

ECE 597AA/ ECE 697AA – Artificial Intelligence Based Wireless Network Design

**Department of Electrical and Computer Engineering
University of Massachusetts Amherst**

FALL 2021

Course Description:

With 5G networks being deployed worldwide, academia and industry are already shifting their attention towards 6G. This course focuses on the evolution, fundamentals, and challenges of 5G/6G wireless network design. It starts with an overview of the evolution from 4G to 5G networks and the technical specifications for 5G. It revises the latest challenges in 5G/6G wireless networks design, which motivates the need for AI-based solutions. Specific examples of network functionalities using AI will be discussed. The technology enablers are based on software-defined networks and virtualization, edge computing, and dynamic networking to support services that require high data rates, low latency, high reliability, and massive connectivity. The course will also provide the analytical tools for modeling and analyzing these networks, including network optimization, game theory, and machine learning. Applications of the latest enabling technologies and real networking problems will be covered in the lectures, analyzed in detail at seminars, and implemented through the project assignment. These problems include virtualization, wireless networks intelligence at the edge, spectrum allocation, caching, and virtual networks, among others.

Course credits: 3 credits

Course website: Class materials will be available on Moodle.

Prerequisites: Preliminary knowledge on networking (ECE 325) and machine learning is encouraged.

Course meetings: Tuesdays and Thursdays 1:00-2:15pm at Engineering Laboratory, room 305. The lectures will be recorded using Echo360, and the recordings can be access through Moodle.

Instructor: Dr. Lorenzo (blorenzo@umass.edu).

Office hours: Tuesdays and Thursdays 2:15-3:15 pm at 309G Knowles Engineering Building or by Zoom. Links to Zoom sessions for office hours can be found on Moodle. Please send me an email to book a time slot.

Teaching Assistant: TBD

Communication:

The course materials, assignments, and announcements will be available on Moodle. If you have any general question about the course or a specific question about any topic covered in the course, please post it in the Student Q&A Forum on Moodle. For questions that require more detailed explanations, please attend the office hours or ask any time during the lectures. For questions related to the homework and project assignments, please contact the TA. For personal questions that only pertain to you or your grades, please email the instructor.

Objectives:

Students completing this course will be able to:

- Explain the evolution of wireless networks and identify the technologies involved
- Understand the theoretical background of the analytical tools presented in this course
- Assess the suitability of the different analytical tools to model a given networking problem
- Model and analyze real networking problems by using the above analytical tools

Textbook:

The class materials are self-contained.

- The following textbook is recommended (*not mandatory*):

Vannithamby, R., & Soong, A. C. K. (Eds.). (2020). 5G verticals: Customizing applications, technologies and deployment techniques. John Wiley & Sons Ltd.

- Additional required resources for the seminars discussions:

Recent papers on advanced wireless networks—provided in Moodle.

- Recommended reading:

Sun, Y., Peng, M. Zhou, Y., Huang, Y., & Mao, S. (2019). Application of machine learning in wireless networks: Key techniques and open issues. *IEEE Communications Surveys & Tutorials*, 21(4), 3072–3108. <https://ieeexplore.ieee.org/document/8743390>

Topics covered:

- Introduction to wireless networks architecture, technology and standards. Introduction to LTE. Architecture of the LTE Air Interface. Evolution from 4G to 5G. Enabling technologies for 5G. Artificial Intelligence-based wireless network design for 5G and beyond.
- Network optimization: Convex vs. non-convex problems, duality theory, decomposition methods for network utility maximization, multi-objective problems, and Pareto optimality. Applications to cross-layer optimization.
- Game theory: Cooperative, non-cooperative, and evolutionary games. Applications to cognitive networks.
- Matching theory: stability, deferred-acceptance, and strategy proof. Applications to heterogeneous networks.
- Machine learning: supervised and unsupervised learning. Reinforcement learning and deep reinforcement learning. Applications to dynamic resource allocation.

Grading:

4 homework assignments	20%
5 seminars	25%
Project assignment	30%
Midterm Exam	25%

Schedule lectures:

Lecture	Section	Topic/Activity During Class	Day
1	Introduction	Wireless networks today, future trends and challenges	Thurs., Sept. 2
2		5G/6G Network Evolution	Tue., Sept. 7
3	Evolution of Mobile Communication Systems	LTE and Small Cells	Thurs., Sept. 9
4		Multi-hop Cellular Networks	Tue., Sept. 14
5		Cognitive Networks	Thurs., Sept. 16
6		Review Machine Learning I	Tue., Sept. 21
7		Seminar 1	Thurs., Sept. 23
8	5G/6G Enabling Technologies	SDN	Tue., Sept. 28
9		Virtualization	Thurs., Sept. 30
10		Fog, Mobile Edge and Cloud Computing	Tue., Oct. 5
11		Seminar 2	Thurs., Oct. 7
12		Exam 1 (Lectures 1-11)	Tue., Oct. 12
13	Wireless Networks Intelligence at the Edge	Adaptive Resource Allocation in Fog RAN	Thurs., Oct. 14
14		Review Machine Learning II	Tue., Oct. 19
15		Seminar 3	Thurs., Oct. 21
16	Network Optimization	Network Utility Function Decomposition	Tue., Oct. 26
17		Convex Optimization Theory	Thurs., Oct. 28
18		Cross-layer Optimization	Tue., Nov. 2
19		Cross-layer Optimization (cont.)	Thurs., Nov. 4
20		Seminar 4	Tue., Nov. 9
21	Game theory	Non-cooperative Games	Tue., Nov. 16
22		Bayesian Games	Thurs., Nov. 18
23		Cooperative Games	Tue., Nov. 23
24		Cooperative Games (cont.)	Tue., Nov. 30
25	Matching Theory	Matching Theory	Thurs., Dec. 2
26		Seminar 5	Tue., Dec. 7

Schedule Midterm Exam: the midterm exam will be on Tue., Oct. 12 at the Engineering Laboratory, room 304. It will cover lectures 1 to 11 (topics described above).

Schedule homework assignments:

	Posted	Deadline
Homework 1	Tue., Sept. 14	Sun., Sept. 26
Homework 2	Tue., Oct. 5	Sun., Oct. 17
Homework 3	Tue., Nov. 2	Sun., Nov. 14
Homework 4	Thurs., Nov. 18	Sun., Dec. 5

The homework assignments will be posted on Moodle and should be submitted on Moodle before the deadline.

Schedule seminars:

	Posted	Presentation
Paper 1	Tue., Sept. 7	Thurs., Sept. 23
Paper 2 – Part 1	Thurs., Sept. 23	Thurs., Oct. 7
Paper 2 – Part 2	Thurs., Sept. 23	Thurs., Oct. 21
Paper 3 – Part 1	Tue., Oct. 26	Tue., Nov. 9
Paper 3 – Part 2	Tue., Oct. 26	Tue., Dec. 7

In the seminars, students will work in groups to prepare a 30-minute seminar presentation based on an assigned paper that utilizes the analytical tools presented in the lectures to solve different networking problems. The presentation should include a summary of the problem addressed in the paper, an explanation of the modeling and analysis of the problem, performance, and suggestions for improvement. After the presentation there will be a discussion. All students are expected to participate in the discussions of their own papers and the other papers that other groups will present. In addition, a seminar sheet should be returned after attending the presentation answering a set of questions. The seminar sheet and the papers will be available on Moodle.

Schedule project assignment:

	Posted	Deadline
Project	Thurs., Sept. 23	Wed., Dec. 15

The project assignment will be posted on Moodle. Students will work in pairs to program several machine learning algorithms applied to solve a networking problem using Python and TensorFlow, analyze the results and make a report.

Attendance policies:

It is mandatory to attend the seminar presentations. If you have a problem to attend the seminars in the slotted times let me know as soon as possible. It is advisable, but not mandatory, to attend the lectures.

Late Policy:

Deadlines are strict. A submission after the deadline will receive zero credit.

In-Class Recordings by Students and Selling of Notes policies: Students can only use the notes they take from class for their own personal use, and not share (sell) these notes via an outside vendor or entity without the faculty/instructor's permission. This pertains to in-class recordings as well. Usage of the notes or in-class recordings in this way without the faculty member's permission is a violation of the faculty member's copyright protection.

This does not pertain to accommodations under the Americans with Disabilities Act (ADA), although recordings or sharing of Notes for ADA accommodations should not pertain to distribution beyond the students in the class receiving the accommodations.

Academic Honesty Statement:

Maintaining the integrity of scholarship and research within institutions of higher education requires a cultural commitment. All members of the UMass Amherst community are expected to be knowledgeable of and uphold our academic honesty policies (<https://www.umass.edu/honesty/>). Academic dishonesty includes but is not limited to cheating, fabrication, plagiarism, and *abetting or facilitating* dishonesty. Instructors are requested to take reasonable steps to address academic misconduct, and appropriate sanctions may be imposed on any student who has committed an act of academic dishonesty. Any person who has reason to believe that a fellow student has committed academic dishonesty should bring such information to the attention of the appropriate course instructor or an alternate, trusted member of the faculty or College administration as soon as possible. Instances of academic dishonesty not related to a specific course should be brought to the attention of the appropriate department Head or Chair. Community members may fill out the College's classroom experience form (<https://tinyurl.com/UMassEngineerClassroom>) to report academic dishonesty anonymously. Since students are expected to be familiar with this policy and the commonly accepted standards of academic integrity, ignorance of such standards is not normally sufficient evidence of lack of intent.

Cheating and Plagiarism Policy:

The University Academic Honesty Policy Applies in this and all courses. This policy can be found on the University Web Page (<https://www.umass.edu/honesty/>). Appendix B covers plagiarism, cheating, fabrication, and facilitating dishonesty. Students are expected to be familiar with the definitions and examples provided.

Health and Wellbeing:

You are not alone at UMass – many people care about your wellbeing and many resources are available to help you thrive and succeed. The College recognizes that coursework is challenging and that classes are not the only demand in your life. Success in this course and the College of Engineering depends heavily on your personal health and wellbeing. Recognize that while stress is an expected part of the college experience, it can be compounded by unexpected setbacks or life changes outside the classroom. Strive to reframe challenges as an unavoidable pathway to success. Reflect on your role in taking care of yourself throughout the term, before the demands of exams and projects reach their peak. Please feel free to reach out to me about any difficulty you may be having that may impact your performance as soon as it occurs and before it becomes too overwhelming.

You can learn about the confidential mental health services available on campus by calling the Center for Counseling and Psychological Health (CCPH) by visiting their website at umass.edu/counseling. There are many other resources on campus for students facing personal, financial or life challenges to find support, stay in school, and graduate (<https://www.umass.edu/studentlife/single-stop>). Within the College, you may reach out to myself, your academic advisor, the Office of Student Affairs (<http://engineering.umass.edu/current-students/academics-advising>) or the Office of Community Equity and Inclusion (rees@umass.edu). I encourage you to contact support services on campus that stand ready to assist you. Remember that I am here to help you find the resources you need.

Accessibility Support Services:

Your success in this class is important to me. We all learn differently and bring different strengths and needs to the class. The University of Massachusetts Amherst is committed to making reasonable, effective and appropriate accommodations to meet the needs of all students and help create a barrier-free campus. If you have a qualifying disability and require accommodations

while participating in this course, please work with Disability Services to have an accommodation letter sent to me in a timely manner. If you have a disability but are not yet affiliated with Disability Services, please register with Disability Services (<https://www.umass.edu/disability/students>). Information on services and materials for registering are also available on their website www.umass.edu/disability.

If you are eligible for exam accommodations, your exams will be administered by the exam proctoring center. Contact Disability Services immediately, and comply with their exam scheduling policies, including the requirement that you book your exams at least seven days in advance of the exam date. *It is incumbent upon you contact me during the first few weeks of the semester, or shortly following registration with Disability Services, to ensure that your accommodations are being sufficiently met, including extra time and note-taking access, as applicable.*

Finally, beyond disability accommodations, if there are aspects of the course that prevent you from being fully included in the class, please let me know as soon as possible. Together we'll develop strategies to meet both your needs and the requirements of the course.

Inclusivity:

Everyone should feel that they are an integral part of the community and that all individuals and their perspectives are respected. A diversity of perspective and experience provides a valuable source of ideas, problem solving strategies, and engineering creativity. If you feel that your contribution is not being valued or respected for any reason, please speak with me privately. If you wish to communicate with someone else in the College or University, there are several ways to do so anonymously or to provide contact information if you so choose:

1. Notify the University Diversity, Equity, and Inclusion Office through the "Report a Climate Incident" form: <https://www.umass.edu/diversity/incident-report-form>
Note that this form requires sharing name and contact information.
2. Speak with Assistant Dean Dr. Paula Rees (rees@umass.edu).
3. Report an incident anonymously to the College of Engineering Diversity, Equity, and Inclusion Office
 - Climate Concerns and Suggestions - <https://tinyurl.com/UMassEngineerClimate>
 - Classroom Experience - <https://tinyurl.com/UMassEngineerClassroom>
 - Reach out to the departmental DEI Committee: Anonymous ECE feedback form: <https://ece.umass.edu/ece-diversity-equity-inclusion> (scroll down for feedback link)

We are all members of an academic community with a shared responsibility to cultivate a climate where all individuals are valued and where both they and their ideas are treated with respect.

Pronouns and Names:

Everyone has the right to be addressed by the name and pronouns that they use for themselves. Students can indicate their preferred/chosen first name and pronouns on SPIRE, which appear on class rosters. Please let me know what name and pronouns I should use for you if they are not on the roster. A student's chosen name and pronouns are to be respected at all times in the classroom. To learn more, please see this resource:

https://www.umass.edu/stonewall/sites/default/files/pronouns_intro.pdf

Gender Respect and Title IX:

The University of Massachusetts Amherst aspires to be a university environment that is free of discrimination, sexual harassment, and sexual violence. Faculty have the responsibility to inform students of resources and reporting options. If you or someone you know has experienced sexual assault, sexual misconduct, or sexual discrimination please see <https://www.umass.edu/titleix/what-to-do> for information about resources and reporting options. A report to the Title IX Coordinator may be made at any time (including during non-business hours) by using the Title IX Coordinator's email (TitleIXCoordinator@umass.edu), telephone number (413.545.6124) or mail. UMass Amherst is committed to supporting community members who report concerns of prohibited conduct. Please reach out to me if you would like assistance connecting with any of these resources/options.