Project title: Underwater QKD with spatially structured squeezed light

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Current state of the art

The concept of Quantum Key Distribution (QKD) using quantum light has been among the first real world examples in field of quantum technology providing means for the unconditional security in communication based on the laws of physics rather than numerical complexity. There are pioneering demonstrations of QKD using optical fibres and free space channels ranging from ground-based and airborne to satellite-based implementations. There are also reports on first realisations of underwater QKD[1, 2, 3].

A well understood obstacle for high-bitrate and long-distance QKD comes from the bulk passive loss of the channel. However, in fluid media like air or water dynamic distortions related to pressure gradients, laminar flow and turbulence effects can be even more critical. The effect of atmospheric turbulence on quantum channels has been studied in detail [4, 5] showing counter-intuitively that losses from turbulence can be less detrimental than passive loss with the same mean magnitude. A similar behaviour in the case of aqueous channels is expected but needs to be studied further. Additionally, effects resulting form the diffusive properties of the channel medium prominently in real sea water are yet to be investigated in detail.

The majority of QKD implementations (DV-QKD) uses discrete variable encoding of information such as the quantum polarisation state of individual photons or the orbital angular momentum, largely due to the intrinsic purification effect upon the detection of a single photon and its proven security. Alternatively, information can be encoded using continuous variables (CV-QKD) [6] such as the quadrature components of quantum states and utilize homodyne detectors instead of single-photon detectors potentially providing higher bandwidth with more affordable components. Protocols using coherent states were demonstrated (e.g. [7, 8, 9] for various channels including the underwater case[3]. While these are relatively straight forward to implement on the hardware side the actual key generation requires sophisticated parameter estimation methods and an unconditional security proof is available in limiting cases only. Using squeezed light instead is more demanding but can offer advantages in terms of the achievable bitrate and the security with certain channels. However, an underwater demonstration and a careful analysis has not been carried out.

Additionally, similar to using the orbital angular momentum degree of freedom as an encoding basis in DV-QKD [10, 11, 1] the continuous spatial degrees of freedom should be usable for CV-QKD ranging from a simple beam displacement to more complex image-like modulations. Squeezing a spatial degree of freedom in the context of quantum-enhanced imaging has been demonstrated [12] and despite not being discussed in the literature can be expected to work analogously in the CV-QKD context.

Research goals and working program

Within the IRTG there is expertise in underwater DV-QKD, parameter estimation, as well as in squeezed light generation, manipulation and detection. On top, in Rostock there is the Ocean Technology Campus (OTC) with more than 20 participating science and technology partners providing a local point of entry to expertise not only in optical experiments underwater but technology in the marine environment in general. The goal of this project is connecting the areas of expertise for the study and implementation of underwater CV-QKD with spatially structured squeezed light. The goals and the steps to get there in more detail:

1. Modify existing experiment for squeezed light preparation, manipulation and detection with quadrature modulation and demodulation elements for information encoding. (Laboratory Rostock)

2. Compile the parameters for loss, turbulence, and diffusion in case of underwater channels for a selection of actual bodies of water. (Laboratory Ottawa)

3. Implement squeezed light assisted CV-QKD protocol using quadrature modulation. Use artificial elements in the beam path mimicking the relevant effects (loss, diffusion, turbulence) of a transmission through

water. (Laboratory Rostock, expertise from Canadian partners)

4. Implement a first demonstrator for image-like CV-QKD using the beam displacement as continuous degree of freedom. (Laboratory Rostock, expertise from Canadian partners)
5. Identify and build suitable end node container and hardware for underwater use. (Laboratory Rostock)
6. Deploy at the baltic coast. (Laboratory Rostock, OTC Rostock)
7. Study spatial shaping in more detail considering displacement encoding the presence of turbulence and diffusion. (Laboratory Rostock and Ottawa)
8. Investigate potential of more complex spatial manipulations. (Laboratory Rostock and Ottawa)

The first four items at the minimum are feasible within a first PhD-project paving the way for at least one follow-up project.

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