

**Course ID and Title:** EE 635 Advanced Wireless Communication: towards 6G

**Units:** 4

**Term—Day—Time:** Fall 2023 — 110mins twice weekly

**Location:** TBD

**Instructor:** A. F. Molisch

**Office:** EEB 530

**Office Hours:** TBD

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**Teaching Assistant:**

**Office:** TBD or NA

**Office Hours:** TBD

**Contact Info:** TBD

### Catalogue Description

Transmission techniques for 6G systems, including massive MIMO, cell-free (distributed) systems, new modulation and multiple-access methods, stochastic geometry, mmWave and THz transmission techniques, precision localization.

### Course Description

This course is intended for PhD and advanced MS students. The course will describe the scientific fundamentals of cutting-edge technology that underlies 5G or will underly 6G communication systems. Students will learn about such physical-layer techniques as cell-free massive MIMO, mmWave and THz communications, and joint communication and sensing. They will also learn to apply advanced mathematical analysis and design techniques such as machine learning and stochastic geometry, and become aware of the crosslayer design problems involved in mobile edge computing and augmented information services. The course will also present the state of the art in 5G standardization and an outlook of what 6G standards will likely include.

### Learning Objectives

By the end of this course, students will

- be able to create an example design and analysis of a (simplified) 5/6G system incorporating advanced techniques such as cell-free massive MIMO, non-orthogonal multiple access, and integrated sensing and communication.
- will demonstrate knowledge of the 5G NR standard as well as the most recent WiFi standard, and will be able to approximate the functionality of the key standard elements.
- will be able to describe quantitatively the interplay between physical and MAC layer in an advanced system and design systems to exploit such crosslayer relationships.

**Prerequisite(s):** EE 535

**Co-Requisite(s):** N/A

**Concurrent Enrollment:** N/A

**Recommended Preparation:** MATLAB coding on the level of EE 503, or 510. Knowledge of Python is beneficial.

## Course Notes

The course will use a combination of an available textbook by the instructor (see “required readings”) and instructor-written notes that provide updates and emphasize current developments. Presentation slides (PPT) will be used in some of the lectures, and made available to the students in electronic form. Piazza will be used for making supplementary material available.

## Technological Proficiency and Hardware/Software Required

Course will be streamed on Zoom for students who cannot attend in person. Computer with MATLAB required for homework and projects.

## Required Readings and Supplementary Materials

Textbook: A. F. Molisch, *Wireless Communications – From Fundamentals to Beyond 5G*, 3<sup>rd</sup> edition, IEEE Press – Wiley. ISBN-10 : 1119117208. Available from the publisher, Amazon, and the USC bookstore. Additional instructor-written handouts as needed.

## Optional Readings and Supplementary Materials

Peer-reviewed survey papers will be recommended as supplementary material as applicable.

## Description of Assignments and How They Will Be Assessed

- 1) Reading assignments: students are required to read specific sections in the textbook *before* each lecture, to enable a teaching style somewhat similar to a “flipped classroom”, i.e., concentrating on the intuitive understanding of the material, computational problems, etc., instead of derivations of equations.
- 2) Weekly homeworks will be assigned, falling mainly into three categories
  - a. Computational exercises related to the specific chapters treated during the past instruction week.
  - b. Computational exercises requiring a “big picture” approach, using material from different lectures throughout the semester
  - c. MATLAB simulations to be written by the students to cover more realistic scenarios for which closed-form equations often do not exist.
- 3) Midterm exam and final project. The final project is a group project. In rare cases, at the discretion of the instructor, the final project will be replaced by a final exam. Such a change will be announced no later than at the end of week 7.

## Participation

Credit for participation can be obtained either by active participation in the classes (answering questions by the instructor, etc.), or by giving a brief presentation about an assigned topic. Time for the presentation will be during lecture time, with at least two weeks between assignment of the topic and the actual presentation. Duration of the presentation 10-15 minutes. Topic will be selected by the instructor, as a detailed aspects of one of the general areas covered in the syllabus.

## Grading Breakdown

Assessment Tool (assignments)	% of Grade
Homework (10 × 3%)	30
Participation	5
Midterm exam	25
Final project (may be replaced by an exam at the discretion of the instructor; if applicable will be announced by the end of week 7)	40
<b>TOTAL</b>	<b>100</b>

## Assignment Submission Policy

Submissions of assignment to be done electronically to the instructor (or TA, if applicable).

## Course-Specific Policies

- **Late Policy:** No late homework will be accepted. A late assignment results in a zero grade. To accommodate personal emergencies, two homeworks (out of the 10 given) can be dropped without loss of point (i.e., the top 8 homeworks count for the grade).
- **Make-up Exams:** No make-up exams will be given. If you cannot make the exam dates due to a class conflict, you must notify me by the last day to add/drop a course. If I cannot accommodate your schedule, you must drop the class. In the case of a required business trip or a medical emergency, a signed letter from your manager or doctor is required. This letter must include the telephone number of your doctor or supervisor. However, remote taking of the exam might be accommodated at the instructor's discretion if sufficient (1 day) advance notification is given,
- **Grade Adjustment:** If you dispute any scoring of a problem on an exam or homework set, you have one week from the date that the graded paper is returned to request a change in the grade. After this time, no further alterations will be considered. All requests for a change in grade must be submitted in writing to me.
- **Illness/Covid policy:** when you are sick, or you have been exposed to Covid, please be considerate of others and **do not come to class in person**. You can follow the class remotely on DEN either live or later on.
- **Changes/Information:** The student is responsible for all assignments, changes of assignments, announcements, lecture notes etc. All such changes should be posted on the course web-site.
- **Other:** As per university guidelines published in Student Handbook Student Handbook [<https://policy.usc.edu/studenthandbook/>], the academic conduct policy will be upheld. Every homework has to contain a cover sheet in which collaborations and auxiliary material are declared. False declarations are a violation of academic integrity.

## Attendance

Attendance of the class is recommended, but exemptions apply for health reasons. Absence for other reasons should be accorded with the instructor. The class will be streamed on Zoom. Students who cannot attend the live session should listen to the recordings of the lecture..

## Academic Integrity

Unless otherwise noted, this course will follow the expectations for academic integrity as stated in the [USC Student Handbook](#). The general USC guidelines on Academic Integrity and Course Content Distribution are provided in the subsequent "Statement on Academic Conduct and Support Systems" section.

For this class, the homework and midterm exam, you are expected to submit work that demonstrates your individual mastery of the course concepts. This also applies to the final exam if given as regular exam. In the final project, you will be expected to cooperate in a group.

Plagiarism is strictly prohibited. All sources for used information (excluding the assigned textbook and instructor-issued material) must be explicitly mentioned with complete referencing. Plagiarism includes the submission of text, computational solutions, or code written by, or otherwise obtained from someone else.

If found responsible for an academic violation, students may be assigned university outcomes, such as suspension or expulsion from the university, and grade penalties, such as an “F” grade on the assignment, exam, and/or in the course.

Please ask the instructor if you are unsure about what constitutes unauthorized assistance on an exam or assignment, or what information requires citation and/or attribution.

You may not record this class without the express permission of the instructor and all other students in the class. Distribution of any notes, recordings, exams, or other materials from a university class or lectures — other than for individual or class group study — is prohibited without the express permission of the instructor.

***Use of Generative AI in this Course***

**Generative AI is not permitted:** Since creating, analytical, and critical thinking skills are part of the learning outcomes of this course, all assignments should be prepared by the student working individually or in groups as described on each assignment. Students may not have another person or entity complete any portion of the assignment. Developing strong competencies in these areas will prepare you for a competitive workplace. Therefore, using AI-generated tools is prohibited in this course, will be identified as plagiarism, and will be reported to the Office of Academic Integrity.

## Course Evaluations

A course evaluation will occur at the end of the semester university-wide. It is an important review of students' experience in the class. The process will follow the university rules, i.e., the students will fill out the evaluation forms in class, with the instructor absent from the classroom

## Course Schedule

	Topics/Daily Activities	Readings/Preparation	Deliverables
Week 1	Summary of key results of EE 535	Review textbook for material from 535	
Week 2	Advanced modulation and coding Generalized OFDM, Multi-carrier OFDM, OTFS Details of turbocodes, LDPC, and polar codes	Chapter 15.10-15.12, 13.6-13.9	HW1 assigned
Week 3	Advanced propagation channels spatial channel generic description, spatial channel models, ultrawideband channels, and mmWave/THz channels	Chapter 6.6—6.7, 7.4-7.9	HW2 assigned
Week 4	Cell planning and ACI computations Advanced reuse schemes; stochastic geometry analysis	Chapter 21.2-21.4	HW3 assigned HW1 due
Week 5	Single-link MIMO systems: Principles of spatial multiplexing, capacity of MIMO systems, BLAST algorithms, space-time coding	Chapter 19	HW4 assigned HW2 due
Week 6	Advanced single-link MIMO Spatial Modulation, MIMO with low-resolution ADC, RIS, holographic MIMO, OAM	Chapter 16.2.10-16.2.15 and handouts	HW5 assigned HW3 due
Week 7	Midterm Exam	No reading assignment	Midterm Exam HW5 due

	<b>Topics/Daily Activities</b>	<b>Readings/Preparation</b>	<b>Deliverables</b>
<b>Week 8</b>	<b>Massive MIMO and distributed massive MIMO:</b> uplink, downlink precoding (zero-forcing, regularization, etc massive MIMO distributed massive MIMO	<b>Chapter 22.9-22.11</b>	HW6 assigned HW4 due
<b>Week 9</b>	<b>Routing and scheduling with stochastic optimization and machine learning</b> Scheduling with random data arrival in cellular networks, deterministic routing in ad-hoc networks, stochastic optimization for multi-hop networks, scaling laws for ad-hoc networks, machine learning for scheduling	<b>Chapter 23</b>	HW7 assigned HW6 due
<b>Week 10</b>	<b>Advanced interference processing and NOMA</b> Multi-user detectors, NOMA, interference alignment	<b>Chapter 28</b>	HW8 assigned
<b>Week 11</b>	<b>Localization</b> Principles of TOA ranging, NLOS detection/mitigation, RSSI and fingerprinting, GPS, localization in cellular systems and WiFi, cooperative localization, tracking	<b>Chapter 29</b>	HW9 assigned HW7 due
<b>Week 12</b>	<b>Joint communication and sensing</b> Principles of radar sensing, figure of merit for JCAS, performance bounds, types of JCAS, practical schemes	<b>handouts</b>	HW10 assigned HW8 due

	<b>Topics/Daily Activities</b>	<b>Readings/Preparation</b>	<b>Deliverables</b>
<b>Week 13</b>	<b>Standardization and WiFi</b> Principles of standardization, WiFi 802.11a,n, ac, WiFi 6 (802.11ax)	<b>Chapter 30 and 33</b>	HW11 assigned HW9 due
<b>Week 14</b>	<b>5G systems (1)</b> basic system structure, physical layer, reference signals, logical channels, physical channels, handover	<b>Chapter 32</b>	<b>HW10 due</b>
<b>Week 15</b>	5G systems (2) and Beyond 5G Carrier aggregation, CoMP, relaying, Sidelink, Beyond 5G	<b>Chapter 32+35</b>	<b>HW11 due</b>
<b>FINAL</b>			<b>See main text</b>

## Statement on Academic Conduct and Support Systems

### Academic Integrity:

The University of Southern California is a learning community committed to developing successful scholars and researchers dedicated to the pursuit of knowledge and the dissemination of ideas. Academic misconduct, which includes any act of dishonesty in the production or submission of academic work, comprises the integrity of the person who commits the act and can impugn the perceived integrity of the entire university community. It stands in opposition to the university's mission to research, educate, and contribute productively to our community and the world.

All students are expected to submit assignments that represent their own original work, and that have been prepared specifically for the course or section for which they have been submitted. You may not submit work written by others or "recycle" work prepared for other courses without obtaining written permission from the instructor(s).

Other violations of academic integrity include, but are not limited to, cheating, plagiarism, fabrication (e.g., falsifying data), collusion, knowingly assisting others in acts of academic dishonesty, and any act that gains or is intended to gain an unfair academic advantage.

The impact of academic dishonesty is far-reaching and is considered a serious offense against the university. All incidences of academic misconduct will be reported to the Office of Academic Integrity and could result in outcomes such as failure on the assignment, failure in the course, suspension, or even expulsion from the university.

For more information about academic integrity see [the student handbook](#) or the [Office of Academic Integrity's website](#), and university policies on [Research and Scholarship Misconduct](#).

Please ask your instructor if you are unsure what constitutes unauthorized assistance on an exam or assignment, or what information requires citation and/or attribution.

### Course Content Distribution and Synchronous Session Recordings Policies

USC has policies that prohibit recording and distribution of any synchronous and asynchronous course content outside of the learning environment.

Recording a university class without the express permission of the instructor and announcement to the class, or unless conducted pursuant to an Office of Student Accessibility Services (OSAS) accommodation. Recording can inhibit free discussion in the future, and thus infringe on the academic freedom of other students as well as the instructor. ([Living our Unifying Values: The USC Student Handbook](#), page 13).

Distribution or use of notes, recordings, exams, or other intellectual property, based on university classes or lectures without the express permission of the instructor for purposes other than individual or group study. This includes but is not limited to providing materials for distribution by services publishing course materials. This restriction on unauthorized use also applies to all information, which had been distributed to students or in any way had been displayed for use in relationship to the class, whether obtained in class, via email, on the internet, or via any other media. ([Living our Unifying Values: The USC Student Handbook](#), page 13).

### Students and Disability Accommodations:

USC welcomes students with disabilities into all of the University's educational programs. [The Office of Student Accessibility Services](#) (OSAS) is responsible for the determination of appropriate accommodations for students who encounter disability-related barriers. Once a student has completed the OSAS process (registration, initial appointment, and submitted documentation) and accommodations are determined to be reasonable and appropriate, a Letter of Accommodation (LOA) will be available to generate for each

course. The LOA must be given to each course instructor by the student and followed up with a discussion. This should be done as early in the semester as possible as accommodations are not retroactive. More information can be found at [osas.usc.edu](https://osas.usc.edu). You may contact OSAS at (213) 740-0776 or via email at [osasfrontdesk@usc.edu](mailto:osasfrontdesk@usc.edu).

### **Support Systems:**

#### [Counseling and Mental Health](#) - (213) 740-9355 – 24/7 on call

Free and confidential mental health treatment for students, including short-term psychotherapy, group counseling, stress fitness workshops, and crisis intervention.

#### [988 Suicide and Crisis Lifeline](#) - 988 for both calls and text messages – 24/7 on call

The 988 Suicide and Crisis Lifeline (formerly known as the National Suicide Prevention Lifeline) provides free and confidential emotional support to people in suicidal crisis or emotional distress 24 hours a day, 7 days a week, across the United States. The Lifeline is comprised of a national network of over 200 local crisis centers, combining custom local care and resources with national standards and best practices. The new, shorter phone number makes it easier for people to remember and access mental health crisis services (though the previous 1 (800) 273-8255 number will continue to function indefinitely) and represents a continued commitment to those in crisis.

#### [Relationship and Sexual Violence Prevention Services \(RSVP\)](#) - (213) 740-9355(WELL) – 24/7 on call

Free and confidential therapy services, workshops, and training for situations related to gender- and power-based harm (including sexual assault, intimate partner violence, and stalking).

#### [Office for Equity, Equal Opportunity, and Title IX \(EEO-TIX\)](#) - (213) 740-5086

Information about how to get help or help someone affected by harassment or discrimination, rights of protected classes, reporting options, and additional resources for students, faculty, staff, visitors, and applicants.

#### [Reporting Incidents of Bias or Harassment](#) - (213) 740-5086 or (213) 821-8298

Avenue to report incidents of bias, hate crimes, and microaggressions to the Office for Equity, Equal Opportunity, and Title for appropriate investigation, supportive measures, and response.

#### [The Office of Student Accessibility Services \(OSAS\)](#) - (213) 740-0776

OSAS ensures equal access for students with disabilities through providing academic accommodations and auxiliary aids in accordance with federal laws and university policy.

#### [USC Campus Support and Intervention](#) - (213) 740-0411

Assists students and families in resolving complex personal, financial, and academic issues adversely affecting their success as a student.

#### [Diversity, Equity and Inclusion](#) - (213) 740-2101

Information on events, programs and training, the Provost's Diversity and Inclusion Council, Diversity Liaisons for each academic school, chronology, participation, and various resources for students.

#### [USC Emergency](#) - UPC: (213) 740-4321, HSC: (323) 442-1000 – 24/7 on call

Emergency assistance and avenue to report a crime. Latest updates regarding safety, including ways in which instruction will be continued if an officially declared emergency makes travel to campus infeasible.

#### [USC Department of Public Safety](#) - UPC: (213) 740-6000, HSC: (323) 442-1200 – 24/7 on call

Non-emergency assistance or information.

#### [Office of the Ombuds](#) - (213) 821-9556 (UPC) / (323-442-0382 (HSC)

A safe and confidential place to share your USC-related issues with a University Ombuds who will work with you to explore options or paths to manage your concern.

[Occupational Therapy Faculty Practice](#) - (323) 442-2850 or [otfp@med.usc.edu](mailto:otfp@med.usc.edu)

Confidential Lifestyle Redesign services for USC students to support health promoting habits and routines that enhance quality of life and academic performance.