Networks (2IRR20)

Introduction: Protocols, layering, performance (01b)

Dr. Tanir Ozcelebi

TU/e Computer Science

Interconnected Resource-aware Intelligent Systems (IRIS)

Slides adapted from the textbook:
Computer Networking: A Top-Down Approach
8th edition, Global Edition by Jim Kurose, Keith Ross

This slide set

Goal:

- Get "feel," "big picture," introduction to terminology
  - more depth, detail *later* in course

- Approach:
  - use Internet as example

Overview/roadmap:

- What *is* a protocol?
- Protocol layering and service models
- Performance: loss, delay, throughput

Protocols, protocol layering

What’s a protocol?

Human protocols:

- “what’s the time?”
- “I have a question”
- introductions

... specific messages sent (or words said, or ...)

... specific actions taken when message received, or upon other events

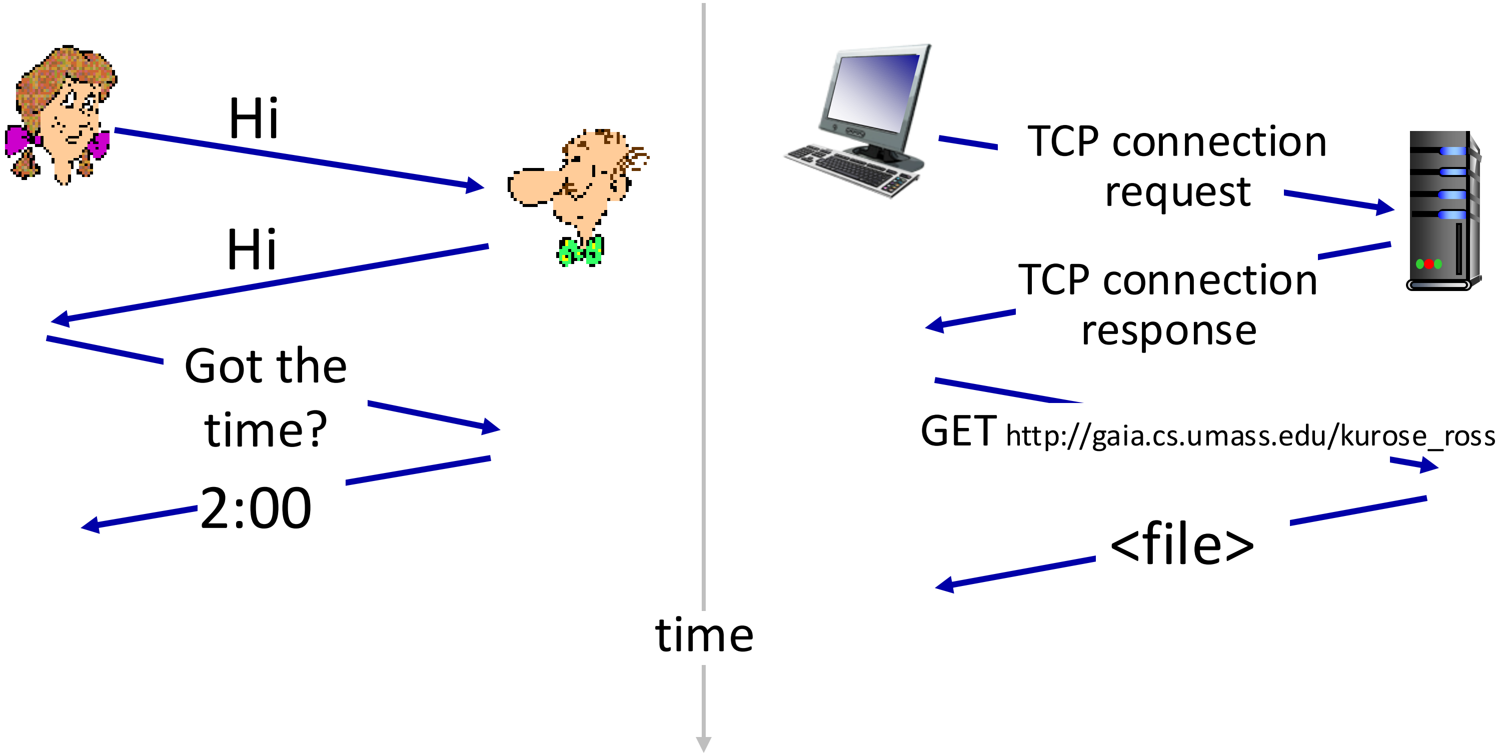
Network protocols:

- computers (devices) rather than humans
- all communication activity in Internet governed by protocols

Protocols define the format, order of messages sent and received among network entities, and actions taken on msg transmission, receipt (or other event).

What’s a protocol?

A human protocol and a computer network protocol:



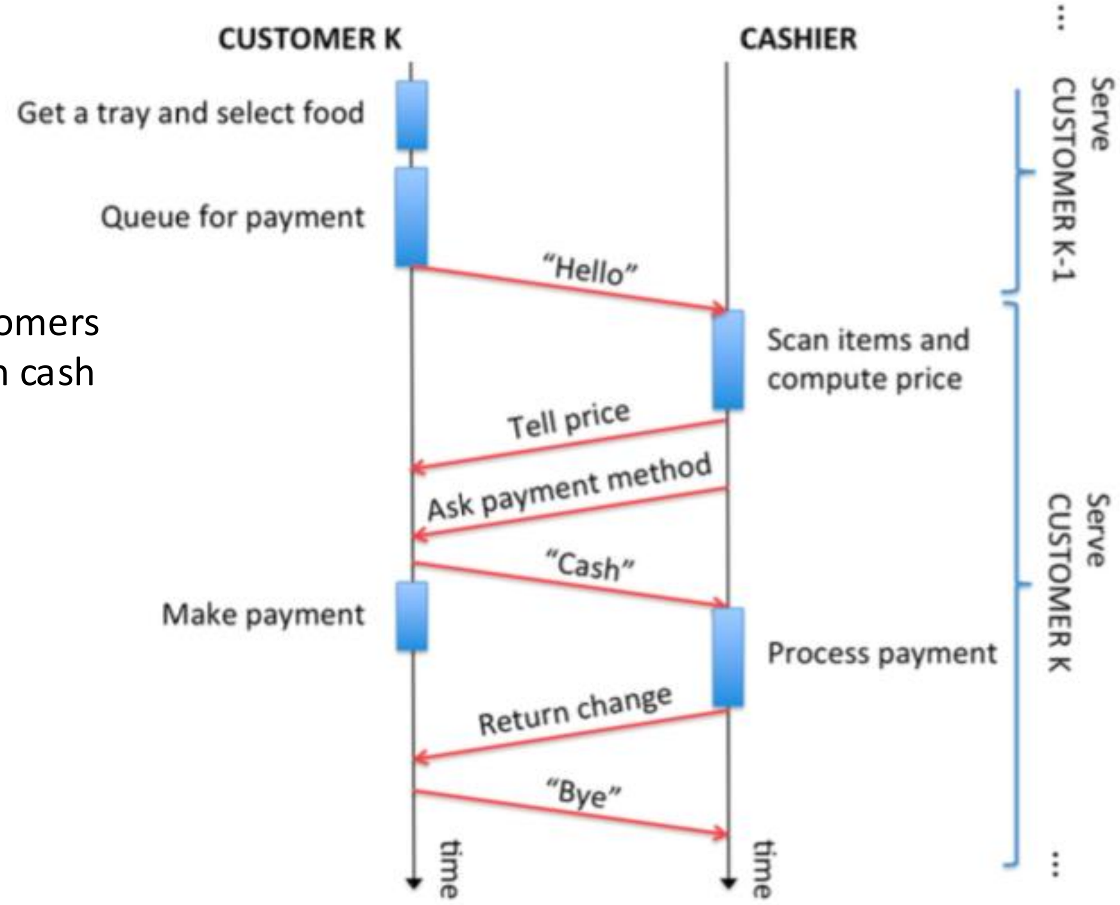
Q: other human protocols?

Dr. Tanir Ozcelebi (t.ozcelebi@tue.nl)

Your typical lunch… (past)

Another human protocol…

- involving cashiers and customers
- utility: pay for your lunch in cash



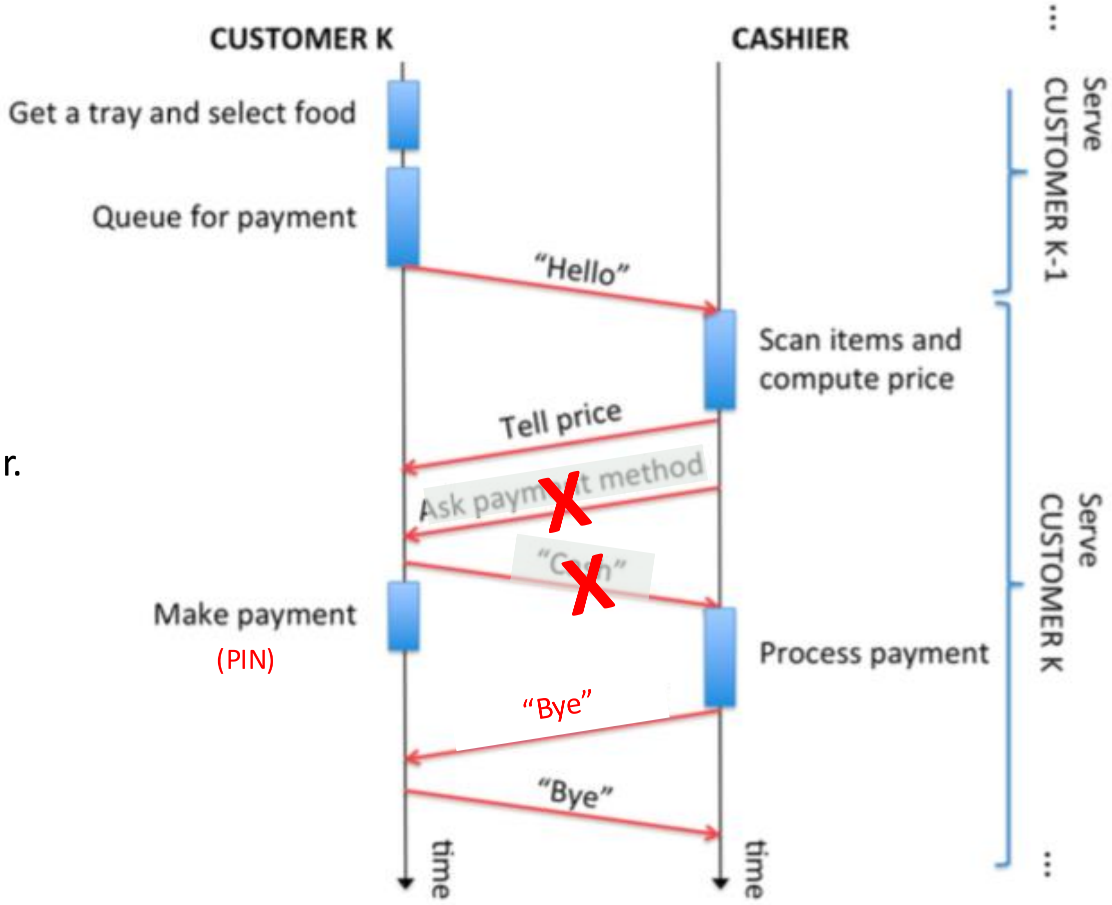
Your typical lunch… (present)

Another human protocol…
- Pay only by card

Faster…
- Takes less time per customer.
- Shorter processing times.
- No more change return.

More efficient…
- Shorter queues.

But limiting…
- Can't pay in cash anymore.



Protocol “layers” and reference models

Networks are complex, with many “pieces”:

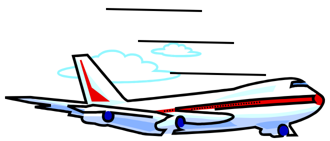
- hosts
- routers
- links of various media
- applications
- protocols
- hardware, software

Question:

is there any hope of *organizing* structure of network?

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

Example: organization of air travel



ticket (purchase)	ticket (complain)
baggage (check)	baggage (claim)
gates (load)	gates (unload)
runway takeoff	runway landing
airplane routing	airplane routing

airplane routing

airline travel: a series of steps, involving many services

Example: organization of air travel

ticket (purchase)	*ticketing service*	ticket (complain)
baggage (check)	*baggage service*	baggage (claim)
gates (load)	*gate service*	gates (unload)
runway takeoff	*runway service*	runway landing
airplane routing	*routing service*	airplane routing

layers: each layer implements a service

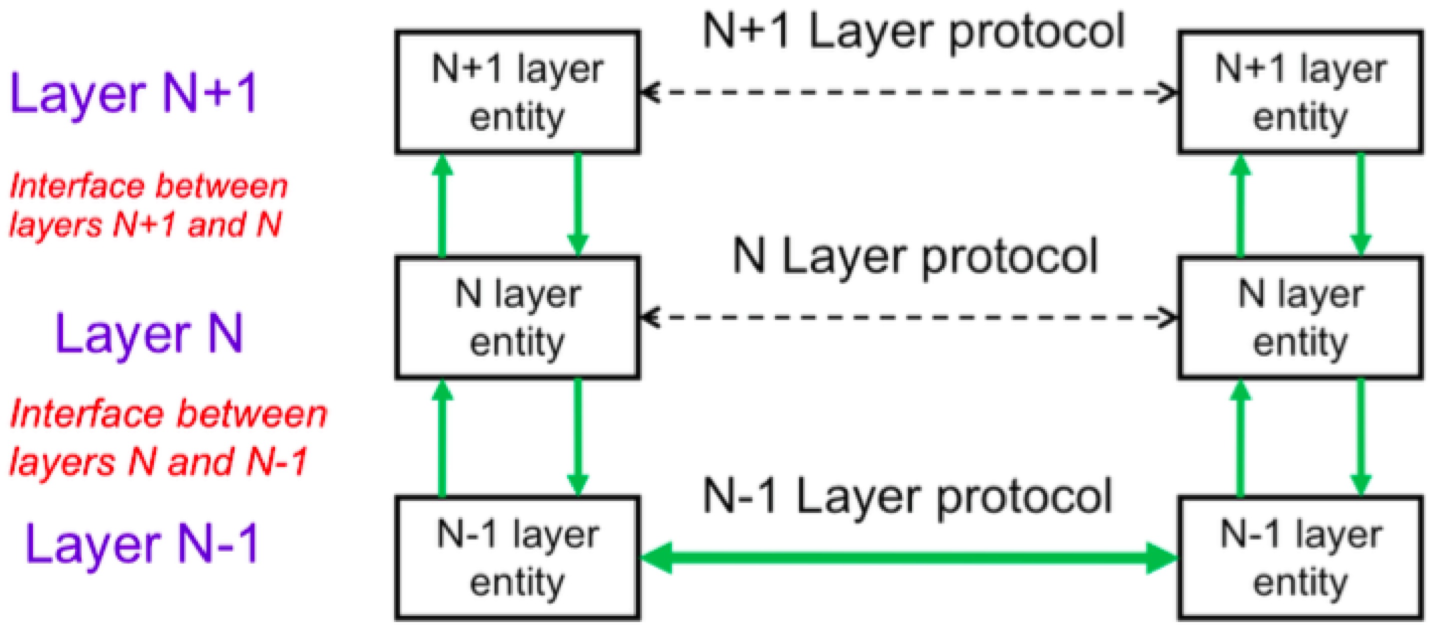
- via its own internal-layer actions
- relying on services provided by layer below

Q: describe in words the service provided in each layer above

Why layering?

- Divide and conquer!
  - divide a complex system into simpler pieces with explicit structure
- Layering makes it easy to maintain and update
  - change in a layer's service transparent to rest of system
    - e.g. change in gate procedure doesn't affect rest of the airline system

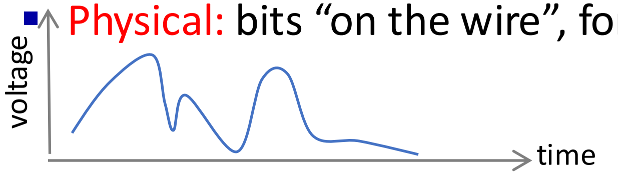
Protocol layer interfaces



Courtesy: Forouzan

Internet protocol stack

- Application: supporting network applications
  - e.g. FTP-based file transfer, HTTP-based web
- Transport: process-to-process data transfer
  - TCP, UDP
- Network: source-to-destination data routing
  - IP, routing protocols
- Link: data transfer between neighboring network elements
  - PPP, Ethernet
- Physical: bits “on the wire”, for example:



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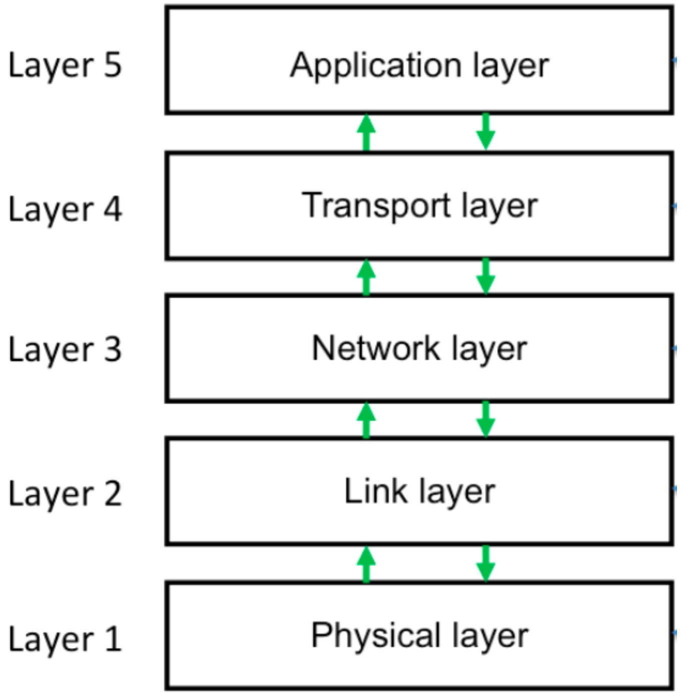


Courtesy: Forouzan

OSI reference model

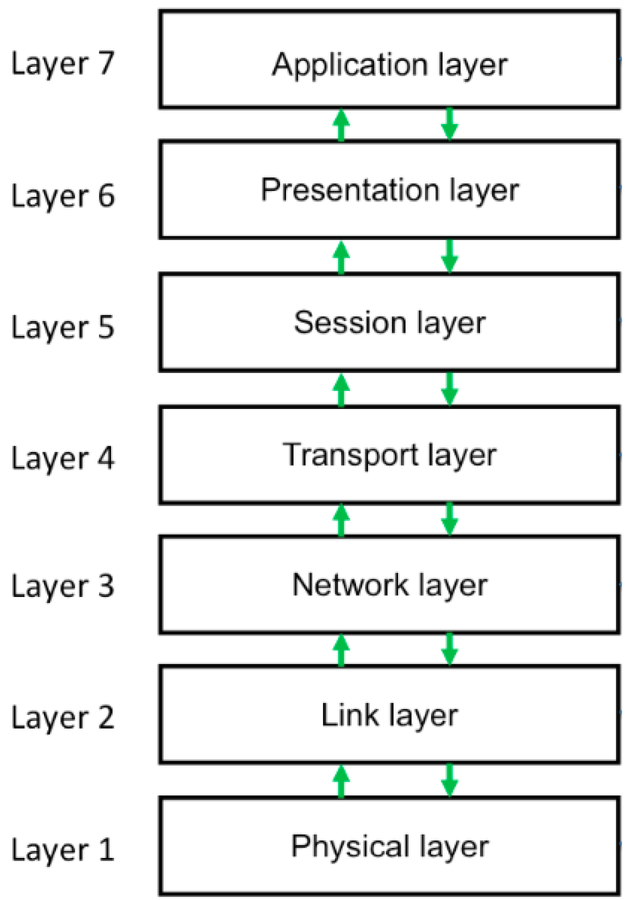
- Open Systems Interconnection (OSI) model is developed by the International Organization for Standardization (ISO).

- Similar to Internet stack since layer services are chosen based on standardized protocols and their services (Internet's TCP/IP stack is older).

Two additional layers

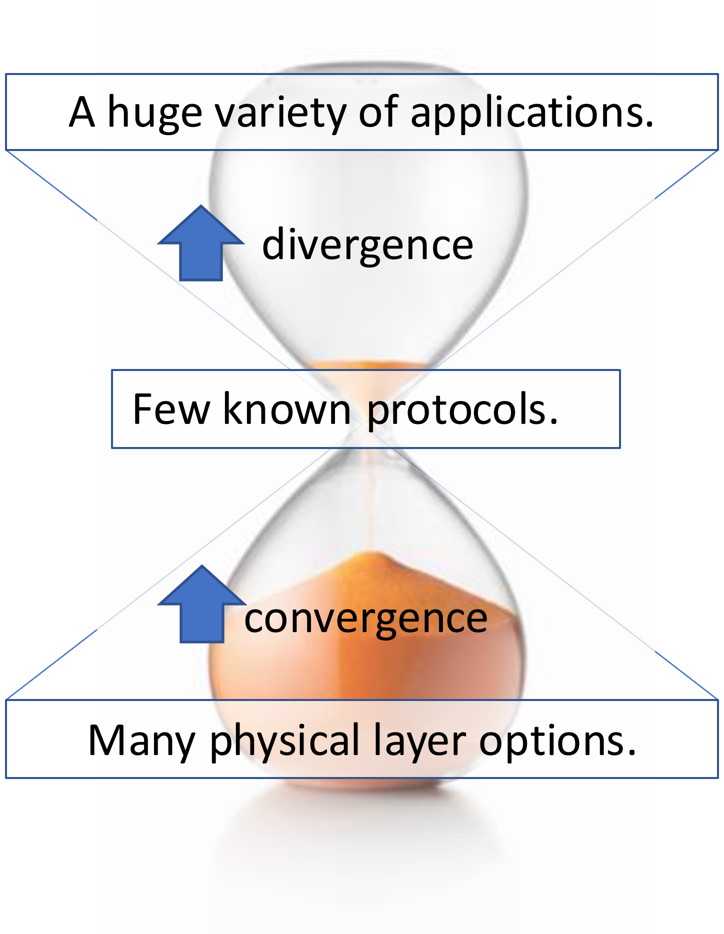
- Presentation: translate data formats and encryptions of sender and receiver
  - e.g. JPEG, Transport Layer Security (TLS)

- Session: establish, maintain and close communication sessions
  - e.g. Real-time Transport Protocol (RTP)



Courtesy: Forouzan

The hourglass of the Internet



Web, e-mail, social media …

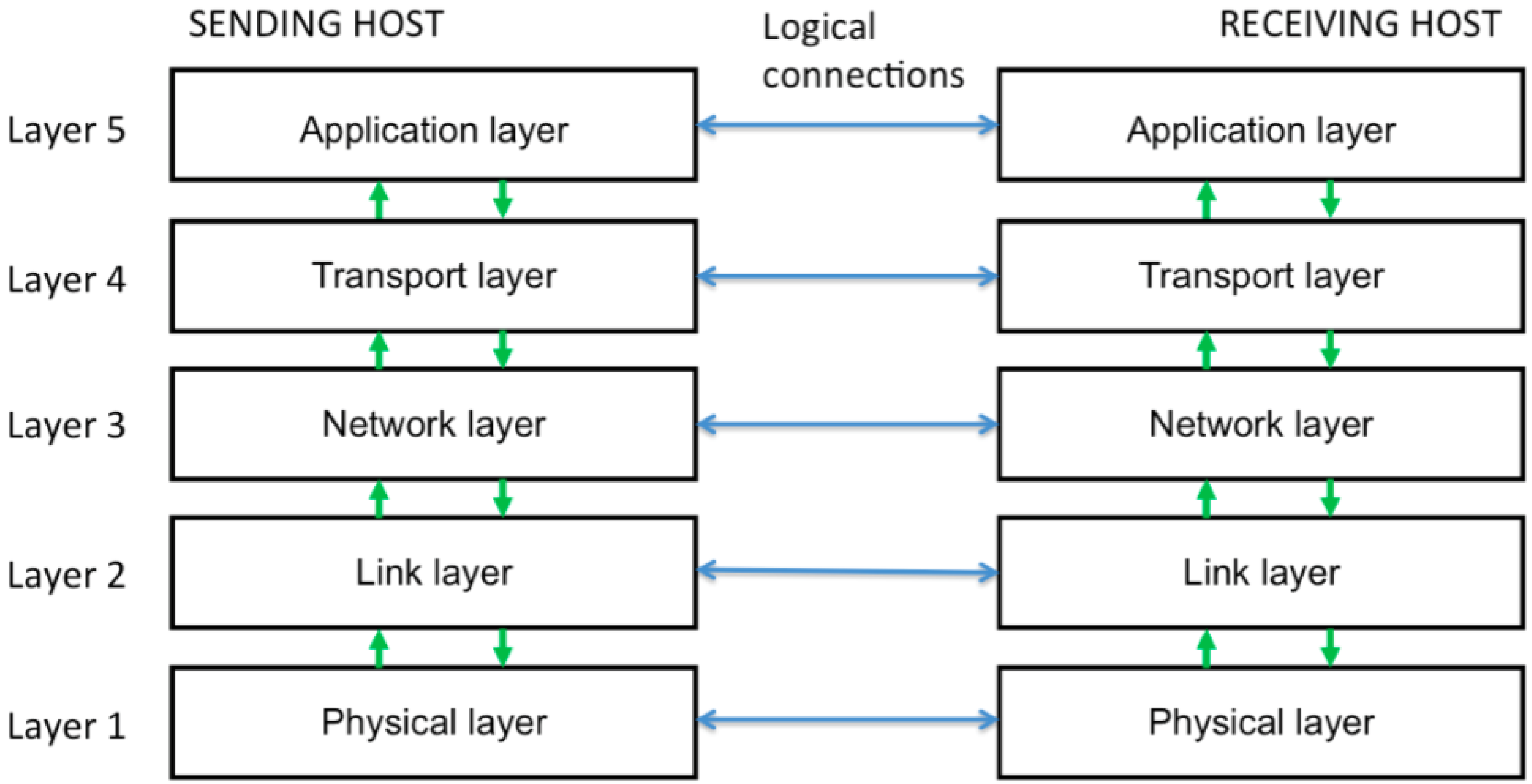
divergence

HTTP, SMTP, FTP…
TCP/IP, UDP/IP

convergence

WiFi, Ethernet, fiber, satellite…

Logical connections within a protocol layer



Courtesy: Forouzan

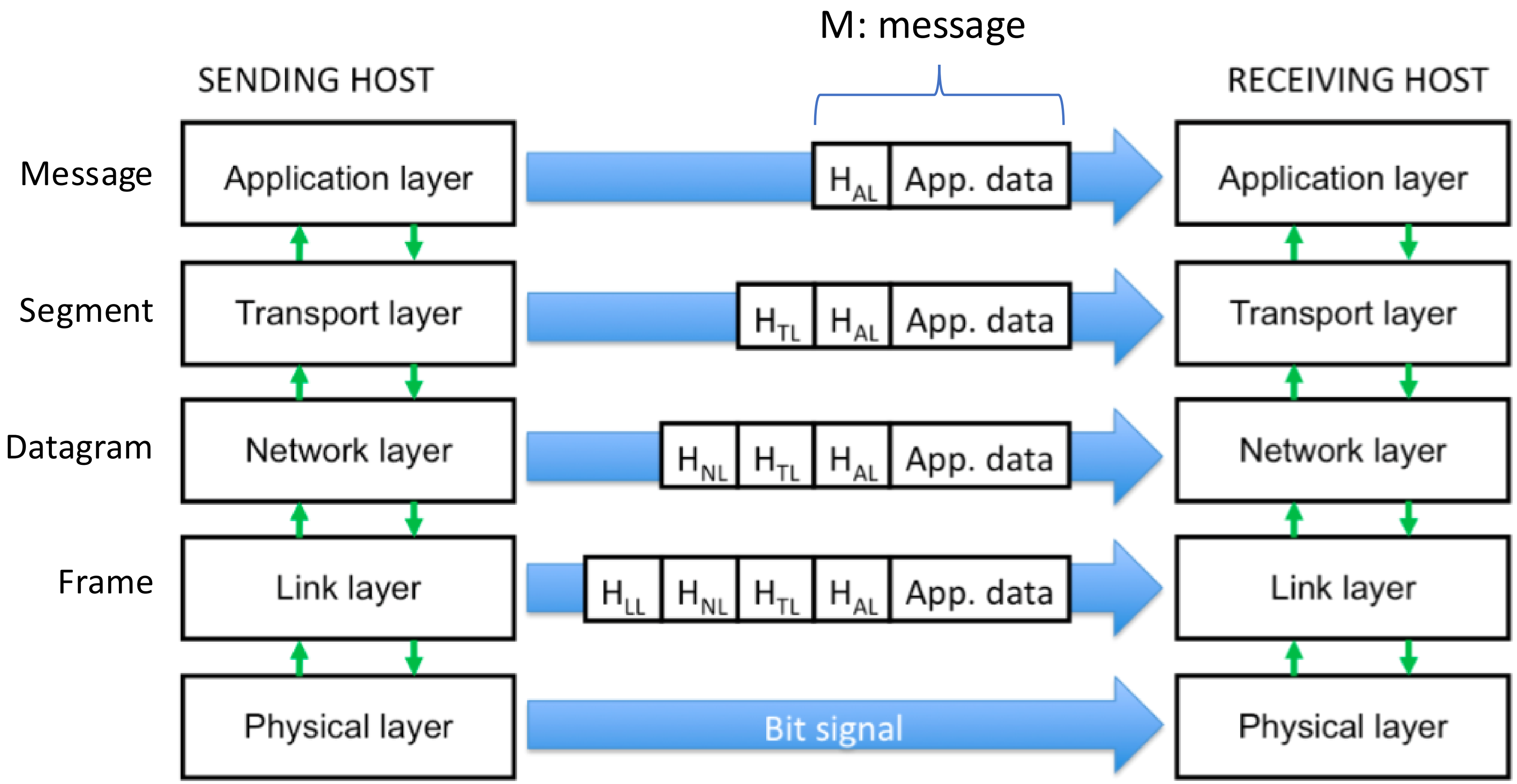
Protocol layer service models

- A service defines what operations can be performed.
  - says nothing about implementation.

- Not the same as protocols. Protocol determines
  - how the service is implemented
  - a set of rules and packet formats for this purpose.

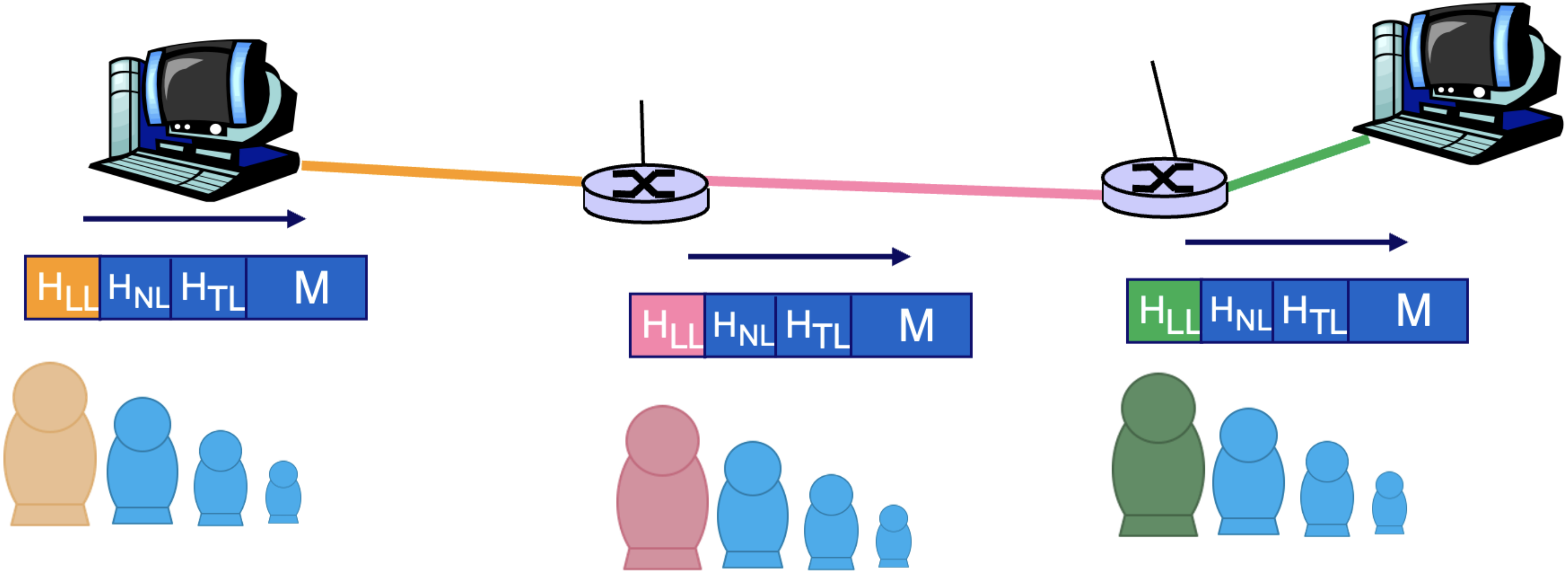
- Example (typical) service: Encapsulation

Data (payload) encapsulation



Encapsulation


image: amazon.com



Encapsulation

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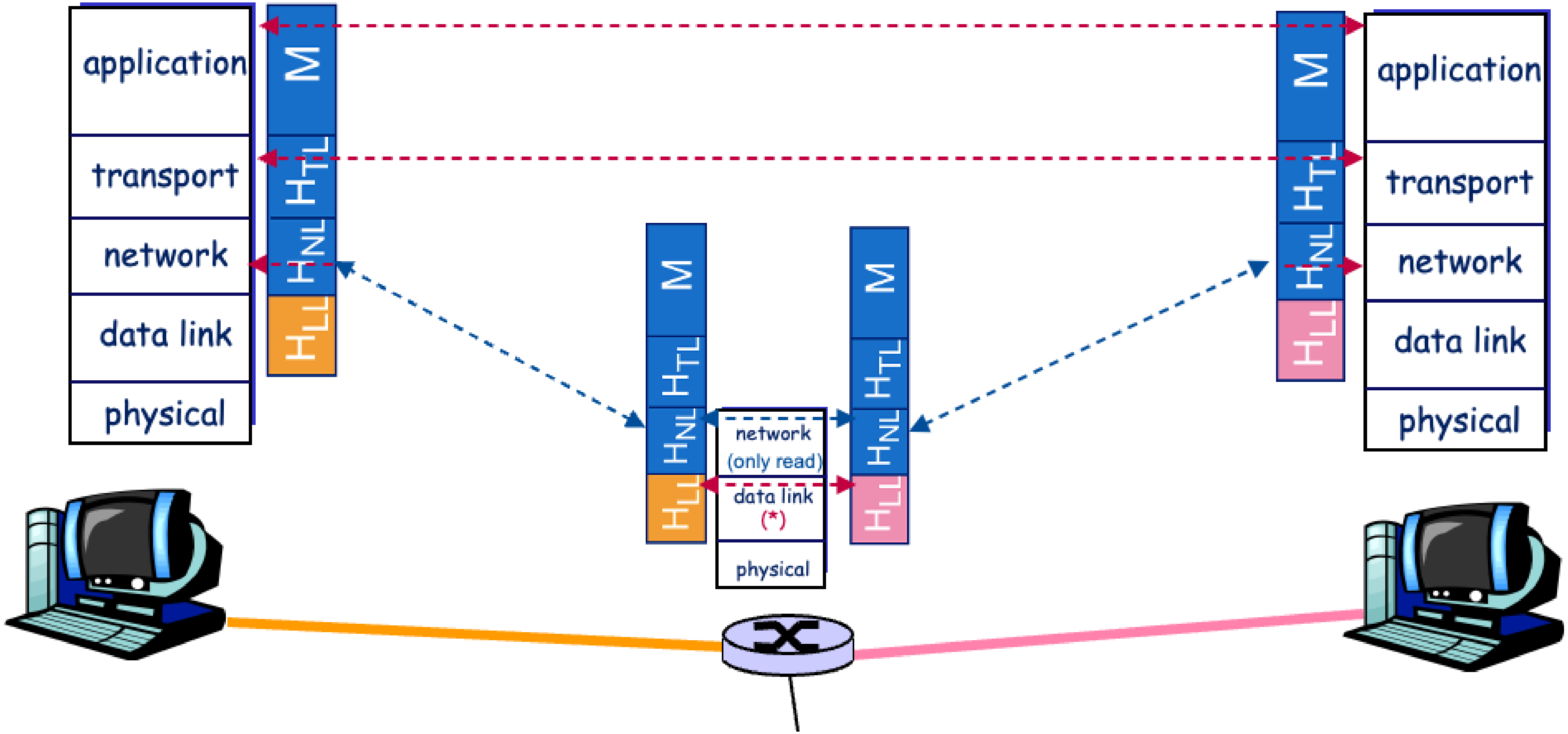
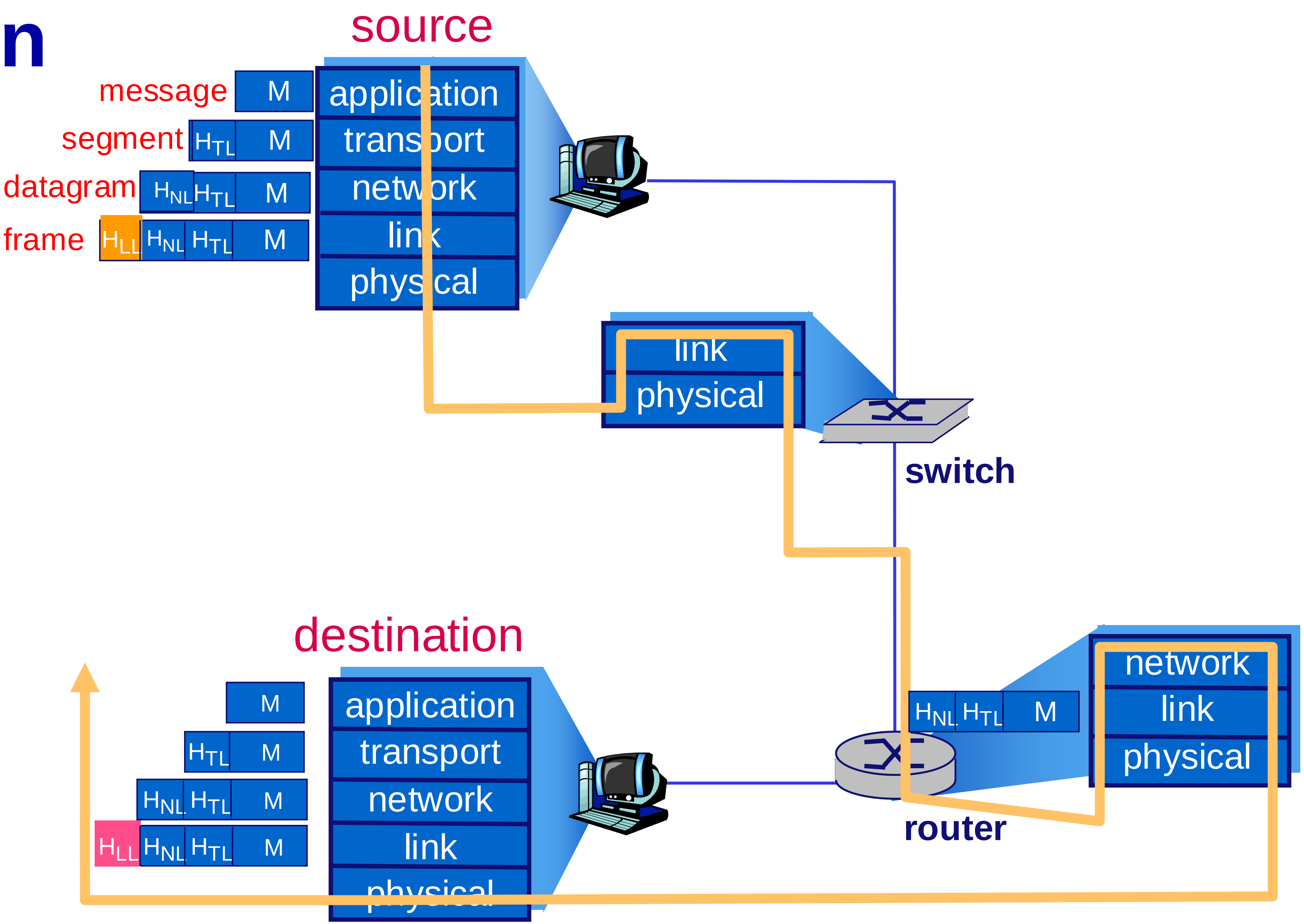


(*): Extract datagram, make new frame…

Encapsulation

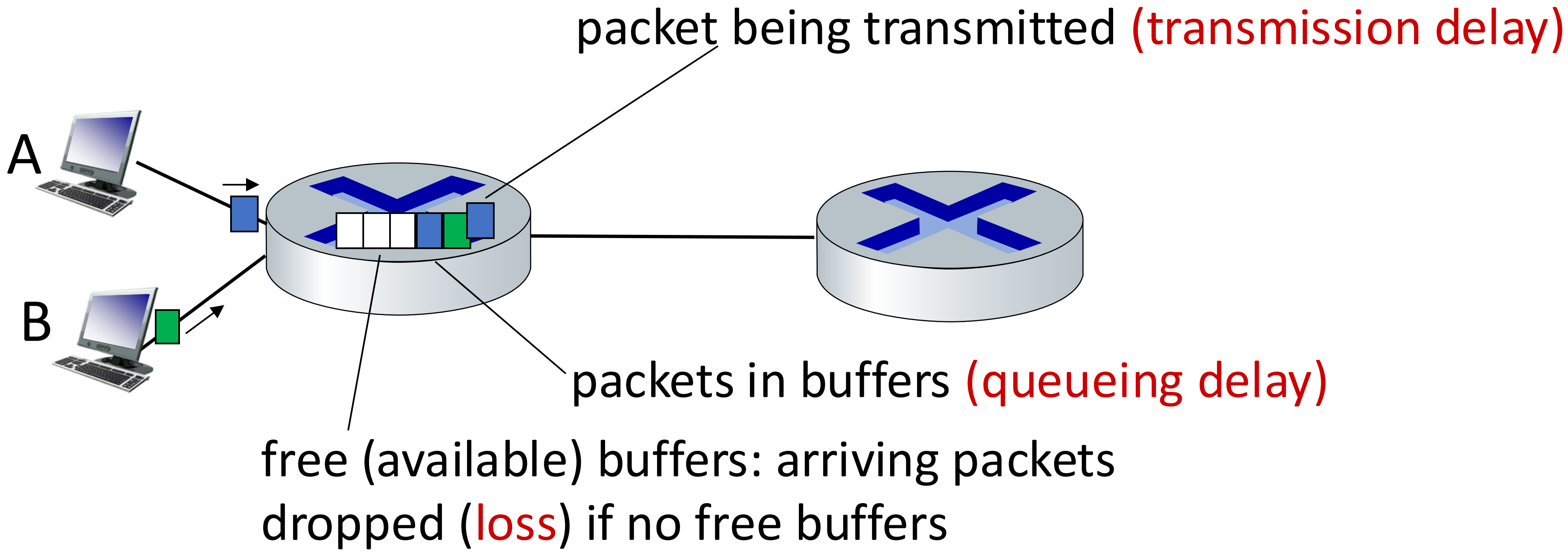


Performance: loss, delay, throughput

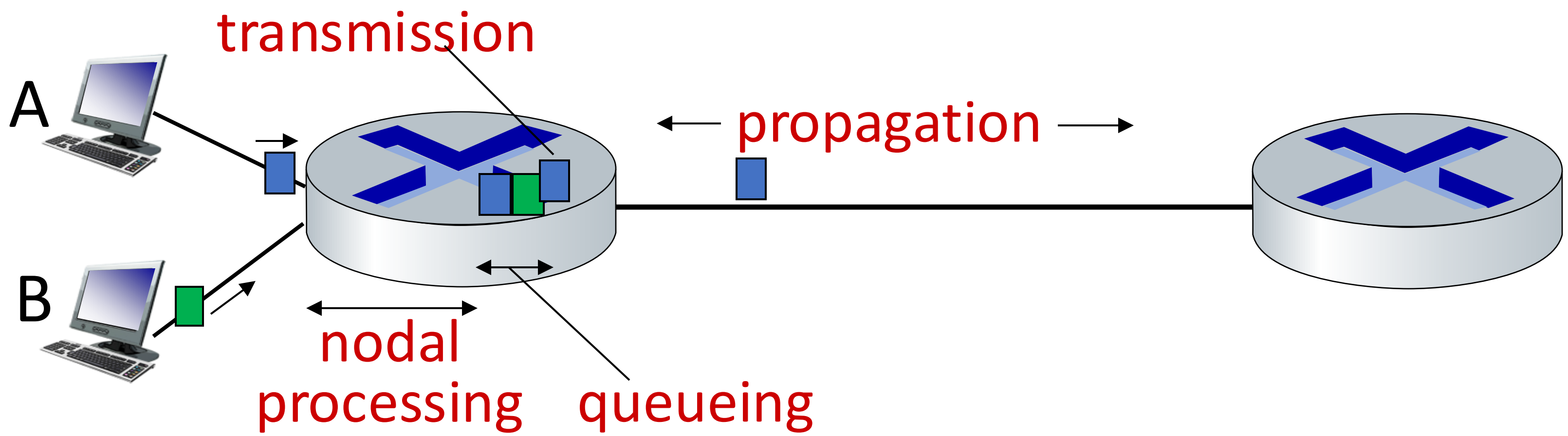
How do packet loss and delay occur?

packets *queue* in router buffers

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



Packet delay: four sources

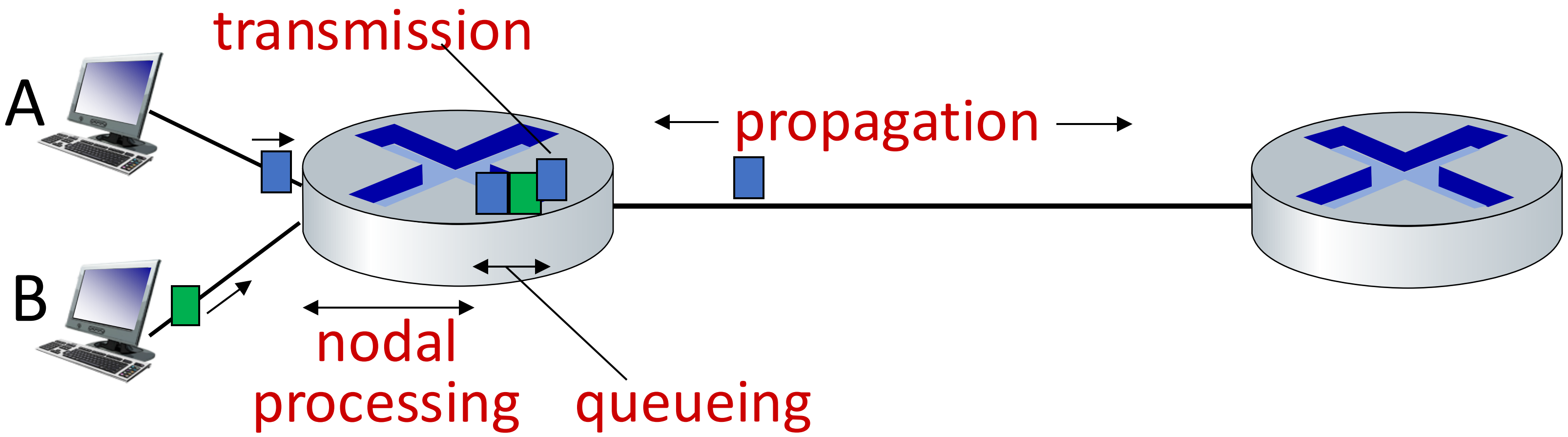


$$d_{\text{nodal}} = d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}}$$

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

Packet delay: four sources



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

d_{trans}: transmission delay:

- L: packet length (bits)
- R: link *transmission rate (bps)*
- $d_{trans} = L/R$

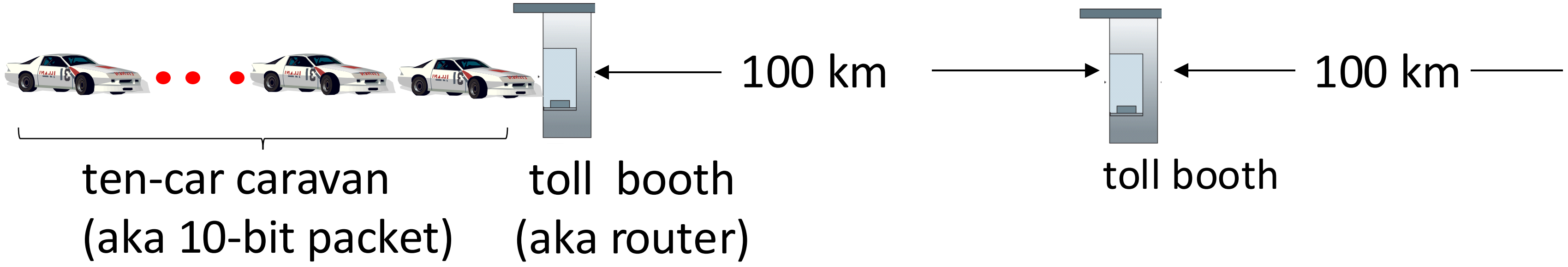
d_{prop}: propagation delay:

- d: length of physical link
- s: propagation speed (~2x10^8 m/sec)
- $d_{prop} = d/s$

d_{trans} and d_{prop}
very different

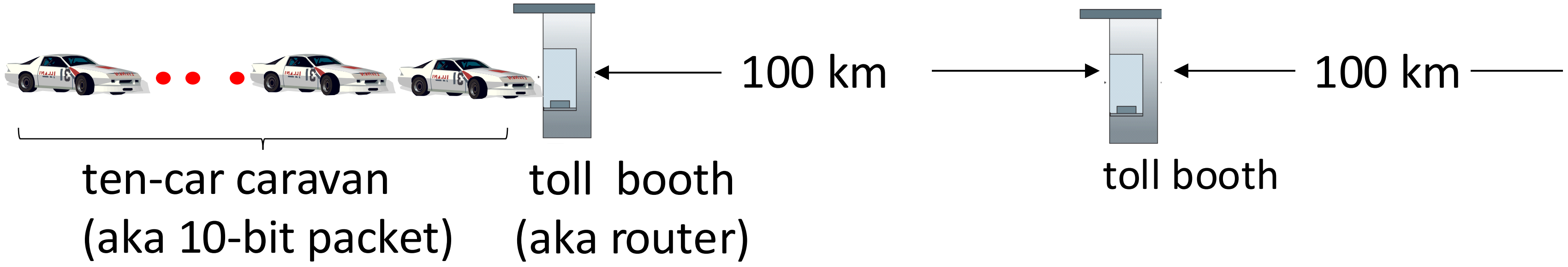
* Check out the online interactive exercises:
http://gaia.cs.umass.edu/kurose_ross

Caravan analogy



- cars "propagate" at 100 km/hr
- toll booth takes 12 sec to service car (bit 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

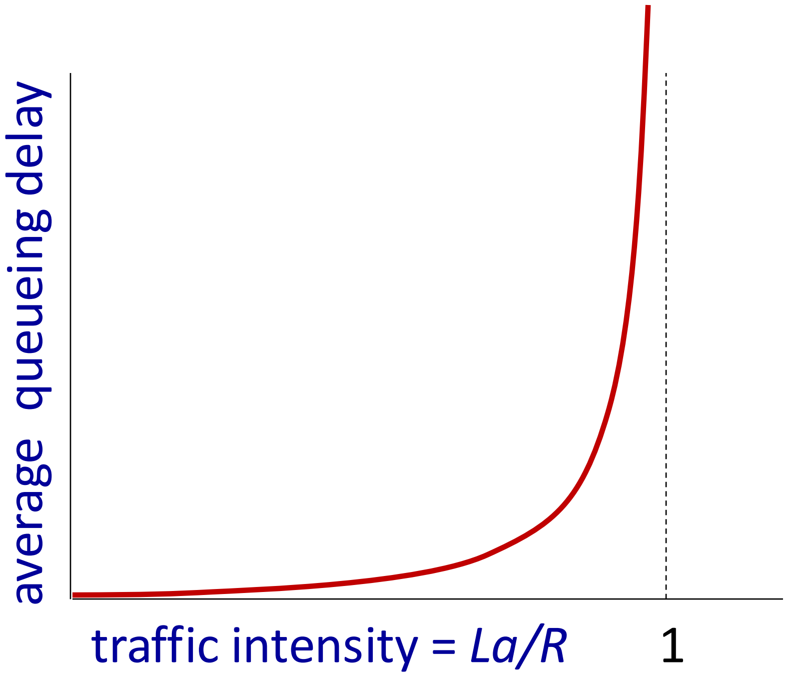
Caravan analogy



- 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

Packet queueing delay (revisited)



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

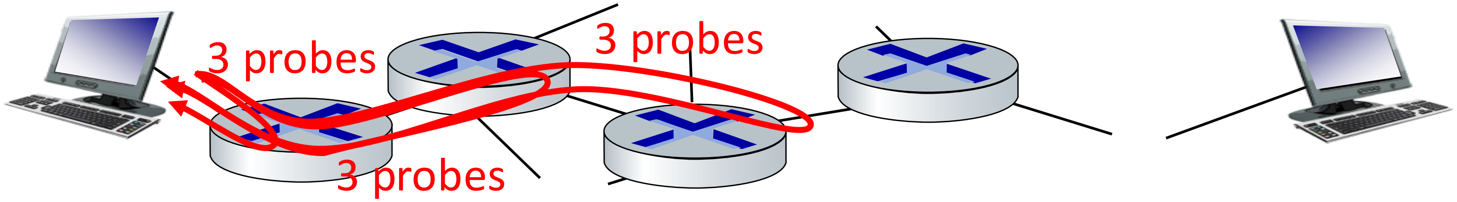
- *La/R* ~ 0: avg. queueing delay small
- *La/R* -> 1: avg. queueing delay large
- *La/R* > 1: more "work" arriving is more than can be serviced - average delay infinite!

La/R ~ 0

La/R -> 1

“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 (with time-to-live field value of *i*)
  - router *i* will return packets to sender
  - sender measures time interval between transmission and reply



Real Internet delays and 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

3 delay measurements
to border1-rt-fa5-1-0.gw.umass.edu

trans-oceanic link

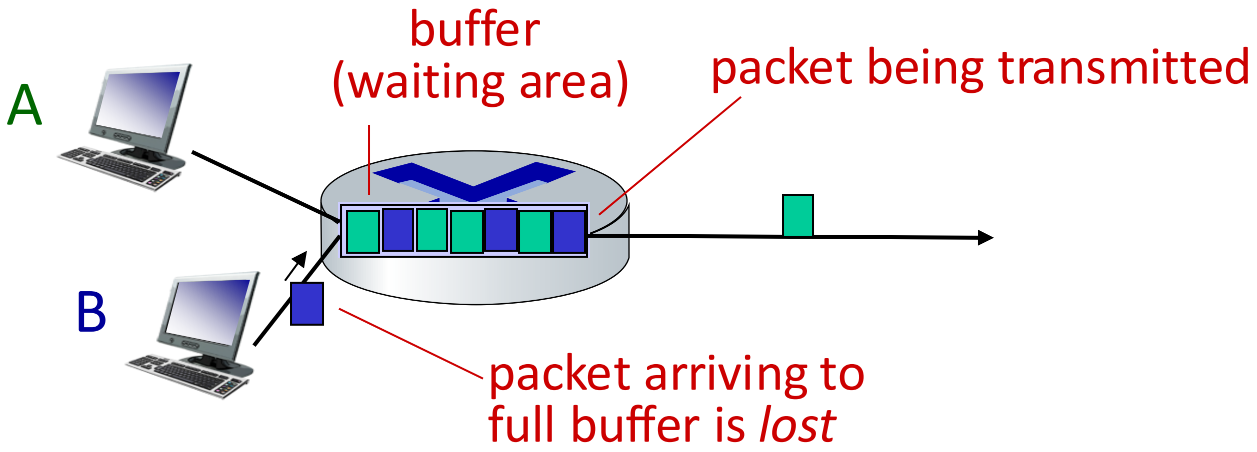
looks like delays
decrease! Why?

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

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

Packet loss

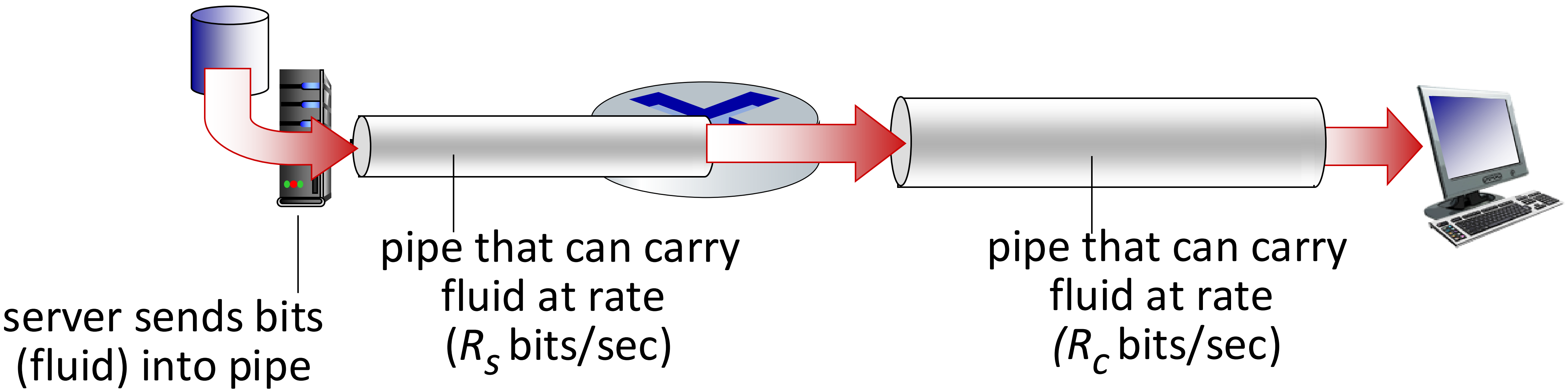
- queue (aka buffer) preceding link in buffer has finite capacity
- packet arriving to full queue dropped (aka lost)
- lost packet may be retransmitted by previous node, by source end system, or not at all



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

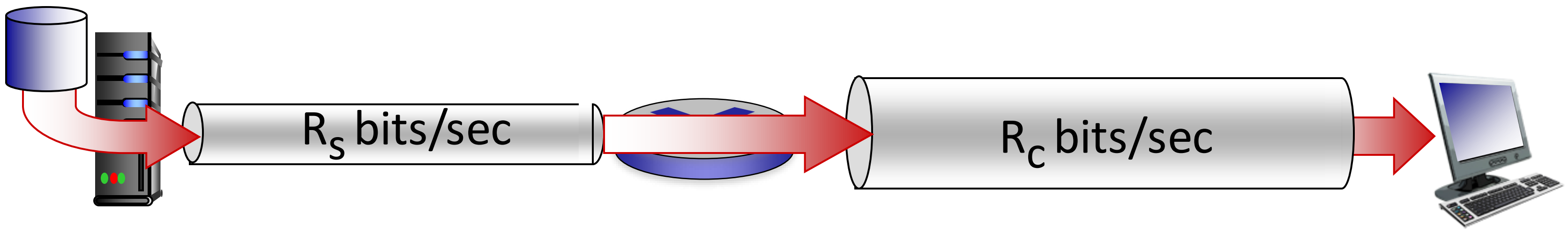
Throughput

- *throughput:* rate (bits/time unit) at which bits are being sent from sender to receiver
  - *instantaneous:* rate at given point in time
  - *average:* rate over longer period of time

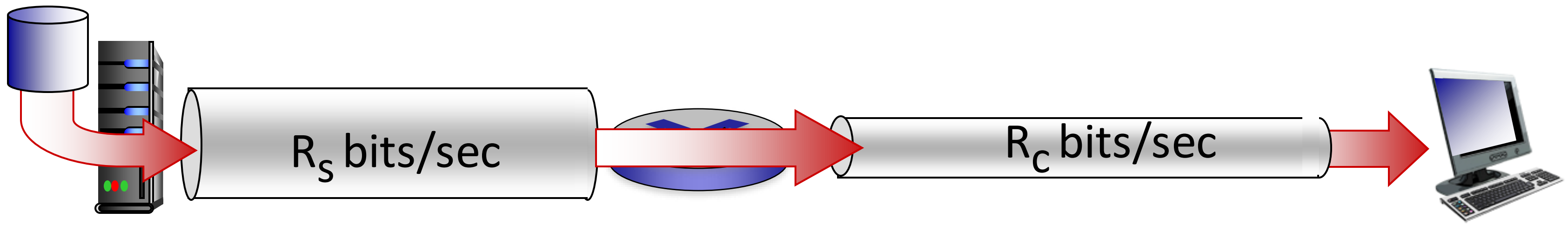


Throughput

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



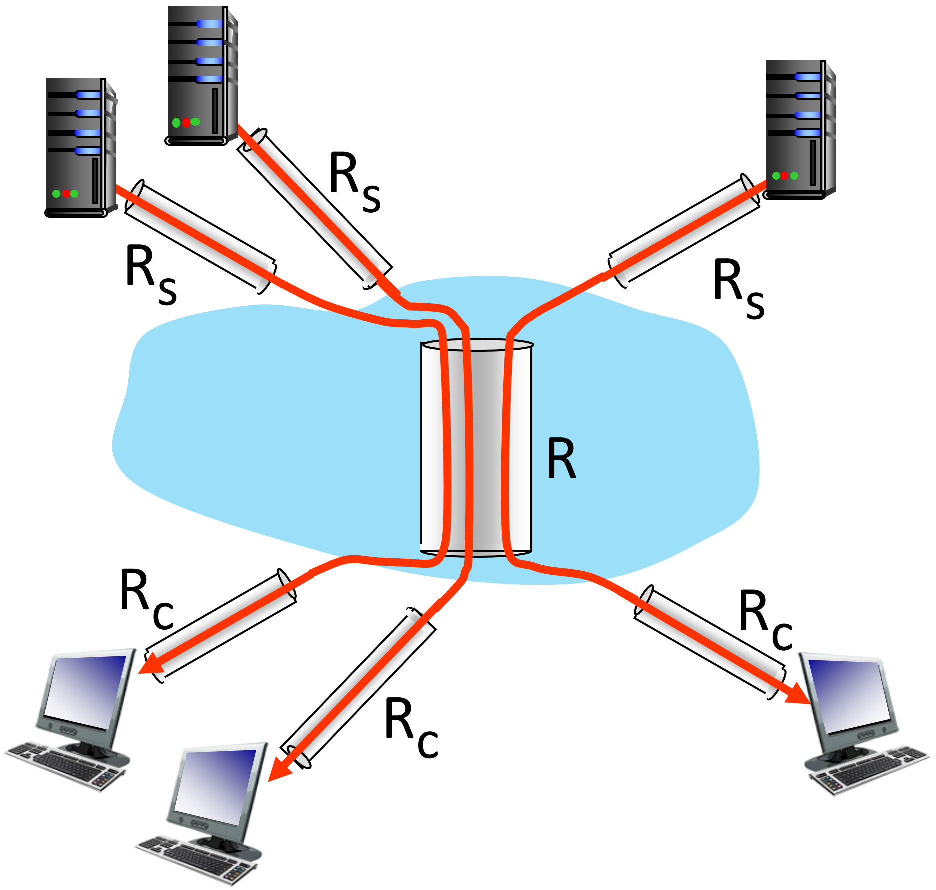
$R_s > R_c$ What is average end-end throughput?



bottleneck link

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

Throughput: network scenario



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

- per-connection end-end throughput: $min(R_c,R_s,R/10)$
- in practice: R_c or R_s is often bottleneck

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