

NSWI090: Computer Networks

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Lecture 2

Taxonomy

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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 O₂ Czech Republic
 - 2014: O₂ 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
 - ⇒ **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 ↔ splitter ↔ local loop ↔ 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 (**D**igital **S**ubscriber **L**ine)

- 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, ...
 - ≈ 10 m – 1 km
- **Metropolitan Area Networks (MAN)**
 - University campus, city, agglomeration, ...
 - ≈ 1 km – 100 km
- **Wide Area Networks (WAN)**
 - Regions, countries, continents, whole planet
 - ≈ 100 km and more

Personal Area Networks

Personal Area Networks (PAN)

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

Devices

- Stationary
 - Computers, laptops, keyboards, mice, printers, ...
- Mobile
 - Smart phones, tablets, headsets, ebook readers, ...

Technologies

- Wired
 - USB, FireWire, ...
- Wireless
 - Bluetooth, IrDA, NFC, Wi-Fi, ...

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