T1: Introduction

1.1 What is computer network?
- Examples of computer network
- The Internet
- Network structure: edge and core

1.2 Why computer networks

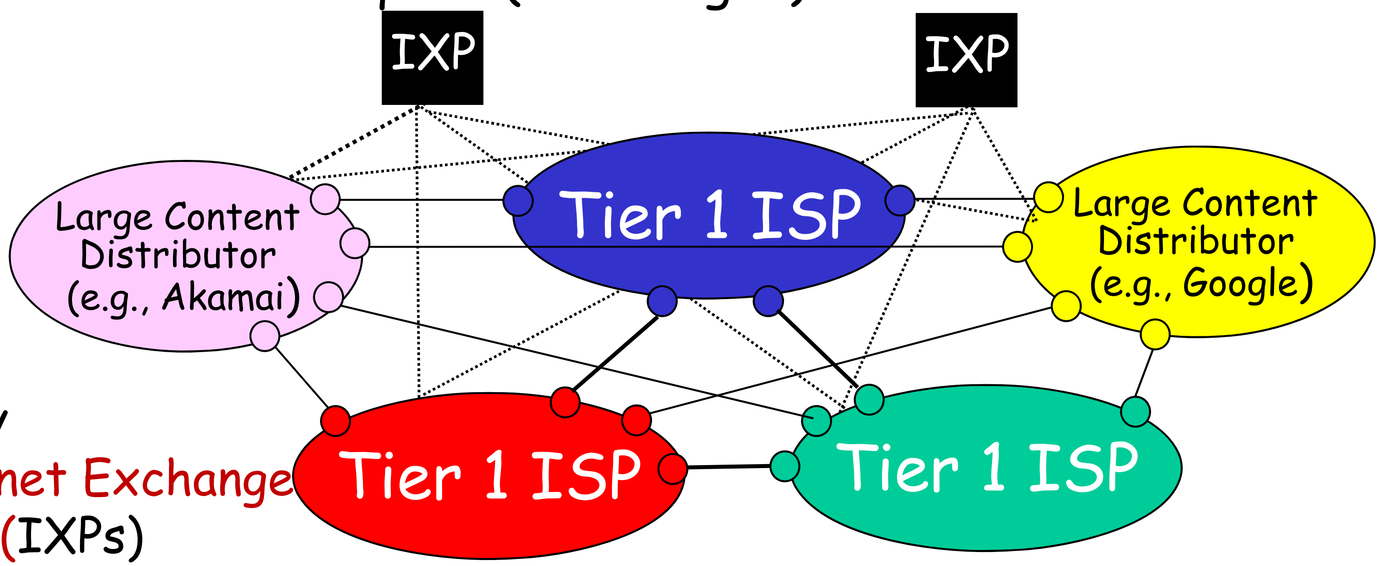
1.3 The way networks work

1.4 Performance metrics:
- Delay, loss and throughput in packet-switched networks

Internet structure: network of networks

- roughly hierarchical
- at center: small # of well-connected large networks
  - "tier-1" commercial ISPs (e.g., Verizon, Sprint, AT&T, Qwest, Level3), national & international coverage
  - large content distributors (Google, Akamai (Netflix: Open Connect), Microsoft)
  - treat each other as equals (no charges)

Tier-1 ISPs & Content Distributors, interconnect (peer) privately … or at Internet Exchange Points (IXPs)

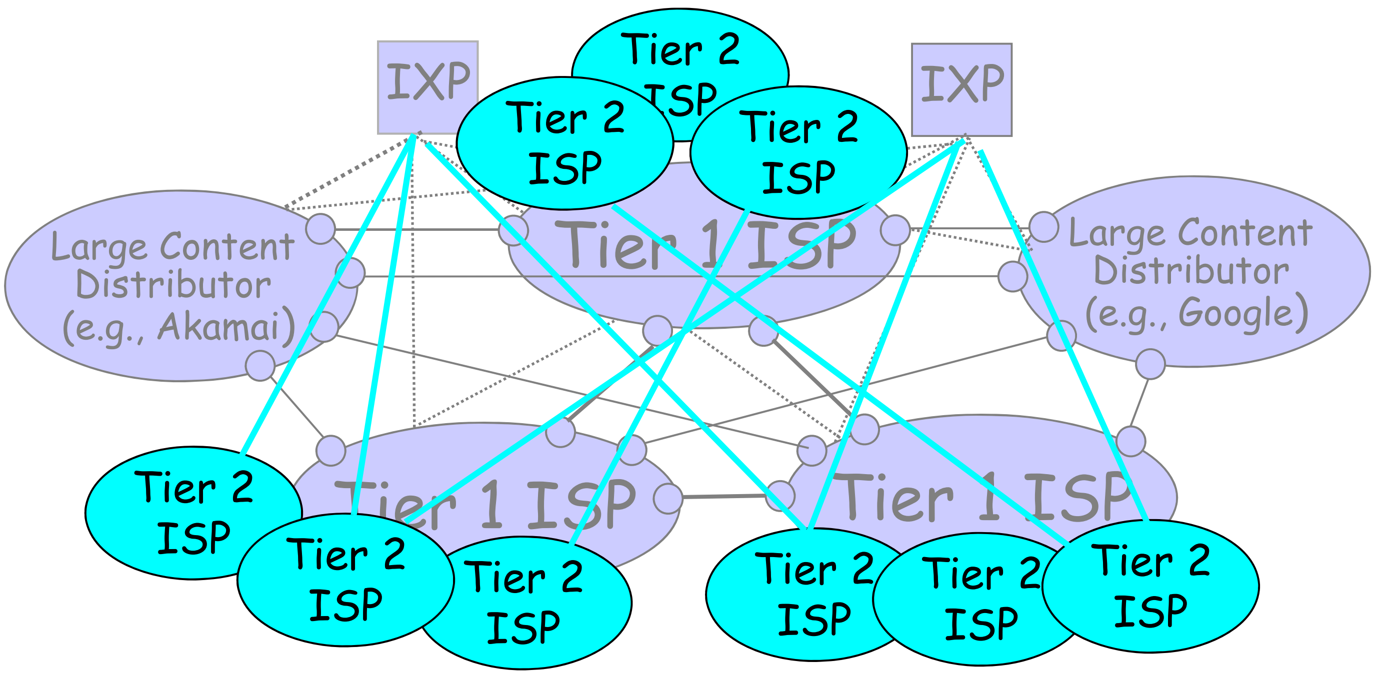


Canadian Tier-1: MTS Allstream
(MTS: Manitoba Teleco Service)

Internet structure: network of networks

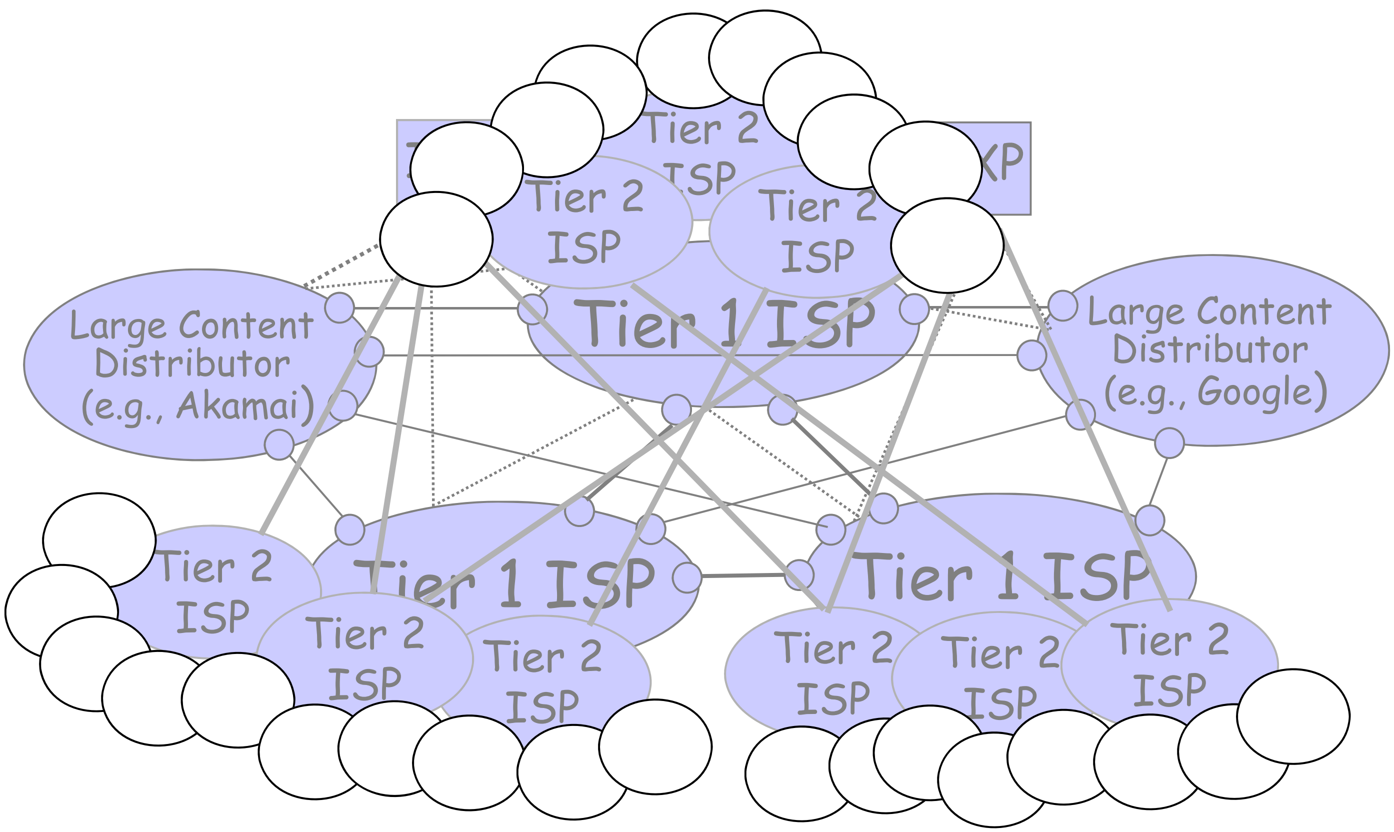
"tier-2" ISPs: smaller (often regional) ISPs

- connect to one or more tier-1 (provider) ISPs
  - each tier-1 has many tier-2 customer nets
  - tier 2 pays tier 1 provider
- tier-2 nets sometimes peer directly with each other (bypassing tier 1) , or at IXP



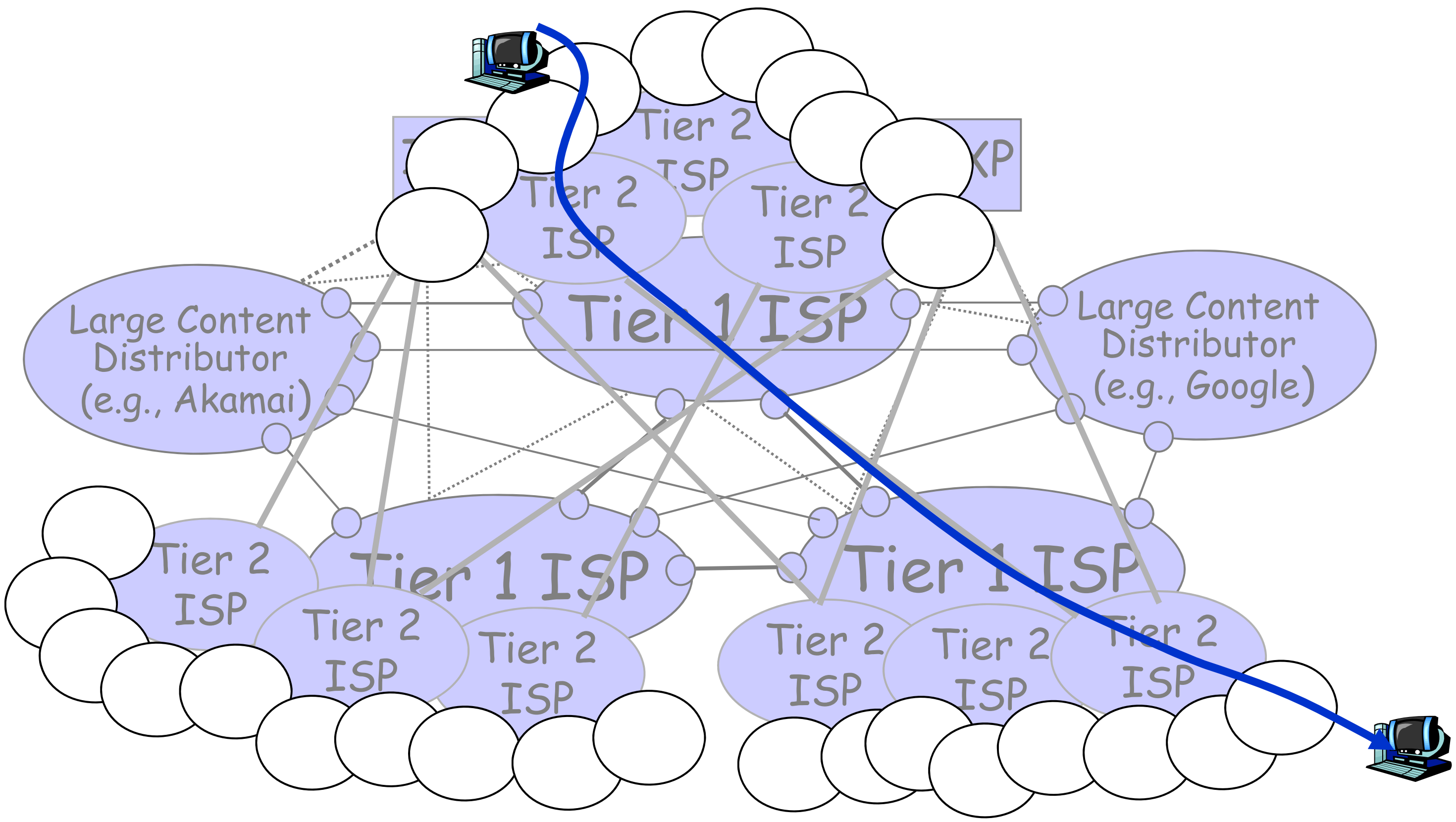
Internet structure: network of networks

- "Tier-3" ISPs, local ISPs
- customer of tier 1 or tier 2 network
  - last hop ("access") network (closest to end systems)



Internet structure: network of networks

- a packet passes through many networks from source host to destination host



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Why Computer Networks

- Resource sharing
- Efficiency
- High reliability
- Access to remote information
- Person to person communication
- Interactive entertainment
- Others ...

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The Way Networks Work

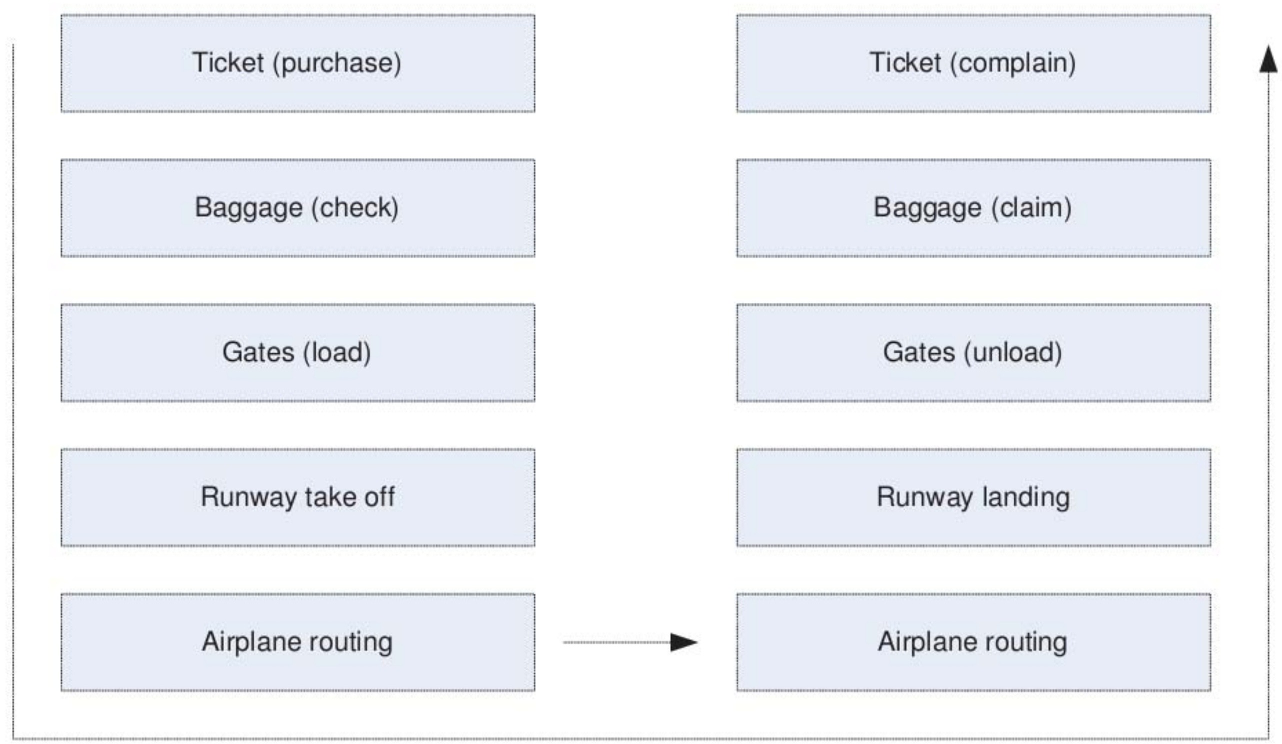
- Network functions are organized in a layered architecture. The services of one layer are implemented on top of the services provided by the layer immediately below.

- The different layers can be designed more or less independently, which greatly simplifies network design.

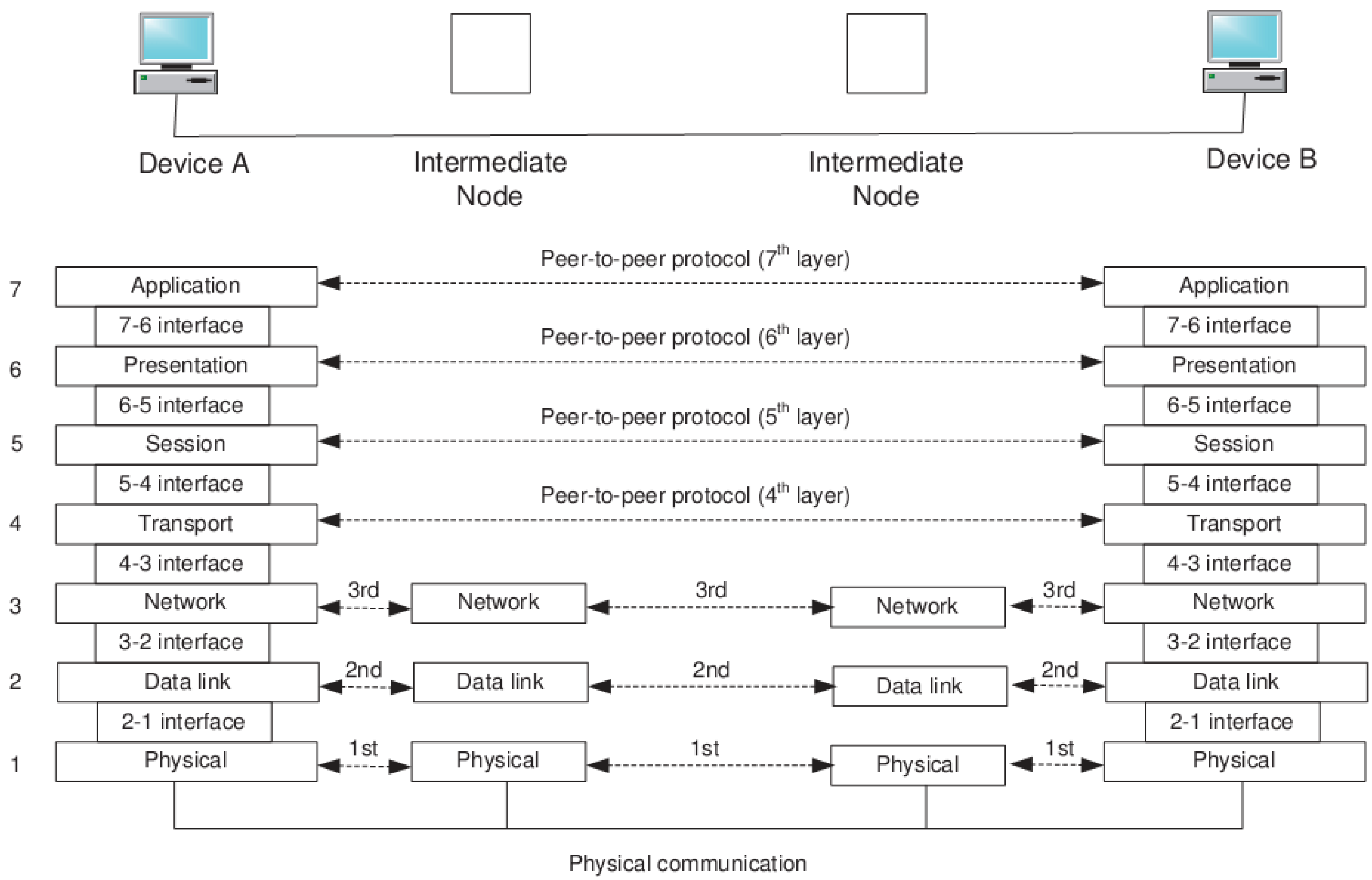
- Another advantage is the compatibility derived from the independence of the layers. For instance, when different networks are interconnected, a computer on one network can access computers on all the networks, independently of the specific implementations of the different networks.

The way Networks Work

The operation is organized in a layered architecture. Each layer implements a service via its own internal-layer actions relying on services provided by layer below.



- The International Organization for Standardization (ISO) proposed the open systems interconnection reference model (OSI model), which is a layered architecture with seven layers.



Definitions

- Protocol: a set of rules that governs communications. (A protocol defines what is communicated, how and when it is communicated);
- Layering: it achieves a functional level of modularity;
- Network architecture: a set of layers and protocols;
- Peer-to-peer protocols: protocols which make the layer N of the source and destination (counterpart) conceptual understanding
- Interface: it defines what information and services a layer must provide for the layer above it

Note:

- Peer-to-peer protocol is achieved using the service provided by their lower layer entities
- Communication functions are partitioned into a vertical set of layers
- Ideally, upper layer entities are independent of the details of the lower layer entities, this is easy to modify protocol at one layer, independent of other layers.
- Allows heterogeneous users to communicate (open system)

Functions of layers

- Application layer implements commonly used communication services e.g., file transfer, directory services, virtual terminal.
- Presentation layer takes care of data compression, security, and format conversions so that nodes using different representations of information can communicate efficiently and securely.
- Session layer uses the transmission layer services to set up and supervise connections between end systems
- Transport layer supervises end-to-end transmission of packets. This layer may arrange for retransmission of erroneous packets.
- Network layer guides the packets from their source to their destination, along a path that may comprise a number of links
- Data link layer provides reliable transmission between nodes that are attached to the same physical link.
- Physical layer transmits raw bit stream over channel

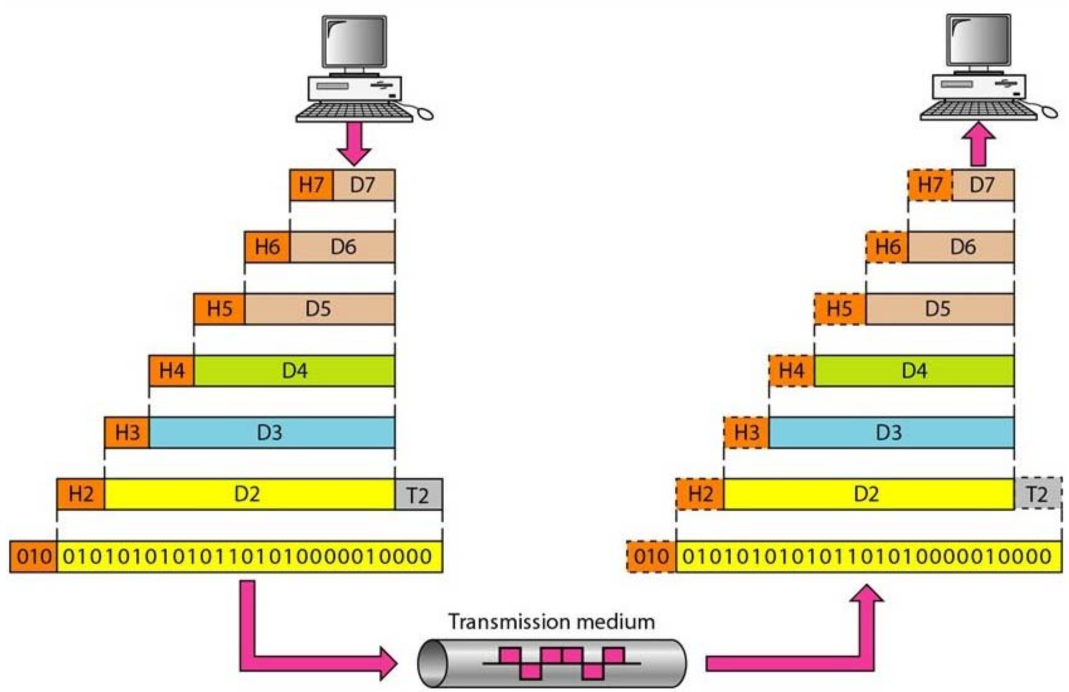
Summary of the functions of layers

The seven layers can be thought of as belonging to three subgroups.

- Layers 1, 2, and 3 are the network support layers. They deal with the physical aspects of moving data from one device to another (such as specifications, physical connections, physical addressing, and transport timing and reliability).
- Layers 5,6, and 7 are the user support layers. They allow interoperability among unrelated software systems.
- Layer 4 links the two subgroups and ensures that what the lower layers have transmitted is in a form that the upper layers can use.

Headers and trailers

H2: physical address of the most recent node and next intended node;
T2: error control information;
H3: source and destination addresses;
H4: sequence number;
H5: connection control information (password and login verification);
H6: type and length of the transmission (type of code, etc)



An exchange using the OSI model

What's a protocol?

human protocols:

- "what's the time?"
- "I have a question"
- introductions

… specific msgs sent

… specific actions taken when msgs received, or other events

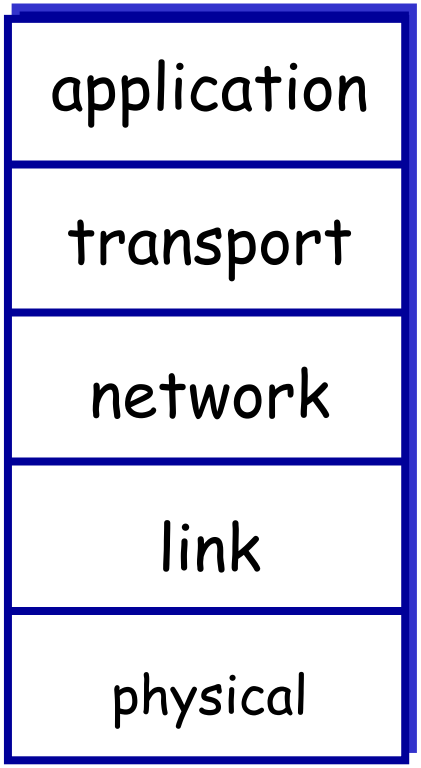
network protocols:

- machines rather than humans
- all communication activity in Internet governed by protocols

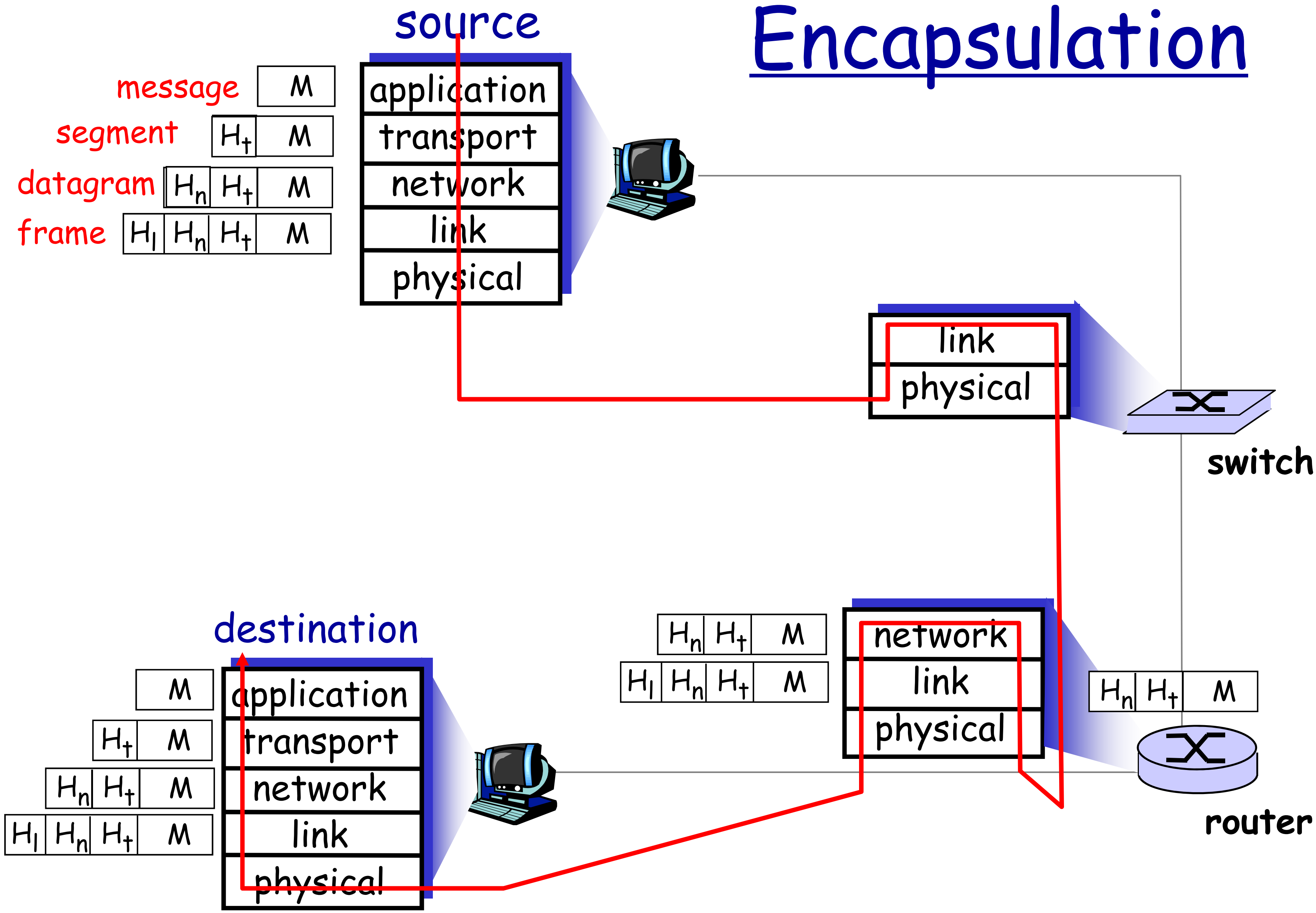
protocols define format, order of msgs sent and received among network entities, and actions taken on msg transmission, receipt

Internet protocol stack

- application: supporting network applications
  - Skype, 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 (MAC/Link)
- physical: bits "on the wire": Ethernet, 802.11 (WiFi)



Encapsulation



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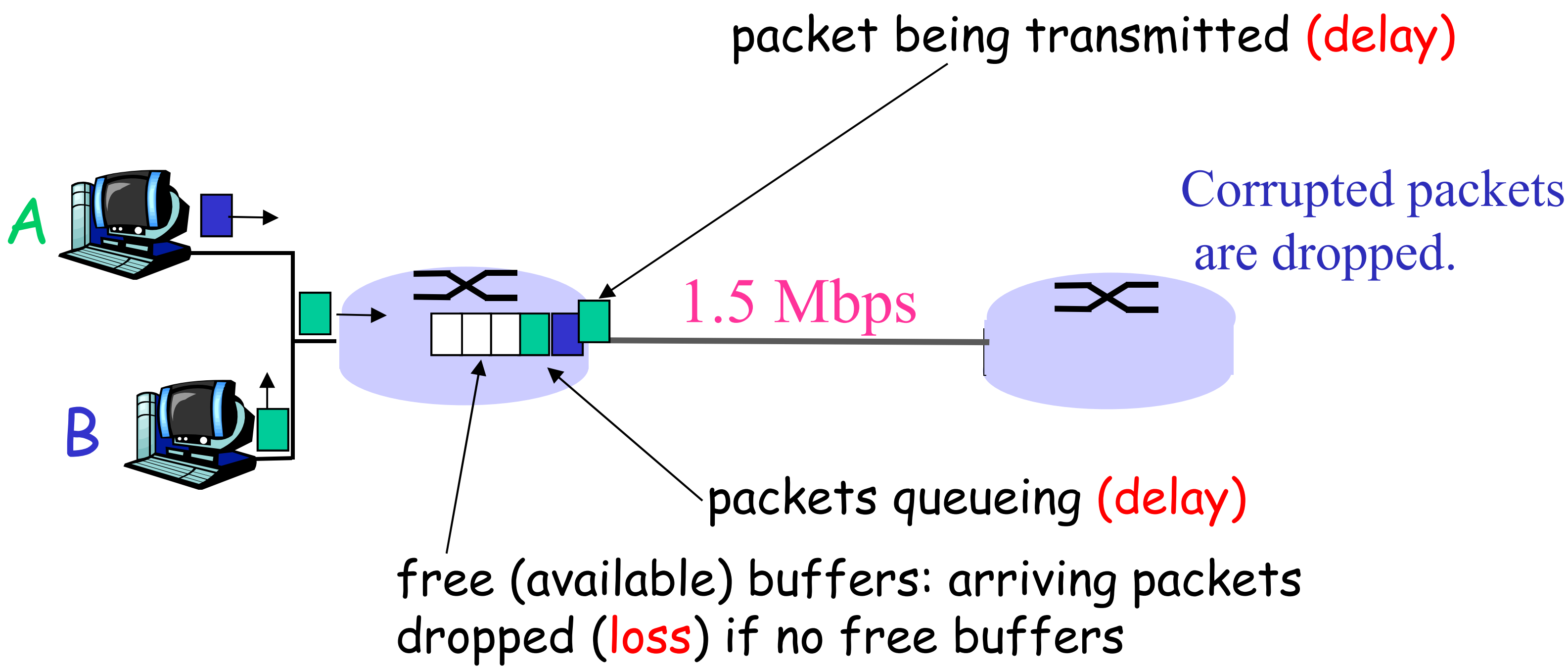
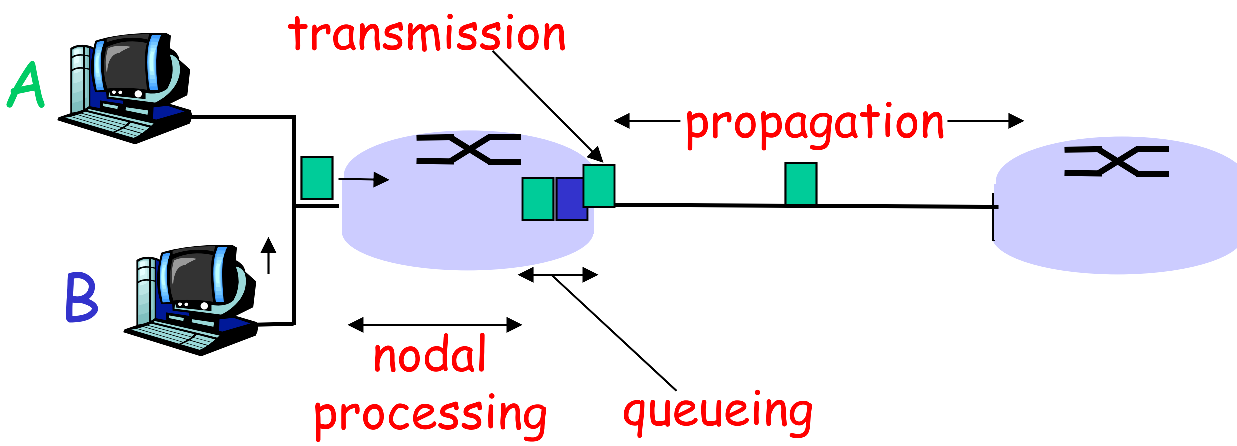
How do loss and delay occur?

packets queue in router buffers (i.e., memory)

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



Four sources of packet delay



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

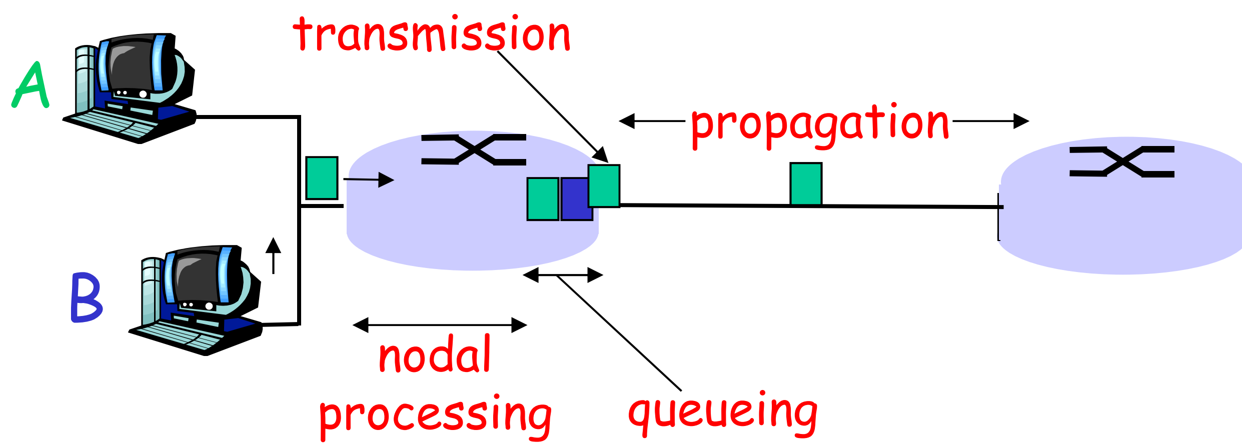
d_{proc}: nodal processing

- 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



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

d_{trans}: **transmission delay:**

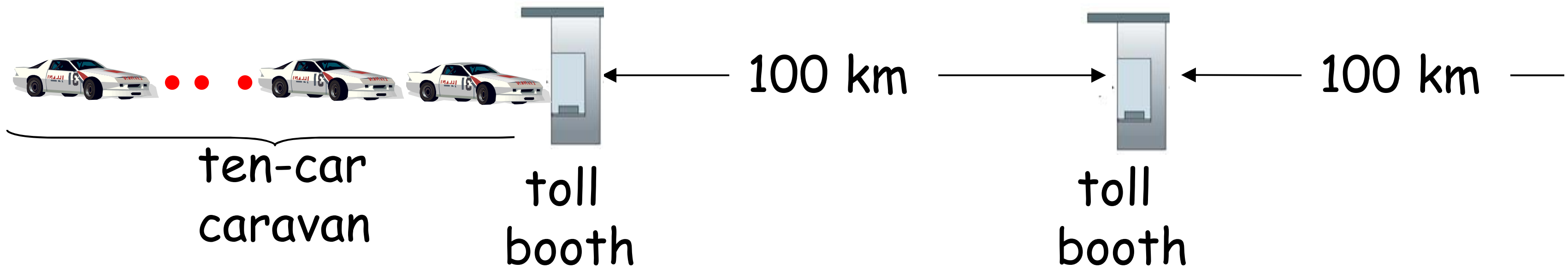
- L: packet length (bits)
- R: link bandwidth (bps)
- $d_{trans} = L/R$

d_{trans} and d_{prop} very different

d_{prop}: **propagation delay:**

- d: length of physical link
- s: propagation speed in medium (~2×10^8 m/sec)
- $d_{prop} = d/s$

Caravan analogy

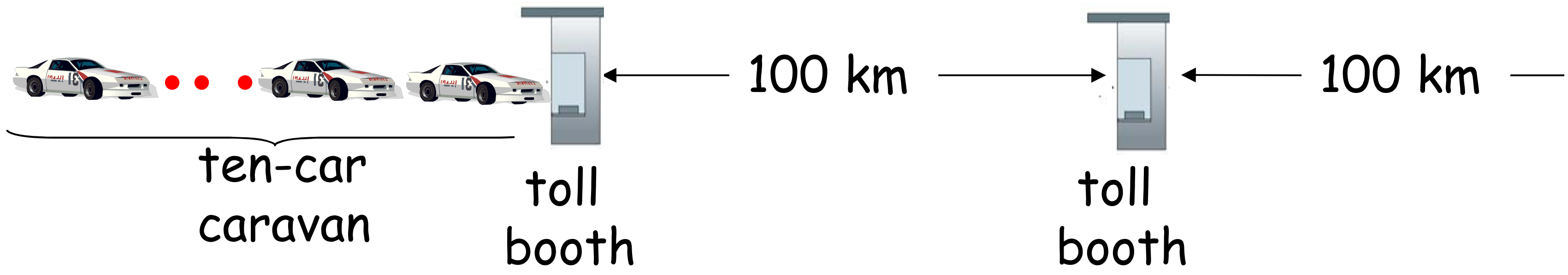


- cars "propagate" at 100 km/hr
- toll booth takes 12 sec to service car (transmission time)
- car~bit; caravan ~ packet

- Q: What is the "queueing delay" experienced by the last car at the first toll booth?

  12*9 = 108 sec

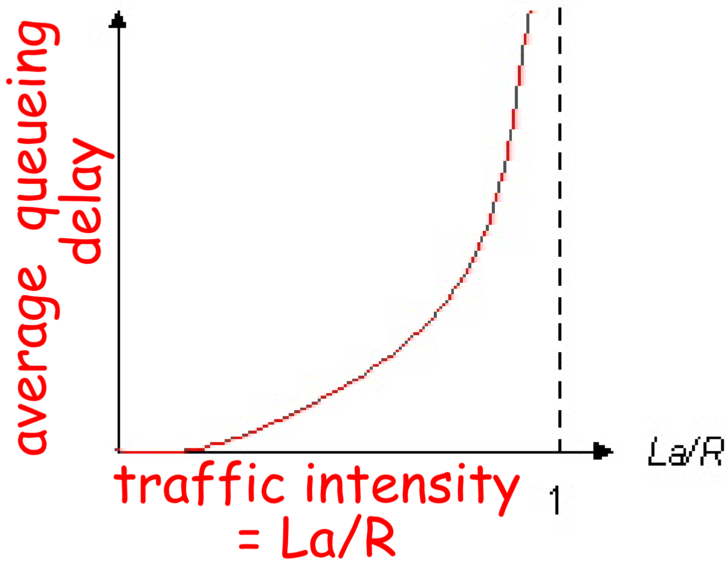
Caravan analogy



- 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?
  - A: Yes! After 7 min, 1st car arrives at second booth; three cars still at 1st booth.
  - 1st bit of packet can arrive at 2nd router before packet is fully transmitted at 1st router!

Queueing delay

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



- La/R ~ 0: avg. queueing delay small
- La/R -> 1: avg. queueing delay large
- La/R > 1: more "work" arriving

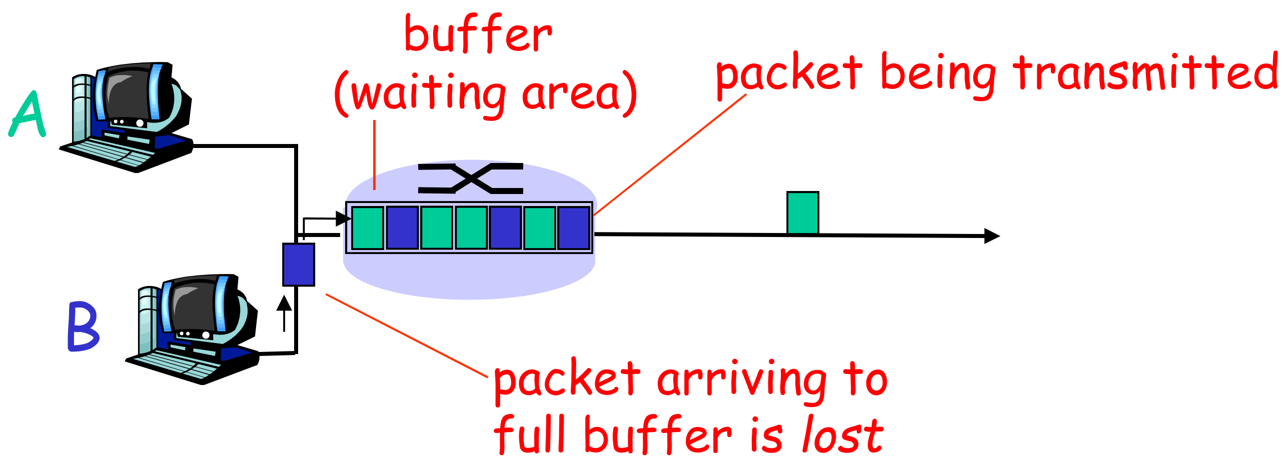
  than that can be serviced, average delay infinite!

La/R ~ 0

La/R -> 1

Packet loss

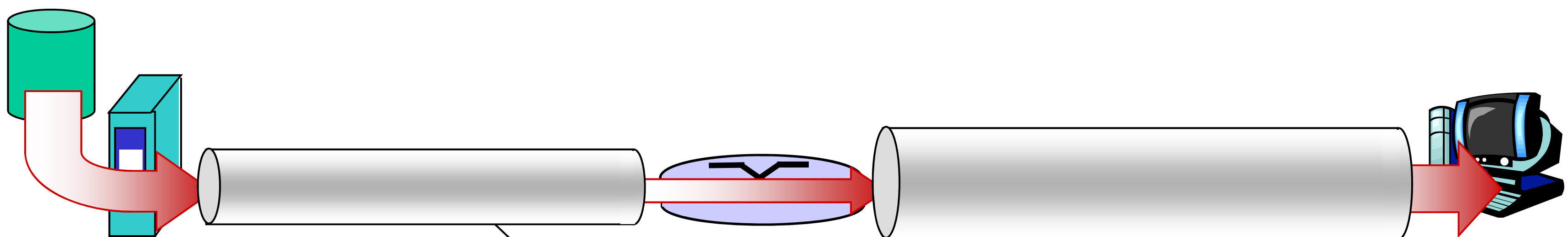
- queue (i.e., buffer) preceding link has finite capacity
- packet arriving to full queue dropped (aka lost)
- lost packet may be retransmitted by previous node, by source end system, or not at all



Throughput

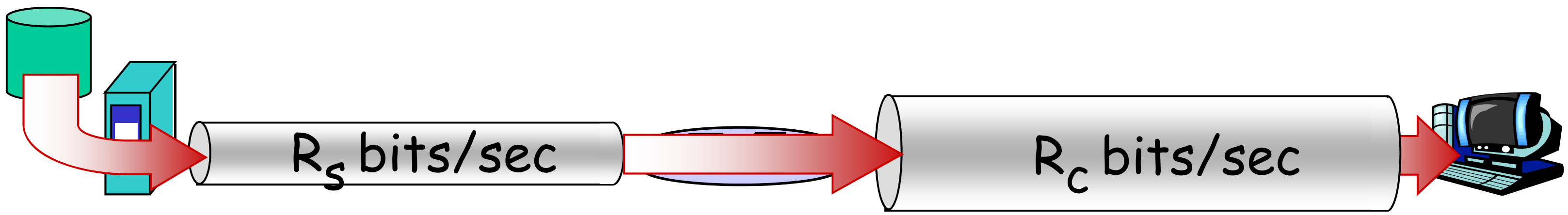
(the output rate of an input/output system)

- 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

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



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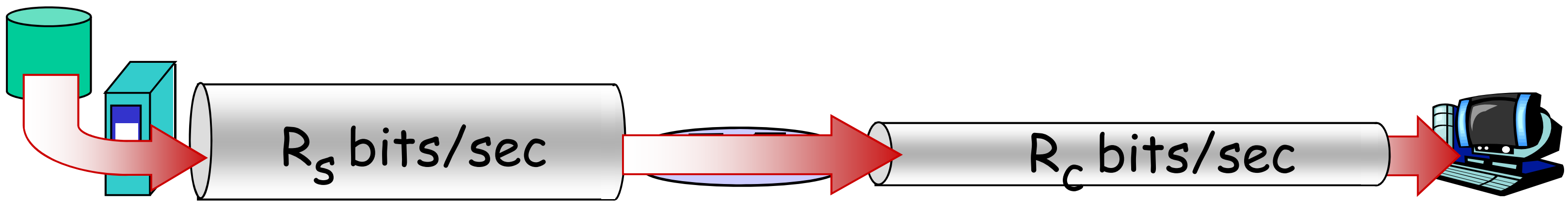
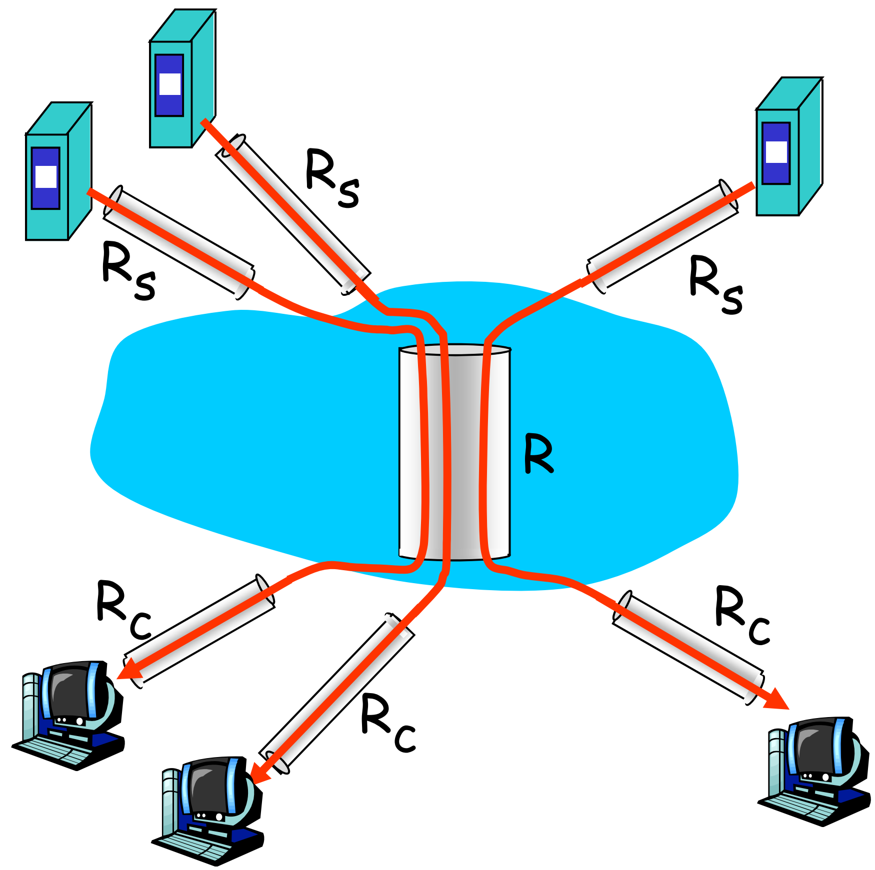


bottleneck link

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

Throughput: Internet scenario

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



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

Summary of T1

1.1 Definition of computer network/the Internet.

Network edge

- end systems, access networks, links

Network core

- circuit switching, packet switching, network structure

1.2 Benefits of computer networks

1.3 The way networks work

1.4 Performance metrics:

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What are we going to learn?

- T2 Network Analysis and Queuing Theory
- T3 Physical layer: digital transmission
- T4 Data link layer: Error detection and correction, Retransmission, Multiple Access protocols (MAC): Aloha, CSMA/CD and CSMA/CA.
- T5 Network layer: IP addressing, fragmentation, routing
- T6 Transport layer: TCP and UDP, Flow control and Congestion control
- T7 Application layer: HTTP, MQTT
- ST Engineering Data Center Networks