A Test Suite for Quantum Network Applications

Quantifying an Application's Ability to Benchmark a Quantum Network

Quantum Networks

Quantum networks are communication networks that utilise principles of quantum mechanics to transmit and process information. Unlike classical networks that rely on classical bits, quantum networks employ quantum bits to encode and transmit data. These mechanisms provide certain advantages over classical systems, such as enhanced security and faster computation[1] [2].

Goal of the project

The goal of this project is to contribute to a benchmarking suite for quantum network systems, by providing an evaluation of a quantum network application's ability to benchmark a quantum system. In this case, we examine the BB84 Protocol's effectiveness in assessing certain properties of a quantum network.

The BB84 Protocol

The BB84 Protocol is a Quantum Key Distribution protocol that allows two parties to establish a secure cryptographic key over an insecure communication channel [3]. This communication is done by preparing a key in one of two bases (the X and Z basis), which is then received and subsequently measured in one of the two possible bases, bit by bit. After this communication, the two parties communicate the basis they used to transmit/measure each bit, and discard any measurements where they used different bases. The matching bits form the raw key.

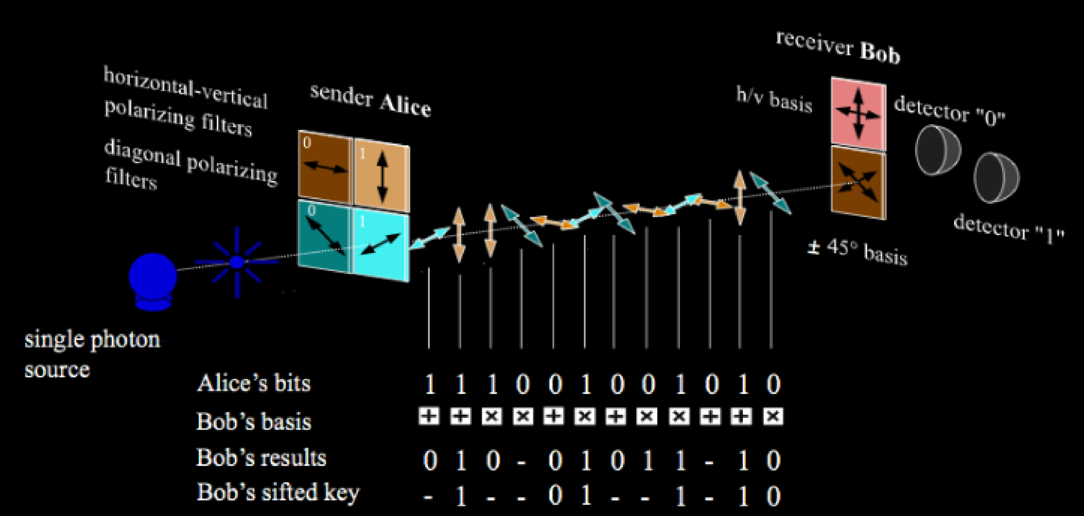

figure 1. visualisation of the the BB84 Protocol

Methodology

We use certain performance metrics in order to assess the application's sensitivity to properties such as quality of entanglement, quality of quantum operations, and memory lifetimes. The two performance metrics that we observe are the Qubit Error Rate (QBER) and the key generation rate.
The QBER is the proportion of bits measured that were different from the bits transmitted, despite being in the same basis. This metric helps us assess properties that cause errors in the qubit state. Moreover, in order to gain further insight into the working of the application, we separately assess the QBER for bits measured in either basis, thus splitting the metric into X and Z basis QBER.
The key generation rate can determine how time based parameters, such as measurement times, affect the amount of bits generated in the raw key, per unit time.

Process

The experiments are conducted by individually varying network parameters, in order to assess the change in performance with respect to changes in the parameter. In most cases, while varying a parameter, other parameters will be set to their "ideal" state, in order to ensure no other parameters cause errors in the system. However, in some cases other parameters are set to a constant but imperfect value due to the dependence between certain parameters.
The experiments are executed on two types of quantum network configurations: generic quantum devices, connected using a depolarising error channel, and Nitrogen Vacancy (NV) centre quantum devices, that are connected using a heralded link.

Results & Discussion

Figures 2-3 show examples of two network parameters and how they affect the performance metrics of the application.

Tables 1-2 outlines whether the parameters of both configurations affect the performance metrics

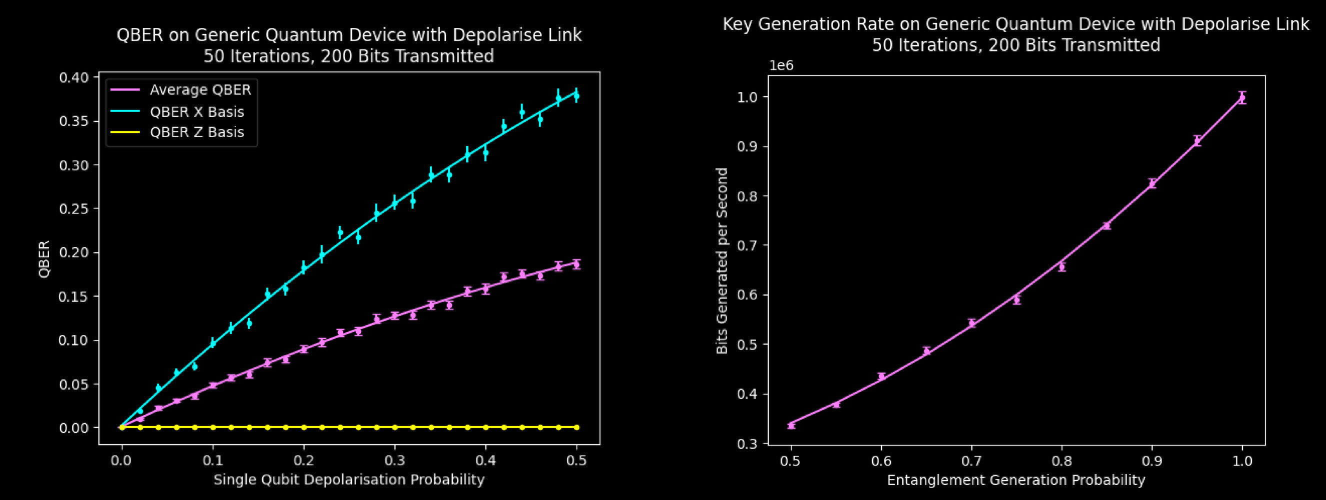

figure 2 & 3. figures showing how the two performance metrics vary with respect to certain network parameters

Depolarise Link	Sensitive
Link fidelity	Yes
Entanglement generation time	Yes
Entanglement generation probability	Yes

Generic Quantum Device	Sensitive
Single qubit depolarisation probability	Yes
Two qubit depolarisation probability	No
Single qubit gate time	Yes
Two qubit gate time	No
Measurement time	Yes
Coherence times	No

Heralded Link	Sensitive
Length	Yes
Attenuation coefficient	Yes
Probability of photons being lost when entering the connection	Yes
Dark count probability	Yes
Detector efficiency	No
Hong-Ou-Mandel visibility	Yes

NV Quantum Device parameters	Sensitive
Single qubit depolarisation probability	Yes
Two qubit depolarisation probability	No
Qubit initialisation depolarisation probability	No
Probability of measuring a 1 instead of 0	Yes
Probability of measuring a 0 instead of 1	Yes
Coherence times	No

table 1 & 2. tables depicting whether the BB84 protocol can detect changes in a network system parameter for a certain system configuration

We find that the application can detect changes in most link parameters. Furthermore, the performance metrics are affected by measurement properties and single qubit gate properties on the quantum devices. We also observe that the application is not sensitive to parameters concerning two qubit gate properties or coherence times, across both systems.

We conclude that the BB84 protocol can be used as an individual localised test for the parameters it is sensitive to, and also in combination with other applications, in a more comprehensive benchmarking suite, that provides coverage for a broader range of parameters.

Future work

Currently, the application being used is quite simplistic. Thus, it might be beneficial to modify the application to use more advanced computational techniques. For example, adding an eavesdropper as an intermediate node. This could provide a more in-depth insight into how the metrics are affected by certain parameters or even extend the application's detection capabilities to include more parameters.

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