Overview

1. Basic Model of a Transmission System
2. Signal Classes
3. Physical Medium
4. Coding
5. Multiplexing
1. Basic Model of a Transmission System

Terminology

- **Transmission**
  - Transport of physical signals via a transmission medium between two directly connected devices (source and sink)

- **Switching**
  - Provision of a complete transmission path between two end systems over several intermediate devices

- **End Systems**
  - Devices used by the end user
    - used for input and output of data
    - responsible for coding/decoding, multiplexing/demultiplexing, modulating/demodulating
    - send and receive data with error detection and correction functionality

Source and Sink

![Source to Sink Diagram](Image)
1. Basic Model of a Transmission System

Basic Model of a Transmission System

Source \[ \rightarrow \] Transmission System \[ \rightarrow \] Sink

\[ u_s(t) \rightarrow u_a(t) \]

**SC** = Source Coding

**LC** = Line Coding

**SDC** = Source Decoding

**LDC** = Line Decoding

2. Signal Classes

Signal Classes

<table>
<thead>
<tr>
<th>continuous time</th>
<th>discrete time</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>analog</strong></td>
<td><strong>digital</strong></td>
</tr>
<tr>
<td>[ Value u ]</td>
<td>[ Value u ]</td>
</tr>
<tr>
<td>Time ( t )</td>
<td>Time ( t )</td>
</tr>
</tbody>
</table>

Digitalization

Communication Networks: 4. Transmission Technique

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2. Signal Classes

Digitalization of an Analog Signal

1. Sampling
   - continuous time \(\rightarrow\) discrete time
   - values are still continuous
   - **Nyquist/Shannon Sampling Theorem**:
     - determination of minimum sampling frequency
     - if \(f_g\) is the highest frequency of a bandlimited analog signal, the sampling frequency should be at least \(2f_g\) to guarantee perfect reconstruction

2. Quantization
   - continuous values \(\rightarrow\) discrete values
   - values are mapped onto value intervals \(\rightarrow\) quantization error (noise in D/A conversion)

3. Source Coding
   - identification of intervals by bit sequence

Example: Digitalization of Human Speech for ISDN

- Theoretically, voice is not a bandlimited signal
- CCITT telephone channel is limited to 300 Hz – 3,400 Hz

- **Sampling**
  - at least with 6,800 Hz, but due to the steepness of the signal’s edge, 8,000 Hz is chosen

- **Quantization**
  - 256 quantization intervals
  - non-linear quantization to improve signal-to-noise ratio SNR (A-law, \(\mu\)-law)

- **Coding**
  - 8 bits per sample

- **Resulting data rate**
  \[
  Data\ Rate_{voice} = \frac{\#\ Samples}{Second} \cdot \frac{Bits}{Sample} = 8\ 000 \cdot 8\ \frac{bit}{s} = 64\ 000\ \frac{bit}{s}
  \]
2. Signal Classes

Digital Speech Transmission

Source Coding

A/D  Line Coding

Network

D/A  Line Decoding

Source Decoding

File Transfer

Source Coding

Digital Signal Conversion  Line Coding

Network

Line Decoding  Digital Signal Conversion

Source Decoding

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3. Physical Medium

**Physical Medium**

*Usage of a physical medium to transfer information*

- **Primary Signals** $x(t), y(t)$: physical parameters related to source/sink
- **Signals** $x'(t), y'(t), z'(t)$: physical parameters related to channel
- **Physical Medium**: e.g. electrical conductor
  \[ y'(t) = F(x'(t), z'(t)) \]

*Transmission over Physical Layer*

*Taken from F. Halsall (2000)*

*Repetition from Chapter 2*
4. Coding

Coding Types (I)

- **Source Coding:**
  - Transforming user information so that they can be transferred via the transmission channel as fast as possible and transformed back at the receiver

- **Channel Coding:**
  - Transforming information to provide transmission on a bandwidth-limited channel over a long distance with as few errors as possible

- **Line Coding:**
  - Transforming digital information into a sequence of physical signals to be transmitted over a physical channel

Coding Types (II)

- **Source Coding**
  - Goal: Reduction of redundancy
  - Example: 01100110

- **Channel Coding**
  - Goal: Detection and correction of transmission errors

- **Line Coding**
  - Goal: Adaptation of code symbols to the physical channel
  - Example: Manchester encoding
4. Coding

Source Coding

Lossless Compression
- Eliminating statistical redundancy
  - No information loss
  - Examples
    - Huffman Encoding
    - Arithmetic Encoding

Lossy Compression
- Removing unnecessary or less important information
  - Received information is unequal to original information
  - Examples
    - MP3 for audio files
    - JPG for photos

Channel Coding

Error Detection
- Adding redundancy
  - Parity bits
  - Check sums
- Tests at the receiver to prove integrity of transmitted information
  - Results to be used together with special protocol functions
    - Acknowledgement
    - Retransmission

Forward Error Correction
- Adding even more redundancy
- Detecting and correcting errors
  - Hamming Distance: the number of bit positions at which two possible symbols are different
- Receiver reconstructs original information
  - Block Code
  - Hamming Code
4. Coding

Line Coding

- Representing the digital signal to be transported by a waveform that is appropriate for the specific properties of the physical channel

- Requirements:
  - Eliminate DC component
  - Facilitate (bit) synchronization
  - Minimize spectral content
  - Ease error detection and correction

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4. Coding

Line Coding: Non Return to Zero (NRZ)

NRZ unipolar

NRZ-Inverted (NRZI) bipolar
4. Coding

Line Coding: Alternate Mark Inversion (AMI)

- **AMI-Code:**
  (modified, as used for ISDN)

  - **Coding Violation (CV):**

  - When "0" and "1" are sent at the same time, the receiver will get a "0"

  


d!-


d

4. Coding

Line Coding: Manchester-Code

- **Coding:**
  1 ⇔ signal transition +A → -A in the middle of the bit interval
  0 ⇔ signal transition -A → +A in the middle of the bit interval
  Eventually, a signal transition at the beginning of the bit interval is required
5. Multiplexing

Multiplexing

- Focus on a physical (analog) channel.
- Information transferred via physical signals that change over time.
- These signals occupy capacity/bandwidth of the transmission channel for a given time (connection time, packet duration, ...)
- Requested and offered bandwidth usually not corresponding:
  - wasted resources
  - not adequate communication

5. Multiplexing

Requested = Offered Bandwidth

The application utilizes the physical channel in an optimal way
5. Multiplexing

Requested > Offered Bandwidth

In order to transmit the complete amount of information, several channels have to be bundled

5. Multiplexing

Requested < Offered Bandwidth

Several applications may utilize the physical channel in an optimal way.

⇒ Multiplexing
5. Multiplexing

Conjoined Transmission of Information Streams

- Different streams of information of concurrently active application entities that use the same frequency range interfere with each other
- They cannot be separated at the receiver

Bandwidth (Frequency)

Application Entity 2

Time

5. Multiplexing

Multiplex Transmission

- Multiplex:
  - Multiple analog message signals or digital data streams combined into one signal over a shared medium
  - Sharing an expensive resource
- Different categories of multiplexing:
  - Space Division Multiplexing
  - Time Division Multiplexing
  - Frequency Division Multiplexing
  - Code Division Multiplexing
  - Wavelength Division Multiplexing
5. Multiplexing

Space Division Multiplex

- Space partitioned into different „areas“
- Each user/application is assigned to one area
- No interference possible
- Examples:
  - analog telephony
  - radio cells in mobile telephony

Frequency Division Multiplex

- Separate frequency range assigned to each user / application
- Different users / applications might send concurrently
- Receiver can separate the transmissions by tuning to according frequency
5. Multiplexing

Time Division Multiplex

- Each user / application has exclusive access to the complete bandwidth of the channel, but only at certain time periods
- Assignment can be done statically or on demand

5. Multiplexing

Code Division Multiplex

- On digital channels, different streams can be separated based on different (mutually orthogonal) codes (chipping sequences)
- The streams occupy the same spectrum
- The receiver can separate the streams
5. Multiplexing

Multiplex Transmission

Time and Frequency Division Multiplex

**Frequency Division Multiplex**

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>108kHz</td>
<td>f</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

frequency range, divided into 12 sub-ranges, 4 kHz each

**Time Division Multiplex**

<table>
<thead>
<tr>
<th>0</th>
<th>125μs</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>29</td>
<td>30</td>
</tr>
</tbody>
</table>

time period divided into 32 time slots, approx. 3.9 μs each
5. Multiplexing

Time Multiplexing / Demultiplexing

**Example of Code Division Multiplex (1)**

- Four senders A, B, C, D
- Assigned chipping sequences:
  - A \( \rightarrow \) \(-1 \ -1 \ +1 \ +1 \ -1 \ +1 \ +1 \)
  - B \( \rightarrow \) \(-1 \ -1 \ +1 \ +1 \ +1 \ -1 \)
  - C \( \rightarrow \) \(-1 \ +1 \ +1 \ +1 \ -1 \ -1 \)
  - D \( \rightarrow \) \(-1 \ +1 \ -1 \ -1 \ -1 \ +1 \ -1 \)
- Sender C sends “1”:

- Sender C sends “0”:

See Tanenbaum 2011
5. Multiplexing

Example of Code Division Multiplex (2)

- A sends “1”, B sends “1”, C sends “0”, D sends “1”
  - A:
  - B:
  - C:
  - D:

- Receiver wants to find out the value sent by C (knowing C’s chipping sequence):
  - combined signal RS

\[
RS \cdot C = \frac{(-2 \cdot -1) + (-2 \cdot +1) + (0 \cdot -1) + (-2 \cdot +1) + (0 \cdot +1) + (-2 \cdot +1) + (+4 \cdot -1) + (0 \cdot -1)}{8} = \frac{2 - 2 + 0 - 2 + 0.24 + 0}{8} = -1 = \text{“0”}
\]
5. Multiplexing

Multiplexing - Recapitulation

- Multiplexing allows the transmission of several streams (logical channels) over one physical channel
- Multiplexing might support
  - *synchronous* communication → fix data rate and transmission time
  - *asynchronous* communication → variable data rate and transmission time

5. Multiplexing

Multiple Access

- According to the multiplexing techniques, several multiple access procedures can be defined for shared media:
  - Space Division Multiple Access (SDMA)
  - Time Division Multiple Access (TDMA)
  - Frequency Division Multiple Access (FDMA)
  - Code Division Multiple Access (CDMA)
- Controlled access to the shared medium → avoid collisions
References