PhD in Information Technology and Electrical Engineering

Università degli Studi di Napoli Federico II

PhD Student: Anna Di Meglio

XXXII Cycle

Training and Research Activities Report – Second Year

"Modelling and control of complex dynamical evolving networks"

Tutor: Prof. Franco Garofalo

Co-Tutor: Pietro De Lellis

1. GENERAL INFORMATION

Graduated in Management Engineering – Università di Napoli, Federico II
XXXII Cycle – ITEE – Università di Napoli, Federico II
M.I.U.R. grant
Tutor: Prof. Franco Garofalo

2. CREDIT SUMMARY

	Credits year 2							
		1	2	3	4	5	6	
	Estimated	bimonthly	bimonthly	bimonthly	bimonthly	bimonthly	bimonthly	**Summary**
MODULES	10	0	0	1	3	5	4,5	**13**
SEMINARS	5	0,8	0	0,9	1,1	1,2	1	**5**
RESEARCH	45	12	0	8	8	7	7	**42**
	60	13	0	9,9	12	13	13	**60**

Maternity. (bimonthly periods 1–3 highlighted)

3. STUDY AND TRAINING ACTIVITIES

i Courses attended:

- "Applied Matrix Theory"; Prof. Jens Lorenz -External- lorenz@math.unm.edu ;
- "Convex Optimization"; Prof. David Coop -External- dcopp@unm.edu ;
- "Paradigmatic model in social science"; Prof. Fabio Dercole -External- fabio.dercole@polimi.it

ii Other courses:

- "Nonlinear control and Chaos"; Prof. Jens Lorenz -External- lorenz@math.unm.edu;

iii Seminars:

- "Optimal input placement in lattice graphs." Isaac Samuel Klicstein;
- "Prediction of optimal drug schedules for controlling autophagy." Afroza Shirin;
- "Exact controllability of complex networks" Ying-Cheng Lai;
- "Study of cluster synchronization by means of spectral characteristics" Fabio Della Rossa;
- "Optimal Attack Strategies for Maximizing Failures of Transmission Lines in Power Grids" Pankaz Das;
- "MPC to efficiently control power grid" David Coop;
- "Networks symmetries and synchronization", Francesco Sorrentino;
- "Optimal control in drug delivery" Francesco Sorrentino;
- "Generating symmetric graphs." Isaac Samuel Klickstein;
- "Sensitivity to a new velocity/pressure-gradient model to Reynolds number" Svetlana Poroseva;
- "Cluster synchronization analysis on multilayer networks" Fabio Della Rossa "Aging and Autophagy" Mark Mc Corminck and Micheal A. Mandell;
- "Prediction of optimal drug schedules for controlling autophagy." Afroza Shirin. "Ultra wide spectrum photovoltaic-thermoelectric solar cell" Tito Busani;

- Optimal regulation of blood glucose level in type I diabetes using insulin and glucagon.” Afroza Shirin;
- “Targeted synchronization in externally driven mechanical oscillators” Karen Blaha;
- “Suenos del Coyote: the Emergence of Genizaros in the Nuevomexicano Literary imagination” Enrique lamadrid.

3. RESEARCH ACTIVITY

“Modelling and control of complex dynamical networks”

This year my research has been focused on how to face with complex dynamical networks [1] in a more realistic scenario in which the interactions among the nodes are time-varying and the information of the underlying model is incomplete.

A complex network is a set of dynamical systems coupled through a graph with non-trivial topological features. Whichever the systems and their interactions are complex, their first attempt model is often borrowed from linear system theory and follows the linear dynamics

$$\dot{x}(t) = A(t)x(t) + B(t)u(t) \qquad (*)$$

where $A(t)$ is the adjacency matrix of the generic graph $\mathcal{G}$, $B(t)$ is the drivers’ matrix and $u(t)$ is the control input. The types of complex networks belonging to this class is enough large to motivate the study in terms of equation (*) and moreover, this formulation is helpful also in nonlinear formulations as it can be used after the linearization process, where needed.

The classical hypothesis in studying complex networks through (*) are:

1. The network topology is static, the number of nodes and the edges’ weights are fixed over the time horizon control, *i.e.* the adjacency matrix is time invariant $A(t) = A$.
2. The knowledge of the network is complete.

Both the above simplified hypotheses are at the base of the widely studied minimum control energy problem [3-5 and references therein]. The control goal is that to find an input $u(t)$ for the complex network (*) that solves the following optimization problem

$$\begin{gathered} \min \int_0^T u(t)^T u(t) dt \\ s.t. \\ \dot{x} = Ax + Bu \\ x(0) = x_0 \\ x(T) = x_T \end{gathered} \qquad (1)$$

where the objective function represents the control energy needed to steer the network from a specified initial condition (x_0) to a desired final condition (x_f). The systems for which nether hypothesis 1. or hypothesis 2. hold are ubiquitous and the list of the applications is very long. For example, we see them in biological (protein-protein interaction, gene regulatory, metabolic and neuronal networks) [13-14]; technological (internet network; power grid system; transportation and distribution networks; sensor network) [12] and social systems (financial markets; social networks; scientific collaboration networks; influence spreading; leadership; political comping; opinion dynamics) [8-11].

Nevertheless, sometimes adding more information about times of interactions can make predictions and so control strategies more accurate. At the same way, consider a scenario with incomplete information makes the selected control strategy more “robust”. Therefore, inspired by [2] we have formulated problem (1) for temporal networks [7], *i.e.* the adjacency matrix is time varying $A = A(t)$, and it is affected by stochasticity, *i.e.* the adjacency matrix over the control horizon is the realization of a stochastic process. In this more realistic scenario we aim to investigate if the fundamental energy control advantages listed in [2] are still effective and which are the possible blinded advantages of the "temporality" of the network. In the second year of my PhD I began the study of the literature on the minimum control energy of complex networks and I began the numerical investigations supporting some prelaminar theoretical conjectures.

[1] Boccaletti S., Latora V., Moreno Y., Chavez M., Hwang D.-U. "Complex networks: structure and dynamics" Physics Reports 424, 4-5 (175-308) 2006.
[2] Li, A., Cornelius, S. P., Liu, Y. Y., Wang, L., & Barabási, A. L. (2017). The fundamental advantages of temporal networks. *Science*, *358*(6366), 1042-1046.
[3] B. Barzel J.-J. Slotine Y.-Y. Liu G. Yan, G. Tsekenis and A.-L. Barabási.Spectrum of controlling and observing complex networks. Nature Physics, 11(9):779, 2015.
[4] I. Klickstein, A. Shirin, and F. Sorrentino. Energy scaling of targeted optimal control of complex networks. Nature communications, 8:15145, 2017.
[5] J. Sutter and A. E. Motter. Controllability transition and nonlocality in network control. Physical review letters, 110(20):208701, 2013.
[6] A. Li, S. P. Cornelius, Y.-Y. Liu, L. Wang, and A.-L. Barabási. Control energy scaling in temporal networks. arXiv preprint arXiv:1712.06434, 2017.
[7] Holme, P., & Saramäki, J. (2012). Temporal networks. *Physics reports*, *519*(3), 97-125.
[8] Iribarren, J. L., & Moro, E. (2009). Impact of human activity patterns on the dynamics of information diffusion. *Physical review letters*, *103*(3), 038702.
[9] De Lellis, P., Di Meglio, A., & Iudice, F. L. (2018). Overconfident agents and evolving financial networks. *Nonlinear Dynamics*, *92*(1), 33-40.
[10] DeLellis, P., DiMeglio, A., Garofalo, F., & Iudice, F. L. (2017). Steering opinion dynamics via containment control. *Computational social networks*, *4*(1), 12.
[11] DeLellis, P., DiMeglio, A., Garofalo, F., & Iudice, F. L. (2017). The evolving cobweb of relations among partially rational investors. *PloS one*, *12*(2), e0171891.
[12] Cattuto C, Van den Broeck W, Barrat A, Colizza V, Pinton J-F, Vespignani A (2010) Dynamics of Person-to-Person Interactions from Distributed RFID Sensor Networks.
[13] G. Chechik, E. Oh, O. Rando, J. Weissman, A. Regev, D. Koller, Activity motifs reveal principles of timing in transcriptional control of the yeast metabolic network, Nature Biotechnol. 26 (2008) 1251–1259.
[14] F. de Vico Fallani, V. Latora, L. Astolfi, F. Cincotti, D. Mattia, M.G. Marciani, S. Salinari, A. Colosimo, F. Babiloni, Persistent patterns of interconnection in time-varying cortical networks estimated from high-resolution eeg recordings in humans during a simple motor act, J. Phys. A 41 (2008) 224014.

4. PRODUCTS

i. Conference Paper:
- DeLellis P., DiMeglio A., Garofalo F., Lo Iudice, F. (2018, October). **"Partial containment control over signed graphs."** Submitted for *European Control Conference (ACC), 2019* IEEE.
- DiMeglio A., Dercole F., Della Rossa F. (2018, October). **"Direct reciprocity and model-predictive rationality: A setup for network reciprocity over social ties."** Submitted for *European Control Conference (ACC), 2019* IEEE.

ii. In preparation:
- "The fundamental challenge of temporal networks"
- "Containment control of large signed networks."
- "Fast leader-following consensus".

5. ACTIVITY ABROAD

- Albuquerque, NM (USA) University of New Mexico, Department of Mechanical Engineering. Research activity under the supervision of Professor Francesco Sorrentino (fsorrent@unm.edu).

6. TUTORSHIP

- Co-supervision of thesis master students for the course of Identificazione dei modelli e controllo ottimo.

TOT. HOURS: 10.