Q 7: Quantum Communication I

Time: Monday 11:00–13:00 Location: HS 3219

Q 7.1 Mon 11:00 HS 3219

Polarization Entanglement Distribution on a Hybrid QKD Link — •Shreya Gouravaram Navalur[1,2], Uday Chandrashekara[2], Gregor Sauer[2,3], and Fabian Steinlechner[2,3] — [1]Friedrich Schiller University, Abbe School of Photonics, Jena, Germany — [2]Fraunhofer Institute for Applied Optics and Precision Engineering, Jena, Germany — [3]Friedrich Schiller University, Institute of Applied Physics, Abbe Center of Photonics, Jena, Germany

Quantum Key Distribution (QKD) uses quantum properties of light to establish secure encryption keys at a distance. Hybrid QKD links are communication channels that incorporate free-space channels as well as fiberoptic links. Fiber-based channels are efficient, reliable, and QKD can be implemented on existing telecom networks with only minor modifications. Free space links, on the other hand, can provide access in urban areas where fiber infrastructure is not deployed and can also scale to long-distance satellite networks. Thus, hybrid QKD networks, that comprise free-space and fiber segments are one of the promising steps towards achieving the goal of a global quantum internet.

In this work, we build and characterize a polarization-entangled photon source that produces highly non-degenerate pairs of signal and idler photons at suitable wavelengths for free-space and fiber-based transmission. Further, we deploy the source on a small-scale hybrid link in Jena to perform entanglement distribution experiments. This way, we can optimize the photon source and study its behaviour on hybrid links, in a real-world environment outside of ideal lab conditions.

Q 7.2 Mon 11:15 HS 3219

Vacuum mediated photon pair emission by a single atom — •Tobias Frank, Gianvito Chiarella, Pau Farrera, and Gerhard Rempe — Max Planck Institute for Quantum Optics

Single atoms coupled to high finesse optical cavities serve as a key platfrom for future quantum networks, where photonic qubits must be distributed, stored and processed efficiently. This platform offers scalability, either by increasing the number of simultaneously coupled emitters or cavity modes. The development of optical-fiber based high finesse Fabry-Perot resonators facilitates the coupling of spatially independent resonator modes to the same emitter. Our group previously implemented such a system using single ^{87}Rb atoms coupled to two crossed optical fiber cavities in the high cooperativity regime. The versatility of this system enables the implementation of a passively heralded quantum memory [1] and a nondestructive qubit detector [2]. We recently extended the capabilities using three atomic energy levels coupled to the two cavities in a ladder configuration. This configuration generates pairs of single photons which are efficiently coupled into separate optical fibers. Using numerical simulations, we find parameters in the regime of strong coupling, for which our system could generate photon pairs without populating the intermediate atomic state. We explain this process in analogy to STIRAP but mediated by the vacuum field in both cavities.

[1] Brekenfeld, M., Niemietz, D., Christesen, J.D. et al. Nat. Phys. 16, 647-651 (2020) [2] Niemietz, D., Farrera, P., Langenfeld, S. et al. Nat. 591, 570-574 (2021)

Q 7.3 Mon 11:30 HS 3219

New atom-cavity setup for engineering entanglement — •Stephan Roschinski, Johannes Schabbauer, Marvin Holten, and Julian Léonard — Technische Universität Wien, Atominstitut, Stadionallee 2, 1020 Wien, Österreich

The efficient and deterministic generation of entanglement in a many-body system poses a challenge for analog and digital quantum simulators. While atomic platforms provide great scalability, they mostly rely on local couplings, for instance, collisional or Rydberg interactions. We report on the current status of a new experimental apparatus to strongly couple an atomic tweezer array to a fiber-based Fabry-Pérot cavity. The cavity geometry with short length, small mirror diameter, and large curvature, places us in a unique regime with simultaneously high single-atom cooperativity and single-atom addressing and readout. Our setup is optimized for fast repetition rates, owing to loading the tweezer array from a magneto-optical trap which is placed within millimeters from the cavity. In future, harnessing this new control will enable us to engineer entanglement through photon-mediated interactions. Further advantages of this platform include partial non-destructive readout and efficient multi-qubit entanglement operations. In the long term, the proposed platform provides a scalable path to studying many-body systems with programmable connectivity, as well as an efficient atom-photon interface for quantum communication applications.

Q 7.4 Mon 11:45 HS 3219

Discrete-modulated continuous-variable QKD over an atmospheric channel — •Kevin Jaksch[1,2], Thomas Dirmeier[1,2], Jan Schreck[1,2], Yannick Weiser[1,2], Stefan Richter[1,2], Ömer Bayraktar[1,2], Bastian Hacker[1,2], Conrad Rössler[1,2], Imran Khan[1,2], Andrej Krzic[3], Markus Rothe[3], Markus Leipe[3], Nico Döll[3], Christopher Spiess[3], Matthias Goy[3], Florian Kanitschar[4,5], Stefan Petscharning[4], Thomas Grafenauer[4], Bernhard Ömer[4], Christoph Pacher[4], Twesh Upadhyaya[5], Jie Lin[5], Norbert Lütkenhaus[5], Gerd Leuchs[1,2], and Christoph Marquardt[2,1] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany — [3]Fraunhofer Institute for Applied Optics and Precision Engineering, Jena, Germany — [4]AIT Austrian Institute of Technology, Center for Digital Safety&Security, Vienna, Austria — [5]Institute for Quantum Computing and Department of Physics and Astronomy, University of Waterloo, Canada

In future metropolitan QKD networks, atmospheric links can provide secure communication complementary to the fiber backbone. For this, we implemented a discrete-modulated continuous-variable QKD system over an urban 1.7 km atmospheric channel in Jena. After subbinning the transmission to cope with the fluctuating nature of the channel, we study the applicability of a recently published security proof in the finite size regime [1] and a fixed set of implemented error correction codes for secret key generation.

[1] Kanitschar et al., PRX Quantum 4, 040306 (2023)

Q 7.5 Mon 12:00 HS 3219

Boosted quantum teleportation — •Simone Evaldo D'Aurelio[1,2], Matthias Bayerbach[1,2], and Stefanie Barz[1,2] — [1]Institute for Functional Matter and Quantum Technologies, Stuttgart, Germany — [2]Center for Integrated Quantum Science and Technology (IQST), Stuttgart, Germany

Quantum teleportation serves as a fundamental pillar across various quantum applications, spanning from quantum communication to quantum computation. Although photons show great promise in these endeavors, the application of linear optics imposes a limitation, capping the success probability of quantum teleportation at 50%. This limitation arises from the fact that a key component, the Bell-state measurement (BSM), faces constraints in success probability when employing linear optics. Here, we demonstrate an enhanced form of quantum teleportation, so-called boosted teleportation, using linear optics only. Introducing an additional ancilla state in the BSM boosts the success probability of the BSM and thus also of the overall quantum teleportation process. The use of extra photons does introduce a more intricate detection pattern compared to the non-boosted scenario. This complexity reveals more information, leading to a higher success probability. Our results show fidelities between the teleported states and the expected outcomes that surpass the maximum fidelity achievable through classical means. This experiment highlights the potential for advanced quantum teleportation protocols, particularly in the realm of photonic quantum computing.

Q 7.6 Mon 12:15 HS 3219

A phase encoding protocol for satellite Quantum Key Distribution — •Kevin Günthner[1,2], Conrad Rössler[1,2], Bastian Hacker[1,2], Ivan Derkach[3], Vladyslav Usenko[3], and Christoph Marquardt[1,2] — [1]Lehrstuhl für Optische Quantentechnologien, Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstr. 7, 91058 Erlangen, Germany — [2]Max Planck Institute for the Science of Light, Staudtstr. 2, 91058 Erlangen, Germany — [3]Department of Optics, Faculty of Science, Palacky University, 17. listopadu 12, 77146 Olomouc, Czech Republic

We report on a novel Quantum Key Distribution (QKD) protocol using relative phase encoding designed and optimized for operational satellite QKD. The protocol is based on the BB84 decoy-state protocol. Its security proof is based on the rigorous finite-size techniques [1] extended by several security aspects of the practical implementation. Besides the quantum state exchange for key creation, the protocol contains two additional time multiplexed parts: a few states at quantum level with deterministic phases and intensities to obtain a live reference error rate and bright reference signals used for Doppler effect compensation, clock recovery and bit synchronization with the satellite (without the need for an absolute time reference) as well as for phase locking of the receiving interferometers [2]. With this approach, the quantum signal train is self-contained and requires no additional reference signals for QKD operation simplifying the practical implementation.

[1] Z. Zhang et al., PRA 95, 012333 (2017)
[2] B. Hacker et al., New J. Physics 25, 113007 (2023)

Q 7.7 Mon 12:30 HS 3219

Temporal mode engineering in pulsed parametric down-conversion — Laura Serino, •Werner Ridder, Jano Gil-Lopez, Abhinandan Bhattacharjee, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), 33098 Paderborn, Germany

Due to the rise of quantum computing, classical secure communication is put at risk. A safer solution is given by entanglement-based high-dimensional quantum key distribution (HD-QKD). Temporal modes of single photons offer an appealing alphabet for HD-QKD. One fundamental component for this protocol is a photon pair source that generates maximally entangled photon pairs with programmable temporal modes and a finite dimensionality. In this work, we demonstrate such a source. The source is based on a type II parametric down-conversion process in a periodically poled potassium titanyl phosphate waveguide. We pump the source with spectrally shaped light pulses and generate photon pairs in the telecom C band. We base our encoding on so-called cosine-kernel modes (equivalent to time-bins) because they yield maximally entangled states. We can, however, realize other encodings by programming other pump pulse spectra. To characterize the performance of the source, the relation between the second-order broadband correlation function $g^{(2)}$ and the Schmidt number K has been exploited, where $g^{(2)} = 1 + 1/K$. We demonstrate the generation of photon pairs with dimensionalities from 1 to 9 and explore other coding alphabets.

Q 7.8 Mon 12:45 HS 3219

Clock recovery with single photon clicks for satellite QKD — •Conrad Rössler[1,2], Bastian Hacker[1,2], Kevin Günthner[1,2], and Christoph Marquardt[1,2] — [1]Lehrstuhl für Optische Quantentechnologien, Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstr. 7, 91058 Erlangen, Germany — [2]Max Planck Institute for the Science of Light, Staudtstr. 2, 91058 Erlangen, Germany

While Quantum Key Distribution (QKD) offers an information theoretical secure way to exchange cryptographic keys, its experimental implementation poses technical challenges, especially in satellite QKD. Since QKD sources work with very weak signals in order to profit from the quantum mechanical no-cloning theorem, the high loss experienced in satellite QKD is particularly disruptive for these fragile states. One way to overcome this is to increase the modulation and sent symbol rate. However, still only very few of these fast modulated signals will arrive at the receiver. For successful key exchange, one must map each of the received states correctly onto the corresponding sent state, which is especially difficult for high rates. Since resources at the satellite are usually limited, the most obvious solution of storing every sent state at the sender for a long time is not practical. Thus, a fast clock recovery is critical in order to allow processing of the received states at runtime. We present our clock recovery algorithm, based on single photon clicks received from reference signal time multiplexed with the quantum states. With this technique, we achieve below nanosecond accuracy within less than a second.