Received: 10 May 2023 | Accepted: 24 May 2023

DOI: 10.1049/qtc2.12062

IET Quantum Communication

The Institution of Engineering and Technology WILEY

ORIGINAL RESEARCH

# Research on information lossless teleportation via the W states

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**Funding information**

National Natural Science Foundation of China, Grant/Award Number: 61873162; the Tang Scholar Project of Soochow University

**Abstract**

In this article, a protocol for information lossless teleportation using W states is proposed. Firstly, the information lossless teleportation of an unknown state with a maximally entangled W-state channel, which protects the original unknown state information even in case of teleportation failure is investigated. Next, we generalise our scheme to non-maximally entangled W-state channels. Finally, the principle of the proposed scheme is validated by performing experiments on the quantum circuit simulator Quirk. Our study shows that W states can be used to teleport any quantum state without information loss through single-qubit measurements and local unitary operations.

**KEYWORDS**

quantum communication, quantum entanglement, teleportation

## 1 | INTRODUCTION

Quantum communication is a method of transmitting information that uses the unique properties of quantum physics to ensure its security. Quantum entanglement [1] is one of the most common quantum mechanical phenomena in quantum communication which plays a key role in different quantum information processing tasks, such as quantum teleportation (QT) [2], quantum secret sharing [3], quantum cryptography [4] and so on. Entanglement pairs are the basic resources for QT. So far, there have been many teleportation protocols based on different entangled states, such as Bell states, W states, and GHZ (Greenberger–Horne–Zeilinger) states [5, 6]. The original QT protocol was proposed by Bennett et al. [7] in 1993, which used pre-shared Einstein-Podolsky-Rosen (EPR [8]) pairs and local operations to enable the sender (Alice) to teleport an unknown state to the receiver (Bob) with the help of classical communication. Bouwmeester et al. [9] implemented the first experimental QT [10] in 1997, which indicated that QT would be a critical ingredient for quantum computation networks [11]. In ref. [12], the authors proposed the first probabilistic QT scheme, which confirmed that it was possible to teleport an unknown state with unit fidelity but less than unit probability with non-maximally entangled states. Luo et al. [13] proposed a scheme for teleportation of arbitrary high-dimensional photonic quantum states in 2019 and demonstrated an example of teleporting a qutrit. This breakthrough paved the way for advanced quantum technologies in high dimensions. In 2020, Hu et al. [14] demonstrated the teleportation of high-dimensional states in a three-dimensional six-photon system, which opened up possibilities for remotely reconstructing complex quantum systems. In 2021, Kumar et al. [15] theoretically and experimentally demonstrated the teleportation of two-qubit and three-qubit states through five-qubit and seven-qubit cluster states respectively. Additionally, in ref. [16], the author proposed a modified QT protocol in 2022, which enabled Alice to reset the state of the entangled pair to its initial state using only local operations.

In refs. [17, 18], the authors found that three-partite GHZ [19, 20] states and W states could also be used as quantum channels for teleportation [21]. W states are maximally symmetrically robust against the loss of any single qubit, making them effective for quantum secure communication. Various QT protocols have been developed based on W states. In 2002, a scheme was presented to produce an entangled W state of four photons using linear optical devices and a four-photon coincidence detection [22]. In 2007, Wang et al. proposed a protocol to prepare a partially entangled W state. Jaewoo Joo et al. proposed a teleportation protocol with a probability of 2/3 that used Bell state measurement and unitary operations [23]. To improve the success probability of QT, Pankaj et al. proposed a teleportation method with a specific set of W states [18]. It has also been proven that W states retain information better and have high security. In refs. [24], Zha et al. presented two schemes for the remote preparation of a four-qubit W state using a six-qubit maximally entangled state as the quantum channel in 2015. In this protocol, the success probability for a general state was $1/4$, and it could be improved to $1/2$ or even 1 for certain states. Tang et al. [25] proposed a two-step efficient quantum dialog protocol with a three-particle entangled W state. In 2015, Debmalya et al. [9] experimentally constructed a three-qubit entangled W state using an Nuclear Magnetic Resonance quantum information processor. In 2018, Zhou et al. [23] proposed a multi-hop teleportation scheme via W states. To enhance the teleportation fidelity in a strong noisy channel, Liang et al. [26] investigated the teleportation of an arbitrary single-qubit state through a three-particle W state under various environments in 2020. Refs. [27] proposed the dissipative preparation of W states in trapped ion systems in 2021. Wen et al. proposed an authenticated semi-quantum key distribution protocol with W states in 2022. Although W states have been widely studied as potential quantum channels due to their robustness against single-qubit loss, almost all QT schemes based on W states are probabilistic, which leads to the risk of unknown information loss when the transmission fails.

Recently, Roa et al. [28] proposed a nondestructive teleportation scheme without information loss if the teleportation failed. This protected the integrity of information and offered the chance to repeat the teleportation process. Fu et al. [29] explored the nondestructive probabilistic teleportation which could restore the original state even if the teleportation failed. In 2021, Pan et al. [30] proposed a novel quantum network coding scheme that achieved perfect transmission of quantum states without information loss. This breakthrough allowed for savings in both quantum and classical channel resources. The idea of nondestructive teleportation has the advantage that the unknown state can be recovered by the sender when teleportation fails. This advantage offers the chance to repeat the teleportation process as many times. It should be noted that constructing and maintaining a perfect quantum channel poses significant challenges, and the process can be both difficult and expensive. While Bell states, GHZ states, and cluster states have all been explored as potential channels in quantum communication, it is worth noting that W states stand out due to their exceptional robustness and security features. As a result, they are particularly appealing for use in quantum communication. Hence, we suggest using W states as the quantum channel for our nondestructive teleportation protocol. By re-teleporting the original unknown state through other available quantum channels, non-destructive teleportation via W states can enhance the reliability and efficiency of quantum communication.

In this paper, we utilise a non-maximally entangled W-state as the quantum channel to develop a non-destructive teleportation scheme that ensures the integrity and safety of the original information. We verify this scheme by implementing the teleportation process using a non-maximally entangled W-state channel on the quantum circuit simulator Quirk. Our proposed method for teleportation relies only on single-qubit measurements and local unitary operations, representing an important innovation that simplifies the experimental setup and reduces the resource requirements for QT.

The paper is structured as follows: Section 2 presents our information lossless teleportation method based on a maximally entangled W-state channel. Section 3 further discusses our information lossless teleportation method, this time based on non-maximally entangled W-state channels. In Section 4, we present the simulation results. Section 5 provides a discussion and comparison of our method. Finally, we conclude the paper with a brief summary in Section 6.

## 2 | INFORMATION LOSSLESS TELEPORTATION METHOD BASED ON MAXIMALLY ENTANGLED W-STATE CHANNEL

Suppose that Alice wishes to teleport an arbitrary quantum state to Bob which is written as

$$|\chi\rangle_t = a|0\rangle_t + b|1\rangle_t \tag{1}$$

where $a$ and $b$ are complex numbers, and satisfy the relationship $|a|^2 + |b|^2 = 1$. The maximally entangled W-state is written as

$$|W\rangle_{ABC} = \frac{1}{\sqrt{3}}(|100\rangle + |010\rangle + |001\rangle)_{ABC} \tag{2}$$

As shown in Figure 1, three participants share the following maximally entangled W-state. The particle $A$ belongs to the sender Alice. The particle $B$ is in the receiver Bob's possession. The particle $C$ is owned by the controller Charlie.

The total state of the system can be written as

$$\begin{aligned}
|\phi\rangle_{tABC} &= |\chi\rangle_t \otimes |W\rangle_{ABC} \\
&= \frac{1}{\sqrt{3}}(a|0\rangle + b|1\rangle)_t \otimes (|100\rangle + |010\rangle + |001\rangle)_{ABC} \\
&= \frac{1}{\sqrt{3}}(a|0100\rangle + a|0010\rangle + a|0001\rangle + b|1100\rangle \\
&\quad + b|1010\rangle + b|1001\rangle)_{tABC}
\end{aligned} \tag{3}$$

In order to teleport the unknown state $|\chi\rangle_t$ from the sender Alice to the receiver Bob, this scenario can be divided into the following three steps.

### 2.1 | Step 1

Alice performs a controlled-not gate ($CNOT$) operation on particle $t$ (labelled as a control qubit) and $A$ (labelled as a target qubit). Which is written as follows:

$$CNOT = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix} \tag{4}$$

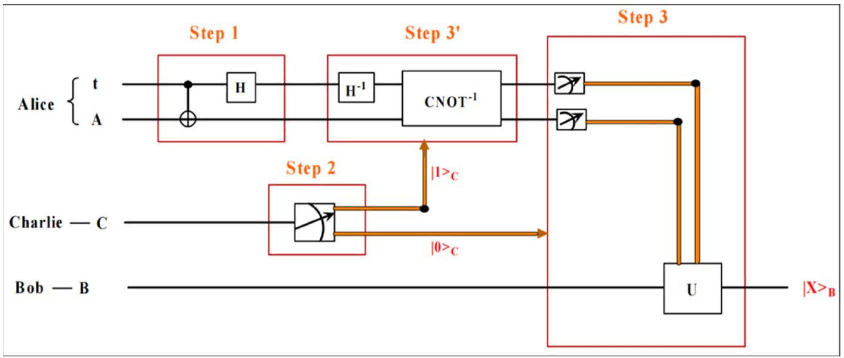


**FIGURE 1** The information lossless teleportation based on the maximally entangled W-state channel.

Note that $CNOT^2 = I$ and $CNOT^{-1} = CNOT$.

Then, Alice performs a Hadamard gate operation on particle $t$. The matrix of the Hadamard gate is represented as follows:

$$H = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \tag{5}$$

Here $H^2 = I$. The inverse of the Hadamard gate ($H^{-1}$) equals to the Hadamard gate itself, $H^{-1} = H$.

After these operations, the total state of system can be re-expressed as follows:

$$\begin{aligned} |\phi\rangle_{tABC} &= \frac{1}{\sqrt{6}}[a(|0100\rangle + |1100\rangle + |0010\rangle + |1010\rangle \\ &\quad + |0001\rangle + |1001\rangle) + b(|0000\rangle - |1000\rangle \\ &\quad + |0110\rangle - |1110\rangle + |0101\rangle - |1101\rangle]_{tABC} \\ &= \frac{1}{\sqrt{6}}\begin{bmatrix} |00\rangle_{tA} \otimes (a|10\rangle + b|01\rangle + b|00\rangle)_{BC} \\ + |01\rangle_{tA} \otimes (a|00\rangle + b|10\rangle + b|01\rangle)_{BC} \\ + |10\rangle_{tA} \otimes (a|10\rangle + a|01\rangle - b|00\rangle)_{BC} \\ + |11\rangle_{tA} \otimes (a|00\rangle - b|10\rangle - b|01\rangle)_{BC} \end{bmatrix} \end{aligned} \tag{6}$$

## 2.2 | Step 2

Charlie performs the single-qubit measurement with the basis of $|0\rangle$ and $|1\rangle$ on particle C and tells the measurement outcome to the receiver Bob. If the measurement outcome of the auxiliary particle is $|0\rangle_c$, the receiver Bob performs step 3. Otherwise, step 3′ is performed to achieve information lossless teleportation.

## 2.3 | Step 3

If the particle C is measured as $|0\rangle_c$, the state of the remaining qubits collapses into the following state:

$$|\phi\rangle_{tAB} = \frac{1}{2}\begin{bmatrix} |00\rangle_{tA} \otimes (a|1\rangle + b|0\rangle)_B \\ + |01\rangle_{tA} \otimes (a|0\rangle + b|1\rangle)_B \\ + |10\rangle_{tA} \otimes (a|1\rangle - b|0\rangle)_B \\ + |11\rangle_{tA} \otimes (a|0\rangle - b|1\rangle)_B \end{bmatrix} \tag{7}$$

Then Alice performs the single-qubit measurement of the basis $\{|0\rangle, |1\rangle\}$ onto her particles. Bob then performs the unitary operation onto particle $B$ based on Alice's measurement outcome. The relationship between the measurement outcomes of Alice and the corresponding operations performed by Bob are shown in Table 1.

Finally, we can see that the information has been successfully transmitted from Alice to Bob.

## 2.4 | Step 3'

If the measurement of particle $C$ is $|1\rangle_t$, the scheme will fail. The state of the remaining particles $t$, $A$, and $B$ can be expressed as follows:

$$|\phi\rangle_{tABC} = \frac{1}{2}\begin{bmatrix} |00\rangle_{tA} \otimes (a|01\rangle_{BC}) \\ + |01\rangle_{tA} \otimes (b|01\rangle_{BC}) \\ + |10\rangle_{tA} \otimes (a|01\rangle_{BC}) \\ + |11\rangle_{tA} \otimes (-b|01\rangle_{BC}) \end{bmatrix} \tag{8}$$

In this case, Alice first performs $H^{-1}$ operations onto the particle $t$.

$$H^{-1} = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \tag{9}$$

Then Alice performs $CNOT^{-1}$ operations onto particles $t$ and $A$.

$$CNOT^{-1} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix} \tag{10}$$

In this scheme, the sender, the receiver and the third party directly share the maximally entangled W-state channel. On the basis of Charlie's measurement result, the unknown quantum state can be recovered at Bob. Alice can also restore the original unknown state after the failure of teleportation to ensure the integrity of the unknown quantum state.

## 3 | INFORMATION LOSSLESS TELEPORTATION METHOD BASED ON NON-MAXIMALLY ENTANGLED W-STATE CHANNELS

Now we turn to a general protocol for transmitting the unknown quantum state over quantum channels that are not the maximally entangled W states. Assume that Alice intends to send the quantum state $|\chi\rangle_t$ in Equation (1) to Bob.

The three parties share the non-maximally entangled W state $|\phi\rangle_{ABC} = (\alpha|001\rangle + \beta|010\rangle + \gamma|100\rangle)_{ABC}$, where $\alpha$, $\beta$, $\gamma$ are real numbers, and satisfy the relationship $\alpha^2 + \beta^2 + \gamma^2 = 1$ $(\beta < \gamma)$. As shown in Figure 2, three participants share the non-maximally entangled W-state. Particle A belongs to the sender Alice. Particle $B$ is in the possession of the receiver. Particle $C$ is owned by the controller Charlie.

Firstly, Bob introduces an auxiliary particle $e$ with the initial state $|0\rangle_e$. We can rewrite the initial product state $|\phi\rangle_{tABCe} = |\chi\rangle_t \otimes |\varphi\rangle_{ABC} \otimes |0\rangle_e$ as

$$\begin{aligned}|\phi\rangle_{tABCe} &= |\chi\rangle_t \otimes |\varphi\rangle_{ABC} \otimes |0\rangle_e = \frac{1}{\sqrt{3}}(a|0\rangle + b|1\rangle)_t \\ &\otimes (\alpha|100\rangle + \beta|010\rangle + \gamma|001\rangle)_{ABC} \otimes |0\rangle_e \\ &= a(\alpha|00010\rangle + \beta|00100\rangle + \gamma|01000\rangle)_{tABCe} \\ &\quad + b(\alpha|10010\rangle + \beta|10100\rangle + \gamma|11000\rangle)_{tABCe}\end{aligned} \tag{11}$$

In order to transmit the unknown quantum state from the sender Alice to the receiver Bob, the information lossless teleportation method is divided into the following four steps.

### 3.1 | Step 1

Alice performs a *CNOT* operation onto the particle $t$ (labelled as a control qubit) and $A$ (labelled as a target qubit). Then she performs the Hadamard gate operation on the particle $t$.

After those operations, the state of the total system can be re-expressed as follows:

$$|\phi\rangle_{tACBe} = \frac{1}{\sqrt{2}}\begin{bmatrix} |00\rangle_{tA} \otimes (a\alpha|100\rangle + a\beta|010\rangle + b\gamma|000\rangle)_{CBe} + \\ |01\rangle_{tA} \otimes (a\gamma|000\rangle + b\alpha|100\rangle + b\beta|010\rangle)_{CBe} + \\ |10\rangle_{tA} \otimes (a\alpha|100\rangle + a\beta|010\rangle - b\gamma|000\rangle)_{CBe} + \\ |11\rangle_{tA} \otimes (a\gamma|000\rangle - b\alpha|100\rangle - b\beta|010\rangle)_{CBe} \end{bmatrix} \tag{12}$$

### 3.2 | Step 2

Charlie performs the single-qubit measurement with the basis of $|0\rangle$ and $|1\rangle$ on the particle $C$, The measurement result of the particle $C$ is $|0\rangle_c$ or $|1\rangle_c$.

### 3.3 | Step 3

While step 2 is executed, Bob performs $U_1$ onto his particles $B$ and $e$, as follows:

**TABLE 1** The relationship between the measurement results of particles $t$ and $A$ hold by Alice and the corresponding operations performed by Bob.

| Measurement results of particles $t$ and $A$ | Bob's operation |
|---|---|
| $\|00\rangle$ | X |
| $\|01\rangle$ | I |
| $\|10\rangle$ | Y |
| $\|11\rangle$ | Z |

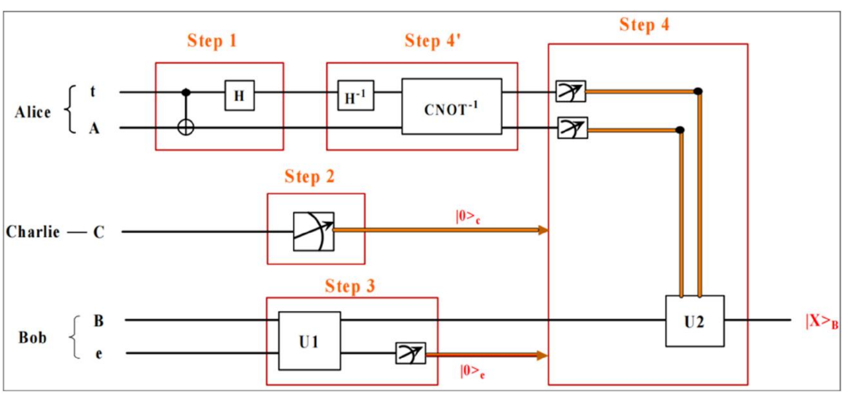


**FIGURE 2** The information lossless teleportation based on the non-maximally entangled W-state channel.

$$U_1 = \begin{bmatrix} \beta/\gamma & \sqrt{1-\beta^2/\gamma^2} & 0 & 0 \\ -\sqrt{1-\beta^2/\gamma^2} & \beta/\gamma & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{13}$$

Then the state of the five-particle system becomes:

$$|\phi\rangle_{tACBe} = \begin{bmatrix} |00\rangle \otimes \begin{pmatrix} a\beta|010\rangle + a\dfrac{\alpha\beta}{\gamma}|100\rangle \\ -a\alpha\sqrt{1-\beta^2/\gamma^2}\,|101\rangle \\ +b\beta|000\rangle - b\sqrt{\gamma^2-\beta^2}\,|001\rangle \end{pmatrix} + \\ |01\rangle \otimes \begin{pmatrix} b\beta|010\rangle + b\dfrac{\alpha\beta}{\gamma}|100\rangle \\ -b\alpha\sqrt{1-\beta^2/\gamma^2}\,|101\rangle \\ +a\beta|000\rangle - a\sqrt{\gamma^2-\beta^2}\,|001\rangle \end{pmatrix} + \\ |10\rangle \otimes \begin{pmatrix} a\beta|010\rangle + a\dfrac{\alpha\beta}{\gamma}|100\rangle \\ -a\alpha\sqrt{1-\beta^2/\gamma^2}\,|101\rangle \\ -b\beta|000\rangle + b\sqrt{\gamma^2-\beta^2}\,|001\rangle \end{pmatrix} + \\ |11\rangle \otimes \begin{pmatrix} -b\beta|010\rangle - b\dfrac{\alpha\beta}{\gamma}|100\rangle \\ +b\alpha\sqrt{1-\beta^2/\gamma^2}\,|101\rangle \\ -a\beta|000\rangle + a\sqrt{\gamma^2-\beta^2}\,|001\rangle \end{pmatrix} \end{bmatrix}_{tACBe} \tag{14}$$

Bob then performs a single-qubit measurement with the basis of $|0\rangle$ and $|1\rangle$ on his particle $e$.

### 3.4 | Step 4

If the measurement outcomes of the particles $e$ and $C$ are $|0\rangle_e$ and $|0\rangle_C$, the state of the three-particle system collapses to:

$$|\phi\rangle_{tAB} = \frac{1}{2}\begin{bmatrix} |00\rangle_{tA} \otimes (a|1\rangle + b|0\rangle)_B \\ +|01\rangle_{tA} \otimes (a|0\rangle + b|1\rangle)_B \\ +|10\rangle_{tA} \otimes (a|1\rangle - b|0\rangle)_B \\ +|11\rangle_{tA} \otimes (-a|0\rangle - b|1\rangle)_B \end{bmatrix} \tag{15}$$

At this moment, Alice carries out the single-qubit measurement of the basis $\{|0\rangle, |1\rangle\}$ onto particles $t$ and $A$. Then Bob performs a unitary operation onto particle B based on Alice's measurement outcome. The relationship between the measurement outcomes of Alice and the corresponding operations performed by Bob is shown in Table 2.

After performing the unitary operation, the unknown state has been successfully transmitted to the receiver Bob.

### 3.5 | Step 4'

If the measurement outcome of the particles $e$ and $C$ are not $|0\rangle_e|0\rangle_C$. In this case, Alice performs $H^{-1}$ operation on particles $t$, and then performs $CNOT^{-1}$ operation on particles $t$ and $A$, which restores the unknown state to the sender Alice.

In this scheme, we extend the maximally entangled channel in Section 2 to the non-maximally entangled channel, which improves the versatility of the scheme. Different from the scheme in Section 2, Bob needs to perform a unitary operation onto his particles $B$ and $e$ in advance. With the aid of the auxiliary particle, Alice can restore the initial state if teleportation fails. Due to the idea of information lossless teleportation, this scheme can avoid the loss of information to ensure integrity.

## 4 | SIMULATION

Quirk is a quantum circuit simulator [31] that allows users to visualise and simulate quantum circuits. It uses a state vector approach to accurately simulate circuits of up to 16 qubits. We used Quirk to verify our scheme without considering the impact of noise. To prepare a three-qubit non-maximally entangled W state in the simulator, we applied an H gate, a Ry gate [32] (Ry($\theta$) = $\begin{bmatrix} cos\frac{\theta}{2} & -sin\frac{\theta}{2} \\ sin\frac{\theta}{2} & cos\frac{\theta}{2} \end{bmatrix}$) and a CNOT gate, as shown in Figure 3.

**TABLE 2** The relationship between the measurement results of particles $t$ and $A$ hold by Alice and the corresponding operations performed by Bob.

| Measurement results of particles $t$ and $A$ | Bob's operation |
|---|---|
| $\|00\rangle$ | X |
| $\|01\rangle$ | I |
| $\|10\rangle$ | Y |
| $\|11\rangle$ | ZYX |

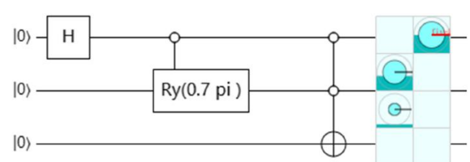


**FIGURE 3** The quantum circuit of generating one three-qubit non-maximally entangled W state.

To illustrate the experimental process, we generated one non-maximally entangled W state. Figure 4 shows the experimental circuit we used to transmit an arbitrary quantum state using this W state, for specific verification.

We simulated the circuit shown in Figure 4 using Quirk and applied the corresponding recovery matrix $\mathrm{Ry}(-0.43\pi)$ to obtain $|t\rangle = \cos(-0.43\pi/2)|0\rangle + \sin(-0.43\pi/2)|1\rangle$. Following the procedure outlined in Section 3, we can then recover the randomly generated quantum state $|t\rangle$ on particle B. This simulation demonstrates the feasibility of our proposed scheme.

## 5 | DISCUSSION AND COMPARISON

Several schemes for QT based on W states have been proposed in recent years. Table 3 compares the differences between previous schemes and our proposed scheme.

In scheme 1 [33], the sender used a maximally entangled W state to perform a Bell state measurement in order to teleport an arbitrary single-qubit state. However, the success probability of this scheme was only 66.7%. In scheme 2 [33], a positive operator valued measurement was used. Although the success probability of this scheme was 83.3%, it did not show any advantage over the standard teleportation of Scheme 1. Instead, it was helpful in exploring the properties of quantum information processing using W states. In scheme 3 [34], the W-class state was used as the quantum channel. After the sender performed von Neumann measurements, the receiver needed to apply local unitary operations based on the sender's three-qubit von Neumann measurement outcomes. However, the success probability of this scheme could not reach 100%. In scheme 4 [35], a unique entangled W state was chosen as the communication channel. The sender performed a single-qubit measurement, and the success probability of this protocol could only reach 100% when the teleported state was $1/\sqrt{2}|0\rangle + 1/\sqrt{2}|1\rangle$.

In contrast, our proposed scheme uses a non-maximally entangled W state as the quantum channel and is able to weaken the requirements of the quantum channel, making it more convenient and practical in physical experiments. Furthermore, even if the teleportation fails, our scheme provides an alternate path to ensure the integrity of the original quantum state, making it a promising approach for future research in quantum communication with W states.

## 6 | SUMMARY

In conclusion, we have proposed an information lossless teleportation scheme using a non-maximally entangled W-state as the quantum channel. Our scheme extends the study of information lossless teleportation based on the maximally entangled W-state channel and weakens the requirements of the quantum channel, making it more convenient and practical for physical experiments. Even if the teleportation fails, our scheme provides an alternative

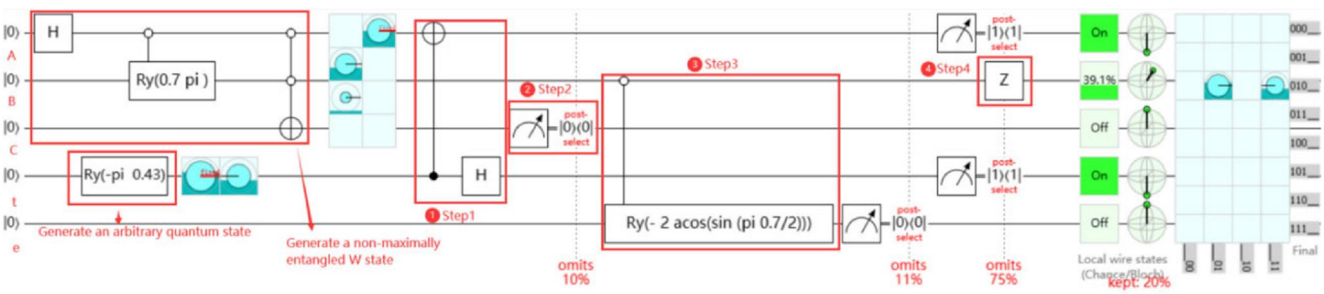


**FIGURE 4** Verification experimental circuit for transmitting an arbitrary quantum state using one non-maximally entangled W state.

**TABLE 3** The differences between the previous schemes with our scheme.

| | Quantum state to be transmitted | Alice's measurement | Success probability | Communication channel |
|---|---|---|---|---|
| Scheme 1 [33] | Arbitrary single-qubit state | The bell measurement | 66.7% | Maximally entangled W-state channel |
| Scheme 2 [33] | Arbitrary single-qubit state | The POVM measurement | 83.3% | Maximally entangled W-state channel |
| Scheme 3 [34] | Arbitrary three-qubit state | The von neumann measurements | <100% | W-class state channel $\frac{1}{2}(|010\rangle + |100\rangle + \sqrt{2}|001\rangle)$ |
| Scheme 4 [35] | Arbitrary single-qubit state | The single-qubit measurement | <100% | a unique three-atom entangled W state $\frac{1}{2}(|010\rangle + |100\rangle + |001\rangle + |000\rangle)$ |
| Our scheme | Arbitrary single-qubit state | The single-qubit measurement | 100% | Non-maximally entangled W-state channel |

path to ensure the integrity of the original quantum state using an auxiliary particle. If the teleportation succeeds, the sender can perform a single-qubit measurement, and the receiver can obtain the quantum state using corresponding unitary transformations. To facilitate the implementation of our proposed scheme, we have created a detailed circuit diagram and step-by-step instructions, which were simulated using the quantum circuit simulator Quirk. We hope our scheme can contribute to future research on quantum communication with W-states.

## AUTHOR CONTRIBUTIONS

**Ao Wang**: Data curation; Writing – original draft; Writing – review & editing. **Yu-Zhen Wei**: Supervision. **Zong-Yi Li**: Validation. **Min Jiang**: Corresponding Author; Supervision for Validation.

## ACKNOWLEDGEMENTS

This project is supported by the National Natural Science Foundation of China (61873162) and the Tang Scholar Project of Soochow University.

## CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

## DATA AVAILABILITY STATEMENT

Data openly available in a public repository.

## PERMISSION TO REPRODUCE MATERIALS FROM OTHER SOURCES

Not Applicable.

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**How to cite this article:** Wang, A., et al.: Research on information lossless teleportation via the W states. IET Quant. Comm. 4(4), 200–207 (2023). https://doi.org/10.1049/qtc2.12062