# Rechnernetze - Computer Networks

## Lecture 1: Foundation

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Institute of Communications Technology
Leibniz Universität Hannover

April 5, 2024

# Outline

# Schedule

Lecture (V2)

- Friday 08:00-09:30
  - except for May 30 and 31
- e-Classroom eNIFE, Schneiderberg 32
- Course cycle: Every summer term

Exercise (Ü2)

- Instructor: Lukas Prause, Mark Akselrod
- Monday 08:30-10:00
- e-Classroom eNIFE, Schneiderberg 32
- Start: April 8

# Exam and consultation hours

Exam

- written, 90 minutes
- Only the lecture/exercise are relevant for the exam
- Usually 5 credit points unless specified otherwise in your examination regulations

Consultation hours

- Instructor: Lukas Prause, Mark Akselrod
- Monday 10:15-11:15
- Room 1432

# General information

Prerequisites

- Basic course, no prior knowledge of networking required
- Some basics of probability are needed
- Interest in computer networks

References and further reading

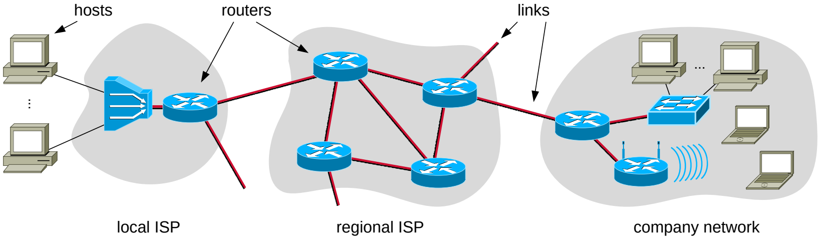
- References to current literature will be provided in the lecture
- Further reading is optional
- Attending the lecture/exercise and taking notes is beneficial
- Course material will be provided on the Stud.IP course page `https://studip.uni-hannover.de/`
- Video recordings via flowcasts `https://flowcasts.uni-hannover.de/`

# Literature

The topics of this course are also covered by the textbooks

- James F. Kurose, Keith W. Ross, Computer Networking: A Top-Down Approach Featuring the Internet, 7th Edition, Pearson, 2016 (also available in German).
- Andrew S. Tanenbaum, David J. Wetherall, Computer Networks, 5th Edition, Pearson, 2013 (also available in German).
- Larry L. Peterson, Bruce S. Davie: Computer Networks: A Systems Approach, 5th Edition, Morgan Kaufmann, 2011.
- Kevin R. Fall, Richard Stevens: TCP/IP Illustrated: The Protocols, 2nd Edition, Addison-Wesley, 2011.

# Internet overview




Nodes

- hosts/end systems run network application programs
  - personal computers, workstations, servers, etc.
  - notebooks, personal digital assistants, cellphones
- routers/intermediate systems forward data to destination hosts

Links connect nodes

- wired, e.g. copper or fibre
- wireless, e.g. radio or infrared

# Delineation



Computer networks

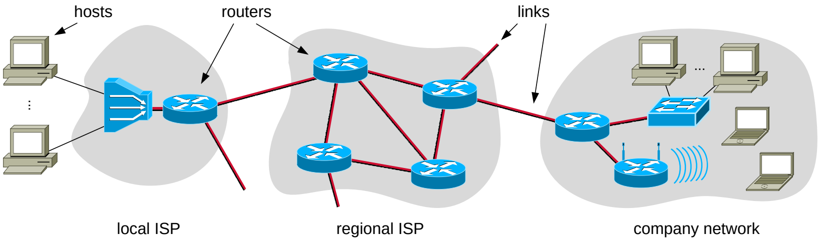
- interconnection of a collection of computers
- implement procedures for data exchange

The Internet is a network of networks.

Distributed systems

- collection of computers that appear as a single system
- uses
  - a computer network
  - a unifying layer of software on top of the operating system, so called middleware
- presents a well-defined application to its users

The World Wide Web (WWW) is a well-known distributed system providing access to web pages, that runs on top of the Internet.




Internet service providers (ISPs)

- autonomous systems
  - can operate on their own
  - internals of an autonomous system are hidden from other ISPs
  - internals need not be changed when connected to other ISPs

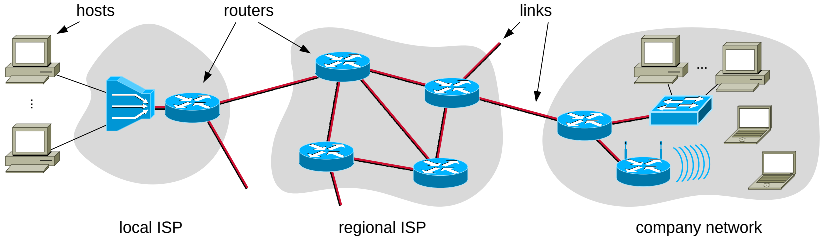
Internetworking

- ISPs form a loosely coupled hierarchy: local, regional, etc.
- peering agreements between ISPs

# Spatial dimension



- LAN: Local area network
  - small spatial dimension, 10-1000 meter
  - typically managed by a single switch
  - medium data rates (1Gb/s), small delays ($< 1$ ms)
  - typically company or privately owned network
- MAN: metropolitan area network
  - campus, city, regional network, several kilometer
  - medium data rates, small delays
  - owned by a network provider, used by several organizations
- WAN: wide area network
  - country wide, worldwide interconnection of networks
  - substantial infrastructure, numerous routers
  - owned by a single or several network providers
  - high data rates (10 Gb/s and more), some delay ($< 100$ ms)




Protocols

- rules for communication and data exchange
  - end-to-end: between hosts respectively end systems
  - hop-by-hop: between routers; between hosts and routers
- examples: HTTP, FTP, SMTP, TCP, UDP, IP

Standardization

- IETF: Internet Engineering Task Force: RFC
- ITU, IEEE, ETSI, 3GPP, ...

# Protocols: an analogy

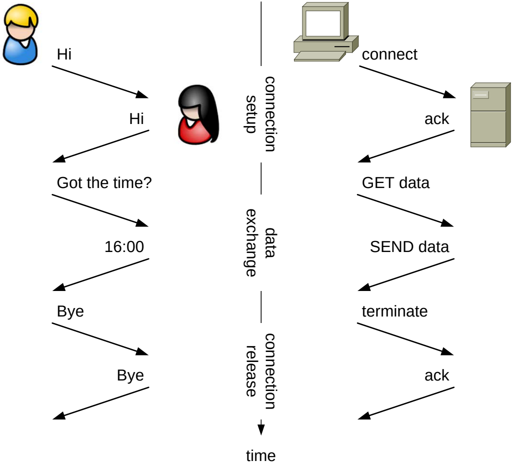
Protocols define

- the format
- the order

of messages and

- the actions

taken in response



# Basic communications relations



A communications relation between two (or more) peers can be

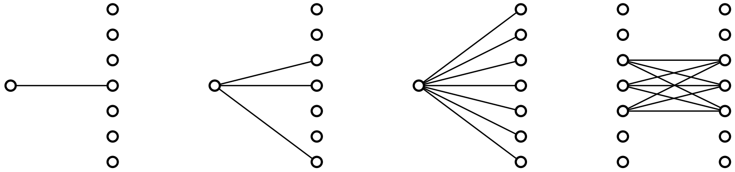
- unidirectional: information flows in one direction only
  - simplex
- bidirectional: information flows in both directions
  - half duplex: the direction of the information flow alternates in time
  - full duplex: information can flow in both directions simultaneously

  moreover bidirectional channels can be distinguished as
  - symmetric: same properties, e.g. data rate, delay, etc., in both directions
  - asymmetric: directional properties, e.g. more download than upload capacity in ADSL

# Cardinality



The cardinality of communications relations can be distinguished as:



unicast

point-to-point

multicast

broadcast

point-to-multipoint

multipoint-to-multipoint
(superposed multicasts)

# Examples

Classify: telephony, pay-per-view TV, DVB, video-conference

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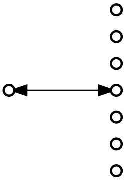
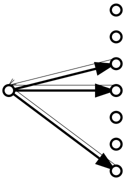
Classify: telephony, pay-per-view TV, DVB, video-conference

telephony



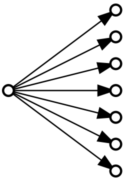
unicast
bidirectional
full duplex
symmetric

pay-per-view



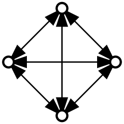
multicast
bidirectional
half/full duplex
asymmetric

digital video
broadcast



broadcast
unidirectional
simplex

video-conference



multipoint-to-
multipoint
bidirectional
full duplex
symmetric

# Physical channels

Institut für Kommunikations-Technik

Two types of transmission technology exist:

- broadcast channels
- point-to-point channels

Broadcast channels

- a single, shared communication channel with many users
  - guided transmission media: e.g. copper cable, fibre
  - unguided transmission media: e.g. radio/air
- transmitted messages are received by all users (broadcast)

Implementation of other communications relations

# Physical channels

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Implementation of other communications relations

- messages are labeled with a destination address
- receivers can filter received messages based on the address
- can be used to implement unicast and multicast

# Physical channels continued



Point-to-point channels

- a single connection between a pair of computers
  - guided transmission media: e.g. copper cable, fibre
  - unguided transmission media: e.g. infrared/air
- messages can only be received by the connected peer (unicast)

Implementation of other communications relations

# Physical channels continued

Point-to-point channels

- a single connection between a pair of computers
  - guided transmission media: e.g. copper cable, fibre
  - unguided transmission media: e.g. infrared/air
- messages can only be received by the connected peer (unicast)

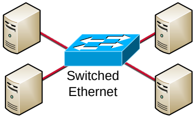
Implementation of other communications relations

- a network comprises several point-to-point links
- messages are labeled with a destination address
- computers can route messages to their destination
- computers can duplicate messages if needed
- can be used to implement multicast and broadcast

# Channel access

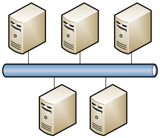
## Centralized control

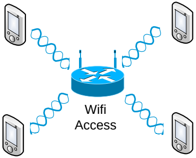
- simple resource allocation, central scheduler has full information
- less reliable, single point of failure
- example: switched Ethernet



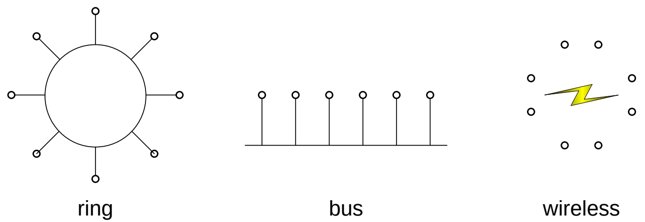

## Distributed control

- difficult resource allocation, incomplete information
- more robust, can be implemented without infrastructure
- examples: shared Ethernet, Wifi access



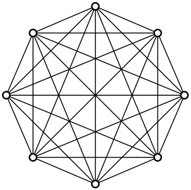



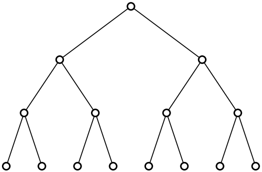
# Topologies: broadcast channels



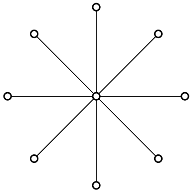

- wired
  - ring (logical)
    - e.g. token ring
  - bus
    - e.g. shared Ethernet
- wireless
  - e.g. Wifi, satellite communications, etc.

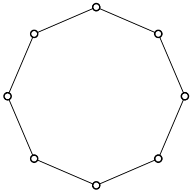
# Topologies: point-to-point channels



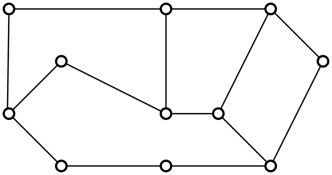




- fully connected mesh
  - full connectivity, no routing required
  - not practical for many nodes
  - used in first telephony systems
- hierarchical tree
  - simple hierarchical routing
  - less reliable, no redundant paths in its basic form
  - used in today's telephony systems




- star
  - simple, one central piece of infrastructure
  - no redundancy, single point of failure
  - used in switched Ethernets
- ring
  - simple routing
  - two redundant paths between any two nodes
  - used in backbone networks



- arbitrary/random topology
  - requires more complex routing algorithms
  - typically redundant paths
  - example: Internet and its predecessor the Arpanet
    - location of nodes and existence of links depends on many factors like geography, economical factors, etc.
    - redundant paths are a key design criterion, the Arpanet was built initially as a military network that could survive the destruction of parts of the network

# German Research Network: DFN X-WiN

Optical platform

- Dense Wavelength Division Multiplex (DWDM)
- equipment from Huawei
- 10000 km fibre, leased from, e.g., Gasline, KPN, Global Connect
- inter-connected optical rings
- working + protection paths

Internet platform

- Routers from Cisco
- 10-40 Gb/s Ethernet
- redundant access links

# Example: Traceroute

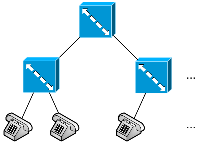


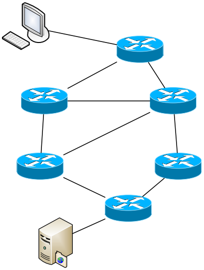
`traceroute www.rwth-aachen.de` (`tracert` in a DOS box) allows you to trace the route of packets through the Internet.

```
1 <1 ms <1 ms <1 ms gateway.ikt.uni-hannover.de [172.23.42.42]
2 <1 ms <1 ms <1 ms 130.75.73.246
3 <1 ms <1 ms <1 ms bwingate.rrzn.uni-hannover.de [130.75.1.253]
4 1 ms <1 ms <1 ms xwingate.rrzn.uni-hannover.de [130.75.9.254]
5 1 ms <1 ms 1 ms xr-han1-te1-3.x-win.dfn.de [188.1.232.205]
6 1 ms 1 ms 1 ms zr-han1-te0-7-0-1.x-win.dfn.de [188.1.145.250]
7 6 ms 6 ms 6 ms xr-dui1-te1-3.x-win.dfn.de [188.1.145.22]
8 9 ms 9 ms 9 ms xr-aac1-te1-1.x-win.dfn.de [188.1.145.26]
9 11 ms 9 ms 9 ms kr-rwth-aachen.x-win.dfn.de [188.1.43.110]
10 * * * time out
11 10 ms 9 ms 9 ms c6k-rwth.noc.RWTH-Aachen.DE [134.130.9.254]
12 9 ms 9 ms 9 ms c6k-hg.noc.RWTH-Aachen.DE [137.226.139.26]
13 * * * time out
14 9 ms 9 ms 9 ms www.RWTH-Aachen.DE [134.130.103.182]
```

How are paths from the sender to the receiver through the network determined?

- end-systems have unique addresses
  - unstructured: MAC addresses
  - (hierarchically) structured: IP-addresses, telephony numbers
- the network performs routing, i.e. it determines the path to the receiver
  - routing algorithms find the best path according to a given metric
  - structured addresses can greatly simplify the task of routing





# IP addresses



## Class C IP address (example)

| 3 | 21 | 8 bit |
|---|---|---|
| 1 1 0 | Network ID | Host ID |

IP addresses have a structure of

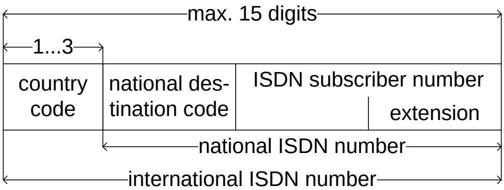
- network identifier
- host identifier

All hosts on the same sub-network have the same network ID

- Internet routing uses only the network ID to forward data to the sub-network of the host
  - reduces the task from at most $2^{29}$ to $2^{21}$ relevant network IDs
  - for comparison Ethernet uses unstructured MAC addresses of 48 bit length, i.e. distinguishes $2^{48}$ addresses
- within the sub-network only the host ID is relevant

# ISDN addresses

ISDN number




ISDN numbers are strictly structured

- country code
- national destination code
- subscriber number (extension)

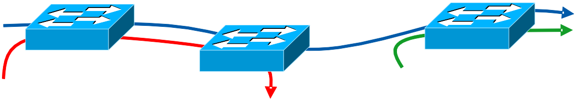
The hierarchical structure matches a tree topology

- routing can be reduced to tree traversal

# Switching



How are resources allocated along a network path?



Fundamental design decision

- circuit switching
  - dedicated circuit
  - e.g. established for each call in telephony networks
- packet switching
  - data are sent through the network in discrete units, i.e. packets
  - no dedicated resources but first-come first-serve principle

# Circuit switching

Circuit switching: Classical method used in telecommunications

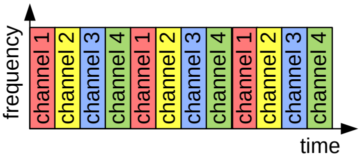
- Connection establishment
- Data transmission (exclusive access to the connection)
- Connection termination

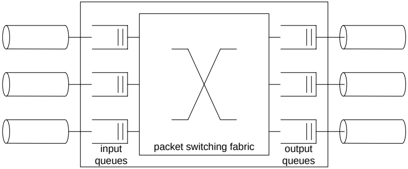
Need to divide a link into multiple 'circuits': Multiplexing

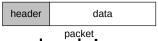
- Time division multiplexing
- Frequency division multiplexing
- Wavelength division multiplexing
- Code division multiplexing

Multiplexing

- Frequency division multiplex (FDM)
  - $n$ frequency bands
  - each frequency band is assigned to one circuit
  - multiplexed signals are transmitted in parallel
- Time division multiplex (TDM)
  - recurrent frame pattern of $n$ timeslots
  - each timeslot is assigned to one circuit
  - multiplexed signals take turns in the medium



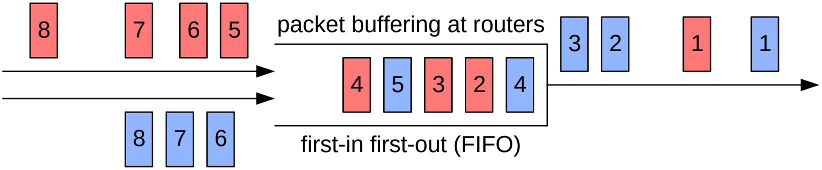

Packet switching: Typical method in computer networks

- before transmission data are divided into packets
- packets carry control information in the header which are used to determine the outgoing interface of the switching fabric
- packets are received and forwarded hop-by-hop
- no fixed capacity allocation
- input and output queues compensate short term overload

# Statistical multiplexing



- Packets are forwarded by the network independently of each other
- Packets of different hosts share and compete for resources
  - During transmission a packet uses all resources of a link
  - If a link is busy subsequent packets have to queue for service
  - Packets are multiplexed on a link statistically



# Comparison of switching technologies



Circuit switching

- Advantages
  - constant, computable quality of service, e.g. bandwidth, delay
  - no interference by third, data loss occurs rarely
- Disadvantages
  - resources remain allocated even if no data is transmitted
  - must establish connection before data transmission
  - connection establishment succeeds only if unused channels exist at every hop

Packet switching

- Advantages
  - queuing and scheduling achieves a flexible resource allocation
  - resources are (theoretically) available to all customers
  - much more efficient resource utilization
- Disadvantages
  - quality of service, e.g. bandwidth, delay, can hardly be ensured
  - applications with defined, fixed resource requirements are difficult to support

# ISO/OSI and TCP/IP reference models

## ISO/OSI reference model

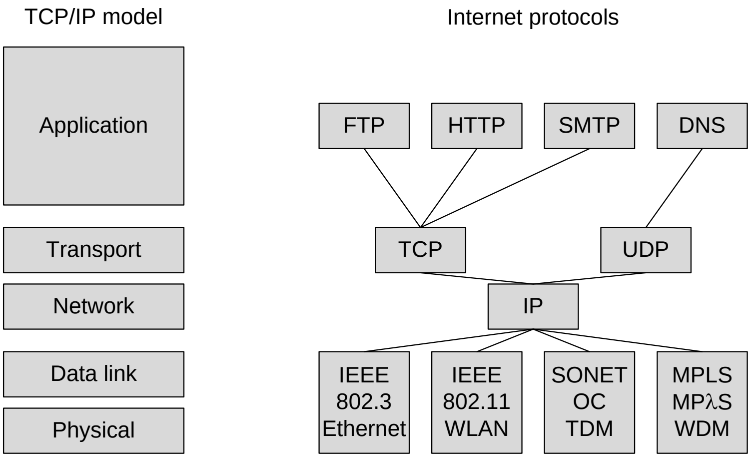
| | |
|---|---|
| Application | Anwendung |
| Presentation | Präsentation |
| Session | Sitzung |
| Transport | Transport |
| Network | Vermittlung |
| Data link | Sicherung |
| Physical | Bitübertragung |

## TCP/IP reference model

| | |
|---|---|
| Application | Anwendung |
| Transport | Transport |
| Network | Vermittlung |
| Data link | Sicherung |
| Physical | Bitübertragung |

# TCP/IP model and protocol suite





# Topics of the lecture



Overview of the lecture

- Foundation
- Direct Link Networks
- Packet Switching
- Internetworking
- End-to-End Protocols
- Applications