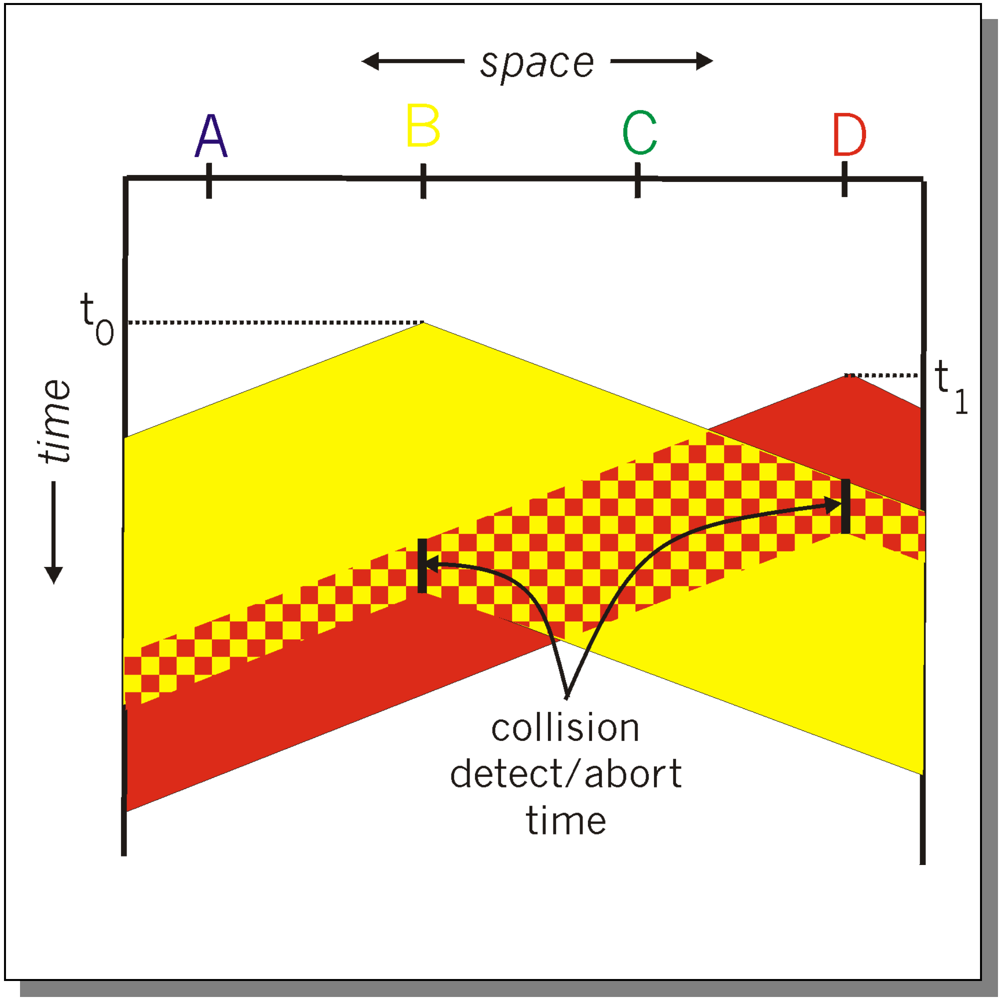
Collisions



Minimum Packet Size

- **What if two people sent really small packets**
  - » **How do you find collision?**



Ethernet Collision Detect

- Min packet length > 2x max prop delay
  - If A, B are at opposite sides of link, and B starts one link prop delay after A
- Jam network for 32-48 bits after collision, then stop sending
  - Ensures that everyone notices collision

End to End Delay

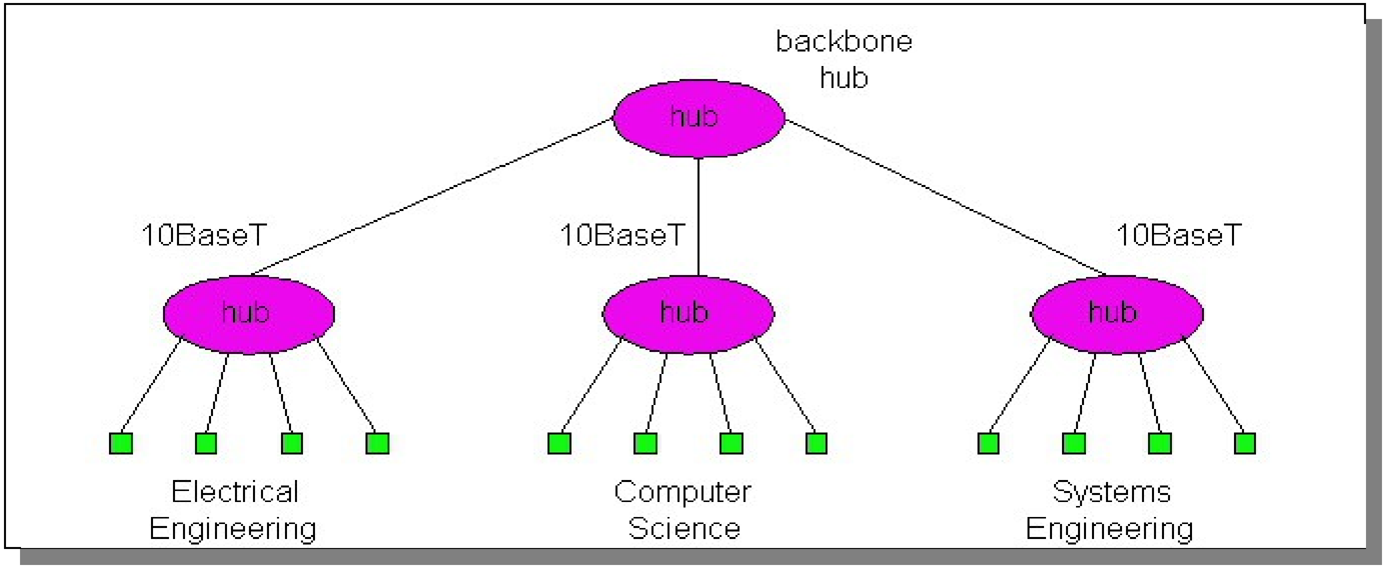
- c in cable = 60% * c in vacuum = 1.8 x 10^8 m/s
- Modern 10Mb Ethernet
  - » 2.5km, 10Mbps
  - » ~= 12.5us delay
  - » +Introduced repeaters (max 5 segments)
  - » Worst case – 51.2us round trip time!
- Slot time = 51.2us = 512bits in flight
  - » After this amount, sender is guaranteed sole access 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
    - – Max length = 1Km and No repeaters
  - » 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

10BaseT and 100BaseT

- 10/100 Mbps rate; latter called “fast ethernet”
- T stands for Twisted Pair (wiring)
- Minimum packet size requirement
  - » Make network smaller → solution for 100BaseT

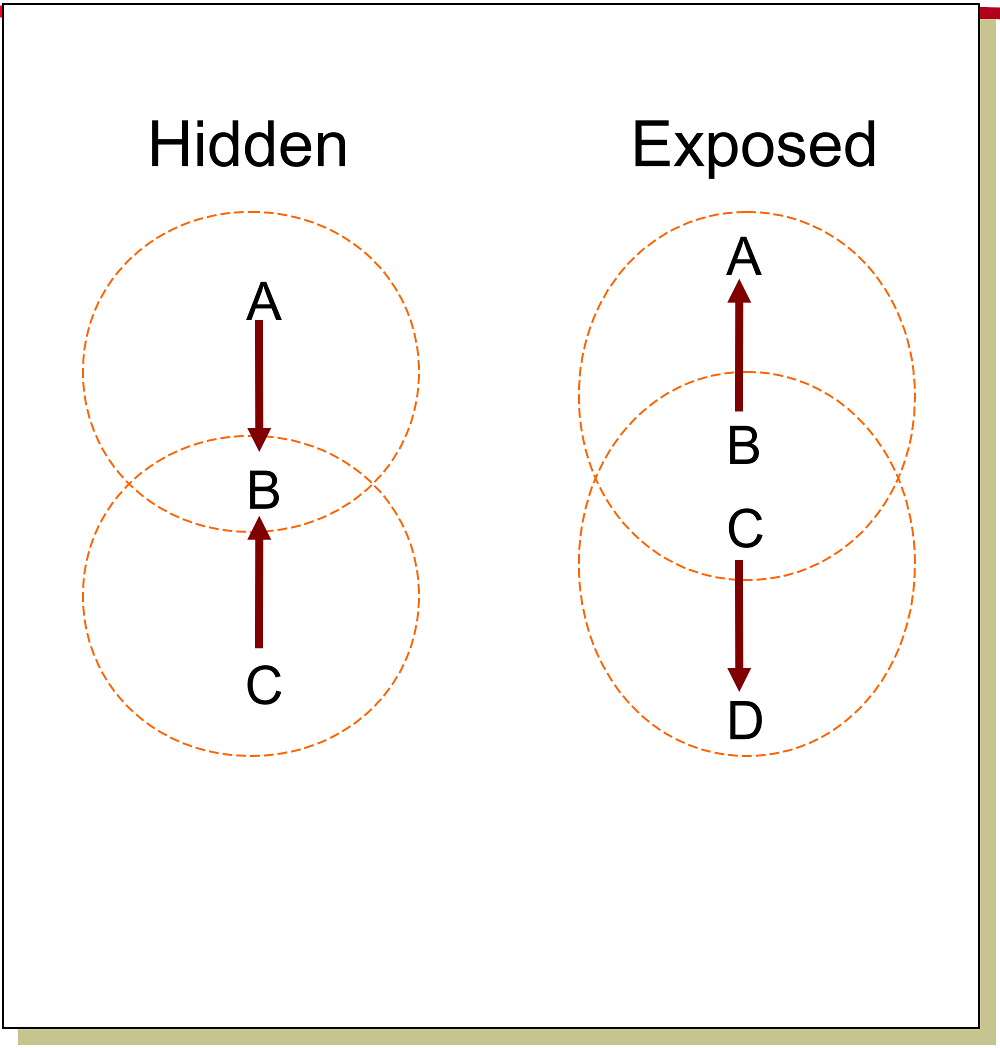


Gbit Ethernet

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

Next: CSMA/CD Does Not Work

- **Recall Aloha**
  - » **Wireless precursor to Ethernet.**
- **Carrier sense problems**
  - » **Relevant contention at the receiver, not sender**
  - » **Hidden terminal**
  - » **Exposed terminal**
- **Collision detection problems**
  - » **Hard to build a radio that can transmit and receive at same time**



RTS/CTS Approach

- Before sending data, send Ready-to-Send (RTS)
- Target responds with Clear-to-Send (CTS)
- Others who hear CTS defer transmission
  - » Packet length in RTS and CTS messages
  - » Why not defer on RTS alone?
- If CTS is not heard, or RTS collides
  - » Retransmit RTS after binary exponential backoff
  - » (There are lots of cool details embedded in this last part that went into the design of 802.11 - if you're curious, look up the "MACAW" protocol).

Outline

- Aloha
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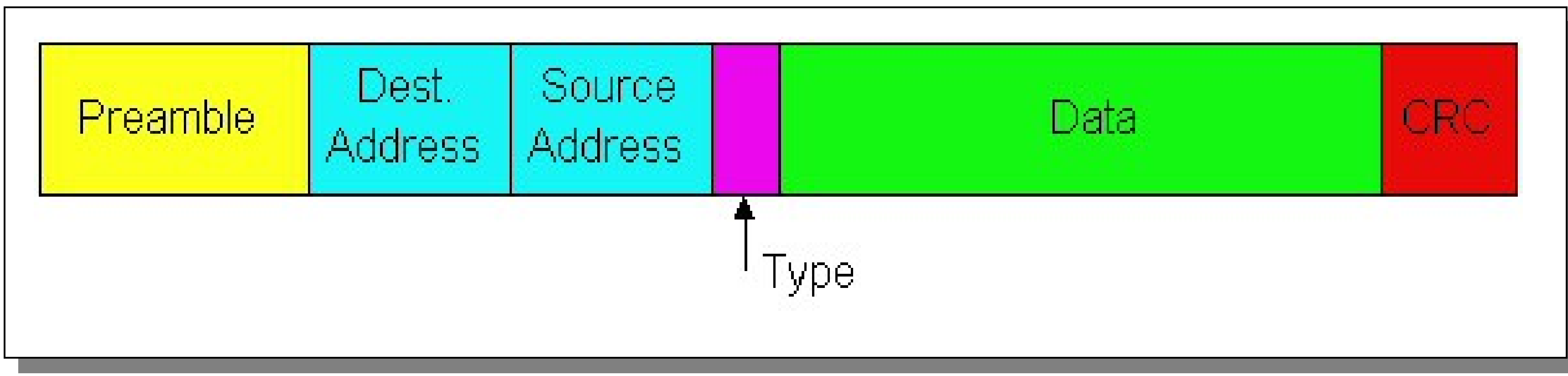
Ethernet Frame Structure

- 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)

Addressing Alternatives

- Broadcast → all nodes receive all packets
  - Addressing determines which packets are kept and which are packets are thrown away
  - Packets can be sent to:
    - Unicast – one destination
    - Multicast – group of nodes (e.g. "everyone playing Quake")
    - Broadcast – everybody on wire
- Dynamic addresses (e.g. Appletalk)
  - Pick an address at random
  - Broadcast "is anyone using address XX?"
  - If yes, repeat
- Static address (e.g. Ethernet)

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**

Why Did Ethernet Win?

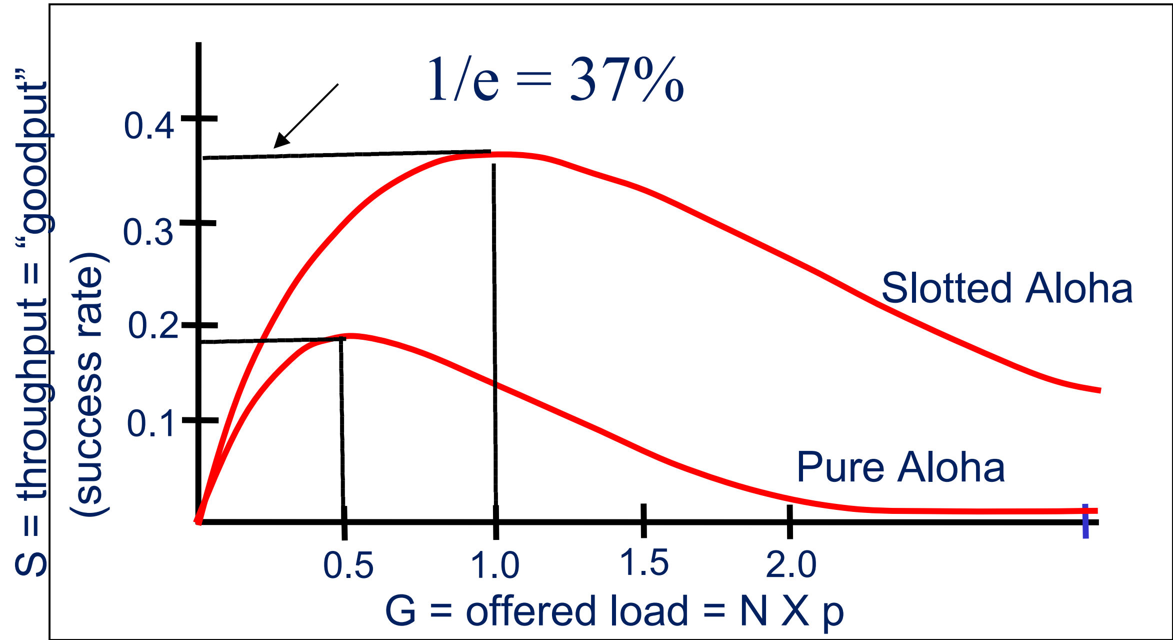
- Failure modes
  - Token rings – network unusable
  - Ethernet – node detached
- Good performance in common case
  - Deals well with bursty traffic
  - Usually used at low load
- Volume → lower cost → higher volume ….
- Adaptable
  - To higher bandwidths (vs. FDDI)
  - To switching (vs. ATM)
- Easy incremental deployment
- Cheap cabling, etc

And .. It is Easy to Manage

- You plug in the host and it basically works
  - » No configuration at the datalink layer
  - » Today: may need to deal with security
- Protocol is fully distributed
- Broadcast-based.
  - » In part explains the easy management
  - » Some of the LAN protocols (e.g. ARP) rely on broadcast
    - – Networking would be harder without ARP
  - » Not having natural broadcast capabilities adds complexity to a LAN
    - – Example: ATM

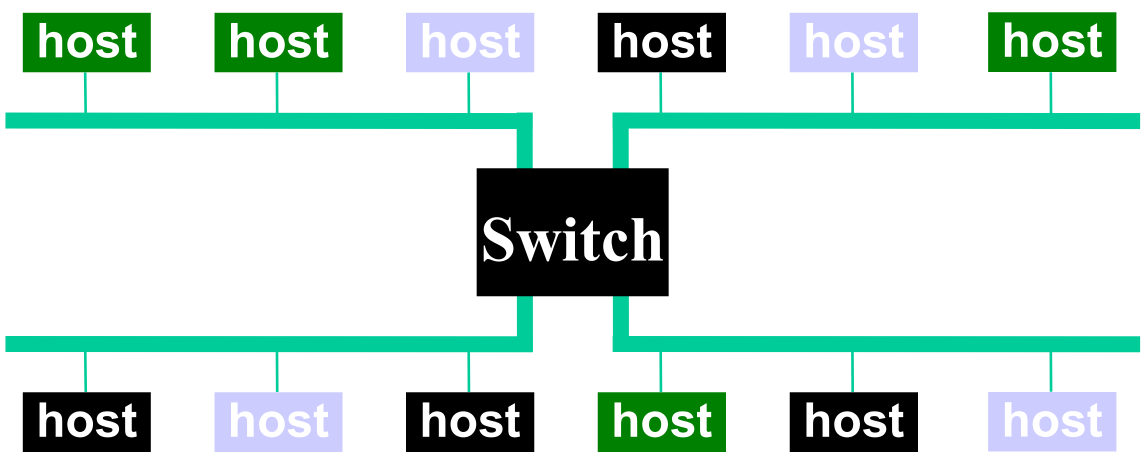
Ethernet Problems: Unstable at High Load

- Peak throughput worst with
  - » More hosts – more collisions to identify single sender
  - » Smaller packet sizes – more frequent arbitration
  - » Longer links – collisions take longer to observe, more wasted bandwidth
- But works well
  - » Can improve efficiency by



Virtual LANs

- Single physical LAN infrastructure that carries multiple "virtual" LANs simultaneously.
- Each virtual LAN has a LAN identifier in the packet.
  - » Switch keeps track of what nodes are on each segment and what their virtual LAN id is
- Can bridge and route appropriately.
- Broadcast packets stay within the virtual LAN.
  - » Limits the collision domain for the packet



Summary

- **CSMA/CD → carrier sense multiple access with collision detection**
  - » **Why do we need exponential backoff?**
  - » **Why does collision happen?**
  - » **Why do we need a minimum packet size?**
    - – **How does this scale with speed?**
- **Ethernet**
  - » **What is the purpose of different header fields?**
  - » **What do Ethernet addresses look like?**
- **What are some alternatives to Ethernet design?**