Fast Polarization Basis Alignment For Quantum Communications

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Abstract: We assess an algorithm for polarization basis alignment for quantum communication systems considering different polarization linewidth and transmission lengths. The algorithm has an overhead below 2% and guarantees an average channel QBER below 1%.
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1. Introduction

~~Quantum communication systems offer the possibility of exchanging cryptography keys over an insecure optical link.~~ Quantum information can be ~~encrypted~~ ~~using single photons with different polarization.~~ However, in a real field experiment, qubits sent through an optical fibre are subject to random polarization drifts, which directly affects the performance of any quantum communication protocol. Polarization random drift depends on the field installation conditions such as stress, temperature or external vibrations, and these conditions can be modelled using the polarization linewidth parameter, which determine how fast the polarization drift evolves [1]. Therefore, the reference frames of the transmitter and receiver will be misaligned, which leads to the increasing of quantum bit error rate (QBER). In this way, an active method for polarization basis alignment (PBA) is required ~~to provide the large deployment of quantum communication systems based on polarization encoding~~ [2]. Mainly two different strategies have been addressed, the interrupted scheme, where the polarization random drift compensation is performed with no data quibts transmission [3] [4], and the real-time schemes, where the data transmission is not interrupted. In this work, we will analyze the polarization random drift of a reference state of polarization for different polarization linewidths, and we will also assess the performance of the ~~QBER based algorithm for~~ PBA proposed in [4], ~~which operates as an interrupted scheme,~~ when ~~it is~~ applied on a real quantum communication system.

2. Polarization Random Drift in a Real Quantum Communication System

The considered algorithm for PBA is based on the continuous estimation of QBER, which can be represented in a shape of a circle on Poincaré sphere [4]. Therefore, each value for QBER can be associated with a set of possible states of polarization. The algorithm uses a pre-defined sequence for control qubits during the monitoring mode, where 1 qubit in each 100 is used to estimate the QBER. Furthermore, during the algorithm's actuation mode,

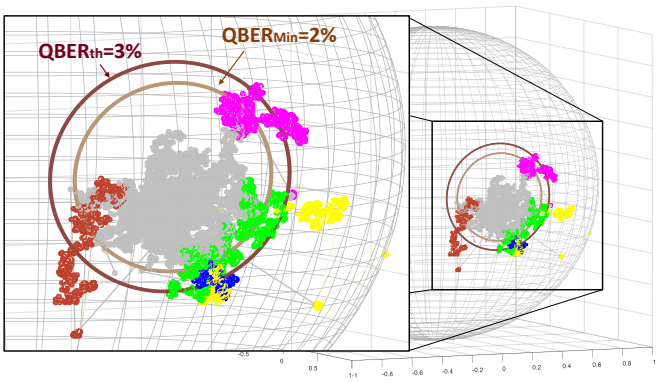

Fig. 1. Random walk of the SOP over the Poincaré sphere for a 1500 nHz polarization linewidth. Circle of a sphere defined for both $QBER_{TH} = 3\%$ and $QBER_{MIN} = 2\%$.

[ID Quantity]

all qubits are used and the data transmission is interrupted. In this work, we modelled a system considering 0.1 photons per pulse at transmitter output (Alice) for data qubits, and an amplitude for control qubits high enough to guarantee a click on the receiver (Bob). Alice will transmit qubits at 100 MHz, since it is the maximum detection frequency enabled by Bob single-photon detectors. These detectors will also operate~~s~~ with a detection efficiency of 25%, a 5×10^{-7} dark count probability, and using a gate width of 2.5 ns. The quantum communication channel will have an attenuation of 0.2dB/km, and it will also comprises a model to emulate the polarization random drift based on polarization linewidth parameter, which in this case we assume to be 1500nHz and a channel length of 50 km. Fig. 1 shows the SOP random walk over the sphere and the QBER is estimated considering a sliding window. A QBER_{MIN} of 2% is defined for a 3% threshold assuring that the estimated value is bellow this threshold. Each set of colored dots correspond to five algorithm's actuation, excluding the light grey dots that represents the regular walk for the considered polarization linewidth. During algorithm's actuation, no data qubits are transmitted until the algorithm compensates the drift, i.e. the SOP is led to a position inside the boundary QBER limit. As one can see in the figure, as soon as the QBER rises this boundary limit, the algorithm actuates and the SOP can go outside the boundary during this interval. However, when the compensation procedure is concluded, a QBER bellow the QBER_{MIN} is guaranteed.

3. Polarization linewidth and attenuation impact on algorithm's for PBA performance

The attenuation induced on the light beam depends on the length of optical fiber. In this way, as the length increases less single-photons reach the receiver, thus increasing the no-click probability. However, this only impacts on data qubits, since the control qubits amplitude is ~~defined~~ to guarantee that at least one single photon reaches the receiver. Moreover, high values for polarization linewidth increase the speed of the drift, so that the algorithm will actuate more times and the overhead also increases as well as the actuation frequency. Table 1 summarizes the results of algorithm's performance for two values of polarization linewidth and fiber length acquired for a 3% threshold. The average QBER is calculated using the data qubits~~, so that its~~ value remains ~~almost the same~~ bellow 1%.

Table 1. Algorithm's performance for different values of polarization linewidth and fiber length.

Fiber Length (km)	Polarization Linewidth (nHz)	Actuation Frequency (Hz)	Overhead (%)	Average QBER (%)	No-Click Probability (%)
50	900	386.76	1.04	0.63	99.76
80	900	416.46	1.16	0.52	99.92
50	1500	407.82	1.25	0.84	99.74
80	1500	771.28	1.32	0.80	99.91

4. Conclusions

For range of distances analyzed in this work, we observed that the performance of te PBA algorithm is not affected by attenuation, since for different fiber lengths the assessment measurements remain almost constant. This specification only affects no-click events, since the attenuation throughout the quantum channel increases with fiber length, and the actuation frequency, since it also impacts the installation conditions leading to a high impact of the polarization linewidth through the quantum channel. Moreover, for high polarization linewidths both actuation frequency and overhead increase, since the speed of polarization random drift increases. Regarding the average QBER it remains below 1% ~~proving a small channel QBER for any communication protocol~~.

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