Introduction to quantum communications and computing

Academic Year: (2024 / 2025) **Review date: 20-01-2025**

Department assigned to the subject: Signal and Communications Theory Department

Coordinating teacher: VAZQUEZ VILAR, GONZALO

Type: Electives ECTS Credits : 3.0

Year : Semester :

REQUIREMENTS (SUBJECTS THAT ARE ASSUMED TO BE KNOWN)

Students are expected to have a basic background in probability theory and linear algebra. Therefore, having passed the 1st year courses 'Statistics' and 'Lineal Algebra' is highly recommended.

LEARNING OUTCOMES

CB1: Students have demonstrated possession and understanding of knowledge in an area of study that builds on the foundation of general secondary education, and is usually at a level that, while relying on advanced textbooks, also includes some aspects that involve knowledge from the cutting edge of their field of study.
CB2: Students are able to apply their knowledge to their work or vocation in a professional manner and possess the competences usually demonstrated through the development and defence of arguments and problem solving within their field of study.
CG3: Knowledge of basic and technological subject areas which enable acquisition of new methods and technologies, as well as endowing the technical engineer with the versatility necessary to adapt to any new situation.
ECRT1: Ability to learn and acquire autonomously the requisite new knowledge for design, development and utilization of telecommunication systems and services.
ETEGISC2: Ability to apply techniques on which telecommunication networks, services and applications are based in fixed environments as well as mobile, personal, local or long distance, with different bandwidths, including telephone, radio broadcasting, television and data, from the point of view of transmission systems.
ETEGISC5: Ability to select antennas, equipment and transmission systems, guided and non-guided wave propagation, by electromagnetics, radiofrequency and optics means and the corresponding management of radio electronic space and frequency allocation.
RA1: Knowledge and Understanding. Knowledge and understanding of the general fundamentals of engineering, scientific and mathematical principles, as well as those of their branch or specialty, including some knowledge at the forefront of their field.
RA4: Research. Graduates will be able to use appropriate methods to carry out detailed research and studies of technical aspects, commensurate with their level of knowledge. The research involves bibliographic searches, design and execution of experiments, interpretation of data, selection of the best proposal and computer simulation. May require consultation of databases, standards and security procedures.
RA5: Applications. Graduates will have the ability to apply their knowledge and understanding to solve problems, conduct research, and design engineering devices or processes. These skills include knowledge, use and limitations of materials, computer models, process engineering, equipment, practical work, technical literature and information sources. They must be aware of all the implications of engineering practice: ethical, environmental, commercial and industrial.
RA6: Generic competences. Graduates will have the generic skills necessary for engineering practice, and which are widely applicable. First, to work effectively, both individually and as a team, as well as to communicate effectively. In addition, demonstrate awareness of the responsibility of engineering practice, social and environmental impact, and commitment to professional ethics, responsibility and standards of engineering practice. They must also have knowledge of business and project management practices, as well as risk management and control, and understand their limitations. Finally, have the capacity for continuous learning.

OBJECTIVES

This course introduces the fundamental concepts of quantum communication and computing. Starting from an experimental basis, we will motivate why the classical theory of probability is not able to model certain real physical systems. We will present a generalization of the concept of probability that allows us to model these experiments, as well as their (unexpected) consequences. Among the applications in communications are quantum cryptography, the use of quantum entanglement and the teleportation protocol. We will study the underlying principles of quantum computers and we will learn to program them exploiting the quantum parallelism. Finally, the current state and the future perspectives of quantum technology will be discussed.

Some of the specific objectives are to:
- Understand the fundamental differences between classical and quantum probability theories.
- Describe mathematically a quantum state of a single qubit and that of several qubits.
- Know and use the axioms that govern the evolution and measurement of a quantum state.
- Model and analyze simple quantum communication channels and their cryptographic guarantees.
- Implement and analyze a quantum computing algorithm.

DESCRIPTION OF CONTENTS: PROGRAMME

Unit 1. Introduction
1.1. Historical remarks
1.2. The polarization of a photon

Unit 2. Axioms of quantum mechanics
2.1. Binary quantum states and superposition
2.2. Combining systems: quantum entanglement
2.3. Evolution of a quantum system

Unit 3. Quantum communications
3.1. Classical and quantum information
3.2. Modeling quantum channels
3.3. Communication protocols: teleportation
3.4. Quantum cryptography

Unit 4. Quantum computing
4.1. Quantum computers and their programming paradigm
4.2. Quantum computing algorithms
4.3. Perspectives and future

LEARNING ACTIVITIES AND METHODOLOGY

· 11 sessions motivating the generalization of the classical probability theory, studying the model for quantum systems with illustrative examples, and presenting the different technologies and applications of the quantum paradigm.
· 2 practical sessions to implement and analyze quantum systems and quantum protocols.
· 1 practical session in which the students will develop and implement an quantum computing algorithm in a real quantum computer.

Teaching material
The material used in the course sessions will be uploaded to the platform Aula Global in electronic format. Before each session, the students will have available all the information and recommended reading for best understanding of the topic. Exercises will also be given to delve into the behavior of simple quantum systems and protocols. Some of the proposed exercises will be solved in the course sessions.

ASSESSMENT SYSTEM

% end-of-term-examination:	0
% of continuous assessment (assigments, laboratory, practicals…):	100

· Homework and quizzes: 50%
· Lab projects: 50%

The course evaluation will be based on the continuous assessment of the student work. To this end, homework deliverables and quizzes will contribute to the 50% of the final grade and reports of the practical assignments will sum up the remaining 50%.

% end-of-term-examination:	0
% of continuous assessment (assigments, laboratory, practicals…):	100

The evaluation in the extra-ordinary period will consist of one single exam covering both theoretical questions and practical problems.

ADDITIONAL BIBLIOGRAPHY

- Eleanor Rieffel, Wolfgang Polak Quantum Computing: A Gentle Introduction, The MIT Press, 2011

BASIC ELECTRONIC RESOURCES

- Gonzalo Vázquez Vilar . Introducción a la comunicación y la computación cuántica. Notas de clase.: https://www.tsc.uc3m.es/~gvazquez/intro-cuantica/