Teleporting an Unknown Quantum State Via Dual Classical and Einstein-Podolsky-Rosen Channels*

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Introduction

Goals/Motivation

- Teleport a quantum particle using quantum entanglement.
- Understand the properties of quantum information.

What does 'teleporting' mean?

Alice want to send Bob a particle. However she does not know anything about the state of the particle and cannot give it to Bob physically. Let the particle be in the state $|\varphi\rangle$. How does Bob obtain a particle in the exact same state $|\varphi\rangle$ without what it is?

Alice can use quantum entanglement to teleport a particle

When two particles interact, their wavefunctions become entangled if measurement of one particle determines the state of the other particle.

$$\frac{1}{\sqrt{2}}\left(|0\rangle_A \otimes |1\rangle_B + |1\rangle_A \otimes |0\rangle_B\right)$$

Entangled state

Measuring A to be $|0\rangle$ means B is $|1\rangle$

The problem of measurement

What happens when I change my basis?

$$(|0\rangle_A, |1\rangle_A) \xrightarrow{Unitary} \left(\tfrac{1}{\sqrt{2}}|0\rangle_A + \tfrac{1}{\sqrt{2}}|1\rangle_A, \tfrac{1}{\sqrt{2}}|0\rangle_A - \tfrac{1}{\sqrt{2}}|1\rangle_A\right) = (|\psi\rangle_+, |\psi\rangle_-)$$

Then my state is $\frac{1}{\sqrt{2}}(|0\rangle_B + |1\rangle_B)\,|\psi\rangle_+ + \frac{1}{\sqrt{2}}(|0\rangle_B - |1\rangle_B)\,|\psi\rangle_-$. Now measuring in this basis yields different results.

Bell basis

$$\begin{cases} |\Psi^-\rangle = \frac{1}{\sqrt{2}}(|01\rangle - |10\rangle) \\ |\Psi^+\rangle = \frac{1}{\sqrt{2}}(|01\rangle + |10\rangle) \\ |\Phi^-\rangle = \frac{1}{\sqrt{2}}(|00\rangle - |11\rangle) \\ |\Phi^+\rangle = \frac{1}{\sqrt{2}}(|00\rangle + |11\rangle) \end{cases}$$

Teleportation Procedure

- Goal: Teleport state $|\varphi\rangle$ from particle *1* to Bob

Source of maximally entangled particle pairs (A) (B)

(A) → Alice (1)

Entangle particle *1* and particle *A*

Apply unitary transformation on (1,A) pair

(1) (A)

Measure and collapse the *(1,A)* entangled pair (and hence change the state of *B*)

Send the result of measurement to Bob with *classical channel*

(B) → Bob

Wait for Alice's result

(B)

Apply unitary transformation (based on message from Alice) on particle *B*

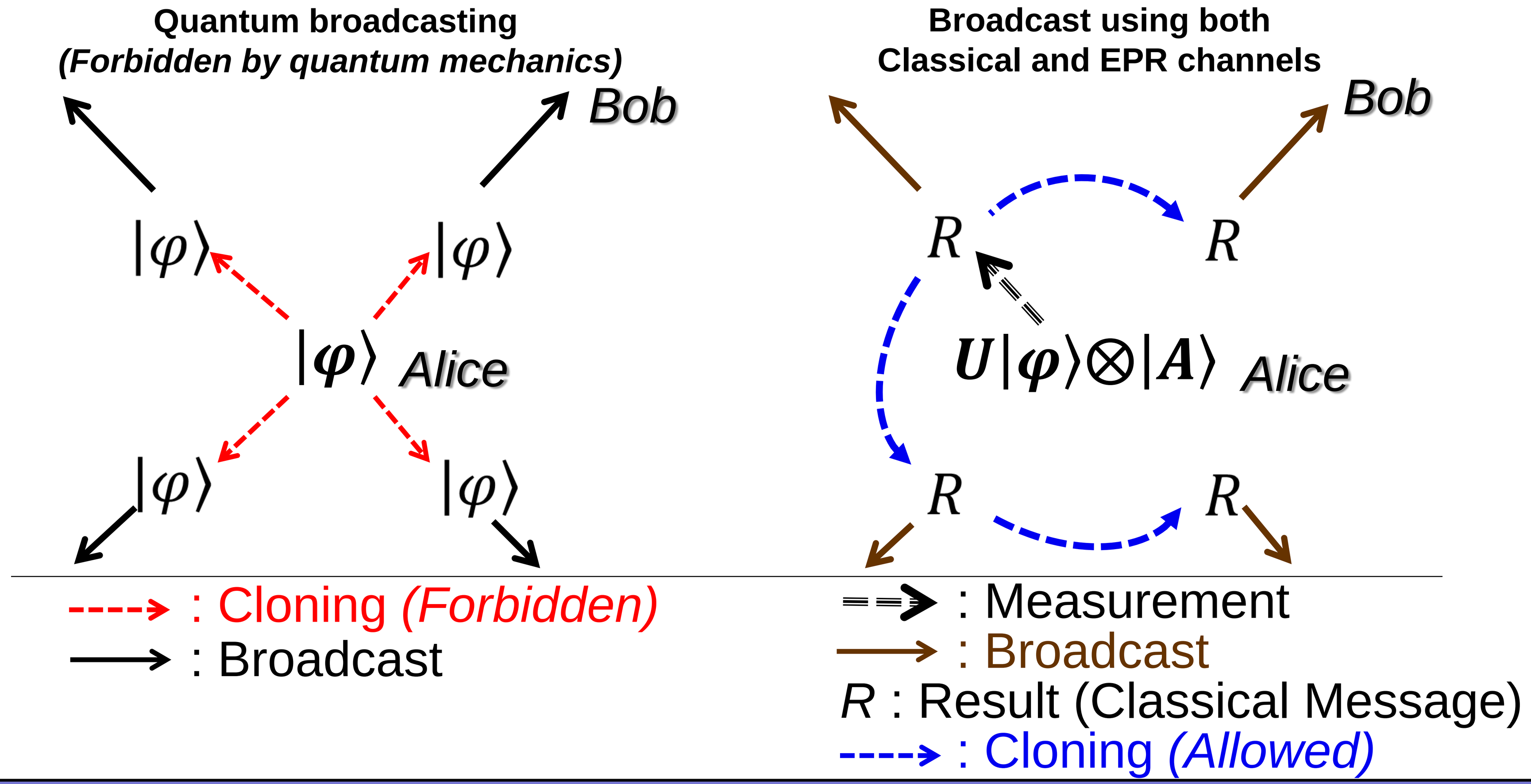
(B) with state $|\varphi\rangle$

→ : EPR Channel
→ : Classical Channel

Possible Implications

"Pseudo-broadcast" of quantum states

- Broadcasts of states in quantum mechanics are forbidden as they require cloning
- In this procedure, Alice need no information on the location of Bob, as classical message can be cloned and broadcasted



Improved Quantum Cryptography

- In this procedure, direct transfer of quantum state was avoided
- By comparing some part of the message (substring) in public, Alice and Bob could detect eavesdropper easily

	Without eavesdropper	With eavesdropper
Alice	100110011101…	100110011101…
Bob	100110011101…	010101011010…

- When Alice and Bob compare the red segment in public in the second case, the discrepancy indicates presence of eavesdropper

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*C. H. Bennett, G. Brassard, C. Crépeau, R. Jozsa, A. Peres, and W. K. Wootters, Phys. Rev. Lett. 70, 1895 (1993).