



PhD in Information Technology and Electrical Engineering
Università degli Studi di Napoli Federico II

PhD Student: Aiwin Thomas Vadakkan

Cycle: XL

Training and Research Activities Report

Year: First

Tutor: Prof. Mario Di Bernardo

Co-Tutor: Prof. Pietro De Lellis

Date: 22nd October 2025

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Author: Aiwin Thomas Vadakkan

1. Information:

- **PhD student: Aiwin Thomas Vadakkan**
- **DR number: 182931**
- **Date of birth: 05/11/2001**
- **Master Science degree: Physics University: Indian Institute of Science Education and Research, Tirupati, India**
- **Doctoral Cycle: XL**
- **Scholarship type: MSCA Doctoral Network - BeyondTheEdge**
- **Tutor: Prof. Mario Di Bernardo**
- **Co-tutor: Prof. Pietro De Lellis**

2. Study and training activities:

Activity	Type ¹	Hou rs	Credits	Dates	Organizer	Certificate ²
November – December						
Sincro Research Seminar	Seminar	1	0.2	11/12/24	Prof. Mario Di Bernardo	N
January - February						
Sincro Reseach Seminar	Seminar	8	1.6	08/01/25 15/01/25 22/01/25 29/01/25 05/02/25 14/02/25 19/02/25 26/02/25	Prof. Mario Di Bernardo	N
Optimisation-based control of flexible resources in sustainable energy networks	Seminar	1	0.2	11/02/25	Prof. Luigi Glielmo	Y (available in Vadakkan Aiwin Thomas – Y1 – ATT)
BeyondTheEdge seminar series “The Topological Dirac operator: theory and applications in Artificial Intelligence”	Seminar	1	0.2	04/02/25	Prof. Ginestra Bianconi and Cyril Rommens - PhD student of the Doctoral Network	N
BeyondTheEdge seminar series “Synchrony and	Seminar	1	0.2	27/02/25	Dr. Eddie Nijholt and Lucas Maekawa – PhD student of the	N

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synchrony-breaking as higher-order effects in hypernetwork systems”					doctoral network	
Control Theory	Course	48	6	From 01/01/25 Till 28/02/25	Prof. Mario Di Bernardo	Y (available in Vadakkan Aiwin Thomas – Y1 – ATT)
March - April						
Sincro Research Seminar	Seminar	8	1.6	05/03/25 12/03/25 19/03/25 26/03/25 02/04/25 09/04/25 16/04/25 23/04/25	Prof. Mario Di Bernardo	N
May - June						
Sincro Seminar series	Seminar	7	1.4	07/05/25 14/05/25 21/05/25 28/05/25 04/06.25 11/06/25 23/06/25	Prof. Mario Di Bernardo	N
PhD Survival Strategies	Seminar	1	0.2	30/05/25	Prof. Pietro Liguori	Y (available in Vadakkan Aiwin Thomas – Y1 – ATT)
Matrix Analysis for Signal Processing with MATLAB	Course	14	3	06/05/25 08/05/25 12/05/25 19/05/25 20/05/25 29/05/25 03/06/25	Dr. Massimo Rosamilia	Y (available in Vadakkan Aiwin Thomas – Y1 – ATT)
Control of complex networks and systems	Course	48	6	From 10/03/25 Till 13/05/25	Prof. Pietro De Lellis	Y (available in Vadakkan Aiwin Thomas – Y1 – ATT)
1 st BeyondTheEdge Doctoral School	Doctoral School	-	2	26/05/25 27/05/25	Prof. Michael Schaub, Prof. Fernando Santos and Agnes Backhausz	N
July - August						
Sincro Seminar Series	Seminar	4	0.8	02/07/25 09/07/25	Prof. Mario Di Bernardo	N

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				16/07/25 23/07/25		
HOOC – Higher Order Opportunitites and challenges	Workshop	-	3	From 11/08/25 Till 13/08/25	Prof. Michael Schaub	Y (available in Vadakkan Aiwın Thomas – Y1 – ATT)
Higher – order interactions: mechanisms, behaviour and networks 20 th Course of the school of complexity	Doctoral school	-	4	From 25/08/25 Till 31/08/25	Prof. Ginestra Bianconi Prof. Daniele Marinazzo, Prof. Giovanni Petri, Dr. Alice Schwarzze	Y (available in Vadakkan Aiwın Thomas – Y1 – ATT)
September - October						
Sincro Seminar series	Seminar	5	1	08/09/25 17/09/25 24/09/25 01/10/25 15/10/25	Prof. Mario Di Bernardo	N
BeyondtheEdge + RUNES workshop	Workshop	-	1	06/10/25 07/10/25	Prof. Giovanni Petri, Prof. Chris Bick and Prof. Alain Barrat	Y (available in Vadakkan Aiwın Thomas – Y1 – ATT)
2nd BeyondtheEdge Doctoral School +Hackathon	Doctoral school	-	2	08/10/25 09/10/25 10/10/25	Dr. Eddie Nijholt, Dr. Raffaella Mulas, Prof. Fernando Santos and Agnes Backhausz	Y (available in Vadakkan Aiwın Thomas – Y1 – ATT)

- 1) Courses, Seminar, Doctoral School, Research, Tutorship
- 2) Choose: Y or N

2.1. Study and training activities - credits earned

	Courses	Seminars	Research	Tutorship	Total
Bimonth 1	0	0.2	3	0	3.2
Bimonth 2	6	2.2	6.8	0	15
Bimonth 3	0	2.6	7.4	0	10
Bimonth 4	11	1.6	4	0	16.6
Bimonth 5	7	0.8	2.2	0	10
Bimonth 6	3	1.2	5.6	0	9.8
Total	27	8.6	29	0	64.6
Expected	30 - 70	10 - 30	80 - 140	0 - 4.8	

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3. Research activity:

Complex systems are often studied by modelling them as complex networks, where each node represents an agent, and the edges represent interactions between pairs of agents. These interactions can give rise to emergent properties in the network that are not present in the individual agents themselves. However, there is a fundamental limitation to such representations: networks capture only pairwise interactions, while many real-world systems rely on collective behaviors that emerge from group-level interactions among multiple agents. These group-level interactions are known as higher-order interactions and can be effectively represented using hypergraphs. Therefore, it is essential to develop analytical and control frameworks that account for these higher-order interactions to better understand and manage the dynamics of such systems.

During my PhD research on “Synchronisation of Hypergraphs with PID Control,” the primary objective is to extend PID control strategies—originally developed for pairwise networks—to the domain of hypergraphs. The focus is on analysing the impact of higher-order interactions among agents, controllers, or both, in achieving synchronization and other desired collective behaviours. A key goal is to identify potential advantages that hypergraph-based interactions can offer in control of complex networks.

First-Year Work Summary

Consensus in pairwise networks of linear agents, both homogeneous and heterogeneous, under constant disturbances, has been extensively studied in the literature. Examples include the use of distributed PI and PID control strategies to achieve consensus in such settings.

In the first year of my PhD, the research objective was to extend this framework to hypergraphs comprising nonlinear, nearly identical agents and to investigate synchronization in the presence of distributed PI control. The main analytical approach used for this study was the Master Stability Function (MSF), originally developed for pairwise networks of homogeneous agents. The MSF provides insight into the local transverse stability of the synchronisation manifold of the network.

In my work, the MSF framework was generalized to hypergraphs with nearly identical agents under distributed PI control. This extension enabled the derivation of necessary conditions for complete synchronisation of hypergraphs and provided a means to study local transverse stability of the synchronisation manifold. The theoretical results were validated numerically through simulations.

Future Work

In the coming months, I plan to extend this analysis to hypergraphs with heterogeneous agents and constant disturbances, incorporating both PI and PID control. Additionally, a major open question concerns understanding the benefits of higher-order interactions for network control, especially in comparison with traditional pairwise networks.

4. Research products: N/A

5. Conferences and seminars attended:

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1. HOOC - Higher Order Opportunities and Challenges

Aachen, Germany

Period – 11th August – 13th August 2025

2. Higher-order interactions: mechanisms, behaviors, and networks 20th Course of the school of complexity

Erice, Sicily, Italy

Period – 25th August to 31st August 2025

3. BeyondtheEdge School + Hackaton work

Aix-Marseille University, France

Period – 8th October – 10th October 2025

4. BeyondtheEdge + RUNES workshop

Aix-Marseille University, France

Period – 6th October – 7th October 2025

6. Activity abroad: *N/A*

7. Activity in partner companies: *N/A*

8. Tutorship: *N/A*