Continuous-variable quantum network coding for coherent states

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Abstract

As far as the spectral characteristic of quantum information is concerned, the existing quantum network coding schemes can be looked on as the discrete-variable quantum network coding schemes. Considering the practical advantage of continuous variables, in this paper, we explore two feasible continuous-variable quantum network coding (CVQNC) schemes. Basic operations and CVQNC schemes are both provided. The first scheme is based on Gaussian cloning and ADD/SUB operators and can transmit two coherent states across with a fidelity of 1/2, while the second scheme utilizes continuous-variable quantum teleportation and can transmit two coherent states perfectly. By encoding classical information on quantum states, quantum network coding schemes can be utilized to transmit classical information. Scheme analysis shows that compared with the discrete-variable paradigms, the proposed CVQNC schemes provide better network throughput from the viewpoint of classical information transmission. By modulating the amplitude and phase quadratures of coherent states with classical characters, the first scheme and the second scheme can transmit $4\log_2 N$ and $2\log_2 N$ bits of information by a single network use, respectively.

I. Motivation

The concept of network coding was first introduced in 2000 [1]. Its main idea is to break through the bottleneck of network throughput by encoding information at intermediate nodes. With the development of quantum information processing, network coding has been applied to quantum networks. Existing QNC schemes encode information on variables with a discrete spectrum, such as polarization of single photons. We can describe them as discrete-variable quantum network coding (DVQNC) schemes. In practical use, the generation, operation, and detection of single photons are difficult so dedicated devices are needed to implement a DVQNC system. Also, transmission rate is rather low because many vacuum pulses are generated when single photons are prepared. High cost and low efficiency are main obstacles for the implementation of DVQNC schemes.

From a conceptual point of view, it is illuminating to consider continuous variables in quantum network coding. Continuous variables denote quantum variables with a continuous spectrum such as the amplitude and phase quadratures of an optical field. Since the basic operations for continuous variables can be efficiently realized by quantum optics, it is more feasible to implement continuous-variable quantum communication systems. Moreover, physical observables of continuous variable quantum states can be modulated with continuous classical characters, which allows the quantum states to carry more information. So continuous-variable quantum network coding (CVQNC), which use continuous variables as information carriers, is a meaningful direction for quantum communication in the perspective of efficiency and feasibility.

Our objective is to design a feasible CVQNC scheme. Concretely, coherent states are used at source nodes as information carrier. The amplitude and phase quadratures of coherent states are modulated with classical characters so as to greatly improve transmission rate. Furthermore, extra resources such as free classical communication and pre-shared entanglement can be used for a high fidelity.

II. Our contributions

We propose two feasible continuous-variable quantum network coding schemes, which are presented in Fig.1.

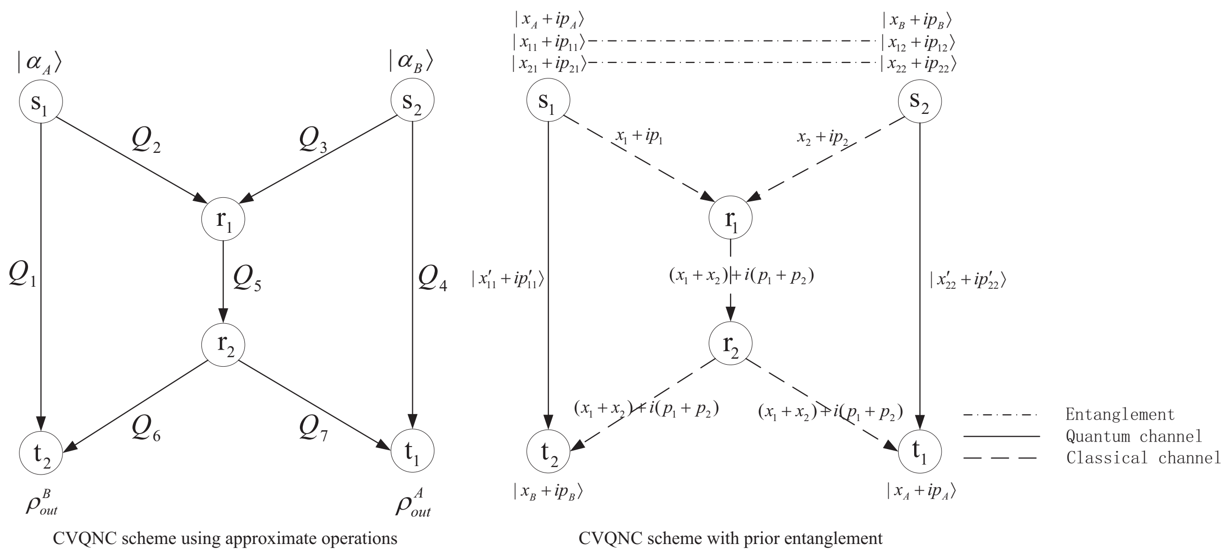

Fig. 1. CVQNC schemes

The first scheme is called the CVQNC scheme using approximate operations. It is based on the butterfly network with all-quantum channels. The basic operations of Gaussian cloning and ADD/SUB operators are provided. The Gaussian cloning (GC) operation [2] is the counterpart for the copying operation in classical network coding. The other basic operation is the ADD/SUB operation. The output of the ADD operator is the sum state of inputs. The output of the SUB operator is an input state subtracted by the other input. In the scheme, quantum states are encoded at intermediate node r_1 by using ADD operator and decoded at two target nodes by using SUB operator. The rest of the nodes only need to clone their quantum states and send the replicas to subsequent nodes. Thereby, two coherent states can be transmitted across from source nodes to target nodes by a single network use, although the fidelity is < 1 due to the imperfection of the cloning operation.

For a higher fidelity, a CVQNC scheme with prior entanglement shared between two source nodes is proposed. The scheme is also based on the butterfly network. Besides quantum channels, the scheme also uses classical channels. Quantum states are encoded at source nodes by utilizing Bell detection and displacement and sent to target nodes via side links. Classical measurement results are sent to r_1. r_1 combines two measurement results and sends the encoded classical message to target nodes via links $r_1 \to r_2 \to t_1$ and $r_1 \to r_2 \to t_2$. Target nodes can obtain the quantum states prepared by their paired source nodes by displacing the received quantum states according to the received classical messages.It utilizes continuous-variable quantum teleportation so that two coherent states can be perfectly transmitted across.

By encoding classical information on quantum states, quantum network coding schemes can be utilized to transmit classical information. Scheme analysis shows that our CVQNC schemes have great advantage over discrete variable paradigms in network throughput from the viewpoint of classical information transmission. By modulating the amplitude and phase quadratures of coherent states with classical characters, the first scheme and the second scheme can transmit $4\log_2 N$ and $2\log_2 N$ bits of information by a single network use, respectively.

III. Importance

We provide two basic models of continuous-variable quantum network coding. By encoding classical information on quantum states, our CVQNC schemes can be utilized to transmit classical information.

Scheme analysis shows that compared with the discrete-variable paradigms, our CVQNC schemes provide better network throughput from the viewpoint of classical information transmission. From the perspective of application, our CVQNC schemes have the advantage of being compatible with standard telecommunication technology, especially no request on single-photon detectors. Therefore, the cost of implementing our CVQNC scheme is much lower than the schemes using discrete variables, which means CVQNC is more feasible in practical use. In conclusion, CVQNC is a meaningful direction for quantum communication in the perspective of communication efficiency and feasibility.

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