Syllabus

EE 471C / EE 381K-17 Wireless Communications Laboratory

Lecture: Mondays & Wednesdays 9:00-10:15am EER 1.512

Lab Sections (unique number 16830/16870): Thursday 6:30pm – 9:30pm EER 1.810
Lab Sections (unique number 16825/16865): Friday 9:00am – 12:00pm EER 1.810

Course URL: http://www.profheath.org/teaching/ee-371c-ee-381v-wireless-communications-lab/

Instructor Information
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Teaching Assistant Information
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Prerequisites for EE 471C (strictly enforced)
EE 445S Real-Time Digital Signal Processing or EE 351M Digital Signal processing or EE 360K Intro to Digital Communications. * Note: there are no pre-requisites for EE 381K-17, the graduate version. It is suggested though that you have the equivalent of one of the above courses.

Reading Materials
Required reading will be from the instructor’s textbook R. W. Heath, Jr., Introduction to Wireless Digital Communication: A Signal Processing Perspective, Pearson Education, Inc. 2017 and supplemented by online sources. Note that all chapters include many examples, which are taken from past homework and exam problems for practice.

Electronic Course Site
Handouts, grading, announcements, and communication via email will be performed using Canvas http://canvas.utexas.edu. You should be able to log in if you have a valid UT ID and are registered for this class. You will be responsible for checking canvas and your email for notifications about assignments.
Course Introduction
Wireless communication is fundamentally the art of communicating information without wires. In principle, wireless communication encompasses any number of techniques including underwater acoustic communication, semaphores, smoke signals, radio communication, and satellite communication, among others. The term was coined in the early days of radio, fell out of fashion for about fifty years, and was rediscovered during the cellular telephony revolution. Wireless now implies communication using electromagnetic waves -- placing it squarely within the domain of electrical engineering. This brings us to the course at hand.

Wireless communication techniques can be classified as either analog or digital. The first commercial systems were analog including AM radio, FM radio, television, and first generation cellular systems. Analog communication is rapidly being replaced with digital communication. The fundamental difference between the two is that in digital communication, the source is assumed to be digital. Every modern wireless system being developed and deployed is built around digital communication including cellular communication, wireless local area networking, personal area networking, and high-definition television. Thus the spotlight of this class will focus on digital wireless communication.

This class approaches wireless communication from the perspective of digital signal processing (DSP). No background in digital communication is assumed, though it would be helpful. The utility of a DSP approach is due to the following fact: wireless systems are bandlimited. This means that with a high enough sampling rate, thanks to Nyquist’s theorem, we can represent the bandlimited continuous-time wireless channel from its samples. This allows us to treat the transmitted signal as a discrete-time sequence, the channel as a discrete-time linear time-invariant system, and the received signal as a discrete-time sequence.

In this class we take an experimental approach to wireless digital communication. We will use a well-known software defined radio platform known as the USRP (universal software radio peripheral) where the radio can be programmed software (in this case LabVIEW) instead of implemented using hardware. The focus will be on the design, implementation, evaluation, and iterative optimization of a digital wireless communication link. A three-hour laboratory period will complement the usual three-hour lecture period each week.

At the end of this class, you will have constructed your own wireless communication link. In this process, you will have achieved the following learning objectives. You should be able to describe the design challenges associated with building a wireless digital communication link. You should be able to define and calculate bit error rates for some common modulation schemes. You should know the difference between binary phase shift keying and quadrature phase shift keying as well as how to implement them. You should understand the connection between pulse-shaping and sampling. You should know how to define excess bandwidth for a raised-cosine pulse. You should understand how to obtain a sampled channel impulse response from a continuous time propagation channel. You should understand how to train and estimate the coefficients of a frequency selective channel. You should understand the various kinds of synchronization required and how to compensate for different sources of asynchronicity. You should be able to explain how to perform equalization using single carrier frequency domain equalization or OFDM modulation. You should be able to justify the use of either zero padding...
or a cyclic prefix to enable frequency domain equalization. You should be able to perform channel estimation and synchronization in an OFDM receiver. You should be able to explain the key features of the IEEE 802.11 and 4G cellular physical layers to enable channel estimation, equalization, and synchronization. You should be able to define two different modes of operation in a MIMO communication system and explain the difficulty of equalization in fading channels. You should be able to define small-scale fading and large-scale fading. You should be able to calculate the coherence time and coherence bandwidth of a channel. You should be able to create and understand a basic link budget including both small-scale and large-scale fading. You should understand the principle of frequency reuse in cellular systems and be able to calculate the signal-to-interference-plus-noise ratio. You should be able to implement everything you learn on our software defined radio platform.

EE 381K-17 Graduate Course Only: Part of the final grade for this course will consist of a final term project, due at the end of the course. There are two possible term projects, which you can choose based on your interests. The first and default option is based on implementation and simulation that goes beyond what is done in the lab. If you choose the research option, you must consult with Prof. Heath during the selection of your project topic by October 15. You are also encouraged to consult your research advisor (if you have one).

(1) IEEE 802.11ad system implementation (default and recommended option) You will implement key features of the IEEE 802.11ad physical layer and demonstrate it using the USRP hardware in the lab. In particular, you will create a frame format based on the IEEE 802.11ad control PHY including the short training field, channel estimation field, and an uncoded data field using p/2-BPSK single carrier modulation and 32x spreading. You will use this waveform and demonstrate how it is used for time and frequency synchronization as well as channel estimation. Your code will be evaluated by applying it to different types of channel impairments and seeing if it meets the guidelines.

(2) Research Paper Here the final deliverable is a research paper in the format of a journal or conference paper. This project should contain some element of innovation, even if it is small or incremental. The paper will be graded as a conference or journal paper. You will be able to choose the format that suits your project and I will grade accordingly. Final project report must be written in LaTeX. Possible topics include synchronization, implementation architectures, distributed antenna systems, small cells, MIMO, millimeter wave cellular, massive MIMO, beamforming, etc.

(3) Special Implementation Project Here the final deliverable is subject to discussion with Professor Heath. You must discuss and get approval to select this option by October 31. One idea is to create an evaluation framework to help with the IEEE 802.11ad system implementation as described above. For example, to create code for generating the transmit signal and for evaluating student code under different impairments. Another idea is to create an additional lab for the course manual that goes beyond what we cover in the class. For example, you could make a lab on MIMO communication, spread spectrum, or radar signal processing. The deliverable here is a draft of the lab and the code.
Outline of Experiments

- Introduction to the USRP (universal software radio peripheral)
- Baseband QAM modulation
- Baseband QAM demodulation
- Channel estimation
- Synchronization
- Frequency offset estimation and correction
- OFDM modulator and demodulator
- OFDM synchronization, frequency offset, and channel estimation

Course Organization

The course consists of two lectures per week and a single laboratory session. The lecture will cover the theory of wireless communication to prepare you for implementation in the lab. Lectures will be supplemented by assignments including theory, preparation for the lab, and observations from past labs.

Technical Area Fulfillment (EE 471C)

This course counts as one of the required lab courses in the Communications, Signal Processing, Networks and Systems technical core, and also as an elective. Consult your academic advisor to see if it can count as a technical elective in other technical cores.

Course Policies

Homeworks – Homework assignments will be due at 7pm on Gradescope on Wednesdays. The homework includes preparation for the lab, questions to test your knowledge of the theory, and questions to help synthesize what was observed in past labs. You may work with other students on the other portions of the homework but you must turn in your own work. Copying another group’s code (including making small changes to avoid it looking like a copy) is considered cheating and appropriate action will be taken. Use of online materials, without acknowledgement, will be considered cheating and appropriate action will be taken. Please refer to the Academic Dishonesty Policy listed below.

Labs – You must attend your lab session unless you have prior approval for that week. For every lab, you must answer the in-lab questions and turn in your answers to the TA. You must also upload your code for the lab that week on canvas by Friday at 1pm. You and your partner can upload the same code. You must arrive to the lab on time but you may leave once you have finished your work.

Due dates and late policy – Because successful completion of the homework is critical for participating in the lab, no late homeworks will be accepted. Note that the lowest homework grade will be dropped at the end of the semester prior to grade calculation.

Exams - There will be two midterm exams and a final exam based on the lecture and the lab.
Participation – Attendance in the laboratory session is mandatory. Attendance in the lecture is at your discretion but highly encouraged. Questions and discussion in class are encouraged. Participation will be noted. Please raise your hand if you would like to respond to a question.

Evaluations - Course and instructor evaluations will tentatively occur late November.

Messaging - Receiving and placing cellular calls during class is prohibited. Interactive text messaging, checking email, etc. is distracting and discouraged.

Grading – This course is cross-listed as both an undergraduate and a graduate course. The graduate course requires a different project. Graduate and undergraduate students are graded differently to maintain fairness. Grades are assigned using the typical cutoffs of 94% for A, 90% for A-, etc. Grades may be curved at the end of the semester in your favor.

Grading EE 471C Undergraduate Course
- 30% Homework
- 30% Lab
- 10% x2 Each midterm exam
- 20% Final exam

Grading EE 381V Graduate Course
- 25% Homework
- 20% Lab
- 10% Each midterm exam
- 20% Final exam
- 15% Final project

Academic Dishonesty
Faculty in the ECE Department are committed to detecting and responding to all instances of scholastic dishonesty and will pursue cases of scholastic dishonesty in accordance with university policy. Scholastic dishonesty, in all its forms, is a blight on our entire academic community. All parties in our community -- faculty, staff, and students -- are responsible for creating an environment that educates outstanding engineers, and this goal entails excellence in technical skills, self-giving citizenship, and ethical integrity. Industry wants engineers who are competent and fully trustworthy, and both qualities must be developed day by day throughout an entire lifetime. Scholastic dishonesty includes, but is not limited to, cheating, plagiarism, copying, collusion, falsifying academic records, or any act designed to give an unfair academic advantage to the student. The fact that you are in this class as an engineering student is testament to your abilities. Penalties for scholastic dishonesty are severe and can include, but are not limited to, a written reprimand, a zero on the assignment/exam, re-taking the exam in question, an F in the course, or expulsion from the University. Don’t jeopardize your career by an act of scholastic dishonesty. Details about academic integrity and what constitutes scholastic dishonesty can be found at the website for the UT Dean of Students Office and the General Information Catalog, Section 11-802. Note: Copying in any form is considered cheating, whether from another student or the solution manual.
Student Rights & Responsibilities

- You have a right to a learning environment that supports mental and physical wellness.
- You have a right to respect.
- You have a right to be assessed and graded fairly.
- You have a right to freedom of opinion and expression.
- You have a right to privacy and confidentiality.
- You have a right to meaningful and equal participation, to self-organize groups to improve your learning environment.
- You have a right to learn in an environment that is welcoming to all people. No student shall be isolated, excluded or diminished in any way.

With these rights come responsibilities:

- You are responsible for taking care of yourself, managing your time, and communicating with the teaching team and with others if things start to feel out of control or overwhelming.
- You are responsible for acting in a way that is worthy of respect and always respectful of others.
- Your experience with this course is directly related to the quality of the energy that you bring to it, and your energy shapes the quality of your peers’ experiences.
- You are responsible for creating an inclusive environment and for speaking up when someone is excluded.
- You are responsible for holding yourself accountable to these standards, holding each other to these standards, and holding the teaching team accountable as well.

Personal Pronoun Preference

Professional courtesy and sensitivity are especially important with respect to individuals and topics dealing with differences of race, culture, religion, politics, sexual orientation, gender, gender variance, and nationalities. Class rosters are provided to the instructor with the student’s legal name. I will gladly honor your request to address you by a name different than what appears on the roster, and by the gender pronouns you use. Please advise me of this preference early in the semester so that I may make appropriate changes to my records.

University Policies

Academic Integrity

Each student in the course is expected to abide by the University of Texas Honor Code: “As a student of The University of Texas at Austin, I shall abide by the core values of the University and uphold academic integrity.” Plagiarism is taken very seriously at UT. Therefore, if you use words or ideas that are not your own (or that you have used in previous class), you must cite your sources. Otherwise you will be guilty of plagiarism and subject to academic disciplinary action, including failure of the course. You are responsible for understanding UT’s Academic Honesty and the University Honor Code which can be found at the following web address:

http://deanofstudents.utexas.edu/sjs/acint_student.php
Q Drop Policy
If you want to drop a class after the 12th class day, you’ll need to execute a Q drop before the Q-drop deadline, which typically occurs near the middle of the semester. Under Texas law, you are only allowed six Q drops while you are in college at any public Texas institution. For more information, see: http://www.utexas.edu/ugs/csacc/academic/adddrop/qdrop

University Resources for Students
Your success in this class is important to me. We will all need accommodations because we all learn differently. If there are aspects of this course that prevent you from learning or exclude you, please let me know as soon as possible. Together we’ll develop strategies to meet both your needs and the requirements of the course. There are also a range of resources on campus:

Services for Students with Disabilities
This class respects and welcomes students of all backgrounds, identities, and abilities. If there are circumstances that make our learning environment and activities difficult, if you have medical information that you need to share with me, or if you need specific arrangements in case the building needs to be evacuated, please let me know. I am committed to creating an effective learning environment for all students, but I can only do so if you discuss your needs with me as early as possible. I promise to maintain the confidentiality of these discussions. If appropriate, also contact Services for Students with Disabilities, 512-471-6259 (voice) or 1-866-329-3986 (video phone). http://ddce.utexas.edu/disability/about/

Counseling and Mental Health Center
Do your best to maintain a healthy lifestyle this semester by eating well, exercising, avoiding drugs and alcohol, getting enough sleep and taking some time to relax. This will help you achieve your goals and cope with stress.

All of us benefit from support during times of struggle. You are not alone. There are many helpful resources available on campus and an important part of the college experience is learning how to ask for help. Asking for support sooner rather than later is often helpful.

If you or anyone you know experiences any academic stress, difficult life events, or feelings like anxiety or depression, we strongly encourage you to seek support. http://www.cmhc.utexas.edu/individualcounseling.html

The Sanger Learning Center
Did you know that more than one-third of UT undergraduate students use the Sanger Learning Center each year to improve their academic performance? All students are welcome to take advantage of Sanger Center’s classes and workshops, private learning specialist appointments, peer academic coaching, and tutoring for more than 70 courses in 15 different subject areas. For more information, please visit http://www.utexas.edu/ugs/slc or call 512-471-3614 (JES A332).

Undergraduate Writing Center: http://uwc.utexas.edu/
Libraries: http://www.lib.utexas.edu/
ITS: http://www.utexas.edu/its/
Student Emergency Services: http://deanofstudents.utexas.edu/emergency/
Important Safety Information:
If you have concerns about the safety or behavior of fellow students, TAs or Professors, call BCAL (the Behavior Concerns Advice Line): 512-232-5050. Your call can be anonymous. If something doesn’t feel right – it probably isn’t. Trust your instincts and share your concerns.

Title IX Reporting
Title IX is a federal law that protects against sex and gender-based discrimination, sexual harassment, sexual assault, sexual misconduct, dating/domestic violence and stalking at federally funded educational institutions. UT Austin is committed to fostering a learning and working environment free from discrimination in all its forms. When sexual misconduct occurs in our community, the university can:

1. Intervene to prevent harmful behavior from continuing or escalating.
2. Provide support and remedies to students and employees who have experienced harm or have become involved in a Title IX investigation.
3. Investigate and discipline violations of the university’s relevant policies.

Faculty members and certain staff members are considered “Responsible Employees” or “Mandatory Reporters,” which means that they are required to report violations of Title IX to the Title IX Coordinator. I am a Responsible Employee and must report any Title IX related incidents that are disclosed in writing, discussion, or one-on-one. Before talking with me, or with any faculty or staff member about a Title IX related incident, be sure to ask whether they are a responsible employee. If you want to speak with someone for support or remedies without making an official report to the university, email advocate@austin.utexas.edu For more information about reporting options and resources, visit titleix.utexas.edu or contact the Title IX Office at titleix@austin.utexas.edu.

The following recommendations regarding emergency evacuation from the Office of Campus Safety and Security, 512-471-5767, http://www.utexas.edu/safety/

Occupants of buildings on The University of Texas at Austin campus are required to evacuate buildings when a fire alarm is activated. Alarm activation or announcement requires exiting and assembling outside.

- Familiarize yourself with all exit doors of each classroom and building you may occupy. Remember that the nearest exit door may not be the one you used when entering the building.
- Students requiring assistance in evacuation shall inform their instructor in writing during the first week of class.
- In the event of an evacuation, follow the instruction of faculty or class instructors. Do not re-enter a building unless given instructions by the following: Austin Fire Department, The University of Texas at Austin Police Department, or Fire Prevention Services office.
- Link to information regarding emergency evacuation routes and emergency procedures can be found at: www.utexas.edu/emergency
About Your Instructor

Robert W. Heath Jr. is a Cullen Trust for Higher Education Endowed Professor in the Dept. of Electrical and Computer Engineering at the University of Texas at Austin. In 2011, the IEEE Board of Directors elevated him to IEEE Fellow for “contributions to multiple antenna wireless communications”, their highest level of membership. He was an elected Distinguished Lecturer in the IEEE Signal Processing Society and the IEEE Vehicular Technology Society. He is also an amateur radio operator and a registered Professional Engineer in Texas.

He has considerable real-world engineering experience, including working at a wireless startup in Silicon Valley, running a consulting company MIMO Wireless Inc, and co-founding a local startup Kuma Signals LLC. He has consulting with many companies around the world and is on the technical advisory board of several startup companies.

His approximately 400 publications are among the most cited in wireless communications and signal processing. He has published three books: Millimeter Wave Wireless Communications (a book on the theory and practice of wireless communications at high frequencies) and Digital Wireless Communication: Physical Layer Exploration Lab Using the NI USRP (a laboratory book on signal processing for wireless communications), and Introduction to Wireless Communications: A Signal Processing Perspective (the book used in this course). He is working on a final book on MIMO wireless communication, which he hopes will be in press at the end of 2018.

He is among the most highly cited researchers in Computer Science and Electronics, with a rank of 67 worldwide and 50 in the USA [http://www.guide2research.com/scientists](http://www.guide2research.com/scientists). He is among the top cited research in wireless communications and signal processing. His papers have received numerous awards including the 2010 and 2013 EURASIP Journal on Wireless Communications and Networking best paper awards, the 2012 Signal Processing Magazine best paper award, a 2013 Signal Processing Society best paper award, the 2014 EURASIP Journal on Advances in Signal Processing best paper award, the 2014 and 2017 Journal of Communications and Networks best paper award, the 2016 IEEE Communications Society Fred W. Ellersick Prize, the 2016 IEEE Communications Society and Information Theory Society Joint Paper Award, and the 2017 IEEE Marconi Prize Paper award. He is an elected member of the IEEE Signal Processing Society Board of Governors. He is a Fellow of the National Academy of Engineering and the IEEE.

Outside of teaching, Prof. Heath is interested in stand-up jetskis (where he has built two custom carbon fiber skis, and is now rebuilding them), running, wakeboarding, and scuba diving. He recently became a private pilot.