Quantum key distribution with authentication

Guihua Zeng
Xinmei Wang

National Key Lab. on ISDN, XiDian University, Xi’an 710071, P.R.China

Abstract

The security of the previous quantum key distribution (QKD) protocols, which is guaranteed by the nature of physics law, is based on the legitimate users. However, impersonation of the legitimate communicators by eavesdroppers, in practice, will be inevitable. In fact, the previous QKD protocols is un secure without authentication in practical communication. In this paper, we proposed an improved QKD protocol that can simultaneously distribute the quantum secret key and verify the communicators’ identity. This presented authentication scheme is provably secure.

PACS:0365.Bz

1 Introduction

Since the first finding that quantum effects may protect privacy information transmitted in an open quantum channel by S.Wiesner [1], and then by C.H.Bennett and G.Brassard [2], a remarkable surge of interest in the international scientific and industrial community has propelled quantum cryptography into mainstream computer science and physics. Furthermore, quantum cryptography is becoming increasingly practical at a fast pace. Several quantum key distribution protocols have been proposed, three main protocols of these are the BB84 protocol [3], B92 protocol [4], and EPR protocol [5]. The first quantum key distribution prototype, working over a distance of 32 centimetres in 1989, was implemented by means of laser transmitting in free space [6]. Soon, several experimental demonstrations by optical fibre were set up[7]. After that, a lot of publications have been presented, which cover three aspects: 1) QKD protocols [8-10], 2) security of QKD protocols and detection of eavesdropper [11-16] and 3) practical application of quantum cryptography [17-20].
Quantum cryptography employs quantum phenomena such as the Heisenberg uncertainty principle and the quantum corrections to protect distributions of cryptographic keys. Key distribution is defined as procedure allowing two legitimate users of communication channel to establish two exact copies, one copy for each user, of a random and secret sequence of bits. In other words, quantum cryptography is a 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 in quantum cryptography have been proposed. The first, by Bennett et al [3], 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, measuring one of the observables necessarily randomizes the other. A further elegant technique has been proposed by Ekert [5], which relies on the violation of the Bell inequalities to provide the secret security. And the third technique, devised by Bennett [4], is based on the transmission of nonorthogonal quantum states.

However, the cryptography and the cryptanalytics are always a pairs contradiction. Once a cryptographic protocol is proposed, eavesdropper (Eve) will try to break it. Quantum cryptography is also no exception, although the quantum cryptography is thought to be provably security. With the quantum key distribution protocols presented, several attacks strategy have been proposed, such as intercept/resend scheme [6], beamsplitting scheme [6], entanglement scheme [14] and quantum copying [15,16]. In the intercept/resend scheme, Eve intercepts selected light pulses and reads them in bases of her choosing. When this occurs, Eve fabricates and sends to Bob a pulse of the same polarization as she detected. However, due to uncertainty principle, at least 25% of the pulse Eve fabricates will yield the wrong result if later successfully measured by Bob. The other attack, beamsplitting, depends on the fact that transmitted light pulses are not pure single-photon states. In the entanglement scheme, Eve involves the carrier particle in an interaction with her own quantum system, referred to as probe, so that the particle and the probe are left in an entangled state, and a subsequent measurement of the probe yields information about the particle. Some investigators are now turning their attention to collective attacks and joint attacks. About these attacks description please see Ref.[13]
and its references. Eve can also use the quantum copying to obtain information between Alice and Bob. Two kind quantum copies are presented [15,16]. It is appropriate to emphasize the limitation of above attacks strategy. All these mentioned attacks strategy are restricted by the uncertainty principle or the quantum corrections, so Eve can not break the quantum cryptography protocols. The risk of eavesdropper is to disturb the information and to be detected finally by the legitimate users. This is the reason why quantum cryptography is declared to be provably secure.

However, The security of the previous quantum key distribution protocols, which is guaranteed by the nature of physics law, is based on the legitimate users. In practice, the impersonation of Alice or Bob by eavesdropper will be existed in a large probability. Circumventing the impersonation needs to verify the identity of communicators, saying Alice and Bob.

In section 2 we give the preliminary ingredients, which are important quantum effects in quantum cryptography. Section 3 reviews the QKD protocols. In section 4 we propose a QKD protocol with authentication function. It is composed of two phases, i.e., the initial phase and QKD with authentication phase. In section 5 we analyze the security of the presented scheme. We conclude in section 6.

2 Preliminaries

The recent results in quantum cryptography are associated with the Heisenberg uncertainty principle of quantum mechanics, EPR effects. In follows, we briefly describe these quantum effects.

2.1 Heisenberg Uncertainty Principle

Using standard Dirac notation, this principle can be succinctly stated as follows:

Heisenberg Uncertainty Principle: For any two quantum mechanical observables $A$ and $B$, if the corresponding operators $\hat{A}, \hat{B}$ satisfy

$$\left[ \hat{A}, \hat{B} \right] = \hat{A}\hat{B} - \hat{B}\hat{A},$$

then

$$\langle \Delta A \rangle \langle \Delta B \rangle \geq \frac{1}{2} \left\| [A, B] \right\|,$$

where $\langle \Delta A \rangle$ and $\langle \Delta B \rangle$ are average value of operators $\Delta \hat{A}$ and $\Delta \hat{B}$, respectively.

$$\Delta \hat{A} = \hat{A} - \langle A \rangle \quad \text{and} \quad \Delta \hat{B} = \hat{B} - \langle B \rangle.$$
Thus, $\langle \Delta A \rangle$ and $\langle \Delta B \rangle$ are variances which measure the uncertainty of observables $A$ and $B$. For incompatible observables, i.e., for observables $A$ and $B$ such that $[A, B] \neq 0$, reducing the uncertainty $\langle \Delta A \rangle$ of $A$ forces the uncertainty $\langle \Delta B \rangle$ of $B$ to increase, and vice versa. Thus the observables $A$ and $B$ can not be simultaneously measured to arbitrary precision. Measuring one of the observables interferes with the measurement of the other.

Heisenberg uncertainty principle can be applied to design a completely secure channel in quantum cryptographic communication protocols, that communicate random binary sequences (i.e., keys) with automatic eavesdropping detection. As a result, the perfect security of the Vernam cipher (i.e., one-time-pad) is an inexpensively implementable reality.

An example is the uncertainty of light polarization, which is extensively used in quantum cryptography. There are two kind photons, one is polarized in one of the two ‘rectilinear’ directions, i.e., vertical (90 degrees) or horizontal (0 degrees), and the other is polarized in one of two ‘diagonal’ directions, i.e., 45 degrees or 135 degrees. The two directions of ‘rectilinear’ photon or ‘diagonal’ photon can be reliably distinguished by a proper measurement. However, the two kind photons can not be distinguished because of the limitation of uncertainty principle. Rectilinear and diagonal polarization are complementary properties in the sense that measuring either property necessarily randomizes the other.

### 2.2 EPR effect and Bell’s Theorem

Einstein-Podolsky-Rosen (EPR) effect play an important role in quantum information processing. It occurs when a spherically symmetric atom emits two photons in opposite directions toward two observers, Alice and Bob. The two photons are produced in an initial state of undefined polarization. But because of the symmetry of the initial state, the polarization of the photons, when measured, must have opposite values, provided that the measurements are of the same type. For example, if Alice and Bob both measure rectilinear polarization, they each equally likely to record either a 0 (horizontal polarization) or a 1 (vertical), but if Alice obtains a 0, Bob will certainly obtain a 1 and vice versa.

The unusual and important aspect of the EPR effect is that the polarization of both photons is determined as soon as, but not before, one of the photons is measured. This happens no matter how far apart the photons may be at the time. This ‘classical’ explanation of the EPR effect is somewhat counterintuitive, and indeed all classic explanations of the EPR effect involve some implausible element, such as instantaneous action at a
distance. Yet the mathematical formalism of quantum mechanics accounts for the EPR effect in a straightforward manner, and experiment have amply confirmed the existence of the phenomenon.

Of course, EPR effect may occur on various particles not only on photons. Einstein, Podolsky, and Rosen (EPR) in the their famous 1935 paper [21] challenged the foundations of quantum mechanics by pointing out a “paradox.” There exist spatially separated pairs of particles, henceforth called EPR pairs, whose states are correlated in such a way that the measurement of a chosen observable $A$ of one automatically determines the result of the measurement of $A$ of the other. Since EPR pairs can be pairs of particles separated at great distances, this leads to what appears to be a paradoxical “action at a distance.” In 1964, Bell [22] gave a means for actually testing for locally hidden variable theories. He proved that all such locally hidden variable theories must satisfy the Bell inequality. Quantum mechanics has been shown to violate the inequality.

Bell’s theorem provides a method for checking eavesdropping. In following we give a brief reviews. For convenience, we explain Bell’s theorem with spin-$\frac{1}{2}$ particle pairs. Consider two measurable quantities $A$ and $B$, and label the (discrete) possible values of $A$ and $B$ by $\alpha_i$ and $\beta_j$, the corresponding unit vectors are $a_i$, and $b_j$, respectively. Then

$$E(a_i, b_j) = P_{++}(a_i, b_j) + P_{--}(a_i, b_j) - P_{+-}(a_i, b_j) - P_{-+}(a_i, b_j),$$

where $P_{\pm\pm}(a_i, b_j)$ denotes the probability that result $\pm 1$ has been obtained along $a_i$ and $\pm 1$ along $b_j$. The correlation coefficient $S$ is obtained

$$S = \sum_{i,j} E(a_i, b_j).$$

According to quantum rules

$$E(a_i, b_j) = -a_i \cdot b_j.$$ 

So, quantum mechanics requires

$$S = -2\sqrt{2}.$$

Intervention of eavesdropper induces

$$S = \int \rho(n_a, n_b) dn_a dn_b [\sqrt{2} n_a \cdot b_b],$$

where $n_a, n_b$ are two unit vectors (for particles a, and b, respectively), $\rho(n_a, n_b)$ is the probability of intercepting a spin component along a given direction for a particular measurement. In this case,

$$-\sqrt{2} \leq S \leq \sqrt{2}.$$ 

By the correlation coefficients, the legitimate user may detect the eavesdropper.
3 Quantum key distribution protocols

A lot of QKD protocols have been presented, they have similar procedure. The legitimate communicators, known as Alice and Bob, communicate over a public channel in following phases. step 1 is dedicated to raw key extraction, step 2 to error estimation, step 3 to checking eavesdropping, step 4 to reconciliation, i.e., to reconciled key extraction, and step 5 to privacy amplification, i.e., extraction of final secret key.

3.1 Quantum key distribution protocols

Step 1. Quantum transmission over quantum communication channel

The communicators set up a quantum channel, then they transmit quantum states (Qubits) over the quantum channel. It is noted that the transmission model is different for different QKD protocol. Two typical transmission are BB84 protocol and EPR protocol. The former transmits non-commute quantum states, and the latter transmits one of each EPR pairs

Step 2. Extraction of raw key over a public channel

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. Such “non-receptions” could be caused by Eve’s intrusion or by dark counts in Bob’s detecting device. The location of the dark counts are, of course, communicated by Bob to Alice over the public channel. By comparison publicly the basis between Alice and Bob, the data sifting procedure is completed.

Step 3. Check of eavesdropper

This step depends on the different QKD protocols. In BB84 protocol, Alice and Bob now use the public channel to estimate the error rate in raw key. They publicly select and agree upon a random sample of raw key, publicly compare these bits to obtain an estimate $R$ of the error-rate. These revealed bits are discarded from raw key. If $R$ exceeds a certain threshold $R_{Max}$, then it will be impossible for Alice and Bob to arrive at a common secret key. If so, Alice and Bob return to stage 1 to start over. On the other hand, If the error estimate $R$ does not exceed $R_{Max}$, then Alice and Bob move onto phase 3. In EPR protocol, one may use the correction of EPR pairs to check eavesdropping.

Step 4. Extraction of reconciled key

In step 2, Alice and Bob’s objective is to remove all errors from what remains of raw
key to produce an error free common key, called reconciled key. This phase is of course
called reconciliation, and takes place in two stage.

In stage 1, Alice and Bob publicly agree upon a random permutation, and apply it
to what remains of their respective raw keys. Next Alice and Bob partition the remnant
raw key into blocks of length $\ell$, where the length $\ell$ is chosen so that blocks of this length
are unlikely to contain more than one error. For each of these blocks, Alice and Bob
publicly compare overall parity checks, making sure each time to discard the last bit of
the compared block. Each time a overall parity check does not agree, Alice and Bob
initiate a binary search for the error, i.e., bisecting the block into two subblocks, publicly
comparing the parities for each of these subblocks, discarding the right most bit of each
subblock. They continue their bisective search on the subblock for which their parities
are not in agreement. This bisective search continues until the erroneous bit is located
and deleted. They then continue to the next $\ell$-block.

Stage 1 is repeated, i.e., a random permutation is chosen, remnant raw key is parti-
tioned into blocks of length $\ell$, parities are compared, etc. This is done until it becomes
inefficient to continue in this fashion.

Alice and Bob then move to stage 2 by using a more refined reconciliation procedure.
They publicly select randomly chosen subsets of remnant raw key, publicly compare par-
ities, each time discarding an agreed upon bit from their chosen key sample. If a parity
should not agree, they employ the binary search strategy of step 1 to locate and delete
the error.

Finally, when, for some fixed number $N$ of consecutive repetitions of stage 2, no error
is found, Alice and Bob assume that to a very high probability, the remnant raw key is
without error. Alice and Bob now rename the remnant raw key reconciled key, and move
on to the final and last phase of their communication.

**Step 5. Privacy amplification**

Alice and Bob now have a common reconciled key which they know is only partially
secret from Eve. They now begin the process of privacy amplification, which is the
extraction of a secret key from a partially secret one [23].

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 $P_{V,W}$ (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 $\{0, 1\}^{n-t-s}$. It can be shown that Eve’s average information about the final secret key is less than $2^{-s/\ln 2}$ bits.

### 3.2 The drawback of previous QKD protocols

Obviously, the above procedure is based on the legitimate users, refereed to as Alice and Bob. However, the practical 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. Unfortunately, there is no known way to initiate authentication without initially exchanging secret key over a secure communication channel in previous protocols.

In fact, quantum key distribution protocol is completely insecurity under the attacking of middle-attack. When Alice communicates Bob, Eve intercepts all qubit sent by Alice, and communicates Bob with impersonating Alice. Finally, Eve obtains two keys $K_{AE}, K_{EB}$, where $K_{AE}$ represents the secret key between Alice and Eve, and $K_{AE}$ represents the secret key between Bob and Eve. As a result Eve can easily decrypt the ciphertext sent by Alice or Bob.

Of course, Alice and Bob may use the classic (where ‘classic’ contraposes quantum) authentication technology to prove the legitimated identity. However, because Alice and Bob can not simultaneously complete the identity verification and quantum key distribution, Eve may avoid the authentication procedure. So, practically, QKD protocol with identity verification is necessary. In the follows, we improve the previous quantum key distribution scheme to guarantee the security of quantum key for truly legitimate users.

### 4 QKD protocol with identity verification

Follows we propose a scheme to implement quantum authentication in QKD protocol. It may be implemented by non-commute quantum states or non-orthogonal quantum states with Heisenberg uncertainty principle. It also can be implement by EPR pairs associated with Bell’s theorem. In this paper, we use EPR pair with the Bell’s theorem to implement
quantum authentication. Both the identity verification and quantum key distribution are used in our proposed secure authentication protocol. There are two phase in the quantum authentication protocol. The initial phase is completed at the key information center to set up the system, and the authentication phase is executed between the two communication parties to achieve mutual authentication and exchange the secure quantum key.

4.1 Initial Phase

Assuming the information center is legitimate and believable. The information center is responsible neither for mutual authentication nor for the generation of quantum keys. The role of this center is to simply help the legitimate user to obtain the authentication key. In initial phase, we use the Biham’s technology[24]. It uses the quantum memory, about the implementation of qubit in quantum memory may refer to reference[24]. In fact, the communicators and the center are composed of a network. When the secure network system is setting up, the information center will execute the following steps.

1. Alice and Bob send the center their $ID_A, ID_B$ to register to this secure network. Then the center sets up quantum channel between Alice and the center, and between Bob and the center.

2. Alice and Bob respectively prepare EPR pairs, and send respectively one of the each EPR pairs to the center.

3. Check eavesdropping between Alice and the center, and between Bob and the center. The center randomly chooses qubits from the strings sent by Alice and Bob, and checks the correction of quantum states like in EPR protocol.

4. The center must be able to keep the quantum states for a while (in case the states do not arrive at the same time from Alice and Bob) and then measures the eigenvalue of the total-spin operator of the first pair, the second pair. etc. Except for the qubits for detection of eavesdropping.

5. The center tells Alice and Bob the result of the measurement.

6. If the result of the measurement is $s = 0$, Bob knows Alice’s bit and vice versa. If the result of the measurement is $s = 1$, Alice and Bob discard the transmission.

7. Alice and Bob keep the bits which correspond to $s = 0$ as the raw authentication key $K'_1$. Proceeding the key $K'_1$ like QKD described in section 3, one obtains the authentication key $K_1$. 

Once the legitimate users obtain the authentication keys $K_1$, the information center is not needed in further communication between Alice and Bob.

### 4.2 Authentication phase

Step 1. Alice and Bob transfer the common key $K_1$ into a sequence of measurement basis. While Alice and Bob need to verify their identification, or need to set up a new communication, they secretly transfer the reserved common key into a sequence of measurement basis. For example, if Alice and Bob use the measurement basis of polarization photon which was used in BB84 quantum key distribution protocol, they may let the bit '0' correspond to rectilinear measurement basis and '1' correspond to diagonal measurement basis, or vice versa. We represent rectilinear measurement basis by the symbol $\bigcirc$, and represent diagonal measurement basis by the symbol $\bigodot$. After transferred, Alice and Bob obtain a sequence of measurement basis, respectively. For example, if the common key is 001101, the sequence of measurement basic is $\bigodot \bigodot \bigcirc \bigcirc \bigcirc \bigodot$.

Step 2. Alice and Bob set up a quantum communication channel. When Alice wants to secretly communicate Bob, Alice and Bob need to set up a quantum channel. The transmitting quantum states in the quantum channel may be arbitrary. For example the polarization photon state or the phase correction states. In this protocol, we use the phase correction states. So the channel consists of a source that emits EPR pairs of spin-$\frac{1}{2}$ particle, in a singlet state. The particles fly apart along the $z$ axis, towards the two legitimate users of the channel. Alice chooses a random basis for measuring one numbering of each EPR pair of particles. The other particle of each EPR pair is measured by Bob in the next step. Alice's measurement results in effect determine, through the EPR corrections, a sequence of states for Bob's particles.

Step 3. Bob measures the strings of quantum states. Bob randomly measures the sequence of quantum states by using two measurement basis $M, M_{K_1}$, where $M$ is the measurement basis for quantum key distribution and for obtaining new authentication key, $M_{K_1}$ is the measurement basis for identity authentication in the current communication. $M$ is like that in EPR protocol.

Step 4. Alice and Bob check the eavesdropper. For secure communication, the legitimates users Alice and Bob need to firstly detect eavesdropper. Bob randomly chooses some measurement results measured by the basis $M$ for checking the correction of EPR pair. According to the Bell’s theorem described in subsection 2.2 to judge the eavesdropping.
Step 5. Bob encrypts his results measured by $M_{K_1}$. Although Bob does not know the qubits measured by Alice, it will not influence the identity verification. Expressing the strings of quantum states for authentication by

$$|\Psi> = \{|\psi_1>, |\psi_2>, \cdots, |\psi_n>\}.$$  

Where $|\psi_i>$ represents a qubit received by Bob. After measurement, Bob obtains

$$|\Phi> = M_{K_1}|\Psi>,$$

where $|\Phi> = \{|\phi_1>, |\phi_2>, \cdots, |\phi_n>\}$ represents the measurement results under measurement basis $M_{K_1}$. Transferring $|\Phi>$ into binary bits strings $m$, and then using $K_1$ to encrypt it, Bob obtains the ciphertext

$$y = E_{K_1}(m).$$

Bob sends Alice the ciphertext $y$, and tells Alice the corresponding sequence numbers of quantum states $|\psi_i>, i = 1, 2, \cdots, n$.

Step 5. Verifying Bob’s identity. Having received Bob’s results, Alice analyzes Bob’s results. Alice decrypts the ciphertext,

$$m = E^{-1}_{K_1}(y),$$

and compare her results with $m$, thereby Alice gets the measurement basis $M_{K_t}$. If $K_t = K_1$, Bob’s identity is true.

Step 6. Verifying Alice’ identity. After Alice decrypted the ciphertext, Alice sends Bob the result $m'$. If $m' = m$, the Alice’s identity is true.

Step 7. Alice and Bob distribute the quantum secret key. If the communicators are legitimate, Alice and Bob distribute the quantum secret key using the remainder Qubits. The process is same as EPR protocol.

Step 8. Alice and Bob discard the authentication keys $K_1$, and set up new authentication keys. After authentication, the authentication key $K_1$ is no longer use. The legitimate users obtain a new authentication key. The method is like that used in QKD protocol. Of course, one can directly take portion bits from the final quantum key as the authentication key.

It has been noted that the presented protocol can not prevent voluntary attack. This is a drawback of quantum cryptography. How to prevent the voluntary attack needs further investigation.
5 Security analysis

The proposed QKD protocol with authentication is provably secure. Obviously, the QKD is provably secure because we use the previous QKD protocol. So in following, we mainly analyze the security of authentication scheme. In initial phase, the security derives from the security of the EPR protocol, and relies on the fact that the singlet state is the only state for which the two spins are anticorrelated both in $\hat{S}_z$ and in the $\hat{S}_x$ basis. So eavesdropper and the center can not obtain the authentication key $K_1$.

In authentication phase, we believe this scheme is secure as the follows reason. i) Our protocol does not have the conspiracy problem of masquerading. If a forger wants to masquerade user Alice or Bob to communicate with others, he must find the common key. However, it is difficult to obtain the shared common secret because of the follows two reasons. First, the authentication key is obtained by the quantum key distribution protocol which is provably secure, so the authentication key is secure. Second the authentication key is used only one times, eavesdropper does not know any information about the authentication key. ii) The replay-attack will also not succeed in our protocol because the key is used only one times. iii) The quantum attacking strategy is invalid, the reason is the same as the analysis for previous QKD protocols.

There is a weakness in our protocol. The only weakness of our protocol is the reservation of authentication key. Although the obtaining of the common key in the last quantum communication is provably secure, the common key reservation has not circumvented the catch 22 problem. In fact, this drawback exists in all symmetric cryptographic authentication system. Of course, we can use the EPR effects or other quantum effect to keep the common key, but the reservation time is very short according to current technology. A long time correction of quantum states is need in the future.

6 Conclusion

The previous QKD protocols are based on the legitimate users. However, the practical 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. Unfortunately, there is no known way to initiate authentication without initially exchanging secret key over a secure communication channel in previous protocols. Of course, one can use the classic authentication protocol to verify identity. However, because the authentication and the QKD can not be simultaneous, Eve can escape the
authentication procedure. In addition, quantum key distribution protocol is completely insecurity under the attacking of middle-attack.

In this paper, we proposed a QKD protocol that can simultaneously distribute the quantum secret key and verify the communicators' identity. The QKD is implemented by the previous EPR protocol, the authentication is implemented by the symmetric cryptographic scheme with quantum effects. The presented scheme is provably secure.

we use EPR effects with Bell’ theorem to implement quantum authentication. It can prevent impersonation and middle-attack. Of course, it can also be implemented by non-commute quantum states or non-orthogonal quantum states with Heisenberg uncertainty principle.

Acknowledgments

This project was supported by the National Natural Science Foundation of China, Grant no: 69803008.
References

1. S. Wiesner, Conjugate coding, Sigact News, vol. 15, no. 1, 1983, pp. 78 - 88; original manuscript written circa 1970.

2. C. H. Bennett, G. Brassard, S. Breidbart, and S. Wiesner, Quantum cryptography, or unforgeable subway tokens, Advances in Cryptology: Proceedings of Crypto 82, August 1982, Plenum Press, New York, pp. 267 - 275.

3. C. H. Bennett, and G. Brassard, An update on quantum cryptography, Advances in Cryptology: Proceedings of Crypto 84, August 1984, Springer - Verlag, pp. 475 - 480.

4. C. H. Bennett, Quantum cryptography using any two nonorthogonal states, Physical Review Letters, vol. 68, no. 21, 25 May 1992, pp. 3121 - 2124.

5. A. K. Ekert, Quantum cryptography based on Bell’s theorem, Physical Review Letters, vol. 67, no. 6, 5 August 1991, pp. 661 - 663. A. K. Ekert, J. G. Rarity, P. R. Tapster, and G. M. Palma, Practical quantum cryptography based on two-photon interferometry, Phys. Rev. Lett. 69, 1293(1992).

6. C. H. Bennett, F. Bessette, G. Brassard, L. Salvail and J. Smolin, Experimental quantum cryptography, J. Cryptology 5, 3 (1992).

7. J. Breguet, A. Muller, and N. Gisin, Quantum cryptography with polarized photons in optical fibres, Journal of Modern Optics, 41, no.12, 2405-2412(1994).

8. S. Phoenix, S. Barnett, P. Townsend and K. Blow, Multi-user quantum cryptography on optical networks, Journal of Modern Optics, 42, no.6, 1155-1163(1995).

9. S. M. Barnett, and S. J. D. Phoenix, ”Bell’s inequality and rejected-data protocols for quantum cryptography”, Journal of Modern Optics, vol. 40, no. 8, August 1993, pp. 1443 - 1448.

10. C. H. Bennett, and G. Brassard, ”Quantum cryptography and its application to provably secure key expansion, public-key distribution, and coin-tossing”, IEEE International Symposium on Information Theory, September 1983, page 91.

11. B. Hutter, A. Ekert, Information gain in quantum eavesdropping, Journal of Modern Optics, 41, 2455-2466(1994).
12. C.A.Fuchs, N.Gisin, R.B.Griffiths, C.S.Niu, and A.Peres, Optimal eavesdropping in quantum cryptography, Phys. Rev. A 56, 1163-1172 (1997).

13. B.A.Slutsky, R.Rao, P.C.Sun, and Y.Fainman, Security of quantum cryptography against individual attacks, Phys. Rev. A 57, 2383(1998).

14. Brandt, Howard E., John M. Meyers, And Samuel J. Lomonaco, Jr., Aspects of entangled translucent eavesdropping in quantum cryptography, Phys. Rev. A, Vol. 56, No. 6, December 1997, pp. 4456 - 4465

15. C.Niu, and R.Griffiths, Optimal copyinf of one quantum bit, Phys.Rev.A, Vol.58, no. 6, 4377-4393,(1998).

16. L.Duan and G.Guo, Probabilistic cloning and identification of Linearly independent quantum states, Phys. Rev. Lett., Vol.80 no.22, 4999-5002,(1998).

17. J.G.Rarity, P.C.M.Owens, and P.R.Tapster, Quantum random-number generation and key sharing, Journal of Modern Optics, 41, 2435(1994).

18. P.D.Townsend, J.G.Rarity, and P.R.Tapster, Single photon interference in a 10 km long optical fibre interferometer, Electronics Letters, vol. 29, no. 7, April 1993, pp. 634 - 635;

19. P.D.Townsend, J.G.Rarity, and P.R.Tapster, Enhanced single photon fringe visibility in a 10 km-long prototype quantum cryptography channel, Electronics Letters, vol. 29, no. 14, 8 July 1993, pp. 1291 - 1293.

20. C.Marand and P.D.Townsend, Quantum key distribution over distances as long as 30 Km, Optics Letters, Vol. 20, no. 16, 1695-1697(1995).

21. A.Einstein, B.Podolsky and N.Rosen, Can quantum mechanical description of physical reality be considered complete? Phys. Rev. 47, 777(1935)

22. J.S.Bell, Physics (Long Island City, N.Y.) 1, 195(1965).

23. C.H.Bennett, G.Brassard, C.Crepeau and U.M.Maurer, Generalized privacy amplification, IEEE Trans. Inform. Theory, 41, 1915(1995).

24. E.Biham, B.Huttner, and T.Mor, Quantum cryptographic network based on quantum memories, Phys.Rev.A, Vol. 54, no. 4, 2651-2658, (1996).