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## **EE 535 – Wireless communications**

**Units: 4 (3+1)**

**Term—Day—Time: Spring, Mo, We, time TBD**

### IMPORTANT:

The general formula for contact hours is as follows:

**Courses must meet for a minimum of one 50 minute session per unit per week over a fifteen-week semester. Standard fall and spring sessions require a final summative experience during the University scheduled final exam day and time.**

(Please refer to the *Contact Hours Reference*, located at [arr.usc.edu/services/curriculum/resources.html](http://arr.usc.edu/services/curriculum/resources.html).)

**Location: TBD**

**Instructor: Andreas F. Molisch**

**Office:** EEB 530

**Office Hours:** Mo, We, 5pm-6h30 pm

**Contact Info:** 213 740 4670, [molisch@usc.edu](mailto:molisch@usc.edu). Emails and phone messages will be typically answered within 48 hours, but no later than by the next office hours.

**Teaching Assistant: TBD**

**Office:** Physical or virtual address

**Office Hours:**

**Contact Info:** Email, phone number (office, cell), Skype, etc.

## Course Description

This course provides the basics for the design and analysis of wireless communications systems. It covers aspects ranging from the wireless propagation channel, digital communications theory, coding, to multiple access methods, frequency planning, and wireless standards. The course not only provides the individual pieces for understanding and designing such systems, but also stresses a holistic system view and shows how the different pieces are connected. The ultimate goal of this course is to give students the ability to take a practically occurring problem (e.g., provide a given number of users, with a prescribed reliability with a data rate of  $x$  Mbit/s), recognize the different challenges to achieve the desired results, and design and analyze systems that meet the performance goals.

## Learning Objectives

The aim is to provide students with the fundamental knowledge for a career in companies producing wireless infrastructure, cellphones, Internet-of-Things devices, wireless healthcare, etc. The course not only provides the individual pieces for understanding and designing such systems, but also stresses a holistic system view and shows how the different pieces are connected. In particular students shall learn: (i) basic properties of wireless propagation channels, such as fading, delay dispersion, Doppler spread; (ii) learn the basics of digital communications systems such as modulation format, signal space diagram, BER analysis and how they apply specifically to wireless systems, (iii) methods to overcome the challenges of wireless channels such as diversity, equalizers, and coding, (iv) multiple-access and multi-cell methods, i.e., ability of multiple devices to access infrastructure simultaneously, (v) analysis of current wireless standards, in particular 5G, (vi) survey of cutting edge wireless technology for 5G and 6G, such as millimeter-wave systems, high-speed fixed wireless access, generalized OFDM, and NOMA.

**Prerequisite(s):** EE 503, EE 510

**Co-Requisite(s):** EE 511

**Concurrent Enrollment:** N/A

**Recommended Preparation:** basic electromagnetic theory, digital communications systems.

## Course registration

The nominal course credit given in the schedule of classes is 3.0 Participants of the course should register also for a 1 unit Directed Research EE 590 under supervision of Prof. Molisch, at [myviterbi.usc.edu](http://myviterbi.usc.edu). In the description box they can indicate "additional unit for EE 535"; they will then be given D clearance so they can register.

Students will receive 3 units of graded course work and 1 unit of non-graded course work, since EE 590 is graded CR/NC. That means a student will NOT receive 4 units of A. If they receive a C or better in EE 535, they will get a CR (Credit) in EE 590. If a student gets a C- or below in EE 535, they will receive NC (no credit) in EE 590. Students having issues with registering for a DR unit should consult a student advisor for a possible exception. However, the work required for EE 535 will correspond to a 4-unit course irrespective of whether DR is registered or not.

## Course Notes

The course will use a combination of an available textbook (by the instructor) and instructor-written notes to provide updates and emphasize current developments. Presentation slides (PPT) will be used in some of the lectures, and made available to the students.

## Technological Proficiency and Hardware/Software Required

MATLAB required for some exercises.

## Required Readings and Supplementary Materials

**Mandatory reading:** chapters/sections from

A. F. Molisch, *Wireless Communications*, 2<sup>nd</sup> ed., Wiley – IEEE Press.

Available at USC Bookstore, Amazon, from the publisher

Additional instructor-written handouts as needed.

**Additional reading material:**

1. S. Benedetto & E. Biglieri, *Principles of Digital Transmission - With Wireless Applications*, Kluwer Academic Publishers, Amsterdam 1999.

2. D. Tse and P. Viswanath, *Fundamentals of Wireless Communication*, Cambridge University Press, 2005.

3. Andrea Goldsmith, *Wireless Communications*, Cambridge University Press, 2005.

## Description and Assessment of Assignments

- 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) Midterms and finals

## Grading Breakdown

Including the above detailed assignments, how will students be graded overall? Participation should be no more than 15%, unless justified for a higher amount. All must total 100%.

Assignment	Points	% of Grade
Homework (10x3 %)		30
Participation/questions on reading assignments		5
Midterms		25
Finals		40
<b>TOTAL</b>	<b>0</b>	<b>100</b>

## Grading Scale (Example)

Course final grades will be determined by grading on a curve

## Assignment Rubrics

Include assignment rubrics to be used, if any.

## Assignment Submission Policy

- **Late Policy:** No late homework will be accepted. A late assignment results in a zero 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.
- **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.
- **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 SCampus, the academic conduct policy will be upheld. You are required to study <http://ee.usc.edu/sacss/> and the material linked there. Every homework has to contain a cover sheet in which collaborations and auxiliary material are declared. False declarations are a violation of academic integrity.

### **Grading Timeline**

Homework will be corrected within 1 week of submission and returned to the students. Results can be discussed during the office hours with the TA or instructor.

### **Additional Policies**

Students are required to read the assigned chapters before class.

## Course Schedule: A Weekly Breakdown

Provide a detailed course calendar that provides a thorough list of deliverables—readings, assignments, examinations, etc., broken down on at least a weekly basis. The format may vary, but the content must include:

- Subject matter (topic) or activity
- Required preparatory reading, or other assignments (i.e., viewing videos) for each class session, including page numbers.
- Assignments or deliverables.

### IMPORTANT:

In addition to in-class contact hours, all courses must also meet a minimum standard for out-of-class time, which accounts for time students spend on homework, readings, writing, and other academic activities. **For each unit of in-class contact time, the university expects two hours of out of class student work per week over a semester.**

(Please refer to the *Contact Hours Reference* at [arr.usc.edu/services/curriculum/resources.html](http://arr.usc.edu/services/curriculum/resources.html).)

	<b>Topics/Daily Activities</b>	<b>Readings and Homework</b>	<b>Deliverable/ Due Dates</b>
<b>Week 1</b>	Fundamental system requirements and challenges	<b>Readings: Chapters 1,2, handouts for modern (5G) requirements</b>	
<b>Week 2</b>	<b>Fundamental propagation effects. Link budgets</b>	Readings: Chapter 3,4 Homework1: computational exercises including MATLAB (henceforth CEM)	Solved homeworks: beginning of Week 4 (henceforth written as BW4)
<b>Week 3</b>	Basics of digital signal processing and modulation formats	Readings: Chapter 11 Homework 2: CEM	<b>Solved homeworks: BW5</b>
<b>Week 4</b>	<b>Demodulation, signal space diagram Hardware structure of digital transceivers and impact on system performance</b>	Readings: Chapter 12.1-12.2; handouts on hardware structure Homework 3: CEM	<b>Solved homeworks: BW6</b>
<b>Week 5</b>	<b>Fading, time variations in mobile and FWA systems, shadowing</b>	<b>Reading: Chapter 5, handouts on FWA systems Homework 4: CEM</b>	Solve homeworks: BW 7
<b>Week 6</b>	<b>BER in fading channels Delay dispersion, equalizers</b>	<b>Reading: Chapter 12.2, Chapter 6.1-6.3, 12.3, 16 Homework 5: CEM</b>	Solve homeworks: BW 8
<b>Week 7</b>	<b>OFDM Midterms</b>	Reading: Chapter 19 No homework	<b>Midterms</b>
<b>Week 8</b>	<b>Diversity</b>	Reading: Chapter 13 Homework 6: CEM	<b>Solve homework: BW10</b>
<b>Week 9</b>	<b>Antenna arrays, MIMO</b>	Reading: Chapter 20 Homework 7: CEM	<b>Solve homework: BW11</b>
<b>Week 10</b>	<b>Multiple access and multi-cell Information theory for wireless</b>	Reading: Chapter 17. handouts Homework 8: CEM	<b>Solve homework: BW12</b>

Week 11	Scheduling for speech, data, and video streaming	Reading: handouts Homework 9: CEM	Solve homework: BW13
Week 12	CDMA, multiuser detection, and NOMA	Reading: chapter 18 and handouts Homework 10: CEM	Solve homework: BW14
Week 13	SDMA and massive MIMO	Reading: Chapter 20.3 and handouts Project (in groups): programming in MATLAB of small wireless system	Project: due end of week 15
Week 14	LTE	Reading: chapter 28 and handouts	
Week 15	5G systems	Reading: handouts	
FINAL			Date: For the date and time of the final for this class, consult the USC <i>Schedule of Classes</i> at <a href="http://www.usc.edu/soc">www.usc.edu/soc</a> .

### Statement on Academic Conduct and Support Systems

#### Academic Conduct:

Plagiarism – presenting someone else’s ideas as your own, either verbatim or recast in your own words – is a serious academic offense with serious consequences. Please familiarize yourself with the discussion of plagiarism in *SCampus* in Part B, Section 11, “Behavior Violating University Standards” <https://policy.usc.edu/scampus-part-b/>. Other forms of academic dishonesty are equally unacceptable. See additional information in *SCampus* and university policies on scientific misconduct, <http://policy.usc.edu/scientific-misconduct>.

#### Support Systems:

*Student Counseling Services (SCS)* - (213) 740-7711 – 24/7 on call

Free and confidential mental health treatment for students, including short-term psychotherapy, group counseling, stress fitness workshops, and crisis intervention. <https://engemannshc.usc.edu/counseling/>

*National Suicide Prevention Lifeline* - 1-800-273-8255

Provides free and confidential emotional support to people in suicidal crisis or emotional distress 24 hours a day, 7 days a week. <http://www.suicidepreventionlifeline.org>

*Relationship and Sexual Violence Prevention Services (RSVP)* - (213) 740-4900 - 24/7 on call

Free and confidential therapy services, workshops, and training for situations related to gender-based harm. <https://engemannshc.usc.edu/rsvp/>

*Sexual Assault Resource Center*

For more information about how to get help or help a survivor, rights, reporting options, and additional resources, visit the website: <http://sarc.usc.edu/>

*Office of Equity and Diversity (OED)/Title IX Compliance* – (213) 740-5086

Works with faculty, staff, visitors, applicants, and students around issues of protected class. <https://equity.usc.edu/>

*Bias Assessment Response and Support*

Incidents of bias, hate crimes and microaggressions need to be reported allowing for appropriate investigation and response. <https://studentaffairs.usc.edu/bias-assessment-response-support/>

*The Office of Disability Services and Programs*

Provides certification for students with disabilities and helps arrange relevant accommodations. <http://dsp.usc.edu>

*Student Support and Advocacy – (213) 821-4710*

Assists students and families in resolving complex issues adversely affecting their success as a student EX: personal, financial, and academic. <https://studentaffairs.usc.edu/ssa/>

*Diversity at USC*

Information on events, programs and training, the Diversity Task Force (including representatives for each school), chronology, participation, and various resources for students. <https://diversity.usc.edu/>

*USC Emergency Information*

Provides safety and other updates, including ways in which instruction will be continued if an officially declared emergency makes travel to campus infeasible, <http://emergency.usc.edu>

*USC Department of Public Safety – 213-740-4321 (UPC) and 323-442-1000 (HSC) for 24-hour emergency assistance or to report a crime.*

Provides overall safety to USC community. <http://dps.usc.edu>