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Controlled Quantum Secure Direct Communication by Using Four Particle Cluster States

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Abstract We present a controlled quantum secure direct communication protocol by using cluster states via swapping quantum entanglement and local unitary operation. In the present scheme, the sender transmit the secret message to the receiver directly and the secret message can only be recovered by the receiver under the permission of the controller.

Keywords Controlled secure direct communication · Cluster state · Entanglement swapping

Quantum key distribution (QKD) is probably one of the most promising concepts in quantum information theory, in which two remote legitimate users (Alice and Bob) establish a shared secret key through the transmission of quantum signals and use this key to encrypt (decrypt) the secret messages. Since Bennett and Brassard presented the pioneer QKD protocol in 1984 [1], a lot of QKD protocols have been advanced [2–6]. Recently, a novel branch of quantum communication, quantum secure direct communication (QSDC) has been proposed and actively pursued [7–10]. Different from QKD whose object is to generate a private key between two remote parties, QSDC can transmit the secret messages directly without creating a key to encrypt them beforehand.

Beige et al. [7] have proposed that messages can be read out only after the transmission of an additional piece of classical information for each qubit. Boströem et al. [8] have proposed a quasi-secure ping-pong QSDC protocol. Deng et al. [9] have proposed a two-step quantum direct communication protocol using Einstein-Podolsky-Rosen (EPR) pair, which attracted a great deal of attention. Wang et al. [10] proposed a protocol for quantum secure direct communication with cluster states, which is easily processed by a one-way quantum computer. Recently, Xia et al. [11] have present a controlled quantum secure direct communication

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(CQSDC) protocol by using Greenberger-Horne-Zeilinger (GHZ) state via swapping quantum entanglement and local unitary operation. The communication is secure under some eavesdropping attacks and that two users can transmit their secret message securely. Wang et al. [12] have presented a multiparty CQSDC protocol using GHZ state. This communication protocol can be used to transmit three bits of secret message and the secret message can only be recovered by the receiver under the permission of all the controllers. Very recently, Xia et al. [13] have proposed a CQSDC protocol using pure entangled W state. This scheme shown that the authorized two users can exchange their secret messages with the help of the controller after purifying the non-maximally entangled states.

Recently, Briegel et al. [14] introduced a special kind of multipartite entangled states, the so-called cluster states, which can be written in the form

$$|\psi_N\rangle = \frac{1}{2^{N/2}} \bigotimes_{a=1}^{N} (|0\rangle_a \sigma_z^{(a+1)} + |1\rangle_a), \tag{1}$$

with the convention $\sigma_z^{(N+1)} \equiv 1$. It has been shown that one-dimensional N-qubit cluster states are generated in arrays of N qubit with an Ising-type interaction. When $N = 2$ (or 3), the cluster states are equivalent to Bell states and Greenberger-Horne-Zeilinger (GHZ) states respectively under stochastic local operation and classical communication (LOCC), but when $N > 3$, the cluster state and the N-particle GHZ state cannot be transformed into each other by LOCC [14]. It has been shown that the cluster state are more immune to decoherence than GHZ state [15]. For $N = 4$, the cluster state can be written in the standard form

$$|\psi_4\rangle = \frac{1}{2}(|0000\rangle + |0011\rangle + |1100\rangle - |1111\rangle). \tag{2}$$

The four particle cluster state has been shown to be useful for quantum information, such as quantum computation [14, 16, 17], quantum error correction [18], quantum dense coding [19], quantum teleportation [19–21], quantum information splitting [22, 23], quantum secure communication [24], etc. Some authors [17, 25–30] have shown several methods for the generation of four particle cluster states, respectively.

In this paper, we propose a CQSDC protocol by using four-qubit cluster state. It is shown that in our protocol, the communication is secure under intercept-resend attack and the secret message can only be recovered by the receiver under the permission of the controller.

(S1) Bob prepares a large enough number (N) of four-qubit cluster states in

$$|\Psi\rangle_n = \frac{1}{2}(|0000\rangle + |0011\rangle + |1100\rangle - |1111\rangle)_{h_n t_n k_n c_n}, \tag{3}$$

where $n \in \{1, N\}$, h_n, t_n, k_n, and c_n represent the four particles of the cluster state. Bob takes the particles h_n from each state to form an ordered particle sequence $[h_1, h_2, \ldots, h_N]$, called the H sequence. The remaining particles compose T sequence, $[t_1, t_2, \ldots, t_N]$, K sequence, $[k_1, k_2, \ldots, k_N]$ and C sequence, $[c_1, c_2, \ldots, c_N]$. Then Bob randomly chooses a sufficiently large subset in the H sequence as a checking set, call the C_h set, with the partner particles in T sequence (K sequence and C sequence) of the same cluster states, call the C_t set (C_k set and C_c set). The rest particles in H sequence are taken as message set, call the M_h set, with the partner particles in T sequence (K sequence and C sequence) denoted by M_t set (M_k set and M_c set).

(S2) Bob performs randomly one of the two unitary operations U_1 and U_2 on the particle c of each qubit in the C_c set, where $U_1 = I = |0\rangle\langle 0| + |1\rangle\langle 1|$ and $U_2 = -i\sigma_y = |1\rangle\langle 0| - |0\rangle\langle 1|$.

These operations can transform the state $|\Psi\rangle_n$ into

$$\begin{aligned} U_1|\Psi\rangle_n &= |\Psi\rangle_n = \frac{1}{2}(|0000\rangle + |0011\rangle + |1100\rangle - |1111\rangle)_{h_n t_n k_n c_n} \\ &= \frac{1}{2\sqrt{2}}\{|+\rangle_{h_n}[(|\phi^-\rangle + |\psi^+\rangle)_{t_n k_n}|+\rangle_{c_n} + (|\phi^+\rangle - |\psi^-\rangle)_{t_n k_n}|-\rangle_{c_n}] \\ &\quad + |-\rangle_{h_n}[(|\phi^+\rangle + |\psi^-\rangle)_{t_n k_n}|+\rangle_{c_n} + (|\phi^-\rangle - |\psi^+\rangle)_{t_n k_n}|-\rangle_{c_n}]\}, \end{aligned} \tag{4}$$

$$\begin{aligned} U_2|\Psi\rangle_n &= |\Psi'\rangle_n = \frac{1}{2}(|0001\rangle - |0010\rangle + |1101\rangle + |1110\rangle)_{h_n t_n k_n c_n} \\ &= \frac{1}{2\sqrt{2}}\{|+\rangle_{h_n}[(|\phi^+\rangle - |\psi^-\rangle)_{t_n k_n}|+\rangle_{c_n} - (|\phi^-\rangle + |\psi^+\rangle)_{t_n k_n}|-\rangle_{c_n}] \\ &\quad + |-\rangle_{h_n}[(|\phi^-\rangle - |\psi^+\rangle)_{t_n k_n}|+\rangle_{c_n} - (|\phi^+\rangle + |\psi^-\rangle)_{t_n k_n}|-\rangle_{c_n}]\}, \end{aligned} \tag{5}$$

where $|+\rangle = \frac{1}{\sqrt{2}}(|0\rangle + |1\rangle)$ and $|-\rangle = \frac{1}{\sqrt{2}}(|0\rangle - |1\rangle)$ are X-basis, $|\phi^{\pm}\rangle = \frac{1}{\sqrt{2}}(|00\rangle \pm |11\rangle)$ and $|\psi^{\pm}\rangle = \frac{1}{\sqrt{2}}(|01\rangle \pm |10\rangle)$ are Bell states. Then Bob sends H sequence to Alice, C sequence to Charlie and keeps T and K sequence, and announces the C_h and C_c sets and M_h and M_c sets in H sequence and C sequence, respectively.

(S3) Alice and Charlie conform that they have received the travel particles. For each particle in C_h checking set, Alice randomly chooses one of two set of measuring basis (MB), X-basis $\{|+\rangle, |-\rangle\}$ and Z-basis $\{|0\rangle, |1\rangle\}$, to measure her particles h_n, and announces the order of the particles, the MB, and the measurement results to Bob and Charlie. According to Alice's public information, Charlie measures on the corresponding particles c_n in C_c checking set using the same MB as Alice applied and publicly announces his measurement results. Then Bob chooses the Bell basis (or Z-basis) to take measurement on the corresponding particles t_n and k_n. In accord with the measurement results of Alice and Charlie by their announcement, Bob can determine, through the error rate, whether there is any eavesdropping in the channel. For example, without loss of generality, supposing Bob performs unitary operation U_2 on particle c_j in C_c set at step (S2), it is clear that, from (5), if Alice's measurement result is $|+\rangle_{h_j}$ and Charlie's result is $|+\rangle_{c_j}$, and no eavesdropping exists, then Bob's measurement result should be $|\phi^+\rangle_{t_j k_j}$ or $|\psi^-\rangle_{t_j k_j}$. After security checking process, if the error rate is high, Bob can conclude that the channel is not secure, and abort the communication. Otherwise, they continue to execute the next step.

(S4) Suppose Alice wants to transmit secret messages to Bob. After insuring the security of the quantum channel, Alice takes M_h set by way of two particles as an encode-decode group, without loss of generality, particles h_1 and h_2 as group 1, particles h_3 and h_4 as group 2, etc., and announces the encoding-decoding groups in the M_h set.

(S5) In accordance with Alice's announcement, Bob and Charlie take the corresponding particles in M_t, M_k set and M_c set to form ordered encoding-decoding groups, respectively.

(S6) Alice asks Charlie to carry out a Hadamard operation on each c_n in order in M_c set. The Hadamard operation has the form

$$\begin{aligned} H|0\rangle &= \frac{1}{\sqrt{2}}(|0\rangle + |1\rangle), \\ H|1\rangle &= \frac{1}{\sqrt{2}}(|0\rangle - |1\rangle), \end{aligned} \tag{6}$$

then (3) will be transformed into the state

$$|\psi_1^+\rangle_n = \frac{1}{2\sqrt{2}}[(|000\rangle + |001\rangle + |110\rangle - |111\rangle)_{h_n t_n k_n}|0\rangle_{c_n} + (|000\rangle - |001\rangle + |110\rangle + |111\rangle)_{h_n t_n k_n}|1\rangle_{c_n}]. \tag{7}$$

Charlie measures particle c_n. If he obtain the result $|0\rangle_{c_n}$, particles (h_n, t_n, k_n) will collapse into the state

$$|\eta^+\rangle_n = \frac{1}{2\sqrt{2}}(|000\rangle + |001\rangle + |110\rangle - |111\rangle)_{h_n t_n k_n}; \tag{8}$$

otherwise, the state of particles (h_n, t_n, k_n) will collapse into the state

$$|\eta^-\rangle_n = \frac{1}{2\sqrt{2}}(|000\rangle - |001\rangle + |110\rangle + |111\rangle)_{h_n t_n k_n}. \tag{9}$$

Then, Charlie informs Alice and Bob of his measurement results via a classical channel.

(S7) Alice and Bob agree that the local unitary operation $\{U_{nm}\}$ $(n, m = 0, 1)$ can encode secret messages, where $U_{00} = I$, $U_{01} = \sigma_x$, $U_{10} = -i\sigma_y$, and $U_{11} = \sigma_z$, and they correspond to the two-bit classical information 00, 01, 10, and 11, respectively.

In accord with the encoding-decoding groups ordering, Alice performs her two-bit encodings via local unitary operations U_{nm} on the encoding-decoding groups in M_c set according to her bit strings (say, $0001\cdots$) needing to be transmitted this time: for example, a U_{00} operation on one particle of group 1 to encoding 00, a U_{01} operation on one particle of group 2 to encoding 01, etc. Then Alice measures all the encoding-decoding groups in Bell states and publishes her Bell measurement results and encoding-decoding group's order.

(S8) Bob performs Bell-basis measurements on their corresponding particles in M_t and M_k set respectively. After he knows Charlie's and Alice's measurement results, he can obtain Alice's secret message, as illustrated in Table 1. For instance, we suppose that Charlie's measurement results are $|0\rangle_{c_1}$ and $|0\rangle_{c_2}$, then $|\Psi\rangle_1$ and $|\Psi\rangle_2$ are collapsed into the state

$$|\eta^+\rangle_1 = \frac{1}{2\sqrt{2}}(|000\rangle + |001\rangle + |110\rangle - |111\rangle)_{h_1 t_1 k_1}, \tag{10}$$

$$|\eta^+\rangle_2 = \frac{1}{2\sqrt{2}}(|000\rangle + |001\rangle + |110\rangle - |111\rangle)_{h_2 t_2 k_2}. \tag{11}$$

If Alice performs U_{00} operation on one particle of encoding-decoding group 1, the state composed of particles $(h_1 t_1 k_1; h_2 t_2 k_2)$ is

$$\begin{aligned} &U_{00}|\eta^+\rangle_1 \otimes |\eta^+\rangle_2 \\ &\quad = \frac{1}{8}(|000\rangle + |001\rangle + |110\rangle - |111\rangle)_{h_1 t_1 k_1} \\ &\qquad \otimes (|000\rangle + |001\rangle + |110\rangle - |111\rangle)_{h_2 t_2 k_2} \\ &\quad = \frac{1}{4\sqrt{2}}(|\phi^+\rangle_{h_1 h_2}|\phi^+\rangle_{t_1 t_2}|\phi^+\rangle_{k_1 k_2} + |\phi^+\rangle_{h_1 h_2}|\phi^-\rangle_{t_1 t_2}|\psi^+\rangle_{k_1 k_2} \\ &\qquad + |\phi^-\rangle_{h_1 h_2}|\phi^+\rangle_{t_1 t_2}|\psi^+\rangle_{k_1 k_2} + |\phi^-\rangle_{h_1 h_2}|\phi^+\rangle_{t_1 t_2}|\phi^+\rangle_{k_1 k_2} \\ &\qquad + |\psi^+\rangle_{h_1 h_2}|\psi^+\rangle_{t_1 t_2}|\phi^-\rangle_{k_1 k_2} - |\psi^+\rangle_{h_1 h_2}|\psi^-\rangle_{t_1 t_2}|\psi^-\rangle_{k_1 k_2} \\ &\qquad - |\psi^-\rangle_{h_1 h_2}|\psi^+\rangle_{t_1 t_2}|\psi^-\rangle_{k_1 k_2} + |\psi^-\rangle_{h_1 h_2}|\psi^-\rangle_{t_1 t_2}|\phi^-\rangle_{k_1 k_2}), \end{aligned} \tag{12}$$

Table 1 Correlations among the unitary operation U_{nm}, the initial states, Alice's and Bob's Bell measurement results ($|\eta^{\pm}\rangle_n = |\eta^{\pm}\rangle_{h_n t_n k_n} = \frac{1}{2\sqrt{2}}(|000\rangle + |001\rangle \pm |110\rangle \mp |111\rangle)_{h_n t_n k_n}$, $|\mu^{\pm}\rangle_n = |\mu^{\pm}\rangle_{h_n t_n k_n} = \frac{1}{2\sqrt{2}}(|100\rangle + |101\rangle \pm |010\rangle \mp |011\rangle)_{h_n t_n k_n}$, $|\eta^-\rangle = U_{11}|\eta^+\rangle$, $|\mu^+\rangle = U_{01}|\eta^+\rangle$, $|\mu^-\rangle = U_{10}|\eta^+\rangle$, $\phi_u^{\pm} = |\phi^{\pm}\rangle_{h_1h_2}$, $\psi_u^{\pm} = |\psi^{\pm}\rangle_{h_1h_2}$, $\phi_v^{\pm} = |\phi^{\pm}\rangle_{t_1t_2}$, $\psi_v^{\pm} = |\psi^{\pm}\rangle_{t_1t_2}$, $\phi_w^{\pm} = |\phi^{\pm}\rangle_{k_1k_2}$, $\psi_w^{\pm} = |\psi^{\pm}\rangle_{k_1k_2}$)

U_{00} $\|\eta^+\rangle_1 \otimes \|\eta^+\rangle_2$	U_{01} $\|\mu^+\rangle_1 \otimes \|\eta^+\rangle_2$	U_{10} $\|\mu^-\rangle_1 \otimes \|\eta^+\rangle_2$	U_{11} $\|\eta^-\rangle_1 \otimes \|\eta^+\rangle_2$
$\phi_u^+\phi_v^+\phi_w^+$	$\phi_u^+\psi_v^+\phi_w^-$	$\phi_u^+\psi_v^+\psi_w^-$	$\phi_u^+\phi_v^+\psi_w^+$
$\phi_u^+\phi_v^-\psi_w^+$	$\phi_u^+\psi_v^-\psi_w^-$	$\phi_u^+\psi_v^-\phi_w^-$	$\phi_u^+\phi_v^-\phi_w^+$
$\phi_u^-\phi_v^+\psi_w^+$	$\phi_u^-\psi_v^+\psi_w^-$	$\phi_u^-\psi_v^+\phi_w^-$	$\phi_u^-\phi_v^+\phi_w^+$
$\phi_u^-\phi_v^-\phi_w^+$	$\phi_u^-\psi_v^-\phi_w^-$	$\phi_u^-\psi_v^-\psi_w^-$	$\phi_u^-\phi_v^-\psi_w^+$
$\psi_u^+\psi_v^+\phi_w^-$	$\psi_u^+\phi_v^+\phi_w^+$	$\psi_u^+\phi_v^+\psi_w^+$	$\psi_u^+\psi_v^+\psi_w^-$
$\psi_u^+\psi_v^-\psi_w^-$	$\psi_u^+\phi_v^-\psi_w^+$	$\psi_u^+\phi_v^-\phi_w^+$	$\psi_u^+\psi_v^-\phi_w^-$
$\psi_u^-\psi_v^+\psi_w^-$	$\psi_u^-\phi_v^+\psi_w^+$	$\psi_u^-\phi_v^+\phi_w^+$	$\psi_u^-\psi_v^+\phi_w^-$
$\psi_u^-\psi_v^-\phi_w^-$	$\psi_u^-\phi_v^-\phi_w^+$	$\psi_u^-\phi_v^-\psi_w^+$	$\psi_u^-\psi_v^-\psi_w^-$

If Alice publicly announces her Bell measurement result is $|\phi^+\rangle_{h_1h_2}$, then Bob's measurement results are $|\phi^+\rangle_{t_1t_2}$ and $|\phi^+\rangle_{k_1k_2}$(or $|\phi^-\rangle_{t_1t_2}$ and $|\psi^+\rangle_{k_1k_2}$). Thus, Bob can conclude that Alice performed a U_{00} operation on one particle of group 1 and, therefore, extract the bits (00), and he can read the two-bit encodings (see Table 1). Similarly, in accordance with the particle group's ordering, he can obtain the bit string $(0001\cdots)$.

(S9) The controlled quantum secure direct communication has been successfully completed.

We now discuss the security for our protocol. To gain useful secret messages, Eve must attack the quantum channel during the particle transmission process. In the present protocol, the particle sequence is transmitted from Bob to Alice and Charlie only one time. For one way quantum communication, Eve has one chance to attack the sending particles and may adopt the intercept-resend attack. Under this attack, Eve may first prepare a series of ordered four particle states which are in the state (3), $|\Phi\rangle = \frac{1}{2}(|0000\rangle + |0011\rangle + |1100\rangle - |1111\rangle)_{h't'k'c'}$, which h', t', k' and c' are four particles correlated mutually and divide them into four sequences, the H', T', K' and C' sequences. When Bob sends the H sequence to Alice and C sequence to Charlie, Eve intercepts H and C sequences and keeps them with her, then she sends her fake sequences H' and C' to Alice and Charlie, respectively, and Alice and Charlie would take H' sequence for H sequence and C' sequence for C sequence, and perform the MB measurement as described above. Subsequently, according to Alice's and Charlie's announcements of her/his MB basis, measurement results, and position for each particle in $C_{h'}$ and $C_{c'}$ sets, Eve performs the same MB measurement as Alice and Charlie applied on the corresponding particles of C_h and C_c sets in H and C sequences she intercepted, respectively. However, Eve's act is no relation between Alice's and Charlie's measurement results and Bob's. Moreover, in our protocol, since Bob performs randomly unitary operations U_1 or U_2 on the particle c of each quantum in the C_c set before he sends H sequence to Alice and C sequence to Charlie, and two particles of each entangled state (i.e. T sequence and K sequence) are always kept in the Bob's site, so Eve is not able to distinguish the unitary operations performed on the particles c in C_c set by Bob at step (S2), she can only guess randomly from the two unitary operations, U_1 and U_2. Thus Eve has only $1/2$ chance to choose the right MB basis to perform on corresponding particles in C_h and

C_c set. Hence, the intercept-resend attack can detected with the probability 3/4 when Alice, Bob and Charlie compare their measurement results.

In conclusion, we have proposed a CQSDC protocol by using a large number of four-qubit cluster states via entanglement swapping and local unitary operations. A set of ordered cluster states is used as quantum information channels for sending secret messages directly. The security of the present protocol is ensured by securing check process of communicators including the unitary operations performed randomly on checking particles before the particles sequences are transmitted and the exchange of the secret messages based on quantum entanglement swapping. Once the perfect quantum channels are shared among three parties and after the security of the quantum channels is assured, the sender Alice encodes the secret messages directly by applying a series local operations on his particles sequence according to their stipulation and send them to distant receiver Bob using entanglement swapping with the help of controller Chailie. Since there is no transmission of the qubit carrying the secret messages between Alice and Bob, it is completely secure for this CQSDC protocol.

References

1. Bennett, C.H., Brassard, G.: In: Proceedings of the IEEE International Conference on Computer, Systems and Signal Processing, vol. 175 (1984)
2. Ekert, A.K.: Phys. Rev. Lett. **67**, 661 (1991)
3. Bennett, C.H., Brassard, G., Mermin, N.D.: Phys. Rev. Lett. **68**, 557 (1992)
4. Bennett, C.H.: Phys. Rev. Lett. **69**, 3121 (1992)
5. Bennett, C.H., Wiesner, S.J.: Phys. Rev. Lett. **69**, 2881 (1992)
6. Gisin, A., Ribordy, G., Tittle, W., Zbinden, H.: Rev. Mod. Phys. **74**, 145 (2002)
7. Beige, A., Englert, B.G., Kurtsiefer, C., Weinfurter, H.: Acta. Phys. Pol. A **101**, 357 (2002)
8. Boström, K., Felbinger, T.: Phys. Rev. Lett. **89**, 187902 (2002)
9. Deng, F.G., Long, G.L., Liu, X.S.: Phys. Rev. A **68**, 042317 (2003)
10. Wang, G.Y., Fang, X.M., Tan, X.H.: Chin. Phys. Lett. **23**, 2658 (2006)
11. Xia, Y., Fu, C.B., Li, F.Y., Zhang, S., Yeon, K.H., Um, C.I.: J. Korean Phys. Soc. **47**, 753 (2005)
12. Wang, J., Zhang, Q., Tang, C.J.: Opt. Commun. **266**, 732 (2006)
13. Xia, Y., Song, J., Song, H.S.: Commun. Theor. Phys. (Beijing) **49**, 919 (2008)
14. Briegel, H.J., Raussendrof, R.: Phys. Rev. Lett. **86**, 910 (2001)
15. Dür, W., Briegel, H.J.: Phys. Rev. Lett. **92**, 180403 (2004)
16. Raussendorf, R., Briegel, H.J.: Phys. Rev. Lett. **86**, 5188 (2001)
17. Walther, P., Resch, K.J., Rudolph, T., Schenck, E., Weinfurter, H., Vedral, V., Aspelmeyer, M., Zeilinger, A.: Nature **86**, 434 (2005)
18. Schlingemann, D., Werner, R.F.: Phys. Rev. A **65**, 012308 (2001)
19. Wang, X.W., Shan, Y.G., Xia, L.X., Lu, M.W.: Phys. Lett. A **364**, 7 (2007)
20. Li, D.C., Cao, Z.L.: Commun. Theor. Phys. **47**, 464 (2007)
21. Cao, Z.L., Li, D.C.: Commun. Theor. Phys. **49**, 369 (2008)
22. Muralidharan, S., Panigrahi, P.K.: Phys. Rev. A **78**, 062333 (2008)
23. Pan, G.X., Liu, Y.M., Yin, X.F., Zhang, W., Zhang, Z.J.: Int. J. Quantum Inf. **6**, 1033 (2008)
24. Yuan, H., He, Q., Hu, X.Y., Hou, K., Han, L.F., Shi, S.H.: Commun. Theor. Phys. **50**, 1105 (2008)
25. Cho, J., Lee, H.W.: Phys. Rev. Lett. **95**, 160501 (2005)
26. Zou, X.B., Mathis, W.: Phys. Rev. A **72**, 013809 (2005)
27. Chen, K., Li, C.M., Zhang, Q., Chen, Y.A., Goebel, A., Chen, S., Mair, A., Pan, J.W.: Phys. Rev. Lett. **99**, 120503 (2007)
28. Ye, L., Guo, G.C.: Phys. Lett. A **361**, 460 (2007)
29. UL-Islam, R., Khosa, A.H., Lee, H.W., Saif, F.: Eur. Phys. J. D **48**, 271 (2008)
30. Wang, X.W., Yang, G.J.: Opt. Commun. **281**, 5282 (2008)