Part I Syllabus

Week	Subject
Week 1 Week 2 Week 3	Introduction
	Network layers & physical resilience
	Data link layer – Flow control
	Data link layer – Error control
	Local area network – Introduction
Week 4 Week 5 Week 7 * No lecture in Week 6 due to Students' Union Day	Local area network – Medium access control
	Local area network – Wired
	Local area network – WLAN
	Mobile access networks: From 1G to 5G
	Network paradigms
Recess Week (e-learning)	Review and examples

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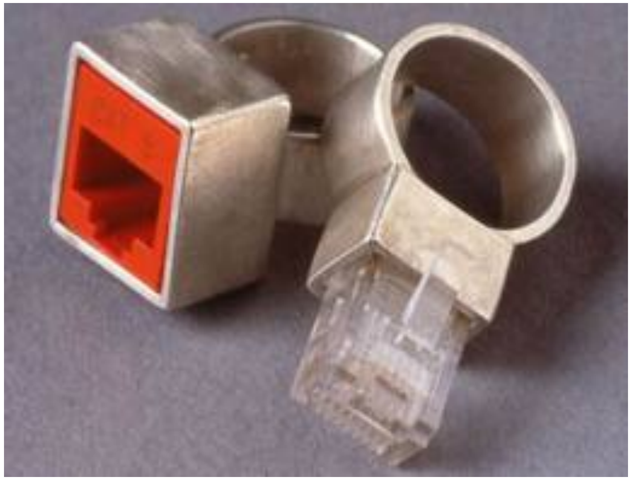
Network Engineer's World

When we design our house



When we design our wedding rings

Lecture 7
Wired LAN: Ethernet

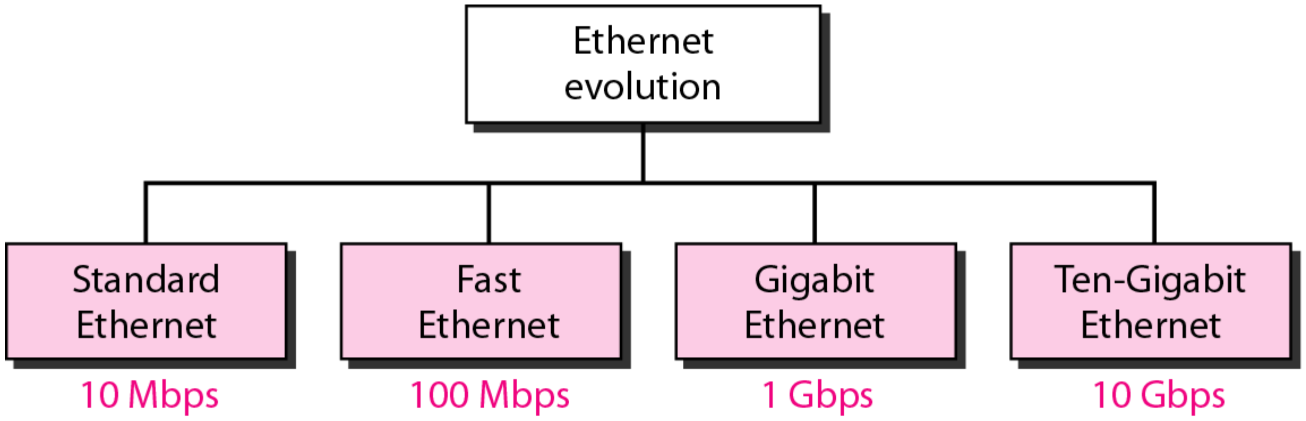
Contents

- **Ethernet Overview**
  - Ethernet Standard
  - Transmission Media
  - Physical Layer
  - Ethernet versions
- **Ethernet Frame Format**
  - Frame Format
  - MAC Address
- **Ethernet MAC Protocol**
  - Minimum Frame Size
  - Binary Exponential Backoff
- **Ethernet Evolution**
  - Bridged and Switched Ethernet
  - Fast, Gigabit and Ten-Gigabit Ethernet
  - Ethernet Pros and Cons

Ethernet Overview

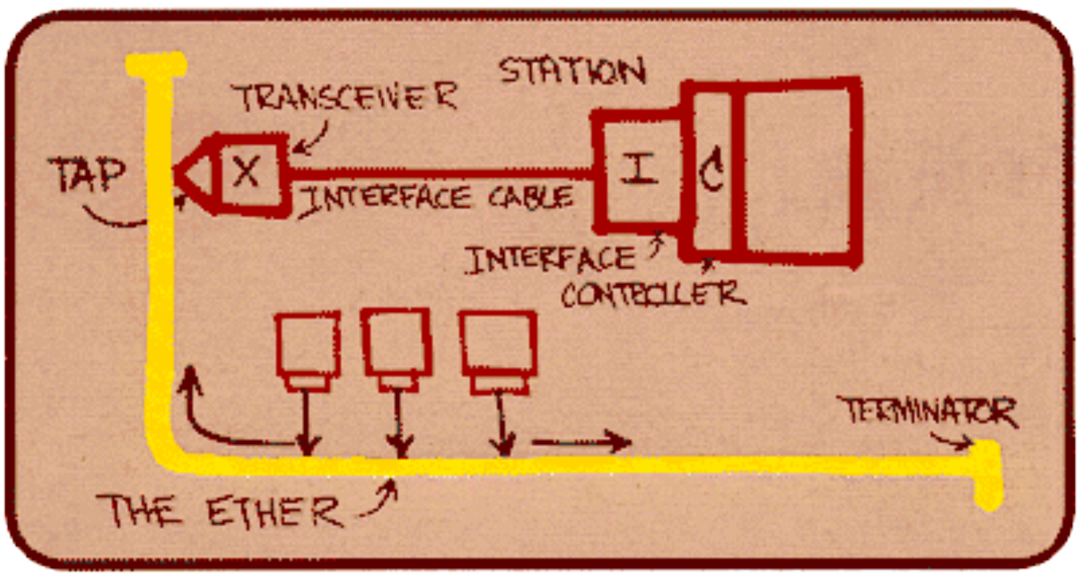
Ethernet: A Brief History

- **History**
  - Invented by *Bob Metcalfe* and others at Xerox PARC in mid-1970s
  - Roots in Aloha packet-radio network
  - Standardized by Xerox, DEC, and Intel in 1978
  - LAN standards define physical and MAC layers
    - IEEE 802.3 (CSMA/CD - Ethernet) standard – originally 2Mbps
    - IEEE 802.3u standard for 100Mbps Ethernet
    - IEEE 802.3z standard for 1,000Mbps Ethernet



Ethernet Standard: Physical Layer

- **802.3 standard defines both physical and MAC layer details**
  - MAC Protocol: CSMA/CD
  - Physical layer:

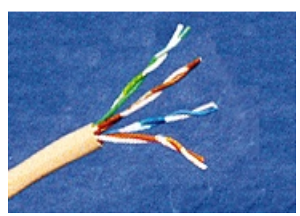


Metcalfe's original Ethernet Sketch: The idea was first documented in a memo that Metcalfe wrote on May 22, 1973, where he named it after the disproven luminiferous ether as an "omnipresent, completely-passive medium for the propagation of electromagnetic waves".

Ethernet Transmission Media

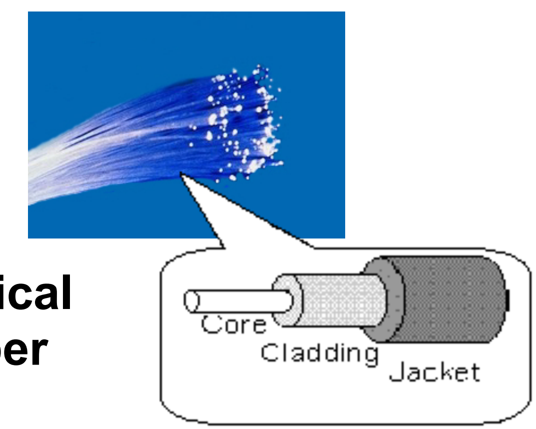
- **Coaxial cable**
  - Thick coax: Used by original Ethernet (bus topology)
  - Thin coax: More flexible, but shorter network span
- **Twisted pair**: For star topology, used with a hub, most commonly used
- **Optical fiber**: Expensive, Difficult to handle, but high data rate. Used in backbone.

coax



twisted pair

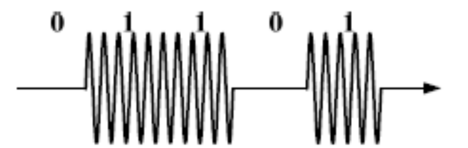
optical fiber



802.3 Physical Layer Configurations

- **Physical layer configurations are specified in three parts**
- **Data rate (10, 100, 1,000)**
  - 10, 100, 1,000Mbps
- **Signaling method (base, broad)**
  - Baseband: digital signaling
  - Broadband: analog signaling
- **Cabling (2, 5, T, F, S, L)**
  - 2 – 200m thin coax
  - 5 – 500m thick coax (original Ethernet cabling)
  - T – Twisted pair
  - F – Optical fiber
  - S – Short wave laser over multimode fiber
  - L – Long wave laser over single mode fiber

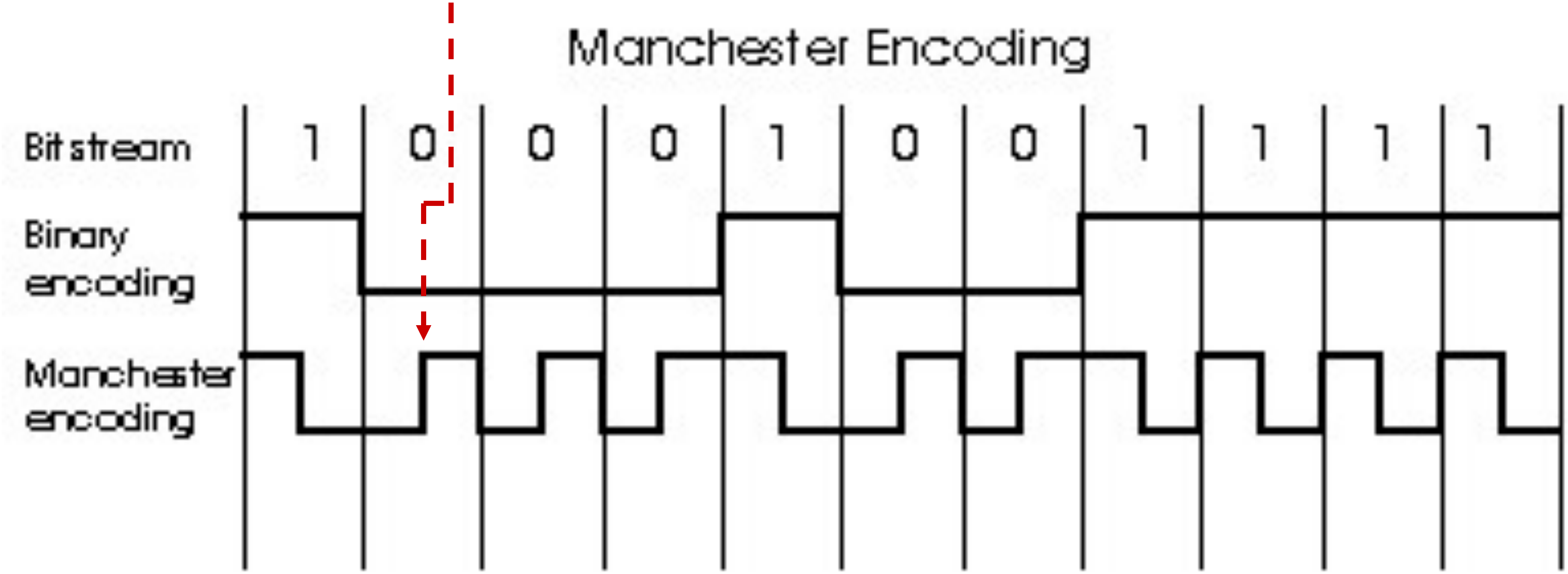
Baseband signaling



Broadband signaling

Baseband Manchester Encoding

- **Baseband here means that no carrier is modulated; instead bits are encoded using Manchester encoding and transmitted directly by modifying voltage of a DC signal.**
- **Manchester encoding ensures that a voltage transition occurs in each bit time which helps receiver in clock synchronization.**



Ethernet Versions

- **Ethernet comes with several versions based on its network configurations. Important ones are:**
  - 10BASE-5 (Original Ethernet)
  - 10BASE-2 (Cheapernet)
  - 10BASE-T (Star topology using a hub)
  - Others (eg 10BASE-FL, 10BASE-FP, etc)

Notation:

10 BASE 5

10 Mbps

Signaling mode, Base or Broad

Medium segment length (in 100m unit) or type. Possible options are: 5,2,T,F,etc

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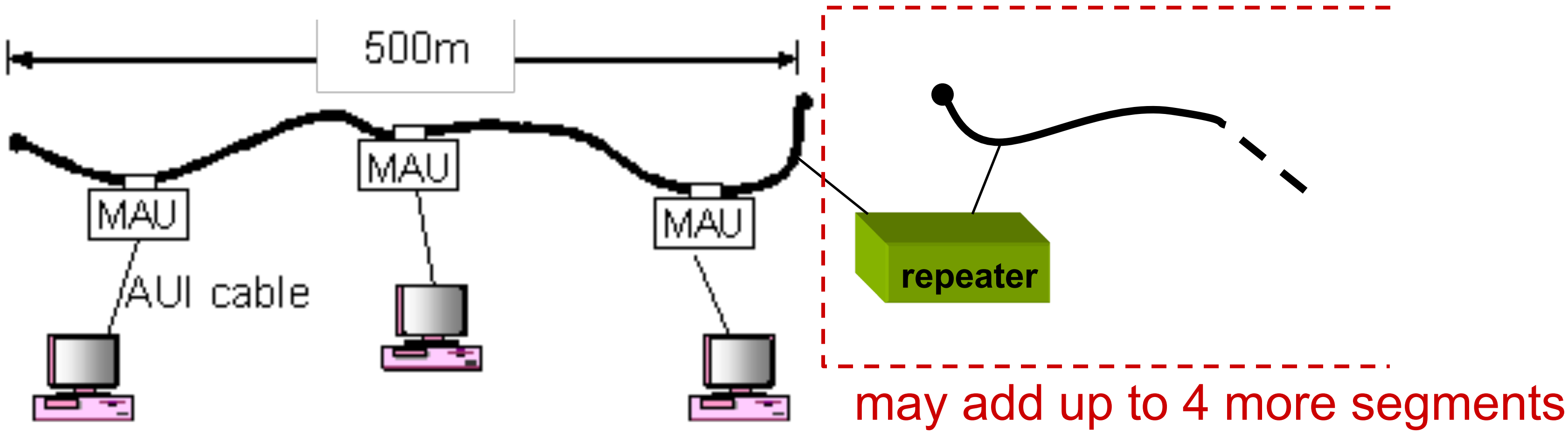
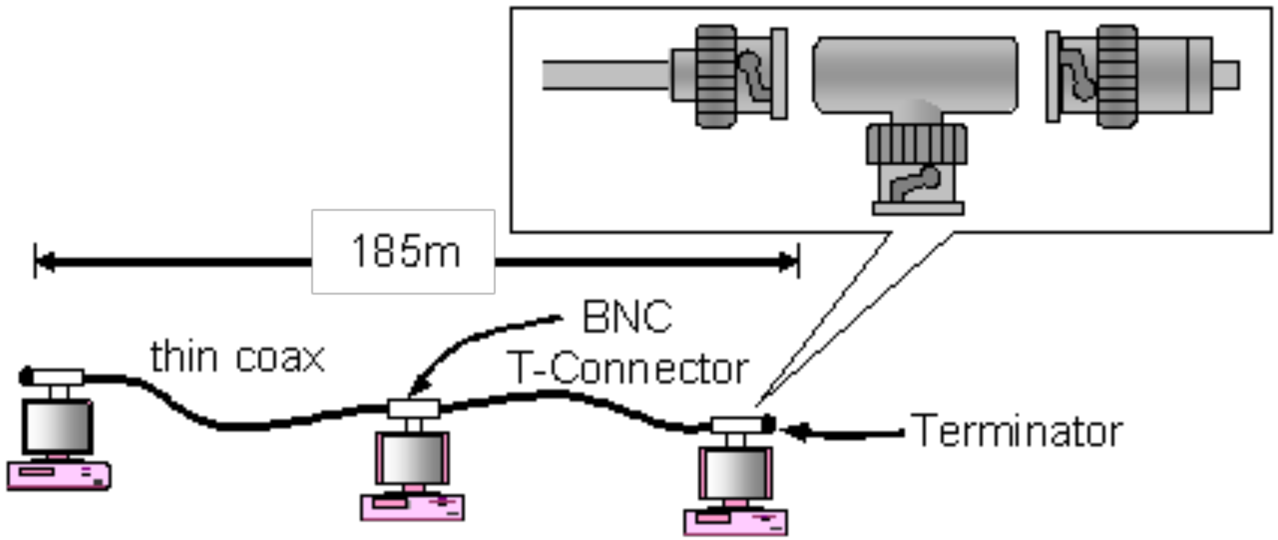
10BASE-5



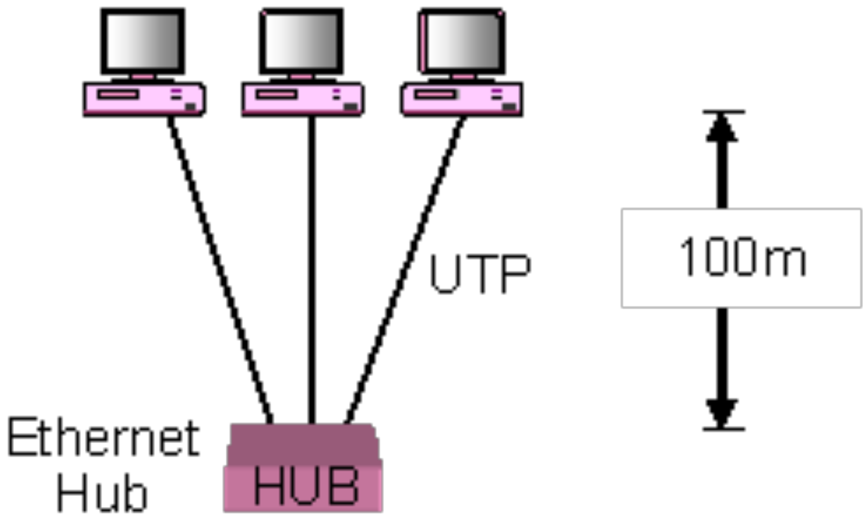
- Original Ethernet design, thick coax (50ohm) is used
- Each segment is of 500m long (max)
- Four repeaters (max) can be used to connect up to 5 segments
- AUI cable connecting the PC and the thick coax cannot be longer than 50m

10BASE-2



- Called cheapernet because it is cheap to deploy. Thin coax is used
- Each segment is of 185m long (max), min cable length between two computers is 0.5m, max 30 nodes
- Up to 4 repeaters, (so entire network cable=925m)

10BASE-T



- 'T' in 10BASE-T stands for Twisted pairs (UTP: unshielded twisted pairs). At least two pairs of wires.
- Most popular Ethernet option
- Cable length between a hub & a computer = 100m

Ethernet Frame Format

Ethernet Frame Format

Ethernet frame (DA through FCS)

Preamble	SFD	DA	SA	L/T	Data + Padding	FCS
7 bytes	1 byte	6 bytes	6 bytes	2 bytes	variable (46-1500 bytes)	4 bytes

SFD = Start Frame Delimiter
SA = Source Address
DA = Destination Address
L/T = Length/Type
FCS = Frame Check Sequence

- **Preamble & SFD: 7 bytes with the pattern 10101010 followed by one byte with the pattern 10101011; used for synchronizing receiver to sender clock (clocks are never exact)**
- **Pad field allows additional dummy data to be included to a frame for min. frame size requirement.**
- **Frame Check Sequence field enables error detection using CRC. It covers between Source Address and Pad fields.**

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Why preamble needed?

- **If we use two voltage levels to represent bits and the default state of the line is low voltage**
  - How can the receiver tell whether the observed low voltage for an extended period of time mean line idle or continuous bits?
  - The issue can be solved if we use preamble to denote the start of a frame
- **Preamble is a sequence of 7 bytes, each set to "10101010"**
  - Used to invoke and synchronize receiver before actual data is sent

Ethernet Frames

- **SFD (start frame delimiter)**
  - Used to separate the preamble and the following "useful" information
- **Addresses**
  - unique, 48-bit unicast address assigned to each adapter
    - example: **`08:00:e4:b1:02:a2`**
    - Each manufacturer gets their own address range
  - broadcast: all **`1`**s
  - multicast: first bit (from right) of the first byte is 1
- **Type field is a demultiplexing key used to determine which higher level protocol the frame should be delivered to**
- **Body can contain up to 1500 bytes of data**

MAC Address Examples

Question

Define the type of the following destination addresses:

a. 4A:30:10:21:10:1A

b. 47:20:1B:2E:08:EE

c. FF:FF:FF:FF:FF:FF

Solution

*To find the type of the address, we need to look at the **second hexadecimal digit from the left**. If it is even, the address is unicast. If it is odd, the address is multicast. If all digits are F's, the address is broadcast. Therefore, we have the following:*

a. This is a unicast address because A in binary is 1010.

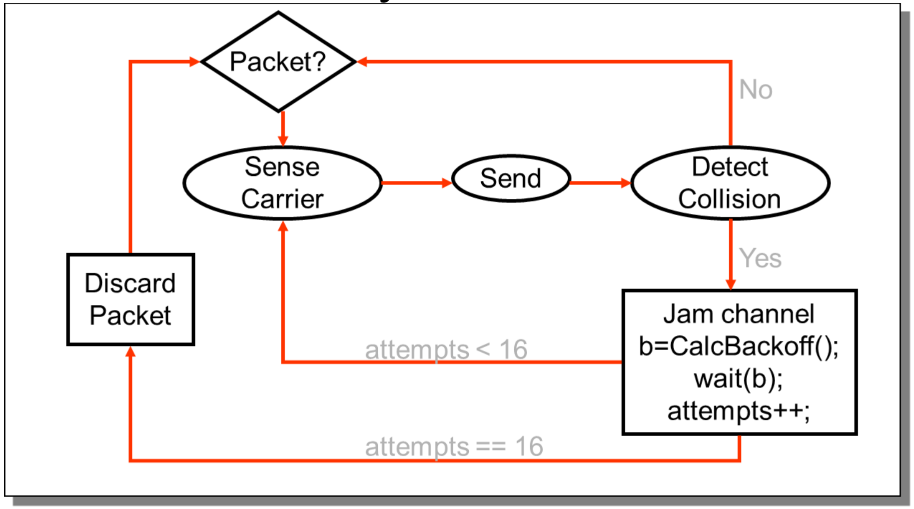
b. This is a multicast address because 7 in binary is 0111.

c. This is a broadcast address because all digits are F's.

Ethernet's MAC

Ethernet's MAC Algorithm

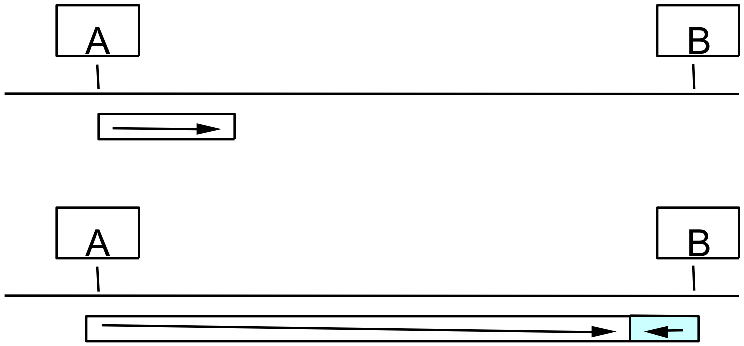
- **Ethernet uses CSMA/CD**
  - Listens to line before/during sending
- **If line is idle (no carrier sensed)**
  - Send packet immediately
  - Upper bound message size of 1500 bytes
  - Must wait 9.6us between back-to-back frames
- **If line is busy (carrier sensed)**
  - Wait until idle and transmit packet immediately
    - called *1-persistent* sending
- **If collision detected**
  - Stop sending and jam signal
  - Try again later



Frame Collisions

- **Collisions are caused when two adaptors transmit at the same time (adaptors sense collision based on voltage differences)**
  - Both found line to be idle
  - Both had been waiting for a busy line to become idle

A starts at time 0



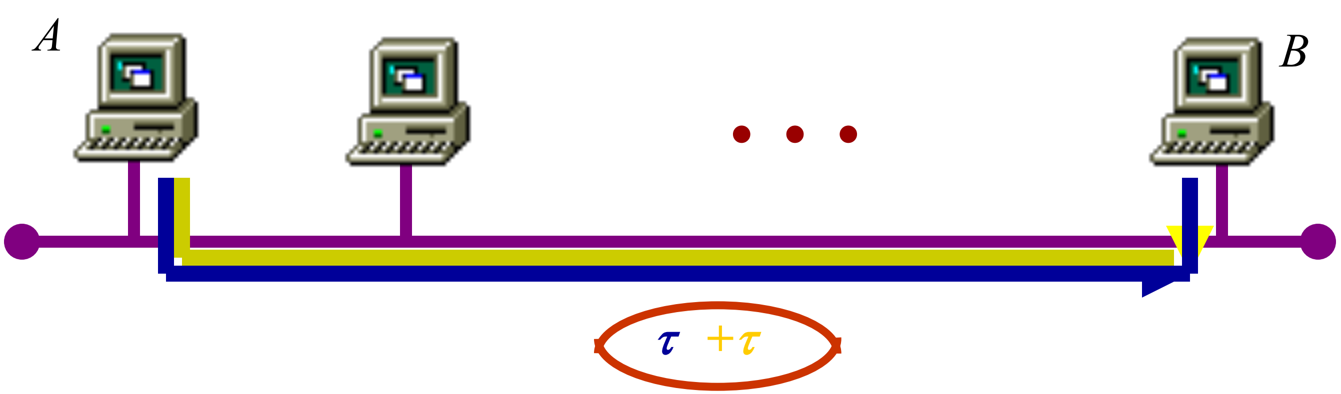
Message almost there at time T when B starts – collision!

How can we be sure A knows about the collision?

Minimum Frame Transmission Time for Collision Detection

So, a sender must keep its transmission until it is sure that there are no other transmissions on the medium it is not aware of before it ends its transmission.
But then how long to keep its transmission?

A transmission requires an end-to-end signal propagation time (τ) to reach all stations (the longest), then a potential collision requires τ unit of time to return to the sender.
So the frame transmission $\geq 2\tau$ (signal round trip time).

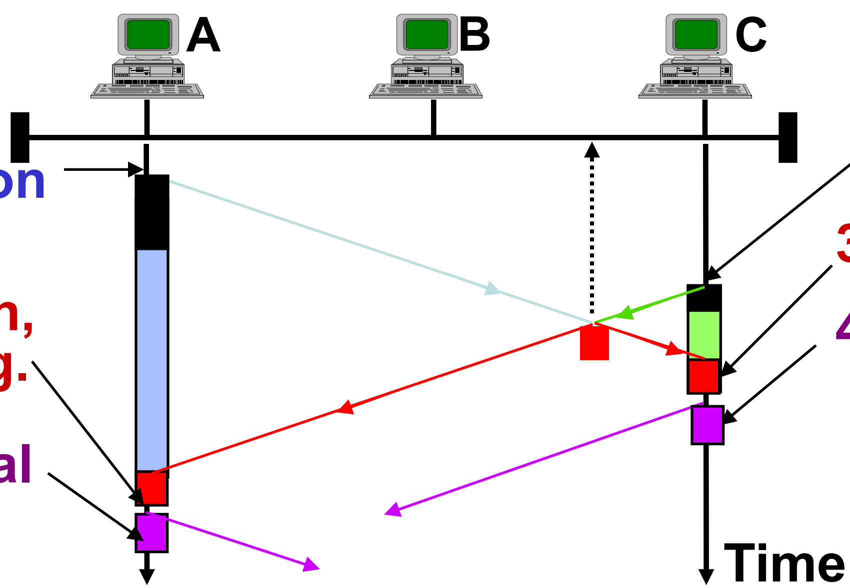


Minimum Ethernet Frame Size for Collision Detection

- **To ensure that A can detect collision, A must still be transmitting at 2τ**
  - A's message reaches B at time τ
  - B's message reaches A at time 2τ
- **IEEE 802.3 specifies max value of 2τ to be 51.2us**
  - This relates to maximum distance of 2500m between hosts
  - At 10Mbps it takes 0.1us to transmit one bit so 512 bits (64B) take 51.2us to send
  - So, Ethernet frames must be at least 64B long
    - 14B header, 46B data, 4B CRC
    - Padding is used if data is less than 46B
- **Send jamming signal after collision is detected**

Ethernet: Jam Signals

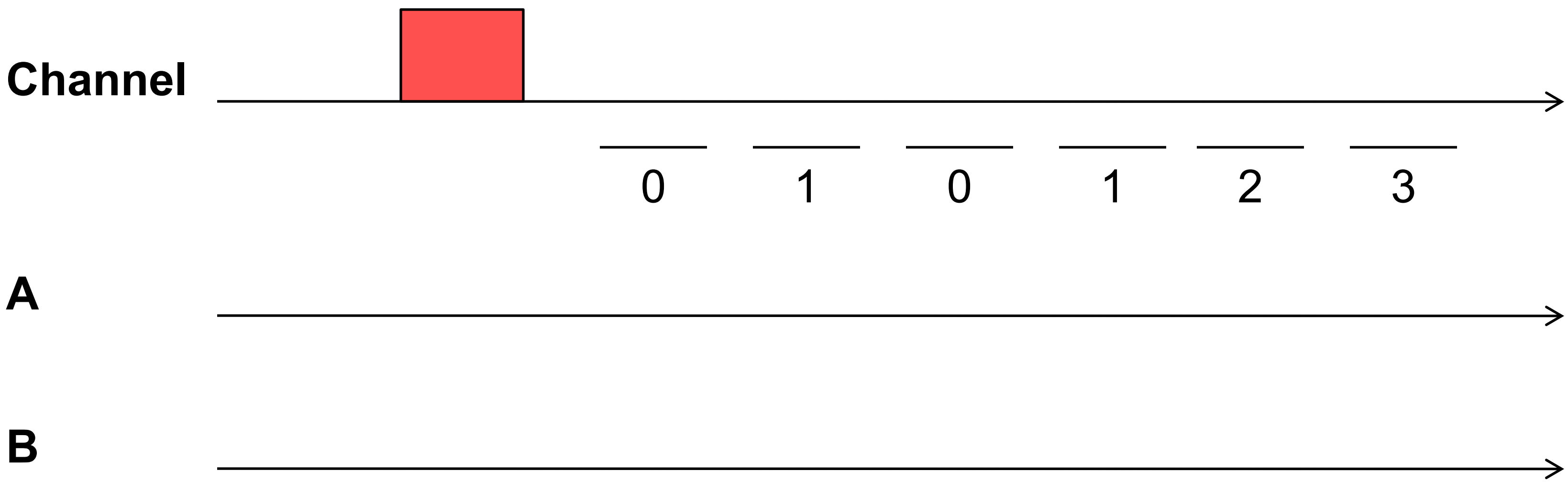
- In the previous example, B's transmission cannot be too brief, otherwise A might not see the collision
- To avoid this, a station is required to transmit a jam sequence (32 to 48 bits long) after it has detected a collision. This will make the collision more obvious.



Binary Exponential Backoff (BEB)

- **What should stations do when a collision is detected?**
  - **Discard the packet and let upper layer protocols do the retransmission as in Aloha, slotted Aloha, and CSMA (☠ NO!!!!!). But how?**
  - **They can choose a future slot randomly to retransmit based on *Binary Exponential Backoff* (BEB).**
- **Delay time is selected using binary exponential backoff**
  - **1**st time: choose K from {0,1} then delay = K * 51.2us
  - **2**nd time: choose K from {0,1,2,3} then delay = K * 51.2us
  - n^{th} time: delay = K x 51.2us, for K=0..2^n – 1
    - Note max value for k = 1023
  - give up after several tries (usually 16)
    - Report transmit error to host
- **If delay were not random, then there is a chance that sources would retransmit in lock step**
- **Why not just choose from small set for K**
  - This works fine for a small number of hosts
  - Large number of nodes would result in more collisions

BEB: Example



1st Retrial

P(Collision) = P(A&B=0) + P(A&B=1)

P(A&B=0) = P(A=0)*P(B=0)

= 0.5*0.5 = 0.25

P(Collision) = 0.25 +0.25 =0.5

2nd Retrial

P(Collision) = P(A&B=0) + P(A&B=1)

+ P(A&B=2) + P(A&B=3)

P(A&B=0) = P(A=0) * P(B=0)

= 0.25 * 0.25 = 0.0625

P(Collision) = 4*0.0625 = 0.25

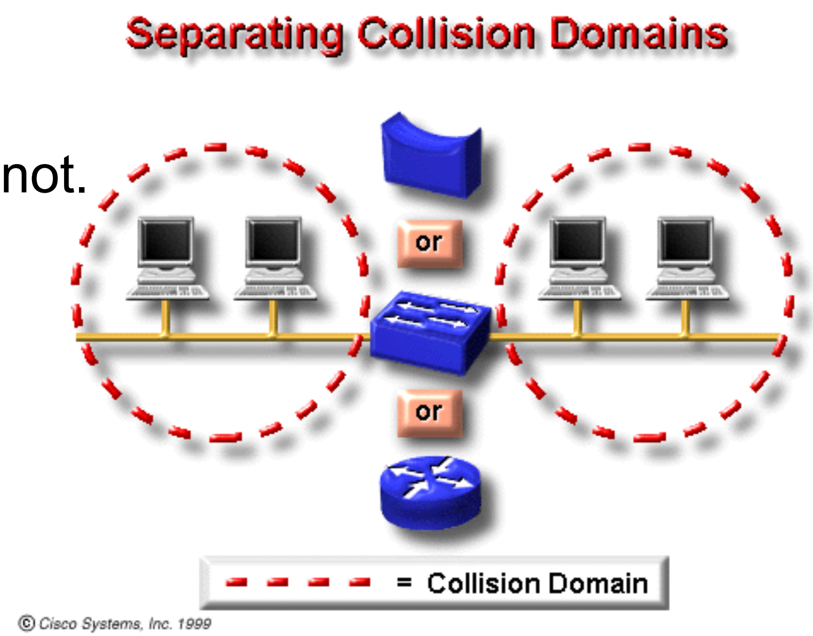
MAC Algorithm from Receiver

- **Senders handle all access control**
- **Receivers simply read frames with acceptable address**
  - Address to host
  - Address to broadcast
  - Address to multicast to which host belongs
  - All frames if host is in promiscuous mode

Ethernet Evolutions

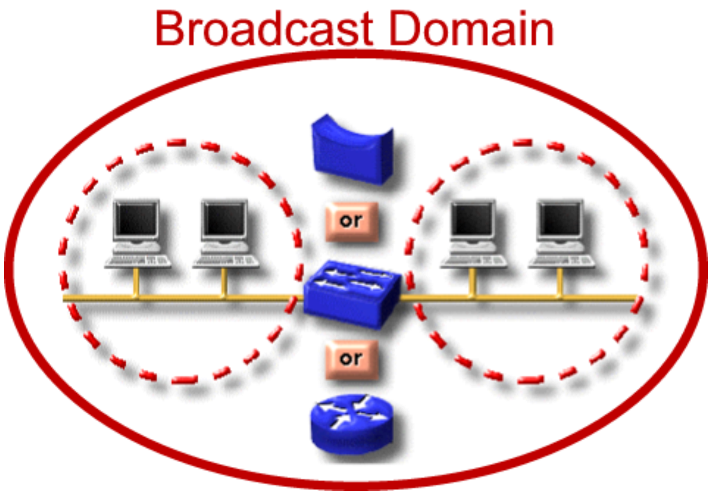
Collision Domain

- **Network region in which collisions are propagated.**
  - Repeaters and hubs propagate collisions.
  - Bridges, switches and routers do not.
- **Collision frequency can be kept low by breaking the network into segments bounded by:**
  - Bridges (simple/old version of switches)
  - Switches
  - Routers

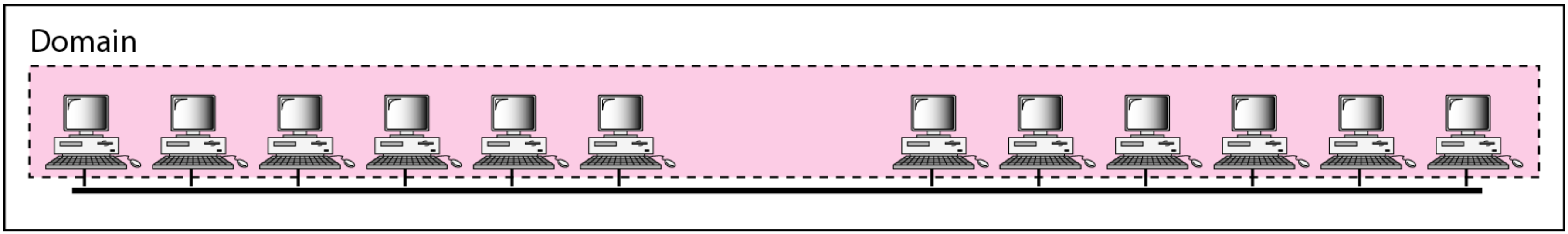


Broadcast Domain

- **Network region in which broadcast frames are propagated.**
  - Repeaters, hubs, bridges, & switches propagate broadcasts. (**Layer 2**)
  - Routers either do or don't, depending on their configuration.(**Layer 3**)
- **Broadcasts are necessary for network function.**
- **Some devices and protocols produce lots of broadcasts; avoid them.**
- **Broadcast frequency can be kept manageable by limiting the LAN size.**
- **LANs can then be cross-connected by <u>routers</u> to make a larger internetwork.**

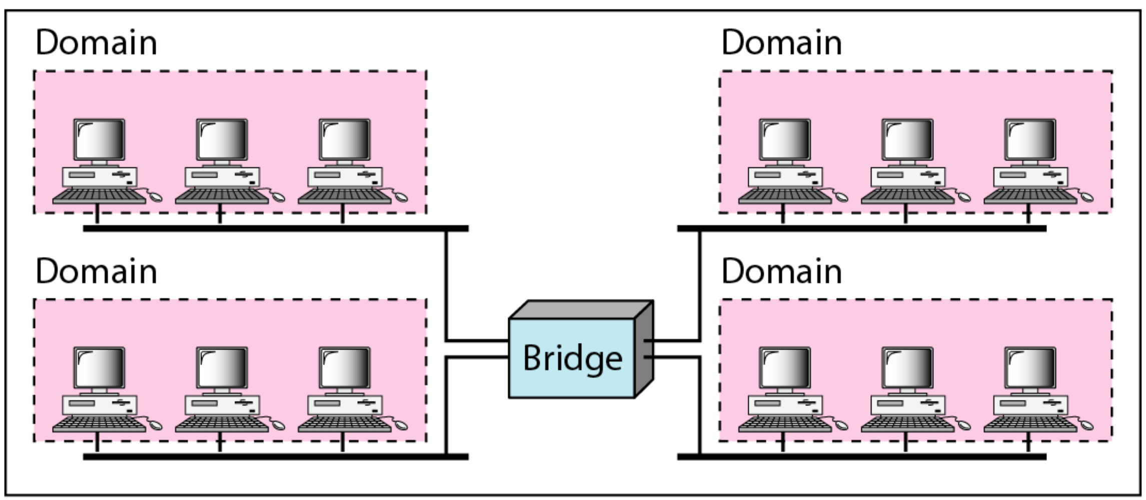


Bridged Ethernet



Same collision & broadcast domain

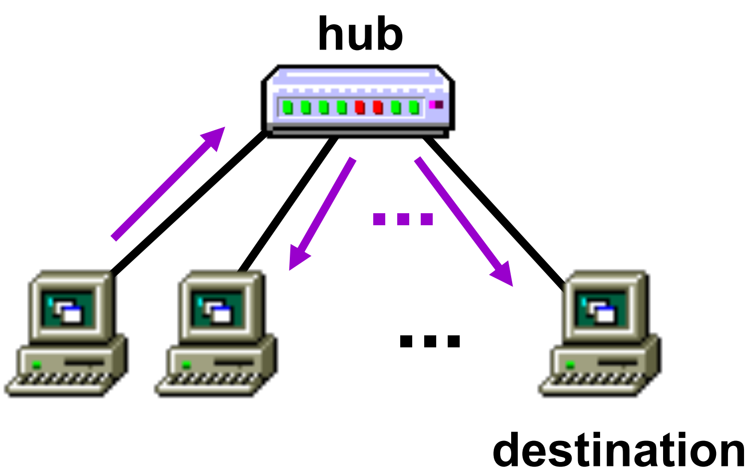
a. Without bridging



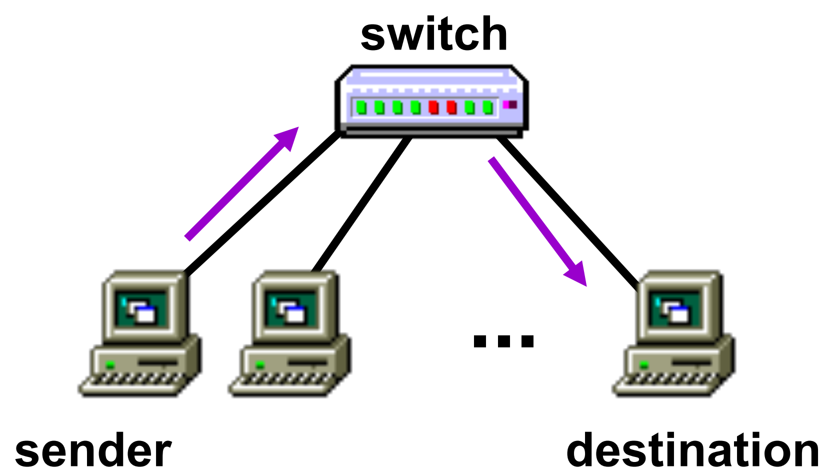
Multiple collision domains
Single broadcast domain

b. With bridging

Shared versus Switched



A repeater (or a hub) forwards the received signals to all output ports except the incoming port.
A collision occurs when two computers transmit at the same time. In this case, the channel carries no useful information.



A switch (or a switching hub) forwards the received signals only to the destination.
When two transmissions arrive at the switch at the same time, they will be stored in different buffers so that their frames can be forwarded later. No collision is resulted.

Switched Ethernet

- **Switches forward and filter frames based on LAN addresses**
  - It's not a bus or a router (simple forwarding tables are maintained)
- **Very scalable**
  - Options for many interfaces
  - Full duplex operation (send/receive frames simultaneously)
- **Connect two or more "segments" by copying data frames between them**
  - Switches only copy data when needed
    - key difference from repeaters
- **Higher link bandwidth**
  - Collisions are completely avoided
- **Much greater aggregate bandwidth**
  - Separate segments can send at once

Fast Ethernet

- **Fast Ethernet (100Mbps) has technology very similar to 10Mbps Ethernet**
  – Uses different physical layer encoding (4B/5B)
    - Use 5 bytes to represent 4 bytes of original data
  – Many NIC's are 10/100 capable
    - Can be used at either speed
- **Summary of Fast Ethernet Implementation**

Characteristics	*100Base-TX*	*100Base-FX*	*100Base-T4*
Media	Cat 5 UTP or STP	Fiber	Cat 4 UTP
Number of wires	2	2	4
Maximum length	100 m	100 m	100 m
Block encoding	4B/5B	4B/5B	
Line encoding	MLT-3	NRZ-I	8B/6T

Gigabit Ethernet

- **Gigabit Ethernet (1,000Mbps)**
  - Compatible with lower speeds
  - Uses standard framing and CSMA/CD algorithm
  - Distances are severely limited
  - Used for backbones and inter-router connectivity
  - Cost competitive

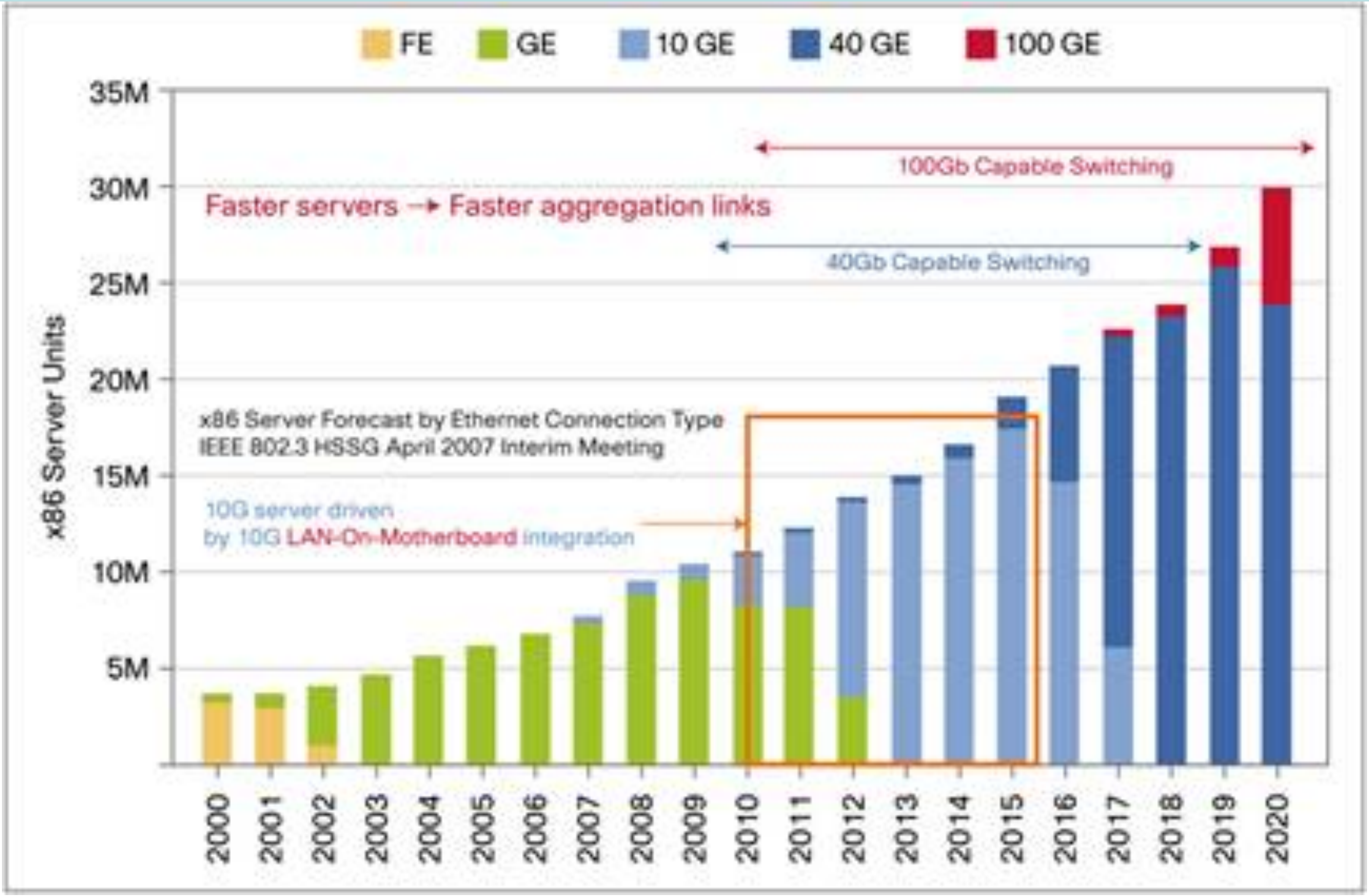
Characteristics	*1000Base-SX*	*1000Base-LX*	*1000Base-CX*	*1000Base-T*
Media	Fiber short-wave	Fiber long-wave	STP	Cat 5 UTP
Number of wires	2	2	2	4
Maximum length	550 m	5000 m	25 m	100 m
Block encoding	8B/10B	8B/10B	8B/10B	
Line encoding	NRZ	NRZ	NRZ	4D-PAM5

Ten-Gigabit Ethernet

- **Ten-Gigabit Ethernet (10Gbps)**
  – Defined by IEEE 802.3ae-2002
  – Higher-grade copper cables required: cat 6a or Class F/Cat 7 cables for links up to 100m

Characteristics	*10GBase-S*	*10GBase-L*	*10GBase-E*
Media	Short-wave 850-nm multimode	Long-wave 1310-nm single mode	Extended 1550-mm single mode
Maximum length	300 m	10 km	40 km

Ethernet Adoption Trends



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Experiences with Ethernet

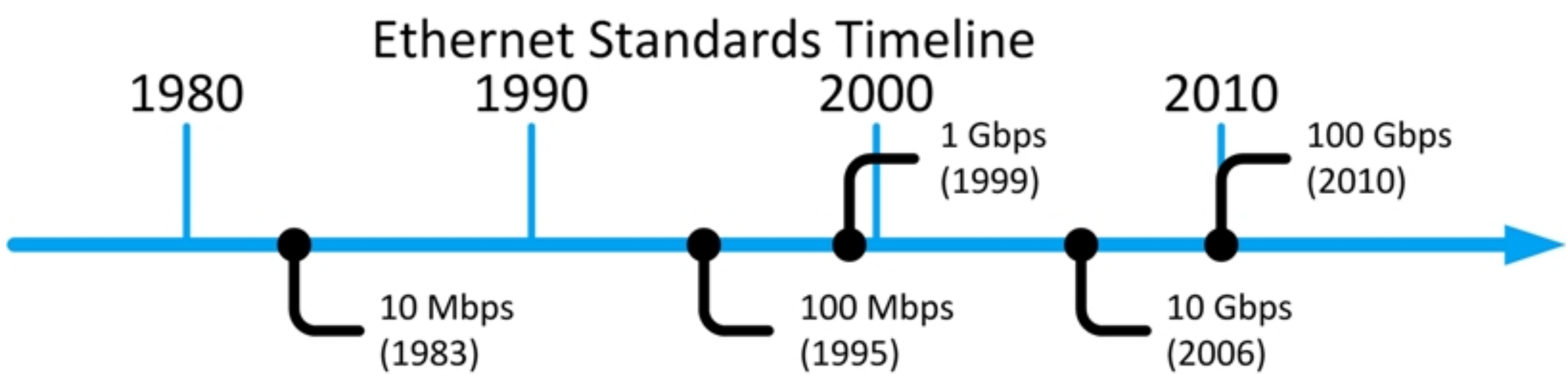
- **Ethernets work best under light loads**
  - Network capacity is wasted by collisions
- **Most networks are limited to about 200 hosts**
  - Specification allows for up to 1024
- **Most networks are much shorter**
  - 5 to 10 microsecond RTT
- **Transport level flow control helps reduce load (number of back to back packets)**
- **Ethernet is inexpensive, fast and easy to administer!**

Ethernet Problems

- **Ethernet's peak throughput is still low**
  - Similar to slotted ALOHA
  - Better than pure ALOHA
- **Peak throughput worsens with**
  - More hosts
    - More collisions
  - Longer links
    - Collisions take longer to observe, more wasted bandwidth
- **Efficiency can be improved by avoiding the above conditions**

Why did Ethernet win?

- **There are many LAN protocols (ARCNET, Token ring, AppleTalk, etc)**
  - Price
  - Performance
  - Availability
  - Ease of use
  - Scalability



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Learning Objectives

- **Ethernet Overview**
  - Read Ethernet versions
- **Ethernet Frame Format**
  - Understand MAC address: unicast/broadcast
- **Ethernet MAC Protocols**
  - Calculate minimum frame size
  - Calculate collision rate under BEB scheme
- **Ethernet Evolutions**
  - Count collision domains for bridged/switched Ethernet
  - Calculate minimum frame size for FE/GbE/10GbE