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Analytical and numerical bounds on entanglement delivery waiting times

Sebastiaan Brand[a], Tim Coopmans[a], David Elkouss[b,c], and Boxi Li[d]

[a]Leiden Institute of Advanced Computer Science, Leiden University, Niels Bohrweg 1, 2333 CA Leiden, The Netherlands
[b]QuTech, Delft University of Technology, Lorentzweg 1, 2628 CJ Delft, The Netherlands
[c]Networked Quantum Devices Unit, Okinawa Institute of Science and Technology Graduate University, Okinawa, Japan
[d]Peter Grünberg Institute - Quantum Control (PGI-8), Forschungszentrum Jülich GmbH, D-52425 Jülich, Germany

ABSTRACT

The vision of a global network that enables quantum communications between any point on Earth is known as the quantum internet. One crucial element of this network is the use of quantum repeater chains, which have the potential to overcome transmission losses and implement entanglement or quantum key distribution protocols over extended distances. There are various proposals for quantum repeaters, but they can generally be evaluated based on two main figures of merit: the average time for end-to-end entanglement delivery and the associated average fidelity. However, characterizing these quantities can be difficult due to factors such as feedback loops, decoherence, entanglement generation being a probabilistic process, and the potential failure of subprotocols. In this talk, I will discuss algorithmic and analytical methods for computing these quantities for relevant families of protocols.

Keywords: Entanglement, Quantum Communication, Quantum Networks, Quantum Repeaters, Quantum Internet, Waiting Time

EXTENDED ABSTRACT

Quantum networks have the potential to enable the implementation of tasks that are beyond the capabilities of the internet we know today. Today, we are seeing the first proof-of-principle implementations of quantum networks.[1] These are the first steps towards a global quantum network that would bring the full potential of quantum communication. While this vision remains in the future, it is an exciting prospect that could revolutionize the way we communicate and process information.

One of the key ingredients for scaling up today's quantum networks are quantum repeater chains that, in principle, can overcome the inherent losses of the transmission medium and deliver long-distance entanglement. There are many proposals for quantum repeaters, but in essence, they can be compared in terms of two main figures of merit: the average time at which it delivers end-to-end entanglement and the associated average fidelity.

Characterizing these quantities can be challenging, as the quantum states undergo decoherence, entanglement generation is typically a stochastic process, and the individual subprotocols of the end-to-end entanglement delivery protocol can fail, requiring going back to an earlier point of the protocol. Even for very simple repeater-chain protocols, computing exactly these figures of merit can take exponential time in the number of nodes.[2] The goal of this presentation is to discuss two different approaches for computing or bounding these quantities

Further author information:
S.B.: E-mail: s.o.brand@liacs.leidenuniv.nl
D.E.: E-mail: david.elkouss@oist.jp
T.C.: E-mail: t.j.coopmans@liacs.leidenuniv.nl
B.L.: E-mail: b.li@fz-juelich.de

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for some relevant families of protocols. The class of repeater protocols that we study include common nested and hierarchical protocols, which may include entanglement distillation. For a recent review on methods for estimating the performance of repeater protocols, see.[3]

The fist approach is an analytical method.[4] It requires that all individual protocols have a success probability bounded from below by a constant. The method builds on a novel connection with reliability theory and provides tighter bounds for the full cumulative distribution of the waiting time. For instance, it improves the estimates for the well-known repeater-chain entanglement distribution protocols consisting of heralded entanglement generation and probabilistic swapping.

The second approach is algorithmic.[5,6] This approach requires that the protocol can be divided into simpler blocks that can be characterized by three maps that represent the evolution of the input state(s), the time it takes to perform the block, and the success probability. In particular, with this method it is possible to efficiently approximate the waiting time and fidelity of protocols consisting of heralded entanglement generation, swapping, distillation and cut-offs.

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