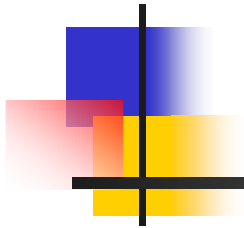


LAN Interconnection



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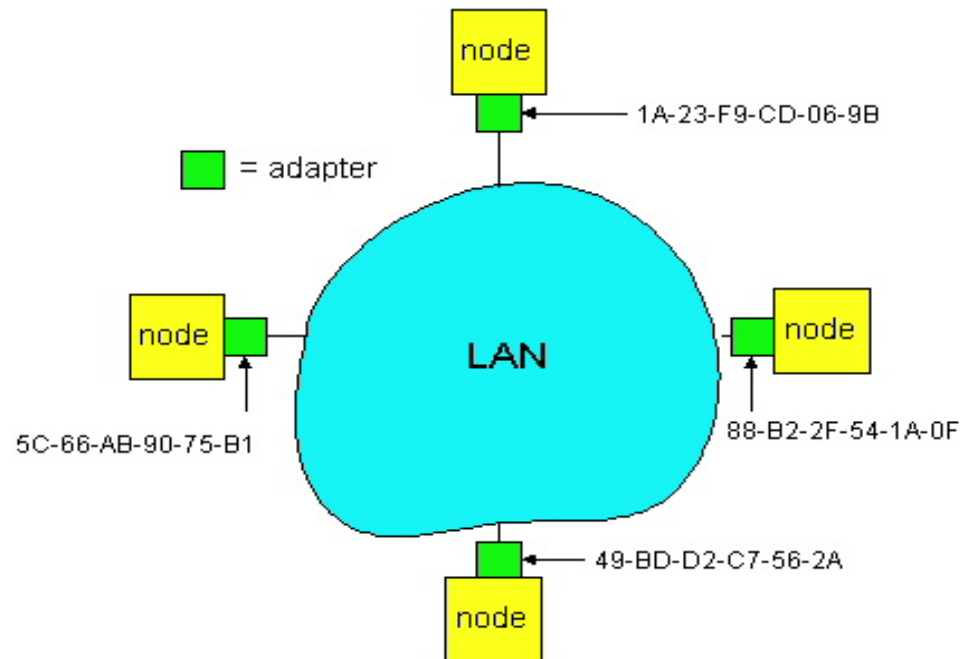
Ethernet

- “dominant” link layer technology for local-area networks
- Ethernet frame structure
- Ethernet multiple access control
 - CSMA/CD
 - exponential back-off
 - its efficiency
- At different speed: 10, 100, 1000 Mbps

Link-layer Addresses

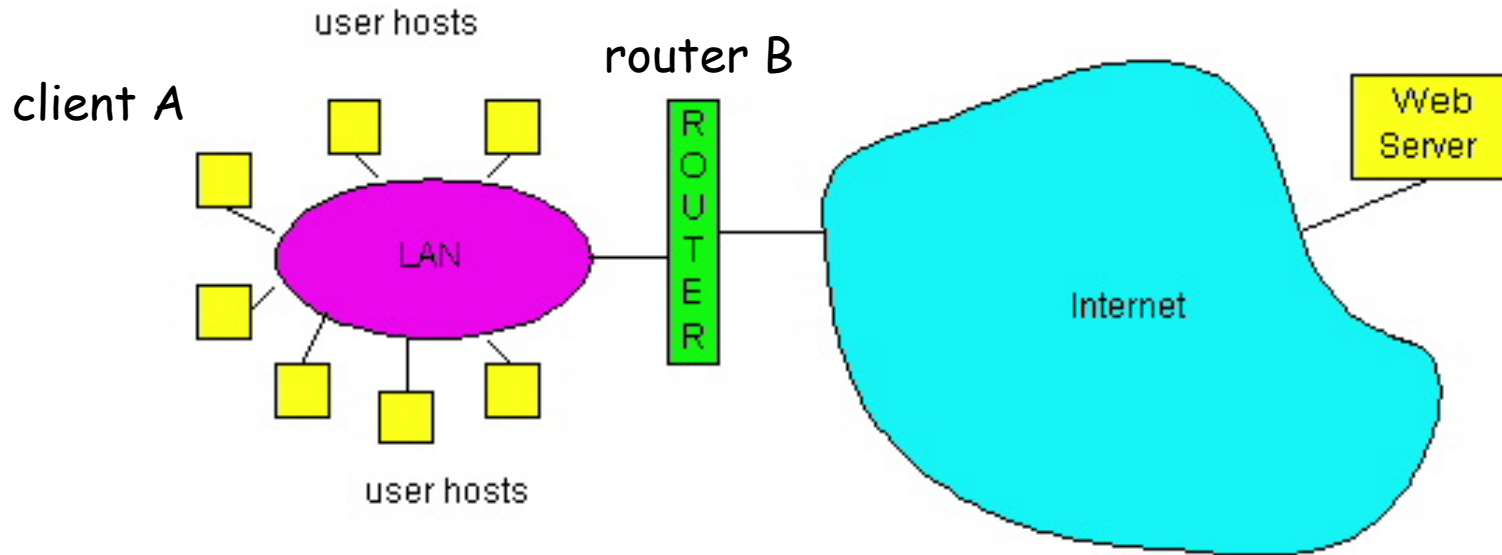
Link-layer (or MAC, LAN) address:

- uniquely identifying each node (or adapter) connected to a shared link
- Universally unique
- Coexistence of link-layer addresses and network-layer addresses.



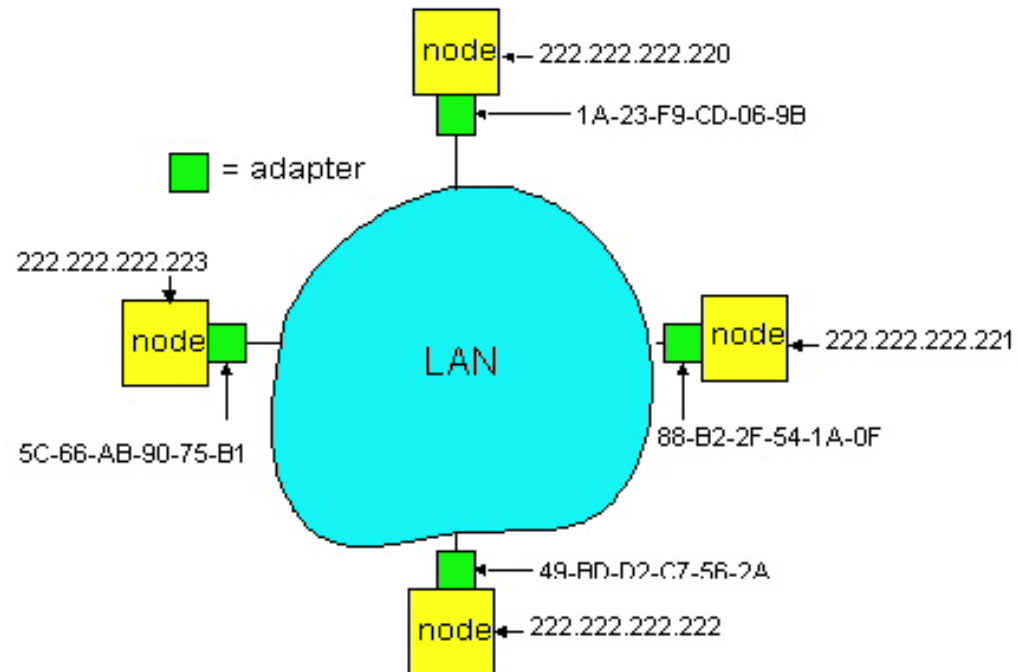
A Problem

Question: how to determine B's link-layer address knowing B's IP address?



ARP: Address Resolution Protocol

- Specific to Internet Architecture
- Each node (Host, Router) on LAN has **ARP** table
- ARP Table: IP/Link-layer address mappings for some LAN nodes
<IP addr; Link-layer addr>



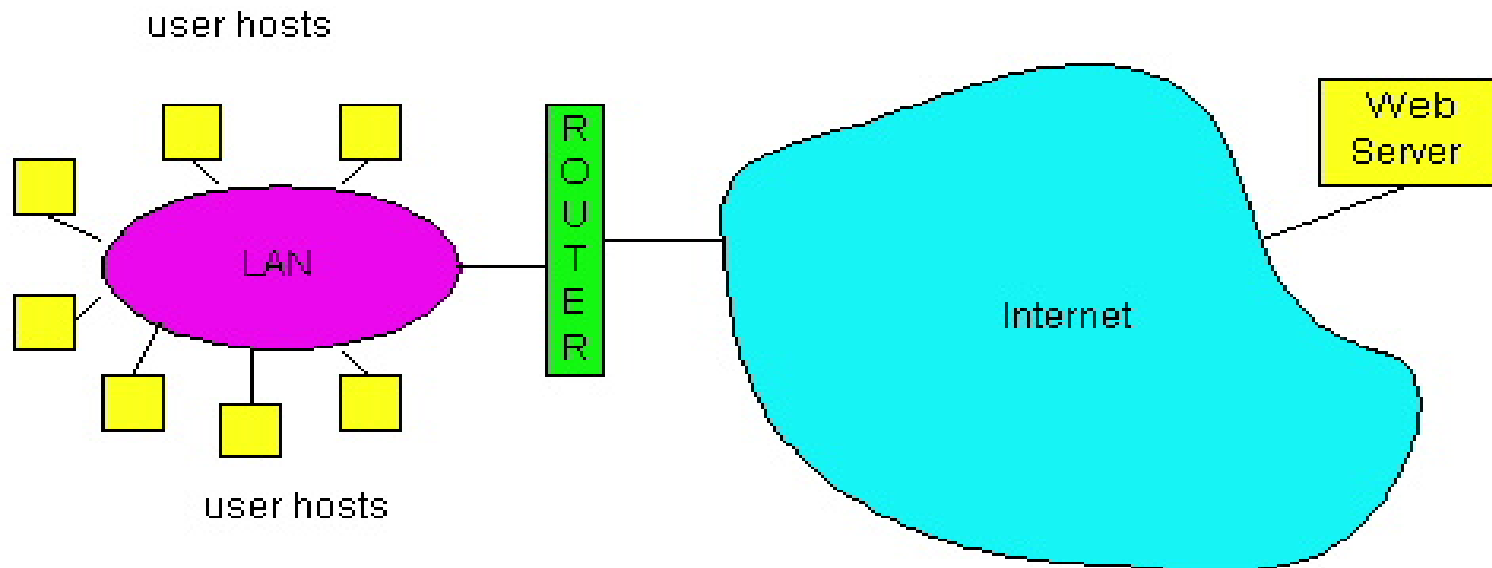
How does ARP work?

- First principle: no manual configuration - "plug-and-play"; must deal with dynamic network changes
 - A wants to send datagram to B with an IP address.
 - Suppose B's link-layer address is not in A's ARP table.
 - A **broadcasts** ARP query packet, containing B's IP address.
 - B receives ARP packet, replies to A with its (B's) link-layer address.
 - A caches (saves) IP-to-link-layer address pair in its ARP table until it times out
 - when can a mapping change?
- Go to any Linux machine at the lab:

 - `"/sbin/arp"` shows the current ARP table;
 - ping any node not in the table, then see the ARP table again.

Interconnecting Nodes in LAN (Local-Area Network)

- Hubs and Repeaters: physical-layer signal regenerators.
- Bridges: understands link-layer (Ethernet) addressing and forwarding - must be smarter than hubs
- Switches: essentially bridges with large number of ports.



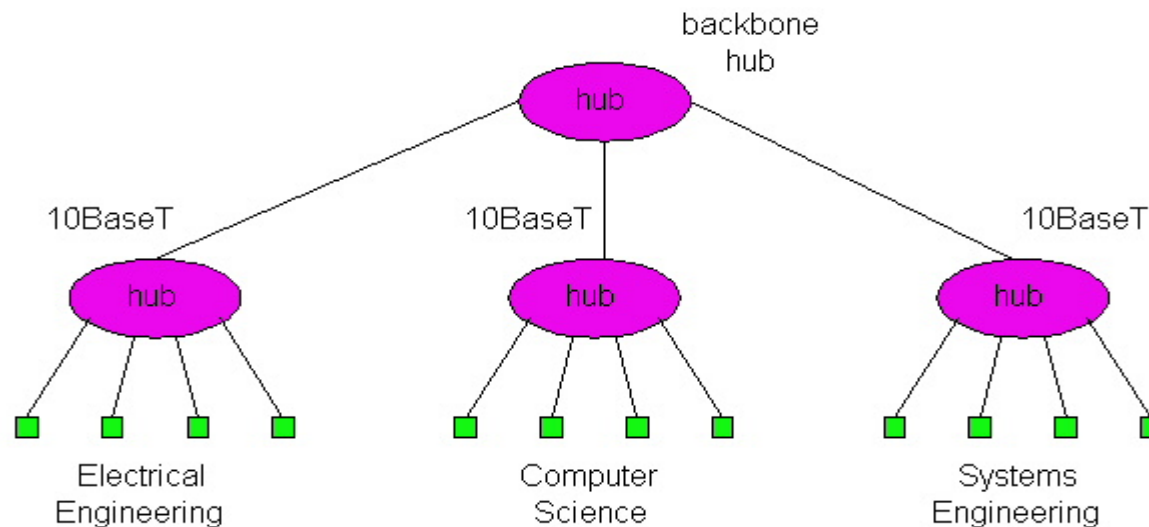
Interconnecting with Hubs

- **Physical-layer** repeater

- Repeat signal on all outgoing links
- Doesn't care whether links are busy or not
- No buffering

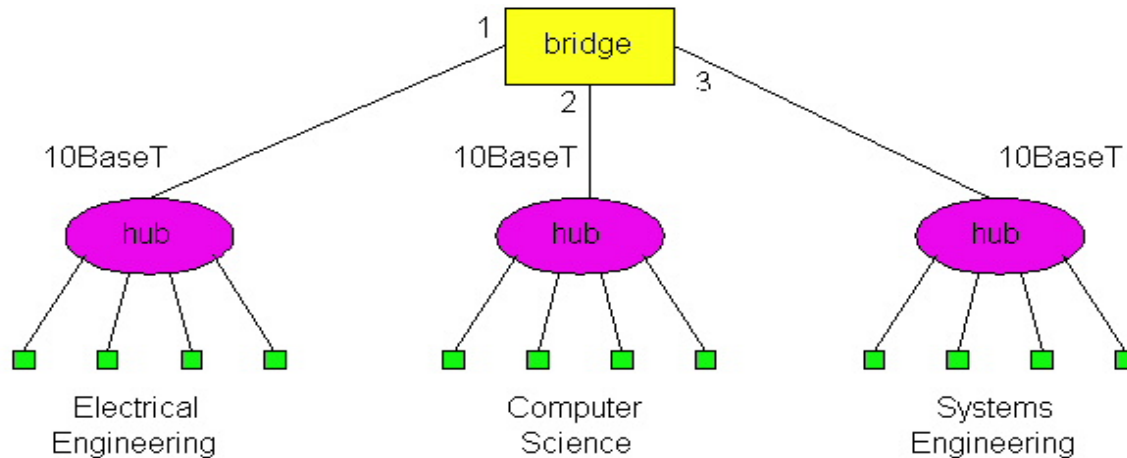
- Problems:

- Simultaneous traffic from multiple segments may collide
- Can't interconnect links at different speed



Bridges

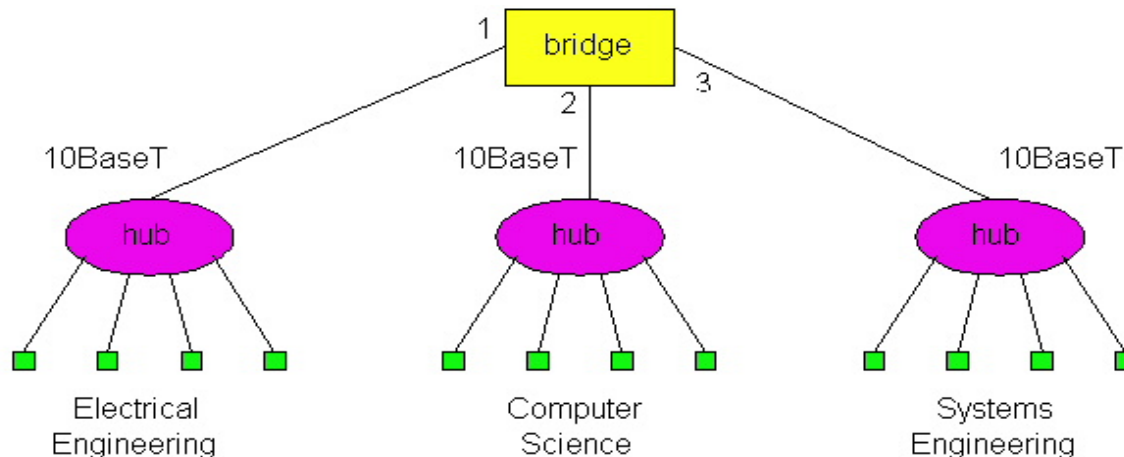
- **Link layer** device
 - stores and forwards Ethernet frames
 - examines frame header and **selectively** forwards frame based on dest. address
 - when frame is to be forwarded to a network segment, uses CSMA/CD to access segment



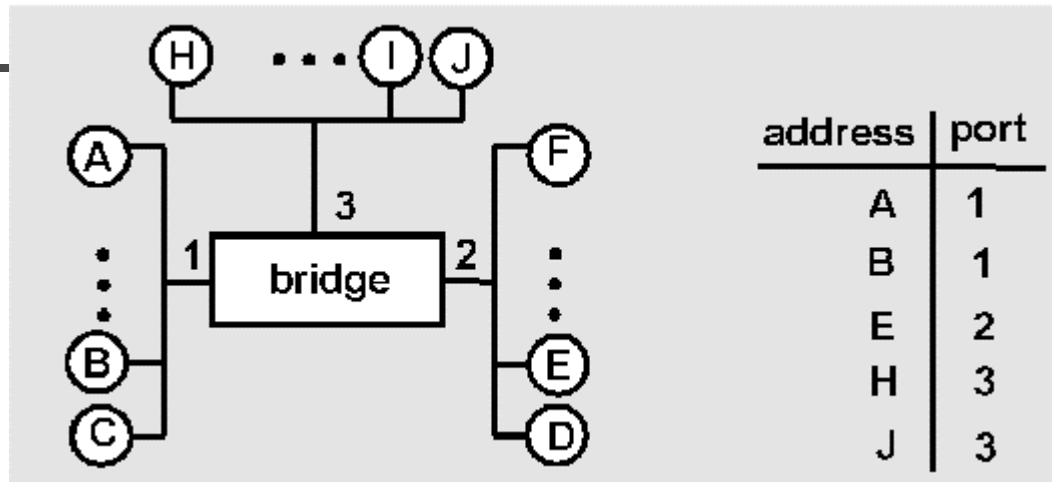
How to determine to which LAN segment to forward frame?

Self Learning

- A bridge has a **bridge table**
 - each entry: (Dest. address, bridge interface, timestamp)
 - stale entries in table are dropped
- bridges **learn** which host is connected through which interface
 - when frame received, bridge "learns" location of sender: incoming LAN segment
 - records sender/location pair in bridge table



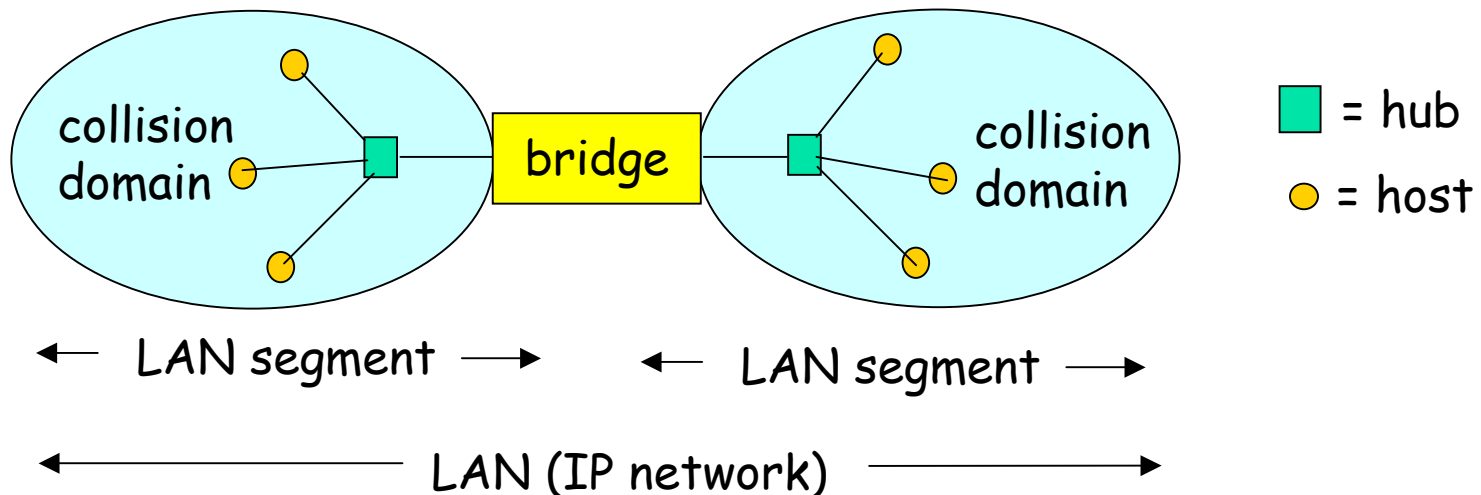
Bridge Example



- Bridge receives frame from C destined to D
 - bridge learns C is on interface 1
 - because D is not in table, bridge floods
- Another frame from C to D?
- Frame received by D, then a reply is sent back to C
 - bridge learns D is on interface 2
 - in bridge table C is on interface 1, so bridge **selectively** forwards frame to interface 1

Bridges: Traffic Isolation

- Bridge understands and participates in CSMA/CD
- 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**



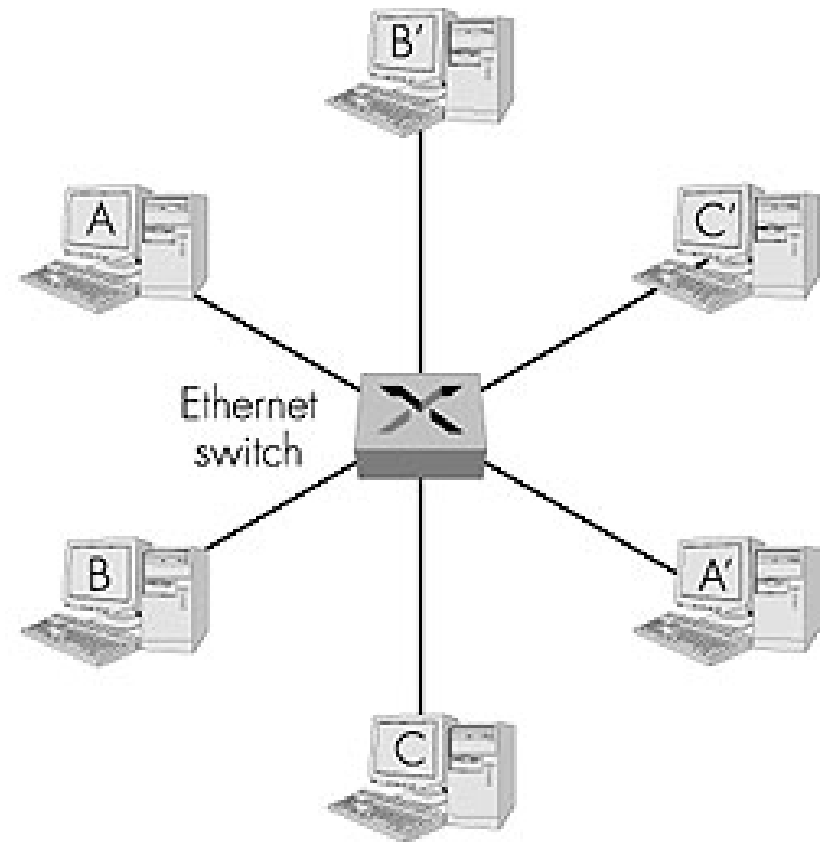


Important Bridge Features

- Transparent (“plug-and-play”): no configuration necessary
- Isolates collision domains resulting in higher total max throughput
- Buffering allow links of different speed on a single bridge: 10/100/1000 Mbps interfaces

Ethernet Switches

- essentially a bridge with a large number of ports
 - ⇒ so many ports that each host can connect to one
 - require high interval bandwidth ⇒ costly to build
- After self-learning
 - A-to-A' and B-to-B' simultaneously, no collisions
 - Ethernet, but a shared link with dedicated channel to every node, no collisions!

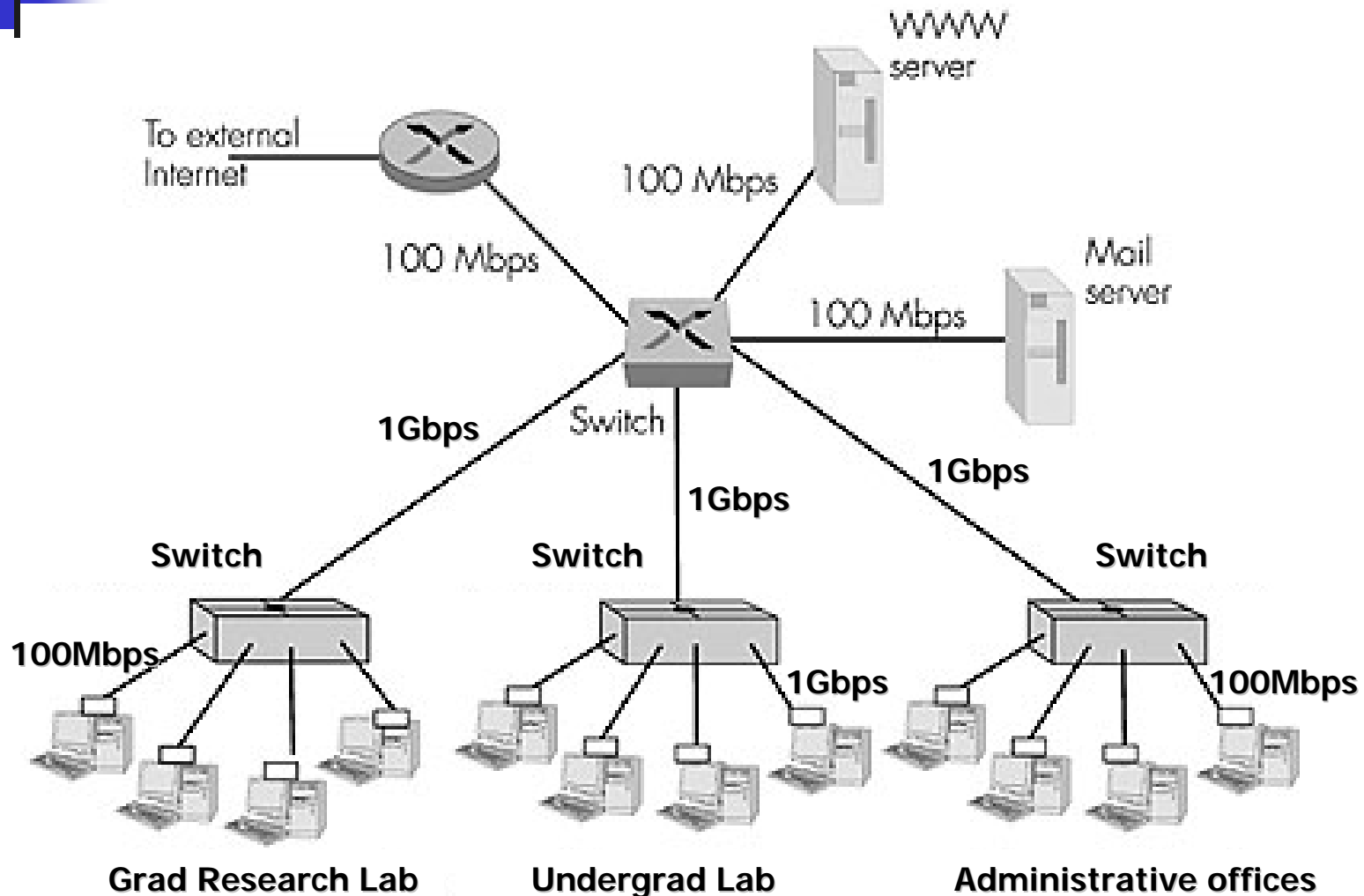




Ethernet Switches (cont.)

- switch allows simultaneous traffic at full link speed
 - even if each link can operate at full speed, congestion can still occur
- forwarding technologies:
 - **stop and forward**: frame is completely buffered before forwarded to the next hop
 - **cut-through switching**: frame forwarded from input to output port without awaiting for assembly of entire frame
 - reduction in latency
 - can we start forwarding after the first bit is received?

Switch Interconnection





Redundant Switch Paths

- Channel Bonding:
 - Switches can be configured to aggregate traffic over multiple parallel links (channel bonding).
- Backup:
 - Broadcast networks can't have cycles – must have tree topology
 - When switch ports are initialized, STP (Spanning Tree Protocol) identifies redundant (backup) links in switched network, disables them, monitors interswitch links, on primary link failure enables backup links.

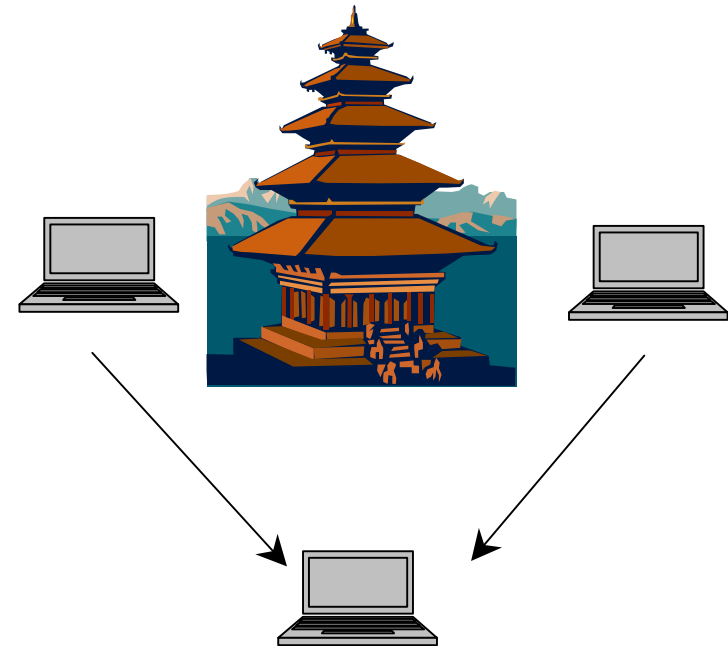


Summary Comparison

- Hubs
 - little more than a physical-layer signal repeater, no traffic isolation, buffering
- Bridges
 - understands link-layer protocol (Ethernet), supports smarter forwarding, traffic isolation
 - supports different Ethernet speeds with buffering
- Switches
 - essentially bridges with large number of ports
 - no collision, but congestion is possible at individual links
 - widespread usage today!

Media Access Control in Wireless LAN -- IEEE 802.11

- Collision if 2 or more nodes transmit at same time
- MAC efficiency goal:
 - get all the bandwidth if you're the only one transmitting
 - share the bandwidth fairly if multiple nodes transmit
- Can we use CSMA/CD?
- Carrier sense and collision detection don't work: **hidden terminal problem**





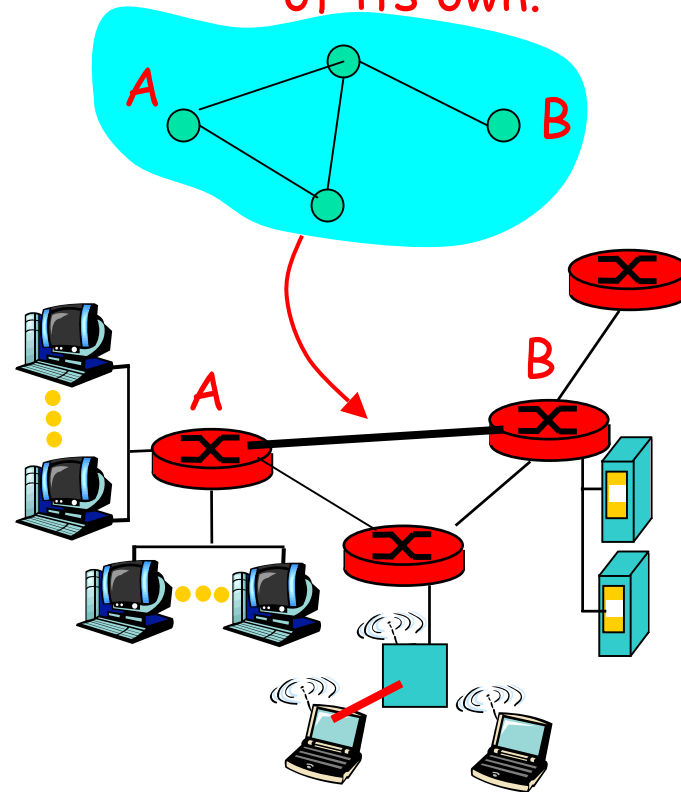
PPP (point-to-point protocol)

- one sender, one receiver, one link:
 - no Media Access Control
 - no need for explicit MAC addressing
 - simpler than broadcast link
- deployed in
 - dialup links over telephone lines
 - long-haul fiber-optics links

Link Virtualization (concept)

- Virtual link
 - virtual communication channel between two Internet nodes
 - the virtual link may not be a single physical wire

The virtual link is composed of a network of its own.





Link Virtualization (practices)

- ATM (asynchronous transfer mode)
 - a multilayer network architecture of its own
 - mainly designed for supporting real-time multimedia, with connection-oriented resource reservation
 - deemed as link layer protocols in Internet architecture → IP over ATM
- Frame relay
 - origins in telephony world
 - Like ATM, a network architecture of its own, with connection-oriented resource reservation
 - can be used to carry IP datagrams → IP over frame relay
- MPLS (multiprotocol label switching)
 - Add a fixed-length header to frame, with label similar to virtual circuit identifier
 - Label management static or dynamic (via resource-reservation protocol)
 - Use for traffic engineering or virtual network routing



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