UNIVERSITÀ DI PISA

# MSc in Computer Engineering

## Quantum Internet Project

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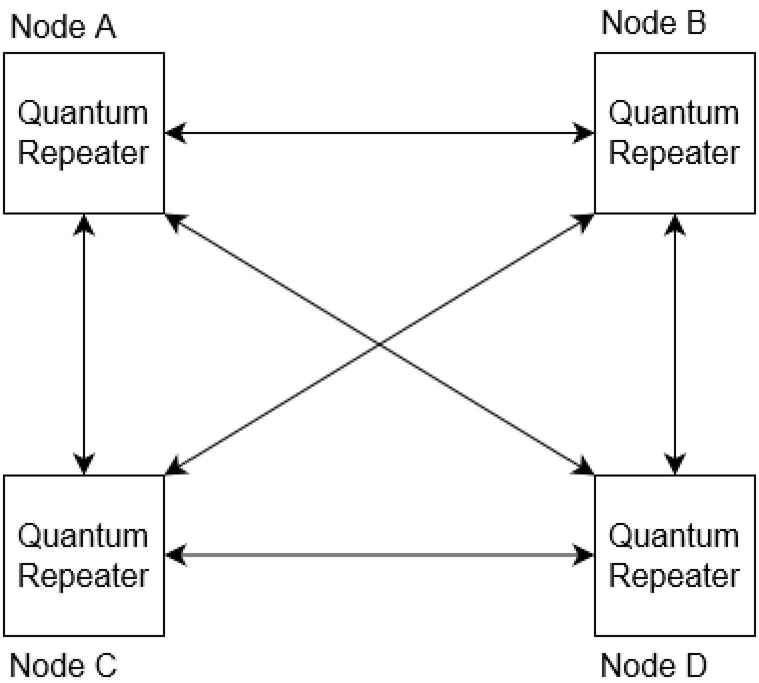
**PROJECT REQUIREMENTS**

Simulate the application-level perspective of a quantum network where applications can directly request the teleportation of an arbitrary qubit state ρ from any end node to another, specifically:

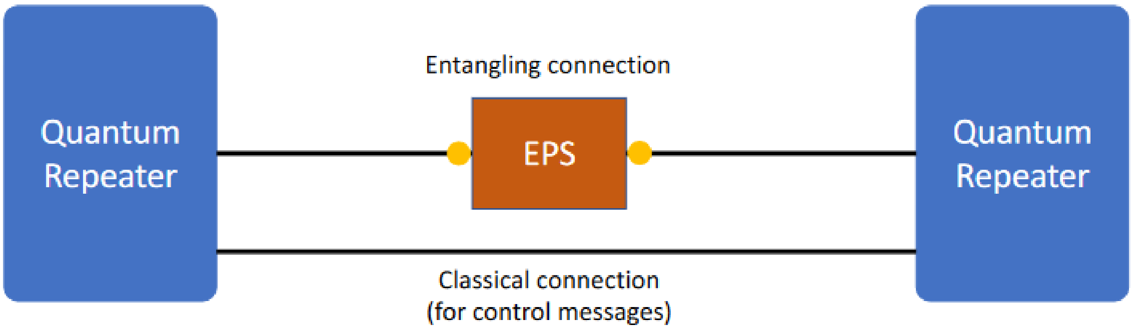
- The QN is represented as a set of N fully-connected end nodes
- An application can request the teleportation of an arbitrary qubit state ρ from an end node to another.
- Evert application request is served by:
  - Delivering the qubits of an EPR pair to the two interested end nodes with a random delay
  - Carrying out quantum teleportation between the two end nodes, employing the qubit state ρ to teleport and the EPR pair.

**NETWORK TOPOLOGY**

In order to develop our network, we decided to implement as a fully connected network with $\frac{n*(n-1)}{2}$ connections as shown in figure below, with each node connected with all the other N-1. We decide to simulate the network with N repeaters, one for each node.



Let's now focus on the individual connections between repeaters.




Every connection has two different channels:
- **Quantum Channel**: dedicated to the transmission of quantum information, such as qubits or quantum states. This type of channel is necessary because quantum information cannot be copied or cloned, as is the case with classical information, and requires special treatment for transmission. Furthermore, the quantum channel must be protected from phenomena such as decoherence and noise to maintain the integrity of the transmitted quantum information.
- **Classical channel**: dedicated to the transmission of classical bit.

**PROTOCOL IMPLEMENTATION**

In our implementation we have three separate phases: the generation of the quantum entanglement pair with the relative send to the two nodes, the purification and finally the quantum teleportation.
Let’s analyze better each phase.

**Quantum entanglement**

Entanglement management within the intermediate source protocol occurs primarily through a cycle of attempted entanglement generation between two nodes. This loop runs until valid entanglement is reached.

During each cycle, the node attempts to detect the presence of a photon sent by the remote node through a quantum channel. If the photon is successfully detected, it is stored in the quantum memory of the local node. This event is indicative of the entanglement generation attempt and is recorded along with the attempt index.

Upon success in detecting the photon, the local node sends a message to the remote node indicating the index of the successful entanglement attempt. The remote node receives this message and checks whether the received index matches the one the remote node had registered. If the two indices match, the entanglement generation is considered to have occurred successfully and the protocol ends. Otherwise, a new cycle of attempts begins.

In case of failure, the protocol also manages the cleaning of the quantum memory, before starting the new round.

**Purification**

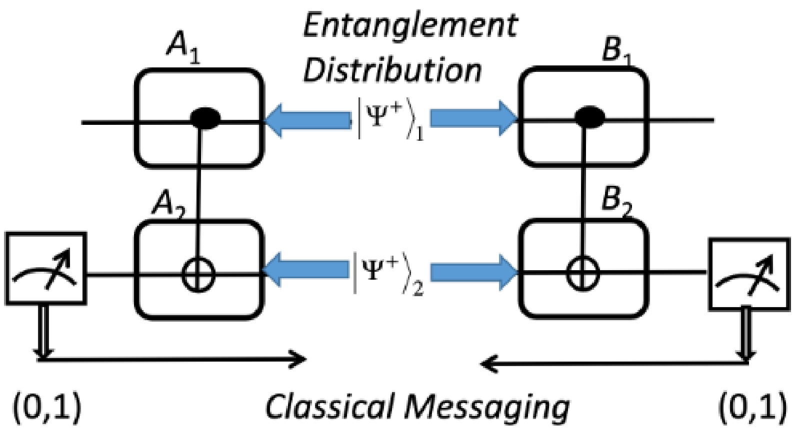
When a qubit is transmitted from repeater A to repeater B through this quantum channel, it is subjected to various phenomena that can compromise its quantum integrity, such as decoherence or channel noise.

Furthermore, the distance between repeaters can affect the speed and efficiency of quantum communication. To reduce the negative effects of distance and channel noise

The quantum channel is often subject to information losses and noise, which can deteriorate the quality of quantum transmission. Therefore, it is essential to implement error correction or purification strategies to ensure that the transmitted qubits maintain their integrity while traveling through the channel.

The entangled state that we obtain at the end of the entanglement distribution process is polluted by several sources of quantum noise like:

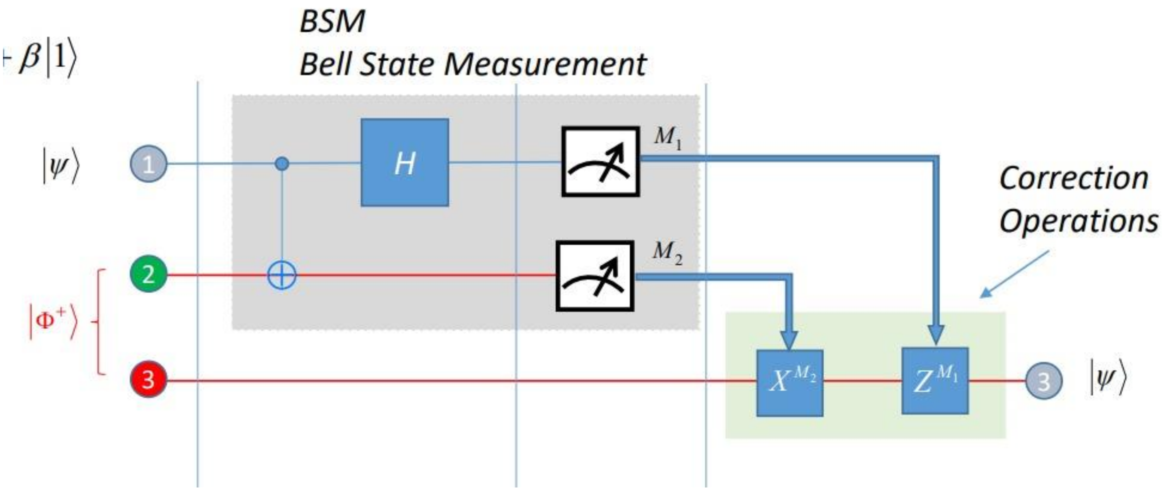
- **Depolarizing noise** applied by the fiber optics channel and imperfect gates.
- **Dephasing noise** (incremental with time) applied by the quantum memory.




the circuit in the above image has been implemented to fulfill this problem.

**Quantum teleportation**

After the entanglement and purification have been done, we move on to teleporting the qubit. Therefore we have implemented the circuit that carries out the teleportation, as shown in the following figure.



On the side of the person teleporting the qubit, first we recover the entangled qubit, then we carry out the appropriate operations:

- CNOT gate on the entangled qubit, with the qubit to be teleported controlling
- H gate on the teleported qubit.

Then both qubits are measured and the classical bits obtained are sent to the other endpoint via a classical channel.
On the other side, the classical bits are received, the entangled qubit is taken, and the correction operations are carried out on this.
After these, we finally got the teleported qubit.
Since we knew a priori the value of the teleported qubit, we were able to measure the fidelity of the teleportation, finding very high values.
Therefore we can conclude that the teleportation operation was successful.