Computer Networks Principles

Introduction

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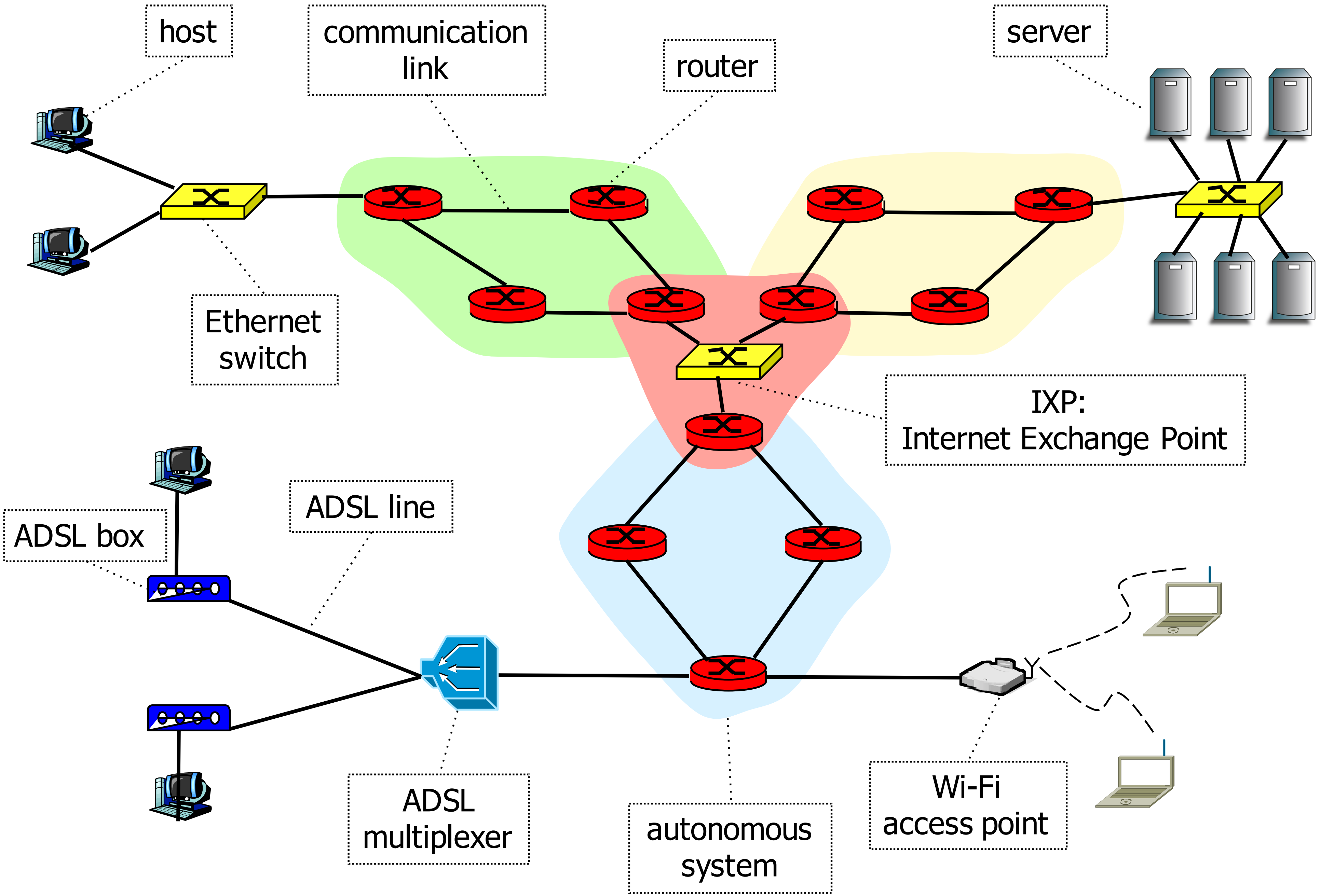
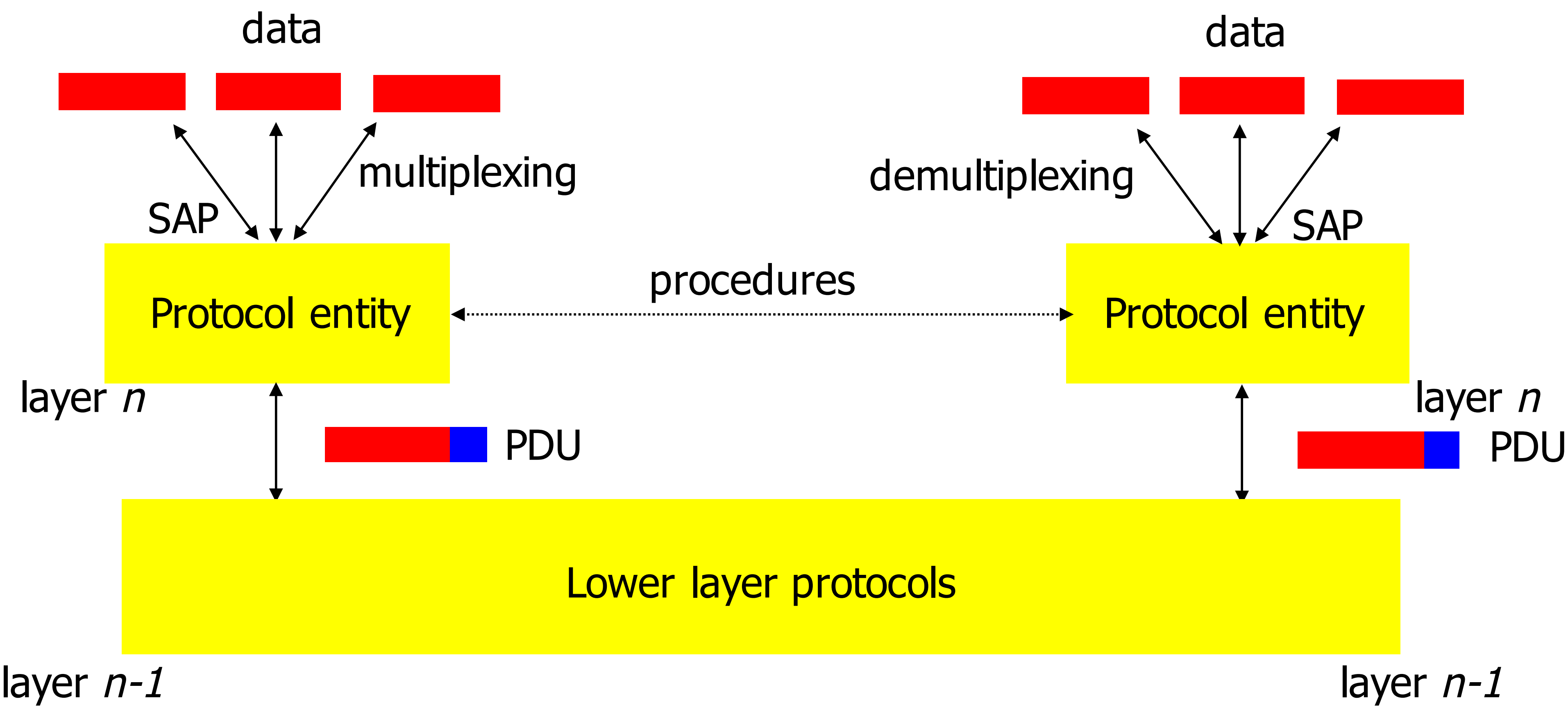
Contents

- Introduction
  - protocols and layered architecture
  - encapsulation
  - interconnection structures
  - performance


host
communication link
router
server
Ethernet switch
IXP: Internet Exchange Point
ADSL line
ADSL box
ADSL multiplexer
autonomous system
Wi-Fi access point

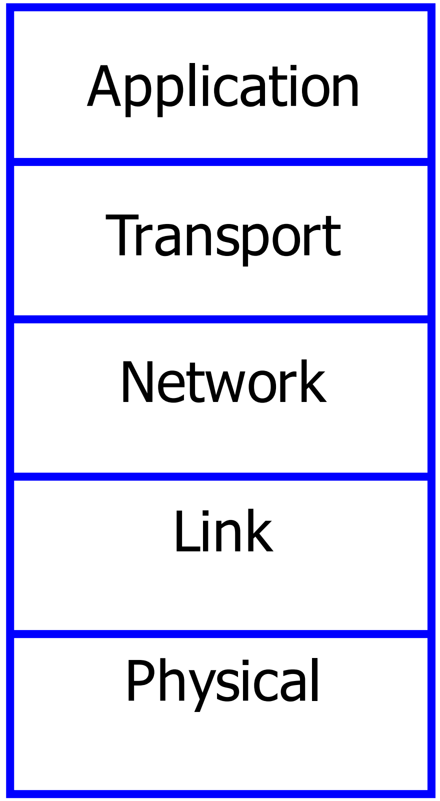
Protocols

Protocol architecture

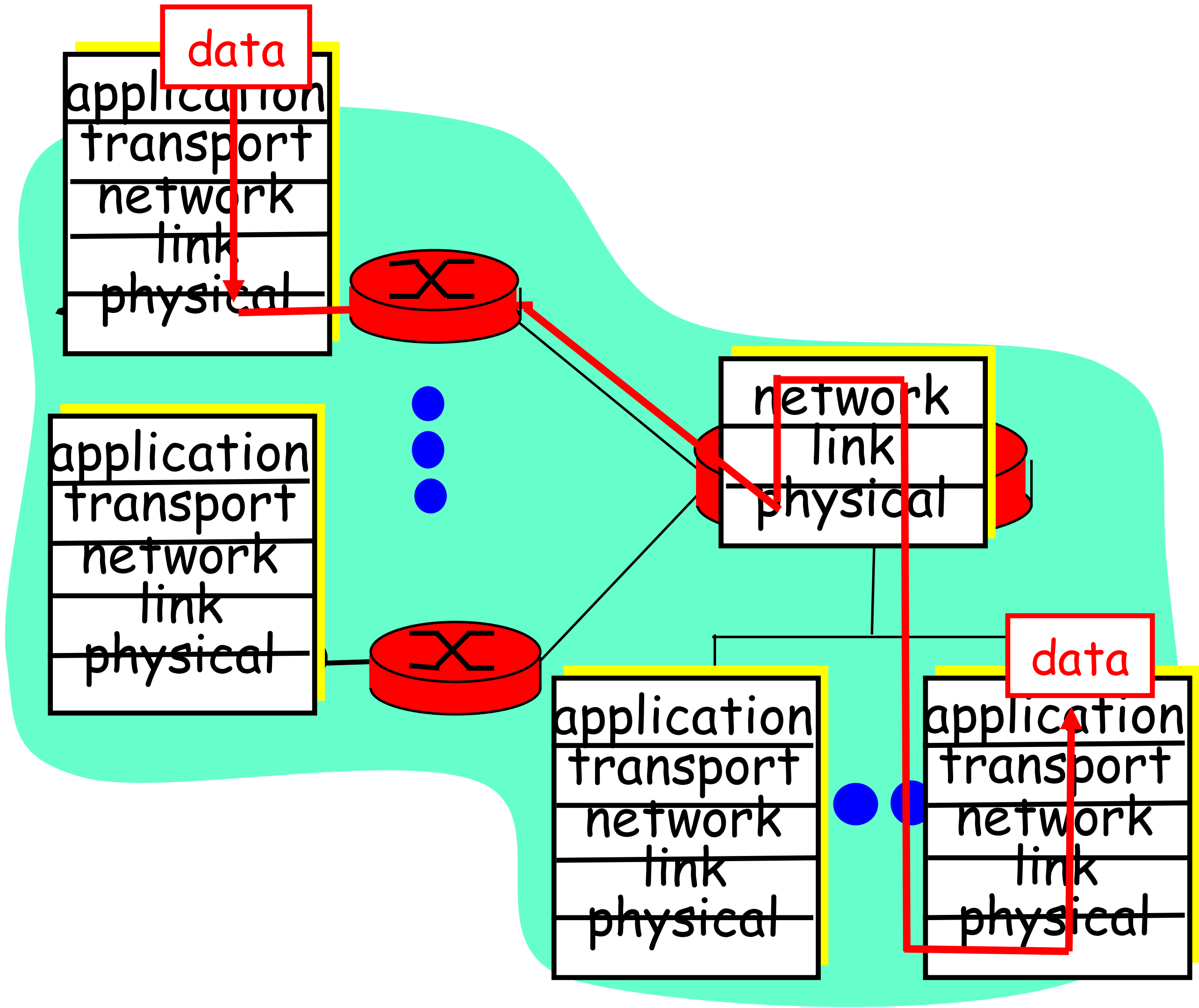


Internet protocol stack

- **Application**: supporting network applications
  - FTP, SMTP, HTTP, OSPF, RIP
- **Transport**: host-host data transfer
  - TCP, UDP
- **Network**: routing of datagrams from source to destination
  - IP
- **Link**: data transfer between neighboring network elements
  - PPP, Ethernet
- **Physical**: bits “on the wire”

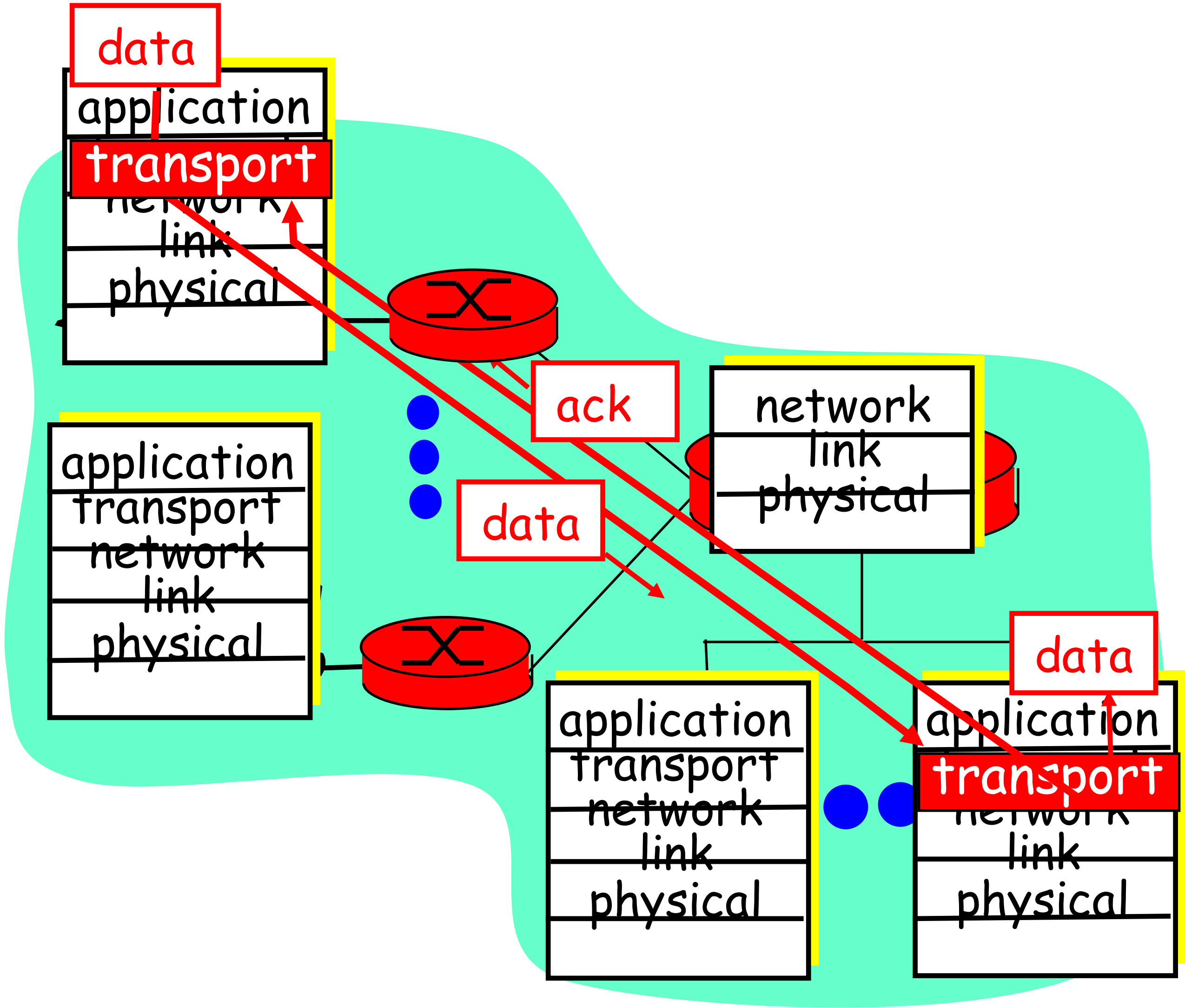


Layering: physical communication

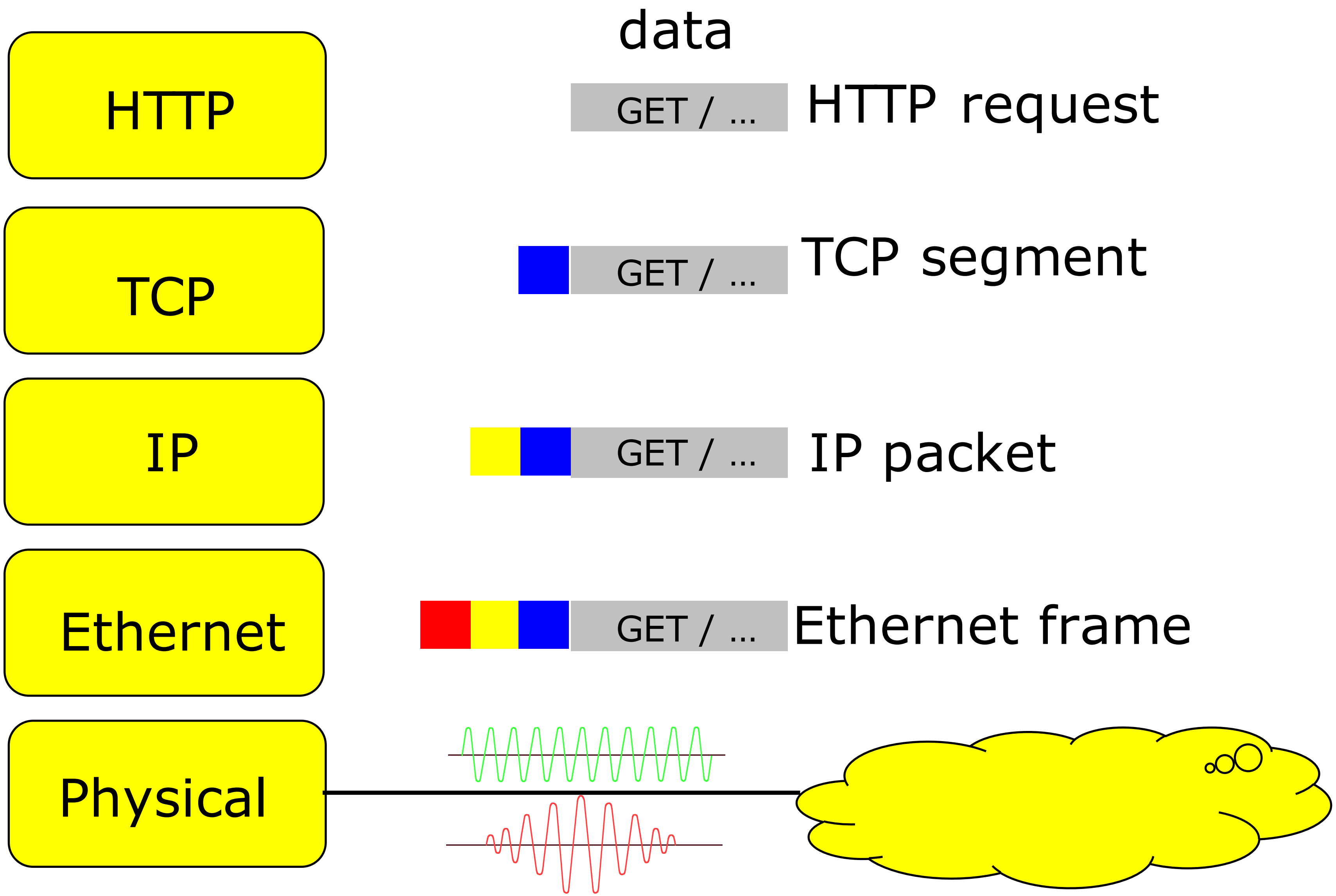


Layering: *logical* communication

- E.g.: transport
- take data from app
- add addressing, reliability check info to form "datagram"
- send datagram to peer
- wait for peer to ack receipt
- analogy: post office

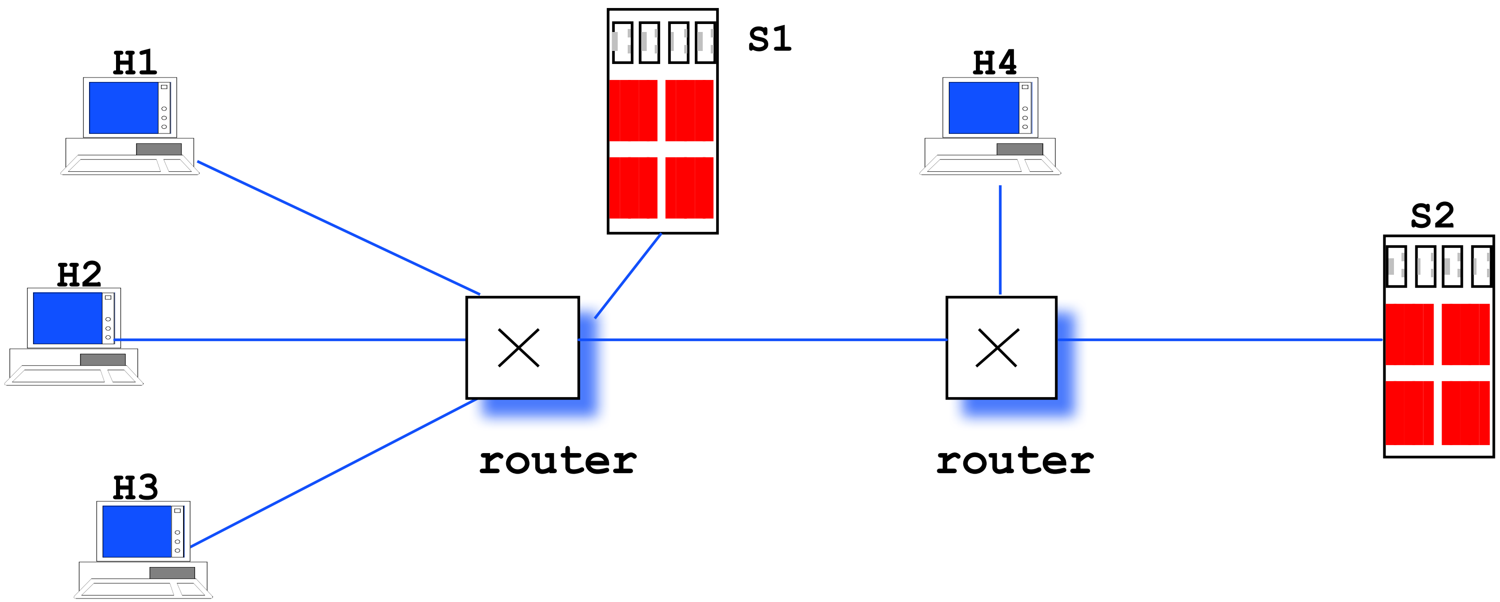


TCP/IP Architecture

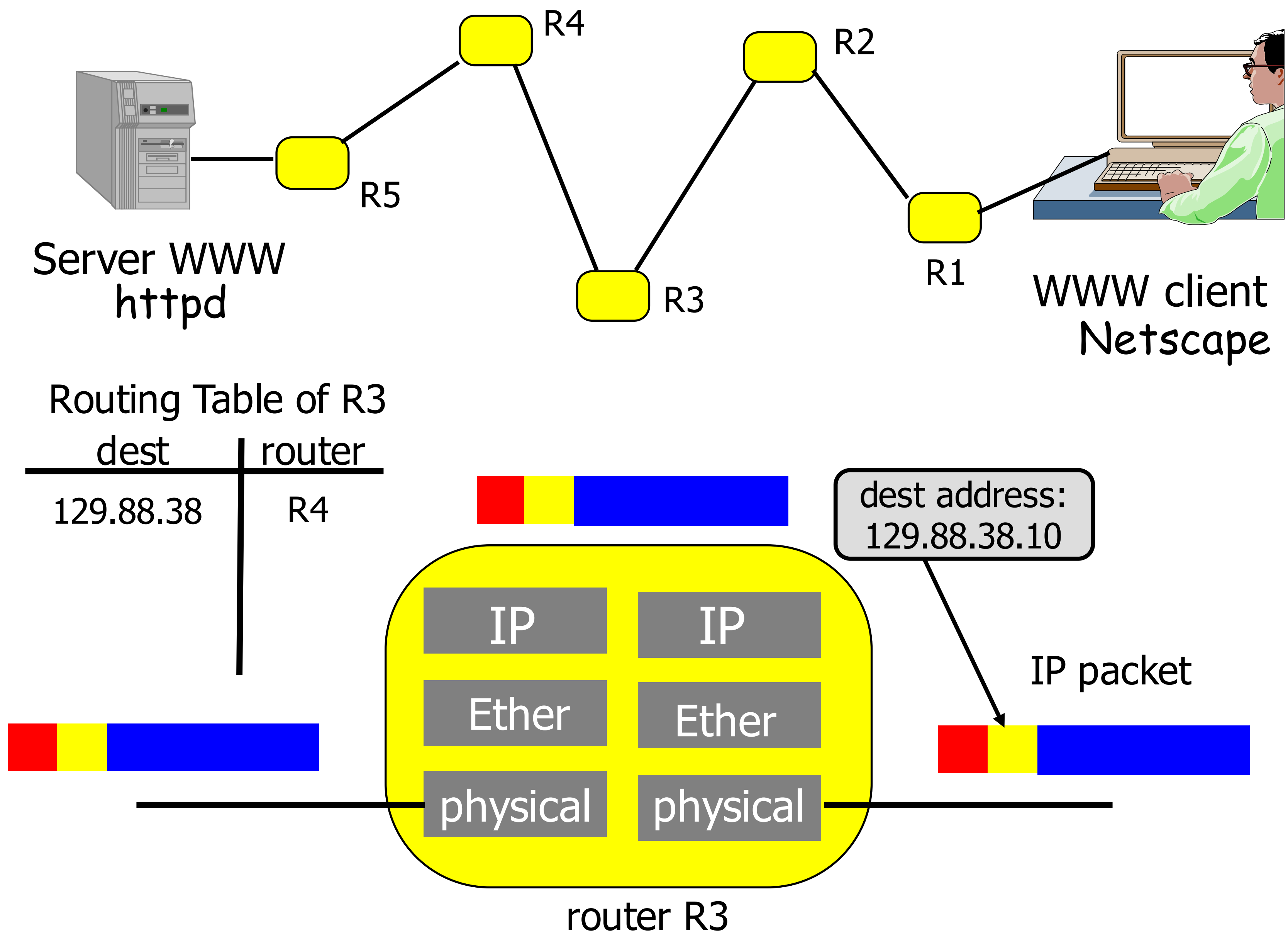


Network Layer

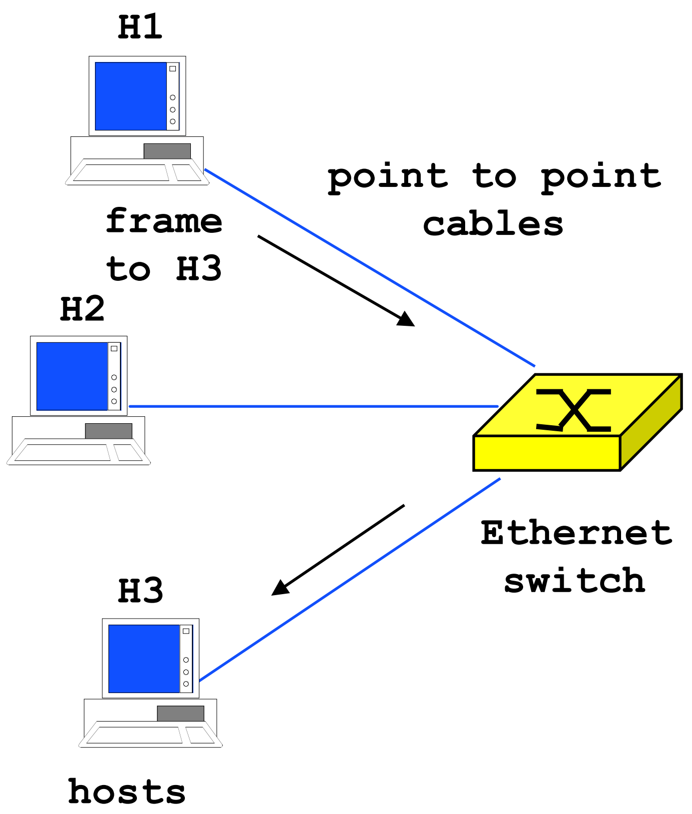
- Set of functions required to transfer packets end-to-end (from host to host)
  - hosts are not directly connected - need for intermediate systems
  - examples: IP, Appletalk, IPX
- Intermediate systems
  - routers: forward packets to the final destination
  - interconnection devices



IP


R4
R2
R5
Server WWW
httpd
R3
R1
WWW client
Netscape
Routing Table of R3
dest
router
129.88.38
R4
dest address:
129.88.38.10
IP
IP
Ether
Ether
physical
physical
IP packet
router R3

Physical Layer
Data Link Layer



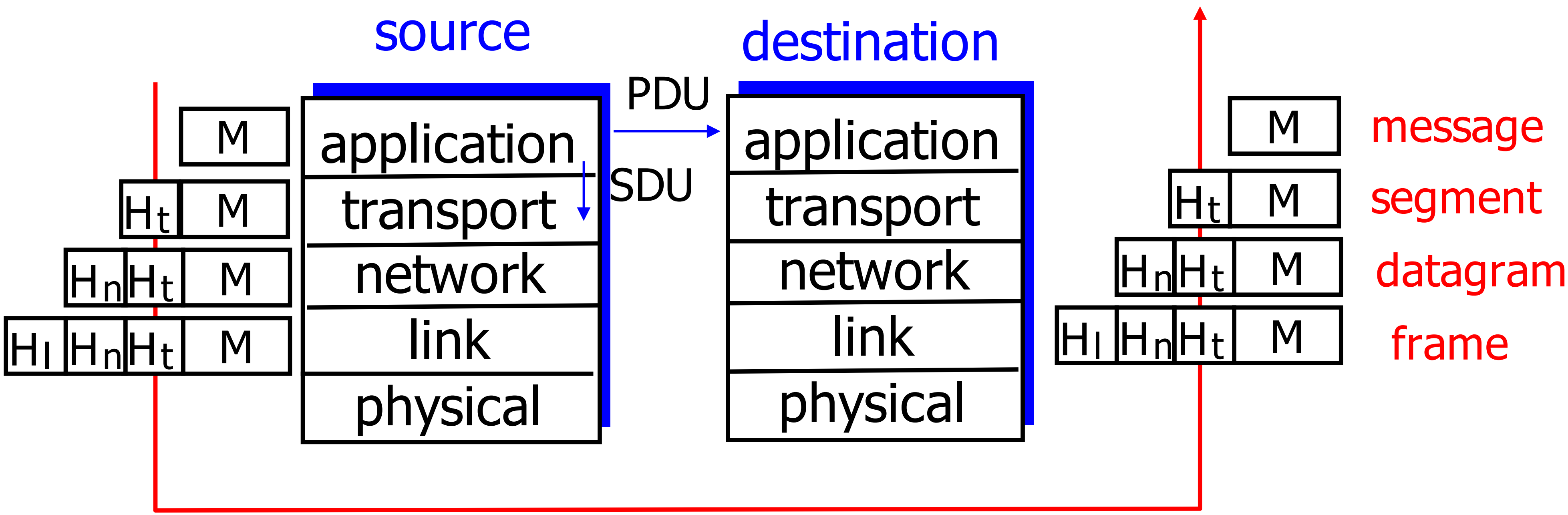
- Physical transmission = **Physical** function
  - bits <-> electrical / optical signals
  - transmit individual bits over the cable: modulation, encoding
- Frame transmission = **Data Link** function
  - bits <-> frames
  - bit error detection
  - packet boundaries
  - in some cases: error correction by retransmission (802.11)
- Modems, xDSL, LANs

Encapsulation

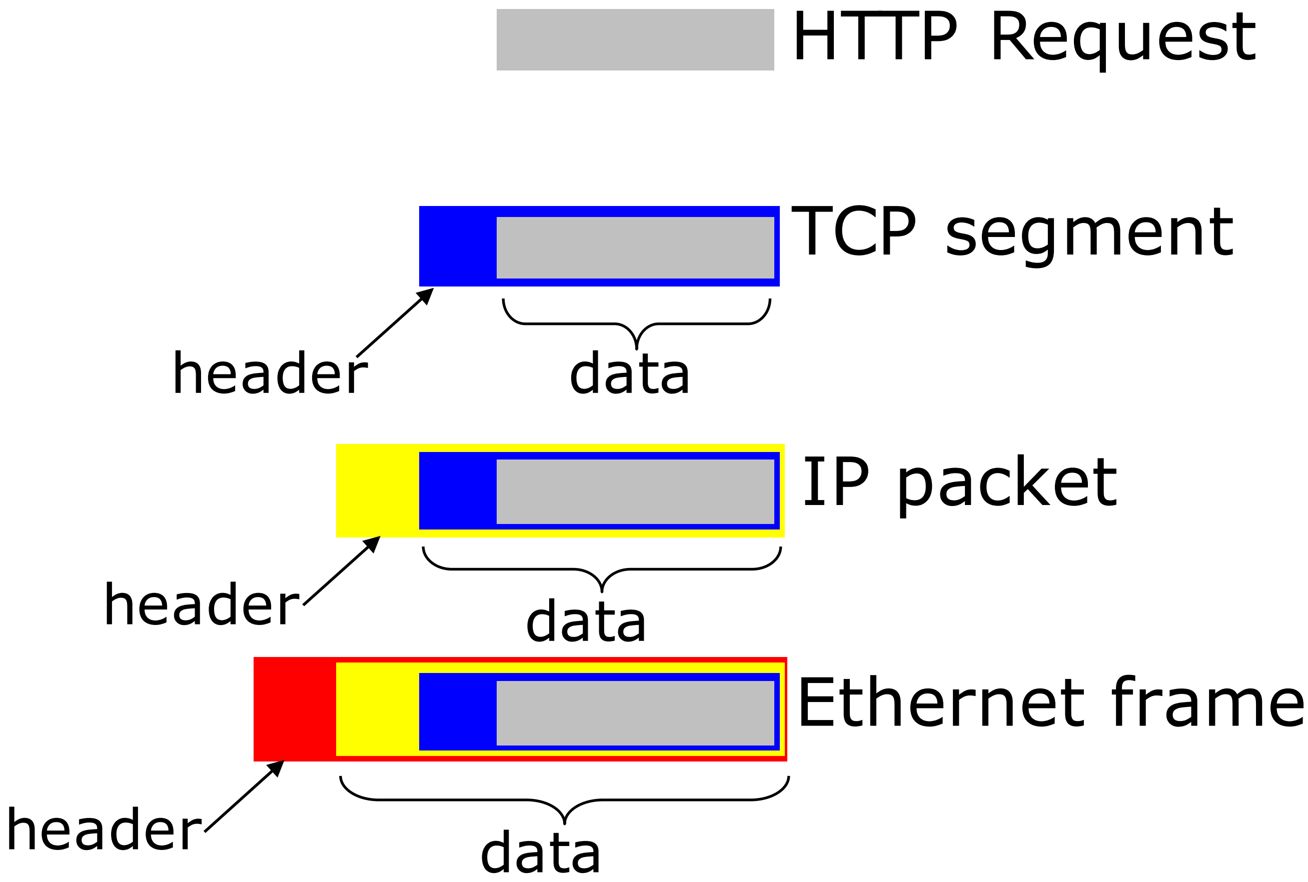
Protocol layering and data

Each layer takes data from above

- adds header information to create new data unit
- passes new data unit to layer below



Encapsulation



Packet capture

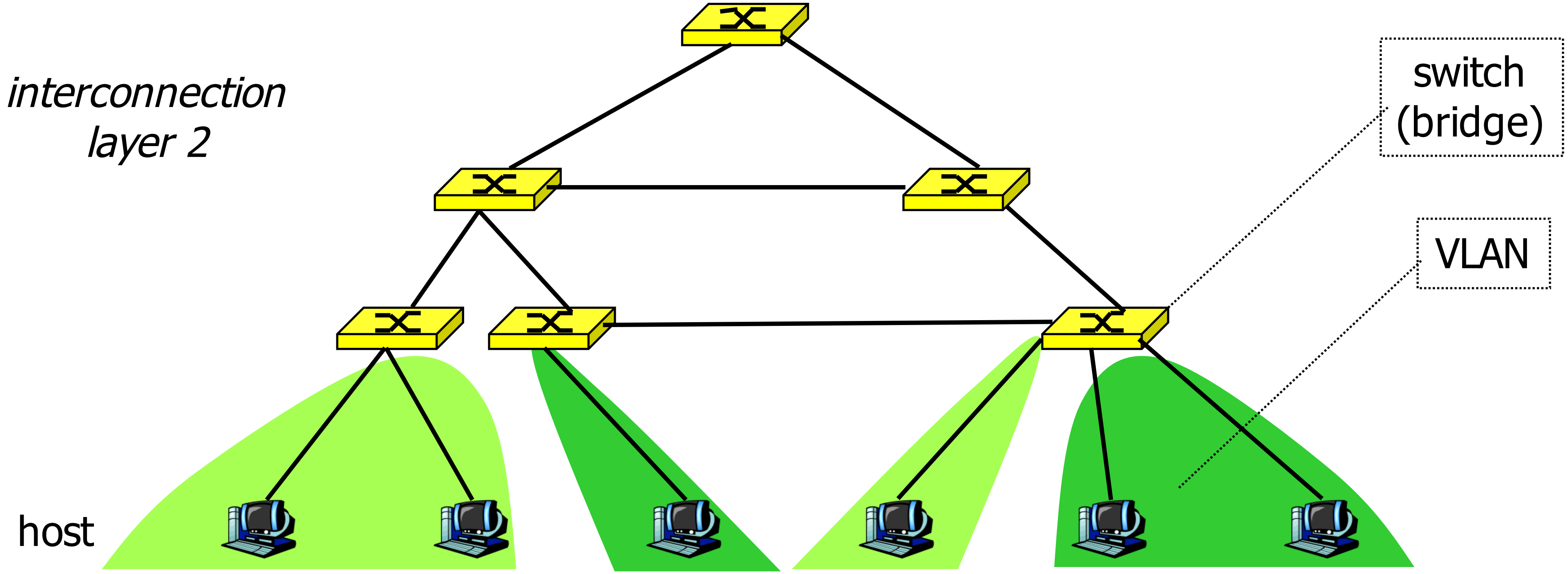
```
Frame 1 (1514 on wire, 1514 captured)
Ethernet II
    Destination: 00:03:93:a3:83:3a (Apple_a3:83:3a)
    Source: 00:10:83:35:34:04 (HEWLETT-_35:34:04)
    Type: IP (0x0800)
Internet Protocol, Src Addr: 129.88.38.94 (129.88.38.94), Dst Addr:
   129.88.38.241 (129.88.38.241)
    Version: 4
    Header length: 20 bytes
    Differentiated Services Field: 0x00 (DSCP 0x00: Default; ECN:
   0x00)
    Total Length: 1500
    Identification: 0x624d
    Flags: 0x04
    Fragment offset: 0
    Time to live: 64
    Protocol: TCP (0x06)
    Header checksum: 0x82cf (correct)
    Source: 129.88.38.94 (129.88.38.94)
    Destination: 129.88.38.241 (129.88.38.241)
```

Ethereal

```
Transmission Control Protocol, Src Port: 34303 (34303), Dst Port:
  6000 (6000), Seq: 4292988915, Ack: 3654747642, Len: 1448
    Source port: 34303 (34303)
    Destination port: 6000 (6000)
    Sequence number: 4292988915
    Next sequence number: 4292990363
    Acknowledgement number: 3654747642
    Header length: 32 bytes
    Flags: 0x0010 (ACK)
    Window size: 41992
    Checksum: 0x9abe (correct)
    Options: (12 bytes)
```

Interconnection

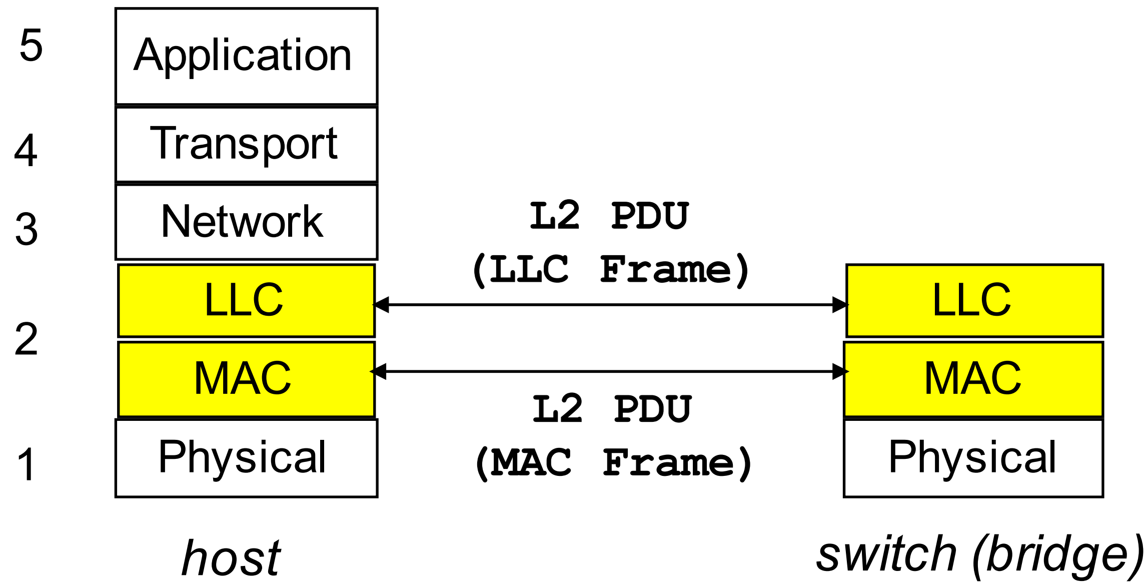
Interconnection structure - layer 2



Interconnection at layer 2

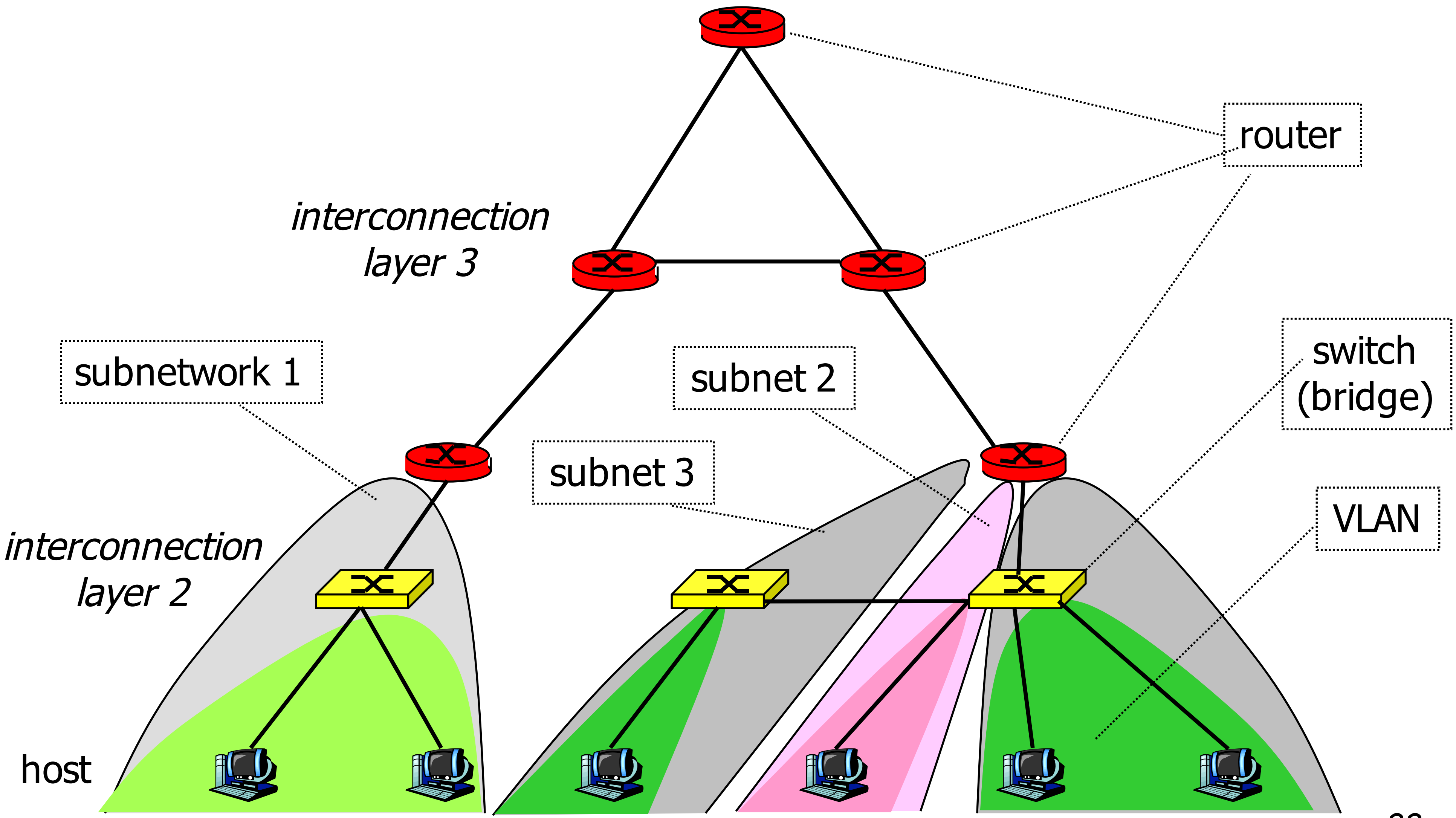
- Switches (bridges)
  - interconnect hosts
  - logically separate groups of hosts (VLANs)
  - managed by one entity
- Type of the network
  - broadcast
- Forwarding based on MAC address
  - flat address space
  - forwarding tables: one entry per host
  - works if no loops
    - careful management
    - Spanning Tree protocol
  - not scalable

Protocol architecture



- Switches are layer 2 intermediate systems
- Transparent forwarding
- Management protocols (Spanning Tree, VLAN)

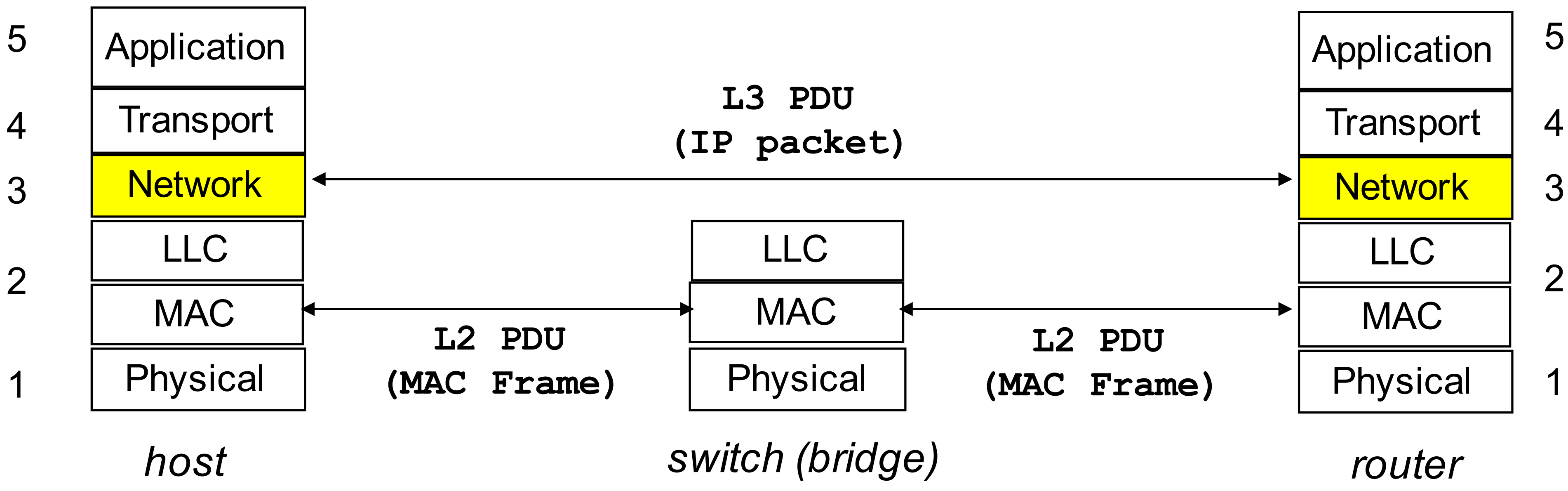
Interconnection structure - layer 3



Interconnection at layer 3

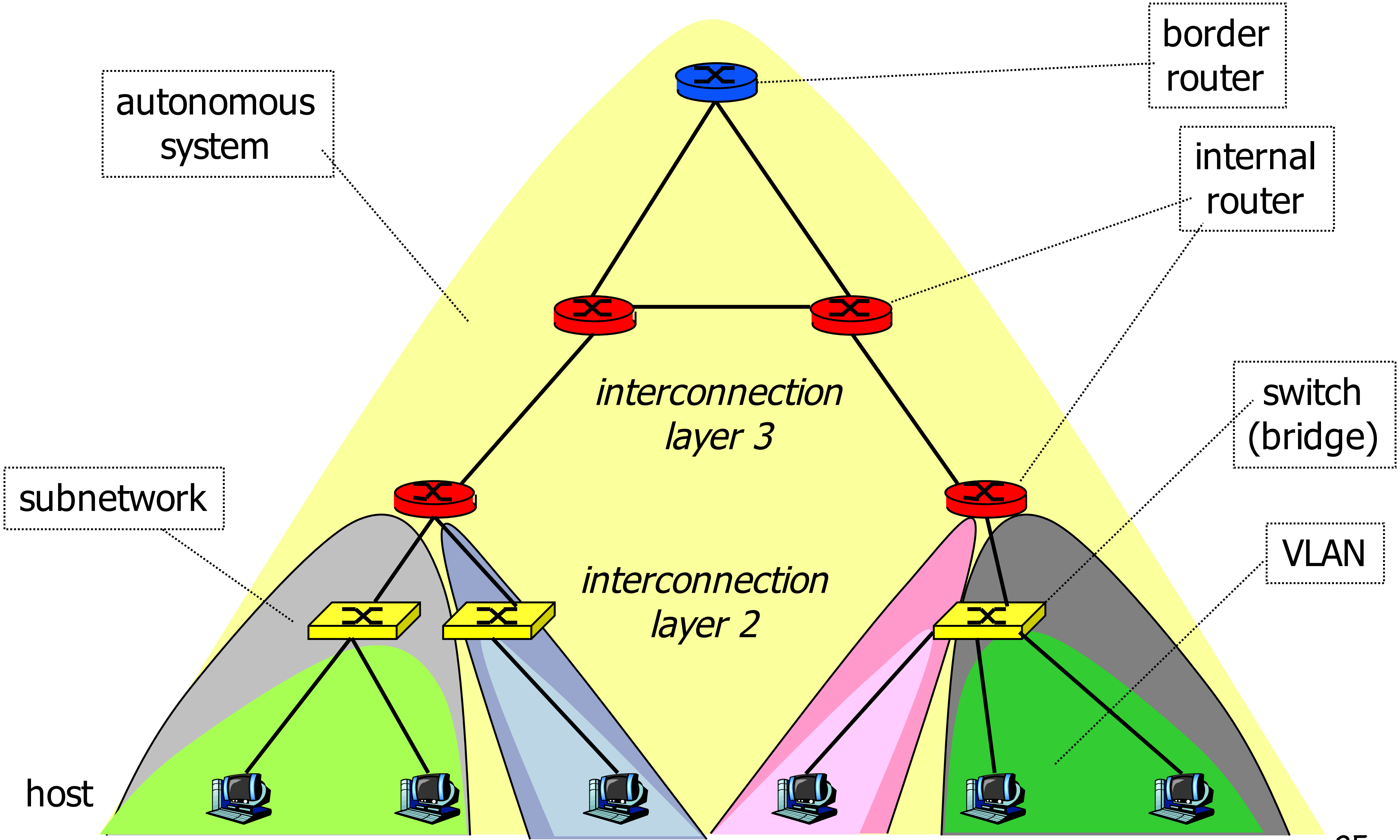
- Routers
  - interconnect subnetworks
  - logically separate groups of hosts
  - managed by one entity
- Forwarding based on IP address
  - structured address space
  - routing tables: aggregation of entries
  - works if no loops - routing protocols (IGP - Internal Routing Protocols)
  - scalable inside one administrative domain

Protocol architecture

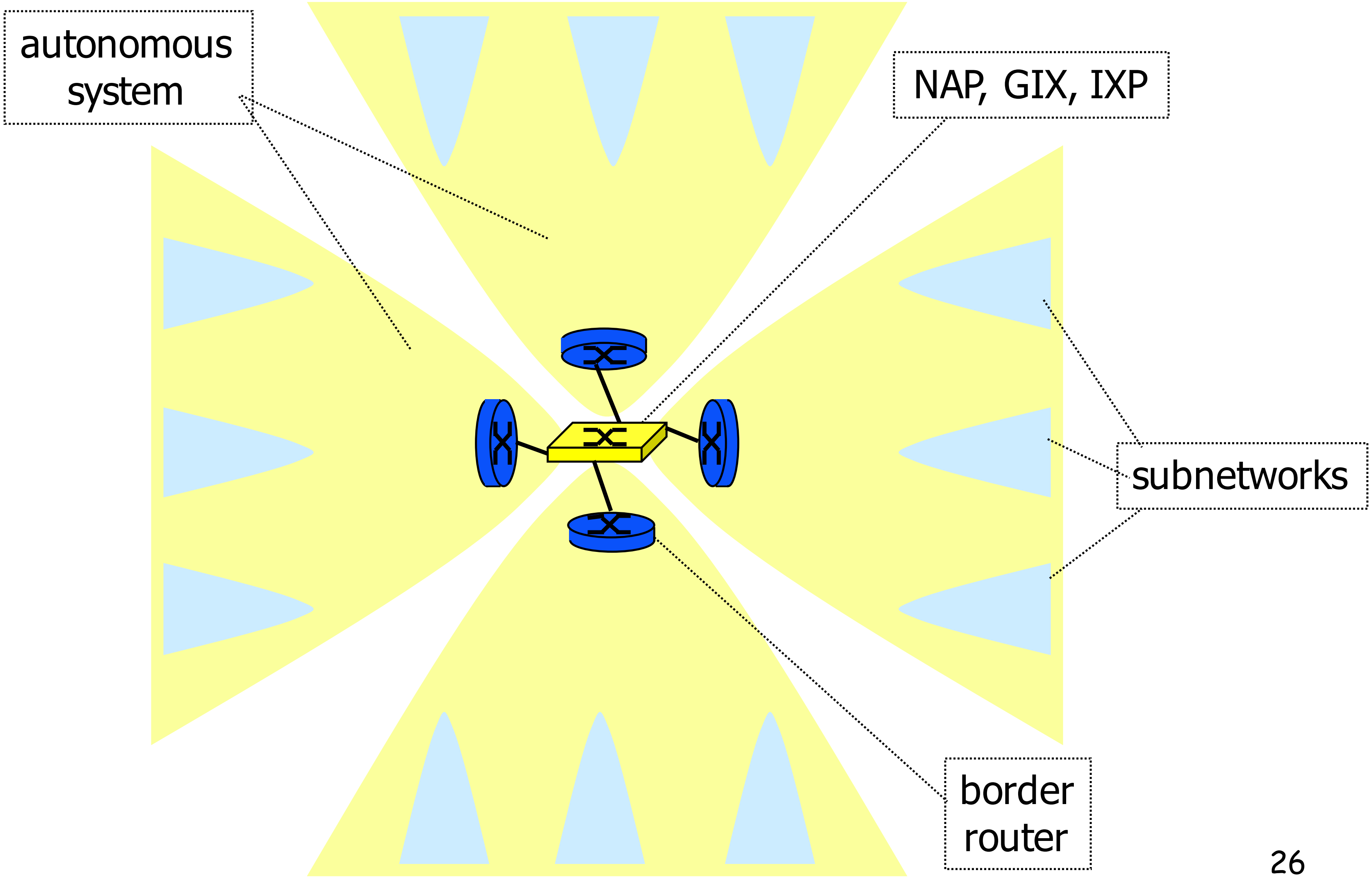


- Routers are layer 3 intermediate systems
- Explicit forwarding
  - host has to know the address of the first router
- Management protocols (control, routing, configuration)

Autonomous systems



Internet



Interconnection of AS

- Border routers
  - interconnect AS
- NAP or GIX, or IXP
  - exchange of traffic - peering
- Route construction
  - based on the path through a series of AS
  - based on administrative policies
  - routing tables: aggregation of entries
  - works if no loops and at least one route - routing protocols (EGP - External Routing Protocols)

Performance

Performance - Motivating example

- Consider this real-life example of a large bank with headquarters in **Europe** and operations in **North America**.
- Problem: a business unit with European users trying to access an important application from across the pond.
- **Performance was horrible (response time).**
- CIO ordered his trusted network operations manager to **fix the problem**. The network manager dutifully investigated, measuring the transatlantic link utilization and router queue statistics: no problems with the network, as it was only **3 percent utilized**.
- "I don't care, **double the bandwidth**!" the CIO ordered. The network manager complied, installing a **second OC-3 link**. And, guess what?
- The network went from **3 percent to 1.5 percent utilized**, and **application performance was still horrible**. That CIO didn't *know jack about network performance*.

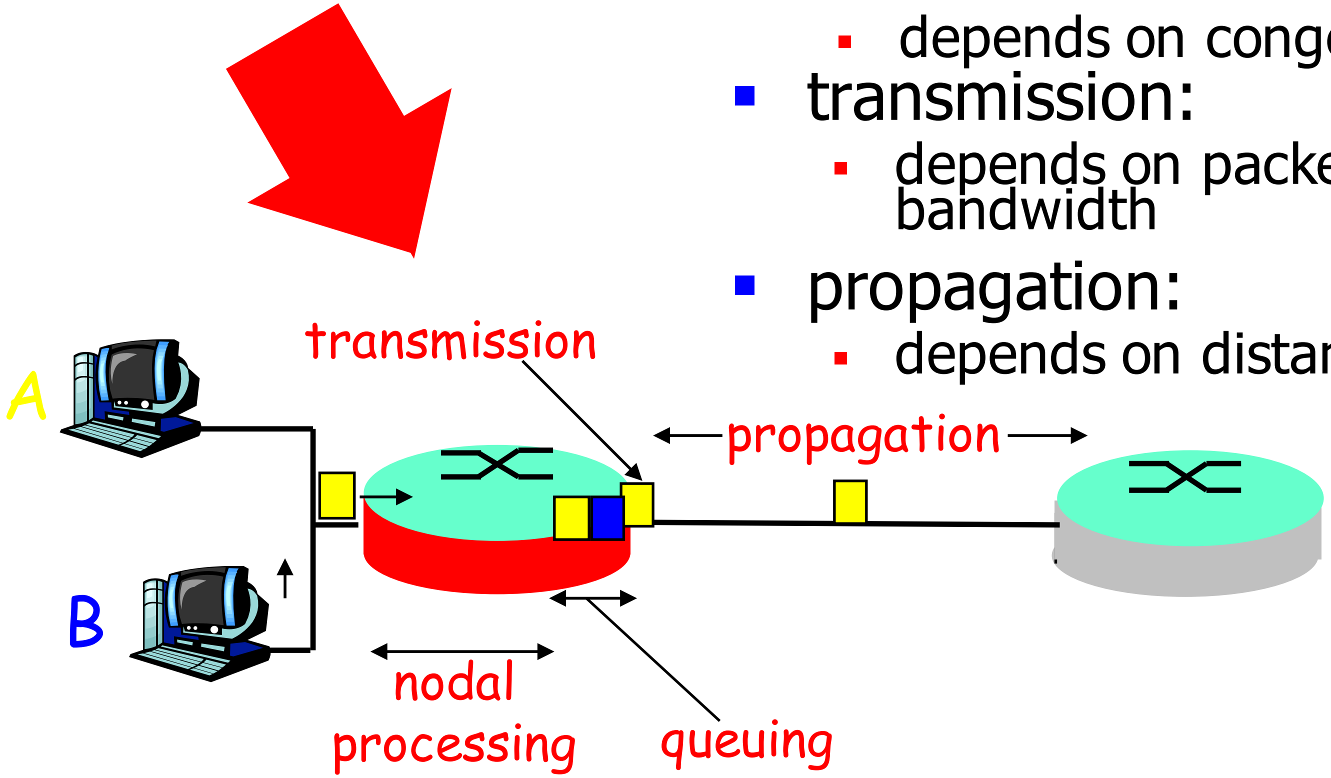
Performance

- Bit Rate (débit binaire) of a transmission system
  - bandwidth, throughput
  - number of bits transmitted per time unit
  - units: b/s or bps, kb/s = 1000 b/s, Mb/s = 10e+06 b/s, Gb/s=10e+09 b/s
  - OC3/STM1 - 155 Mb/s, OC12/STM4 - 622 Mb/s, and OC48/STM-16 - 2.5 Gb/s, OC192/STM-48 10 Gb/s
- Latency or Delay
  - time interval between the beginning of a transmission and the end of the reception
  - RTT - Round-Trip Time

Delay in packet-switched networks

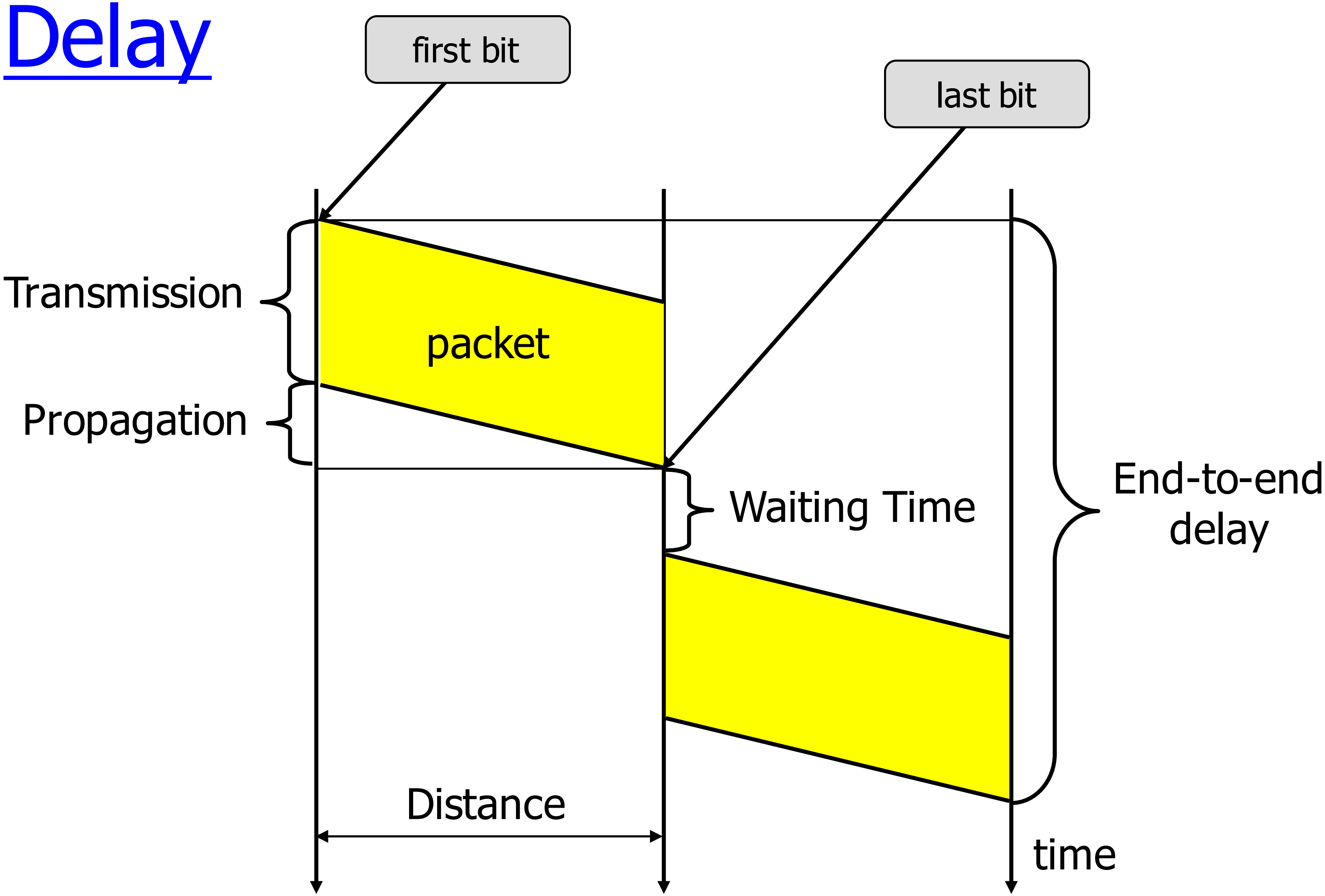
packets experience delay on end-to-end path

- four sources of delay at each hop



- nodal processing:
  - check bit errors
  - determine output link
- queuing
  - time waiting at output link for transmission
  - depends on congestion level of node
- transmission:
  - depends on packet length and link bandwidth
- propagation:
  - depends on distance between nodes

Delay


first bit
last bit
Transmission
packet
Propagation
Waiting Time
End-to-end
delay
Distance
time

Performance

- Latency
  - Latency = Propagation + Transmission + Wait
  - Propagation = Distance / Speed
    - copper : Speed = 2.3×10^8 m/s
    - glass : Speed = 2×10^8 m/s
    - Transmission = Size / BitRate
- 5 μs/km
- New York - Los Angeles in 24 ms
  - request - 1 byte, response - 1 byte: 48 ms
  - 25 MB file on 10 Mb/s: 20 s
- World tour in 0.2 s

Example

- At time 0, computer A sends a packet of size 1000 bytes to B; at what time is the packet received by B (speed = 2e+08 m/s)?

distance	20 km	20000 km	2 km	20 m
bit rate	10kb/s	1 Mb/s	10 Mb/s	1 Gb/s
propagation	0.1ms	100 ms	0.01 ms	0.1μs
transmission	800 ms	8 ms	0.8 ms	8 μs
latency	?	?	?	?
	modem	*satellite*	*LAN*	*Hippi*

Example

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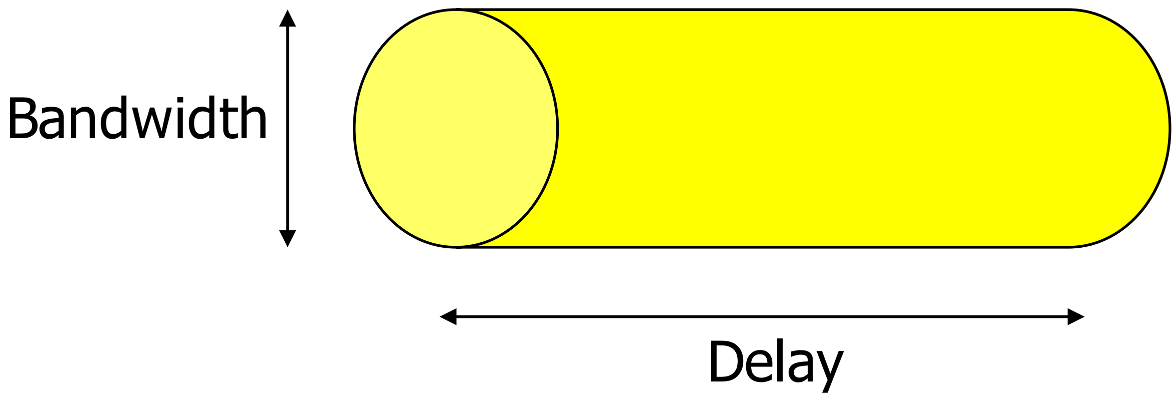
latency	800.1 ms	108 ms	0.81 ms	8.1 μs
	modem	*satellite*	*LAN*	*Hippi*

Bandwidth-Delay Product



- Bandwidth-Delay product
  - how many bits should we send before the arrival of the first bit?
  - good utilization - keep the pipe filled!

A Simple Protocol: Stop and Go

- Packets may be lost during transmission:
  bit errors due to channel imperfections, various noises.
- Computer A sends packets to B; B returns an acknowledgement packet immediately to confirm that B has received the packet;

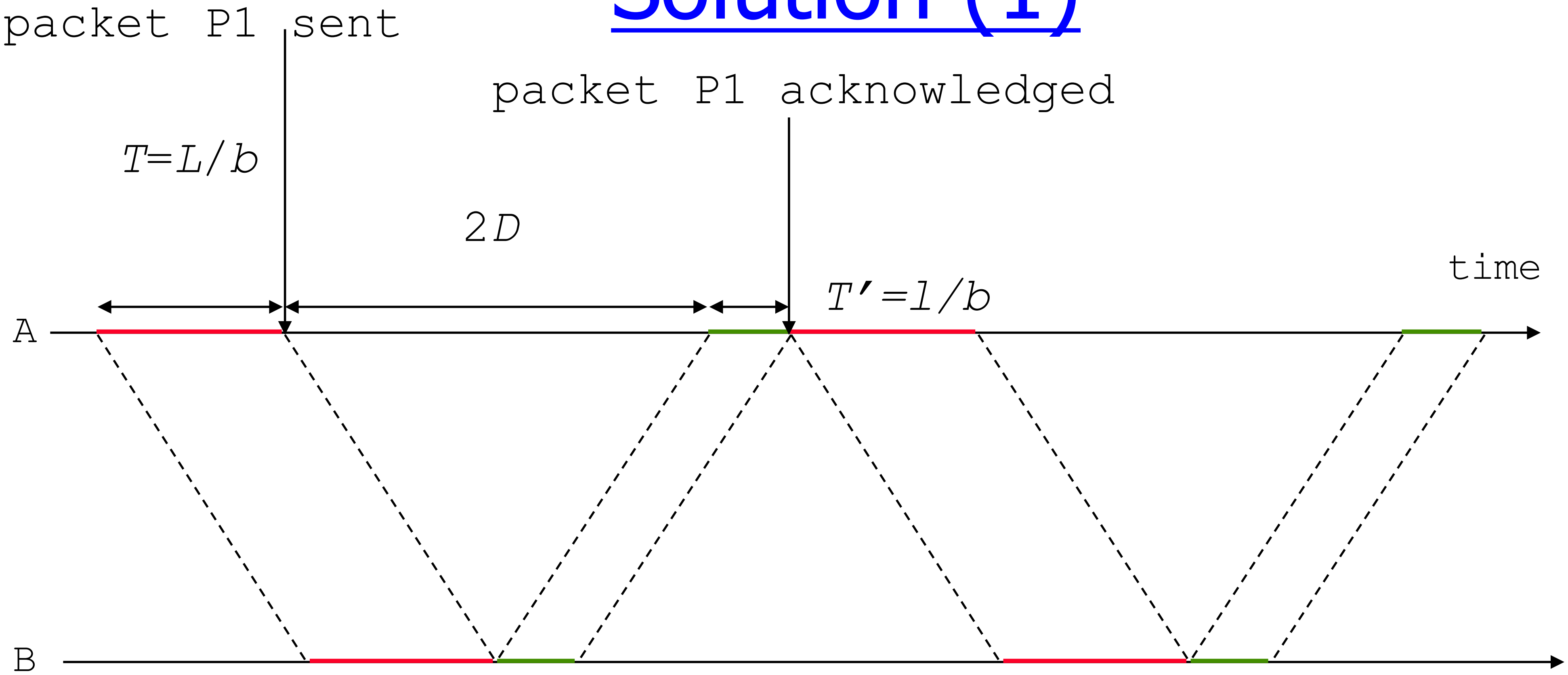
  A waits for acknowledgement before sending a new packet; if no acknowledgement comes after a delay *T1*, then A retransmits

A Simple Protocol: Stop and Go

- **Question**: What is the maximum throughput assuming that there are no losses?

  notation:
  - packet length = *L*, constant (in bits);
  - acknowledgement length = *l*, constant
  - channel bit rate = *b*;
  - propagation = *D*
  - processing time = 0

Solution (1)



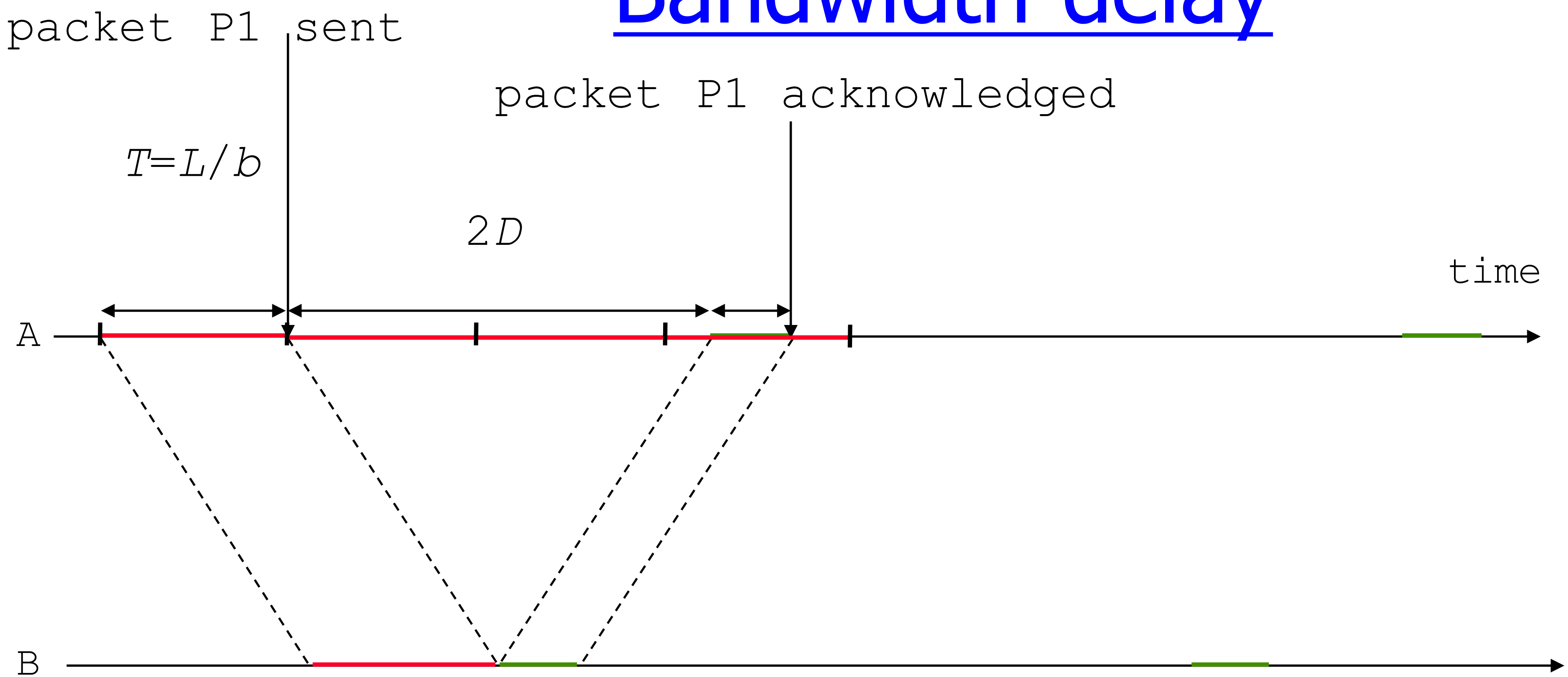
cycle time = $T + 2D + T'$

useful bits per cycle time = L

throughput = $Lb\ /\ (L + l + 2Db) = b\ /(\omega + \beta/L)$

with $\omega = (L+l)/L$=overhead and $\beta = 2Db$=**bandwidth-delay product**

Bandwidth delay



window in time = $T + 2D + T$

window in bits = $(T + 2D + T)b = 2L + \beta$

Solution (2)

distance	20 km	20000 km	2 km	20 m
bit rate	10kb/s	1 Mb/s	10 Mb/s	1 Gb/s
propagation	0.1ms	100 ms	0.01 ms	0.1μs
transmission	800 ms	8 ms	0.8 ms	8 μs
reception time	800.1 ms	108 ms	0.81 ms	8.1 μs
	modem	*satellite*	*LAN*	*Hippi*
$\beta = 2Db$	2 bits	200 000 bits	200 bits	200 bits
throughput = *bx*	99.98%	3.8%	97.56%	97.56%

Summary

- Network architectures
  - protocol architectures
    - different protocol stacks, overlaid stacks
  - interconnection structure
    - switches, routers
  - related protocols
    - complex protocol families
- Performance
  - transmission
  - propagation
  - bandwidth-delay product
  - queueing delay