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Quantum Teleportation via Qutrit Entangled State

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ABSTRACT

Quantum entanglement is currently seen to be a resource that may be created, concentrated when needed, transported, and consumed. In quantum information processing, three-level quantum systems (qutrits) provide more advantages than qubits, such as higher security and resistance to noise. This work considers Unknown qubit and qutrit states may be teleported over a two-qutrit maximally entangled pair. as a quantum channel with less resource requirements than current protocols based on three-particle entanglement. The scheme presented here designs special measurement bases to realize faithful teleportation. In qubit teleportation, the protocol involves six measurement outcomes, each of which specifies a different unitary transformation for state recovery. Nine measurement bases are used in qutrit teleportation, with corresponding unitary operations to retrieve the initial state. The results demonstrate that a two-qutrit entangled state is sufficient to teleport the states of qubits and qutrits, being an economic resource with three-particle GHZ states. The novelty is the less entanglement resource and the straightforward building of measurement and unitary operations for high-dimensional systems. The paper illustrates the feasibility of qutrit teleportation and indicates the need for studying qutrit applications and experimental implementations.

Keywords: Quantum Teleportation, Qutrit State, Quantum entanglement.

Introduction

A key component of quantum mechanics, quantum entanglement is a tool for quantum information processing such as quantum computation, quantum teleportation [1], and quantum cryptography [2]. In the context of quantum computation [3], teleportation is defined in as the disembodied transfer of a system's quantum state and its correlations to an alternative system in space, where "system" denotes any singular or collective assemblage of matter or energy particles, including protons, neutrons, electrons, photons, atoms, ions, and so on [4].

Quantum teleportation works by erasing the original unknown quantum state at the sender's site and perfectly recreating it at the distant receiver's end. This process relies on both a quantum channel and a classical channel: quantum entanglement links the two parties, while classical communication allows the transmission of measurement results. Remarkably, one way to think about teleportation is the use of just two classical bits to encode the information of a qubit. sent over the classical channel [3–5]. Excellent

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applications of quantum teleportation can be achieved when combined with quantum entanglement techniques [5]. Bennett et al. put up the first teleportation plan in 1993 [6].

This intriguing phenomenon has since been the subject of in-depth theoretical research [7–18] and experimental demonstration [19–22]. Earlier teleportation protocols have primarily focused on transferring unknown qubit states or multi-qubit (N-qubit) systems, whether deterministically or probabilistically [6–19]. In contrast, investigations into qutrit teleportation the three-dimensional analogue of the qubit-remain relatively scarce. Notably, Zubairy, Stenholm, and Bardroff independently explored the transfer of N-dimensional quantum states [23]. Additionally, an developed a method for Teleporting an unidentified Entangled state of two qutrits inside a three-level Greenberger-Horne-Zeilinger (GHZ) quantum channel. In the year 2005 [24]. This framework was subsequently extended to include the more general context of arbitrary units. Chamoli and Bhandari have proposed the transporting both a double-qutrit and an unidentified single-qutrit state over the aforementioned three-level GHZ quantum channel [25].

However, compared to two-particle entanglement, three-particle entanglement preparation is Squantum channel and accomplish the same goal as those in Refs? [24,25]. We provide an affirmative response to this query in this work. We show that it is possible to faithfully teleport an arbitrary qutrit passing information from Alice to Bob across two qutrits sharing a fully entangled state. depending on how well-built the measuring bases are. Additionally, we illustrate that an unidentified qubit may be transported from Alice to Bob via a maximally entangled two-qutrit state. rather than an EPR pair, as was done in Ref. [26].

This is how the remainder of the paper is structured. We go over the qutrit preliminary steps in brief. The authors provide two separate methods for using A bipartite entangled quantum system with three levels channel to transfer unknown qubits and qutrits. This paper also contains discussions and conclusions. Alice, Bob, and Charlie are the owners of qutrits 1, 2, and 3, respectively. Alice wishes to transport Bob into an unidentified condition that looks like this:

$$|\psi\rangle_n = (\alpha|a\rangle + \beta|b\rangle + \gamma|c\rangle)_n \quad \text{.....(1)}$$

where |a⟩, |b⟩, and |c⟩ are column vectors in three dimensions that are defined by their values.

$$|a\rangle = \begin{pmatrix}0\\0\\0\end{pmatrix}, \ |b\rangle = \begin{pmatrix}1\\1\\1\end{pmatrix}, \ |c\rangle = \begin{pmatrix}2\\2\\2\end{pmatrix} \quad \text{.....(2)}$$

With the values, hence the complex numbers α, β, and γ meet the normalizing requirement.

$$|\alpha|^2 + |\beta|^2 + |\gamma|^2 = 1 \quad \text{.....(3)}$$

With the values, Qutrits are superior to qubits in a few ways. For instance, in quantum bit commitment, qutrits offer greater security than qubits [27], with the values. Their potential application in the fundamental quantum mechanical tests, which are very noise-resistant, is another example [28]. With the values Klimov and colleagues [29] and Chekhova and colleagues [30] have investigated the experimental implementation of arbitrary qutrit states, with the values. These applications provide qutrits in the field of quantum information a promising future with the values Two non-orthogonal qutrit states are indistinguishable, much like qubits. With the values, Numerous researchers have explored not only the entanglement between two qutrits, but also the intriguing prospect of creating entangled pairs consisting of a qubit and a qutrit.

The quantum measurement strategy outlined in Section III gains further credibility from the groundbreaking 2008 demonstration of qubit-qutrit entanglement by Lanyon et al [31]. Moreover, Ma et al. advanced the field in 2016[32], by developing an entanglement-specific quantum feedback control system for qubits and qutrits; their results show that local feedback applied to the qutrit subsystem more effectively enhances entanglement than when applied to the qubit

Moreover, she wishes to transport Bob into this condition. Assume Alice and Bob possess a pre-existing entangled qutrit pair.

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$$|\phi\rangle_{12} = \frac{1}{\sqrt{3}}(|00\rangle + |11\rangle + |22\rangle \ldots\ldots..(4)$$

Alice employs the following set of bases to carry out jointly measuring particles 0 and 1, allowing the transfer of the state $|\phi\rangle_0$.

$$|\phi\rangle_{012} = |\phi\rangle_0 \otimes |\phi\rangle_{12}$$

$$= \frac{1}{\sqrt{3}}(\alpha|000\rangle + \alpha|011\rangle + \alpha|022\rangle + \beta|100\rangle + \beta|111\rangle + \beta|122\rangle_{012} \ldots(7)$$

Alice uses the following bases to measure particles 0 and 1 and transmit the state $|\phi\rangle_0$.

$$|\phi_1\rangle = \frac{1}{\sqrt{2}}(|00\rangle + |11\rangle)\ldots\ldots(8)$$

$$|\phi_2\rangle = \frac{1}{\sqrt{2}}(|00\rangle - |11\rangle)\ldots\ldots(9)$$

$$|\phi_3\rangle = \frac{1}{\sqrt{2}}(|01\rangle + |12\rangle) \ldots\ldots..(10)$$

$$|\phi_4\rangle = \frac{1}{\sqrt{2}}(|01\rangle - |12\rangle)\ldots\ldots\ldots(11)$$

$$|\phi_5\rangle = \frac{1}{\sqrt{2}}(|02\rangle + |10\rangle) \ldots\ldots\ldots(12)$$

$$|\phi_6\rangle = \frac{1}{\sqrt{2}}(|02\rangle - |10\rangle)\ldots\ldots\ldots (13)$$

Indeed, Eq. (6) may be elegantly reformulated as follows for $|\phi\rangle_{012}$:

$$= \frac{1}{\sqrt{6}}[|\phi_1\rangle_{01}(\alpha|0\rangle + \beta|1\rangle)_2 + |\phi_2\rangle_{01}(\alpha|0\rangle - \beta|1\rangle)_2 + |\phi_3\rangle_{01}(\alpha|1\rangle + \beta|2\rangle)_2$$

$$+|\phi_4\rangle_{01}(\alpha|1\rangle - \beta|2\rangle)_2 + |\phi_5\rangle_{01}(\alpha|2\rangle + \beta|0\rangle)_2 + |\phi_6\rangle_{01}(\alpha|2\rangle - \beta|0\rangle)_2] \ldots\ldots. (14)$$

where Eqs. (7)–(12) define $|\Phi_i\rangle (i \in \{1, 6\})$. This makes it easier for us to comprehend the teleportation system mentioned above.

Quantum Teleportation of an Arbitrary Single-Qutrit State

We will now examine the procedure for sending an unidentified qutrit using the same three-level bipartite entangled quantum channel outlined in Section III. Assume Alice intends to transport a certain quantum state.

$$|\psi\rangle_0 = \alpha|0\rangle + \beta|1\rangle + \gamma|2\rangle \ldots\ldots.(15)$$

Return to Equation (5), where Alice and Bob share the same fully entangled pair $|\llbracket\psi\rangle\rrbracket_12$.

$$|\psi\rangle_{12} = \frac{1}{\sqrt{3}}(|00\rangle + |11\rangle + |22\rangle \ldots\ldots\ldots(16)$$

Bob still has Qutrit 2, and Alice still has Qutrit 1. Currently, the complete system comprising qutrits 0, 1, and 2 initially resides in the state:

$$|\psi\rangle_{012} = |\psi\rangle_0 \otimes |\psi\rangle_{12}$$

$$= \frac{1}{\sqrt{3}}(\alpha|000\rangle + \alpha|011\rangle + \alpha|022\rangle + \beta|100\rangle + \beta|111\rangle$$

$$+ \beta|122\rangle + \gamma|200\rangle + \gamma|211\rangle + \gamma|222\rangle)_{012} \ldots\ldots\ldots (17)$$

In a similar manner, Eq. (17) takes the following rewritten form:

$$|\psi\rangle_{012} = \frac{1}{3}[|\psi_1\rangle_{01}(\alpha|0\rangle + \beta|1\rangle + \gamma|2\rangle)_2$$

$$"+|\psi_2\rangle_{01}(\alpha|0\rangle + \frac{\sqrt{3}-i}{2}\beta|1\rangle - \frac{\sqrt{3}+i}{2}\gamma|2\rangle)_2$$

$$+|\psi_3\rangle_{01}(\alpha|0\rangle - \frac{\sqrt{3}+i}{2}\beta|1\rangle + \frac{\sqrt{3}-i}{2}\gamma|2\rangle)_2$$

$$+|\psi_4\rangle_{01}(\alpha|1\rangle + \beta|2\rangle + \gamma|0\rangle)_2$$

$$+|\psi_5\rangle_{01}(\alpha|1\rangle + \frac{\sqrt{3}-i}{2}\beta|2\rangle - \frac{\sqrt{3}+i}{2}\gamma|0\rangle)_2$$

$$+|\psi_6\rangle_{01}(\alpha|1\rangle - \frac{\sqrt{3}+i}{2}\beta|2\rangle + \frac{\sqrt{3}-i}{2}\gamma|0\rangle)_2$$

$$+|\psi_7\rangle_{01}(\alpha|2\rangle + \beta|0\rangle + \gamma|1\rangle)_2$$

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$$+|\psi_8\rangle_{01}\,(\alpha\,|2\rangle + \tfrac{\sqrt{3}-i}{2}\,\beta|0\rangle - \tfrac{\sqrt{3}+i}{2}\gamma\,|1\rangle)_2$$

$$+|\psi_9\rangle_{01}\,(\alpha\,|2\rangle - \tfrac{\sqrt{3}+i}{2}\,\beta|0\rangle + \tfrac{\sqrt{3}-i}{2}\gamma|1\rangle)_2\text{"} \quad \text{……..(18)}$$

Where |ψ_j⟩ (j∈{1,9}) are delineated as follows:

$$|\psi_1\rangle = \tfrac{1}{\sqrt{3}}(|00\rangle + |11\rangle + |22\rangle) \quad \text{…… (19)}$$

$$|\psi_2\rangle = \tfrac{1}{\sqrt{3}}(|00\rangle + \tfrac{\sqrt{3}-i}{2}|11\rangle - \tfrac{\sqrt{3}+i}{2}|22\rangle) \quad \text{…..……(20)}$$

$$|\psi_3\rangle = \tfrac{1}{\sqrt{3}}(|00\rangle - \tfrac{\sqrt{3}+i}{2}|11\rangle + \tfrac{\sqrt{3}-i}{2}|22\rangle) \quad \text{……(21)}$$

$$|\psi_4\rangle = \tfrac{1}{\sqrt{3}}(|01\rangle + |12\rangle + |21\rangle) \quad \text{……..(22)}$$

$$|\psi_5\rangle = \tfrac{1}{\sqrt{3}}(|01\rangle + \tfrac{\sqrt{3}-i}{2}|12\rangle - \tfrac{\sqrt{3}+i}{2}|20\rangle) \quad \text{……(23)}$$

$$|\psi_6\rangle = \tfrac{1}{\sqrt{3}}(|01\rangle - \tfrac{\sqrt{3}+i}{2}|12\rangle + \tfrac{\sqrt{3}-i}{2}|20\rangle) \quad \text{……(24)}$$

$$|\psi_7\rangle = \tfrac{1}{\sqrt{3}}(|02\rangle + |12\rangle + |21\rangle) \quad \text{……..……(25)}$$

$$|\psi_8\rangle = \tfrac{1}{\sqrt{3}}(|02\rangle + \tfrac{\sqrt{3}-i}{2}|12\rangle - \tfrac{\sqrt{3}+i}{2}|21\rangle) \quad \text{……(26)}$$

$$|\psi_9\rangle = \tfrac{1}{\sqrt{3}}(|02\rangle - \tfrac{\sqrt{3}+i}{2}|12\rangle + \tfrac{\sqrt{3}-i}{2}|21\rangle) \quad \text{……..(27)}$$

Alice conducts a joint quantum measurement on qutrits 0 and 1 and communicates her findings to Bob through classical communication, utilizing the premise established in Eqs. (19)–(27). Bob reconstructs the state $|\psi\rangle_0$ by applying the appropriate unitary transformation to his qutrit 2 using these four pieces of information. For instance, Bob's qutrit 2 is projected to the state upon receiving Alice's outcome. $\alpha|2\rangle - \frac{\sqrt{3}+i}{2}\beta|0\rangle + \frac{\sqrt{3}-i}{2}\gamma|1\rangle$ if Alice's measurement result is $|\psi_9\rangle$. His objective now is to convert $|2\rangle$, $-\frac{\sqrt{3}+i}{2}|0\rangle$ and $\frac{\sqrt{3}-i}{2}|1\rangle$ into $|0\rangle$, $|1\rangle$ and $|2\rangle$, respectively, using unitary operations. One way to do this is by using a unitary operation.

$$U_9 = |0\rangle\langle 2| - \tfrac{\sqrt{3}-i}{2}|1\rangle\langle 0| + \tfrac{\sqrt{3}+i}{2}|2\rangle 1| \quad \text{……(28)}$$

Details are in Table 1.

It is important to note that Bob's qutrit 2 is described as he compresses his hand into $(\alpha|0\rangle + \beta|1\rangle + \gamma|2\rangle)$ when Alice's measurement yields $|\psi_9\rangle$. Bob is not required to take any action in this situation, as the teleportation has already been executed accurately.

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Table 1: Alice's measurement outcome determines the status of Bob's unitary operations and • Qutrit 2.

The result of Alice's test	Qutrit state 2	Bob's one-step process
$\|\psi_1\rangle$	$\alpha\|0\rangle + \beta\|1\rangle + \gamma\|2\rangle$	None
$\|\psi_2\rangle$	$\alpha\|0\rangle + \frac{\sqrt{3}-i}{2}\beta\|1\rangle - \frac{\sqrt{3}+i}{2}\gamma\|2\rangle$	$\|0\rangle\langle 0\| + \frac{\sqrt{3}+i}{2}\|1\rangle\langle 1\| - \frac{\sqrt{3}-i}{2}\|2\rangle\langle 2\|$
$\|\psi_3\rangle$	$\alpha\|0\rangle - \frac{\sqrt{3}+i}{2}\beta\|1\rangle + \frac{\sqrt{3}-i}{2}\gamma\|2\rangle$	$\|0\rangle\langle 0\| - \frac{\sqrt{3}-i}{2}\|1\rangle\langle 1\| + \frac{\sqrt{3}+i}{2}\|2\rangle\langle 2\|$
$\|\psi_4\rangle$	$\alpha\|1\rangle + \beta\|2\rangle + \gamma\|0\rangle$	$\|0\rangle\langle 1\| + \|1\rangle\langle 2\| + \|2\rangle\langle 0\|$
$\|\psi_5\rangle$	$\alpha\|1\rangle + \frac{\sqrt{3}-i}{2}\beta\|2\rangle - \frac{\sqrt{3}+i}{2}\gamma\|0\rangle$	$\|0\rangle\langle 1\| + \frac{\sqrt{3}+i}{2}\|1\rangle\langle 2\| - \frac{\sqrt{3}-i}{2}\|2\rangle\langle 0\|$
$\|\psi_6\rangle$	$\alpha\|1\rangle - \frac{\sqrt{3}+i}{2}\beta\|2\rangle + \frac{\sqrt{3}-i}{2}\gamma\|0\rangle$	$\|0\rangle\langle 1\| - \frac{\sqrt{3}-i}{2}\|1\rangle\langle 2\| + \frac{\sqrt{3}+i}{2}\|2\rangle\langle 0\|$
$\|\psi_7\rangle$	$\alpha\|2\rangle + \beta\|0\rangle + \gamma\|1\rangle$	$\|0\rangle\langle 2\| + \|1\rangle\langle 0\| + \|2\rangle\langle 1\|$
$\|\psi_8\rangle$	$\alpha\|2\rangle + \frac{\sqrt{3}-i}{2}\beta\|0\rangle - \frac{\sqrt{3}+i}{2}\gamma\|1\rangle$	$\|0\rangle\langle 2\| + \frac{\sqrt{3}+i}{2}\|1\rangle\langle 0\| - \frac{\sqrt{3}-i}{2}\|2\rangle\langle 1\|$
$\|\psi_9\rangle$	$\alpha\|2\rangle - \frac{\sqrt{3}+i}{2}\beta\|0\rangle + \frac{\sqrt{3}-i}{2}\gamma\|1\rangle$	$\|0\rangle\langle 2\| - \frac{\sqrt{3}-i}{2}\|1\rangle\langle 0\| + \frac{\sqrt{3}+i}{2}\|2\rangle\langle 1\|$

Conclusions

The most strongly connected three-qutrit states are suggested as the way for quantum transfer to work. of an unknown qutrit state. The quantum channel of Ref. [26] necessitates a greater number of entanglement resources than our method for a single qutrit in the teleportation procedure. This is due to the fact that in the initial and subsequent scenarios, we implemented a GRZ state with three levels instead of a two-qutrit entangled dyad. On top of that, we proved that a single qubit may be accurately transferred via an entangled pair of two qubits. Qutrit has a more promising future than Qubit. In this case, Bob can precisely extract the unknown state by employing the appropriate unitary operator when Alice publishes the measurement findings. Alice and Bob possess a two-qutrit maximally entangled dyad, which enables her to transmit two qutrits in an entangled state. Nonetheless, more research should be done on both its ideas and experimental realizations. The current work's approaches demonstrate that quantum measurements employing qutrits are somewhat more complex than those involving qubits. This serves as a reminder that qutrit schemes need to be handled with caution and expertise in further work.

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