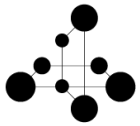


INFORMATION CODING
Linköping University

TSIN02 Internetworking

Lecture 1 - Introduction

People involved in the course

- Robert Forchheimer, lecturer, examiner
- Ajmal Muhammad, lecturer, teaching assistant
- Niklas Carlsson, Jan-Åke Larsson, special topic lecturers
- Ingemar Ragnemalm, main supervisor - home assignment
- Guest lecturer: Björn Rudin, Combitech AB

Lecture program

Lecture	Date	Topic	Lecturer
1	Nov 3	Introduction to Internet, basic principles	RF
2	Nov 8	Network-of-networks, lower layers	RF
3	Nov 10	Transport and Application layers	RF
4	Nov 15	Optical Networking – Components	AM
5	Nov 17	Optical networking – Internet backbone	AM
6	Nov 22	Network economics	AM
7	Nov 24	Data center networks	AM
8	Nov 30	Source coding and channel modeling	RF
9	Dec 1	Streaming video	NC
10	Dec 6	Network security	JÅL
11	Dec 8	Guest lecture	
12	Dec 13	*Reserve*	

Course organization

- Lecture and problem solving classes
- Examination
  - Written exam (4.5 hp)
  - Home assignment (1.5 hp)
- All info is at course web page
  - http://www.icg.isy.liu.se/en/courses/tsin02/
  - Schedule
  - Literature, additional readings
  - Lecture slides
  - Problems for the problem classes
  - Guide lines for the home assignment
  - Previous exams
  - News

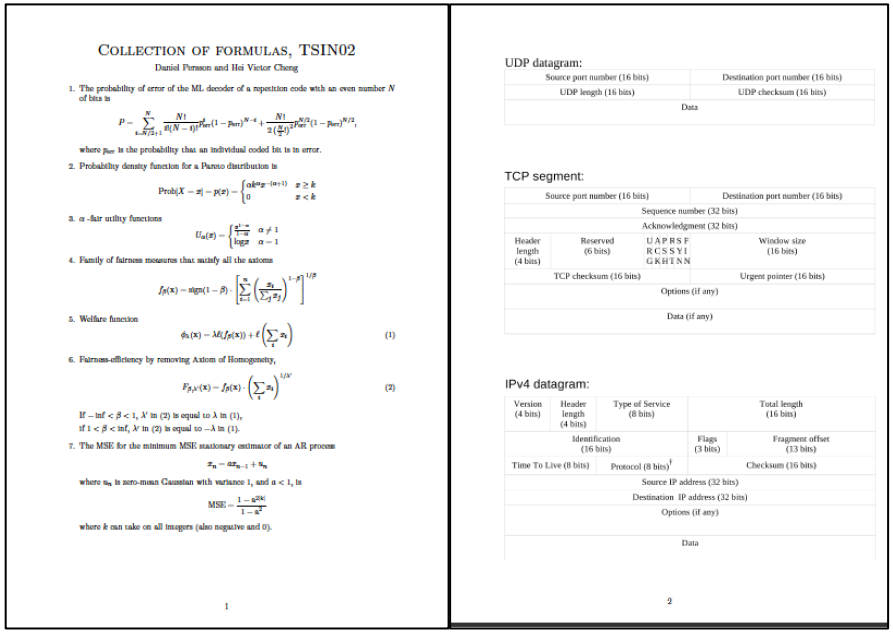
Literature

- TCP/IP Protocol Suite, 4th Ed, *Behrouz A. Forouzan* (main course book)
- Networked Life, 20 Questions and Answers, *Mung Chiang*, Cambridge University Press (specific chapters: 11, 12, 16, 17, 20)
- Optical Networks: A Practical Perspective, 3rd Edition, *Rajiv Ramaswami* (Specific chapters: 1,7,10)
- **Lecture material and problem classes material are the most important!**
- Alternative literature:

  See course home page

TSIN02 collection of formulas

- Will be posted on the web
- You are expected to bring the TSIN02 collection of formulas yourself to the exam!



COLLECTION OF FORMULAS, TSIN02

Daniel Persson and Hoi Victor Cheng

1. The probability of error of the ML decoder of a repetition code with an even number N of bits is

$$P = \sum_{k=N/2+1}^{N} \frac{N!}{k!(N-k)!} p_{err}^{k} (1-p_{err})^{N-k} + \frac{N!}{2\left(\frac{N}{2}\right)!^2} p_{err}^{N/2} (1-p_{err})^{N/2},$$

where p_{err} is the probability that an individual coded bit is in error.

2. Probability density function for a Pareto distribution is

$$\text{Prob}(X = x) = p(x) = \begin{cases} \alpha k^{\alpha} x^{-(\alpha+1)} & x \geq k \\ 0 & x < k \end{cases}$$

3. α -fair utility functions

$$U_{\alpha}(x) = \begin{cases} \frac{x^{1-\alpha}}{1-\alpha} & \alpha \neq 1 \\ \log x & \alpha = 1 \end{cases}$$

4. Family of fairness measures that satisfy all the axioms

$$f_{\beta}(\mathbf{x}) = \text{sign}(1-\beta) \cdot \left[\sum_{i=1}^{n} \left(\frac{x_i}{\sum_j x_j} \right)^{1-\beta} \right]^{1/\beta}$$

5. Welfare function

$$\phi_{\lambda}(\mathbf{x}) = \lambda \ell(f_{\beta}(\mathbf{x})) + \ell\left(\sum_i x_i \right) \quad (1)$$

6. Fairness-efficiency by removing Axiom of Homogeneity,

$$F_{\beta,\lambda'}(\mathbf{x}) = f_{\beta}(\mathbf{x}) \cdot \left(\sum_i x_i \right)^{\lambda'} \quad (2)$$

If $-\inf < \beta < 1$, λ' in (2) is equal to λ in (1),
if $1 < \beta < \inf$, λ' in (2) is equal to $-\lambda$ in (1).

7. The MSE for the minimum MSE stationary estimator of an AR process

$$x_n = \alpha x_{n-1} + u_n$$

where u_n is zero-mean Gaussian with variance 1, and $a < 1$, is

$$\text{MSE} = \frac{1 - a^{2|k|}}{1 - a^2}$$

where k can take on all integers (also negative and 0).

1

UDP datagram:

Source port number (16 bits)	Destination port number (16 bits)
UDP length (16 bits)	UDP checksum (16 bits)
Data	

TCP segment:

Source port number (16 bits)			Destination port number (16 bits)
Sequence number (32 bits)			
Acknowledgment (32 bits)			
Header length (4 bits)	Reserved (6 bits)	U A P R S F R C S S Y I G K H T N N	Window size (16 bits)
TCP checksum (16 bits)			Urgent pointer (16 bits)
Options (if any)			
Data (if any)			

IPv4 datagram:

Version (4 bits)	Header length (4 bits)	Type of Service (8 bits)	Total length (16 bits)	
Identification (16 bits)			Flags (3 bits)	Fragment offset (13 bits)
Time To Live (8 bits)		Protocol (8 bits)	Checksum (16 bits)	
Source IP address (32 bits)				
Destination IP address (32 bits)				
Options (if any)				
Data				

2

What to expect from the course

- No prior networking knowledge needed.
- The course is broad but has a focus on the lower network layers.
- After the course, you will understand the main principles of Internet. You will also have some specific insight into optical fiber networks, radio access, source coding, network economics, special-purpose networks for data centers and Internet-of-Things.
- Sufficient learning of inter-networking language, words, and abbreviations, to be able to communicate with the people in the networking field. Few protocol details.
- Some mathematical descriptions and models that are used in the networking field.
- The lessons may be treating complementary material, not treated in the lectures, and vice versa.

Home assignment – online Pac-Man or Future Internet

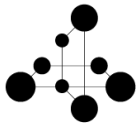
- Detailed guidelines on homepage
- Find partners, you work in groups of 4 students
- Choose assignment (online Pac-Man game or Future Internet)
- Not later than November 9: Announce your group using the sign-up page.
- Lab assistant will get back to you as soon as possible per email to tell who will be your supervisor, as well as the email of your supervisor.
- Checkpoint, not later than November 21: Send an outline of the report, marked with your group number, by mail to your supervisor as a pdf file attachment.
  - The purpose of the outline is to show that you have started to work with the assignment and has some initial plan.
  - Your supervisor will get back to you as soon as possible with an OK or comments about things to take into consideration. You may book a shorter meeting with your supervisor for further discussion.

Home assignment cont'd

- Not later than December 7: Print out or mail the final report to your supervisor.
- The hand-in of the report will be graded P=Pass, C=Complement or F=Fail. The graded report will be handed back to you on December 12 at the latest.
- If you need to complement your report, the complemented report must be handed in not later than January 20. You are allowed to book a short meeting with your supervisor until December 19, if you have some questions regarding improvement of the report. The graded reports will be handed back to you on January 31.
- Detailed info on course homepage!

Lecture outline

- Course info
- Internet – background and history
- The basic principles
- Layers – from modulation to application
- Internet usage
- Internet devices – some examples



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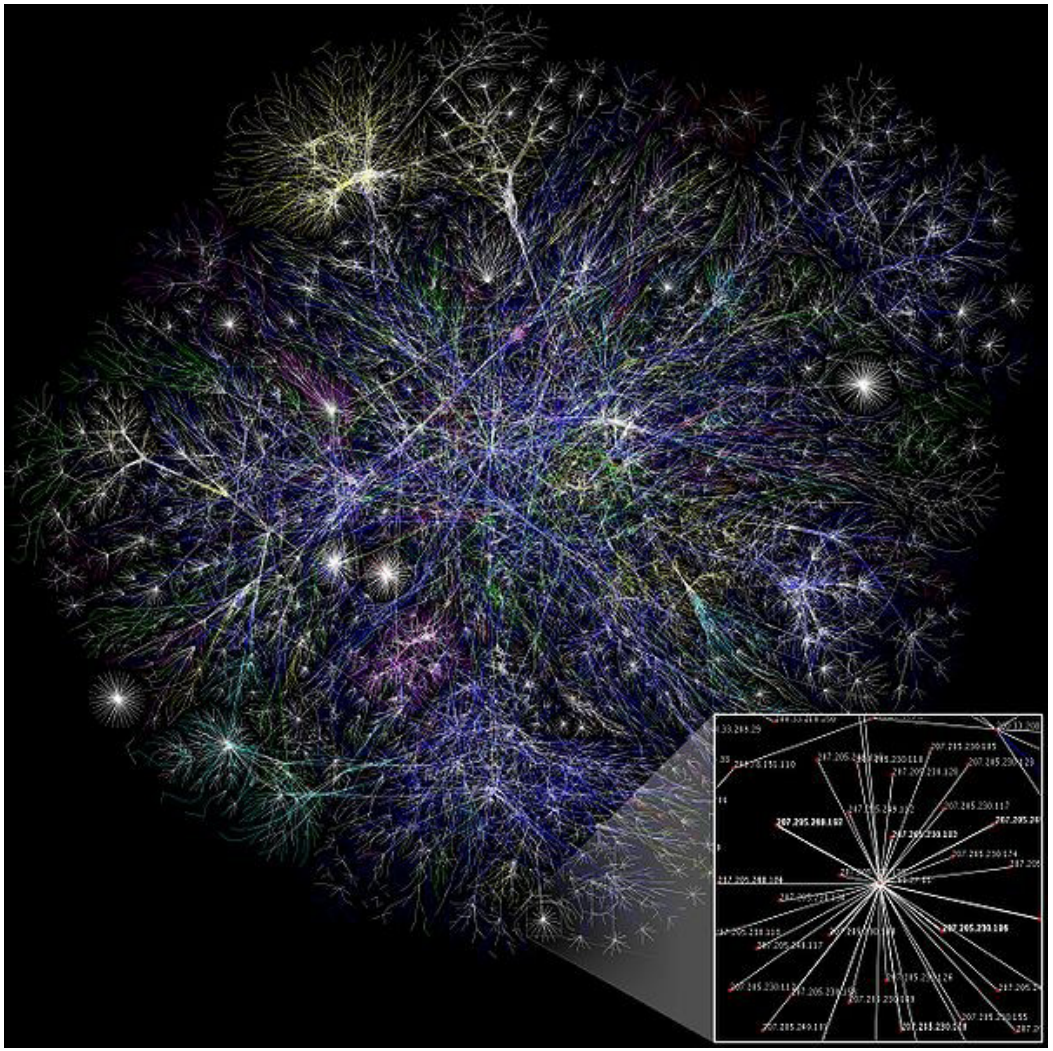
What is inter-networking?

"The art and science of connecting individual local-area networks (LANs) to create wide-area networks (WANs), and connecting WANs to form even larger WANs."

from the Webopedia Computer Dictionary

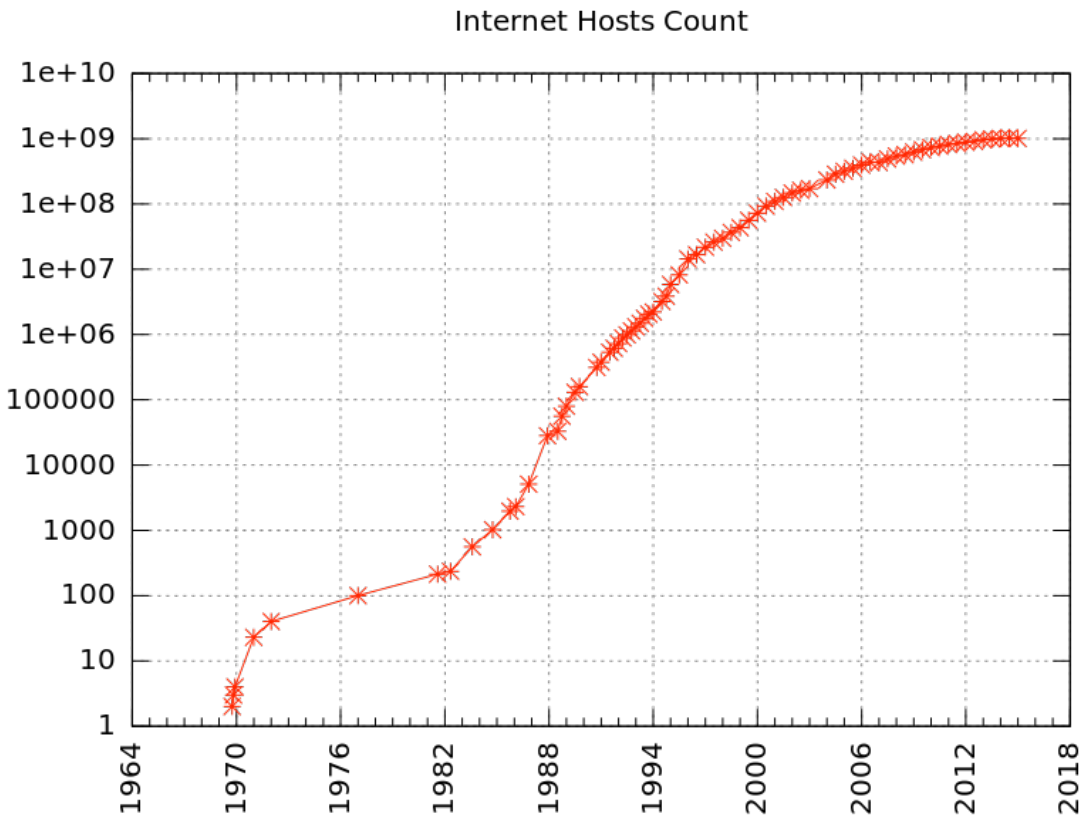
One example: The Internet



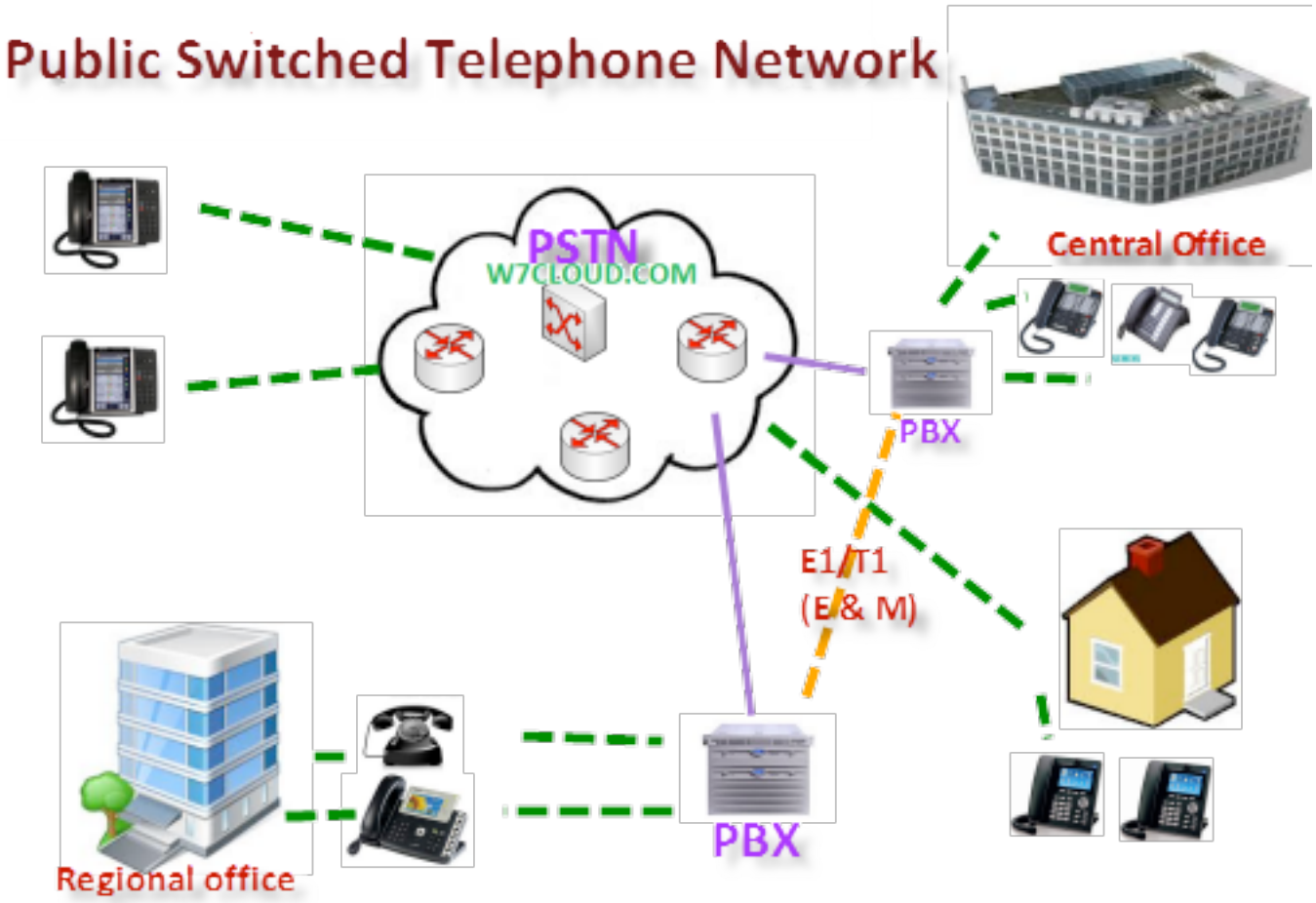
Picture from
wikipedia.se: “Internet”

Number of Internet hosts

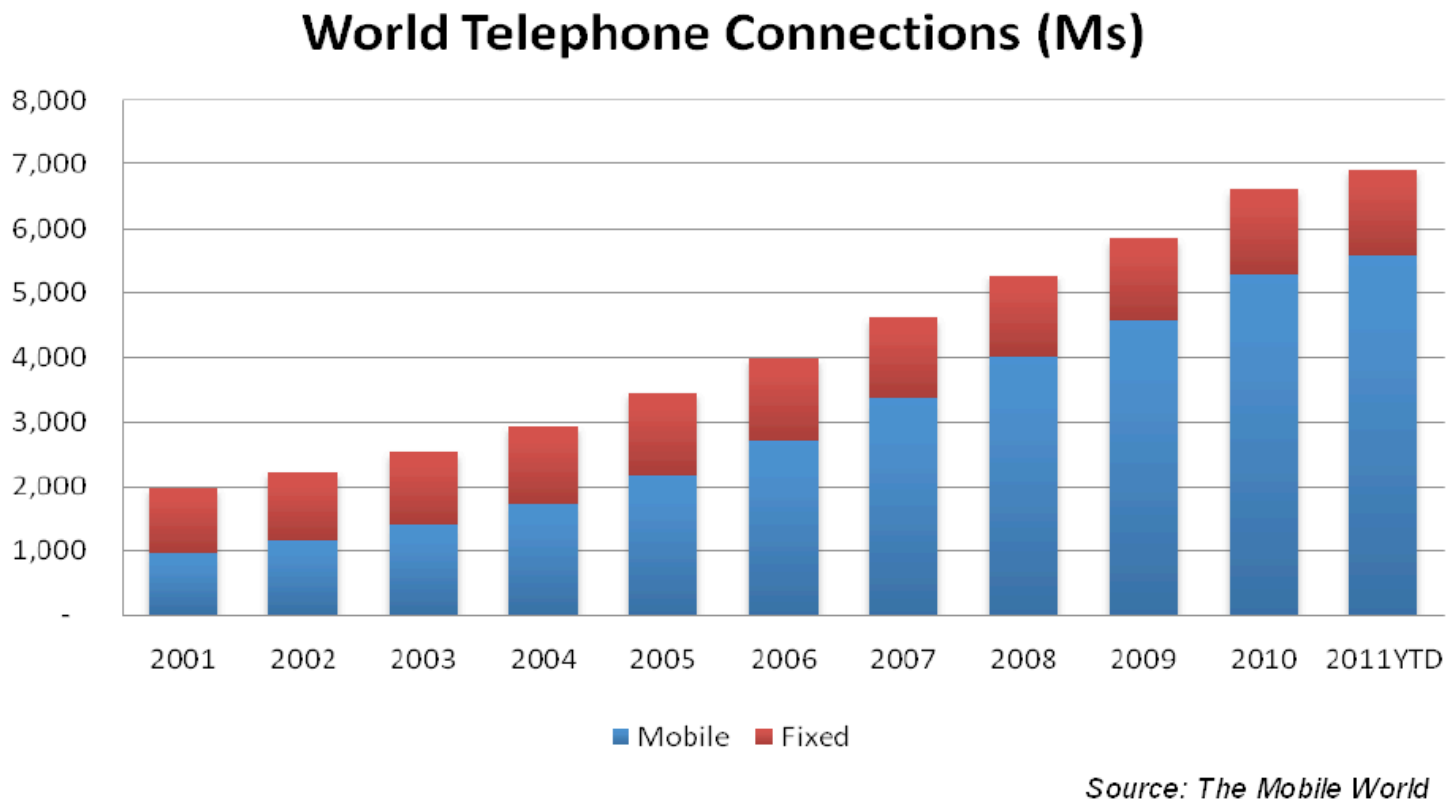
- **1981: 213 hosts**
- **2001: 100 million**
- **2015: 1 billion**



Second example: The telephone network



Size of the telephone network



The fixed phones (landlines) alone are as many as the current number of hosts on Internet.

Traffic comparison

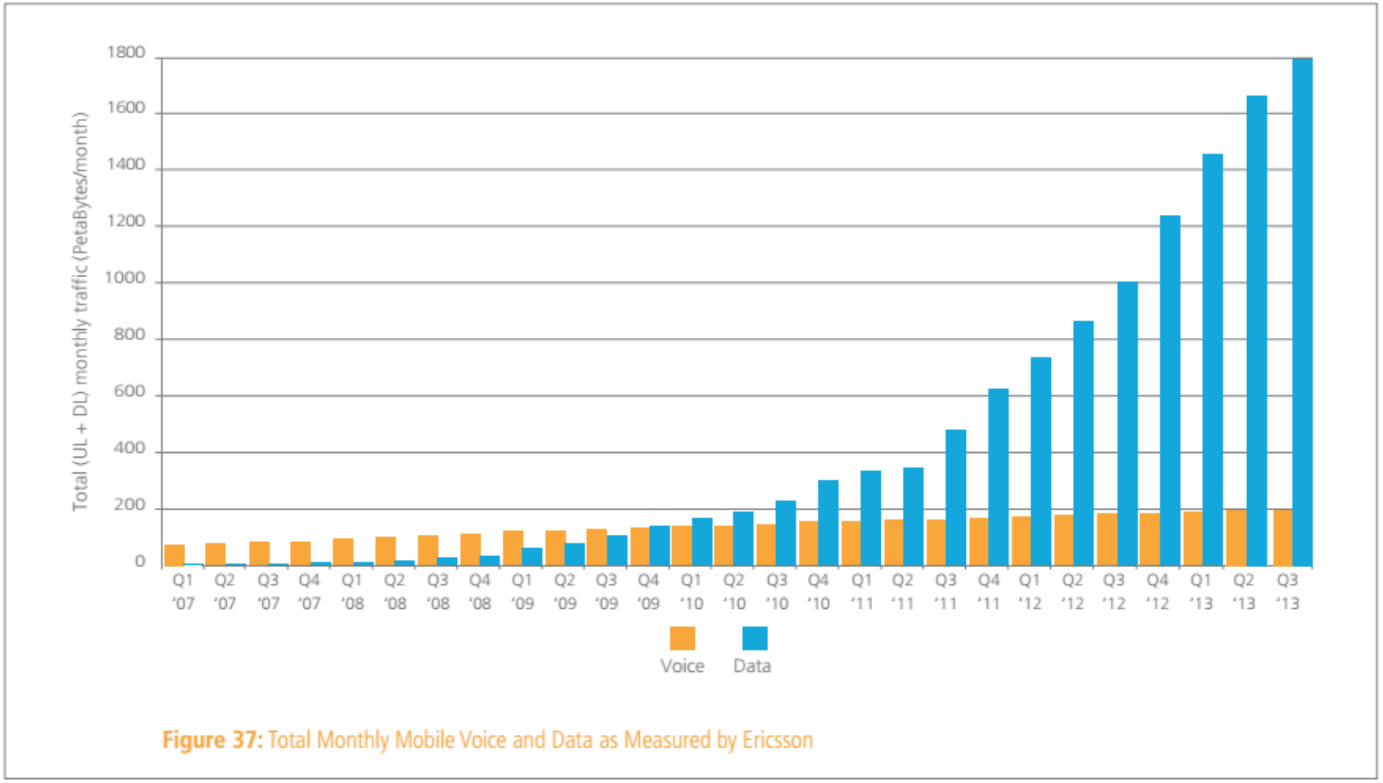
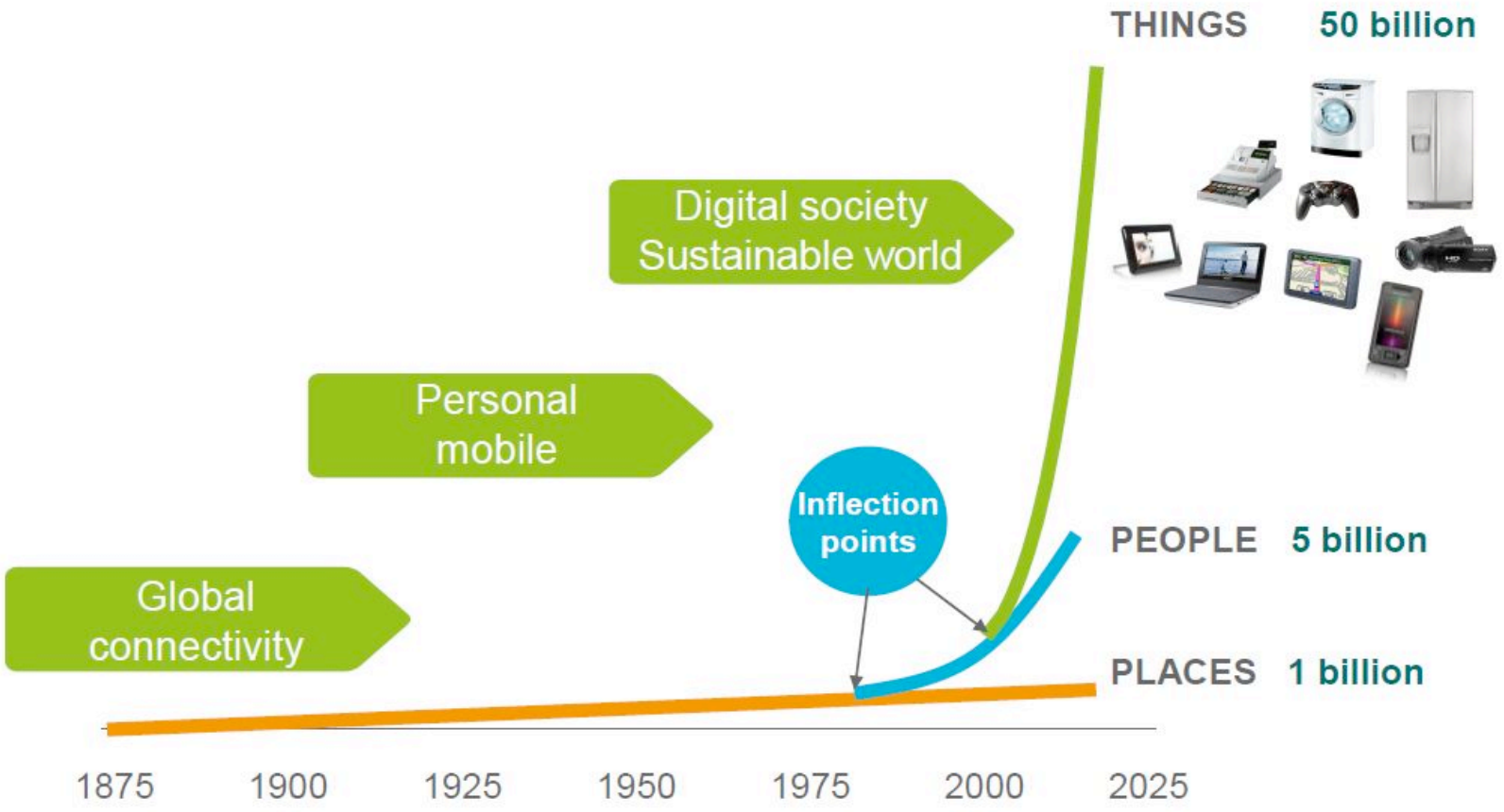


Figure 37: Total Monthly Mobile Voice and Data as Measured by Ericsson

Internet traffic exceeds phone traffic by far!

Internet-of-things (IoT)



Ericsson predicts that in the year 2020 we will have 50 billion devices connected to Internet!

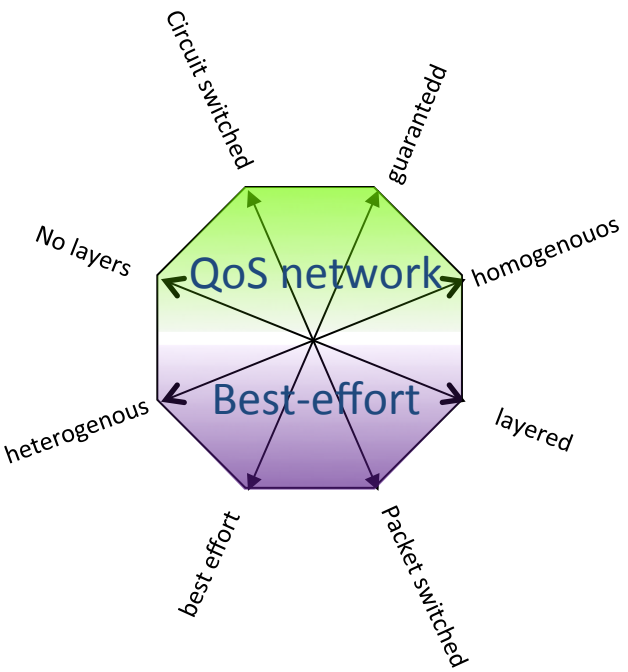
Inter-networks today

- The Public Switched Telephone Network (PSTN)

  Circuit-switched: bandwidth, delay and error rate guarantees

- The Internet

  Packet-switched, connection-less, no Quality of Service (QoS) guarantees



Why focus on Internet in this course?

- The Internet carries by far more data than PSTN today
- More versatile/flexible than PSTN
- Internet provides more services than PSTN. You can use voice over IP (VoIP = name for technology and protocols for voice over IP).
- We will however discuss circuit-switched networks also, particularly new optical fiber proposals, as well as IPv6, the new version of the IP protocol which is becoming increasingly connection-oriented.

Brief history of the Internet

- 1964: Leonard Kleinrock presents a mathematical theory for “message switching”
- 1969: (Advanced Research Projects Agency Network- ARPANET), four nodes at American Universities based on the new concept of Packet switching
- 1974: Vint Cerf and Robert (Bob) Kahn, Transmission Control Protocol (TCP). Cerf and Kahn worked in a project called the Internetting project, wanting to connect different networks
- 1977: First internet with three different nets: ARPANET, packet radio and packet satellite
- Late 1970’s: TCP divided into TCP and the Internet protocol (IP)!
- 1980’s-: The Internet – a collection of networks, communicating using the TCP/IP protocols
- 1995: Companies known as Internet service providers (ISPs) started offering users access to the Internet.

Inter-networking terms

- An end-user device (computer, smart-phone): **a host**
- Connecting two hosts: **a link**
- Connecting several hosts: **a network**
- Connecting networks: **inter-networking** (verb)
- An inter-network (inter-net): **a network of networks**
- The world's largest inter-network: **Internet**
- Border ("Edge") part of a global network: **Access** network
- Inner part of a global network: **Core** ("Backbone") network
- A set of rules for communication: **a protocol**
- An agreed-upon protocol: **a standard**
- Name for the protocols that are the fundament of the Internet: **The Transmission Control Protocol (TCP)/Internet Protocol (IP) protocol suite**, cf book title.

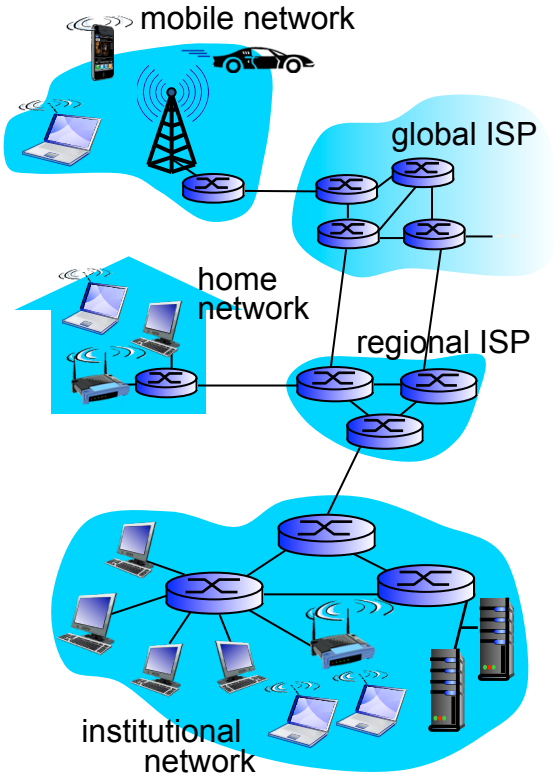


Figure from: J.F Kurose and K.W. Ross, Computer Networking: A Top-Down Approach

Connectionless and connection-oriented services

- **Circuit-switched network:** Physical resources along the propagation path are reserved.
- **Quality of service (QoS):** to guarantee a certain level of performance to a data flow. Some services, e.g. delay and bandwidth are guaranteed.
- **Packet-switched network can be either**
  - **connection-less**
  - **connection-oriented/the virtual circuit approach**

Connection-less: Resources along the propagation path are not reserved.

Connection-oriented: A connection service that reserves resources along the propagation path but may not cover all demands on a full circuit-switched network.

Communication standards

- Standardization organizations: govermental/companies/international
- Internet Engineering Task Force, (IETF), part of the Internet Society, non-profit organization, V. Cerf and B.Kahn involved in the startup
- IETF published **Request for Comment (RFC)**, see www.rfc-editor.org, protocol may become standard after different maturity levels
- RFC 2026: specifies the process for the standardization of all protocols
- RFC 675: “Specification of Internet Transmission Control Protocol”, the first TCP version
- Institute of Electrical and Electronics Engineers (IEEE): Ethernet, WiFi
- International Telecommunications Union (ITU), United Nations, e.g. IMT-Advanced, requirements which 3rd Generation Partnership Projects (3GPP) Long Term Evolution (LTE) tries to fulfill.
- International standardization Organisation (ISO) issues standards in many areas, also in telecommunication such as the OSI layered network model and MPEG video standards.

Internet administration

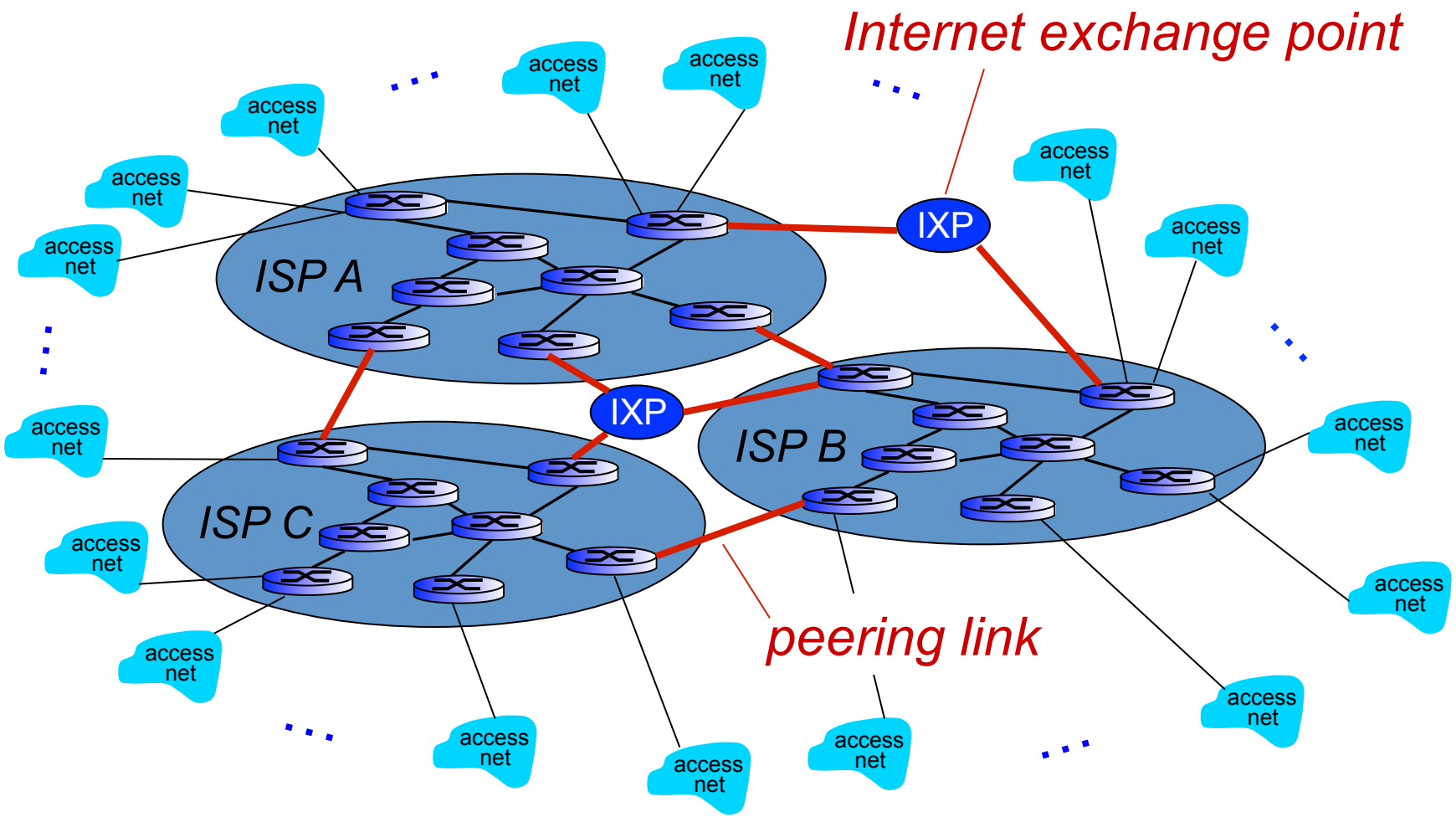
- Internet society, with e.g. IETF
- Internet Corporation for Assigned Names and Numbers (ICANN), nonprofit private organization.

  E.g.:
  - IP address block allocations to Internet service providers (ISPs)
  - Mapping between human- and computer-readable addresses…(“liu.se” -> 130.236.5.66)

Internet – the basic principles

- A network of networks
- Packet switching
- Unified addresses (IP address)
- Layered protocols

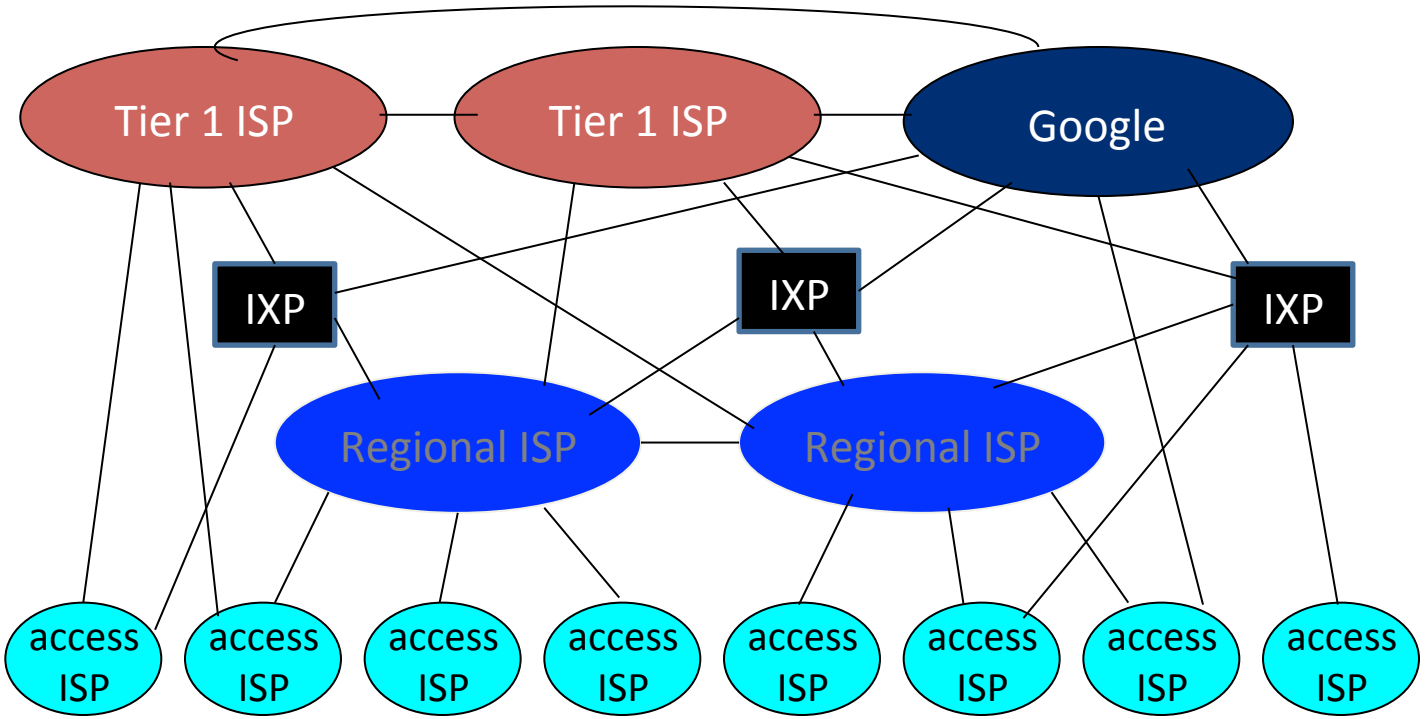
"A network of networks"



ISP = Internet Service Provider

Slide adapted from: J.F Kurose and K.W. Ross, Computer Networking: A Top-Down Approach

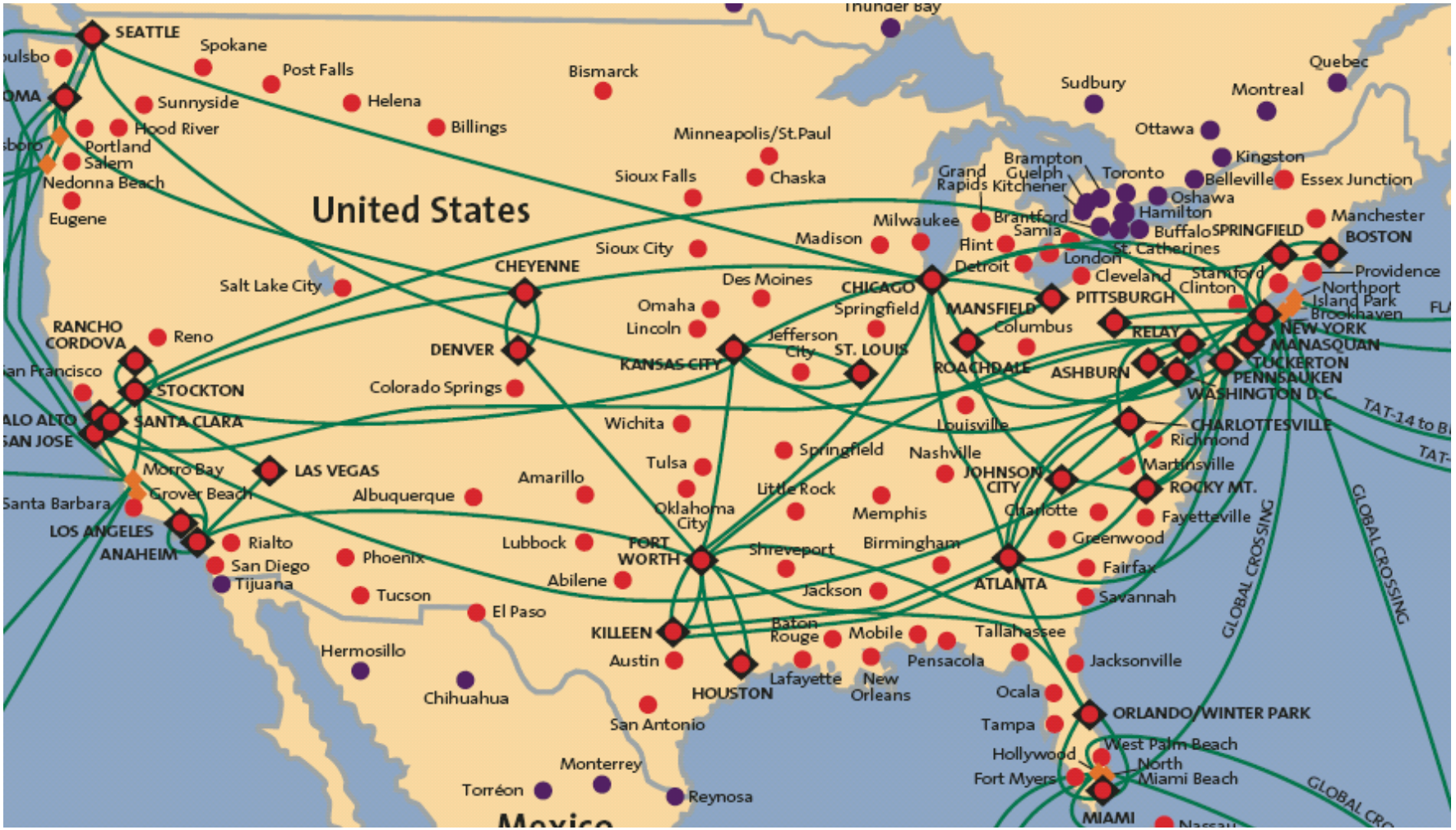
Internet Service Providers



- "Tier 1" commercial ISPs (e.g., Level 3, Sprint, AT&T, NTT), national & international coverage
- content provider network (e.g, Google): private network that connects it data centers to Internet, often bypassing tier-1, regional ISPs

Slide adapted from: J.F Kurose and K.W. Ross, Computer Networking: A Top-Down Approach

Example Tier-1 ISP: Sprint

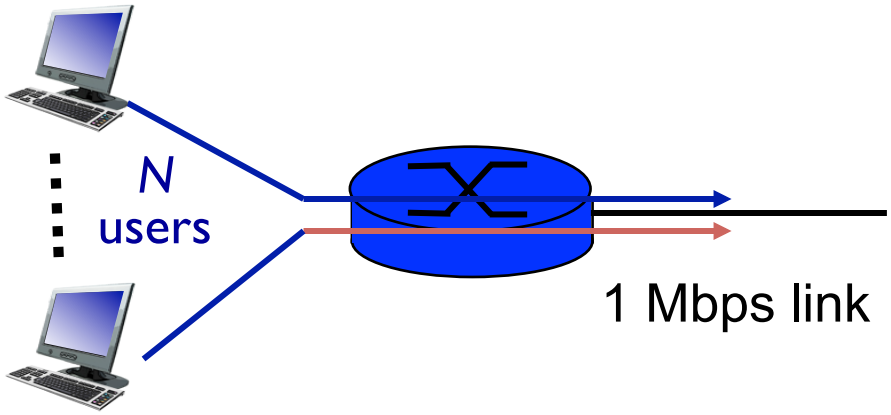


Packet switching vs circuit switching

***Common opinion**: packet switching allows more users to use the network*
***However**, the issue is not that simple…*

example:

- 1 Mb/s link
- each user:
  - 100 kb/s when "active"
  - active 10% of time



- *circuit-switching:*
  - 10 users
- *packet switching:*
  - with 35 users, probability >10 active at same time is less than .0004 *

Q1: what happens if > 35 users ?

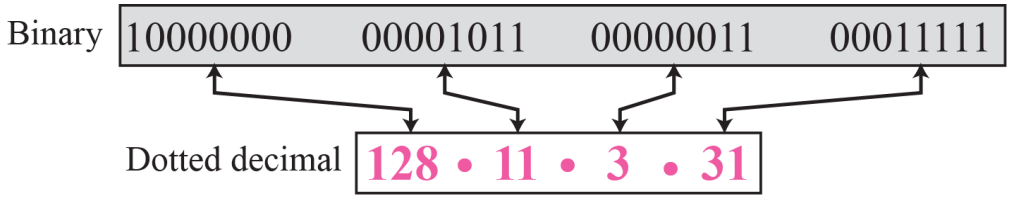
Q2: what if the rate for *CS* can be chosen in increments of 10 kb/s ?

* Based on i.i.d assumption with probability P = 0.1

Packet switching - Properties

- great for (random) bursty data
  - resource sharing
  - simpler, no call setup
- excessive congestion possible
  - packet delay and loss may appear
  - protocols needed for reliable data transfer, congestion control
- *Q:* How to provide circuit-like behavior?
  - bandwidth guarantees needed for audio/video apps
  - still an unsolved problem (see lectures 8 and 9)

IPv4 addressing



- Each host is assigned a 32 bit IP address
- $2^{32} \approx 4.3$ billion possible addresses/hosts
- Dotted decimal notation, e.g. 128.11.3.31
- An IP datagram has a source and a destination address

IP addresses: how to get one?

Q: How does a *host* get its IP address?

- hard-coded by system admin
  - Windows: control-panel->network->configuration->tcp/ip->properties
  - UNIX: /etc/rc.config
- DHCP: Dynamic Host Configuration Protocol: dynamically get the address from a server
  - “plug-and-play”

Protocol layering

Networks are complex, with many "pieces":

- hosts
- routers
- links of various media
- applications
- protocols
- hardware, software

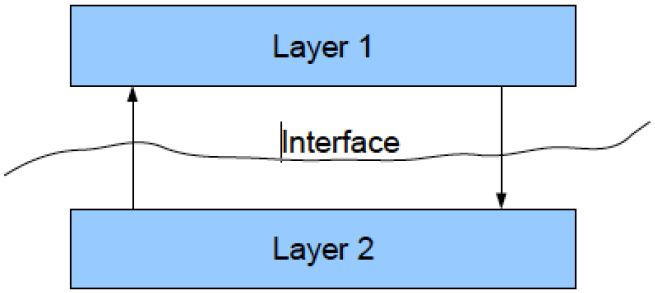
Question:

is there any hope of *organizing* the structure of a network?

…. or at least our discussion of networks?

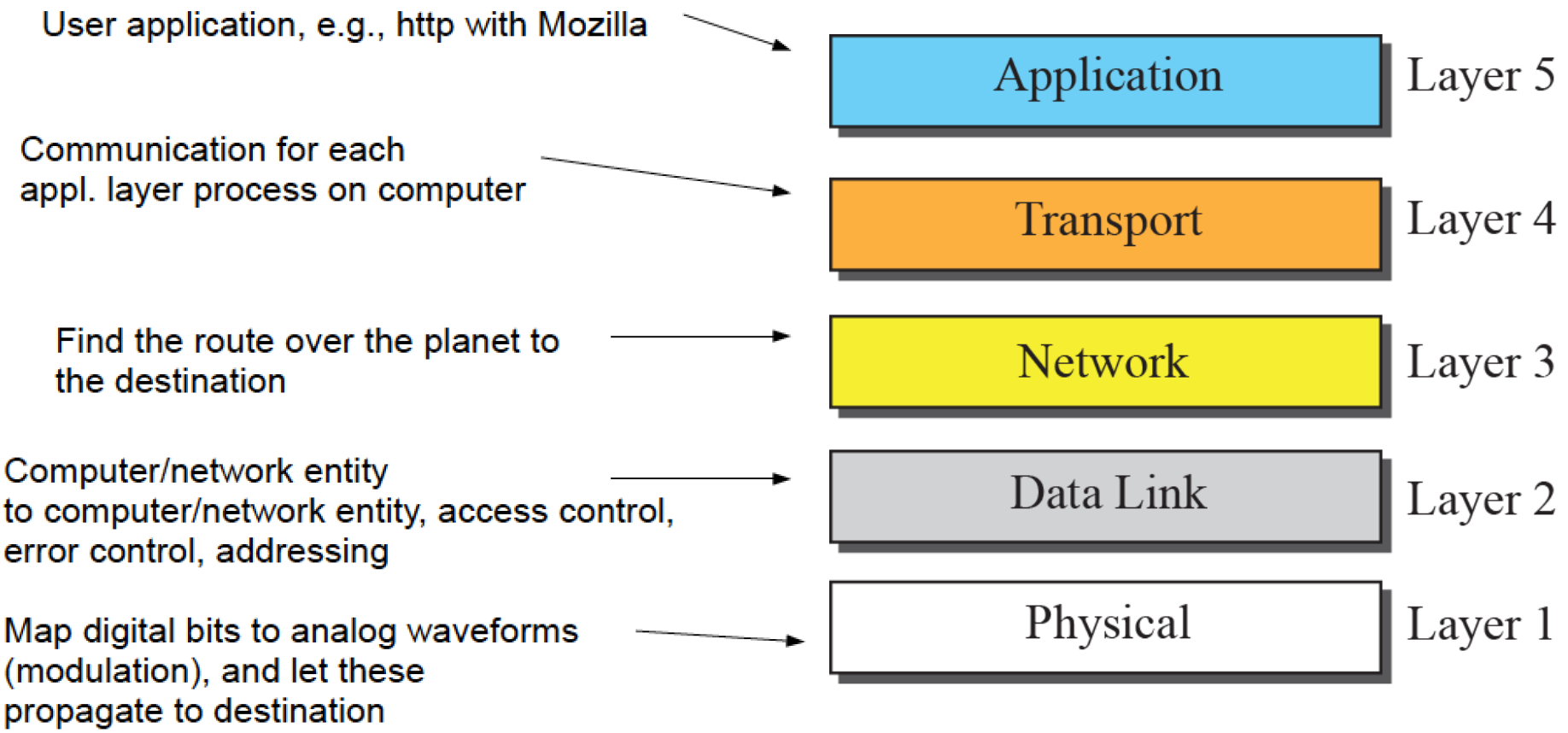
layers: each layer implements a service

- via its own internal-layer actions
- relying on services provided by layer below



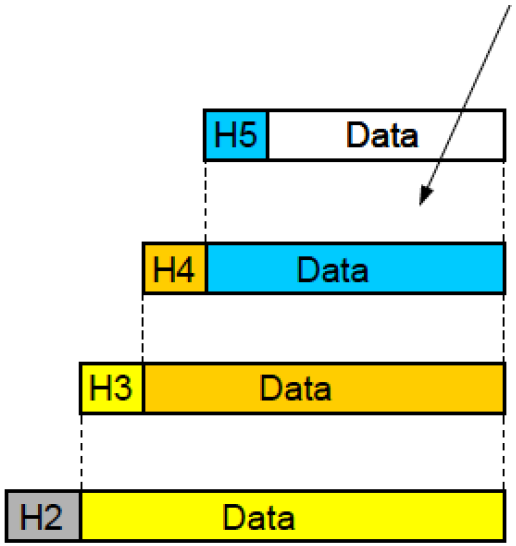
Slide adapted from: J.F Kurose and K.W. Ross, Computer Networking: A Top-Down Approach

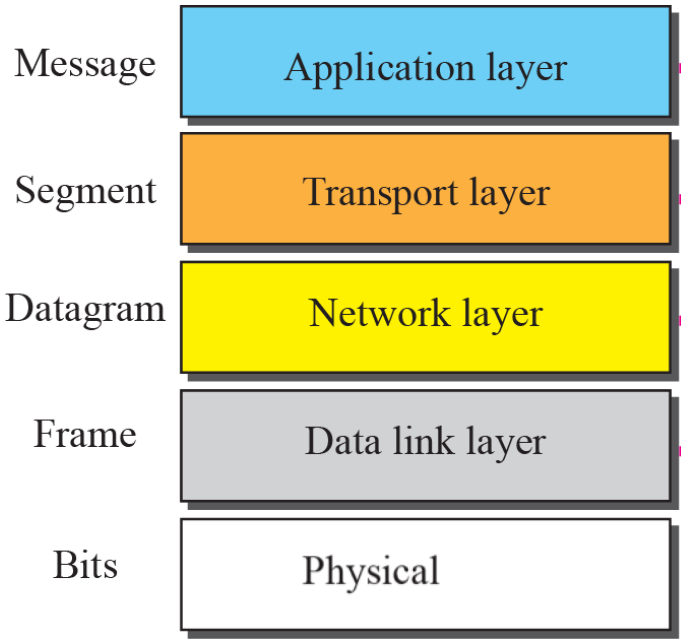
TCP/IP protocol suite



Encapsulation

Every new layer encapsulates previous layer data with a header



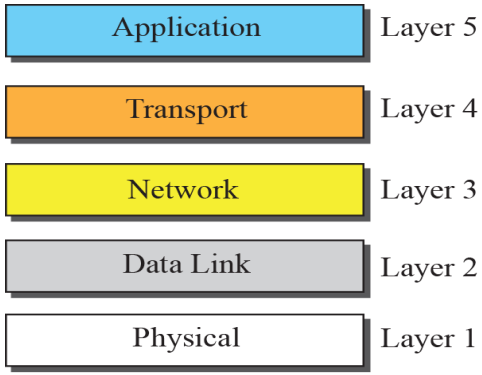


Layering pros & cons

- A way to structure a complex system
  - Simplifies the relationships between the parts
- Modularization eases maintenance and updating of system parts
  - Change of parts on one level is transparent to the rest of the system
- Layering introduces constraints – may lead to suboptimal performance (e.g. video transmission)!
  - Lower layer unaware of real-time requirement of the application

Layer 1: Physical layer

How to put digital bits onto an analog signal waveform (modulation).



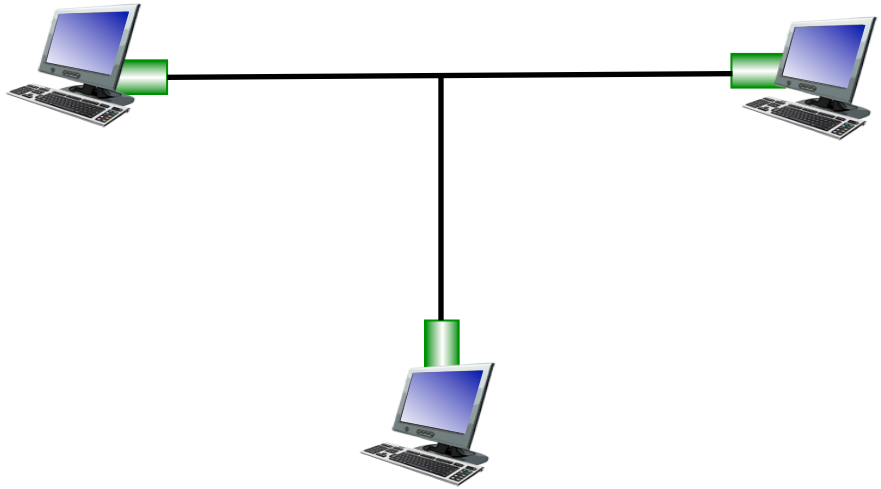
Example:

- On-Off switching (*wire, fiber*)
- Amplitude/frequency/phase modulation of a sine wave (*radio, wire*)
- Cable/Connector standards (e.g. CAT5, RJ-45…)

Layer 2: Link layer

Sending data (a frame) between two network interfaces 

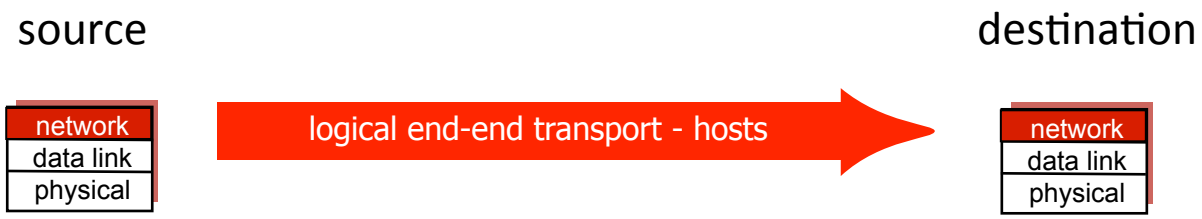
- Single-hop addressing, the MAC address
- Handling multiple access
  - FDMA, TDMA, CSMA
- Handling errors
  - FEC, ARQ



Layer 3: Network layer

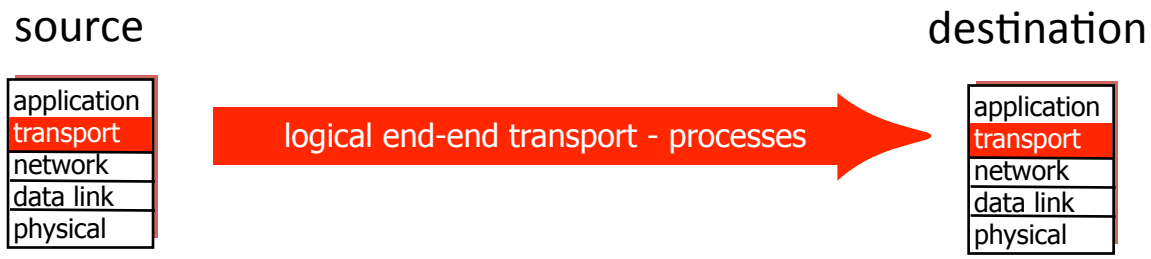
Sending a packet (datagram) between two computers

- Understanding the IP address
- Routing of packets



Layer 4: Transport layer

- Sending data (segment) between two computer processes using the port number
- UDP for “best effort” packets
- TCP for “reliable” connection

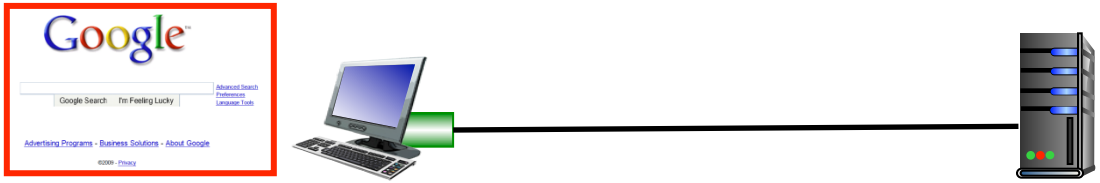


Layer 5: Application layer

Sending data (message) between computer applications.

Example:

- Email service (SMTP protocol)
- File transport (FTP protocol)
- Web browser to server (HTTP protocol)



Internet usage

- by traffic 2013

Total traffic: 35 EB/Months*

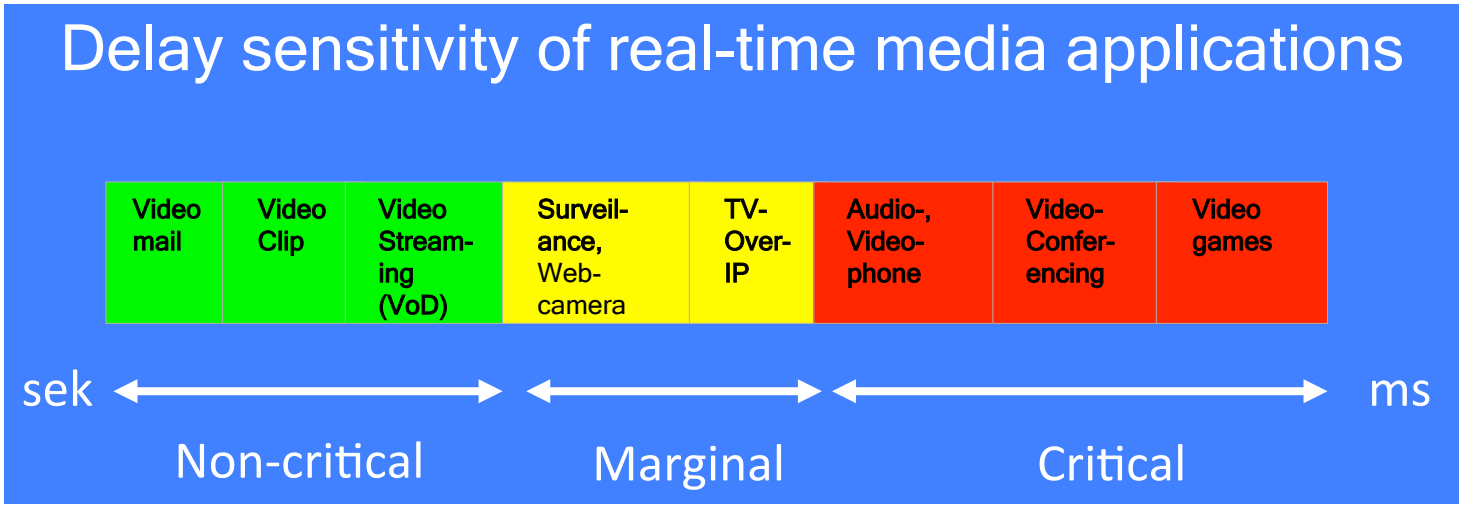
In addition, 15 EB/Month use TCP/IP for closed-networks (IP-TV)

Video is predicted to amount to >80 % by the year 2018.
The two main traffic classes are highly jitter sensitive (video) or delay sensitive (gaming)!

*EB: Exabytes = 10^{18} bytes

Real-time demands

- Network gaming, audio and video conferencing and Video-on-demand (VoD) are examples of real-time services
- These put particular requirements on the network, such as delay and error behavior
- Tradeoff – retransmit lost packets or add error correction or conceal the errors. To be further discussed in later lectures.



IPv6

- IP version 6 is an extension of IPv4
- 128-bit addresses. $2^{128} \approx 3.4*10^{38}$ instead of $4.2*10^{9}$ addresses in IPv4!
- IPv6 was defined already in 1998
- As of 2016 about 12% of domain names use IPv6
- Mobile network LTE is based on IPv6
- IoT is expected to speed up the deployment of IPv6

Example of Internet devices

Most of the technical terms will be explained in the next lecture!

ADSL

- Asymmetric digital subscriber line (ADSL)
- Example at home: Telia/Tele2 ADSL modem
- Access control: FDM/TDM
- Use of frequencies not used during PSTN voice call
- FEC (Forward error correction)

DOCSIS

- Data Over Cable Service Interface Specification (DOCSIS)
- Example at home: Comhem
- Access control: FDM/TDM
- Use of bandwidth not used by cable TV
- FEC

Traditional Ethernet, IEEE 802.3

- Home/office local area networks (LANs): e.g. from ADSL modem to a computer
- 100BASE-TX flavor common, 100 Mbit/s
- Over copper wire
- Access control CSMA-CD (error detection, ARQ)
- CAT 5, CAT 6 cable, RJ45 connector

IEEE 802.11 = WiFi

- CSMA-CA method 2
- FEC
- Example at home: wireless home network
  (e.g. from ADSL modem to home PC)

Cellular (mobile) devices

- GSM: TDMA, FEC

- LTE: TDMA/FDMA, FEC

Internet-of-things

- M2M using cellular networks
- Local networks: Bluetooth, Zigbee,…
- Example: Electricity monitor

Fiber optic communication

- Internet core: SONET OC-768: 40 Gbit/s
- FEC

Fiber-optic cables under seas