BB84 Quantum Key Distribution Protocol

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*Abstract*—In this paper, we discuss one of the first Quantum Key Distribution Protocols, BB84 protocol proposed by Bennett and Brassard in 1984. Quantum Key Distribution is the mechanism of sharing a secret key among two parties that wish to encrypt their data using the shared secret key and encryption algorithms of their choice. BB84 uses both quantum channel and a public channel for communication of messages to agree upon a common key. We also discuss how an eavesdropper can be detected based on the no cloning theorem of the quantum mechanics and also focus on the various approaches for the last phase of the BB84 protocol called as the reconciliation phase which reduces the Quantum Bit Error Rate (QBER).

*Keywords—BB84, Quantum Key Distribution, QKD protocol, Quantum Bit Error Rate (QBER), Reconciliation phase, Qubit*

1. INTRODUCTION

With quantum technology becoming a reality, we need techniques that are secure against the quantum attacks. The cryptographical methods that are resistant to the quantum attacks are referred to as post-quantum or quantum-safe cryptography. BB84 is a quantum key distribution protocol which was coined by Charles Bennett and Gilles Brassard in the year 1984 and hence the name BB84. Quantum key distribution is a mechanism of sharing a private key among two parties using two channels for communication; an authenticated classical channel and a quantum channel.

We will use the classical cryptographical notation to represent the two parties Alice and Bob who want to communicate with each other privately, and an eavesdropper Eve tries to intercept their communication and read their messages.

1. BB84 Quantum key distribution Protocol

Without the knowledge of the key, it is difficult to break the encryption algorithm i.e., the data is safe as long as the key is kept safe and private. Quantum key distribution provides a mechanism to distribute the key among the two parties. It takes advantage of the quantum mechanics to ensure that the key being shared is not intercepted. Even if Eve tries to intercept the data, the scheme detects that the breach and discards the key and generates a new key.

In a Quantum key distribution mechanism, quantum channel and an authenticated classical channel are used for communication between Alice and Bob to generate a new private key. Both the channels are public and are subject to eavesdropping. The quantum channel is not used for any meaningful communication but is used to send random bits between users who do not share any kind of secret information initially. Based on the sequence of messages exchanged in the quantum channel and the ordinary classical channel, the end users come to an agreement for a shared private key. If an eavesdropper happens to measure the photons being exchanged in the quantum channel, then the original information that is transmitted by a user is disturbed based on No cloning theorem. There is a high probability to detect the eavesdropping in the quantum transmission. If eavesdropping is detected, then the current process of generating a key is stopped and the whole process is started again to generate a new key or they could choose to defer the process. After they agree upon a shared private key, they use it as a one-time pad to encrypt their communication or any other required cryptographic purposes which require secret communication.

Alice first generates a random bit string consisting of bits 0s and 1s. She generates another random sequence of bases, rectilinear (+) or diagonal (x) which is the same length as the random bit string. She encodes the generated random bit string using the random sequence of bases which generates photons in one of the four possible states. These photons represent one bit of string based on the generated basis. For a rectilinear basis, one is represented by 90-degree photon and zero is represented by a 0-degree photon. For a diagonal basis, one is represented by 135-degree photon and zero is represented by a 45-degree photon.

TABLE I. BASIS ENCODING

|  |  |  |
| --- | --- | --- |
| Basis | 0 | 1 |
| Rectilinear (+) | → | ↑ |
| Diagonal (x) | ↘ | ↗ |

Table I shows the encoding procedure for the bits based on the basis. Alice transmits these encoded photons to Bob over a quantum channel one by one and records the bit, basis and timestamp before transmission. At this point in time, Alice only shares the photons, but the generated bit sequence is private and only known to Alice. Alice records the timestamp to detect any delay in transmission which could be due to eavesdropping by Eve.

Bob receives the photons from Alice representing 1s or 0s based on their state represented by the arrows as shown in table 1. Bob also records the timestamps at which he receives the photons. It is also possible that there might be loss in information during the transmission due to imperfect detectors at the Bob’s end or a few photons could be lost in the channel during their transit. He generates new sequence of bases to measure each of the photons received from Alice. This sequence is random and independent of what the message received was. He then measures each of the received photons using the random sequence of bases. If the received photon is in rectilinear representation and the randomly generated basis is also rectilinear then the photon is measured in rectilinear as is. If the basis is diagonal, then either 45-degree or 135-degree photon is generated randomly with equal probability. But the received photon is in diagonal representation say 45-degree or 135-degree and the randomly generated basis happens to be a rectilinear basis then the photon is measured as a 0-degree or a 90-degree photon with an equal probability. The received photon is in diagonal representation and the randomly chosen basis is also diagonal basis then the photon is measured with the same value. The values measured correspond to a binary 0 or 1. Bob and Alice both have a sequence of bits they can compare and come to an agreement for a private key if no eavesdropping is detected. After measuring all the photons received Bob communicates with Alice to see which of his generated bases was right. Bob sends the measured information and timestamps to Alice over public ordinary channel subject to passive eavesdropping by Eve.

TABLE II. Measuring photon based on randomly generated basis at Bob’s end

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Bob’s basis | Received Alice’s transmitted photon | | | |
| → | ↑ | ↘ | ↗ |
| Rectilinear (+) | → | ↑ | → or ↑ | → or ↑ |
| Diagonal (x) | ↘ or ↗ | ↘ or ↗ | ↘ | ↗ |

Alice analyses the timestamps to check for unusual delay in the transmission. Alice based on the received photons, checks which of the random bases chosen by bob was the same as the bases chosen by her. Alice

Roughly on an average, more than half the bits produced at Bob’s end match the one’s generated at Alice’s end.

##### iii References

1. A. I. Nurhadi and N. R. Syambas, “Quantum Key Distribution (QKD) Protocols: A Survey,” 2018 4th International Conference on Wireless and Telematics (ICWT), 2018.

1. C. H. Bennett and G. Brassard, “Quantum cryptography: Public key distribution and coin tossing," in Proc. IEEE Int. Conf. Computers, Systems, and Signal Processing. Bangalore, India, December 10 -12,1984. pp. 175-179.
2. Y. Wang, H. Wang, Z. Li, and J. Huang, “Man-in-the-middle attack on BB84 protocol and its defence,” 2009 2nd IEEE International Conference on Computer Science and Information Technology, 2009.
3. F. Zamani and P. K. Verma, “A QKD protocol with a two-way quantum channel,” 2011 Fifth IEEE International Conference on Advanced Telecommunication Systems and Networks (ANTS), 2011.
4. S. Salemian and S. Mohammadnejad, “An error-free protocol for quantum entanglement distribution in long-distance quantum communication,” Chinese Science Bulletin, vol. 56, no. 7, pp. 618–625, 2011.
5. V. Padamvathi, B. V. Vardhan, and A. Krishna, “Quantum Cryptography and Quantum Key Distribution Protocols: A Survey,” 2016 IEEE 6th International Conference on Advanced Computing (IACC), 2016.
6. J. Bobrysheva and S. Zapechnikov, “Post-Quantum Security of Communication and Messaging Protocols: Achievements, Challenges and New Perspectives,” 2019 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (EIConRus), 2019.
7. A. I. Nurhadi and N. R. Syambas, “Quantum Key Distribution (QKD) Protocols: A Survey,” 2018 4th International Conference on Wireless and Telematics (ICWT), 2018.
8. A. Gabriel, B. Alese, A. Adetunmbi, and O. Adewale, “Post-Quantum Crystography: A combination of Post-Quantum Cryptography and Steganography,” 2013 IEEE Third International Conference on Information Science and Technology (ICIST), 2013.