Workshop on Entanglement-Assisted Communication Networks

Bad Honnef, Germany, February 03–06, 2022

Program and Booklet of Abstracts

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Boulat Bash	Christian Deppe	Janis Nötzel
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Benjamin Kambs	Marianne Lenzen	Uzi Pereg
Matteo Rosati	Simon Sekavčnik	

ENTANGLEMENT-ASSISTED COMMUNICATION NETWORKS

On February 03–06, 2022, the Workshop on Entanglement Assisted Communication Networks (EACN) will take place at Physikzentrum Bad Honnef. This event is a joint workshop of the Emmy Noether Group "Theoretical Quantum System Design" supported by the Deutsche Forschungsgemeinschaft (DFG) and the Institute for Communications Engineering supported by the German Federal Ministry of Education and Research (BMBF) with the project QR.X.

EACN Workshop Website: `https://mcqst.de/news-and-events/eacn-2022/`

Topics of interest

Will quantum communication reshape classical network design? What will be the next technological breakthrough in quantum communication? This interdisciplinary workshop focusses on entanglement as a resource assisting classical communication systems. We welcome participants from academic institutions, research labs and industry. Selected approaches to entanglement-assisted communication will be presented, along with insights into the status of repeater technology, sensing, quantum networks, technical advancements in entanglement-based Quantum Key Distribution and theoretical insights.

Thanks

The organizers acknowledge funding by the DFG via grant NO 1129/2-1 and by the Bundesministerium für Bildung und Forschung via grant 16KISQ028 and 16KISK001 and 16KISK002 and thank the MCQST for supporting us.

About this booklet

This booklet contains hyperlinks to help you navigate:

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- Clicking the talk date/time in the abstract will take you to the schedule
- Clicking the name of a chair will open their email address

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Thursday, February 9

15:30	*— Coffee and Sandwiches —*	
16:15	*— Welcome —*	
16:30	Dan Kilper Chair: Boulat Bash	Driving Forces in Systems Research: from Optical Transmission to Quantum-Optical Transmission (20' + 10')
17:00	Poster Session	
18:30	*— Dinner —*	
19:30	Matthieu Bloch Chair: Boulat Bash	Quantum secured networks? (20')
20:00		Open Round

Friday, February 4

S1	**QR.X Session**	**Chair: Christian Deppe**
9:00	Christoph Becher	Towards elementary quantum repeater links – an overview on the research network QR.X (30’)
9:30	Tim van Leent	Experimental device-independent quantum key distribution (30’ + 15’)
10:15	*— Coffee Break —*	
10:35	Jon Finley	Hardware for semiconductor-based quantum repeater technologies (30’ + 15’)
11:20	Alexander Kubanek	Towards Quantum Repeater based on SiV-center in Diamond (30’ + 15’)
12:05	Peter van Loock	Analytical Quantum Repeater Modelling (30’ + 15’)
13:00	*— Lunch —*	
14:00	Christine Silberhorn	Quantum communication with nonlinear integrated optics and pulsed light (20’ + 10’)
14:30	Christine Silberhorn	PANEL DISCUSSION: Quantum Repeater (45’)
15:15	*— Coffee Break —*	

S2	**Technical Quantum Modelling Session**	**Chair: Janis Nötzel**
15:35	Lee Ray-Kuang	Machine-learning enhanced quantum state tomography (10’ + 5’, online)
15:50	Alexander Streltsov	Catalytic Transformations of Pure Entangled States (10’ + 5’)
16:05	Christian Kurtsiefer	Quantum communication in urban networks and single photon engineering (10’ + 5’)
16:20	*— Coffee Break —*	
17:10	Riccardo Bassoli	Practical quantum networks for 6G: requirements and limitations – a theoretical perspective (10’ + 5’, online)
17:25	Francisco Elohim Becerra	Non-Gaussian optical measurements surpassing the quantum noise limit (10’ + 5’, online)
17:40	Boulat Bash	PANEL DISCUSSION: Panel on Proper Modelling (45’)
18:15		Platform meetings (QR.X / 45’)
19:15	*— Conference Dinner —*	

Saturday, February 5

S3	**Industry/Field Trials**		**Chair: Christian Deppe**
09:00	Marc Geitz	The OpenQKD/QR.X Testbed in Berlin (15’ + 5’)	
09:20	Sebastian Schaile	Compact Cooling Solutions (15’ + 5’)	
09:40	Adrià Sansa Perna	Entanglement-based QKD, from Lab to Fab (15’ + 5’)	
10:00	Bart Van der Vecht	Application programming for the quantum internet (15’ + 5’)	
10:20	*— Coffee Break —*		
10:40	Manfred Lochter	Quantum Key Distribution from a security perspective: developments and issues (15’ + 5’)	
11:00	Manfred Lochter	PANEL DISCUSSION: Challenges in Field Trials, Prototyping, and Product Development (30’)	
11:30		Open Round (30’)	
13:00	*— Lunch —*		
S4	**Networks and Sensing**		**Chair: Uzi Pereg**
14:00	Caspar Hopfmann and Riccardo Bassoli	Practical quantum networks for 6G: requirements, limitations and perspectives – an experimentalist perspective (15’ + 5’)	
14:20	Wenhan Dai	Entanglement Swapping Protocols for Quantum Networks (15’ + 5’, online)	
14:40	Kirill Fedorov	Quantum teleportation of propagating microwaves (15’ + 5’)	
15:00	*— Coffee Break —*		
15:20	Amit Ashok	Quantum-inspired Optical Super-resolution Imaging (15’ + 5’)	
15:40	Animesh Datta	Quantum light microscopy and spectroscopy (15’ + 5’, online)	
16:00	*— Coffee Break —*		
16:30	Andreas Winter	PANEL on Quantum Networks	
18:30	*— Dinner —*		

Sunday, February 6

S5	**Quantum Receiver Technology**		**Chair: Janis Nötzel**
09:00	Marcin Jarzyna	Quantum receivers in optical communication (15’ + 5’)	
09:20	Michal Jachura	Joint detection receivers in photon-efficient communication and quantum key distribution (15’ + 5’)	
09:40	*— Coffee Break —*		
10:00	Michał Parniak	Quantum memory time-frequency processor for collective measurements (15’ + 5’)	
10:20	Janis Nötzel	PANEL: outlook, the role of quantum communications in 6G	
11:30	*— Good Bye —*		
12:00	*— Lunch —*		

POSTERS

The poster session will host the following scientific posters:

Semi-quantum key distribution
Konrad Banaszek

QKD mission – Quantsat-PT Cubesat
Vladlen Galetsky

Discussion on design principles towards quantum enabled communication networks
Thomas Hühn and Julius Schulz-Zander

Quantum Clustering for Nonlinear Noise Mitigation in Fibre Communication Systems
Ark Modi

Reducing energy consumption of fiber networks via quantum communication technology
Janis Nötzel and Matteo Rosati

Quantum memory time-frequency processor for collective measurements
Michał Parniak

Communication with Unreliable Entanglement Assistance
Uzi Pereg

Compact Cooling Solutions
Sebastian Schaile

Simultaneous transmission of classical and quantum information under channel uncertainty and jamming attacks
Sajad Saeedinaeeni

Quantum link emulation in Software defined networks
Simon Sekavcnik

Quantum Semantic Security
Nicolo Toniolo

Furthermore, posters about various research projects connected to this workshop will be presented.

TALKS

Quantum-inspired Optical Super-resolution Imaging

Amit Ashok Saturday, February 5, 15:20, 15' + 5'

Traditionally, the resolving power of passive optical imaging systems was thought to be determined by the Rayleigh resolution limit. However, a rigorous analysis of the two-point resolution problem by Tsang et al. and others, using Quantum information theory, has demonstrated that the Rayleigh limit is not fundamental. In fact, we now know that the fundamental quantum optical resolution limit can be achieved by spatial mode de-multiplexing (SPADE) or mode sorting measurements. In this talk, I will discuss our work on pursuing a broader understanding and analysis of the quantum limits of passive optical imaging in the sub-Rayleigh domain (i.e., optical super-resolution) for more complex scenes (such as point source constellations, continuous line sources etc.). This includes exploring the impact of optical coherence on resolution as well as quantifying the performance of adaptive imaging systems within a Bayesian inference framework.

Practical quantum networks for 6G: requirements and limitations – a theoretical perspective

Riccardo Bassoli Friday, February 4, 17:10, 10' + 5', online

In recent years quantum networks have attracted enormous interest due to their enticing promises such as distributed quantum computing [1], ultra-precise remote synchronization [2] and distributed quantum sensing combined with inherent physically secure communication schemes [3]. While these perspective use-cases and applications have been analyzed from a theoretical view point, the experimental realization of such systems remains a major challenge. In order to tackle this challenge and realize first practical quantum networks a keen understanding of the current state-of-the-art, the required components as well as their limitations is fundamental. This essential background knowledge will inform current and future research foci of both theory and experiment and enable identification of possible alternatives to existing quantum network paradigms. An example for such an alternative approach are photon graph states – and in particular cluster states – which open up new possibilities for the realization of robust multi-partite entanglement distribution in future quantum networks. Recent experimental advances on photonic graph [4] and cluster-states [5], high throughput entangled photon pair sources [6], memory-enhanced entanglement distribution [7] and entanglement swapping [8] bring the goal of practical realization of scalable quantum networks ever closer to reality and promise exciting new perspectives.

[1] R. Van Meter and S. J. Devitt, "The Path to Scalable Distributed Quantum Computing," Computer, vol. 49, pp. 31-42, 2016.

[2] P. Kómár, E. M. Kessler, M. Bishof, L. Jiang, A. S. Sørensen, J. Ye and M. D. Lukin, "A quantum network of clocks," Nature Physics, vol. 10, p. 582–587, 2014.

[3] Y.-A. Chen, Q. Zhang, T.-Y. Chen, W.-Q. Cai, S.-K. Liao, J. Zhang, K. Chen, J. Yin, J.-G. Ren, Z. Chen, S.-L. Han, Q. Yu, K. Liang, F. Zhou, X. Yuan, M.-S. Zhao, T.-Y. Wang, X. Jiang, L. Zhang, W.-Y. Liu, Y. Li, Q. Shen, Y. Cao, C.-Y. Lu, R. Shu, J.-Y. Wang, L. Li, N.-L. Liu, F. Xu, X.-B. Wang, C.-Z. Peng and J.-W. Pan, "An integrated space-to-ground quantum communication network over 4,600 kilometres," Nature, vol. 589, p. 214–219, 2021.

[4] X.-L. Wang, Y.-H. Luo, H.-L. Huang, M.-C. Chen, Z.-E. Su, C. Liu, C. Chen, W. Li, Y.-Q. Fang, X. Jiang, J. Zhang, L. Li, N.-L. Liu, C.-Y. Lu and J.-W. Pan, "18-Qubit Entanglement with Six Photons' Three Degrees of Freedom," Phys. Rev. Lett., vol. 120, no. 26, p. 260502, 6 2018.

[5] I. Schwartz, D. Cogan, E. R. Schmidgall, Y. Don, L. Gantz, O. Kenneth, N. H. Lindner and D. Gershoni, "Deterministic generation of a cluster state of entangled photons," Science, vol. 354, p. 434–437, 2016.

[6] C. Hopfmann, W. Nie, N. L. Sharma, C. Weigelt, F. Ding and O. G. Schmidt, "Maximally entangled and gigahertz-clocked on-demand photon pair source," Phys. Rev. B, vol. 103, no. 7, p. 075413, 2 2021.

[7] M. K. Bhaskar, R. Riedinger, B. Machielse, D. S. Levonian, C. T. Nguyen, E. N. Knall, H. Park, D. Englund, M. Lončar, D. D. Sukachev and M. D. Lukin, "Experimental demonstration of memory-enhanced quantum communication," Nature, vol. 580, p. 60–64, 2020.

[8] M. Zopf, R. Keil, Y. Chen, J. Yang, D. Chen, F. Ding and O. G. Schmidt, "Entanglement Swapping with Semiconductor-Generated Photons Violates Bell's Inequality," Phys. Rev. Lett., vol. 123, no. 16, p. 160502, 10 2019.

Non-Gaussian optical measurements surpassing the quantum noise limit

Francisco Elohim Becerra Friday, February 4, 17:25, 10' + 5', online

Quantum state discrimination is a central problem in quantum measurement theory, with applications spanning from quantum communication to computation. Quantum mechanics allows for the realization of optimized measurements based on photon counting for the discrimination of nonorthogonal coherent states able to surpass the conventional limits of detection, such as the homodyne and heterodyne limits. Such measurements have a large potential for increasing sensitivities and information transfer in communications and for information processing. In this talk I will describe our current work in the problem of generalized measurements for coherent state discrimination. We implement an optimal inconclusive measurement for binary coherent states [1], a non-projective measurement that allows for achieving the lowest probability of error for a given rate of inconclusive results. This measurement encompasses standard measurement paradigms for state discrimination, specifically minimum error and unambiguous discrimination, and allows to transition between them in an optimal way.

[1] K. Nakahira and T. S. Usuda, Phys.Rev.A 86, 052323 (2012).

Towards elementary quantum repeater links – an overview on the research network QR.X

Christoph Becher Friday, February 4, 9:00, 30'

A quantum repeater [1] enables secure communication in quantum networks based on the distribution of entangled quantum states as a communication resource. In this context, only the concept of quantum repeaters allows for secure communication to be realized over several nodes and thus over arbitrary distances, without having to rely on reliable or secured classical nodes (trusted nodes). The realization of an infrastructure for quantum networks and hardware components for quantum nodes and repeaters is a technically challenging task. Nevertheless, it not only forms the basis for secure quantum communication, but at the same time offers opportunities for other quantum technologies, such as distributed quantum computing or networks of quantum sensors. The German research network "Quantum Repeater Link – QR.X" investigates a bottom-up approach to realizing basic elements of fiber-based quantum repeaters (QR). QR.X employs three different hardware platforms to realize these elements, i.e. trapped neutral atoms and ions, semiconductor quantum dots and color centers in diamond and created a theoretical model to simulate their performance and guide further developments [2]. The talk will present the basic concepts and an overview on recent experimental achievements in QR.X.

[1] H.-J. Briegel et al., Quantum Repeaters: The Role of Imperfect Local Operations in Quantum Communication, Phys. Rev. Lett. 81, 5932 (1998).
[2] P. van Loock et al., Extending Quantum Links: Modules for Fiber- and Memory-Based Quantum Repeaters, Adv. Quantum Technol. 3, 1900141 (2020).

Quantum secured networks?

Matthieu Bloch Thursday, February 9, 19:30, 20’

The massive investments in quantum technologies have spurred renewed interested for quantum communications and their benefits over classical ones. Chief amount these benefits is the ability to exploit the unique properties of quantum states to ensure levels of security unattainable with classical cryptosystems. The prime example of a quantum-secured system is quantum key distribution, which has attracted significant interests over the few decades with both experimental and theoretical success, but recent efforts have also started exploring other security aspects, including covert quantum communications.

In this talk, we will discuss a (very biased) perspective on what the future of quantum secured networks might hold. While, the recent technological progresses in photonics have enabled quantum communications to "leap out of the lab," many challenges remain to address for quantum secured network to become a reality at a large scale. Despite the many remaining hurdles to overcome, current efforts hold many promises, including fostering the convergence of fields of research that have evolved somewhat independently over the last decades: classical information theory, quantum information theory, quantum optics, cryptography, etc. Time permitting, we will highlight examples of such convergence.

Entanglement Swapping Protocols for Quantum Networks

Wenhan Dai Saturday, February 5, 14:20, 15’ + 5’, online

Distributing entanglement between distant nodes is an essential task in quantum networks. Protocols that schedule entanglement swapping operations can significantly affect the entanglement distribution rate. To maximize the entanglement distribution rate, we introduce the concept of e-nodes, representing the entangled quantum bit (qubit) pairs in the network. This concept enables us to design entanglement swapping protocols based on the solutions of some linear programming problems. Moreover, suppose entanglement requests randomly arrive at a network, and the goal is to stabilize the network so that the number of unfinished entanglement requests is bounded with a high probability. For a star-shaped network, we determine the capacity region for the rates of entanglement requests and develop entanglement swapping protocols accordingly.

Quantum light microscopy and spectroscopy

Animesh Datta Saturday, February 5, 15:40, 15’ + 5’, online

I will present two works: The first is an experimental collaboration on microscopy enhanced using pulses of squeezed light. The second is an ongoing theoretical work on estimating the dipole moment of a two-level atom probed by a (travelling) pulse of quantum light. Both involve ingredients necessary for quantum communication networks.

Quantum teleportation of propagating microwaves

Kirill Fedorov Saturday, February 5, 14:40, 15’ + 5’

We demonstrate a successful realization of unconditional quantum teleportation in the microwave regime over the distance of 42 cm by exploiting two-mode squeezing and analog feedforward. We generate squeezed and feedforward signals in the GHz regime by using superconducting Josephson parametric amplifiers. We demonstrate a violation of the no-cloning limit for the teleported states, thus, proving the unconditional security of the protocol. Furthermore, our experiments reveal the influence of the feedforward gain and entanglement strength on the fidelity of teleported states in the presence of finite noise and losses. In the end, we discuss perspectives of microwave quantum communication in the cryogenic environment and beyond, which enables future implementations of microwave quantum local area networks and distributed quantum computing with superconducting circuits.

Hardware for semiconductor-based quantum repeater technologies

Jonathan Finley Friday, February 4, 10:35, 30' + 15'

Amongst the various hardware platforms explored within the QR.X project, semiconductor quantum dots (QDs) have favorable properties that make them suitable for building quantum links operating over optical fiber channels. They have near-unity quantum efficiencies, can emit near transform-limited single photons at rates approaching 1GHz, exhibit high photon indistinguishability (>90% HOM) and can generate entangled photon pairs on demand. Their ability to natively emit in the telecoms O- and C-bands and the possibility to integrate them into advanced quantum photonic devices with photon extraction efficiencies >60%, make them highly attractive as quantum sources for field testing of repeater links.

This talk will give an overview of the activities of the semiconductor groups working in QR.X. We will begin by exploring advances in the growth of exceptionally low noise semiconductor QD nanomaterials and demonstrate the ability to tune emission frequencies from 950nm into the telecoms O- and C-bands. We will summarize the factors currently limiting the performance metrics discussed above and explore how coherent two-pulse quantum state preparation provides several advantages. Experiments and simulations demonstrate that this excitation scheme both suppresses re-excitation processes, that lead to multi-photon errors, while a precisely timed stimulation pulse reduces the timing jitter of emitted photons, leading to improved quantum state indistinguishability. Moreover, we will see how the polarization of the emitted photon can be programmed by the stimulation pulse. We will continue to explore activities related to spin-qubits and spin-photon interfaces in single and coupled QDs and discuss how hole spin qubits promise better coherence properties than electron, by virtue of their weaker coupling to the fluctuating bath of nuclear spins in III-V semiconductors. We will explore how nano-photonic, opto-electronic, and strain-tunable device geometries can enhance the performance metrics of semiconductor-based sources. Finally, we will move from single dots to tunnel coupled pairs of QDs forming electrically tunable molecules. In this context, we will demonstrate electrically tunable coherent coupling of quantum states in the QD-molecule, high-rate quantum light generation and selective all optical spin-qubit preparation. Such QD-molecule devices are capable of hosting two interacting spin qubits with the potential to deterministically generate 2D photonic repeater graph states for measurement-based quantum communication protocols.

The OpenQKD/QR.X Testbed in Berlin

Marc Geitz Saturday, February 5, 09:00, 15' + 5'

The Berlin OpenQKD Testbed demonstrates the integration of QKD technology into a field installed network infrastructure using a PQC secured key management system and hybrid key exchange protocols to secure communication applications. Within QR.X, the testbed's quantum layer will be enhanced to run entanglement based QKD, demonstrate entanglement swapping and a teleportation experiment under industry lab conditions.

Practical quantum networks for 6G: requirements, limitations and perspectives – an experimentalist perspective

Caspar Hopfmann and Riccardo Bassoli Saturday, February 5, 14:00, 15' + 5'

In recent years quantum networks have attracted enormous interest due to their enticing promises such as distributed quantum computing [1], ultra-precise remote synchronization [2] and distributed quantum sensing combined with inherent physically secure communication schemes [3]. While these perspective use-cases and applications have been analyzed from a theoretical view point, the experimental realization of such systems remains a major challenge. In order to tackle this challenge and realize first practical quantum networks a keen understanding of the current state-of-the-art, the required components as well as their limitations is fundamental. This essential background knowledge will inform current and future research foci of both theory and experiment and enable identification of possible alternatives to existing quantum network paradigms. An example for such an alternative approach are photon graph states – and in particular cluster states – which open up new possibilities for the realization of robust multi-partite entanglement distribution in future quantum networks. Recent experimental advances on photonic graph [4] and cluster-states [5], high throughput entangled photon pair sources [6], memory-enhanced entanglement distribution [7] and entanglement swapping [8] bring the goal of practical realization of scalable quantum networks ever closer to reality and promise exciting new perspectives.

[1] R. Van Meter and S. J. Devitt, "The Path to Scalable Distributed Quantum Computing," Computer, vol. 49, pp. 31-42, 2016.

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Joint detection receivers in photon-efficient communication and quantum key distribution

Michal Jachura Sunday, February 6, 09:20, 15' + 5'

We propose a joint detection technique for photon-starved communication using binary phase shift keying modulation format. The BPSK codewords are converted to PPM format using a cascade of interferometric stages [1]. We also present a method for photon-efficient quantum key distribution (QKD) which relies on nested encoding of multiple logical qubits into the discretized temporal degree of freedom of a single photon. The states of individual logical qubits are measured using a similar cascade of interferometric stages followed by time-resolved photon counting [2].

[1] W. Zwoliński, M. Jarzyna, L. Kunz, M. Jachura and K. Banaszek, "Photon-Efficient Communication Based on BPSK Modulation with Multistage Interferometric Receivers," 2020 European Conference on Optical Communications (ECOC), 2020, pp. 1-4, DOI: 10.1109/ECOC48923.2020.9333190.

[2] M. Jachura, M. Jarzyna, M. Pawłowski, and K. Banaszek "Photon-efficient quantum key distribution using multiqubit time-bin encoding", Proc. SPIE 11852, International Conference on Space Optics — ICSO 2020.

Quantum receivers in optical communication

Marcin Jarzyna Sunday, February 6, 09:00, 15' + 5'

Quantum receivers offer a promise to enhance optical communication rates beyond classical limits. The advantage, however, depends on the presence of noise and the power of the signal. I will discuss when quantum enhancement is possible in various optical communication scenarios and show some examples of realistic detection schemes, such as joint detection receivers, in adequate instances.

Driving Forces in Systems Research: from Optical Transmission to Quantum-Optical Transmission

Daniel Kilper Thursday, February 9, 16:30, 20' + 10'

The early development of fiber optic transmission systems held many similarities to the situation today around the development of entanglement-based quantum communication networks. There were many technologies such as coherent transceivers, all-optical regenerators, and semiconductor optical amplifiers, that emerged as key technologies but, in the end, did not find commercial application, although coherent transceivers finally had their day roughly 20 years later, as several technologies matured. Once optical transmission settled on fiber amplified wavelength division multiplexed systems, research to maximize the bandwidth distance product created a technology race that led to more than five orders of magnitude of capacity growth over several decades. What are the prospects for finding a similar technology evolution in quantum communications that will drive quantum optical transmission systems research? Can it even happen for quantum systems and what can we learn from optical transmission systems?

Towards Quantum Repeater based on SiV-center in Diamond

Alexander Kubanek Friday, February 4, 11:20, 30' + 15'

Quantum-Repeater and their integration into a Quantum-Networks-Infrastructure is among the most important applications of the upcoming Quantum-Technology. In this talk, I will discuss our recent investigations on SiV-center in diamond towards application as Quantum Repeater. I will discuss main concepts and challenges and focus on the experimental realization of cavity-assisted Spin-Photon interfaces to realize an efficient and scalable platform.

[1] R. Waltrich, et al., New Journal of Physics 23, 113022 (2021).
[2] K. G. Fehler, et al., ACS Photonics 8, 9, 2635-2641 (2021).
[3] K. G. Fehler, et al., Nanophotonics 20200257 (2020).
[4] S. Häußler, et al., New Journal of Physics 21, 103047 (2019).
[5] S. Häußler, et al., Physical Review B 99, 165310 (2019).
[6] S. Häußler, et al., New Journal of Physics 19, 063036 (2017).

Quantum communication in urban networks and single photon engineering

Christian Kurtsiefer Friday, February 4, 16:05, 10' + 5'

In this presentation, I will highlight two areas of research in the area of quantum optics at the Centre for Quantum Technologies in Singapore. On the more applied side, I will report on efforts on implementing entanglement-based quantum key distribution over a metropolitan fiber network [1], and a recent development of addressing physical vulnerabilities of quantum key distribution systems. On the more upstream side, I will present a technique to change the temporal shape of a single photon, a technique that may help to interface different physical qubits through optical photons in a quantum internet of heterogenous physical systems [2].

[1] Yicheng Shi, Soe Moe Thar, Hou Shun Poh, James A. Grieve, Christian Kurtsiefer, Alexander Ling: Stable Polarization Entanglement based Quantum Key Distribution over Metropolitan Fibre Network, Appl. Phys. Lett. 117, 124002 (2020).
[2] Mathias A. Seidler, Xi Jie Yeo, Alessandro Cerè, Christian Kurtsiefer: Spectral Compression of Narrowband Single Photons with a Resonant Cavity, Phys. Rev. Lett. 125, 183603 (2020).

Experimental device-independent quantum key distribution

Tim van Leent Friday, February 4, 9:30, 30' + 15'

Device-independent quantum key distribution (DIQKD) is the art of establishing secure keys over untrusted channels even when using untrusted devices. It allows the users to check the secure functioning of the underlying quantum devices by leveraging non-classical correlations between measurement results, thereby also ensuring security against implementation flaws—a major vulnerability to quantum key distribution protocols realized so far. Here we present the first experimental system that enables for DIQKD between two distant users [1]. For this, we employ event-ready entanglement between two single-atom quantum memories, independently trapped and manipulated in buildings 400 metres apart [2]. By achieving an entanglement fidelity of 0.892(19) and implementing a DIQKD protocol with random key basis we show that—based on asymptotic security estimates—our system can establish secure keys in a fully device-independent way.

[1] W. Zhang et al., `arXiv:2110.00575` (2021).
[2] W. Rosenfeld et al., Phys. Rev. Lett. 119, 010402 (2017).

Quantum Key Distribution from a security perspective: developments and issues

Manfred Lochter Saturday, February 5, 10:40, 15' + 5'

The presentation will explain BSI's approach to quantum communication and discuss open questions. In addition, necessary standardization and certification processes will be outlined.

Analytical Quantum Repeater Modelling

Peter van Loock Friday, February 4, 12:05, 30' + 15'

We give an overview of our efforts to model quantum repeaters for long-range quantum key distribution or more general quantum network applications. Under given experimental assumptions such as the possibility of probabilistic or deterministic entanglement swapping we calculate and optimize the final (secret key) rates for medium-size repeaters including the most important experimental parameters.

Quantum memory time-frequency processor for collective measurements

Michał Parniak Sunday, February 6, 10:00, 15' + 5'

Optical quantum memories are most well known for their application in quantum repeater networks. Their capabilities can be significantly enhanced when embedded with processing power. We use a cold-atom quantum memory and employ Zeeman and ac-Stark shifts to perform time-frequency processing operations. This allows us to sort incoming pulses of light [1], interfere them with each other, or perform measurements in optimized (also collective) bases. Recently, we employed the memory to achieve spectral super-resolution, which may find applications in distinguishing nearby channels [2]. The proposed protocols may also be mapped to other platforms.

[1] M. Mazelanik et al., Coherent spin-wave processor of stored optical pulses, npj Quantum Information 5, 22 (2019).
[2] M. Mazelanik, A. Leszczyński, M. Parniak, Optical-domain spectral super-resolution via a quantum-memory-based time-frequency processor, Nature Communications (in print), `arXiv:2106.04450`.

Machine-learning enhanced quantum state tomography

Lee Ray-Kuang Friday, February 4, 15:35, 10' + 5', online

By implementing machine learning architecture with a convolutional neural network, we illustrate a fast, robust, and precise quantum state tomography for continuous variables, through the experimentally measured data generated from squeezed vacuum states [1]. With the help of machine learning-enhanced quantum state tomography, we also experimentally reconstructed the Wigner's quantum phase current for the first time [2]. Applications of squeezed states for the implementations of optical cat states and fault-tolerant quantum computing will also be introduced. At the same time, as a collaborator for LIGO-Virgo-KAGRA gravitational wave network and Einstein Telescope, I will introduce our plan to inject this squeezed vacuum field into the advanced gravitational wave detectors [3].

[1] Yi-Ru Chen, et al., "Experimental Reconstruction of Wigner Distribution Currents in Quantum Phase Space", `arXiv:2111.08285`.
[2] Hsien-Yi Hsieh, et al., "Extract the Degradation Information in Squeezed States with Machine Learning", `arXiv:2106.04058`.
[3] Yuhang Zhao, et al., "Frequency-dependent squeezed vacuum source for broadband quantum noise reduction in advanced gravitational-wave detectors", Phys. Rev. Lett. 124, 171101 (2020); Editors' Suggestion; Featured in Physics.

Compact Cooling Solutions

Sebastian Schaile Saturday, February 5, 09:20, 15’ + 5’

The mission to enable scientific impact has kept attocube at the frontier of cutting edge research instrumentation. Decades of combined experience in all relevant fields, an excellent team, and close connections to leading universities worldwide have evolved into a portfolio of cryostats for the use in academic institutions. All systems are developed in accordance with attocube’s principles of compact design and precision, while new projects target even more compact and more autonomous designs to help the implementation of quantum technologies.

In this talk we give an overview on existing cooling solutions for applications with and without magnetic field as well as upcoming, revolutionary solutions for the use in the quantum industry. The core ingredient is a new compressor technology to strongly reduce current infrastructure requirements.

Quantum communication with nonlinear integrated optics and pulsed light

Christine Silberhorn Friday, February 4, 14:00, 20’ + 10’

Photonic quantum information encoding is key for implementing quantum communication systems. The use of entanglement and non-classicality in high dimensional systems enable advanced system performance beyond standard qubit encoding. Yet, this required advanced setups, which poses considerable challenge on the technological implementation of useful systems. Our research focuses on the realization of novel non-linear integrated quantum devices with the combination of different functionalities and the control of the time-frequency structure of pulsed states of quantum light. Here we will review our latest progress of our work.

Catalytic Transformations of Pure Entangled States

Alexander Streltsov Friday, February 4, 15:50, 10’ + 5’

Quantum entanglement of pure states is usually quantified via the entanglement entropy, the von Neumann entropy of the reduced state. Entanglement entropy is closely related to entanglement distillation, a process for converting quantum states into singlets, which can then be used for various quantum technological tasks. The relation between entanglement entropy and entanglement distillation has been known only for the asymptotic setting, and the meaning of entanglement entropy in the single-copy regime has so far remained open. Here we close this gap by considering entanglement catalysis. We prove that entanglement entropy completely characterizes state transformations in the presence of entangled catalysts. Our results imply that entanglement entropy quantifies the amount of entanglement available in a bipartite pure state to be used for quantum information processing, giving asymptotic results an operational meaning also in the single-copy setup.

Application programming for the quantum internet

Bart Van der Vecht Saturday, February 5, 10:00, 15’ + 5’

A quantum internet enables new types of applications, including quantum key distribution, blind quantum computing, and more. In order to program arbitrary such applications and actually run them on a real quantum internet, a software suite is needed that consists of a development kit and an execution stack. I will present NetQASM, a low-level instruction set format for hybrid classical-quantum network programs, and the NetQASM SDK, which enables programming quantum network applications in Python.

Entanglement-based QKD, from Lab to Fab

Adrià Sansa Perna Saturday, February 5, 09:40, 15' + 5'

Digital information is an inalienable resource, which drives business models and society. Quantum computers enable for new ways of data processing, optical fibers or satellite links connect continents and realize global networks. Security and sovereignty of information are granted today by complex mathematical algorithm-based cryptography. On the other hand, while the rise of quantum computers will allow for completely new ways of computing, it poses a threat to classical cryptography and leads to the key question: how to protect your data in times of quantum supremacy? The answer to this question will be given by quantum optics, which enables both the possibilities to create photonics-based quantum computer architectures, as well as unique systems for secure communication – based on the laws of physics.

The talk explains the realization of encrypted communication based on entangled photon pairs and how it will be possible to create a quantum-based internet in the future – from fiber connected systems to satellite networks.

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