Data Link Layer

Our goals:

- understand principles behind data link layer services:
  - link layer addressing

- instantiation and implementation of various link layer technologies

Outline

- **Introduction and services**
- LAN addresses and ARP
- Ethernet
- Hubs, bridges, and switches

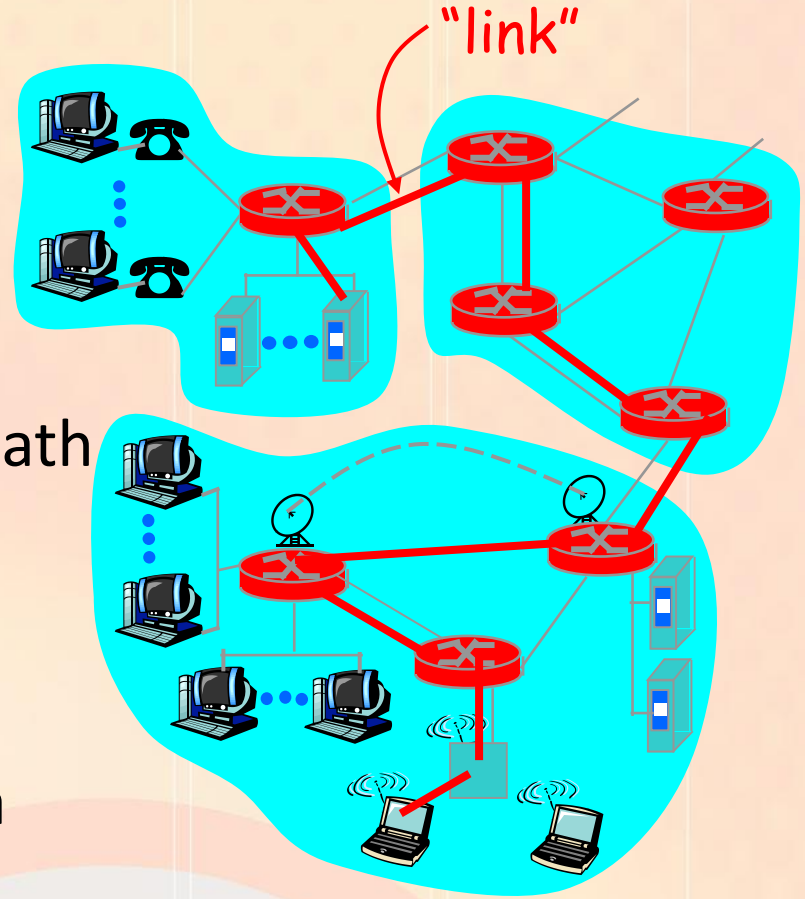
Link Layer: Introduction

Terminology:

- hosts and routers are **nodes**

  (bridges and switches too)

- communication channels that connect adjacent nodes along communication path are **links**
  - wired links
  - wireless links
- Layer 2-PDU is a **frame,** encapsulating a datagram



data-link layer has responsibility of transferring datagram from one node to adjacent node over a link

Link layer: context

- Datagram transferred by different link protocols over different links:
  - e.g., Ethernet on first link, frame relay on intermediate links, 802.11 on last link
- Each link protocol provides different services
  - e.g., may or may not provide reliable data transfer over link

transportation analogy

trip from Princeton to Lausanne

limo: Princeton to JFK

plane: JFK to Geneva

train: Geneva to Lausanne

tourist = datagram

transport segment = communication link

transportation mode = link layer protocol

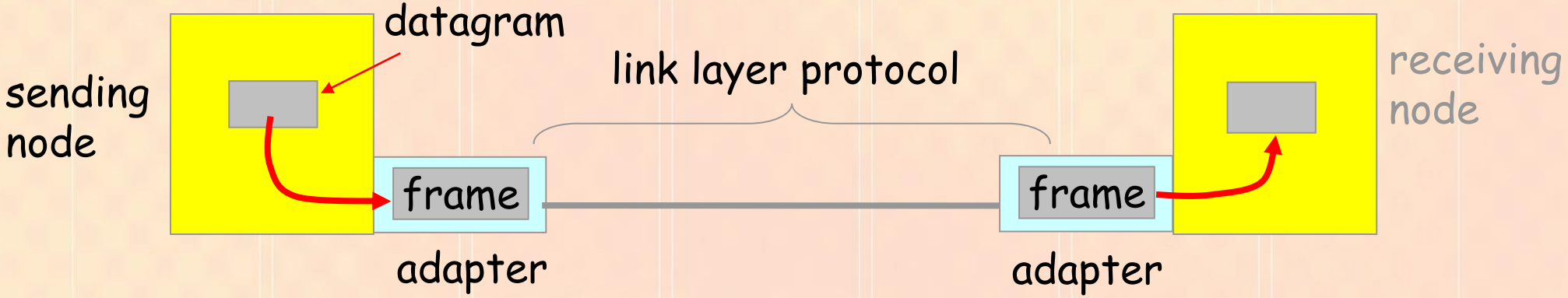
travel agent = routing algorithm

Link Layer Services

- **Framing, link access:**
  - encapsulate datagram into frame, adding header, trailer
  - channel access if shared medium
  - '**physical addresses**' used in frame headers to identify source and destination
    - different from IP address!
- **Reliable delivery between adjacent nodes**
  - seldom used on low bit error link (fibre, twisted pair)
  - wireless links: high error rates

    - Q: why both link-level and end-end reliability?

Adaptors Communicating



- link layer implemented in "adaptor" (NIC)
  - Ethernet card, PCMCI card, 802.11 card
- sending side:
  - encapsulates datagram in a frame
  - adds error checking bits, rdt, flow control, etc.

receiving side

looks for errors, rdt, flow control, etc

extracts datagram, passes to receiving node

adapter is semi-autonomous

link & physical layers

LAN Addresses and ARP

32-bit IPv4 (Logical) address:

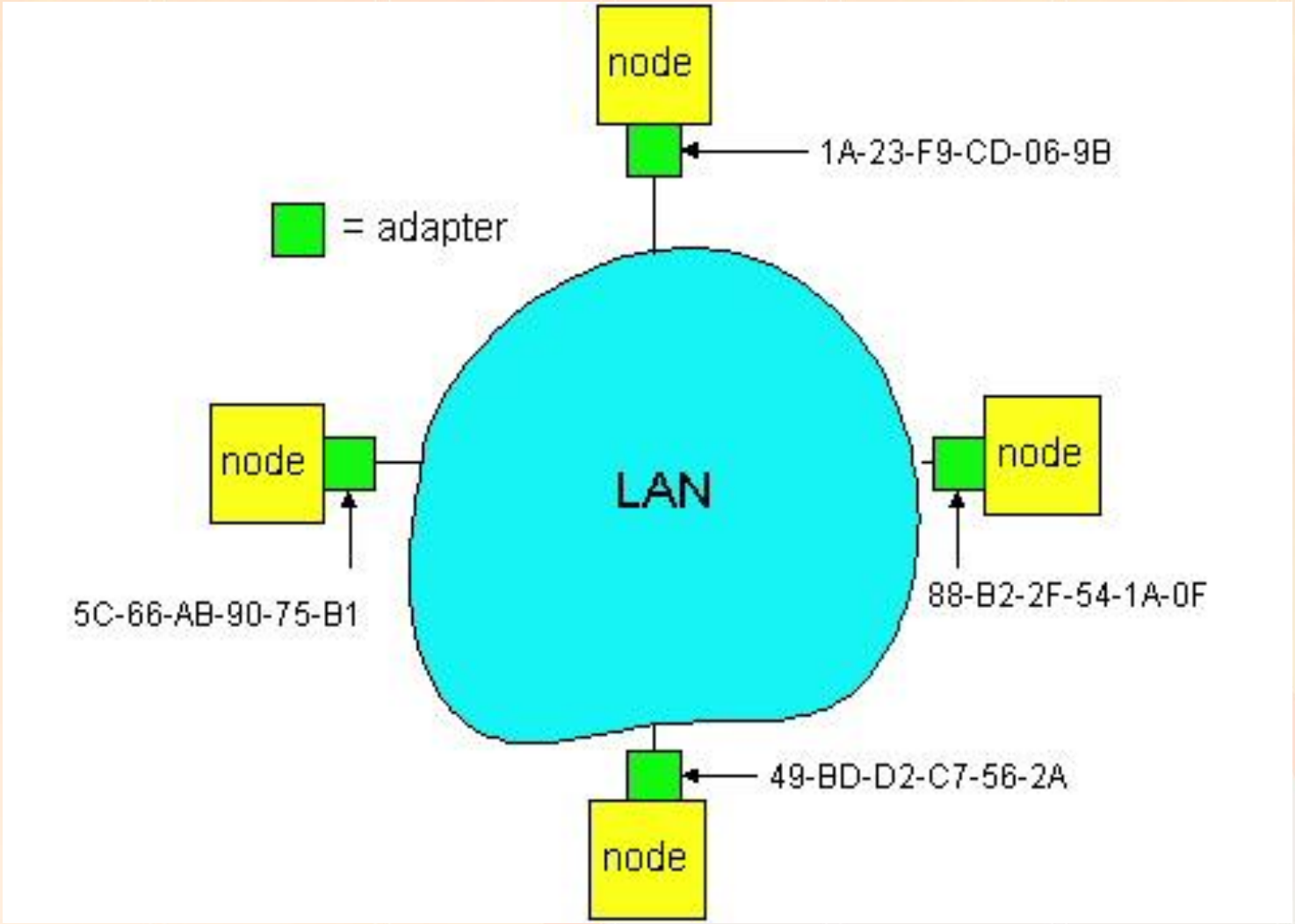
- *network-layer* address
- used to get datagram to destination IP network (recall IP network definition)

48-bit LAN (MAC/Physical/Ethernet/Hardware) address:

- used to get datagram from one interface to another physically-connected interface (same network)
- 48-bit MAC address (for most LANs) burned in the adapter ROM hence cannot be changed.

LAN Addresses and ARP

Each adapter on LAN has unique LAN address



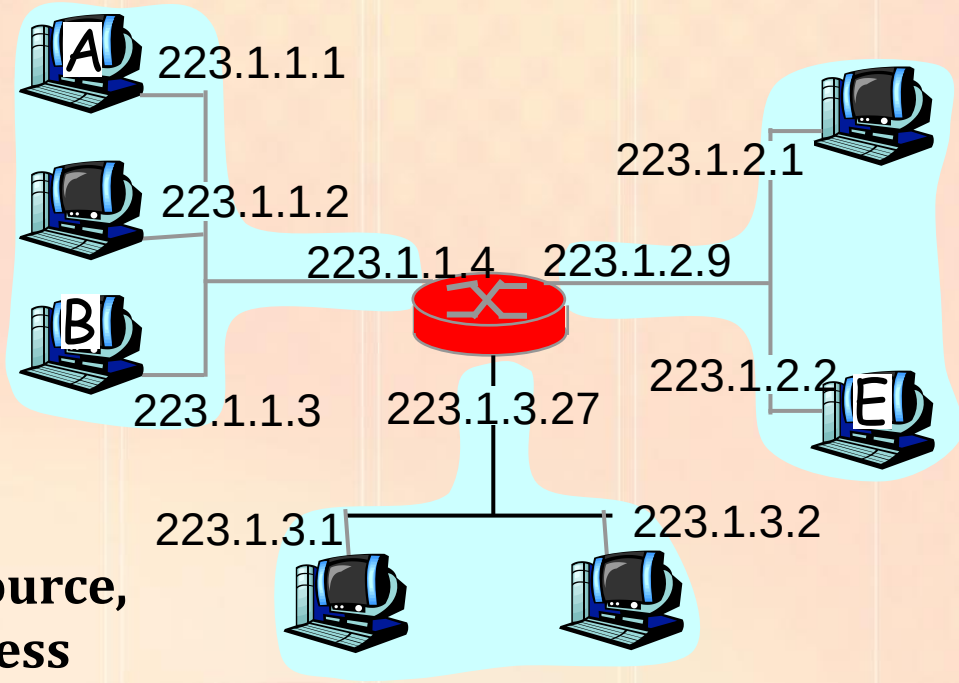
LAN Address

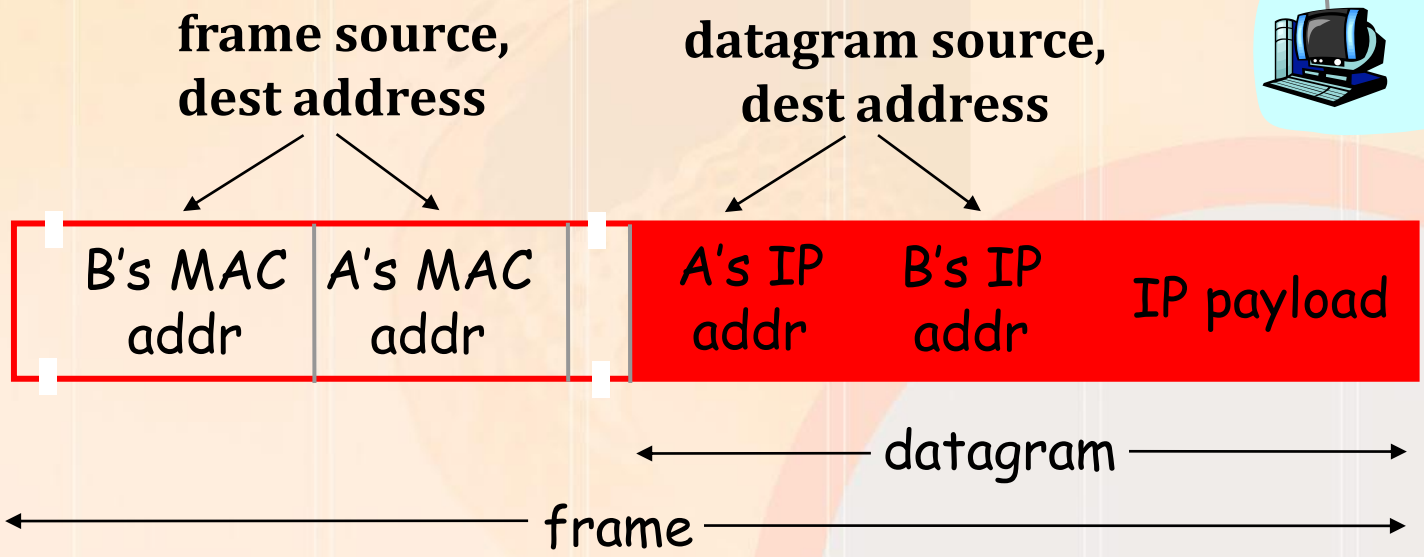
- MAC address allocation administered by IEEE
- manufacturer buys portion of MAC address space (to assure uniqueness)
- Analogy:
  - (a) MAC address: like NIC Number
  - (b) IP address: like postal address
- MAC flat address => portability
  - can move LAN card from one LAN to another
- IP hierarchical address NOT portable
  - depends on IP network to which node is attached

Recall earlier routing discussion

Starting at A, given IP datagram addressed to B:

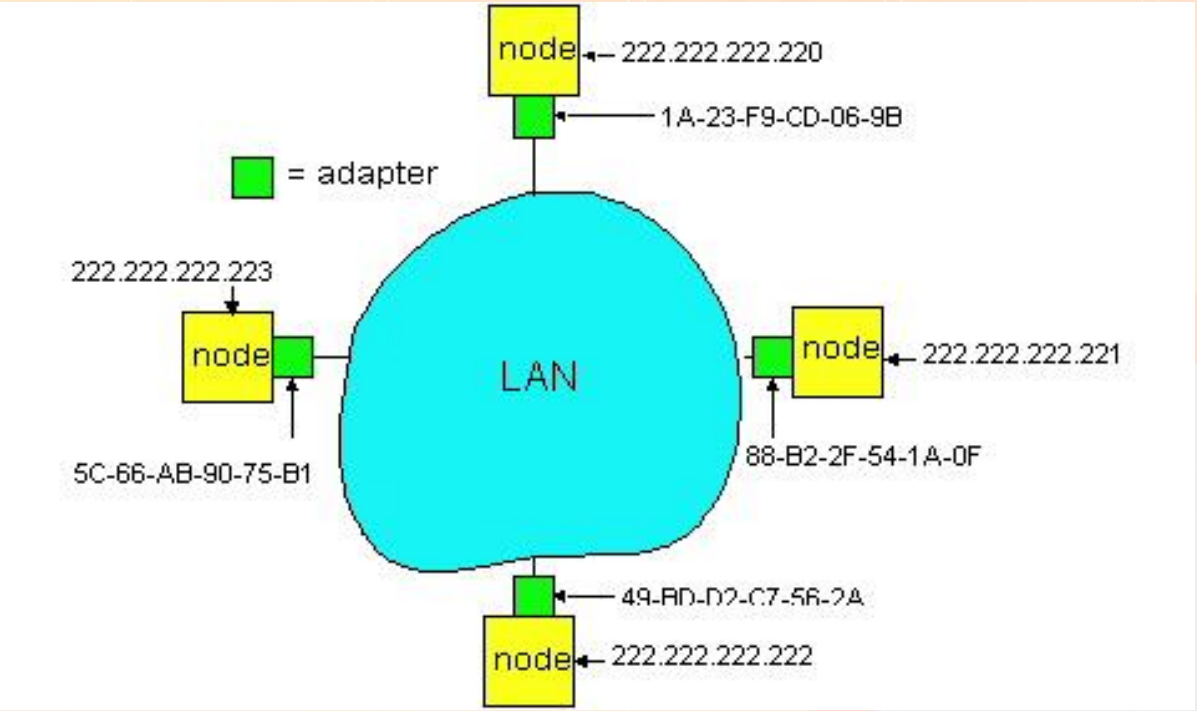
- look up net. address of B, find B on same net. as A
- link layer send datagram to B inside link-layer frame





ARP: Address Resolution Protocol

***Question**: How to determine MAC address of B knowing B's IP address?*



- Each IP node (*host/router*) on LAN has ARP table
- ARP Table: IP/MAC address mappings for some LAN nodes

< IP address; MAC address; TTL>

- TTL (Time To Live): time after which address mapping will be forgotten (typically 20 min)

ARP protocol

- A wants to send datagram to B, and A knows B's IP address.
- Suppose B's MAC address is not in A's ARP table.
- A broadcasts ARP query packet, containing B's IP address
  - all machines on LAN receive ARP query
- B receives ARP packet, replies to A with its (B's) MAC address
  - frame sent to A's MAC address (*unicast*)

A caches (saves) IP-to-MAC address pair in its ARP table until information becomes old (times out)

soft state: information that times out (goes away) unless refreshed

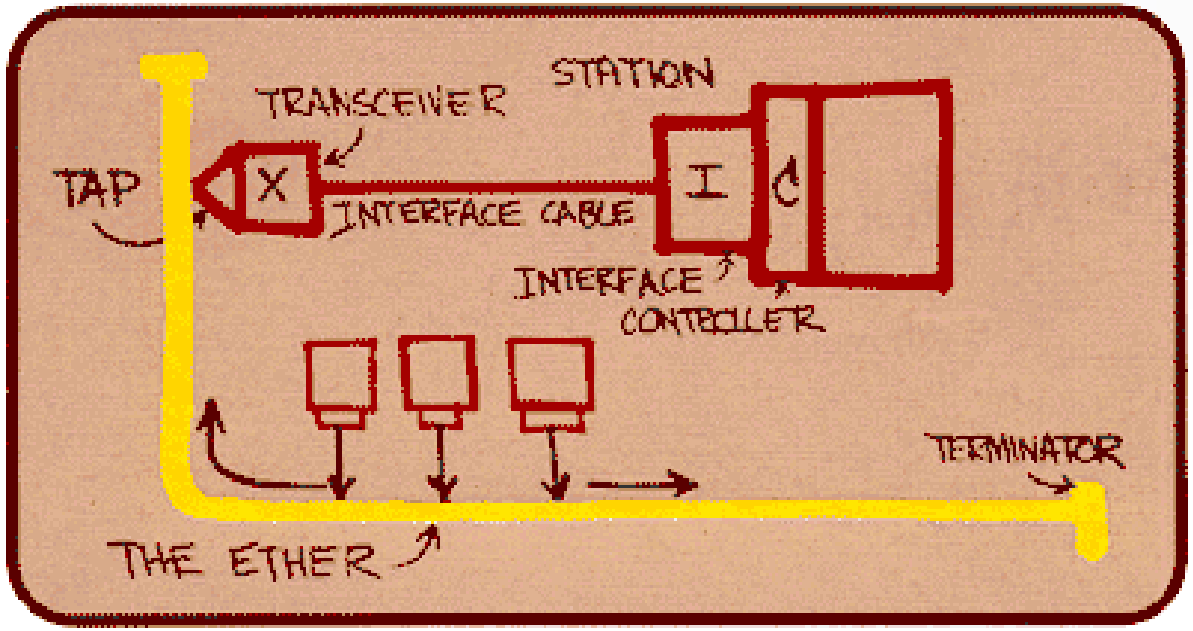
ARP is "plug-and-play":

nodes create their ARP tables without intervention from net administrator

Ethernet

"dominant" LAN technology:

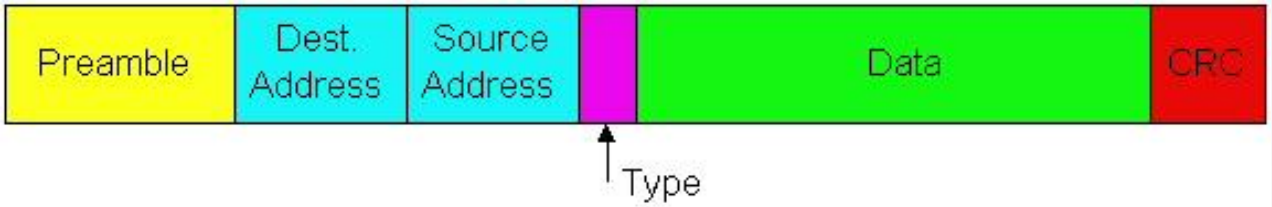
- cheap $20 for 100Mbps !
- first widely used LAN technology
- Simpler, cheaper than token LANs and ATM
- Kept up with speed race: 10,100,1000 Mbps, 10 Gbps



Metcalfe's Ethernet sketch

Ethernet Frame Structure

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

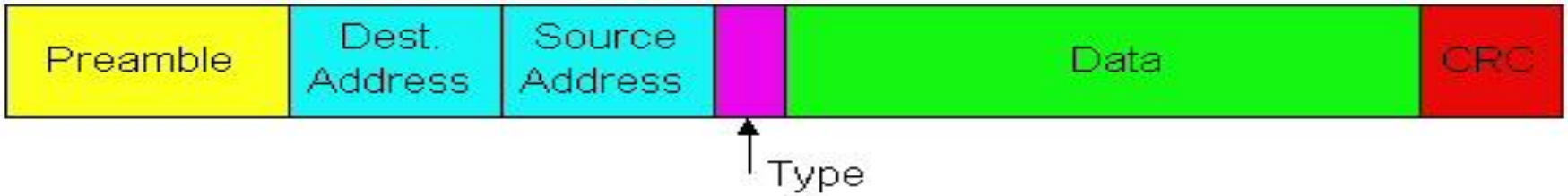


Preamble:

- 7 bytes with pattern 10101010 followed by one byte with pattern 10101011
- used to synchronize receiver, sender clock rates

Ethernet Frame Structure (more)

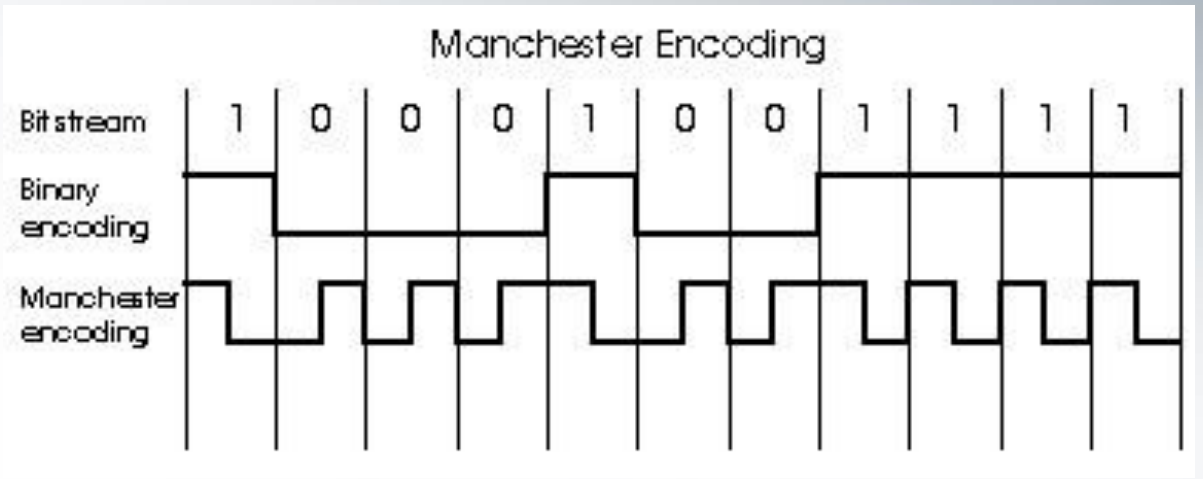
- Addresses: 6 bytes
  - if adapter receives frame with matching destination address, or with broadcast address (e.g. ARP packet), it passes data in frame to network layer protocol
  - otherwise, adapter discards frame
- Type: indicates the higher layer protocol, mostly IP but others may be supported such as Novell IPX and AppleTalk)
- CRC: checked at receiver, if error is detected, the frame is simply dropped



Unreliable, connectionless service

- Connectionless: No handshaking between sending and receiving adapter.
- Unreliable: receiving adapter doesn't send *acks* or *nacks* to sending adapter
  - stream of datagrams passed to network layer can have gaps
  - gaps will be filled if app is using TCP
  - otherwise, app will see the gaps

Manchester Encoding



- Used in 10BaseT, 100BaseT, 1000 BaseT
- Each bit has a transition
- Allows clocks in sending and receiving nodes to synchronize to each other
  - no need for a centralized, global clock among nodes!
- This is physical-layer stuff ! (more later)

Gigabit Ethernet

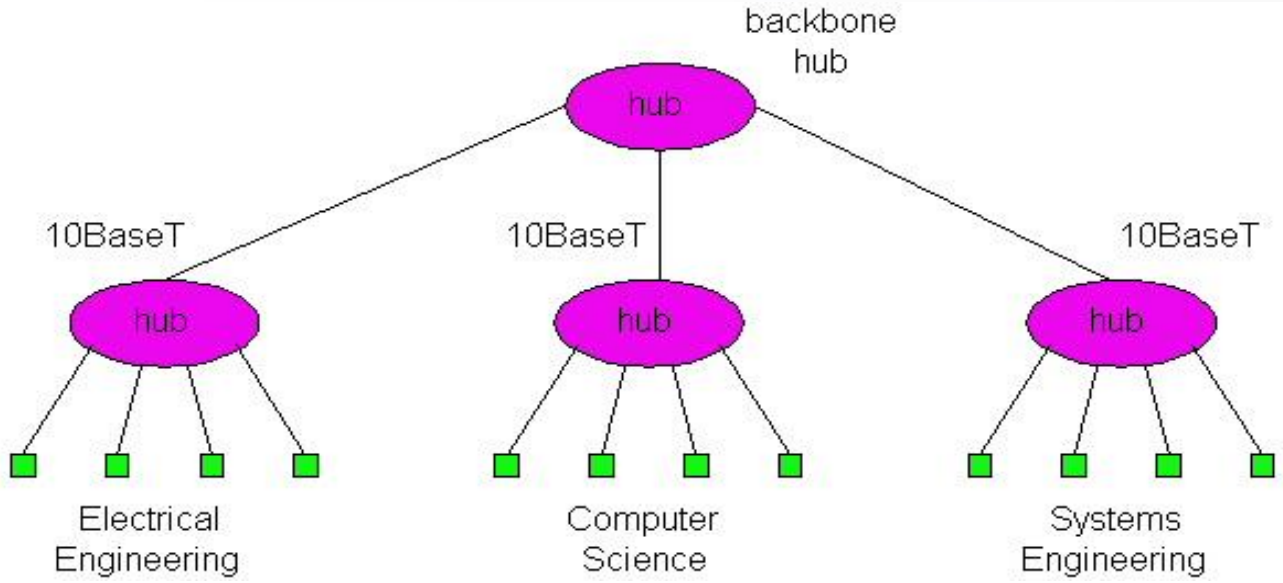
- use standard Ethernet frame format
- allows for point-to-point links and shared broadcast channels
- in shared mode, CSMA/CD is used; short distances between nodes to be efficient
- uses hubs, called here “Buffered Distributors”
- Full-Duplex at 1 Gbps for point-to-point links
- 10, 40, 100 Gbps now !!!

Interconnecting LAN segments

- Hubs
- Bridges
- Switches
  - Remark: switches are essentially multi-port bridges.
  - What we say about **bridges** also holds for **switches**!

Interconnecting with hubs

- Backbone hub interconnects LAN segments
- Extends max distance between nodes
- But individual segment collision domains become one large collision domain
  - if a node in CS and a node EE transmit at same time: collision
- Can't interconnect 10BaseT & 100BaseT

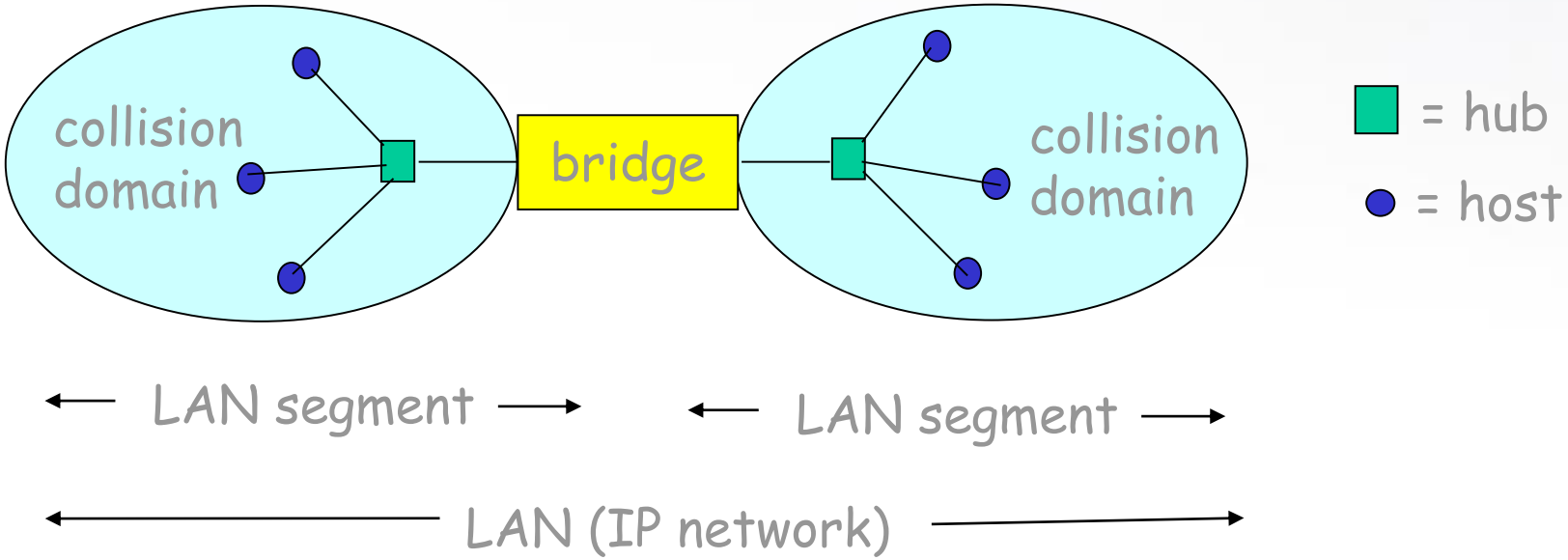


Bridges

- **Link layer device**
  - stores and forwards Ethernet frames
  - examines frame header and selectively forwards frame based on MAC destination address
  - when frame is to be forwarded on segment, uses CSMA/CD to access segment
- transparent
  - hosts are unaware of presence of bridges
- plug-and-play, self-learning
  - bridges do not need to be configured

Bridges: traffic isolation

- Bridge installation breaks LAN into LAN segments
- bridges filter packets:
  - same-LAN-segment frames not usually forwarded onto other LAN segments
  - segments become separate collision domains



Self learning

- A bridge has a bridge or forwarding table
- entry in bridge table:
  - (*Node LAN Address, Bridge Interface, Time Stamp*)
  - stale entries in table dropped (TTL can be 60 min)
- bridges *learn* which hosts can be reached through which interfaces
  - when frame received, bridge "learns" location of sender: incoming LAN segment
  - records sender/location pair in forwarding table

Filtering / Forwarding

When bridge receives a frame:

index bridge table using MAC dest address

if entry found for destination

then{

if dest on segment from which frame arrived

then drop the frame

else forward the frame on interface indicated

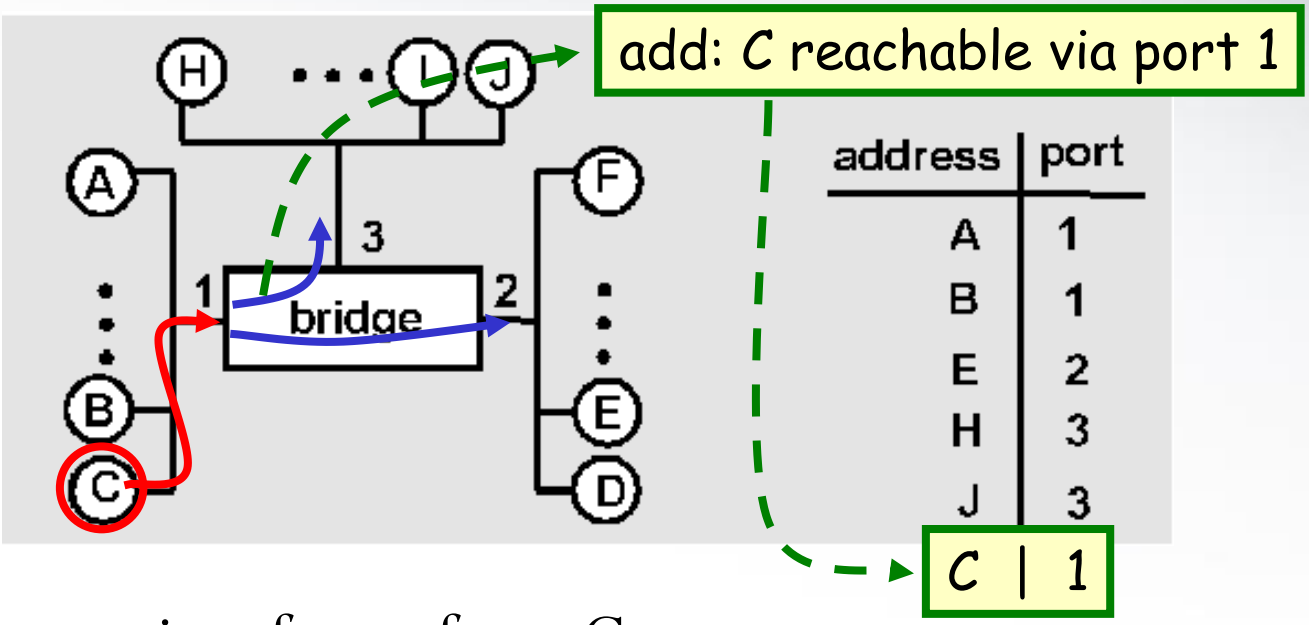
}

else flood

forward on all but the interface on which the frame arrived

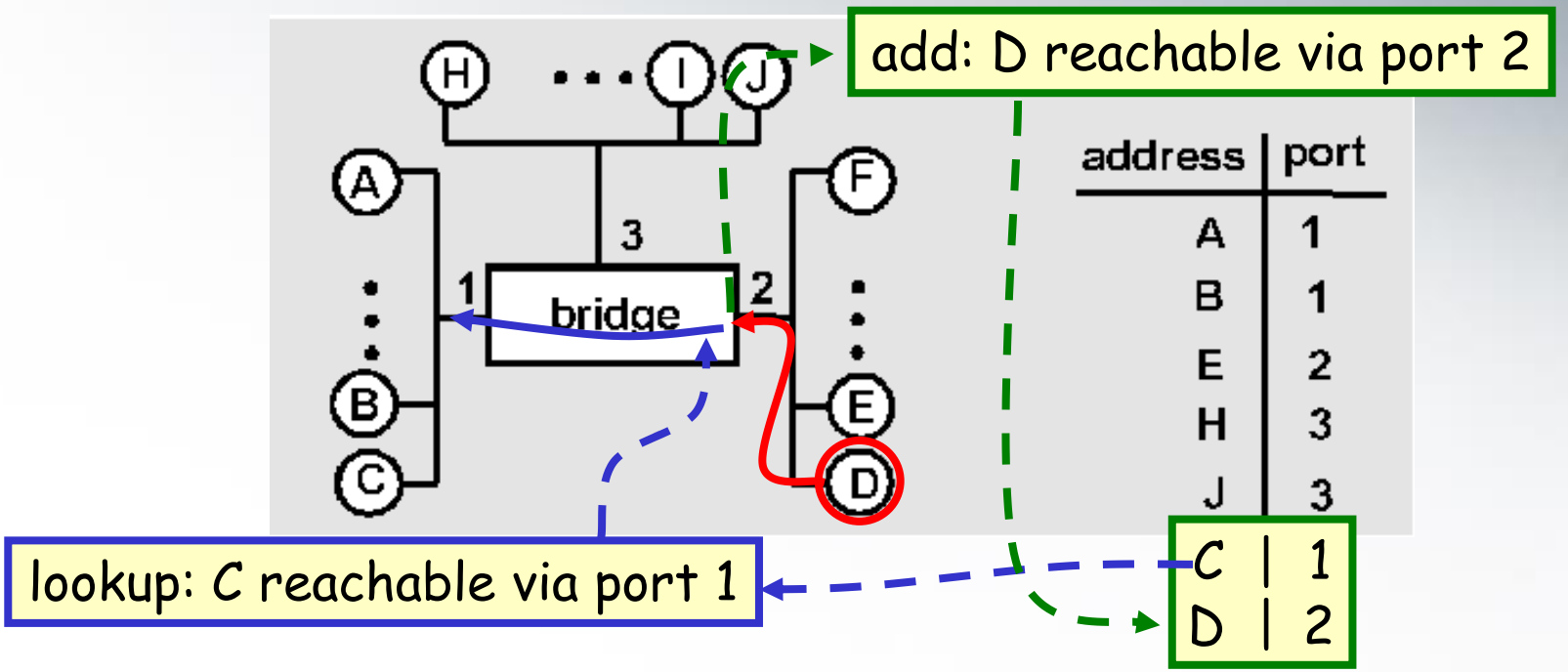
Bridge Learning: example

Suppose C sends frame to D and D replies back with frame to C.



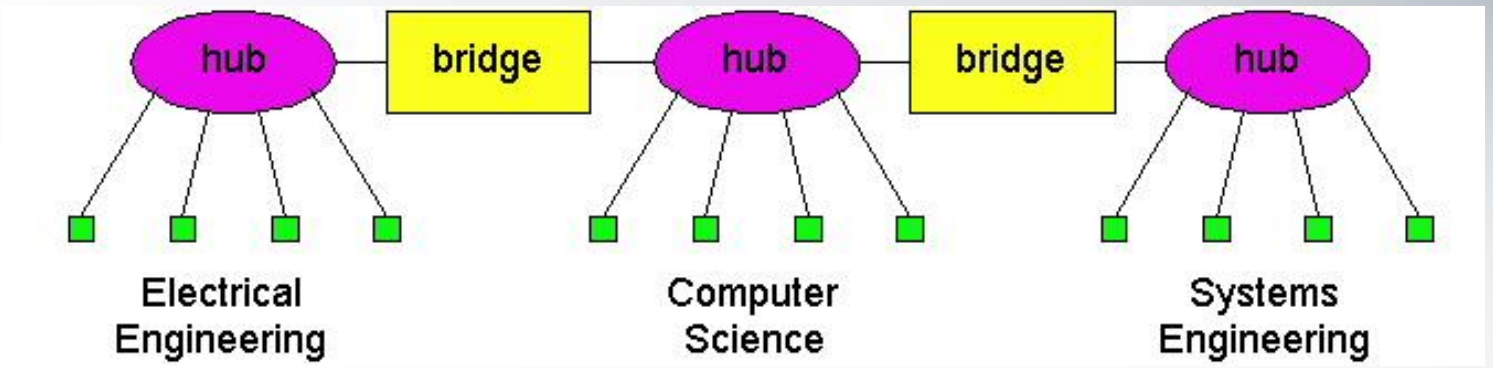
- Bridge receives frame from C
  - Insert entry in bridge table that C is on interface 1
  - because D is not in table, bridge sends frame into interfaces 2 and 3 (flooding)
- frame received by D

Bridge Learning: example



- D generates frame for C, sends
- bridge receives frame
  - Insert entry in bridge table that D is on interface 2
  - bridge knows C is on interface 1, so *selectively* forwards frame to interface 1

Interconnection without backbone

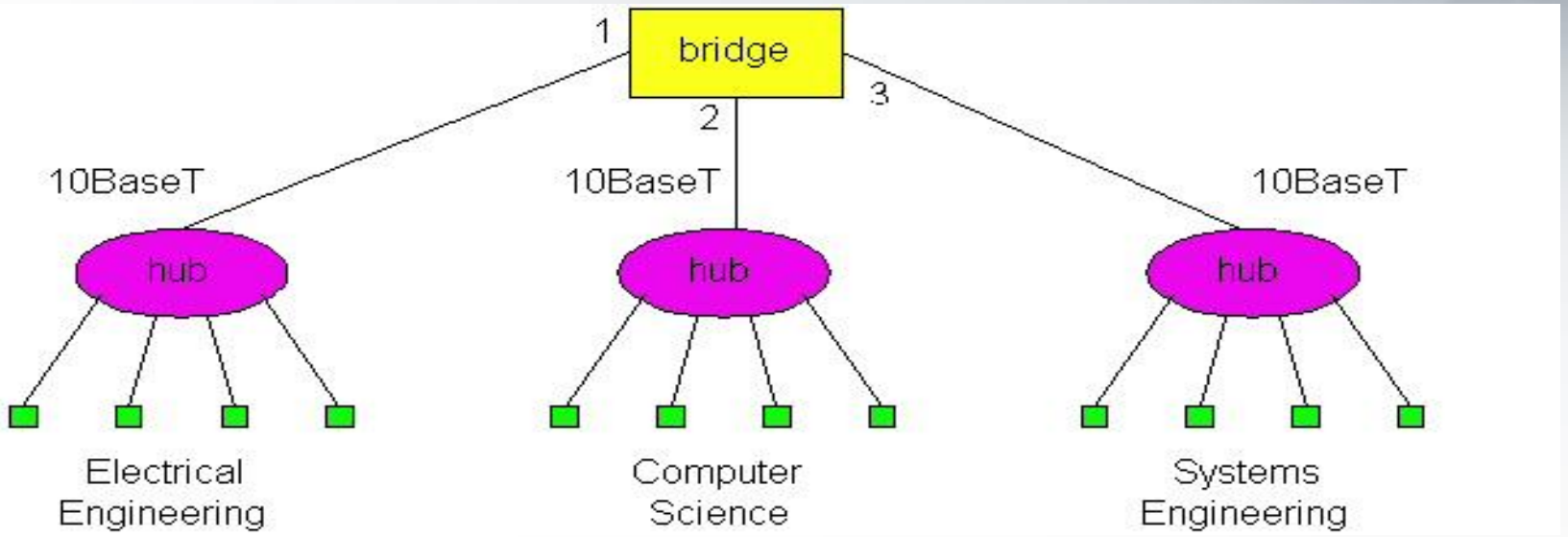


- Not recommended for two reasons:

- single point of failure at Computer Science hub

- all traffic between EE and SE must pass through the CS segment

Backbone configuration



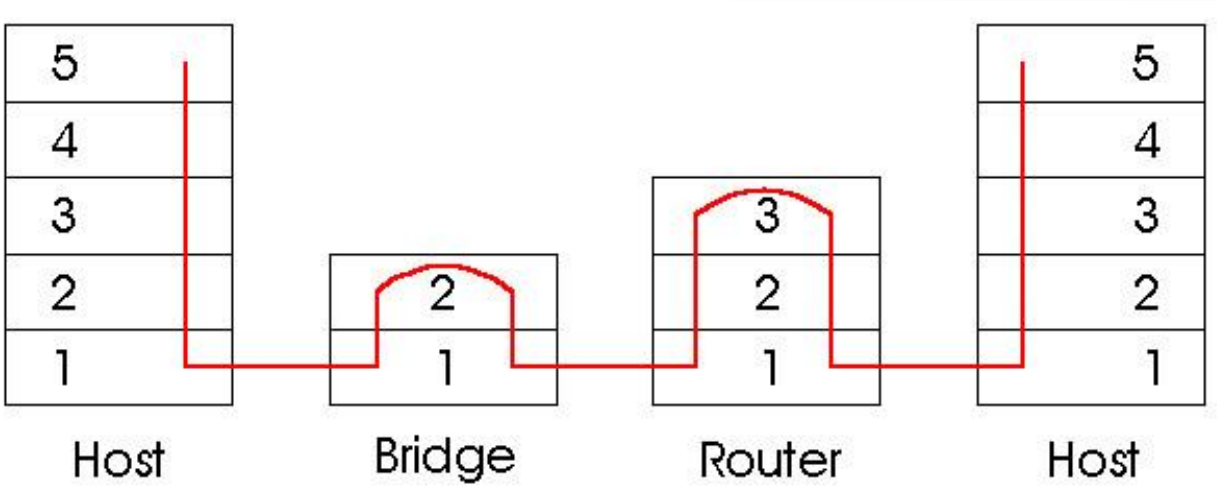
Recommended !

Some Bridge features

- Isolates collision domains resulting in higher total maximum throughput
- limitless number of nodes and geographical coverage
- Can connect different Ethernet types
- Transparent (“plug-and-play”): no configuration necessary

Bridges vs. Routers

- ***Both*** store-and-forward devices
  - routers: network layer devices (examine network layer headers)
  - bridges are link layer devices
- ***Routers*** maintain routing tables, implement routing algorithms
- ***Bridges*** maintain bridge tables, implement filtering, learning and spanning tree algorithms



Routers vs. Bridges

Bridges + and -

+ Bridge operation is simpler requiring less packet processing

+ Bridge tables are self learning

- All traffic confined to spanning tree, even when alternative bandwidth is available

- Bridges do not offer protection from *broadcast storms*

Routers vs. Bridges

Routers + and -

+ arbitrary topologies can be supported, cycling is limited by TTL counters (and good routing protocols)

+ provide protection against broadcast storms

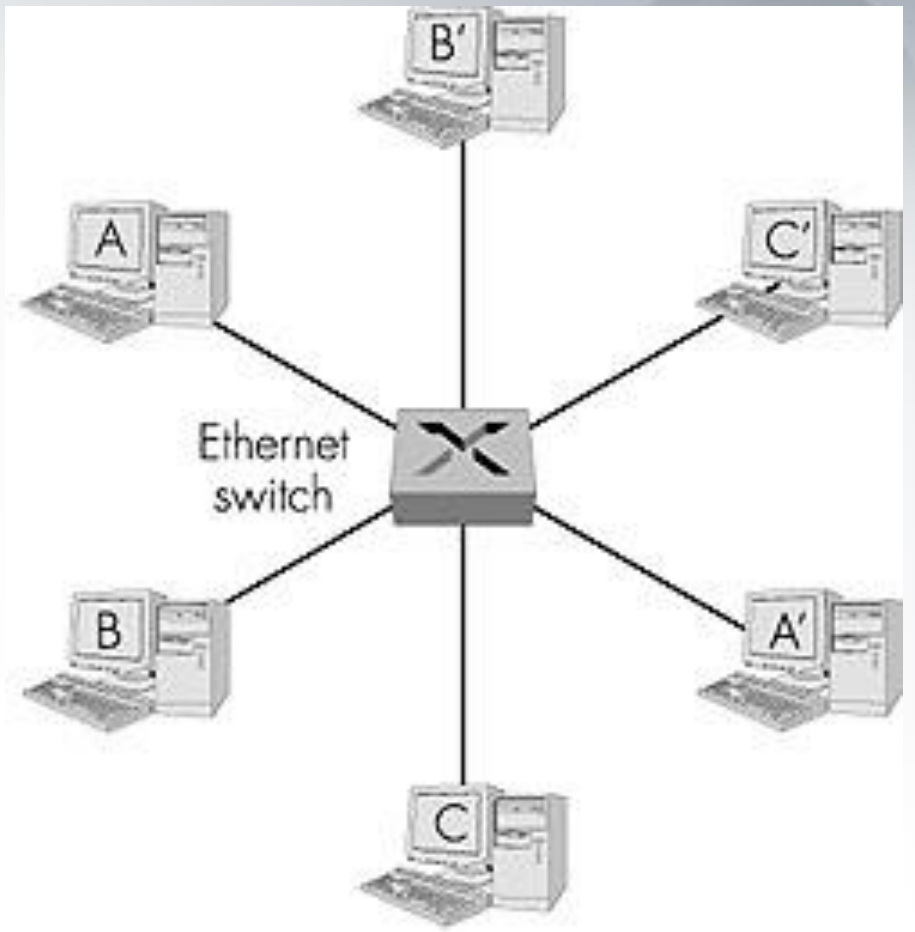
- require IP address configuration (not plug and play)

- require higher packet processing

- bridges do well in small (few hundred hosts) while routers used in large networks (thousands of hosts)

Ethernet Switches

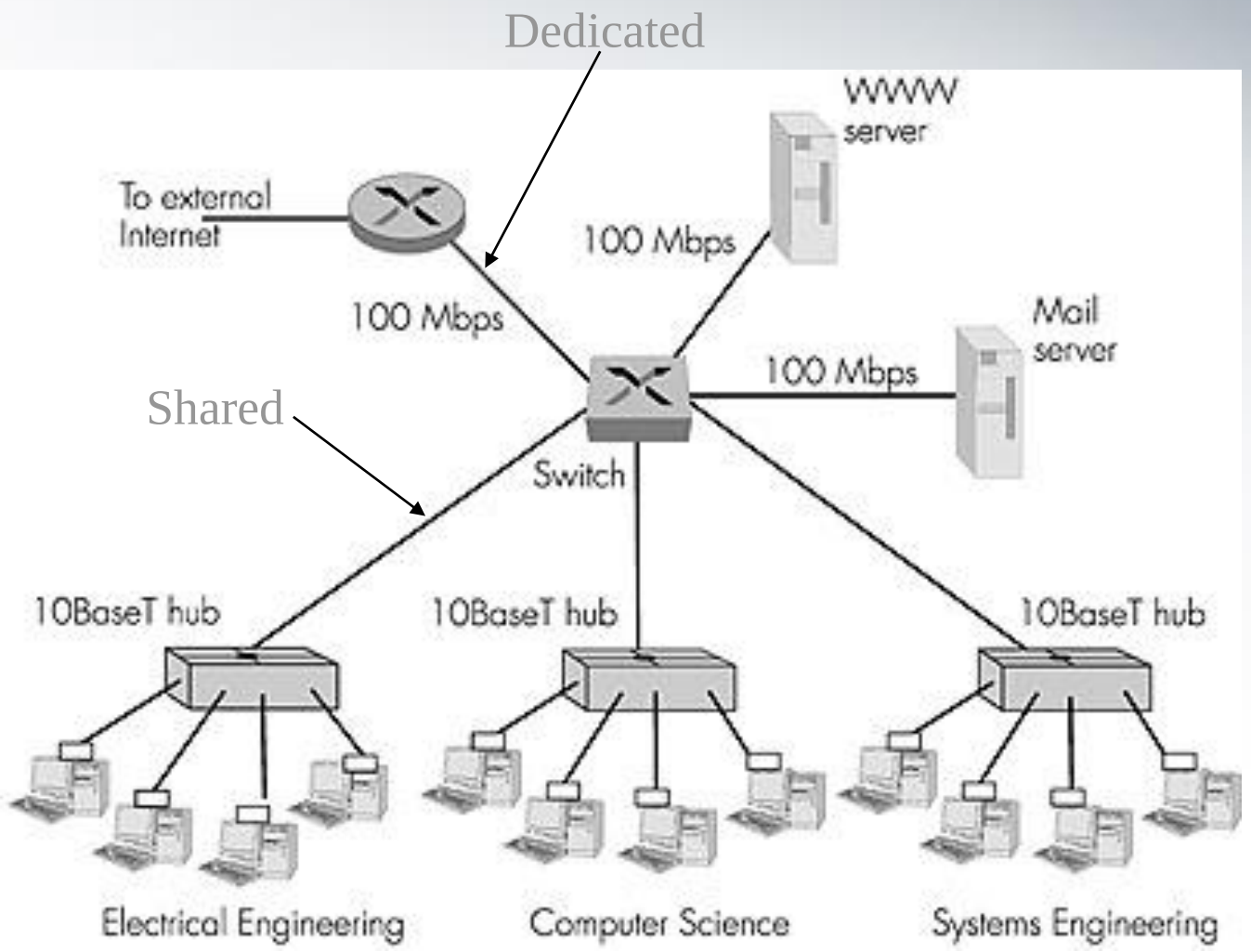
- Essentially a multi-interface bridge
- layer 2 (frame) forwarding, filtering using LAN addresses
- Switching: A-to-A' and B-to-B' simultaneously, no collisions
- large number of interfaces
- often: individual hosts, star-connected into switch
  - Ethernet, but no collisions!



Ethernet Switches

- cut-through switching: frame forwarded from input to output port without awaiting for assembly of entire frame
  - slight reduction in latency
- Store-N-Forward switching: frame buffered completely and error-checked (via CRC) before being forwarded.

A typical LAN (IP network)



Summary comparison

	hubs	bridges	routers	switches
traffic isolation	no	yes	yes	yes
plug & play	yes	yes	no	yes
optimal routing	no	no	yes	no
cut through	yes	no	no	yes