Introduction

Advanced Computer Networks

Summer Semester 2012

Organizational Information

- https://wiki.net.informatik.uni-goettingen.de/wiki/Advanced_Computer_Networks_(Summer_2012)

- Slides are available online
- Course is held in English

- 6 ECTS credits (old + new PO)
- M.Inf.1222.Mp, M.Inf.1223.Mp, M.Inf.221.3C1

Organizational Information

- Exam: 2012-07-19
- Additional requirement to pass the course is to give a 20-30min talk on a topic provided
  - Topics are typically research papers covering material discussed throughout the lecture
  - Presentations: 2012-06-21
- Check the FlexNow registration deadlines

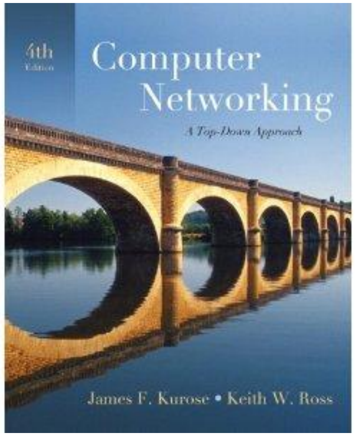
Course Overview

- This course covers (currently):
  - P2P Networks
  - Distributed Hash Tables
  - CDN/CCN
  - Cloud Computing
  - Security
  - Social Networks
  - Mathematical Models

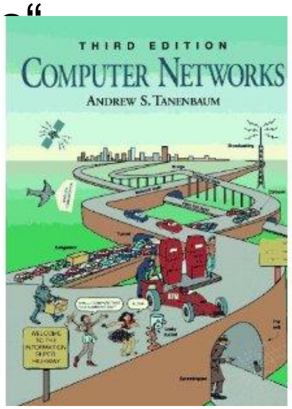
- Please note that the slides are subject to change. Before the exam, please check again the wiki for updated slides and other info!

Course Materials - Basics

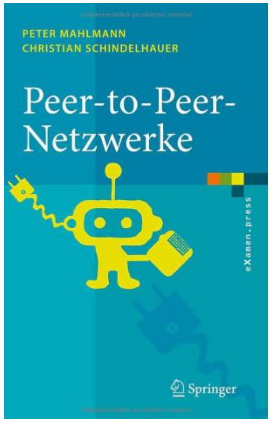
- J. Kurose and K. Ross, "Computer Networking: A Top-Down Approach Featuring the Internet“ (some slides are based on the book)



- A. S. Tanenbaum, "Computer Networks“



- C. Schindelhauer, Peer-to-Peer Netzwerke (german)

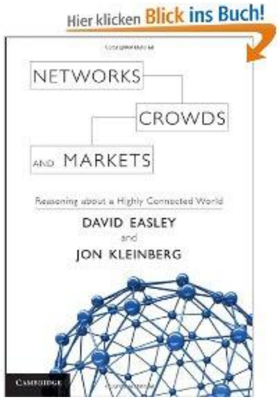


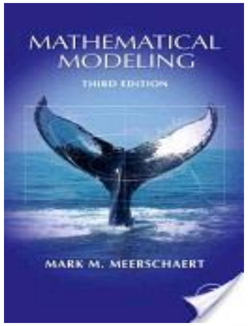
- Further materials are released on the wiki

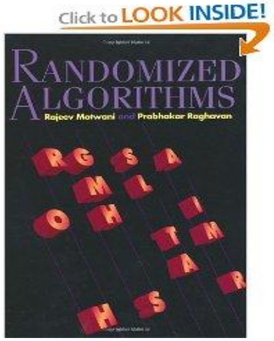
computer NETWORKS

Course Materials - Advanced

- References
  - David Easley and Jon Kleinberg, Networks, Crowds, and Markets: Reasoning About a Highly Connected World, Cambridge University Press, 2010.
  - Mark M. Meerschaert, Mathematical Modeling (3th Edition), Elsevier Academic Press, 2007.
  - Rajeev Motwani and Prabhakar Raghavan, Randomized Algorithms, Cambridge University Press, 1995







Recap of Basics

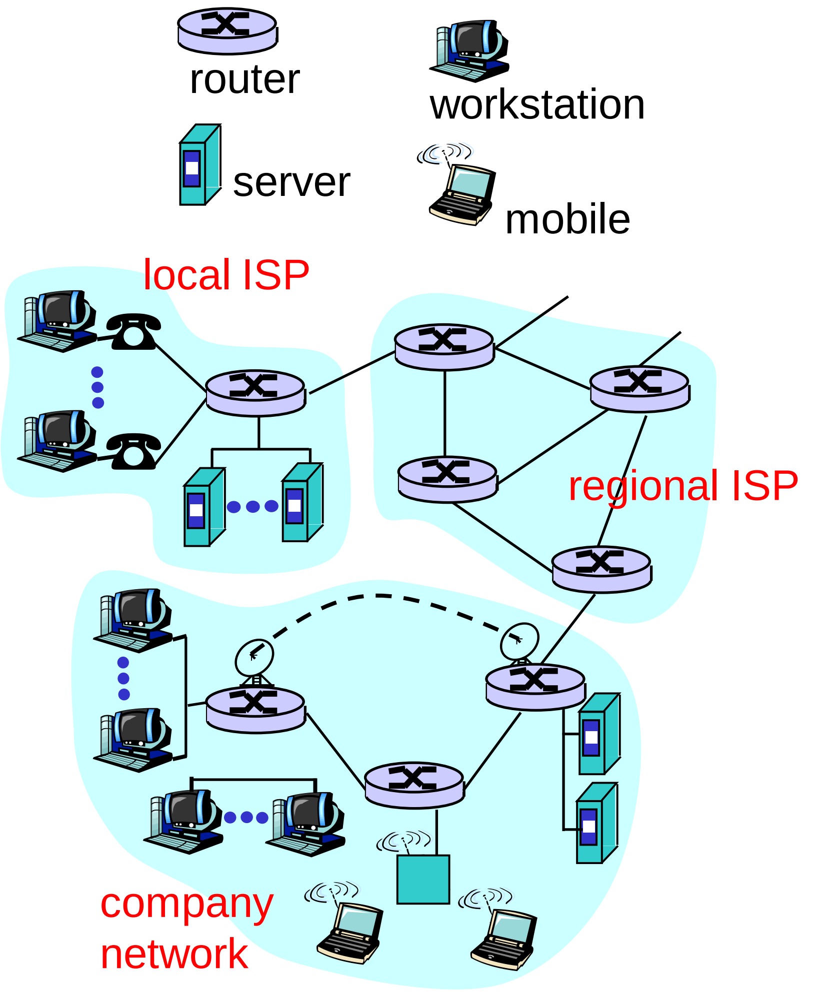
- The following slides repeat fundamentals for advanced networks:
  - Protocols / Layering
  - The hierarchical structure of the Internet
  - Addressing on the different layers
  - Routing and IP subnet aggregation
  - Layer 4 services such as reliable data transfer

- If something is new for you, please review the Computer Networks slides at: https://wiki.net.informatik.uni-goettingen.de/wiki/Computer_Networks_(Winter_2011/2012)

What is the Internet?

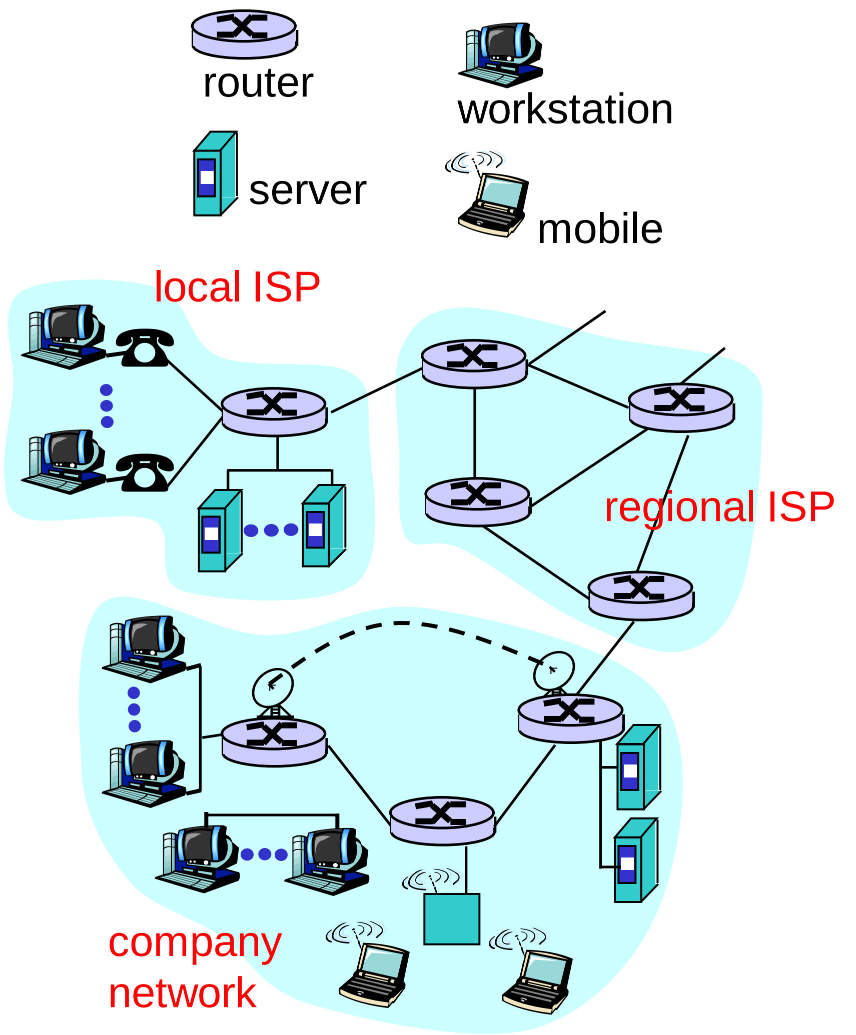
What is the Internet?

- millions of connected computing devices: *hosts, end-systems*
  - PCs, workstations, servers
  - PDAs, phones, toasters
  - running *network apps*
- *communication links*
  - fiber, copper, coax, radio, satellite
  - transmission rate = *bandwidth*
- *routers:* forward packets (chunks of data)



What is the Internet?

- *protocols* define format, order of msgs sent and received among network entities, and actions taken on msg transmission, receipt
- *Internet:* "network of networks"
  - loosely hierarchical
  - public Internet versus private intranet
- *Internet standards*
  - RFC: Request for Comments
  - IETF: Internet Engineering Task Force



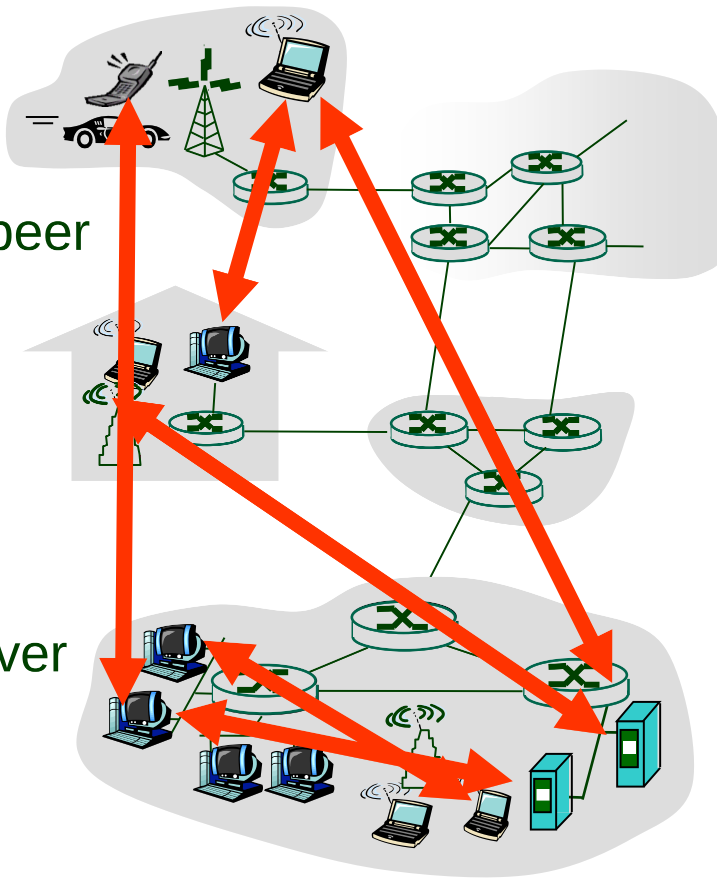
What is the Internet?

- The network is typically divided into the network core and the network edge
  - Edge: end systems, access networks, links
  - Core: circuit switching, packet switching, network structure, routers etc.

- Users access the Internet from the edge: e-mail, http web access, applications, social networks

At the edge

- client/server model
  - client host requests, receives service from always-on server
  - e.g. web browser/server; email client/server
  - **Is that optimal for large scale?**
- peer-peer model:
  - minimal (or no) use of dedicated servers
  - e.g. Skype, BitTorrent

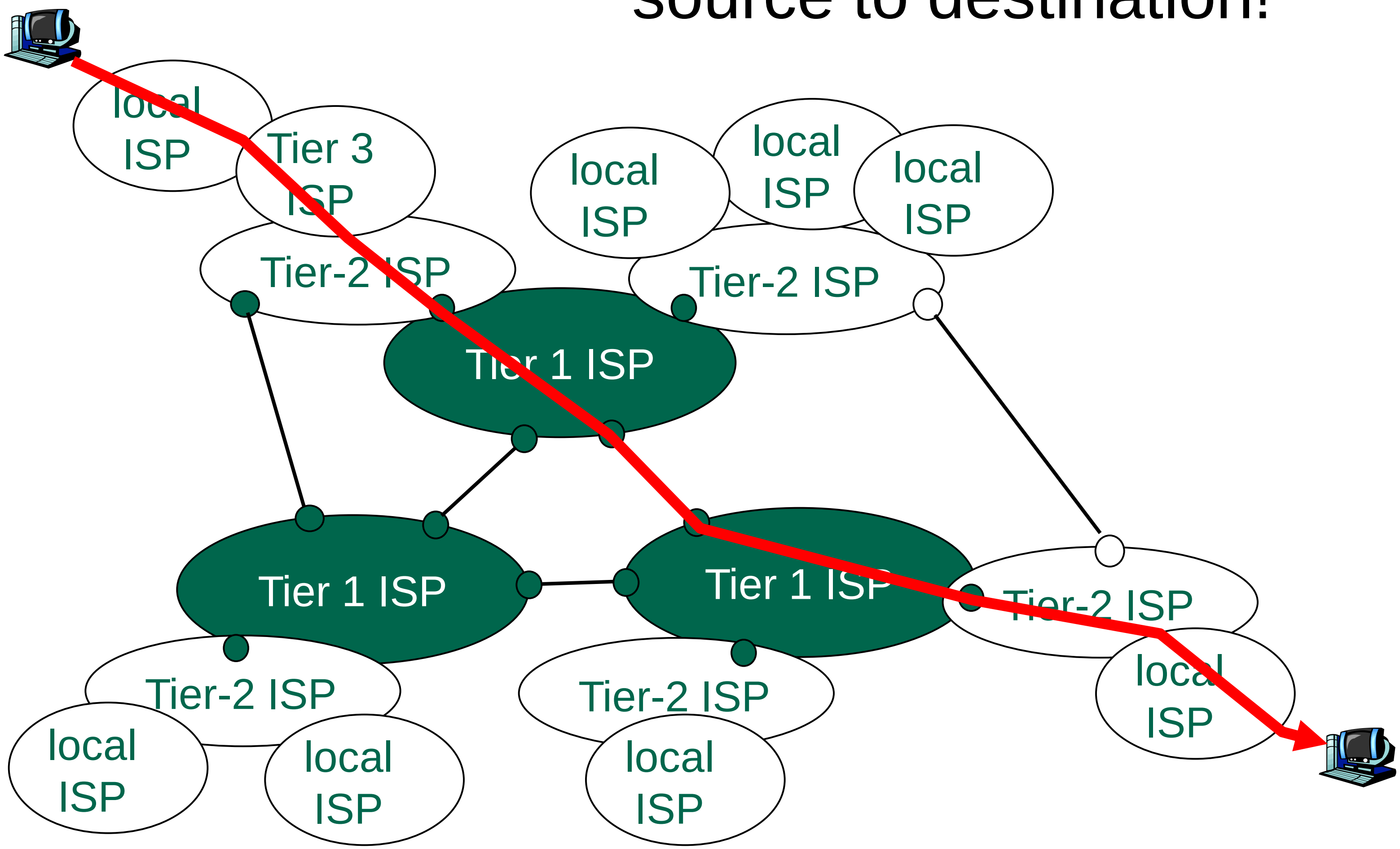


Packet Switching Implications

- End data stream is divided into „packets“
- Multiple users share network resources
  - Sequence of packets does not have fixed pattern, this effect is called statistical multiplexing
  - Each packet uses full bandwidth
  - Resources are used as needed
- No dedicated resource allocation!
- Demand may exceed resources:
  - Congestion, delay, loss

Hierachical Structure

- A packet traverses multiple networks from source to destination!



Impact of Hierarchy

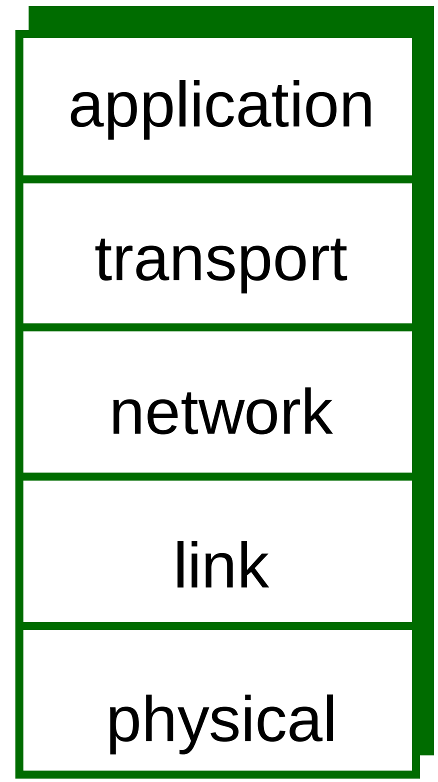
- Main goal accomplished:
  - Efficient, works!
- But:
  - Providers have to buy resources from higher tiers or exchange directly on low tier level (peering)
  - Transferring data through external network is costly
  - Many modern technologies make it relevant HOW a packet traverses through the net
    - File sharing consumes large of resources, P2P is not business model of providers! Providers have an incentive to control P2P flows!
  - Efficient content delivery of large amounts of data (IP-Television, Video etc…)

Protocol Layering

- Networks are complex and consist of many pieces: hosts, routers, links, applications, protocols et cetera...
- Idea: Simplify by using layers to distinguish organizational parts of networking.
- Inspired by other, real-world „layered“ processes

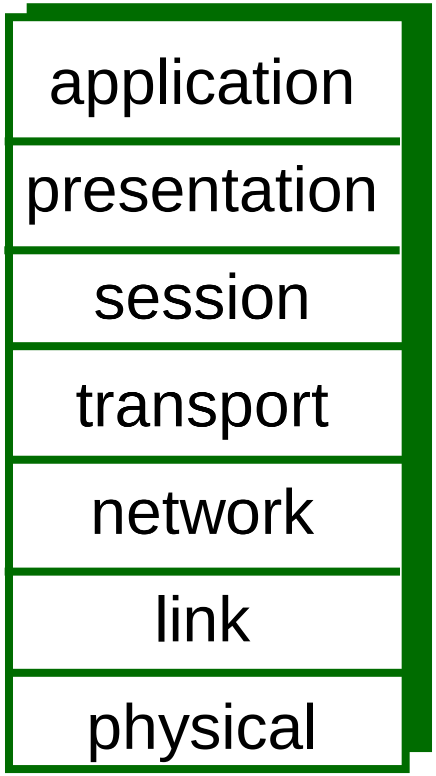
Internet Protocol Stack

- Application: network apps
  - FTP, SMTP, HTTP
- Transport: process-to-process data transfer
  - TCP, UDP
- Network: routing of datagrams from source to destination
  - IP, other routing protocols
- Link: data transfer between neighboring network elements
  - PPP, Ethernet
- Physical: bits „on the wire“



ISO/OSI Reference Model

- Presentation: allow applications to interpret meaning of data, e.g., encryption, compression, machine-specific conventions
- Session: synchronization, checkpointing, recovery of data exchange
- Internet stack "missing" these layers!
  - these services, *if needed,* must be implemented in application
  - needed?



Layering Challenges

- Many modern networks are application level networks
  - Social Networks such as Facebook, Twitter etc.
- P2P networks are a mixture of different layers
  - Sometimes implementing application level data lookup, packet (chunck) forwarding etc.
- Large scale applications demand optimizations on various levels:
  - Content delivery of large data streams!

Layer 2 - Principles

- Switch processes up to layer 2
- Principles:
  - Reliable transmission of data over a link
  - Error detection, correction
  - Sharing a broadcast channel: multiple access
  - Link layer addressing
- Layer 2 packet is referred to as frame

data-link layer has responsibility of transferring datagram from one node to adjacent node over a link

Layer 2 – Error Detection

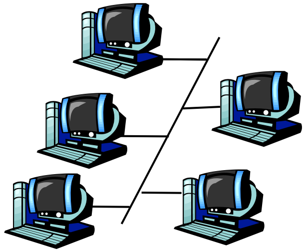
- Implemented in layer 2 adaptors (network interface cards etc.)
- Idea: Combine data payload with a Checksum to detect transmission errors

- Implemented using Cyclic Redundancy Checksum

- Typically frame is dropped if error occured. Re-transmit (reliability) has to be implemented at other layer

Layer 2 – Multiple Access Prot.

- In general two types of „links“:
  - Point-to-Point (e.g., PPP for dial-up, link between Ethernet switch and host)
  - Broadcast medium
    - Shared wire in old Ethernet
    - 802.11 wireless LAN



shared wire (e.g., cabled Ethernet)

- In broadcast:
  - Distributed algorithms determine how nodes share channel and transmit
  - No „out-of-band“ channel for coordination

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Layer 2 – Addressing

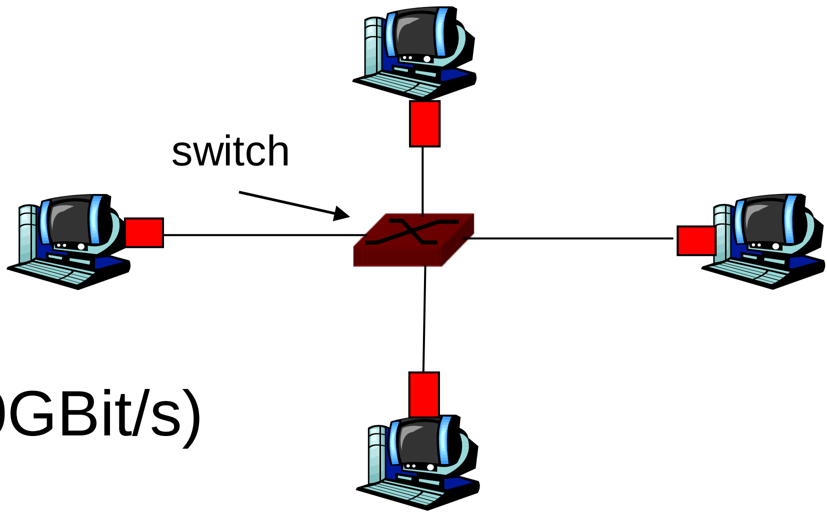
- 48 BIT MAC address
  - Burned in NIC Rom (sometimes software settable)
  - Should be unique (vendors have MAC-ranges)
  - No hierachical or aggregatable information! Also called flat address.
- IP to MAC address resolved using the Address Resolution Protocol (ARP)
  - Idea: Broadcast query: „Who has IP ...?“. Host with queried IP replies unicast „IP ... is at MAC ...“.

Layer 2 – Forwarding

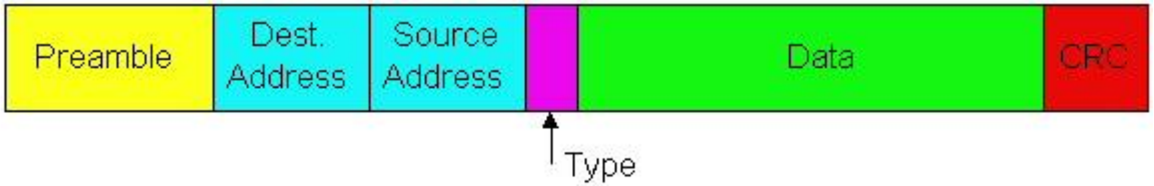
- Solved by switches
  - Learns in a plug and play mode, no configuration necessary!
  - Question: On what switch-port to forward incoming dataframe
    - If destination MAC is known (in forwarding table) and associated to a port, use that port
    - If destination MAC is unknown, broadcast the dataframe on all ports
    - If a packet with an unknown source MAC is observed, create an entry in the forwarding table that binds port to MAC

- Only works in the broadcast domain! No routing!

Layer 2 – Ethernet



- Very common, very cheap
- Scales well (from 10MBit/s – 10GBit/s)
- Star topology used (no collisions!)
- Frame:

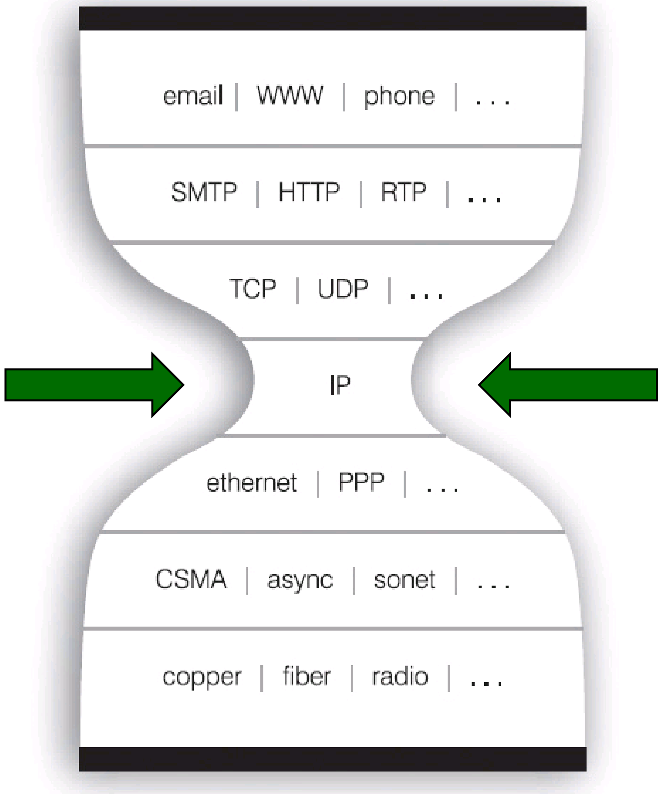


- Connectionless, unreliable
- Access protocol: CSMA/CD

Layer 3 – Principles

- Internet Protocol dominant networking technology
- Network layer transports datagrams from sending to receiving host
- Protocol runs in every host and router (not in switches!)

Hourglass architecture



Layer 3 – Routing

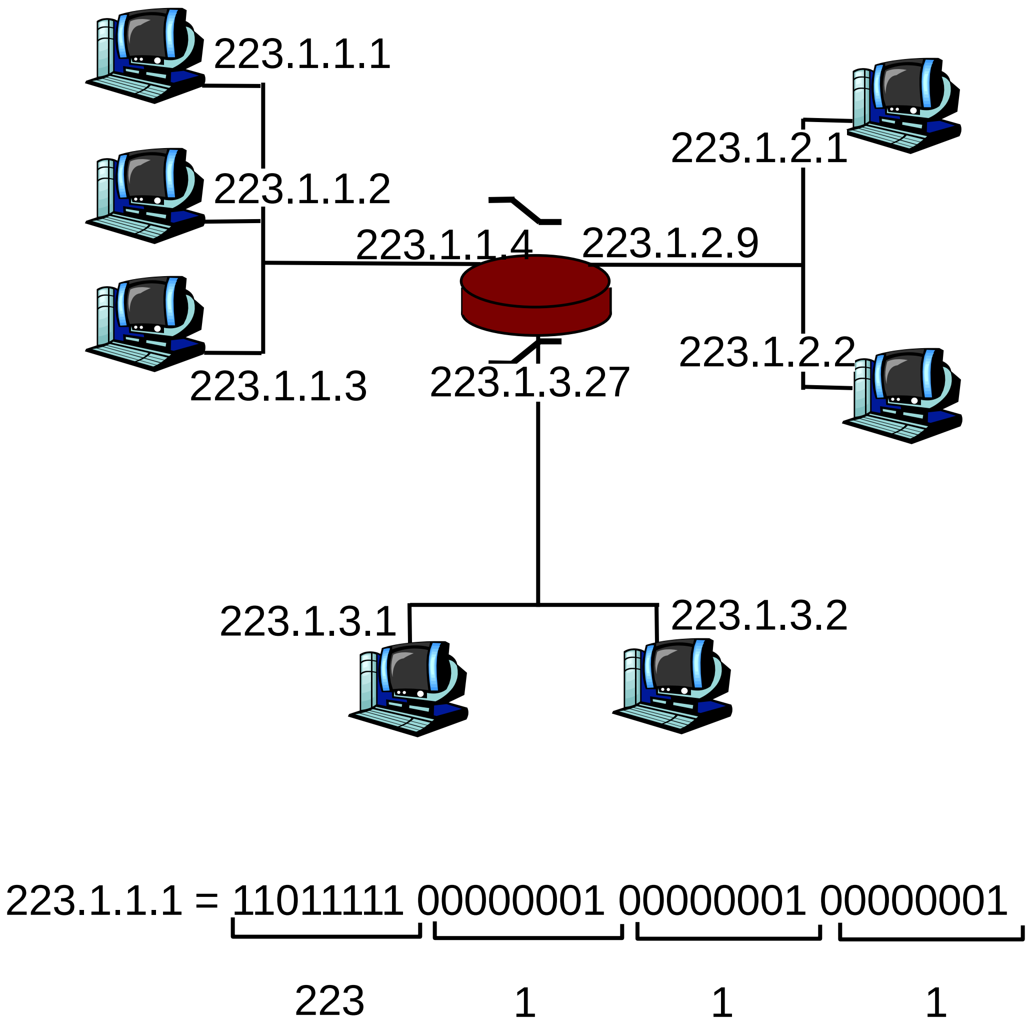
- Routing: determine the route taken by packts from source to destination
  - Analogy: planning a road trip from one city to another

- Functions of a router:
  - Forward datagram from incoming to outgoing link
  - Select outgoing link by running a routing algorithm
    - Examples: RIP, OSPF, BGP

- Routers buffer packets (buffer size rule of thumb: Round-Trip-Time times link capacity
  - Buffering source of delay, overflowing buffer causes loss

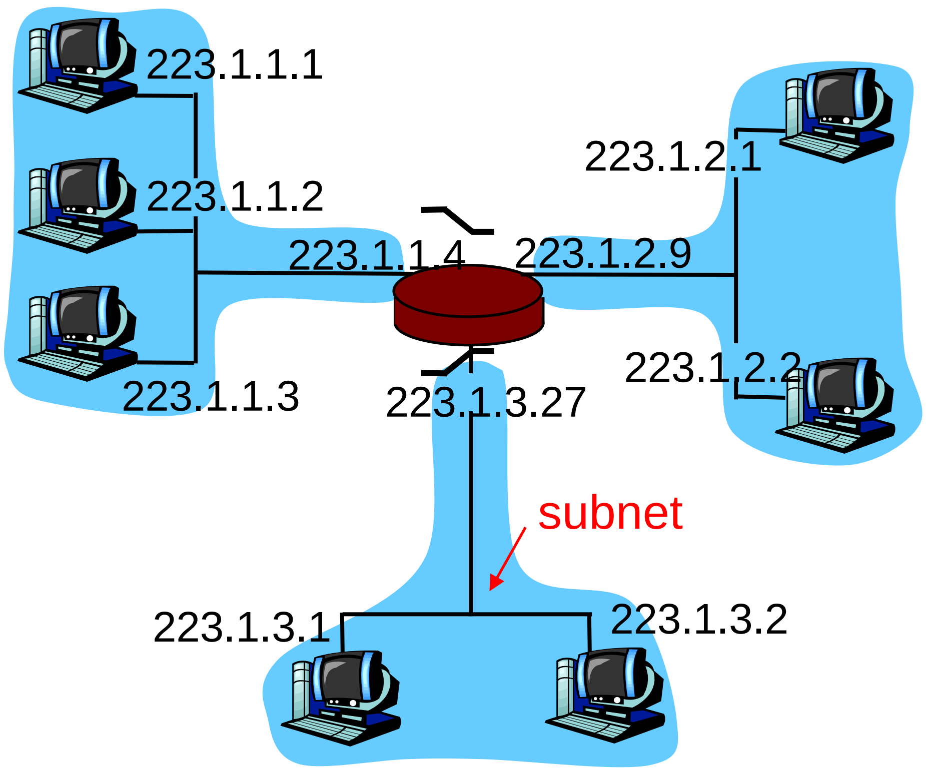
Layer 3 – Addressing

- IP address: 32 bit identifier for host, router interface
- Interface: connection between host/router and physical link
  - Routers typically have multiple interfaces
  - Hosts typically have one interface
  - IP address associated with each interface



Layer 3 – Subnets

- IP address not flat
- Hierachical structure of „subnets“
- Inside a subnet:
  - All device interfaces share part of IP address
  - Devices can reach each other without intervening a router



network consisting of 3 subnets

Layer 3 – How to get an IP?

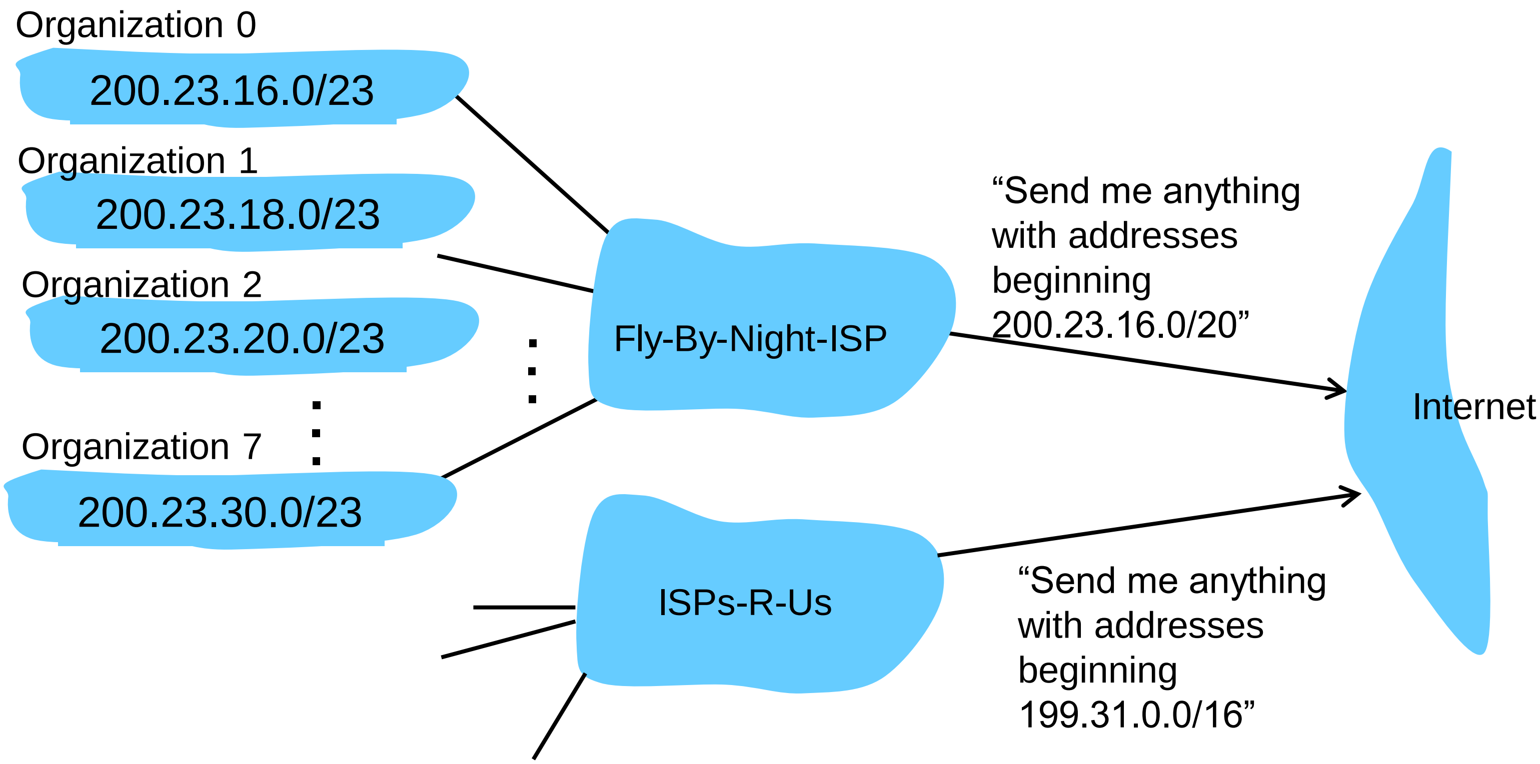
- MAC address was set by vendor

- IP needs to be obtained from ISP
  - Either in a fixed configuration
  - Or using the Dynamic Host Configuration Protocol (DHCP) (server offers service and hosts request IPs)

- How does the ISP get address space?
  - Allocated by higher Tier! (remember the hierachy)
  - Highest assignment done by Internet Assigned Numbers Authority (IANA) via ICANN in the US

Layer 3 – Aggregation

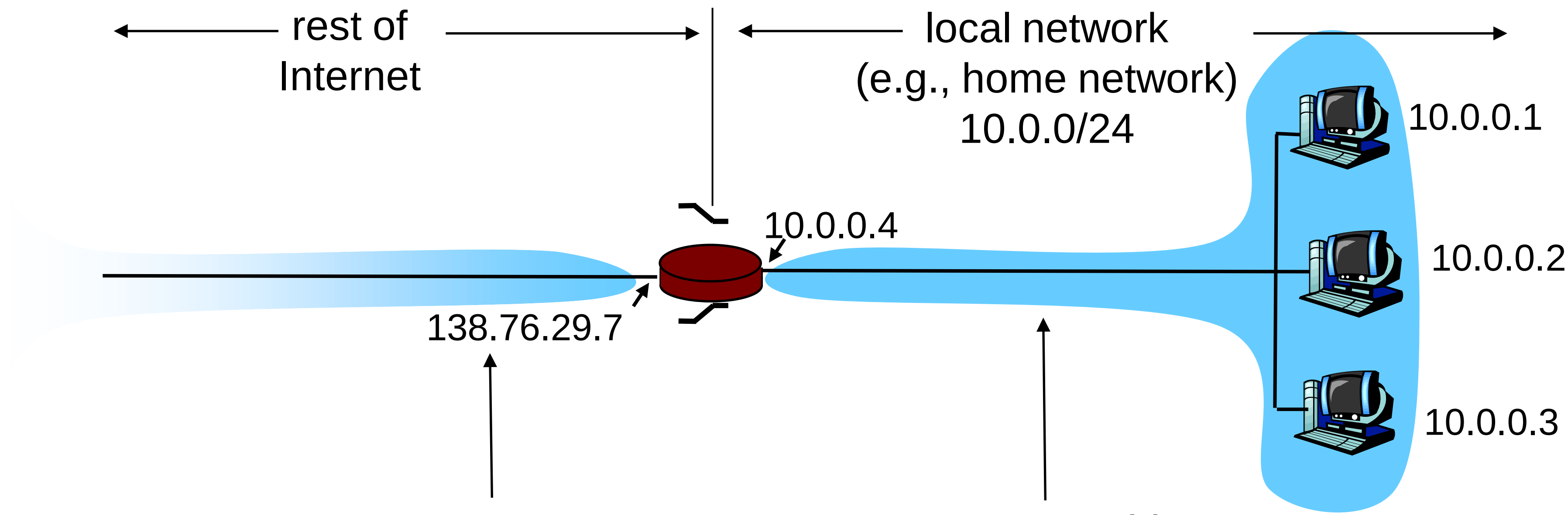
- Hierachical addresses allow to aggregate some prefixes:



Layer 3 – NAT

- Network address translation (NAT) allows local network to have more users than assigned IP addresses!
  - Use one IP address for all devices
  - Addresses inside the network can change without need to notify the outside world
  - The ISP may change without changes necessary inside the network
  - Devices inside the local network are not explicitly addressable by the outside world!
    - Security plus but makes connections more difficult!

Layer 3 – NAT



All datagrams *leaving* local network have same single source NAT IP address: 138.76.29.7, different source port numbers

Datagrams with source or destination in this network have 10.0.0/24 address for source, destination (as usual)

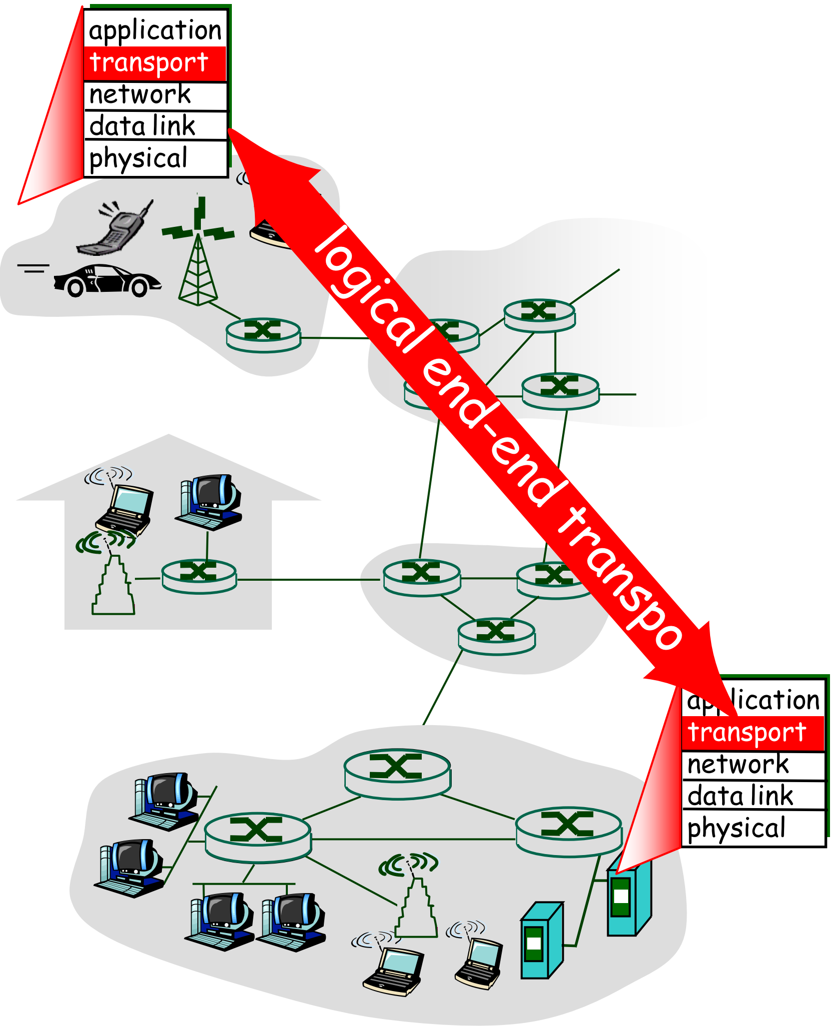
Layer 3 – NAT Challenges

- NAT violates end-to-end argument
- NAT traversal hard to solve for certain applications, for example P2P
- Address shortage should instead be solved by IPv6

- P2P Networks require to directly connect the destination host! How can this be solved?

Layer 4 – Principles

- Provide logical communication between app processes running on different hosts
- Relies on and enhances network layer services
- Analogy: Network = postal service, Transport = secretaries at sender and receiver



Layer 4 – UDP and TCP

- UDP provides unreliable, unordered delivery
  - Conceptually minimal transport layer protocol with „best-effort“ IP
- TCP provides
  - Reliable data transfer
  - In-order delivery
  - Congestion control
  - Flow control
  - Connection setup

- Both protocols do not guarantee certain delays or bandwidths

Layer 4 – UDP and TCP

- UDP is minimalistic, therefore
  - Used in time-critical applications (Voice over IP)
  - Used when loss or out-of-order delivery is not critical
  - When the concept of connection is not of high relevance
- TCP ensures reliable data transfer:
  - Used when correctness is important
  - Typically used in all long-term non voice/video connections such as file transfers

Layer 4 – Addressing

- TCP socket is identified by 4-tuple:
  - Source IP address
  - Source port number
  - Destination IP address
  - Destination port number
- This allows multiple apps to communicate simulataniously with same source and destination host but, for example, different source port

Layer 4 – Data Transfer

- Reliable data transfer (TCP only) is ensured by
  - Maintaining state for each packet or group of packets (timeout timers)
  - Resend upon loss
    - Loss is inferred by missing Acknowledgments
  - Only send new packets if previous ones got acked
- Speeding things up: Pipelining
  - Idea: Maintain a large group of packets „on the fly" using a window. Examples: Go-back-N, Selective Repeat

Layer 4 – TCP Properties

- Point-to-Point - one sender, one receiver
- Reliable, in-order delivery
- Pipelined – TCP congestion and flow control sets window sizes
- Send & receive buffers
- Full-duplex data transfer
- Connection oriented
- Flow-Control – Sender prevents to overwhelm receiver

Application Layer

- Applications and application layer protocols:
  - HTTP/HTTPs for Web-Access
  - SMTP for e-mail
  - FTP/SFTP for data transfer
  - Many more…

- Challenge:
  - Utilize social information, peer-to-peer services, intelligent data storage and services (cloud) etc. to optimize content delivery!

Different kinds of networks

- Content Distribution/Delivery Networks
  - Traditional client/server architecture
  - Centralized using multiple data centers
  - Utilizing server replication to enhance reliability
  - Big issues: load balancing, bandwidth allocation

- Idea: use P2P to decentralize network traffic

Peer-to-Peer Networks

- Totally decentralized
- Self organized
- Every peer acts as a server and client
- Distributed algorithms

- How to find and retrieve data in the P2P network?
  - Distributed Hash Tables!
- How to ensure high service quality?
  - Security

Cloud Computing

- Many networks composed of computationally weak clients
  - Smartphones, low energy devices
- Idea: Outsource all heavy computation to a centralized, powerful resource
  - Cloud computing
  - Again centralized infrastructure!
- Different from CDN as it provides not only delivery of content:
  - Also can provide computational services
  - Infrastructure services
  - Platform services
  - Software as a service

Networks in General

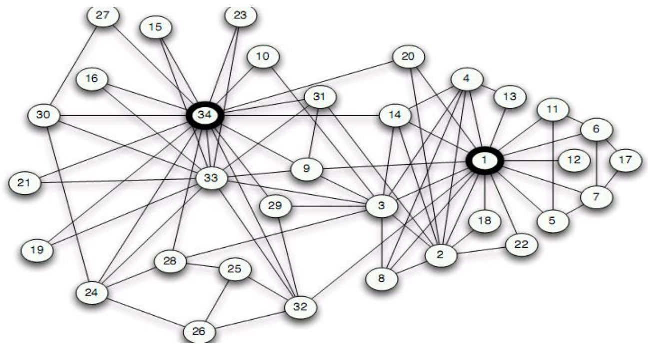
- Motivation: What can we learn from IP networking that can be used in different fields for good?

- Many classical networks known:
  - Street network
  - Railroad network
  - Power grid

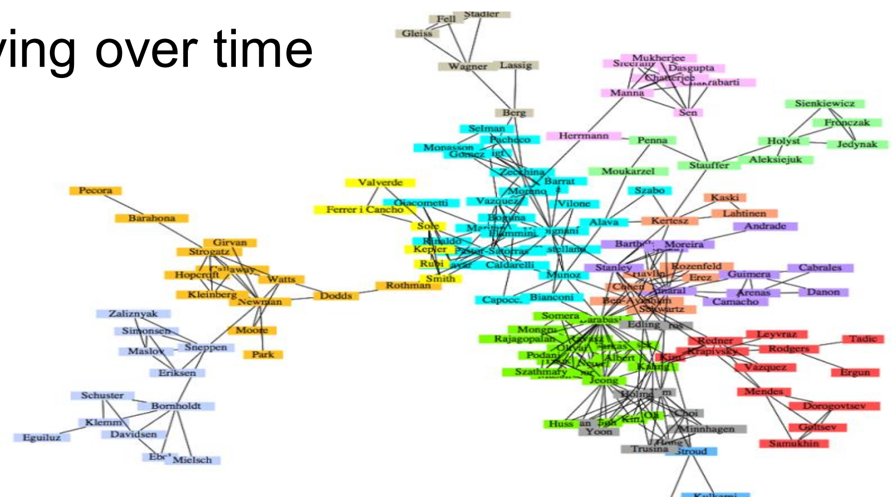
- But also networks that only recently found their technical representation:
  - Social networks

Social Networks Preview

- Social Network
  - A network made up by a set of individuals interconnecting with each other basing on social relationships (such as friendships, partnerships, etc.)
- Characteristics
  - Virtual: it is not physically exists
  - Complex: it consists of a large scale number of nodes
  - Grouping: it forms communities due to different interests
  - Dynamic: it's structure is evolving over time



A friendship network in a karate club



A co-authorship network

Social Networks Preview

- Structure: concepts and principles
- Power law distribution in node degree
- Cascading behavior in social networks
- The Small-World phenomenon
- Epidemics: disease and information transmission in social networks

Outlook

- In the next lectures:
  - Peer to Peer – From Napster to BitTorrent
  - Efficient lookup and data localization with distributed hash tables
  - Efficient content delivery with content centric networking…