

Computer Networks

Principles

Introduction

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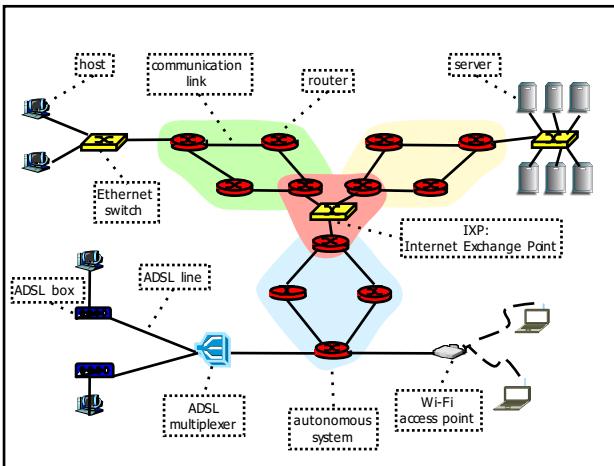
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1

Contents

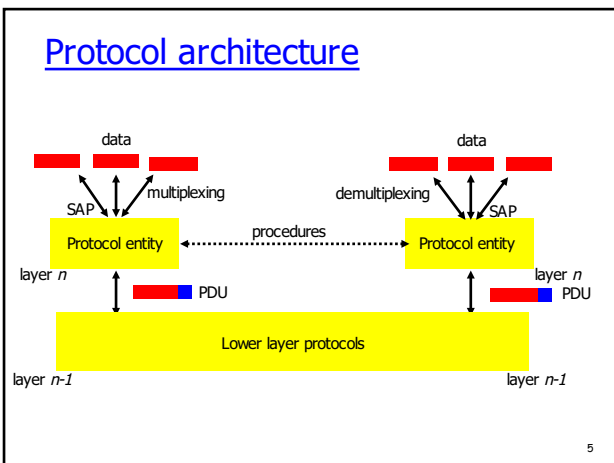
- Introduction
 - protocols and layered architecture
 - encapsulation
 - interconnection structures
 - performance

2



Protocols

4



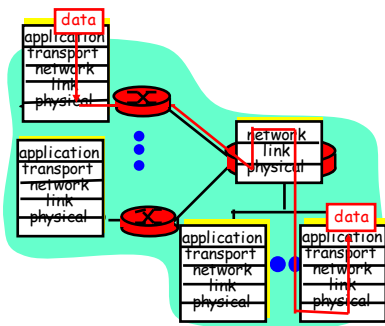
Internet protocol stack

- **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"

Application
Transport
Network
Link
Physical

6

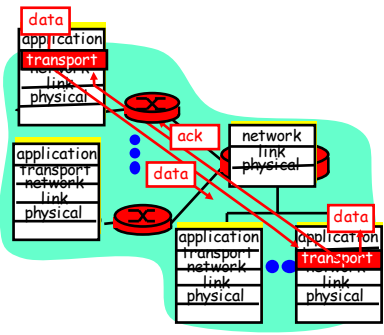
Layering: physical communication



7

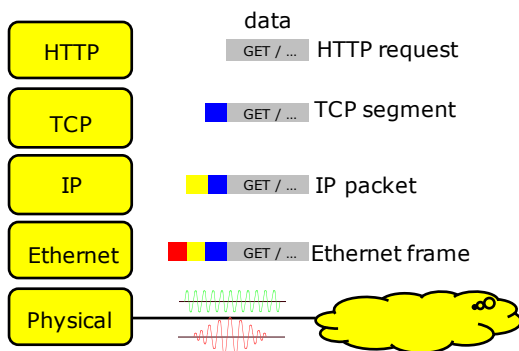
Layering: logical communication

- 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



8

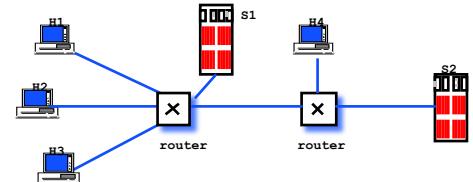
TCP/IP Architecture



9

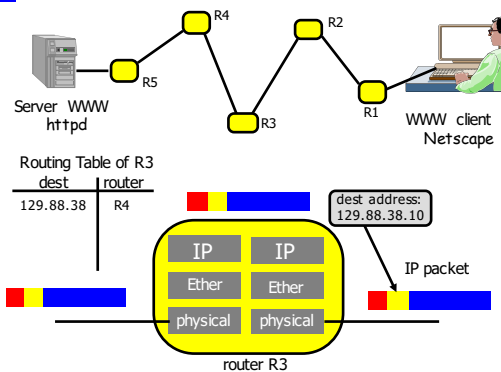
Network Layer

- 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



10

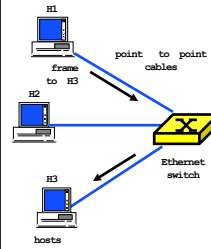
IP



11

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



12

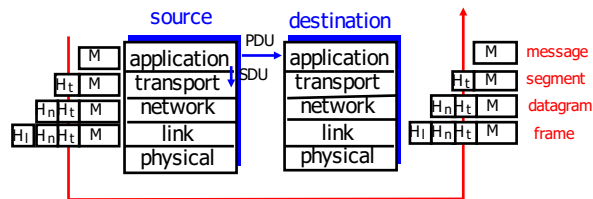
Encapsulation

13

Protocol layering and data

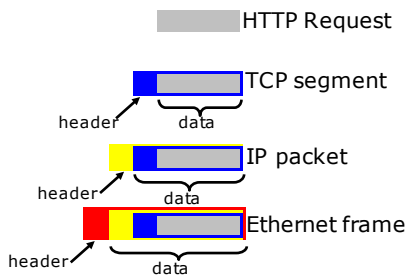
Each layer takes data from above

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



14

Encapsulation



15

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)
    
```

16

Ethereal

```

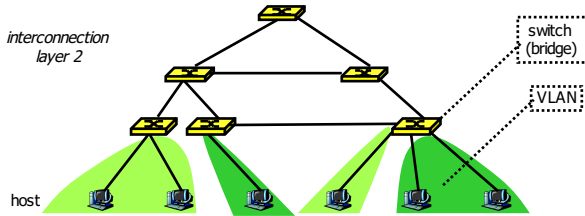
Transmission Control Protocol, Src Port: 34303 (34303), Dst Port:
6000 (6000), Seq: 4292988915, Ack: 3654747642, Len: 1448
  Source port: 34303 (34303)
  Destination port: 6000 (6000)
  Sequence number: 4292988915
  Next sequence number: 4292990363
  Acknowledgement number: 3654747642
  Header length: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

17

Interconnection

18

Interconnection structure - layer 2



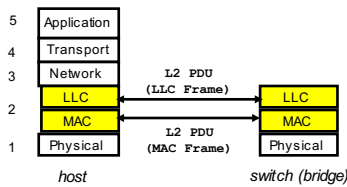
19

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

20

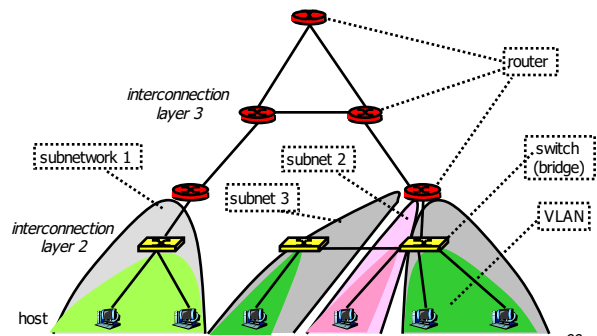
Protocol architecture



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

21

Interconnection structure - layer 3



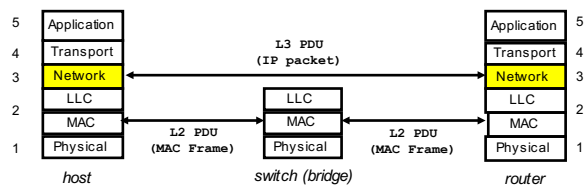
22

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

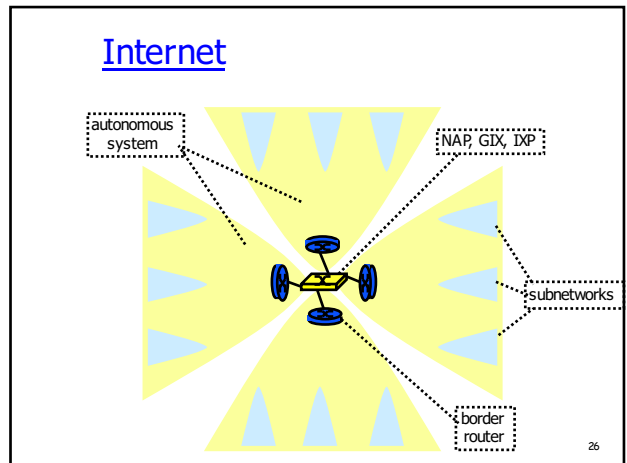
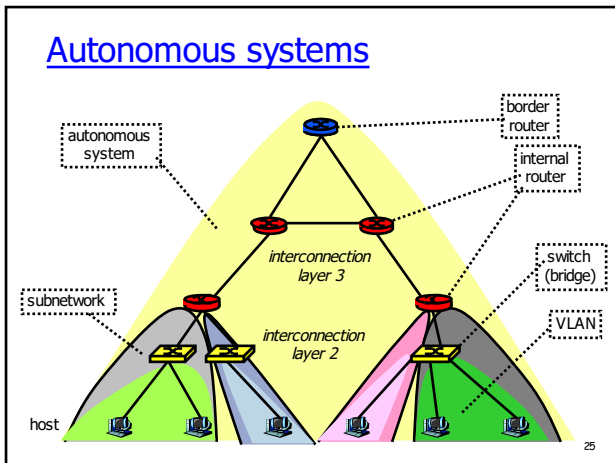
23

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)

24



- ### 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)

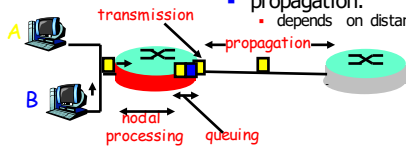
Performance

- ### 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

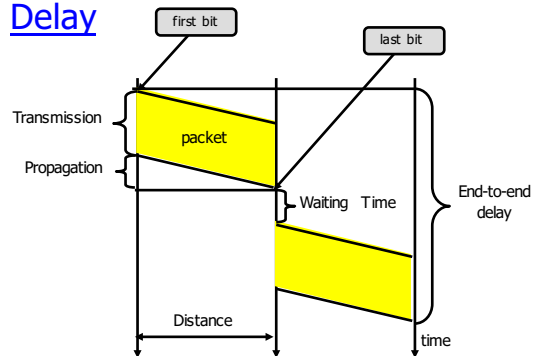
Delay in packet-switched networks

- 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



31

Delay



32

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 μ s/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

33

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 = 2×10^8 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	0.1 μ s
transmission	800 ms	8 ms	0.8 ms	8 μ s
latency	?	?	?	?

modem satellite LAN Hippi

34

Example

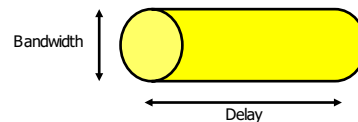
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propagation	0.1ms	100 ms	0.01 ms	0.1 μ s
transmission	800 ms	8 ms	0.8 ms	8 μ s
latency	800.1 ms	108 ms	0.81 ms	8.1 μ s

modem satellite LAN Hippi

35

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!

36

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 T_1 , then A retransmits

37

A Simple Protocol: Stop and Go

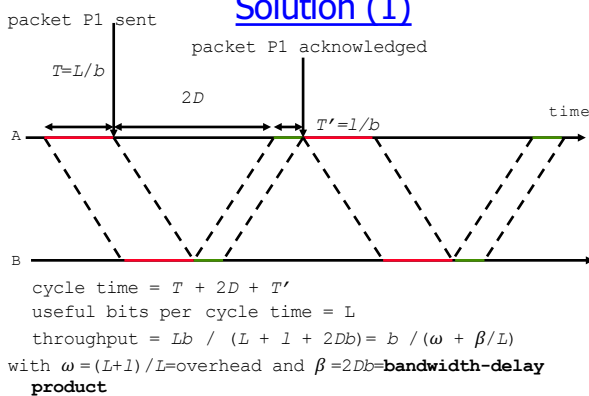
- **Question:** What is the maximum throughput assuming that there are no losses?

notation:

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

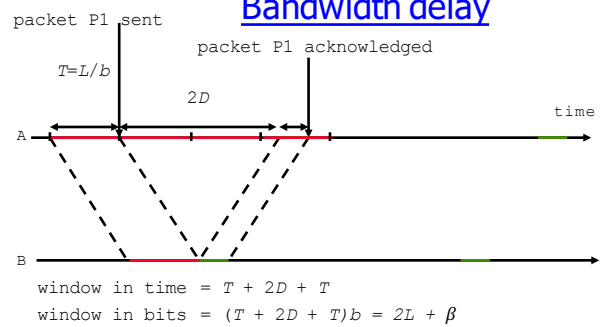
38

Solution (1)



39

Bandwidth delay



40

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 = Lb	99.98%	3.8%	97.56%	97.56%

41

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

42