Modelling and analysis of routing and purification in a satellite quantum network via simulation

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Abstract: Realizing a network of quantum repeaters via Low Earth Orbit satellites could unlock the path towards a global Quantum Internet but has several technical challenges associated that can be studied via numerical simulation.

One critical aspect of quantum networks is the fidelity that quantum applications require to operate correctly. The *fidelity* is a measure of the quality of the entangled and it is a relative measure, between 0 and 1, of how close a quantum state is to a reference one, and in general it should be higher than 0.5. There are models in the literature to estimate the fidelity across a chain of quantum repeaters under some assumptions. For instance, according to [1], assuming we know p_2 (two-qubit gate fidelity) and η (measurement fidelity), and we disregard p_1 (one-qubit gate fidelity), for a given path, we can compute the minimum per-link fidelities to match the minimum fidelity requested by an application:

$$F = \frac{1}{4} + \frac{3}{4}\left[\frac{p_2(4\eta^2 - 1)}{3}\right]^{n-1} \prod_{i=1}^{n} \frac{4F_i - 1}{3}$$

The formula above, even assuming optimistic values for all the parameters, suggests that purification would be needed to obtain end-to-end entanglement of qubits with sufficient fidelity. However, purification in a satellite network (see Fig. 1) may have additional difficulties compared to a terrestrial quantum network.

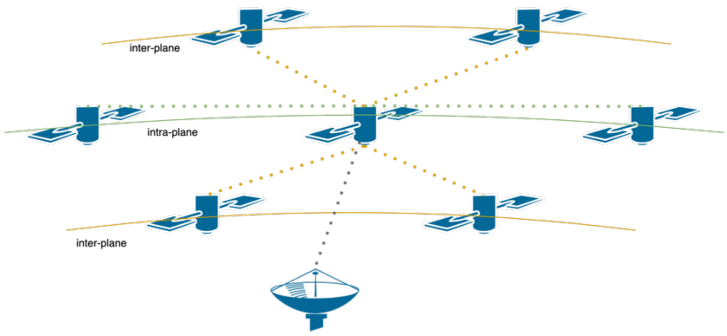

Fig. 1 The system under study is a network of quantum repeaters hosted by LEO satellites in a multi-plane constellation.

The good vs. bad model has been studied in the literature [2] under some simplified assumptions. Due to the instantaneous classical channel exchange, the closed formulas derived in the paper are not directly applicable to the case of satellite quantum networks, where the one-way latency is significant compared to the other time scales of interest, in particular the entangled photon source generation rate and decoherence times. To overcome the long delay incurred by the protocol, a study has been published in the literature that proposed to perform heralding and purification at the same time [3].

However, prior literature does not address several key issues, including the following: How to keep the pipe full? How to perform system provisioning, e.g., finding the configuration that minimized the system cost? How is performance is affected by the quantum memory size and path length? Which protocol is to be executed by the receivers? To study the implications, a simulator could be implemented to evaluate the performance with different values of the physical and configurable parameters of the system. This tool can also lead to the definition of a Medium Access Control (MAC) protocol for user/application multiplexing.

References

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