



POLITÉCNICA

INTERNATIONAL  
CAMPUS OF  
EXCELLENCE

COORDINATION PROCESS OF  
LEARNING ACTIVITIES  
PR/CL/001



E.T.S. de Ingeniería y Sistemas  
de Telecomunicación

# ANX-PR/CL/001-01

## LEARNING GUIDE

### SUBJECT

**593000602 - Mobile Communication Systems**

### DEGREE PROGRAMME

59AJ - Master Universitario En Comunicaciones Inalámbricas

### ACADEMIC YEAR & SEMESTER

2024/25 - Semester 1

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## 1. Description

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### 1.1. Subject details

<b>Name of the subject</b>	593000602 - Mobile Communication Systems
<b>No of credits</b>	6 ECTS
<b>Type</b>	Compulsory
<b>Academic year of the programme</b>	First year
<b>Semester of tuition</b>	Semester 1
<b>Tuition period</b>	September-January
<b>Tuition languages</b>	English
<b>Degree programme</b>	59AJ - Master Universitario en Comunicaciones Inalámbricas
<b>Centre</b>	59 - Escuela Técnica Superior De Ingeniería Y Sistemas De Telecomunicación
<b>Academic year</b>	2024-25

## 2. Faculty

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### 2.1. Faculty members with subject teaching role

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

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### 3.1. Recommended (passed) subjects

- Network Architecture And Protocols

### 3.2. Other recommended learning outcomes

- Operation of RF instrumentation
- Management of technical information
- Programming in MATLAB

## 4. Skills and learning outcomes \*

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### 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/ Students have demonstrated knowledge and understanding providing the groundwork or opportunity for innovation in developing and/or applying ideas, often within a research context

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/Students are capable of applying their knowledge, understanding, and problem-solving abilities in new or unfamiliar environments within broader (or multidisciplinary) contexts related to their field of study

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/Students are capable of integrating knowledge and making complex decisions, which, although based on incomplete or limited information, require reflection on social and ethical responsibilities linked to the application of their knowledge and opinions

CEM03 - Analizar y diseñar la arquitectura, servicios y protocolos de la red de acceso radio de un sistema de comunicaciones móviles 4G y 5G / Analyze and design the architecture, services, and protocols of the radio access

network in a 4G or 5G mobile communication system.

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. / Understand the procedure, value, and limits of the scientific method, being able to identify, locate and obtain data required in a research work, to design and guide analytical, modeling, and experimental investigations, as well as to critically evaluate data and extract conclusions.

CGI03 - Valorar la importancia de las fuentes documentales, manejarlas y buscar la información para el desarrollo de cualquier trabajo de investigación. / Assess the importance of documentary sources, manage them and search for information for the development of any research work.

CGI04 - Leer y comprender publicaciones dentro de su ámbito de estudio/investigación, así como su catalogación y valor científico. / Read and understand publications within their field of study / research, as well as their cataloging and scientific value.

UPM1 - Uso de la lengua inglesa / Use of the English language

UPM4 - Organización y planificación / Planning and organization

UPM5 - Gestión de la Información / Information management

## 4.2. Learning outcomes

RA7 - Aplicar el conocimiento adquirido a la solución de problemas cualitativos y cuantitativos relacionados con las comunicaciones móviles personales/ Apply the knowledge acquired to the solution of qualitative and quantitative problems related to personal mobile communications

RA8 - Identificar el impacto social y económico de las comunicaciones móviles en un contexto global/ Identify the social and economic impact of mobile communications in a global context.

RA3 - Elegir los métodos y herramientas matemáticas necesarios para abordar la solución de un problema/ Choose the mathematical methods and tools necessary to tackle the solution of a problem

RA2 - Aplicar el conocimiento adquirido a la comprensión de problemas cualitativos y cuantitativos relacionados con la codificación fuente y la codificación de canal/ Apply the knowledge acquired to the understanding of qualitative and quantitative problems related to source coding and channel coding

RA15 - Diseñar y desarrollar los componentes de una red de comunicaciones móviles y sus protocolos a partir de especificaciones técnicas/ Design and develop the components of a mobile communications network and its protocols based on technical specifications

RA5 - Interpretar los datos derivados de observaciones empíricas y mediciones en términos de su importancia y relacionarlos con la teoría apropiada/ Interpret data derived from empirical observations and measurements in terms of their importance and relate them to the appropriate theory

\* 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

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### 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	<p><b>T1. LTE and 5G overview</b> Duration: 02:00</p> <p><b>T2. Architecture of the Radio Access Network</b> Duration: 04:00</p>	<p><b>T2. Architecture of the Radio Access Network</b> Duration: 02:00</p>		<p><b>T1-T2. LTE and 5G overview</b> Progressive assessment and Global Examination Not Presential Duration: 01:00</p> <p><b>T2. Architecture of the Radio Access Network</b> Progressive assessment and Global Examination Not Presential Duration: 02:00</p>
2	<p><b>T3. PHY transmission structure</b> Duration: 08:00</p>			
3	<p><b>T4. PHY signal processing: modulation and channel coding</b> Duration: 04:00</p>	<p><b>T3. PHY transmission structure</b> Duration: 04:00</p>		<p><b>T3. PHY transmission structure</b> Progressive assessment and Global Examination Presential Duration: 02:00</p>
4	<p><b>T5. PHY signal processing: multi-antenna transmission</b> Duration: 04:00</p>	<p><b>T4. PHY signal processing: modulation and channel coding</b> Duration: 04:00</p>		<p><b>T4. PHY signal processing: modulation and channel coding</b> Progressive assessment and Global Examination Presential Duration: 02:00</p>
5	<p><b>T5. PHY signal processing: multi-antenna transmission</b> Duration: 02:00</p> <p><b>T6. Air Interface L1</b> Duration: 02:00</p>	<p><b>T5. PHY signal processing: multi-antenna transmission</b> Duration: 02:00</p> <p><b>T6. Air Interface L1</b> Duration: 02:00</p>		<p><b>T5. PHY signal processing: multi-antenna transmission</b> Progressive assessment and Global Examination Presential Duration: 02:00</p> <p><b>T6. Air Interface L1</b> Progressive assessment and Global Examination Presential Duration: 02:00</p>

6	<p><b>T7. Cell Acquisition</b> Duration: 02:00</p> <p><b>T8. Link Adaptation</b> Duration: 02:00</p> <p><b>T9. Mm-wave for wireless communications</b> Duration: 04:00</p>			<p><b>T7-T8. Cell Acquisition and Link Adaptation</b></p> <p>Progressive assessment and Global Examination Not Presential Duration: 01:00</p> <p><b>T9. Mm-wave for wireless communications</b></p> <p>Progressive assessment and Global Examination Presential Duration: 01:00</p>
7	<p><b>T10. Channel sounding</b> Duration: 04:00</p> <p><b>T11. AI-powered radio access networks</b> Duration: 04:00</p>			<p><b>T10. Channel sounding</b></p> <p>Progressive assessment and Global Examination Not Presential Duration: 01:00</p> <p><b>T11. AI-powered radio access networks</b></p> <p>Progressive assessment and Global Examination Not Presential Duration: 01:00</p>
8				
9				
10				
11				
12				
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17				

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		No Presential	01:00	5%	5 / 10	UPM4 CEM03 UPM1 UPM5
1	T2. Architecture of the Radio Access Network		No Presential	02:00	15%	5 / 10	UPM1 UPM5 CGI03 CEM03 CB7
3	T3. PHY transmission structure		Face-to-face	02:00	15%	5 / 10	UPM1 UPM5 CGI03 CEM03 CB7
4	T4. PHY signal processing: modulation and channel coding		Face-to-face	02:00	15%	5 / 10	UPM1 UPM5 CGI03 CEM03 CB6 CB7 CGI02
5	T5. PHY signal processing: multi-antenna transmission		Face-to-face	02:00	15%	5 / 10	UPM1 CGI03 CB8 UPM4 CEM03
5	T6. Air Interface L1		Face-to-face	02:00	15%	5 / 10	UPM1 UPM5 CGI03 UPM4 CEM03 CGI04
6	T7-T8. Cell Acquisition and Link Adaptation		No Presential	01:00	5%	5 / 10	UPM1 UPM5 CB8 CGI02

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

### 7.1.2. Global examination

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

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

### 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

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### 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, <a href="http://www.3gpp.org/">http://www.3gpp.org/</a>
The 3G4G Blog	Web resource	<a href="https://blog.3g4g.co.uk">https://blog.3g4g.co.uk</a>
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