Efficient iterative entanglement distillation without quantum memory

Daniela Schulze,[1,2] Mareike Syllwasschy,[2] Nicolas J. Cerf,[3] Jaromír Fiurášek,[4] and Roman Schnabel[1,2,*]

[1]*Institut für Laserphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany*
[2]*Institut für Gravitationsphysik, Leibniz Universität Hannover and Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut), Callinstr. 38, 30167 Hannover, Germany*
[3]*Quantum Information and Communication, Ecole Polytechnique de Bruxelles, CP 165, Université libre de Bruxelles, 1050 Brussels, Belgium*
[4]*Department of Optics, Palacký University, 17. listopadu 50, 77200 Olomouc, Czech Republic*

The distribution of entanglement between two distant parties is an essential step in many quantum information protocols. However, optical loss and decoherence effects like phase noise reduce or even destroy the entanglement.

Distillation protocols can restore parts of the original entanglement by distilling a few strongly entangled states from a large amount of weakly entangled states. For stronger distillation the protocol can be performed iteratively in such a way that the resulting state is purer and more strongly entangled in comparison to a single distillation step. However, each additional iteration step exponentially increases the required number of entangled copies, as depicted in Fig. 1. Demonstrating a protocol with several distillation steps would therefore represent an enormous experimental challenge, and until now only two steps have been experimentally demonstrated [1]. An additional challenge is that individual distillation steps need to succeed simultaneously, which decreases the success rate of the protocol. A proposal that addresses both of these problems relies on quantum memories [2], but quantum memories pose their own significant challenges. However the number of possible iteration steps is limited by the finite storage lifetime of the memories, limiting again the efficiency of the protocol.

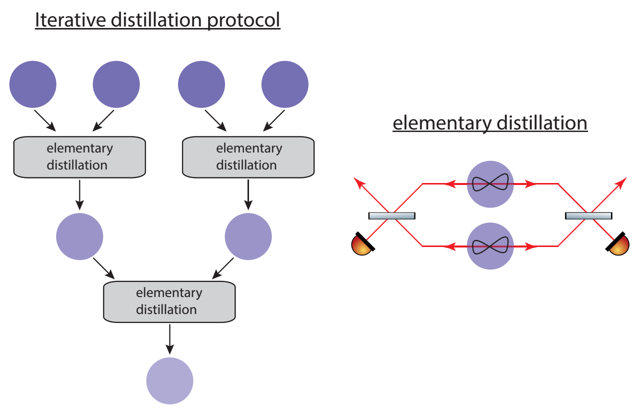

FIG. 1. Iterative entanglement distillation protocol. Each elementary distillation step requires two copies of the entangled state to produce, with some probability, a new state which can serve as an input for the next stage. With each additional iteration step the resulting state gets purer and more entangled but the required amount of entangled copies increases exponentially.

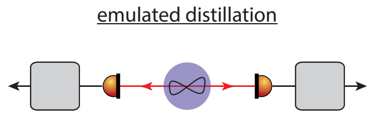

FIG. 2. Emulated entanglement distillation protocol. We assume two-mode squeezed states decohered by phase noise. The modes are detected locally with eight-port homodyne detection and the distillation protocol is emulated in post-processing.

We propose a new iterative distillation protocol that is efficient in terms of success probability and only requires limited entanglement resources, but does not rely on quantum memories. The protocol can accommodate an arbitrary number of iteration steps in principle, and is only limited practically by data collection time. The key innovation of our proposal is to perform the distillation in post-processing, which allows us to create and measure copies one after the other, and thereby circumvent the need for storing quantum states in memory. Our protocol specifically considers two-mode squeezed states (continuous variable entanglement) with a distillation protocol based on Gaussification, which counteracts effects like phase noise. The general setup is depicted in Fig. 2.

Distillation protocols based on post-selection have the drawback that the distilled state cannot be used for further quantum information processing. Nevertheless, this approach is highly suitable for scenarios in which the entangled states will be directly measured by distant parties, like in quantum key distribution (QKD) for example. Our protocol is capable of distilling a secret key from a larger shared ensemble of de-phased and otherwise useless states.

* roman.schnabel@physnet.uni-hamburg.de

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