Implementation of nonlocal Bell-state measurement and quantum information transfer with weak Kerr nonlinearity*

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We propose a protocol to implement the nonlocal Bell-state measurement, which is nearly determinate with the help of weak cross-Kerr nonlinearities and quantum non-destructive photon number resolving detection. Based on the nonlocal Bell-state measurement, we implement the quantum information transfer from one place to another. The process is different from conventional teleportation but can be regarded as a novel form of teleportation without entangled channel and classic communication.

Keywords: weak cross-Kerr nonlinearities, nonlocal Bell-state measurement, quantum information transfer

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1. Introduction

Quantum information enables the implementation of certain communication and computation tasks which are unavailable with classical technology, this is why quantum information processing (QIP) always has a huge attraction. Photons as the most ideal quantum information carriers for long distance communication can suffer lower decoherence generally than other qubit systems, optical QIP has been a very active field of research. Knill, Laflamme and Miburn have provided an important theoretical breakthrough to show that universal quantum computation based on the quantum gates is possible in principle with only signal photon resources, detectors and linear elements such as beam splitters and wave plates.[1] Soon after, researchers carried out some experimental demonstrations of quantum gates, which were introduced through photon bunching effects and measurement.[1−4] However, the gates in linear optical QIP are intrinsically probabilistic, which means that the scheme of using photon resources is uncertain or even inefficient to implement in practice.[5,6]

Recently, much attention has been paid to Kerr nonlinearities,[7,8] which offer the promise of performing certain optical quantum computation and communication.[9−13] Because of some theoretical features moving beyond linear optics, strong Kerr nonlinearities would realize deterministic quantum gates and efficient QIP. However, this strong Kerr nonlinearities are difficult to realize in practice, while fortunately much smaller nonlinearities can be generated with Electromagnetically Induced Transparencies (EIT)[14,15] or cavity quantum electrodynamics systems.[16,17] With weak Kerr nonlinearities and coherent state with large amplitude, it is possible to construct effective quantum gates to implement the non-destructive quantum computing and quantum communication.[9−13]

For a cross-Kerr nonlinearity, its Hamiltonian under the interaction picture can be described as $\hat{H}_{\rm ck} = \hbar\chi\hat{n}_{\rm s}\hat{n}_{\rm p}$, where $\hat{n}_{\rm s}$ and $\hat{n}_{\rm p}$ are the photon number operators of signal mode and probe mode, respectively, χ is a constant of the nonlinearity medium. When there is a photon in signal mode s, the coherent state in probe mode p will receive a phase shift $\theta = \chi t$,

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where t is the interaction time, θ is proportional to the number of photons in signal mode s. That is, when the signal mode contains $n_{\rm s}$ photons and the probe mode initially is in a coherent state with amplitude $\alpha_{\rm p}$, the cross-Kerr nonlinear interaction will cause the signal and probe mode system to evolve as $U_{\rm ck}|\psi\rangle_{\rm s}|\alpha\rangle_{\rm p} = |n_{\rm s}\rangle|\alpha_{\rm p}\,{\rm e}^{{\rm i}n_{\rm s}\theta}\rangle$.

In quantum physics, entangled state as an important quantum resource plays an important role in QIP.[18] Quantum teleportation,[19,20] quantum cryptography,[21,22] quantum dense coding,[23,24] etc. all need entangled state to construct quantum channel or provide initially entangled resource. So entangled state preparation and measurement naturally become very important and urgent. Bell states are the simplest and most important bipartite entangled state, and Bell-state measurement on a product of two separate photon systems is an essential step in optical quantum communication. There have been many protocols to implement the Bell-state measurement in different systems, such as photon systems,[25,26] electronic systems,[27] atomic systems,[28] and continuous variable systems,[29,30] but most of them are proceeded locally. To our knowledge, the nonlocal entangled state measurement protocol is seldom. However the implementation of the long distance quantum communication should distribute entangled states between distant location. Therefore nonlocal entanglement processing is also necessary. So we proceed to implement the nonlocal Bell-state measurement between two distant particles, based on the weak cross-Kerr nonlinearity.

The article is organized as follows. Our work is inspired by the distributed parity gate, so in Section 2, we briefly review the scheme of distributed parity gate and make a tiny change on it. In Section 3, the nonlocal Bell-state measurement is implemented. In Section 4, a scheme of quantum information transfer based on nonlocal Bell-state measurement is put forward and compared with conventional teleportation. At last, discussions and summary are given.

2. Distributed entanglement preparation based on a distributed parity gate

In 2005, Munro *et al.* proposed a distributed parity gate scheme[11] to implement distributed quantum computation. In the scheme, they used intense coherent light as a communication "bus" to mediate the interaction between photon qubits, which are separated by distances amounted to the scale over which quantum communication works. With the help of the cross-Kerr nonlinearity medium, the coherent light can provide the natural communication and distribution of quantum information after interaction with the signal photons. Next, we prepare nonlocal entangled state by using the distributed parity gate.

Two participants, named Alice and Bob, initially are located in different places and each has one photon in arbitrary single superposition state, i.e.

$$\begin{aligned}|\psi_A\rangle &= a_1|H\rangle + a_2|V\rangle,\\ |\psi_B\rangle &= b_1|H\rangle + b_2|V\rangle.\end{aligned} \tag{1}$$

Here H and V represent horizontal and vertical polarization photons, respectively. Coefficients satisfy $|a_1|^2 + |a_2|^2 = |b_1|^2 + |b_2|^2 = 1$.

In Ref. [11], the V component of Bob's photon qubit causes a θ phase on the probe beam, while the H component leaves the probe beam unchanged. Here we make a tiny change, the V component of Bob's photon qubit causes zero phase on the probe beam and the H component makes the probe beam having a $-\theta$ phase. After the tiny change, a further linear phase shift of $-\theta$ in Ref. [11] could be omitted. The simplified schematic diagram of distributed parity gate is shown in Fig. 1. After the interaction between signal and probe beam with the help of the cross-Kerr nonlinearities, the final state of the whole system is

$$\begin{aligned}&U|\psi_A\rangle|\psi_B\rangle|\alpha\rangle_{\rm p}\\ &= [a_1b_1|HH\rangle + a_2b_2|VV\rangle]|\alpha\rangle_{\rm p} + a_1b_2|HV\rangle|\alpha\,{\rm e}^{{\rm i}\theta}\rangle_{\rm p}\\ &\quad + a_2b_1|VH\rangle|\alpha\,{\rm e}^{-{\rm i}\theta}\rangle_{\rm p}.\end{aligned} \tag{2}$$

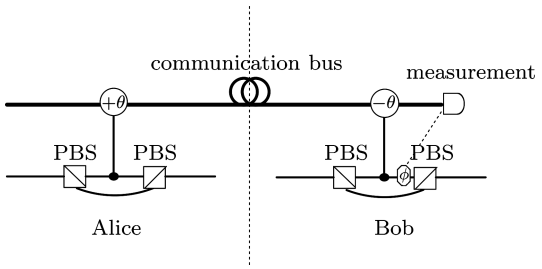


Fig. 1. Schematic diagram of distributed parity gate. The measurement is photon number measurement and the dashed line with ϕ represents the classical feed-forward. Each polarization beam splitter (PBS) is used to pass through H photon and reflect V photon.

Then Bob makes measurement on the probe beam by using the quantum non-destructive (QND) photon number measurement, which can distinguish between $|\alpha\rangle_{\rm p}$ and $|\alpha\,{\rm e}^{{\rm i}\theta}\rangle_{\rm p}$ ($|\alpha\,{\rm e}^{-{\rm i}\theta}\rangle_{\rm p}$), but cannot distinguish between $|\alpha\,{\rm e}^{{\rm i}\theta}\rangle_{\rm p}$ and $|\alpha\,{\rm e}^{-{\rm i}\theta}\rangle_{\rm p}$ both in principle and in practice, details are stated as follows.

Before performing photon number measurement, a displacement operation $D(-\alpha)$[11] is applied, it can evolve $|\alpha\rangle_{\rm p}$ and $|\alpha\,{\rm e}^{{\rm i}\theta}\rangle_{\rm p}$ ($|\alpha\,{\rm e}^{-{\rm i}\theta}\rangle_{\rm p}$) to $|0\rangle$ and $|\alpha({\rm e}^{{\rm i}\theta}-1)\rangle$ ($|\alpha({\rm e}^{-{\rm i}\theta}-1)\rangle$) respectively. According to the number of photons detected, the state $|\alpha({\rm e}^{{\rm i}\theta}-1)\rangle$ and $|\alpha({\rm e}^{-{\rm i}\theta}-1)\rangle$ can be distinguished from $|0\rangle$, but cannot be distinguished from each other. The photon states of Alice and Bob become entangled whatever the detection outcome is. When photon number is zero, the entangled state of Alice and Bob is an even parity state $(a_1b_1|HH\rangle+a_2b_2|VV\rangle)$; otherwise, the entangled state is $(a_1b_2\,{\rm e}^{{\rm i}\phi(n_{\rm p})}|HV\rangle+a_2b_1\,{\rm e}^{-{\rm i}\phi(n_{\rm p})}|VH\rangle)$, which can be converted to an odd parity state $(a_1b_2|HV\rangle+a_2b_1|VH\rangle)$ by a classical feed-forward[11] (a phase shift depends on the measurement result, phase factor $\phi(n_{\rm p})=n_{\rm p}\tan^{-1}[\cot(\theta/2)]$). Based on the distributed parity gate, we will next implement the nonlocal Bell-state measurement.

3. Nonlocal Bell-state measurement

Bell states are important quantum resources and Bell-state measurement is one of the important steps in quantum communication and quantum computation, whether local or nonlocal. However, in fact entanglement is vulnerable to be affected or even destroyed in transport channel or by detection. Finding an efficiently deterministic non-destructive measurement is critically important in optical information processing. Non-destructive local Bell-state measurement schemes have been proposed in many literatures,[10,28] yet nonlocal Bell-state measurement scheme is less proposed other than Ref. [31], which proposed a protocol of nonlocal Bell-state analysis by hyper-entanglement and classical communication. Now, we propose an alternative scheme of nonlocal Bell-state measurement, based on the work in Section 2.

We use two probe beams ($|\alpha\rangle_{\rm p1}, |\alpha\rangle_{\rm p2}$) to distinguish Alice' and Bob's entangled states, which may initially be one of the four Bell states

$$|\Phi^{\pm}\rangle_{AB}=\frac{1}{\sqrt{2}}(|HH\rangle\pm|VV\rangle)_{AB},$$
$$|\Psi^{\pm}\rangle_{AB}=\frac{1}{\sqrt{2}}(|HV\rangle\pm|VH\rangle)_{AB}, \tag{3}$$

where subscripts A, B are used to distinguish Alice's and Bob's qubits.

The experimental setup and operations of two participants are illustrated in Fig. 2. In the beginning, Alice makes the two probe beams interact with her photon qubit, the state of the whole system will evolve into one of the following four cases:

$$\begin{aligned}&|\Phi^{+}\rangle_{AB}|\alpha\rangle_{\rm p1}|\alpha\rangle_{\rm p2}\\ \rightarrow\ &\frac{1}{\sqrt{2}}[(|H\rangle_A|\alpha\,{\rm e}^{{\rm i}\theta}\rangle_{\rm p2}+|V\rangle_A|\alpha\rangle_{\rm p2})|H\rangle_B|\alpha\,{\rm e}^{{\rm i}\theta}\rangle_{\rm p1}\\ &+(|H\rangle_A|\alpha\,{\rm e}^{{\rm i}\theta}\rangle_{\rm p2}-|V\rangle_A|\alpha\rangle_{\rm p2})|V\rangle_B|\alpha\rangle_{\rm p1}],\end{aligned} \tag{4}$$

$$\begin{aligned}&|\Phi^{-}\rangle_{AB}|\alpha\rangle_{\rm p1}|\alpha\rangle_{\rm p2}\\ \rightarrow\ &\frac{1}{\sqrt{2}}[(|H\rangle_A|\alpha\,{\rm e}^{{\rm i}\theta}\rangle_{\rm p2}+|V\rangle_A|\alpha\rangle_{\rm p2})|H\rangle_B|\alpha\,{\rm e}^{{\rm i}\theta}\rangle_{\rm p1}\\ &-(|H\rangle_A|\alpha\,{\rm e}^{{\rm i}\theta}\rangle_{\rm p2}-|V\rangle_A|\alpha\rangle_{\rm p2})|V\rangle_B|\alpha\rangle_{\rm p1}],\end{aligned} \tag{5}$$

$$\begin{aligned}&|\Psi^{+}\rangle_{AB}|\alpha\rangle_{\rm p1}|\alpha\rangle_{\rm p2}\\ \rightarrow\ &\frac{1}{\sqrt{2}}[(|H\rangle_A|\alpha\,{\rm e}^{{\rm i}\theta}\rangle_{\rm p2}+|V\rangle_A|\alpha\rangle_{\rm p2})|V\rangle_B|\alpha\,{\rm e}^{{\rm i}\theta}\rangle_{\rm p1}\\ &+(|H\rangle_A|\alpha\,{\rm e}^{{\rm i}\theta}\rangle_{\rm p2}-|V\rangle_A|\alpha\rangle_{\rm p2})|H\rangle_B|\alpha\rangle_{\rm p1}],\end{aligned} \tag{6}$$

$$\begin{aligned}&|\Psi^{-}\rangle_{AB}|\alpha\rangle_{\rm p1}|\alpha\rangle_{\rm p2}\\ \rightarrow\ &\frac{1}{\sqrt{2}}[(|H\rangle_A|\alpha\,{\rm e}^{{\rm i}\theta}\rangle_{\rm p2}+|V\rangle_A|\alpha\rangle_{\rm p2})|V\rangle_B|\alpha\,{\rm e}^{{\rm i}\theta}\rangle_{\rm p1}\\ &-(|H\rangle_A|\alpha\,{\rm e}^{{\rm i}\theta}\rangle_{\rm p2}-|V\rangle_A|\alpha\rangle_{\rm p2})|H\rangle_B|\alpha\rangle_{\rm p1}].\end{aligned} \tag{7}$$

After that she sends the two probe beams to Bob through the channels. After receiving the probe beams, Bob originally makes the first probe beam $|\alpha\rangle_{\rm p1}$ interact with his photon qubit. Then he performs displacement operation $D(-\alpha)$, QND photon number measurement and classical feed-forward as described in Section 2. If the measurement result is no photon, the initial state is $|\Phi^{\pm}\rangle$; otherwise, the initial state is $|\Psi^{\pm}\rangle$. The other states (photon entangled state and coherent state $|\alpha\rangle_{\rm p2}$) above after the first measurement will respectively evolve into

$$\begin{aligned}&\frac{1}{\sqrt{2}}[(|H\rangle_A|\alpha\,{\rm e}^{{\rm i}\theta}\rangle_{\rm p2}+|V\rangle_A|\alpha\rangle_{\rm p2})|H\rangle_B\\ &+(|H\rangle_A|\alpha\,{\rm e}^{{\rm i}\theta}\rangle_{\rm p2}-|V\rangle_A|\alpha\rangle_{\rm p2})|V\rangle_B],\end{aligned} \tag{8}$$

$$\begin{aligned}&\frac{1}{\sqrt{2}}[(|H\rangle_A|\alpha\,{\rm e}^{{\rm i}\theta}\rangle_{\rm p2}+|V\rangle_A|\alpha\rangle_{\rm p2})|H\rangle_B\\ &-(|H\rangle_A|\alpha\,{\rm e}^{{\rm i}\theta}\rangle_{\rm p2}-|V\rangle_A|\alpha\rangle_{\rm p2})|V\rangle_B],\end{aligned} \tag{9}$$

$$\begin{aligned}&\frac{1}{\sqrt{2}}[(|H\rangle_A|\alpha\,{\rm e}^{{\rm i}\theta}\rangle_{\rm p2}+|V\rangle_A|\alpha\rangle_{\rm p2})|V\rangle_B\\ &+(|H\rangle_A|\alpha\,{\rm e}^{{\rm i}\theta}\rangle_{\rm p2}-|V\rangle_A|\alpha\rangle_{\rm p2})|H\rangle_B],\end{aligned} \tag{10}$$

$$\begin{aligned}&\frac{1}{\sqrt{2}}[(|H\rangle_A|\alpha\,{\rm e}^{{\rm i}\theta}\rangle_{\rm p2}+|V\rangle_A|\alpha\rangle_{\rm p2})|V\rangle_B\\ &-(|H\rangle_A|\alpha\,{\rm e}^{{\rm i}\theta}\rangle_{\rm p2}-|V\rangle_A|\alpha\rangle_{\rm p2})|H\rangle_B].\end{aligned} \tag{11}$$

Here we ignore some unimportant coefficients. In order to distinguish $|\Phi^{+}\rangle(|\Psi^{+}\rangle)$ from $|\Phi^{-}\rangle$ ($|\Psi^{-}\rangle$), Bob need to complete the remaining operations in the schematic diagram. Finally the possible states of the system before measurement 2 are

$$\frac{1}{\sqrt{2}}\ (|HH\rangle_{AB}+|VV\rangle_{AB})|\alpha\rangle_{\rm p2}, \tag{12}$$

$$\frac{1}{\sqrt{2}}\ |HV\rangle_{AB}|\alpha\,\mathrm{e}^{\mathrm{i}\theta}\rangle_{\mathrm{p2}}+|VH\rangle_{AB}|\alpha\,\mathrm{e}^{-\mathrm{i}\theta}\rangle_{\mathrm{p2}}, \quad (13)$$

$$\frac{1}{\sqrt{2}}\ (|HH\rangle_{AB}-|VV\rangle_{AB})|\alpha\rangle_{\mathrm{p2}}, \quad (14)$$

$$\frac{1}{\sqrt{2}}\ (-|HV\rangle_{AB}|\alpha\,\mathrm{e}^{\mathrm{i}\theta}\rangle_{\mathrm{p2}}+|VH\rangle_{AB}|\alpha\,\mathrm{e}^{-\mathrm{i}\theta}\rangle_{\mathrm{p2}}). \quad (15)$$

Then Bob performs the photon number measurement on the second probe beam. Similar to measurement 1, if the measurement result is no photon, the initial state is $|\Phi^+\rangle$ or $|\Psi^+\rangle$; otherwise, the initial state is $|\Phi^-\rangle$ or $|\Psi^-\rangle$. So far, Bob has completely distinguished the four Bell-state non-locally, simultaneously, he could also recover the initial state by appropriate operation, see all details listed in Table 1.

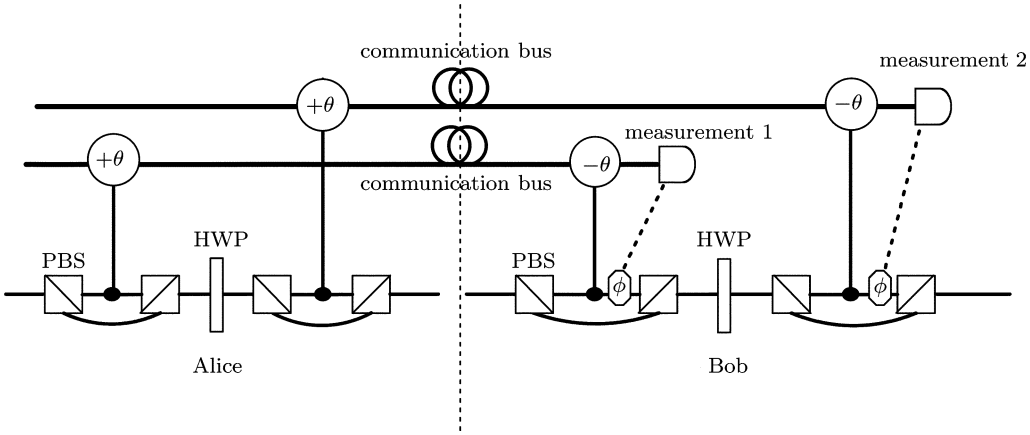


Fig. 2. Schematic diagram of nonlocal Bell-state measurement. Two communication "buses", two classical feed-forward (dashed lines with ϕ) and two photon number measurement are needed in this scheme. The function of half-wave plate (HWP) is equivalent to a Hadamard operation: $|H\rangle \to (|H\rangle+|V\rangle)/\sqrt{2}, |V\rangle \to (|H\rangle-|V\rangle)/\sqrt{2}$.

Table 1. The outcomes of the nonlocal Bell-state measurement made by Bob and the corresponding states obtained by Alice and Bob, and the operation done by Bob to recover the initial state. Here 1 and 2 indicate measurement 1 and measurement 2 in Fig. 2, respectively.

Initial entangled state	Bob's measurement result	Achieved entangled states	Bob's operation
$\|\Phi^+\rangle$	no photon	$\|\Phi^+\rangle$	I
$\|\Phi^-\rangle$	2 has photons	$\|\Psi^+\rangle$	σ_x
$\|\Psi^+\rangle$	1 has photons	$\|\Phi^-\rangle$	σ_z
$\|\Psi^-\rangle$	both 1 and 2 have photons	$\|\Psi^-\rangle$	I

Our nonlocal Bell-state measurement only needs Bob to make some measurements and operations and Alice to give off the two probe beams, and this is simpler than the scheme in Ref. [31], which need both Alice and Bob to do the above-mentioned jobs. Furthermore our work does not need to prepare the hyperentangled state and carry out classical communication, so its process is much easy to implement.

4. Quantum information transfer

Now we present simple application of our work above. Considering the situation, two participants, named Alice and Bob, are in their own laboratory located in different places. Alice wants to teleport a state to Bob, but she knows nothing about the state, and there is no entanglement sharing with Bob initially. In normal circumstances, Alice will notice Bob to jointly construct an entanglement channel, which must be a maximally entangled state. Then Alice will perform local Bell-state measurement and then tell Bob the measurement result with classical communication. This is called quantum teleportation. However, can they complete the work without constructing a maximally entangled channel? Here we propose a scheme to achieve the target by using our nonlocal Bell-state measurement.

Suppose that the state Alice wants to teleport to Bob is an arbitrary single particle superposition state $|\varphi\rangle_A = (\alpha|H\rangle + \beta|V\rangle)_A$. In order to know the state, Bob needs to prepare a maximally entangled state in advance in his own laboratory. Assuming the maximally entangled state is $|\Phi^+\rangle_{B_1B_2} = (|HH\rangle + |VV\rangle)_{B_1B_2}/\sqrt{2}$. The subscripts A, B_1, B_2 are used to distinguish Alice's and Bob's qubits. In that way, the joint state of the whole system is

$$|\psi\rangle = |\varphi\rangle_A|\Phi^+\rangle_{B_1B_2}$$

$$= (\alpha|H\rangle + \beta|V\rangle)_A \left[\frac{1}{\sqrt{2}}(|HH\rangle + |VV\rangle)_{B_1B_2}\right]$$
$$= \frac{1}{\sqrt{2}}(\alpha|HHH\rangle + \alpha|HVV\rangle + \beta|VHH\rangle + \beta|VVV\rangle)_{AB_1B_2}. \quad (16)$$

Rewrite Eq. (16) in terms of the four Bell state bases as

$$|\psi\rangle = \frac{1}{2}[|\Phi^+\rangle_{AB_1}(\alpha|H\rangle + \beta|V\rangle)_{B_2} + |\Phi^-\rangle_{AB_1}(\alpha|H\rangle - \beta|V\rangle)_{B_2} + |\Psi^+\rangle_{AB_1}(\alpha|V\rangle + \beta|H\rangle)_{B_2} + |\Psi^-\rangle_{AB_1}(\alpha|V\rangle - \beta|H\rangle)_{B_2}]. \quad (17)$$

Then Alice and Bob carry out the nonlocal Bell-state measurement on the qubits A and B_1. During the operation, Alice is sender and Bob is receiver, the schematic diagram is seen in Fig. 3(a). According to his own measurement result, Bob can know the state of his second qubit B_2 and the operation he needs to do to reinstate Alice's state. See in Table 2.

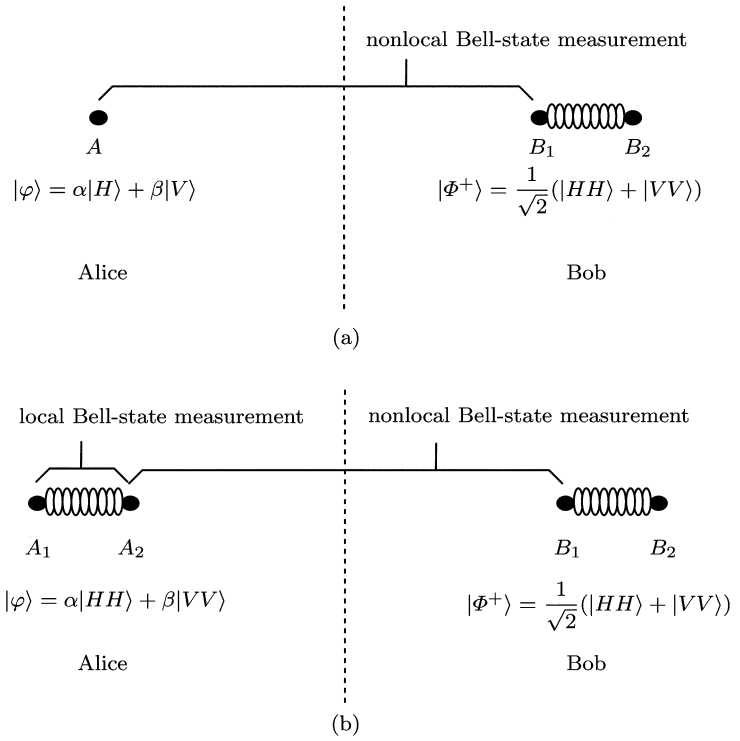


Fig. 3. Schematic diagram of quantum information transfer. The A_i and B_i indicate qubits at Alice and Bob, respectively: (a) single quantum state information transfer and (b) arbitrary bipartite entangled quantum state information transfer.

Table 2. The outcomes of the nonlocal Bell-state measurement on qubits A and B_1 made by Bob and the corresponding states on qubit B_2.

Bob's results	Achieved entangled states	Bob's operation	Bob's remaining qubit
No photon	$\|\Phi^+\rangle$	I	$I(\alpha\|H\rangle + \beta\|V\rangle)$
2 has photons	$\|\Phi^-\rangle$	σ_z	$\sigma_z(\alpha\|H\rangle - \beta\|V\rangle)$
1 has photons	$\|\Psi^+\rangle$	σ_x	$\sigma_x(\alpha\|V\rangle + \beta\|H\rangle)$
Both 1 and 2 have photons	$\|\Psi^-\rangle$	$\sigma_z\sigma_x$	$\sigma_z\sigma_x(\alpha\|V\rangle - \beta\|H\rangle)$

Through the above process, information on qubit A has been transferred to qubit B_2 in a distant location. Our protocol could be regarded as a novel form of teleportation scheme. The differences here include the following aspects. First, the initially entangled quantum channel between two distant parties is not required. And, consequently, it is unnecessary for us to preserve the nonlocal entanglement, which enables our scheme to be insensitive to decoherence. It should be noted that there have been proposals to teleport a quantum state without channel,[32,33] but their research purposes are to implement teleportation in the same place. What is more, compared to conventional quantum teleportation, our protocol has dispensed with the classical communication after Bell-state measurement. In spite of that, because the probe beams have to be transported from Alice to Bob during the state information transfer process, implemen-

tation scheme here cannot realize the superluminal communication, which makes it avoiding to contradict any physical law. In addition, it is shown that we accomplish not only transferring quantum state information but also obtaining a pair of two-particle maximally entangled state between two distant parties, which can be used as initial physical resource in other quantum information processing tasks.

Finally, it is worth while pointing out that the proposed nonlocal Bell-state measurement scheme can transfer not only single quantum state information, but also arbitrary bipartite entangled state information and comparing to the former, the implementation procedure of the latter just adds a local Bell-state measurement for Alice after Bob's nonlocal Bell-state measurement on one particle of each participant. Figure 3(b) diagrammatizes the specific process and detailed calculations are omitted.

5. Discussion and conclusion

In this section, we discuss the experimental feasibility of the nonlocal Bell-state measurement. The scheme here requires two beams of intense coherent light as communication "buses" to mediate the interaction between photons located in different places. The ideal final state after the whole process should be pure state. However, the actual final state will become a mixed state owing to decoherence. Photon losses may occur both in probe modes and signal modes. But as the short interaction time ($t = \theta/\chi$), the possibility of the photon losses in signal modes becomes low. While the losses of photons in probe modes are still large, because the coherent light contains large quantities of photons, which is easy to loss even if in a very short time. Therefore the main source of decoherence of the whole system is the loss of the photons in probe modes. Such photon losses in probe modes will cause the loss of phase information in the output state of signal modes.[11,34] So the selection of measurement which operates on probe beam becomes very critical.

An intense coherent light with a large amplitude is necessary in the quantum information processing based on weak cross-Kerr nonlinearity. Also reference [34] has shown that with the increase of the amplitude of the coherent light, the decoherence will increase rapidly when the homodyne detection is used, but contrarily, the decoherence will decrease under the same condition when the photon number resolving detection is used. This indicates that the QIP based on weak nonlinearity can greatly reduce decoherence by using intense coherent light with a large amplitude, and simultaneously photon number resolving detection. So our work is more feasible in principle in comparison with previous schemes using homodyne measurement.

In conclusion, we have proposed a scheme to implement nonlocal Bell-state measurement by using weak cross-Kerr nonlinearities and strong coherent states. In our scheme, only the receiver of the probe beam needs to perform some measurements and operations to distinguish the four Bell states. In addition, based on the nonlocal Bell-state measurement, we have put forward a scheme of quantum information transfer and compared it with conventional teleportation. So our scheme may be useful in quantum computation and quantum communication of long distance in the near future.

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