Joint Optimization of Source and Detection System in Entanglement Based BB84 Protocol

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Various imperfections in realistic setup components limit the performance of quantum key distribution (QKD) protocols in terms of both the maximum secure transmission distance and the achievable key generation rate. One of the most effective ways to maximize the performance of a QKD protocol is to use temporal filtering [1] [2]. In this method, the receiver optimizes the detection windows based on the signal parameters in order to minimize the effect of dark count rate and the noise introduced in the quantum channel. However, the detection windows cannot be made infinitely short, because on one hand the detectors cannot measure the detection times with infinite precision and on the second hand, the signal always has some finite temporal bandwidth. This may be an issue, especially, if the dispersion is present in the fibers [3]. Therefore, to maximize the secure key rate the detection windows and the source parameters should be jointly optimized.

In this work, we study the entanglement-based BB84 protocol, where information is encoded in the polarization of photon pairs generated via spontaneous parametric down-conversion (SPDC) with a pulsed pumping laser. We perform the joint optimization of source parameters and detection system used by Alice and Bob in order to improve the performance of the protocol in a realistic set-up. We take into account several key parameters of the source, including the crystal's phase-matching function width, pump pulse duration, and number of the photon pairs emitted per one use of the source. For the detection system, we optimize the detection windows taking into account several characteristics of the setup, such as, timing jitter, dead time and dark count rate. Finally, we include transmission losses in the quantum channel.

In our work, we first optimize the detection windows for a fixed set of source parameters. This is done by considering both an ideal scenario, with no dark counts or timing jitter, and a realistic scenario where non-zero dark counts and timing jitter are included. We demonstrate that, under realistic conditions, it is possible to define optimized detection windows for both Alice and Bob that maximize the key generation rate. In the next step, we illustrate how changes in the source parameters influence the key generation rate. In our analysis, we examine two cases: strongly correlated photon pairs and photon pairs with no correlation generated from the SPDC source. Our results show that, depending on the level of correlation, the optimized values of various realistic parameters can differ significantly. Finally, we conclude our study by performing a joint, simultaneous optimization of both the source and the detection system as a function of transmission loss. Our work is an important step towards refining practical parameter values for realistic QKD systems across wide range of experimental conditions.

References

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