Virtual Exchange Seminars: Quantum Mobile Networking

Coordinator: Dr. A. Di Maio

Spring Semester 2023

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Webpage: ILIAS e-Learning Platform

Time: Friday 15:00 (UTC+1), to be confirmed

Place: Online Zoom Meeting

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Student List

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TBD	Inst. of Computer Science, University of Bern, Switzerland
TBD	Inst. of Applied Physics, University of Bern, Switzerland
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Abstract

Over the last decades, performance requirements on mobile computer networks have constantly increased. Users need to use high-throughput, low-latency, and secure applications anytime while moving indoors and outdoors. Quantum communications have the potential to establish more secure and performing channels and are a promising technology to meet modern use-case requirements. Moreover, classical networks could be efficiently optimized with the help of quantum algorithms. However, current research focuses on mobile networking and quantum networking as separate disciplines, lacking joint works at their interface to improve understanding and make Quantum Mobile Networks (QMNs) practical. In this Seminar, we identify a list of aspects and perspectives on mobile and quantum networks that are fairly researched in isolation but whose mutual relation is still to be fully explored. Seminar participants will learn about various topics in Computer Science and Physics that will help them understand and imagine possible ways to model, design, and enhance Quantum Mobile Networks, including capacity models, mobility effects on performance, routing, Age of Information, Gossip protocols, physical channel features, and simulation tools.

Goals

This seminar aims to encourage students to discuss cutting-edge research in mobile and quantum networking under the supervision of field experts, with the objective of identifying research questions that span across both fields to foster interdisciplinary knowledge exchange between the seminar's participating students and researchers. During the seminar, the students will select a pair of articles from those listed in the literature related to their preferred topic (one related to classical networks, and one on quantum communications), find the link between them, and present it to an audience made of peers and experts. In particular, the Seminar's goals can be summarized as follows:

- Foster collaboration and experience exchange between students at the University of Bern and the partner universities abroad.

- Introduce Quantum Communication to Computer Science students and, on the other hand, allow Physics students to learn about Advanced Networking concepts.
- Explore future joint research avenues.
- Improve the students' scientific presentation skills, critical thinking, question answering, and independence in formulating research questions.
- Help students to identify an open research question in Quantum Mobile Networks to be tackled during their BSc or MSc joint thesis between the partner universities.

Prerequisites

Students who participate in the seminar should have basic knowledge of wireless and mobile networking OR basic knowledge of quantum communications and networking. Students are not required to have basic knowledge on both fields, as acquiring it is one of the seminar's goals.

Organization and Schedule

Weekly online meetings in which one group (each group made of one student, BSc or MSc, from each partner university) gives a 30-minute talk, followed by a Q&A session in which all other students can ask questions. Active participation is rewarded. The topic of each talk is to be agreed upon with the organizers (e.g., picked from the topic list hereafter). Each topic comprises articles from both fields (quantum communications and mobile networking). Each group prepares three questions on the presented topic for the other students to answer by uploading the answers on the University's digital learning platform.

Evaluation and Grading

Weekly Schedule

Week	Date	Topic	Group
1	Mar 3	Welcome and Seminar Presentation	-
2	Mar 10	Group Formation	-
3	Mar 17	*No meeting: Preparation of Talks*	-
4	Mar 24	*No meeting: Preparation of Talks*	-
5	Mar 31	**Performance in QMNs: Capacity, Delay, Buffering**	1
6	Apr 7	**Media Access Control in QMNs**	2
7	Apr 14	*No meeting: Easter Break*	-
8	Apr 21	**Effects of Mobility Patterns on QMN Performance**	3
9	Apr 28	**Physical Implementations of Quantum Channels in QMNs**	4
10	May 5	**Simulation Tools for QMNs**	5
11	May 12	**Age of Information in QMNs**	6
12	May 19	**Gossip Protocols in QMNs**	7
13	May 23	**Routing in QMNs**	8

Agenda: Welcome and Seminar Presentation

- Introduction of the seminars
- Round table of presentations: advisors
- Round table of presentations: students
- Introduction to Quantum Mechanics (Prof. Stefanov)

Agenda: Group Formation

- Discussion of preferences and group formation

Topics List

In this section, we have defined a set of topics that can be selected by the students and presented in a seminar talk. Each topic is associated with a set of articles according to the topics they are related to. The topics can be further redefined, according to the student's interests.

1 Gossip Protocols in QMNs

Abstract

Gossip Networks are a type of network in which nodes execute a distributed task (e.g., aggregation, dissemination) by exchanging information over direct opportunistic links. Fundamental works have extensively studied the properties of gossip networks in terms of dynamics, diameter, and information propagation when nodes are mobile [1]. However, the literature lacks works that propose, study, evaluate, or adapt classical gossip protocols for mobile networks to disseminate information in quantum mobile networks. Some recent works show the potential and limitations of Gossip Protocols in QMNs by studying how consensus is reached in Quantum Gossip Networks [2], how the information distribution in Quantum Networks could be sped-up by gossiping [3], and investigating how quantum communications could accelerate traditional gossip algorithms in network cliques that spontaneously occur in mobile networks [4]. More theoretical works allow us to model Quantum Gossip Networks as random graphs and study their performance statistically [5]. In this Seminar Topic, we discuss recent advances in Gossip Protocols on QMNs and works that study their performance.

Group Members

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References

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2 Routing in QMNs

Abstract

Users in an infrastructure-less mobile network may need to exchange data without being in direct communication range of each other, which requires the cooperation of other peers to relay the information. Extensive literature has studied the performance of routing protocols in traditional mobile networks (ad hoc [6], gossip [7], vehicular [8], delay-tolerant [9] [10], epidemic [11]), characterizing their capacity and limitations. Other works have shown that applying quantum communications principles for entanglement generation and distribution in opportunistic [12], static [13], and large-scale [14] networks can increase performance compared to classic networks, even though with scalability challenges. In this Seminar Topic, we explore how quantum applications can improve routing performance in mobile networks and, vice versa, how mobile networks can support quantum applications. One early work [15] showed that applying Quantum Genetic Algorithms (QGAs) to compute MANET routes can bring route utility closer to the global optimum for proactive routing protocols (e.g., OLSR). Another exploratory work [16] augments AODV, a popular reactive MANET routing protocol, to improve the efficiency for establishing quantum channels between consecutive hops, and proposes considering quantum end-to-end fidelity to select the optimal path. Finally, [17] balances the load for relaying multiple flows over network devices by applying quantum game theory, which increases performance over classical load balancing mechanisms.

Group Members

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References

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3 Performance in QMNs: Capacity, Delay, Buffering

Abstract

The capacity [18] of any wireless network is influenced by several factors [19], including the physical characteristics of the communication channel between nodes, packet arrival process, node density and transmission radius, queuing policy, and nodes' buffer size [20] [21]. Memory buffers at forwarding wireless devices are needed to temporarily store information on its way to the intended recipient, and their policy determines which information to store and for how long. Recent works have studied the impact of buffering and packet lifetime on mobile networks' throughput and delay [22]. Quantum networks need to store quantum states in quantum memories, which requires adaptation of memory technology, size, and queuing disciplines. Recent works studied the capacity [23] [24] and stability [25] of quantum networks. Other works studied delay in quantum networks with buffered nodes [26], and showed that increasing buffer size benefits performance, especially for highly-heterogeneous, nearly saturated networks [27], as it counters the negative effect of decoherence. However, a significant challenge for applying quantum communications to mobile networks is that mobile nodes can be modeled as quantum repeaters that communicate over non-optical channels (e.g., microwaves), which makes entanglement generation more difficult than it is for optical channels [28]. Recent works have studied the capacity of quantum switches, which distribute entanglement over a set of nodes connected via optical links [29] [30]. Such capacity models and, more generally, entanglement distribution analyses, could be extended to characterize the communication capacity among a set of neighboring mobile nodes that are "connected" by non-optical links. In this Seminar Topic, we investigate recent advances in models to predict capacity and delay in mobile networks when communication links between nodes are quantum channels.

Group Members

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References

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4 Media Access Control in QMNs

Abstract

When a wireless station receives simultaneous data packet transmissions, it may be unable to decode the information contained in the transmitted packets and therefore the senders need to retransmit the information later, causing a reduction of the network's overall performance in capacity, end-to-end throughput, and delay. Media Access Control (MAC) protocols aim at reducing packet interference by preventing simultaneous transmissions from interfering at receivers. Recent works have modeled the capacity of networks based on the CSMA/CA MAC protocol when the traffic is non-saturated and the topology is fully-connected [31] or partially-connected [32]. However, in quantum networks, communication links between nodes lay over quantum channels, which follow different physical laws than classical channels and require mobile nodes to use specialized MAC protocols to regulate simultaneous channel access by multiple users. Several works proposed MAC protocols in Quantum Networks to schedule channel access and reduce packet retransmission by exploiting the properties of the quantum channels [33]–[36]. Other works propose scheduling optimization to improve network utility directly [37], [38]. In this Seminar Topic, we explore the impact of specialized Quantum MAC protocols on network performance.

Group Members

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References

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5 Effects of Mobility Patterns on QMN Performance

Abstract

Research has studied several node mobility models and their impact on capacity [39] and delay performance of mobile networks (e.g., i.i.d./non-i.i.d. [40], generalized i.i.d. [41], random walk [42], correlated [43], and general [44] mobilities). Depending on the node mobility models [45], and the presence or absence of fixed infrastructure [46], different types of mobile networks arise, each with specific characteristics. For example, MANETs (slow mobility), vehicular networks (high mobility, constrained degrees of freedom, possible presence of infrastructure), FANETs (high mobility, high degrees of freedom), and satellite networks (high mobility, predictable trajectories, infrastructure). Researchers have recently modeled the capacity of quantum networks composed of fixed nodes [23], [24]. However, the impact of quantum nodes' mobility on the network performance (e.g., link instability, topology changes, rerouting) is still unknown. In this Seminar Topic, we aim to find analogies between performance models of classical mobile networks and quantum fixed networks, to speculate how a joint capacity model for mobile quantum networks can benefit from the advances in both fields to reach a unified capacity model for quantum mobile networks.

Group Members

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References

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6 Age of Information in QMNs

Abstract

The computer networking community has long been working on the complex issue of maximizing the freshness of the information delivered to devices in a mobile network. Researchers have proposed a large number of models to quantify the tradeoff between the age of information and data throughput in single-hop broadcast network [47], [48], and methods to optimize the network's offered load to minimize age of information for isolated queues [49] and ad hoc networks (vehicular [50] and multi-hop [51]). Researchers have also studied models to describe the Age of Information (AoI) in networks where communication links are unstable and the information is propagated opportunistically (gossip networks) [52], [53]. Distributed quantum applications, as computing, require to share entanglement, where the entanglement is subject to a progressive degradation over time (decoherence) which imposes stringent conditions on the quantum networks' capacity. Future quantum applications that will operate on mobile networks with potentially unstable links between nodes will require new models to characterize and optimize how the age of information is distributed over mobile devices in Quantum Mobile Networks. For instance, [54] proposes a scheme to reduce the communication delay in Quantum wireless multi-hop communication. This Seminar Topic explores how current age-of-information models for classical networks can be extended to characterize the AoI in networks that contain quantum communication channels.

Group Members

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References

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7 Physical Implementations of Quantum Channels in QMNs

Abstract

The physical implementations of mobile quantum are limited by the fundamental differences between classical and quantum information. In particular, the necessity to generate and detect a single photon as an information carrier imposes that quantum communication can only be established in the optical range with our current technology. Therefore, the realistic implementation of future mobile quantum networks will be led by satellite-ground or satellite-satellite links, or by flying platforms such as drones [55]–[60]. Recent works [28] show the potential of using microwave channels for quantum communication, but highlight that this field is still in its infancy. This Seminar Topic introduces the students to the physical limits and constraints that characterize quantum communications.

Group Members

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References

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8 Simulation Tools for QMNs

Abstract

Several tools have been developed for the simulation of quantum network [61]–[66]. One promising tool is QuISP [64] a module built for OMNeT++, a component-based, C++ discrete-event network simulator, used primarily for executing classical-network simulations. In this Seminar Topic, we discuss the features and potential of quantum network simulation tools, focusing on QuISP.

- SeQUeNCe [61]: https://github.com/sequence-toolbox/SeQUeNCe
- QuNetSim [62]: https://tqsd.github.io/QuNetSim/
- NetSquid [63]: https://netsquid.org/
- QuISP [64]: https://aqua.sfc.wide.ad.jp/quisp_website/
- SimulaQron [65]: http://www.simulaqron.org/
- Squanch [66]: https://att-innovate.github.io/squanch/overview.html

Group Members

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References

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