



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

PhD Student: Annalisa Navarro

Cycle:

Training and Research Activities Report

Year: First

Student signature:

Annalisa Navarro

Tutor: prof. Roberto Canonico

Tutor signature:

Roberto Canonico

Date: October 18, 2020

Training and Research Activities Report

PhD in Information Technology and Electrical Engineering

Cycle: XXXVIII

Author: Annalisa Navarro

1. Information:

- **PhD student:** Annalisa Navarro
- **DR number:** DR996622
- **Date of birth:** 17/02/1998
- **Master Science degree:** Computer Engineering, **University:** University of Napoli Federico II
- **Doctoral Cycle:** XXXVIII
- **Scholarship type:** UNINA
- **Tutor:** Roberto Canonico

2. Study and training activities:

Activity	Type ¹	Hours	Credits	Dates	Organizer	Certificate ²
Connecting the dots: Investigating an APT campaign using Splunk	Seminar	2	0.4	11/11/2022	Prof. S. P. Romano, R. Natella	Y
Stabilizer Renyi Entropy and Quantum Complexity	Seminar	1	0.2	09/11/2022	Prof. P. Lucignano, D. Montemurro, D. Massarotti, V. D'Ambrosio, F. Cardano, M. Esposito	Y
Cybercrime and Information Warfare: National and International Actors	Seminar	2	0.4	18/11/2022	Prof. S.P. Romano, R. Natella	Y
Privacy and data protection	Seminar	2	0.4	22/11/2022	Prof. S.P. Romano, R. Natella	Y
Optimizing Video Transport Over IP	Seminar	2	0.4	25/11/2022	Prof. R. Canonico, A. Botta	N
Automated Offensive Security	Seminar	2	0.4	28/11/2022	Prof. S.P Romano	Y
From Cyber Situational Awareness to Adaptive Cyber Defense: Leveling the Cyber Playing Field	Seminar	2	0.4	13/12/2022	Prof. G. Sperli	Y
Game Theory for Information Engineering	Seminar	3	0.6	13/12/2022	Prof M. Caleffi	Y
Entangled Relativity	Seminar	1	0.2	15/12/2022	Prof. F Bajardi, G. Ascione, S. Mancini	Y

Training and Research Activities Report

PhD in Information Technology and Electrical Engineering

Cycle: XXXVIII

Author: Annalisa Navarro

Machine Learning for CPS Security: Limitations and Novel Attack Discovery Techniques	Seminar	3	0.6	30/11/2022	IEEE LATINCOM Conference 2022	Y
Feature Extraction leveraging Programmable Data Planes for Traffic Analysis based on Machine Learning	Seminar	3	0.6	30/11/2022	IEEE LATINCOM Conference 2022	Y
Using Deep Learning Properly	Course	10	4	10-12-17-19-24/01/2023	Prof. A. Apicella	Y
Scientific Programming and Visualization with Python	Course	20	2	21-22-23/02/2023	Prof. A. Botta	Y
(5G seminar series) Principi Architeturali – TOGAF I	Seminar	3	0.6	30/01/2023	Prof A.M. Tulino	N
(5G seminar series) Data Strategy	Seminar	3	0.6	03/02/2023	Prof A.M. Tulino	N
(5G seminar series) Blockchain and 5G in business	Seminar	3	0.6	13/02/2023	Prof A.M. Tulino	N
(5G seminar series) Il cloud e gli hyperscaler	Seminar	3	0.6	28/02/2023	Prof. A.M. Tulino	N
Embracing Data Imperfections Via Domain Enriched Visual Task Learning	Seminar	1	0.2	13/02/2023	Prof. A. De Maio	Y
Statistical Data Analysis for Science and Engineering Research	Course	12	4	06-08-10-13-15-16/02/2023	Prof. R. Pietrantuono	Y
Virtualization technologies and their applications	Course	22	5	30/01/03-06-10-13-20-24-27/02/03/03/2023	Prof. Luigi De Simone	Y
Using fuzzing to detect network vulnerabilities	Seminar	1	0.2	08/05/2023	IEEE ComSoc	N
AI for networking, networking for AI	Seminar	2	0.4	10/05/2023	IEEE ComSoc	N
Security for IoT Networks and Devices in 6G	Seminar	3	0.6	12/06/2023	IFIP Networking Conference	Y
Impact of IT/OT Convergence on the Resilience of Critical Infrastructure	Seminar	4	0.8	12/06/2023	IFIP Networking Conference	Y
From Data Plane Programmability to	Seminar	4	0.8	19/06/2023	IEEE NetSoft Conference	Y

Training and Research Activities Report

PhD in Information Technology and Electrical Engineering

Cycle: XXXVIII

Author: Annalisa Navarro

Slicing Automation for Softwarized Infrastructures towards 6G						
Intent Based Networking	Seminar	3	0.6	19/06/2023	IEEE NetSoft Conference	Y
Measuring Routing Performance, a P4 practice with source routing	Seminar	2.4	0.48	26/06/2023	TMA Conference (PhD School)	Y
Privacy-preserving Data Processing	Seminar	3.6	0.72	26/06/2023	TMA Conference (PhD School)	Y
Big Data Architecture And Analytics	Course	20	5	26-29/06 06-07-10-12-14-19-20/07/2023	Prof. Giancarlo Sperli	Y
RESTART Tech Camp on 5G and Open RAN	Course	20	3	13-14-15/09/2023	RESTART, CNIT	Y
Research and Education in the Digital Transition Society	Seminar	5	1	22/09/2023	CINI	N
Research with Amazon Web Services: Opportunities and Tools	Seminar	2	0.4	29/09/2023	AWS Education and Research	N
Lessons learned from 40+ years of the Internet	Seminar	1	0.2	04/10/2023	Prof. H. Schulzrinne and Prof. J. Kurose	N

- 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	4.6	5.4	0.0	10.0
Bimonth 2	6.0	2.6	1.4	0.0	10.0
Bimonth 3	9.0	0.0	4.0	0.0	13.0
Bimonth 4	0.0	4.6	5.0	0.32	9.92
Bimonth 5	5.0	0.0	5.0	0.0	10.0
Bimonth 6	3.0	1.6	5.4	0.0	10.0
Total	23.0	13.4	26.2	0.32	62.92
Expected	30 - 70	10 - 30	80 - 140	0 - 4.8	

3. Research activity:

Training and Research Activities Report

PhD in Information Technology and Electrical Engineering

Cycle: XXXVIII

Author: Annalisa Navarro

My research focused on addressing the evolving needs for connectivity of the modern enterprises through SD-WAN (Software Defined Wide Area Network). The application of the Software Defined Networking (SDN) paradigm to such complex, large, and time-varying environments unfolded many issues, such as poor performance, scalability limitations, and difficulties in achieving global network intents. The aim of my research concerns designing methodologies for addressing these problems and fulfilling the promises of SD-WAN technology.

Over the last year, I conducted a thorough analysis of the pressing challenges and state-of-art solutions related to SD-WAN technology. This comprehensive exploration included considerations of openness, interoperability, network automation, monitoring, QoS guarantees, scalability, and security.

Later on, I focused on developing a novel framework based on Reinforcement Learning for fine-grained, policy-based traffic control in SD-WAN infrastructures. The framework exhibited promising results, achieving a significant 33% reduction in Quality of Service (QoS) policy violations under heavy load conditions compared to conventional benchmark approaches.

Subsequently, I posed the problem of scaling the RL solutions designed to large SD-WANs, with particular emphasis on scenarios involving multiple distributed sites connected through numerous paths. To tackle the increased complexity associated with such scenarios, I proposed a solution based on Multi-Agent Reinforcement Learning (MARL). This approach leveraged individual agents for each site, leading to a significant reduction in overall complexity. Real experiments conducted in an emulated environment affirmed the viability and effectiveness of this approach, particularly in multi-site scenarios.

Another important concern was ensuring high availability in SD-WANs. Continuous monitoring of WAN links was identified as crucial for seamless failover and tunnel handoff between WAN links. The analysis of the use of the Bidirectional Forwarding Detection (BFD) protocol for tunnel handoff in SD-WAN, along with an automatic tuning mechanism for BFD parameters, highlighted the sensitivity of BFD to WAN types and conditions. Additionally, dynamic configuration was found to be essential for optimizing performance.

In the most recent research phase, I introduced a decentralized control plane reference architecture that leveraged edge-based network monitoring and edge-based configuration. I also introduced a novel Reinforcement Learning-based orchestration plane that employs per-site agents leveraging local information while also exchanging minimal inter-sites information, ensuring both scalability and enhanced performance. Experimental evaluations were conducted across diverse SD-WAN scenarios, validating the effectiveness of this framework in satisfying global network policies, particularly in multi-site SD-WAN environments with varying Quality of Service (QoS) requirements and cost constraints.

In addition to considering SD-WANs, I have also conducted research activities in the field of security, specifically focusing on Low Power Wide Area Networks (LP-WANs) and Cyber-Physical Systems (CPSs). For the former, I conducted a state-of-the-art study regarding the

Training and Research Activities Report

PhD in Information Technology and Electrical Engineering

Cycle: XXXVIII

Author: Annalisa Navarro

security features offered by various LP-WAN technologies and an examination of vulnerabilities and commonly launched attacks on these infrastructures. This led to the development of a general threat model for LP-WAN architectures aimed at enhancing the security of these network infrastructures.

Similarly, a study was conducted on threats specific to CPS. These environments are highly susceptible to cyberattacks, which can have catastrophic consequences for both business operations and the surrounding environment. Consequently, an Intrusion Detection System (IDS) specifically tailored for industrial CPS was designed. This IDS - based on Unsupervised Deep Learning Anomaly Detection – has the novelty of taking both network and sensor/actuator data as input, utilizing statistical characteristics to identify physical or network attacks as anomalies, meaning deviations from normal behavior.

4. Research products:

- 1) Botta, R. Canonico, A. Navarro, S. Ruggiero and G. Ventre, "AI-enabled SD-WAN: the case of Reinforcement Learning," 2022 IEEE Latin-American Conference on Communications (LATINCOM) [PUBLISHED]
- 2) A. Botta, R. Canonico, A. Navarro, G. Stanco and G. Ventre, "Scalable Reinforcement Learning for Dynamic Overlay Selection in SD-WANs," 2023 IFIP Networking Conference (IFIP Networking), 2023 [PUBLISHED]
- 3) A. Navarro, R. Canonico and A. Botta, "Software Defined Wide Area Networks: Current Challenges and Future Perspectives," 2023 IEEE 9th International Conference on Network Softwarization (NetSoft)[PUBLISHED]
- 4) A. Botta, R. Canonico, A. Navarro, G. Stanco and G. Ventre, "Towards a Highly-Available SD-WAN: Rapid Failover based on BFD Protocol" 2023 9th IEEE Conference on Network Functions Virtualization and Software-Defined Networking (IEEE NFV-SDN 2023) [ACCEPTED]
- 5) G. Stanco, A. Navarro, F. Frattini, G. Ventre, A. Botta "A Comprehensive Survey on the Security of Low Power Wide Area Networks for the Internet of Things", ICT Express [UNDER REVIEW]
- 6) R. Canonico, G. Esposito, A. Navarro, S.P. Romano, G. Sperli, A. Vignali, "CPS Security Unleashed: Anomaly Detection for Cyber-Physical Threats in Critical Infrastructures". IEEE Transaction on Dependable and Secure Computing, [UNDER REVIEW]
- 7) R. Canonico, G. Esposito, A. Navarro, S.P. Romano, G. Sperli, A. Vignali, "Network and Physical Data Fusion for Cyber-Physical Systems Protection", IEEE Transaction on Industrial Informatics [UNDER REVIEW]
- 8) A. Botta, R. Canonico, A. Navarro, G. Stanco and G. Ventre, "Adaptive Overlay Selection at the SD-WAN Edges: A Reinforcement Learning Approach with Networked Agents", Computer Networks [SUBMITTED]

5. Conferences and seminars attended

- 1) IEEE Latin-American Conference on Communications, 30 November–2 December 2022, Rio de Janeiro, Brazil [PRESENTED A PAPER]

Training and Research Activities Report

PhD in Information Technology and Electrical Engineering

Cycle: XXXVIII

Author: Annalisa Navarro

- 2) *International Federation for Information Processing (IFIP) Networking 2023 Conference (NETWORKING 2023), June 12-15 2023, Barcelona, Spain [PRESENTED A PAPER]*
- 3) *IEEE International Conference on Network Softwarization (NETSOFT) 19–23 June 2023, Madrid, Spain [PRESENTED A PAPER]*
- 4) *Network Traffic Measurement and Analysis Conference (TMA CONFERENCE) 26-29 June, 2023, Napoli, Italy*

6. Activity abroad:

None

7. Tutorship

- Practical Kubernetes demo based on Minikube for a lesson of the “Cloud and Network Infrastructure” course (by Prof. Roberto Canonico). (2h)
- Explanation of the theoretical background of Software Defined Wide Area Networks (SD-WANs), for the course of “Cloud and Network Infrastructure” by Prof. Roberto Canonico. (2h)
- Explanation about network simulation and emulation tools with practical exercises based on Cisco Packet Tracer, for “Computer Networks” course by Prof. Giorgio Ventre. (2h)
- Explanation about Wireless technologies, for “Computer Networks” course by Prof. Giorgio Ventre. (2h)