

## More on Link Layer

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1

## Recap of Last Class

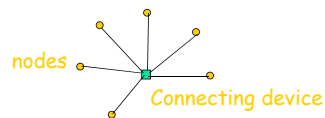
- Ethernet
  - dominant link layer technology for local-area networks
  - Ethernet frame size
  - Ethernet multiple access control
    - CSMA/CD, exponential back-off
    - factors for its efficiency
  - Speed: 10Mbps, 100Mbps, 1Gbps, 10Gbps, ...
- Link-layer addresses
  - Static per-device, universally unique
  - Why multiple addresses at multiple layers?
  - ARP

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2

## Interconnecting Nodes in Local-Area Networks



- Hubs: physical-layer signal repeaters.
- Bridges: smarter, understands link-layer protocol (Ethernet).
- Switches: essentially bridges with large number of ports.

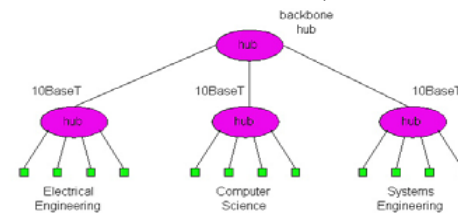
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3

## 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 speeds



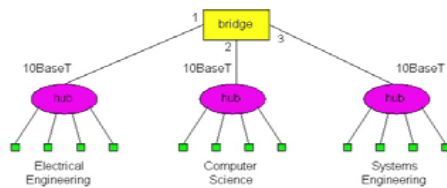
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4

## Bridges

- **Link layer** device
  - understands and participates in Ethernet
  - buffers frame, uses CSMA/CD to access link
  - traffic isolation  $\Rightarrow$  **selectively** forwards frame based on dest. address (avoid flooding all links)



How to determine to which LAN segment to forward frame?

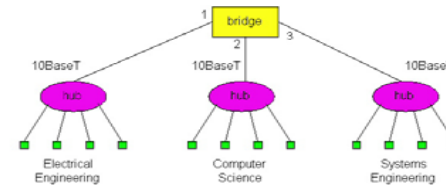
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5

## Self Learning

- A bridge has a **bridge table**
  - each entry: (Dest. address, bridge interface, timestamp)
- 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

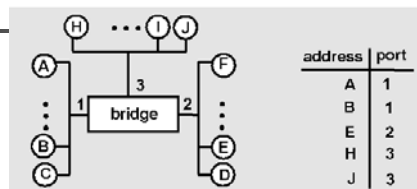


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6

## 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

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7

## Bridge Forwarding

- When to start forwarding?
- **stop and forward**: frame is completely buffered before forwarded to the next hop
- **cut-through forwarding**: frame forwarded from input to output port without waiting for assembly of entire frame
  - reduction in latency
  - implication on Ethernet frame structure?

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8

## Important Bridge Features

- Isolates collision domains resulting in higher total throughput
- “Plug-and-play”: no configuration necessary
- Buffering allow links of different speeds on a single bridge: 100Mbps/1Gbps interfaces
- Cut-through forwarding

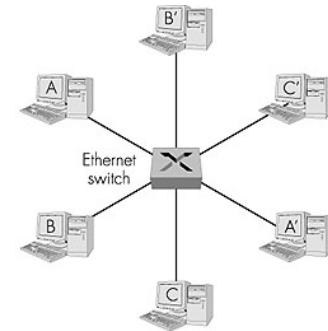
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9

## Ethernet Switches

- Essentially a bridge with a large number of ports  
⇒ so many ports that each host can connect to one
- After self-learning
  - A-to-A' and B-to-B' simultaneously at full link speed, no collisions
  - Ethernet but no collisions for simultaneous uses
  - How about congestion?



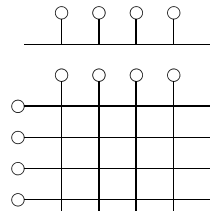
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10

## Ethernet Switch Scalability

- Switch allows simultaneous traffic at full link speed. How does it scale?
- Switch architectures
  - Bus
  - Crossbar
- A switch with a large number of ports
  - High implementation complexity ⇒ costly to build

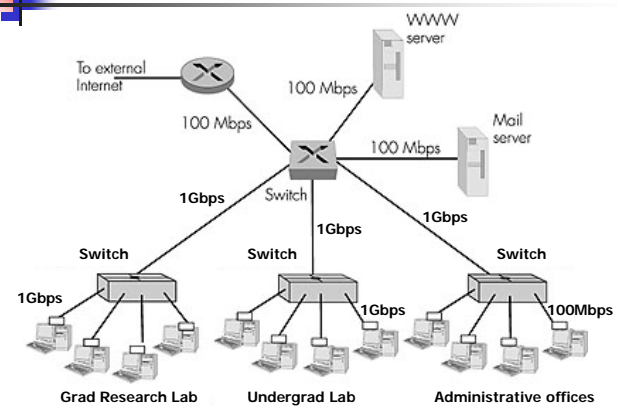


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11

## Switch Interconnection (no enough ports on a single switch)



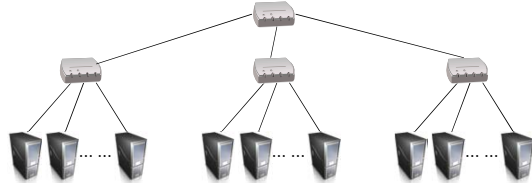
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12

## Network Switching at Multi-Server Data Centers

- Thousands of servers with hierarchical network switching



- Reduce congestions:
  - Network load balance across nodes
  - Place highly communicating server modules within same switch domain, or better yet, in same machines
  - Redundant backbone links → Equal-Cost Multi-Path (ECMP) routing

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13

## 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!

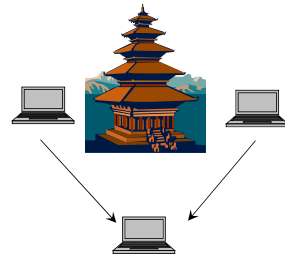
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14

## Media Access Control in Wireless LAN -- IEEE 802.11

- Collision if 2 or more nodes transmit at same time
- Can we use CSMA/CD?
  - hidden terminal problem ⇒ carrier sense and collision detection don't work
- Repair carrier sense:
  - carrier probing
- Repair collision detection:
  - success acknowledgement



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15

## 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

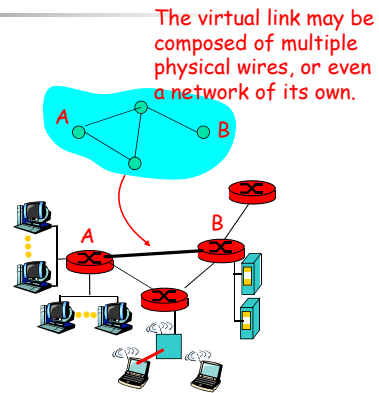
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16

## Link Virtualization

- What is a link?
  - physical wire
  - connection between two IP network-aware nodes
- Virtual link
  - in the case of switched Ethernet?
  - in the case of phone/modem link?
- Why virtual link?
  - flexibility of technology evolution
  - link up legacy networks



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17

## Link Virtualization

- ATM (asynchronous transfer mode)
  - a multilayer network architecture at 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 at its own, with connection-oriented resource reservation
  - can be used to carry IP datagrams → IP over frame relay

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18

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19