NSWI090: **Computer Networks**

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Lecture 1

Paradigms

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2022

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Lecture Outline

Introduction and motivation

- Basic concepts
- **Network paradigms**
- Telecommunication / computer networks

Motivation

Ultimate objective

- Transmission **of data**
  - I.e., **not processing**
    - Algorithms, data structures, time complexities, …
  - As well as **not storing**
    - Database systems, logical models, query languages, …

Major requirement

- **Transmitted data should not change**
  - However…

Relevant questions

- Distance, volume, velocity, latency, reliability, …

Basic Concepts

Transmission path

- Path between the sender and recipient in a network
- Includes **any means of transmission**
  - Regardless of technical implementation
    - Wired (metallic, optical), wireless
  - At different levels of abstraction
    - Physical, virtual

Transmission channel

- One-way transmission path in telecommunication networks

Transmission circuit

- Two-way transmission path
  - Physical, emulated / virtual

Basic Concepts

Simplex mode

- Allows for transmissions in **one direction only**
  - E.g., television and radio broadcasting

Half-duplex mode

- Allows for transmissions in **both directions**, but **not simultaneously**
  - Communicating entities need to take turns

Full-duplex mode

- Allows for transmissions in **both directions** at the same time

Basic Concepts

Unicast transmissions

- One sender, one intended recipient
  - The most common situation

Anycast transmissions

- Any node in a given predefined group

Multicast transmissions

- Every node in a static / dynamically created group

Broadcast transmissions

- Any reachable node (in a given network, …)

Basic Concepts

Telecommunication / computer network / infrastructure

- System of nodes mutually interconnected by transmission paths formed by network elements

Nodes

- Anything wanting to communicate
  - Servers, terminals, personal computers, laptops, …
  - Printers, mobile phones, smart TVs, …

Network elements

- Active
  - Repeaters, switches, routers, gates, …
  - Switchboards, controllers, transceivers, …
- Passive

Basic Concepts

Networks provide services to their users

- Television and radio broadcasting
- Voice and video calls
- Video on demand
- Electronic mail
- Messaging platforms
- File transfers
- Web pages browsing
- …

Basic Concepts

Services (cont'd)

- Provided at different levels of abstraction
  - Internal implementation details are concealed
  - Services can be built on top of other services
    - **HTTP** web page request at $\mathtt{L7} \rightarrow$ reliable connection-oriented **TCP** at $\mathtt{L4} \rightarrow$ best effort **IP** at $\mathtt{L3} \rightarrow$ **Ethernet** at $\mathtt{L2}$
- **Different requirements and expectations**
  - Different principles, protocols, and technologies are needed

Network Paradigms

Fundamental questions to be figured out

- **Stream vs. block transmissions**
  - *In what form will the data be transmitted?*
- **Circuit vs. packet switching**
  - *How will the data reach the intended recipient?*
- **Connection-oriented vs. connectionless transmissions**
  - *Do we need to agree on the communication in advance?*
- **Reliable vs. unreliable transmissions**
  - *What level of transmission reliability is required?*
- **Guaranteed vs. non-guaranteed services**
  - *Will sufficient resources be available all the time?*
- …

Data Transmission

In what form will the data be transmitted?

Stream transmissions

- Data is sent as a continuous stream without any logical division

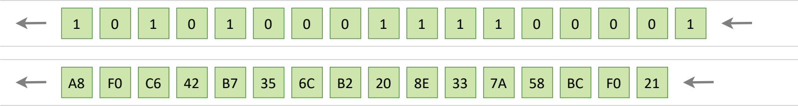
Block transmissions

- Data is divided into reasonably large blocks,
  these blocks are then sent one by one

Stream Transmissions

Streams

- Data is transferred as a continuous unstructured **stream**
  - At the level of individual **symbols** (bits, bytes, words, …)

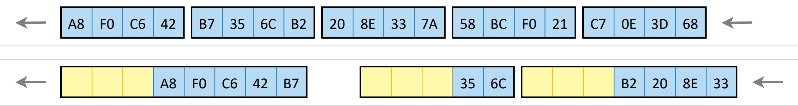


- Features
  - **Preserves order** (works as a FIFO queue)
  - Suitable for point-to-point connections
    - I.e., in case there is only one intended recipient
- Examples
  - `L1`: **Ethernet**, **Wi-Fi**, …
  - `L4`: **TCP** (virtual streams for `L7` over `L3` blocks)

Block Transmissions

Blocks

- Data is divided into reasonably large units called **blocks**
  - **Fixed size**
  - **Variable size**
    - Restrictions on maximal / minimal lengths may be in effect, too



- Features
  - Blocks may not directly follow each other
    - Nothing is remaining to be sent at a moment
    - Intentional delays between the blocks may be needed
  - **Order may not be preserved**

Block Transmissions

May (but also may not) be enriched with additional **metadata**

- **Sender / recipient addresses**
  - So that blocks can be correctly forwarded when a given transmission path is not direct
- **Transmission identification**
  - So that multiple different transmissions can be mutually distinguished on a shared path
- **Block ordinal numbers**
  - So that the original data can once again be reconstructed
- …

Block Transmissions

Main tasks

- Internal structure
  - **Header**, **body**, **footer**
- Combinations of both the approaches
  - **Blocks over streams** (framing)
  - **Blocks over blocks** (encapsulation)
  - **Streams over blocks**

Names of blocks

- Depend on particular layers / technologies / protocols
  - L2: Ethernet **frames**, ATM **cells**, …
  - L3: IPv4 **datagrams**, IPv6 **packets**, …
  - L4: TCP **segments**, UDP **datagrams**, …
  - L7: HTTP **messages** (requests, responses), …

Switching Mechanisms

How will the data reach the intended recipient?

Circuit switching

- Transmission circuit is created first,
  all data is then sent through this circuit
- Based on **reserved capacity**
  - Mainly in **telecommunication** networks

Packet switching

- Each block of data is routed and forwarded separately
- Based on **shared capacity**
  - Mainly in **computer** networks
  - Very revolutionary idea in its time (in 1960s)
  - Aims at **robustness and resilience** against failures and outages

Circuit Switching

Basic mechanism

- Transmission **circuit is created on demand**
  - I.e., transmission path is **found** and **laid out**
    - Physically interconnected
    - Marked virtually at higher layers
- All **data is then sent directly** through this circuit

Examples

- PSTN (traditional Public Switched **Telephone Network**)
  - Originally **manual** switching by operators $\rightarrow$ later on automated **electronic** switching $\rightarrow$ fully **digital** switching nowadays

Circuit Switching

Features and consequences

- Illusion of a **direct connection**
  - Though a circuit will most likely in reality be laid out across multiple network elements
- $\Rightarrow$ low and **constant latency**
- $\Rightarrow$ **preserves order**
- Effect of **reserved capacity**
  - No one else is entitled to use a given circuit
- $\Rightarrow$ enables **guarranteed** transmissions
- Supports both **streams and blocks**
- Always is **connection-oriented**

Packet Switching

Switching node logic

- Each interface (path) has its own **inbound / outbound buffer**
- Whenever a new block is received
  - It is stored within a given inbound buffer
- **Waiting blocks are perpetually iterated over and processed**
  - Routing decision is made for a given block
  - It is then moved to the corresponding outbound buffer
  - Finally, it is send as soon as it is possible

Examples

- L2: Ethernet **switches**, …
- L3: IP **routers**, …

Packet Switching

Only possible for **block transmissions**

$\Rightarrow$ the following pieces of metadata is necessary

- **Recipient** identification
  - So that the intended recipient can be located as well as the individual ongoing transmissions mutually distinguished
- **Sender** identification
  - So that error messages can be sent back in case of failures

Packet Switching

Available **capacity is shared** and limited

- Transmission capacity of paths
- Computing (switching) capacity of switching nodes
  - Buffer sizes, processor throughput

$\Rightarrow$ significantly **higher, variable, and unpredictable latency**

- Which also **depends on the current load**
  - I.e., it can never be estimated in advance

$\Rightarrow$ **available capacity may be insufficient**

- Excessive blocks will then need to be discarded

Connection Schemes

Do we need to agree on the communication in advance?

Connection-oriented transmissions

- Both the communicating parties need to **establish, maintain, and eventually terminate a connection** with each other
- Order of data is / must be preserved
- Unique **connection ID** is usually assigned

Connectionless transmissions

- Communication is based on **sending separate messages**
- Order of data is not preserved

Connection-Oriented Transmissions

Connection-oriented **approach**

- **Connection is established**
  - This means that…
    - Both the parties really **exist**
    - They are able to locate each other
    - They **agree** with the communication
  - Communication **parameters can be negotiated**
  - Transmission path can be laid out, resources allocated, …
- The actual data is then transferred
- Connection is **eventually terminated**
  - E.g., resources are returned, marked circuits are released, …

Connection-Oriented Transmissions

Analogy

- Traditional **voice call** over a **telephone network**
  - Phone number is dialed $\rightarrow$ call is established $\rightarrow$ parties are talking to each other $\rightarrow$ call is hanged up and terminated

Examples

- L2: ATM (Asynchronous Transfer Mode)
- L4: **TCP** (over a connectionless IP at L3)
  - Ordering of segments needs to be enforced
- L7: HTTP, SMTP, POP3, …
  - I.e., anything over TCP from L4

Connection-Oriented Transmissions

Stateful operation

- Communicating parties **transition between the states**
  - E.g.: *closed*, *established*, …
- Transitions must be **correct and coordinated**
  - Mutual misunderstandings must be avoided
  - Deadlocks must be avoided
- **Non-standard situations** must be detected and treated
  - Connection failures, …

Connectionless Transmissions

Connectionless **approach**

- Separate messages called **datagrams are sent**
  - No connection is established
    - Recipient may not exist, may not want to communicate, …
    - Nothing is established, no termination is required, …
  - Stateless operation
  - **Datagrams are delivered independently on each other**
    - They may be routed differently
    - Their order cannot be guaranteed
  - Must contain full **recipient identification**

Connectionless Transmissions

Analogy

- Traditional **postal services**
  - Postcards, letters, parcels, …

Examples

- L4: **UDP**
- L3: **IP**, **ICMP**
- L2: **Ethernet**

Packet Switching

Circuit switching is always **connection-oriented**

Packet switching itself may be…

- Connection-oriented: **virtual circuits**
  - Transmission **path is laid out only virtually**
    - Suitable **Virtual Circuit Identifier** (VCI) is assigned
    - Individual network elements must note the actual path
  - Blocks are then forwarded based on these VCIs
    - Each is delivered via the same path
  - Example
    - L2: **ATM**
- Connectionless: **datagram service**

Reliability Levels

What level of transmission reliability is required?

Observations

- Transmissions are never ideal
  - It may always happen that the data will be damaged
    - Entire **blocks can be lost**
    - Actual **data can be corrupted**

Reliable transmissions

- Sender considers their duty to take care of the remedy
- **Errors are detected and treated**

Unreliable transmissions

- Errors are not detected, nor treated
- **Transmission simply goes on**

Reliable Transmissions

Detection mechanisms

- Parity, checksums, CRC, …
  - Whatever particular approach is exploited, **it is impossible to detect all the possible errors and extents of damage**

Remedy options

- Error correction codes
- **Repeated transmission**
  - **Positive acknowledgment** when received successfully
  - **Negative acknowledgment** otherwise
    - I.e., request for a retransmission

Example

- L4: **TCP** (Go-Back-N or Selective Repeat ARQ)

Reliable Transmissions

Consequences

- **Higher number of messages**
  - Positive / negative acknowledgments
  - Repeated data transmissions
- Delivery **regularity is disrupted**
  - Significant delays occur
- Messages are slightly bigger (because of the checksums)
- **Higher usage of computing and transmission capacity**
  - Sender / recipient nodes
    - The entire mechanism needs to be deployed
  - Network: handling of extra messages
- **Reliability is never absolute**

Unreliable Transmissions

In other words…

- Reliability is always **relative only**
  - While insufficient in one case, excessive in another
- It is always connected with a **non-zero overhead**

$\Rightarrow$ unreliable **transmissions** make sense as well

- Especially in case of **multimedia applications**
  - Audio / video, interactive / non-interactive
- **Regularity** of delivery is essential, **low latency** may as well

Examples

- L4: **UDP**
- L3: **IP**
- L2: **Ethernet**, ATM

Guarantee Options

Will sufficient resources be available all the time?

Guaranteed transmission / service

- Provides such a guarantee for all the currently ongoing data transmissions
  - In terms of computing and transmission capacity
- Resources must be **reserved in advance**
  - During the connection process
- Realized via **circuit switching**

Non-guaranteed transmission / service

- It may happen that sufficient resources will be missing
- Realized via **packet switching**

Guaranteed Transmissions

Exclusive **capacity**

- Solely for the purpose of the given communicating parties

$\Rightarrow$ **disadvantages**

- Must be high enough to cover the **maximum expected load**
- **Unused capacity** cannot be left to anyone else
  - It is forfeited uselessly
- The whole approach is **ineffective** and **expensive**
  - Everything must be dimensioned for the sum of maxima

Non-Guaranteed Transmissions

Shared capacity

- Cheaper and more efficient solution
  - Everything can be **dimensioned for the average load**

$\Rightarrow$ **disadvantages**

- When sufficient remaining resources are not available
  - Because of…
    - Completely filled buffers
    - Overloaded processor
    - Transmission capacity of individual paths
- Certain **packets will need to be discarded**!
  - Note that this is the only possible measure
- The question is which…

Non-Guaranteed Transmissions

Best Effort principle

- *Maximum effort…*
  - All packets are delivered as long as it is possible
- *… but uncertain outcome*
  - Should packet loss be inevitable, **all data is treated equally**
    - I.e., there are no rules, no priorities, no criteria
- Examples
  - L3: **IP**
  - L2: **Ethernet**, ATM (but also various QoS alternatives)

Quality of service (QoS)

- Anything else compared to the best effort principle
  - The extent of particular **guarantees may vary**

Quality of Service

Relative QoS – principle of **prioritization**

- Better conditions are provided for certain kinds of data
  - Based on **different priorities**

Absolute QoS – principle of **reservation**

- Guarantees the same conditions regardless of the current situation and load
- Resources must be **reserved in advance**
  - Reservation request must be **rejected when not attainable**
- Similar to circuit switching
  - And so has the same advantages, but disadvantages as well

Different Worlds

World of telecommunication **networks**

- Significantly older
  - Communication was considered a strategic interest
- **Smart network, dumb devices** paradigm

World of computer **networks**

- **Dumb network, smart devices** paradigm

Both the worlds traditionally built their own **separate networks**

- They have always **differed greatly** in many aspects
- But **integration and convergence attempts** are intensifying

Telecommunication Networks

Smart network, dumb devices

- All intelligence is concentrated in the network
  - Network elements are **often single-purpose**
  - Easier and usually **central management**
  - **Expensive, cumbersome, inflexible**
- User devices can, therefore, be very simple and foolproof

Preferred transmission characteristics

- **Circuit switching**
- **Connection-oriented**
- **Reliable**
- **Guaranteed** (QoS)

Telecommunication Networks

Additional observations

- Assumption of **insufficient resources**
  - There are not enough resources to satisfy everyone
  - Focusing on **exclusive resource allocation**
  - Afraid to sell unreliable services
- Considered a matter of **strategic importance**
  - High level of **regulation**
    - Directive decision-making by national governments
  - Gradually liberalized
    - Monopolies are becoming incumbents
- Network **owners and users are different** entities

Computer Networks

Dumb network, smart devices

- Intelligence is concentrated in user devices
- Network should be minimalist and as efficient as possible
  - The only goal is to **transfer data without understanding it**
  - Easily adaptable to changes in user behavior
  - **Cheaper, straightforward, flexible**

Preferred transmission characteristics

- **Packet switching**
- **Connectionless**
- **Unreliable**
- **Non-guaranteed** (Best Effort)

Computer Networks

Additional observations

- **Availability of resources is not a major limiting factor**
  - I.e., resources are sufficient
  - Technical factors have higher importance than the commercial
- **Liberalized** from the very beginning
  - Bottom-up approach
  - **Standardization and coordination challenges**
    - In order to achieve compatibility and interoperability
- Network **owners and users are often** the same entities

Management of Resources

Moore's law

- Observation that the **number of transistors** in a dense integrated circuit **doubles about every 2 years**
  - Projection of a historical trend
  - In effect for more than 55 years…
  - Originally 1 year, later 1.5 years, now 2 years
- Implication
  - **Cost** of equivalent computing power **drops in half every 2 years**

Gilder's law

- **Transmission capacity triples every 1 year**

Disk law

- **Storage capacity doubles every 1 year**

Lecture Conclusion

Basic concepts

- **Stream** / **block** transmissions
- **Circuit** / **packet** switching
- **Connection-oriented** / **connectionless** transmissions
- **Reliable** / **unreliable** transmissions
- **Guaranteed** / **non-guaranteed** transmissions
  - **Best Effort** / **Quality of Service**