Energy Informatics
3-1 Introduction to Computer Networking

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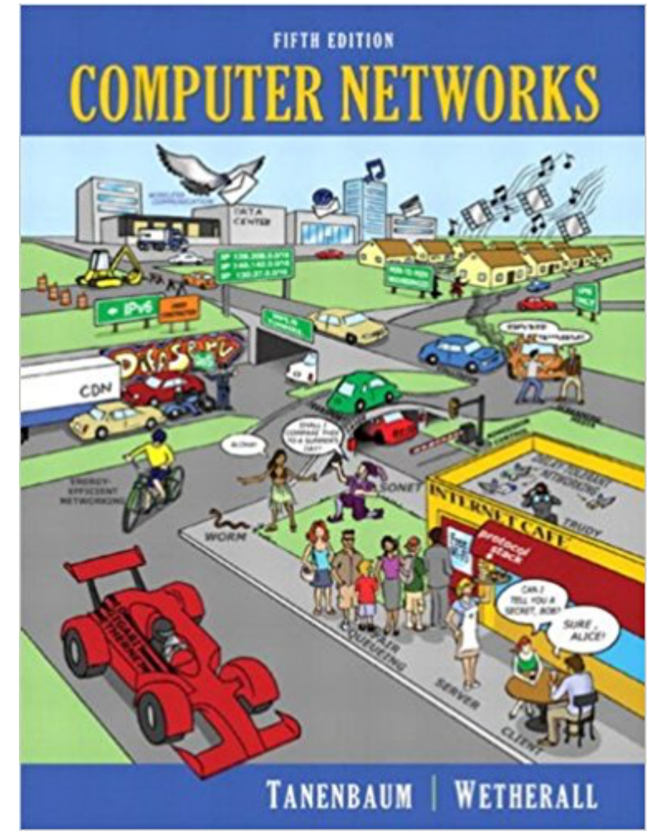
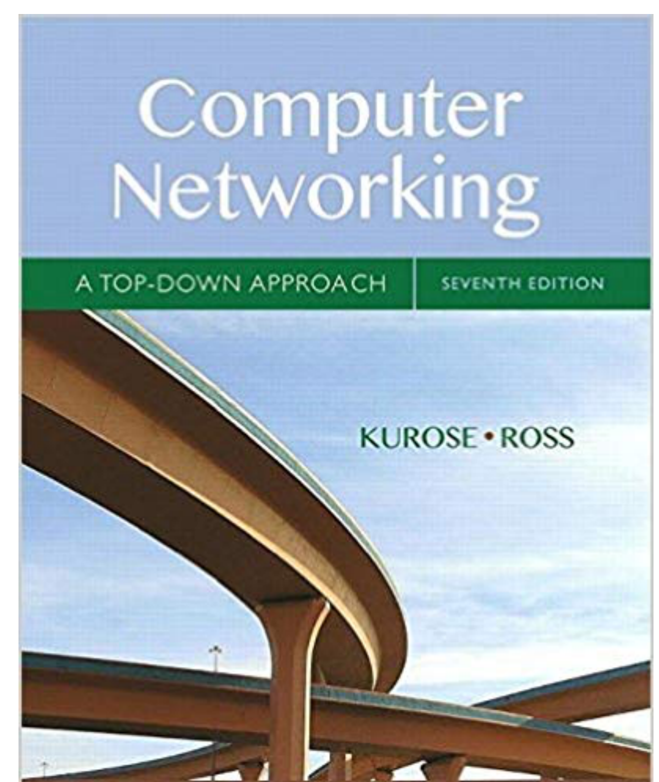
Literature

- Andrew S. Tanenbaum, David J. Wetherall, *Computer Networks,* Pearson, 2013



- James F. Kurose, Ketz W. Ross, Computer Networking: A Top-Down-Approach, 2016



Overview

- Challenges of Computer Networks
  - Size, complexity, technology
- Fundamental concepts in Computer Networks
  - Layers
  - Protocols
  - Distributed Systems
- Network Layers
  - Physical
  - Data link
  - Network
  - Transport
  - Application

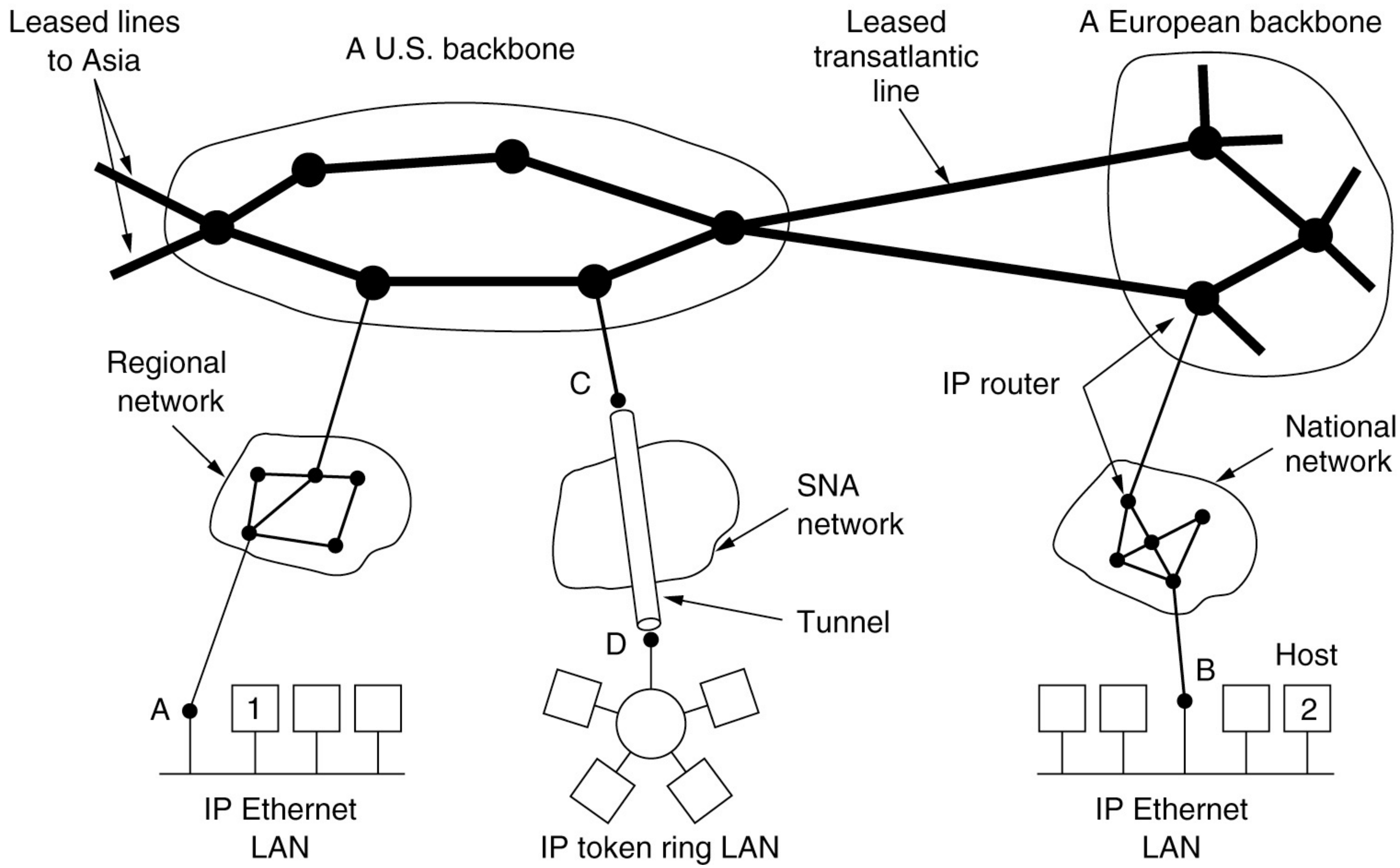
Types of Computer Networks

Interprocessor distance	Processors located in same	Example	
1 m	Square meter	Personal area network	**PAN**
10 m	Room	Local area network	**LAN**
100 m	Building	Local area network	**LAN**
1 km	Campus	Local area network	**LAN**
10 km	City	Metropolitan area network	**MAN**
100 km	Country	Wide area network	**WAN**
1000 km	Continent	Wide area network	**WAN**
10,000 km	Planet	The Internet	

(Tanenbaum)

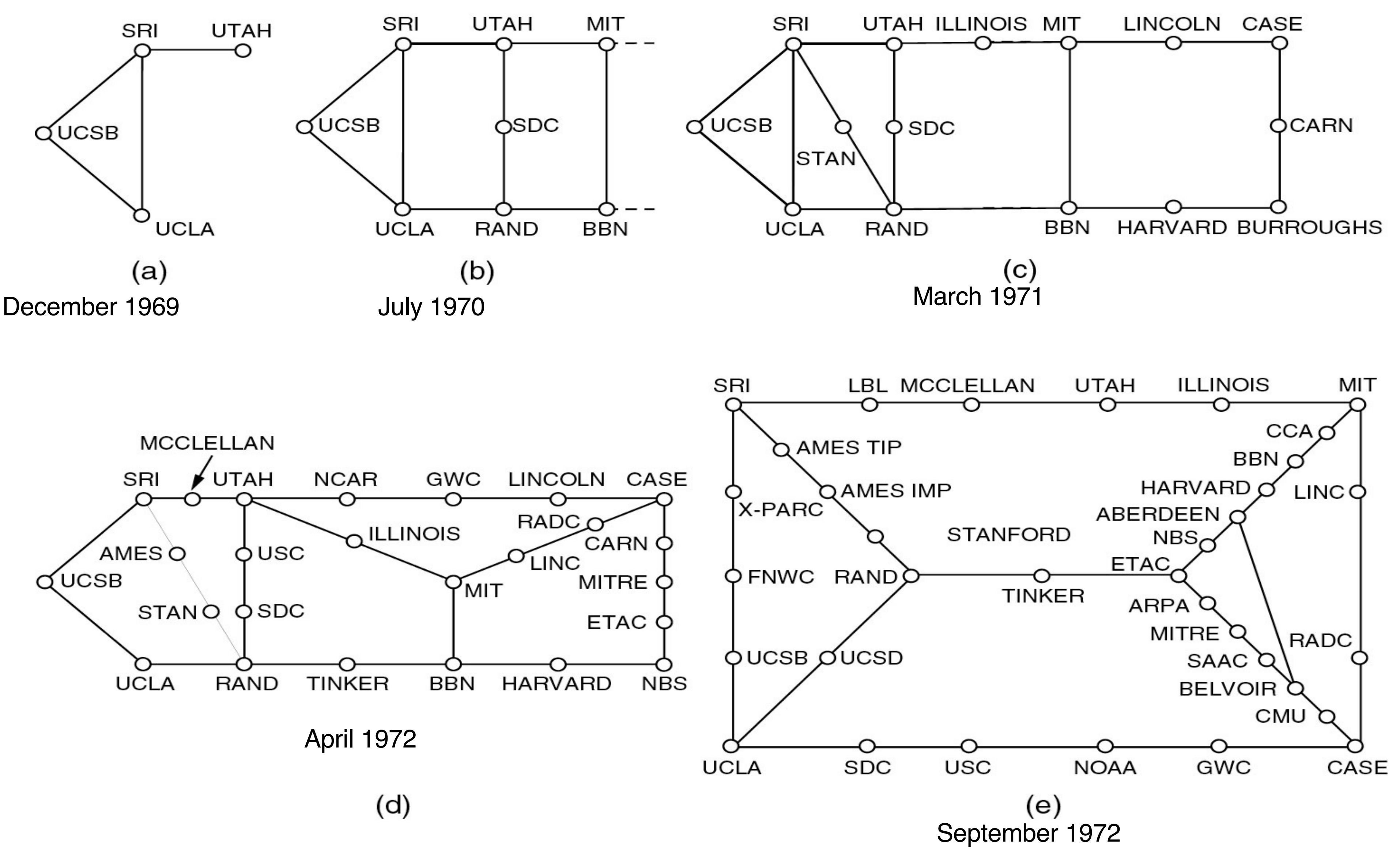
The Internet

- global system of interconnected WANs and LANs
- open, system-independent, no global control



[Tanenbaum, Computer Networks]

ARPANET – the Precursor of the Internet



(a) December 1969

(b) July 1970

(c) March 1971

(d) April 1972

(e) September 1972

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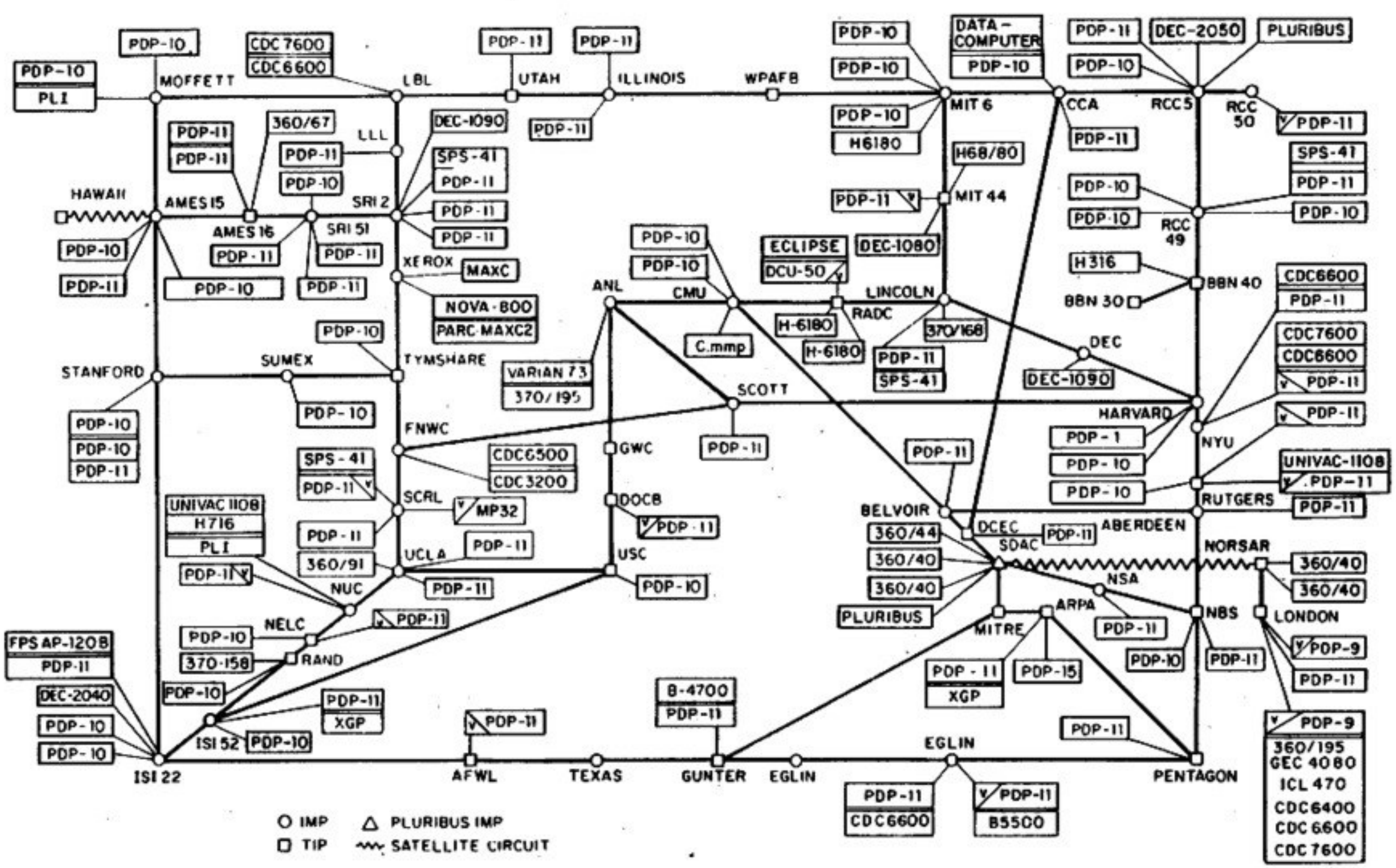
ARPANET

ARPANET LOGICAL MAP, MARCH 1977



(PLEASE NOTE THAT WHILE THIS MAP SHOWS THE HOST POPULATION OF THE NETWORK ACCORDING TO THE BEST INFORMATION OBTAINABLE, NO CLAIM CAN BE MADE FOR ITS ACCURACY)

NAMES SHOWN ARE IMP NAMES, NOT (NECESSARILY) HOST NAMES

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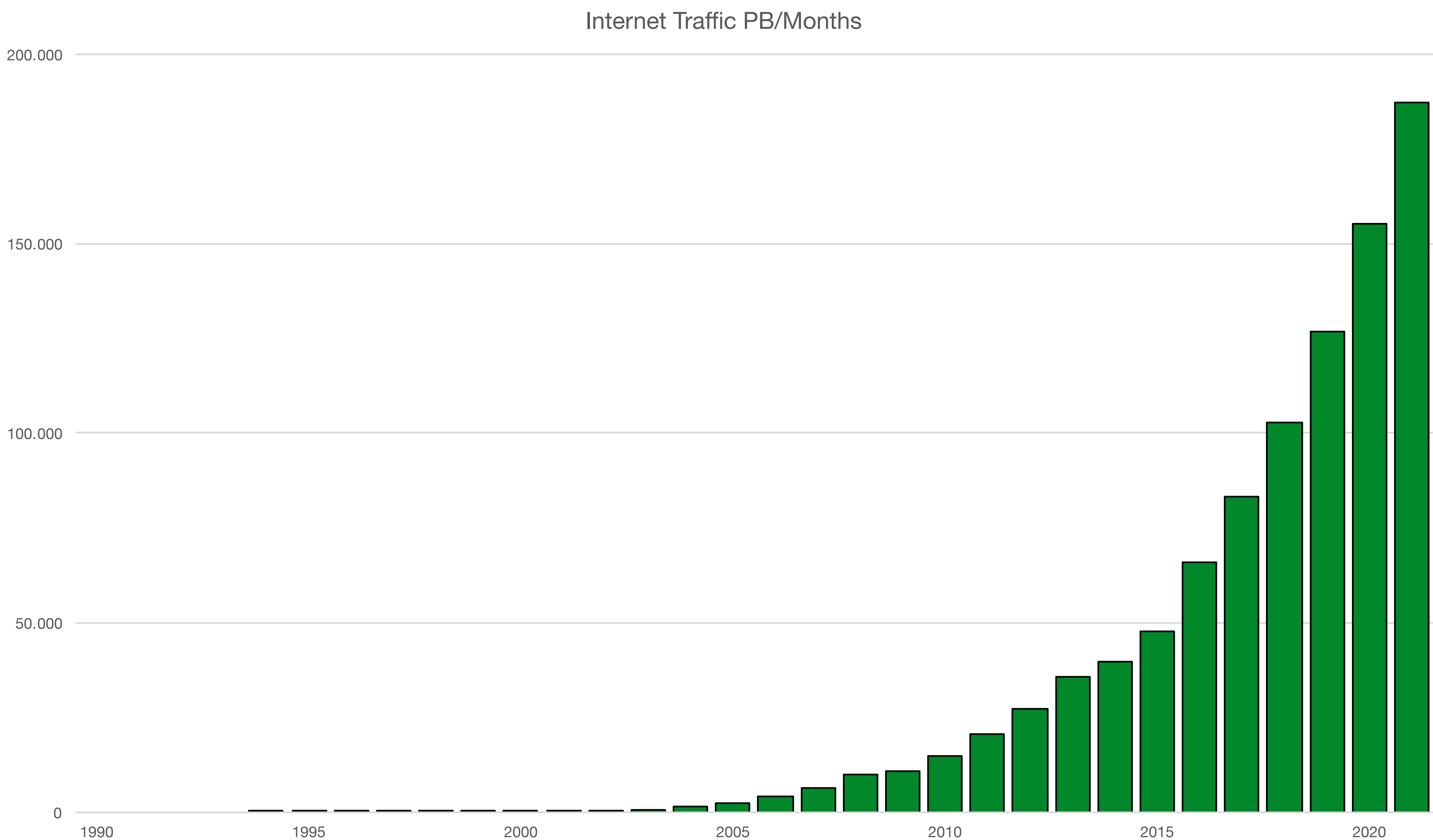
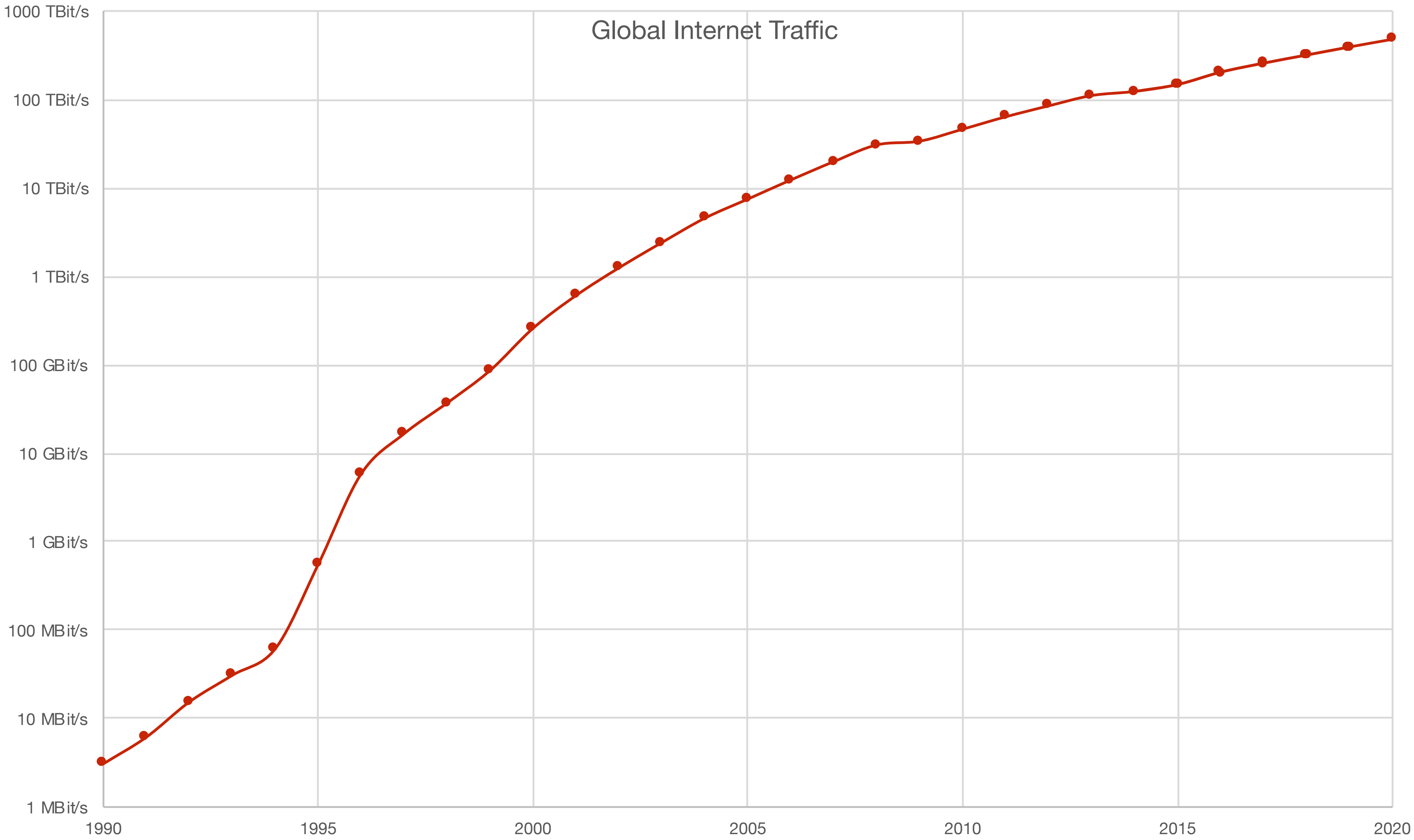
Internet Traffic



Source: CISCO VNI 2009,2010,2012,2014,2016,2017

Internet Traffic

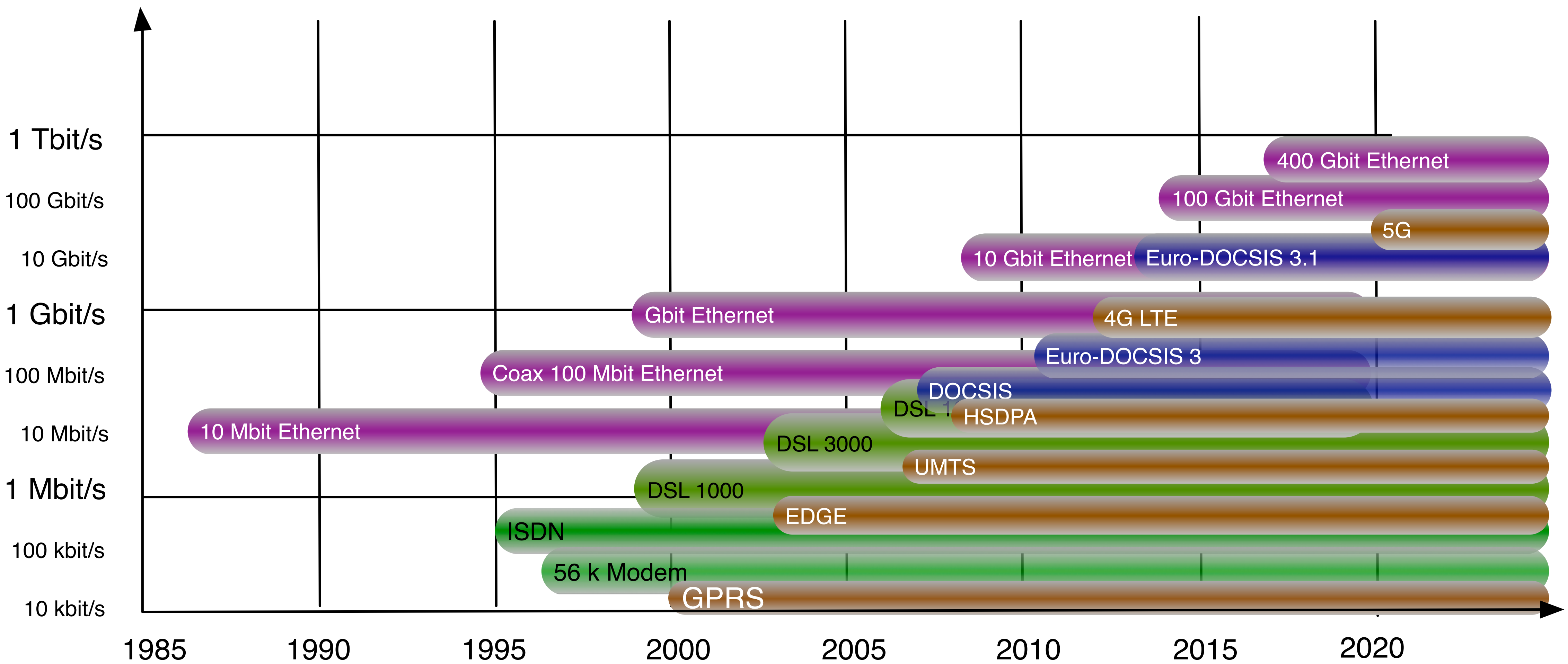


Source: CISCO VNI 2009,2010,2012,2014,2016, 2017

From Kilo To Yotta

- **Data**
  - 1 Byte = 1 B = 8 Bit = 8b
  - 1 kilobyte = 1 kB = 1000 Bytes
  - 1 megabyte = 1 MB = 1000 kB = 10^6 Bytes
  - 1 gigabyte = 1 GB = 1000 MB = 10^9 Bytes
  - 1 terabyte = 1 TB = 1000 GB = 10^{12} Bytes
  - 1 petabyte = 1 PB = 1000 TB = 10^{15} Bytes
  - 1 exabyte = 1 EB = 1000 PB = 10^{18} Bytes
  - 1 zettabyte = 1 ZB = 1000 EB = 10^{21} Bytes
  - 1 yottabyte = 1 YB = 1000 ZB = 10^{24} Bytes
- **Storage**
  - 1 Byte = 1 B = 8 Bit = 8b
  - 1 kibibyte = 1 kB = 1024 Bytes
  - 1 mebibyte = 1 MiB = 1024 kiB = 1.04 10^6 Byte
  - 1 gibibyte = 1 GiB = 1024 MiB = 1.07 10^9 Bytes
  - 1 tebibyte = 1 TiB = 1024 GiB = 1.10 10^{12} Bytes
  - 1 pebibyte = 1 PiB = 1024 TiB = 1.12 10^{15} Bytes
  - 1 exbibyte = 1 EiB = 1024 PiB = 1.15 10^{18} Bytes
  - 1 zebibyte = 1 ZiB = 1024 EiB = 1.18 10^{21} Bytes
  - 1 yobibyte = 1 YiB = 1024 ZiB = 1.21 10^{24} Bytes

The Last Mile



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
    - packet information is not stored
    - no flow control
  - no global control
- Basic principles of the Internet

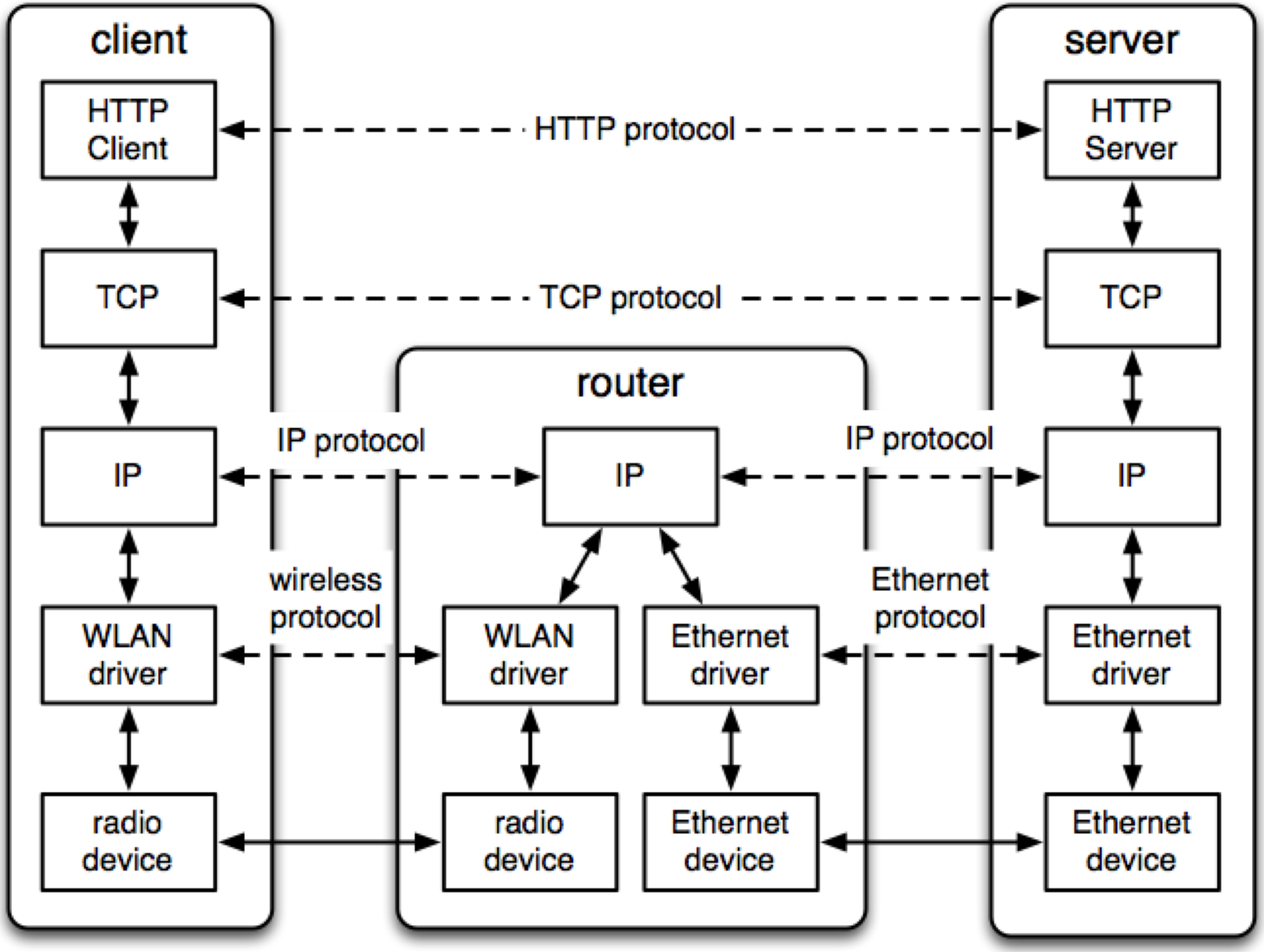
Protocols of the Internet

Application	Telnet, FTP, HTTP, SMTP (E-Mail), ...
Transport	TCP (Transmission Control Protocol)UDP (User Datagram Protocol)
Network	IP (Internet Protocol) IPv4 + IPv6 + ICMP (Internet Control Message Protocol) + IGMP (Internet Group Management Protococol)
Host-to-Network	LAN (e.g. Ethernet, W-LAN)

TCP/IP Layers

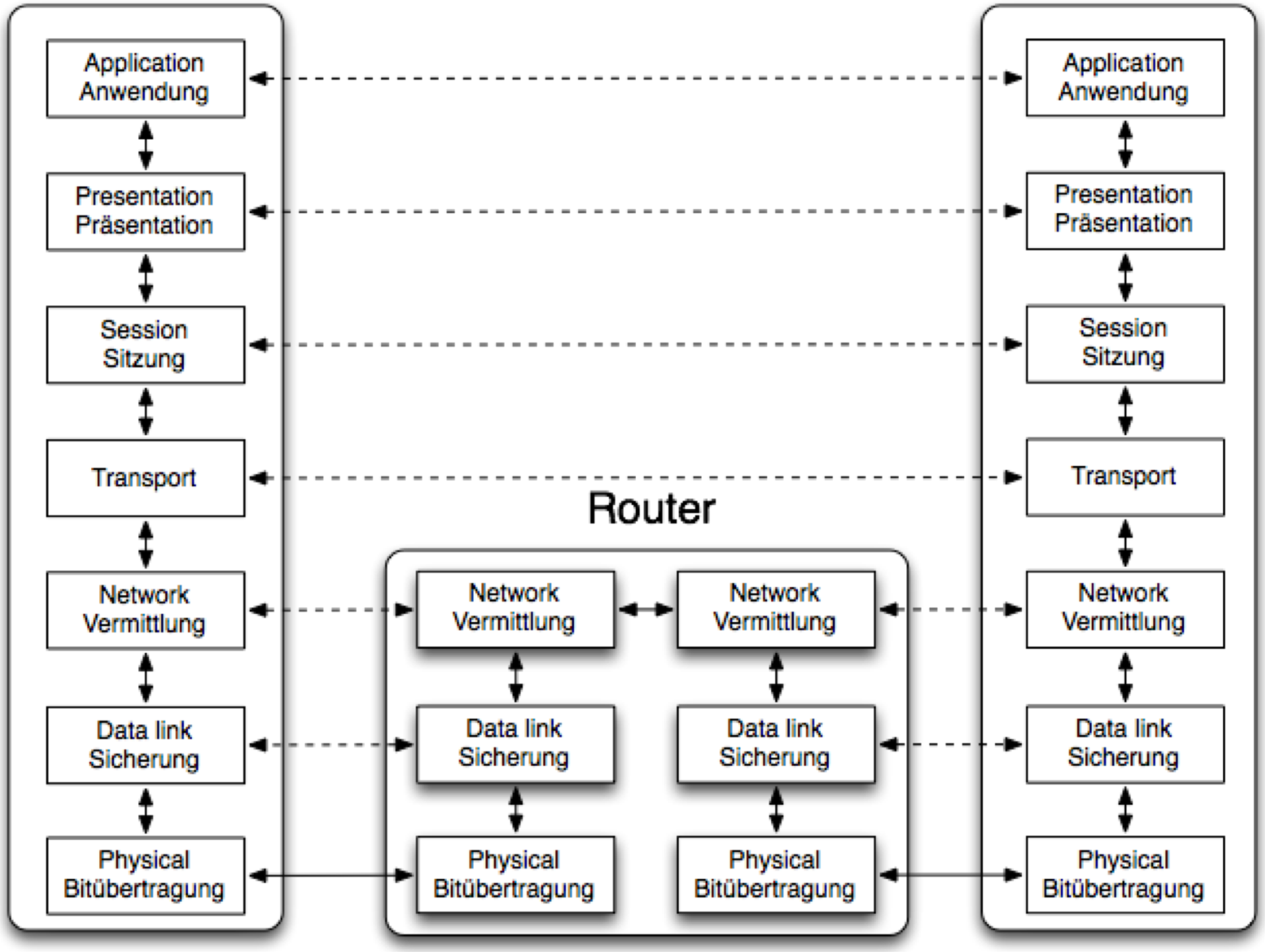
1. Host-to-Network
   - Not specified, depends on the local network e.g. Ethernet, WLAN 802.11, PPP, DSL
2. Routing Layer/Network Layer (IP - Internet Protocol)
   - Defined packet format and protocol
   - Routing
   - Forwarding
3. Transport Layer
   - TCP (Transmission Control Protocol)
     - Reliable, connection-oriented transmission
     - Fragmentation, Flow Control, Multiplexing
   - UDP (User Datagram Protocol)
     - hands packets over to IP
     - unreliable, no flow control
4. Application Layer
   - Services such as e-mail, file transfer, Web, DNS, Games …

Example: Routing between LANs

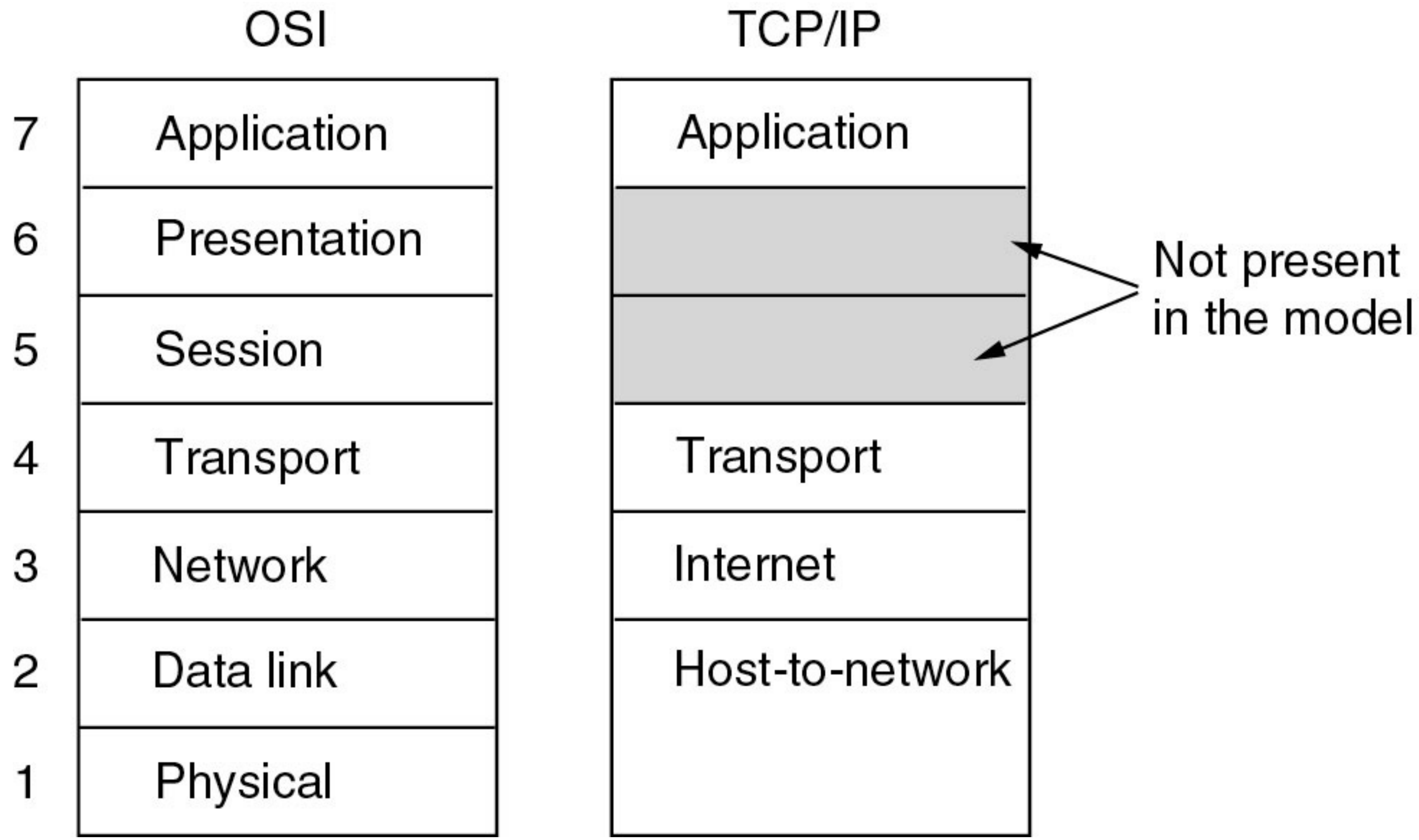


ISO/OSI Reference model

7. Application
   - Data transmission, e-mail, terminal, remote login
6. Presentation
   - System-dependent presentation of the data (EBCDIC / ASCII)
5. Session
   - start, end, restart
4. Transport
   - Segmentation, congestion
3. Network
   - Routing
2. Data Link
   - Checksums, flow control
1. Physical
   - Mechanics, electrics



Reference Models: OSI versus TCP/IP



(Aus Tanenbaum)

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Physics – Background

- Moving particles with electric charge cause electromagnetic waves
  - **frequency**
    - f : number of oscillations per second
      - unit: Hertz
  - **bandwidth**
    - difference between the upper and lower frequencies in a continuous set of frequencies
  - **wavelength**
    - λ: distance (in meters) between two wave maxima
  - antennas can create and receive electromagnetic waves
  - the transmission speed of electromagnetic waves in vacuum is constant
    - **speed of light $c \approx 3 \cdot 10^8$ m/s**
- Relation between wavelength, frequency and speed of light:

$$\lambda \cdot f = c$$

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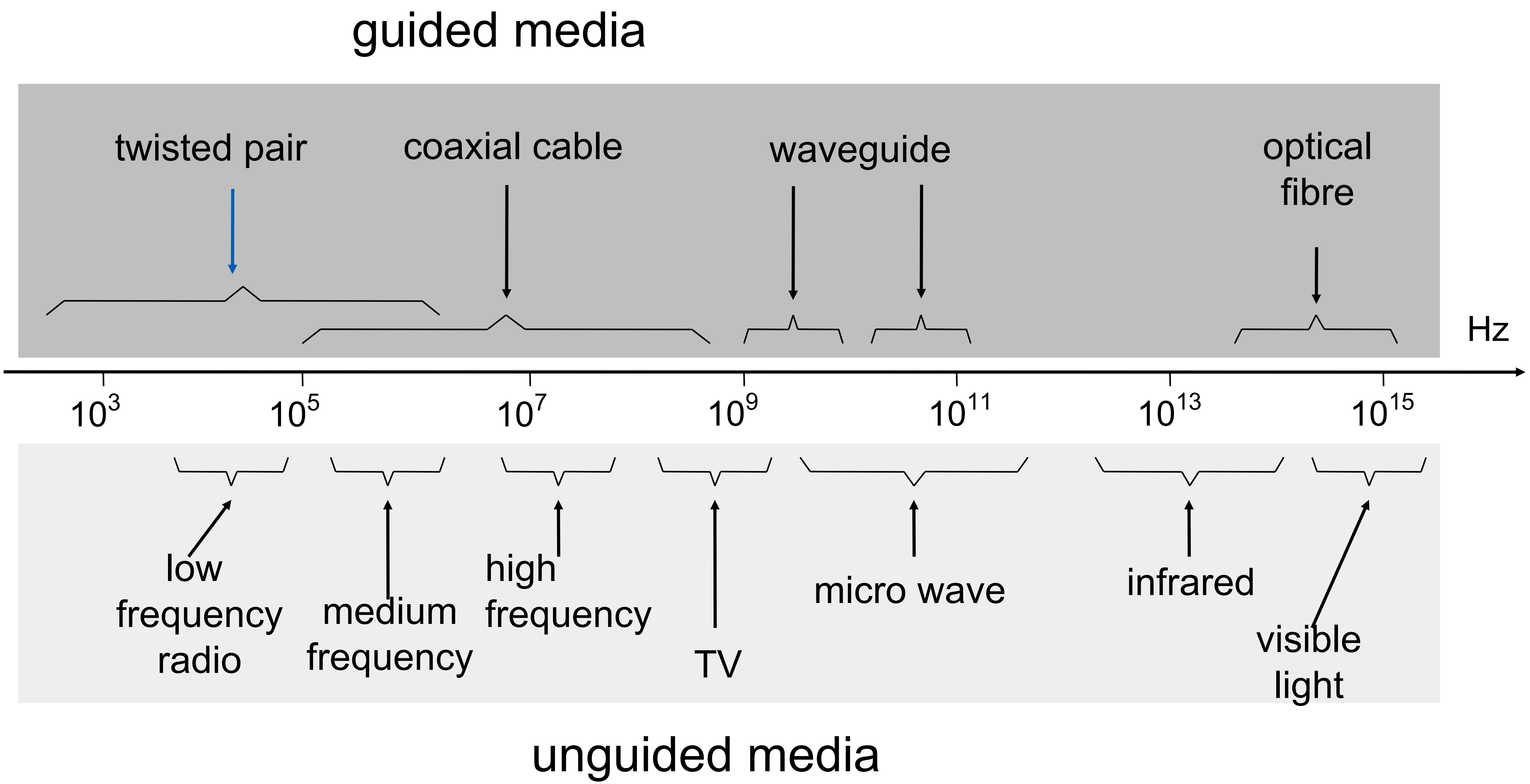
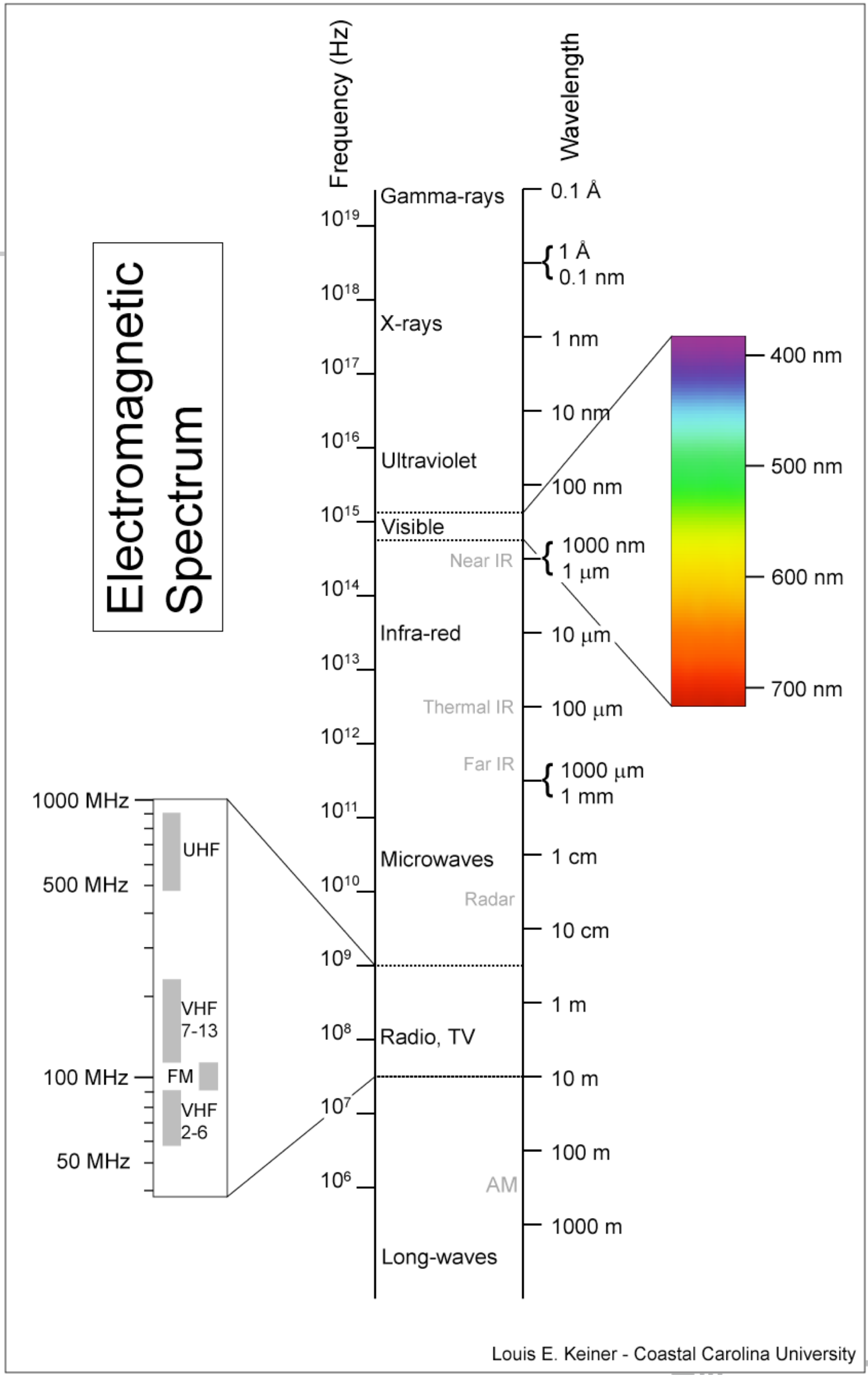
Electromagnetic Spectrum



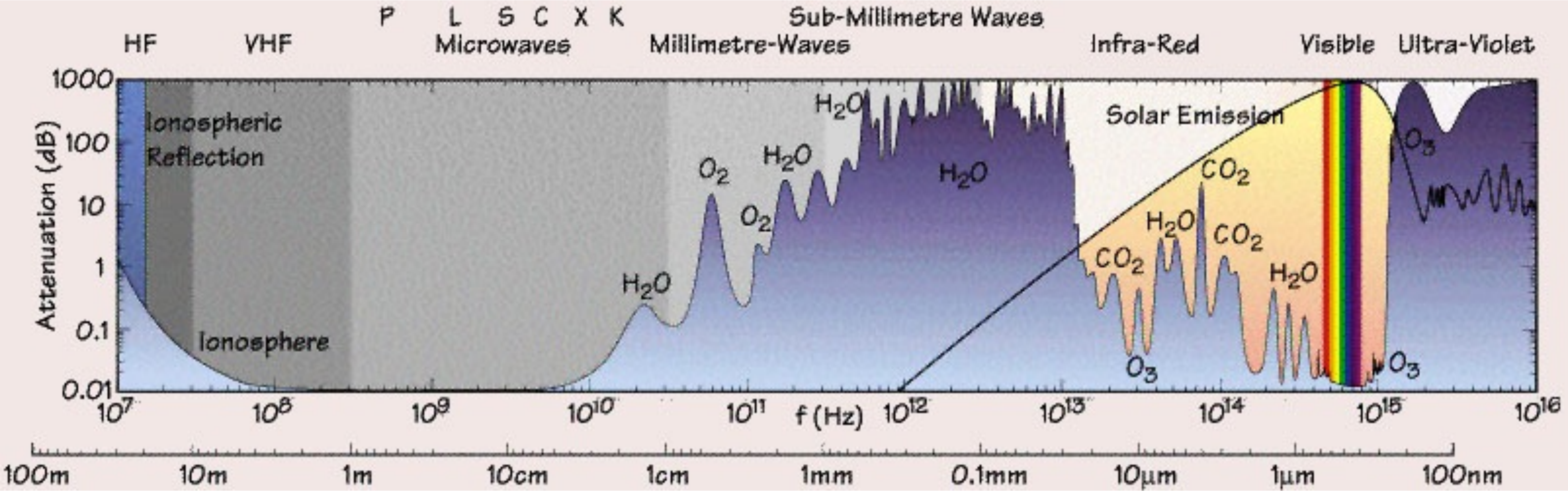
Bands

- LF Low Frequency
- MF Medium Frequency
- HF High Frequency
- VHF Very High Frequency
- UHF Ultra High Frequency
- UV Ultra Violet light



Attenuation for Different Frequentes

- Attenuation in earth's atmosphere



http://www.geographie.uni-muenchen.de/iggf/Multimedia/Klimatologie/physik_arbeit.htm

Noise and Interference

- Noise
  - inaccuracies and heat development in electrical components
  - modeled by normal distribution
- Interference from other transmitters
  - in the same spectrum
  - or in neighbored spectrum
    - e.g. because of bad filters or nearby frequency bands
- Effect
  - Signal is disrupted

Signal Interference Noise Ratio

- reception energy = transmission energy · path loss
  - path loss ~ $1/d^{\gamma}$
    - $\gamma \in [2,5]$
- Signal to Noise Ratio
  - Necessary condition for reception
  - S = (desired) Signal energy
  - N = Noise

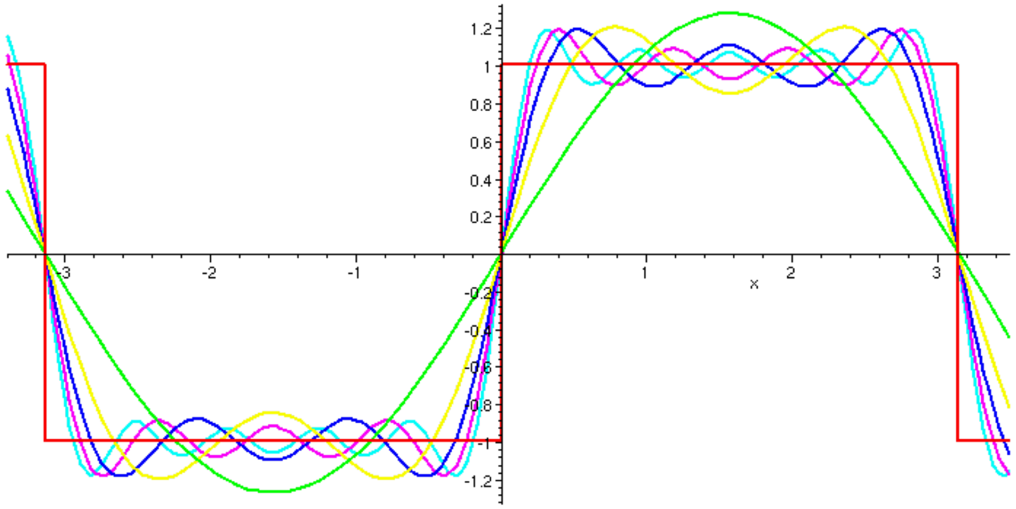
$$\mathrm{SNR} = \frac{S}{N} \geq \mathrm{Threshold}$$

- Signal to Interference and Noise Ratio = SINR
  - I = energy of interfering signals

$$\mathrm{SINR} = \frac{S}{I+N} \geq \mathrm{Threshold}$$

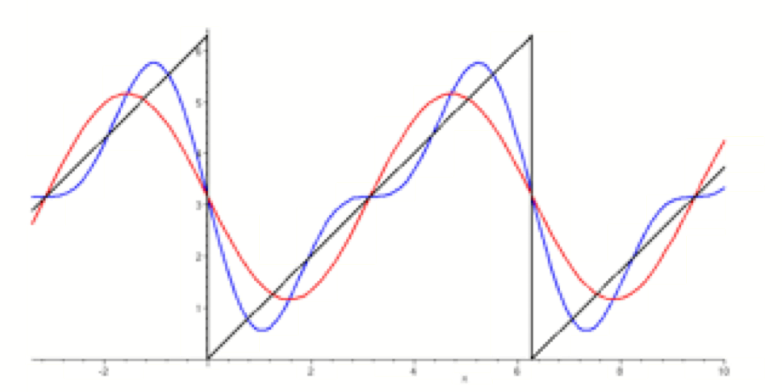
Fourier Transform

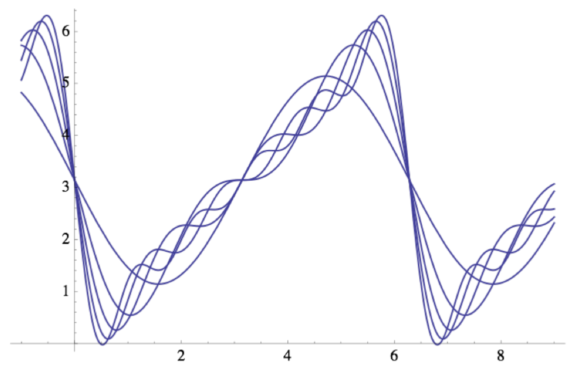
- Fourier transform of a **periodic function**
  - decomposition in an infinite series of sine and cosine functions
- Dirichlet condition of a periodic function f
  - f(x) = f(x+2π)
  - f(x) in (-π,π) in finitely many intervals continuous and monotonic
  - If f is discontinuous at x_0, then $f(x_0) = (f(x_0-0)+f(x_0+0))/2$
- **Theorem of Dirichlet:**
  - If f(x) satisfies (-π,π) the Dirichlet condition then there exists Fourier coefficients $a_0,a_1,a_2,\ldots,b_1,b_2,\ldots$ such that



$$\lim_{n\to\infty} \frac{a_0}{2} + \sum_{k=1}^{n} a_k \cos kx + b_k \sin kx = f(x) \ .$$

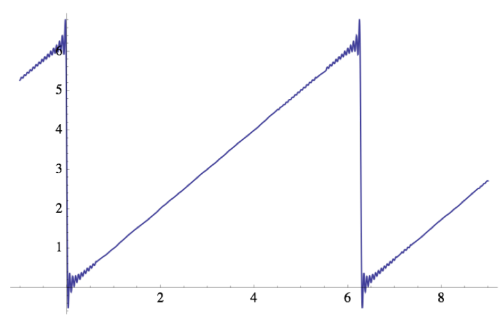
Example





$f(x) = x$, für $0 < x < 2\pi$

$$f(x) = \pi - 2\left(\frac{\sin x}{1} + \frac{\sin 2x}{2} + \frac{\sin 3x}{3} + \dots\right)$$



Fourier Analysis for General Period

- **Theorem of Fourier for period T=1/f**
  - The coefficients c, a_n, b_n are then obtained as follows

$$g(t) = \frac{a_0}{2} + \sum_{k=1}^{\infty} a_k \cos(2\pi k f t) + b_k \sin(2\pi k f t)$$

$$a_k = \frac{2}{T}\int_0^T g(t)\cos(2\pi n f t)dt$$

$$b_k = \frac{2}{T}\int_0^T g(t)\sin(2\pi n f t)dt$$

- The sum of squares of the k-th terms is proportional to the energy consumed in this frequency: $(a_k)^2 + (b_k)^2$

Equivalent Representations of the FFT

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- **Real** number representation
  - Sine and cosine functions of different frequencies

$$g(x) = \sum_{k=0}^{N-1} a_k cos\frac{2\pi kt}{T} + b_k sin\frac{2\pi kt}{T}$$

- Computation of the inverse by cosine/sine integral product

$$a_k = \frac{2}{T}\int_0^T g(t)\cos(2\pi kft)\mathrm{d}t$$

$$b_k = \frac{2}{T}\int_0^T g(t)\sin(2\pi kft)\mathrm{d}t$$

- **Complex** number representation
  - real part of the exponential function of different frequencies

$$f(x) = \sum_{k=0}^{N-1} z_k\ e^{i2\pi kt/T}$$

- Computation of the inverse by the integral over the product with the complex conjugated carrier wave

$$z_k = \frac{1}{T}\int_0^T \left(e^{i2\pi kt/T}\right)^* f(x)dt$$

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Repetition: Complex Numbers

- i: imaginary number with
  - $i^2 = -1$
- A complex number is a linear combination of a real part a and imaginary part b
  - z = a + bi
- Calculation rules:
  - $(a+bi)+(c+di)=(a+c)+(b+d)i$
  - $(a+bi)(c+di)=(ac-bd)+(ad+bc)i$
  - $\frac{1}{a+bi} = \frac{a-bi}{a^2+b^2}$
- Complex conjugate

$$a+bi = a-bi$$

Exponentiation of Complex Numbers

- Important equation

  $$e^{i\pi} = -1$$

  - $e^{i\phi} = \cos\phi + i\sin\phi$

- Exponentiation of a complex number

  - $e^{a+bi} = e^a e^{bi} = e^a(\cos b + i\sin b)$

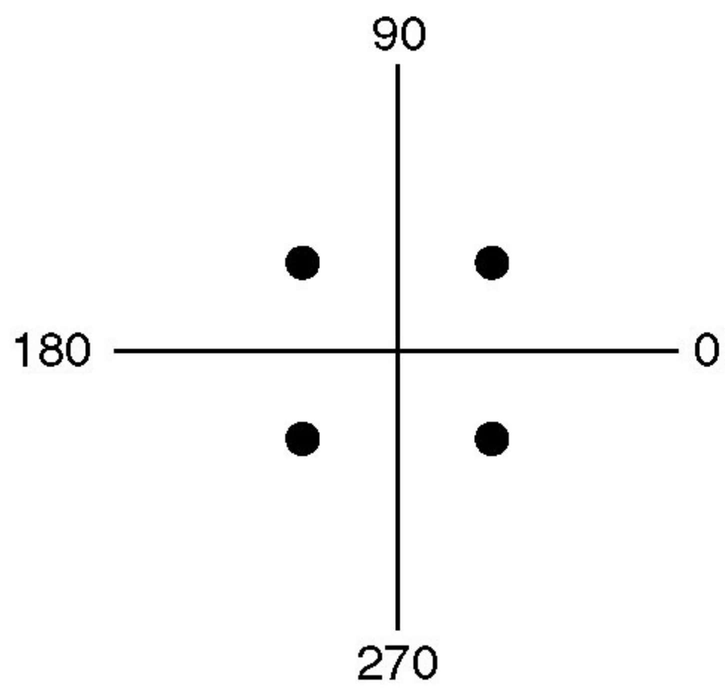
- Therefore

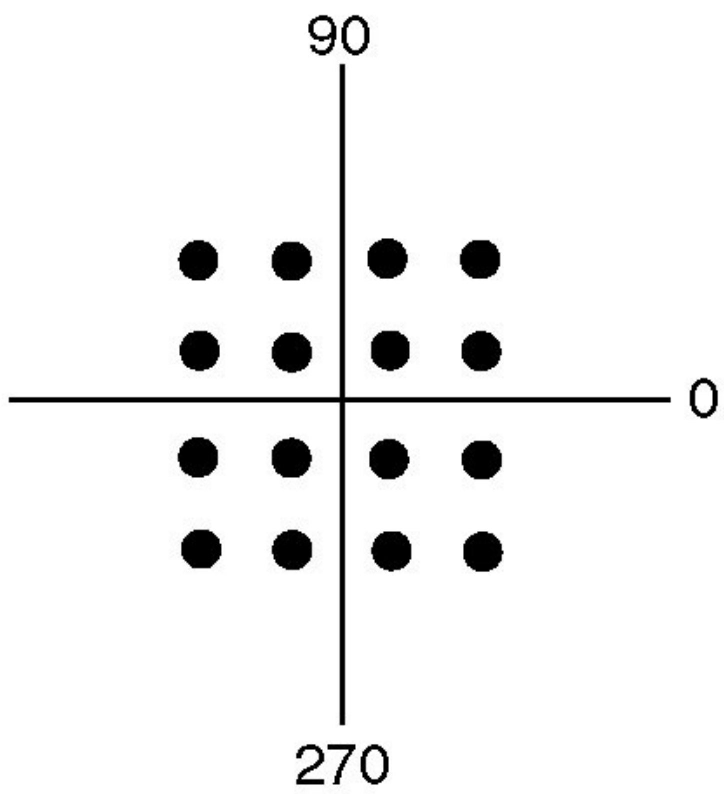
  - real part of $e^{i\phi}: \quad \Re(e^{i\phi}) = \cos\phi$

  - imaginary part of $e^{i\phi}: \quad \Im(e^{i\phi}) = \sin\phi$

QPSK/16-QAM

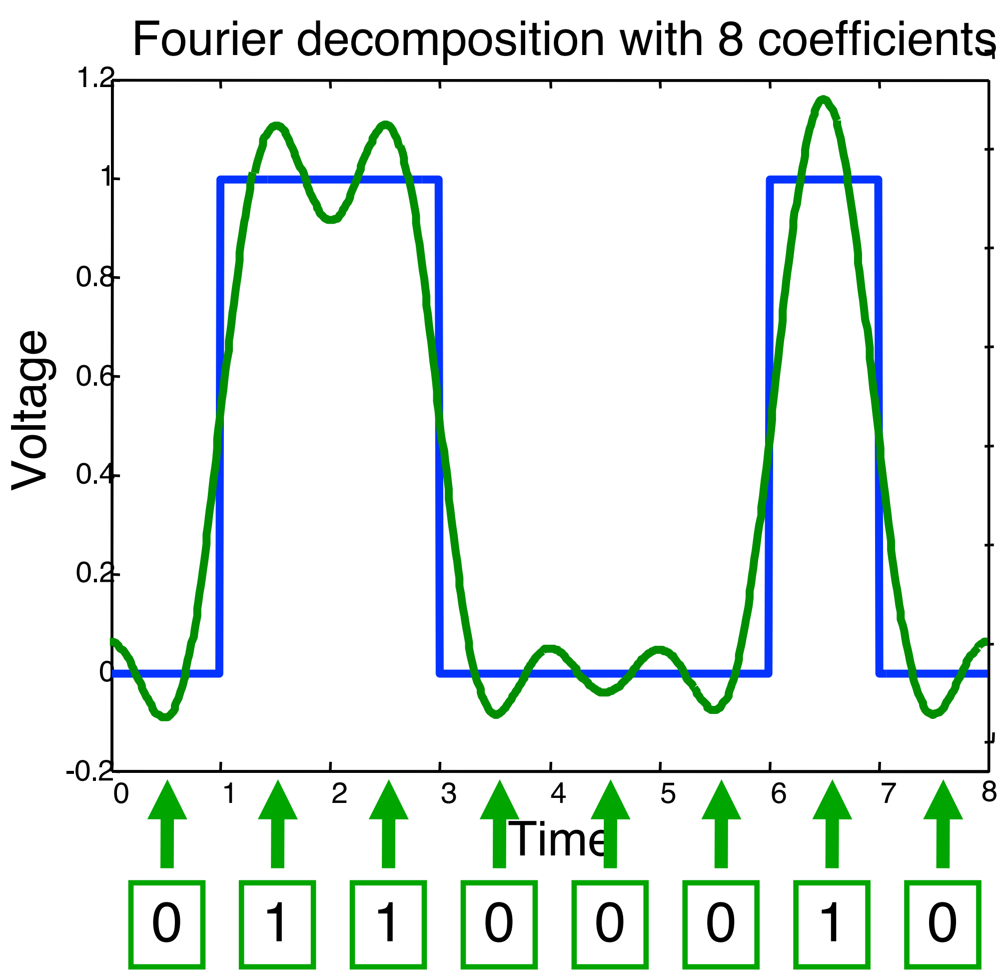
$$f(x) = \sum_{k=0}^{N-1} z_k \; e^{i2\pi kt/T}$$





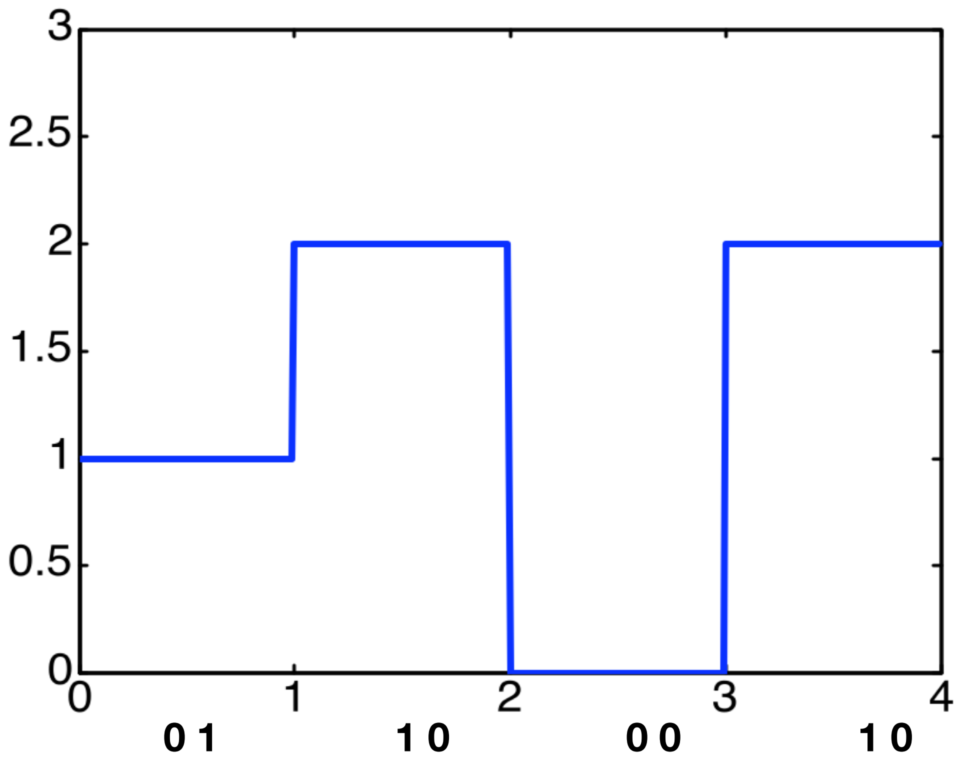
How often do you measure?

- How many **measurements** are necessary
  - to determine a Fourier transform to the k-th component exactly?
- **Nyquist-Shannon sampling theorem**
  - To reconstruct a continuous band-limited signal with a maximum frequency f_{max} you need at least a sampling frequency of 2 f_{max}.



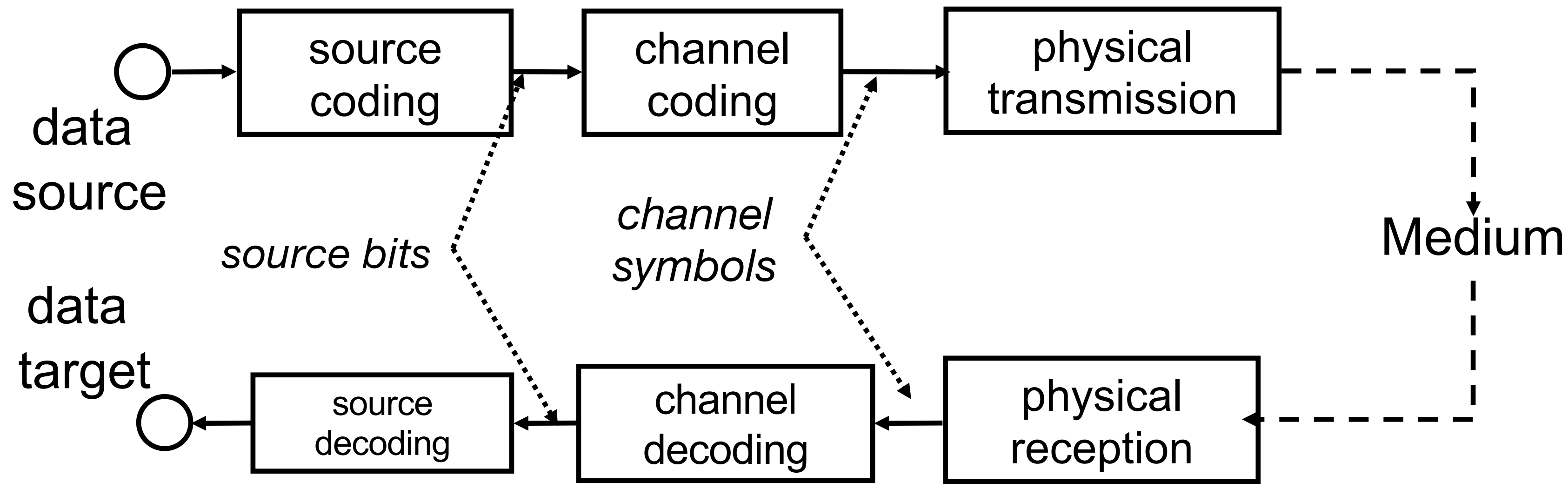
Symbols and Bits

- For data transmission instead of bits can also be used **symbols**
  - E.g. 4 Symbols: A, B, C, D with A = 00, B = 01, C = 10, D = 11
- **Symbol rate**
  - Measured in baud
  - Number of symbols per second
- **Data rate**
  - Measured in bits per second (bit/s)
- Example
  - 2400 bit/s modem is 600 baud (uses 16=2^4 symbols)



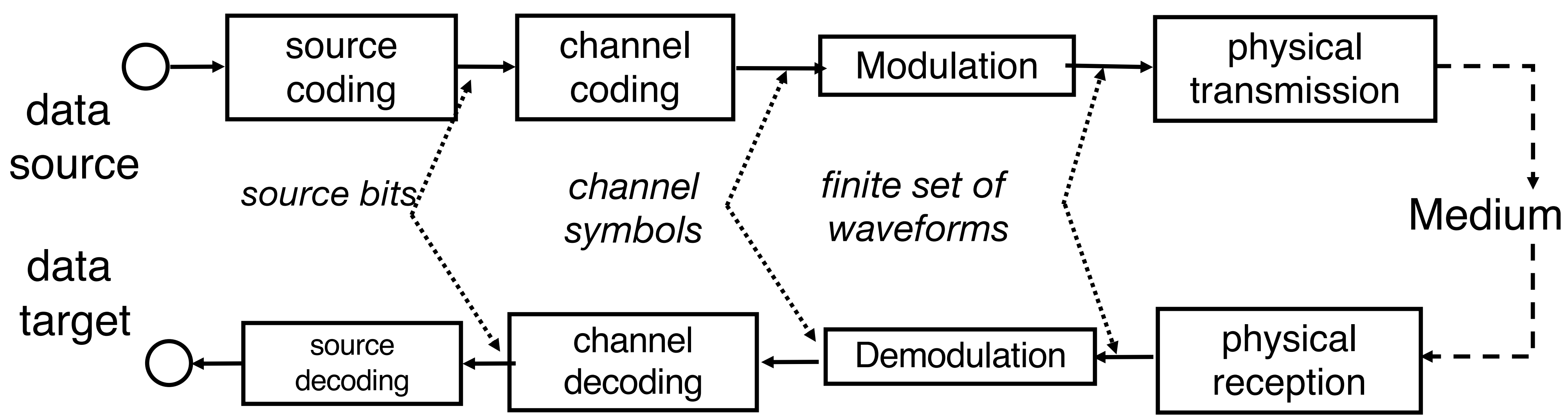
Structure of a Baseband Digital Transmission

- Source Coding
  - removing redundant or irrelevant information with lossy or lossless compression
- Channel Coding
  - mapping of source bits to channel symbols
  - possibly adding redundancy adapted to the channel characteristics
  - physical transmission
- Conversion into physical events



Structure of a *Broadband* Digital Transmission

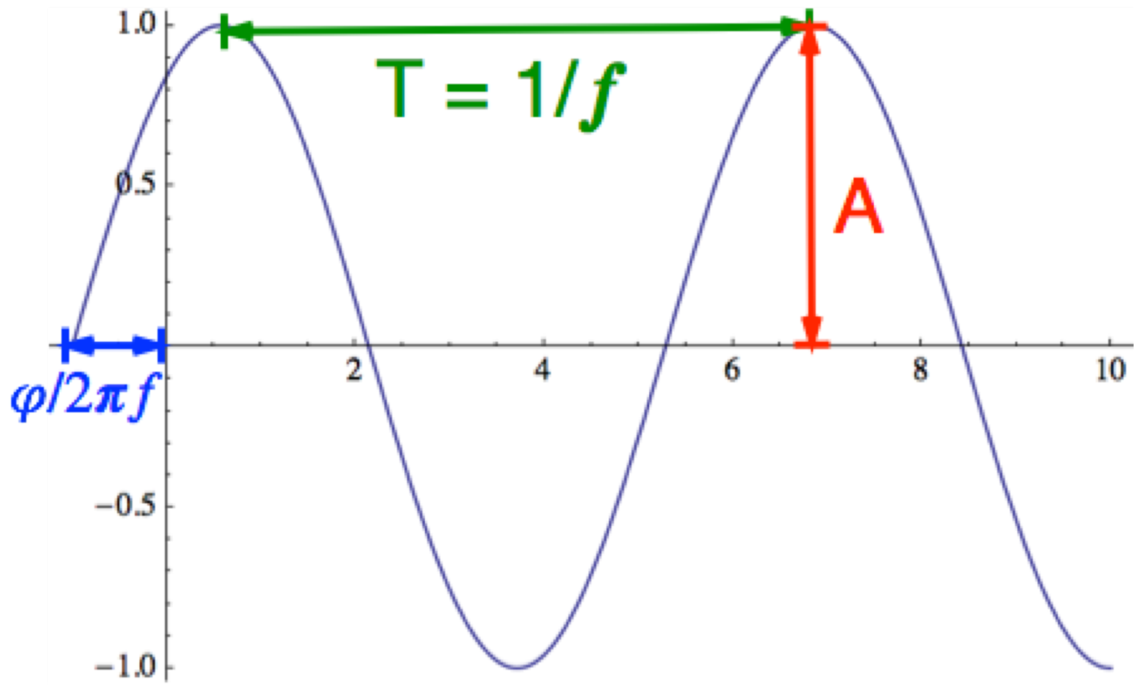
- MOdulation/DEModulation
  - Translation of the channel symbols by amplitude/phase/frequency modulation



Carrier Wave

- Idea
  - Use ideal frequency of the medium
  - Using a sine wave as the carrier wave
- Carrier wave has no information
  - the sine curve continuously (modulated) changes for data transmission,
  - implies spectral widening (more frequencies in the Fourier analysis)
- The following parameters can be changed:
  - Amplitude A
  - Frequency f=1/T
  - Phase φ

$$s(t) = A \sin(2\pi f t + \phi)$$

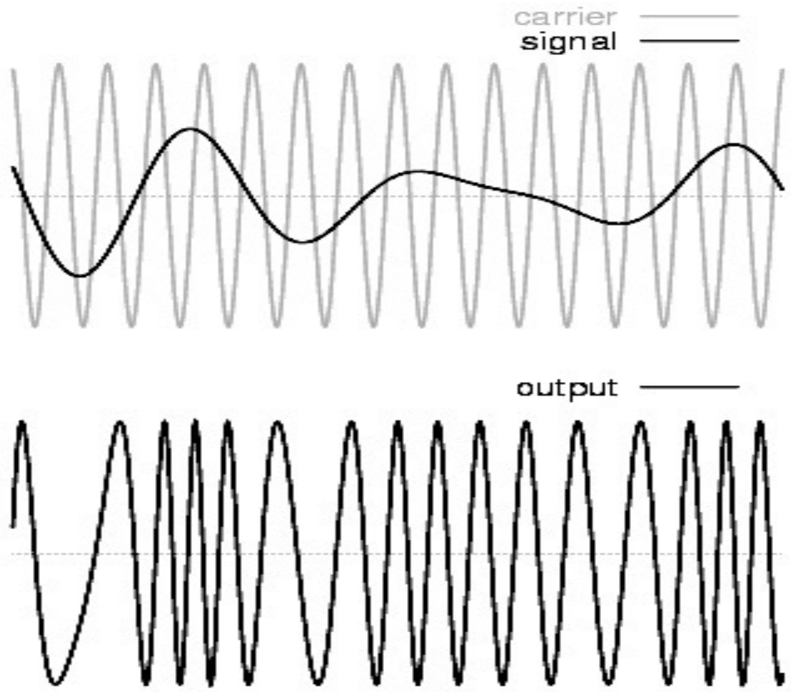


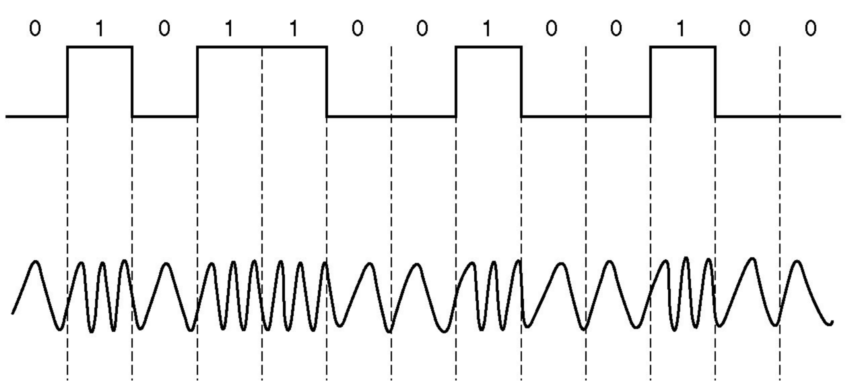
Frequency Modulation

- The time-varying signal s(t) is encoded in the frequency of the sine curve:

$$f_F(t) = a \sin(2\pi s(t) t + \phi)$$

- Analog signal
  - Frequency modulation (FM)
  - Continuous function in time
- Digital signal
  - Frequency Shift Keying (FSK)
  - E.g. frequencies as given by symbols

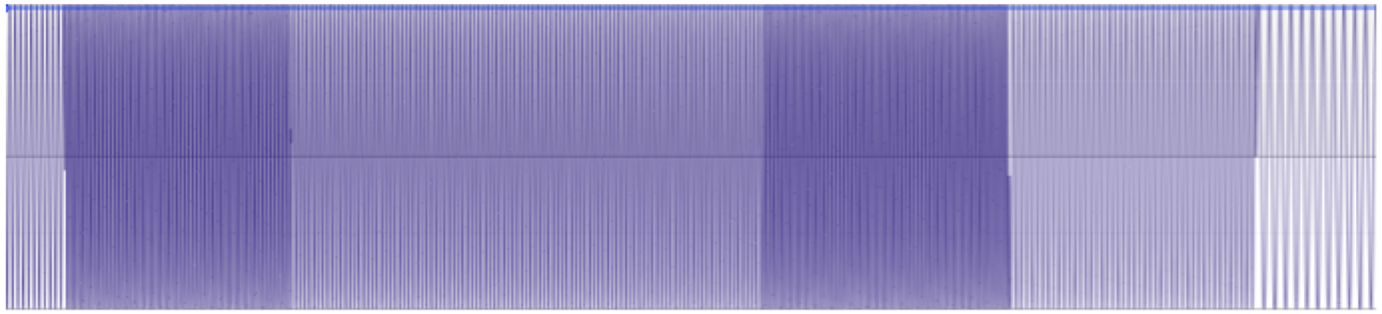


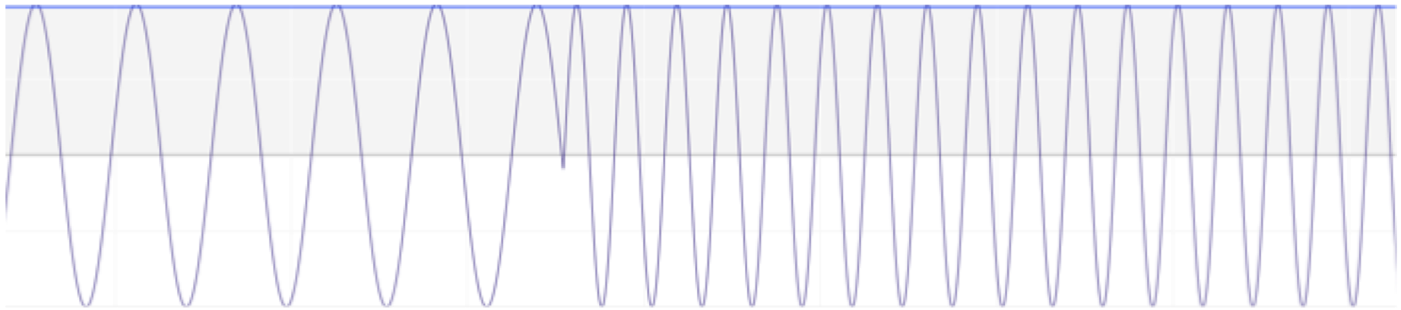


(Tanenbaum)

Audio Sample

- frequency modulated sine signal



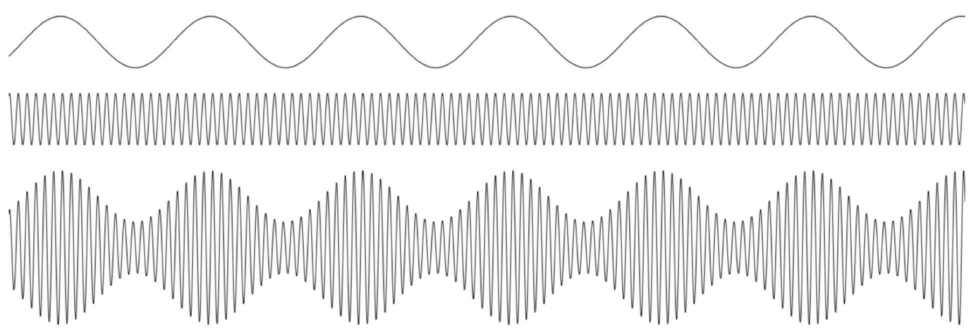


Amplitude Modulation

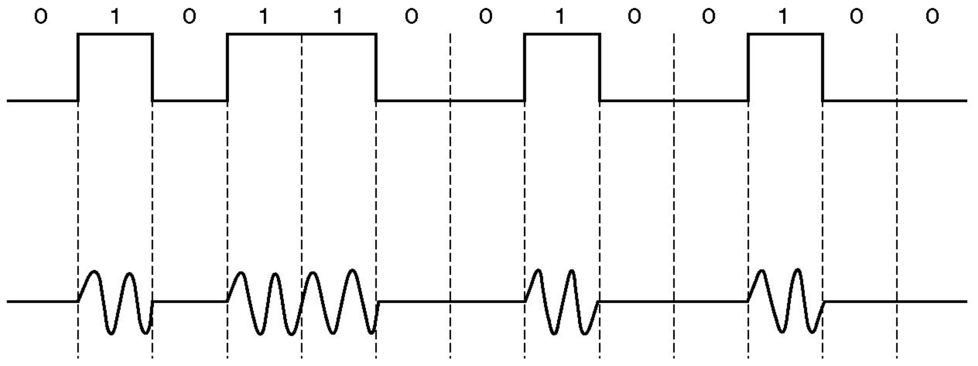
- The time-varying signal s (t) is encoded as the amplitude of a sine curve:

$$f_A(t) = s(t)\,\mathsf{sin}(2\pi f t + \phi)$$

- Analog Signal



- Digital signal
  - amplitude keying
  - special case: symbols 0 or 1
    - on / off keying



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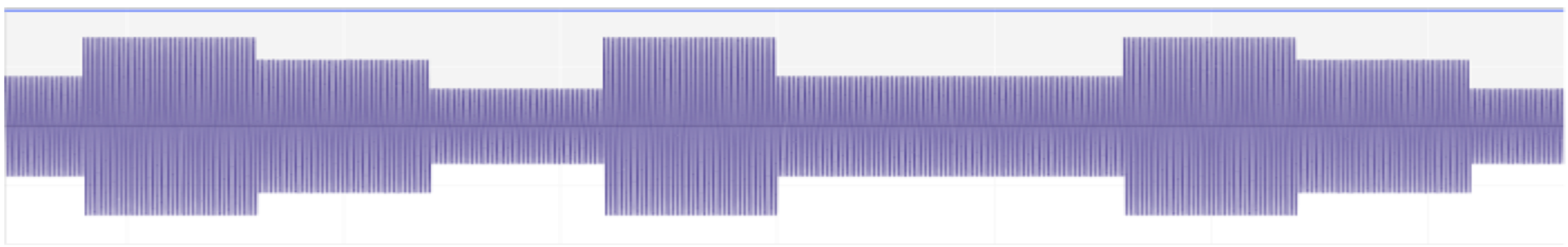
Audio Sample

- amplitude modulated sine signal

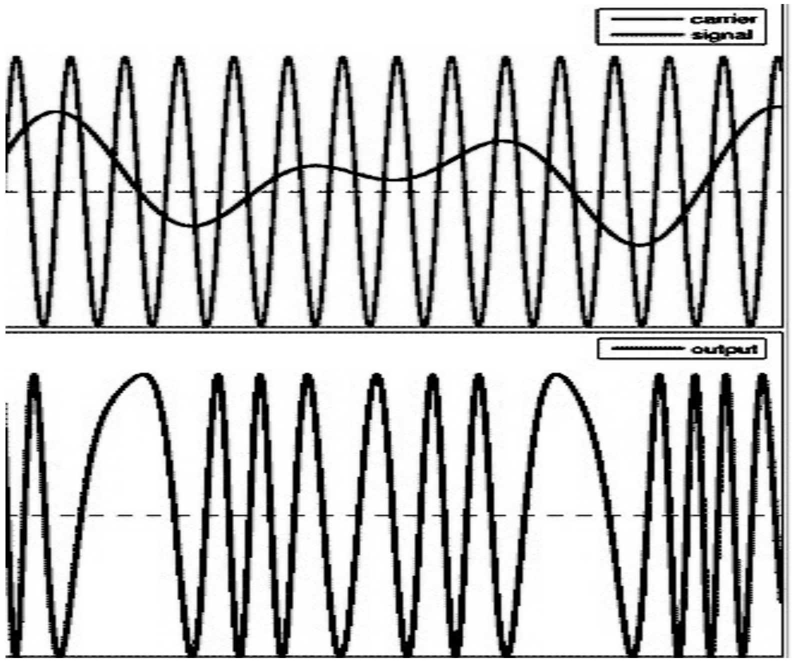


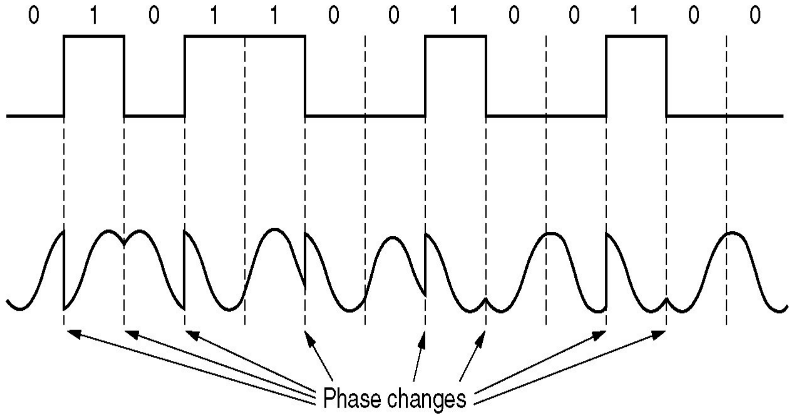
Phase Modulation

- The time-varying signal s(t) is encoded in the **phase** of the sine curve:

$$f_P(t) = a \sin(2\pi f t + s(t))$$

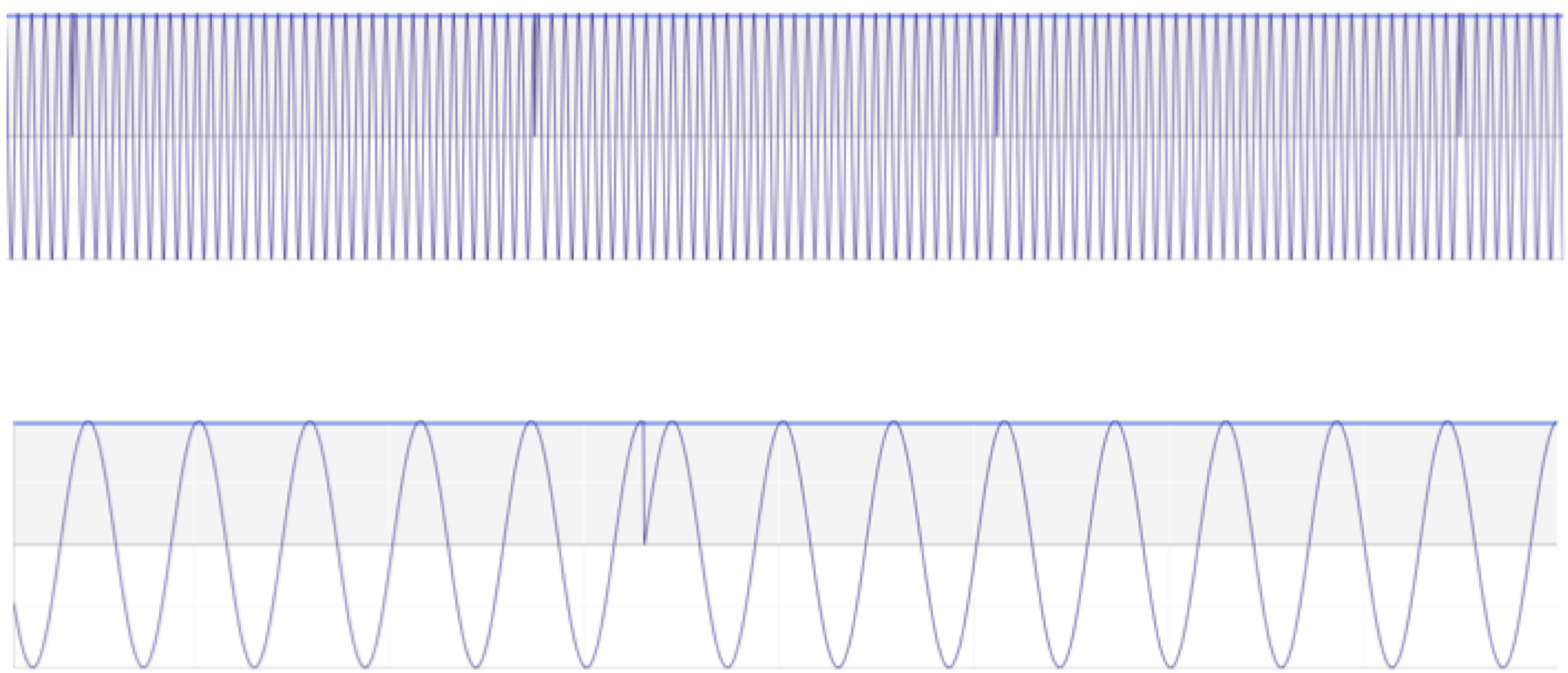
- Analog signal
  - phase modulation (PM)
  - very unfavorable properties
  - es not used
- Digital signal
  - phase-shift keying (PSK)
  - e.g. given by symbols as phases





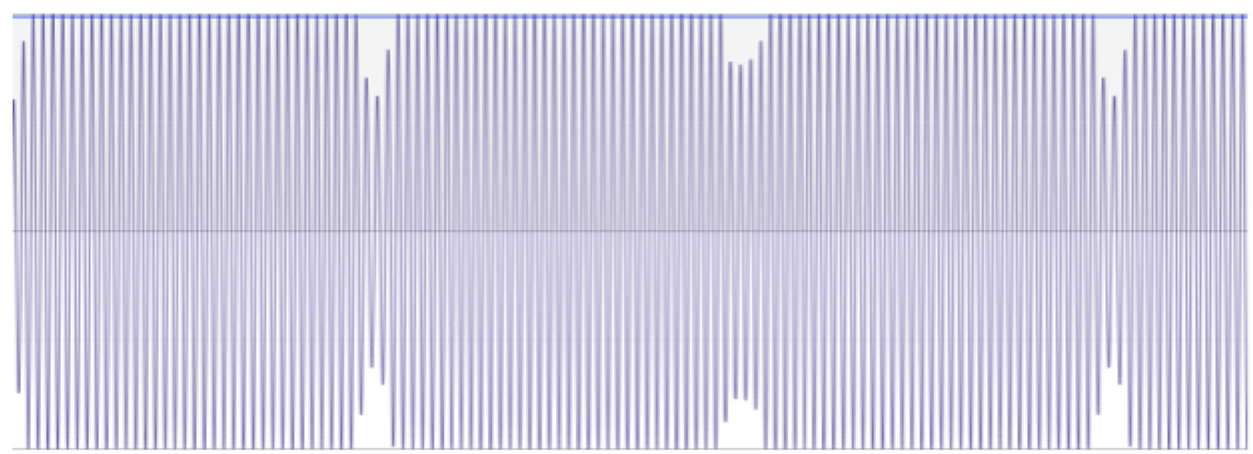
Audio Sample

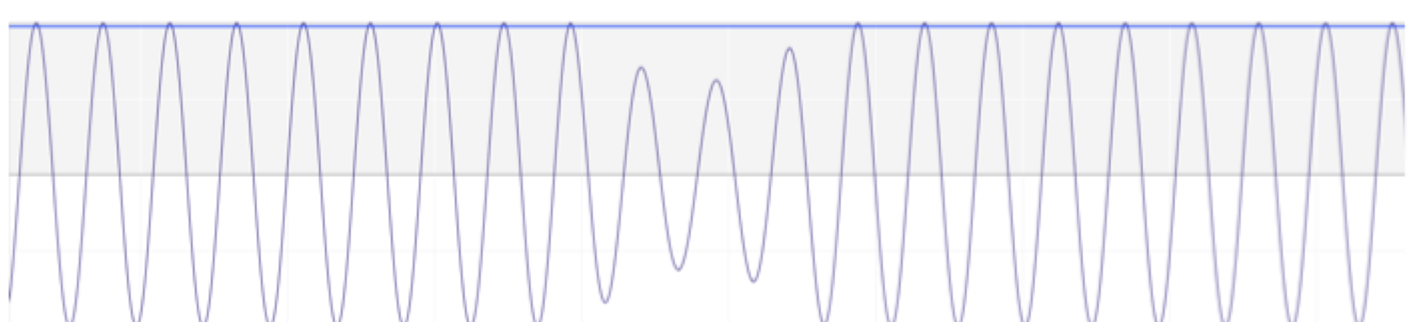
- phase modulated sinus signal



Audio Sample

- phase modulated sinus signal
  - with smooth transition



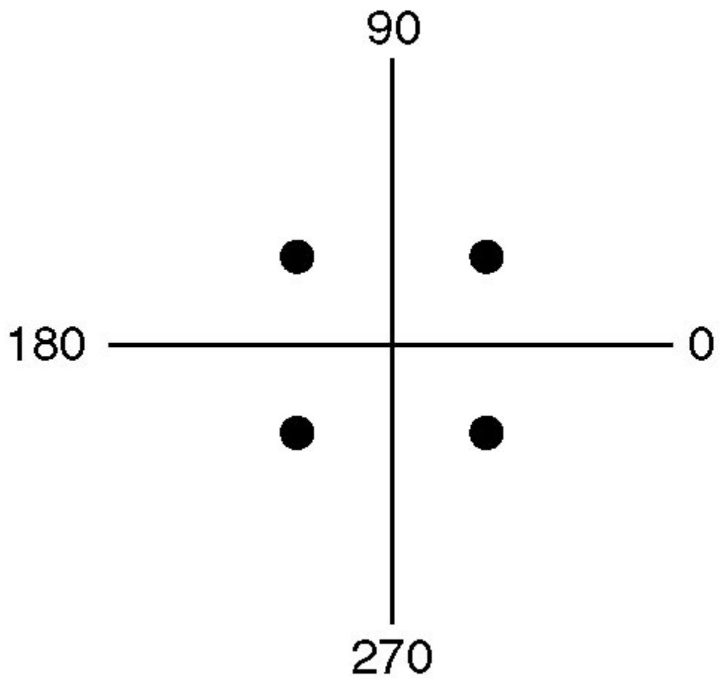


For comparison

PSK with Different Symbols

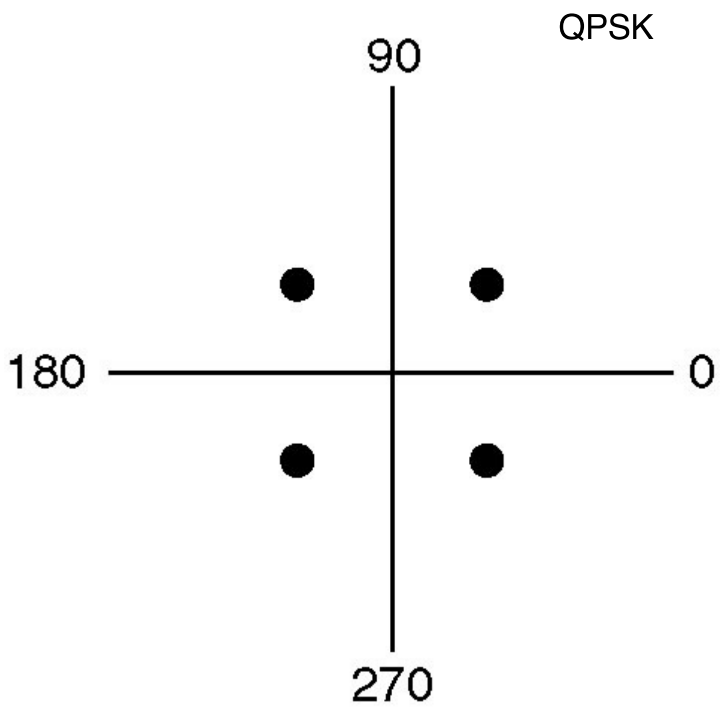
- Phase shifts can be detected by the receiver very well
- Encoding various Symble very simple
  - Using phase shift e.g. π/4, 3/4π, 5/4π, 7/4π
    rarely: phase shift 0 (because of synchronization)
  - For four symbols, the data rate is twice as large as the symbol rate
- This method is called Quadrature Phase Shift Keying (QPSK)

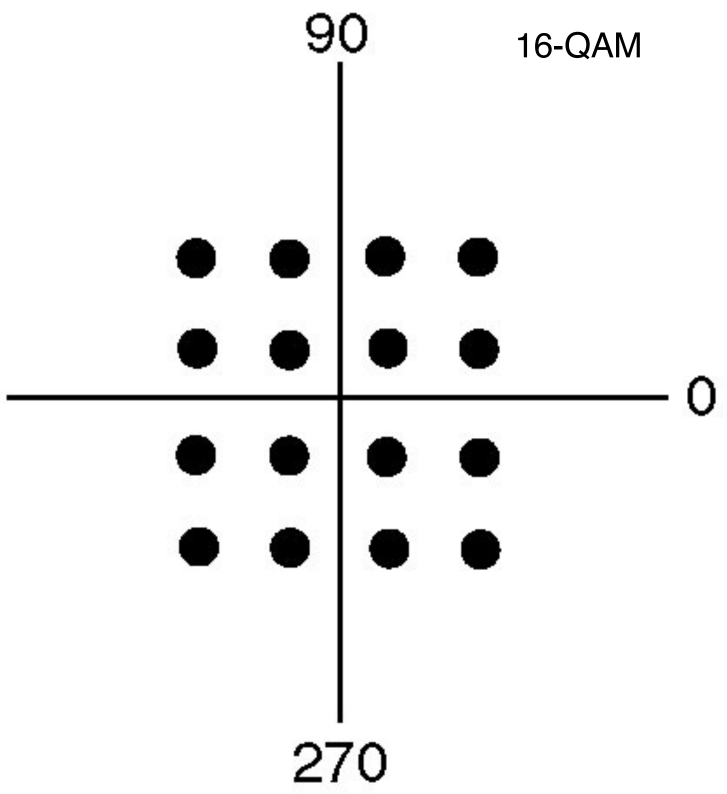
constellation diagram



Amplitude and Phase Shift Modulation

- 16-QAM (Quadrature Amplitude Modulation)
  - 16 combinations of phase and amplitude
  - Every symbol encodes 4 bits for 16-QAM

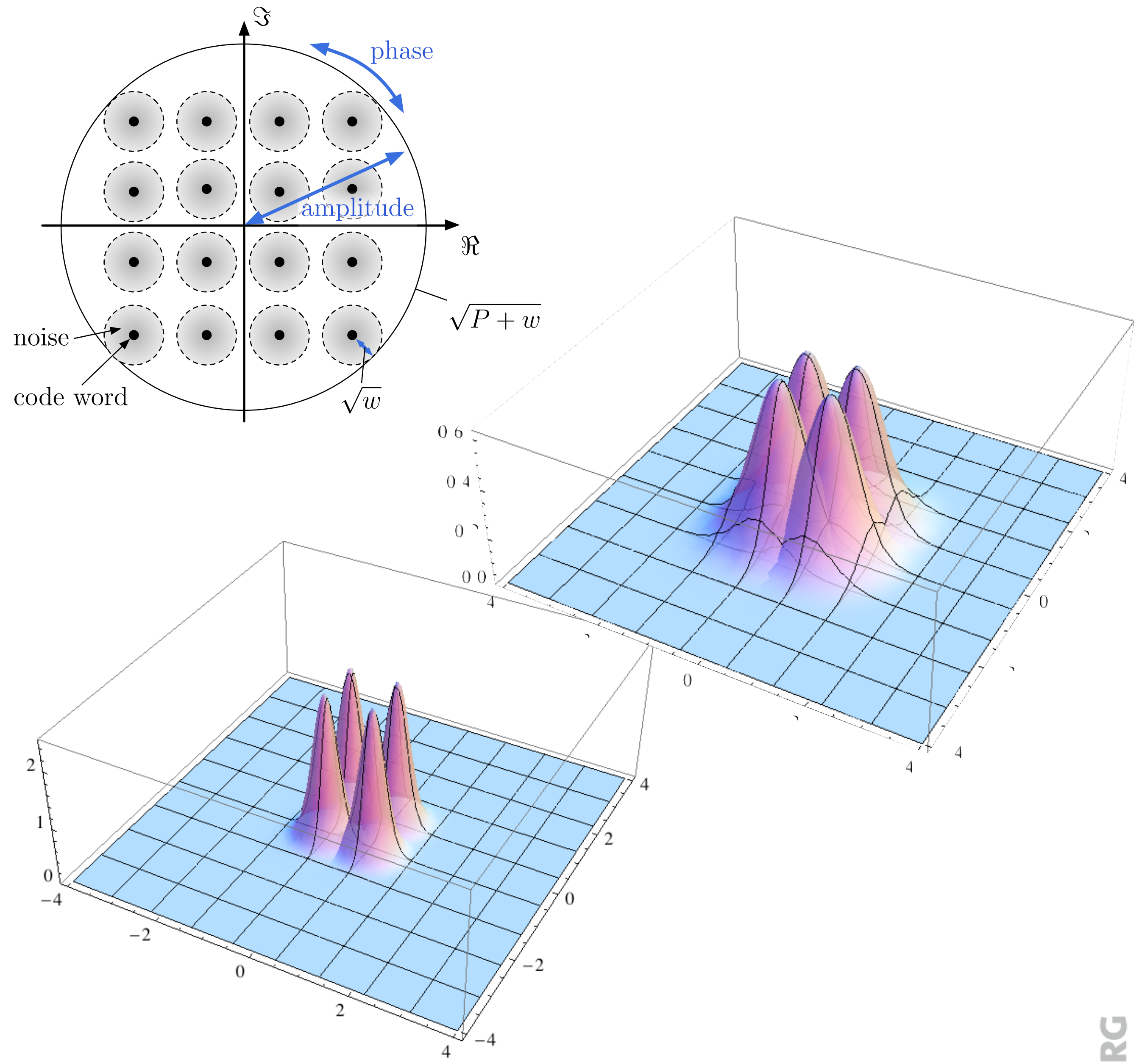




QAM and Noise

- **Noise** represented by Gaussian distribution

$$f(x) = \frac{1}{\sigma \cdot \sqrt{2\pi}} \cdot e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$$



- Bit errors by wrong interpretation of signal
- Standard deviation σ correlates with signal/noise energy ratio

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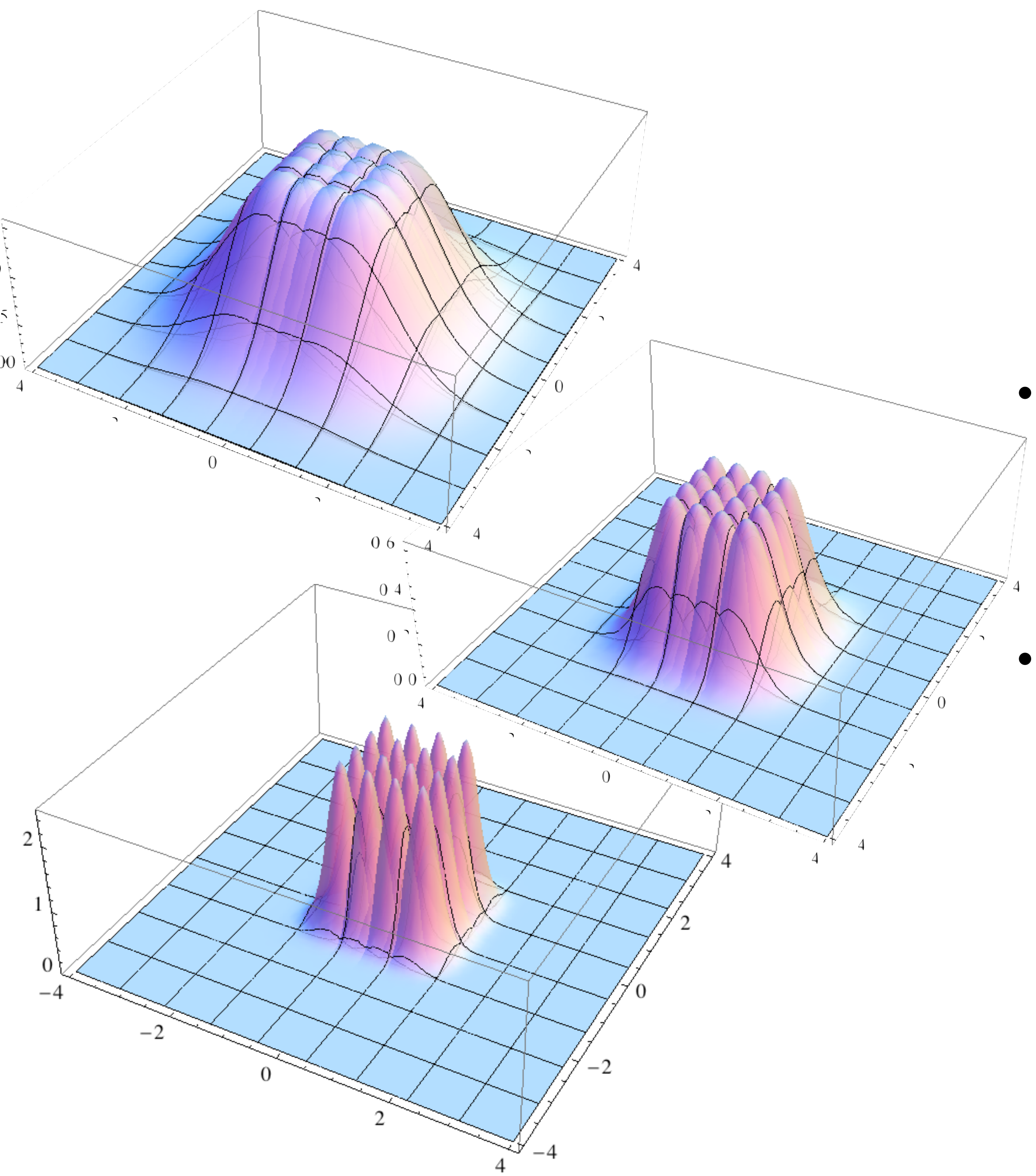
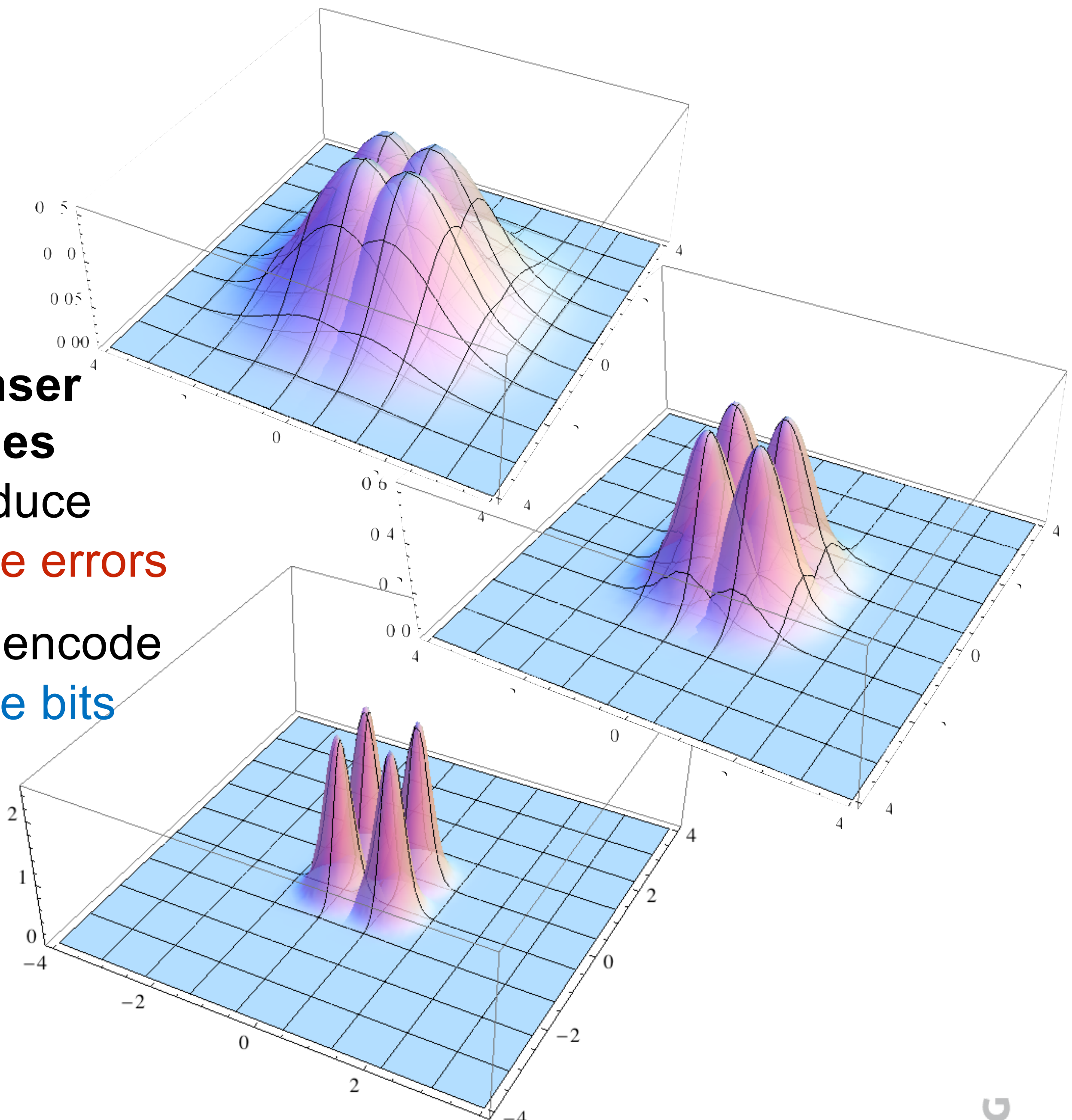
16QAM versus QPSK



- **Denser codes** produce more errors
- But encode more bits



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The Theorem of Shannon

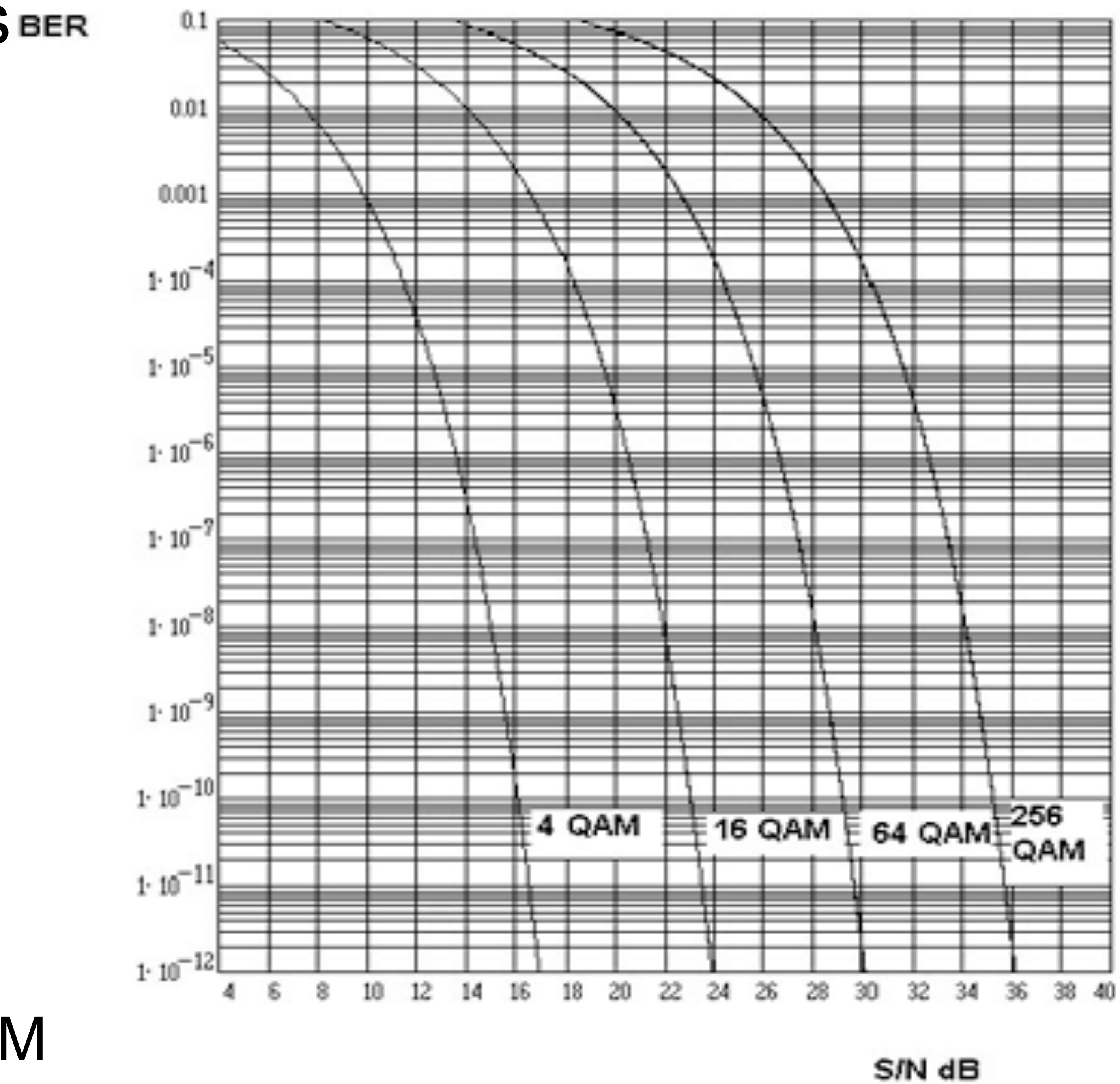
- the influence of the noise is fundamental
  - with less noise more signals can be recognized
- Theorem of Shannon
  - The maximum possible data rate is

$$H \log_2 \left(1 + \frac{S}{N}\right)$$

    - for bandwidth H
    - signal energy S
    - noise energy N

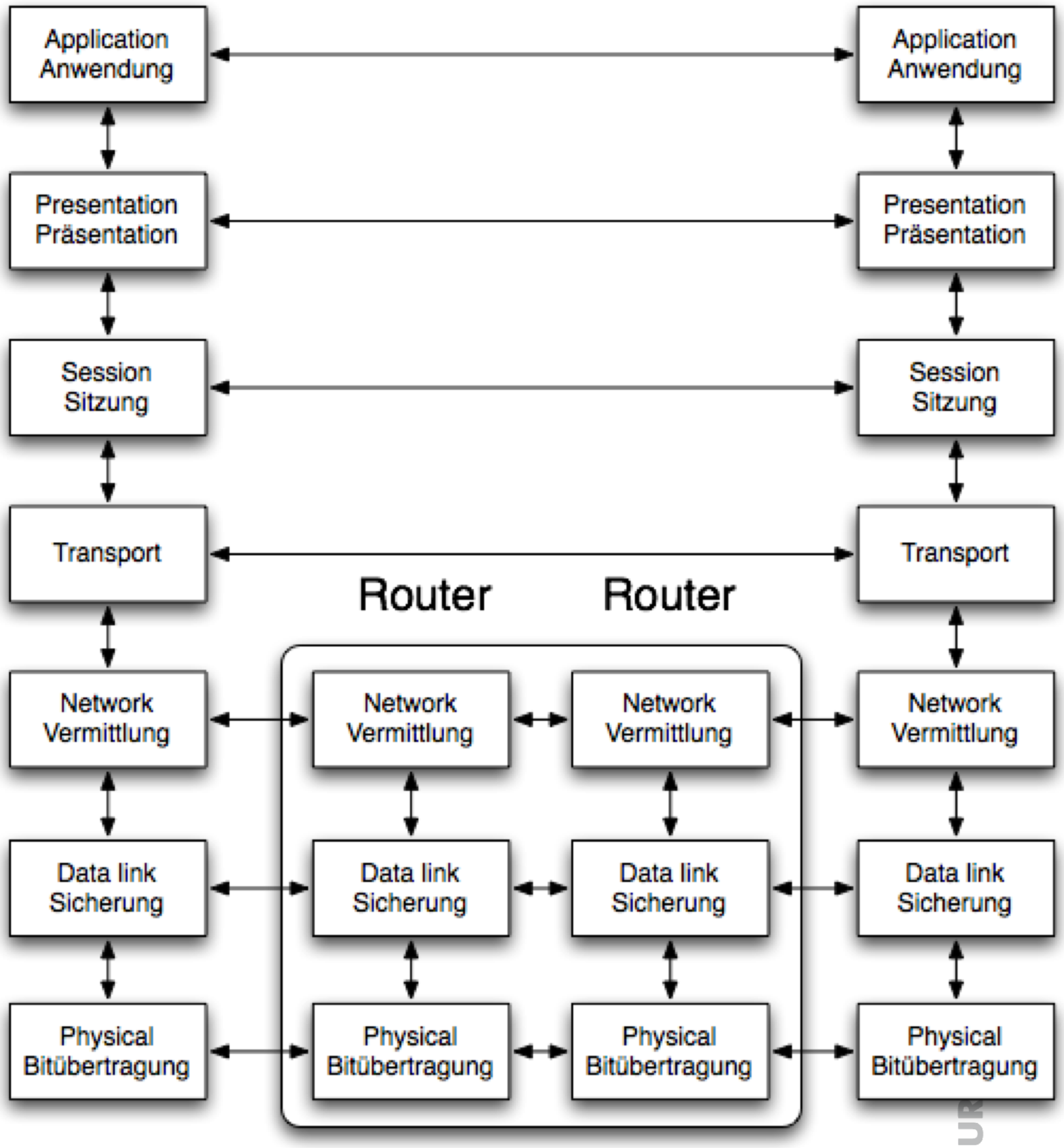
Bit Error Rate and SINR

- Higher SIR decreases Bit Error Rate (BER)
  - BER is the rate of faulty received bits
- Depends from the
  - signal strength
  - noise
  - bandwidth
  - encoding
- Relationship of BER and SINR
  - Example: 4 QAM, 16 QAM, 64 QAM, 256 QAM



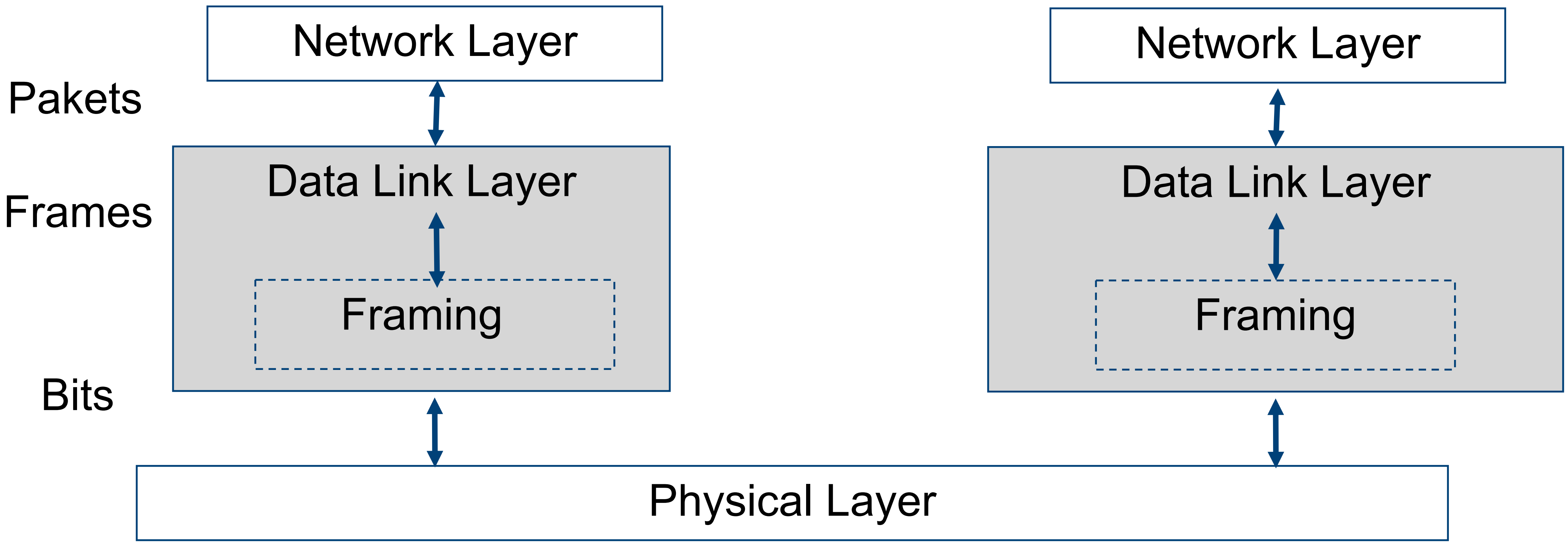
ISO/OSI Reference model

- 7. Application
  - Data transmission, e-mail, terminal, remote login
- 6. Presentation
  - System-dependent presentation of the data (EBCDIC / ASCII)
- 5. Session
  - start, end, restart
- 4. Transport
  - Segmentation, congestion
- 3. Network
  - Routing
- 2. Data Link
  - Checksums, flow control
- 1. Physical
  - Mechanics, electrics



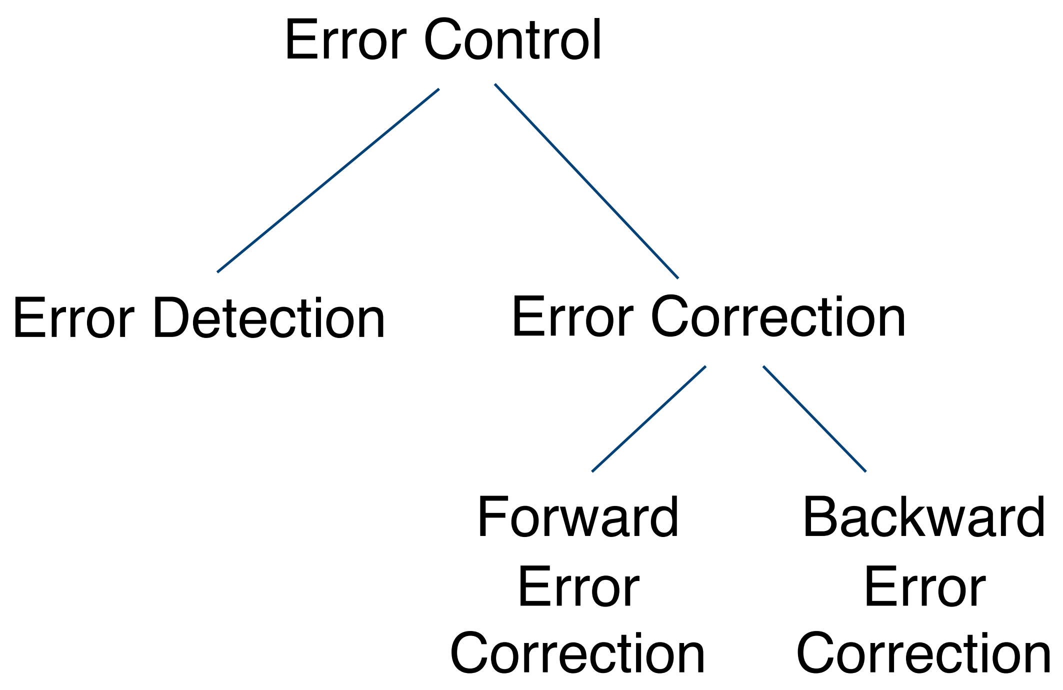
Data Link Layer: Frames

- Framing for the physical layer into „frames“
  - for error control



Error Control

- Performed by link and transmission layer
  - required by network and application layer
  - frames help (CRC trailer)
- Error detection
  - Are erroneous bits (flipped, skipped or duplicate bits)?
- Error correction
  - Correction of bit errors
  - Forward Error Correction
    - Uses redundant encoding
  - Backward Error Correction
    - After error detection errors are corrected by retransmission of messages



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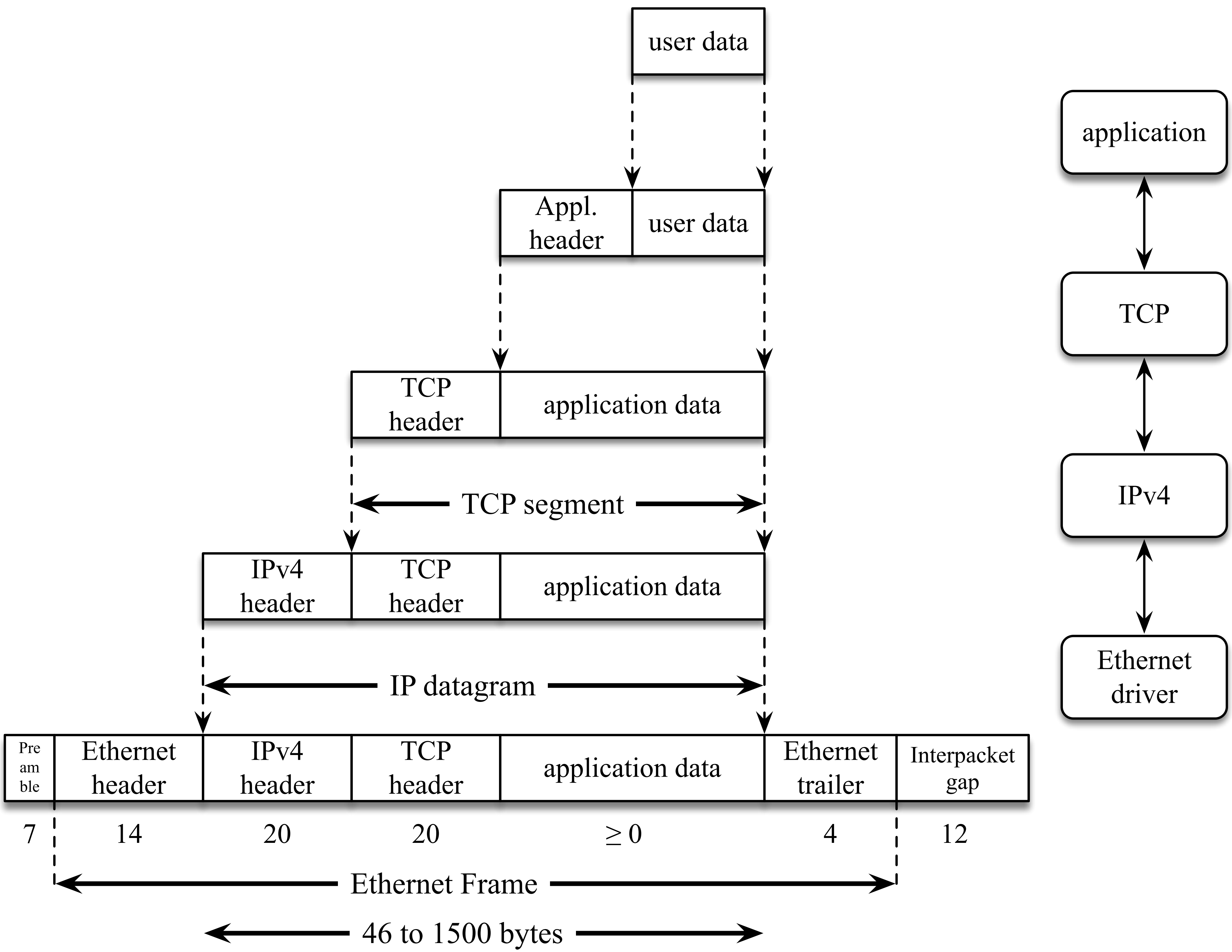
Sessions

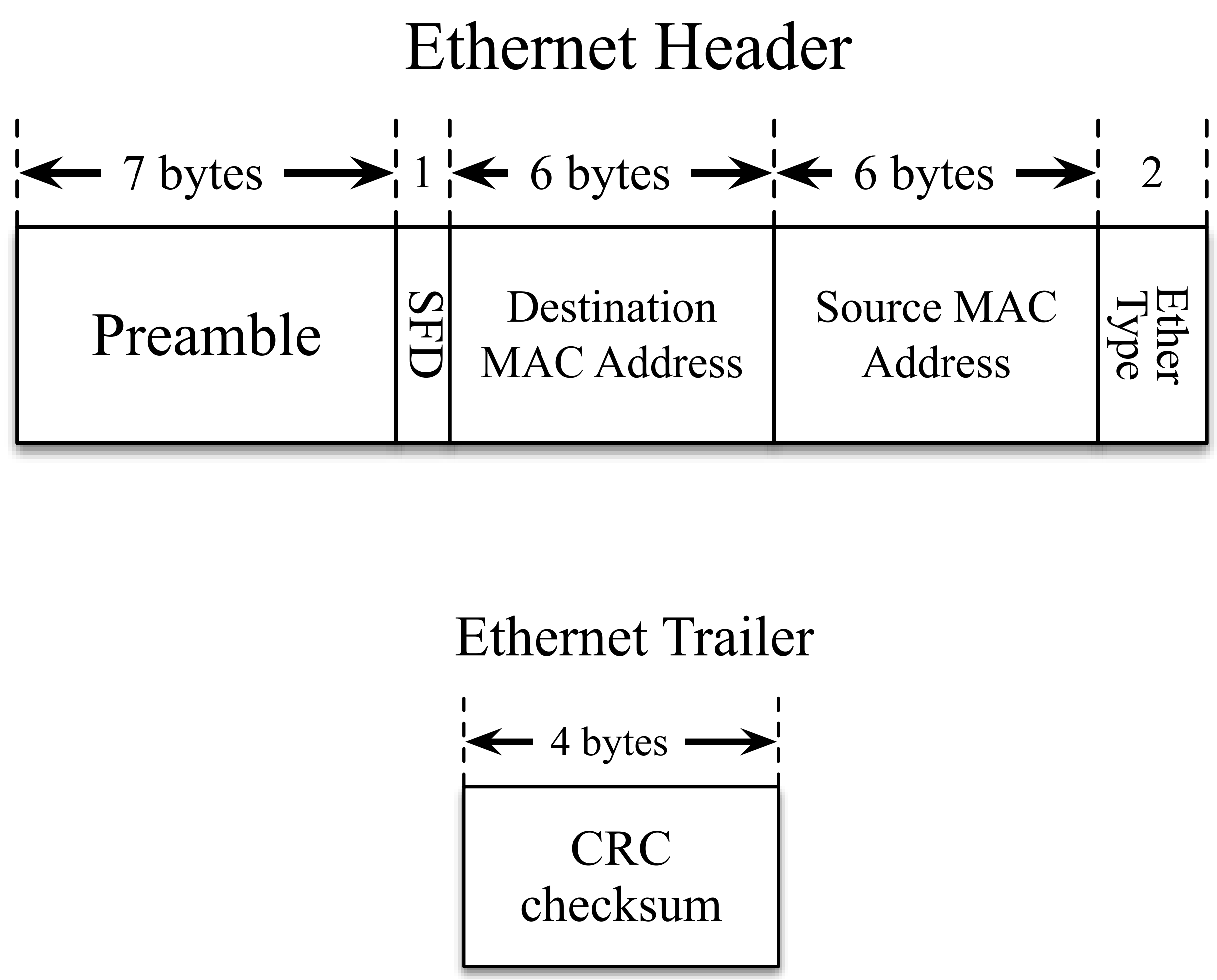
- Use of conections
  - control of the connection status
    - correctness of the protocol
  - error control
    - common context between sender and receiver

Data/Packet Encapsulation



IEEE 802.3 Ethernet frame structrue

- Destination MAC Address
- Source MAC Address
  - unique 6 byte addresses
  - prefix: company
  - suffix: given at production
- EtherType
  - type of next protocol, e.g.
    - 0x0800: IPv4
    - 0x0806: ARP
    - 0x86DD: IPv6
- CRC
  - Cyclic redundancy check



IPv4-Header (RFC 791)

- Version: 4 = IPv4
- IHL: IP header length
- Type of service
- Checksum (only IP-header)
- Source and destination 32 bit IP Address
- Protocol identifies protocol
  - e.g. TCP, UDP, ICMP, IGMP
- Time to Live:
  - maximal number of hops

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Version|  IHL  |Type of Service|          Total Length         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|         Identification        |Flags|      Fragment Offset    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Time to Live |    Protocol   |         Header Checksum       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                       Source Address                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Destination Address                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Options                    |    Padding    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

IPv6-Header (RFC 2460)

- Version: 6 = IPv6
- Traffic Class
  - for QoS (priority)
- Flow Label
  - QoS or real-time
- Payload Length
  - size of the rest of the IP packet
- Next Header (IPv4: protocol)
  - e..g. ICMP, IGMP, TCP, EGP, UDP, Multiplexing, ...
- Hop Limit (Time to Live)
  - maximum number of hops
- Source Address
- Destination Address
  - 128 bit IPv6 addresses

```
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Version| Traffic Class |           Flow Label                  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|         Payload Length        |  Next Header  |   Hop Limit   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+                                                               +
|                                                               |
+                         Source Address                        +
|                                                               |
+                                                               +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+                                                               +
|                                                               |
+                      Destination Address                      +
|                                                               |
+                                                               +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

TCP-Header (RFC 793)

- Sequence number
  - number of the first byte in the segment
  - bytes are numbered modulo 2^{32}
- Acknowledge number
  - activated by ACK-Flag
  - number of the next data byte
    - = last sequence number + last amount of data
- Port addresses
  - for parallel TCP connections
- TCP Header length
  - data offset
- Check sum
  - for header and data

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|          Source Port          |       Destination Port        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                        Sequence Number                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Acknowledgment Number                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Data |           |U|A|P|R|S|F|                               |
| Offset| Reserved  |R|C|S|S|Y|I|            Window             |
|       |           |G|K|H|T|N|N|                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|           Checksum            |         Urgent Pointer        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Options                    |    Padding    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                             data                              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

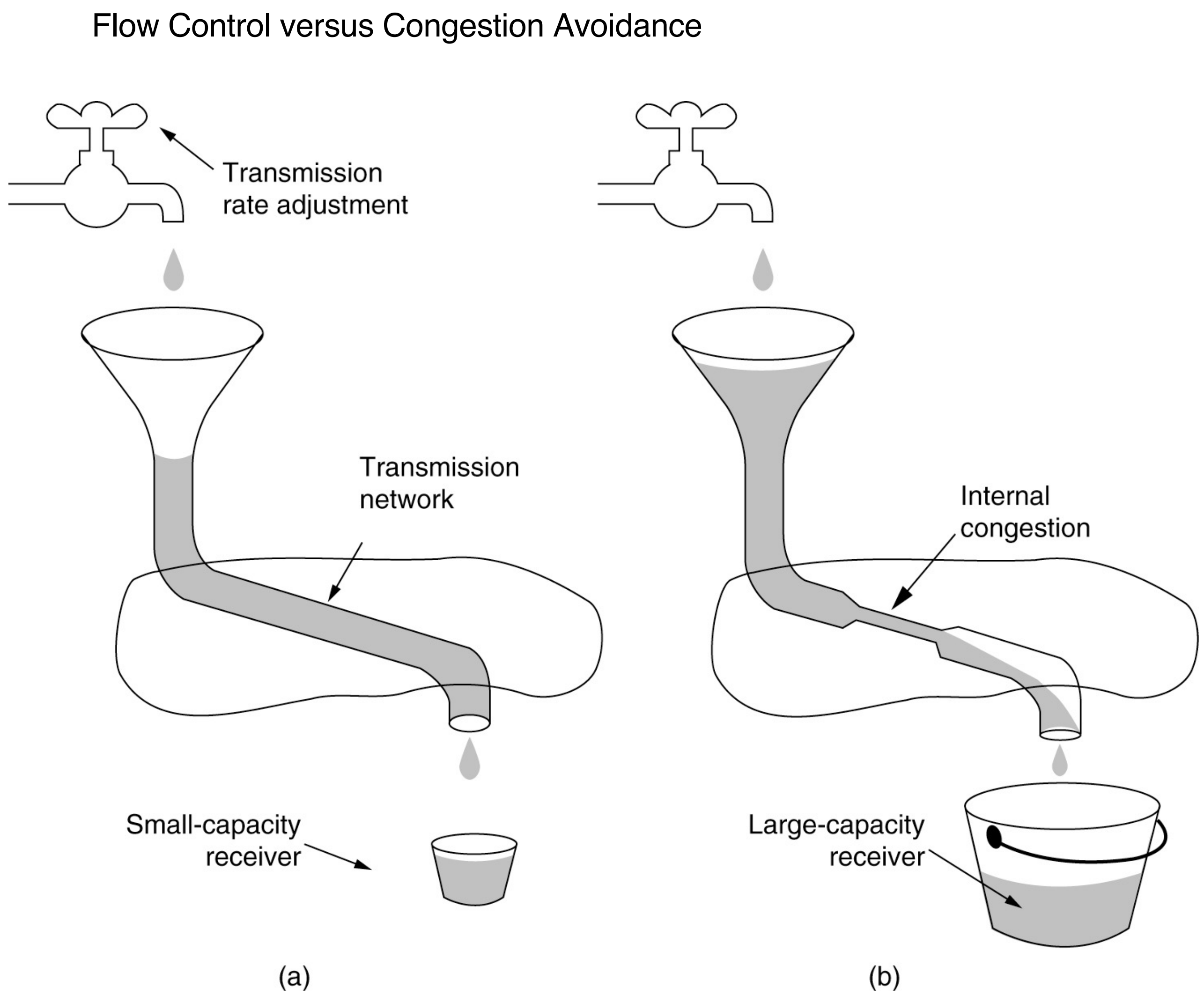
UDP-Header

- Port addresses
  - for parallel UDP connections
- Length
  - data + header length
- Checksum
  - for header and data

```
0      7 8     15 16    23 24    31
+--------+--------+--------+--------+
|     Source      |   Destination   |
|      Port       |      Port       |
+--------+--------+--------+--------+
|                 |                 |
|     Length      |    Checksum     |
+--------+--------+--------+--------+
|
|          data octets ...
+---------------- ...
```

Flow Control

- Problem: Fast sender and slow receiver
  - The sender overwhelms the receiver‘s buffer
  - Waste of bandwidth because of unneccessary retransmissions
- Adaption of the sender rate to the receiver



[Tanenbaum, Computer Networks]

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

Introduction to Future IP

- IP version 6 (IP v6 – around July 1994)
- Why switch?
  - rapid, exponential growth of networked computers
  - shortage (limit) of the addresses
  - new requirements towards the Internet infrastructure (streaming, real-time services like VoIP, video on demand)
- evolutionary step from IPv4
- interoperable with IPv4

IP addresses and Domain Name System

- IP addresses
  - every interface in a network has a unique world wide IP address
  - separated in Net-ID and Host-ID
  - Net-ID assigned byInternet Network Information Center
  - Host-ID by local network administration
- Domain Name System (DNS)
  - replaces IP addresses like 132.230.167.230 by names, e.g. falcon.informatik.uni-freiburg.de and vice versa
  - Robust distributed database

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

IP Packet Forwarding

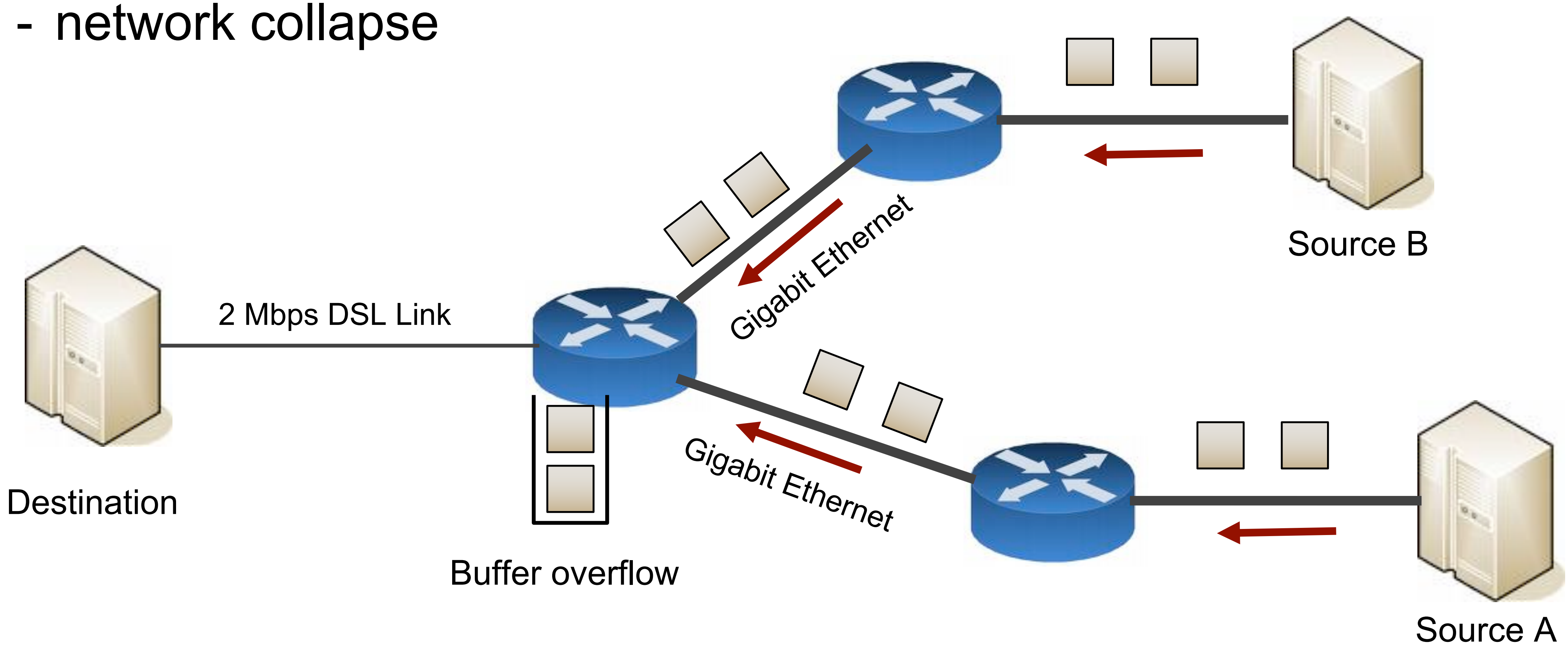
- IP -Packet (datagram) contains...
  - TTL (Time-to-Live): Hop count limit
  - Start IP Address
  - Destination IP Address
- Packet Handling
  - Reduce TTL (Time to Live) by 1
  - If TTL ≠ 0 then forward packet according to routing table
  - If TTL = 0 or forwarding error (buffer full etc.):
    - delete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

Capabilities of IP

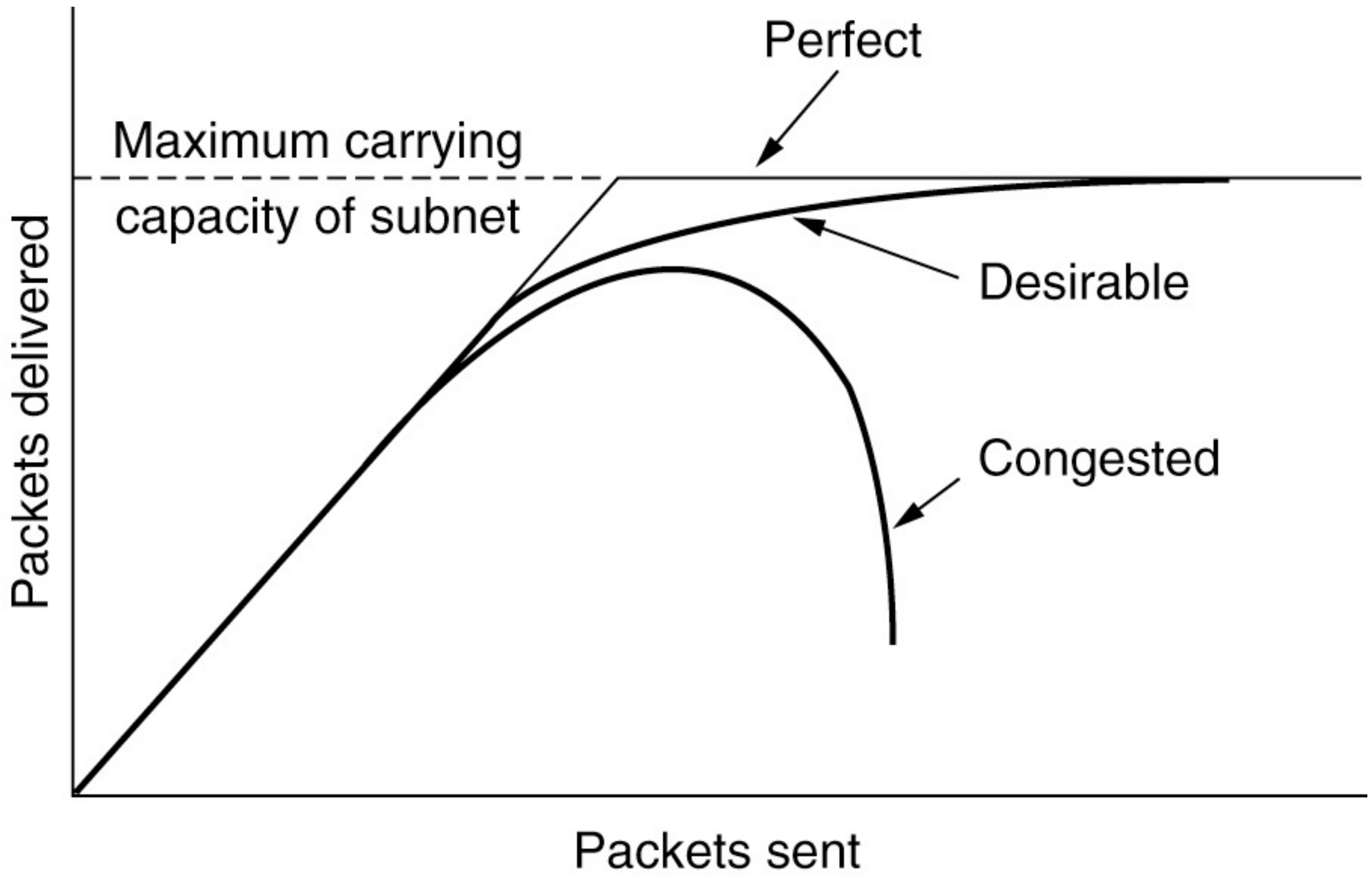
- dramatic changes of IP
  - Basic principles still appropriate today
  - Many new types of hardware
  - Scale of Internet and interconnected computers in private LAN
- Scaling
  - Size - from a few tens to a few tens of millions of computers
  - Speed - from 9,6Kbps (GSM) to 10Gbps (Ethernet)
  - Increased frame size (MTU) in hardware

Network Congestion

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

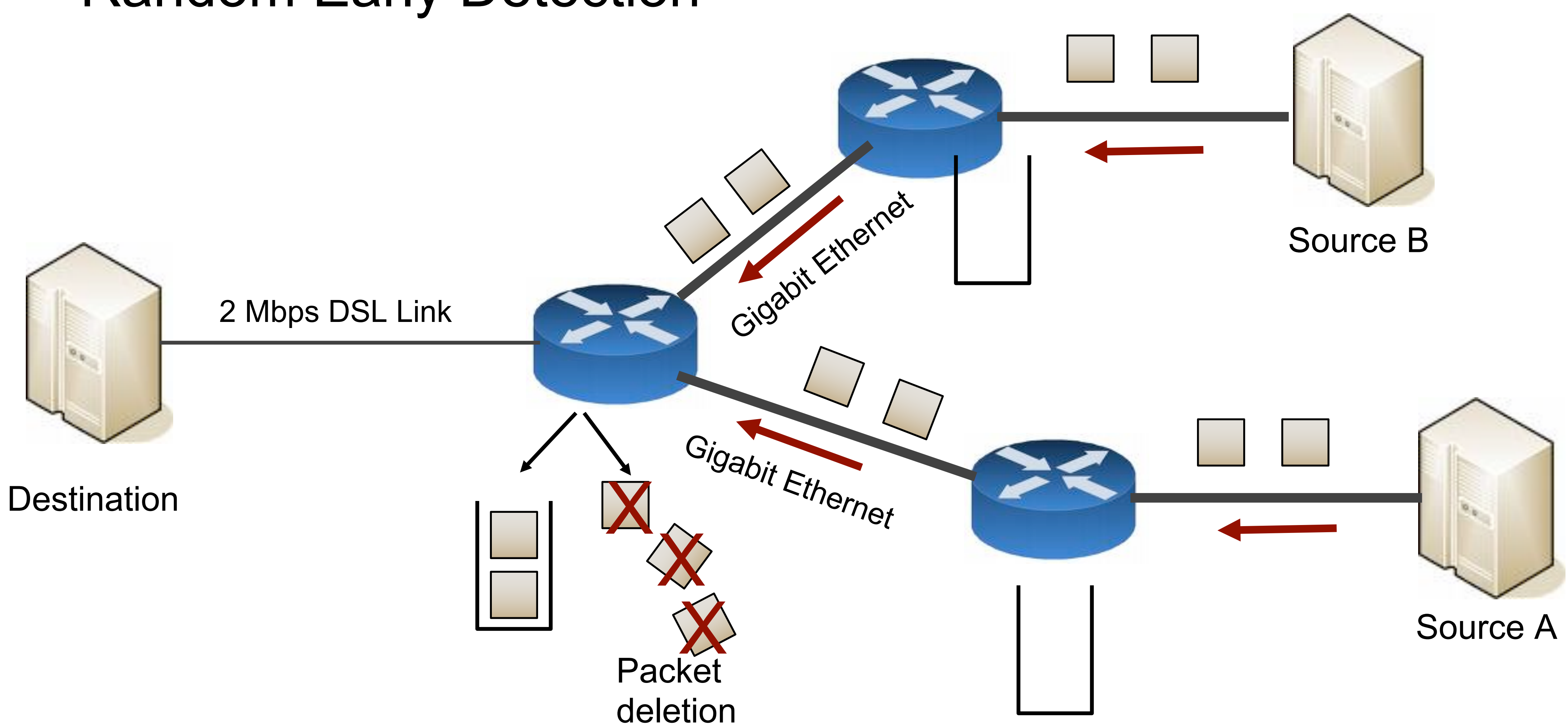


Congestion and capacity



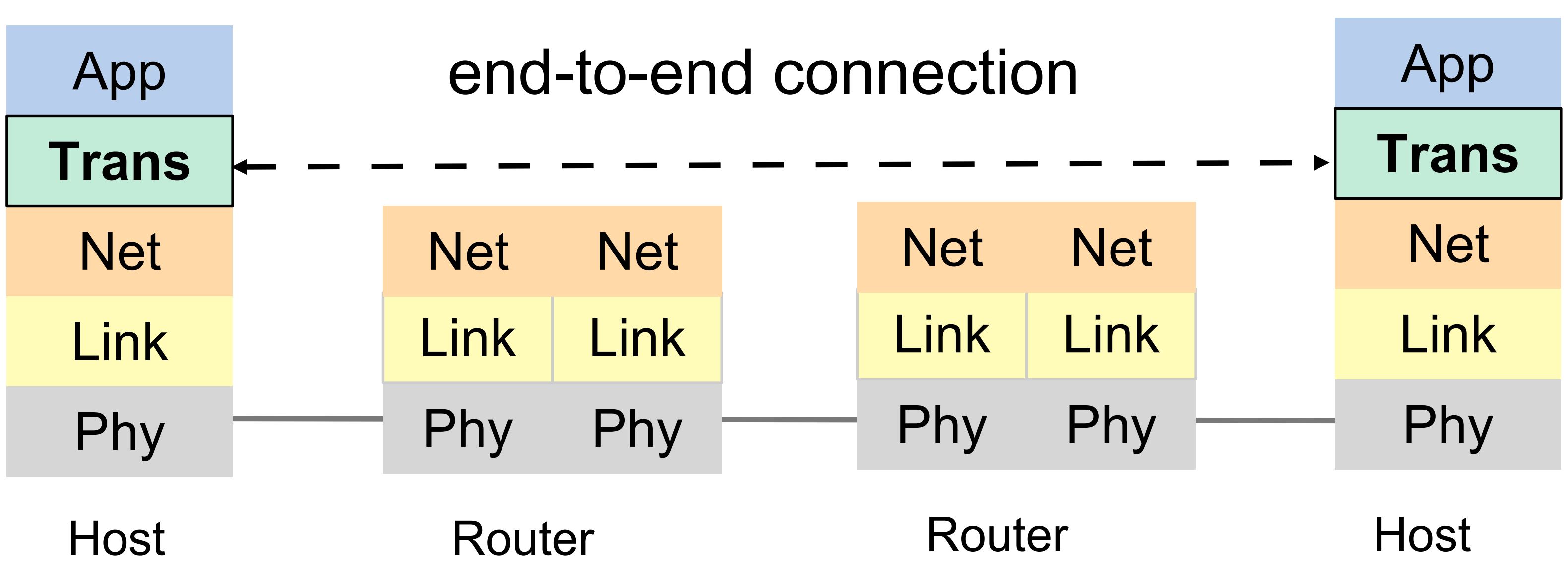
Congestion Prevention by Routers

- 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-Header

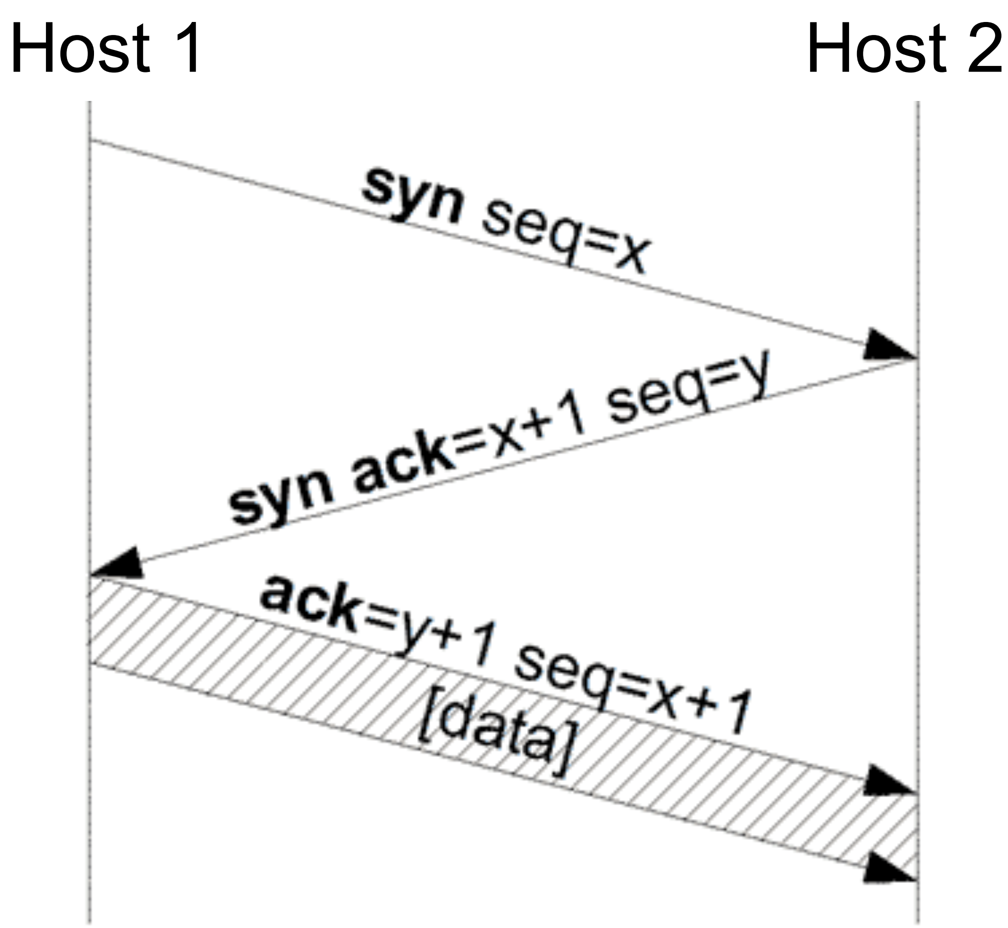
- Sequence number
  - number of the first byte in the segment
  - bytes are numbered modulo 2^{32}
- Acknowledge number
  - activated by ACK-Flag
  - number of the next data byte
    - = last sequence number + last amount of data
- Port addresses
  - for parallel TCP connections
- TCP Header length
  - data offset
- Check sum
  - for header and data

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|          Source Port          |       Destination Port        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                        Sequence Number                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Acknowledgment Number                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Data |           |U|A|P|R|S|F|                               |
| Offset| Reserved  |R|C|S|S|Y|I|            Window             |
|       |           |G|K|H|T|N|N|                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|           Checksum            |         Urgent Pointer        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Options                    |    Padding    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

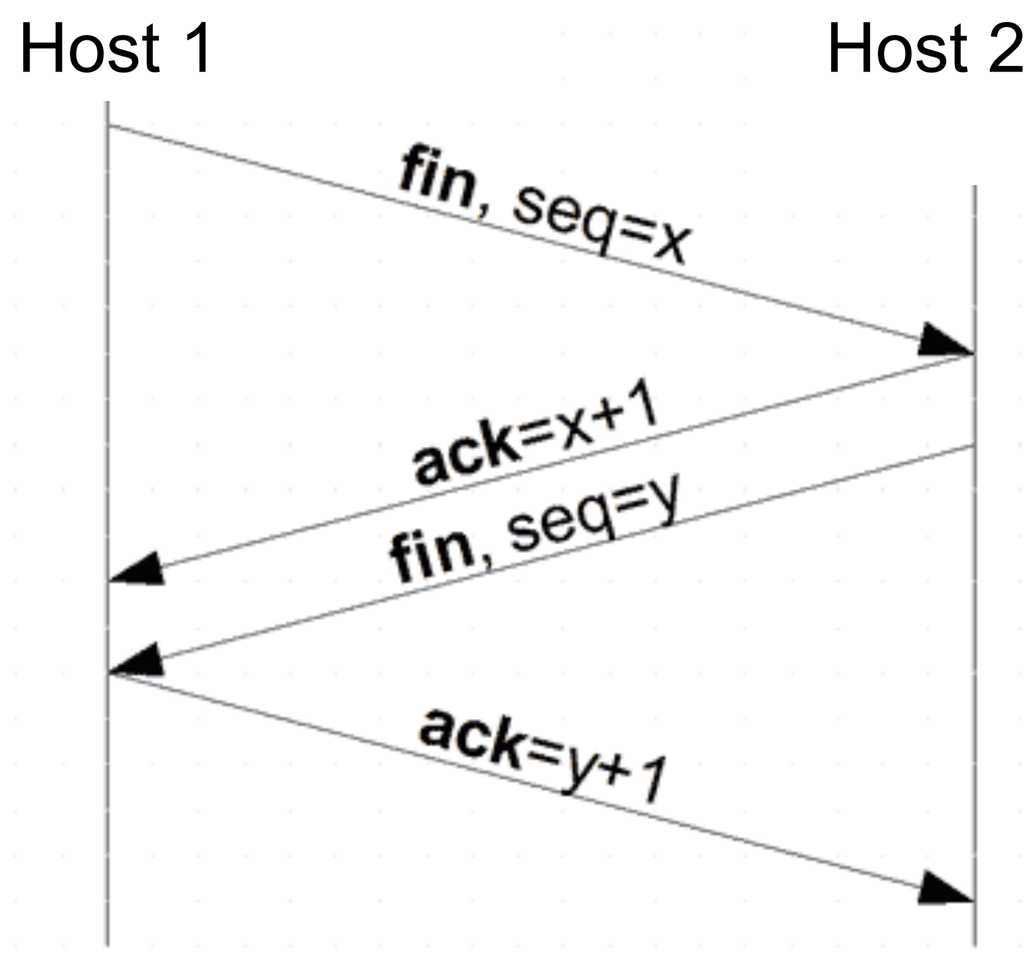
TCP Connections

- Connection establishment and teardown by 3-way handshake

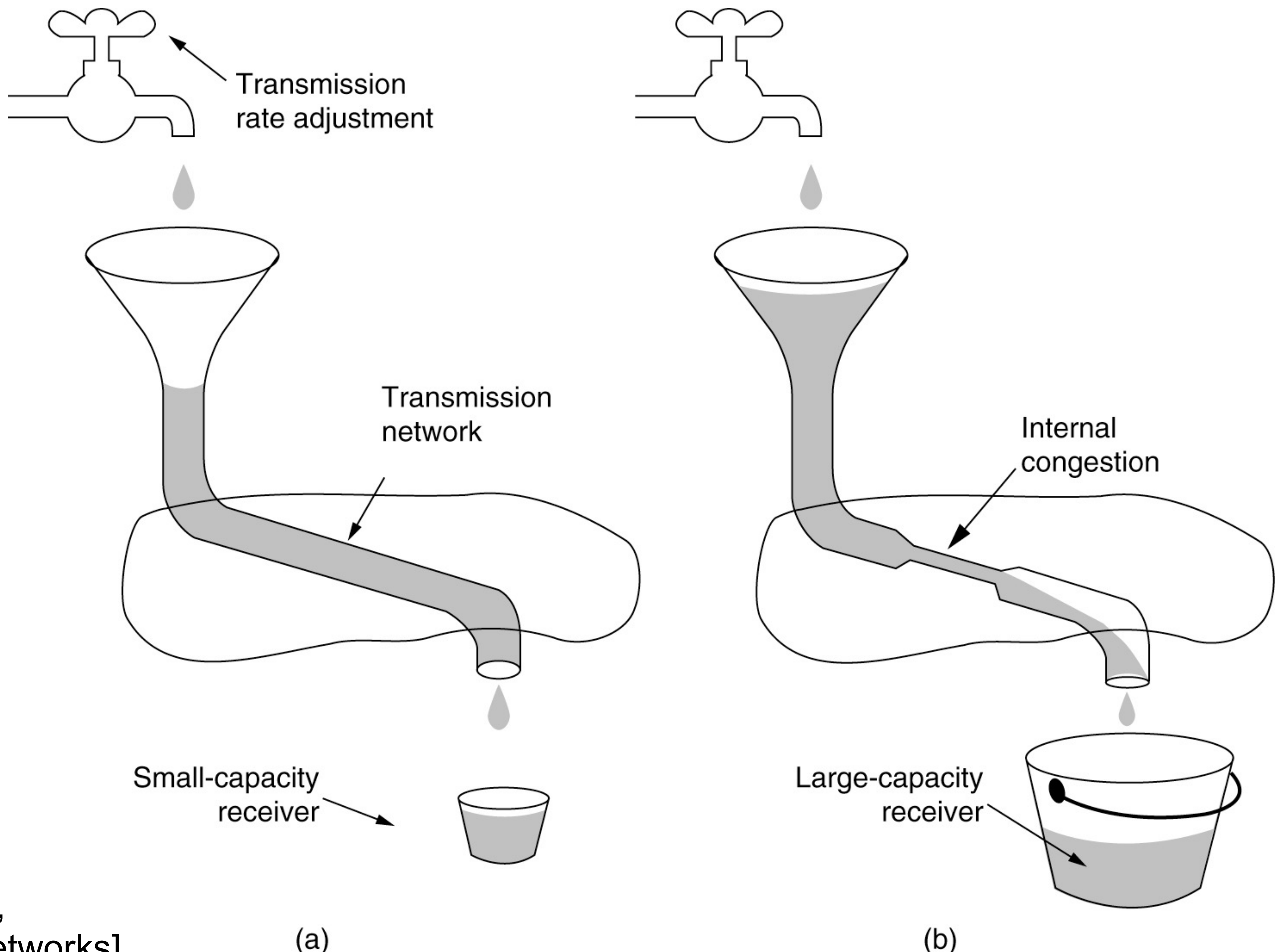
Connection establishment



Connection termination



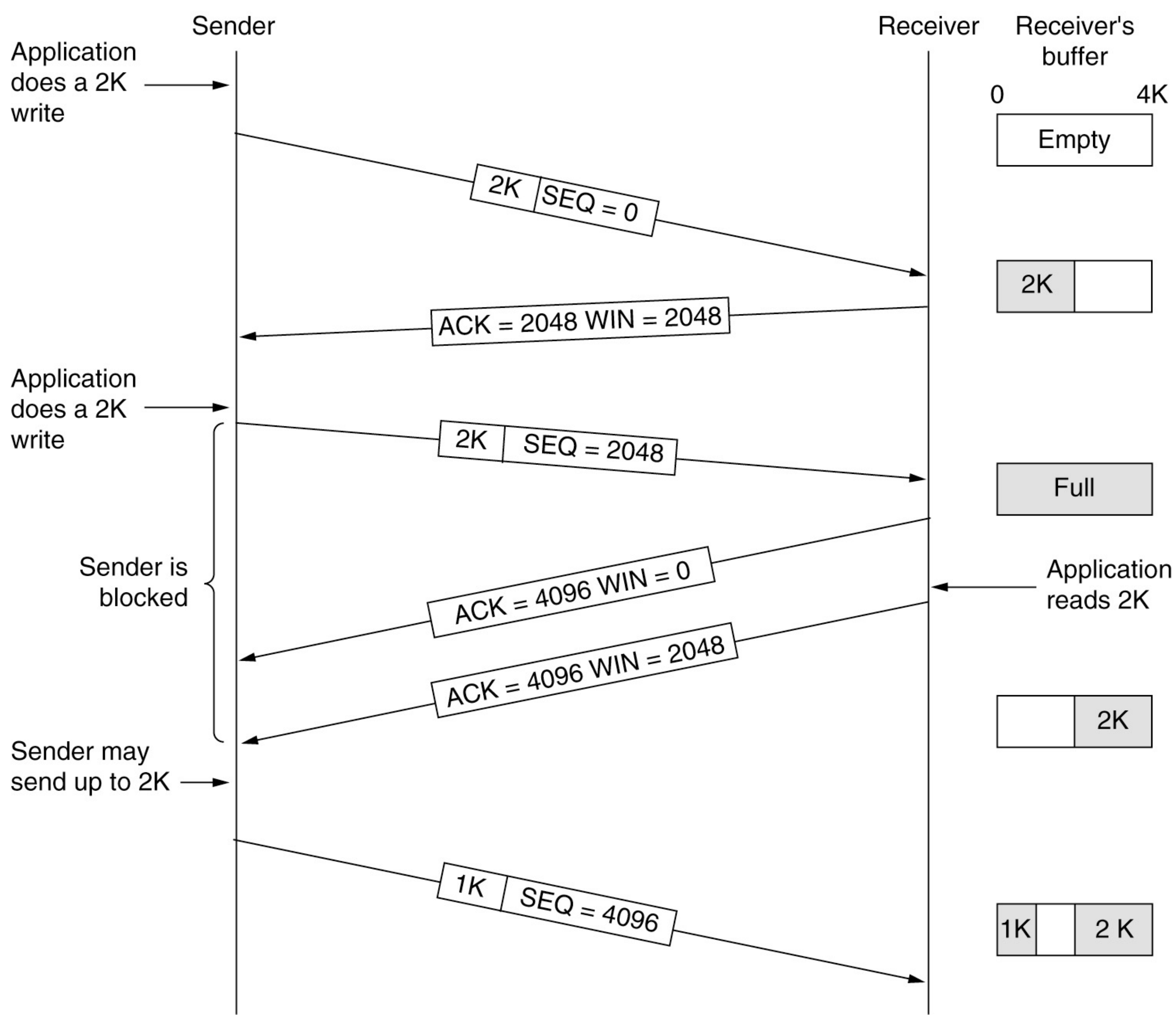
Flow control and congestion control



[Tanenbaum,
Computer Networks]

Flow Control

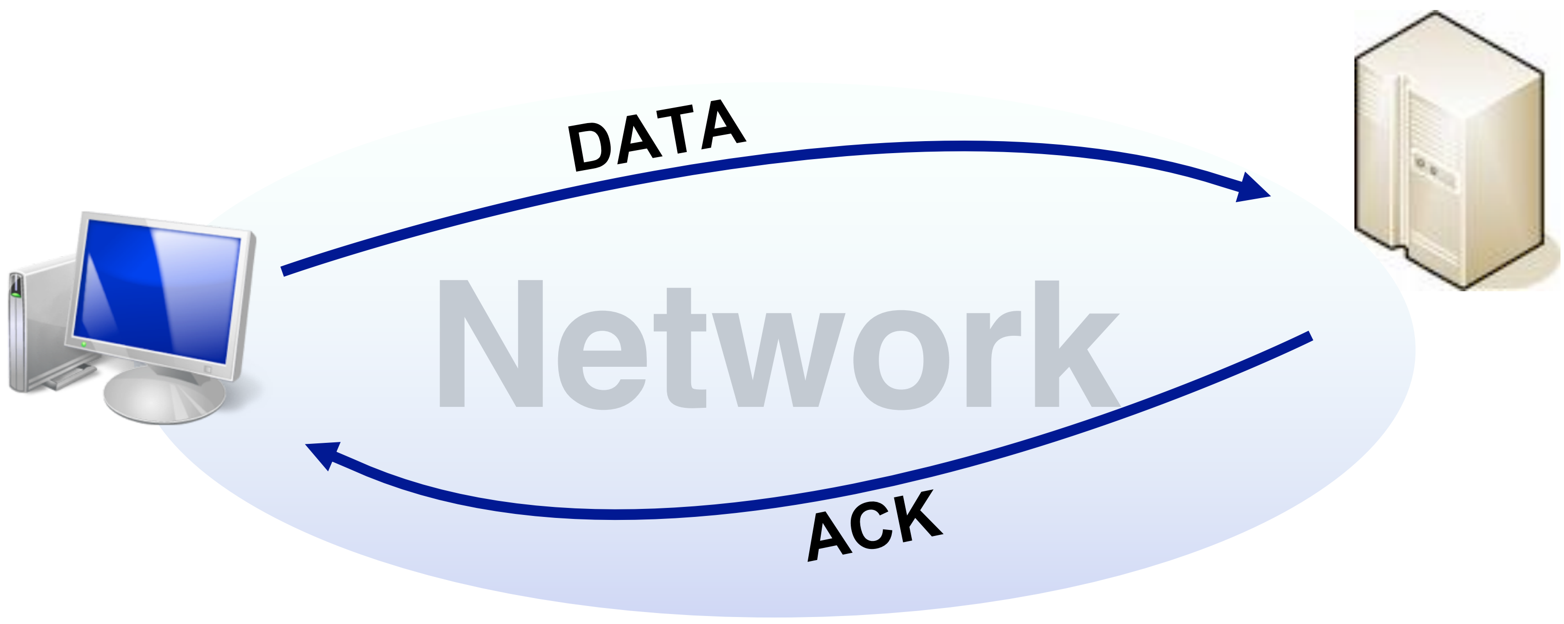
acknowledgements and window management



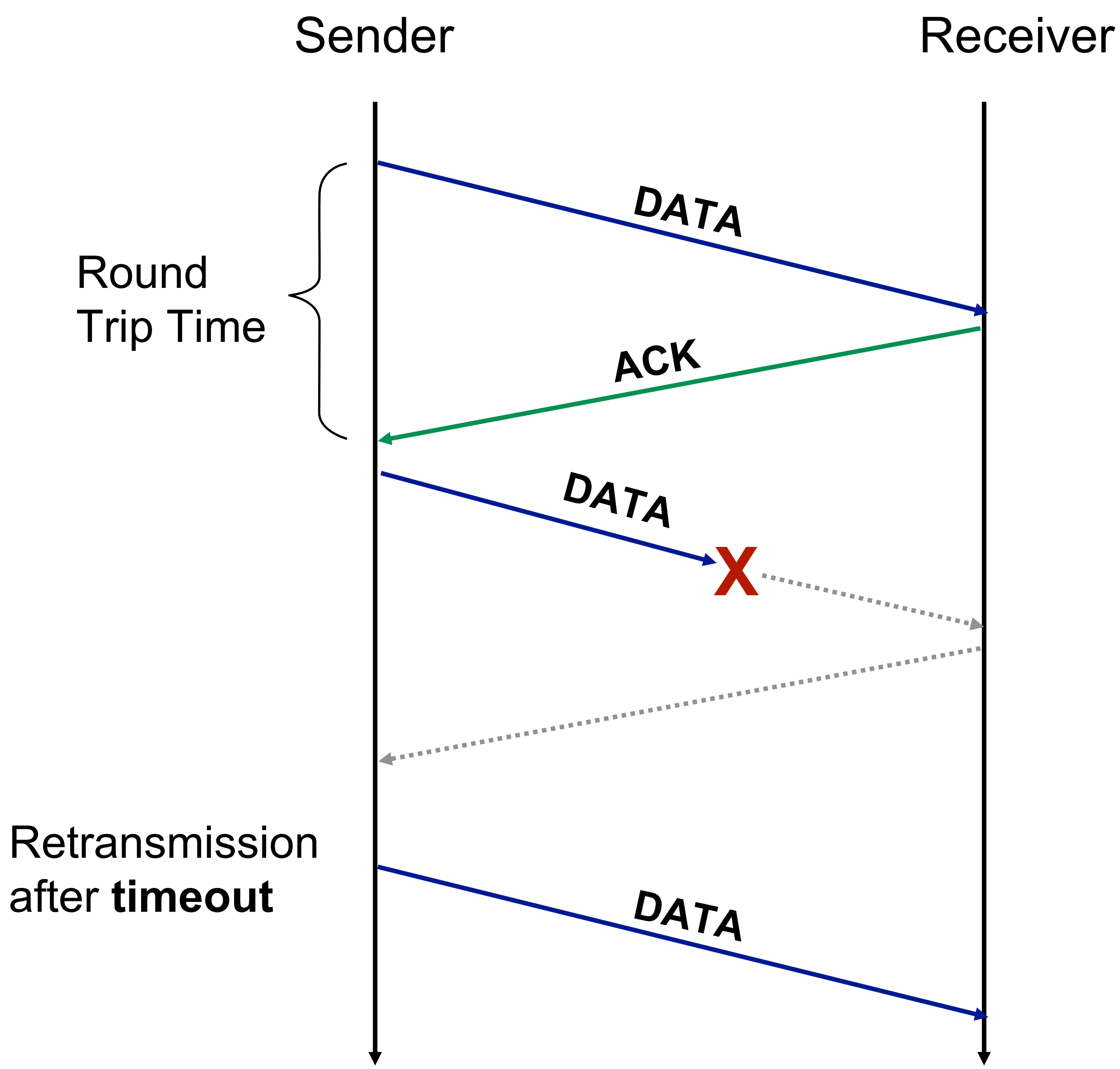
Retransmissions

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

- Measurement of the round trip time (RTT)



Retransmissions and RTT

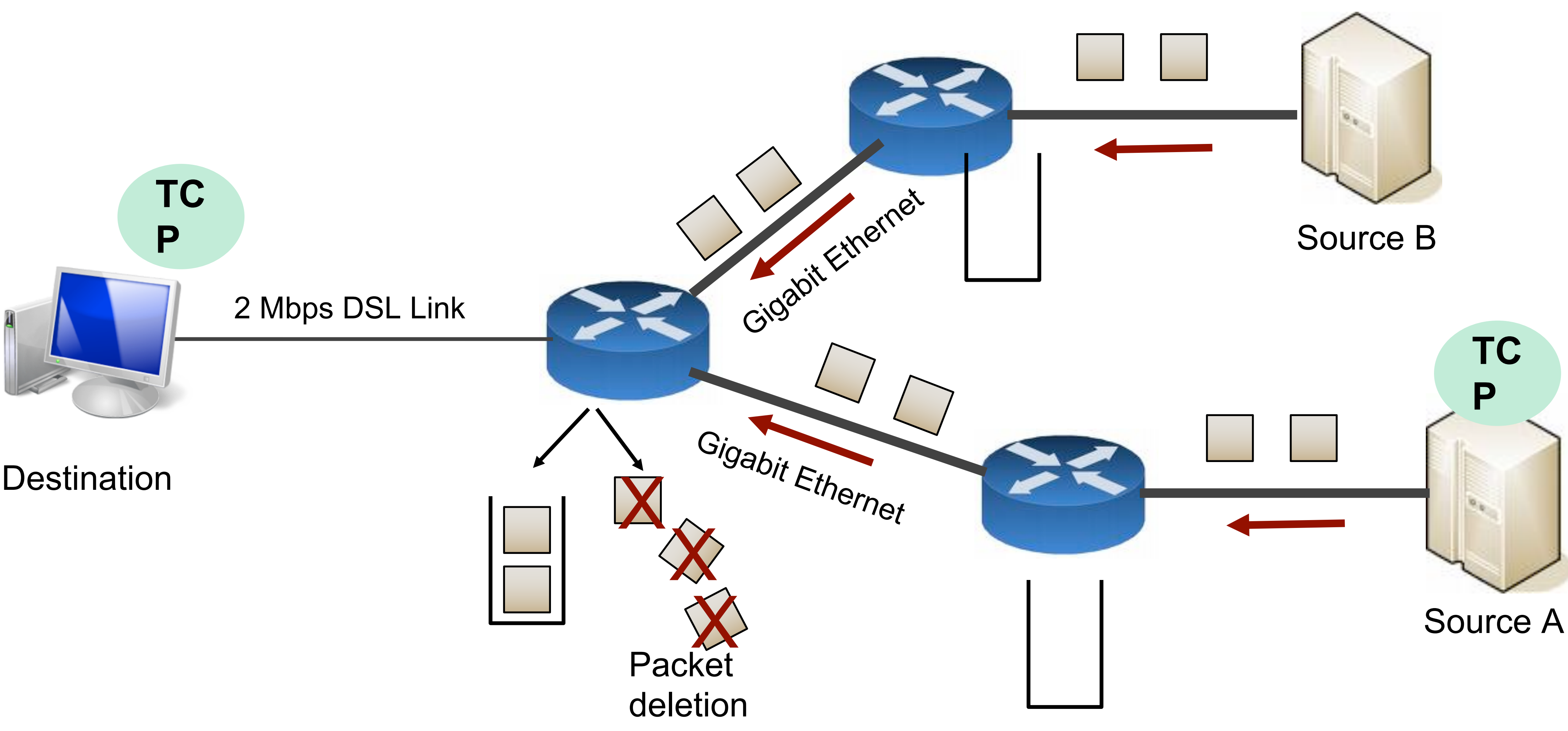


TCP - Algorithm of Nagle

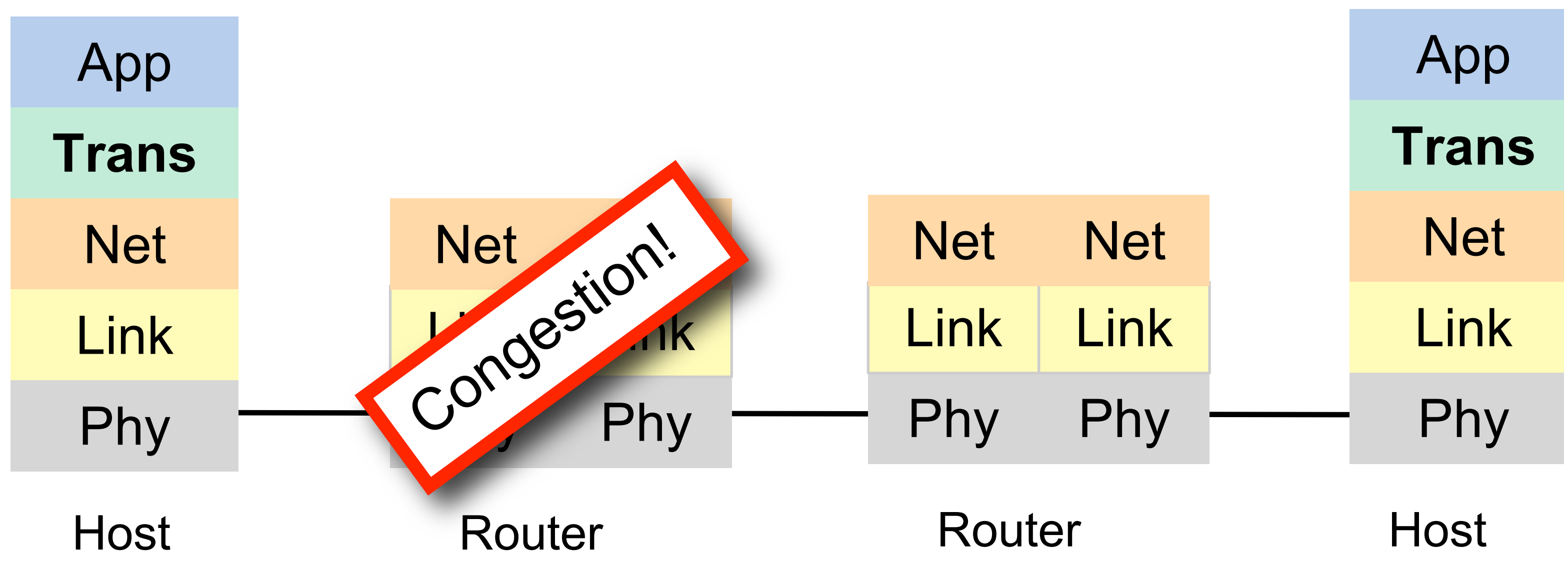
- How to ensure
  - small packages are shipped fast
  - yet, large packets are preferred
- Algorithm of Nagle
  - Small packets are not sent, as long as acks are still pending
    - Package is small, if data length <MSS
  - when the acknowledgment of the last packet arrives, the next one is sent
- Example:
  - terminal versus file transfer versus ftp
- Feature: self-clocking:
    - Quick link = many small packets
    - slow link = few large packets

Congestion revisited

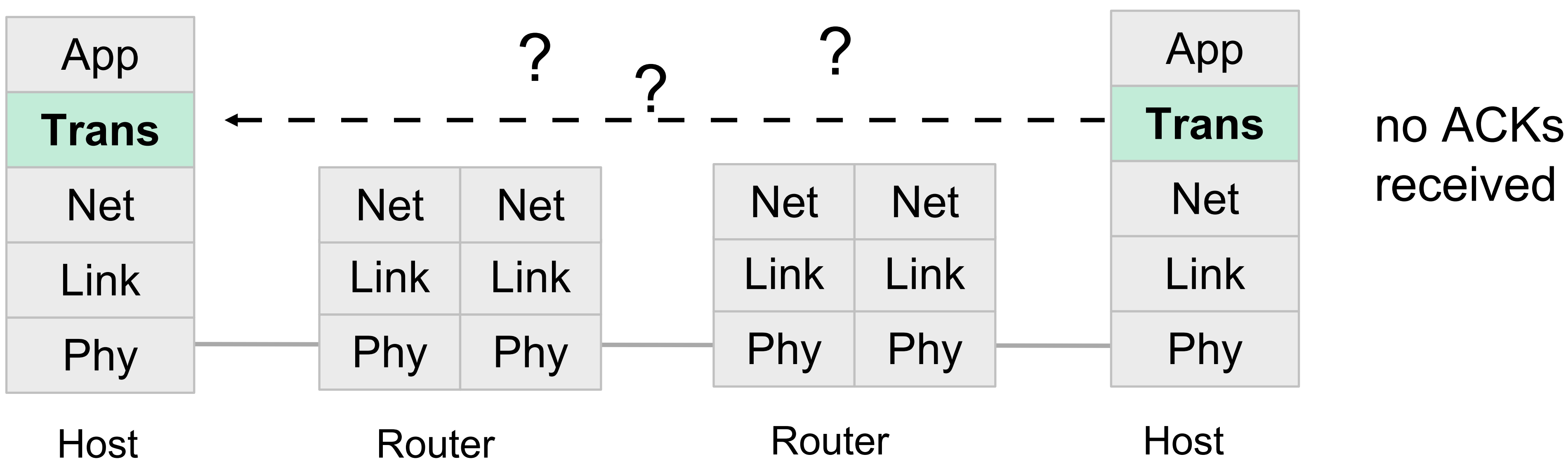
- IP Routers drop packets
- TCP has to react, e.g. lower the packet injection rate



Congestion revisited

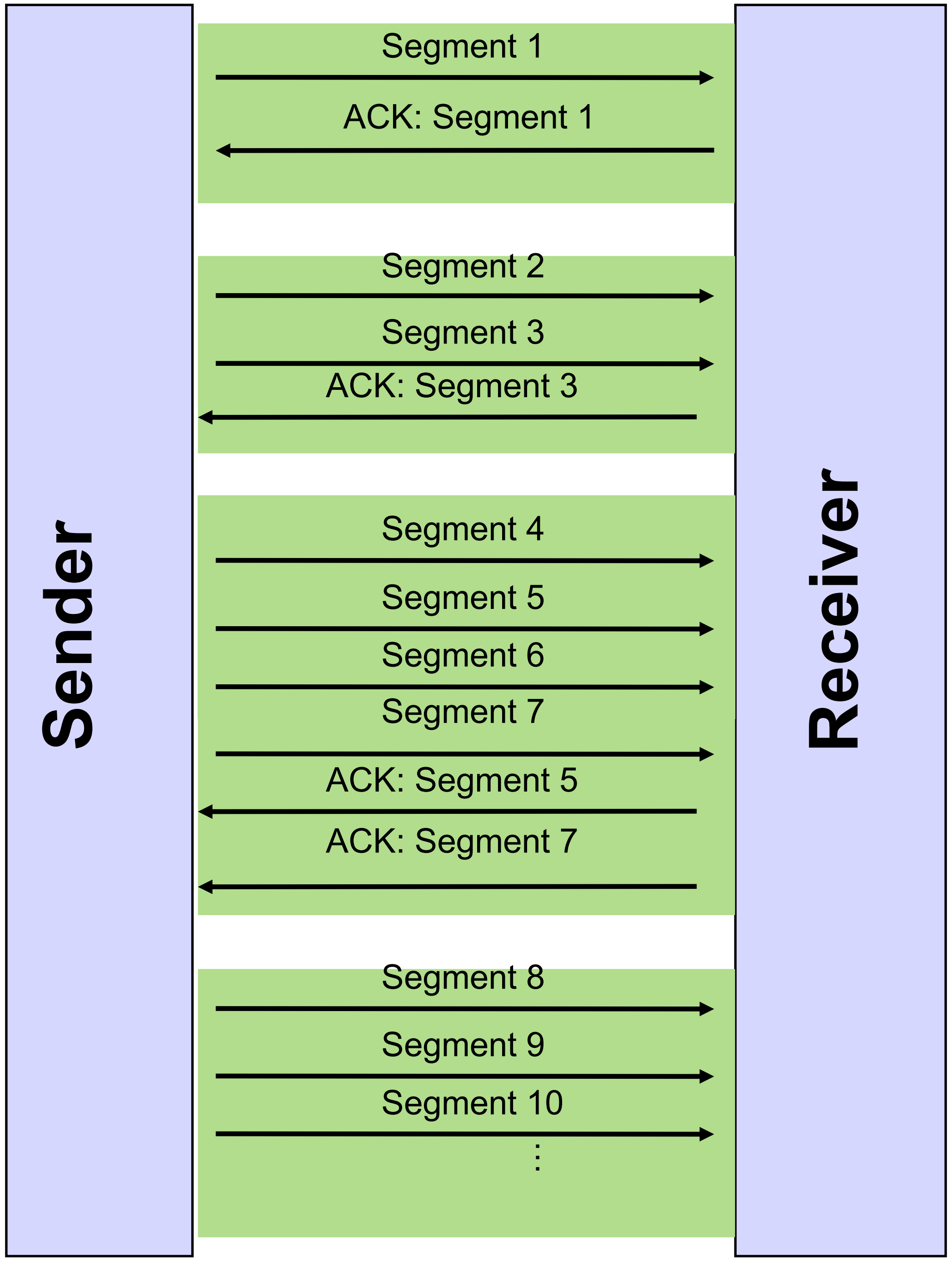


from a transport layer perspective:

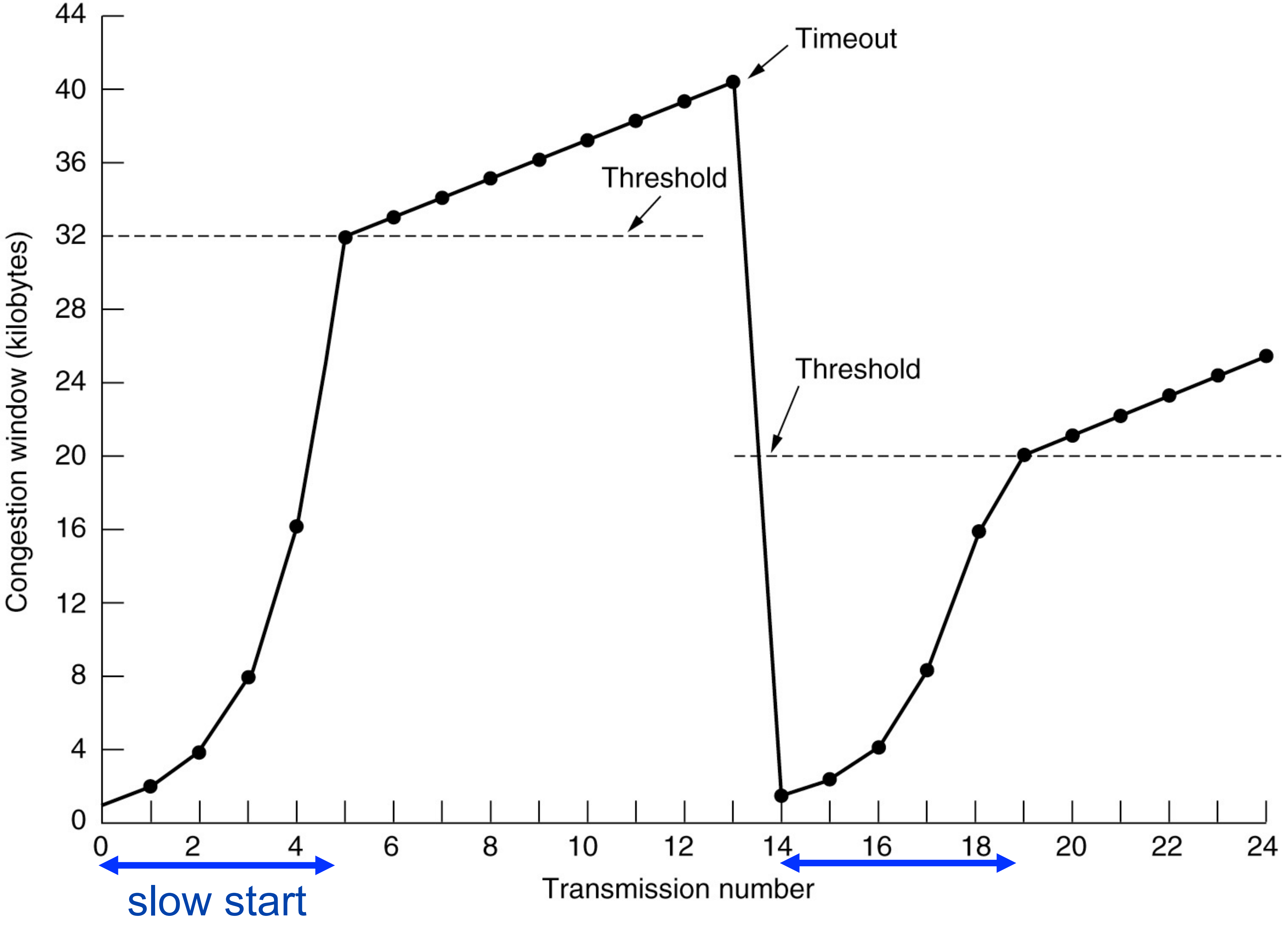


Data rate adaption and the congestion window

- 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 $\leftarrow$ S
  - For each received acknowledgement:
    - cwnd $\leftarrow$ cwnd + S
  - ...until a packet remains unacknowledged



Slow Start of TCP Tahoe



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The AIMD principle

- TCP uses the following mechanism to adapt the data rate x
  - data rate x:#packets sent per RTT

- **Initialization:** $\mathbf{x \leftarrow 1}$

- **Packet loss: multiplicative decrease (MD)** $\mathbf{x \leftarrow x/2}$

- **Acknowledgement arrives: additive increase (AI)** $\mathbf{x \leftarrow x + 1}$

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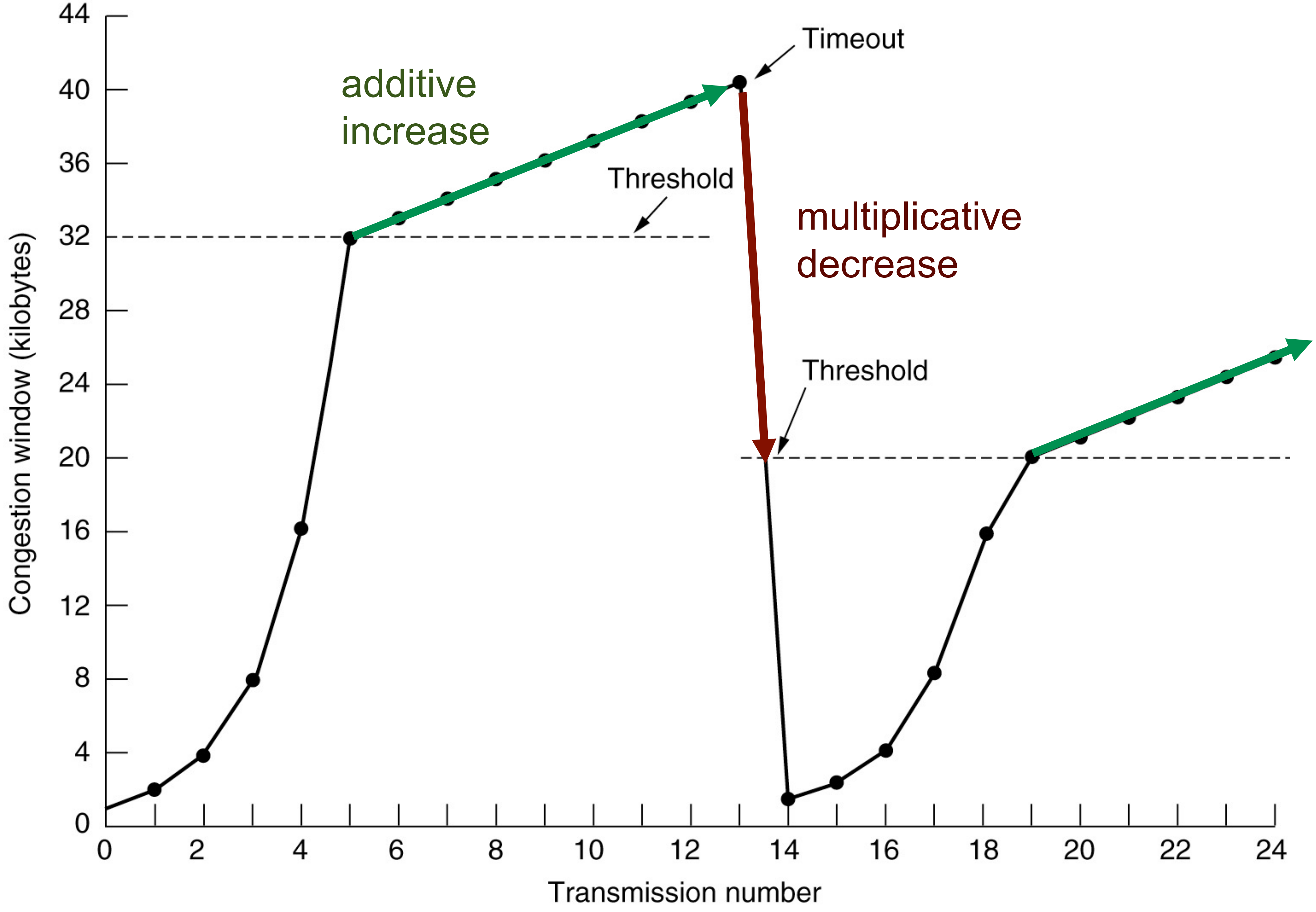
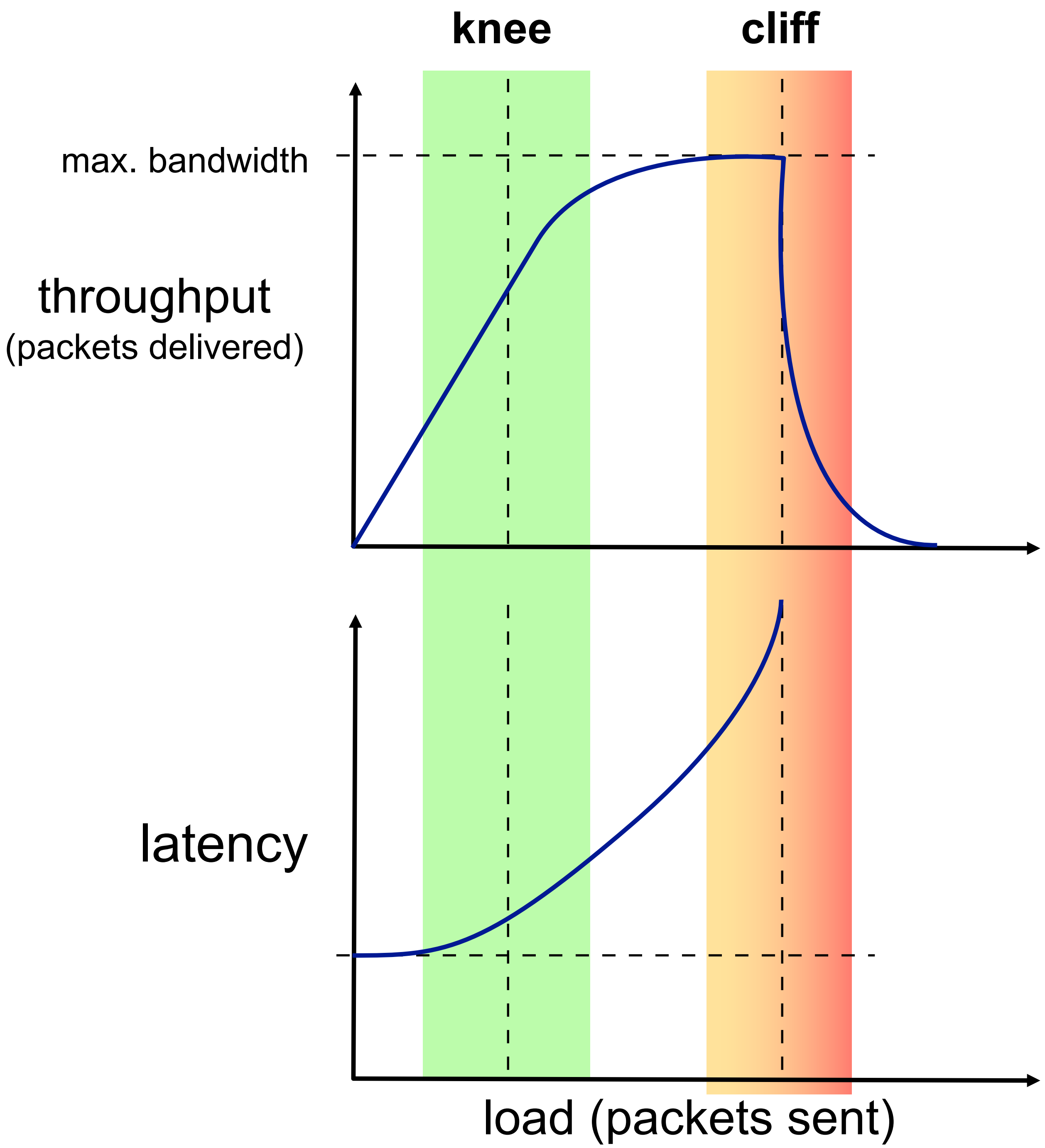
AIMD

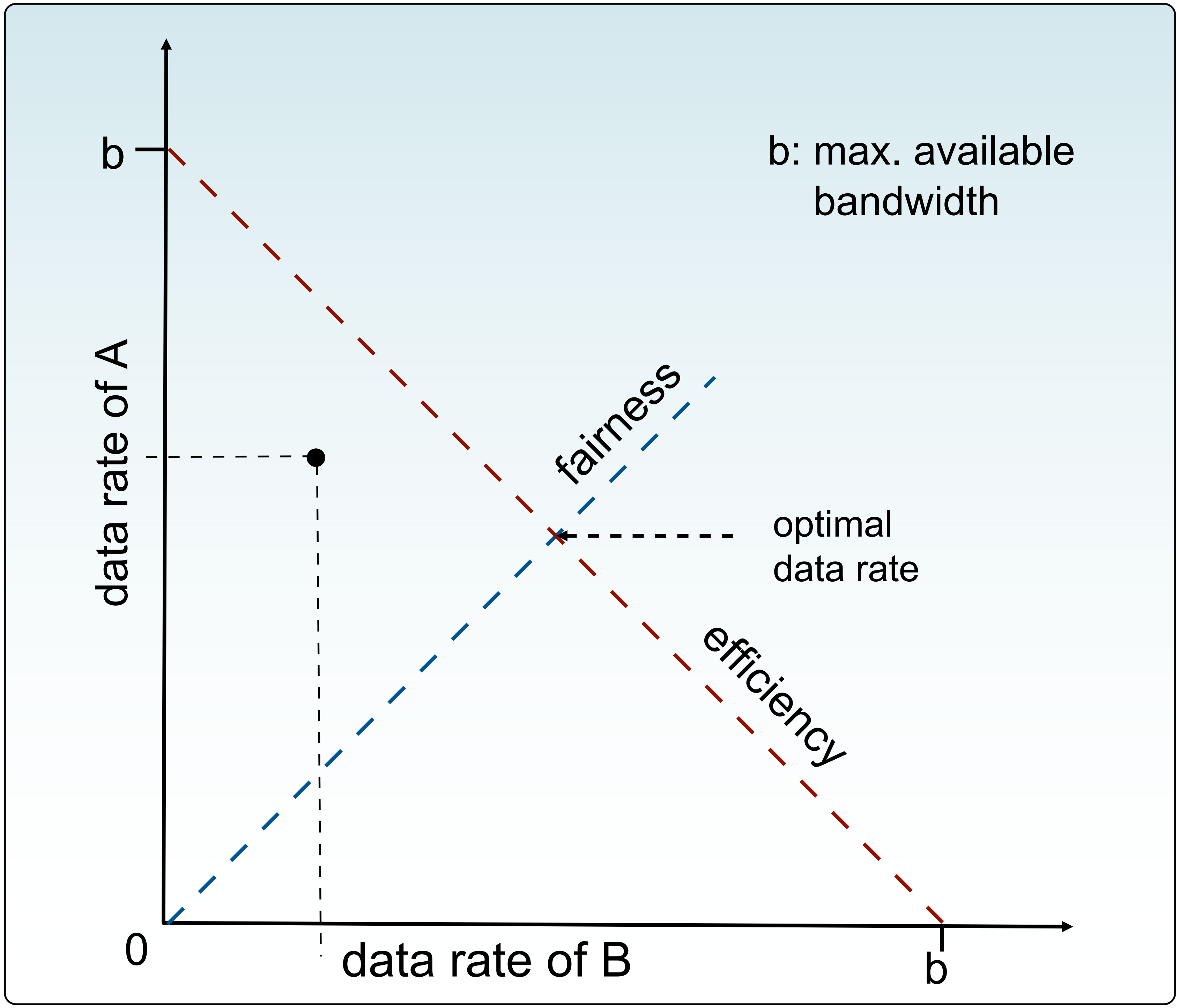

Timeout
additive increase
Threshold
multiplicative decrease
Threshold
Congestion window (kilobytes)
Transmission number
0 4 8 12 16 20 24 28 32 36 40 44
0 2 4 6 8 10 12 14 16 18 20 22 24

Throughput and Latency

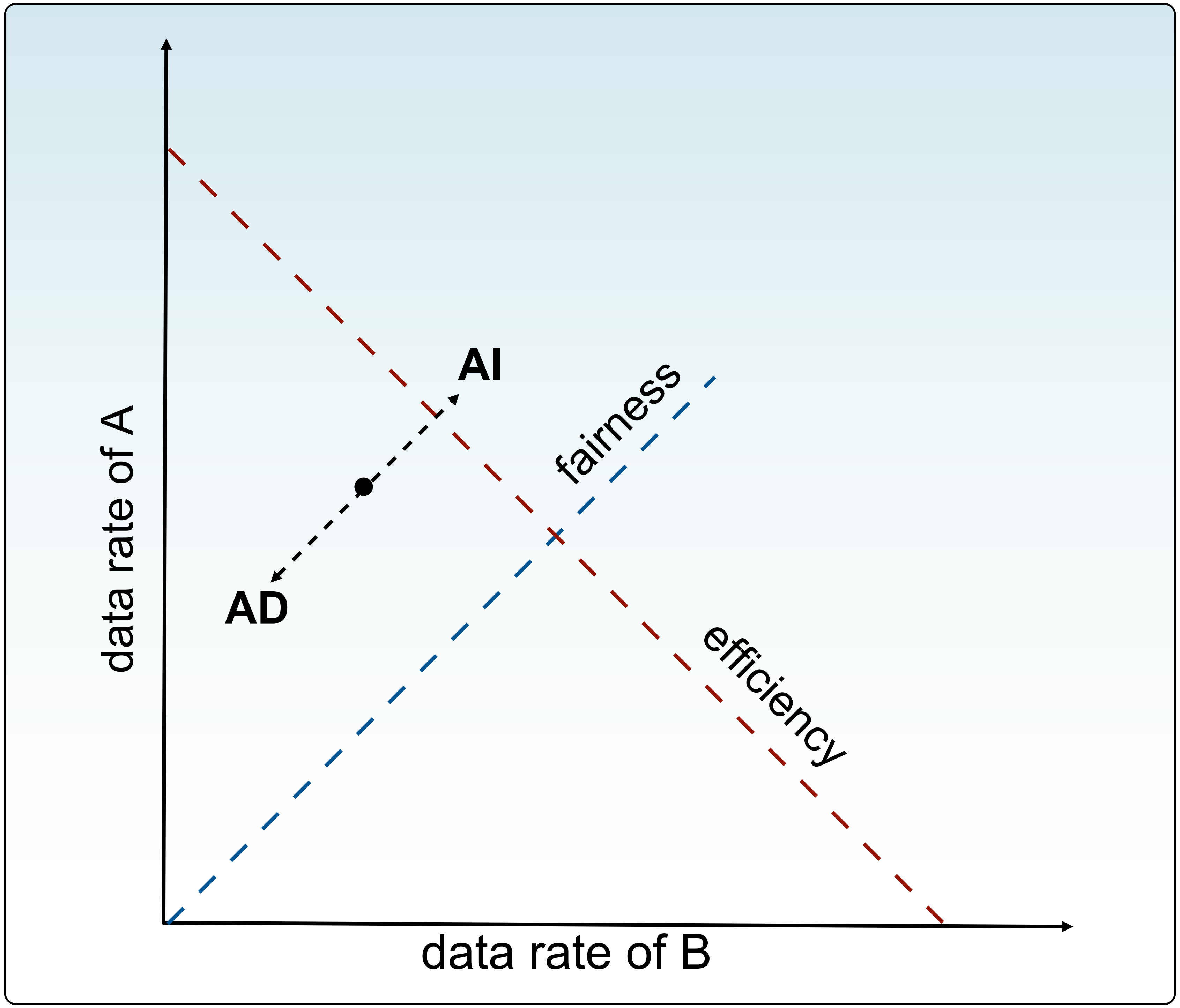
- Congested situation (cliff):
  - high load
  - low throughput
  - all data packets are lost
- Desired situation (knee):
  - high load
  - high throughput
  - few data packets get lost



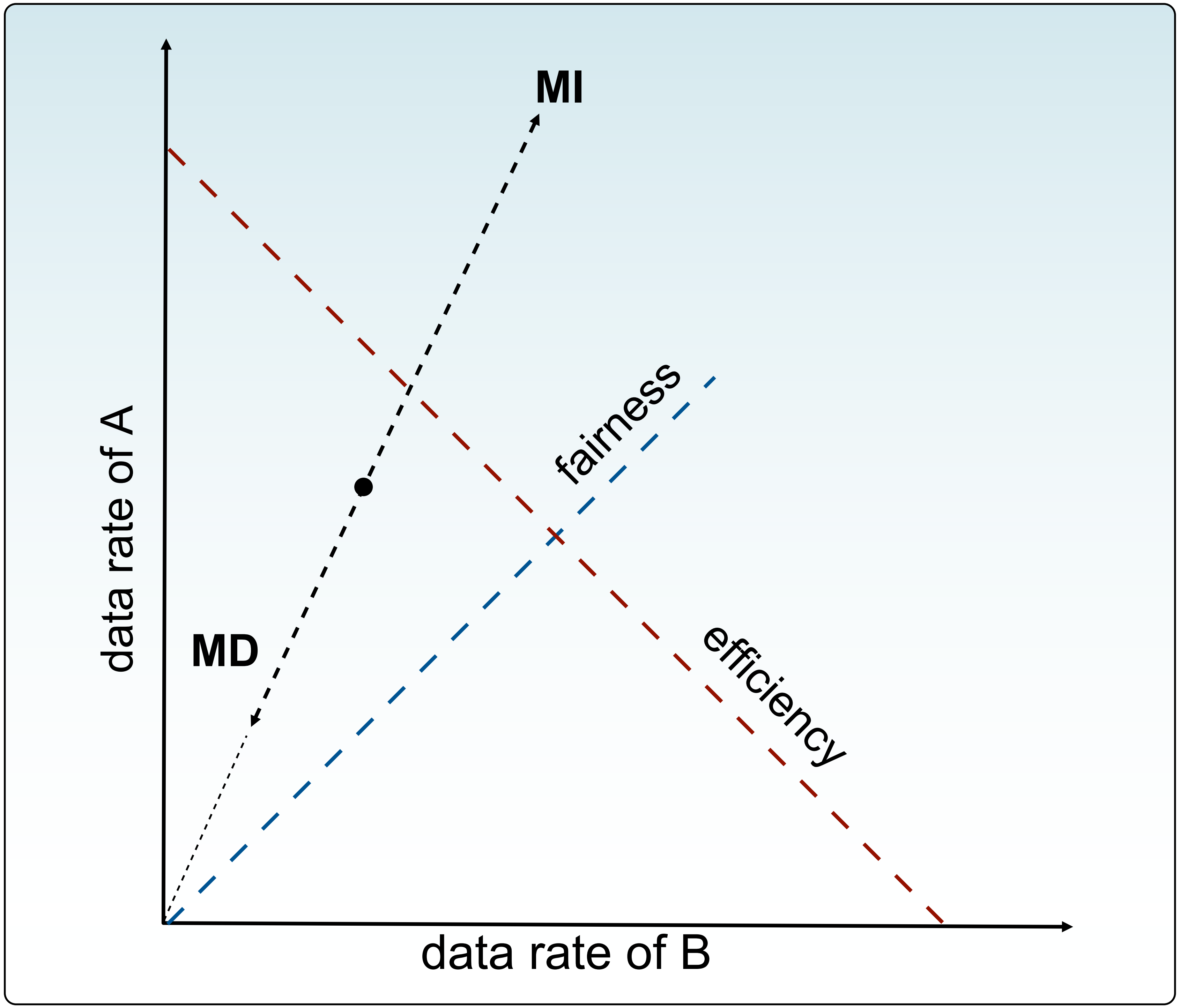
Vector diagram for 2 participants



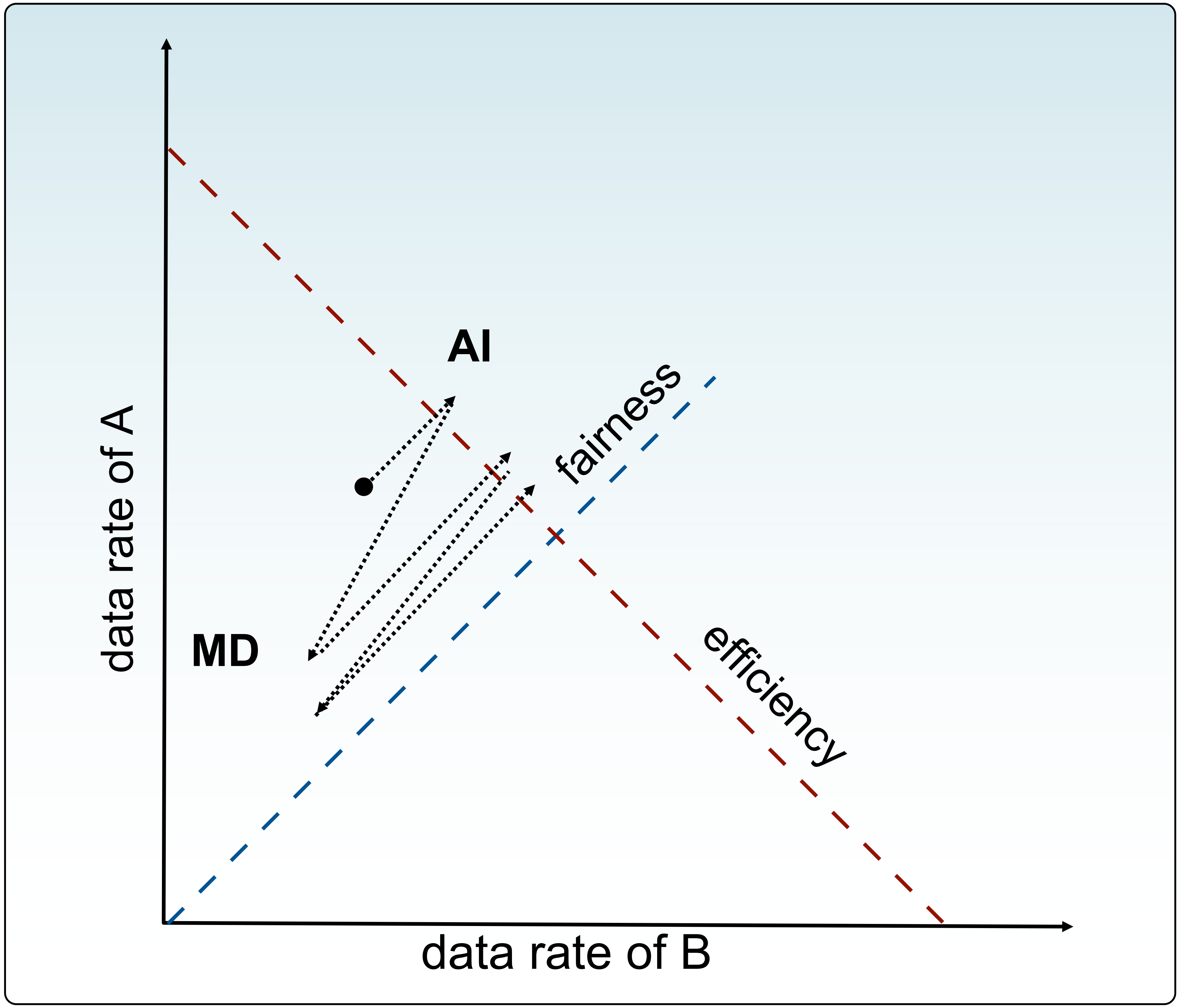
AIAD Additive Increase/ Additive Decrease



MIMD: Multiplicative Incr./ Multiplicative Decrease

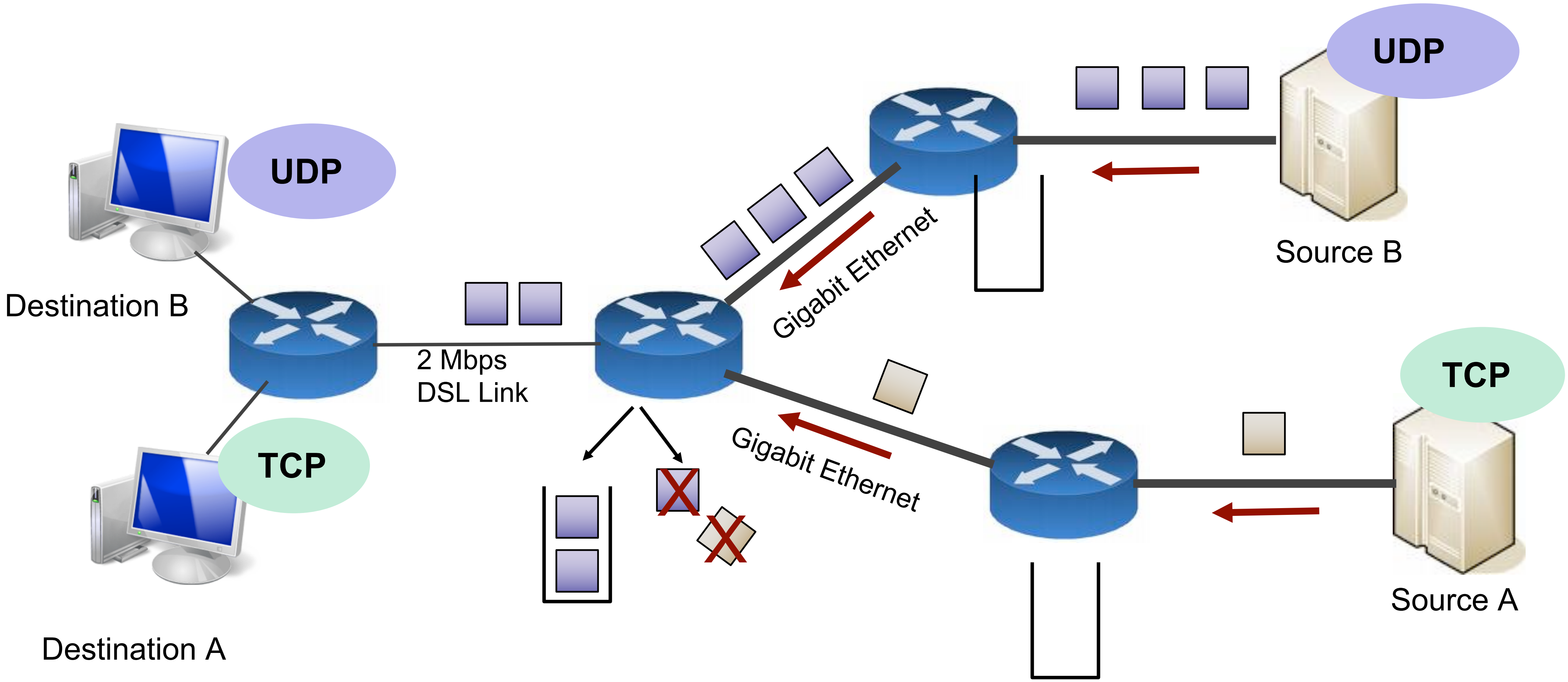


AIMD: Additively Increase/ Multiplicatively Decrease



TCP vs. UDP

- TCP reduces data rate
- UDP does not!

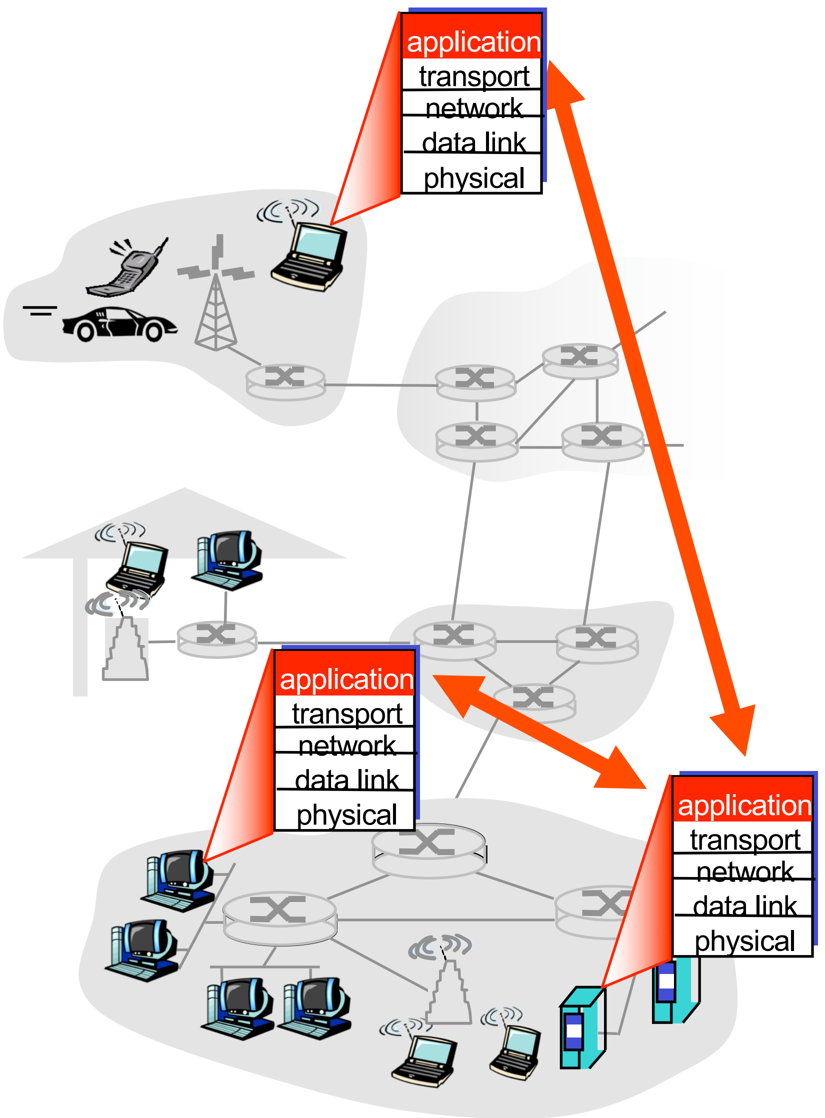


TCP - Conclusion

- 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

Creating a Network App

- Programs that
  - run on (different) end systems
  - communicate over network
  - e.g., web server software communicates with browser software
  - No need to write software for network-core devices
- Network-core devices do not run user applications
  - applications on end systems
  - allows for rapid app development, propagation



Computer Networking: A Top Down Approach
Jim Kurose, Keith Ross

Processes communicating

- Process: program running within a host.
  - within same host, two processes communicate using inter-process communication (defined by OS).
  - processes in different hosts communicate by exchanging messages
- Client process: process that initiates communication
- Server process: process that waits to be contacted
- Applications with **P2P** architectures **have both**
  - client processes & server processes

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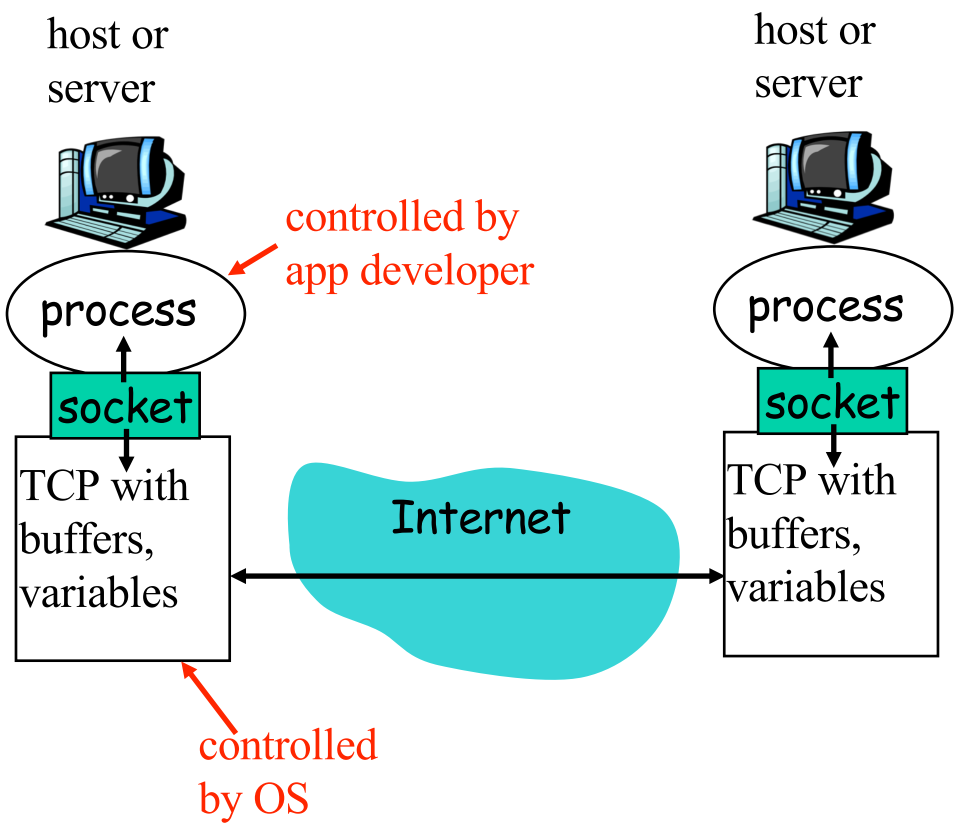
Sockets

- Process sends/receives messages to/from its socket
  - socket analogous to door
  - sending process shoves message out door
  - sending process relies on transport infrastructure on other side of door which brings message to socket at receiving process



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Energy Informatics
3-1 Introduction to Computer Networking

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