Efficient optimization of secret-key rates in quantum repeater chains

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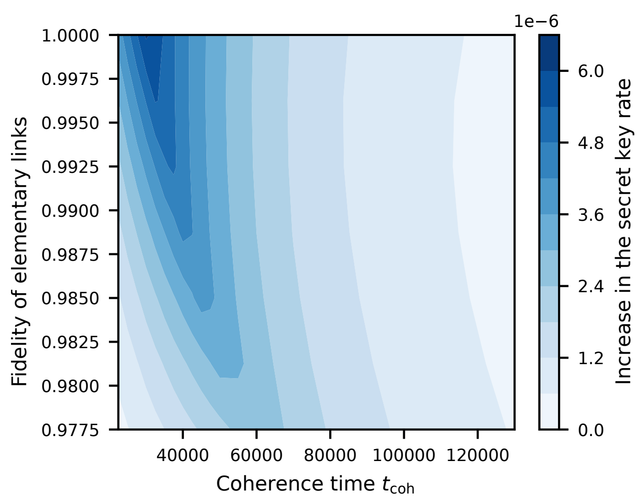
Losses in the physical transmission medium fundamentally limit the distance that quantum key distribution schemes can cover [3]. By means of quantum repeaters, the reach of these schemes can be extended and chains of quantum repeaters could in principle cover arbitrarily long distances.

Existing analytical work on determining the behavior of quantum repeater schemes is mostly aimed at bounds or approximations of the mean waiting time until entanglement delivery [4], or exact calculation of the waiting time which, due to rapidly growing complexity of the problem, has been limited to small repeater chains [5, 6, 7, 8].

Knowledge of the full distribution of waiting time and fidelity, rather than merely the mean, is relevant for analyzing the effect of hardware characteristics on a repeater protocol's performance. An example is decoherence of a quantum state over time: in order to connect two segments via an intermediate repeater, both segments need to produce an entangled pair. When the first pair in one of the segments is ready, it has to wait until the second segment finalizes, and it decoheres while waiting. Another example involves cut-off strategies, where one mitigates decoherence by imposing a maximum storage time for entanglement after which it is discarded. The knowledge of the full distribution allows to precisely estimate and optimize the impact of different cut-off strategies.

Here, we first provide an efficient algorithm for completely characterizing the behavior of a large class of repeater chain protocols. The algorithm determines the fidelity and generation time (waiting time) of the first generated entangled pair between the end nodes of a quantum repeater chain. The algorithm has polynomial runtime in the size of the support of the waiting time probability distribution. This runtime improves upon the exponential runtime of existing algorithms [6, 8] and allows us to analyze repeater chains of thousands of segments for some parameter regimes.

Second, we use our open-source implementation [9] of the algorithm for optimizing the achievable secret key rate. For this, we consider a family of repeater schemes generalizing the BDCZ scheme [10], which include a cut-off condition. We find that the use of the optimal cut-off extends the parameter regime for which secret key can be generated and moreover significantly increases the secret-key rate for a large range of parameters (see figure for the absolute rate increase for a 9-node protocol). Our algorithm thus serves as useful tool for the design and realization of long-distance quantum key distribution networks.



This abstract combines the work by Brand, Coopmans and Elkouss [1] and by Li, Coopmans and Elkouss [2].

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