ECE6970/SYSEN5420

Network Systems and Games

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1 Course description

Motivation

Network systems pervade our society in both social and technological contexts. On the one hand, social networks play a central role in the transmission of information or viruses with fundamental consequences for product marketing, technology adoption, voting decisions, spread of false news and epidemiology. On the other hand, network topology fundamentally affects the performance and resilience properties of large-scale multi-agent systems, such as the power grid, the internet of things, traffic and robotic sensor networks.

This course will provide the necessary mathematical and modeling tools needed to describe and understand these network systems. Questions of interest will be how the network structure impacts the dynamics of network systems, how network properties can be exploited to maximize system performance or resilience and how one can address these questions while also accounting for strategic human behavior. The course will introduce tools that can be used to address these questions and successfully overcome challenges related to the coupled, distributed, and large-scale nature of network systems in environments with limited sensing, communication, and control capabilities.

Course description

This course is composed by 4 modules. The first module introduces concepts from linear algebra, graph theory and stability theory that will be needed throughout the course. The next three modules will cover: (i) *linear dynamics over networks* with emphasis on averaging algorithms, (ii) *nonlinear dynamics over networks* with emphasis on compartmental and epidemic models, (iii) *games on networks* with emphasis on traffic, power and marketing applications. The course draws on studies by economists, mathematicians, computer scientists and engineers. Classic results will be complemented with current research outlooks.

Topics covered in the course include:

- the theory of graphs (with emphasis on algebraic and spectral graph theory);
- network properties and centrality measures, with application to web-search algorithms;
- basic models and stability properties of multi-agent and interconnected dynamical systems;
- distributed averaging algorithms (consensus) with applications to social influence, wireless sensor networks, robotic coordination, optimal sensor placement, electric networks;
- epidemic models and network contagion;
- models of strategic behavior (game theory) and variational inequalities with application to traffic and power networks;
- network games and targeted interventions with application to marketing and economic systems;
- applications in social and economic networks, sensor and robotic networks, electric power grid, and traffic networks.

2 Prerequisite

MATH 2930, MATH 2940, ECE 2200 or permission of instructor.
Recommended: good background in linear algebra. Additionally, students should be comfortable with some mathematical rigor and mathematical proofs. Beyond those concepts, the course will be self-contained. In case of doubt, please contact me.

3 Textbooks

The class will be mainly based on lecture notes and on the following book:

B18: Francesco Bullo, *Lectures on network systems*, CreateSpace, 2019. (Available online at: http://motion.me.ucsb.edu/book-lns/)

Additional (optional) references are:

BT89: Dimitri P. Bertsekas and John N. Tsitsiklis, *Parallel and Distributed Computation: Numerical Methods*, Prentice hall Englewood Cliffs, 1989

J08: Matthew O. Jackson, *Social and Economic Networks*, Princeton University Press, 2008

FP07: Francisco Facchinei and Jong-Shi Pang, *Finite-dimensional variational inequalities and complementarity problems*, Springer Science & Business Media, 2007

EK10: David Easley and Jon Kleinberg, *Network, Crowds and Markets*, Cambridge University Press, 2010

Connection to recent journal publications will also be provided.

4 Tentative course outline

This is a tentative schedule and may be subject to changes.

Week	Topic	Material
Module 1: Preliminaries		
Week 1-3	Introduction; Elements of matrix and graph theory; Algebraic graph theory and centrality measures (examples of application to page-rank and web search)	B18: Chapters 1-5, (J08: Chapters 1-2) (EK10: Chapters 2, 4, 14)
Module 2: Linear network dynamics		
Week 4-6	Discrete time averaging and convergence rates (examples of application to social influence, wireless sensor networks, robotic coordination, optimal sensor placement, electric networks); Random graph models	B18: Chapter 5, 11, (J08: Chapters 4, 5, 8)
Module 3: Nonlinear network dynamics		
Week 7-8	Stability of dynamical systems, epidemic models (examples of application to flow model, ecosystem, epidemiology and testing)	B18: Chapter 10, 15, 16, (J08: Chapter 7), (EK10: Chapter 21), lecture notes
Module 4: Network games and dynamics		
Week 9-11	Fundamentals of game theory and potential games; Connection with variational inequalities and dynamics; Network games (examples of application to price competition, demand response methods, traffic and energy network, marketing and economic systems)	(J08: Chapter 9), (FP07: Chapters 1, 2, 12), (BT89: Part 3), (EK10: Chapters 6, 8), lecture notes
Week 12-13	**Presentations**	

5 Teaching modality

This is a 3 credit course, with two lectures per week each of 75 minutes. Lectures will be delivered online in real time, recordings will be made available.

6 Assignments, Exams and Projects:

There will be 4 homeworks (approximately due every two weeks up to week 10). Students will also participate in a group project, which could either be a literature review or an innovative research project (depending on individual preferences) on a topic to be agreed with the instructor. The projects will be presented to the class online in the last two weeks of the course.
Evaluation:

- Homeworks: 60%
- Final project: 40%