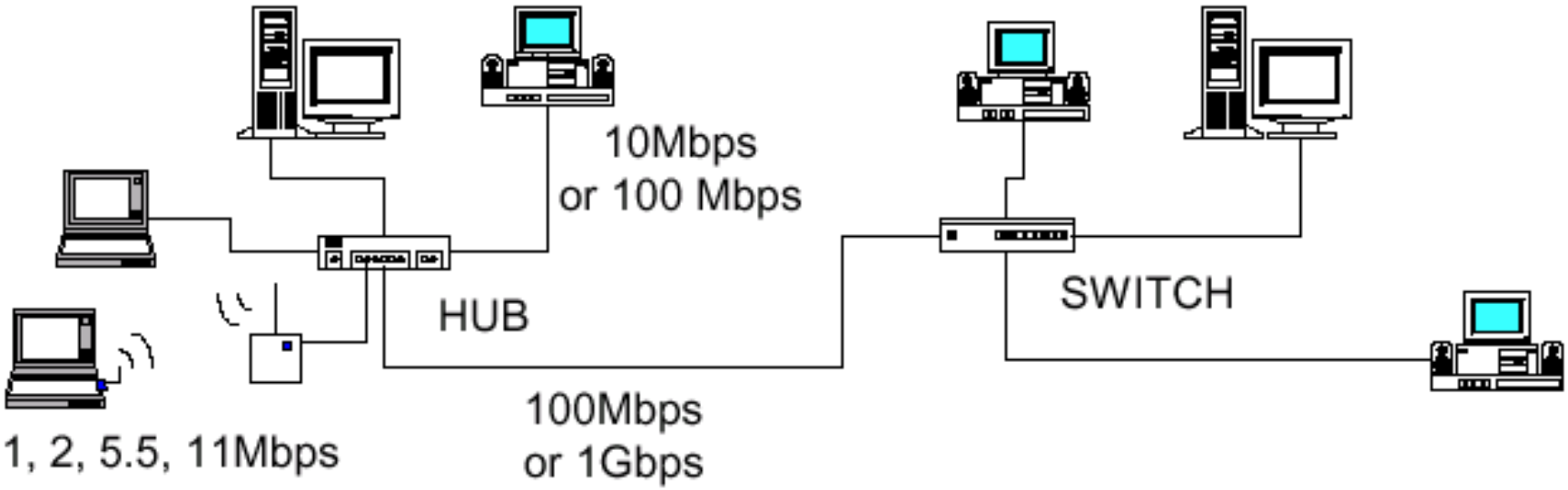
Ethernet

Overview

- Typical Setup
- Names
- Operations
- Perspective

Typical Setup



Names

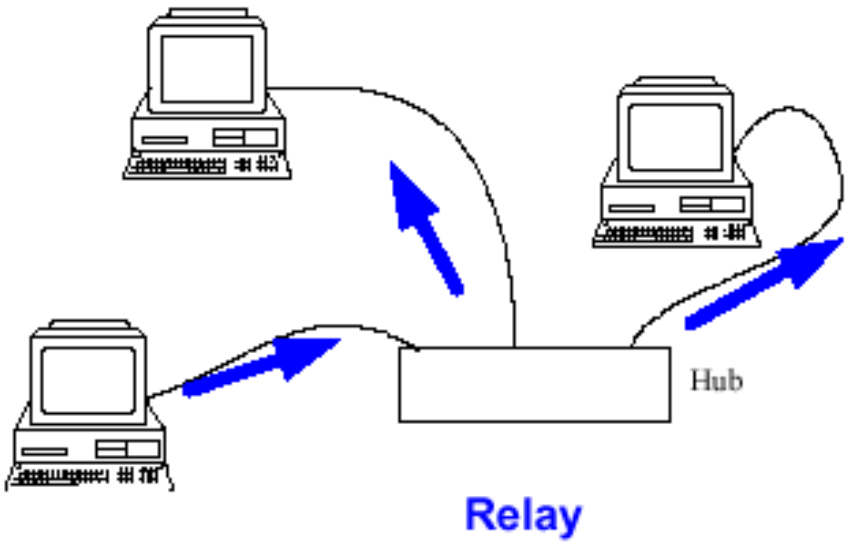
- Structure

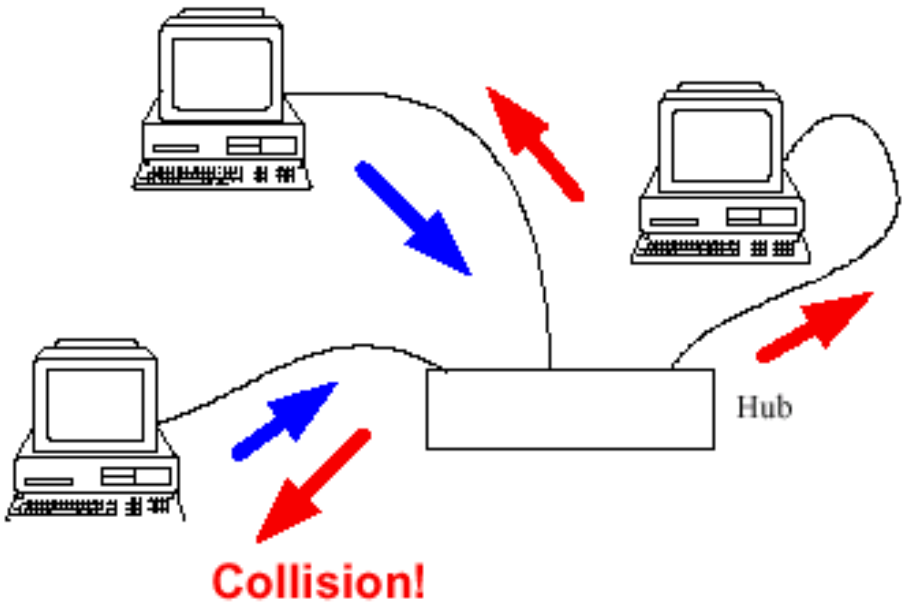
  [rate][modulation][media or distance]

  - 10Base5 (10Mbps, baseband, coax, 500m)
  - 10Base-T (10Mbps, baseband, twisted pair)
  - 100Base-TX (100Mbps, baseband, 2 pair)
  - 100Base-FX (100Mbps, baseband, fiber)
  - 1000Base-CX for two pairs balanced copper cabling
  - 1000Base-LX for long wavelength optical transmission
  - 1000Base-SX for short wavelength optical transmission.
- Wireless:
  - Wi-Fi = 802.11
  - Versions: a, b, g

Operations

- Hub: Single Collision Domain



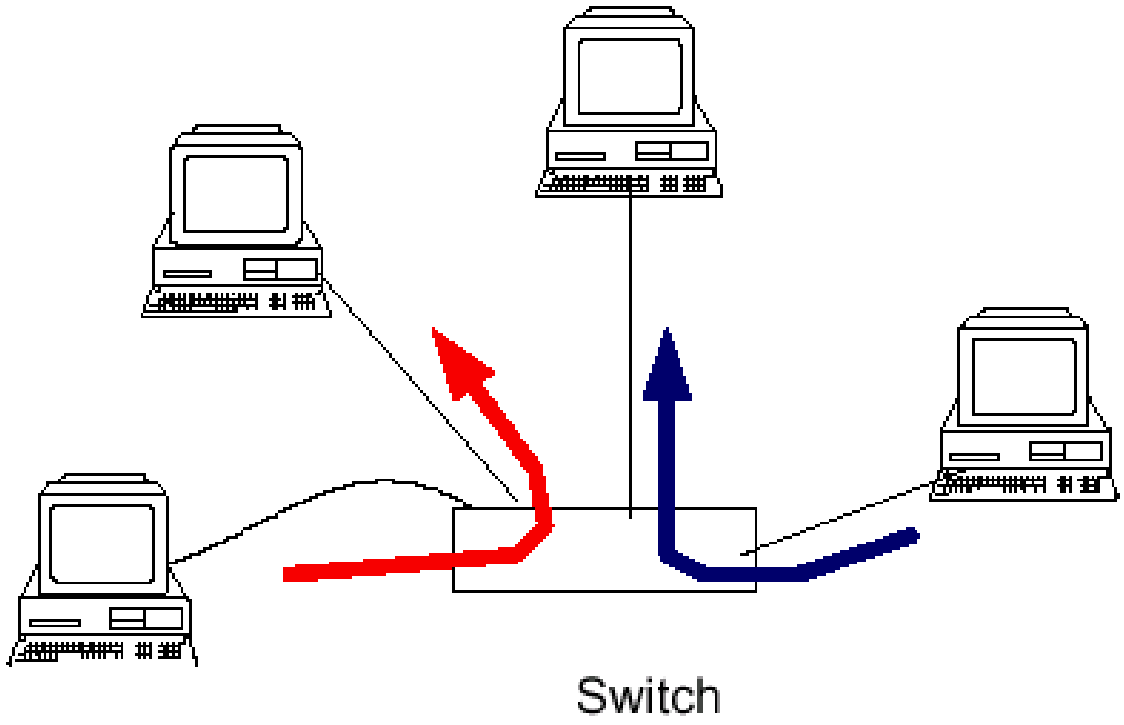


MAC Protocol: Wait until silent (carrier sense)
Transmit
If collision, wait random time & repeat

CSMA/CD

Operations

- Switch: No Collisions



Multiple transmissions are possible
Switch stores packets that wait for same output

Perspective

- Ethernet is wildly successful, partly due to low cost (compare with FDDI or Token Ring--- see text book)
- Some issues:
  - nondeterministic service
  - no priorities
  - min frame size may be large

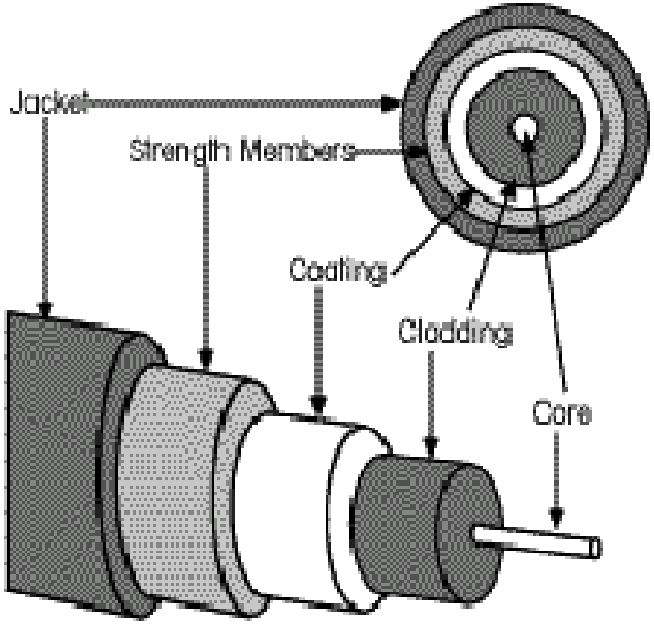
Physical Layer

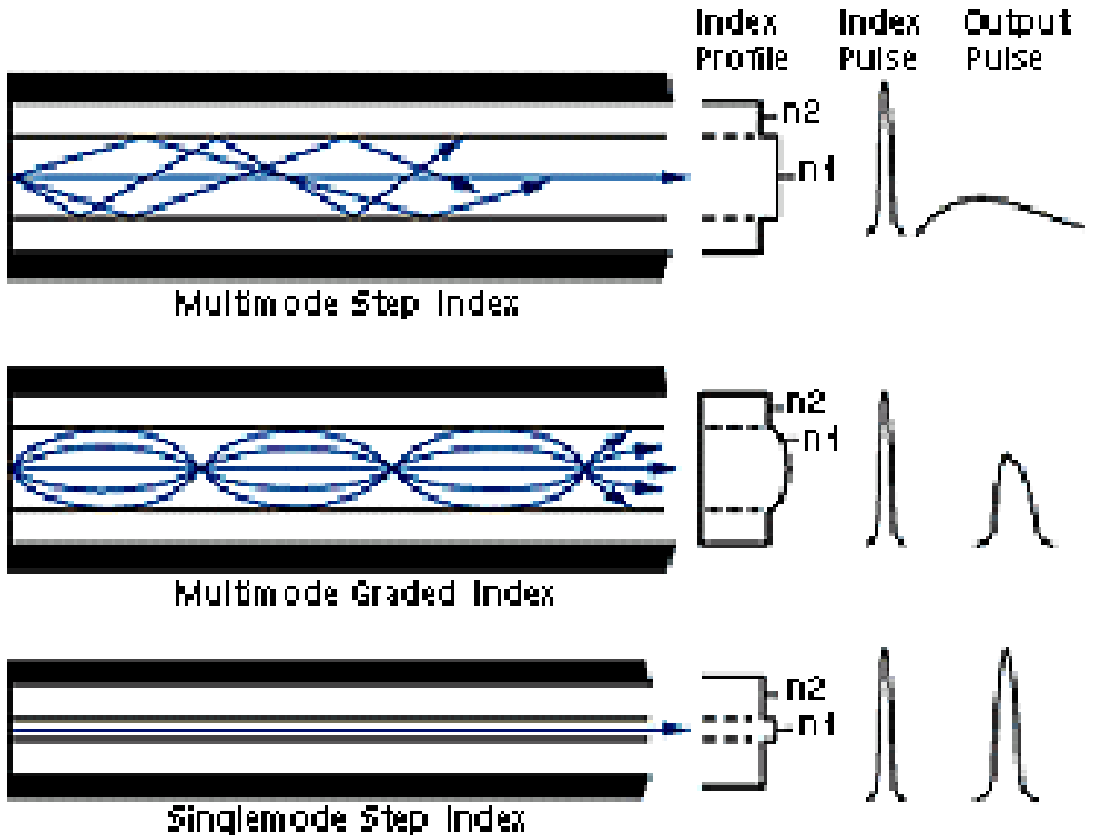
UTP
unshielded twisted pair
up to 110m

Fiber
100Mbps: 2000m
Gbps: 220m, 500m, 5000m

Wireless
2.4GHz DSSS: 1Mbps, 2Mbps, 5.5Mbps, and 11Mbps
25m - 200m

Physical


Jacket
Strength Members
Coating
Cladding
Core


Index Profile
Index Pulse
Output Pulse
n2
n1
Multimode Step Index
n2
n1
Multimode Graded Index
n2
n1
Singlemode Step Index

MAC: Media Access Control

- Frame
- Multiple Access

Frame

PRE 8	DA 6	SA 6	T/L 2	USER DATA 46-1500	CRC 4

- PREamble: alternating 1/0 combination producing 10Mhz square wave [@ 10Mbps] for 5.6 μsec; used for receiver synchronization; ends with 11 to indicate start of frame.

- DA, SA: Destination and Source MAC addresses (All 1's means broadcast)

- T/L: Length if <= 1500 → followed by 802.3 frame
  Type if > 1500.
  Examples: 2,048: IP (length in IP header) -
  2,054: ARP (28 byes)

Multiple Access

High-Level View

- Goal: share a communication medium among multiple hosts connected to it
- Problem: arbitrate between connected hosts
- Solution goals:
  - High resource utilization
  - Avoid starvation
  - Simplicity (non-decentralized algorithms)

Medium Access Protocols

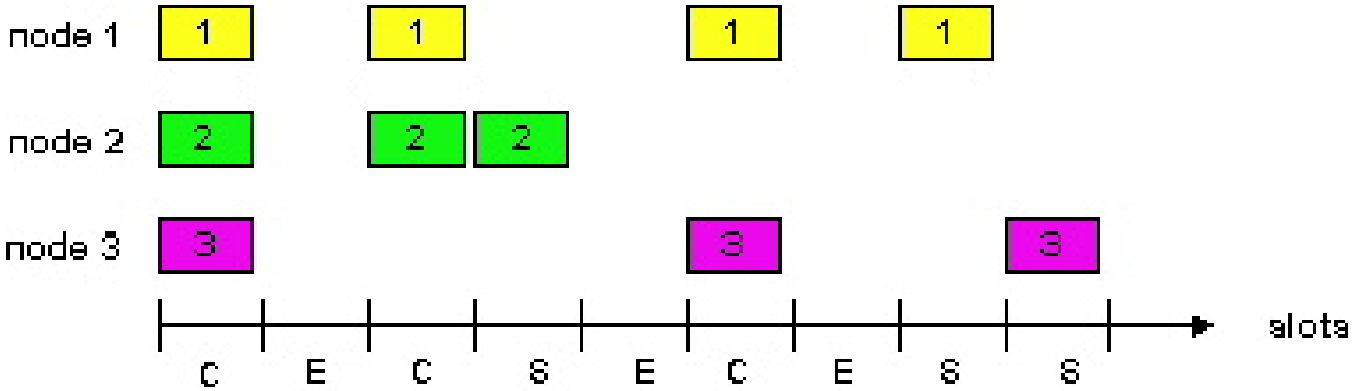
- Channel partitioning
  - Divide channel into smaller “pieces” (e.g., time slots, frequency)
  - Allocate a piece to node for exclusive use
- Random access
  - Allow collisions
  - “recover” from collisions
- “Taking-turns”
  - Tightly coordinate shared access to avoid collisions

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
- Examples of random access MAC protocols:
  - Slotted ALOHA
  - CSMA and CSMA/CD

Slotted Aloha

- Time is divided into equal size slots (= packet transmission time)
- Node with new arriving pkt: transmit at beginning of next slot



Success (S), Collision (C), Empty (E) slots

Slotted Aloha: Efficiency

- What is the maximum fraction of successful transmissions?
- Suppose N stations have packets to send
  - Each transmits (independently) in slot with probability *p*
  - Prob. successful transmission
    - by a particular node: $p(1 - p)^{(N-1)}$
    - by any of N nodes:

$$S = \text{Prob (only one transmits)}$$

$$= Np(1 - p)^{(N-1)} \approx 1/e = \mathbf{0.37}$$

if $p = 1/N$ (optimal value)

Note: $(1 - a/N)^N \approx e^{-a}$ for N >> 1

CSMA: Carrier Sense Multiple Access

- CS (Carrier Sense) means that each node can distinguish between an idle and a busy link
- Sender operations:
  - If channel sensed idle: transmit entire packet
  - If channel sensed busy, defer transmission
    - Persistent CSMA: retry immediately with probability p when channel becomes idle
    - Non-persistent CSMA: retry after a random time interval

CSMA: collisions

Collisions *can* occur:

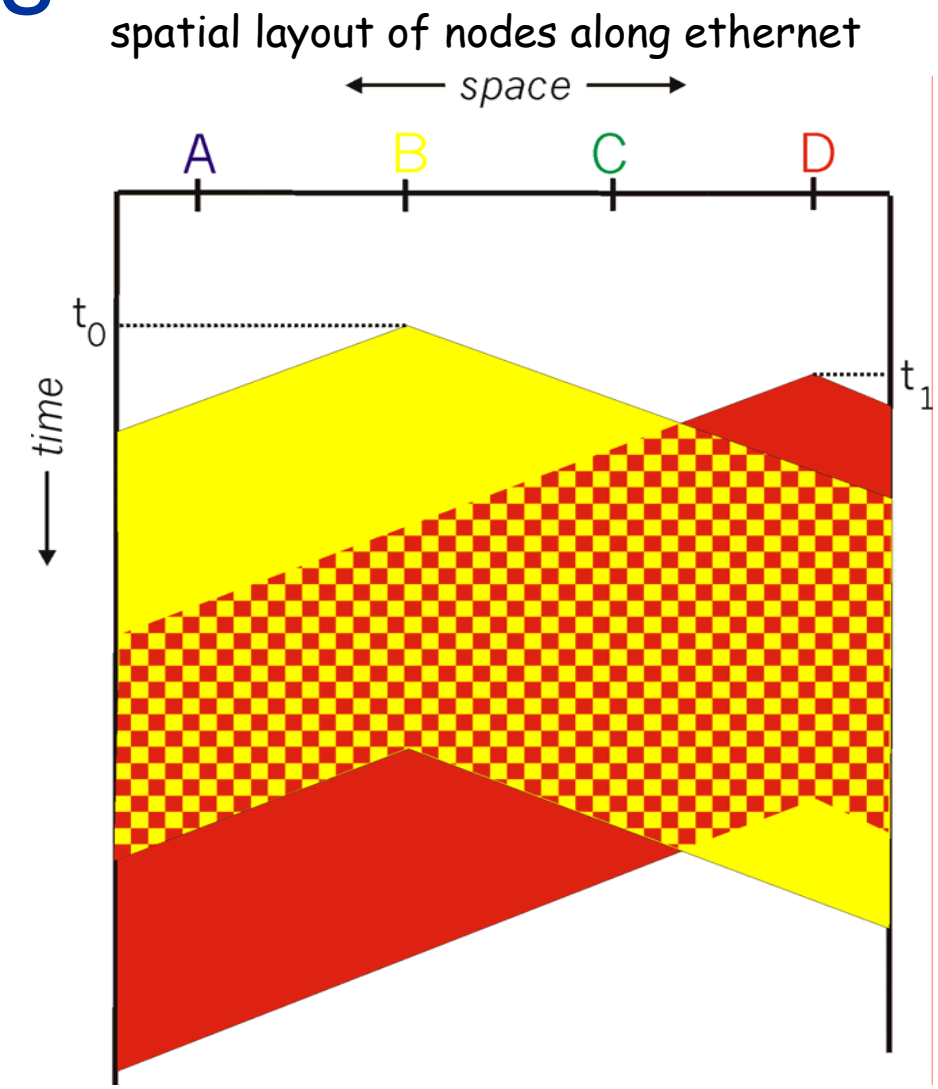
propagation delay means two nodes may not hear each other's transmission

Collision:

entire packet transmission time wasted

Note:

role of distance and propagation delay in determining collision prob.



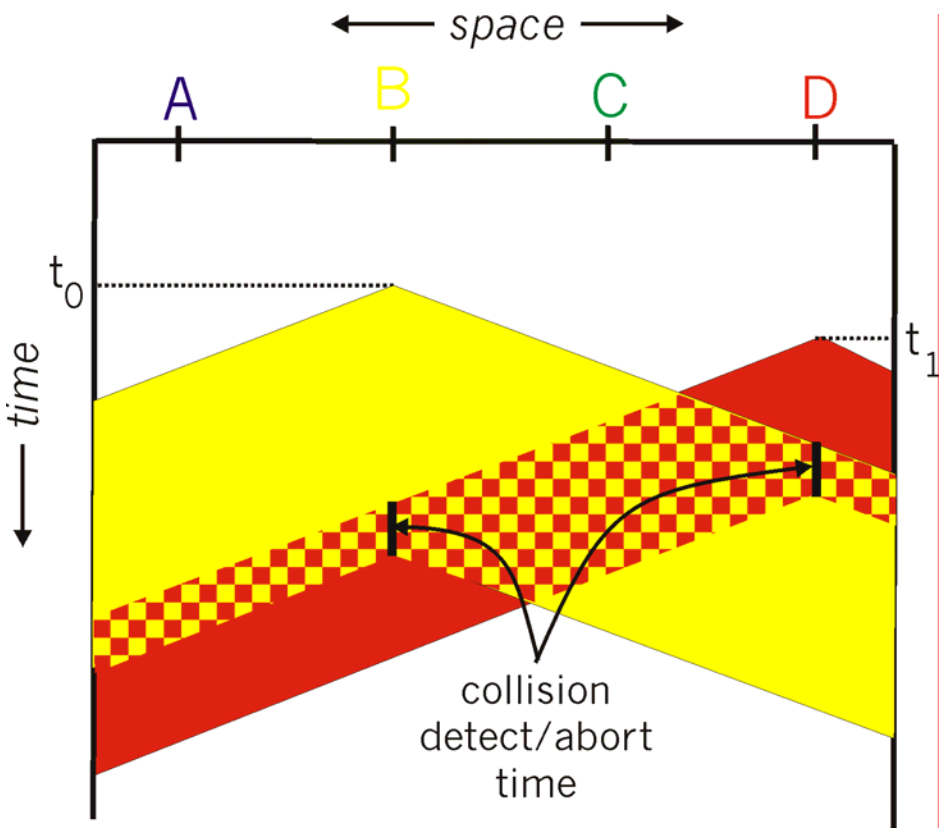
CSMA/CD (collision detection)

- Overview
- Timing
- Ethernet

Overview

- Collisions *detected* within short time
- Colliding transmissions aborted, reducing channel wastage
- Easy in wired LANs: measure signal strengths, compare transmitted, received signals
- Difficult in wireless LANs

Timing



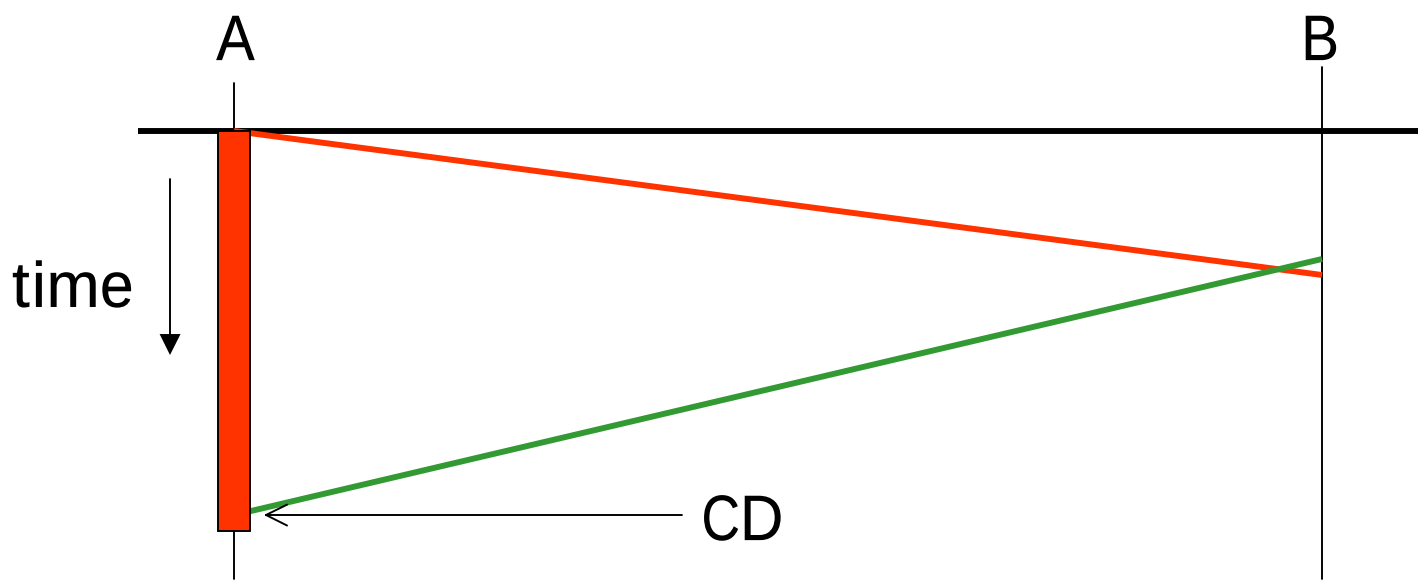
Ethernet

Overview

- Will discuss “classical” Ethernet primarily
- Single segments up to 500m; with up to 4 repeaters gives 2500m max length
- Baseband signals broadcast, Manchester encoding, 32-bit CRC for error detection
- Max 100 stations/segment, 1024 stations/Ethernet

Collision Detection

- CD circuit operates by looking for voltage exceeding a transmitted voltage
- Want to ensure that a station does not complete transmission prior to 1st bit arriving at farthest-away station
- Time to CD can thus take up to 2x{max prop. delay}



Minimum Frame Size

- Speed of light is about 4μs/km in copper
- So, max Ethernet signal prop time is about 10 μsec, or 20μsec RTT
- With repeaters, etc. 802.3 requires 51usec, corresponding to 512 bit-times
- Thus, minimum frame size is 512 bits (64 bytes); also called *slot time*

Maximum Frame Size

- 1500 byte limitation on maximum frame transmission size
- We will call this the *MTU*
- limits maximum buffers at receiver
- allows for other stations to send
  - also requires 96 bit Inter-Packet-Gap (IPG)

Operations

- When ready & line idle, await IPG (96 bit times) and send while listening (CD)
- If CD true, send max 48-bit jamming sequence and do exponential backoff
- Jamming sequence used to inform all stations that a collision has occurred

Operations

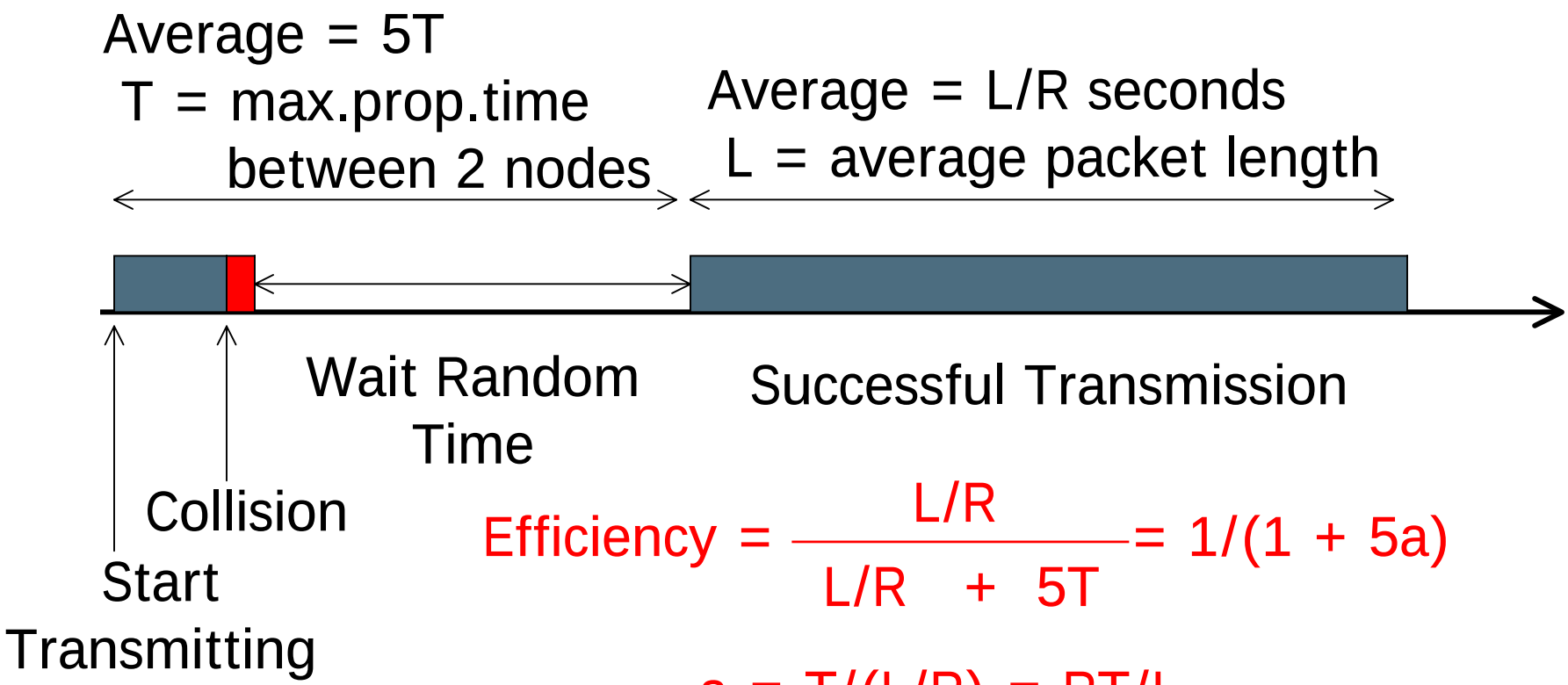
- For retransmission N (1<=N<=10)
  - choose k at random on U(0..2^N-1)
  - wait k * (51.2μsec) to retransmit
  - send on idle; repeat on another collision
  - for (11<=N<=15), use U(0..1023)
  - if N = 16, drop frame
- Longer wait implies lower priority (strategy is not “fair”)

Operations: Capture Effect

- Given two stations A & B, unfair strategy can cause A to continue to “win”
- Assume A & B always ready to send:
  - if busy, both wait, send and collide
  - suppose A wins, B backs off
  - next time, B’s chances of winning are halved

Efficiency

- Typical Sequence of Events:



$$\text{Efficiency} = \frac{L/R}{L/R + 5T} = 1/(1 + 5a)$$

$$a = T/(L/R) = RT/L$$

Efficiency

- *a* impacts what happens during simultaneous transmission:
  - *a* small → early collision detection
    → Efficient
  - *a* large → late detection
    → Inefficient

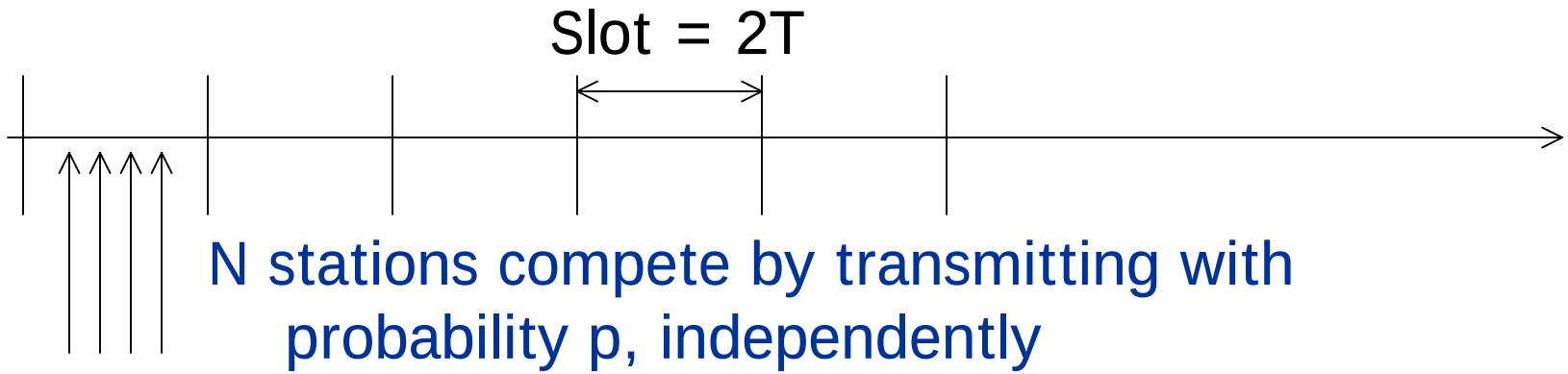
$a = RT/L$
$eff = 1/(1 + 5a)$

Example 1: 10Mbps, 1000m
=> T = (1km)(4μs/km) = 4μs; RT = 400 bits
L = 4000 bits, say
5a = 2000/4000 = 0.5 => efficiency = 66%

Example 2: 1Gbps, 200m
=> T = (0.2km)((4μs/km) = 0.8μs; RT = 800 bits
L = 4000 bits; 5a = 4000/4000 = 1 => efficiency = 50%

Efficiency - Analysis

- Model:



N stations compete by transmitting with probability p, independently

If success => transmit L bits

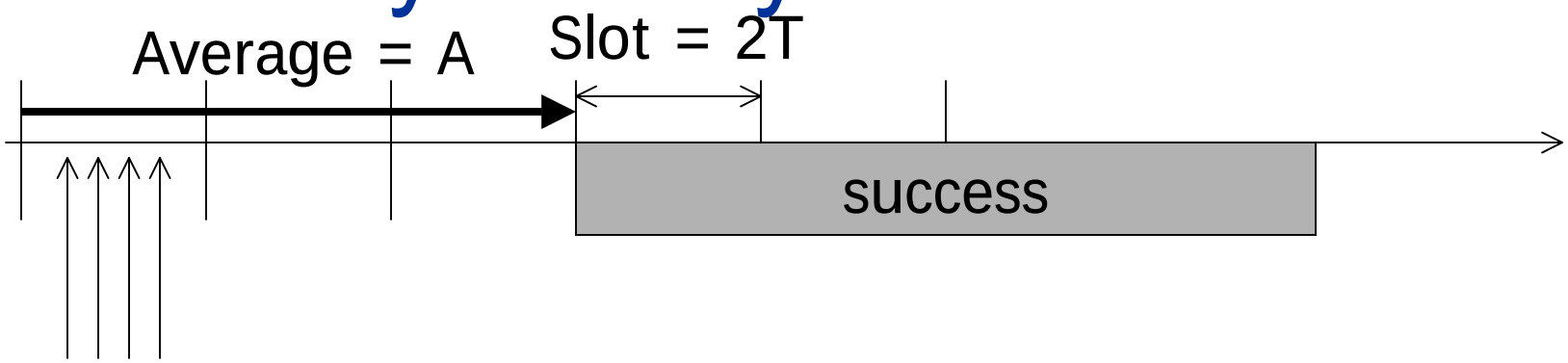
If failure (idle or collision), try next slot

P(success) = P(exactly 1 out of N transmits) = $Np(1 - p)^{N-1}$

Indeed: N possibilities of station that transmits

P(one given station transmits, others do not) = $p(1 - p)^{N-1}$

Efficiency - Analysis



$P(\text{success}) = Np(1 - p)^{N-1}$

Assume backoff algorithm results in best $p = 1/N$

$\Rightarrow P(\text{success}) \approx 1/e = 0.36$

Average time until success:

$$A = 0.36 \times 0 + 0.64 \times (2T + A)$$

$$\Rightarrow \quad A = 1.28T/0.36 = 3.5T$$

In practice, backoff not quite optimal => 5T

Addressing

- 48 bit Ethernet/MAC/Hardware Addresses
- Prefix assigned per-vendor by IEEE
- Unique per-adapter, burned in ID PROM
- Multicast & Broadcast (all 1's) addresses
- Many adapters support *promiscuous* mode

Addressing - Multicast

- Each vendor assignment supports 2^24 individual and group (multicast) addresses
- Each adapter supports multiple group "subscriptions"
  - usually implemented as hash table
  - thus, software may have to filter at higher layer

Fast Ethernet

- “Fast Ethernet” (1995) adds:
  - 10x speed increase (100m max cable length retains min 64 byte frames)
  - replace Manchester with 4B/5B (from FDDI)
  - full-duplex operation using switches
  - speed & duplex auto-negotiation

Gigabit Ethernet

IEEE 802.3{z,ab} 1000 Mb/s

- “Gigabit Ethernet” (1998,9) adds:
  - 100x speed increase
  - carrier extension (invisible padding...)
  - packet bursting

Bridged Ethernets

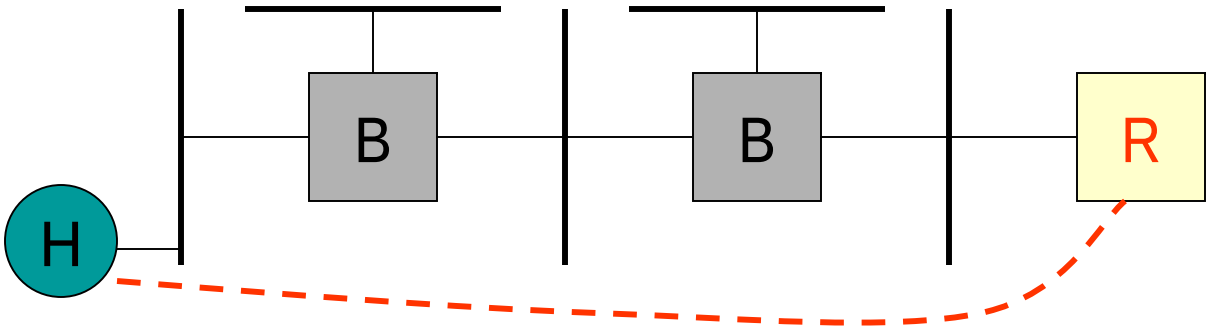
- Objectives
- No-Frills Bridge
- Learning Bridge
- Spanning Tree Algorithm
- Bridge Limitations

Objectives

- Bridges interconnect network segments at the *link* layer (layer 2)
- Handle any layer 3 protocol (incl. non-routable ones); some can interconnect different media
- Mostly for LANs, also used in WANs (2 “half bridges” on ends of pt-to-pt links

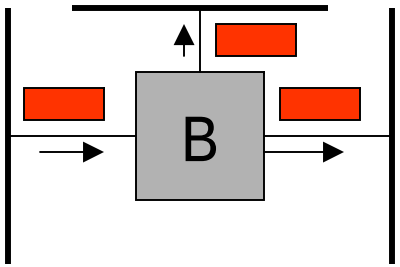
Objectives – Extending LANs

- Extending (interconnecting) multiple LANs. Appears as single LAN to layer 3.
- Essentially accepts and forwards all frames
- Benefits:
  - extend number of stations
  - extend size
  - limit interfering traffic



“No-Frills” Bridge

- Interconnect 2 or more LAN segments
- Listens in promiscuous mode, buffers packets and transmits them on other interfaces when able
- On average, still cannot exceed link bandwidth
  - bridge copies all traffic
  - small bursts accommodated in buffers



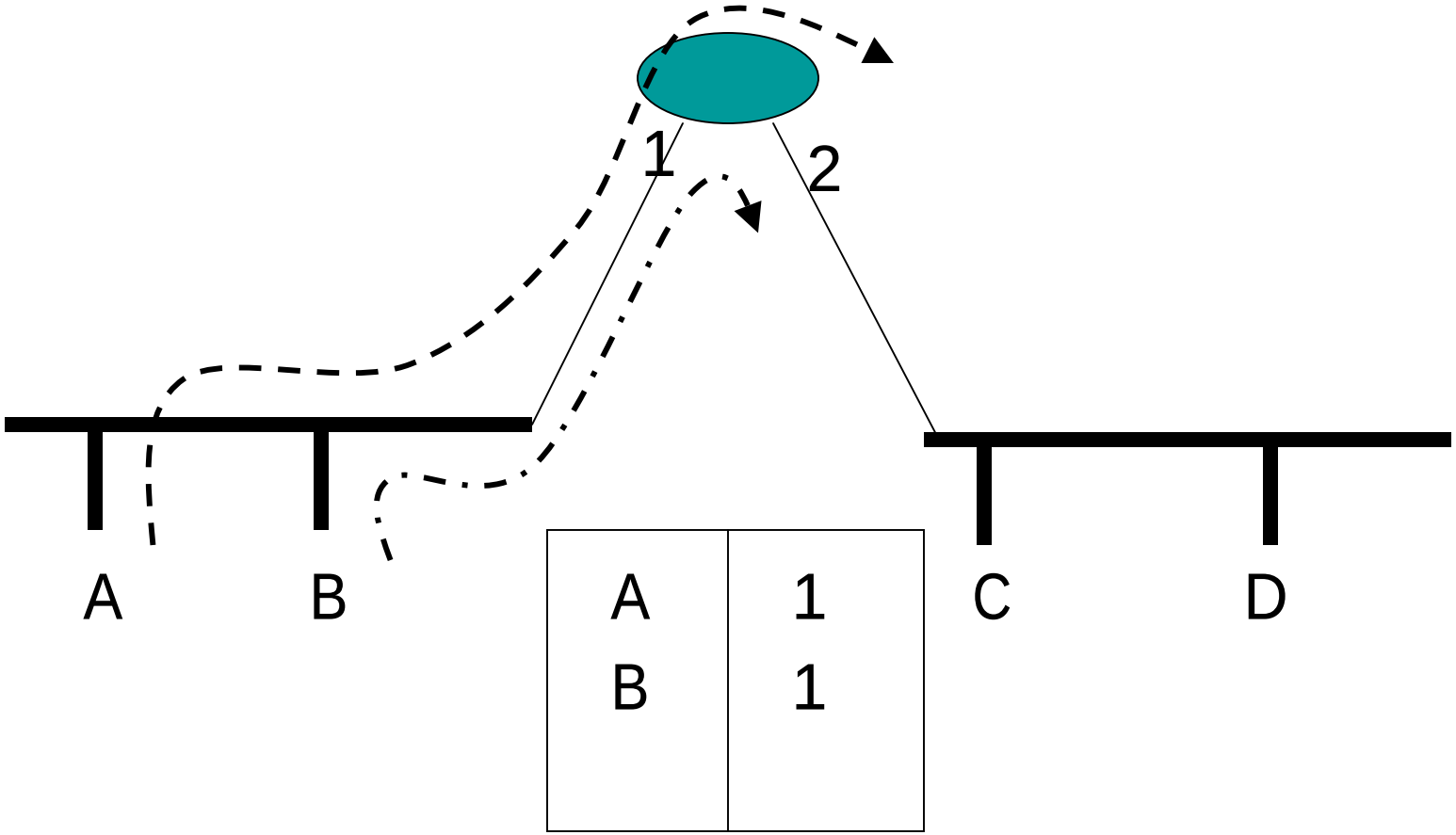
Learning Bridge

- Bridges “learn” which interfaces reach which end stations
  - could do this “by hand”, but a hassle
  - best if this happens *transparently*
- Learn by watching source addresses in frames
  - senders usually use their own addresses
  - (note that bridges don’t!)

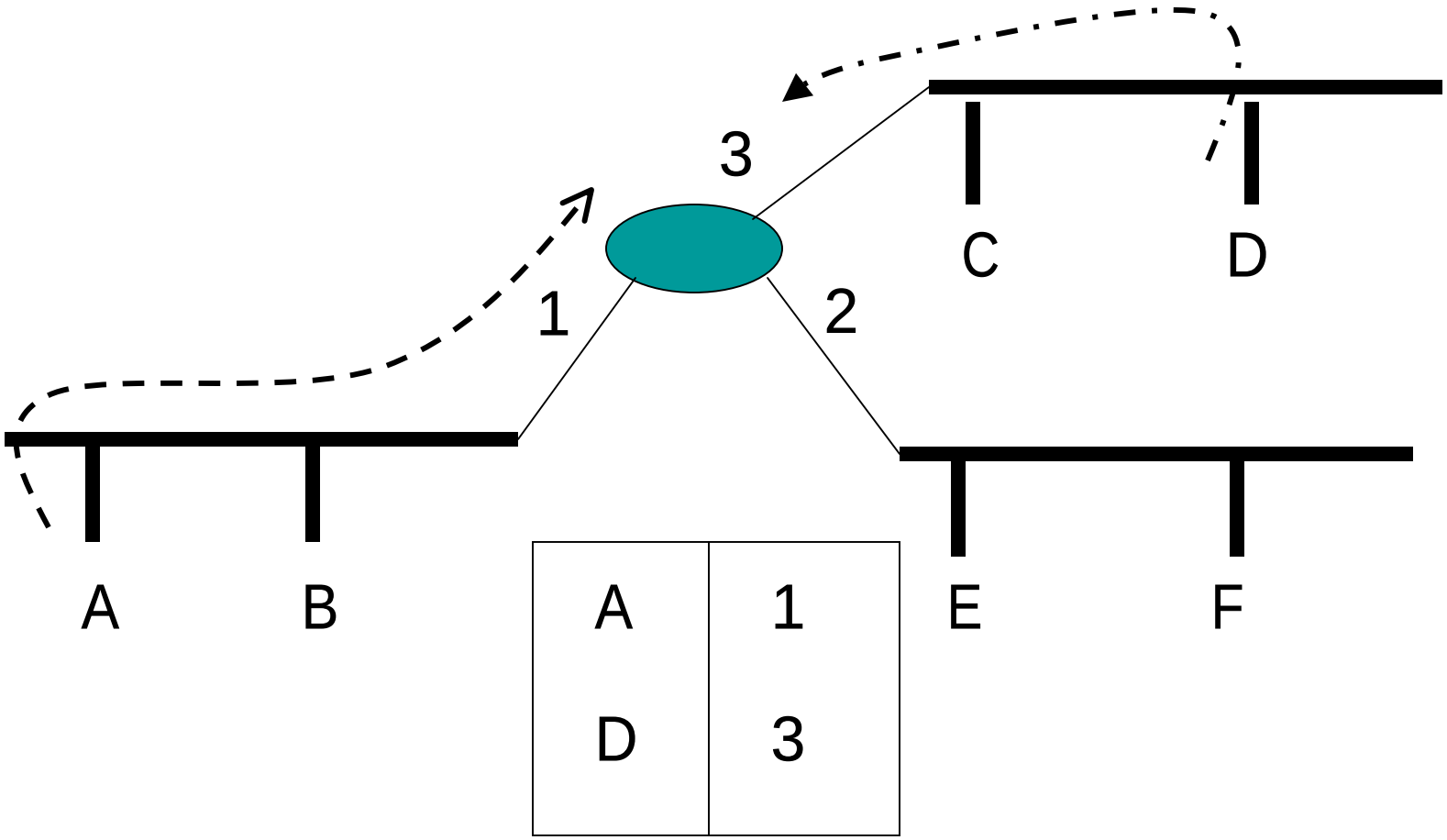
Learning Bridge

- Listen promiscuously for all traffic
- Store (src addr, port) tuple in “station cache” for each new sender observed
- For each received frame:
  - try to match frame dest to cache src entry
  - not there->send on all interfaces except rcv
  - is there->send on indicated, or filter if same as rcv interface
- Age cache entries

Learning Bridge – Example 1



Learning Bridge – Example 2



Spanning Tree Algorithm

- Loops hurt!
- Spanning Tree
- Algorithm
- Example
- Topology Change

Loops Hurt

- With redundant paths, bridges can loop traffic
  - can happen forever (example)
  - with more than 2, can *cascade*
- Cascade
  - each bridge with N interfaces may produce up to N -2 new copies!

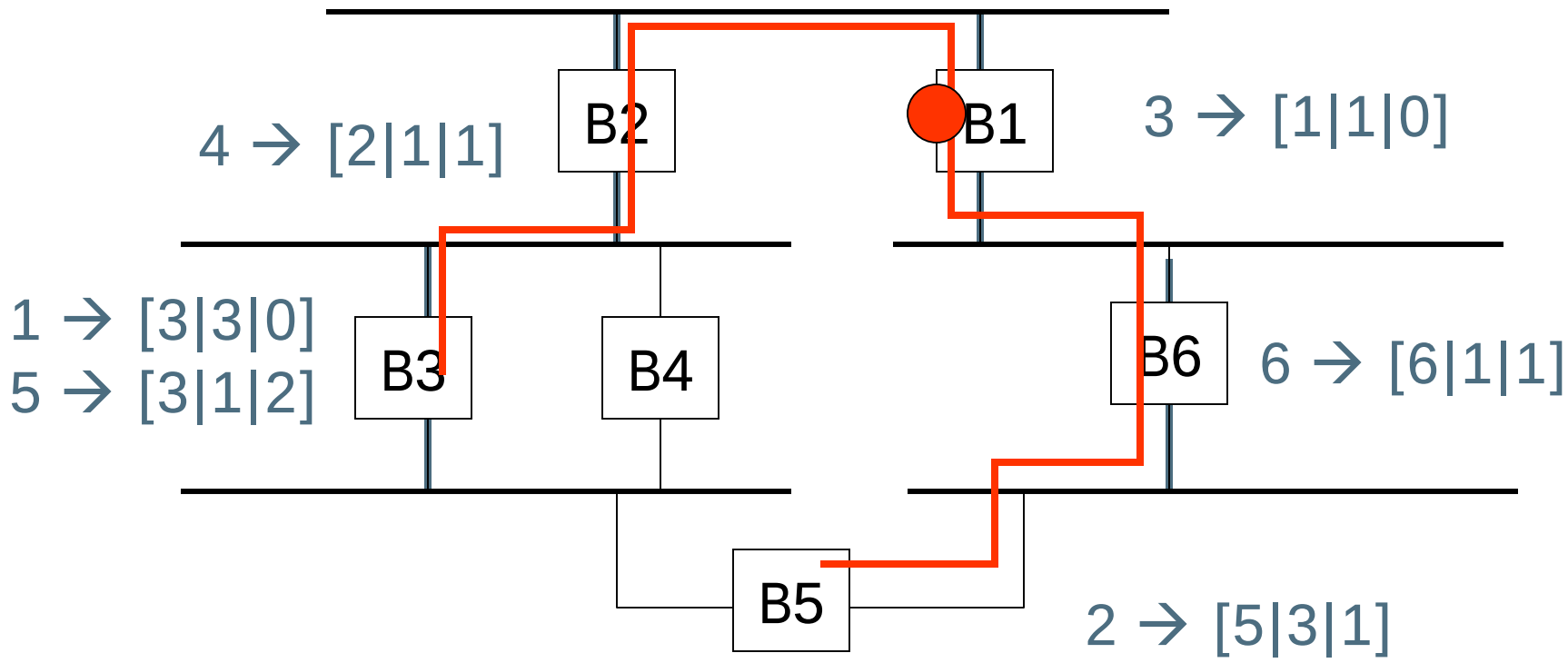
Spanning Tree

- Consider LAN a graph G = (E, V), with LANs as vertices, and bridges as edges
- Spanning Tree:
  - A spanning tree of an undirected, connected graph G is a subgraph which is both a tree and contains all vertices in G
  - Thus, the ST will throw out some edges and be cycle-free
- Purpose will be to provide a single path to reach each network
- Generally, graphs have many STs
- Must be a distributed algorithm
- Can result in some bridges not forwarding at all!

Algorithm

- Each bridge will decide over which ports it will forward frames
  - bridges have unique addresses *per port*
  - ports are also numbered by each bridge
  - bridges have a single unique identifier (e.g. the lowest address)
- Ultimately
  - Root of tree = bridge with smallest ID
  - Tree = shortest paths to root
  - Resolve ties in favor of link to bridge with smallest ID
- Steps
  - Send [my ID | current root ID | my distance to current root]
  - Update when receive smaller root ID

Example



Format: [my ID | current root ID | distance to current root]

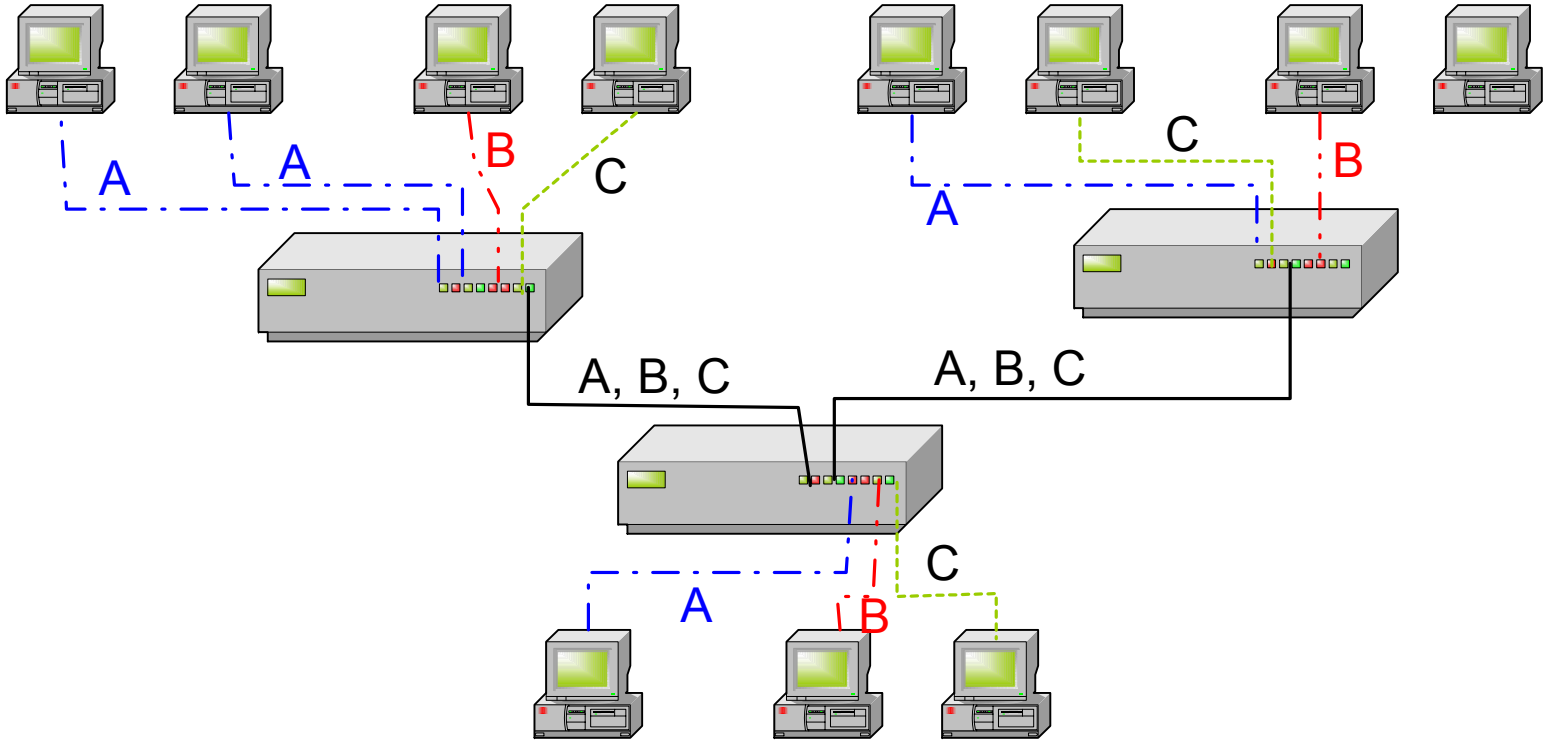
Topology Change

- Want to inform all bridges, but without having traffic scale as # of bridges
- Operation
  - bridges noticing change send message on root port toward root
  - root config messages subsequently contain “topology changed” flag

Limitations

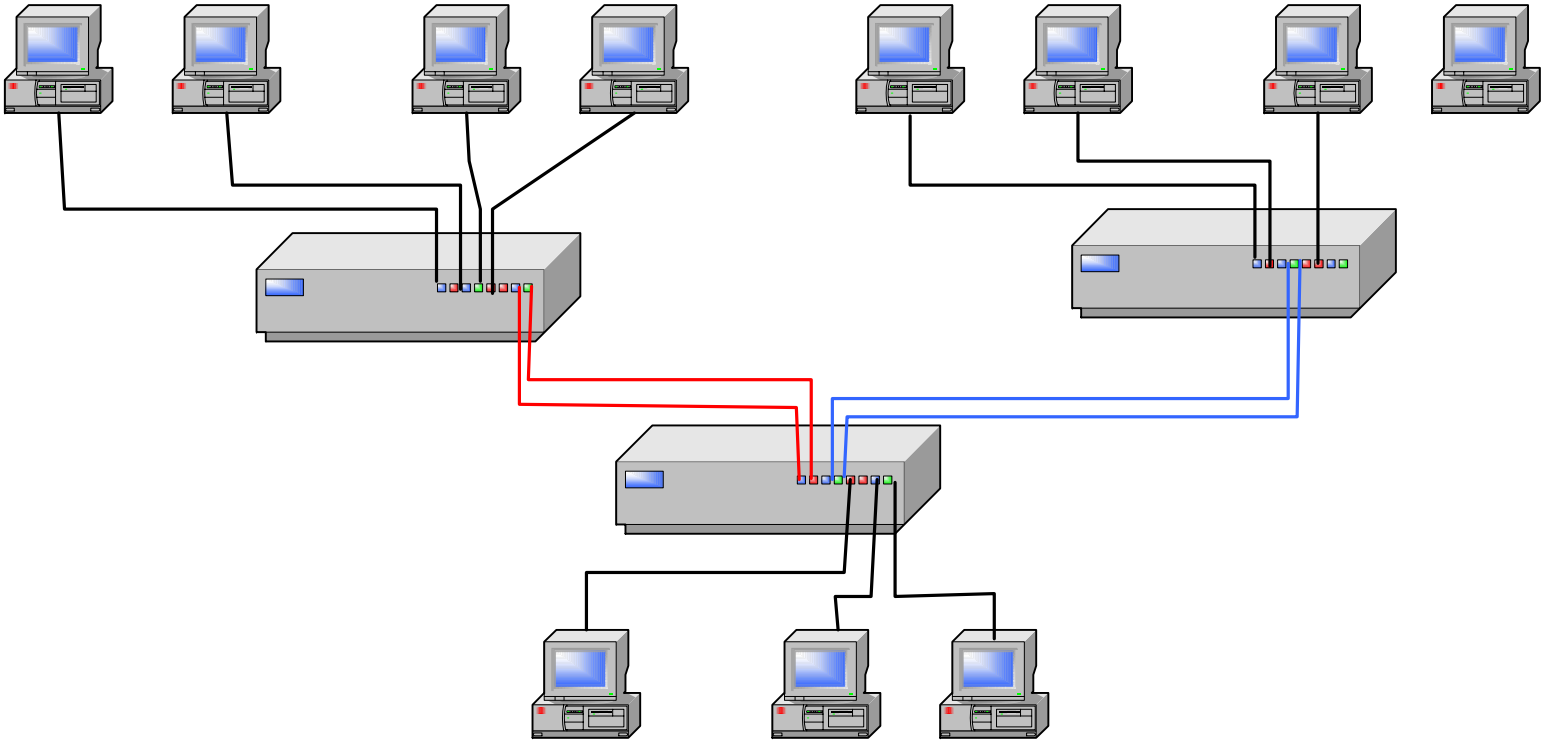
- Scale: not very realistic to interconnect more than 10's of LANs
- Heterogeneity: really works best for homogeneous systems
- All broadcasts and multicasts are flooded

VLAN – Virtual LAN



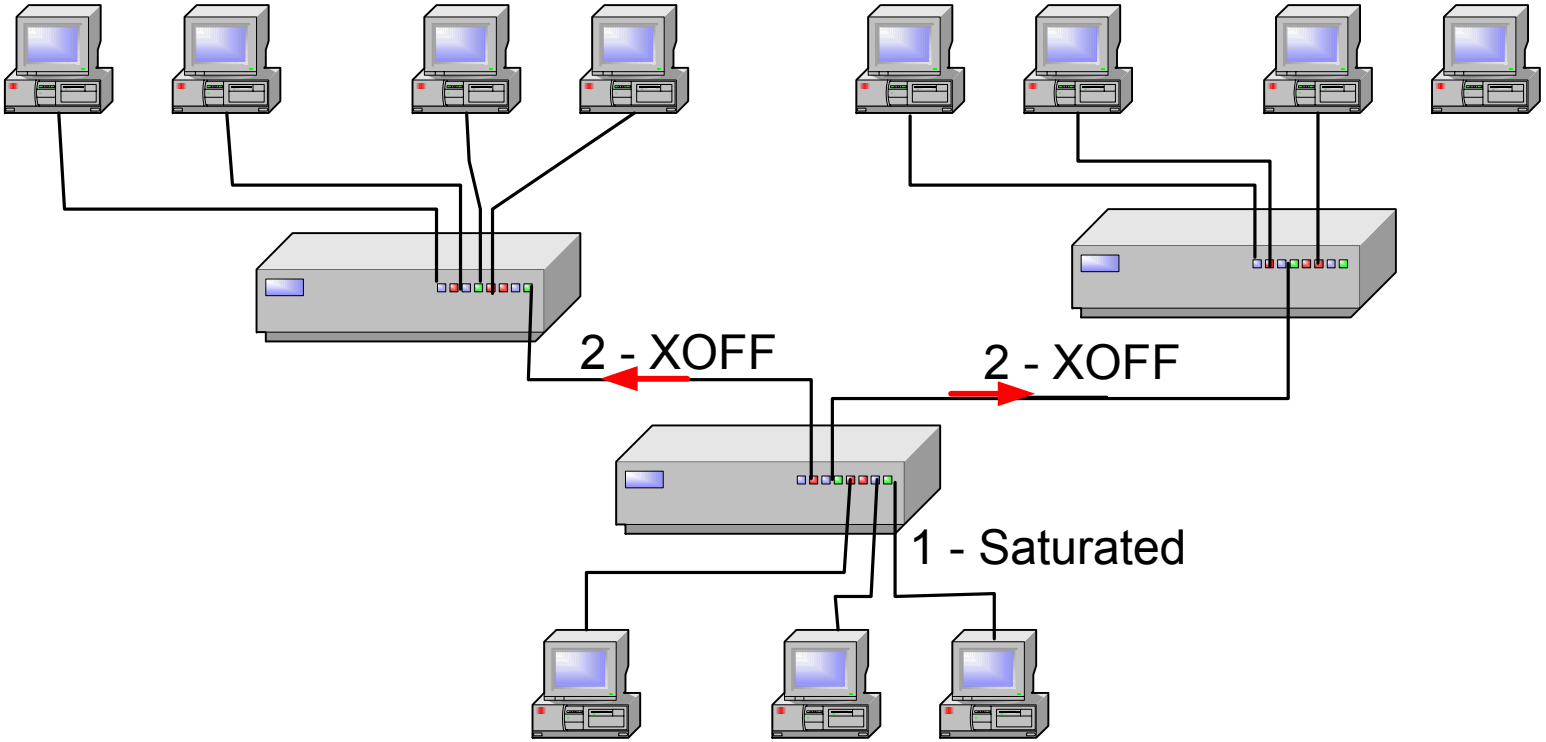
Each port belongs to a set of VLANs and transmits only packets that belong to these VLANs

Link Aggregation



Links are combined. Hello protocol determines which links are working and transmits across working links.

XON/XOFF



XON/XOFF is a backpressure scheme designed to prevent nodes from saturating links. Unfortunately, in its present version, the scheme is not very effective – it stops too many flows.

Wireless (802.11)

- Overview
- Physical
- MAC

Overview

- Designed for use in limited geographical area (i.e., couple of hundreds of meters)
- Designed for three physical media (run at either 1Mbps or 2 Mbps)
  - Two based on spread spectrum radio
  - One based on diffused infrared

Physical

- Frequency hoping (OFDM)
  - Transmit the signal over multiple frequencies
  - The sequence of frequencies is pseudo-random, i.e., both sender and receiver use the same algorithm to generate their sequences
- Direct sequence (DSSS)
  - Represent each bit by multiple (e.g., *n*) bits in a frame; XOR signal with a pseudo-random generated sequence with a frequency *n* times higher
- Infrared signal
  - Sender and receiver do not need a clear line of sight
  - Limited range; order of meters

Physical

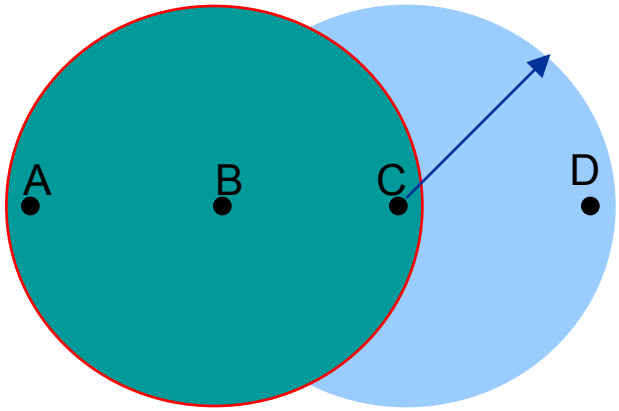
- 802.11b
  - DSSS: 1, 2, 5.5, or 11 Mbps (depending on SNR)
  - 2.4GHz
  - Each channel occupies 22MHz
  - There are 11 channels,
    but only 3 non-overlapping ones (1, 6, 11)
  - Max. power = 1W
- 802.11a
  - OFDM: 6, 9, 12, 18, 24, 36, 48, 54 Mbps (last 3 are optional)
  - 5GHz
  - 12 channels
  - Max. power = 40mW, 200mW, 800mW (depending on freq.)

Physical

- 802.11g
  - OFDM: 6, 12, 24, 18, 36, 48, 54 Mbps (last 4 are optional)
  - 2.4GHz
  - Backward compatible with 802.11b
  - 3 non-overlapping channels

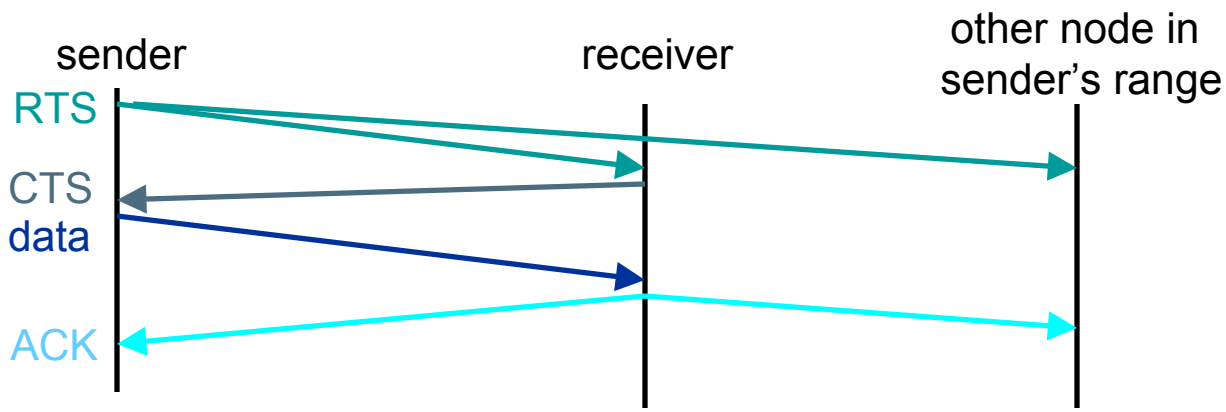
MAC: The Problems

- Reachability is not transitive: if A can reach C, and C can reach D, it doesn't necessary mean that A can reach D



- Hidden nodes: A and C send a packet to B; neither A nor C will detect the collision!
- Exposed node: B sends a packet to A; C hears this and decides not to send a packet to D (despite the fact that this will not cause interference)!

MAC: RTS/CTS



- Before every data transmission
  - Sender sends a Request to Send (RTS) frame containing the length of the transmission
  - Receiver respond with a Clear to Send (CTS) frame
  - Sender sends data
  - Receiver sends an ACK; now another sender can send data
- When sender doesn't get a CTS back, it assumes collision

MAC: CSMA/CA

- CA instead of CD: cannot listen while transmitting
- NAV: Network Allocation Vector: time until channel will become available – transmitted in every frame
- Distributed Coordinated Function: Before transmitting
  - Check if channel is busy, or
  - In an interval between frames [as determined from NAV], or
  - In an interval reserved for retransmission of an erroneous frame [as determined from previous transmission].
  - If one of the above, exponential backoff; else transmit.
- Centralized Controlled Access Mechanism: A point coordinator (in access point) coordinates transmissions.
  - Stations request that the PC puts them in polling list
  - Periodically, PC polls stations for traffic.
  - Without hidden terminal; with hidden terminal

Summary

- Arbitrate between multiple hosts sharing a common communication media
- Wired solution: Ethernet (use CSMA/CD protocol)
  - Detect collisions
  - Backoff exponentially on collision
- Wireless solution: 802.11
  - Use MACA protocol
  - Cannot detect collisions; try to avoid them