A Computing Perspective towards Quantum Cryptography

In the continuous evolution process of the computer age, the next big step in security is being achieved by embracing quantum cryptography. As the unit of information shifts from the currently used ‘bit’ towards the ‘Qubit’ (Quantum bit), it offers a new realm of untapped features which can be used to ensure the confidentiality of the information being shared amongst participants. The confidentiality of the system is ensured by the use of a quantum channel for exchanging secret keys. These keys are then used to encrypt the data being shared. The system is a combination of cryptography and quantum computing which together are aided by the laws of Physics.

The term cryptography (also referred to as cryptology) meaning ‘Hidden/Secret Writing’ is a practice to enable secure communication. The basic principle of cryptography involves the two parties, that wish to communicate securely, agree upon a method to encrypt (encode) and decrypt (decode) the data as shown in Fig 1. Once a method is agreed upon, a secret key (also known as the encryption key) is shared between the parties using which the data is encrypted and decrypted. The strength of the encryption depends upon the method/algorithm used for encryption or decryption of data and the size of the secret key used to do so.

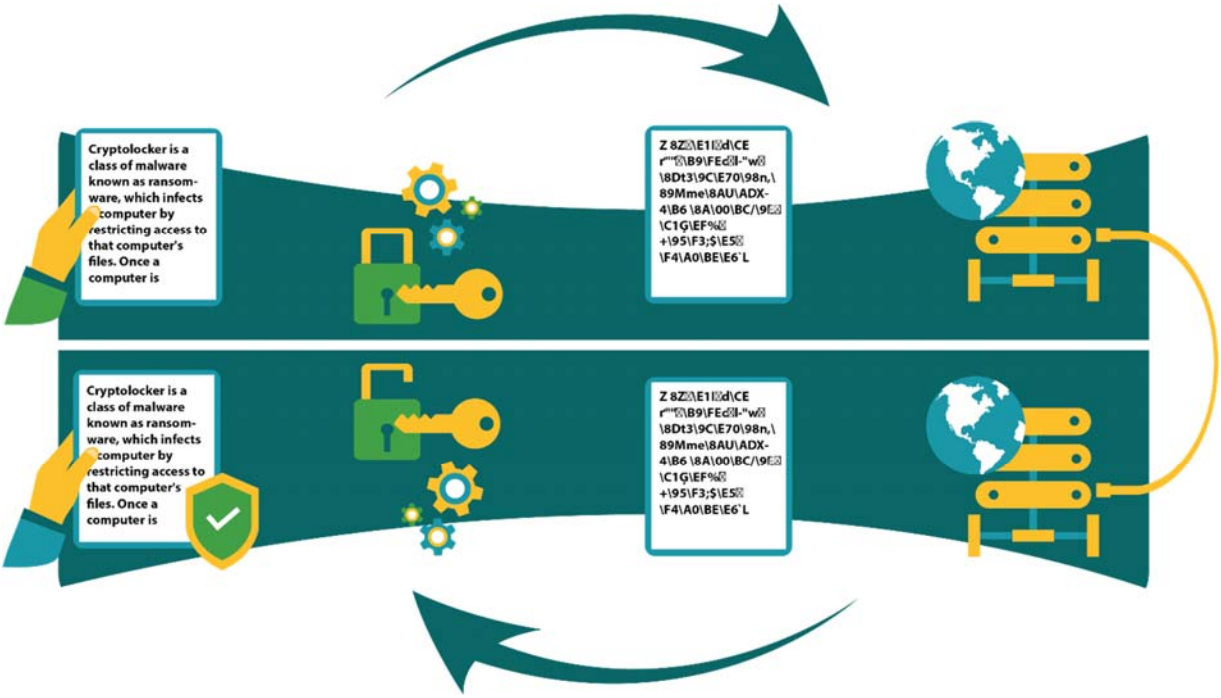

Fig. 1: Cryptography – The encryption and decryption process

What is Quantum Computing?

The history of computing starts with humans performing mathematical tasks by hand (using pen and paper) in order to get a result. The first big leap came with the use of mechanical calculators starting with a hand operated abacus in 2300 BC and culminating in the 18th Century with Charles Babbage's automatic difference and analytical engine. The next big leap came in the 19th Century with the introduction of digital computers which used bits (0's and 1's) and were deemed Turing-Complete (Being able to compute every Turing-Computable Function). Now we are taking another great leap with the introduction of quantum computers.

Quantum computers are based on quantum-mechanical principles, such as quantum superposition [9], quantum annealing [5,8] and quantum entanglement [10]. Hence, they use a much complex unit known as Qubit. A Qubit, in classic computer terminology, can have a value of 1 or 0 or any superposition of both 1 & 0 together as shown in Fig 2. In computational terms, it implies that a quantum computer can process several combinations of zeros and ones at the same time with very high speeds. Current quantum computers, can however, only implement quantum annealing [11] (a way to find an optimal solution for problems with multiple variables) which is essentially a subset of what a quantum computer can truly perform. Even so, a true quantum computer may just be around the corner as various tech giants race towards achieving the goal [4,6,7].

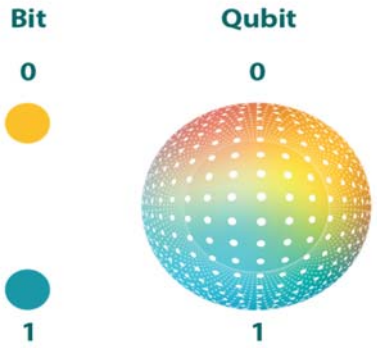

Fig. 2: Bit and Quantum Bit

Quantum Cryptography!

Quantum cryptography uses the quantum mechanical properties (as defined above) to perform cryptographic tasks in order to provide a fool-proof security system [2,3]. It constitutes of various applications, most of which require a true quantum computer and are currently theoretical. However, quantum key distribution (one of the applications) is currently achievable as it does not require any quantum computation and can be implemented using currently available lasers and fiber optics [1].

Quantum Key Distribution (QKD) can be used to securely share secret keys or encryption keys using Qubits over a quantum channel. This application is guaranteed by the laws of physics, especially the Hinesburg's Uncertainty principle which states that it is impossible to accurately calculate the location and speed of an atomic as calculating one aspect would change the other. It relies in the fact that if the precise location is calculated, the speed of the atomic particle would be changed in the process and a precise calculation of speed would result in a change of location.

How Quantum Key Distribution works

The security in QKD is achieved by providing totally secure key distribution technique as shown in Figure 3. For instance, if Jerry and Sue wish to exchange secret information, Jerry must initially create a secret key 'K_S' using random numbers as the seed value. The K_S can be of any desired bit length where the length of the key is directly proportional to the strength of encryption. Once created, K_S is then converted into Qubits which are then sent across the quantum channel. The quantum channel can be formed with any atomic particles that follow the laws of quantum physics like the currently implementable photons.

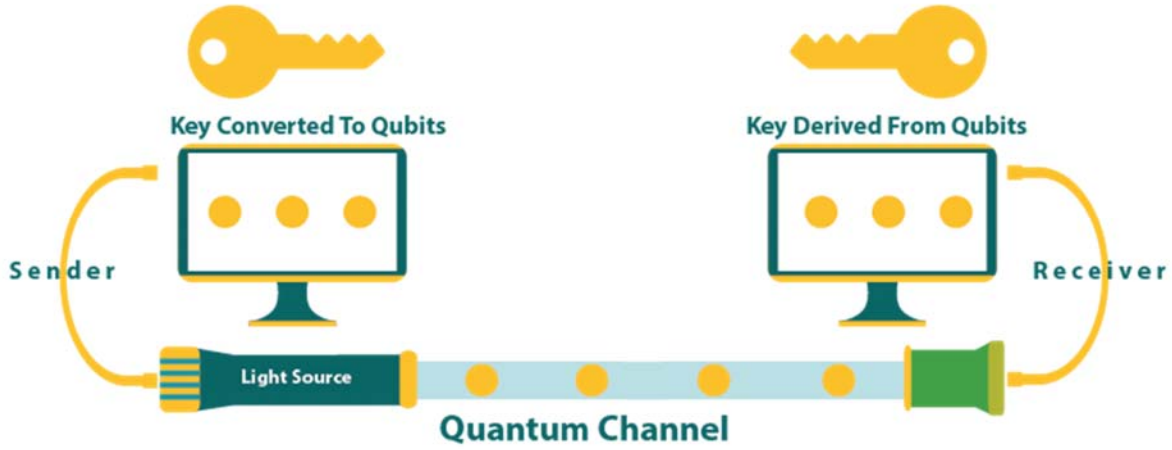

Fig. 3: Quantum Key Distribution

If an intruder, say Tom, were to intercept the quantum channel in order to eavesdrop/steal the secret key, Tom would unwillingly create errors or changes in the original state of the transmitted data as stated by Heisenberg's uncertainty principle as shown in Figure 4. These errors/changes can be detected by Sue in the form of transmission errors. Once the K_S is verified, it can be used through current encryption schemes to send and receive data securely over the public classical authenticated channel.

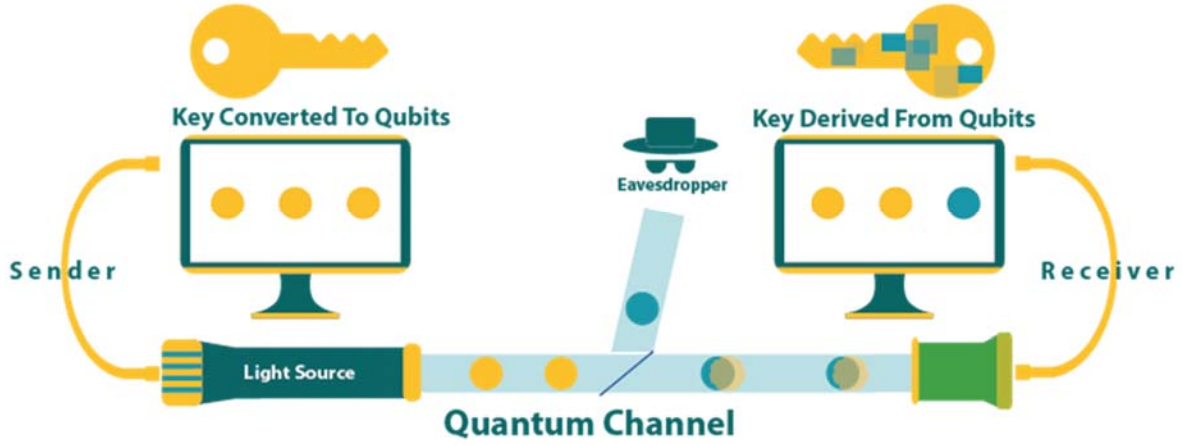

Fig. 4: Impact of eavesdropping on a quantum channel

In a scenario where Sue has detected transmission errors, the received secret key is dropped and Jerry is requested to start the process once again unless an un-tampered transmission is received. This however raises a concern when settling on a secret key as Tom might not give up on eavesdropping. In addition, a practical implementation cannot be perfect and may be influenced by various environmental disturbances (such as noise) causing transmission errors. In this particular case, secret-key distillation is used to make a new K_S. This is achieved by calculating the 'bit error rate' which can deduce the information that may be known to Tom. Hence, using the remaining bits of information, Jerry and Sue will be able to distill a new K_S.

Limitations of QKD

As pointed out above, the quantum key distribution technique can only ensure the security of the initial secret exchange. The actual strength of the security provided depends upon the length of the key and the complexity of the algorithm used [1]. Although QKD is tamper-proof, it can still be compromised if the process is not setup properly. The various aspects of QKD that must be followed are as below:

1. As QKD is not used for encryption and can only provide a safe distribution channel, the strength of the secret key used must be strong enough. In addition, the encryption/decryption algorithm used must also be impossible to break using current technology (excluding quantum computers that is).
2. The equipment used in order to send the secret must be setup properly. If the equipment itself causes major errors/changes in the transmission, Jerry and Sue will keep discarding the secret keys.
3. The people involved in the exchange, Jerry and Sue, must keep K_S safe in order to prevent Tom from impersonation one of them.
4. The seed value used to generate K_S should be truly random numbers (and not pseudo-random) to provide a true K_S.

Future of Quantum Cryptography!

At the moment, much of the quantum cryptography lies in theory as the equipment required is still under development or exists as a prototype yet to be named a true quantum computer. However, the introduction of true quantum computers will bring about a major change in the technological world by not only enabling other theoretical components of quantum cryptography but also begin a domino effect potentially taking the digital world into the next big leap.

Conclusion

Our current stand regarding quantum cryptography is only the beginning towards a new era. As true quantum computers render the legacy encryption systems useless, quantum cryptography can open the door towards an enhanced system which, unlike the current encryptions, are not protected by the complexity of mathematics but are bound by the laws of quantum physics.

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