Quantum Key Distribution with Vacua or Dim Pulses as Decoy States

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Abstract — Recently, Hwang has proposed a decoy state method in quantum key distribution (QKD). In Hwang’s proposal, the average photon number of the decoy state is about two. Here, we propose a new decoy state scheme using vacua or very weak coherent states as decoy states and discuss its advantages.

I. INTRODUCTION

The security of conventional cryptography is often based on unproven computational assumptions such as the hardness of factoring. In contrast, quantum cryptography offers unconditional security based on fundamental laws of physics, particularly, the quantum no-cloning theorem. The best-known application of quantum cryptography is quantum key distribution (QKD). The goal of QKD is to allow two users to communicate in absolute security in the presence of an eavesdropper. The best-known QKD protocol (BB84) was published by Bennett and Brassard in 1984.

The procedure of standard BB84 QKD scheme is as follows. First, Alice sends Bob a time-ordered sequence of single photons, each of which in one of the four possible polarizations—horizontal, vertical, 45-degrees and 135-degrees. Second, for each photon, Bob makes randomly one of two measurements: diagonal or rectilinear. Third, Bob writes down the bases and measurement outcomes and publicly acknowledges his receipt of Alice’s photons. Fourth, Alice and Bob then broadcast their bases. For the cases when they use different bases, they throw away their polarization data. For the cases when they use the same bases, they keep their polarization data. Note that in the absence of noise and Eve, Alice and Bob’s polarization data should be the same. Next, Alice and Bob perform some test for tampering. For instance, Alice and Bob can pick a random subset of their photons and broadcast their polarization data. From there, they compute the quantum bit error rate (QBER) of their transmission. If this QBER is larger than some prescribed value, they abort the protocol. On the other hand, if this QBER is within some prescribed value, then the QKD protocol is successful and they proceed with key generation. Key generation may be done by applying two different operations: a) error correction and b) privacy amplification.

The security of QKD protocols with ideal devices and, more recently, with imperfect devices has been proven. Since a single-photon source is an experimental challenge, a common experimental source is a weak (coherent) laser pulse, which, if phase randomized, can be regarded as a Poisson distribution in the number of photons. This means that there is a non-zero probability of having multi-photons. In principle, Eve can perform a quantum non-demolition measurement in photon number. If she sees a single photon, she suppresses the signal. If she sees a multi-photon, she steals one photon and resends the rest to Bob. She may try to mask her presence by the usual loss in a quantum channel. Note, however, that with such an attack, multi-photon signals exhibit different outcomes from single-photon signals. For instance, multi-photons give a much higher yield than single photons.

Recently, Hwang has provided an ingenious method to defend against the above attack by Eve. His idea is that, in addition to regular signal states, Alice also uses some decoy states. For each signal, Alice randomly chooses to send either a signal state or a decoy state. After Bob’s measurements of all signals, Alice tells Bob which signals are decoy states. They can then compare their outcomes for the decoy states and use their data to detect eavesdropper’s attack.

In Hwang’s original proposal, the average photon number of the decoy state is about two and is, thus, rather high by QKD standard. The goal there is to use the observed fractional loss of the decoy state to constrain the multi-photon yield in QKD, thus detecting eavesdropping attacks.

II. OUR IDEA

We propose several new ideas here. First of all, we propose a refined data analysis where the specific properties of the decoy state such as the bit error rate are analyzed separately from the original signal. Second, we show that Hwang’s scheme can be combined with existing security proofs of QKD, thus allowing rigorous proofs of security. Third, we show that it may be advantageous to use either vacua or very weak coherent states or both as decoy states. On one hand, by using a vacuum as a decoy state, Alice and Bob can verify the so-called dark count rates of their detectors. On the other hand, by using a very weak coherent pulse as a decoy state, Alice and Bob can easily lower bound the yield of single-photon pulses. These two types of decoy states can be easily combined with each other and with Hwang’s original proposal. The usage of decoy states may have some advantages. For instance, they may provide useful testing procedure and may increase the secure key generation rate, increase security and the distance of QKD. One specific example is that they can achieve secure QKD even at high loss.

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