Jessica Illiano
Quantum Communication Protocols for Quantum Security and Quantum Internet

Tutor: Prof.ssa Angela Sara Cacciapuoti
co-Tutor: Dr. Antonio Manzalini (TIM)
Cycle: XXXVI          Year: First
My background

- MSc degree in Telecommunication Engineering
- Quantum Internet Research group
  http://www.quantuminternet.it
- PhD start date: 1/11/2020
- Company founded Scholarship
- Partner company: TIM S.p.A.
Quantum Network
Collection of nodes that is able to exchange qubits and distribute entangled states amongst themselves.

- Qubits
- No Cloning Theorem
- Entanglement
- Quantum Teleportation process
Summary of study activities

• Courses borrowed from MSc curricula:
  – Quantum Information (6 CFU)
  – Nanotechnologies for Electrical Engineering (6 CFU)
  – Introduction to Quantum Circuits (9 CFU)

• Seminars (partial list):
  – Quantum Simulators
  – Second Quantum Revolution: innovation trends and expected industrial impacts
  – TeamUp5g Workshop on Ethics and Inclusiveness for Telecommunications Engineers

• IEEE/DEI Summer Ph.D. School of Information Engineering “SilvanoPupolin”–SSIE2021
• PhD Summer School of Quantum Technologies
  – Student Presentation: On The Impact of the Quantum Data Plane on the Throughput

• Attended Conferences:

• Side Activity:
  – TIM Remote Shadow Experience: soft skills
Research activity: Overview

• Problem:
  The Quantum Internet is governed by the laws of quantum mechanics and it is based on phenomena with no counterpart in classical networks. This imposes new challenging constraints for network design. Specifically, classical network functionalities are based on the assumption that classical information can be safely read and copied. This assumption does not hold in the Quantum Internet. As a consequence, its design requires a major network-paradigm shift to harness the quantum mechanics specificities.

• Objective:
  – Interaction between classical network and quantum network
  – Network protocol stack for the Quantum Internet

• Methodology:
  – Study of the characterizing phenomena
  – System Model
  – Mathematical Analysis
  – Numerical Simulations
Research activity: Interaction between classical network and Quantum Network

The Impact of the Quantum Data Plane Overhead on the Throughput

Interaction between classical network and Quantum Network

The teleporting throughput as a function of the link length.

\[ \Gamma = \frac{\mathcal{R}_b \Gamma_e}{2\Gamma_e + \mathcal{R}_b + \mathcal{R}_b \Gamma_e (\mathcal{T}_{SW} + \mathcal{T}_{BSM} + \mathcal{T}_c)} \]

Upper bounds

\[ \Gamma < \frac{\mathcal{R}_b}{2} \]

\[ \Gamma < \Gamma_e \]
Interaction between classical network and Quantum Network

The teleporting throughput as a function of the link length.

\[ \Gamma^N \text{ increases with } N \text{ and it does not exceed } N\Gamma \]

Teleporting Throughput

\[ \Gamma^N = \frac{N \Gamma R_b}{R_b + 2(N - 1)\Gamma} \]

Upper bounds

\[ \Gamma^N < NT < \frac{N}{2} R_b \]

\[ \Gamma^N < NT < NT_e \]
Interaction between classical network
and Quantum Network

Quantum repeater architecture

Teleporting Throughput

\[ \Gamma_r = \frac{\min_{i=0,\ldots,H} R_{b_i} \Gamma_{er}}{2 \Gamma_{er} + \min_{i=0,\ldots,H} R_{b_i} + \min_{i=1,\ldots,H} R_{b_i} \Gamma_{er}} \left[ T_{SW} + T_{BSM} + \sum_{i=0}^{H} T_{c_i} \right] \]
On the Network Protocol Stack for the Quantum Internet

- Bipartite and Multipartite Entanglement
- The impact of entanglement on network connectivity
- Quantum Protocol Stack State-of-the-art

Van Meter

- Application
- Error Management
- Quantum state Propagation
- Error Management
- Link Entanglement Control
- Physical entanglement

App: Entanglement Purification (end to end)
Prop: Entanglement Swapping
Purification: Entanglement Purification
Link: Link Entanglement Management
EPR: EPR Physical Generation

Wehner et al.

- Application
- Transport
- Network
- Link
- Physical

App: Qubit transmission
Trans: End to end Entanglement
Net: Robust Entanglement Generation
Link: Entanglement Generation Attempt
Phys: EPR Physical Generation

Pirker and Dür

- Network
- Link
- Connectivity
- Physical

Net: Enable for inter-network graph state request
Link: Generate arbitrary graph states on request
Con: Ensure point-to-point connectivity
Phys: Connect quantum devices

EPR based
Multipartite entanglement based

Layer model
Main Functionality
Next Year

• The Impact of the Quantum Data Plane Overhead on the Throughput
  – Quantum Repeater architecture: throughput upper bounds analysis
  – Insight on noise models for experimental evaluation

• On the Network Protocol Stack for the Quantum Internet:
  – Lower layers protocols
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