NSWI090: **Computer Networks**

http://www.ksi.mff.cuni.cz/~svoboda/courses/212-NSWI090/

Lecture 2

Taxonomy

Martin Svoboda
martin.svoboda@matfyz.cuni.cz

2022

Charles University, Faculty of Mathematics and Physics

Lecture Outline

Telecommunication networks

- Core networks
- Access networks

Data networks

Computer networks

- Geographic scales
  - PAN, LAN, MAN, WAN, …
- Internet architecture

Objectives

Categorization of networks

- *What types of networks exist?*
  - Their characteristics, mutual differences, …
- It will help us to understand what these networks are

Observations

- **Not entirely exact**
  - Boundaries may not be sharp
  - Contains subjective components
- **May be overlapping**
- **Evolving in time**
  - New technologies appear
  - Behavior of users changes

Broadcast Networks

Broadcast networks

- Solely **broadcast** transmissions (1:N)
  - The same content is distributed to all reachable recipients
    - No routing and forwarding is needed at all

Examples

- **Television** or **radio** broadcasting
  - Traditional analog or recent digital

Technologies

- **DVB** (Digital Video Broadcasting)
  - DVB-T2 (**Terrestrial**), DVB-C2 (**Cable**), DVB-S2 (**Satellite**), …
- **DAB** (Digital Audio Broadcasting)
- …

Switched Networks

Switched networks

- Primarily **unicast** transmissions (1:1)
  - Targeted routing and forwarding needed

Meaningful possibilities

- **Circuit switching**
  - Necessarily connection-oriented and guaranteed
  - Both block / stream and reliable / unreliable transmissions
- **Packet switching**
  - Necessarily block transmissions
  - **Connection-oriented**: **virtual circuits**
    - Both reliable / unreliable and Best Effort / QoS
  - **Connectionless**: **datagram service**
    - Both reliable / unreliable and Best Effort / relative QoS

Basic Categories

Telecommunication networks

- Provide dedicated one-purpose services only
  - Broadcast: television and radio broadcasting
  - Switched: fixed or mobile telephony
- **Smart network, dumb devices**

Data networks

- Allow transmissions of digital data of any form
- **Dumb network, smart devices**

Computer networks

- Interconnect computers and other devices into networks
- **Dumb network, smart devices**

Telecommunication Networks

Typical infrastructure

- **Core network** (backbone network, transport network)
  - **Interconnects core components of the entire infrastructure**
    - Relatively small number
    - Usually greater distances
    - Usually using optical fibers
- **Access network**
  - **Allows the connection of end users to the core network**
  - Point of Presence (POP)
    - Forms the interface between the core and access networks
  - Customer Premises (CP)
    - Place of occurrence of potential subscribers

Fixed Telephone Network

Fixed telephone network in the Czech Republic

- Historical development of owners
  - SPT Praha (Správa pošt a telekomunikací)
  - 1993: SPT Telecom
  - 2000: Český Telecom
  - 2006: Telefónica O_2 Czech Republic
  - 2014: O_2 Czech Republic
  - 2015: **CETIN** (Česká telekomunikační infrastruktura)
- Greatest development in 1990s
- Current situation
  - Core: 38 000 km optical cables
  - Access: 20 000 000 km pairs of metallic cables

Fixed Telephone Network

Core network

- Hierarchy of **telephone exchanges**
  - 2 international
  - 8 transit
  - 140 local
  - Thousands advanced – **Remote Subscriber Units** (RSU)
- Context: territorial administrative units
  - 14 regions
  - 77 districts
  - 6 258 municipalities
  - 15 094 municipality parts
  - 82 262 streets

Fixed Telephone Network

Access network

- **POP**: local exchanges / RSUs with main switchboards
- **Local loops** – between POPs and individual CPs
  - Metallic cables (twisted pairs)
  - Formed by individual sections
    - Bundles of cables
    - Can be branched in network switchboards
  - Maximal length: up to 5 km
- **CP**: houses, flats, offices, …
  - 8 million local loops
  - Active ones: 3.8 million (2001), 700 thousand (2019)
    - 634 thousand pending applicants in 1994
    - Waiting times several years before 1989

Mobile Telephone Network (2G)

Core network: Network Switching Subsystem (NSS)

- Mobile Switching Center (MSC)
- Gateway MSC: gateways to different networks

Access network: Base Station Subsystem (BSS)

- **GERAN** (GSM EDGE Radio Access Network)
  - Base Station Controller (BSC)
  - **Base Transceiver Station** (**BTS**)
    - Facilitates communication between end users and a network
    - Typically several transceivers
    - One BTS forms one cell, can have multiple sectors
    - Each with a different frequency
- Example (T-Mobile)
  - 13 MSC, 150 BSC, 4 500 BTS, 13 100 sectors

Access Networks

Features of (fixed) access networks

- **Allover** and **dense**
  - Cover the whole territory
  - Must lead to all potential customers
- Pass through **public spaces**
  - Sidewalks, streets, or roads must be dug up
  - Requires planning, synchronization, and formal permits
  - It is **expensive and complicated**
    - Earthworks represent 85% of all costs
- **Build forward**
  - **State-of-the art technology** is used
    - With the greatest transmission potential
  - Intentionally designed as **oversized**
    - Higher number of cables, usage of protectors, …

Last / First Mile

Last mile (last kilometer)

- Refers to the final leg of (telecommunication) networks
  - I.e., **access network**, units of kilometers
- Describes the perspective of the provider
- Alternatively: **first mile** (as seen by end users)

Possible spanning solutions

- Building of an **entirely new network**
  - **Wireless**, wired (nowadays **optical**)
  - Costly, unclear regulatory aspects, …
    - Local loop unbundling in past
- Exploitation of an already existing infrastructure
  - $\Rightarrow$ **overlay access networks**

Overlay Access Networks

Overlay access networks

- **New network is built on top of another one**
  - Modification or extension of the original technology
    - Usage of different frequencies, encapsulation of data, …
- **Original functionality** is preserved

Existing options

- **Fixed telephone networks**
  - Usage of twisted pairs in local loops
- **Electrical power networks**
  - Usage of electrical power wirings
- **Cable television networks**
  - Usage of coaxial cables for television broadcast delivery

xDSL Technologies

Traditional **fixed telephone network**

- **Plain Old Telephone Service** (POTS)
  - Metallic local loops based on twisted pairs
  - Usage of **voice band only**
    - 300 Hz – 3.4 kHz

Overlaying strategy and issues

- Usage of **non-voice frequencies**
  - Above 3.4 kHz
  - Based on the general principle of **frequency multiplex**
- Digitization
- **Distance** as a major limiting factor

xDSL Technologies

Technical solution

- Principle
  - DSL modem $\leftrightarrow$ splitter $\leftrightarrow$ local loop $\leftrightarrow$ DSLAM
- **CP** side
  - **Modem** (modulator-demodulator)
    - Device converting digital data into / from analog signal
  - **Splitter**
    - Passive device separating / joining different frequency bands
- **POP** side (local exchange / RSU)
  - The same principle, only integrated in one structural unit
  - **DSLAM** (DSL Access Multiplexer)
  - Data transmissions are diverted to a separate core network

xDSL Technologies

Family of **xDSL** technologies (**Digital Subscriber Line**)

- 1998: **ADSL** (Asymmetric Digital Subscriber Line)
  - 25 kHz – 1.1 MHz
  - Up to several kilometers
  - 8 Mb/s downstream, 1.5 Mb/s upstream
- …
- 2006: **VDSL2** (Very High-Speed Digital Subscriber Line 2)
  - Up to 35 MHz
  - Up to 300 meters
  - 200 Mb/s downstream, 100 Mb/s upstream

PLC Technologies

Underlying **electrical power network**

- AC (alternating current) electric power transmission
  - 110 V, 120 V, 220 V, **230 V**, …
  - **50 Hz**, 60 Hz

Overlaying strategy and issues

- Usage of **higher frequencies**
- Different standards in different countries
- **Radio emissions** of unshielded wires (act as antennas)
  - Regulations are therefore in effect
- **Very noisy** environment with **high attenuation**
  - Transformers completely prevent signal propagation
  - Turning electrical appliances on or off produces noise

PLC Technologies

Power-Line Communication (PLC)

- **Long haul**
  - Low frequencies, only a few hundred bits per second
  - Infrastructure monitoring and maintenance only
- **Last mile**
  - Expensive and not used in practice
  - **Broadband over Power Line** (BPL)
    - Medium voltage transmissions between transformers
    - Low voltage transmissions between transformer and outlets
- **Last meter** (withing a building, …)
  - **HomePlug**
    - Home networking
    - Up to 500 Mb/s, below 100 MHz
    - Behind the residential electricity meter

DOCSIS Technologies

Traditional **cable television network**

- **Community Antenna Television** (CATV)
  - Broadcast network for television program
  - Based on coaxial cables
  - Originally **analog** and **one-way** only

EuroDOCSIS (Data Over Cable Service Interface Specification)

- 1997: **DOCSIS 1.0**
  - 40 Mb/s downstream, 10 Mb/s upstream
- …
- 2017: **DOCSIS 4.0**
  - 10 Gb/s downstream, 6 Gb/s upstream

DOCSIS Technologies

Access network infrastructure

- **Hybrid Fiber-Coaxial** cable system (HFC)
  - Combination of **optical fibers** and **coaxial cables**
  - **CMTS** (Cable Modem Termination System)
    - Located at **distribution hubs** (headends)
    - Forms a POP
    - Represents an analogy to DSLAMs
  - **Optical node**
    - Optical fibers towards CMTS
    - Coaxial cables towards customer premises
  - **Cable Modem** (CM)

Wireless Access Networks

Wireless access networks

- Do not require (extensive) earthworks
- Require suitable **frequencies**
  - Very scarce resource
  - **Licensed** / **unlicensed** spectrum

Mobility options

- **Mobile**
  - Communication possible even while moving
- **Nomadic**
  - Communication impossible while moving
- **Fixed**
  - Without any mobility support

Wireless Access Networks

Operation principles

- **P2P**: **Point-to-Point**
  - Wireless Local Loop (WLL)
- **P2MP**: **Point-to-MultiPoint**
  - Mobile networks
    - GSM, CDMA, 3G/UMTS, LTE, …
  - Fixed Wireless Access (FWA)
    - WiMAX, …
  - Wi-Fi networks

Optical Access Networks

Optical networks in general

- **Active**
  - **Active powered network elements** are used for **branching**
    - Act as amplifiers
    - Maintenance and monitoring needed
  - **Higher rates**, **longer distances**
  - Expensive
- **Passive**
  - Only passive elements are used
    - Can be buried underground
  - **Lower rates**, **shorter distances**
  - Sufficient enough for access networks

FTTx Technologies

Optical access networks

- Usually built as Passive Optical Networks (PON)

Family of **Fiber to the x** technologies (FTTx)

- *How close to the end user is the optical network terminated?*
  - The closer, the better…
    - Higher rate, but also more complex and expensive
  - **Last meter** is often solved using a different technology
- **FTTH**: Fiber to the **Home**
- **FTTB**: Fiber to the **Building**
- **FTTC**: Fiber to the **Curb**
- **FTTN**: Fiber to the **Node** (used by DOCSIS in HFC)
- …

Data Networks

Telecommunication networks

- Provide dedicated telecommunication services
  - E.g., voice calls, television broadcast, …
- **Smart network** paradigm

Data networks

- Allow **transmissions of data** in digital form
  - I.e., data of various applications, services, …
- **Dumb network** paradigm
- Principles
  - Both circuit switching and packet switching
  - Usually Best Effort but QoS as well
- **Private**, **public**, and **virtual private** alternatives

Private Data Networks

Private data network

- **User = owner** (operator can be outsourced, though)
- Advantages
  - **Owner decides everything**
    - Technologies, protocols, addresses, policies, security, users, …
- Disadvantages
  - **Expensive**
    - Only bigger subjects can afford such a solution

Example

- **Data network of Ministry of the Interior**
  - Operated by Czech Post
  - Used primarily within the integrated rescue system
    - Police, medical rescue, fire rescue, regional authorities, …

Public Data Networks

Public **data network**

- Intended to be **used by customers on a commercial basis**
  - Owners
    - Do not use the network
    - Usually **telecommunication operators**
  - Customers
    - Basically anyone willing to pay
- **Charging** principles
  - Volume of data, number of established connections, …
- Documentation needed
  - How to connect, how to address, how to send data, …

Public Data Networks

Public data network (cont'd)

- Advantages for users
  - More convenient **for smaller subjects**
  - **Flexibility**
    - Used as a service, no investments
- Disadvantages for users
  - **Shared by all users**
    - Aspects of security, …
  - **Owner decides everything**
- Advantages for owners
  - **Higher financial revenues**
    - Data network has added value compared to ordinary circuits

Virtual Private Data Networks

Virtual private **data network**

- Principle
  - **Shared infrastructure**
    - Either private or public data network
  - **Illusion of a private network**
    - Individual networks are **logically separated** from each other
    - Other networks (their users, addresses, data) are not visible
- Intended users are companies and their users
- Advantages
  - **Lower costs**
  - Considerable **autonomy** in decision-making
    - Essentials are given by the owner (technology, protocols, …)
    - Everything else is decided by a customer (permissions, …)

Computer Networks

Geographic scale of computer networks

- **Personal Area Networks** (PAN)
  - Personal operating space
  - $\approx$ 1 – 10 m
- **Local Area Networks** (LAN)
  - Household, building, school, office, company, …
  - $\approx$ 10 m – 1 km
- **Metropolitan Area Networks** (MAN)
  - University campus, city, agglomeration, …
  - $\approx$ 1 km – 100 km
- **Wide Area Networks** (WAN)
  - Regions, countries, continents, whole planet
  - $\approx$ 100 km and more

Personal Area Networks

Personal Area Networks (PAN)

- Interconnect **devices within operational space of one person**

Devices

- Stationary
  - Computers, laptops, keyboards, mouses, printers, …
- Mobile
  - Smart phones, tablets, headsets, ebook readers, …

Technologies

- Wired
  - USB, FireWire, …
- Wireless
  - Wi-Fi, Bluetooth, IrDA, …

Local Area Networks

Local Area Networks (LAN)

- Interconnect **closely related computers and other devices**
  - Within the scope of one household, building, company, …
- Two different meanings
  - **LAN** in the **broader sense**
    - Any short-range network as described above
    - May contain routers and so technically multiple networks
  - **LAN** in the **narrower sense**
    - Individual nodes are only interconnected at `L1` and `L2` layers
    - I.e., there can be repeaters and switches but no routers

Devices

- Personal computers, laptops, servers, printers, …

Local Area Networks

Technologies

- **Ethernet**, **Wi-Fi**, …

Properties (when compared to WAN)

- Lower latency
- Higher reliability
- Systematic topology
  - Bus, star, tree, …
- Limited availability of nodes
  - According to the needs of users

Metropolitan Area Networks

Metropolitan Area Networks (MAN)

- Interconnect **individual LAN networks**

Examples

- **PASNET** (**Prague Academic and Scientific Network**)
  - High speed metropolitan academic network
  - Members
    - Academy of Sciences
    - Charles University
    - Czech Technical University in Prague
    - Prague University of Economics and Business
- **MEPNET** (**Metropolitan Prague Network**)
  - Private network for city administration
- …

Metropolitan Area Networks

Technologies

- Gigabit Ethernet, WiMAX, ATM, FDDI, …

Properties

- Owned by groups of legal entities, individual cities, …
  - Owner may or may not be the intended user
- Often pass through **public spaces**
  - Which is not the case of LAN networks

Wide Area Networks

Wide Area Networks (WAN)

- Interconnect **individual MAN or LAN networks**
- **Transfer data over longer distances**
  - Often cross public spaces as well as borders of countries
- Typical owners
  - Big companies
    - Internal usage
  - **Providers and telecommunication operators**
    - Provide services on a commercial basis

Wide Area Networks

Examples

- **CESNET**
  - **National e-infrastructure for science, research and education**
    - Interconnects largest university cities and other areas
    - 27 member universities
  - **Connectivity**
    - 100 Gb/s to GÉANT (pan-European research and education network)
    - 10 Gb/s to Internet via Telecom Italia (Tier 1 provider)
    - 10 Gb/s to Google
    - 2x100 Gb/s peering to NIX.cz (IXP)
    - …
- …

Wide Area Networks

Technologies

- L1 paths
  - Usually **optical fibers**
- L2 technologies
  - ATM, Frame Relay, X.25, **MPLS**, **Packet over SONET/SDH**, …
- L3 protocols
  - **TCP/IP**

Properties (when compared to LAN)

- Higher latency
- Lower reliability
- Unsystematic topology
- Permanent availability

Internet Architecture

Original situation

- Only **one backbone network**
- **ARPANET**
  - The very first wide-area **packet switching** network
  - Financed by **military** grant agency ARPA
- **NSFNET**
  - Financed by **civil** grant agency NSF
  - Objective of promoting research and education networking

Later situation

- **Multiple commercial backbone networks**
- Compete with each other
- Interconnected by Network Access Points (NAPs)

Internet Architecture

Contemporary situation

- Hierarchy
  - **Tier 1** / **Tier 2** / **Tier 3** Internet Service Provider (ISP) networks
  - Access networks
- Backbone: **system of Tier 1 networks**
- Networks are mutually interconnected by IXP points
  - Within or across tiers

Internet Exchange Point (IXP)

- Point where networks interconnect to peer or exchange traffic
- Examples
  - **NIX.cz** (Neutral Internet eXchange)
    - 195 networks, capacity 10 Tb/s
  - …

Internet Architecture

Types of traffic

- **Peering**
  - Based on a mutual agreement of two ISPs
  - Allows for **direct exchange of traffic** between their networks
- **Transit**
  - End user or ISP pays another (usually larger) ISP to carry all their traffic to the Internet

Internet Architecture

Tier 1 providers (backbone providers)

- **Network that can reach every other network on the Internet without purchasing transit or paying for peering**
  - Direct access to basically any other network in the world
  - Vast physical infrastructure
  - Mutual charging does not make any sense
- Examples
  - AT&T, Deutsche Telekom, Verizon, …
  - Can have even more than 800 000 km of optical paths
  - Altogether 15 ISPs

Internet Architecture

Tier 2 providers

- **Network that peers for free with some networks, but still purchases transit or pays for peering to reach at least some portion of the Internet**
  - Usually have their own physical infrastructure
    - But significantly smaller
- Regional or national scope

Tier 3 providers

- **Network that solely purchases transit or peering from other networks to participate in the Internet**
- Local last mile providers
  - Provide connection to end users

Organizational Scopes

Intranet

- Services and resources intended to be used by internal users
  - Shared printers, data storages, …
  - Applications (accounting, CRM, …), document sharing, …

Extranet

- Services and resources intended to be used by external users
  - Marketing, e-commerce, e-business, …
  - Updates, support, helpdesk, …

Internet

Darknet

- Overlay network, anonymized and not publicly accessible
  - File sharing, computer crime, black markets, whistleblowing, …

Lecture Conclusion

Telecommunication networks

- Core networks
- (Overlay) access networks
  - xDSL, PLC, DOCSIS, wireless, optical

Data networks

- Private, public, virtual private

Computer networks

- Geographic scales
  - PAN, LAN, MAN, WAN, …
- Internet architecture
  - Peering and transit traffic
  - Tier 1, Tier 2, and Tier 3 ISPs