# GUARANTEERRING SECURITY OF FINANCIAL TRANSACTION BY USING QUANTUM CRYPTOGRAPHY IN BANKING ENVIRONMENT

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Abstract: Protocols and applications could profit of quantum cryptography to secure communications. The applications of quantum cryptography are linked to telecommunication services that require very high level of security such as bank transactions.

The aim of this paper is to present the possibility to use quantum cryptography in critical financial transactions, to analyse the use of quantum key distribution within IPSEC to secure these transactions and to present the estimated performances of this solution.

After having introduced basic concepts in quantum cryptography, we describe a scenario of using quantum key distribution in bank transactions in Switzerland. Then, we propose a solution that integrate quantum key distribution into IPSEC. A performance analysis is done to demonstrate the operational feasibility of this solution.

## 1 INTRODUCTION

Banks and financial establishments need to secure transaction and communication between them and their clients. In fact, everyday thousand of million dollars transactions are performed between banks. This transmission must be secure and need to satisfy security requirement such as authentication, confidentiality and integrity. Quantum cryptography could be used, in this context, to offer unconditional secure communication.

The next section presents a scenario for quantum cryptography application to secure bank transaction over Internet and Intranet architectures. Then, we prove the feasibility of the use of quantum cryptography within the framework of IPsec.

Quantum cryptography could be applied to IP Security protocol (IPsec) [RFC 2401]. This protocol is related to a collection of standards that was designed specifically to create secure end-to-end secure connections. The standard was developed by the Internet Engineering Task Force (IETF) to secure communications over both public and private networks.

## 2 QUANTUM CRYPTOGRAPHY FOR BANKS AND FINANCIAL ESTABLISHMENTS

Nowadays, Banks and financial institutions use either symmetric cryptography or asymmetric cryptography. Both techniques, as proved above, are not unconditionally secure. So transactions could be corrupted and altered without the awareness of the bank. This constitutes a serious danger because criminals and malicious organizations could profit of the breach to steal and highjack. Securing critical financial transaction is mandatory and will be more and more necessary to master economical crime.

### 2.1 Quantum Cryptography solution

To ensure maximum security, we need to maximize the security in each field such as storage, generation, processing and transmission of data. In this paragraph, we will focus on securing transmissions. The transmissions are either from bank building to another bank building of the same company, from cash dispenser to bank and from a bank to another. The difference resides in the distance, the degree of security

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required and the duration and the quantity of information to send. Quantum cryptography ensures the unconditional security of transmission and the awareness if an eavesdropper tries to intercept or modify the content of the transmission. Quantum cryptography aims exploiting the laws of quantum physics in order to carry out a cryptographic task. The uncertainty relations of Heisenberg can in particular be exploited to implement communication channels that cannot be passively - i.e. without disturbance of the transmission - eavesdropped. Its legitimate users can detect eavesdropping, no matter what technology is available to the spy (Bennet1984; Gisin2002).

The power of quantum cryptography lies primarily in the fact that the keys distributed on the quantum channel are invulnerable to eavesdropping and can be guaranteed without assumptions on the computing power of an eavesdropper (Mayers1998; Lo1999). Banks can actually use quantum cryptography at least in two of the three types of transaction: bank building to another bank building of the same bank company or/and cash dispenser to the bank. In fact, we assume that the distance connecting two bank buildings in less than 100 km. So, the use of quantum cryptography based on optical fiber is possible (IdQuan2004). In this case, either a big amount of data could be exchange or a tiny amount of data that could be transmitted frequently between bank buildings. Transmission from cash dispenser to banks (if the cash dispenser is not in the bank) can also be done using quantum cryptography based on optical fiber. In fact, the danger is that a malicious person could intercept the communications between the bank and the cash dispenser and modify them like for instance credit some bank account or change the identification of debited account. Transaction, using quantum cryptography, would be at that moment unconditionally secure and no one can intercept them. Here we ensure the integrity and the confidentiality of the transmitted data.

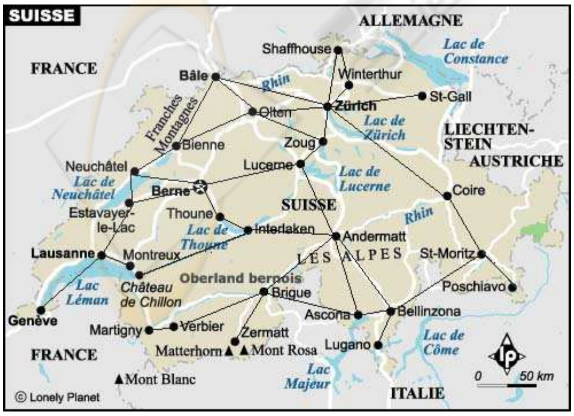


Figure 1: Swiss bank - application of quantum cryptography

## 2.2 Example of a bank scenario

In this paragraph, we present a scenario of quantum cryptography implementation in Switzerland (small country size). The bank company is called Swiss Bank (SB). We assume that each bank have a head quarter in every Canton. A main data base is located in Zurich and every head quarter bank has to communicate all transaction to the data base in Zurich. SB installs optic fiber between some head quarters in order to create a ”private” quantum network (Figure 1). At least, each head quarter has a quantum cryptography receiver/sender. In order to reduce the volume of exchanged data every 6 hours all head quarters send data about transaction to Zurich (6h30, 12h30, 18h30 and 0h30).

The steps are the following:
All head quarters gather all transactions realized in the Canton. Bank head quarter located in the farthest Cantons from Zurich sends their adjacent canton. For instance, Lugano’s SB head quarter sends data to Bellinzona, Poschiavo sends to Brigue... using quantum cryptography. These ”nodes” has to wait until all adjacent cantons send have finished sending data (or time-out) then decrypt data and send them to the following BS head quarter according to a list. Finally, the nearest and direct linked to Zurich head quarters (Winterthur, Zoug, St-Gall, Coire...) exchange keys and communicate in a secure way using quantum cryptography.

Every head quarter (say H) has two different lists. Reception list: it is a list of all the head quarters that send data to H. Send List: usually it contains only one head quarter (the nearest to Zurich) but for availability purpose it contains 2 BS head quarters.

Example of such lists (for Bellinzona):

| Reception list | Send list |
|---|---|
| Lugano<br>St-Moriz<br>Ascona | Coire |

The possible cost of such scenario is:
The optical fiber total length: about 2000 Km
Number of quantum cryptography station: (twice the number of links) about 80
The cost of optical fiber per meter = 6 CHF
The cost of 2 quantum cryptography station = 150,000 CHF
The total cost of the scenario is 12000000 + 6000000 = 18 Million CHF   12 Million Euros.
So the price to ensure an unconditional secure transmission is about 12 Million Euros.
This cost is huge but if we estimate the prestige gain (in the image, the reputation and in term of confidence) of the bank this expense is justifiable. This long term investment will be beneficial to the bank.

To apply this solution, we need to use algorithms and protocols. IPsec could support the use of quantum cryptography. We present the feasibility and the theoretical performances of such application.

## 3 SEQKEIP OPERATING MODE

As IPsec uses classical cryptography to secure communication, in this paragraph, we propose to use quantum cryptography to replace the classical cryptographic protocols used for symmetric distribution.

Using QKD in IPsec has already been proposed and implemented by Elliot of BBN technologies (Elliott2002). It proposes the idea of using QKD in IPsec as Key generator for AES. In 2003, BBN technologies describes the possibility of integrating QKD within the standard IKE (Elliott2003) and announces some concerns linked to the compatibility of QKD with IKE. In our paper, we propose a QKD solution for IPsec called SEQKEIP that is not based on IKE but on ISAKMP. Using this method, we avoid the problem of compatibility between IKE and QKD.

The idea is to stick to the traditional IPsec and the Internet Security Association and Key management Protocol (ISAKMP). In fact, ISAKMP does not impose any condition to is the negotiation mechanisms or to the SAs parameters. To use quantum cryptography with IPsec we have simply to define the two phases described above. We create a Secure Quantum Key Exchange Internet Protocol (SeQKEIP). The SeQKEIP like IKE uses ISAKMP mechanisms and takes advantage of quantum cryptography in order to build a practical protocol.

SeQKEIP runs nearly like the IKE. It includes 3 phases: the phase 1 for the negotiation of the ISAKMP SA, phase 2 for the negotiation of SA and we add a phase called ”phase 0” in which Alice and Bob will share the first secret key. There are only three modes in SeQKEIP: Quantum Mode, Main Mode and Quick mode. Quantum mode is the quantum cryptography key exchange in the phase 0. Main Mode is used during the phase 1 and Quick Mode is an exchange in phase 2. Both the Main Mode and the Quick Mode are nearly the same of those in IKE.

*Phase 0: Key exchange - Quantum Mode*

This phase is the beginning of the secure exchange using quantum cryptography. After, these exchange both the sender and the receiver share a secret key. This key constitutes the pre-shared secret in IKE mechanism.

*Phase 1: Negotiation of ISAKMP SA - Main Mode*

During this phase, the cryptographic algorithm and the hash function are negotiated. Only the two parameters discussed in the phase 1 constitute the SeQKEIP attribute. The method to authenticate is the pre-shared secret (the secret key exchanged with Quantum Key Exchange method). Contrarily to IKE, SeQKEIP do not define DH groups and do not need to use digital signature nor digital certificates (Figure 2). No cryptographic key are generated in this phase. The first exchanged key is used to encipher packets and to authenticate users.

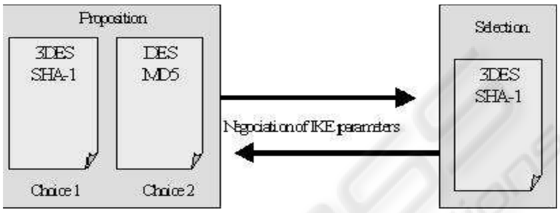


Figure 2: Message exchanged during the first phase

After the phase 0 and the phase 1, both sender and receiver will have the following information:

| | |
|---|---|
| Shared secret key | This key is generated during the phase 0 with Quantum Key exchange mechanism. The secret key is used to authenticate users and to encrypt packet. |
| Encryption algorithm | The encryption algorithm is applied to the phase 2 (negotiation of SA parameters). The algorithm could be 3DES, DES, AES. But, if we want to have the maximum security, we have to use One-Time-Pad function (OTP). |
| Hash function | The hash function will give the opportunity to the sender and the receiver to check the integrity of the message and the authentication of the correspondents. |

Note that the phase 0 and the phase 1 are totally independent and could be done at the same time. We need the secret key only from the phase 2.

*Phase 2: Negotiation of SA - Quick Mode*

As in IKE, the exchanged messages in phase 2 are protected in authentication and confidentiality by the negotiated parameters of the phase 1 and phase 0. The authentication is guaranteed by the addition of the HASH block after the ISAKMP header and the confidentiality is ensured by the encryption of the whole message blocks. The aim of this phase is to negotiate the SA. i.e. to negotiate the ”IPsec” parameters. The SA parameters are (Mason2002): Destination address, Security Parameter Index (SPI), the security mechanism (AH or ESP) and encryption & Hash function, the session key and additional attribute like the lifetime of SA.

For SeQKEIP, to extend security, we can use One-Time-Pad encryption function. The first exchanged key, in this case, will have the length of the message. We do not need thus any encryption algorithm for SA. We still need a Hash function to verify the integrity of the data. The run of IPsec could be modified in order to use one-time-pad function.

In the beginning (Figure 3), the phase 0 and the phase 1 start (1&2). After these two phases the parameters of the protocol are fixed. In (3), we will use key exchanged thanks to quantum cryptography. This key will be used either as a session key (4) or in the one-time-pad function (4').

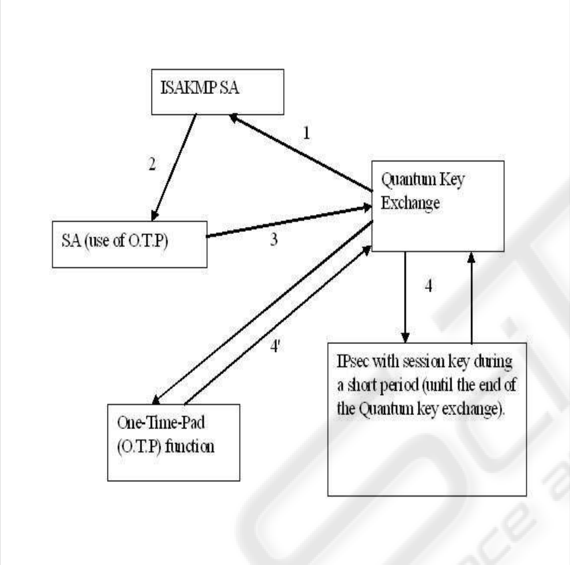
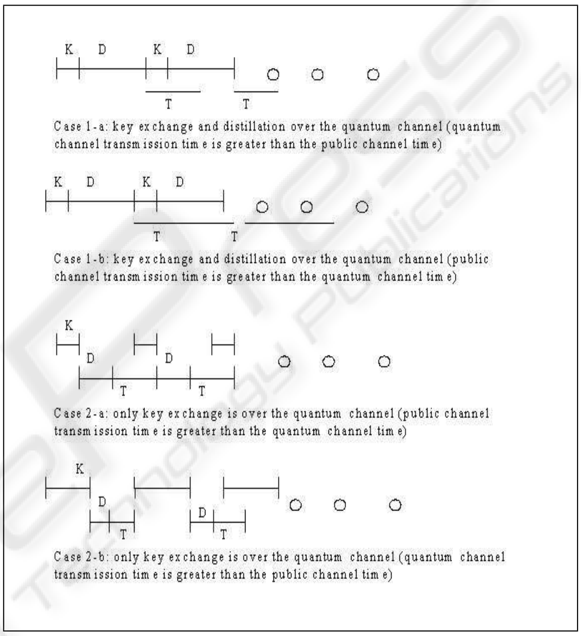

ISAKMP SA
1
2
Quantum Key Exchange
SA (use of O.T.P)
3
4
4'
IPsec with session key during a short period (until the end of the Quantum key exchange).
One-Time-Pad (O.T.P) function

Figure 3: Functioning of IPsec with Quantum Cryptography

In (4), we use traditional symmetric cryptography algorithms to exchange data. The IPsec packets are the same as without the use of quantum cryptography. The session key, therefore, is exchanged using quantum key exchange. The lifetime duration of the session key is very short and it is equal to the time needed to exchange the secret key using quantum cryptography. This solution is a transition solution to the (4')

In (4'), we use quantum cryptography concepts totally. The idea is to shift completely to the unconditional secure functions .i.e. quantum key exchange and one-time-pad function. After fixing the SA parameters, the "session" keys length will be of the size the data in the IPsec packet. Then, it is possible to use one-time-pad function (simply perform an XOR of the message and the key and then send the result). We need to exchange key for every packet. The weakness of this solution resides in the time needed to exchange the key. The total bit rate is highly affected due to this problem but as the quantum cryptography technology is progressing, this issue will soon be solved.

There are two possibilities. The first case is to exchange the key and distillation using the quantum channel (Time division multiplexing). The other is to exchange only the key over the quantum channel and all the other data over the public channel (Figure 4).



Case 1-a: key exchange and distillation over the quantum channel (quantum channel transmission time is greater than the public channel time)

Case 1-b: key exchange and distillation over the quantum channel (public channel transmission time is greater than the quantum channel time)

Case 2-a: only key exchange is over the quantum channel (public channel transmission time is greater than the quantum channel time)

Case 2-b: only key exchange is over the quantum channel (quantum channel transmission time is greater than the public channel time)

Figure 4: the two cases of using totally quantum cryptography in IPsec

K: the duration to exchange the quantum key
D: the duration of key distillation
T: the duration of transmitting the message

**1-first solution:**

In this case, we propose to use the quantum channel to exchange the key and for distillation. There are two possibilities: K+D is greater than T (K+D>T) and K+D is less or equal to T (K+D≤T).

The effectiveness ($\theta$) of this solution is given by ( $\theta$ represents the difference between the use of quantum cryptography and the use of unenciphered transmission):

*a- K+D > T*
If K+D>T then

$$\theta = \frac{T \times N}{(K+D) + T \times N + (N-1) \times ((K+D) - T)} \quad (1)$$

Where N is the number of packet.

$$\theta = \frac{T \times N}{(K+D) + T \times N - (N-1) \times T + (K+D) \times (N-1)} \tag{2}$$

Finally, after simplification:

$$\theta = \frac{T \times N}{T + (K+D) \times N} \tag{3}$$

If N is very large (infinite), $\theta$ is equal to:

$$\lim_{N \to \infty} \theta = \frac{T}{K+D} \tag{4}$$

**Example 1** *Traditionally, the size of MTU (Maximum Transmission Unit) is 1500 bytes (i.e. 12 Kbits); we suppose that the unprotected header size is 250 bytes, so we have to secure 1250 bytes i.e. 10 Kbits. Therefore, the key length will be 10Kbits if we want to use One-Time-Pad function. The flow rate to exchange the key is 1 MBit/s and about 100 MBit/s to exchange normal data on optical fiber. We suppose that we have an Internet connection of 1 Mbit/s. As the error rate for exchanging quantum key is normally 50%, we need to exchange 20 Kbits in order to get 10Kbits of key length. We estimate the distillation data to be 40 Kbits. The time to XOR data with the key is neglected.*

*Having the previous assumption:*
*K = 20/1000 = 0.02 s*
*D = 40/100000 = 0.0004 s*
*And T = 12/1000 = 0.012 s*

*In this case, K+D (20.4 ms) is greater than T (12 ms). The effectiveness $\theta$ when the number of packet N is infinite (4) is equal to 120/204 ˜60 % of the total performance.*

**NB:** if we have a faster Internet connection, say 10Mbit/s, the effectiveness $\theta$ given by (4) will be equal to 6 % of the total performance. In this case, the use of SeQKEIP is useless if we see only the performance. But, as the rate of quantum key exchange is progressing the effectiveness will increase.

*b- K+D$\leq$T*
If K+D$\leq$T then

$$\theta = \frac{T \times N}{(K+D) + T \times N} \tag{5}$$

if N is very large (infinite), $\theta$ is equal to:

$$\lim_{N \to \infty} \theta = \frac{T}{T} = 1 \tag{6}$$

So, in this case, there is no difference in the performance between using SeQKEIP and IP. The additional time cost induced by the use of quantum cryptography is negligible.

**2-second solution**

The quantum channel is used only to exchange the key. The distillation is done over the public channel. There are also two possibilities depending on the time needed to exchange the key and, on the other hand, the time to validate and send the message.

We take the same notation as previous:
K: the duration to exchange the quantum key
D: the duration of the key distillation
T: the duration of transmitting the message

So, we distinguish two scenarios: when K $>$ D+T and K $\leq$T+D.

*a- K $>$ D+T*
If K>T+D then

$$\theta = \frac{T \times N}{K + (T+D) \times N + (N-1) \times (K - (D+T))} \tag{7}$$

And, after simplification:

$$\theta = \frac{T \times N}{(T+D) + K \times N} \tag{8}$$

if N is very large (infinite), $\theta$ is equal to:

$$\lim_{N \to \infty} \theta = \frac{T}{K} \tag{9}$$

**Example 2** *We take the same parameters as in the "NB" the previous example (10 Mbit/s for the Internet connection, 1Mbit/s to exchange the quantum key). Having the previous assumption:*
*K = 20/1000 = 0.02 s*
*D = 40/10000 = 0.004 s*
*And T = 12/10000 = 0.0012 s*

*In this case, K (20 ms) is greater than T +V (42 ms). The effectiveness $\theta$ if the number of packet N is infinite (9) is equal to 12/200 = 6 % of the total performance.*

The flow rate configuration is the both solutions gives the same performance rate (6 %) of the whole performance. To upgrade this rate, the only solution is to have the K $\leq$T+D in this case and K+D $\leq$T in the previous solution.

*b- If K$\leq$T+D*
If K$\leq$T+D then

$$\theta = \frac{T \times N}{K + (T+D) \times N} \tag{10}$$

if N is very large (infinite), $\theta$ is equal to:

$$\lim_{N\to\infty} \theta = \frac{T}{T+D} \tag{11}$$

If we take the following configuration: the rate of quantum key exchange is 1Mbit/s and the Internet connection is 1Mbit/s, then T= 0.012 s and D = 0.04s. T+V is greater than K (0.02 s). So, the effectiveness $\theta$ if the number of packet N is infinite (11) is equal to 12/52 = 23 % of the total performance.

## 4 CONCLUSION

Classical cryptography algorithms are based on mathematical functions. The robustness of a given cryptosystem is based essentially on the secrecy of its (private) key and the difficulty with which the inverse of its one-way function(s) can be calculated. Unfortunately, there is no mathematical proof that will establish whether it is not possible to find the inverse of a given one-way function. On the contrary, quantum cryptography is a method for sharing secret keys, whose security can be formally demonstrated.

As we have seen, using quantum cryptography in conjonction with IPsec to offer a better level of security for organisations is possible. If, we apply the quantum key exchange and one-time-pad function, we reach the unconditional security in communication. The distillation of the quantum key could be done in two different ways: over the optical channel or over the public channel. The cost of installing this solution stills expensive nowadays. The performance obtained when distilling the key over the optical channel is higher than when using public channel (up to 100% when using optical channel versus 23% when using public channel). Actually, we can reach 100Kbit/s when exchanging the quantum key and hope to reach 1Mbit/s next few years. The possible flow rate over an optical fiber is 100Mb/s. If, we use an Internet connection of 1Mbit/s, we get 60% of the total performance (solution1, a) i.e. a flow rate of 600Kbit/s if the distillation of the key is done over the optical channel and we get only 23% of the total performance if we validate the key over the public channel (solution 2, b) i.e. a flow rate of 230Kbit/s. If we could reach the rate of 10Mbit/s in quantum key exchange and we use the first solution, we will get a performance of 100% in the flow rate i.e. 1Mbit/s.

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