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

# PhD Student: Jessica Illiano

**Cycle: XXXVI**

## Training and Research Activities Report

**Academic year: 2021-22 - PhD Year: Second**

Illiano Jessica

**Tutor: prof. Angela Sara Cacciapuoti**

**Co-Tutor: Dr. Antonio Manzalini**

**Date: October 30, 2022**

# Training and Research Activities Report

PhD in Information Technology and Electrical Engineering

**Cycle:XXXVI** **Author: Jessica Illiano**

## 1. Information:

- **PhD student: Jessica Illiano PhD Cycle:XXXVI**
- **DR number:DR995140**
- **Date of birth:16/12/1996**
- **Master Science degree: Telecommunication Engineering University: University of Naples Federico II**
- **Scholarship type: Funding company**
- **Tutor: Prof. Angela Sara Cacciapuoti**
- **Co-tutor: Dr. Antonio Manzalini**

## 2. Study and training activities:

| Activity | Type[1] | Hours | Credits | Dates | Organizer | Certificate[2] |
|---|---|---|---|---|---|---|
| Entanglement transitions in the quantum Ising chain: A comparison between different unravelings of the same Lindbladian | Seminar | 0.45 | 0.1 | 27-07-2022 | Department of Physics | Y |
| Seeqc: the digital quantum computing company | Seminar | 1 | 0.2 | 24-02-2022 | Department of Physics | Y |
| Cavity magnonics in strong coupling regime – from magnon-polariton hybrid states to perspectives for quantum sensing | Seminar | 1 | 0.2 | 26-06-2022 | Department of Physics | Y |
| The Quantum Internet: the quest for a network paradigm shift | Seminar | 0.45 | 0.1 | 12-04-2022 | Department of Physics | Y |
| SQMS/GGI Summer School on Quantum Simulation of Field Theories | PhD School | 4 days | 4.5 | 25-29/07/2022 | Galileo Galilei Institute | Y |
| ACM NanoCom 2022, 9th ACM International | Research | - | - | 5-7/10/2022 | Universitat Politecnica | Y |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Conference on Nanoscale Computing and Communication**<br>**- Paper presentation** | | | | | **de Catalunya** | |
| **Quantum Photonic technologies** | **Course** | **18** | **4** | **27-05-2022/15-06-2022** | **CNR-INO Florence** | **Y** |

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 | 0,7 | 10 | 0 | 10,7 |
| Bimonth 2 | 5 | 0,5 | 10 | 0 | 15,5 |
| Bimonth 3 | 0 | 0,2 | 10 | 0 | 10,2 |
| Bimonth 4 | 0 | 0,6 | 12 | 0 | 12,6 |
| Bimonth 5 | 0 | 4,5 | 5 | 0 | 9,5 |
| Bimonth 6 | 4 | 0 | 9,6 | 0 | 14,6 |
| **Total** | 9 | 6,5 | 56,6 | 0 | 72,1 |
| **Expected** | 30 - 70 | 10 - 30 | 80 - 140 | 0 – 4.8 | |

## 3. Research activity:

*The Quantum Internet, i.e., an heterogeneous network interconnecting remote quantum devices through quantum – and classical – links, is envisioned as the final stage of the quantum revolution. Indeed, it will enable applications with no-counterpart in the classical world ranging from intrinsically secure communications, through sensing to the Quantum Distributed Computing (QDC). The design of the Quantum Internet is a breakthrough since it is governed by the laws of quantum mechanics. Specifically, classical network protocols and services assume that classical information can be safely read and copied. Surprisingly, this assumption does not hold in the Quantum Internet, namely, according to the so-called no-cloning theorem it is forbidden to copy an unknown quantum bit (qubit). Therefore, not only the physical layer is affected by these different phenomena but also the upper layer protocols are no longer effective in the Quantum Internet. Hence, a major network-paradigm shift is mandatory to harness the quantum mechanics specificities. Indeed, the design of an abstract quantum network model that leads to the definition of a reference standard is still an open problem. My research works aims at studying and designing a Quantum Internet model that harnesses both the peculiarities of quantum mechanics and the intrinsic interactions between the Quantum Internet and the classical Internet. In this light, I focused my research activities on different aspects. A first aspect is the impact of the quantum entanglement on the network design. Indeed, the quantum entanglement represents a key resource for quantum communications and the quantum networks functionalities as it enables communication strategies such as quantum teleportation and entanglement swapping. By simply pre-sharing a bipartite entangled state, these strategies allow long distance communications without the physical transfer of the particle encoding the information or the violation of the no cloning theorem. There exist different*

*typologies of entangled states. Besides the widely-known bipartite entanglement, I studied multipartite entanglement, i.e., entanglement between more than two parties. The typologies of multipartite entangled state vary with the state space of the quantum system. Indeed, this astonishing phenomenon revolutionizes the very concept of network connectivity. Specifically, entanglement enables a new connectivity that is deeply different in its nature and evolution from the classical physical connectivity and affects the entire protocol stack functionalities*

*With the reference to multipartite entanglement, the concept of the so-called on-demand connectivity arises. By accounting for the challenges – as well as the different possibilities – arising from the on-demand connectivity, during my second year of research activities I designed the Entanglement Access Control protocol. The EAC protocol jointly solves the access to the shared resource, i.e., the virtual link that comes with the distributed entangled state and the communication need. Furthermore, it abstains from delegating the signaling arising with entanglement access control to the classical network and supports the anonymity of the transmitter and receiver identities.*

*Stemming from the unexpected properties of multipartite entangled states, I analyzed how the concept of network connectivity is changed by the entanglement and how this in turn prohibits a one-to-one mapping between the classical layers and their quantum counterpart. The aforementioned analysis leads me to focus on another research direction constituted by the study and analysis of the interplay between the classical Internet and the Quantum Internet. In fact, the entanglement-based connectivity requires the support of the entire classical Internet protocol stack. Moreover, it entails a tangle of cross-layer interactions that unlikely allow for the quantum Internet an abstract layered model based on the separation of concerns. The interplay between the classical Internet and the Quantum Internet is bi-directional rather than uni-directional. The aim of my research is to deepen the discussion towards a complete and effective design strategy for the Quantum Internet.*

### Research products:

- *J. Illiano, A. S. Cacciapuoti, A. Manzalini and M. Caleffi. "The Impact of the Quantum Data Plane Overhead on the Throughput" Proc. of The Eight Annual ACM International Conference on Nanoscale Computing and Communication (NANOCOM '21) September 7–9, 2021*
- *J. Illiano, M. Caleffi, A. Manzalini, A. S. Cacciapuoti, "Quantum Internet Protocol Stack: a comprehensive survey", Computer Networks,p. 109092, 2022*
- *A. S. Cacciapuoti, J. Illiano, S. Koudia, K. Symonov, M.Caleffi "The Quantum Internet: Enhancing Classical Internet Services one Qubit at a Time." IEEE Network, in press ,2022.*
- *A.S. Cacciapuoti, J. Illiano, M. Viscardi, M. Caleffi, "Quantum Internet: the Dawn of the Quantum Paths", Invited Paper, Proc. Of ACM NANOCOM , 2022.*
- *J. Illiano, M. Viscardi ,S. Koudia, M. Caleffi " Quantum Internet: from Medium Access Control to Entanglement Access Control." Proc. of IEEE GLOBECOM '22 Dec. 4-8, 2022.*

## 5. Conferences and seminars attended

Seminar: *"Entanglement transitions in the quantum Ising chain: A comparison between different unravelings of the same Lindbladian"* Department of Physics - Federico II, Dr. Angelo Russomanno, 27/01/2022

Seminar: "*Seeqc: the digital quantum computing company*", Department of Physics – Federico II, Dr. Marco Arzeo, 24/02/2022

Seminar: "*The quest of quantum advantage with a photonics platform*", Prof. Fabio Sciarrino, Scuola Superiore Meridionale, 03/02/2022

Seminar: "*The Quantum Internet: the quest for a network paradigm shift*", Department of Physics - Federico II, Prof. Angela Sara Cacciapuoti, 12/04/2022

Seminar: "*Cavity magnonics in strong coupling regime – from magnon-polariton hybrid states to perspectives for quantum sensing*" ,Department of Physics - Federico II, Prof. Giuseppe Maruccio, 26/06/2022

PhD School: SQMS/GGI Summer School on Quantum Simulation of Field Theories, GGI - Galileo Galilei Institute, Florence. 25-29/07/2022

Conference: ACM NanoCom 2022, 9th ACM International Conference on Nanoscale Computing and Communication Barcelona, Catalunya, Spain, October 5-7, 2022.

Presentation of the paper : *A.S. Cacciapuoti, J. Illiano, M. Viscardi, M. Caleffi, "Quantum Internet: the Dawn of the Quantum Paths", Invited Paper, Proc. Of ACM NANOCOM , 2022.*

## 6. Periods abroad and/or in international research institutions

*On October 27th I started the Internship at Nu-Quantum Ltd in Cambridge (UK). My period abroad will end on January 26th. At Nu Quantum I'll join the team that is responsible of interconnecting multiple quantum chips. Specifically, I'll participate in the design of the entanglement scheduler and routing protocols for mulitichip architectures.*

## 7. Tutorship

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## 8. Plan for year three

*With the respect to the third year activities, I plan to continue the work I started within my research period abroad. Furthermore, I will focus on a theoretical model for the Entanglement Access Control and on the design of protocols for the interaction between the classical Internet and the Quantum Internet.*