

Chapter 1: roadmap

1.1 what is the Internet?

1.2 network edge

- end systems, access networks, links

1.3 network core

- packet switching, circuit switching, network structure

1.4 delay, loss, throughput in networks

1.5 protocol layers, service models

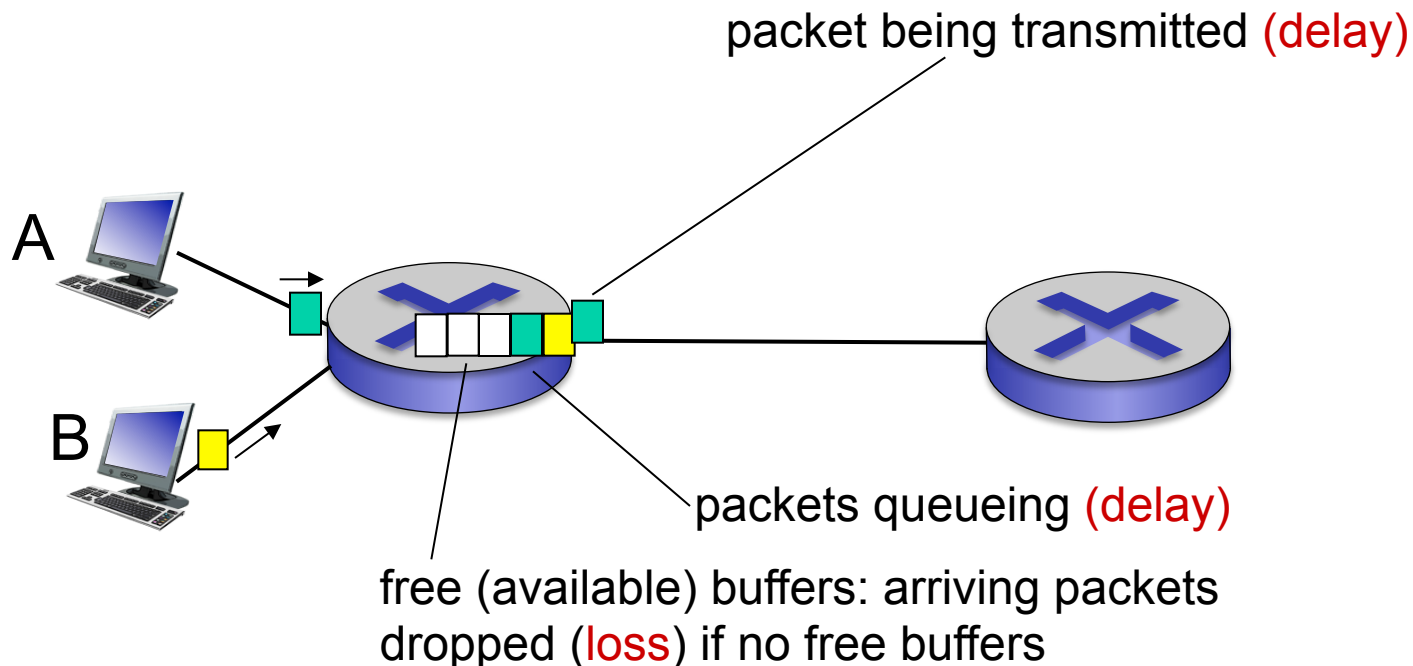
1.6 networks under attack: security

1.7 history

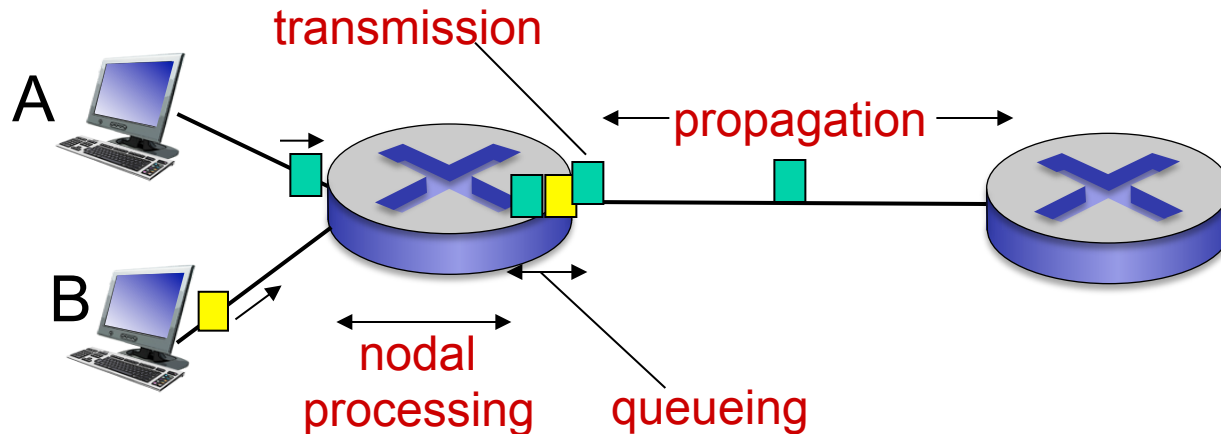
How do loss and delay occur?

packets *queue* in router buffers

- packet arrival rate to link (temporarily) exceeds output link capacity
- packets queue, wait for turn



Four sources of packet delay



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

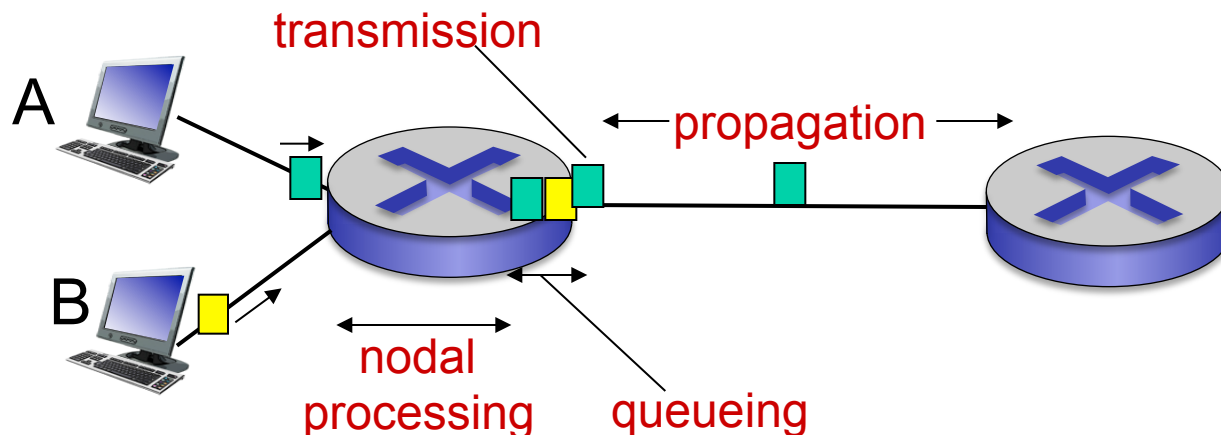
d_{proc} : nodal processing

- check bit errors
- determine output link
- typically < msec

d_{queue} : queueing delay

- time waiting at output link for transmission
- depends on congestion level of router

Four sources of packet delay



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

d_{trans} : transmission delay:

- L : packet length (bits)
- R : link bandwidth (bps)

$$d_{\text{trans}} = L/R$$

← d_{trans} and d_{prop} →
very different

d_{prop} : propagation delay:

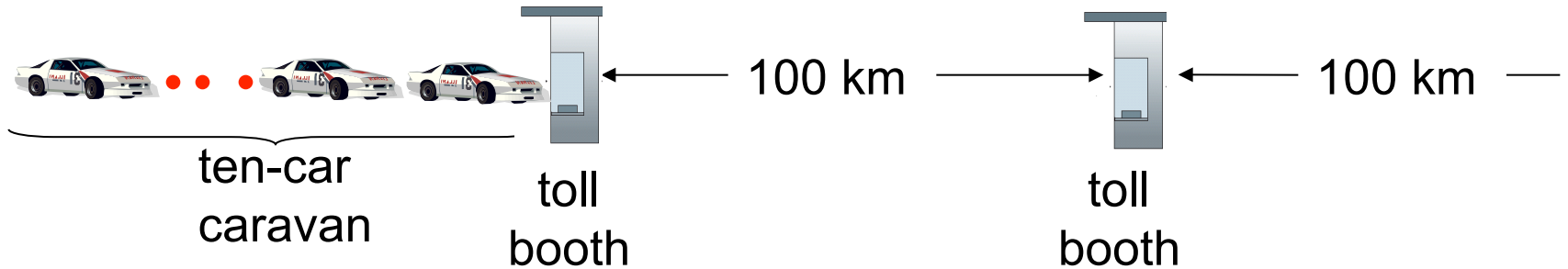
- d : length of physical link
- s : propagation speed ($\sim 2 \times 10^8$ m/sec)

$$d_{\text{prop}} = d/s$$

* Check out the online interactive exercises for more examples: http://gaia.cs.umass.edu/kurose_ross/interactive/

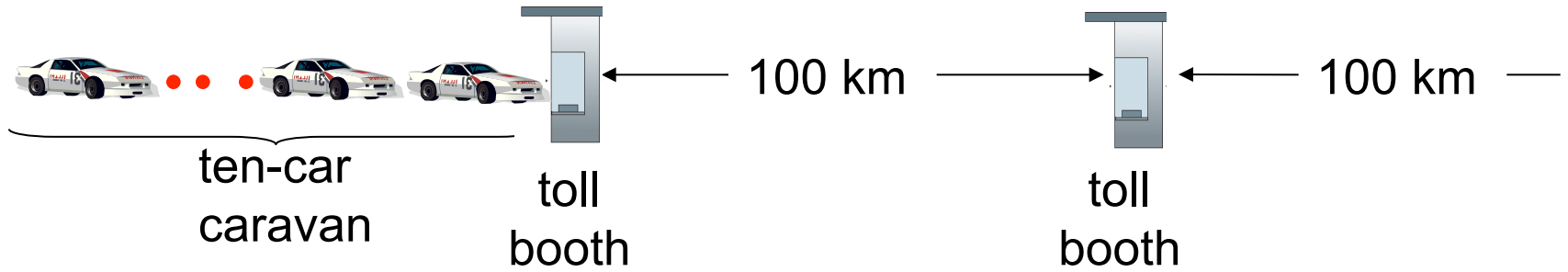
* Check out the Java applet for an interactive animation on trans vs. prop delay

Caravan analogy



- cars “propagate” at 100 km/hr
- toll booth takes 12 sec to service car (bit transmission time)
- car \sim bit; caravan \sim 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: $100\text{km} / (100\text{km/hr}) = 1$ hr
- **A: 62 minutes**

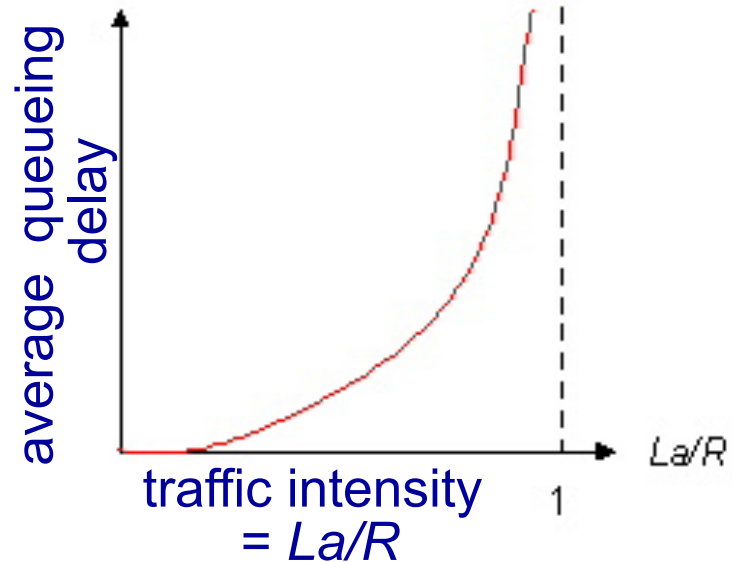
Caravan analogy (more)



- suppose cars now “propagate” at 1000 km/hr
- and suppose toll booth now takes one min to service a car
- **Q: Will cars arrive to 2nd booth before all cars serviced at first booth?**
 - **A: Yes!** after 7 min, first car arrives at second booth; three cars still at first booth

Queueing delay (revisited)

- R : link bandwidth (bps)
- L : packet length (bits)
- a : average packet arrival rate



- $La/R \sim 0$: avg. queueing delay small
- $La/R \rightarrow 1$: avg. queueing delay large
- $La/R > 1$: more “work” arriving than can be serviced, average delay infinite!



$La/R \sim 0$

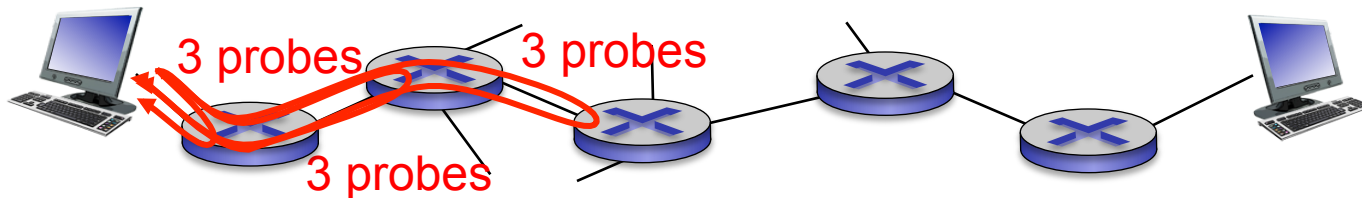


$La/R \rightarrow 1$

* Check online 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 end-end Internet path towards destination. For all 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.



“Real” Internet delays, routes

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

3 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

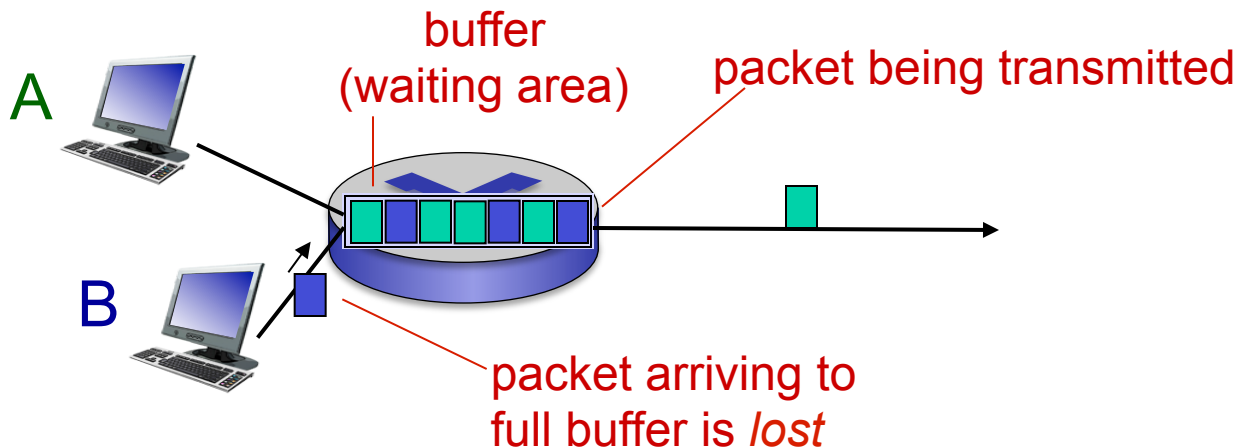
trans-oceanic link

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

* Do some traceroutes from exotic countries at www.traceroute.org

Packet loss

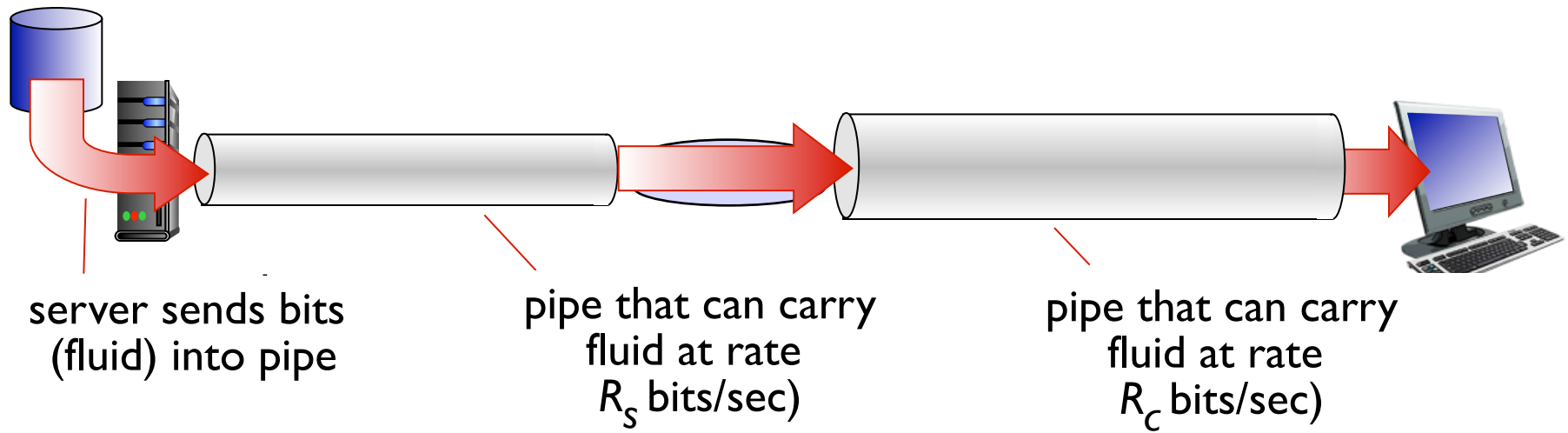
- queue (aka buffer) preceding link in buffer has finite capacity
- packet arriving to full queue dropped (aka lost)
- lost packet may be retransmitted by previous node, by source end system, or not at all



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

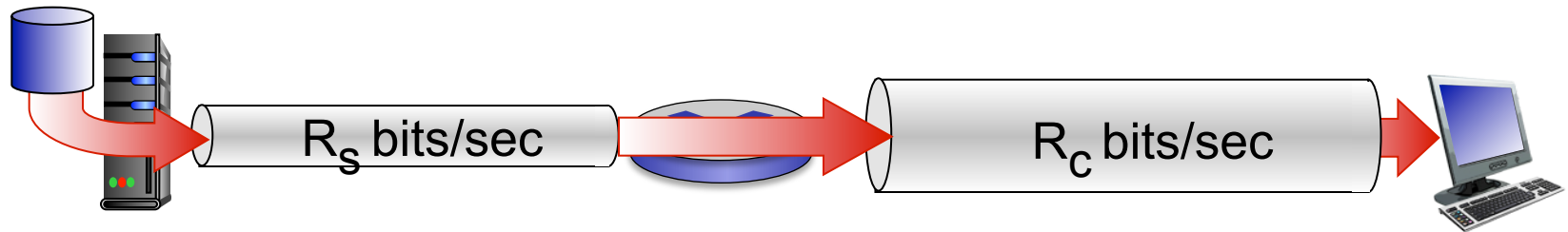
Throughput

- **throughput**: rate (bits/time unit) at which bits transferred between sender/receiver
 - **instantaneous**: rate at given point in time
 - **average**: rate over longer period of time

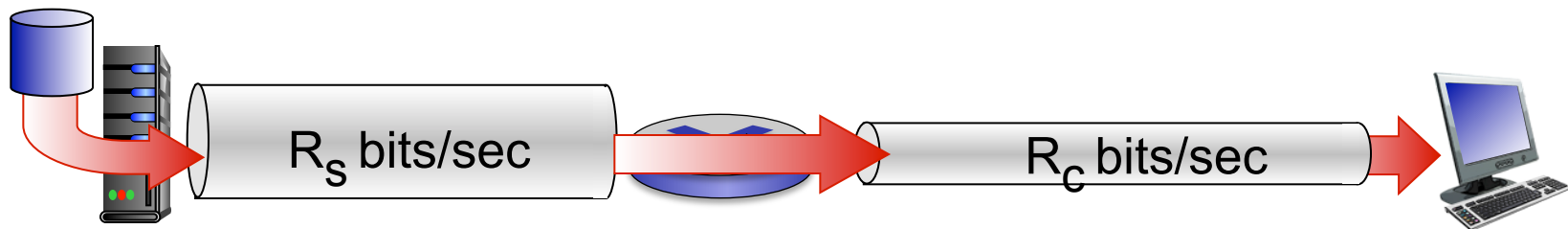


Throughput (more)

- $R_s < R_c$ What is average end-end throughput?



- $R_s > R_c$ What is average end-end throughput?

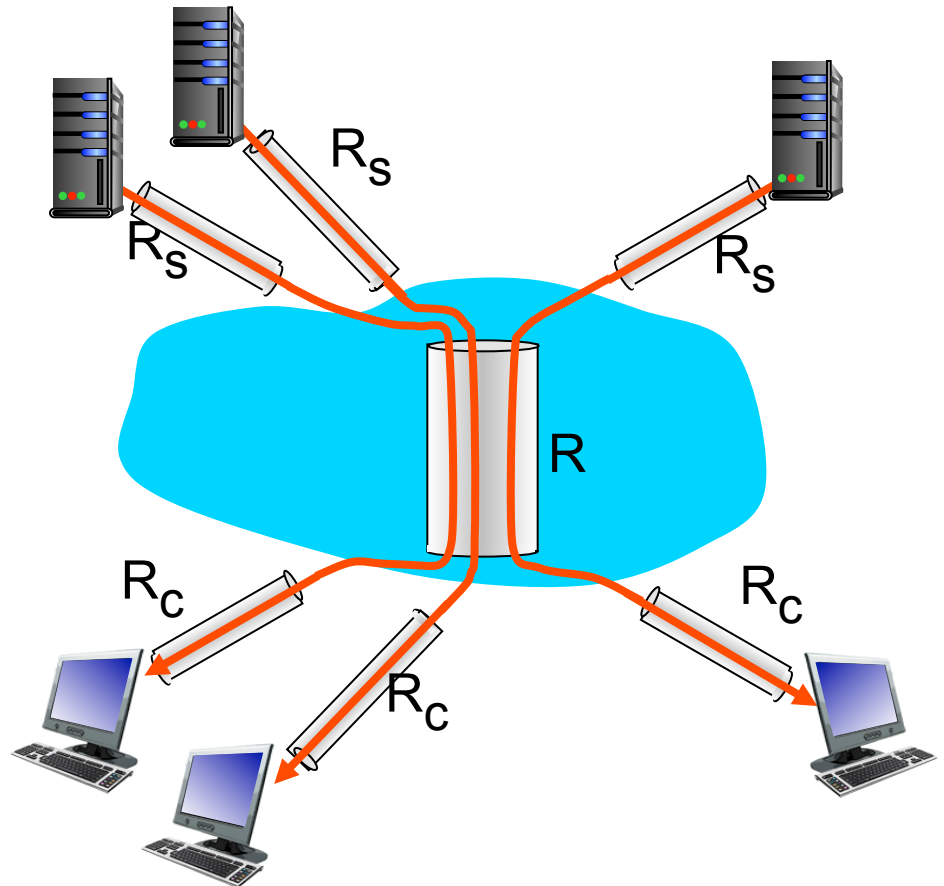


bottleneck link

link on end-end path that constrains end-end throughput

Throughput: Internet scenario

- per-connection end-end throughput:
 $\min(R_c, R_s, R/I)$
- in practice: R_c or R_s is often bottleneck



10 connections (fairly) share
backbone bottleneck link R bits/sec

* Check out the online interactive exercises for more examples: http://gaia.cs.umass.edu/kurose_ross/interactive/

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Protocol “layers”

*Networks are complex,
with many “pieces”:*

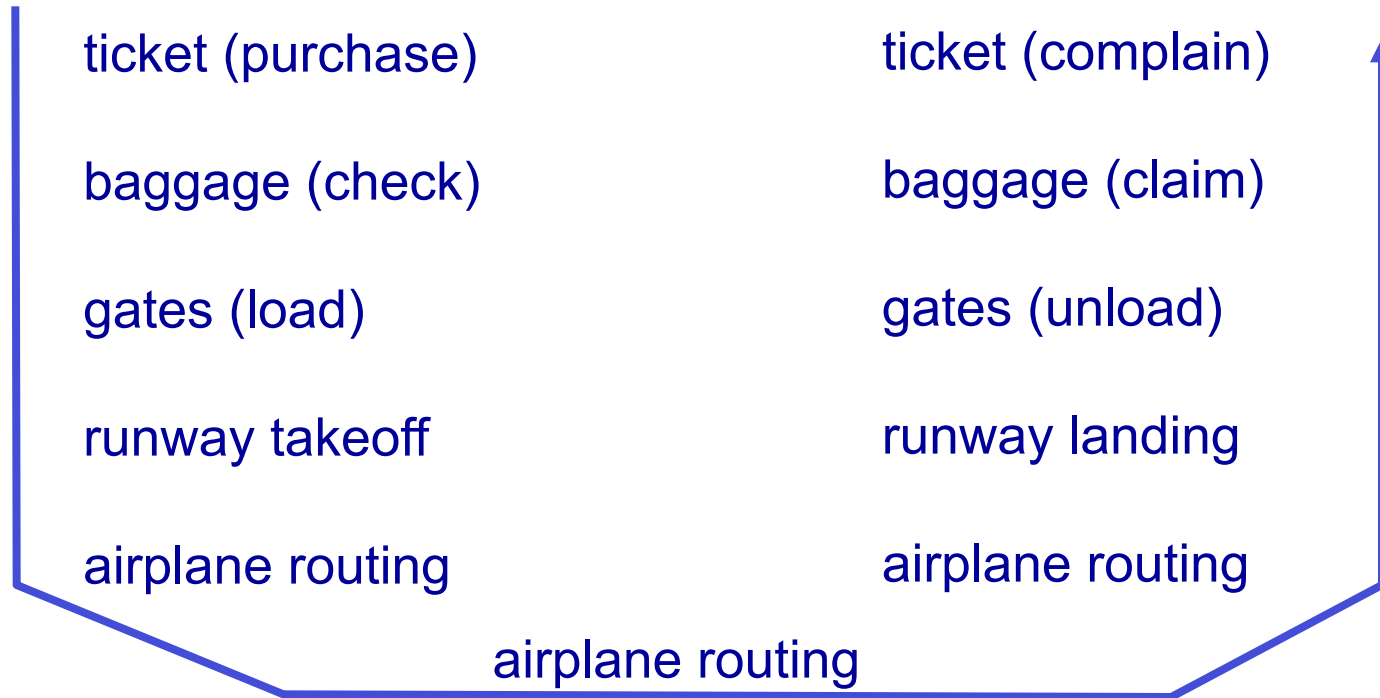
- hosts
- routers
- links of various media
- applications
- protocols
- hardware, software

Question:

is there any hope of
organizing structure of
network?

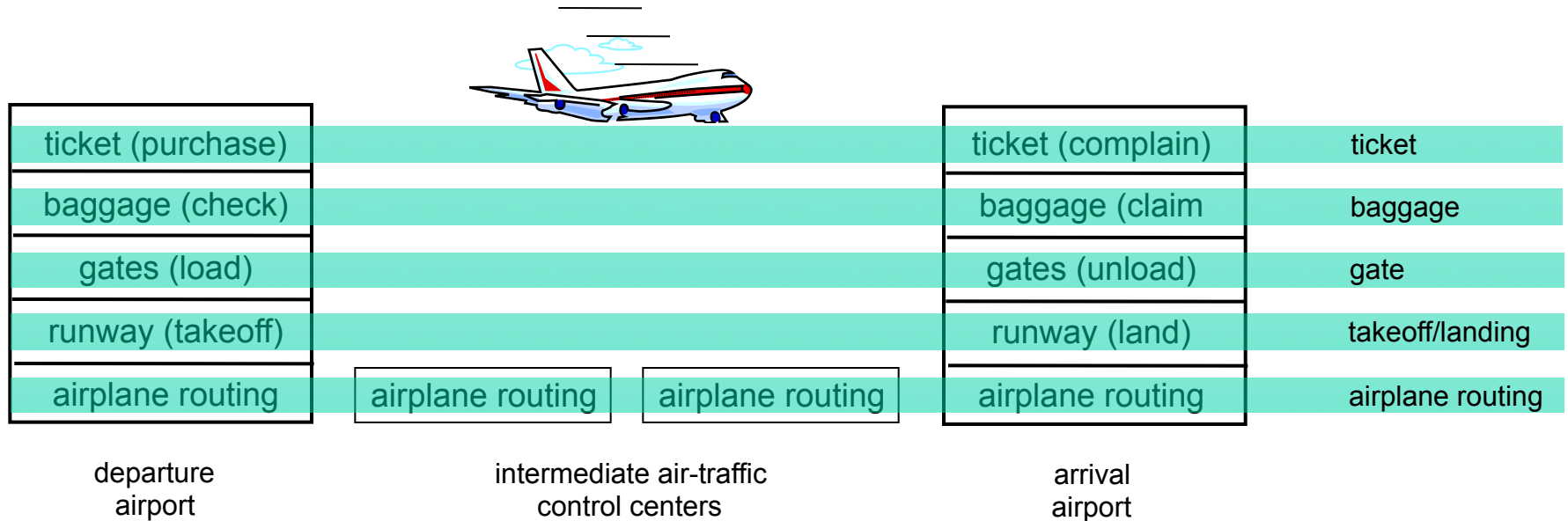
.... or at least our
discussion of networks?

Organization of air travel



- a series of steps

Layering of airline functionality



layers: each layer implements a service

- via its own internal-layer actions
- relying on services provided by layer below

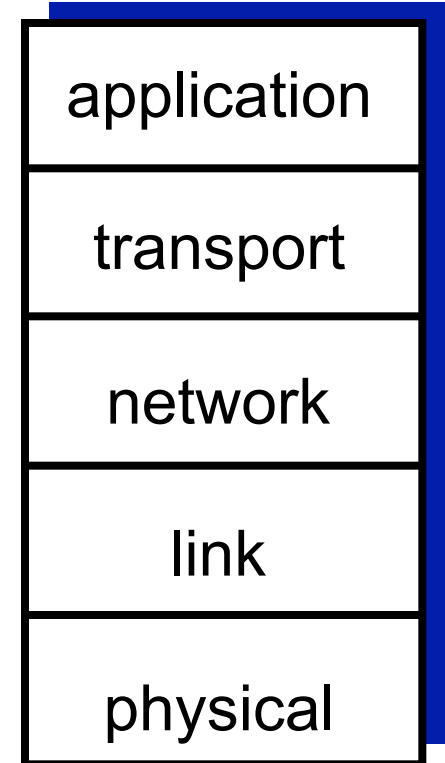
Why layering?

dealing with complex systems:

- explicit structure allows identification, relationship of complex system's pieces
 - layered *reference model* for discussion
- modularization eases maintenance, updating of system
 - change of implementation of layer's service transparent to rest of system
 - e.g., change in gate procedure doesn't affect rest of system
- layering considered harmful?

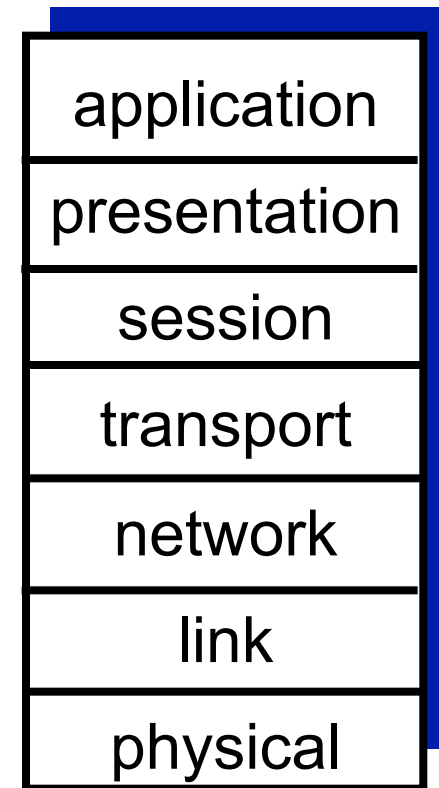
Internet protocol stack

- **application:** supporting network applications
 - FTP, SMTP, HTTP
- **transport:** process-process data transfer
 - TCP, UDP
- **network:** routing of datagrams from source to destination
 - IP, routing protocols
- **link:** data transfer between neighboring network elements
 - Ethernet, 802.111 (WiFi), PPP
- **physical:** bits “on the wire”

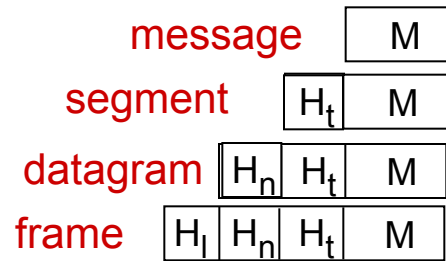


ISO/OSI reference model

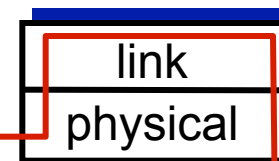
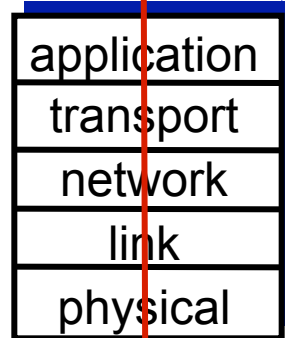
- **presentation:** allow applications to interpret meaning of data, e.g., encryption, compression, machine-specific conventions
- **session:** synchronization, checkpointing, recovery of data exchange
- Internet stack “missing” these layers!
 - these services, *if needed*, must be implemented in application
 - needed?



Encapsulation

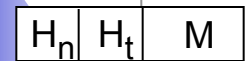
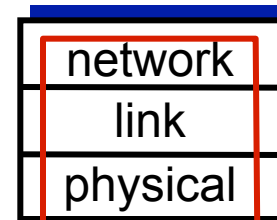
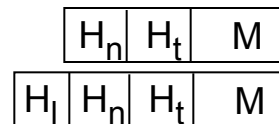
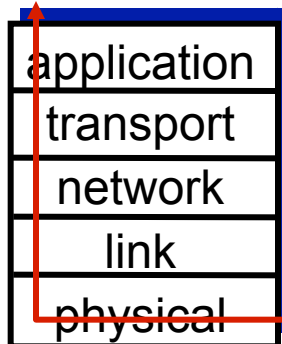


source



switch

destination



router

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Network security

- **field of network security:**
 - how bad guys can attack computer networks
 - how we can defend networks against attacks
 - how to design architectures that are immune to attacks
- **Internet not originally designed with (much) security in mind**
 - *original vision:* “a group of mutually trusting users attached to a transparent network” 😊
 - Internet protocol designers playing “catch-up”
 - security considerations in all layers!

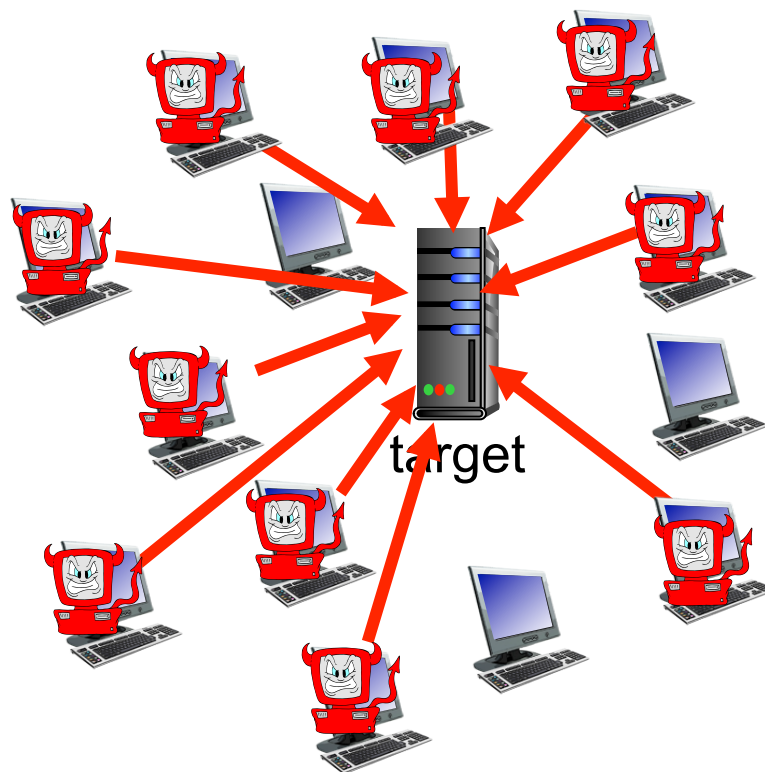
Bad guys: put malware into hosts via Internet

- malware can get in host from:
 - *virus*: self-replicating infection by receiving/executing object (e.g., e-mail attachment)
 - *worm*: self-replicating infection by passively receiving object that gets itself executed
- **spyware malware** can record keystrokes, web sites visited, upload info to collection site
- infected host can be enrolled in **botnet**, used for spam. DDoS attacks

Bad guys: attack server, network infrastructure

Denial of Service (DoS): attackers make resources (server, bandwidth) unavailable to legitimate traffic by overwhelming resource with bogus traffic

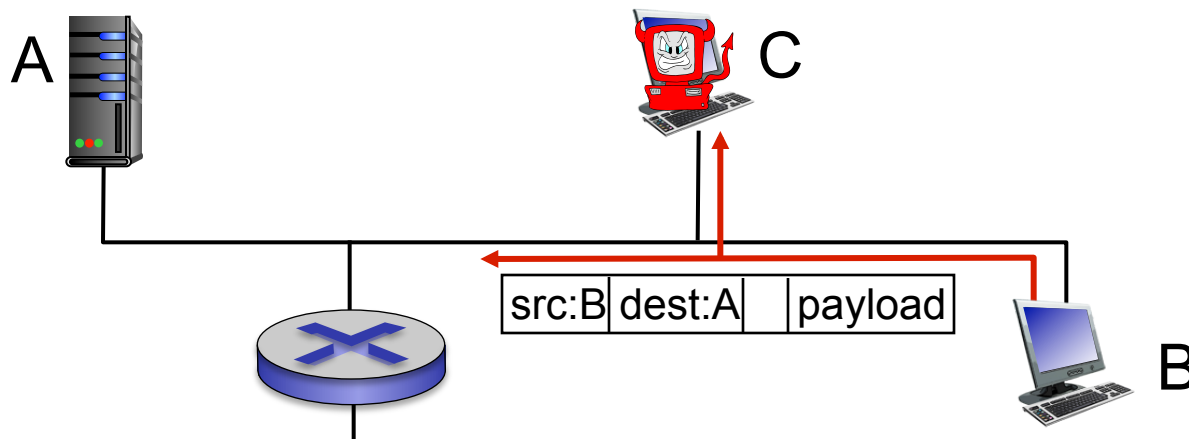
1. select target
2. break into hosts around the network (see botnet)
3. send packets to target from compromised hosts



Bad guys can sniff packets

packet “sniffing”:

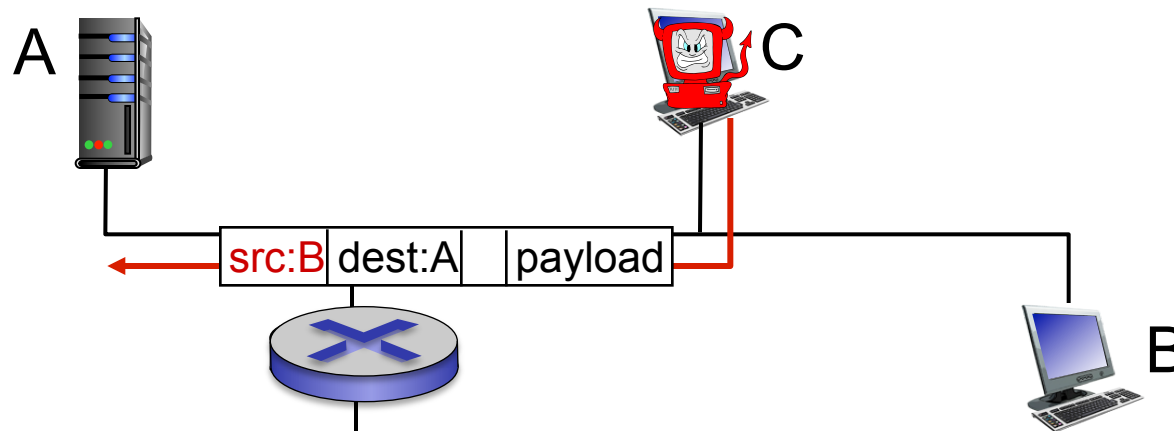
- broadcast media (shared Ethernet, wireless)
- promiscuous network interface reads/records all packets (e.g., including passwords!) passing by



- wireshark software used for end-of-chapter labs is a (free) packet-sniffer

Bad guys can use fake addresses

IP spoofing: send packet with false source address



... lots more on security (throughout, Chapter 8)

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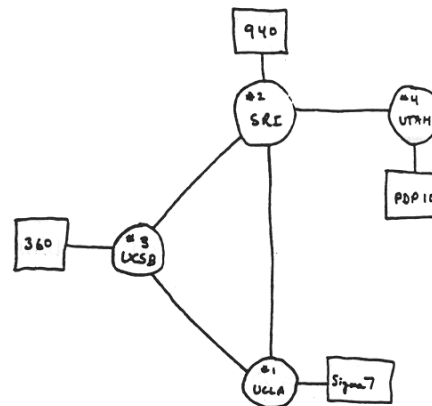
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Internet history

1961-1972: Early packet-switching principles

- **1961:** Kleinrock - queueing theory shows effectiveness of packet-switching
- **1964:** Baran - packet-switching in military nets
- **1967:** ARPAnet conceived by Advanced Research Projects Agency
- **1969:** first ARPAnet node operational
- **1972:**
 - ARPAnet public demo
 - NCP (Network Control Protocol) first host-host protocol
 - first e-mail program
 - ARPAnet has 15 nodes



THE ARPA NETWORK

Internet history

1972-1980: Internetworking, new and proprietary nets

- **1970:** ALOHAnet satellite network in Hawaii
- **1974:** Cerf and Kahn - architecture for interconnecting networks
- **1976:** Ethernet at Xerox PARC
- **late70' s:** proprietary architectures: DECnet, SNA, XNA
- **late 70' s:** switching fixed length packets (ATM precursor)
- **1979:** ARPAnet has 200 nodes

Cerf and Kahn' s internetworking principles:

- minimalism, autonomy - no internal changes required to interconnect networks
- best effort service model
- stateless routers
- decentralized control

define today' s Internet
architecture

Internet history

1980-1990: new protocols, a proliferation of networks

- **1983:** deployment of TCP/IP
- **1982:** smtp e-mail protocol defined
- **1983:** DNS defined for name-to-IP-address translation
- **1985:** ftp protocol defined
- **1988:** TCP congestion control
- new national networks: CSnet, BITnet, NSFnet, Minitel
- 100,000 hosts connected to confederation of networks

Internet history

1990, 2000 's: commercialization, the Web, new apps

- early 1990' s: ARPAnet decommissioned
- 1991: NSF lifts restrictions on commercial use of NSFnet (decommissioned, 1995)
- early 1990s: Web
 - hypertext [Bush 1945, Nelson 1960' s]
 - HTML, HTTP: Berners-Lee
 - 1994: Mosaic, later Netscape
 - late 1990' s: commercialization of the Web
- late 1990' s – 2000' s:
 - more killer apps: instant messaging, P2P file sharing
 - network security to forefront
 - est. 50 million host, 100 million+ users
 - backbone links running at Gbps

Internet history

2005-present

- ~5B devices attached to Internet (2016)
 - smartphones and tablets
- aggressive deployment of broadband access
- increasing ubiquity of high-speed wireless access
- emergence of online social networks:
 - Facebook: ~ one billion users
- service providers (Google, Microsoft) create their own networks
 - bypass Internet, providing “instantaneous” access to search, video content, email, etc.
- e-commerce, universities, enterprises running their services in “cloud” (e.g., Amazon EC2)

Introduction: summary

covered a “ton” of material!

- Internet overview
- what’s a protocol?
- network edge, core, access network
 - packet-switching versus circuit-switching
 - Internet structure
- performance: loss, delay, throughput
- layering, service models
- security
- history

you now have:

- context, overview, “feel” of networking
- more depth, detail *to follow!*

Chapter I

Additional Slides

