ANX-PR/CL/001-01

LEARNING GUIDE

SUBJECT

593000602 - Mobile Communication Systems

DEGREE PROGRAMME

59AI - Master Universitario En Comunicaciones Inalámbricas

ACADEMIC YEAR & SEMESTER

2024/25 - Semester 1

Index

Learning guide

1. Description

1.1. Subject details

Name of the subject	593000602 - Mobile Communication Systems
No of credits	6 ECTS
Type	Compulsory
Academic year ot the programme	First year
Semester of tuition	Semester 1
Tuition period	September-January
Tuition languages	English
Degree programme	59AI - Master Universitario en Comunicaciones Inalámbricas
Centre	59 - Escuela Tecnica Superior De Ingenieria Y Sistemas De Telecomunicacion
Academic year	2024-25

2. Faculty

2.1. Faculty members with subject teaching role

Name and surname	Office/Room	Email	Tutoring hours *
Juan Anton Moreno Garcia-Loygorri	8418	juan.moreno.garcia-loygorri@upm.es	Sin horario.
Antonio Perez Yuste (Subject coordinator)	8304	antonio.perez@upm.es	Sin horario.
Angel Martinez Jimenez	7010	angel.martinez.jimenez@upm.es	Sin horario.

* 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

- Management of technical information

- Operation of RF instrumentation

- Programming in MATLAB

4. Skills and learning outcomes *

4.1. Skills to be learned

CB6 - Poseer y comprender conocimientos que aporten una base u oportunidad de ser originales en el desarrollo y/o aplicación de ideas, a menudo en un contexto de investigación

CB7 - 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

CB8 - Que los estudiantes sean capaces de integrar conocimientos y enfrentarse a la complejidad de formular juicios a partir de una información que, siendo incompleta o limitada, incluya reflexiones sobre las responsabilidades sociales y éticas vinculadas a la aplicación de sus conocimientos y juicios

CEM03 - Analizar y diseÃ±ar la arquitectura, servicios y protocolos de la red de acceso radio de un sistema de comunicaciones mÃ³viles 4G y 5G

CGI02 - Comprender el procedimiento, valor y límites del método científico, siendo capaz de identificar, localizar y obtener datos requeridos en un trabajo de investigación, de diseñar y guiar investigaciones analíticas, de modelado y experimentales, así como de evaluar datos de una manera crítica y extraer conclusiones.

CGI03 - Valorar la importancia de las fuentes documentales, manejarlas y buscar la información para el desarrollo de cualquier trabajo de investigación.

CGI04 - Leer y comprender publicaciones dentro de su ámbito de estudio/investigación, así como su catalogación y valor científico.

UPM1 - Uso de la lengua inglesa

UPM4 - OrganizaciÃ³n y planificaciÃ³n /

4.2. Learning outcomes

RA30 - Design and develop the components of a mobile communications network and its protocols based on technical specifications

RA17 - RA02.- Apply the knowledge acquired to the understanding of qualitative and quantitative problems related to source coding and channel coding.

RA11 - Identify the social and economic impact of mobile communications in a global context

RA12 - Apply the knowledge acquired to the solution of qualitative and quantitative problems related to personal mobile communications

RA18 - RA03.- Choose the mathematical methods and tools necessary to tackle a problem and finds the solution.

* 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

Mobile communications have become an impressive worldwide service extended to the point of achieving outstanding coverage figures close to one hundred percent penetration nowadays. Socially speaking, that makes mobile communications an indispensable element for modern lifestyle; and economically speaking, it provides an essential global enabler for many world businesses as well.

LTE represents the fourth generation of mobile communications technologies, currently representing the most successful wireless mobile broadband technology across the globe. Although LTE is a very capable technology which is still evolving and expected to be used for many years to come, a new 5G radio access known as New Radio (NR) has been introduced to meet future requirements.

A higher mobile broadband is, without a doubt, the main objective but, more and more, future wireless networks will also be about a wider range of new use cases. That includes, among others, mission critical communications, intelligent energy distribution, smart vehicles and roads, ubiquitous transport solutions, remote healthcare and telesurgery, expanded industrial IoT, etc.

This course is aimed to gain a clear understanding on present and future mobile communication systems, particularly 4G-LTE and 5G-NR, and mainly focused to both the Radio Access Network (RAN) and to the Physical Layer (PHY). Both generations will be jointly presented, moving from the former key features to the latter?s new enhancements, although paying more attention to the latter one.

5.2. Syllabus

1. LTE and 5G overview
    1.1. Public Land Mobile Networks (PLMN)
    1.2. Stakeholder Roles in a modern PLMN
    1.3. 3GPP Usage Scenarios
    1.4. RAN Technology Enablers
    1.5. 5G Radio Scenarios
    1.6. 5G Rollout in the World
    1.7. 5G End-to-end KPIs
    1.8. 6G Expected Features
2. Architecture of the Radio Access Network
    2.1. E-UTRAN Architecture
    2.2. 5G-NR Architecture
    2.3. Multi-Radio Dual Connectivity
    2.4. Radio Cell Features
    2.5. Radio Network IDs
    2.6. RRC State Diagram
    2.7. Signaling and Data Radio Bearers
    2.8. Air Interface Protocol Stack and Channels
    2.9. Quality of Service
3. PHY transmission structure
    3.1. Duplexing scheme
    3.2. Frequency-domain structure
    3.3. Bandwidth parts
    3.4. Time-domain structure
    3.5. Synchronization signal block (SSB)
    3.6. Antenna ports
    3.7. Resource grid

4. PHY signal processing: modulation and channel coding
   4.1. General scheme of a communication system
   4.2. The wireless channel
   4.3. Modulation and demodulation
   4.4. Error management
   4.5. Adaptive modulation and coding
   4.6. OFDM basics
   4.7. The cyclic prefix
   4.8. OFDMA basics
   4.9. Channel coding
5. PHY signal processing: multi-antenna transmission
   5.1. Beamforming
   5.2. Spatial multiplexing
   5.3. Massive MIMO
   5.4. Downlink and uplink precoding
   5.5. Beam management
6. Air Interface L1
   6.1. Layer 2 summary
   6.2. Layer 1 review
   6.3. Synchronisation signal block
   6.4. Control resource set
   6.5. Channel state information
   6.6. Data transmission
7. Cell Acquisition
   7.1. Acquisition procedure
   7.2. Resource mapping
   7.3. Acquisition of the SS/PBCH block
   7.4. System information
8. Link Adaptation

8.1. CSI reference signals

8.2. Channel state information

8.3. Physical Uplink Control Channel

9. Mm-wave for wireless communications

9.1. Spectrum for NR flexibility

9.2. Radio wave propagation for Mm-wave

9.3. Mm-wave standardization

9.4. Types of base stations. Requirements.

9.5. Antennas and Arrays for Mm-Wave applications

9.6. Mm-wave RF and analog devices and circuits

9.7. Multi-Gbps digital baseband circuits

10. Channel sounding

10.1. Motivation

10.2. Channel Modelling

10.3. Propagation measurements in extreme environments

10.4. Channel models in vehicular scenarios

11. AI-powered radio access networks

11.1. ML-Modeling with ORAN

11.2. Non-Real-Time (Non-RT) RIC

11.3. Near-Real-Time (Near-RT) RIC

11.4. O-DU and O-RU AI control loop

6. Schedule

6.1. Subject schedule*

Week	Type 1 activities	Type 2 activities	Distant / On-line	Assessment activities
1	**T1. LTE and 5G overview** Duration: 02:00 Lecture **T2. Architecture of the Radio Access Network** Duration: 04:00 Lecture	**T2. Architecture of the Radio Access Network** Duration: 02:00 Laboratory assignments		**T1-T2. LTE and 5G overview** Online test Progressive assessment and Global Examination Not Presential Duration: 01:00 **T2. Architecture of the Radio Access Network** Individual work Progressive assessment and Global Examination Not Presential Duration: 02:00
2	**T3. PHY transmission structure** Duration: 08:00 Lecture			
3	**T4. PHY signal processing: modulation and channel coding** Duration: 04:00 Lecture	**T3. PHY transmission structure** Duration: 04:00 Laboratory assignments		**T3. PHY transmission structure** Individual work Progressive assessment and Global Examination Presential Duration: 02:00
4	**T5. PHY signal processing: multi-antenna transmission** Duration: 04:00 Lecture	**T4. PHY signal processing: modulation and channel coding** Duration: 04:00 Laboratory assignments		**T4. PHY signal processing: modulation and channel coding** Individual work Progressive assessment and Global Examination Presential Duration: 02:00
5	**T5. PHY signal processing: multi-antenna transmission** Duration: 02:00 Lecture **T6. Air Interface L1** Duration: 02:00 Lecture	**T5. PHY signal processing: multi-antenna transmission** Duration: 02:00 Laboratory assignments **T6. Air Interface L1** Duration: 02:00 Laboratory assignments		**T5. PHY signal processing: multi-antenna transmission** Individual work Progressive assessment and Global Examination Presential Duration: 02:00 **T6. Air Interface L1** Individual work Progressive assessment and Global Examination Presential Duration: 02:00

6	**T7. Cell Acquisition** Duration: 02:00 Lecture **T8. Link Adaptation** Duration: 02:00 Lecture **T9. Mm-wave for wireless communications** Duration: 04:00 Lecture			**T7-T8. Cell Acquisition and Link Adaptation** Online test Progressive assessment and Global Examination Not Presential Duration: 01:00 **T9. Mm-wave for wireless communications** Online test Progressive assessment and Global Examination Presential Duration: 01:00
7	**T10. Channel sounding** Duration: 04:00 Lecture **T11. AI-powered radio access networks** Duration: 04:00 Lecture			**T10. Channel sounding** Online test Progressive assessment and Global Examination Not Presential Duration: 01:00 **T11. AI-powered radio access networks** Online test Progressive assessment and Global Examination Not Presential Duration: 01:00
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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.

7. Activities and assessment criteria

7.1. Assessment activities

7.1.1. Assessment

Week	Description	Modality	Type	Duration	Weight	Minimum grade	Evaluated skills
1	T1-T2. LTE and 5G overview	Online test	No Presential	01:00	5%	5 / 10	UPM1 UPM4 UPM5 CEM03
1	T2. Architecture of the Radio Access Network	Individual work	No Presential	02:00	15%	5 / 10	CGI03 CB7 UPM1 UPM5 CEM03
3	T3. PHY transmission structure	Individual work	Face-to-face	02:00	15%	5 / 10	CGI03 CB7 UPM1 UPM5 CEM03
4	T4. PHY signal processing: modulation and channel coding	Individual work	Face-to-face	02:00	15%	5 / 10	CGI02 CGI03 CB6 CB7 UPM1 UPM5 CEM03
5	T5. PHY signal processing: multi-antenna transmission	Individual work	Face-to-face	02:00	15%	5 / 10	CGI03 CB8 UPM1 UPM4 CEM03
5	T6. Air Interface L1	Individual work	Face-to-face	02:00	15%	5 / 10	CGI03 CGI04 UPM1 UPM4 UPM5 CEM03
6	T7-T8. Cell Acquisition and Link Adaptation	Online test	No Presential	01:00	5%	5 / 10	CGI02 CB8 UPM1 UPM5

6	T9. Mm-wave for wireless communications	Online test	Face-to-face	01:00	5%	5 / 10	CGI03 CGI04 CB6 UPM1 UPM4 UPM5
7	T10. Channel sounding	Online test	No Presential	01:00	5%	5 / 10	CGI02 CGI04 UPM1
7	T11. AI-powered radio access networks	Online test	No Presential	01:00	5%	5 / 10	CGI02 CGI04 CB7 UPM1 UPM4

7.1.2. Global examination

Week	Description	Modality	Type	Duration	Weight	Minimum grade	Evaluated skills
1	T1-T2. LTE and 5G overview	Online test	No Presential	01:00	5%	5 / 10	UPM1 UPM4 UPM5 CEM03
1	T2. Architecture of the Radio Access Network	Individual work	No Presential	02:00	15%	5 / 10	CGI03 CB7 UPM1 UPM5 CEM03
3	T3. PHY transmission structure	Individual work	Face-to-face	02:00	15%	5 / 10	CGI03 CB7 UPM1 UPM5 CEM03
4	T4. PHY signal processing: modulation and channel coding	Individual work	Face-to-face	02:00	15%	5 / 10	CGI02 CGI03 CB6 CB7 UPM1 UPM5 CEM03
5	T5. PHY signal processing: multi-antenna transmission	Individual work	Face-to-face	02:00	15%	5 / 10	CGI03 CB8 UPM1 UPM4 CEM03
5	T6. Air Interface L1	Individual work	Face-to-face	02:00	15%	5 / 10	CGI03 CGI04 UPM1 UPM4 UPM5 CEM03

6	T7-T8. Cell Acquisition and Link Adaptation	Online test	No Presential	01:00	5%	5 / 10	CGI02 CB8 UPM1 UPM5
6	T9. Mm-wave for wireless communications	Online test	Face-to-face	01:00	5%	5 / 10	CGI03 CGI04 CB6 UPM1 UPM4 UPM5
7	T10. Channel sounding	Online test	No Presential	01:00	5%	5 / 10	CGI02 CGI04 UPM1
7	T11. AI-powered radio access networks	Online test	No Presential	01:00	5%	5 / 10	CGI02 CGI04 CB7 UPM1 UPM4

7.1.3. Referred (re-sit) examination

No se ha definido la evaluación extraordinaria.

7.2. Assessment criteria

The type of course and the approach described above make more convenient to select an assessment mechanism different to the traditional final exam. A progressive evaluation methodology is here proposed for this course, based on a set of short quizzes. This way, main concepts can be properly set up while the attractive of the contents are increased. In addition, the assessment of lab practices are based on the realisation of a report by students. This report will be also evaluated in order to get the final grade.

Those students who do not meet the goals and do not pass the regular activities, will be able to attend an extraordinary exam organised on July. This will consist of two parts: firstly, a questionnaire selected among all topics in this course must be responded on-line and, secondly, a lab practice with several exercises related to the practical activities carried out along the course must be duly done. It is mandatory to pass the first part before moving to the second part, which also needs to be passed in order to get the final grade.

8. Teaching resources

8.1. Teaching resources for the subject

Name	Type	Notes
Slide shows	Web resource	Moodle LMS
Lab scripts	Web resource	Moodle LMS
3GPP	Web resource	The 3rd Generation Partnership Project, http://www.3gpp.org/
The 3G4G Blog	Web resource	https://blog.3g4g.co.uk
Cox, 2021	Bibliography	Cox, C., "An Introduction to 5G. The New Radio, 5G Network and Beyond", Ed. John Wiley & Sons, 2021
Cox, 2014	Bibliography	Cox, C., "An Introduction to LTE. LTE-Advanced, SAE, VoLTE and 4G Mobile Communications", 2nd ed, Ed. John Wiley & Sons, 2014
Dahlman, 2018	Bibliography	Dahlman, E. et al, "5G NR: The Next Generation Wireless Access Technology", Academic Press, Elsevier, 2018
Dahlman, 2011	Bibliography	Dahlman, E. et al, "4G: LTE/LTE-Advanced for Mobile Broadband", Academic Press, 2011