Probabilistic teleportation of a three-particle state via three pairs of entangled particles

Jianxing Fang, Yinsheng Lin, Shiqun Zhu,* and Xianfeng Chen
Department of Physics, College of Sciences, Suzhou University, Suzhou, Jiangsu 215006, People's Republic of China

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A scheme for teleporting an arbitrary three-particle state is proposed when three pairs of entangled particles are used as quantum channels. Quantum teleportation can be successfully realized with a certain probability if the receiver adopts an appropriate unitary-reduction strategy. The probability of successful teleportation is determined by the smallest coefficients of the three entangled pairs.

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Quantum teleportation has received much attention both theoretically and experimentally in recent years due to its important applications in quantum calculation [1,2] and quantum communication [3–11]. Quantum teleportation was originally proposed by Bennett *et al.* [3]. In their scheme, an unknown two-level particle state is transmitted from a sender (Alice) to a receiver (Bob) via a quantum channel with the help of some classical information. The quantum channel is presented by a maximally entangled Bell state and the original state can be transferred to the receiver deterministically. Experimental demonstration of quantum teleportation was realized with the polarization photon [1] and a single coherent mode of a field [4] in optical systems. Several schemes of quantum teleportation of a two-particle entangled state by using a three-particle entangled state as quantum channels were presented [5–9]. Recently, quantum teleportation of a three-particle entangled Greenberger-Horne-Zeilinger (GHZ) state to three distant users by local measurement was proposed [10,11]. In the scheme of teleportation, an unknown three-particle entangled state and a two-particle entangled state are used as quantum channels.

In this Brief Report, the teleportation of an arbitrary unknown three-particle state via entanglement swapping is investigated. In our scheme, three nonmaximally entangled particle pairs are used as quantum channels. After Alice operates the Bell-state measurements, Bob performs a corresponding unitary-reduction transformation followed by a measurement to reconstruct the original state. The probability of successful teleportation is determined by the smallest coefficients of three entangled pairs.

An arbitrary three-particle entangled state with unknown coefficients χ_i $(i=0,1,\ldots,7)$ can be written as

$$|\psi\rangle_{123}=(x_0|000\rangle+x_1|001\rangle+x_2|010\rangle+x_3|011\rangle \\ +x_4|100\rangle+x_5|101\rangle+x_6|110\rangle+x_7|111\rangle)_{123}, \tag{1}$$

where

$$|x_0|^2+|x_1|^2+|x_2|^2+|x_3|^2+|x_4|^2+|x_5|^2+|x_6|^2+|x_7|^2=1,$$

and

$$\{|000\rangle_{123},|001\rangle_{123},|010\rangle_{123},|011\rangle_{123},|100|_{123},|101|_{123}, \\ |110|_{123},|111|_{123}\}$$

is the basis of an eight-dimensional Hilbert space. To teleport the state $|\psi\rangle_{123}$ from Alice to receiver Bob, Alice needs to set up three distant entangled pairs (particles 45, 67, and 89) between herself and Bob, which are located, respectively, in the following entangled states with unknown amplitudes a, b, c, d, e, and f:

$$|\psi\rangle_{45}=a|00\rangle_{45}+b|11\rangle_{45} \quad (|a|^2+|b|^2=1), \tag{2}$$

$$|\psi\rangle_{67}=c|00\rangle_{67}+d|11\rangle_{67} \quad (|c|^2+|d|^2=1), \tag{3}$$

$$|\psi\rangle_{89}=e|00\rangle_{89}+f|11\rangle_{89} \quad (|e|^2+|f|^2=1). \tag{4}$$

Alice uses these states as quantum channels between Bob and herself. Since a, b, c, d, e, and f are unknown probabilistic amplitudes of these states, the simplest situation is $|a|=|b|=|c|=|d|=|e|=|f|=1/\sqrt{2}$. Generally speaking, all the coefficients a, b, c, d, e, and f are different, and with $|a|\neq|b|$, $|c|\neq|d|$, and $|e|\neq|f|$. Without losing generality, we may assume $|a|\leqslant|b|$, $|c|\leqslant|d|$, and $|e|\leqslant|f|$, and particles 1, 2, 3, 4, 6, and 8 belong to Alice while particles 5, 7, and 9 belong to Bob. For other combinations of the inequality, such as $|a|\geqslant|b|$, $|c|\leqslant|d|$, and $|e|\leqslant|f|$, similar results can be obtained.

The state of the system is $|\Psi\rangle=|\psi\rangle_{123}|\psi\rangle_{45}|\psi\rangle_{67}|\psi\rangle_{89}$ at this time. The four Bell states of particles 14, 26, and 38 can be expressed as

$$|\Phi^{\pm}\rangle_{ij}=\frac{1}{\sqrt{2}}(|00\rangle_{ij}\pm|11\rangle_{ij}), \tag{5}$$

$$|\Psi^{\pm}\rangle_{ij}=\frac{1}{\sqrt{2}}(|01\rangle_{ij}\pm|10\rangle_{ij}), \tag{6}$$

where $ij=14$, 26, and 38, respectively. In order to realize the teleportation, Alice first operates a Bell-state measurement on particles 1 and 4. Then she performs another Bell-state measurement on particles 2 and 6. Finally, she measures the Bell state of particles 3 and 8. There are probably 64 kinds of outcomes in all,

*Email address: szhu@suda.edu.cn

$$\langle\Phi^{\pm}|_{38}\langle\Phi^{\pm}|_{26}\langle\Phi^{\pm}|_{14}\Psi\rangle=\frac{1}{2\sqrt{2}}(acex_0|000\rangle\pm++acfx_1|001\rangle+\pm+adex_2|010\rangle\pm\pm+adfx_3|011\rangle)_{579}+\frac{1}{2\sqrt{2}}\times(++\pm bcex_4|100\rangle\pm+\pm bcfx_5|101\rangle+\pm\pm bdex_6|110\rangle\pm\pm\pm bdfx_7|111\rangle)_{579}, \quad (7)$$

$$\langle\Psi^{\pm}|_{38}\langle\Phi^{\pm}|_{26}\langle\Phi^{\pm}|_{14}\Psi\rangle=\frac{1}{2\sqrt{2}}(acfx_0|001\rangle\pm++acex_1|000\rangle+\pm+adfx_2|011\rangle\pm\pm+adex_3|010\rangle)_{579}+\frac{1}{2\sqrt{2}}(++\pm bcfx_4|101\rangle\pm+\pm bcex_5|100\rangle+\pm\pm bdfx_6|111\rangle\pm\pm\pm bdex_7|110\rangle)_{579}, \quad (8)$$

$$\langle\Phi^{\pm}|_{38}\langle\Psi^{\pm}|_{26}\langle\Phi^{\pm}|_{14}\Psi\rangle=\frac{1}{2\sqrt{2}}(adex_0|010\rangle\pm++adfx_1|011\rangle+\pm+acex_2|000\rangle\pm\pm+acfx_3|001\rangle)_{579}+\frac{1}{2\sqrt{2}}(++\pm bdex_4|110\rangle\pm+\pm bdfx_5|111\rangle+\pm\pm bcex_6|100\rangle\pm\pm\pm bcfx_7|101\rangle)_{579}, \quad (9)$$

$$\langle\Psi^{\pm}|_{38}\langle\Psi^{\pm}|_{26}\langle\Phi^{\pm}|_{14}\Psi\rangle=\frac{1}{2\sqrt{2}}(adfx_0|011\rangle\pm++adex_1|010\rangle+\pm+acfx_2|001\rangle\pm\pm+acex_3|000\rangle)_{579}+\frac{1}{2\sqrt{2}}(++\pm bdfx_4|111\rangle\pm+\pm bdex_5|110\rangle+\pm\pm bcfx_6|101\rangle\pm\pm\pm bcex_7|100\rangle)_{579}, \quad (10)$$

$$\langle\Phi^{\pm}|_{38}\langle\Phi^{\pm}|_{26}\langle\Psi^{\pm}|_{14}\Psi\rangle=\frac{1}{2\sqrt{2}}(bcex_0|100\rangle\pm++bcfx_1|101\rangle+\pm+bdex_2|110\rangle\pm\pm+bdfx_3|111\rangle)_{579}+\frac{1}{2\sqrt{2}}(++\pm acex_4|000\rangle\pm+\pm acfx_5|001\rangle+\pm\pm adex_6|010\rangle\pm\pm\pm adfx_7|011\rangle)_{579}, \quad (11)$$

$$\langle\Psi^{\pm}|_{38}\langle\Phi^{\pm}|_{26}\langle\Psi^{\pm}|_{14}\Psi\rangle=\frac{1}{2\sqrt{2}}(bcfx_0|101\rangle\pm++bcex_1|100\rangle+\pm+bdfx_2|111\rangle\pm\pm+bdex_3|110\rangle)_{579}+\frac{1}{2\sqrt{2}}(++\pm acfx_4|001\rangle\pm+\pm acex_5|000\rangle+\pm\pm adfx_6|011\rangle\pm\pm\pm adex_7|010\rangle)_{579}, \quad (12)$$

$$\langle\Phi^{\pm}|_{38}\langle\Psi^{\pm}|_{26}\langle\Psi^{\pm}|_{14}\Psi\rangle=\frac{1}{2\sqrt{2}}(bdex_0|110\rangle\pm++bdfx_1|111\rangle+\pm+bcex_2|100\rangle\pm\pm+bcfx_3|101\rangle)_{579}+\frac{1}{2\sqrt{2}}(++\pm adex_4|010\rangle\pm+\pm adfx_5|011\rangle+\pm\pm acex_6|000\rangle\pm\pm\pm acfx_7|001\rangle)_{579}, \quad (13)$$

$$\langle\Phi^{\pm}|_{38}\langle\Phi^{\pm}|_{26}\langle\Phi^{\pm}|_{14}\Psi\rangle=\frac{1}{2\sqrt{2}}(bdfx_0|111\rangle\pm++bdex_1|110\rangle+\pm+bcfx_2|101\rangle\pm\pm+bcex_3|100\rangle)_{579}+\frac{1}{2\sqrt{2}}(++\pm adfx_4|011\rangle\pm+\pm adex_5|010\rangle+\pm\pm acfx_6|001\rangle\pm\pm\pm acex_7|000\rangle)_{579}. \quad (14)$$

In the above equations, the notes "±" or "+" from right to left correspond to the Bell-state measurements of particles 14, 26, and 38, respectively.

After these measurements, Alice informs Bob of her measured results via a classical channel. Next, Bob will try to reconstruct the original state with his particles 5, 7, and 9. In the standard teleportation scheme [3], this is achieved by performing an appropriate unitary transformation on Bob's particles. However, at present, the states of particles 5, 7, and 9 in Eqs. (7)–(14) depend not only on a, b, c, d, e, and f, but

TABLE I. Unitary transformations U_1 corresponding to the states of particles 5, 7, and 9.

Alice's measurement results	Bob's unitary transformations
$\|\Phi^{\pm}\rangle_{38}$, $\|\Phi^{\pm}\rangle_{26}$, and $\|\Phi^{\pm}\rangle_{14}$	$(\|0\rangle\langle 0\|\pm\|1\rangle\langle 1\|)_5\otimes(\|0\rangle\langle 0\|\pm\|1\rangle\langle 1\|)_7\otimes(\|0\rangle\langle 0\|\pm\|1\rangle\langle 1\|)_9$
$\|\Psi^{\pm}\rangle_{38}$, $\|\Phi^{\pm}\rangle_{26}$, and $\|\Phi^{\pm}\rangle_{14}$	$(\|0\rangle\langle 0\|\pm\|1\rangle\langle 1\|)_5\otimes(\|0\rangle\langle 0\|\pm\|1\rangle\langle 1\|)_7\otimes(\|0\rangle\langle 1\|\pm\|1\rangle\langle 0\|)_9$
$\|\Phi^{\pm}\rangle_{38}$, $\|\Psi^{\pm}\rangle_{26}$, and $\|\Phi^{\pm}\rangle_{14}$	$(\|0\rangle\langle 0\|\pm\|1\rangle\langle 1\|)_5\otimes(\|0\rangle\langle 1\|\pm\|1\rangle\langle 0\|)_7\otimes(\|0\rangle\langle 0\|\pm\|1\rangle\langle 1\|)_9$
$\|\Psi^{\pm}\rangle_{38}$, $\|\Psi^{\pm}\rangle_{26}$, and $\|\Phi^{\pm}\rangle_{14}$	$(\|0\rangle\langle 0\|\pm\|1\rangle\langle 1\|)_5\otimes(\|0\rangle\langle 1\|\pm\|1\rangle\langle 0\|)_7\otimes(\|0\rangle\langle 1\|\pm\|1\rangle\langle 0\|)_9$
$\|\Phi^{\pm}\rangle_{38}$, $\|\Phi^{\pm}\rangle_{26}$, and $\|\Psi^{\pm}\rangle_{14}$	$(\|0\rangle\langle 1\|\pm\|1\rangle\langle 0\|)_5\otimes(\|0\rangle\langle 0\|\pm\|1\rangle\langle 1\|)_7\otimes(\|0\rangle\langle 0\|\pm\|1\rangle\langle 1\|)_9$
$\|\Psi^{\pm}\rangle_{38}$, $\|\Phi^{\pm}\rangle_{26}$, and $\|\Psi^{\pm}\rangle_{14}$	$(\|0\rangle\langle 1\|\pm\|1\rangle\langle 0\|)_5\otimes(\|0\rangle\langle 0\|\pm\|1\rangle\langle 1\|)_7\otimes(\|0\rangle\langle 1\|\pm\|1\rangle\langle 0\|)_9$
$\|\Phi^{\pm}\rangle_{38}$, $\|\Psi^{\pm}\rangle_{26}$, and $\|\Psi^{\pm}\rangle_{14}$	$(\|0\rangle\langle 1\|\pm\|1\rangle\langle 0\|)_5\otimes(\|0\rangle\langle 1\|\pm\|1\rangle\langle 0\|)_7\otimes(\|0\rangle\langle 0\|\pm\|1\rangle\langle 1\|)_9$
$\|\Psi^{\pm}\rangle_{38}$, $\|\Psi^{\pm}\rangle_{26}$, and $\|\Psi^{\pm}\rangle_{14}$	$(\|0\rangle\langle 1\|\pm\|1\rangle\langle 0\|)_5\otimes(\|0\rangle\langle 1\|\pm\|1\rangle\langle 0\|)_7\otimes(\|0\rangle\langle 1\|\pm\|1\rangle\langle 0\|)_9$

also on x_i $(i=0,1,\ldots,7)$, so Bob cannot be rotated back to the desired state only by performing a unitary transformation. If a unitary-reduction operation is introduced, this problem can be solved as follows.

First, Bob needs to establish a correspondence between x_i $(i=0,1,\ldots,7)$ and $|000\rangle_{579}$, $|001\rangle_{579}$, $|010\rangle_{579}$, $|011\rangle_{579}$, $|100\rangle_{579}$, $|101\rangle_{579}$, $|110\rangle_{579}$, and $|111\rangle_{579}$, shown in Eq. (1), respectively. This can be achieved by performing a unitary transformation U_1 on particles 5, 7, and 9. For instance, if the first measurement result of Alice is $|\Psi^-\rangle_{14}$, the state of the system collapses into $\langle\Psi^-|_{14}\Psi\rangle$, and the entanglement is established between particles 2, 3, and 5. Then Alice measures the Bell state of particles 26 and 38, respectively. If the measurement results are $|\Phi^+\rangle_{26}$ and $|\Psi^+\rangle_{38}$, the state of particles 5, 7, and 9 collapses into the following state:

$$\begin{aligned}\langle\Psi^+|_{38}\langle\Phi^+|_{26}\langle\Psi^-|_{14}\Psi\rangle &= \frac{1}{2\sqrt{2}}(bcfx_0|101\rangle+bcex_1|100\rangle+bdfx_2|111\rangle \\ &\quad +bdex_3|110\rangle)_{579}+\frac{1}{2\sqrt{2}}(-acfx_4|001\rangle \\ &\quad -acex_5|000\rangle-adfx_6|011\rangle-adex_7|010\rangle)_{579}.\end{aligned} \tag{15}$$

That is, after three measurements, the entanglement among particles 1, 2, and 3 disappears, the new entanglement among particles 5, 7, and 9 is set up, and the entanglement swapping occurs. Next, Alice informs Bob of her measurement result by a classical channel. Bob operates unitary transformation according to Alice's measurement results,

$$\begin{aligned}U_1 &= (|0\rangle\langle 1|-|1\rangle\langle 0|)_5\otimes(|0\rangle\langle 1|+|1\rangle\langle 0|)_7 \\ &\quad \otimes(|0\rangle\langle 1|+|1\rangle\langle 0|)_9,\end{aligned} \tag{16}$$

which will transform the states $\langle\Psi^+|_{38}\langle\Phi^+|_{26}\langle\Psi^-|_{14}\Psi\rangle$ into

$$\begin{aligned}U_1(\langle\Psi^+|_{38}\langle\Phi^+|_{26}\langle\Psi^-|_{14}\Psi\rangle) &= \frac{1}{2\sqrt{2}}(bcfx_0|000\rangle \\ &\quad +bcex_1|001\rangle+bdfx_2|010\rangle+bdex_3|011\rangle)_{579} \\ &\quad +\frac{1}{2\sqrt{2}}(acfx_4|100\rangle+acex_5|101\rangle+adfx_6|110\rangle \\ &\quad +adex_7|111\rangle)_{579}.\end{aligned} \tag{17}$$

It is evident that Bob must operate relevant unitary transformation U_1 against Alice's different measurement results. Table I shows all 64 kinds of different measurement results by Alice and Bob's relevant 64 kinds of unitary transformations. It will be mentioned that the note "$\pm$" of particles 5, 7, and 9 in the right column is dependent on the Bell-state measurements of particles 14, 26, and 38, respectively. The note "$\pm$" will be "$+$" if the Bell state is "$+$," while in the other case it will be "$-$."

Secondly, Bob introduces an auxiliary two-state particle A with the initial state $|0\rangle_A$ and performs a collective unitary transformation on particles 5, 7, 9, and A. In order for Bob to reconstruct the original state under the basis $\{|\psi_0\rangle_{579}|0\rangle_A, |\psi_0\rangle_{579}|1\rangle_A\}$ (where $|\psi_0\rangle_{579}$ stands for the basis of an eight-dimensional Hilbert space), a unitary transformation (a 16×16 matrix) may take the form

$$U_2=\begin{pmatrix} A_1 & A_2 \\ A_2 & -A_1\end{pmatrix}, \tag{18}$$

where A_1 and A_2 are 8×8 matrixes and can be expressed as

$$A_1=\mathrm{diag}(a_0,a_1,a_2,a_3,a_4,a_5,a_6,a_7) \tag{19}$$

and

$$\begin{aligned}A_2=\mathrm{diag}(&\sqrt{1-a_0^2},\sqrt{1-a_1^2},\sqrt{1-a_2^2},\sqrt{1-a_3^2},\sqrt{1-a_4^2}, \\ &\sqrt{1-a_5^2},\sqrt{1-a_6^2},\sqrt{1-a_7^2}),\end{aligned} \tag{20}$$

respectively, where a_i $(i=0,1,2,3,4,5,6,7$ and $|a_i|\leqslant 1)$ depends on the state of particles 5, 7, and 9. In Eq. (17), one may take

$$\begin{aligned}&a_0=\frac{ae}{bf},\quad a_1=\frac{a}{b},\quad a_2=\frac{ace}{bdf},\quad a_3=\frac{ac}{bd},\quad a_4=\frac{e}{f}, \\ &a_5=1,\quad a_6=\frac{ce}{df},\quad a_7=\frac{c}{d}.\end{aligned} \tag{21}$$

The unitary transformation U_2 will transform $U_1(\langle\Psi^+|_{38}\langle\Phi^+|_{26}\langle\Psi^-|_{14}\Psi\rangle)\otimes|0\rangle_A$ into

TABLE II. Values of a_i ($i=0,1,2,...,7$) corresponding to the states of particles 5, 7, and 9.

States of particles 5, 7, and 9	a_0	a_1	a_2	a_3	a_4	a_5	a_6	a_7
$U_1\langle\Phi^{\pm}\|_{38}\langle\Phi^{\pm}\|_{26}\langle\Phi^{\pm}\|_{14}\Psi\rangle$	1	$\frac{e}{f}$	$\frac{c}{d}$	$\frac{ce}{df}$	$\frac{a}{b}$	$\frac{ae}{bf}$	$\frac{ac}{bd}$	$\frac{ace}{bdf}$
$U_1\langle\Psi^{\pm}\|_{38}\langle\Phi^{\pm}\|_{26}\langle\Phi^{\pm}\|_{14}\Psi\rangle$	$\frac{e}{f}$	1	$\frac{ce}{df}$	$\frac{c}{d}$	$\frac{ae}{bf}$	$\frac{a}{b}$	$\frac{ace}{bdf}$	$\frac{ac}{bd}$
$U_1\langle\Phi^{\pm}\|_{38}\langle\Psi^{\pm}\|_{26}\langle\Phi^{\pm}\|_{14}\Psi\rangle$	$\frac{c}{d}$	$\frac{ce}{df}$	1	$\frac{e}{f}$	$\frac{ac}{bd}$	$\frac{ace}{bdf}$	$\frac{a}{b}$	$\frac{ae}{bf}$
$U_1\langle\Psi^{\pm}\|_{38}\langle\Psi^{\pm}\|_{26}\langle\Phi^{\pm}\|_{14}\Psi\rangle$	$\frac{ce}{df}$	$\frac{c}{d}$	$\frac{e}{f}$	1	$\frac{ace}{bdf}$	$\frac{ac}{bd}$	$\frac{ae}{bf}$	$\frac{a}{b}$
$U_1\langle\Phi^{\pm}\|_{38}\langle\Phi^{\pm}\|_{26}\langle\Psi^{\pm}\|_{14}\Psi\rangle$	$\frac{a}{b}$	$\frac{ae}{bf}$	$\frac{ac}{bd}$	$\frac{ace}{bdf}$	1	$\frac{e}{f}$	$\frac{c}{d}$	$\frac{ce}{df}$
$U_1\langle\Psi^{\pm}\|_{38}\langle\Phi^{\pm}\|_{26}\langle\Psi^{\pm}\|_{14}\Psi\rangle$	$\frac{ae}{bf}$	$\frac{a}{b}$	$\frac{ace}{bdf}$	$\frac{ac}{bd}$	$\frac{e}{f}$	1	$\frac{ce}{df}$	$\frac{c}{d}$
$U_1\langle\Phi^{\pm}\|_{38}\langle\Psi^{\pm}\|_{26}\langle\Psi^{\pm}\|_{14}\Psi\rangle$	$\frac{ac}{bd}$	$\frac{ace}{bdf}$	$\frac{a}{b}$	$\frac{ae}{bf}$	$\frac{c}{d}$	$\frac{ce}{df}$	1	$\frac{e}{f}$
$U_1\langle\Psi^{\pm}\|_{38}\langle\Psi^{\pm}\|_{26}\langle\Psi^{\pm}\|_{14}\Psi\rangle$	$\frac{ace}{bdf}$	$\frac{ac}{bd}$	$\frac{ae}{bf}$	$\frac{a}{b}$	$\frac{ce}{df}$	$\frac{c}{d}$	$\frac{e}{f}$	1

$$
\begin{aligned}
&\frac{1}{2\sqrt{2}}ace(x_0|000\rangle+x_1|001\rangle+x_2|010\rangle+x_3|011\rangle+x_4|100\rangle \\
&\quad +x_5|101\rangle+x_6|110\rangle+x_7|111\rangle)_{579}|0\rangle_A \\
&\quad +\frac{1}{2\sqrt{2}}[c\sqrt{(bf)^2-(ae)^2}x_0|000\rangle+ce\sqrt{b^2-f^2}x_1|001\rangle \\
&\quad +\sqrt{(bdf)^2-(ace)^2}x_2|010\rangle]_{579}|1\rangle_A \\
&\quad +\frac{1}{2\sqrt{2}}[e\sqrt{(bd)^2-(ac)^2}x_3|011\rangle+ac\sqrt{f^2-e^2}x_4|100\rangle \\
&\quad +a\sqrt{(df)^2-(ce)^2}x_6|110\rangle]_{579}|1\rangle_A \\
&\quad +\frac{1}{2\sqrt{2}}(ae\sqrt{d^2-c^2}x_7|111\rangle)_{579}|1\rangle_A .
\end{aligned} \tag{22}
$$

Then Bob measures the state of particle A. If the measured result is $|1\rangle_A$, the teleportation is failed. If the measurement result is $|0\rangle_A$, the state of particles 5, 7, and 9 collapses to

$$
\begin{aligned}
&\frac{1}{2\sqrt{2}}ace(x_0|000\rangle+x_1|001\rangle+x_2|010\rangle+x_3|011\rangle \\
&\quad +x_4|100\rangle+x_5|101\rangle+x_6|110\rangle+x_7|111\rangle)_{579}.
\end{aligned} \tag{23}
$$

The teleportation is successfully realized. The probability of successful teleportation is $|ade|^2/8$.

For the other cases, the values of a_i ($i=0,1,2,3,4,5,6,7$ and $|a_i|\leqslant 1$) of unitary transformation U_2 that corresponds to the states of particles 5, 7, and 9 are shown in Table II. There are eight kinds in all.

In conclusion, a scheme for teleportation of an arbitrary three-particle state via entanglement swapping is proposed. In this scheme, the quantum channel is composed of three nonmaximally entangled particle pairs by sender (Alice) and receiver (Bob). Synthesizing all 64 kinds of conditions, the total probability of successful teleportation is $8|ace|^2$, where a, c, and e are the smallest coefficients of the three entangled pairs, respectively. When $|a|=|b|=|c|=|d|=|e|=|f|=1/\sqrt{2}$, the total probability equals 1. This means that if the quantum channels are composed of three Einstein-Podolskey-Rose (EPR) states, complete teleportation can be realized by this method.

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