Improvement of quantum key distribution protocols

Guilhua Zeng  Xinmei Wang
National Key Laboratory on ISDN of XiDian University, Xi’an, 710071, China

Abstract

The security of the previous quantum key distribution protocols, which is guaranteed by the nature of physics law, is based on the legitimate users. However, the impersonation of Alice or Bob by eavesdropper, in practice, will be existed in a large probability. In this paper an improvement scheme for the security quantum key is proposed.

KeyWords: Quantum cryptography

Quantum cryptography [1] is a recently developed technique that permits two parties, who share no secret information initially, to communicate over an open channel and to establish between themselves a shared secret sequence of bits. Quantum cryptography is provably secure against eavesdropping attack, in that, as a matter of fundamental principle, the secret data can not be compromised unknowingly to the legitimate users of the channel. Three ingenious protocols [2-4] in quantum cryptography have been proposed. The first, by Bennett et al, relies on the uncertainty principle of quantum mechanics to provide key security. The security guarantee is derived from the fact that each bit of data is encoded at random on either one of a conjugate pair of observables of quantum-mechanical object. Because such a pair of observables is subjected to the Heisenberg uncertainty principle [5], measuring one of the observables necessarily randomizes the
other. A further elegant technique has been proposed by Ekert, which relies on the violation of the Bell inequalities [6] to provide the secret security. And the third technique, devised by Bennett, is based on the transmission of nonorthogonal quantum states.

Raw quantum cryptography is useless in practice because limited eavesdropping may be undetectable, yet it may leak some information, and errors are to be expected even in the absence of eavesdropping. Also, we must protect against an eavesdropper who would impersonate Alice for Bob and Bob for Alice. For these reasons, quantum cryptography must be supplemented by classical tools such as privacy amplification [7], error correction [8]. To obtain more high security quantum privacy key, in general, four processes has be included in the quantum key distribution:

a). Quantum transmission
b). Data sifting
c). Error-correction
d). Privacy amplification

Obviously, the tools from steps b) to d) are classic supplement. For demonstration we use the quantum cryptographic protocols known as BB84 or four-state protocols. In general, the BB84, Ekert92, and B92 protocols possess the same process, the different is only in the method of quantum transmission, the process is described in figure 1.

In the first step of establishing the key, Alice sends a random sequence of signal built up from the four possibly signal state, each appearing with equal probability. Bob possesses two measurements apparatuses adapted to the two sets of signal states. He may distinguish either between vertical and horizontal linear polarize photons or between right and left circular polarize photons. For each of the signals sent to him by Alice he chooses with equal probability an apparatuses to use. After Bob’s receiving and measurement, he sends publicly the measurement base to Alice, and Alice compares the base between Alice and Bob’s base.

After Alice and Bob obtain what is call the raw data by the quantum transmission, the raw data must be sifted because it consists of those bits which Bob either did not receive at all or did not correctly measure in the basis used to transmit them. By comparison publicly the basis between Alice and Bob, the data sifting procedure is completed.
The Third step is the data correction. A distinct feature of error correction in quantum cryptography is that the error correction process is public, while the transmission itself is secret. In other words, Alice and Bob must conduct a public discussion to identify, with a high degree of confidence, all errors in their data, while at the same time leaking as little information as possible about the data. The basic idea is that Alice and Bob compute and exchange a series of block check sums of their data and proceed by bi-section to locate the error in each of the problem blocks. After their block check sums agree several times in a row, Alice and Bob conclude that all transmission errors have been removed. Each disclosed check sum is presumed to have been recorded by eavesdropper Eve, and to be worth one bit of Renyi information to Eve. The number of iterations required, and hence the amount of Renyi information leaked, depends on the desired confidence level, the initial error rate, and the manner in which Alice and Bob select their check sum blocks.

By the distillation art of secret key, the so called privacy amplification, a final secure quantum key is generated and distributed. The basic principle of privacy amplification is as follows. Let Alice and Bob shared a random variable $W$, such as a random $n$-bit string, while an eavesdropper Eve learns a corrected random variable $V$, providing at most $t < n$ bits of information about $W$, i.e., $H(W|V) \leq n - t$. Eve is allowed to specify an arbitrary distribution $P_{VW}$ (unknown to Alice and Bob) subject to the only constraint that $R(W|V = v) \leq n - t$ with high probability (over values $v$), where $R(W|V = v)$ denotes the second-order conditional Renyi entropy of $W$, given $V = v$. For any $s < n - t$, Alice and Bob can distill $r = n - t - s$ bits of the secret key $K = G(W)$ while keeping Eve’s information about $K$ exponentially small in $s$, by publicly choosing the compression function $G$ at random from a suitable class of maps into $\{0, 1\}^{n-t-s}$.

Obviously, the above procedure is based on the legitimate users, refereed to as Alice and Bob. However, the practice existence of impersonation of Alice or Bob by eavesdropper, make us have to take some action to against the eavesdropper, an efficient way is to verify the communicators’ identity. In the follows, we improve the previous quantum key distribution scheme to guarantee the security of quantum key for truly legitimate users.

After the privacy amplification, a compressed key is obtained, but it can not be acted as the final key because of the impersonation. So the fifth step for identity verification
following the previous schemes, which is described in figure 1, must be added for the security quantum key. The improving scheme is shown in figure 2. Of course, the identity verification step can also be inserted in the front of the privacy amplification according to the sequence: quantum transmission $\rightarrow$ data sifting $\rightarrow$ error correction $\rightarrow$ identity verification $\rightarrow$ privacy amplification, the schematic diagram is described in figure 3. It is more practicable according to the latter sequence, because if one of the communicators is impersonation, the procedure may be over before the step of privacy amplification.

The key problem of the identity verification is to obtain the authentication key, it can be established by the technique that divides the initial quantum secret key $K$ (it may be called Raw Key) into two parts, i.e., $K = K_a \oplus K_m$, where the sign $\oplus$ represents the logic plus, the key $K_a$ is used for identity verification, while the key $K_m$ is as a final shared secret key between Alice and Bob. The $K_a$ may be obtained by two techniques. A single method is to choose the bits from $K$ according to a proper ‘rule’, which is adapted publicly by users Alice and Bob, for example, one may take the bits in odd position in $K$. The guaranteed security of the quantum key $K$ keeps the taken bits a high degree of security, although the ‘rule’ is chosen publicly. Then Alice and Bob constructs independently the authentication key $K_a$. At last Alice and Bob correct the $K_a$ like that techniques used in the second step (Data Sifting) of quantum key distribution. More complexity, one can adopt the privacy amplification technique again or the hash function to obtain a shorter key as $K_a$ from the “Raw key” $K$. In this way, the $K_a$ is more secure and the quantum key will be not influenced.

As shown in figure 2, after obtaining the shared dynamical-key $K_a$, Alice and Bob use it to verify themselves identity, the technique may be like that base on the symmetric cryptosystem. If the processes of identity verification give the ‘yes’, the $K_m$ may act as the final key, otherwise the communication is over or re-set up.

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**Figures captions**

- Figure 1. Schematic diagram of the quantum key distribution system.

- Figure 2. Schematic diagram of the quantum key distribution system with identity verification. The identity verification step is in front of privacy amplification step a) and acts as the last step b).