Quantum Communication and Networking

A NoteBook

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Please have fun with quantum world

Contents

Chapter 1

Quantum Information Science: An Introduction

The three main aspects of quantum science and technology are:

- Quantum Computing and Simulation (Optimization, Machine Learning, Material design, Drug discovery, etc.)
- Quantum Sensing (Magnetice field, Biomedical imaging, GPS-free navigation, etc.)
- Quantum Communication (Secure data encryption, Remote Q computing, Distributed quantum sensing, etc.)

Here we take a brief look at Quantum Computing:

Note

Quantum Computing
Using qubits to perform computations that are infeasible for classical computers.
In traditional computers, bits are either 0 or 1. In quantum computers, qubits can be in superpositions of basis states, enabling potentially exponential speedups for certain problems. The basic states of a qubit can be represented as: $|0\rangle$ and $|1\rangle$.
So we can represent a qubit state as: $|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$, where α and β are complex numbers satisfying $|\alpha|^2 + |\beta|^2 = 1$.
In matrix form, we can write:

$$|0\rangle = \begin{pmatrix} 1 \\ 0 \end{pmatrix}, \quad |1\rangle = \begin{pmatrix} 0 \\ 1 \end{pmatrix} \tag{1.1}$$

And there are various way to making qubits, such as
SPIN QUBITS (from spins of electrons or nuclei trapped in a solid substrate such as nitrogen vacancy cneters in diamond),
PHOTONIC QUBITS (from polarization or path of single photons),
SUPERCONDUCTING QUBITS (from Josephson junctions in superconducting circuits),
ION TRAP QUBITS (from internal states of trapped ions).
In quantum computing, we need error correction.

And now we look at Quantum Communication:

Note

Quantum Communication
Using quantum states to transmit information securely over long distances.
Plateforms for quantum communication include satellite to ground or satellite to satellite links (long distance but low rate), ground to ground fiber links (potentially high rate with quantum repeaters).
Here we introduce some misconceptions:

- **Misconception 1:** A qubit cannot have two values at the same time.
- **Misconception 2:** Measuring one particle cannot affect the other.
- **Misconception 3:** Quantum entanglement does not allow faster-than-light communication.

In quantum communication, we need network, repeaters, and protocols.

Next, we discuss quantum sensing:

Note

Quantum Sensing
Using quantum systems to measure physical quantities with high precision and sensitivity.
Distributed quantum sensing can enhance the system's overall sensitivity by utilizing entanglement.
In quantum sensing, we need special materials, focus on doing well in economical, and also need networking.

Please remember:

Warning

Please bear in mind that the uncertainty of quantum mechanics is fundamental, not due to lack of knowledge. This means that certain pairs of physical properties, like position and momentum, cannot be simultaneously known to arbitrary precision. This is a key principle that underpins the security of quantum communication protocols. Until you measure a quantum state, it exists in a superposition of all possible states. Measurement causes the state to collapse to one of the possible outcomes.

But we still have two quantum advantages:

Note

Quantum Advantages

Quantum Advantage 1: We can finish certain known computational tasks faster, better, more precisely than classical methods (quantum computer).

Quantum Advantage 2: We can do certain task that is impossible for classical methods.

Chapter 2

The physical principle behind quantum networks

What is your highest level understanding of quantum mechanics?

Don't worry, nothing will be scary. We will just take a brief look at the physical principle behind quantum networks.

2.1 Quantum Information Science

Let's first look at Classical Information Science:

Note

Classical Information Science Two types of classical information:

- **Semantic information**: Meaningful information, such as text, images, audio, and video.
- **Technical information**: Is the set of symbols that are used.

What is a bit?

Note

Classical Bit A single bit can be in one of two states (ordinary bit), typically like a switch that can be either "on" (1) or "off" (0). And we call the condition of being in one of these two states as *"STATE"*.

What is a memory cell?

Note

Memory Cell A memory cell is a box that containing two classical bits. So it can be in one of four states: 00, 01, 10, or 11. These probabilities mean different states. So we can use multiple bits to represent more complex information. Like 3 bits can represent 8 states (000 to 111), and so on. But in given time, a memory cell can only be in one of these states.

What is a quantum bit (qubit)?

Note

Quantum Bit (Qubit) A qubit is the quantum analog of a classical bit. Unlike a classical bit that can be either 0 or 1, a qubit can exist in a superposition and entanglement of both states simultaneously. This means that a qubit can be represented as:

$$|\psi\rangle = \alpha |0\rangle + \beta |1\rangle , \quad \text{where } |\alpha|^2 + |\beta|^2 = 1 \tag{2.1}$$

Please bear in mind that you only can know the state of a qubit after you measure it. Before measurement, it exists in a superposition of both states.

So, compare to classical bits, in a "quantum memory cell" containing two qubits, the system can exist in a superposition of all four possible states (00, 01, 10, 11) simultaneously. This means that the quantum memory cell can represent and process multiple states at once, thanks to the principles of superposition and entanglement.

Here is a simple example about superposition and measurement:

Note

Superposition and Measurement Example Consider a qubit in the state:
If we prepare a qubit in 0 degree of rotation, and it spins clockwise, so after we measure it, we will get a qubit spinning clockwise with 100% probability.
If we prepare a qubit in 90 degree of rotation, and it spins clockwise, so after we measure it, we will get a qubit spinning clockwise with 50% probability, and counter-clockwise with 50% probability.
If we prepare a qubit in 30 degree of rotation, and it spins clockwise, so after we measure it, we will get a qubit spinning clockwise with 80% probability, and counter-clockwise with 20% probability.

So what dose superposition mean?

Note

Superposition Meaning Evidently, superposition means that before measurement, the qubit is in a combination of both states (clockwise and counter-clockwise). The probabilities of measuring each state depend on the coefficients in the superposition. This is a fundamental principle of quantum mechanics that allows qubits to represent more information than classical bits.
And after measurement, the qubit collapses to one of the basis states (either clockwise or counter-clockwise) based on the probabilities determined by its superposition.
Please bear in mind that after measurement, the original superposition state is lost, and the qubit is now in a definite state. Which means you do a measurement again, you will get the same result with 100% probability. Repeating measurements on the same qubit will yield the same outcome.

Let's play with two qubits entangled:

Note

Entangled Qubits Example We have two qubits, A and B, in the entangled state, which means, we have two small quantum memeory cells, one contains A and B but in 0 state, the other contains A and B but in 1 state. So the total state is:

$$|\psi\rangle = \frac{1}{\sqrt{2}}(|00\rangle + |11\rangle) \tag{2.2}$$

If we measure qubit A and find it in state 0, qubit B will instantaneously collapse to state 0 as well. Similarly, if we measure qubit A and find it in state 1, qubit B will collapse to state 1.

So you can't use this entanglement correlation to send information, it's only tell you the state of the other qubit after you measure one qubit.

2.2 Encoding and transmitting quantum information

2.3 Bell state measurements

2.4 The quantum internet

Python Example

def hello(): print("Hello, LaTeX book!") hello()

C++ Example

include ¡iostream¿ int main() std::cout ¡¡ "Hello!" ¡¡ std::endl; return 0;

Chapter 3

Second Chapter

Acknowledgments