Introduction

Advanced Computer Networks

Summer Semester 2017

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Organizational Information

- https://wiki.net.informatik.uni-goettingen.de/wiki/Advanced_Computer_Networks_(Summer_2016)

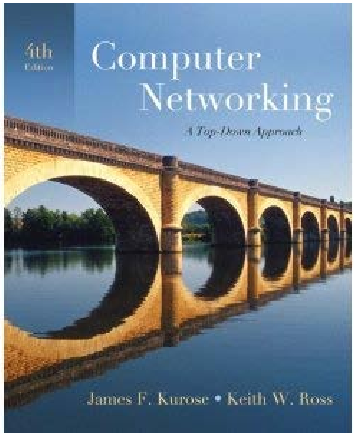
- Slides are available online
- Course is held in English

- 5 ECTS credits
- AI: M.Inf.1223.Mp
- ITIS: 3.17

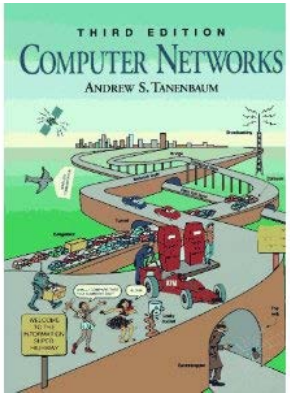
Organizational Information

- Grading: 100% final exam (July 13th 2017)
- Check the FlexNow registration deadlines

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“



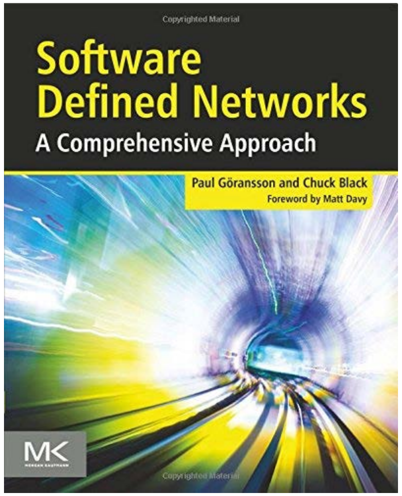
- Further materials are released on the wiki

Other related courses in SS17

- Practical Course on Advanced Computer Networking: Data Science Edition
- Seminar on Internet Technology

Course Materials - Advanced

- New Networking Technologies
  - Paul Goransson and Chuck Black, Software Defined Networks: A Comprehensive Approach (1st edition), Morgan Kaufmann, 2014.



Recap of Basics

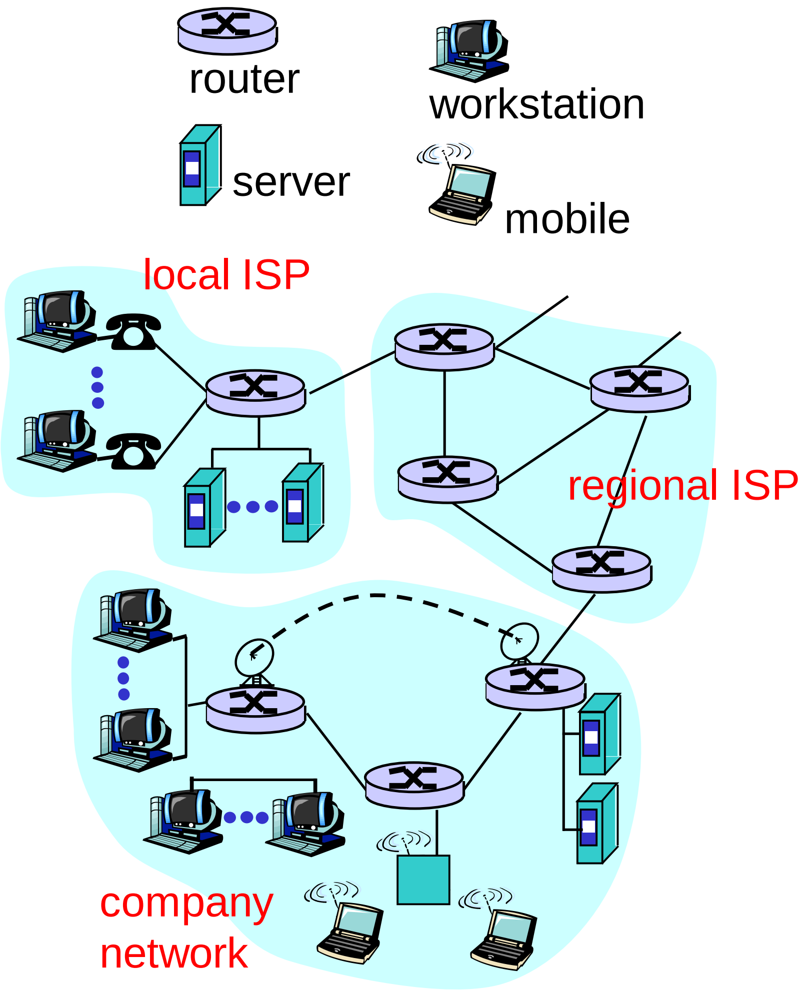
- The following slides repeat fundamentals for advanced networks:
  - Protocols / Layering
  - The hierarchical structure of the Internet
  - Addressing on the different layers
  - Routing and IP subnet aggregation
  - Layer 4 services such as reliable data transfer

- If something is new for you, please review the Computer Networks slides at: https://wiki.net.informatik.uni-goettingen.de/wiki/Computer_Networks_(Winter_2016/2017)

What is the Internet?

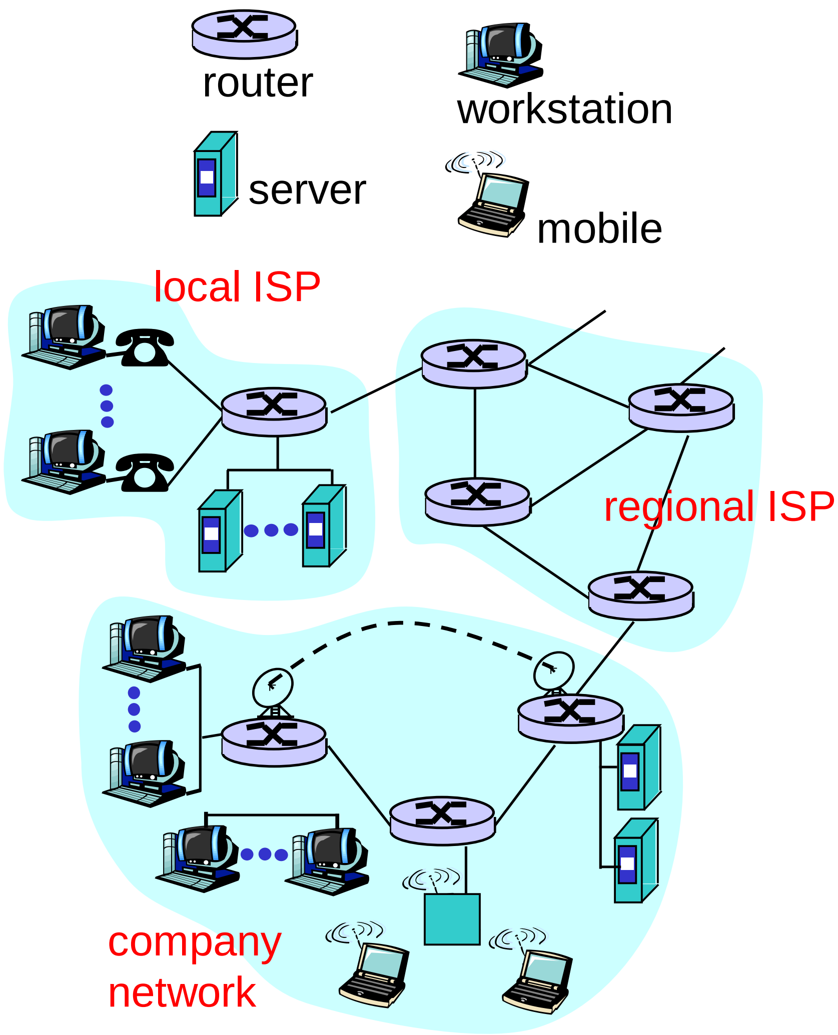
What is the Internet?

- 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?

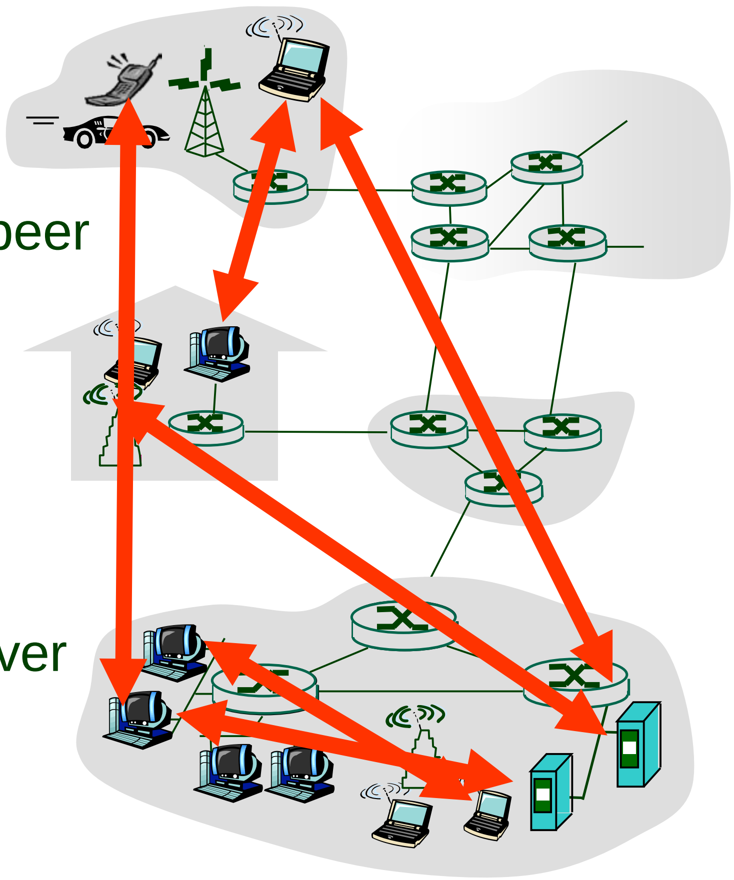
- The network is typically divided into the network core and the network edge
  - Edge: end systems, access networks, links
  - Core: circuit switching, packet switching, network structure, routers etc.

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

computer 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

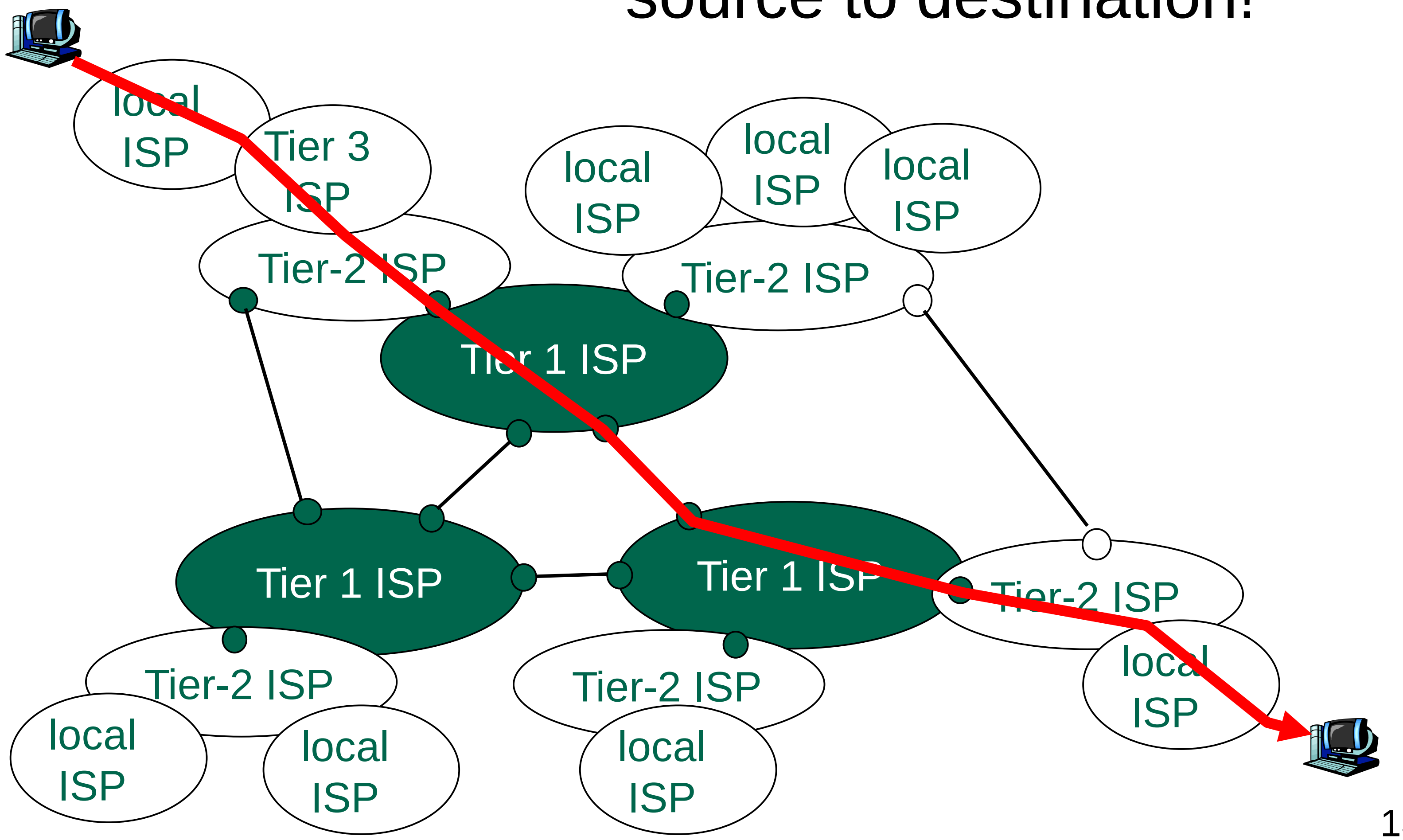


Packet Switching Implications

- 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

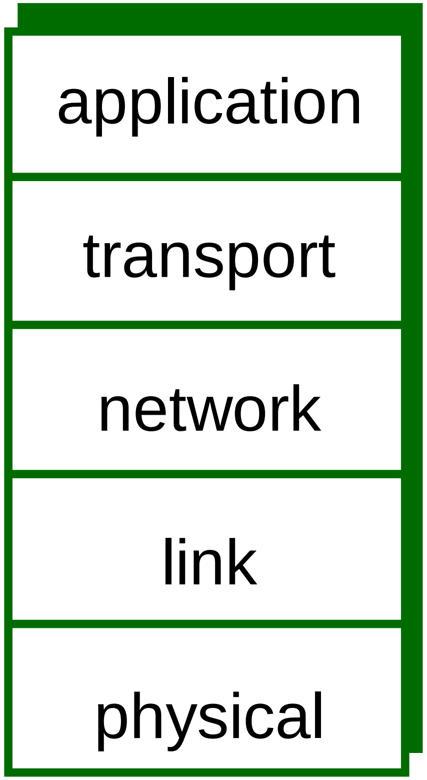
- Main goal accomplished:
  - Efficient, works!
- But:
  - Providers have to buy resources from higher tiers or exchange directly on low tier level (peering)
  - Transferring data through external network is costly
  - Many modern technologies make it relevant HOW a packet traverses through the net
    - 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

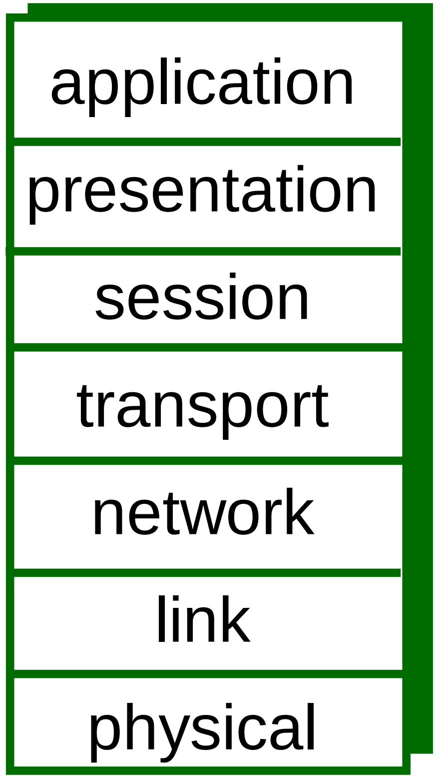
Internet Protocol Stack

- 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 (chunk) 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

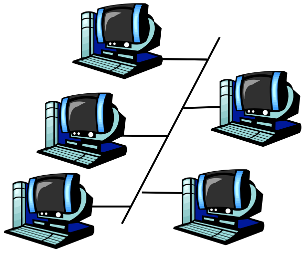
- Implemented in layer 2 adaptors (network interface cards etc.)
- Idea: Combine data payload with a Checksum to detect transmission errors

- 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

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 ...“.

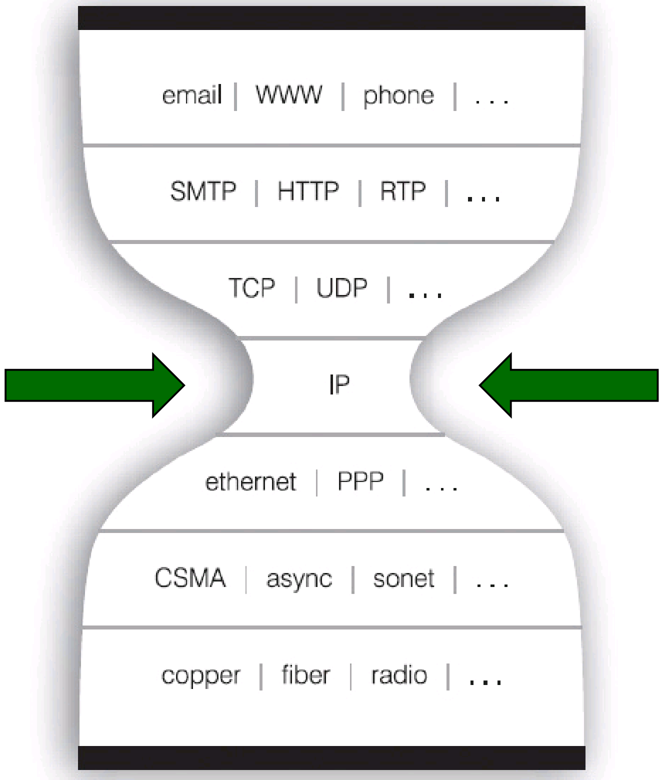
Layer 2 – Forwarding

- 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 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

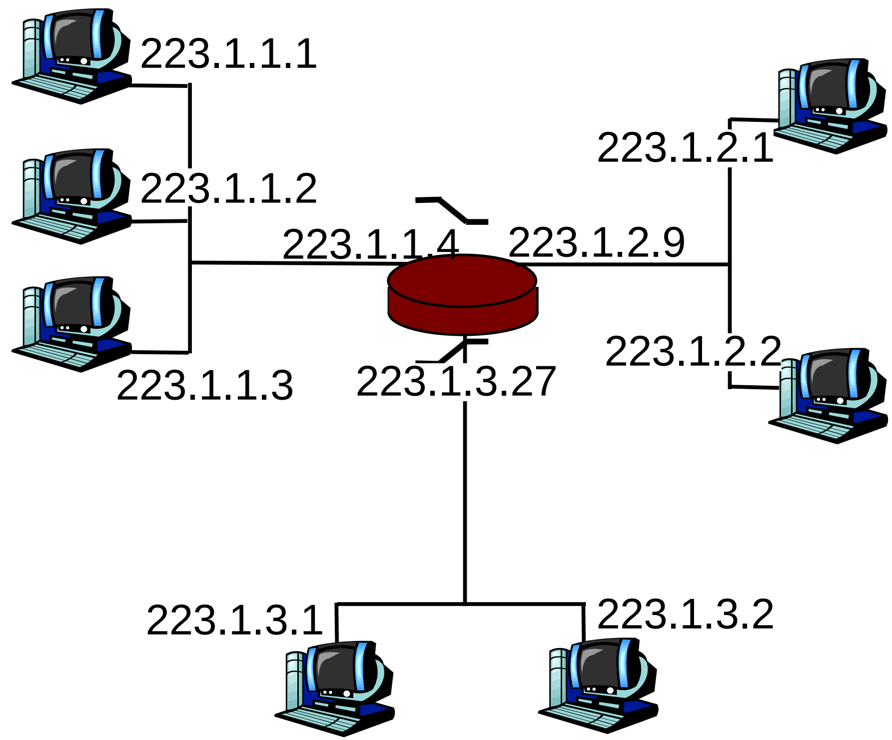


Layer 3 – Routing

- 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

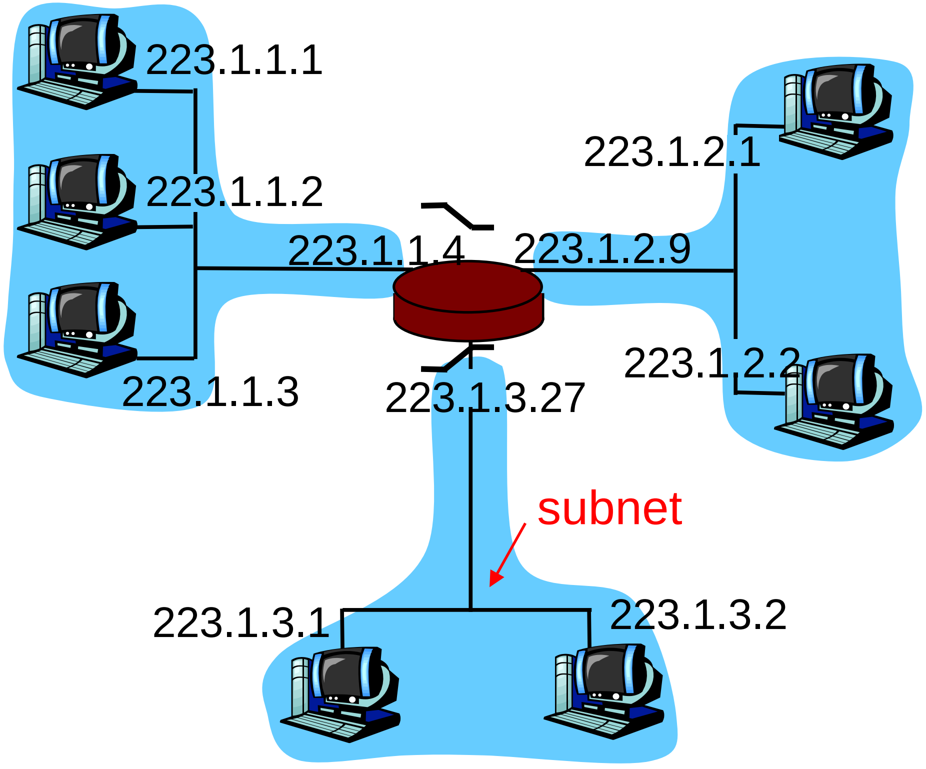


223.1.1.1 = 11011111 00000001 00000001 00000001

223 1 1 1

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



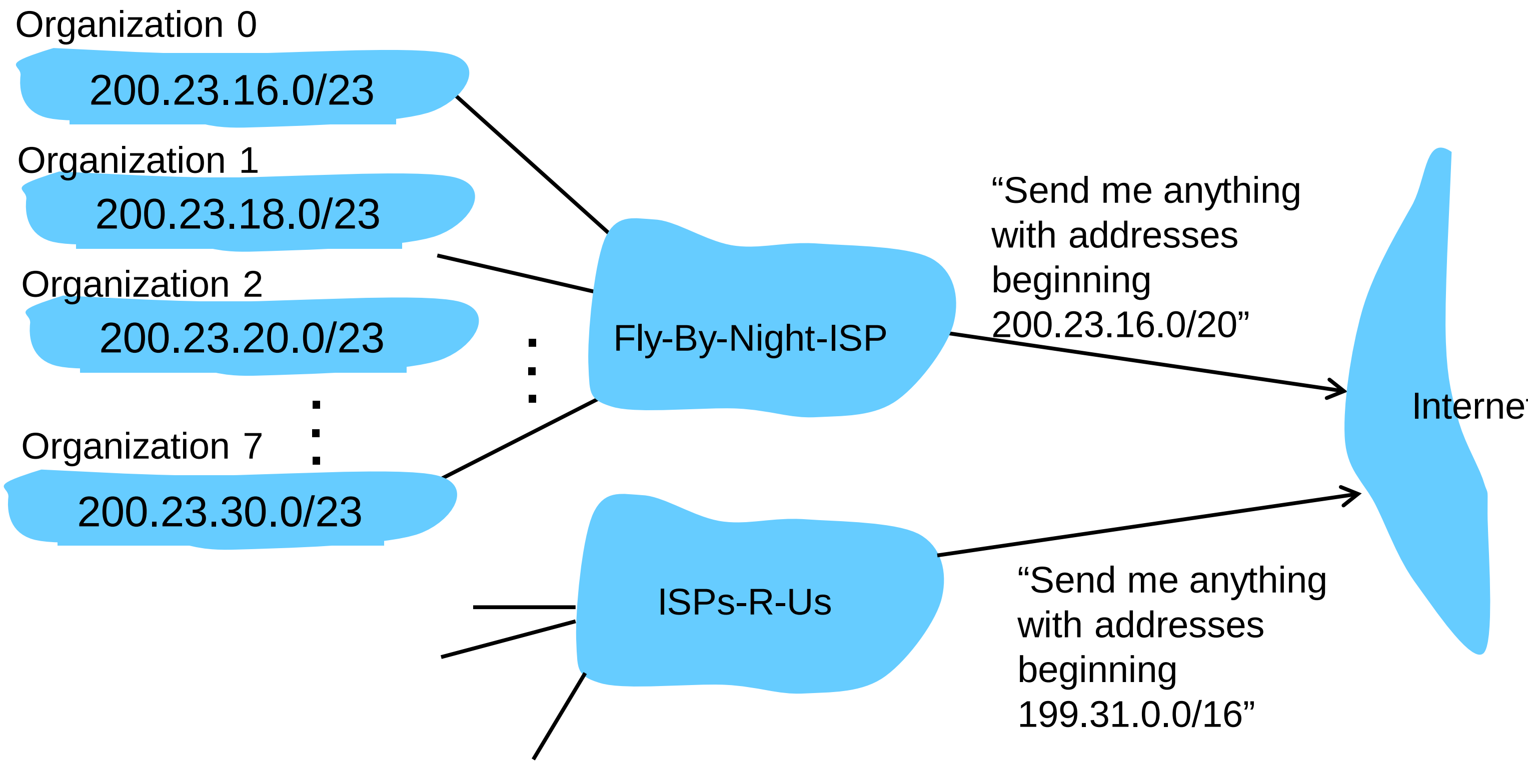
network consisting of 3 subnets

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

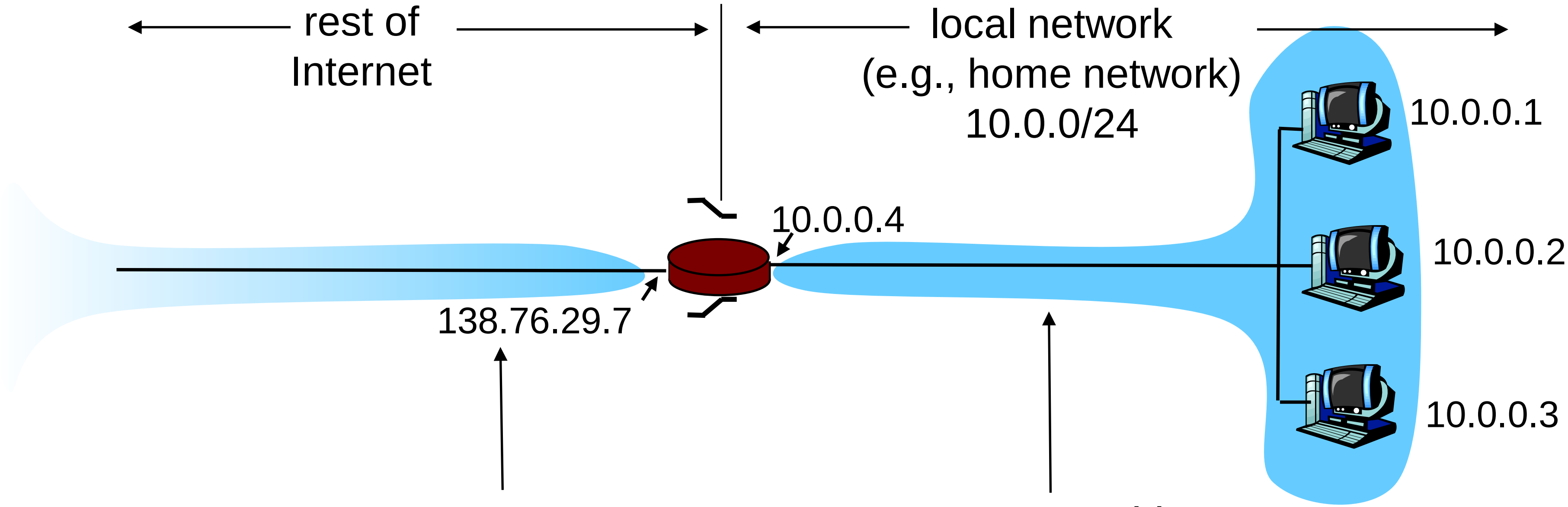
- Hierachical addresses allow to aggregate some prefixes:



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

Layer 3 – Routing

- Internet divided into Autonomous Systems (ASes)
- AS internal routing = intra-AS routing
  - E.g., OSPF
- Routing between ASes = inter-AS routing
  - E.g., BGP

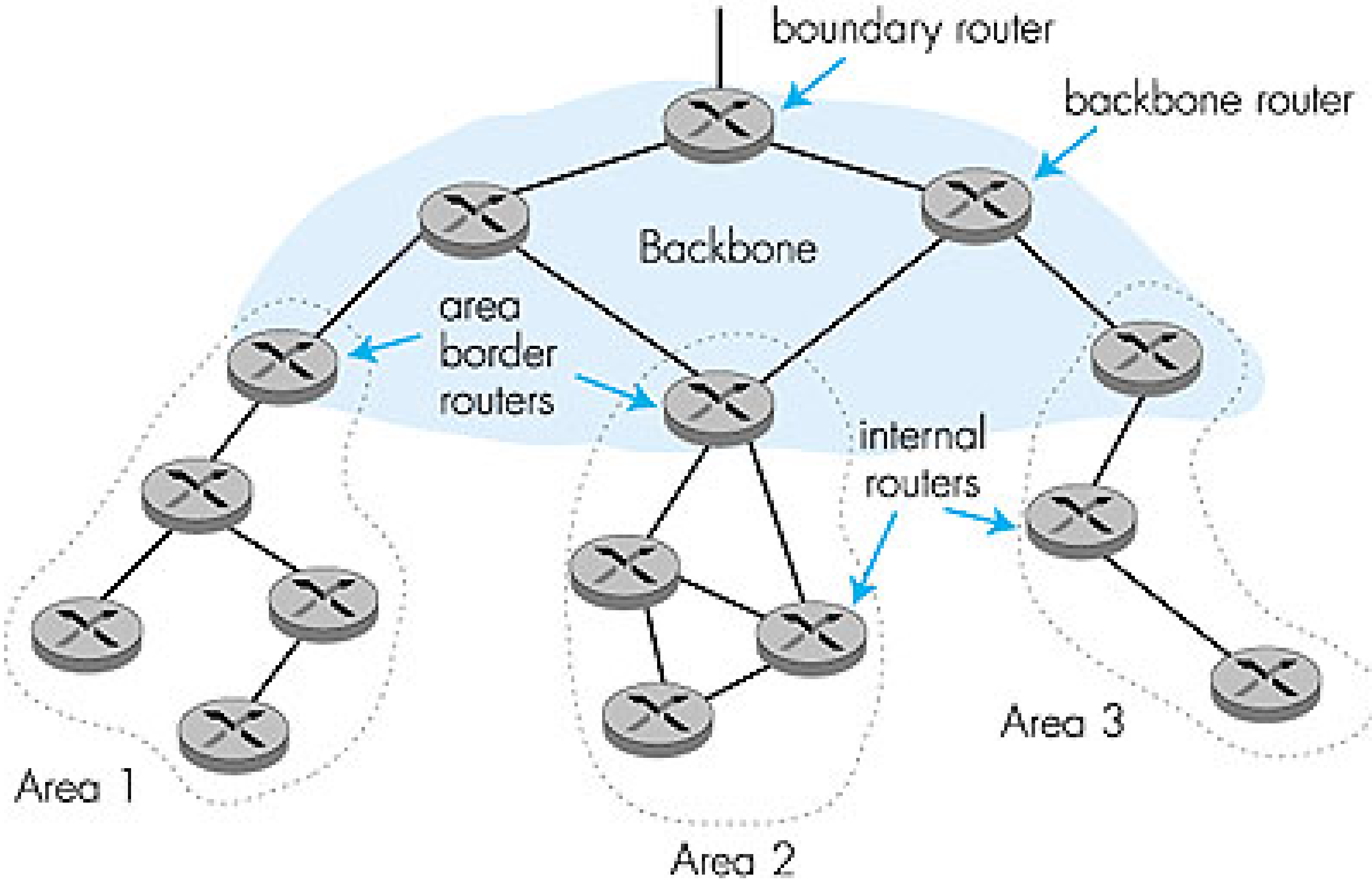
Layer 3 – Intra-AS: OSPF

- “open”: publicly available
- uses Link State algorithm
  - LS packet dissemination
  - topology map at each node
  - route computation using Dijkstra’s algorithm
- OSPF advertisement carries one entry per neighbor router
- advertisements disseminated to entire AS (via flooding)
  - carried in OSPF messages directly over IP (rather than TCP or UDP

Layer 3 - OSPF features

- Security: all OSPF messages authenticated (to prevent malicious intrusion)
- multiple same-cost paths allowed
- For each link, multiple cost metrics for different TOS
- Integrated uni- and multicast support:
  - Multicast OSPF (MOSPF) uses same topology data base as OSPF
- Hierarchical OSPF in large domains.

Layer 3 - Hierarchical OSPF



Layer 3 - Hierarchical OSPF

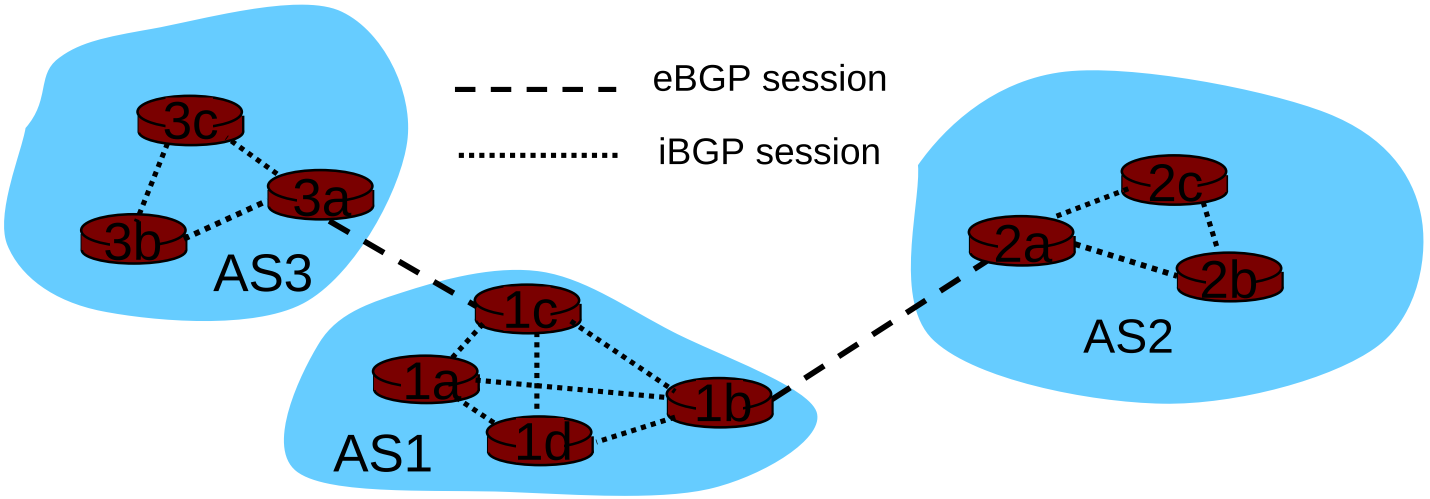
- two-level hierarchy: local area, backbone.
  - Link-state advertisements only in area
  - each nodes has detailed area topology; only know direction (shortest path) to nets in other areas.
- area border routers: “summarize” distances to nets in own area, advertise to other Area Border routers.
- backbone routers: run OSPF routing limited to backbone.
- boundary routers: connect to other AS’s.

Layer 3 - Inter-AS routing: BGP

- BGP (Border Gateway Protocol): the de facto standard
- allows subnet to advertise its existence to rest of Internet: “I am here”

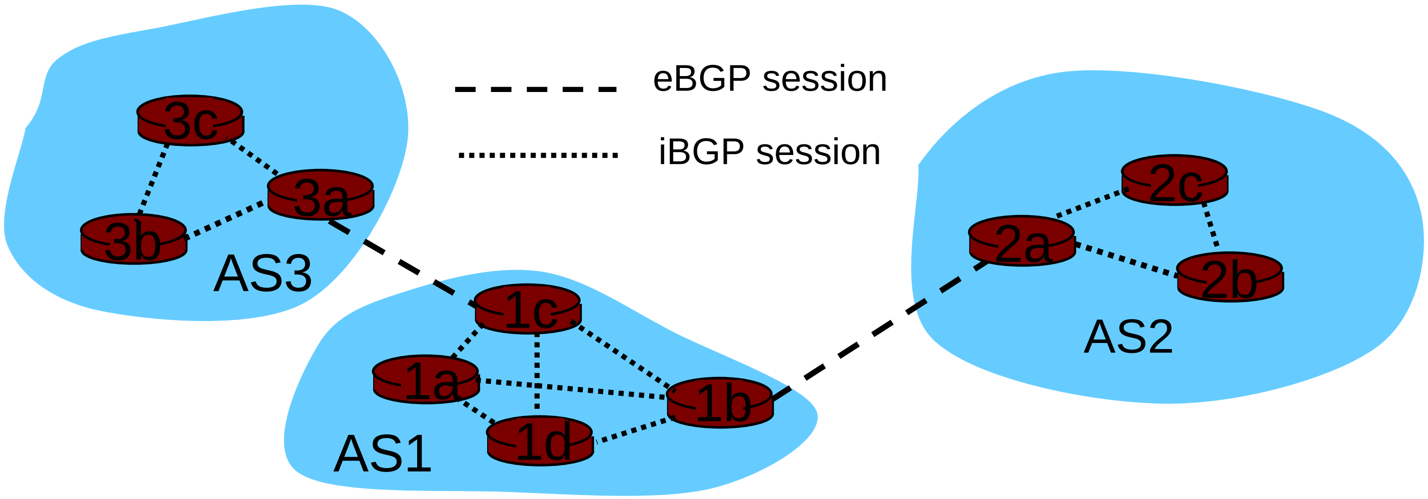
Layer 3 - BGP basics

- pairs of routers (BGP peers) exchange routing info over semi-permanent TCP connections: BGP sessions
  - BGP sessions need not correspond to physical links.
- when AS2 advertises a prefix to AS1:
  - AS2 *promises* it will forward datagrams towards that prefix.
  - AS2 can aggregate prefixes in its advertisement



Layer 3 – BGP Reachability

- using eBGP session between 3a and 1c, AS3 sends prefix reachability info to AS1.
  - 1c can then use iBGP do distribute new prefix info to all routers in AS1
  - 1b can then re-advertise new reachability info to AS2 over 1b-to-2a eBGP session
- when router learns of new prefix, it creates entry for prefix in its forwarding table.



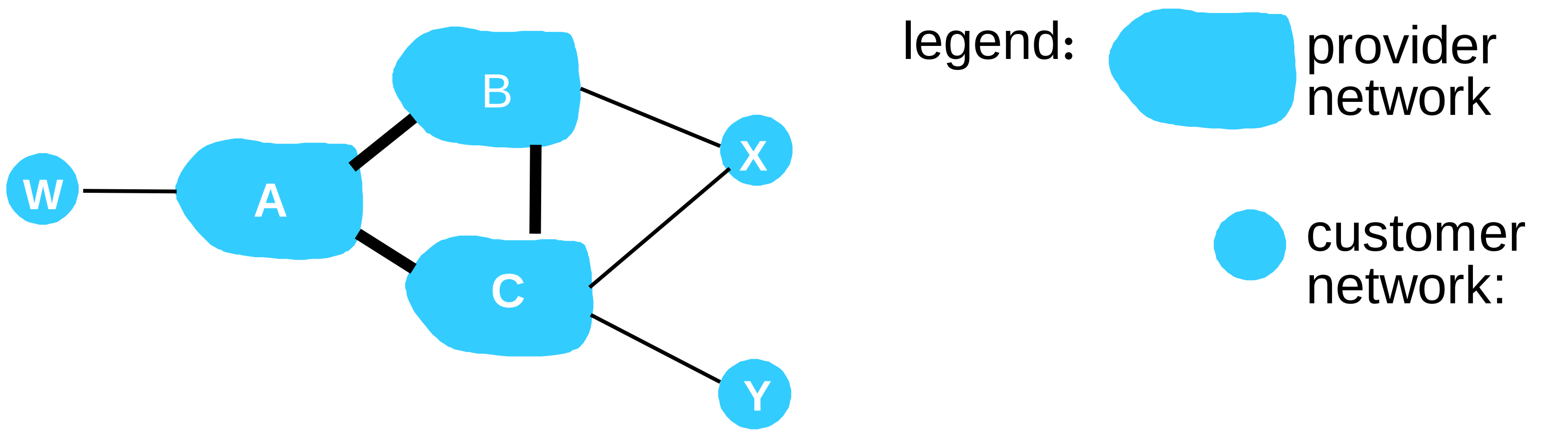
Layer 3 – BGP Paths and Routes

- advertised prefix includes BGP attributes.
  - prefix + attributes = “route”
- two important attributes:
  - AS-PATH: contains ASs through which prefix advertisement has passed: e.g, AS 67, AS 17
  - NEXT-HOP: indicates specific internal-AS router to next-hop AS. (may be multiple links from current AS to next-hop-AS)
- when gateway router receives route advertisement, uses import policy to accept/decline.

Layer 3 - BGP route selection

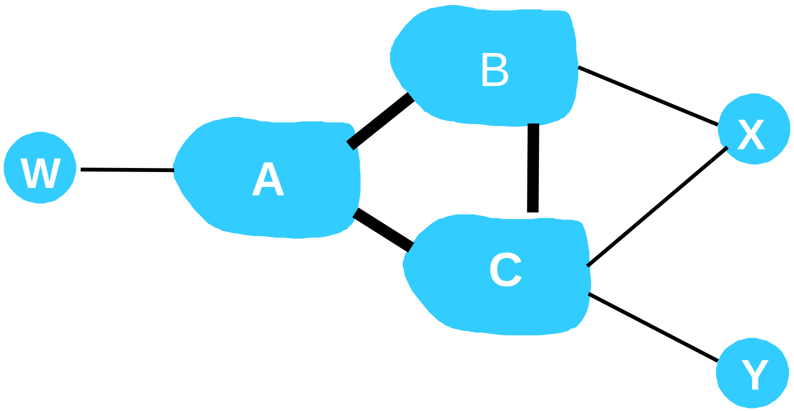
- Router may learn about more than 1 route to same prefix:
  - Router must select route
- Elimination rules:
  - Local preference value attribute: policy decision
  - Shortest AS-PATH
  - Closest NEXT-HOP router: hot potato routing
  - Additional criteria

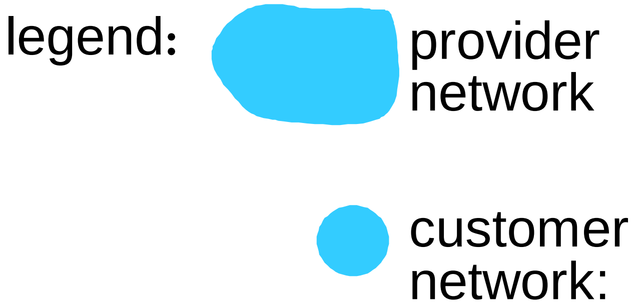
Layer 3 – BGP Policies



- A,B,C are provider networks
- X,W,Y are customer networks
- X is dual-homed: attached to two networks
  - X does not want to route from B via X to C
  - .. so X will not advertise to B a route to C

Layer 3 – BGP Policies





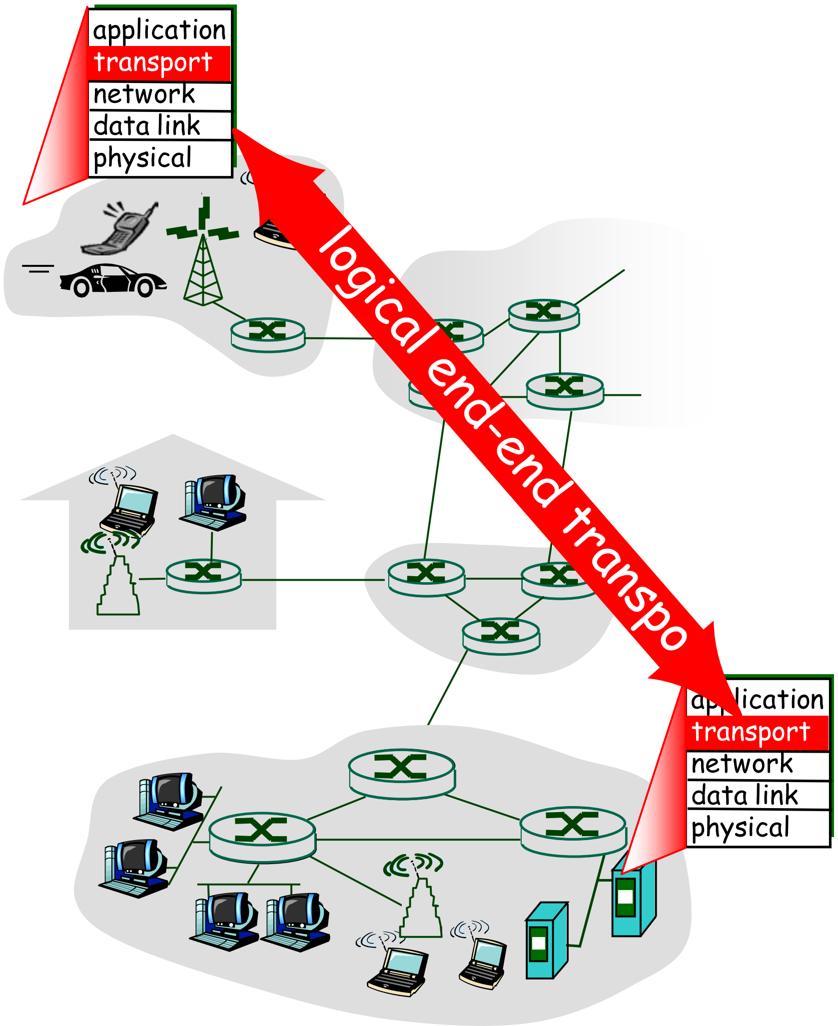
- A advertises path AW to B
- B advertises path BAW to X
- Should B advertise path BAW to C?
  - No way! B gets no “revenue” for routing CBAW since neither W nor C are B’s customers
  - B wants to force C to route to w via A
  - B wants to route *only* to/from its customers!

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

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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

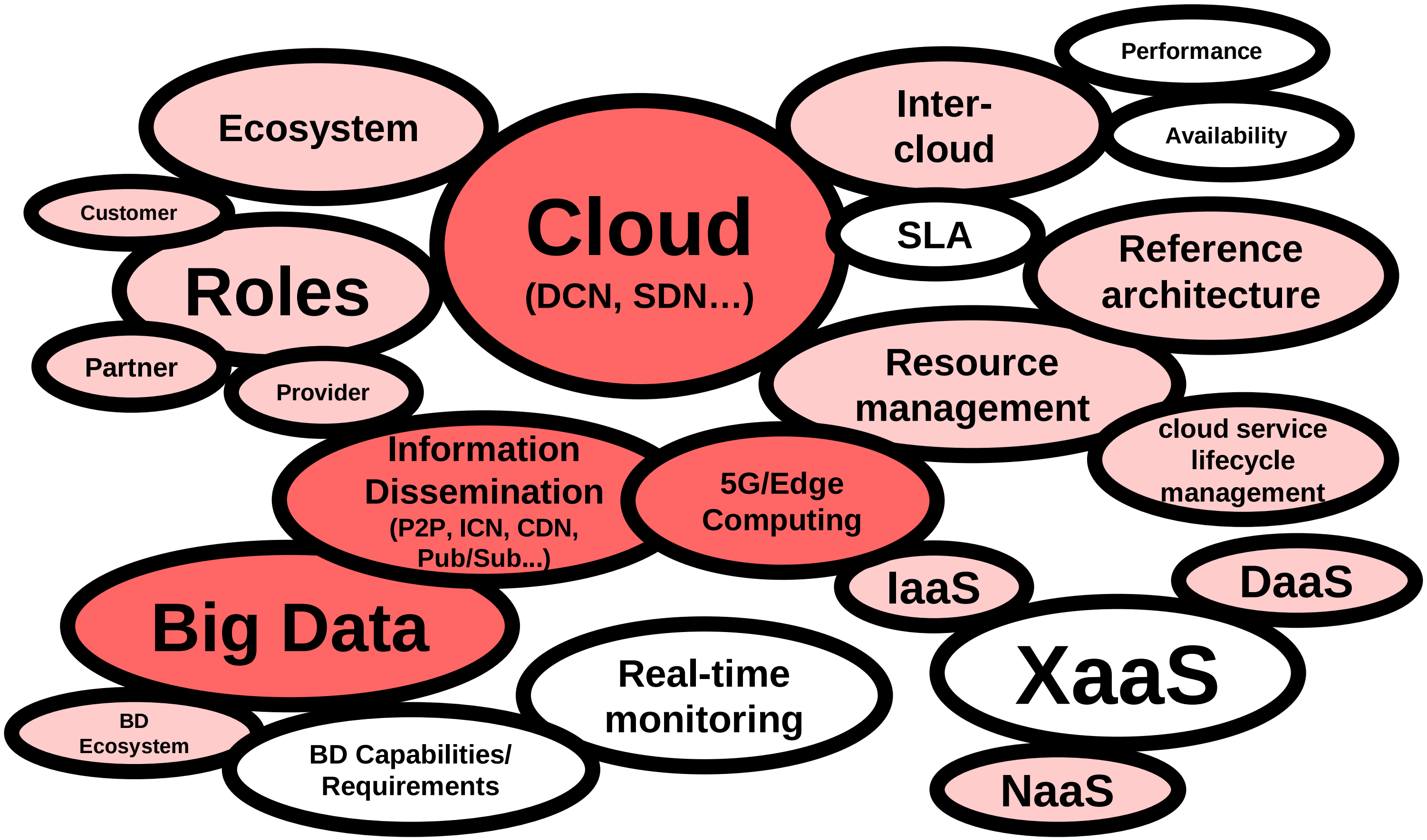
- Point-to-Point - one sender, one receiver
- Reliable, in-order delivery
- Pipelined – TCP congestion and flow control sets window sizes
- Send & receive buffers
- Full-duplex data transfer
- Connection oriented
- Flow-Control – Sender prevents to overwhelm receiver

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!

Cloud computing/Big data



Outlook

- In the next lectures:
  - Introduction to mobile edge computing (Fu);
  - Introduction to big data analytics (Huang);
  - Problems with the traditional networking paradigms and what can be done to alleviate them
    - ICN/NDN (Arumaithurai)
    - Data Center Networks, Cloud Computing (Koll)
    - SDN/NFV (Arumaithurai, Koll)