Quantum Network Project

Distributed Systems

Lorenzo Zaniol (lorenzo.zaniol@usi.ch)
Edoardo Riggio (edoardo.riggio@usi.ch)
Işın Su Ecevit (isin.su.ecevit@usi.ch)

Project Repository

December 18, 2022

1. Project Description

We implemented a *Quantum Network* (QN) using the simulator Netsquid that follows the star topology, one of the most common network topologies, shown in Figure 1. The center of the network is a node with only a Quantum Source as component. All the other nodes are composed of quantum processors, and are connected to the source node by means of quantum connections. One of the points of the network is a repeater connected to another node.

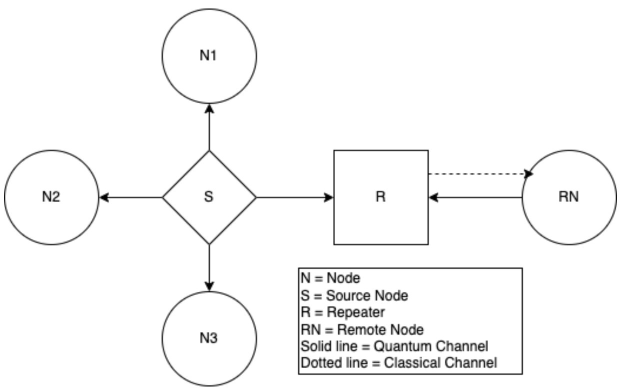

Figure 1: Diagram of the generated QN

1.1. Key features

The key features of the structure we created are:

- *Quantum Networks* (QNs) composed of directly connected nodes (called *Quantum Node* (N_i), where i is the respective index) as well as a indirectly connected node (called *Remote Node i* (RN_i)) connected using a *Quantum Repeater* (R).
- Generating QNs dynamically with n nodes, from which the following are created: [(n-2) $\times$ N_i], [1 $\times$ R], [1 $\times$ RN_i] and [1 $\times$ *Quantum Source* (S)].
- The ability to have one entangled Qbit each, between any two nodes.
- Automatic statistics data export and summary plot of multiple experiments, over different channel length.

2. Implementation

2.1. Network Components

The nodes in the network contain the following components: Quantum Source, which generates `|00> + |11>` (QS); Quantum Processor (QP); Quantum Memory with 1 memory position (QM1) and 2 memory positions (QM2). The distribution of the components can be found in Table 1. Both types of channels (classical and quantum) used in the network are unidirectional.

	Quantum Source	Quantum Processor	Q. Memory 1	Q. Memory 2
S	✓			
R		✓		✓
N_i		✓	✓	
RN_i	✓	✓	✓	

Table 1: Distribution of the Quantum components to the nodes.

2.2. *Quantum Channel* (QC) models

The following well established techniques with (mean) parameters observed in real QNs are added as models to make the simulations on the QN realistic:

Fibre loss: Model for exponential photon loss on fibre optic channels. Uses length of transmitting channel to sample an exponential loss probability.

T1T2 noise: Commonly used phenomenological noise model based on T1 and T2, where T1 time dictates amplitude damping component and T2 time (called T2 Hahn) dictates the dephasing component.

Fibre delay: Transmission delay model based on constant speed of photons through fibre. The travel distance is given by the length of channel. The default parameter, c refers to the speed of light in a F1 fibre cable (the best available), which is 200,000 km/s, 30% slower than the speed of light in a vacuum.

2.3. Challenges

Most of the challenges we faced during the implementation were mainly caused by Netsquid not being widely used, and support for the tool not being enough, which affected the installation and implementation processes greatly. The lack of documentation as well as false or incomplete information on the tool resulted in occasional misunderstandings of the components we were able/allowed to utilize.

For a proper installation of Netsquid, we created our own Dockerfile since the problems we faced during the process were not properly addressed in the documentation.

While tuning the T1 and T2 values, we had trouble finding public data about it, so we had to cross reference in order to retrieve them (see references in the code). This is due to the limited number of actual quantum networks as well as research done in the area, but more importantly the lack of willingness to disclose such information.

3. Results & Discussions

The aim of this experiment was to create an operational quantum network with the star topology. We extended our implementation by introducing a quantum repeater that connects a remote node (that is further away from the other nodes) to the network.

We wanted to observe the relationship between the distance of the quantum channel and the fidelity between two entangled qubits that are transmitted across the network. This relationship is expected to be inversely proportional, meaning that as the distance gets longer, the fidelity decreases.

The first experiment is done over a very simple network, where only one of the entangled qbits is transmitted through a quantum channel of the specified length and the fidelity between the transmitted and the stored (at the source) qbits are measured. Figure 2 represents change of fidelity between two entangled qbits, when the distance of the channel increases.

Each point is the mean of the fidelity of 100 simulations, with the models mentioned in Section 2.2 applied over the quantum channel. We observe that sometimes there is quite a substantial difference in fidelity (y axis) between close length (x axis), this is due to the models (in particular T1T2 Noise and Fibre loss) that introduce uncertainty between simulations. So we run the simulation 100 times and take the mean to counteract this behaviour. In order to make the tendency of decreased fidelity over a wider distance, we plotted the line of best fit based on the least mean squared of the points.

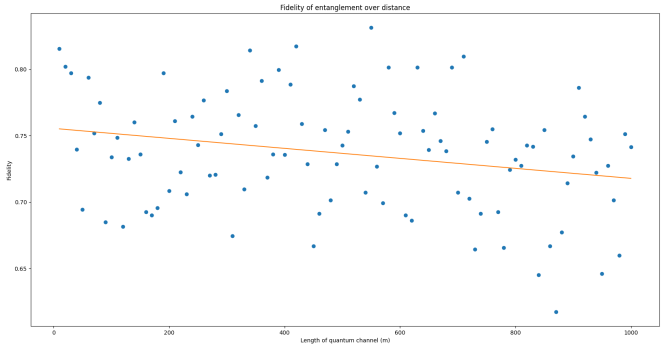

Figure 3: Fidelity/length for 2 qbits transmitted to 2N.

Figure 3 shows the results of a similar experiment between 2 (directly connected nodes) N. We start with a lower initial fidelity across the board since this time both qbits are transmitted to and stored in different quantum nodes. However, the fidelity when the distance increases still decreases as expected. Results of another experiment between 1 node N and 1 node RN can be observed in Figure 4, which produces, as expected, an average fidelity in-between the ones in Figure 2 and 3, since the presence of a repeater through the path reduces the effects of distance on the fidelity.

4. Conclusion

This project accomplished its aim of creating a fully-functional quantum star network. We were able to observe the relationship between fidelity of two qbits and their distance. The addition of further features was also successful, despite the restriction of available functionality offered by the tool, and the results clearly show that the effect of the channel length over the fidelity between two qbits. The fidelity is the highest when only one qbit is transmitted through the network, whereas it is the lowest when both qbits are transmitted. As observed, this could be improved by the addition of a repeater that the qbits are transmitted through.

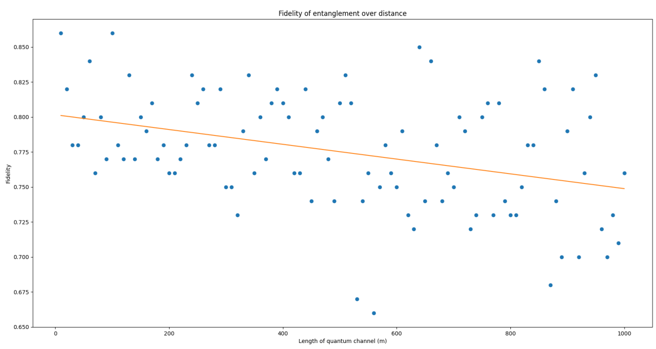

Figure 2: Fidelity/length for 1 qbit transmitted.

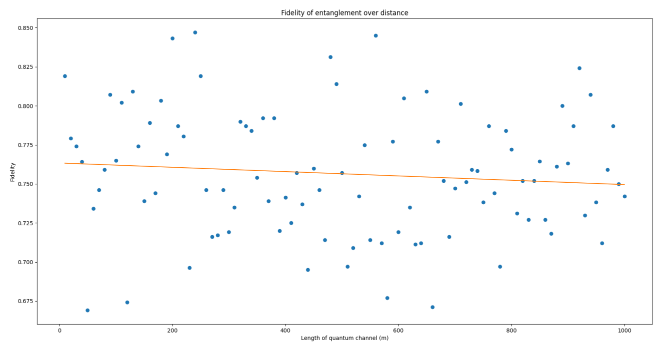

Figure 4: Fidelity/length for 2 qbits transmitted to 1N & 1RN.