Course guides
300038 - LCSF - Wireless Communications Laboratory

Unit in charge: Castelldefels School of Telecommunications and Aerospace Engineering
Teaching unit: 739 - TSC - Department of Signal Theory and Communications.
Degree: BACHELOR'S DEGREE IN TELECOMMUNICATIONS SYSTEMS ENGINEERING (Syllabus 2009). (Compulsory subject).
Academic year: 2021 ECTS Credits: 6.0 Languages: Catalan, Spanish

LECTURER

Coordinating lecturer: Definit a la infoweb de l'assignatura.
Others: Definit a la infoweb de l'assignatura.

PRIOR SKILLS

• Operation with complex numbers, matrices, random variables and processes.
• Analysis of signals and systems, analog and digital, in the temporal and frequency domain. Fourier analysis.
• Single and multi-carrier modulations. Operation with complex baseband notation and phasor representations.
• Basic electromagnetic theory: free space propagation, polarization, reflection coefficient, Doppler effect ...
• Channel coding strategies.
• Basic knowledge of communications, antennas and transmitters and receivers.
• Basic teletraffic theory. Erlang-B and Erlang-C formulas.

REQUIREMENTS

WIRELESS COMMUNICATIONS - Prequisite

DEGREE COMPETENCES TO WHICH THE SUBJECT CONTRIBUTES

Specific:
7. CE 22 SIS. Capacidad para aplicar las técnicas en que se basan las redes, servicios y aplicaciones de telecomunicación tanto en entornos fijos como móviles, personales, locales o a gran distancia, con diferentes anchos de banda, incluyendo telefonía, radiodifusión, televisión y datos, desde el punto de vista de los sistemas de transmisión. (CIN/352/2009, BOE 20.2.2009.)

General:
5. EFFICIENT USE OF EQUIPMENT AND INSTRUMENTS - Level 2: Use the correct instruments, equipment and laboratory software for specific or specialized knowledge of their benefits. A critical analysis of the experiments and results. Correctly interpret manuals and catalogs. Working independently, individually or in groups, in the laboratory.

Transversal:
1. SELF-DIRECTED LEARNING - Level 2: Completing set tasks based on the guidelines set by lecturers. Devoting the time needed to complete each task, including personal contributions and expanding on the recommended information sources.
2. EFFICIENT ORAL AND WRITTEN COMMUNICATION - Level 2. Using strategies for preparing and giving oral presentations. Writing texts and documents whose content is coherent, well structured and free of spelling and grammatical errors.
3. THIRD LANGUAGE. Learning a third language, preferably English, to a degree of oral and written fluency that fits in with the future needs of the graduates of each course.
4. TEAMWORK - Level 1. Working in a team and making positive contributions once the aims and group and individual responsibilities have been defined. Reaching joint decisions on the strategy to be followed.
6. EFFECTIVE USE OF INFORMATION RESOURCES - Level 2. Designing and executing a good strategy for advanced searches using specialized information resources, once the various parts of an academic document have been identified and bibliographical references provided. Choosing suitable information based on its relevance and quality.
TEACHING METHODOLOGY

The course combines the following teaching methodologies:
• Autonomous learning: the students will work the self-learning materials at home and booking the lab for extra practice out of class time.
• Students will develop different team projects where they must organize the work autonomously to achieve certain goals with the teacher's guidance.
• Master lectures: part of the theoretical lectures should be concentrated at the beginning of the semester. The projects will not start until the students have the necessary theoretical content. Since the projects will be carried out in parallel by the different groups, a part of the theoretical classes should be concentrated at the beginning of the semester. In this way, the projects will not start until the students have the necessary theoretical content.

Generic competencies are addressed:

CG3. Third language,
CG3.1 Read and understand documents (...). Most of the references are in English, so they are equipment specifications and software manuals..

CG4. Effective oral and written communication
CG4.2 Select and use appropriate strategies to (...) write texts and documents with a consistent content, structure and appropriate style, with a good use of graphic resources and a good level of spelling and grammar. The production of quality written technical reports will be especially important in evaluating projects. Students must be able to successfully synthesize the results of complex problems and new situations in a final project report.

CG5. Teamwork
CG5.1 Define objectives and operating rules of the group (...). Even though there will be a laboratory guide to establish tasks and milestones, students will have a significant degree of autonomy as a group. Especially in projects where groups are composed of 3 people. Coordination, integration and sharing of tasks is important to complete the objectives.

CG6. Effective use of information resources
CG6.2 Perform a good search strategy using advanced information resources, selecting adequate information considering criteria of relevance and quality. Due to the complexity of the projects, they all require the preparation of a preliminary study where advanced search of information will be important. Students will have complex specifications and manuals from which relevant information will be obtained. The success of this phase of search and understanding are prerequisite to successfully perform projects. For this reason an initial control is included, it will allow or not the laboratory work.

CG7. Independent learning
CG7.2 Guided Learning: Perform the tasks from basic orientation provided by teachers, deciding the time to spend on each task, including personal contributions and expanding the sources indicated (...). This aspect has been discussed in previous sections and addresses in a natural manner in the module of projects.

CG8. Efficient use of equipment and instrumentation
CG8.2 Proper use of laboratory equipment and specialized software. Perform a critical analysis of experiments and results. Correctly interpret manuals and catalogs. Work independently, individually or in groups, in the laboratory. LCSF is course in the 3B semester where very specialized equipment and software is used in the field of radio communications: software for calculation of coverage and planning of cellular systems and TV, DVB measurement equipment, DVB OFDM signal generators, base station emulators, software to analyse radio measurements and propagation models adjustment, etc...
LEARNING OBJECTIVES OF THE SUBJECT

LCSF aims to provide students a complete overview of the problems that arise in wireless communications systems. Not only from a detailed knowledge of the radio medium but also placing a lot of emphasis on system design.

The subject is divided into 4 main modules with a theoretical component and a project that will last approximately one quarter of the semester in each case: (a) propagation, (b) cellular radio engineering, (c) planning of mobile communication networks, (d) broadcasting systems (digital TV). After completing the course, the student should be able to:

1. Characterize the statistical behavior of the radio signal (first and second moments) and to model it for coverage calculations and predict the bit error rate. The student must be able to do it both from a theoretical and experimental viewpoint, in this last case from measurement campaigns. Differentiate the characteristics of different operating environments: urban, rural, indoor, highways and other communicating ways and tunnels.

2. Explain the advantages of cellular deployments and the main procedures that govern them. Experimentally set the parameters controlling these procedures. Know the characteristics of a base station equipment in operation.

3. Design cellular systems to achieve a degree of service in terms of coverage (SINR and throughput probability), blocking probability and monthly data consumption done by users. Students should know all the steps to plan a network both theoretically and by means of planning and simulation computing tools. The student will be able to explain the PHY features of LTE systems.

4. Do simple designs of digital broadcasting (digital video broadcasting, DVB) based on OFDM. Perform measurements with commercial equipment and understand the effects of radio channel on the OFDM signal as well as strategies to compensate them. Understand the characteristics of planning single frequency networks, and the process of setting internal transmission delays. The student will be able to explain the PHY features of DVB-T systems of 1st and 2nd generation.

Thanks to the organization of the course in projects:

- Students will acquire social and cooperative skills for the proper functioning of the group work. Specifically, they will work in groups towards the implementation of projects looking at all stages: project planning, information search, choice of solutions, implementation, distribution of tasks, integration of results, writing of technical reports and presentation, defense and argumentation of final decisions and results achieved (mostly in English).
- Learn to plan and lead a project and take responsibility within the group.
- Improve self-learning ability.
- Agility in the use of wireless communications laboratory equipment for calibration, measurements, processing and analysis of data.

STUDY LOAD

<table>
<thead>
<tr>
<th>Type</th>
<th>Hours</th>
<th>Percentage</th>
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<tbody>
<tr>
<td>Self study</td>
<td>84,0</td>
<td>56.00</td>
</tr>
<tr>
<td>Guided activities</td>
<td>26,0</td>
<td>17.33</td>
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<tr>
<td>Hours small group</td>
<td>26,0</td>
<td>17.33</td>
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<tr>
<td>Hours large group</td>
<td>14,0</td>
<td>9.33</td>
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</tbody>
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Total learning time: 150 h

CONTENTS

- Course presentation

Description:
Make the student know:
- The contents of the course and recommended bibliography per topic.
- Description of projects and guidelines on how groups should work.
- Establishment of project schedules for each group.

Specific objectives:
Look at description

Full-or-part-time: 0h 30m
Theory classes: 0h 30m
### Characterization of the radio signal

**Description:**
At the end of this section the student should be able to:

- List and calculate the effect of a radio channel with few reflectors: propagation in free space, reflection against the ground, variations of the refractive index, diffraction effect, attention by hydro-meteors, gases and clutter. The student should be able to find models of n-ray propagation, calculate diffraction losses from the result of Fresnel integrals, implications of blocking different percentages of the 1st Fresnel zone. Anticipate the effect in the direction of the wave front under the effect of atmospheres with different refractive gradients.
- Characterize the statistical behavior of the radio signal in multipath conditions and with many reflectors:
  - Calculation of the average attenuation based on statistical propagation models in different environments: outdoor (rural, urban), indoor and tunnels. The student should be able to explain the differences between free space, Flat Earth, Egli, Okumura-Hata, Cost231-Hata, and Cost231-Walfish-Ikegami models.
  - Characterization of the standard deviation of attenuation in the presence of shadowed areas. At the end of this lesson, the student should be able to perform coverage calculations with any propagation model and ensure perimeter coverage with any degree of service that is defined. It should be able to calculate the margins required to account for fading with log-Normal statistics, identify the limiting link, analyze the differences between link budgets in different environments (urban, rural, communication routes, indoor and tunnel implementations) and for different services. Calculate the number of nodes required to provide service in a target area.
  - Statistical characterization of attenuation deviations due to multipath propagation:
    1. Identify broadband and narrowband conditions. Students should be able to interpret a power delay profile (PDP), select an appropriate tap model in the evaluated environment, and calculate the spread delay. It should be able to predict the type of impulse response in different environments (rural, urban, mountain...).
    2. Efficiently analyze the consequences of the Doppler effect: at the time level: Calculate the channel coherence time, predict the presence of slow or fast fades. Differentiate between Rayleigh and Rice channels (vs. Gaussians) and its effects on the signal (module and phase) and the probability of error in the bit. You will need to be able to find the minimum distance between two antennas to ensure spatial diversity and evaluate variations in diversity gain depending on the number of antennas, as well as explain the different methods of signal combination. Frequency level: Calculate frequency deviation, and power spectral density according to Jakes model.
    3. Efficiently analyze the consequences of multipath propagation in high delay dispersion environments and assess whether the channel is selective or plane in frequency. From the PDP, you need to know how to find the consistency bandwidth.
- List the different steps to follow in a measurement campaign to correctly fit a propagation model and propose alternatives by minimizing the mean square error between prediction and measurement. Understand and apply Lee's criterion for short-term fading removal. To be able to enunciate and calculate the main merit factors of a propagation model from measurements: first and second order moments of error, Pearson correlation factor, total hit rate, etc. Obtain the standard deviation by shadowing from field measurements.
- Describe the particularities of leaky coaxial deployments and calculate attenuation in these scenarios. Correctly interpret the specifications of these elements to establish communications in tunnels and railway communication channels.

**Specific objectives:**

Look at description

**Related activities:**

- A.1. Project A. Measurements in an ISM band and propagation model fitting under outdoor conditions and with radiant cable.
- A.5. Study with Matlab of some of the models / phenomena explained in theory.

**Full-or-part-time:** 39h 30m

- Theory classes: 3h 30m
- Laboratory classes: 8h
- Guided activities: 8h
- Self study : 20h
- Cellular radio-communications engineering

**Description:**
- Students should be able to justify the advantages of cellular deployments, as well as the different typologies that exist.
- They must be able to describe the architecture of a cellular system of any generation (2-5G) as well as the functions of the elements that compose them, back and fronthaul circuits, architectural changes with cloud RAN, etc.
- They must be able to describe and calculate the parameters that conform to the main procedures governing cellular systems, and the basic modes of operation associated with users: (de)attach, handover and handover events, with special emphasis on LTE systems, Open and closed loop power control, paging process, the need for localization/routing areas and lists of tracking areas, timing advance, types of scheduling, link adaptation with special emphasis on LTE systems.

**Specific objectives:**
Look at description

**Related activities:**
- A.2. Project 2B. Cellular procedure enginyering and the physical layer of LTE.

**Full-or-part-time:** 36h
Theory classes: 2h
Laboratory classes: 7h
Guided activities: 7h
Self study : 20h

- Engineering, design and planning of cellular systems

**Description:**
- Students should be able to design cellular systems to achieve a degree of service in terms of coverage (SINR and throughput probability), blocking probability and monthly data consumption done by users. Students should know all the steps to plan a network both theoretically and by means of planning and simulation computing tools. The student will be able to explain the PHY features of LTE systems:
  - Calculation of interferences. They should know how to calculate CIR in theoretical cellular deployments and communication pathways under different interference reduction and coordination configurations: basic frequency reuse and co-channel distances, multiple reuse patterns, fractional reuse options, temporal coordination with almost blank subframes, impact of radiant system configuration on azimuth and elevation... They will also need to show how to proceed with actual calculations with simulation tools.
  - Traffic calculation to ensure a certain probability of blocking and to ensure a certain volume of monthly data. Dimensioning of control channels. All this with special emphasis on the LTE standard.
  - For this reason, the student will need to be able to explain the physical layer of LTE, the definition of its frequency-time grid, capacity calculations for different modulation and coding schemes, impact of signaling and control, impact of PCI planning, 3D planning and integration of aerial users, introduction to MIMO systems.
  - Choice of equipment from specifications and to achieve design quality criteria

**Specific objectives:**
Look at description

**Related activities:**
- A.6. Final theoretical exam

**Full-or-part-time:** 56h
Theory classes: 4h
Laboratory classes: 9h
Guided activities: 9h
Self study : 34h
**Introduction to broadcasting systems engineering. Digital Video Broadcasting.**

**Description:**
The objectives of this module are:
- Do simple designs of digital broadcasting (digital video broadcasting, DVB) based on OFDM.
- The student should be able to explain the PHY features of DVB-T systems of 1st and 2nd generation.
- Perform measurements with commercial equipment and understand the effects of radio channel on the OFDM signal as well as strategies to compensate them.
- Understand the characteristics of planning single frequency networks, and the process of setting internal transmission delays.

**Specific objectives:**
Look at description

**Related activities:**
- A.7. Final theoretical exam.

**Full-or-part-time:** 18h
Theory classes: 4h
Laboratory classes: 2h
Guided activities: 2h
Self study: 10h

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**ACTIVITIES**

**A.1. PROJECT 1. CHARACTERIZATION OF RADIO ATENUATION BY MEANS OF PROPAGATION MODELS**

**Description:**
Project of the propagation module. The project will involve the analysis of a campaign of measures, evaluation of existing propagation models, learning to create new models and extraction of the typical deviation of the attention caused by shadowing

**Specific objectives:**
- The first objective of this project is that students learn the steps in a measurement campaign to fine tune existing propagation models.
- They also must be able to propose alternatives using regression techniques and minimizing the quadratic error between prediction and measurement. Students must be able to process measurements with correctness and be able to state and calculate the main factors of merit of a propagation model: first-order moments of error, Pearson correlation factor, total hit rate, etc.
- From experimental observation, the student should be able to identify the three major components of the signal in the radio environment (mean attenuation, short and long term fading). Also, to apply the Lee criterion and statistically characterize the long-term fading and use these findings in the design of systems.
- A second objective is to familiarize students with regular measurement software in the context of wireless local area networks.
- The student must be able to explain the benefits of a radiating cable in terms of propagation and development of radio systems versus propagation with classic antennas as well as predict its range when used in a complete communication system.

**Material:**
- Measuring Software.
- Software developed in Matlab to import measurements and ease its processing
- Specifications of transmitting equipment, antennas and radiating cable.
- Project guide and milestones

**Delivery:**
- Test on the theoretical aspects necessary for the project.
- At the end of the project, students shall prepare a report based on its objectives.

**Full-or-part-time:** 16h
Laboratory classes: 8h
Self study: 8h
A.2. PROJECT 2B. CELLULAR PROCEDURE ENGINEERING AND THE PHYSICAL LAYER OF LTE.

Description:
Project associated to the module on cellular engineering. With the help of Matlab, the student will analyze the physical layer of LTE and create a full grid step by step. Different configurations will be compared and its impact on the user throughput, it will be analyzed the impact of the propagation on the grid and the direct consequences on the procedures of handover, scheduling, PCI planning. The impact of the terminal category on the quality of service will also be evaluated. Vertical handovers will be performed and quality measurements will be carried out on commercial networks with net monitoring tools as well as visualization of the parameters necessary to (de)attach (from)into the network and guaranteeing mobility in idle mode. It will also be analyzed the problems in the integration of air terminals in the network.

Material:
- Software Matlab
- Software for net monitoring in Android and IOS
- Forms and templates for result sharing among working groups.
- Measurement campaign done in EETAC facilities with specific software.
- Project description.

Delivery:
Same as in Project 1

Full-or-part-time: 16h
Laboratory classes: 8h
Self study: 8h

A.3. PROJECT 3. PLANNING OF A CELLULAR SYSTEM WITH A TOOL FOR COVERAGE CALCULATIONS

Description:
Project associated with the planning module. The student has to do the planning of a realistic system using simulation tools. The deployment will be over an area of Catalonia with at least three environments to be considered: urban, rural and communication ways. Students should be able to execute all design stages typical of a radio planning engineer for the case FDMA/TDMA.

Specific objectives:
They are directly the first point of the third module of contents

Material:
- Specification of equipment, antennas.
- Documents from CMT about service penetration and market shares.
- Link budget to calibrate the ones student have to prepare.
- Manual of planning tool and tutorial to get started.
- Project guide and milestones

Delivery:
View Project 1

Full-or-part-time: 30h
Laboratory classes: 12h
Self study: 16h
A.4. PROJECT 4. EXPERIMENTAL ANALYSIS OF THE DVB-T PHYSICAL LAYER

Description:
Project associated with Module 4. Optional. With professional laboratory instrumentation (generators and specific analyzers). The student will carry out an advanced experimental study of the OFDM signal in the digital video broadcasting terrestrial (DVB-T).

Specific objectives:
They are directly the contents of the fourth module.

Material:
· Specification of equipment, antennas.
· Project guide and milestones

Delivery:
Oral presentation with experiment results.

Full-or-part-time: 12h
Laboratory classes: 4h
Self study: 8h

A.5. ASSESSMENT OF RADIO MEDIUM BEHAVIOUR WITH MATLAB

Description:
The student will experience and evaluate variations of behavior for different realistic input parameters.
- Impact of antenna separation in a two ray environment (flat earth).
- Power spectral density of the signal in a Doppler environment.
- Phasor representation and frequency selective fading in a doppler environment.

Specific objectives:
Strengthen the knowledge of the propagation module.

Material:
Already programmed scripts in Matlab

Full-or-part-time: 3h
Guided activities: 1h
Self study: 2h

MID SEMESTER EXAM

Description:
Evaluation activity

Full-or-part-time: 1h 30m
Theory classes: 1h 30m

FINAL EXAM

Description:
Evaluation activity

Full-or-part-time: 1h 30m
Theory classes: 1h 30m
GRADING SYSTEM

Evaluation criteria that are defined in the course infoweb will be applied.

EXAMINATION RULES.

• Attendance at laboratory sessions is mandatory.
• At the end of the project, the group should write a report based on the objective index. Likewise, a self-analysis of group work must be done. Both documents will be delivered within the established limits.
• Some project tasks will be done cooperatively between different groups.

BIBLIOGRAPHY

Basic:

Complementary: