Links: physical media

- bit: propagates between transmitter/receiver pairs
- physical link: what lies between transmitter & receiver
- guided media:
 - signals propagate in solid media: copper, fiber, coax
- unguided media:
 - signals propagate freely, e.g., radio

Twisted pair (TP)

- two insulated copper wires
 - Category 5: 100 Mbps, 1 Gbps Ethernet
 - Category 6: 10Gbps Ethernet



Links: physical media

Coaxial cable:

- two concentric copper conductors
- bidirectional
- broadband:
 - multiple frequency channels on cable
 - 100's Mbps per channel



Fiber optic cable:

- glass fiber carrying light pulses, each pulse a bit
- high-speed operation:
 - high-speed point-to-point transmission (10's-100's Gbps)
- Iow error rate:
 - repeaters spaced far apart
 - immune to electromagnetic noise



Links: physical media

Wireless radio

- signal carried in electromagnetic spectrum
- no physical "wire"
- broadcast and "half-duplex" (sender to receiver)
- propagation environment effects:
 - reflection
 - obstruction by objects
 - interference

Radio link types:

- terrestrial microwave
 - up to 45 Mbps channels
- Wireless LAN (WiFi)
 - Up to 100's Mbps
- wide-area (e.g., cellular)
 - 4G cellular: ~ 10's Mbps
- satellite
 - up to 45 Mbps per channel
 - 270 msec end-end delay
 - geosynchronous versus lowearth-orbit

Chapter 1: roadmap

- What is the Internet?
- What is a protocol?
- Network edge: hosts, access network, physical media
- Network core: packet/circuit switching, internet structure
- Performance: loss, delay, throughput
- Security
- Protocol layers, service models
- History



The network core

- mesh of interconnected routers
- packet-switching: hosts break application-layer messages into packets
 - forward packets from one router to the next, across links on path from source to destination
 - each packet transmitted at full link capacity



Packet-switching: store-and-forward



- Transmission delay: takes L/R seconds to transmit (push out) L-bit packet into link at R bps
- Store and forward: entire packet must arrive at router before it can be transmitted on next link
- End-end delay: 2L/R (above), assuming zero propagation delay (more on delay shortly)

One-hop numerical example:

- *L* = 10 Kbits
- *R* = 100 Mbps
- one-hop transmission delay
 = 0.1 msec

Packet-switching: queueing delay, loss



Packet queuing and loss: if arrival rate (in bps) to link exceeds transmission rate (bps) of link for a period of time:

- packets will queue, waiting to be transmitted on output link
- packets can be dropped (lost) if memory (buffer) in router fills up

Two key network-core functions

Forwarding:

local action: move arriving packets from router's input link to appropriate router output link

routing algorithm local forwarding table header value output link 0100 3 0101 2 0111 2 1001 destination address in arriving packet's header

Routing:

 global action: determine sourcedestination paths taken by packets

routing algorithms

Alternative to packet switching: circuit switching

end-end resources allocated to, reserved for "call" between source and destination

- in diagram, each link has four circuits.
 - call gets 2nd circuit in top link and 1st circuit in right link.
- dedicated resources: no sharing
 - circuit-like (guaranteed) performance
- circuit segment idle if not used by call (no sharing)
- commonly used in traditional telephone networks



Circuit switching: FDM and TDM

Frequency Division Multiplexing (FDM)

- optical, electromagnetic frequencies divided into (narrow) frequency bands
- each call allocated its own band, can transmit at max rate of that narrow band

Time Division Multiplexing (TDM)

- time divided into slots
- each call allocated periodic slot(s), can transmit at maximum rate of (wider) frequency band, but only during its time slot(s)





Packet switching versus circuit switching

packet switching allows more users to use network!

Example:

- 1 Gb/s link
- each user:
 - 100 Mb/s when "active"
 - active 10% of time
- circuit-switching: 10 users
- packet switching: with 35 users, probability > 10 active at same time is less than .0004 *



Q: how did we get value 0.0004?*Q:* what happens if > 35 users ?

Packet switching versus circuit switching

Is packet switching a "slam dunk winner"?

- great for "bursty" data sometimes has data to send, but at other times not
 - resource sharing
 - simpler, no call setup
- excessive congestion possible: packet delay and loss due to buffer overflow
 - protocols needed for reliable data transfer, congestion control
- *Q:* How to provide circuit-like behavior?
 - bandwidth guarantees traditionally used for audio/video applications

Q: human analogies of reserved resources (circuit switching) versus on-demand allocation (packet switching)?