Educational Project of the course

Course	TELETRAFFIC AND QUALITY OF SERVICE		
Module	TELEMATIC ENGINEERING		
Title	MASTER IN TELECOMMUNICATIONS ENGINEERING		
Plan	544	**Code**	75099
Teaching period	1st SEMESTER	**Type**	OPTIONAL
Level	MASTER	**Year**	2021-2022
ECTS credits	6 ECTS		
Teaching language	ENGLISH		
Professor in charge	JUAN IGNACIO ASENSIO PÉREZ		
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Department	SIGNAL THEORY, COMMUNICATIONS AND TELEMATIC ENGINEERING		

1. Context and goals

1.1 Context

The Quality of Service (QoS) provided by telematics services (voice, TV, messaging, network games, …) largely relies on the features of the data networks they depend on. Such networks must be capable of delivering the data generated by the aforementioned services between geographically distant locations. Therefore, in the field of telematics engineering, it is of great importance:

- To be able to determine the required capacity of data networks (as well as the associated required resources) so as to achieve a desired level of quality in the services they provide. To do so, telecommunication engineers, as is the case of engineers in other disciplines, need mathematical models that explain how data networks work and that can help them carry out the quantitative assessment of different network designs, as well as the associated resource planning, to satisfy the desired requirements.
- To understand the architectural requirements that data networks should fulfil in order to guarantee desired levels of quality of service and how those requirements are mapped to specific cases, with special emphasis in the case of TCP/IP networks.

This course provides an introduction to:

- Teletraffic engineering is defined as: "*the application of probability theory to the solution of problems concerning planning, performance evaluation, operation and maintenance of telecommunication systems*" [1]. Teletraffic engineering makes use of multiple disciplines and techniques. However, this course will only cover two of them: Queuing Theory and Simulation. These two techniques have been selected because their underlying mathematical models have a reasonable level of difficulty (for a master student) and because they can be easily used for identifying/discussing/analysing the basic trade-offs that a telecommunications engineers should master when designing/planning/evaluating/managing a data network.
- The architectonical alternatives for QoS provision in the context of TCP/IP networks. The course will pay special attention to IETF proposals (Internet Engineering Task Force): Intserv, Diffserv, MPLS, constraint-based routing, etc.

1.2 Relation with other modules

This course, together with the other two that are part of the module "Telematic complements for Graduates in Specific Telecommunication Technologies Engineering" fosters the acquisition of competences and skills that were not covered by the degree on "Specific Telecommunication Technologies – Specialization in Electronic Systems", and that are needed for tackling the module "Telematic Networks, Systems and Services Engineering".

[1] V.B. Iversen, *Teletraffic Engineering Handbook*, ITU-D SG 2/16, 2001. Available at: https://www.itu.int/ITU-D/study_groups/SGP_1998-2002/SG2/StudyQuestions/Question_16/RapporteursGroupDocs/teletraffic.pdf. Last access: April 2021.

1.3 Prerequisites

From the point of view of students from universities abroad, this course requires reasonable good skills in English language, both for listening and at writing. Additionally, students should have basic knowledge about data networks: typical architectures, protocols, services, etc. Since the course introduces mathematical models typically employed in telematics engineering, students should have basic knowledge about Probability Theory (random variables, stochastic processes, etc…). The course also introduces the use of data network simulators that requires basic programming skills in order to be used.

2. Competences

2.1 General

- Ability to manage mandatory specifications, regulations and standards.
- Ability to apply numeric and analytic methods to problems in the fiend of telecommunication engineering.
- Ability to solve problems with initiative, creativity and critical reasoning.
- Ability to design and implement experiments, analyse them and understand the data.
- Ability to generate reports based on critical analysis of technical literature, as well as on the knowledge about the current status of the application domain.
- Ability to apply methods and skills for autonomous and efficient learning aimed at adapting and updating new knowledge and scientific innovations.
- Ability to organise and manage time.
- Ability to communicate knowledge, procedures, results and ideas, both written and spoken, related to telecommunications and electronics.
- Ability to work in any context, either individually or in group, educational or professional, local or international, respecting fundamental rights, including sex, ethnics or religion equality, and the universal accessibility principles, applying a philosophy of peace to each action

2.2 Specific

- Ability to apply techniques typically employed in telematics networks, services and applications, including: management systems; signalling and switching; routing; security (cryptographic protocols, tunnelling, firewall, billing, authentication, and privacy), teletraffic engineering (graph theory, queuing theory and teletraffic); quality of service in mobile, non-mobile, personal, local and wide area context, with different available bandwidths, including voice and data communications.
- Ability to describe, program, validate and optimize communication protocols and interfaces at different layers within a communications architecture.
- Ability to design architectures for telematics networks and services.

3. Objectives

At the end of the course, the students should be able to:

- Know, understand and apply basic quantitative techniques involved in the planning, dimensioning and analysis of telematics networks and services.
- Understand the trade-offs involved in the design of protocols and architectures for telematics networks.

4. Workload distribution

Face to face activities	Hours	Remote activities	Hours
Lectures at classroom (T/M)	24	Individual work	60
Lectures at lab (A)		Group work	30
Lab work (L)	20		
Field work assignments			
Seminars (S)	16		
Group Tutoring sessions (TG)			
Assessment activities not included in the official calendar			
Total	**60**	**Total**	**90**

5. Contents and sections

Section 1: Introduction to Teletraffic Engineering

Workload in ECTS credits: 0,8

a. Context and rationale

This section provides a basic introduction to Teletraffic Engineering. In addition to providing a short summary of how this discipline has evolved historically, it will explain, by means of a case study in which students will work collaboratively, why it is important and how it is related to the concept of Quality of Service. Then, the section will introduce the main concepts underlying Teletraffic Engineering, and will also provide a short introduction and comparison of the two quantitative techniques that will be further developed in subsequent sections (Queuing Theory and Simulation).

b. Learning objectives

At the end of this section, the students should be able to:

- Identify the main historic events associated to Teletraffic Engineering, paying special attention to its influence in the beginning and evolution of the Internet.
- Relate the concepts of data traffic, quality of service, grade of service.
- Identify which features of a data network need to be modelled in order to quantify the level of Quality of Service it is capable of providing.
- Compare pros and cons when applying Queuing Theory vs. Simulation for assessing quantitatively the performance of a data network.

c. Contents

TOPIC 1: Introduction to Teletraffic Engineering

1.1 Objectives
1.2 Motivation: an illustrative case
1.3 What is Teletraffic Engineering?
1.4 A brief history of Teletraffic Engineering
1.5 Basic concepts
1.6 Teletraffic Engineering techniques: Queuing Theory and Simulation
1.7 Summary

d. Teaching methods

- Interactive lectures
- Study of practical cases at the classroom and at the lab
- Collaborative Learning

e. Work plan

See Annex I.

f. Assessment

Competence-based assessment will be based on:

- Attitude and participation assessment during the academic activities.
- Written collaborative report about the practical case.
- Final exam

g. Basic references

- V. B. Iversen, *Teletraffic Engineering and Network Planning*, Technical University of Denmark, 2011. Available at ftp://ftp.dei.polimi.it/users/Flaminio.Borgonovo/Teoria/teletraffic_Iversen.pdf. Last access: April 2021.

h. Additional References

- L. Kleinrock, *Queueing Systems*, volúmenes 1 y 2, John Wiley, 1976.
- X. Xiao, Technical, *Commercial and Regulatory Challenges of QoS: an Internet Service Model Perspective*, Morgan Kaufmann, 2008.
- J.J. Pazos, A. Suárez, R. Díaz, *Teoría de Colas y Simulación de Eventos Discretos*, Prentice-Hall, 2003

i. Required Resources

A set of materials will be necessary, most of them supplied by the university or the professor:

- Work environment in the LCMS Moodle, hosted in the *Virtual campus* of the university.
- Computers and specific software for carrying out the learning activities.
- Supporting documentation.

Section 2: Introduction to Queuing Theory

Workload in ECTS credits: 2,2

a. Context and rationale

This section provides a basic introduction to the first of the quantitative techniques covered in the course: Queuing Theory. It will start by describing the basic model of a queuing system, including the probabilistic characterization of some of its features. Then, it will explain which components of a data network will be modelled using such queuing systems (mostly buffers employed for statistically switching data frames and packets). Then, the section will review some basic concepts from Probability Theory that are required for understanding the mathematical models employed in Queuing Theory. Those concepts include: Poisson processes, exponential random variables, and birth-death processes. Then, basic results derived from Queuing Theory will be particularized to a set of specific traffic models with different waiting time distributions, queue size, numbers of servers, etc. Finally, a short introduction to queuing networks will be provided. The application of the results derived from Queuing Theory to data networks and teletraffic will be illustrated by solving a set of practical problems.

b. Learning objectives

At the end of this section, the students should be able to:

- Identify which elements of a data network can be modelled using Queuing Theory.
- Identify the main elements of a queuing system and how they can be modelled mathematically.
- Compare different types queuing systems and networks.
- Identify under which conditions queuing system models can be applied to real data networks.
- Solve problems related to the planning/dimensioning/diagnosis of data networks using results from Queuing Theory.

c. Contents

TOPIC 2: Introduction to Queuing Theory

2.1 Objectives, motivation, brief history
2.2 Defining and modelling queuing systems. Basic parameters
2.3 Little Formula
2.4 Poisson Processes. Definition and properties
2.5 Birth-Death Processes. Definition and properties. Relationship with Poisson processes and queuing systems.
2.6 Summary

TOPIC 3: Traffic models

3.1 Objectives
3.2 Kendall Notation
3.3 Models: M/M/1, M/M/m, M/M/m/m, M/M/m/m/N, M/M/m/k, M/G/1
3.4 Summary

TOPIC 4: Queuing networks

4.1 Objectives
4.2 Queuing networks: definition and typology
4.3 Solving queuing networks: Birth-Death processes
4.4 Burke and Jackson theorems
4.5 Summary

d. Teaching methods

- Interactive lectures
- Problem-based learning
- Collaborative Learning

e. Work plan

See Annex I.

f. Assessment

Competence-based assessment will be based on:

- Attitude and participation assessment during the academic activities.
- Problem solving.
- Final exam

g. Basic references

- J. A. Hernández, P. Serrano, *Probabilistic models for computer networks: Tools and solved problems,* lulu.com*, 2015.*
- V. B. Iversen, *Teletraffic Engineering and Network Planning*, Technical University of Denmark, 2011. Available at ftp://ftp.dei.polimi.it/users/Flaminio.Borgonovo/Teoria/teletraffic_Iversen.pdf. Last access: April 2021.

h. Additional References

- L. Kleinrock, *Queueing Systems*, volúmenes 1 y 2, John Wiley, 1976.
- J.J. Pazos, A. Suárez, R. Díaz, *Teoría de Colas y Simulación de Eventos Discretos*, Prentice-Hall, 2003.

i. Required Resources

A set of materials will be necessary, most of them supplied by the university or the professor:

- Work environment in the LCMS Moodle, hosted in the *Virtual campus* of the university.
- Supporting documentation.

Section 3: Introduction to the simulation of Data Networks

Workload in ECTS credits: 1,7

a. Context and rationale

This section provides a basic introduction to the second of the quantitative techniques covered in the course: simulation of data networks. The section will present basic notions regarding the simulation of data networks and will foster the use of an actual discrete event simulator (ns-3) in order to:

- Illustrate the affordances of simulation when analysing quantitatively the behaviour of protocols (already studied in previous courses) in situations that are difficult to reproduce in a real network (e.g., the teaching lab networks).

- Illustrate basic quantitative techniques for estimating working parameters of data networks under random conditions. This way it is possible to assess pros and cons of simulation techniques vs. analytical techniques such as Queuing Theory.

b. Learning objectives

At the end of this section, the students should be able to:

- Design, perform, and analyse parameter-sweep simulations for analysing the behaviour of data network protocols.
- Design, perform, and analyse data network simulations under random conditions so as to optimize design parameters.
- Identify pros and cons of the use of data network simulations vs. analytical techniques (e.g., queuing theory).

c. Contents

TOPIC 5: Introduction to data network simulation

5.1 Objectives
5.2 What does simulating consist of? Alternatives. Comparison
5.3 Simulation models
5.4 Types of simulations. Examples
5.5 Introduction to the ns-3 simulator
5.6 Summary

TOPIC 6: Simulation and estimation. Comparison with Queuing Theory

6.1 Objectives
6.2 Goals and techniques for inferential statistics
6.3 Estimating the mean. Confidence Intervals
6.4 Queuing Theory and Simulation
6.5 Summary

LAB ASSIGNMENT 1: Introduction to the ns-3 data network simulator
LAB ASSIGNMENT 2: Queuing Theory and simulation with ns-3

d. Teaching methods

- Interactive lectures
- Collaborative Learning
- Lab assignments (practical cases)

e. Work plan

See Annex I.

f. Assessment

Competence-based assessment will be based on:

- Attitude and participation assessment during the academic activities.
- Written collaborative report about the lab assignments.
- Oral presentations
- Final exam

g. Basic references

- W. Navidi, “Statistics for Engineers and Scientists”, 3rd Edition, McGraw-Hill. 2011.

h. Additional References

- B. Rosner. “Fundamentals of Biostatistics”, 7th Edition, Brooks/Cole, Cengage Learning. 2011.

i. Required Resources

A set of materials will be necessary, most of them supplied by the university or the professor:

- Work environment in the LCMS Moodle, hosted in the *Virtual campus* of the university.
- Computers and specific software for carrying out the learning activities.
- Supporting documentation.

Section 4: Quality of Service in Data Networks

Workload in ECTS credits: 1,3

a. Context and rationale

This section introduces the main concepts, techniques and standards that influence the quality of service provision in telematic networks and, more concretely, in TCP/IP networks. This section complements the previous ones, more theoretical and conceptual, with a more pragmatic view of current specific technologies. The goal is that the students can understand the practical applications of the concepts and techniques presented in the course.

b. Learning objectives

At the end of this section, the students should be able to:

- Know and understand the basic concepts related with the provision of Quality of Service in telematics networks.
- Know and understand the requirements that the provision of Quality of Service pose to telematics protocols, networks and services.
- Know and compare the different technological proposal made by IETF (Internet Engineering Task Force) for provisioning Quality of Service in TCP/IP

c. Contents

TOPIC 7: Quality of Service in TCP/IP Networks

7.1 Objectives

7.2 Basic concepts about Quality of Service

7.3 Evolution of Quality of Service solutions (PSTN, ATM, FR, IEEE 802, IntServ, DiffServ, Transport/Application)

7.4 Traffic Management (classification, tagging, shaping, policy, queue management, scheduling), QoS routing, Traffic Engineering (IP-TE, MPLS-TE, Planning)

7.5 Challenges for current approaches to QoS provision: business models, network neutrality, QoS and regulation

LAB ASSIGNMENT 3: Quality of Service in TCP/IP networks: the case of DiffServ.

d. Teaching methods

- Interactive lectures
- Collaborative Learning
- Lab assignments (practical cases)

e. Work plan

See Annex I.

f. Assessment

Competence-based assessment will be based on:

- Attitude and participation assessment during the academic activities.
- Written collaborative report about the lab assignments.
- Final exam

g. Basic references

- X. Xiao, Technical, *Commercial and Regulatory Challenges of QoS: an Internet Service Model Perspective*, Morgan Kaufmann, 2008.

h. Additional References

- J. Evans, C. Filsfils, *Deploying IP and MPLS QoS for Multiservice Networks*, Morgan Kaufmann, 2007.
- M. Marchese, *QoS over Heterogenous Networks*, John Wiley & Sons, 2007.

i. Required Resources

A set of materials will be necessary, most of them supplied by the university or the professor:

- Work environment in the LCMS Moodle, hosted in the *Virtual campus* of the university.
- Computers and specific software for carrying out the learning activities.
- Supporting documentation.

6. Timing (per thematic sections)

Thematic section	ECTS workload	Expected period
Section 1: Introduction to Teletraffic Engineering	ECTS	Weeks 1 to 2
Section 2: Introduction to Queuing Theory	ECTS	Weeks 3 to 15
Section 3: Introduction to the simulation of Data Networks	ECTS	Weeks 1 to 7
Section 4: Quality of Service in Data Networks	ECTS	Weeks 8 to 15

7. Assessment criteria

INSTRUMENT/PROCEDURE	WEIGHT IN THE FINAL MARK	COMMENTS
Assessment of individual attitude and level of participation of the student in learning activities	5%	Importance of active participation of the student in face-to-face activities, especially in seminars (problems resolution) Requirement: at least 5 points (out of 10) in this instrument
Group assessment of lab assignment reports	30%	Requirement: at least 5 points (out of 10) after averaging the marks of all lab assignment reports
Individual assessment of oral presentations	10%	Assessment carried out by the teacher. Requirement: participation
Group assessment of oral presentations	5%	Assessment carried out by both the teacher and the other students. Requirement: participation
Final exam	50%	Requirement: at least 5 points (out of 10) in this instrument

In the case one student doesn't fulfil one or several of the requirements in the column "comments" of one or several instruments, the final mark will be calculated taking into account only the marks of those instruments.