Workshop on Entanglement-Assisted Communication Networks

Eurecom, France, September 10–12, 2025

Program and Booklet of Abstracts

Organizers:

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Local Organization:

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Entanglement-Assisted Communication Networks

On September 10–12, 2025, the Workshop on Entanglement-Assisted Communication Networks (EACN) took place at Eurecom, France.

EACN Workshop Website: `https://eacn2025.eurecom.fr/`

Topics of Interest

Shared entanglement is widely acknowledged as the key enabler to future quantum information processing tasks. Yet, from a technological perspective, it has remained largely unclear how exactly one should approach the transfer from ideas and laboratory experiments to actual technology. In particular this is true for the domain of quantum communication. To find answers to multidisciplinary questions connecting theory, experiment and network design, this interdisciplinary workshop focuses on entanglement as a resource assisting classical communication systems, covering topics such as Quantum Memories, Quantum Simulators, Entanglement Generation and Quantum Security. We welcome participants from academic institutions, research labs and industry.

Thanks

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About this booklet

This booklet contains hyperlinks to help you navigate:

- Clicking a talk title in the schedule takes you to the abstract
- Clicking the talk date/time in the abstract takes you back to the schedule
- Clicking the name of a chair opens their email address

Contents

Wednesday, September 10

09:00 **Director of Eurecom** — Welcome and Opening Remarks

09:15 **Matthieu Bloch** — Towards Robust and Resource-Efficient Covert Quantum Communication over Bosonic Channels

10:15 **Coffee Break**

10:45 **Ilja Gerhardt** — What is entanglement?

11:15 **Farzin Salek** — Three-Receiver Quantum Broadcast Channels: Classical Communication with Quantum Non-unique Decoding

11:45 **Zahra Khanian** — Unified Framework for Quantum Reverse Shannon Theorem

12:15 **Lunch** — Elysee Restauration, 950 Rte des Colles, 06410 Biot

13:30 **Organization Session**

13:45 **Saikat Guha** — Bringing quantum communication in optical domain from theory to practice

14:45 **Omar Fawzi** — Channel coding: algorithmic aspects and non-signalling correlations

15:15 **Coffee Break**

15:45 **Igor Litvin** — Phase stabilization and calibration techniques for high-fidelity integrated photonic processors

16:15 **Poster Lightning Talks**

16:45 **Poster Session and Coffee**

19:00 **Buffet Dinner**

Thursday, September 11

09:00 **Sebastien Tanzilli** — A Quantum-safe network across the French Riviera: operation, performance, and future

09:55 **Coffee Break**

10:15 **Caspar Hopfman** — Mobile and industrial-compatible entangled photon pair sources for scalable quantum communication networks

10:45 **Romain Alleaume** — Quantum cryptography from decoherence and short-term computational assumptions

11:15 **Marc Geitz** — Towards the Quantum Internet

11:45 **Lunch** — Elysee Restauration, 950 Rte des Colles, 06410 Biot

13:00 **Lab Tour and Sightseeing**

Friday, September 12

09:00 **Robin Kaiser** — Trapping photons with atoms

09:55 **Coffee Break**

10:15 **Matteo Rosati** — Secure and Distributed Information Processing over Quantum Networks

10:45 **Benedikt Baier** — Combined Physical and Link Layer Protocols for Quantum Networks

11:15 **Kambiz Jamshidi** — Quantum Random Bit Generation using Degenerate Optical Parametric Oscillations

11:45 **Lunch** — Elysee Restauration, 950 Rte des Colles, 06410 Biot

13:00 **Organization Session**

13:30 **Holger Boche** — Feynman Meets Turing: Uncomputability of Quantum Gate-Circuit Emulation

14:00 **Marco Ruffini** — Towards a Quantum Internet: Entanglement Distribution over Existing Fibre-Optic Telecom Networks

14:30 **Coffee Break**

14:50 **Marc Olivier Renou** — Distributed Quantum Advantage for Local Problems

15:20 **Matheus Sena** — From the lab to the streets of Berlin: entanglement distribution, multiplexing and routing over field-deployed fibers

15:50 **Panel discussion**

16:50 **Conclusion and Farewell**

Posters and Demos

The poster and demo session hosted the following scientific posters and demos:

Quantum Multiuser Coordination
Husein Natur

Quantum Secret Sharing Rates
Gabrielle Lalou

Tessellated distributed computing of non-linearly separable functions
Ahmad Tanha

Network oblivious transfer: An information theoretical view
Hadi Aghaee

Hardware Root of Trust: Quantum PUF based security
Nilesh Kumar

Capacity Formulas for the Lossy Bosonic Compound Wiretap Channel
Florian Seitz

Simultaneous Decoding of Coset Codes over Quantum Interference and Quantum Broadcast Channels: An Information Theoritic Study
Fatma Gouiaa

Talks

Towards Robust and Resource-Efficient Covert Quantum Communication over Bosonic Channels
Matthieu Bloch

What is entanglement?
Ilja Gerhardt

Three-Receiver Quantum Broadcast Channels: Classical Communication with Quantum Non-unique Decoding
Farzin Salek

Unified Framework for Quantum Reverse Shannon Theorem
Zahra Khanian

Bringing quantum communication in optical domain from theory to practice
Saikat Guha

Channel coding: algorithmic aspects and non-signalling correlations
Omar Fawzi

Phase stabilization and calibration techniques for high-fidelity integrated photonic processors
Igor Litvin

A Quantum-safe network across the French Riviera — operation, performance, and future
Sebastien Tanzilli

Mobile and industrial-compatible entangled photon pair sources for scalable quantum communication networks
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Quantum cryptography from decoherence and short-term computational assumptions
Romain Alleaume

Towards the Quantum Internet
Marc Geitz

Trapping photons with atoms
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Secure and Distributed Information Processing over Quantum Networks
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Quantum Random Bit Generation using Degenerate Optical Parametric Oscillations
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Holger Boche

Towards a Quantum Internet: Entanglement Distribution over Existing Fibre-Optic Telecom Networks
Marco Ruffini

Towards Robust and Resource-Efficient Covert Quantum Communication over Bosonic Channels

Matthieu Bloch Wednesday, September 10, 09:15

The emerging Quantum Internet, envisioned as an entanglement sharing network, aims to enable distant computers, transceivers, and sensors to process information in a coordinated manner. Recent theoretical and experimental findings support the feasibility of these networks and underscore the advantages of quantum operations, ranging from enhanced security to improved sensing capabilities. However, entanglement is expected to remain a high-cost resource for the foreseeable future, necessitating the development of efficient schemes and protocols for entanglement resource allocation. In this talk, we will present two theoretical findings that contribute to the design and development of a robust and efficient Quantum Internet. Firstly, we will re-examine the issue of entanglement-assisted communications over bosonic channels and present a bound for the performance of Phase Shift Keying (PSK)-modulated Two-Mode Squeezed Vacuum (TMSV) communication. This bound, which is non-asymptotic in the physical parameters of the bosonic channel, offers insights into the threshold where quantum benefits begin to manifest. Secondly, we will revisit the issue of entanglement-assisted covert communication over bosonic channels as an application. We will demonstrate that two-layer coding allows for the advantageous use of entanglement with significantly fewer TMSV pairs than previously reported.

Three-Receiver Quantum Broadcast Channels: Classical Communication with Quantum Non-unique Decoding

Farzin Salek Wednesday, September 10, 11:15

In network communication, it is common in broadcasting scenarios for there to exist a hierarchy among receivers based on information they decode due, for example, to different physical conditions or premium subscriptions. This hierarchy may result in varied information quality, such as higher-quality video for certain receivers. This is modeled mathematically as a degraded message set, indicating a hierarchy between messages to be decoded by different receivers, where the default quality corresponds to a common message intended for all receivers, a higher quality is represented by a message for a smaller subset of receivers, and so forth. We extend these considerations to quantum communication, exploring three-receiver quantum broadcast channels with two- and three-degraded message sets. Our technical tool involves employing quantum non-unique decoding, a technique we develop by utilizing the simultaneous pinching method. We construct one-shot codes for various scenarios and find achievable rate regions relying on various quantum Rényi mutual information error exponents. Our investigation includes a comprehensive study of pinching across tensor product spaces, presenting our findings as the asymptotic counterpart to our one-shot codes. By employing the non-unique decoding, we also establish a simpler proof to Marton's inner bound for two-receiver quantum broadcast channels without the need for more involved techniques. Additionally, we derive no-go results and demonstrate their tightness in special cases.

Unified Framework for Quantum Reverse Shannon Theorem

Zahra Khanian Wednesday, September 10, 11:45

Reverse Shannon theorems concern the use of noiseless channels to simulate noisy ones. This is dual to the usual noisy channel coding problem, where a noisy (classical or quantum) channel is used to simulate a noiseless one. The Quantum Reverse Shannon Theorem is extensively studied by Bennett and co-authors in [IEEE Trans. Inf. Theory, 2014]. They present two distinct theorems, each tailored to classical and quantum channel simulations respectively, explaining the fact that these theorems remain incomparable due to the fundamentally different nature of correlations they address. The authors leave as an open question the challenge of formulating a unified theorem that could encompass the principles of both and unify them. We unify these two theorems into a single, comprehensive theorem, extending it to the most general case by considering correlations with a general mixed-state reference system. Furthermore, we unify feedback and non-feedback theorems by simulating a general side information system at the encoder side.

Bringing quantum communication in optical domain from theory to practice

Saikat GUHA Wednesday, September 10, 13:45

Quantum resources could play various roles in future optical communications networks. Examples include: achieving high photon information efficiencies using quantum receivers in the low-received-photon-flux regime, boosting classical communications rate using pre-shared entanglement among the transmitter and the receiver in the high-noise low-transmitter-brightness regime, small-signal quantum light piggybacking on bright modulated classical laser light pulses for boosting network resilience, and novel high-order quantum optical modulation formats enabling capacity-approaching entanglement generation among quantum memory registers separated by an optical channel. In this talk, I will discuss open theory problems, state of the art experimental realizations, and practical challenges that lie ahead in bringing the exciting theory ideas into practice.

Channel coding: algorithmic aspects and non-signalling correlations

Omar FAWZI Wednesday, September 10, 14:45

We consider the problem of reliable information transmission between parties connected by a noisy communication channel and study two related questions. The first one is the computational complexity of determining optimal encoding strategies and the second one is the effect of non-signalling resources shared between the parties on the communication capacity. I will focus on classical multiple access channels and broadcast channels, and if time permits, I will discuss quantum channels. The talk will mostly be based on https://arxiv.org/abs/1508.04095, https://arxiv.org/abs/2206.10968 and https://arxiv.org/abs/2310.05515.

Phase stabilization and calibration techniques for high-fidelity integrated photonic processors

Igor Litvin Wednesday, September 10, 15:45

Multimode photonic processors—reconfigurable interferometers realised in low-loss stoichiometric silicon nitride—are central to large-scale optical quantum and classical information processing. Their performance, however, is limited by phase jitter from active cooling and by fabrication-induced phase- and amplitude errors. We demonstrate a self-referenced feedback loop that drives an on-chip phase shifter, cutting multiport phase fluctuations by over an order of magnitude and enabling stable, repeatable 2x2 Hadamard operations. We then introduce a calibration protocol that iteratively compares measured and ideal transfer matrices to retune each Mach–Zehnder and external phase shifter, eliminating systematic errors and paving the way for high-fidelity optical transforms in advanced photonic processors.

Mobile and industrial-compatible entangled photon pair sources for scalable quantum communication networks

Caspar Hopfman Thursday, September 11, 10:15

The development of scalable quantum communication networks critically depends on reliable sources of entangled photons. Conventional approaches based on parametric down-conversion have been widely adopted due to their simplicity but are fundamentally limited by Poissonian photon statistics, restricting their usefulness for large-scale multipartite networks and quantum repeater systems. In contrast, deterministic quantum emitters such as semiconductor quantum dots (QDs) offer Fock state-like photon number distributions and thus the potential to deliver on-demand entangled photon pairs with high efficiency, fidelity, and indistinguishability—key requirements for Bell-state interference and distributed quantum information processing. Among these, droplet-etched GaAs QDs have emerged as particularly promising, providing highly entangled photon pairs via the resonantly driven exciton–biexciton cascade. However, practical deployment of such sources is hindered by their reliance on cryogenic operation and the need for compact, fiber-coupled integration compatible with existing communication infrastructure. Here we demonstrate an ultra-compact, fiber-coupled quantum light source based on single GaAs QDs embedded in monolithic microlenses and interfaced with a lensed single-mode fiber. A 3D-printed micro-objective (NA = 0.6) integrated directly in the cryogenic environment (3.8 K) enables near-diffraction-limited coupling with 600 nm resolution. Using two-photon resonant excitation, the device achieves high single-photon emission rates of 392 kHz with purities of 99.2%, and generates near-maximally entangled photon pairs with peak entanglement negativities of 2n = 0.96. The system combines state-of-the-art quantum light source performance with long-term stability in a dramatically reduced footprint, representing a significant step toward practical, industrial-scale quantum network implementations.

Quantum cryptography from decoherence and short-term computational assumptions

Romain ALLEAUME Thursday, September 11, 10:45

We introduce an explicit construction for a key distribution protocol in the Quantum Computational Timelock (QCT) security model, where one assumes that computationally secure encryption may only be broken after a time much longer than the coherence time of available quantum memories. Taking advantage of the QCT assumptions, we build a key distribution protocol called HM-QCT from the Hidden Matching problem for which there exists an exponential gap in one-way communication complexity between classical and quantum strategies. We establish that the security of HM-QCT against arbitrary i.i.d. attacks can be reduced to the difficulty of solving the underlying Hidden Matching problem with classical information. Legitimate users, on the other hand, can use quantum communication, which gives them the possibility of sending multiple copies of the same quantum state while retaining an information advantage. This leads to an everlasting secure key distribution scheme over n bosonic modes. Such a level of security is unattainable with purely classical techniques. Remarkably, the scheme remains secure with up to $\mathrm{O}(\mathrm{n}\sqrt{log(n)})$ input photons for each channel use, extending the functionalities and potentially outperforming QKD rates by several orders of magnitudes.

Towards the Quantum Internet

Marc Geitz Thursday, September 11, 11:15

Telecommunication operators are expected to play a pivotal role in enabling future quantum communication networks. This talk will present Deutsche Telekom / T-Labs' ongoing efforts to explore key technological challenges, investigate architecture options and prepare for the deployment of quantum network infrastructures.

Trapping photons with atoms

Robin Kaiser Friday, September 12, 09:00

Cold atoms have emerged as an efficient medium to store photons. In this talk, I will discuss several phenomena to trap photons in large clouds of cold atoms.

Secure and Distributed Information Processing over Quantum Networks

Matteo Rosati Friday, September 12, 10:15

As quantum networks become increasingly viable, a natural question arises: what kinds of information processing will they enable? In this talk, we explore a class of applications where quantum communication supports secure, distributed protocols between a powerful quantum provider and end-users with limited quantum capabilities. We present two protocols that exemplify this framework. The first is a secure delegated quantum sensing scheme, in which a client performs quantum-enhanced sensing using entangled probes remotely prepared by a provider. The protocol remains secure against collective attacks, preserving the privacy of the client's sensing target and outcome. The second is a distributed quantum bit commitment protocol, achieving binding and concealing commitments between spatially separated parties—an important foundational primitive, whose implementation leverages LOCC constraints among the users. These results highlight how quantum communication can enable asymmetric, yet secure, collaboration between network nodes—suggesting new use-cases for the emerging quantum internet infrastructure.

Combined Physical and Link Layer Protocols for Quantum Networks

Benedikt Baier Friday, September 12, 10:45

Future communication systems are expected to integrate quantum networks to enable highly secure communication and enhance computational capabilities. In quantum networks, communication is accomplished by sharing entanglement between remote locations, which is the basis for most known quantum protocols. Entanglement is a correlation between qubits that is not reproducible with classical means. However, as entanglement is susceptible to noise limiting its range, quantum repeaters can enable entanglement over more considerable distances. Using the entanglement swapping protocol, quantum repeaters can be placed between remote locations to establish entanglement. This requires each repeater to first generate entanglement with its neighboring nodes, named entanglement generation. However, as the size of current quantum networks is limited, the development and evaluation of quantum networks and quantum protocols is based on simulations. To simulate quantum networks accurately, accurate and high-performance models of the entanglement generation process must be employed. This paper proposes two new models for generating entanglement in simulations and develops quantum protocols for generating and purifying entanglement. The protocols are evaluated in thorough simulations under perfect and realistic conditions regarding delay and fidelity. Furthermore, the accuracy and runtime of the models are evaluated. The results show the models are accurate, with delay primarily influenced by the source duration, while longer coherence times significantly enhance fidelity. The model runtimes are consistently shorter than the simulation runtimes across all protocols, averaging about 2% of the total simulation time.

Quantum Random Bit Generation using Degenerate Optical Parametric Oscillations

Kambiz Jamshidi Friday, September 12, 11:15

An integrated all-optical quantum random number generator (QRNG) will be introduced. The idea is based on the bi-phase states of degenerate optical parametric oscillators (DOPOs), implemented using a silicon nitride microresonator. Silicon nitride-based microring resonators using two pumps are used for this purpose. The required hardware and the parameters required for this purpose will be discussed.

Towards a Quantum Internet: Entanglement Distribution over Existing Fibre-Optic Telecom Networks

Marco Ruffini Friday, September 12, 14:00

Quantum computing has advanced rapidly over the past decade, with architectures supporting ever larger numbers of qubits now emerging. To fully unlock their potential, these systems must be complemented by quantum networks, whose operation fundamentally relies on the reliable distribution of entanglement. Such networks will enable the formation of scalable clusters of quantum processors and the interconnection of quantum resources across metropolitan and long-haul distances. This talk explores the feasibility of deploying quantum networks over existing fibre-optic telecommunications infrastructure. We discuss strategies for distributing entanglement by reusing deployed optical cables, including scenarios where quantum signals coexist with classical data traffic on the same fibres. In addition, the talk examines how the exchange of classical information, essential for entanglement distribution, purification, and related protocols, can be efficiently supported by conventional IP-based networks, with an analysis of the resulting performance implications.

Distributed Quantum Advantage for Local Problems

Marc-Olivier RENOU Friday, September 12, 14:50

This talk addresses a central question: which problems admit a distributed quantum advantage? In other words, if we replace classical computers in a network with quantum computers, and classical communication channels with quantum ones, which distributed

tasks can be solved faster?
I will work within the framework of distributed algorithms in a synchronous setting, where multiple processing units collaborate on a distributed problem using local computation and communication with their neighbors. I will focus on scenarios where large distances form the main bottleneck, assuming unlimited bandwidth and local computational power. This corresponds to the LOCAL model of distributed algorithms.
I will show that, for the problem of distributed c-coloring of graphs already known to be x-colorable, there is essentially no quantum advantage. On the other hand, I will present the first local problem that exhibits a super-constant quantum advantage in the LOCAL model of distributed computing.
The talk is based on the works: "No distributed quantum advantage for approximate graph coloring" (STOC 2024, pp. 1901–1910), "Online locality meets distributed quantum computing" (STOC 2025, arXiv:2403.01903), and "Distributed quantum advantage for local problems" (STOC 2025, arXiv:2411.03240).

From the lab to the streets of Berlin: entanglement distribution, multiplexing and routing over field-deployed fibers

Matheus Sena Friday, September 12, 15:20

The Quantum Internet is set to revolutionize telecommunications by enabling capabilities beyond the reach of classical networks. A key step toward this vision is the seamless integration of entanglement distribution into existing telecommunication infrastructure. We demonstrate a real-world quantum networking testbed deployed on Deutsche Telekom's metropolitan fiber network in Berlin. Using commercially available devices and standard multiplexing techniques, quantum signals coexist with conventional data traffic without requiring dedicated fibers or infrastructure modifications. Active stabilization ensures robust and long-term operation under real-world conditions. Our results establish practical deployment benchmarks and provide a clear roadmap for integrating quantum capabilities into current telecom networks, paving the way toward large-scale quantum communication.

Participants

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Ilja Gerhardt	*Institute of Solid State Physics*
Farzin Salek	*Technical University of Munich*
Zahra Khanian	*Technical University of Munich*
Saikat Guha	*University of Maryland*
Omar Fawzi	*Ecole Normale Supérieure de Lyon*
Igor Litvin	*CSIR National Laser Centre*
Sebastien Tanzilli	*Institut de Physique de Nice, CNRS, Université Côte d'Azur, France*
Caspar Hopfmann	*Technische Universität Dresden*
Romain Alleaume	*Telecom Paris*
Marc Geitz	*Deutsche Telekom*
Robin Kaiser	*CNRS, Institut de Physique de Nice, INPHYNI, Université Côte d'Azur*
Matteo Rosati	*Università Roma Tre*
Benedikt Baier	*TU Munich*
Kambiz Jamshidi	*Technische Universität Dresden*
Holger Boche	*TUM School of Computation, Information and Technology*
Marco Ruffini	*University of Dublin, Trinity*
Marc Olivier Renou	*Inria Paris-Saclay,CPHT, Ecole polytechnique, Institut Polytechnique de Paris*
Matheus Sena	*Deutsche Telekom*
Husein Natur	*Israel Institute of Technology*
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