2EL2610 – Communications Theory

Instructors: Sheng Yang
Department: DÉPARTEMENT SIGNAL, INFORMATION, COMMUNICATION
Language of instruction: ANGLAIS
Campus: CAMPUS DE PARIS - SACLAY
Workload (HEE): 60
On-site hours (HPE): 35,00
Elective Category : Engineering Sciences
Advanced level : Yes

Description

Communication is a fundamental need in all our societies. The ever-evolving communication networks and the emerging Internet of Things have become a decisive transforming factor in a large number of industrial sectors (e.g., telecommunications, multimedia, space exploration, surveillance, control, navigation, transport, health, agriculture, construction, environment). The amount of information exchanged has increased dramatically, and connectivity is becoming ubiquitous thanks to technological innovations and advanced processing. There are many new challenges: record-breaking high throughput and long-distance optical fiber channels, ultra-reliable low-latency mobile links for critical missions, reliable connection between billions of energy-efficient objects, exploding traffic of multimedia content delivery, outer space exploration ... The communication theory allows for a deep understanding of the fundamental limits of a communication system and how existing algorithms works, and more importantly, lays down the foundation for future engineers to solve the unknown use cases.

In this course, we focus on the general point-to-point communication system consisting of a source, a transmitter, a channel, a receiver, and a destination. The student will learn the mathematical tools and methods to model, analyze, design, and optimize the key components of a communication chain. First notions of information theory will allow the student to understand the minimum number of bits needed to describe a given source losslessly, as well as the maximum number of bits that the transmitter can communicate reliably with the receiver through a noisy channel for a given resource (e.g., time, bandwidth, power). This course also aims at providing a methodology to conceive a communication system with practical constraints due to technological or regulatory limitations (e.g., reliability, latency, energy efficiency, spectral efficiency, complexity, storage capacity, cost, consumption).

Quarter number

SG6

Prerequisites (in terms of CS courses)

- Model representations and analysis
- Signal processing
- Statistics and learning

Syllabus

1- Overview of communication systems

The communication chain : source, transmitter, channel, receiver, destination.

Layering and binary interfaces.

2- Digital representation of source and coding

Signal space point of view, equivalence between sequences and waveforms.

Sequence representation of a continuous-time source, sampling theorem. Quantization.

Different source models and their properties.

Information, entropy, source coding, construction of source codes.

Examples of practical compression algorithms : Lempel-Ziv, JPEG, MP3

3- Digital communication

Different communication channel models and their properties.

Additive white Gaussian noise channel. Digital modulation (PAM, QAM, PSK), Nyquist's criterion, passband modulation, baseband-passband equivalence.

Optimal detection rules, analysis of probability of error, signal to noise ratio. Practical implementation of transmitter/receiver.

4- Channel coding

Equivalence between continuous-time and discrete-time channels. Mutual information, Shannon's channel capacity.

Channel codes: linear block codes, convolutional codes, LDPC codes, polar codes.

Hard decoding, soft decoding, Viterbi algorithm. Performance analysis.

Lab sessions (with Python notebook):

Lab 1: Image compression with the Huffman algorithm

Lab2: Audio compression with subsampling and Fourier analysis

Lab3: Baseband modulation and communication

Lab4: Encoding and decoding of QR codes

Class components (lecture, labs, etc.)
Courses (19,5 H)
Exercise sessions (7,5 H)
Lab sessions (6H)
Final written exam (2H)

Grading
Lab report (30%) Written exam (70%)

Course support, bibliography

- R.G. Gallager. Principles of digital communication. Cambridge University Press; 2008.
- A. Lapidoth. A foundation in digital communication. Cambridge University Press; 2017.
- T.M. Cover, J.A. Thomas. Elements of information theory, Wiley, 2nd edition, 2005.

Resources
Lecturers:

- Sheng Yang teaches the lectures
- Sheng Yang, Richard Combes, and Antoine Berthet for the exercise sessions
- Sheng Yang and Richard Combes for the lab sessions

Group size for the exercise sessions: 20 students per group (max. 3 groups)
Software: Python

Learning outcomes covered on the course
At the end of the course, the student will learn the underlying mathematical principles of modern communication systems, essential both in further education and in the workplace in the long term. In particular, the student will be able to
- model, analyze, design, and optimize the key components of a point-to-point communication channel,
- construct simple source codes and channel codes for different purposes,
- build optimal decoder/detector for the receiver,
- manipulate the vector space of information sources and communication signals.

Description of the skills acquired at the end of the course
C6.7 Understand the transmission of information
C1.2 Use and develop suitable models, choose the right modeling scale and simplifying hypotheses to deal with the problem
C1.4 Specify, design, build, and validate all or part of a complex system
C2.1 Have deep knowledge of a field or discipline relating to the basic sciences or the engineering sciences