300038 - LCSF - Wireless Communications Laboratory

Coordinating unit: 300 - EETAC - Castelldefels School of Telecommunications and Aerospace Engineering
Teaching unit: 739 - TSC - Department of Signal Theory and Communications
Academic year: 2019
Degree: BACHELOR'S DEGREE IN AEROSPACE SYSTEMS ENGINEERING/BACHELOR'S DEGREE IN TELECOMMUNICATIONS SYSTEMS ENGINEERING (Syllabus 2015). (Teaching unit Compulsory)
BACHELOR'S DEGREE IN TELECOMMUNICATIONS SYSTEMS ENGINEERING (Syllabus 2009). (Teaching unit Compulsory)
ECTS credits: 6
Teaching languages: Catalan, Spanish

Teaching staff
Coordinator: Definit a la infoweb de l'assignatura.
Others: Definit a la infoweb de l'assignatura.

Prior skills
- Operate with complex numbers, matrix algebra and random variables and processes.
- Analysis of signals and systems, both analog and digital and both in time and frequency domain. Fourier analysis.
- Operate in both linear and logarithmic scale (dB).
- Basic knowledge of communications, antennas, transmitters and receivers.
- Basic theory of teletraffic. Formulas of Erlang-B and Erlang-C.

Requirements
WIRELESS COMMUNICATIONS - Irerequisite

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 methods:
- Independent learning: students work on self-learning materials at home and reserving the lab. outside of class time.
- Students will develop 4 projects where each team must organize work autonomously to achieve certain goals with the guidance of the teacher. Within the time limits of the course, a project based learning strategy is intended as much as possible.
- Lectures: part of the lectures should be concentrated at the beginning of the semester. Projects can not begin until students do not have the necessary theoretical background.

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 4/5 persons. 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.
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 FDMA and CDMA systems, (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 FDMA/TDMA cellular systems to achieve a degree of service in terms of coverage and blocking probability. Students should know all the steps to plan a network both theoretically and by means of planning and simulation computing tools. Similarly, design CDMA systems taking into account the previous steps when appropriate and introduce the specifics of this access technology.

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.

Thanks to the organization of the course in 4 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>Study load</th>
<th>Hours large group:</th>
<th>Hours medium group:</th>
<th>Hours small group:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total learning time</strong>: 150h</td>
<td>13h</td>
<td>0h</td>
<td>29h</td>
</tr>
<tr>
<td>Guided activities:</td>
<td>24h</td>
<td>0h</td>
<td>19.33%</td>
</tr>
<tr>
<td>Self study:</td>
<td>84h</td>
<td>0h</td>
<td>56.00%</td>
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</tbody>
</table>
# Content

| - **Course presentation** | **Learning time:** 0h 30m  
Theory classes: 0h 30m |
|---------------------------|------------------------|

**Specific objectives:**

To inform the student:

- The contents of the course.
- Description of projects and guidelines on how groups should work.
- Establishment of project schedules for each group.
Characterization of the radio signal

Description:
Characterization of the radio signal

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.
· A.6. Mid semester exam.

Specific objectives:
At the end of this section the student should be able to:
· List and discuss the main characteristics of radio signal propagation, and know how to apply the main techniques and propagation models to estimate its range in different environments: outdoor (rural, urban), indoor and tunnels. The student must be able to explain the differences among free space model, two-ray (flat earth), Egli, Okumura-Hata, COST231-Hata and COST231-Walfish-Ikegami models. Similarly, the differences between the calculation of diffraction losses over one single obstacle and several ones.
· To characterize the statistical behavior of the radio signal:
  * In the presence of radioelectrically shadowed areas (shadowing). At the end of this lesson the student should be able to perform calculations of coverage with any propagation model and ensure a given probability of perimetral coverage.
  * Analyze the impact of Doppler effect:
    - Time viewpoint: Calculate the channel coherence time, predict the presence of slow or fast fading. The student should be able to differentiate between Rayleigh and Rice channels (vs. Gaussian) and their effects on the radio signal (module and phase) and the bit error rate. Students should be able to find the minimum distance between two antennas to ensure spatial diversity.
    - Frequency viewpoint: Calculate the frequency spread, and power spectral density according to Jakes model.
  * Analyze the impact of multipath propagation:
    - Time viewpoint: understand a Power Delay Profile (PDP), select a tap model suitable to the environment being analysed and calculate its delay spread. Know how to anticipate the type of impulse response in different environments (rural, urban, mountain ...).
    - Frequency viewpoint: To assess whether the channel is frequency selective or flat. To find the bandwidth of coherence from the PDP.
· List the different steps in a measurement campaign to properly adjust a propagation model and propose alternatives to minimize the mean square error between prediction and measurement. Understand and apply Lee criterium to get rid off short-term fading. Being able to calculate the main factors of merit of a propagation model from the measurements: first-order moments of the mean error, Pearson correlation factor, total hit rate, etc..
· Describe the characteristics of deployments with radiating cable and calculate the overall attenuation. Understand the specifications of these elements to establish communications in tunnels and railway communications pathways.
### Cellular radio-communications engineering

<table>
<thead>
<tr>
<th>Learning time: 31h</th>
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<tbody>
<tr>
<td>Theory classes: 2h</td>
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<tr>
<td>Laboratory classes: 7h</td>
</tr>
<tr>
<td>Self study (distance learning): 16h</td>
</tr>
<tr>
<td>Guided activities: 6h</td>
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</tbody>
</table>

### Related activities:


### Specific objectives:

- The student shall be able to justify the advantages of cellular deployments and their main procedures: hard and soft handover, open/closed/internal/external loop power control, paging procedure, the need for areas of location / routing / tracking, timing advance, admission and congestion control, etc...
- Must be able to properly use a base station emulator to:
  - Run the above processes and understand their response to changes in the configuration parameters.
  - Verify the typical processes of cellular communication systems.
  - Understand the characteristics of operation FDMA/TDMA access technology
  - Set frequency hopping patterns to reduce deep fading effects and interference. Justify its impact on the bit error rate with different degrees of channel coding.
- Be able to use AT commands for configuring DTEs and automate communications thereof.
  - Knowing how this equipment is used for approval of commercial terminals:
    - To be able to visualize and analyze power masks and calculate power ramping time
    - Display the radio signal through the integrated spectrum analyzer.
    - Set loops for calculating bit error rates with different degrees of channel coding.
    - Adjust transmission power in both communication links so that they are balanced and coverage is symmetrical.
### - TDMA/ FDMA systems engineering

<table>
<thead>
<tr>
<th>Learning time:</th>
<th>37h</th>
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<tbody>
<tr>
<td>Theory classes:</td>
<td>3h</td>
</tr>
<tr>
<td>Laboratory classes:</td>
<td>7h</td>
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<tr>
<td>Self study (distance learning):</td>
<td>21h</td>
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<tr>
<td>Guided activities:</td>
<td>6h</td>
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### Related activities:
- A.6. Mid-semester exam

### Specific objectives:
- The student shall be able to design cellular FDMA/TDMA systems to achieve a certain grade of service in terms of coverage and blocking probability. They need to know to run every step of network planning in theory and a tool for planning and simulation software:
  - * Balance the link: You will be able to calculate margins for fading with log-normal statistics, identify the binding constraint, master the differences between balances in different environments (urban, rural, inland communications, indoor and deployment considerations in tunnels) and different services. Calculate the number of nodes needed to serve a target area.
  - * Traffic calculation to ensure a certain blocking probability: define the main parameters of the different types of traffic and services, perform capacity calculations and dimension the required radio resources. Be able to revise the number of needed nodes (set power requirements) to also meet the condition of capacity.
  - * Sizing of control channels.
  - * Calculation of interference. Students must know how to calculate the CIR in hexagonal cell deployments and roads and demonstrate how to proceed with real calculations with computing tools.
  - * Choice of equipment from specifications to achieve the quality criteria of the design.
  - * Frequency Planning. To be able to find the reuse factor in the preliminary stages of planning, know its limitations and understand the need for metaheuristics. Introduction to international frequency coordination.
### CDMA systems engineering

**Learning time:** 24h  
- Theory classes: 2h  
- Self study (distance learning): 16h  
- Guided activities: 6h

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

**Specific objectives:**  
At the end of this section the student should be able to explain the main elements that influence the planning of CDMA systems and the effect they have on the system capacity:  
- Apart from all the common steps with FDMA/TDMA systems, students must be able to consider the specific aspects that this access mechanism introduces:  
  * Novelties in link budget: Estimates of load factor. Iterations in the link budget to balance system capacity and coverage. Being able to estimate soft handover gain. Role of deep fading margin and relationship to power control.  
  * Perform capacity calculations when it is limited by uplink interference, downlink power, use of codes, channel elements and capabilities of backhaul circuits. Explain the concept of admission region and calculate it for different configurations of the above conditions. To be able to perform calculations to identify the need for a twin carrier or additional Scrambling codes that allow a second tree of channelization codes.  
  * Use of codes by the control channels.  
  * Calculation of intracellular interference and relationship with the intercellular one by means of the geometry factor.  
- Students shall know how to justify the need for accurate power control and the problems this mechanism solves in CDMA systems.  
- To distinguish between families of spreading codes based on their orthogonality properties and propose their use in the right situation.

### Introduction to broadcasting systems engineering. Digital Video Broadcasting.

**Learning time:** 23h 30m  
- Theory classes: 3h  
- Laboratory classes: 7h  
- Self study (distance learning): 13h 30m

**Related activities:**  

**Specific objectives:**  
The objectives of this module are:  
- To be able to do simple designs of digital broadcasting (digital video broadcasting, DVB) based on OFDM.  
- To be able to perform measurements with commercial equipment and understand the effects of radio channels on the OFDM signal as well as strategies to compensate them.  
- Explain the characteristics of planning in single frequency networks, and the process of setting internal transmission delays.
## Planning of activities

| PROJECT 1. CHARACTERIZATION OF RADIO ATTENUATION BY MEANS OF PROPAGATION MODELS | Hours: 14h  
Laboratory classes: 7h  
Self study: 7h |
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<tr>
<td><strong>Description:</strong></td>
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This is one of the four projects of the course. Specifically, the core of the propagation module. The project will consist of two parts: outdoor measurement campaign in the campus and in a tunnel covered with radiating cable.  
1. In the first part students will have to use commercial software for measurements, process them in Matlab, adjust existing propagation models and propose new ones by means of regression analysis (minimum quadratic error).  
2. The second part is a comparative study of radiating cable solution versus conventional antennas. |
| **Support materials:** |  
- 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 |
| **Descriptions of the assignments due and their relation to the assessment:** |  
- The group may only perform the experimental part if it passes a test on the theoretical aspects necessary for the project and their content.  
- At the end of the project, students shall prepare a report based on its objectives.  
- The total weight of each project in the final grade will be 15% = 2.5% (first mark of the test) + 12.5% (report). |
| **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. |

| PROJECT 2. USE OF A BASE STATION EMULATOR TO STUDY CELLULAR COMMUNICATION ENGINEERING PROCEDURES | Hours: 14h  
Laboratory classes: 7h  
Self study: 7h |
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<tr>
<td><strong>Description:</strong></td>
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</table>
This is one of the four projects of the subject. Specifically, the module is the core of wireless cellular systems engineering. Students will use 3 emulators of base stations to experiment with different processes explained in the cellular radio engineering module |
Support materials:
· Specification of the terminals with AT commands
· Manual of Nokia Netmonitor
· Manual of base station emulator
· Project guide and milestones

Descriptions of the assignments due and their relation to the assessment:
View Project 1

Specific objectives:
· The student should be able to efficiently use the advanced equipment of LCSF for achieving the experimental objectives of the second module of the course.

PROJECT 3. PLANNING OF A FDMA/ TDMA RADIO SYSTEM

Description:
This is one of the four projects of the subject. Specifically, it is the core of 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.

Support materials:
· 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

Descriptions of the assignments due and their relation to the assessment:
View Project 1

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

PROJECT 4. EXPERIMENTAL ANALYSIS OF OFDM RADIO SIGNAL

Description:
This is one of the four projects of the subject. Specifically, complements contents on modulations in the CSF course and the LCSF module on broadcasting systems radio engineering. With professional laboratory instrumentation (generators and analyzers of specific use), the student will perform an advanced experimental study of the OFDM signal from digital video broadcasting (DVB) system.

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

Descriptions of the assignments due and their relation to the assessment:
View Project 1
Specific objectives:
They are directly the contents of the fourth module.

Assessment of Radio Medium Behaviour with MATLAB

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

Support materials:
Already programmed scripts in Matlab

Specific objectives:
Strengthen the knowledge of the propagation module.

Mid Semester Exam

<table>
<thead>
<tr>
<th>Hours: 2h 30m</th>
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<tbody>
<tr>
<td>Guided activities: 0h 30m</td>
</tr>
<tr>
<td>Self study: 2h</td>
</tr>
</tbody>
</table>

Support materials:
Already programmed scripts in Matlab

Specific objectives:
- Upon completion of the project, the group should prepare a report based on the index of objectives, in some cases the project will be guided. Students should also write a self-analysis of the group. Both documents will be delivered within the established time limits, otherwise the grade will be 0.

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

Regulations for carrying out activities
- Upon completion of the project, the group should prepare a report based on the index of objectives, in some cases the project will be guided. Students should also write a self-analysis of the group. Both documents will be delivered within the established time limits, otherwise the grade will be 0.
Bibliography

Basic:


