Distribution of Gaussian Einstein-Podolsky-Rosen steering by separable states

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February 28, 2019

Abstract

Einstein-Podolsky-Rosen (EPR) steering is an intermediate type of quantum correalation between entanglement and Bell nonlocality, where local measurements on one subsystem can apparently adjust (steer) the state of another distant subsystem. Distribution of quantum correlations among remote users is a key precedure for quantum information processing. We propose and demonstrate the distribution of Gaussian EPR steering by separable states. All the proposed steering distribution protocols can be implemented with squeezed states, beam splitters and displacements. The presented protocols demonstrate that one can switch multipartite states between different steerability classes by operations on parts of the states.

In a quantum network, it is not practical to require that all users are capable of producing steerable states, moreover directly distributing steering is unsafe since an eavesdropper may attack the transmitted quantum states and obtain confidential information. A simpler and more efficient scenario would be to have a quantum *Cloud Server* which can generate quantum states and perform appropriate operations for different quantum tasks, and then establish desired correlations between the users mediated by transmission of ancillary systems with minimal resources. Somehow counterintuitively, it has been recently shown theoretically and experimentally that entanglement can be distributed between two parties via a separable ancilla. As Einstein-Podolsky-Rosen (EPR) steering is strictly stronger than entanglement, a question that naturally arises is as to whether also steering can be distributed between two or more distant users via a separable system?

We propose a protocol that can distribute EPR steering among many parties in continuous variable Gaussian states by transmitting a separable ancilla mode between the users [1]. A quantum *Cloud Server* locally produces the quantum states and analyzes the classical information of the displacements required by the task, then sends the separable quantum states to the users. By preparing locally initial quantum states and performing suitably tailored local correlated displacements on them, we can distribute rich steering properties, such as one-way Gaussian steering in two-users scenario, two-way steering and collective steering, and so on. In particular, we derive analytical thresholds on the displacements as a function of the squeezing degree of the initial states such that the protocol succeeds, and prove that the largest steerability that can be distributed recovers that of the multimode states created by the same optical network without the correlated displacements. This means that the displacements only make the transmitted ancilla mode separable from the rest without reducing the amount of steering. Notably, all the modes used for the distribution are separable from the users, so the eavesdropper cannot decipher any useful information from the channel, making the protocol robust against loss and leakage in long distance transmissions. We further present a modified scheme with a relaxed condition that the ancilla is nonsteerable instead of separable from the users, yielding a broader range of parameters for which the protocol works.

By distributing two-mode Gaussian EPR steering to two users, quantum communication protocol between two users can be implemented, for example, quantum teleportation and quantum key distribution. By distributing three-mode Gaussian EPR steering to three users, quantum secret sharing can be implemented among these three users. The experimental demonstration of distribution of Gaussian EPR steering by separable states is in progress.

[1] Y. Xiang, X. Su, L. Mišta, Jr. G. Adesso, and Q. He, *Multipartite Einstein-Podolsky-Rosen steering sharing with separable states*, Phys. Rev. A **99**, 010104(R) (2019).