Analysis and Control of Multi-agent Systems

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Timetable: 20 hrs (see Class Schedule on https://phd.dei.unipd.it/course-catalogues/)

Course requirements: Linear Algebra and basic Calculus

Examination and grading: oral presentation of either any topic contained in the references [2], [3], [5], [6], [9], [10] or any other related work in the scientific literature that may also include the own student’s research

SSD: Information Engineering

Aim: Multi-agent systems (MASs), or networked dynamic systems (NDS), are systems composed of dynamic agents that interact with each other over an information exchange network. These systems can be used to perform team objectives with applications ranging from formation flying to distributed computation. Challenges associated with these systems are their analysis and synthesis, arising due to their decoupled, distributed, large-scale nature, and due to limited interagent sensing and communication capabilities. This course provides an introduction to these systems via tools from graph theory, dynamic systems and control theory. The course will cover a variety of modeling techniques for different types of networked systems and proceed to show how their properties, such as stability, performance and security, can be analyzed. The course will also explore techniques for designing these systems. The course will also cover novel applications by presenting recent results obtained in the secure-by-design consensus and optimal time-invariant formation tracking.

Course contents:

- Lecture 1. Introduction to MASs, synchronization and coordination, illustration of the course goals. Modeling NDSs and related examples such as opinion dynamics, wireless sensing networks, robot rendezvous, cyclic pursuit.
- Lecture 2. Elements of graph theory: basic notation and algebraic graph theory.
- Lecture 3. Consensus theory: the linear agreement protocol both in continuous and discrete time, firstly for unweighted graphs and then for weighted digraphs.
- Lecture 4. Secure-by-design linear agreement protocol against edge-weight perturbations seen as an application of the small-gain theorem.
- Lecture 5. The nonlinear agreement protocol along with examples such as coupled oscillators and the Kuramoto model. Passivity as a tool to analyze stability of the nonlinear agreement protocol.
- Lecture 8. The optimal time-invariant formation tracking (OIFT) problem as an application of the Pontryagin’s Maximum Principle. Distributed OIFT.
• Lectures 9-10. Bearing-based formation control. Bearing rigidity. A bearing-only forma-
tion controller. Bearing-based formation maneuvering.

References:
1 D. Zelazo’s Ph.D. course “Analysis and Control of Multi-agent systems”, held at the De-
partment of Information Engineering (UniPD), 2019.
2 F. Bullo with the contribution of Jorge Cortés, Florian Dörfler, and Sonia Martínez, “Lec-
tures on Networked Systems”, Vol. 1. No. 3. Seattle, DC, USA: Kindle Direct Publishing,
2020.
3 M. Mehran and M. Egerstedt, “Graph theoretic methods in multiagent networks”, Prince-
7 M. Fabris and D. Zelazo, “Secure consensus via objective coding: Robustness analysis
to channel tampering”, IEEE Transactions on Systems, Man, and Cybernetics: Systems
52.12 (2022): 7885-7897.
8 M. Fabris and D. Zelazo, “A Robustness Analysis to Structured Channel Tampering over
9 W. Ren and R. Beard, “Distributed Consensus in Multi-Vehicle Cooperative Control”,
11 M. Fabris, A. Cenedese and J. Hauser, ”Optimal time-invariant formation tracking for a
12 M. Fabris and A. Cenedese, “Optimal Time-Invariant Distributed Formation Tracking for
13 S. Zhao and D. Zelazo, “Bearing rigidity and almost global bearing-only formation stabi-

Further potentially relevant recent papers will be referred to and distributed during the lectures.