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Entanglement concentration of W-class states on nonlocal atoms using low-Q optical cavity

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As one of the most striking features of quantum phenomena, quantum entanglement has been identified as a key nonlocal resource in quantum information processing such as quantum cryptography [1–3]. In particular, the maximally entangled states give rise to the best fidelity in general, for instance, perfect teleportation. Nevertheless, in practical, during the transmission of quantum entanglement, a maximally entangled state would become less entangled due to the interaction with environments, which decreases the security of quantum cryptography protocols, and the fidelities for, e.g., quantum dense coding and quantum teleportation. Therefore, in long distance quantum communication and quantum communication network, quantum repeaters are required.

The entanglement concentration is a useful quantum technique for depressing the decoherence of the entanglement, which provides an interesting possibility for the remote parties in quantum communication to extract some maximally entangled quantum systems from an ensemble in a less-entangled (or partially entangled) pure state. Up to now, there are some interesting entanglement concentration protocols (ECPs) focusing on various different quantum systems, see e.g. [4–10]. However, most of the existing ECPs are, in essence, based on the Schmidt projection method and they exploit a pair of multiqubit partially entangled systems to obtain a maximally entangled system with the success probability limited by the entanglement of the initial less-entangled pure state.

Recently, by combining the photonic Faraday rotation in cavity quantum electrodynamics and the parameter-splitting method, Cao et al. [11] proposed a novel ECP for nonlocal atom systems, which reveals a much simpler and more efficient idea than previous protocols based on the Schmidt projection.

The photonic Faraday rotation in cavity quantum electrodynamics has attracted much attention due to the possible applications in quantum information processing with atoms and photons. This mechanism has also shown the great potential to constitute future quantum networks. One only requires the cavities of low-Q factors and with weak coupling to the atom to achieve these goals, which makes the requirement for quantum information processing and quantum networks with the Faraday rotation much less stringent and more achievable with near future cavity QED techniques, see e.g. [12, 13]. The Faraday rotation also provides a method to realize entanglement concentration on the nonlocal atoms by using the mobile photon.

The schematic setup to realize entanglement concentration on nonlocal three-atom system in a partially entangled W state is shown in Figure 1 [11]: the trapped atoms hold static qubits encoded in atomic levels. The mobile qubit, i.e.,

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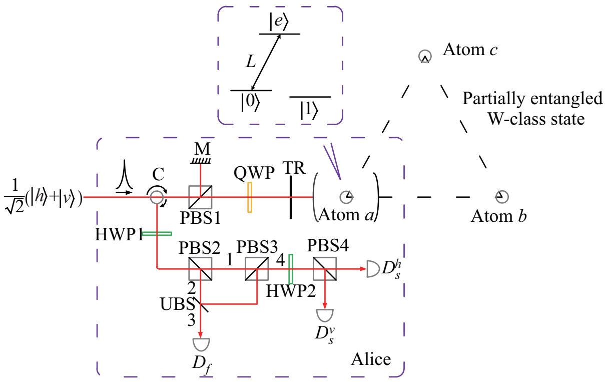

Figure 1 (Color online) Setup for entanglement concentration on nonlocal three-atom system in a partially entangled W state. The inset shows the configuration of the confined atom with one of the ground levels driven resonantly by the input L-polarized photon [11].

photon, can entangle with the static qubits in a controllable way. Once the mobile qubit has entangled with the static qubits, one can detect the mobile qubit in an appropriate way, and the maximal entanglement of the static qubits can be obtained.

The most significant advantage of this presented protocol is that the entanglement concentration is based on the parameter-splitting method in a large Hilbert space. Thus the ECP does not depend on a pair of systems in a partially entangled state in each round of concentration. It concerns just the partially entangled system itself and an ancillary single photon, which makes it far different from other ECPs based on the Schmidt projection.

On the other hand, the ECP presented in [11] is optimal for nonlocal atom systems in the partially entangled W-class states, by using the single-photon input-output process with low-Q cavity and linear optical elements. It requires only one round of concentration to obtain the optimal success probability. The related success probability can only be achieved by iterating the entanglement concentration process several times in some other ECPs [14, 15].

In addition, this ECP has high efficiency and fidelity in realistic experiments. Some imperfections during the experiment can be avoided efficiently with currently available techniques. Moreover, the parameter splitting is on the mobile photon, which can be easily achieved with feasible linear optics. This reduces the difficulty of experimental implementation.

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