Computer Networks

Notes 3

KOÇ UNIVERSITY

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 Gpbs Ethernet
  - Category 6: 10Gbps

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Physical media: coax, fiber

coaxial cable:
- two concentric copper conductors
- bidirectional
- broadband:
  - multiple channels on cable

fiber optic cable:
- glass fiber carrying light pulses, each pulse a bit
- high-speed operation:
  - high-speed point-to-point transmission (e.g., 10's-100's Gpbs transmission rate)
- low error rate:
  - repeaters spaced far apart
  - immune to electromagnetic noise

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Physical media: radio

- signal carried in electromagnetic spectrum
- no physical "wire"
- bidirectional
- propagation environment effects:
  - reflection
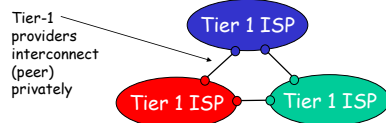 - obstruction by objects
  - interference

radio link types:
- terrestrial microwave
  - e.g. up to 45 Mbps channels
- LAN (e.g., WiFi)
  - 11Mbps, 54 Mbps
- wide-area (e.g., cellular)
  - 3G cellular: ~ few Mbps
- satellite
  - Kbps to 45Mbps channel (or multiple smaller channels)
  - 270 msec end-end delay
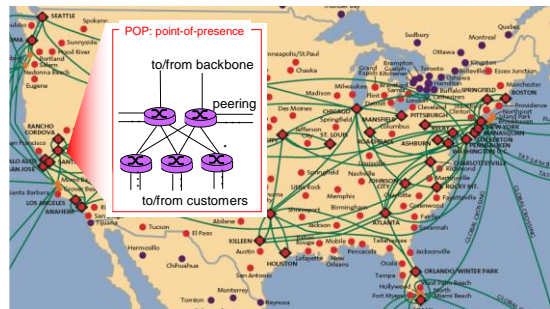 - geosynchronous versus low altitude

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Internet structure: network of networks

- roughly hierarchical
- at center: "tier-1" ISPs (e.g., Verizon, Sprint, AT&T, Cable and Wireless), national/international coverage
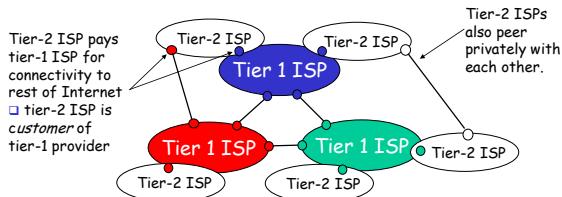 - treat each other as equals

Tier-1 providers interconnect (peer) privately

Tier 1 ISP

Tier 1 ISP

Tier 1 ISP

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Tier-1 ISP: e.g., Sprint

POP: point-of-presence

to/from backbone

peering

to/from customers

Sprint US backbone network

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Internet structure: network of networks

- ❏ "Tier-2" ISPs: smaller (often regional) ISPs
  - ▪ Connect to one or more tier-1 ISPs, possibly other tier-2 ISPs

Tier-2 ISP pays tier-1 ISP for connectivity to rest of Internet ❏ tier-2 ISP is *customer* of tier-1 provider

Tier-2 ISPs also peer privately with each other.

Tier-2 ISP Tier-2 ISP
Tier 1 ISP
Tier 1 ISP Tier 1 ISP Tier-2 ISP
Tier-2 ISP Tier-2 ISP

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Internet structure: network of networks

- ❏ "Tier-3" ISPs and local ISPs
  - ▪ last hop ("access") network (closest to end systems)

Local and tier-3 ISPs are *customers* of higher tier ISPs connecting them to rest of Internet

local ISP Tier 3 ISP local ISP local ISP local ISP
Tier-2 ISP Tier-2 ISP
Tier 1 ISP
Tier 1 ISP Tier 1 ISP Tier-2 ISP local ISP
Tier-2 ISP local ISP Tier-2 ISP local ISP
local ISP local ISP
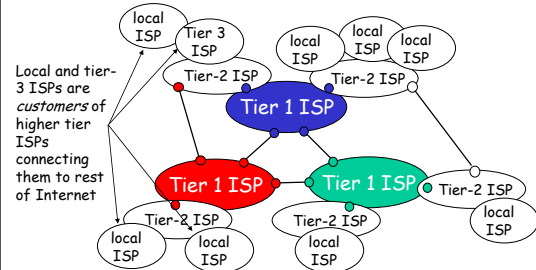
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Internet structure: network of networks

- ❏ a packet passes through many networks!

local ISP Tier 3 ISP local ISP local ISP local ISP
Tier-2 ISP Tier-2 ISP
Tier 1 ISP
Tier 1 ISP Tier 1 ISP Tier-2 ISP local ISP
Tier-2 ISP local ISP Tier-2 ISP local ISP
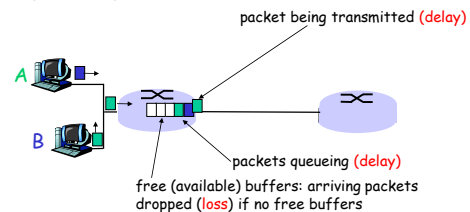local ISP local ISP
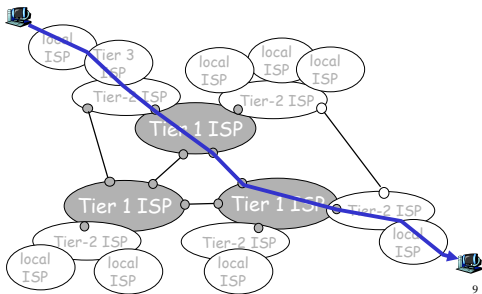
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How do loss and delay occur?

packets *queue* in router buffers
- ❏ packet arrival rate to link (temporarily) exceeds output link capacity
- ❏ packets queue, wait for turn

packet being transmitted (delay)

A

B

packets queueing (delay)

free (available) buffers: arriving packets dropped (loss) if no free buffers

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Four sources of packet delay

- ❏ 1. nodal processing:
  - ▪ check bit errors
  - ▪ determine output link
- ❏ 2. queueing
  - ▪ time waiting at output link for transmission
  - ▪ depends on congestion level of router

A
transmission
propagation
B
nodal processing queueing
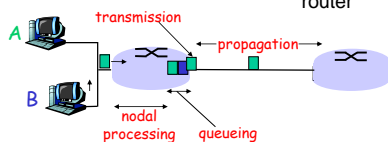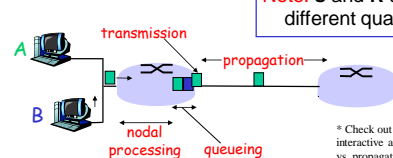
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Delay in packet-switched networks

3. Transmission delay:
- ❏ **R**=link bandwidth (bps)
- ❏ **L**=packet length (bits)
- ❏ time to send bits into link = **L / R**

4. Propagation delay:
- ❏ **d** = length of physical link
- ❏ **s** = propagation speed in medium (~2x10^8 m/sec)
- ❏ propagation delay = **d / s**
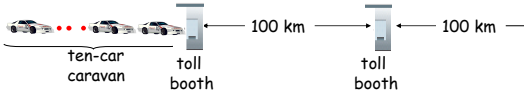
Note: **s** and **R** are *very* different quantities!

A
transmission
propagation
B
nodal processing queueing

* Check out the Java applet for an interactive animation on transmission vs. propagation delay

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Caravan analogy

- cars "propagate" at 100 km/hr
- toll booth takes 12 sec to service car (transmission time)
- car~bit; caravan ~ packet
- Q: How long until caravan is lined up before 2nd toll booth?

- Time to "push" entire caravan through toll booth onto highway = 12*10 = 120 sec
- Time for last car to propagate from 1st to 2nd toll both: 100km/(100km/hr)= 1 hr
- A: 62 minutes

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Caravan analogy (more)
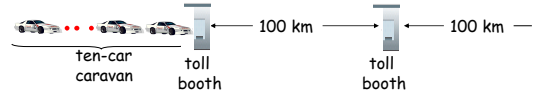
- Cars now "propagate" at 1000 km/hr
- Toll booth now takes 1 min to service a car
- Q: Will cars arrive to 2nd booth before all cars serviced at 1st booth?

- Yes! After 7 min, 1st car at 2nd booth and 3 cars still at 1st booth.
- 1st bit of packet can arrive at 2nd router before packet is fully transmitted at 1st router!
  - See applet (in video note)
  Student Resources

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Nodal delay

$$d_{\text{nodal}} = d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}}$$

- d_{proc} = processing delay
  - typically a few microsecs or less
- d_{queue} = queuing delay
  - depends on congestion
- d_{trans} = transmission delay
  - = L / R, significant for low-speed links
- d_{prop} = propagation delay
  - a few microsecs to hundreds of msecs

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Queueing delay (revisited)

- R=link bandwidth (bps)
- L=packet length (bits)
- a=average packet arrival rate (packets/sec)

traffic intensity = La/R
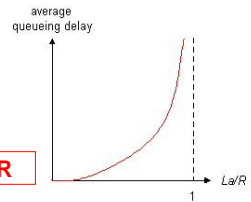
- La/R ~ 0: average queueing delay small
- La/R → 1: average queueing delay large
- La/R > 1: more "work" arriving than can be serviced, average delay infinite!

* Check out the Java applet for an interactive animation on queuing and loss

"Real" Internet delays and routes

- what do "real" Internet delay & loss look like?
- **traceroute** program: provides delay measurement from source to router along the end-end Internet path towards the destination. For all router *i*:
  - sends three packets that will reach router *i* on path towards destination
  - router *i* will return packets to sender
  - sender times interval between transmission and reply.

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"Real" Internet delays and routes

traceroute: gaia.cs.umass.edu to www.eurecom.fr

Three delay measurements from gaia.cs.umass.edu to cs-gw.cs.umass.edu

```
1  cs-gw (128.119.240.254)  1 ms  1 ms  2 ms
2  border1-rt-fa5-1-0.gw.umass.edu (128.119.3.145)  1 ms  1 ms  2 ms
3  cht-vbns.gw.umass.edu (128.119.3.130)  6 ms 5 ms 5 ms
4  jn1-at1-0-0-19.wor.vbns.net (204.147.132.129)  16 ms 11 ms 13 ms
5  jn1-so7-0-0-0.wae.vbns.net (204.147.136.136)  21 ms 18 ms 18 ms
6  abilene-vbns.abilene.ucaid.edu (198.32.11.9)  22 ms  18 ms  22 ms
7  nycm-wash.abilene.ucaid.edu (198.32.8.46)  22 ms  22 ms  22 ms
8  62.40.103.253 (62.40.103.253)  104 ms 109 ms 106 ms
9  de2-1.de1.de.geant.net (62.40.96.129)  109 ms 102 ms 104 ms
10  de.fr1.fr.geant.net (62.40.96.50)  113 ms 121 ms 114 ms
11  renater-gw.fr1.fr.geant.net (62.40.103.54)  112 ms  114 ms  112 ms
12  nio-n2.cssi.renater.fr (193.51.206.13)  111 ms  114 ms  116 ms
13  nice.cssi.renater.fr (195.220.98.102)  123 ms 125 ms 124 ms
14  r3t2-nice.cssi.renater.fr (195.220.98.110)  126 ms  126 ms  124 ms
15  eurecom-valbonne.r3t2.ft.net (193.48.50.54)  135 ms  128 ms  133 ms
16  194.214.211.25 (194.214.211.25)  126 ms  128 ms  126 ms
17  * * *
18  * * *
19  fantasia.eurecom.fr (193.55.113.142)  132 ms  128 ms  136  ms
```

trans-oceanic link

*means no response (probe lost, router not replying)

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"Real" Internet delays and routes

❑ On MS Windows machines, the **traceroute** functionality is implemented as the "***tracert***" command:

Usage: tracert [-d] [-h maximum_hops] [-j host-list] [-w timeout] target_name

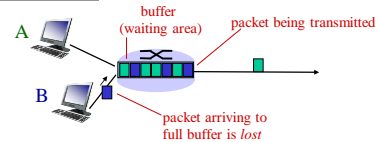**Options:**
-d   **Do not resolve addresses to hostnames.**
-h maximum_hops   **Maximum number of hops to search for target.**
-j host-list   **Loose source route along host-list.**
-w timeout   **Wait timeout milliseconds for each reply**

❑ Check out the web site **http://network-tools.com/** for a web implementation of the traceroute functionality.

❑ Do some traceroutes at www.traceroute.org

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Packet loss

❑ queue (aka *buffer*) preceding a link has finite capacity
❑ when packet arrives to a full queue, packet is dropped (aka *lost*)
❑ lost packets may be retransmitted
  ▪ by the previous node
  ▪ by the source end system, or
  ▪ not retransmitted at all
❑ packets may also be dropped due to bit errors, but this is <u>not that common</u> on wired networks

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