# Quantum Communication Complexity on Near-Term Networks

## Solving the Equality Problem with Realistic Noise

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## The Problem and the Network

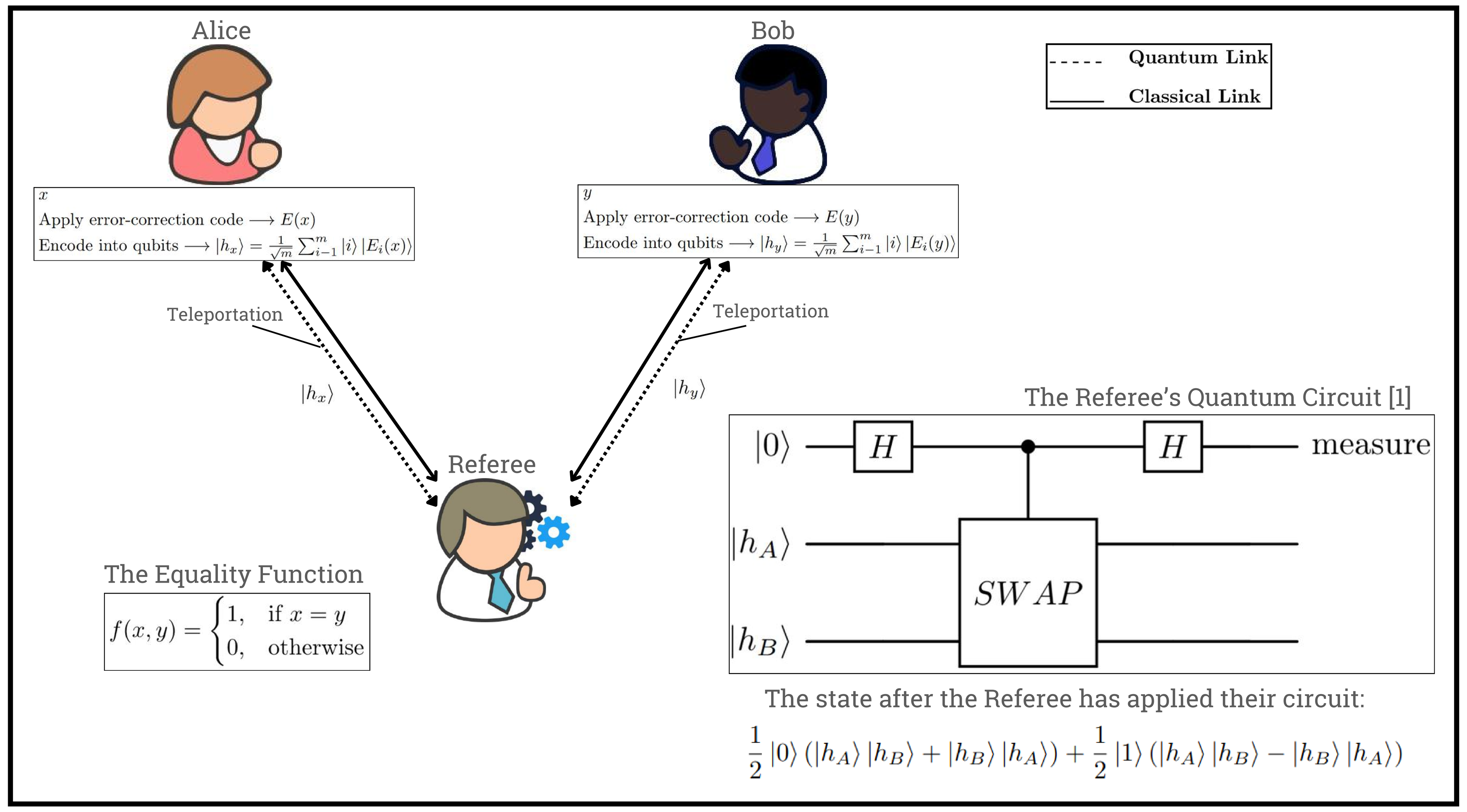
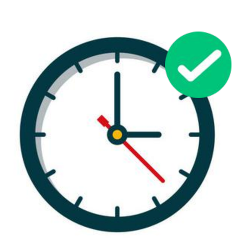



Figure 1: The Network. The goal of this network is for the Referee the determine whether Alice and Bob have the same bit string with a small error while minimizing the amount of bits and qubits sent between the nodes.

## Adding Noise to the System

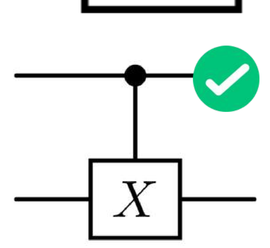
This problem has been studied on a quantum network in a noiseless environment. However adding noise to into the equation has the potential to change a lot and might even effect the scaling, such that quantum solutions may not be faster than the classical solution at all until we build better computers with less noise.


Coherence time:
Qubits have a chance to decohere and lose their information. The teleportation as well as the Referee's quantum circuit need to happen before the qubits decay.



Single-Qubit Gate Fidelity:
Every gate has a chance to be executed in the wrong way. The fidelity is likely a gate is to apply it's transformation correctly.


Two-Qubit Gate Fidelty
The same as single-qubit gate fidelity, but now for gates that act on 2 qubits.




Fidelity of the Bell States
The actual states used in teleportation are usually not exactly the same as the ideal Bell states. The fidelity tells us how similar they are.

$$|\phi^+\rangle = \frac{1}{\sqrt{2}}(|00\rangle + |11\rangle)$$

## Results

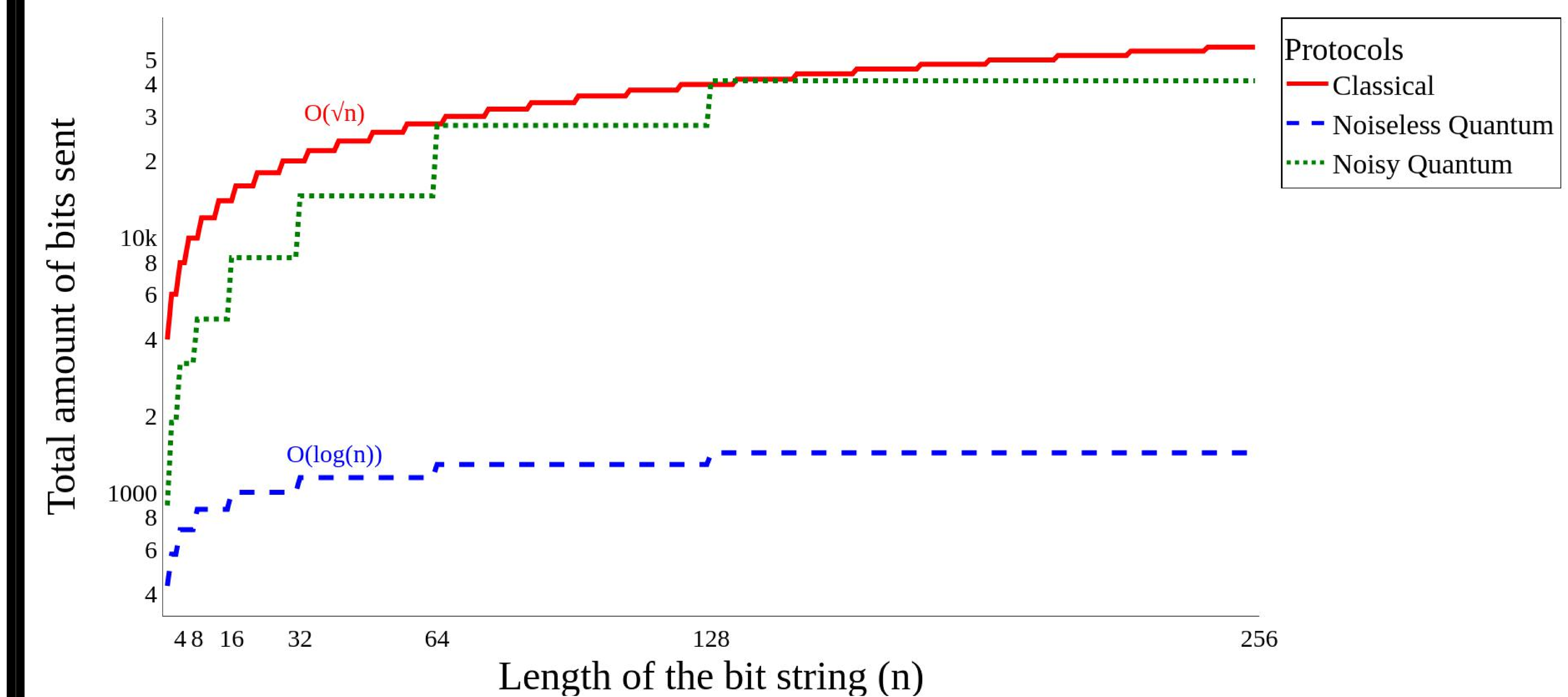



Figure 2:
The results of running the simulation using parameters from a quantum computer network involving trapped ions in a laboratory. It can be seen that despite this being a controlled environment with relatively little noise, this noise still ruins the scaling of quantum solution. The parameters for this simulation were:

- Single-Qubit Gate Fidelity: 0.999934
- Two-Qubit Gate Fidelity: 0.9991
- Bell Pair Fidelity: 0.99025
- Coherence Time: 62ms

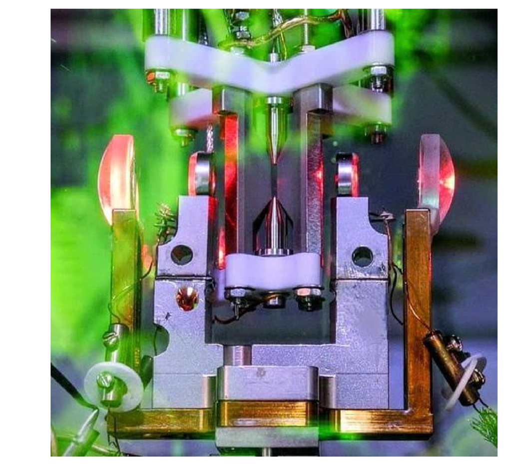


Figure 3: A trapped ion from the quantum interfaces group from the university of Innsbruck

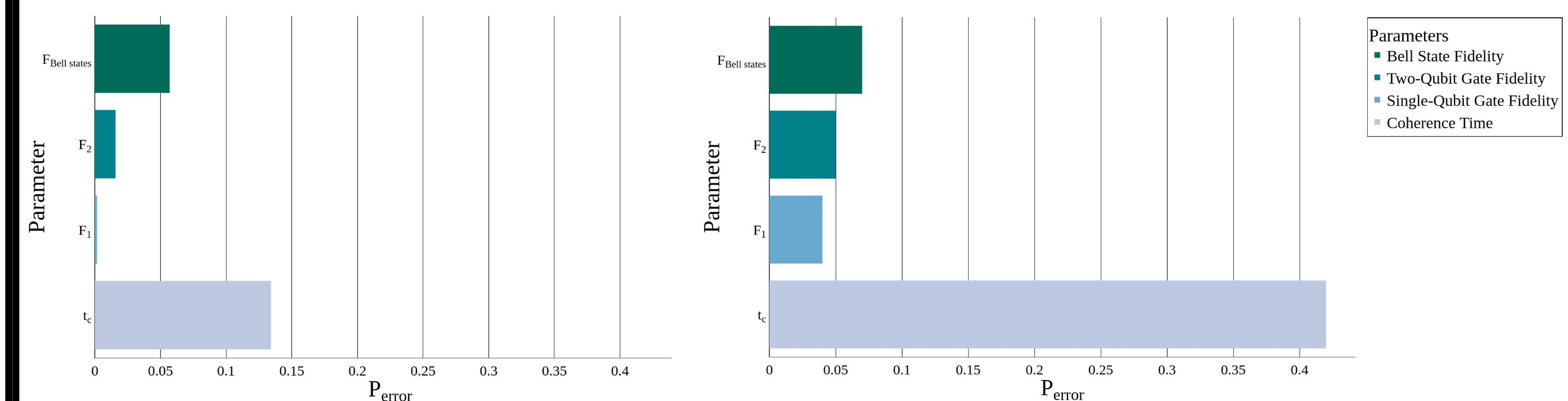



Figure 4:
A comparison between the contribution of the four different noise parameters to the overall noise for bit strings of length 2 to 3 (left) and 16 to 31 (right). These correspond with Alice and Bob having to send 4 qubits (left) or 7 qubits (right) each. It can be seen that coherence time is the leading factor in both cases. The scaling of the coherence time with the length of the input is so bad, that it ruins the scaling of the quantum solution.

## Code Availability

In order to determine the actual communication complexity of the quantum algorithm to solve the equality problem, we will simulate a three node network using SquidASM (https://github.com/QuTech-Delft/squidasm). The code will be written in Python version 3.10.16 and can be found here: https://github.com/TomTUD/research_project.

## Conclusion

Even a small amount of noise ruins the scaling of this quantum protocol so despite having a quantum advantage on a small scale we lose it in the long run. Increasing the noise parameters to something more realisitic like a real world setup, where the quantum computers are in different cities, makes it impossible to simulate even for the smallest inputs. More research is necessary, but it looks like this protocol will not work without quantum error correction, meaning it is doomed for near-term quantum networks.

## References

[1] H. Buhrman, R. Cleve, J. Watrous, and R. de Wolf, "Quantum fingerprinting," Phys. Rev. Lett., vol. 87, p. 167 902, 16 Sep. 2001. doi: 10.1103/PhysRevLett.87.167902. [Online]. Available: https://link.aps.org/doi/10.1103/PhysRevLett.87.167902
[2] A. Ambainis, "Communication complexity in a 3-computer model," Algorithmica, vol. 16, pp. 298–301, Sep. 1996. doi: 10.1007/BF01955678