ANX-PR/CL/001-01

LEARNING GUIDE

SUBJECT

93000926 - From array processing to mimo communications

DEGREE PROGRAMME

09AT - Master Universitario En Teoria De La Señal Y Comunicaciones

ACADEMIC YEAR & SEMESTER

2018/19 - Semester 2

Index

Learning guide

1. Description

1.1. Subject details

Name of the subject	93000926 - From array processing to mimo communications
No of credits	6 ECTS
Type	Optional
Academic year ot the programme	First year
Semester of tuition	Semester 2
Tuition period	February-June
Tuition languages	English
Degree programme	09AT - Master universitario en teoria de la señal y comunicaciones
Centre	09 - Escuela Tecnica Superior de Ingenieros de Telecomunicacion
Academic year	2018-19

2. Faculty

2.1. Faculty members with subject teaching role

Name and surname	Office/Room	Email	Tutoring hours *
Santiago Zazo Bello	C-326	santiago.zazo@upm.es	Sin horario. Appointment arranged by email
Ramon Martinez Rodriguez-Osorio	C-411	ramon.martinez@upm.es	Sin horario. Appointment arranged by email

Manuel Sierra Perez (Subject coordinator)	C-418	manuel.sierra.perez@upm.es	Sin horario. Appointment arranged by email
Jose Manuel Fernandez Gonzalez	C-416	josemanuel.fernandez.gonzalez@upm.es	Sin horario. Appointment arranged by email
Miguel Alejandro Salas Natera	C-411	miguel.salas@upm.es	Sin horario. Appointment arranged by email

* The tutoring schedule is indicative and subject to possible changes. Please check tutoring times with the faculty member in charge.

3. Prior knowledge recommended to take the subject

3.1. Recommended (passed) subjects

El plan de estudios Master Universitario en Teoria de la Señal y Comunicaciones no tiene definidas asignaturas previas recomendadas para esta asignatura.

3.2. Other recommended learning outcomes

- It is recommended to have a strong knowledge in basic concept about antennas, radiated fields, electromagnetic waves and basic antenna parameters

- It is recommended to know Matlab programming

4. Skills and learning outcomes *

4.1. Skills to be learned

CB10 - Que los estudiantes posean las habilidades de aprendizaje que les permitan continuar estudiando de un modo que habrá de ser en gran medida autodirigido o autónomo

CE01 - Analizar y aplicar técnicas para el diseño y desarrollo avanzado de equipos y sistemas, basándose en la teoría de la señal y las comunicaciones, en un entorno internacional

CE02 - Evaluar y sintetizar los resultados de un trabajo en equipo en proyectos relacionados con la teoría de la señal y las comunicaciones, en un entorno internacional.

CE03 - Valorar y contrastar la utilización de las diferentes técnicas disponibles para la resolución de problemas reales dentro del área de teoría de la señal y comunicaciones.

CT01 - Capacidad para comprender los contenidos de clases magistrales, conferencias y seminarios en lengua inglesa

CT03 - Capacidad para adoptar soluciones creativas que satisfagan adecuadamente las diferentes necesidades planteadas

CT04 - Capacidad para trabajar de forma efectiva como individuo, organizando y planificando su propio trabajo, de forma independiente o como miembro de un equipo

CT05 - Capacidad para gestionar la información, identificando las fuentes necesarias, los principales tipos de documentos técnicos y científicos, de una manera adecuada y eficiente

4.2. Learning outcomes

RA26 - Ability of oral and written communication

RA22 - Knowing conduct a technical presentation before an audience of peers, describing the work and results clearly and well structured, on time, and using precise language

RA27 - Ability to design antenna arrays (arrays)

RA29 - Knowing the mathematical algorithms of adaptive antenna systems

RA31 - To carry out novel designs and applications in the field of MIMO antennas and systems

RA24 - Knowledge of advanced techniques used in the Radio Access Technologies

RA47 - Knowing and evaluating MIMO systems

* The Learning Guides should reflect the Skills and Learning Outcomes in the same way as indicated in the Degree Verification Memory. For this reason, they have not been translated into English and appear in Spanish.

5. Brief description of the subject and syllabus

5.1. Brief description of the subject

This course begins with multiple input-multiple output (MIMO) channel characterization. It makes special emphasis on the main MIMO architectures, beginning with the antenna and RF fronted models. A second group of lessons deals with the beam conforming problems and MIMO schemas. The most important of these schemas are the special multiplexing and space-time coding. We will pay special attention to both, the one user and multiuser systems. The last block deals with the actual massive MIMO problems. We present the basic core and limits and possible uplink and downlink optimized design. These contents are presented under the theoretical point of view and complemented with the practical simulation of the main mathematical algorithms. Lately the course deepens in the radio frequency and antenna non ideal behavior that limits the system performance, like phase noise, nonlinear response, antenna coupling and phase and quadrature branches mismatch.

5.2. Syllabus

1. Introduction to the MIMO systems
   1.1. Overview of information theory
   1.2. MIMO channel modelling
   1.3. Modelling of MIMO OFDM systems
2. Single user communications
   2.1. Diversity combining
   2.2. Alamouti coding
   2.3. Space-time block coding
   2.4. Space-time trellis coding
   2.5. Single user MIMO
3. MIMO communications
   3.1. Multi-User MIMO - Multiple Access Channels (Uplink)
   3.2. Multi-User MIMO - Broadcast Channels (Downlink)
4. Massive MIMO
   4.1. Fundamentals and limitations
   4.2. Downlink / Uplink optimization
5. Receiving array processing
   5.1. Fundamentals of array processing
   5.2. Optimum Beamforming
   5.3. Adaptive Beamformers
   5.4. Direction of arrival estimation
   5.5. Subspace Methods
6. Implementation of MIMO arquitectures
   6.1. System modelling. Antennas and RF front-ends
   6.2. RF and analog channel impairments.
   6.3. Compensation from the digital part
   6.4. Codesign of base-band / RF

6.5. Future trends.

6. Schedule

6.1. Subject schedule*

Week	Face-to-face classroom activities	Face-to-face laboratory activities	Other face-to-face activities	Assessment activities
1	**Introduction to the course** Duration: 02:00 Lecture **MIMO systems introduction** Duration: 02:00 Lecture			
2	**Diversity combining and Alamuti codes** Duration: 02:00 Lecture	**MIMO systems introduction** Duration: 02:00 Laboratory assignments		
3	**Single user MIMO** Duration: 02:00 Lecture **Spatial multiplexing-MIMO** Duration: 02:00 Lecture			
4		**Space-time block coding** Duration: 02:00 Laboratory assignments		**Single user mimo codes** Individual work Continuous assessment Duration: 00:00 **First project presentation** Group presentation Continuous assessment Duration: 02:00
5	**Multi-User MIMO - Multiple Access Channels (Uplink)** Duration: 02:00 Lecture **Multiuser MIMO. Broadcast chanels** Duration: 02:00 Lecture			
6	**Multiuser MIMO. Broadcast chanels** Duration: 02:00 Lecture	**Multi-User MIMO** Duration: 02:00 Laboratory assignments		
7	**Massive MIMO Fundamentals** Duration: 02:00 Lecture			**Multi user MIMO codes** Individual work Continuous assessment Duration: 00:00 **Second project presentation** Group presentation Continuous assessment Duration: 02:00

8	**Massive MIMO Uplink-Downlink** Duration: 04:00 Lecture			
9		**Masive MIMO coding** Duration: 02:00 Laboratory assignments		**Massive MIMO codes** Individual work Continuous assessment Duration: 00:00 **Third project presentation** Group presentation Continuous assessment Duration: 02:00
10	**Fundamentals of array processing** Duration: 02:00 Lecture **Optimum Beamforming** Duration: 02:00 Lecture			
11	**Direction of arrival estimation** Duration: 02:00 Lecture	**Adaptive beamforming and DOA models** Duration: 02:00 Laboratory assignments		
12	**RF impairments.** Duration: 02:00 Lecture			**Adaptive antenna codes** Individual work Continuous assessment Duration: 00:00 **Fourth project presentation** Group presentation Continuous assessment Duration: 02:00
13	**Antenna and RF circuits modeling** Duration: 02:00 Lecture **Impairments compensation.** Duration: 02:00 Lecture			
14		**Base band and RF coding.** Duration: 02:00 Laboratory assignments		**Final student work oral presentation.** Group presentation Continuous assessment Duration: 02:00 **Final work report evaluation** Group work Continuous assessment Duration: 00:00
15				
16				
17				**Final exam based in a personal work oral presentation answering the questions from the professors** Individual presentation Final examination Duration: 04:00

The independent study hours are training activities during which students should spend time on individual study or individual assignments.

Depending on the programme study plan, total values will be calculated according to the ECTS credit unit as 26/27 hours of student face-to-face contact and independent study time.

* The subject schedule is based on a previous theorical planning of the subject plan and might go to through experience some unexpected changes along throughout the academic year.

7. Activities and assessment criteria

7.1. Assessment activities

7.1.1. Continuous assessment

Week	Description	Modality	Type	Duration	Weight	Minimum grade	Evaluated skills
4	Single user mimo codes	Individual work	No Presential	00:00	5%	3 / 10	CB10 CE01 CT05 CE03 CT01
4	First project presentation	Group presentation	Face-to-face	02:00	10%	3 / 10	CT04 CT03 CT05 CE03 CE02
7	Multi user MIMO codes	Individual work	No Presential	00:00	5%	3 / 10	CB10 CE01 CT04 CT05 CE03 CT01
7	Second project presentation	Group presentation	Face-to-face	02:00	10%	3 / 10	CE02 CT04 CT03 CE03 CT01
9	Massive MIMO codes	Individual work	No Presential	00:00	5%	3 / 10	CT04 CB10 CE01 CT05 CT01
9	Third project presentation	Group presentation	Face-to-face	02:00	10%	3 / 10	CE02 CT04 CT03 CT05 CE03 CT01
12	Adaptive antenna codes	Individual work	No Presential	00:00	5%	3 / 10	CE01 CT05 CE03 CT01

12	Fourth project presentation	Group presentation	Face-to-face	02:00	10%	3 / 10	CE02 CT04 CT03 CE03 CT01
14	Final student work oral presentation.	Group presentation	Face-to-face	02:00	20%	/ 10	CE02 CT04 CT03 CE03 CT01
14	Final work report evaluation	Group work	No Presential	00:00	20%	/ 10	CE01 CT04 CT05 CE03 CT01

7.1.2. Final examination

Week	Description	Modality	Type	Duration	Weight	Minimum grade	Evaluated skills
17	Final exam based in a personal work oral presentation answering the questions from the professors	Individual presentation	Face-to-face	04:00	100%	/ 10	CB10 CE02 CE01 CT04 CT03 CT05 CE03 CT01

7.1.3. Referred (re-sit) examination

Description	Modality	Type	Duration	Weight	Minimum grade	Evaluated skills
Final exam based in a personal work oral presentation answering the questions from the professors	Individual presentation	Face-to-face	04:00	100%	/ 10	CB10 CE02 CE01 CT04 CT03 CT05 CE03 CT01

7.2. Assessment criteria

Students will be qualified through continuous evaluation by default. According to the Normativa de Evaluación del Aprendizaje de la Universidad Politécnica de Madrid, students willing to renounce to continuous evaluation must complete the Moodle task entitled "Renounce to continuous evaluation" before the first project presentation (week four).

Evaluation will assess if students have acquired all the competences of the subject. Thus, evaluation through final assessment will be carried out considering all the evaluation techniques used in continuous evaluation (EX, ET, TG, etc.), and will be celebrated in the exam period approved by Junta de Escuela for the current academic semester and year. Evaluation activities that assess learning outcomes that cannot be evaluated through a single exam can be carried out along the semester.

Extraordinary examination will be carried out exclusively by the final assessment method.

Continuous evaluation

The evaluation is made based in a Group Project (GP) to be made along the course and personal evaluations in oral presentations.

The GP is defined by the teachers with a clear agenda to perform along the course.

The GP is made in three steps after the the subject presentation:

1- Description selected way to solve the problem associated to the project goals. Description of the work chronogram and definition of the work to be done in the next two periods. Selection of the documentation needed to develop the work

2- First development of the GP with a personal software code to demonstrate the possibility of the designed system to solve the problem presented in the GP.

3- Final demonstration of the solution of the system with the evaluation of the satisfied goals.

Each presentation is made through a written memory and an oral presentation in the classroom. The final memory must summarize all the work done along the course. All this project memory and oral presentations reach the 80% of the final evaluation. Al the laboratory work memories are evaluated and complete the 20% of the evaluation.

Final ordinary exam

Students renouncing to the continuous evaluation will receive the guide for a personal work to be developed and presented in the final exam. This work guide will be defined before the week 4 of the course.

The final exam can include a written exam, the presentation of the memory of personal work done and the oral exam about the entire subject in the course.

Students that could not reach the minimum qualification in the continuous evaluation process, may take the final exam and present a new work memory and oral presentation about the project done during the course.

Final extraordinary exam

The extraordinay exam can include a written exam, the presentation of the personal work selected in previous exams and the oral exam about the entire subject in the course.

Students that could not reach the minimum qualification in the continuous evaluation process or in the final ordinary exam, may take the final extraordinary exam and present a new work memory and oral presentation about the project done during the course.

8. Teaching resources

8.1. Teaching resources for the subject

Name	Type	Notes
David Tse, Fundamentals of Wireless Communications.	Bibliography	
Chandran. Advances in direction of arrival estimation	Bibliography	
Compton. Adaptive antennas. Concepts and performance	Bibliography	