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# Beam up my quantum state, Scotty!

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# 1 Introduction

## Bullet points

- Quantum teleportation protocol
- Why is it needed?
- Areas of application, quantum communications, quantum computers
- what is needed to realize it on a large scale, i.e. quantum repeaters, memory...
- EPR-pairs and bell basis

## 1.1 Preliminaries

In quantum teleportation the sender and receiver are referred to as Alice and Bob, and are denoted A and B respectively. Sometimes a third party is relevant which will be called Charlie and be denoted C.

### 1.1.1 EPR-pairs and the Bell Basis

An Einstein-Podolsky-Rosen-pair (EPR-pair) is a maximally entangled state of two qubits [1] which can be written as

$$|\Phi^\pm\rangle = \frac{|00\rangle \pm |11\rangle}{\sqrt{2}} \quad \text{and} \quad |\Psi^\pm\rangle = \frac{|01\rangle \pm |10\rangle}{\sqrt{2}}. \quad (1)$$

When measuring a quantum state the basis of measurement is important as this determines the possible outcome states. Common basis used are the computational basis, consisting of  $|0\rangle$  and  $|1\rangle$ , and the Bell basis consisting of the EPR-pairs, also known as Bell states, seen in Eq. (1). EPR-pairs and projective measurements in the Bell basis play a crucial role in quantum teleportation protocols. [1]

## 1.2 Quantum Teleportation Protocol

# 2 Experimental Evidence

Experimental evidence for quantum teleportation in quantum communications.

**Bullet points**

- Quantum teleportation has experimental evidence
- Experimental hurdles

## 2.1 Satellite Based

1400 km [2]

**Bullet points**

- Protocol used
- distance
- technical difficulties and innovations
- what does this mean for quantum communications?

## 2.2 Fibre Network Based

100 km [3]. Metropolitan [4]

**Bullet points**

- Protocol used
- distance
- technical difficulties and innovations
- what does this mean for quantum communications?

### 3 Teleportation of Complex Quantum Systems

#### Bullet points

- What is a complex system?
- How does the protocol differ from simple systems?
- Why is it important to be able to teleport complex quantum systems?
- Theoretical and experimental limits

### 4 Quantum Repeaters and Quantum Memory

Quantum internet [5]

#### Bullet points

- quantum repeater analogues to normal repeater?
- How to realize quantum memory
- why do we need quantum memory for quantum repeaters
- how much does a quantum repeater reduce attenuation
- how good are today's quantum repeaters?

## References

- [1] M. A. Nielsen and I. L. Chuang, *Quantum Computation and Quantum Information: 10th Anniversary Edition*. Cambridge: Cambridge University Press, 2010.
- [2] J.-G. Ren, P. Xu, H.-L. Yong, L. Zhang, S.-K. Liao, J. Yin, W.-Y. Liu, W.-Q. Cai, M. Yang, L. Li, K.-X. Yang, X. Han, Y.-Q. Yao, J. Li, H.-Y. Wu, S. Wan, L. Liu, D.-Q. Liu, Y.-W. Kuang, Z.-P. He, P. Shang, C. Guo, R.-H. Zheng, K. Tian, Z.-C. Zhu, N.-L. Liu, C.-Y. Lu, R. Shu, Y.-A. Chen, C.-Z. Peng, J.-Y. Wang, and J.-W. Pan, “Ground-to-satellite quantum teleportation,” *Nature*, vol. 549, no. 7670, pp. 70–73, 2017.
- [3] H. Takesue, S. D. Dyer, M. J. Stevens, V. Verma, R. P. Mirin, and S. W. Nam, “Quantum teleportation over 100 km of fiber using highly efficient superconducting nanowire single-photon detectors,” *Optica*, vol. 2, no. 10, pp. 832–835, 2015.
- [4] R. Valivarthi, M. I. G. Puigibert, Q. Zhou, G. H. Aguilar, V. B. Verma, F. Marsili, M. D. Shaw, S. W. Nam, D. Oblak, and W. Tittel, “Quantum teleportation across a metropolitan fibre network,” *Nature Photonics*, vol. 10, no. 10, pp. 676–680, 2016.
- [5] K. Azuma, S. E. Economou, D. Elkouss, P. Hilaire, L. Jiang, H.-K. Lo, and I. Tzitrin, “Quantum repeaters: From quantum networks to the quantum internet,” *Reviews of Modern Physics*, vol. 95, pp. 045006–, 12 2023.