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Algorithms for Distributed Storage and Computer Forensics

11 Networking

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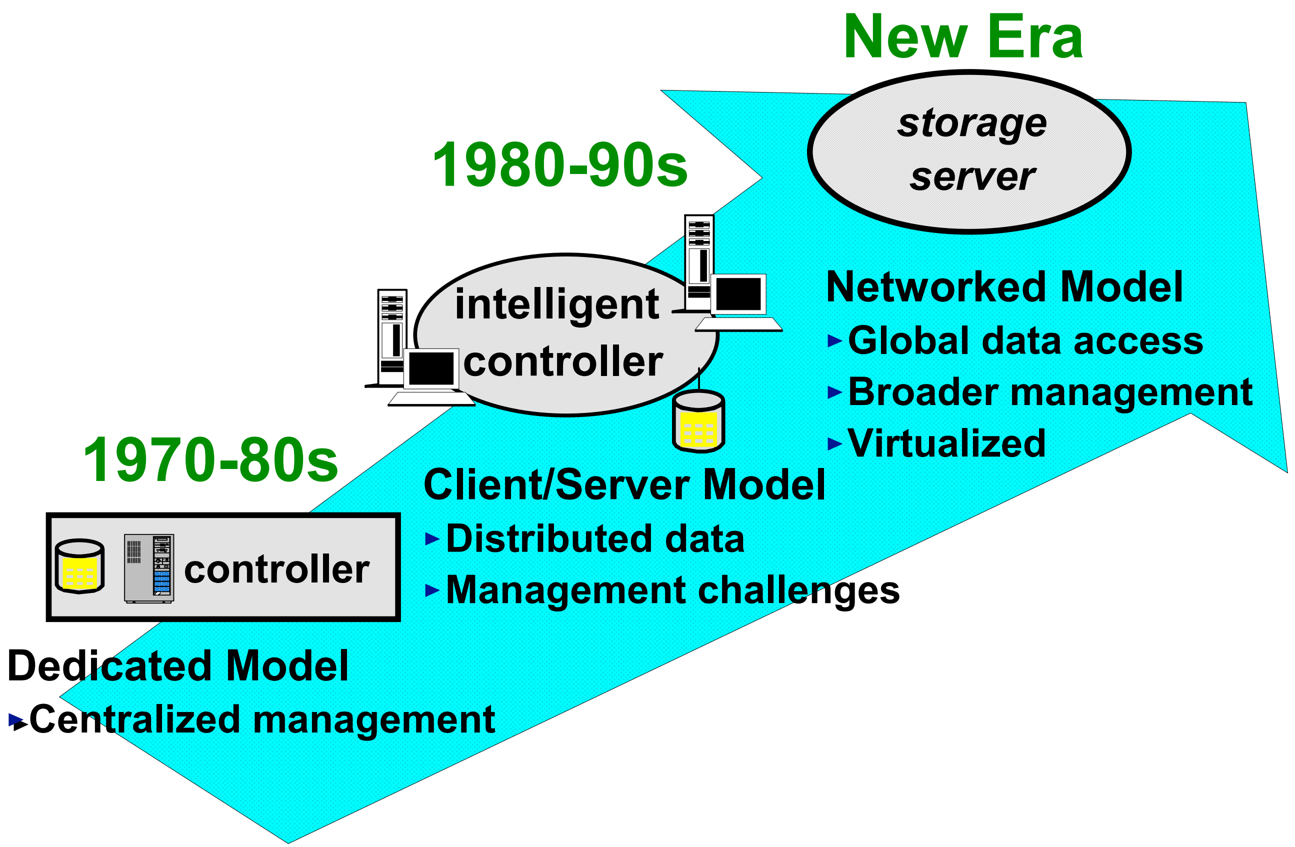
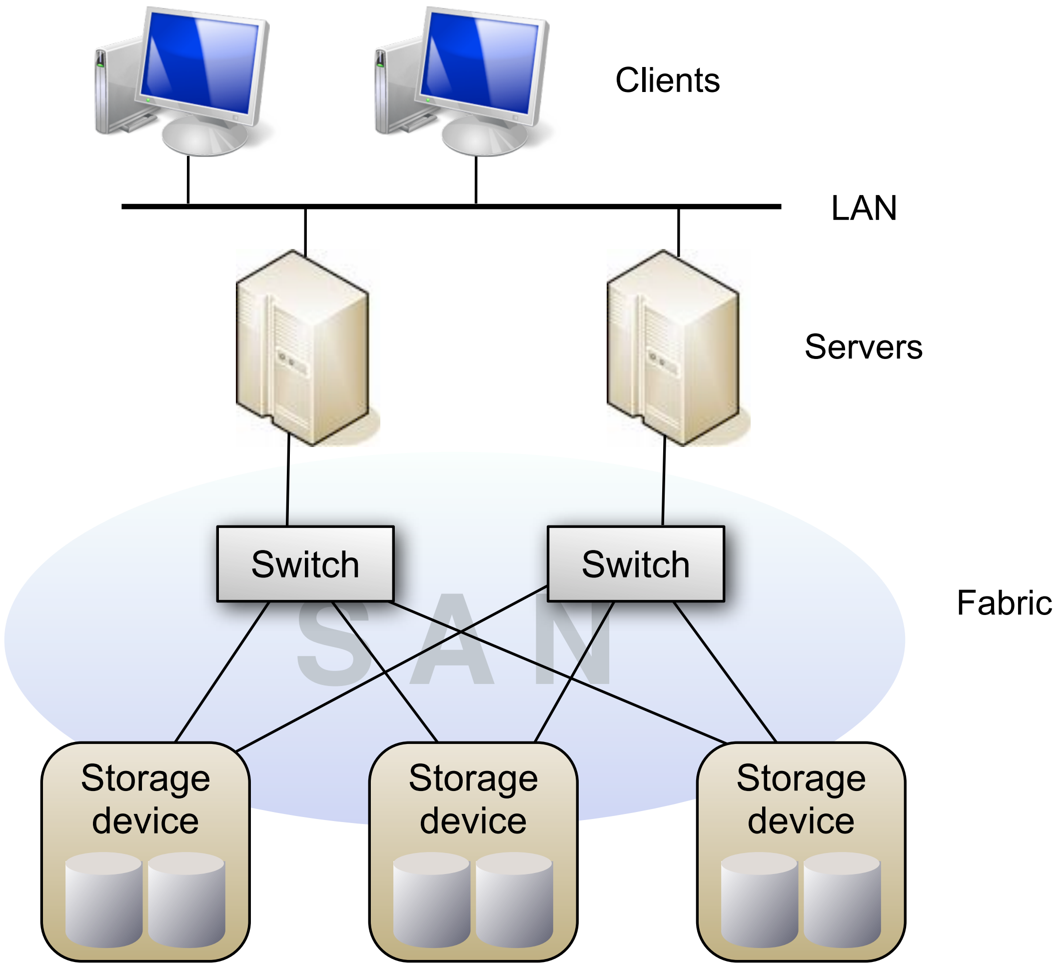
Winter Semester 2011/12

Evolution of Storage



[Tate, Lucchese, Moore: Introduction to Storage Area Networks, IBM 2006]

Storage Area Network

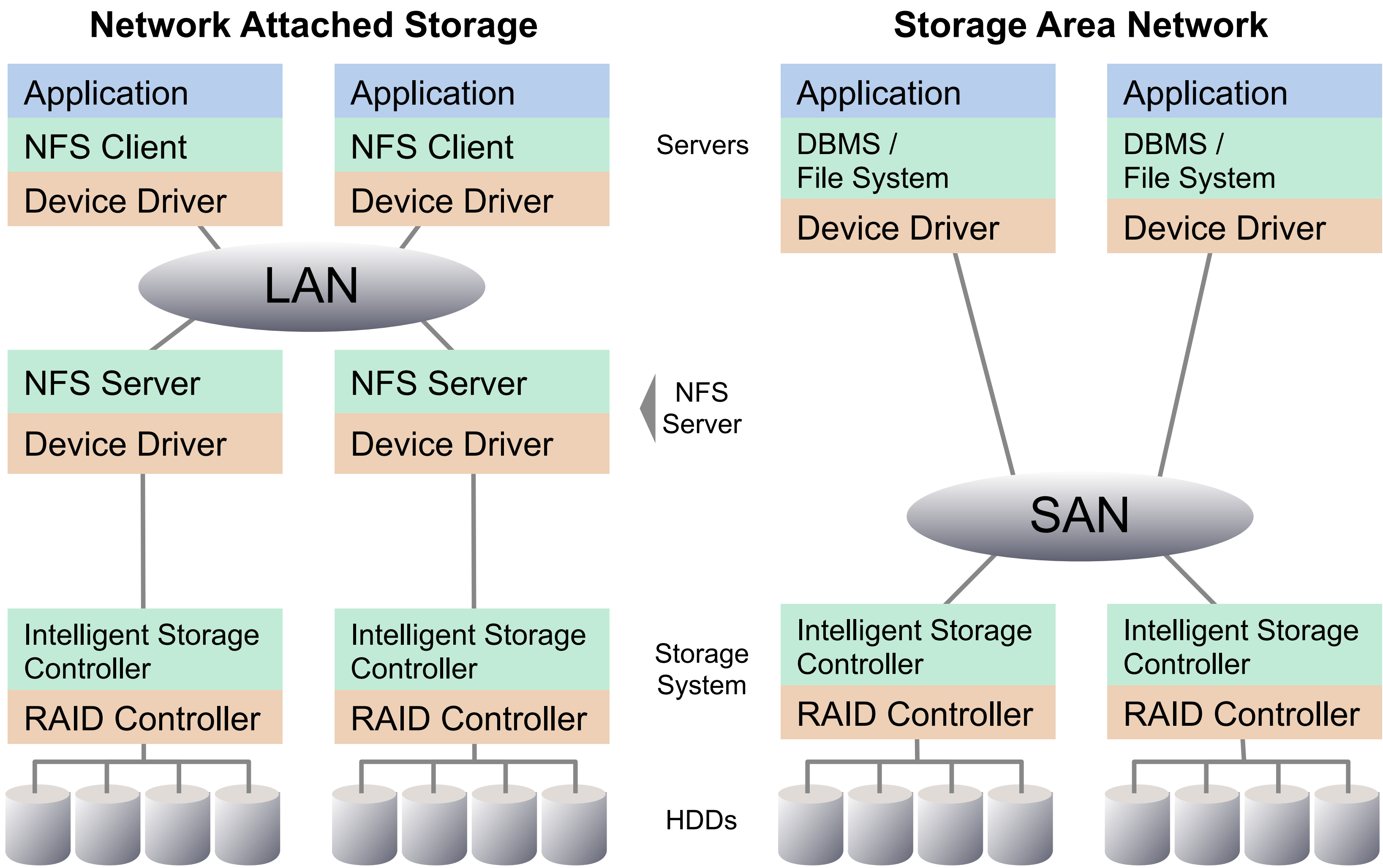


NAS and SAN

- **Network-attached Storage**
  - storage device attached to a network
  - access through NFS, AFS, SMB, etc. (file level)

- **Storage Area Network**
  - storage system of interconnected storage devices
  - access through FCP, iFCP, iSCSI (block level)

NAS and SAN



[Morris, Truskowski: The evolution of storage systems, IBM Systems Journal, 42(2), 2003]

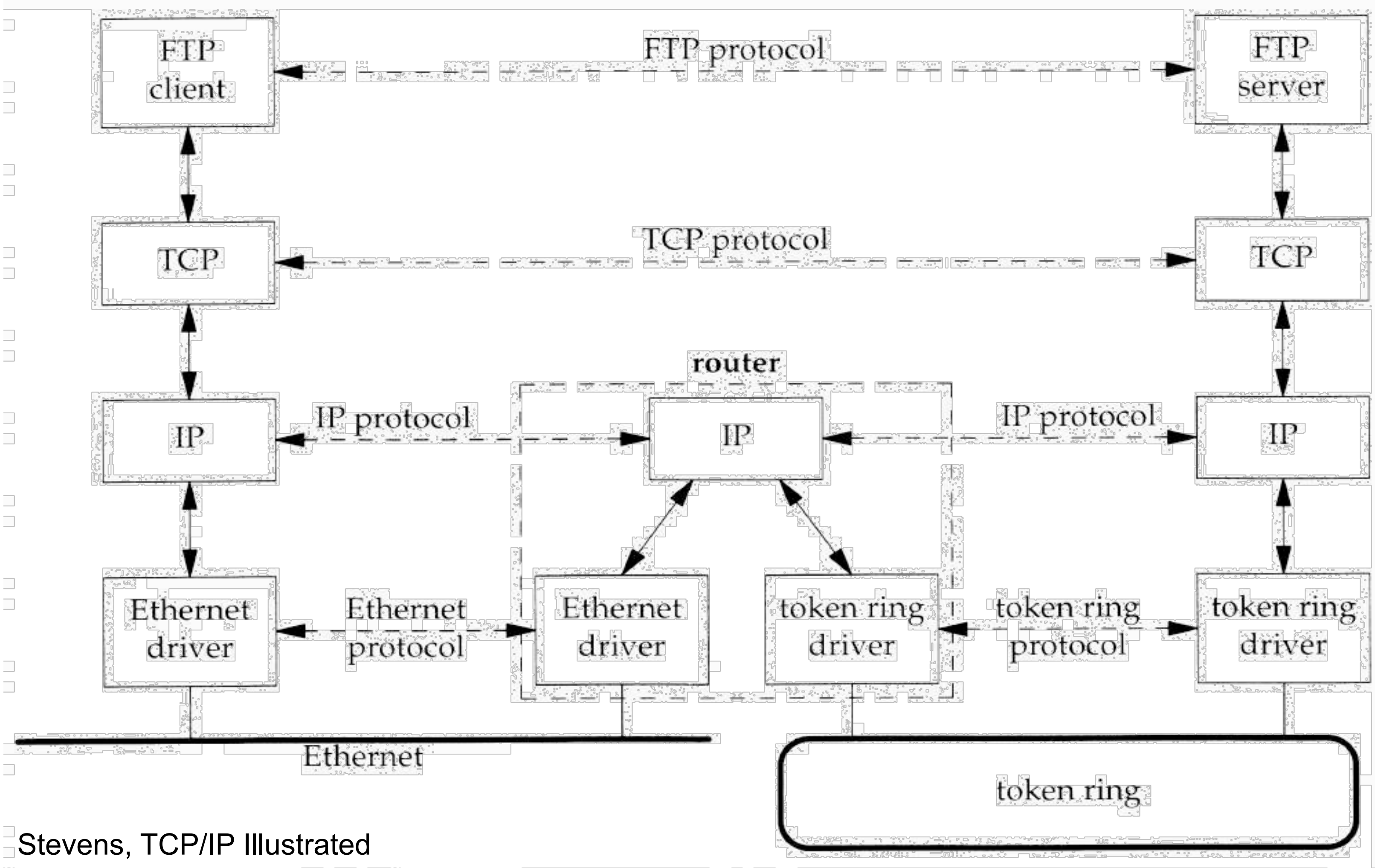
Internet: An Open Network Architecture

- **Concept of Robert Kahn (DARPA 1972)**
  - Local networks are autonomous
    - independent
    - no WAN configuration
  - **packet-based** communication
  - “**best effort**” communication
    - if a packet cannot reach the destination, it will be deleted
    - the application will re-transmit
  - black-box approach to connections
    - black boxes: gateways and routers

Protocols of the Internet

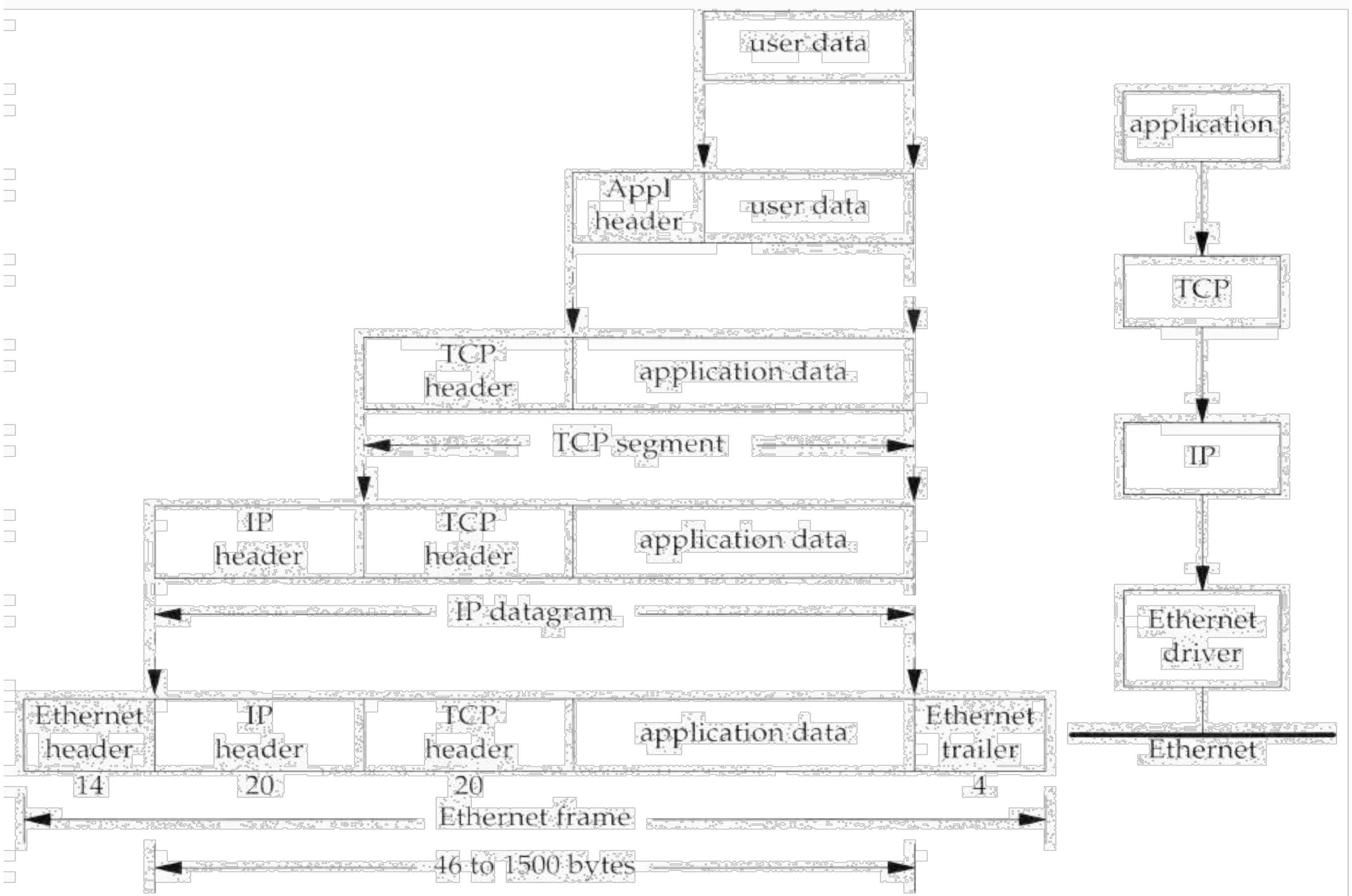
Application	Telnet, FTP, HTTP, SMTP (E-Mail), ...
Transport	TCP (Transmission Control Protocol) UDP (User Datagram Protocol)
Network	IP **(Internet Protocol)** + ICMP **(Internet Control Message Protocol)** + IGMP **(Internet Group Management Protococol)**
Host-to-Network	LAN **(e.g. Ethernet, Token Ring etc.)**

Example: Routing between LANs



Stevens, TCP/IP Illustrated

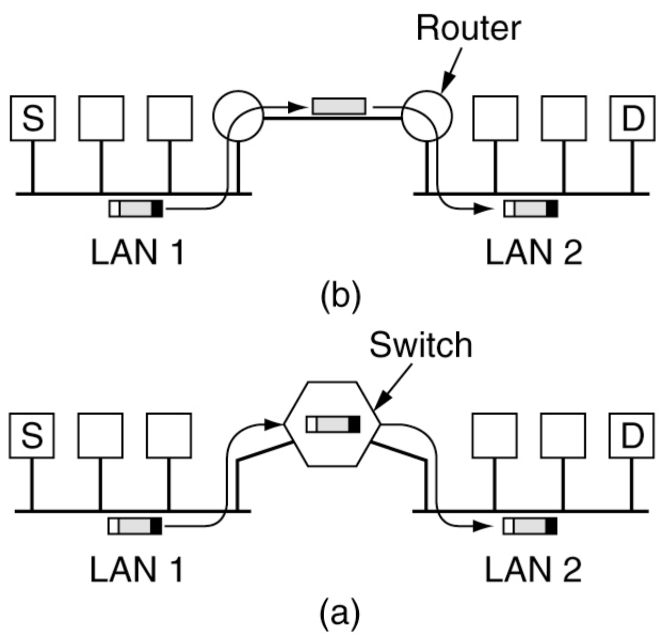
Data/Packet Encapsulation



Stevens, TCP/IP Illustrated

Network Interconnections

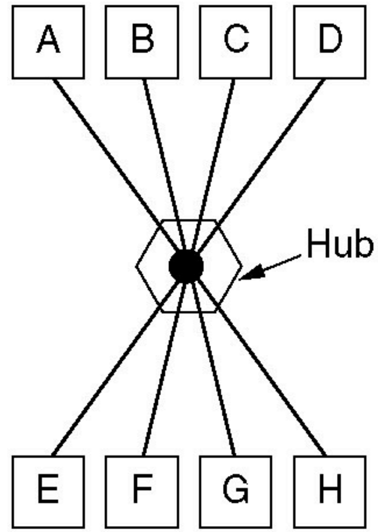
Application layer	Application gateway
Transport layer	Transport gateway
Network layer	Router
Data link layer	Bridge, switch
Physical layer	Repeater, hub

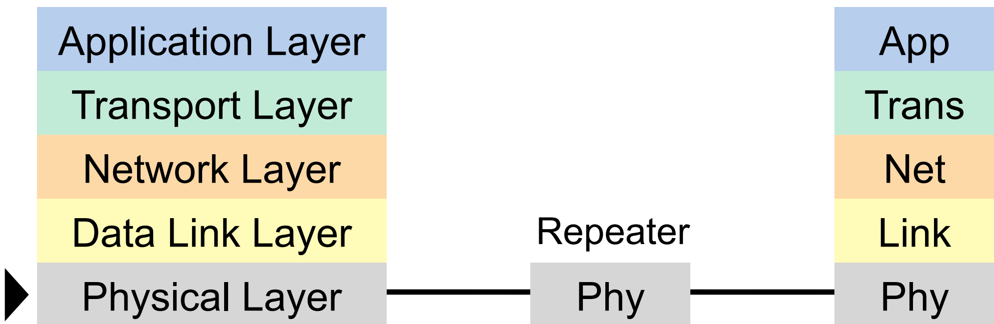


[Tanenbaum, Computer Networks]

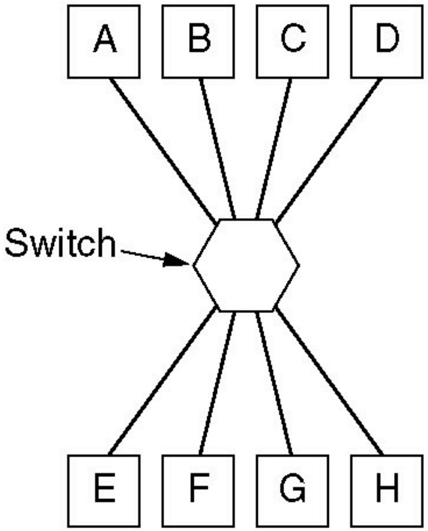
Repeater and Hub

- **Receives, aplifies, re-transmits**
  - only on the signal level
  - Information remains untouched





Switch

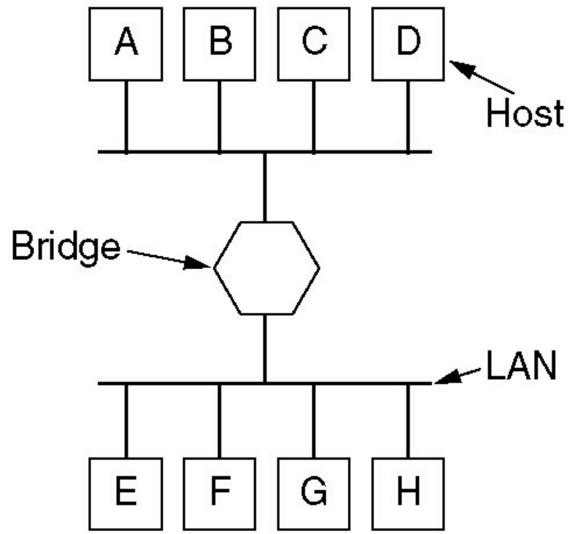


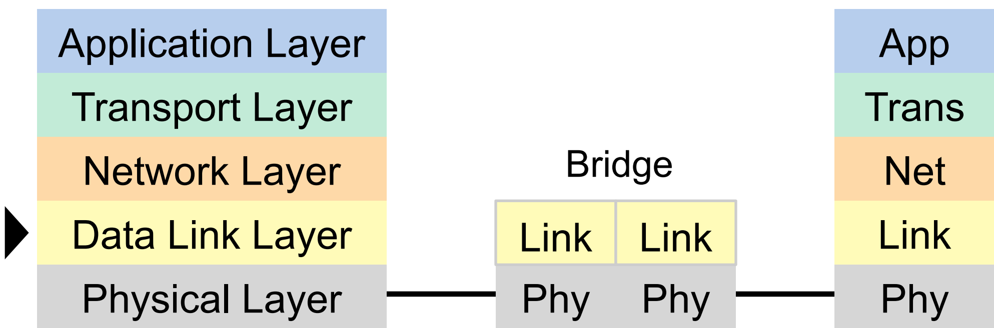
Application Layer
Transport Layer
Network Layer
Data Link Layer
Physical Layer

- **Connection of multiple network segments**
  - frames are forwarded only to the target segment
  - collisions are not repeated
  - store & forward (w. error correction)
  - cut through switching: forwarding starts after the header is read

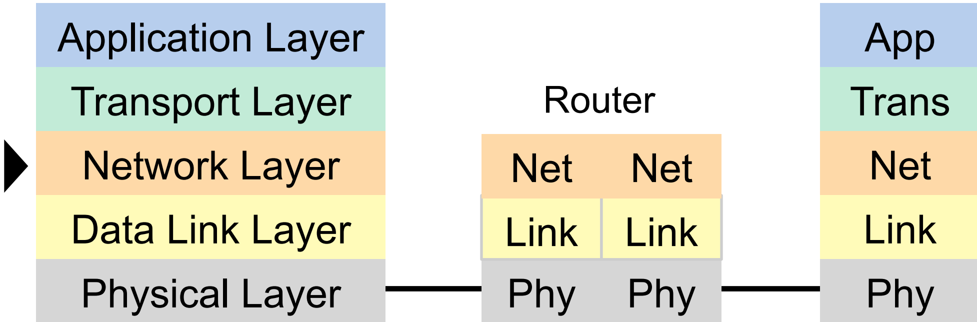
Bridge

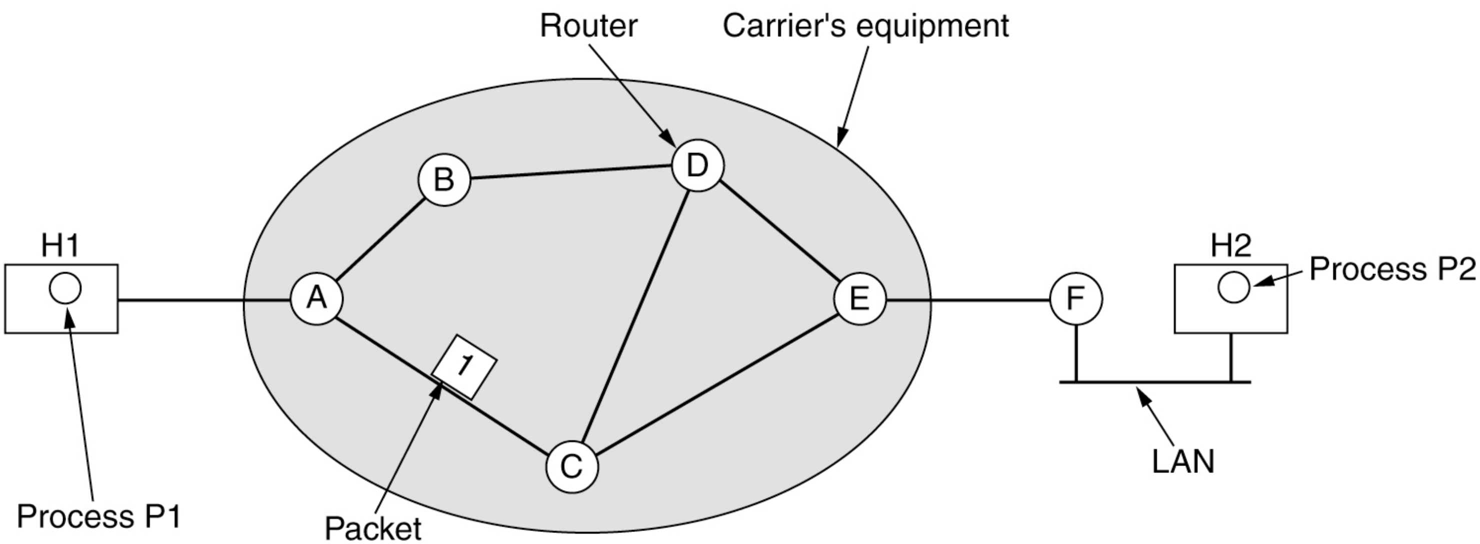
- **Connection of two network segments**
  - different access methods
  - multiport bridge similar to switch





Routing


Application Layer
Transport Layer
Network Layer
Data Link Layer
Physical Layer
Router
Net
Net
Link
Link
Phy
Phy
App
Trans
Net
Link
Phy


Router
Carrier's equipment
B
D
H1
A
E
F
H2
Process P2
1
C
LAN
Process P1
Packet

Why do we need a network layer?

- **Local Networks can be connected by hubs, switches, bridges**
  - Problems:
    - Hubs propagate collisions
    - Switching: Inefficient collection of routing information
    - Problem of broadcasting
    - Internet connects >> 10 Mio. local networks

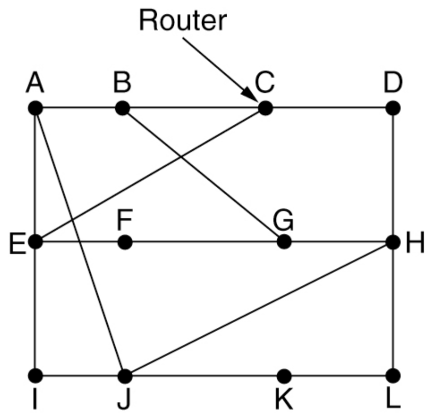
- **In large networks, routing information becomes necessary**
  - How is it collected?
  - How are packets forwarded?

Routing Tables and Packet Forwarding

- **IP Routing Table**
  - contains for each destination the address of the next gateway
  - destination: host computer or sub-network
  - default gateway

- **Packet Forwarding**
  - IP packet (datagram) contains start IP address and destination IP address
    - if destination = my address then hand over to higher layer
    - if destination in routing table then forward packet to corresponding gateway
    - if destination IP subnet in routing table then forward packet to corresponding gateway
    - otherwise, use the default gateway

Routing Table (Distance Vector)



(a)

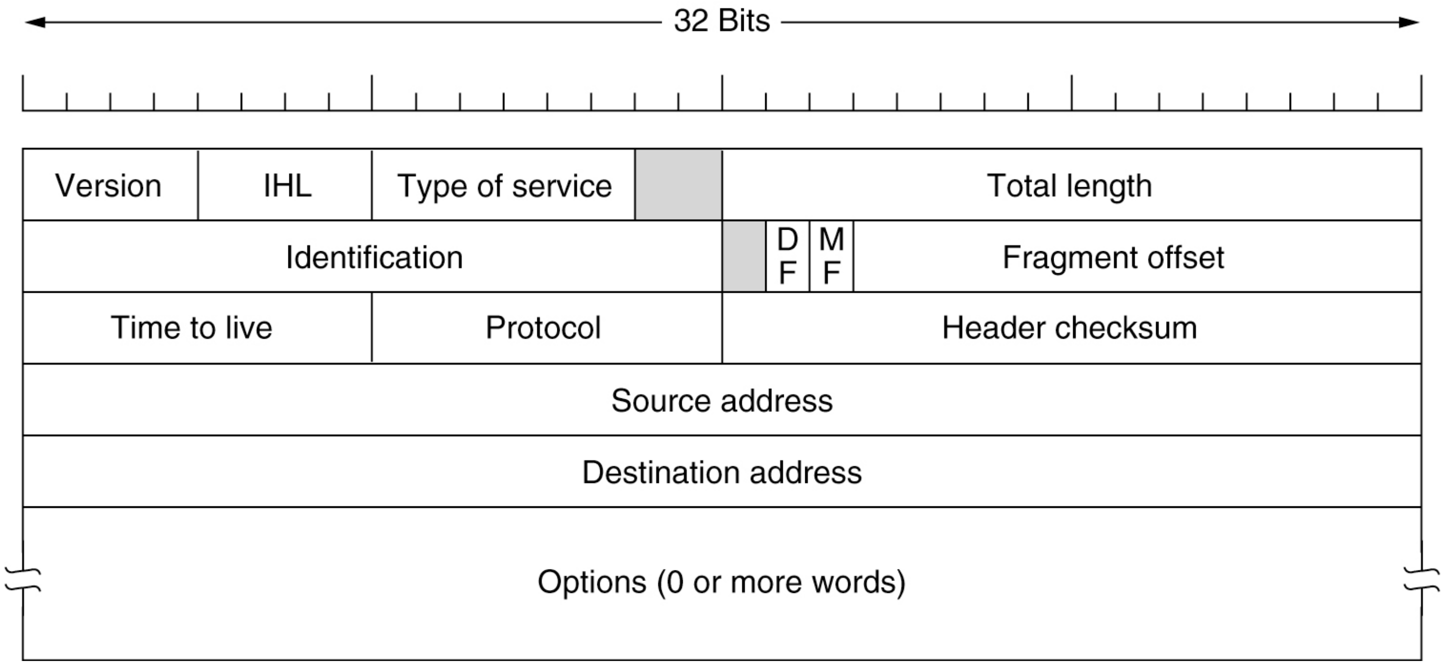
[Tanenbaum, Computer Networks]

To	A	I	H	K	New estimated delay from J	Line
A	0	24	20	21	8	A
B	12	36	31	28	20	A
C	25	18	19	36	28	I
D	40	27	8	24	20	H
E	14	7	30	22	17	I
F	23	20	19	40	30	I
G	18	31	6	31	18	H
H	17	20	0	19	12	H
I	21	0	14	22	10	I
J	9	11	7	10	0	–
K	24	22	22	0	6	K
L	29	33	9	9	15	K
	JA delay is 8	JI delay is 10	JH delay is 12	JK delay is 6	New routing table for J	

Vectors received from J's four neighbors

(b)

IPv4 Packet Header



IP Packet Forwarding

- **IP -Paket (datagram) contains...**
  - TTL (Time-to-Live): Hop count limit
  - Start IP Address
  - Destination IP Address
- **Packet Handling**
  - Reduce TTL (Time to Live) by 1
  - If TTL ≠ 0 then forward packet according to routing table
  - If TTL = 0 or forwarding error (buffer full etc.):
    - delete packet
    - if packet is not an ICMP Packet then
      - sende ICMP Packet with
        - start = current IP Address
        - destination = original start IP Address

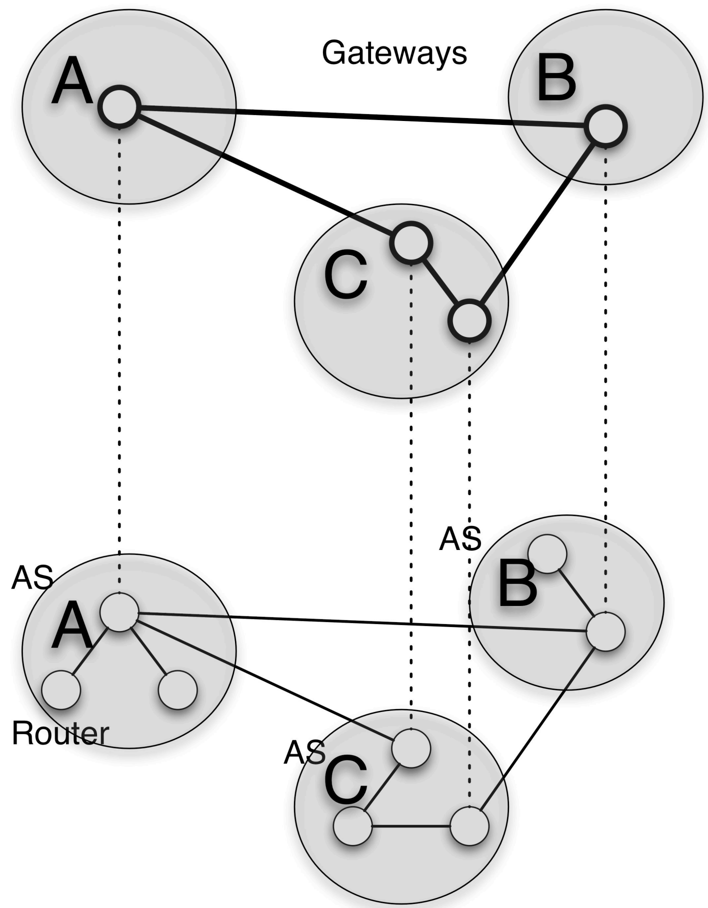
Static and Dynamic Routing

- **Static Routing**
  - Routing table created manually
  - used in small LANs

- **Dynamic Routing**
  - Routing table created by Routing Algorithm
  - **Centralized**, e.g. Link State
    - Router knows the complete network topology
  - **Decentralized**, e.g. Distance Vector
    - Router knows gateways in its local neighborhood

Hierarchical Routing

- **Internet consists of Autonomous Systems (AS)**
  - example: uni-freiburg.de
- **Intra-AS-Routing (Interior Gateway Protocol)**
  - z.B. RIP, OSPF, IGRP, ...
- **Inter-AS-Routing (Exterior Gateway Protocol)**
  - between Gateways
  - decentralized
  - everybody can define a metric
  - z.B. BGP



Intra-AS Routing

- **Inter-AS**
  - Routing Information Protocol (RIP)
    - Distance Vector Algorithmus
    - Metric = hop count
    - exchange of distance vectors (by UDP)
  - Interior Gateway Routing Protocol (IGRP)
    - successor of RIP
    - different routing metrics (delay, bandwidth)
  - Open Shortest Path First (OSPF)
    - Link State Routing (every router knows the topology)
    - Route calculation by Dijkstra’s shortest path algorithm

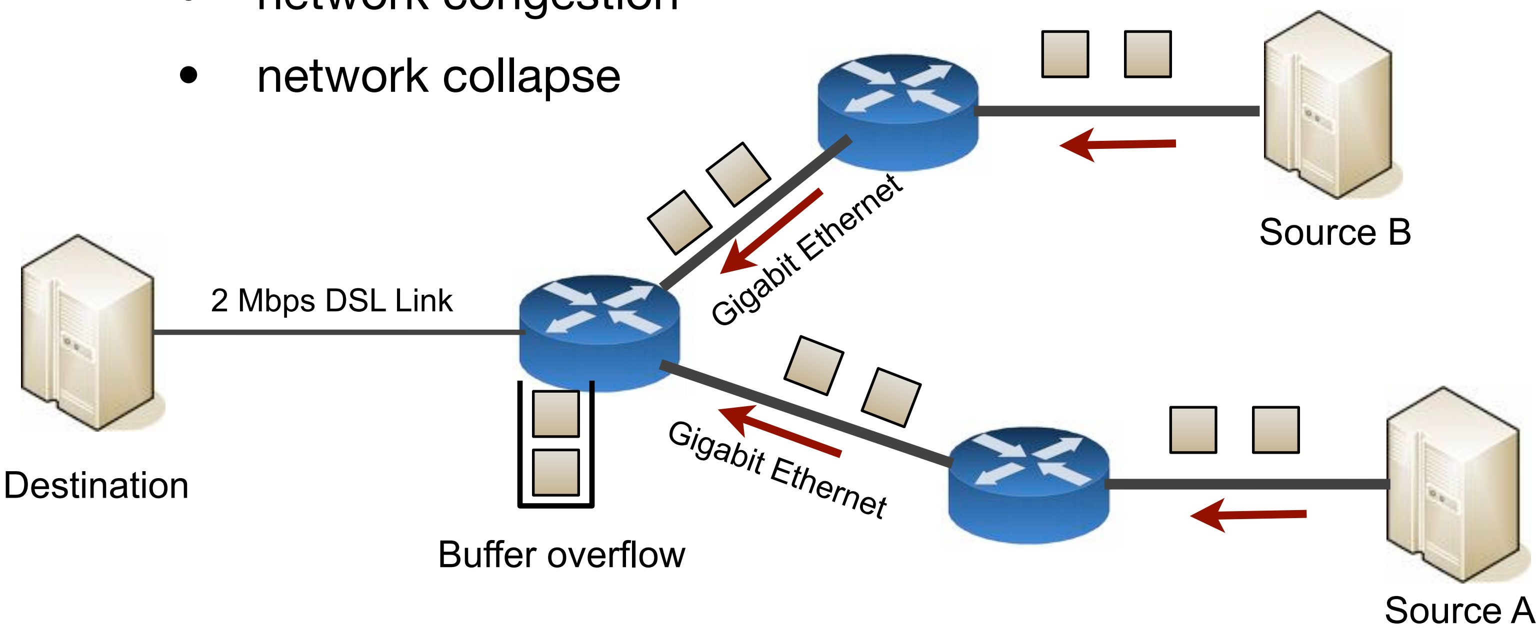
Inter-AS Routing

- **Problems of Inter-AS Routing**
  - AS may reject packets
  - Political consideration: Routing through other contries?
  - Routing metrics of different AS are not compatible
    - path optimization impossible
    - Inter-AS Routing tries to achieve reachability
  - Currently, Inter-Domain Router know more than 140.000 Networks

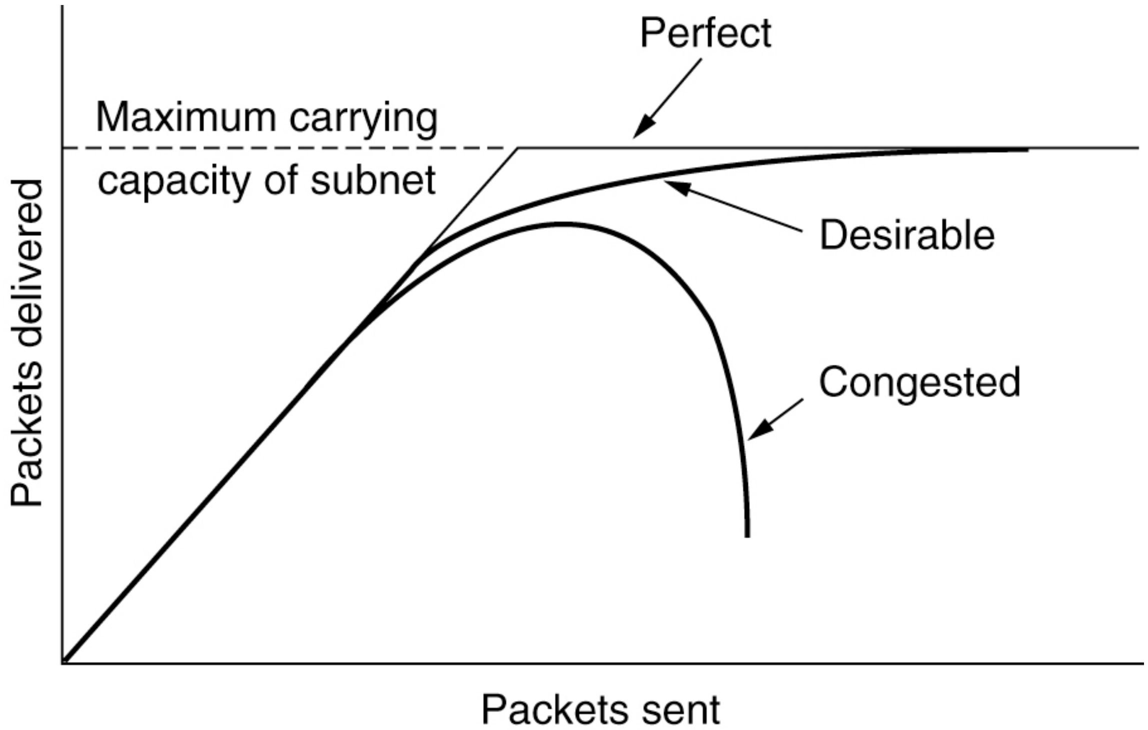
- **Border Gateway Protocol (BGP)**
  - Path-Vector Protocol

Network Congestion

- **(Sub-)Networks have limited bandwidth**
- **Injecting too many packets leads to**
  - network congestion
  - network collapse



Congestion and capacity

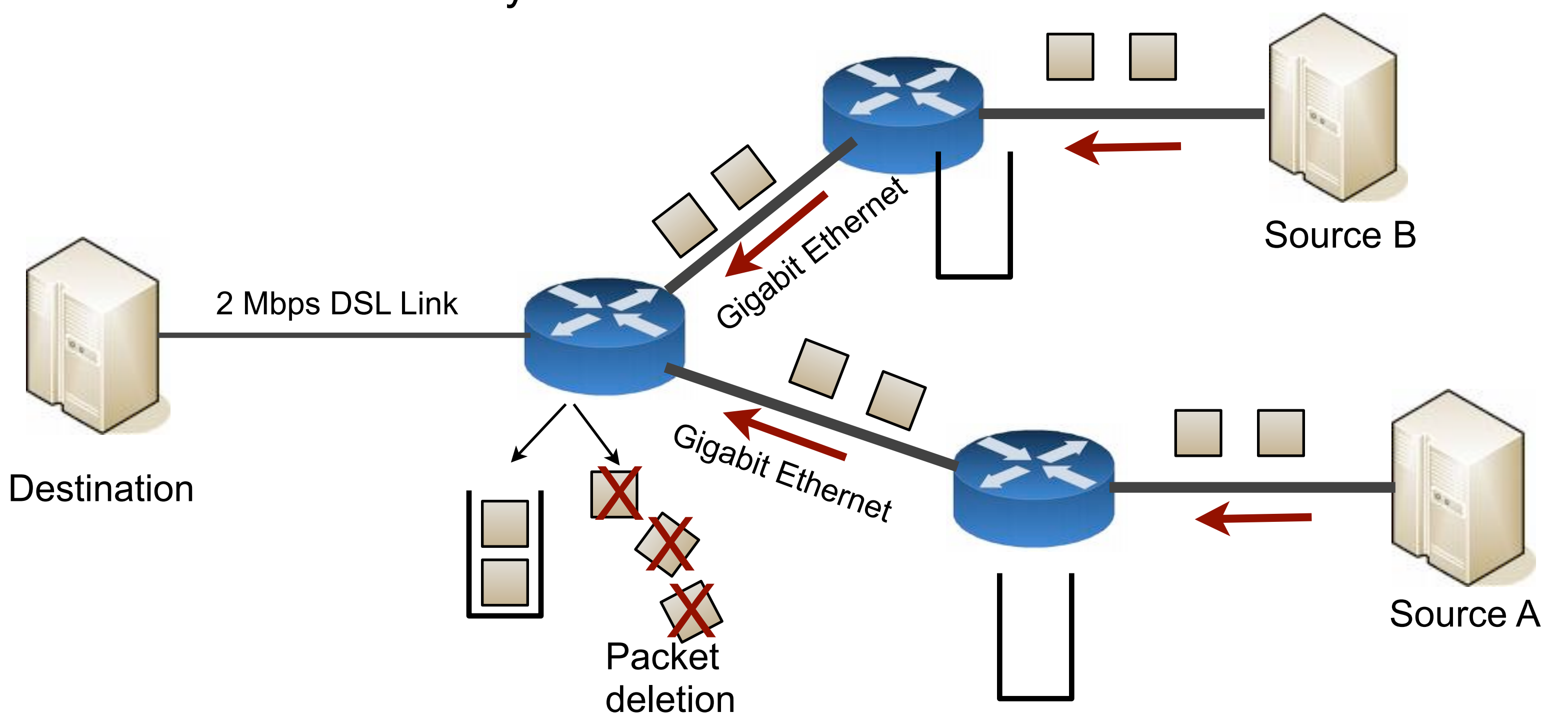


Congestion Prevention

Layer	Policies
Transport	• Retransmission policy • Out-of-order caching policy • Acknowledgement policy • Flow control policy • Timeout determination
Network	• Virtual circuits versus datagram inside the subnet • Packet queueing and service policy • Packet discard policy • Routing algorithm • Packet lifetime management
Data link	• Retransmission policy • Out-of-order caching policy • Acknowledgement policy • Flow control policy

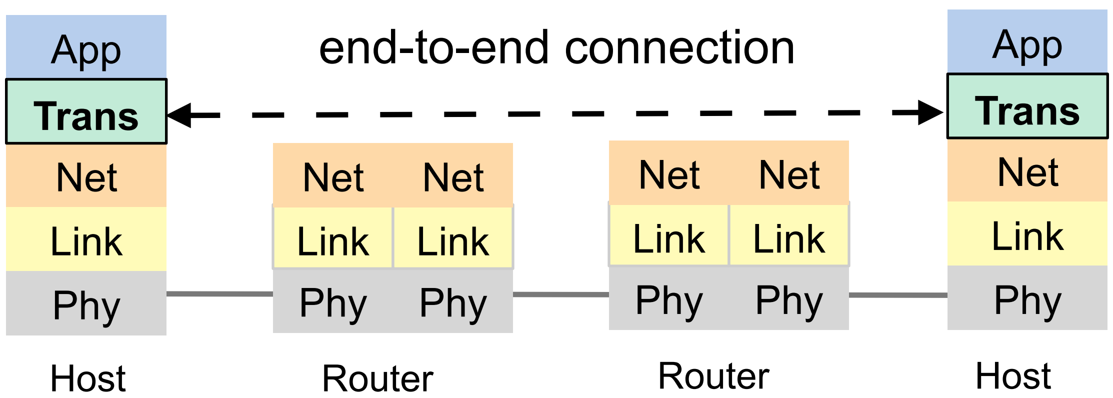
Congestion Prevention by Routers

- **IP Routers drop packets**
  - Tail dropping
  - Random Early Detection



The Transport Layer

- **TCP (Transmission Control Protocol**
  - connection-oriented
  - delivers a stream of bytes
  - reliable and ordered
- **UDP (User Datagram Protocol)**
  - delivery of datagrams
  - connectionless, unreliable, unordered



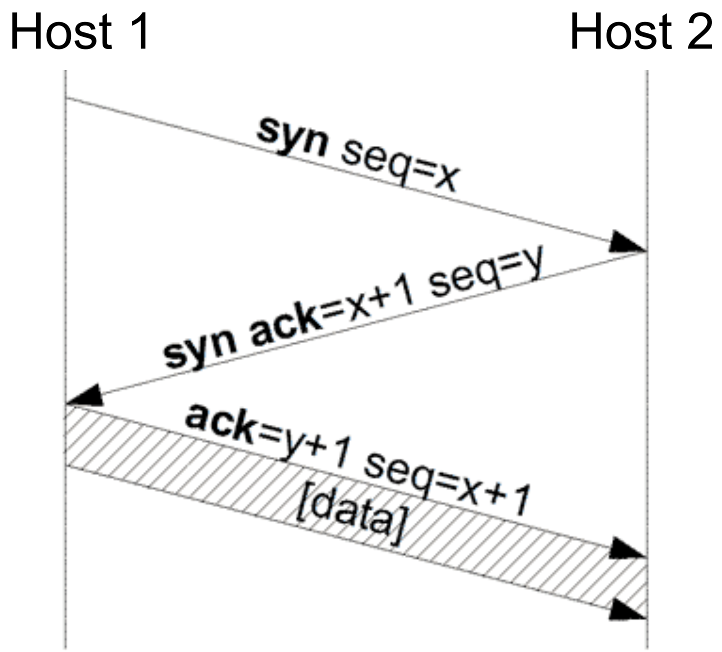
The Transmission Control Protocol (TCP)

- Connection-oriented
- Reliable delivery of a byte stream
  - fragmentation and reassembly (*TCP segments*)
  - acknowledgements and retransmission
- In-order delivery, duplicate detection
  - sequence numbers
- Flow control and congestion control
  - window-based (receiver window, congestion window)

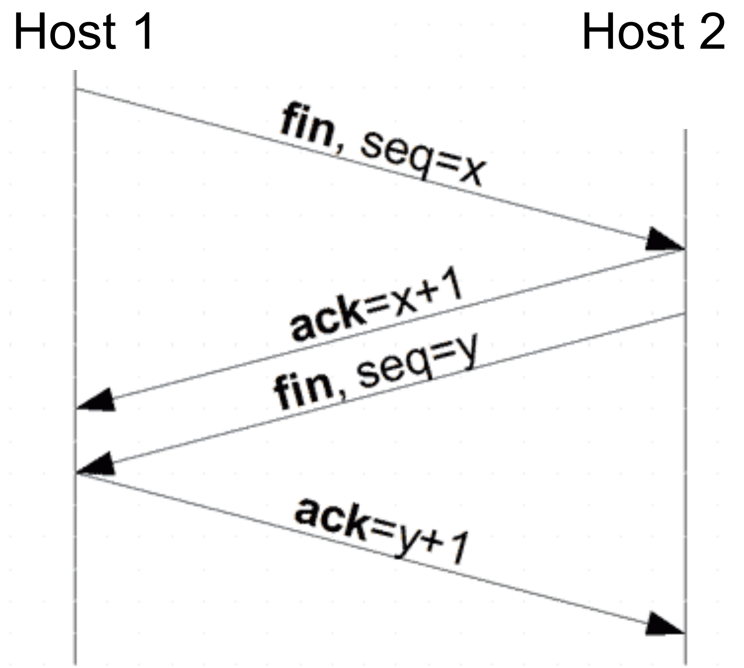
- **challenge**: IP (network layer) packets can be dropped, delayed, delivered out-of-order ...

TCP Connections

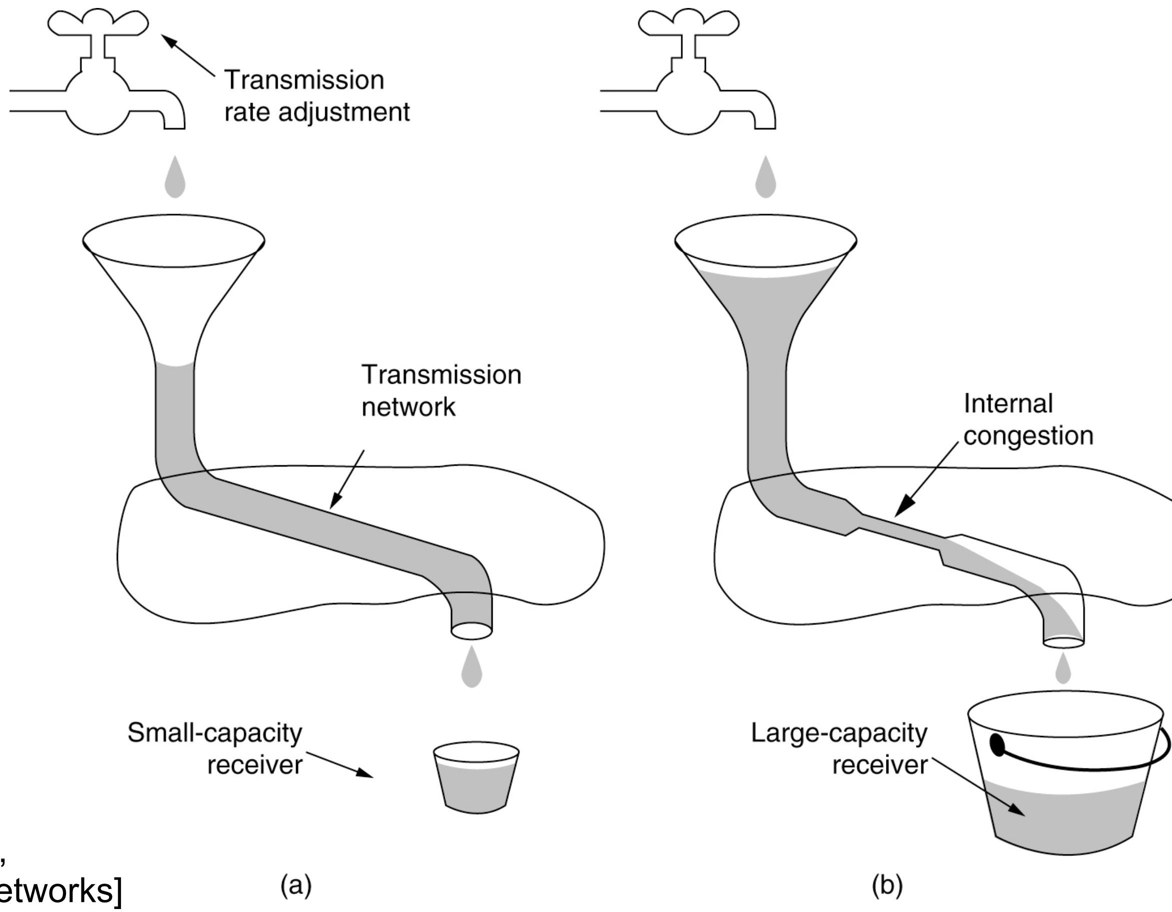
Connection establishment



Connection termination



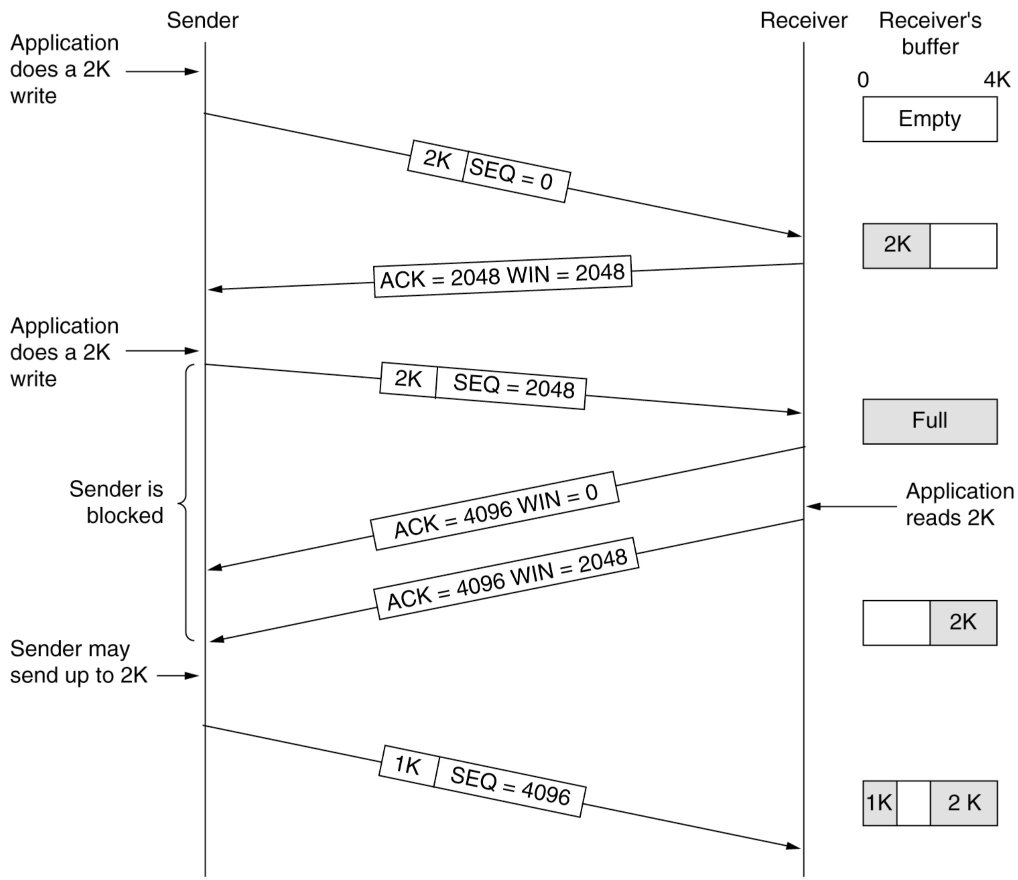
Flow control and congestion control



[Tanenbaum,
Computer Networks]

Flow Control

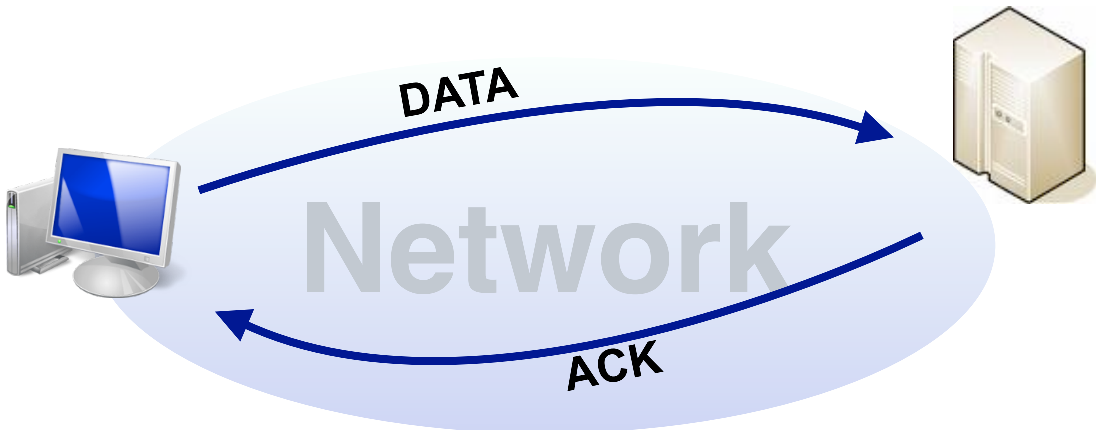
acknowledgements and window management



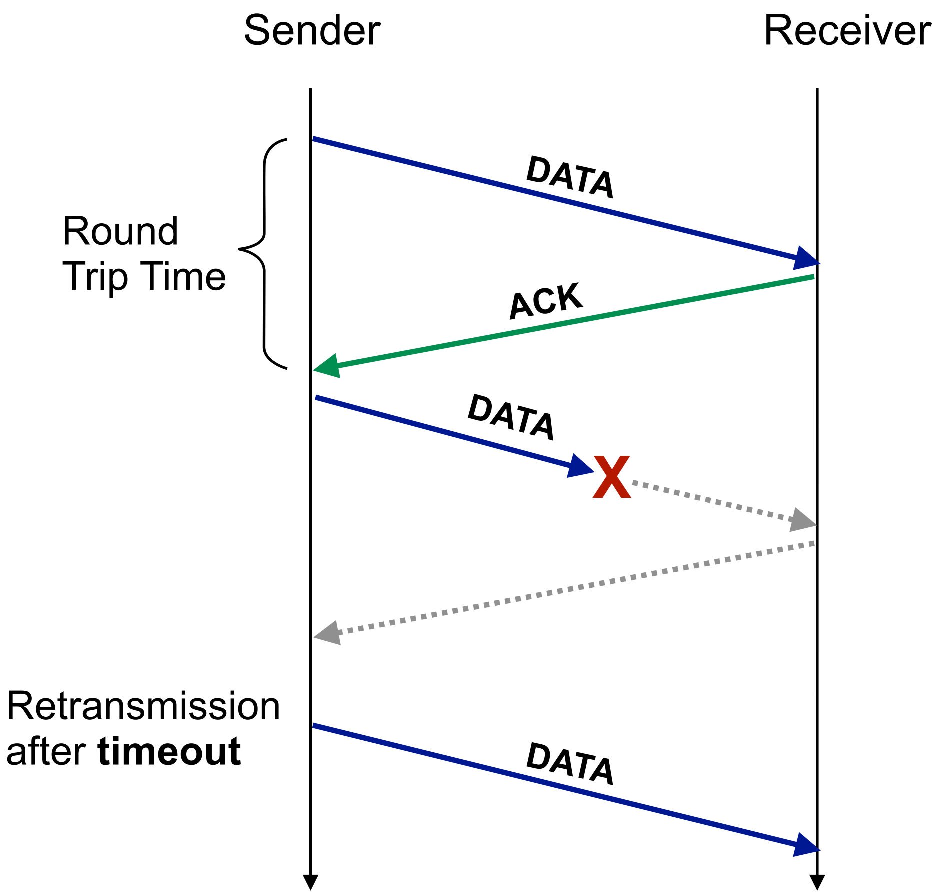
Retransmissions

- Retransmissions are triggered, if acknowledgements do not arrive
  ... but how to decide that?

- Measurement of the **round trip time (RTT)**

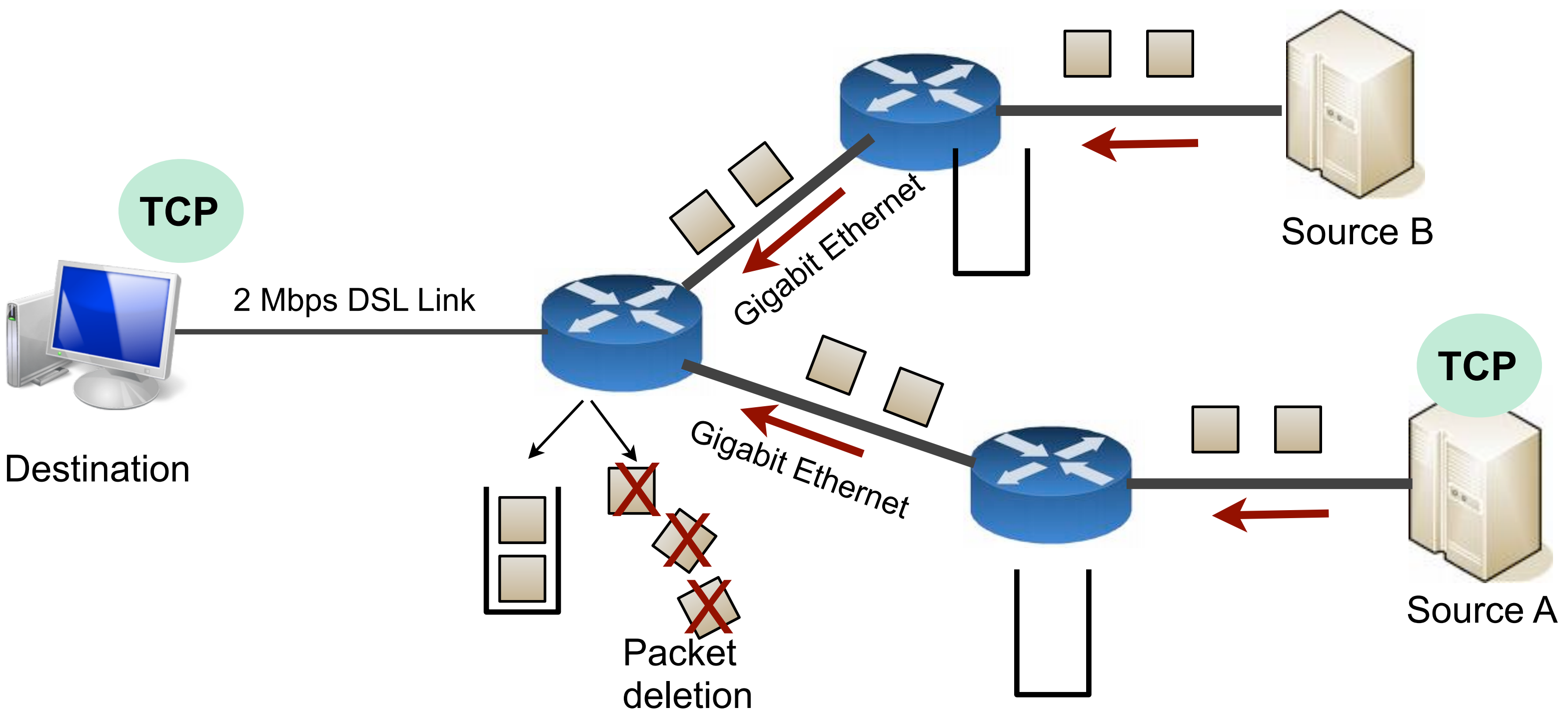


Retransmissions and RTT

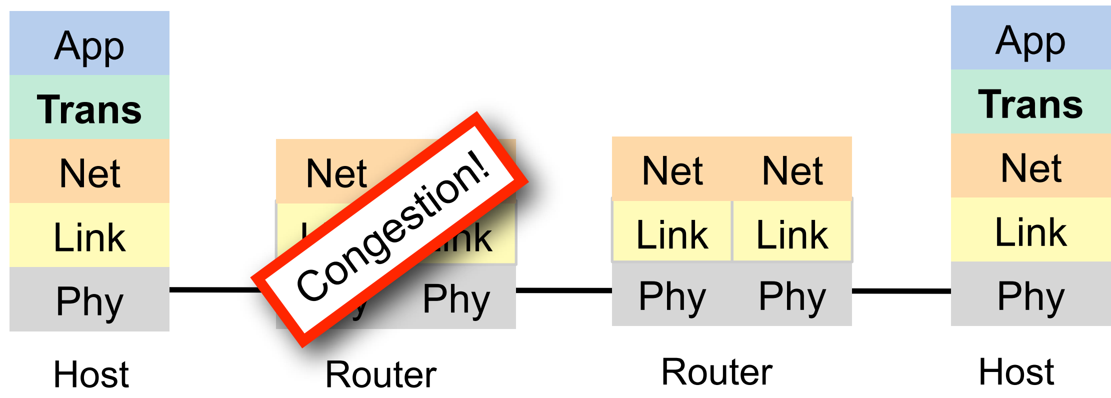


Congestion revisited

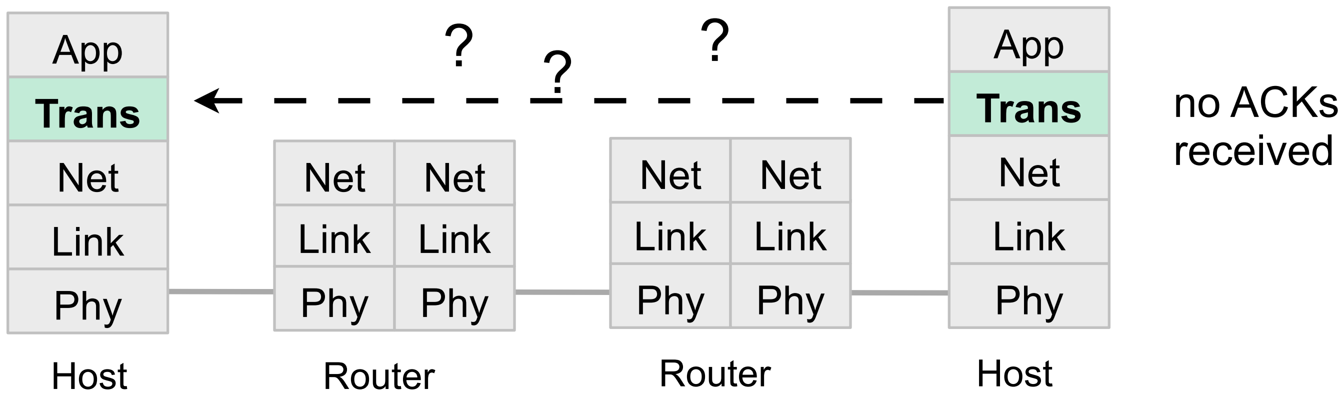
- **IP Routers drop packets**
- **TCP has to react, e.g. lower the packet injection rate**



Congestion revisited

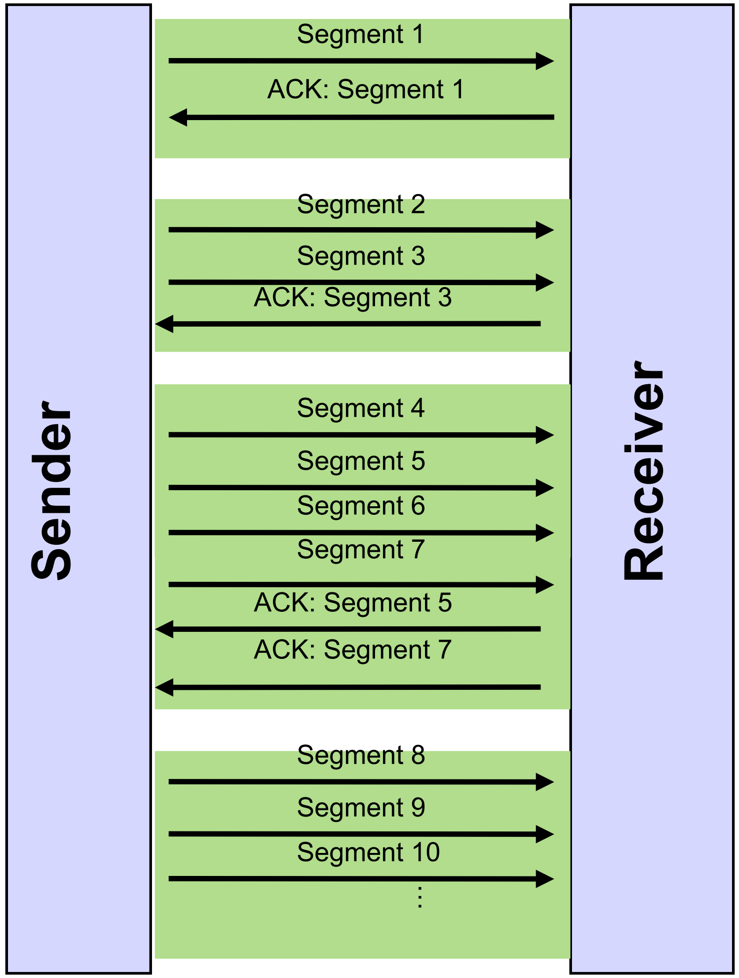


from a transport layer perspective:

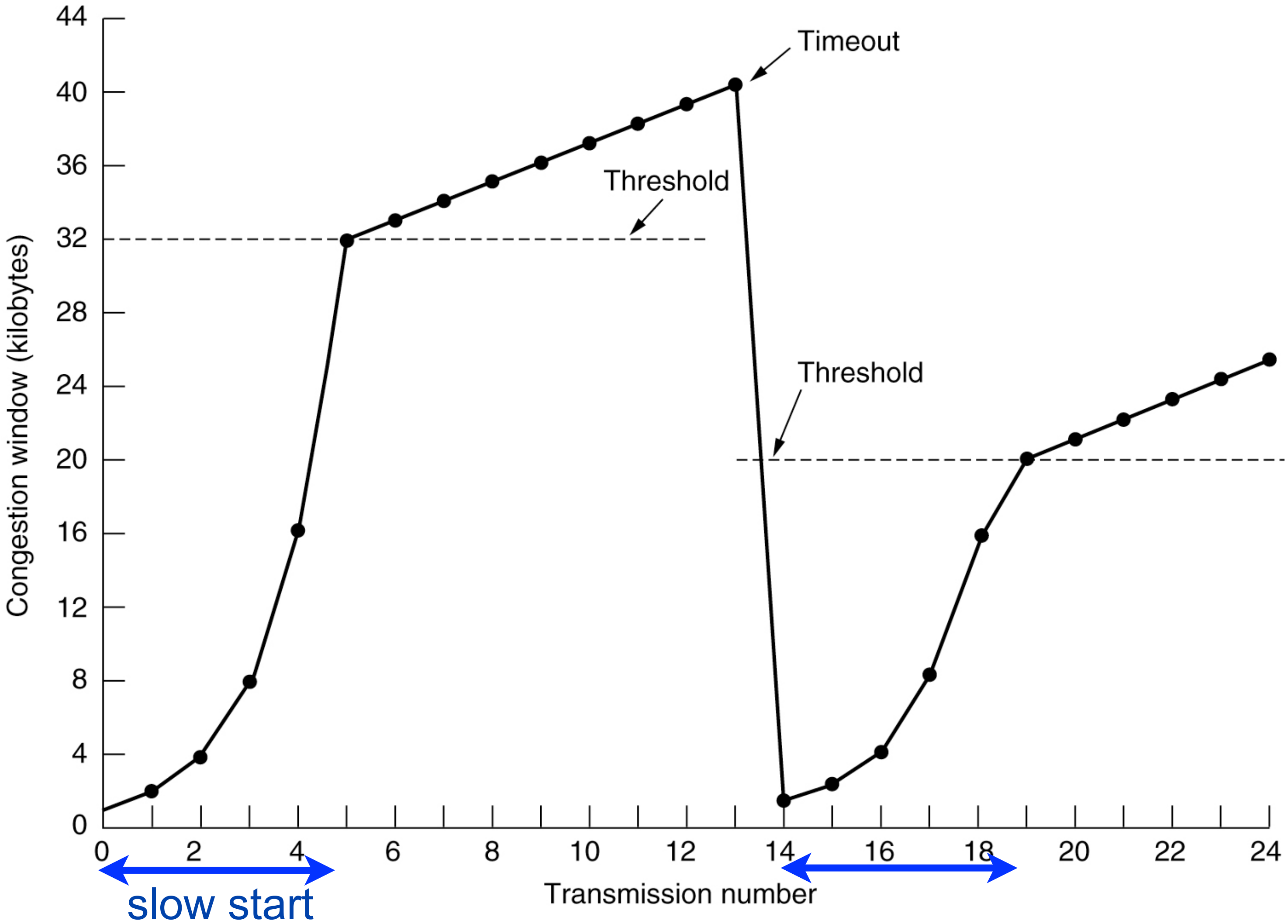


Data rate adaption and the congestion window

- **Sender does not use the maximum segment size in the beginning**
- **Congestion window (cwnd)**
  - used on the sender size
  - sending window: min {wnd,cwnd} (wnd = receiver window)
  - S: segment size
  - Initialization:
    - cwnd ← S
  - For each received acknowledgement:
    - cwnd ← cwnd + S
  - ...until a packet remains unacknowledged



Slow Start of TCP Tahoe



The AIMD principle

- **TCP uses basically the following mechanism to adapt the data rate x (#packets sent per RTT):**
  - Initialization:

    $x \leftarrow 1$

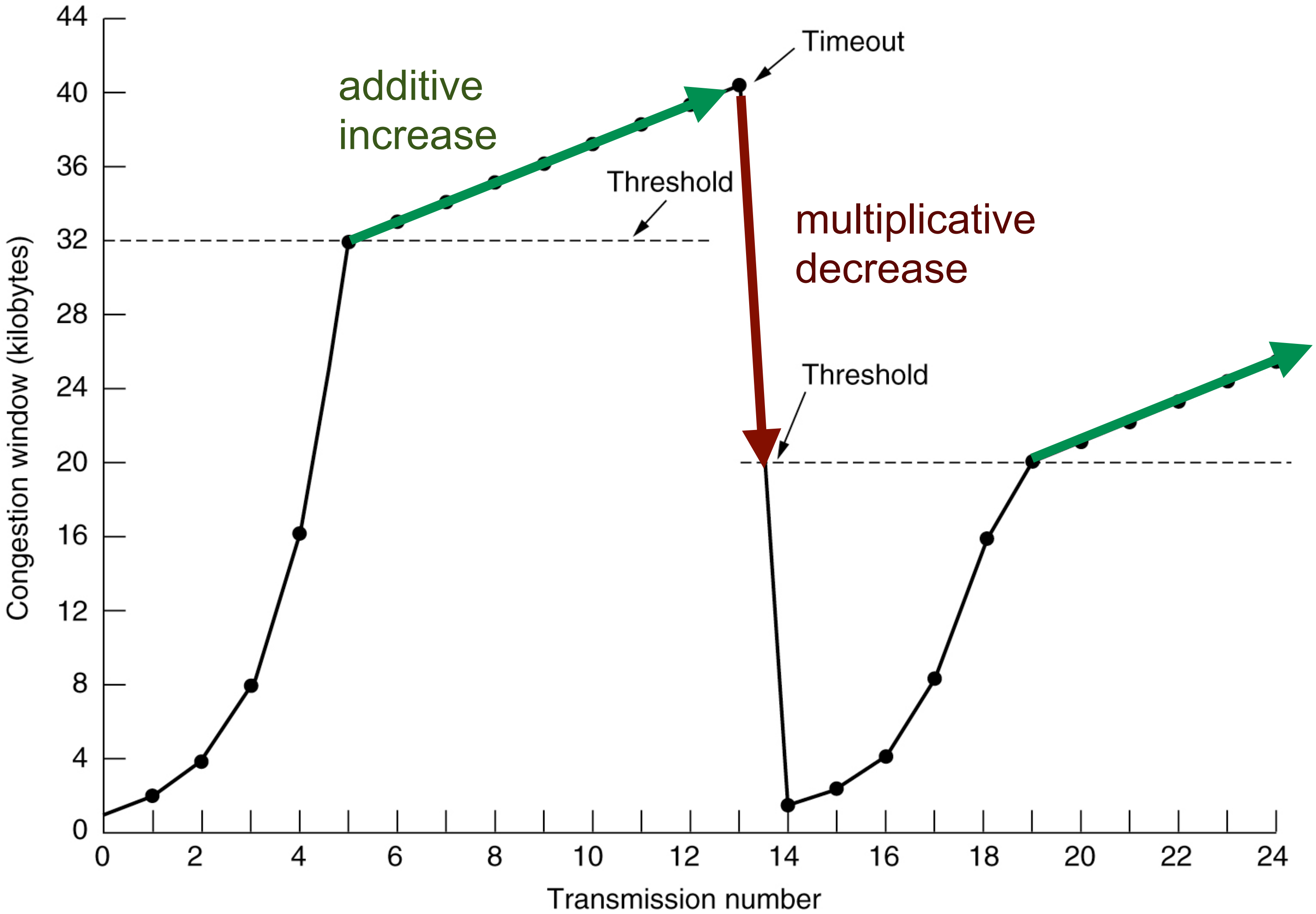
  - on packet loss: multiplicative decrease (MD)

    $x \leftarrow x/2$

  - if the acknowledgement for a segment arrives, perform additive increase (AI)

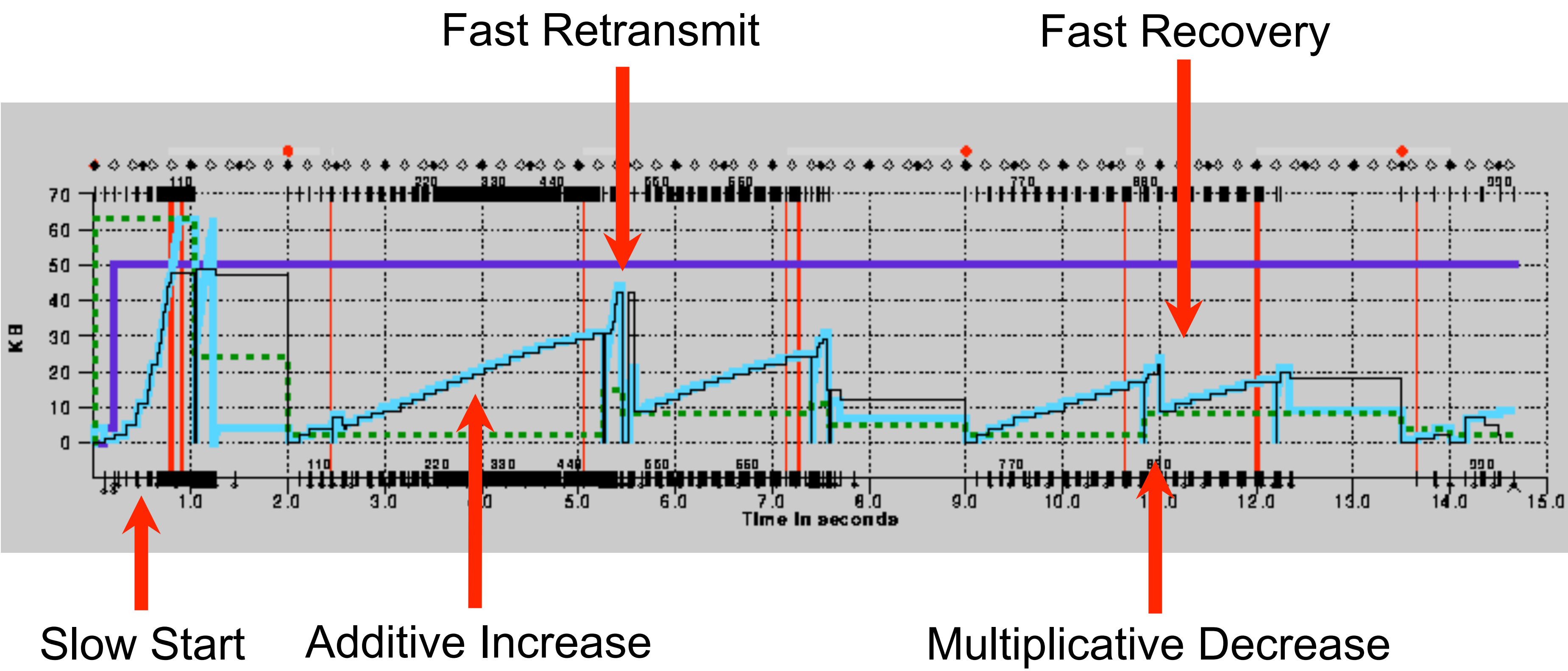
    $x \leftarrow x + 1$

AIMD



additive
increase
Timeout
Threshold
multiplicative
decrease
Threshold
Congestion window (kilobytes)
44
40
36
32
28
24
20
16
12
8
4
0
0
2
4
6
8
10
12
14
16
18
20
22
24
Transmission number

Example of TCP Reno



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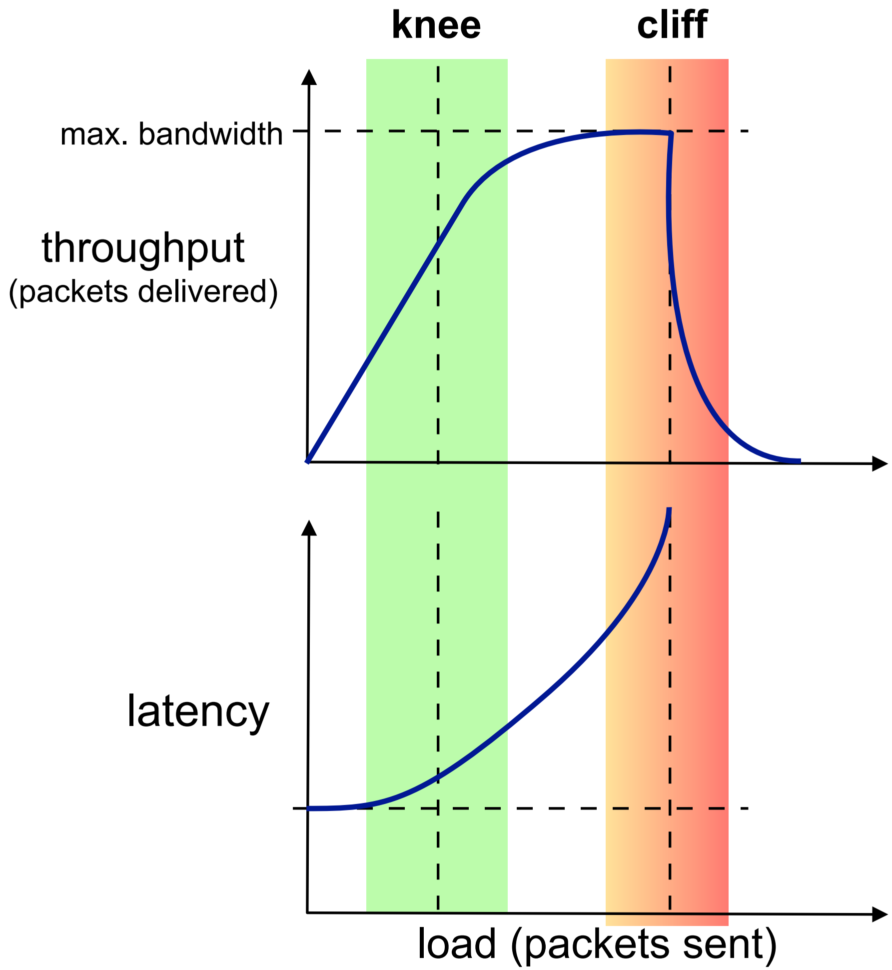
Throughput and Latency

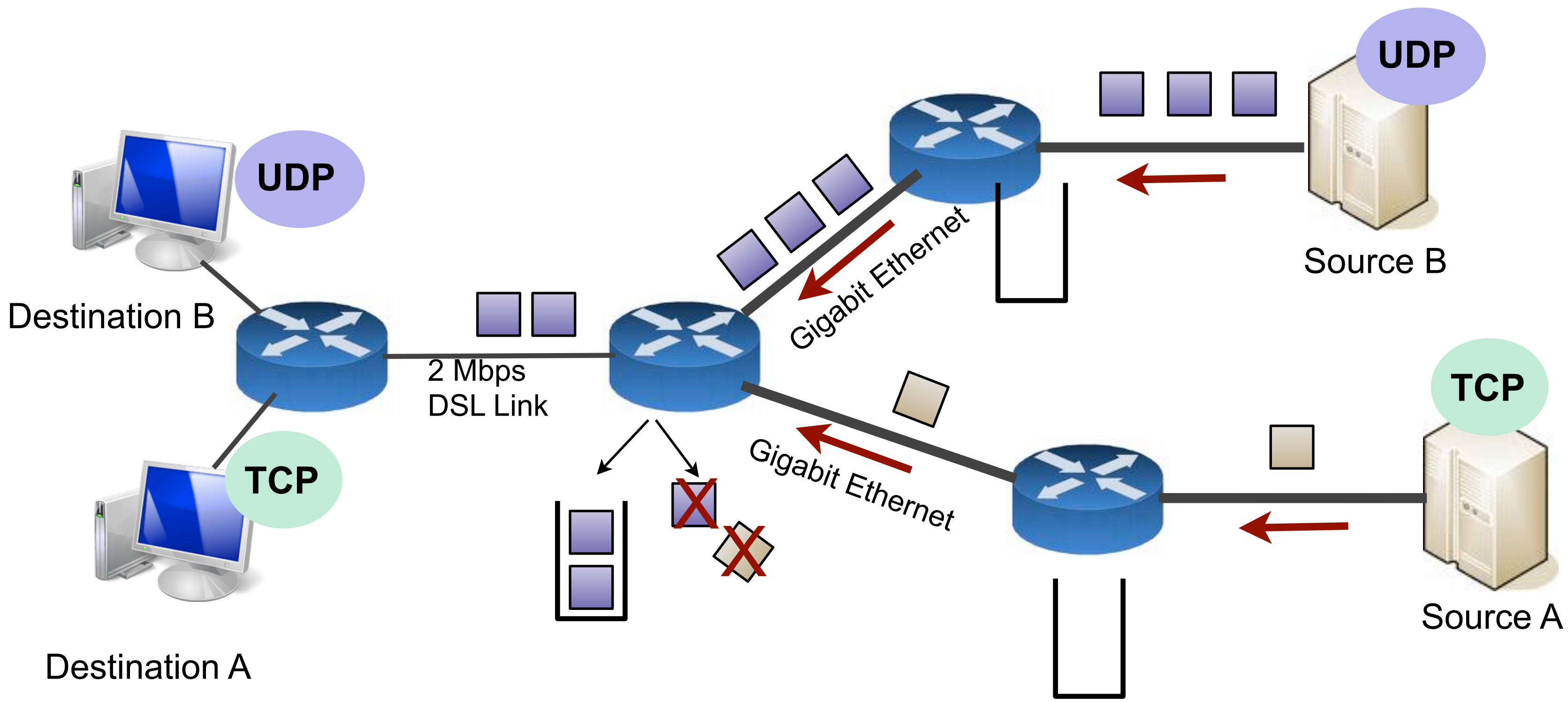
- **Congested situation (cliff):**
  - high load
  - low throughput
  - all data packets are lost

- **Desired situation (knee):**
  - high load
  - high throughput
  - few data packets get lost



TCP vs. UDP

- **TCP reduces data rate**
- **UDP does not!**



TCP - Conclusion

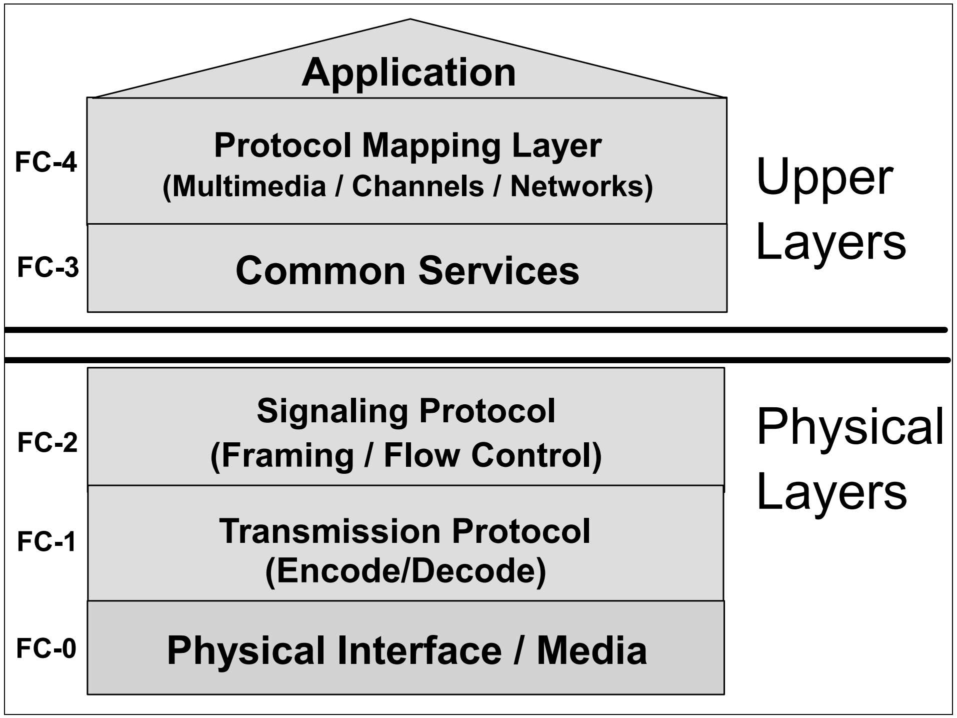
- Connection-oriented, reliable,
  in-order delivery of a byte stream
- Flow control and congestion control
  - Fairness among TCP streams
  - Unfair behavior of other protocols, e.g. UDP
  - Impact on latency
  - Tweaking the congestion avoidance mechanism has an impact on other applications

Storage networking

- **Fibre Channel**
  - standard connection for SANs
  - Medium: fibre-optic but also twisted pair
  - Protocol: channel-like transport of SCSI commands
  - Topologies: From point-to-point to networks
  - Advantages: flexible connectivity, networking capabilities

Fibre Channel Protocol (FCP)

- **Transport protocol for SCSI commands**
- **Layered architecture**

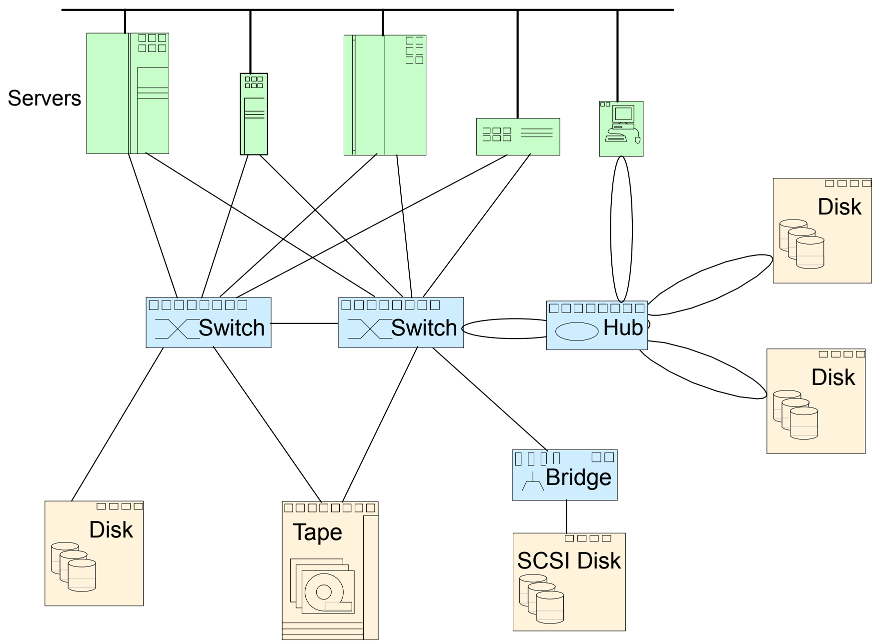


FCP Layers

FC4	**Protocol Mapping Layer**	encapsulation of other protocols
FC3	**Common Services**	encryption, striping, RAID, etc.
FC2	**Framing and Signalling**	data transport, routing
FC1	**Transmission Protocol**	8b/10b encoding and decoding
FC0	**Physical Layer**	medium

Fibre Channel Topologies

- **Point-to-Point**
  - connection of 2 nodes
- **Arbitrated Loop (FC-AL)**
  - shared bus of up to 126 nodes
- **Switched Fabric (FC-SW)**
  - interconnection network
  - routing and transport protocols



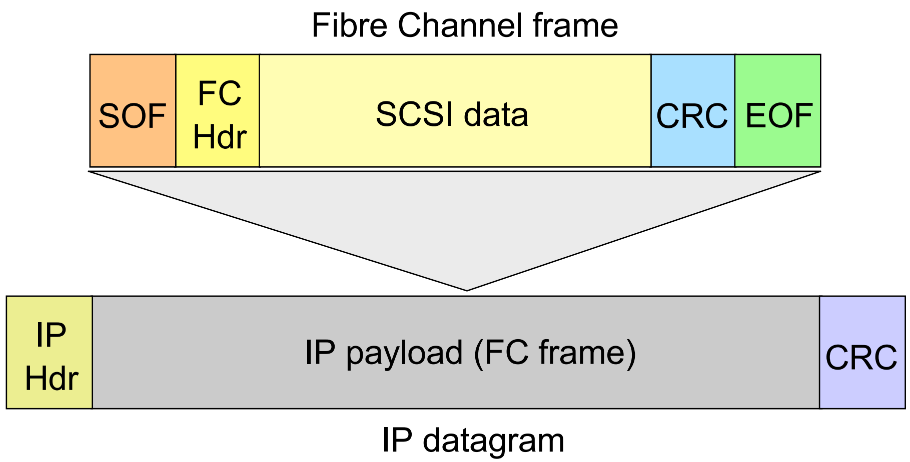
switched fabric

Network Storage Types

- **Direct attached storage (DAS)**
  - traditional storage
- **Network attached storage (NAS)**
  - storage attached to another computer accessible at file level over LAN or WAN
- **Storage area network (SAN)**
  - specialized network providing other computers with storage capacity with access on block-addressing level

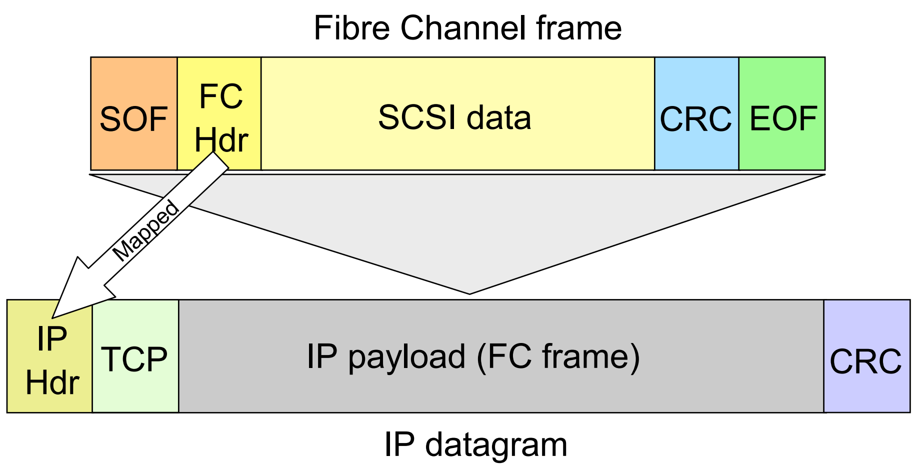
IP storage networking protocols

- **Fibre Channel over IP (FCIP)**
  - Tunneling data between SAN devices through IP networks
  - based on TCP connections
  - links SAN devices and switch fabrics over IP networks
  - Merging switch fabrics over IP links problematic
    (frequent switch reconfigurations because of link unreliability)



IP storage networking protocols

- **Internet Fibre Channel Protocol (iFCP)**
  - Fibre Channel switch fabric services over IP networks
  - based on TCP connections
  - uses IP routing and switching
  - can replace the Fibre Channel switch fabric



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Algorithms and Methods for Distributed Storage

6 Networking

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Institut für Informatik
Rechnernetze und Telematik
Wintersemester 2008/09

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