ANX-PR/CL/001-01

LEARNING GUIDE

SUBJECT

93001069 - From array processing to mimo communications

DEGREE PROGRAMME

09AQ - Master Universitario En Ingenieria De Telecomunicacion

ACADEMIC YEAR & SEMESTER

2018/19 - Semester 2

Index

Learning guide

1. Description

1.1. Subject details

Name of the subject	93001069 - From array processing to mimo communications
No of credits	6 ECTS
Type	Optional
Academic year ot the programme	Second year
Semester of tuition	Semester 4
Tuition period	February-June
Tuition languages	English
Degree programme	09AQ - Master universitario en ingenieria de telecomunicacion
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 *
Miguel Alejandro Salas Natera	C-411	miguel.salas@upm.es	Sin horario. Appointment arranged by email
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

* 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

The subject - recommended (passed), are not defined.

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

CE1 - Capacidad para aplicar métodos de la teoría de la información, la modulación adaptativa y codificación de canal, así como técnicas avanzadas de procesado digital de señal a los sistemas de comunicaciones y audiovisuales.

CE2 - Capacidad para desarrollar sistemas de radiocomunicaciones: diseño de antenas, equipos y subsistemas, modelado de canales, cálculo de enlaces y planificación.

CG2 - Que los estudiantes sepan aplicar los conocimientos adquiridos y su capacidad de resolución de problemas en entornos nuevos o poco conocidos dentro de contextos más amplios (o multidisciplinares) relacionados con su área de estudio.

CG4 - Que los estudiantes sepan comunicar sus conclusiones ?y los conocimientos y razones últimas que las sustentan? a públicos especializados y no especializados de un modo claro y sin ambigüedades.

CG5 - 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.

CT1 - Capacidad para comprender los contenidos de clases magistrales, conferencias y seminarios en lengua inglesa.

CT2 - Capacidad para dinamizar y liderar equipos de trabajo multidisciplinares.

CT3 - Capacidad para adoptar soluciones creativas que satisfagan adecuadamente las diferentes necesidades planteadas.

CT4 - Capacidad para trabajar de forma efectiva como individuo, organizando y planificando su propio trabajo, de forma independiente o como miembro de un equipo.

CT5 - 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

RA10 - Saber realizar una presentación de carácter técnico, ante una audiencia de pares, que describa el trabajo realizado y sus resultados, de forma clara y bien estructurada, en el tiempo establecido, y usando un lenguaje preciso

RA134 - Manejar con soltura las bases de álgebra lineal y cálculo infinitesimal necesarias para formular problemas de optimización.

RA117 - Conocer los aspectos básicos de los sistemas y servicios de radiocomunicaciones, su marco regulatorio y estándares técnicos de referencia.

RA136 - Manejar con soltura las bases del modelado matemático de señales aleatorias.

RA207 - Tener capacidad de diseño de antenas para sistemas de comunicaciones y radar

RA210 - Tener capacidad de diseño de agrupaciones de antenas (arrays) tanto activos como pasivos

RA211 - Conocer los algoritmos matemáticos de los sistemas adaptativos de antena

RA135 - Conocer y dominar herramientas para la resolución de problemas fundamentales de optimización.

RA212 - Tener capacidad de diseño de sistemas de medida de antena en campo proximo

RA119 - Conocimiento de técnicas avanzadas utilizadas en las Tecnologías de Acceso Radio

RA209 - Conocer los sistemas de medida de antenas y sus limitaciones

RA208 - Conocer las bases de diseño de los sistemas de multiples antenas (MIMO)

* 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	CE1 CG2 CG5 CT1 CT5
4	First project presentation	Group presentation	Face-to-face	02:00	10%	3 / 10	CE1 CG4 CG5 CE2 CT1 CT4 CT3 CT2
7	Multi user MIMO codes	Individual work	No Presential	00:00	5%	3 / 10	CE1 CG2 CG5 CT1 CT5
7	Second project presentation	Group presentation	Face-to-face	02:00	10%	3 / 10	CE1 CG4 CE2 CT1 CT4 CT3 CT2
9	Massive MIMO codes	Individual work	No Presential	00:00	5%	3 / 10	CE1 CG2 CG5 CT1 CT5
9	Third project presentation	Group presentation	Face-to-face	02:00	10%	3 / 10	CE1 CG4 CG5 CE2 CT1 CT4 CT3 CT2

12	Adaptive antenna codes	Individual work	No Presential	00:00	5%	3 / 10	CE1 CG2 CG5 CT1 CT5
12	Fourth project presentation	Group presentation	Face-to-face	02:00	10%	3 / 10	CE1 CG4 CE2 CT1 CT4 CT5 CT3 CT2
14	Final student work oral presentation.	Group presentation	Face-to-face	02:00	20%	/ 10	CG2 CG4 CG5 CE2 CT1 CT4 CT5 CT3 CT2
14	Final work report evaluation	Group work	No Presential	00:00	20%	/ 10	CE1 CG2 CG4 CG5 CE2 CT1 CT4 CT5 CT3 CT2

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	CE1 CG2 CG4 CG5 CE2 CT1 CT4 CT5 CT3 CT2

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	CG2 CG4 CG5 CE2 CT1 CT4 CT5 CT3 CT2

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	

9. Adendas

- The evaluation process has been changed toward a more specific evaluation in the areas of the course syllabus. The guide changes according to these changes in the following parts: 6.1. Subject Schedule Week 1 Introduction to the course Duration: 02:00 MIMO systems introduction Duration: 02:00 Lecture by RMRO/MSN Week 2 Diversity combining and Alamouti codes Duration: 02:00 Lecture by RMRO/MSN MIMO systems introduction Duration: 02:00 Laboratory assignments Lecture by RMRO/MSN Week 3 Single user MIMO Duration: 02:00 Lecture by RMRO/MSN Spatial multiplexing-MIMO Duration: 02:00 Lecture by RMRO/MSN Week 4 Space-time block coding Laboratory assignments Duration: 02:00 Lecture by RMRO Single user MIMO codes Individual work Continuous assessment Duration: 00:00 Multi-User MIMO Duration: 02:00 Lecture by SZB Week 5 Multiuser MIMO. Duration: 02:00 Lecture by SZB Multiuser MIMO. Duration: 02:00 Lecture by SZB Week 6 Multi-User MIMO Duration: 02:00 Lecture by SZB Massive MIMO Duration: 02:00 Lecture by SZB Week 7 Massive MIMO Duration: 04:00 Lecture by SZB Week 8 Massive MIMO Duration: 02:00 Lecture by SZB Individual work on Massive MIMO Continuous assessment Duration: 00:00 Fundamentals of array processing Duration: 02:00 Lecture by MSP Week 9 Optimum Beamforming Duration: 02:00 Lecture by MSP Adapting Beamforming Process Duration: 02:00 Lecture by MSP Week 10 Direction of arrival estimation Duration: 02:00 Lecture by MSP Adaptive beamforming models Laboratory assignments Duration: 02:00 Lecture by MSP Week 11 Direction of arrival Errors Duration: 02:00 Lecture by MSP DOA models Laboratory assignments Duration: 02:00 Lecture by MSP Adaptive antenna codes Individual work Continuous assessment Duration: 00:00 Week 12 RF impairments. Duration: 02:00 Lecture by JMFG Impairments compensation. Duration: 02:00 Lecture by JMFG Week 13 Antenna and RF circuits modeling Duration: 02:00 Lecture by JMFG System modeling Laboratory assignments Duration: 02:00 Lecture by JMFG Week 14 Error compensation. Calibration Duration: 02:00 Lecture by JMFG System modeling codes Laboratory assignments Duration: 02:00 Lecture by MSN System modeling codes Individual work Continuous assessment Duration: 00:00 Week 15 Week 16 Week 17 Final exam Individual presentation Duration: 04:00 7.1. Assessment activities 7.1.1. Continuous assessment The continuous assessment changes in the sense that no group projects have been programmed. All the continuous and final exam evaluations are based on several laboratory work and simulation codes about the studied matter. Week 4 Single user MIMO codes Individual work No Presential Value: 20% Minimum grade: 3 / 10 Evaluation skills: CE1 CG2 CG5 CT1 CT5 Week 8 Multi user and Massive MIMO codes Individual work No Presential Value: 20% Minimum grade: 3 / 10 Evaluation skills: CE1 CG2 CG5 CT1 CT5 Week 11 Adaptive antenna codes Individual work No Presential Value 20% Minimum grade 3 / 10 Evaluation skills: CE1 CG2 CG5 CT1 CT5 Week 14 System model codes Individual work No Presential Value 20% Minimum grade 3 / 10 Evaluation skills: CE1 CG2 CG5 CT1 CT5 Week 14 Written exam. Presential Value 20% Minimum grade 3/ 10 Evaluation skills: CE1 CG2 CG4 CG5 CE2 CT1 CT4 CT5 CT3 CT2