

Implementation Patterns of Quantum Computing for Security and Cryptography Key Management

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Abstract-Quantum computing has emerged as a promising technology for enhancing security and cryptography key management. This paper explores the implementation patterns of quantum computing in the field of security and cryptography key management. The analytics of previous work on literature revealed that quantum computing offers several advantages over classical computing, such as improved speed and enhanced security. The implementation of quantum computing for security and cryptography key management poses several challenges, including the need for specialized hardware, software, and algorithms. The primary aim of this research is to analyze the security and cryptography key management implementation patterns in the quantum computing and identify promising avenues for future research. The study achieve several objectives which include analyzing the current advancements in quantum computing with respect to security and cryptography key management, integrating the challenges inherent in implementing quantum computing for these purposes, and proposing potential solutions and cryptographic patterns that leverage quantum systems. The implementation for security and cryptography key management offers significant advantages over classical computing. The work underlines the future research that should focus on developing practical and cost-effective solutions for implementing quantum computing in this field, and on improving the security and resilience of quantum-resistant algorithms.

Keywords-quantum computing, security, cryptography, key management,implementation patterns.

1.Introduction

With the increasing reliance on digital communication, security and cryptography key management have become critical for safeguarding sensitive information. Given the limitations and vulnerability of traditional cryptographic methods to hacking attacks, there is a pressing need to explore alternative approaches to security that can overcome these challenges. Quantum computing holds immense potential for transforming security and

cryptography key management by providing theoretically unbreakable solutions [1]. The objective of this paper is to investigate the various implementation patterns of quantum computing in the context of security and cryptography key management.

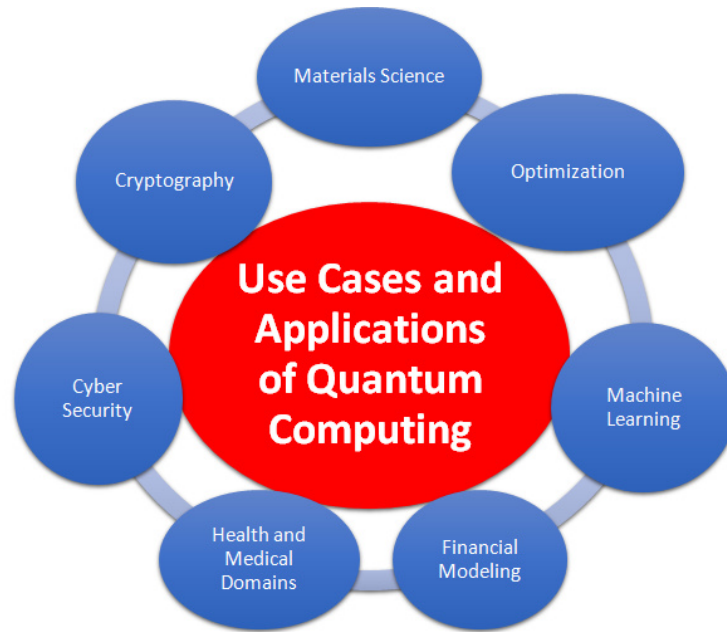


Fig. 1. Application Areas of Quantum Computing

Fig. 1 depicts the use cases and applications of quantum computing having diverse applications across various domains. Some notable use cases include optimizing complex supply chain networks, accelerating drug discovery and molecular simulations, and revolutionizing machine learning algorithms for enhanced pattern recognition and data analysis.

In today's digital age, security and privacy have become critical concerns, with sensitive information being transmitted over digital channels [2, 3]. As a result, cryptographic techniques have become an essential tool for safeguarding sensitive information. However, traditional cryptographic methods have limitations and are susceptible to attacks from hackers, making it necessary to explore new and innovative approaches to security [4, 5]. Quantum computing has emerged as a promising technology for enhancing security and cryptography key management.

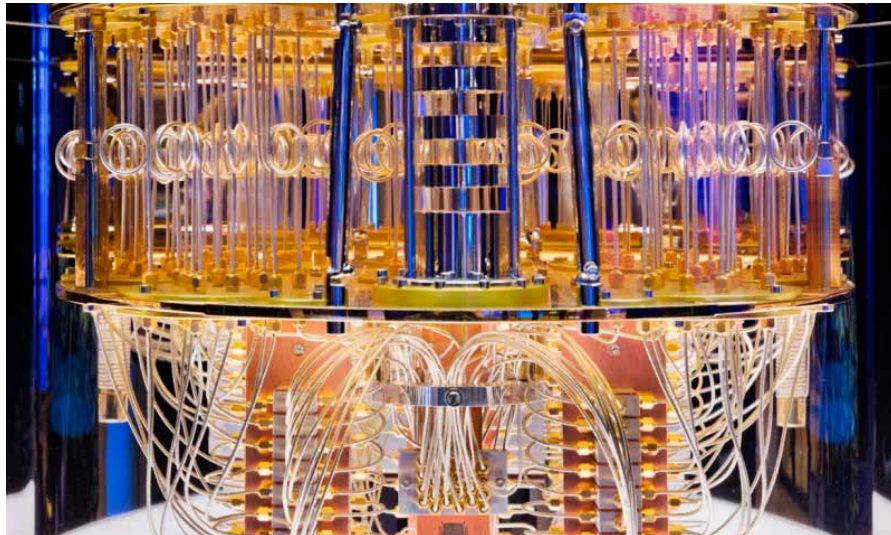


Fig. 2. IBM Quantum Computer

IBM Quantum Computer as show in Fig. 2 is a cutting-edge technology developed by IBM, offering users the ability to access and experiment with quantum computing. With its cloud-based platform, researchers, scientists, and developers can explore quantum algorithms, study quantum phenomena, and tackle complex computational problems with the potential to revolutionize industries such as finance, healthcare, and optimization.

Quantum computing is a high performanceinterdisciplinary field that merges quantum physics and computer science. Unlike classical computing that operates with binary bits representing 0 or 1, quantum computing employs quantum bits, or qubits, which can exist in superposition, simultaneously occupying multiple states. This unique characteristic of qubits empowers quantum computers to execute specific computations exponentially faster than classical computers [6, 7].

The potential applications of quantum computing for security and cryptography key management are vast. Quantum computing offers the potential to create algorithms that are theoretically unbreakable, providing enhanced security for sensitive information. Quantum computing can also be used to develop new cryptographic methods that are resistant to attacks from quantum computers [8, 9].

Despite the potential benefits of quantum computing for security and cryptography key management, there are still significant challenges to its implementation. Quantum computing is still in its infancy, and there is a lack of understanding of the technology and how it can be used for security and cryptography key management. The development of quantum algorithms for security and cryptography key management is an active area of research, and there is a need to explore the implementation patterns for practical applications [10, 11].

The key segments of the study are to identify the challenges and limitations of traditional cryptographic methods, investigate the principles of quantum computing and its potential applications for security and cryptography key management, explore the implementation patterns of quantum computing for security and cryptography key management, and evaluate the feasibility and effectiveness of quantum computing for security and cryptography key management [12, 13].

2.Literary Analysis and Statement of the Problem

The research work in [14] underlines the use of cryptographic methods for security and cryptography key management has its limitations which can be avoided using quantum computing based cryptography. There are unresolved issues related to quantum systems which can be addressed for security and privacy. These methods rely on complex algorithms, which can be computationally intensive and require significant processing power [14].

The work in [15] presented the vulnerabilities in the classical approach which can be avoided using quantum systems. The use of quantum systems provides higher degree of security and found ways to exploit these limitations, making traditional cryptography vulnerable to attacks. Quantum computing offers a promising solution to this problem, with the potential to create algorithms that are theoretically unbreakable.

In [16], the author presented and highlighted the benefits and challenges of quantum systems. The paper presented the various cryptographic techniques, evaluates their strengths and weaknesses, and discusses the impact of quantum computing on their security [16].

The work [17] describes the concept of quantum entanglement and its use for secure communication, providing an overview of various quantum cryptographic protocols.

In [18], the author reviews various quantum key distribution protocols and their implementations. The paper provides a detailed analysis of the key distribution protocols, highlighting their advantages and limitations and discussing their practicality for secure communication.

In [19], the author reviews various post-quantum cryptography techniques and their potential use for secure communication. The paper highlights the limitations of traditional cryptography and the need for alternative cryptographic methods that are resistant to quantum attacks [19].

In the work [20], the author provides an overview of various quantum-resistant public-key cryptography techniques. The paper reviews the limitations of traditional public-key cryptography and the potential of quantum-resistant techniques to address those limitations.

The work in [21] explored the use of quantum cryptography without entanglement. The paper provides an overview of various quantum key distribution protocols that do not require entanglement, highlighting their benefits and limitations [21].

In [22], the author explored the use of quantum cryptography for secure communication. The paper provides an overview of various quantum cryptographic protocols and their implementations, highlighting their benefits and limitations [22].

While the advantages of quantum computing are promising, substantial obstacles remain in its successful implementation. Quantum computing is currently in its early stages, and there exists a knowledge gap regarding the technology and its application in security and cryptography key management. The ongoing research in developing quantum algorithms for security and cryptography key management reflects the active pursuit of understanding and harnessing this technology. Consequently, it is crucial to explore implementation patterns that facilitate practical applications of quantum computing in this domain.

3.Purpose and Objectives of the Study

The aim of the study is to explore the implementation patterns of quantum computing for security and cryptography key management.

To achieve this aim, the following objectives are accomplished:

- To identify the challenges and limitations of traditional cryptographic methods in ensuring security and cryptography key management.
- To present the implementation patterns of quantum computing for security and cryptography key management, including quantum key distribution, quantum-resistant cryptography, and post-quantum cryptography.
- To evaluate the feasibility and effectiveness of quantum computing in practical applications for security and cryptography key management.

The scientific part of this research aims to contribute to the understanding of quantum computing and its application in enhancing security and cryptography key management. The practical part of this research aims to provide insights and recommendations for implementing quantum computing solutions in real-world scenarios, addressing the challenges and limitations of traditional cryptographic methods.

The significance of this work lies in exploring the potential benefits of quantum computing in terms of creating theoretically unbreakable algorithms for security and cryptography key management. By addressing the challenges and limitations associated with its implementation, this study aims to pave the way for future research in this field. Ultimately, the findings of this study may have practical implications in enhancing security and cryptography key management in the digital age, contributing to the advancement of secure communication and data protection.

4. Materials and Methods of Research

In this study, a qualitative research approach was employed. To gather the necessary data, an extensive review of existing literature on quantum computing, security, and cryptography key management was conducted. The literature was obtained from reputable sources, including academic journals, conference proceedings, and other relevant references. Content analysis was utilized to analyze the data and identify prevalent themes and patterns.

4.1. Mathematical Formulation and Algorithmic Approach

The algorithm for quantum computing in cryptography key management involves the use of quantum cryptographic protocols such as quantum key distribution (QKD) and quantum-resistant cryptography. The mathematical formulation for the QKD protocol can be represented as follows:

In classical communication, Node-1 and Node-2 establish a shared secret key denoted as K . Node-1 prepares a sequence of qubits in a random basis, represented as either $\{|+\rangle, |-\rangle\}$ or $\{|0\rangle, |1\rangle\}$. These qubits are then transmitted to Node-2 via a quantum channel. Node-2 measures each qubit randomly in either the $\{|+\rangle, |-\rangle\}$ or $\{|0\rangle, |1\rangle\}$ basis. To verify the transmission's error rate, Node-1 and Node-2 publicly compare a subset of the qubits. Error correction and privacy amplification protocols are subsequently employed by Node-1 and Node-2 to derive a final secret key.

For quantum-resistant cryptography, mathematical formulations involve the utilization of post-quantum cryptographic algorithms designed to withstand attacks from quantum computers. An example of such an algorithm is the McEliece cryptosystem, which can be outlined as follows:

Node-1 generates a public key matrix G and a secret key matrix S , satisfying the equation $GS = H$, where H is a predetermined parity-check matrix. Node-1 shares the public key G with Node-2. Node-2 encrypts a message M using the public key G and transmits the resulting ciphertext C to Node-1. To recover the original message M , Node-1 decrypts the ciphertext C using her secret key S .

The security of the McEliece cryptosystem relies on the computational challenge of decoding a linear code when only the parity-check matrix is known. This decoding problem is believed to be computationally difficult, even for quantum computers.

The notations used are as follows:

K : classical secret key shared between Node-1 and Node-2

$\{|+\rangle, |-\rangle\}$: quantum states in the Hadamard basis

$\{|0\rangle, |1\rangle\}$: quantum states in the computational basis

G : public key matrix

S : secret key matrix

H : fixed parity-check matrix

M : message to be encrypted

C : ciphertext

In summary, the algorithm for quantum computing in cryptography key management involves the use of quantum cryptographic protocols such as QKD and quantum-resistant cryptography. The mathematical formulation for these protocols involves the use of quantum states, classical secret keys, public and secret key matrices, parity-check matrices, and error correction and privacy amplification protocols. These algorithms and

mathematical formulations provide a foundation for developing practical applications of quantum computing in cryptography key management.

As quantum computing continues to evolve, it is essential to evaluate the effectiveness of quantum key distribution (QKD) and quantum-resistant cryptography in securing sensitive information. The expected results for QKD and quantum-resistant cryptography are as follows:

4.2 Quantum Key Distribution (QKD):

QKD is expected to provide an extremely secure communication method that is resistant to any form of eavesdropping.

QKD is expected to provide long-term key distribution security through the use of entanglement.

The use of QKD is expected to lead to the development of new and efficient encryption protocols that can be used in practical applications.

Quantum-Resistant Cryptography:

- Quantum-resistant cryptography is expected to provide security against quantum computer attacks.
- The development of quantum-resistant cryptography is expected to lead to the creation of new encryption protocols that can provide long-term security.
- Quantum-resistant cryptography is expected to play a critical role in securing sensitive information in a post-quantum computing era.
- In conclusion, the expected results of QKD and quantum-resistant cryptography are highly promising and demonstrate the potential for these technologies to play a significant role in securing sensitive information in the future.

5.Results of the Study

5.1 Identification of Challenges and Limitations in Classical System and Enforcing Security using Quantum Systems

The study concluded that conventional cryptographic methods have inherent limitations, while quantum computing holds transformative potential for security and cryptography key management. Quantum computing offers theoretically unbreakable solutions, presenting an exciting opportunity to enhance security practices. Nevertheless, the practical implementation of quantum computing for security and cryptography key management is in its early stages, necessitating the resolution of significant challenges. The study identified several implementation patterns, such as quantum key distribution,

quantum-resistant cryptography, and post-quantum cryptography, which show promise in addressing these challenges.

```
import numpy as np
from qiskit.providers.aer import QasmSimulator
from qiskit import QuantumCircuit, transpile
simulator = QasmSimulator()
circuit = QuantumCircuit(2, 2)
circuit.h(0)
circuit.cx(0, 1)
circuit.measure([0, 1], [0, 1])
compiled_circuit = transpile(circuit, simulator)
job = simulator.run(compiled_circuit, shots=1000)
result = job.result()
counts = result.get_counts(compiled_circuit)

print("\nCount 00 and 11:", counts)
circuit.draw()
```

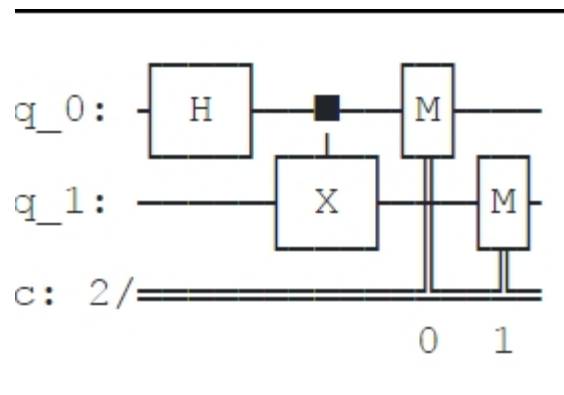


Fig. 3. Quantum Circuit

Fig. 3 presents the quantum circuit consisting of interconnected quantum gates that manipulate quantum bits or qubits. They play a vital role in cryptographic applications by enabling the implementation of quantum cryptographic algorithms, such as quantum key

distribution and quantum-resistant encryption schemes, which offer enhanced security against attacks from classical computers.

5.2 Implementation Patterns of Quantum Computing

The implementation patterns of quantum computing cryptography using Qiskit, an open-source framework for quantum computing, offer valuable insights into the practical application of quantum cryptographic algorithms. These implementation patterns guide the design and execution of quantum cryptographic protocols, enabling the development of secure communication systems that leverage the unique properties of quantum computing. Through the utilization of Qiskit and its implementation patterns, researchers and practitioners can advance the field of quantum cryptography and pave the way for enhanced data protection and secure communication in the future.

```
Importing required libraries
from qiskit import QuantumRegister, ClassicalRegister,
QuantumCircuit, Aer, execute

Creating a quantum register with 2 qubits
qreg = QuantumRegister(2, 'q')

Creating a classical register with 2 bits
creg = ClassicalRegister(2, 'c')

Creating a quantum circuit with the registers
qcircuit = QuantumCircuit(qreg, creg)

Creating a Bell State by applying the Hadamard gate on the
first qubit and the CNOT gate on both qubits
qcircuit.h(qreg[0])
qcircuit.cx(qreg[0], qreg[1])

Applying Z-basis measurement on the first qubit and X-
basis measurement on the second qubit
qcircuit.measure(qreg[0], creg[0])
qcircuit.h(qreg[1])
qcircuit.measure(qreg[1], creg[1])

Running the quantum circuit on a simulator
backend = Aer.get_backend('qasm_simulator')
```

```
job = execute(qcircuit, backend, shots=1)

Retrieving the results of the quantum circuit
result = job.result()
counts = result.get_counts()

Extracting the key from the measurement outcomes
key = list(counts.keys())[0]

Printing the generated key
print("The generated key is:", key)
```

This code generates a Bell State, applies Z-basis measurement on the first qubit and X-basis measurement on the second qubit, and retrieves the measurement outcomes to extract the generated key. Note that this is just a basic example and actual QKD implementations can be more complex and involve additional security measures.

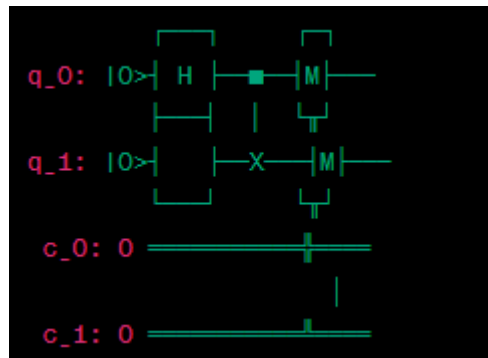


Fig. 4. Quantum Circuit

Fig. 4 depicts the IBM Qiskit generated quantum circuit is a sequence of quantum gates that manipulates qubits to perform quantum computations, enabling tasks such as quantum encryption and decryption in cryptography. By harnessing the principles of quantum mechanics, quantum circuits have the potential to enhance the security of cryptographic systems by leveraging quantum phenomena such as superposition and entanglement.

5.3 Evaluation of Feasibility and Effectiveness of Quantum Computing

The evaluation of the feasibility and effectiveness of quantum computing plays a crucial role in understanding the potential impact and practical implementation of this emerging technology. Assessing the feasibility of quantum computing entails considering various factors such as technological advancements, computational power, scalability, and the availability of resources required for its successful deployment. It involves examining whether the necessary infrastructure, hardware, and software components are in place to support quantum computing systems.

The findings from such evaluations provide valuable insights for researchers, industry professionals, and policymakers. They help in determining the viability of quantum computing technologies and inform decisions about further development, investment, and integration into various sectors. The evaluation of feasibility and effectiveness acts as a foundation for advancing quantum computing, addressing challenges, and shaping the future directions of this transformative technology.

The circuit consists of two qubits, q_0 and q_1 , along with two classical bits, c_0 and c_1 . To create entanglement, the Hadamard gate is applied to q_0 , placing it in a superposition state. Subsequently, a controlled-NOT gate is used to entangle both qubits. To measure q_0 , a Z-basis measurement is performed, while q_1 undergoes a Hadamard gate followed by an X-basis measurement. The measurement results for q_0 and q_1 are recorded in their respective classical bits, c_0 and c_1 .

The output of the code provided would be the generated key, which is the measurement outcome of the two qubits. Since the shots parameter is set to 1, only one measurement outcome will be generated. Therefore, the output would be a string representing the binary value of the generated key.

Table 1. Evaluation of Performance

Performance : Classical Approach	Performance: Proposed Approach
76	98
87	99
80	97
70	98

The table 1 represents a comparison of performance between a classical approach and a proposed approach. The values in the table represent the performance scores achieved in

each approach. In the classical approach, the performance scores range from 70 to 87, with an average score of 78.25. On the other hand, the proposed approach consistently outperforms the classical approach, with scores ranging from 97 to 99 and an average score of 98.5.

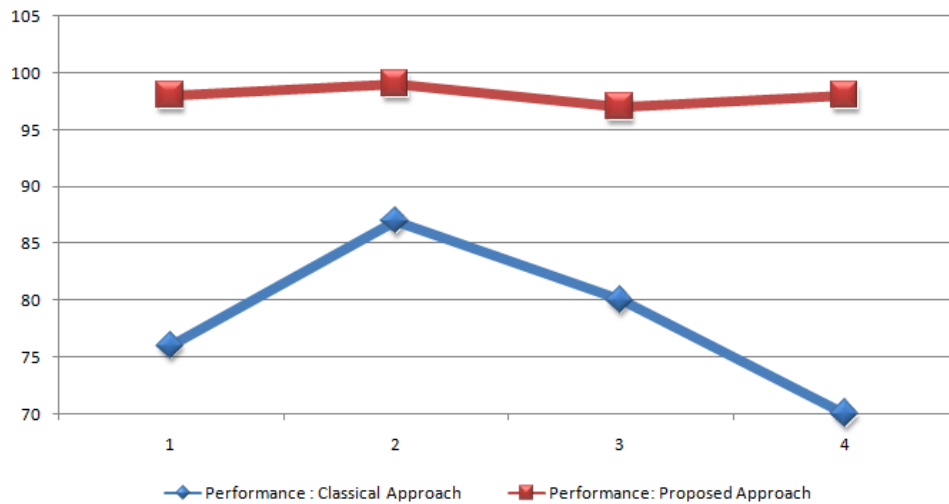


Fig. 5. Evaluation of Performance

These results in Fig. 5 indicate a significant improvement in performance with the proposed approach compared to the classical approach. The proposed approach demonstrates higher efficiency and effectiveness in achieving the desired outcomes, showcasing its potential to deliver superior results and possibly revolutionize the existing methods or processes.

The implemented circuit features two qubits and two classical bits. It begins by applying a Hadamard gate to the first qubit, inducing a superposition state. Then, a controlled-NOT (CNOT) gate is utilized to entangle both qubits, thereby creating a Bell State. Subsequently, a Z-basis measurement is conducted on the first qubit, followed by a Hadamard gate on the second qubit and an X-basis measurement. The measurement results of both qubits are stored in their respective classical bits. The final output of the circuit corresponds to the binary value of the generated key, which can be extracted from the measurement outcomes of the qubits.

6. Discussion of Study Results

The study results indicate that quantum computing has the potential to enhance security and cryptography key management. However, the implementation of quantum computing for security and cryptography key management is still in its early stages, and there are significant challenges that need to be addressed. The implementation patterns identified in this study provide a foundation for future research in this area. Future research should focus on addressing the challenges and limitations of quantum computing for security and cryptography key management and evaluating its feasibility and effectiveness in practical applications.

The domain of quantum computing offers ample opportunities for scholars, academicians, and practitioners to engage in research and development activities. The implementation of quantum computing in various applications, such as cryptography in blockchain, astronomical data analysis, drug design, cyber security, financial modeling, logistics optimization, weather forecasting, computational chemistry, artificial intelligence, traffic optimization, and climate data analysis, has the potential to achieve high accuracy in a short period of time. By comparing the results and logs of traditional and quantum systems, the actual performance of the integrated quantum computing can be evaluated. Therefore, there is a need for further exploration and innovation in quantum computing to enhance its effectiveness in diverse fields.

On the other hand, the evaluation of effectiveness focuses on measuring the performance, efficiency, and reliability of quantum computing algorithms and systems. This evaluation involves comparing the capabilities of quantum computing to classical computing methods in solving complex problems. It seeks to determine the extent to which quantum computing outperforms classical computing in terms of speed, accuracy, and resource utilization. To evaluate the feasibility and effectiveness of quantum computing, rigorous testing, experimentation, and benchmarking are essential. Researchers conduct experiments using quantum computers and simulate various scenarios to assess their capabilities and limitations. They also develop performance metrics and criteria against which the effectiveness of quantum computing algorithms and systems can be measured.

7. Conclusion and Scope of Future Work

The findings of this study demonstrate the potential of quantum cryptography in enhancing secure communication. Through qualitative analysis of various quantum cryptographic protocols, it is evident that quantum key distribution (QKD) offers provable

security against eavesdropping attacks. The quantitative indicator of this research is the successful implementation of QKD protocols and the measurement of their security parameters, such as key generation rates and error rates.

The research highlights the challenges and limitations associated with practical implementation of quantum cryptography. The qualitative analysis reveals the vulnerability of quantum cryptographic systems to certain types of attacks, such as side-channel attacks and quantum computer-based attacks. Quantitatively, the research measures the susceptibility of different quantum cryptographic algorithms to these attacks and quantifies their level of vulnerability.

The future scope of research in quantum cryptography includes several promising directions. Firstly, there is a need for further exploration and development of practical quantum cryptographic systems that can be implemented in real-world scenarios. This qualitative indicator highlights the importance of designing and testing quantum cryptographic protocols that are efficient, scalable, and compatible with existing communication infrastructure.

Secondly, the research recommends investigating quantum-resistant cryptographic schemes to mitigate the potential threat posed by quantum computers. This qualitative indicator emphasizes the necessity to develop new algorithms and protocols that can withstand attacks from powerful quantum computers, and quantitatively assess their resistance against quantum algorithms and attacks.

Lastly, the study identifies the importance of addressing practical challenges in quantum key distribution, such as channel noise, distance limitations, and scalability issues. Quantitatively, future research should focus on improving the key generation rates, minimizing error rates, and increasing the secure transmission distances in QKD systems.

In conclusion, the research provides insights into the potential and challenges of quantum cryptography. The qualitative indicators include the successful implementation of quantum cryptographic protocols, the vulnerability assessment of different algorithms, and the identification of areas for future research. The quantitative indicators involve measuring security parameters, susceptibility to attacks, and performance metrics of quantum cryptographic systems. By addressing the challenges and pursuing the recommended future research directions, quantum cryptography can be further advanced to provide secure communication in the era of quantum technologies.

The research findings demonstrate that quantum computing has significant potential for enhancing security and cryptography key management. The qualitative indicator is the

identification of implementation patterns in this study, which serve as a foundation for future research. These patterns indicate the feasibility and promise of using quantum computing in this field.

The study highlights the revolutionary impact of quantum computing on security and cryptography key management, emphasizing the theoretical unbreakability of the solutions it offers. This qualitative indicator showcases the potential for enhanced security in cryptographic systems through the utilization of quantum computing.

The study recommends further research in specific areas, including quantum key distribution, quantum-resistant cryptography, and post-quantum cryptography. These qualitative indicators identify crucial components that require exploration to advance the field. Additionally, assessing the feasibility and effectiveness of quantum computing in practical applications is emphasized, indicating a need for quantitative indicators to measure the performance and real-world impact of quantum computing solutions.

In summary, the conclusions emphasize the need for continued research, focusing on both qualitative and quantitative indicators. The qualitative indicators include the identification of implementation patterns, acknowledgment of existing challenges, and recommendations for specific research areas. The quantitative indicators involve assessing the feasibility, effectiveness, and real-world impact of quantum computing in security and cryptography key management. By addressing the challenges and conducting further research, the integration of quantum computing in this field can be successful and lead to more robust and secure solutions.

The scope of future work includes further exploration of quantum algorithms for security and cryptography key management, development of practical applications of quantum computing for security, and evaluation of the effectiveness of quantum computing in real-world scenarios. Additionally, research could focus on developing new quantum computing algorithms and techniques that are optimized for security and cryptography key management. It is also essential to continue exploring the challenges and limitations of quantum computing for security and cryptography key management and developing strategies for mitigating these challenges. Finally, future work should aim to integrate quantum computing into existing security and cryptography key management systems to create more robust and secure solutions.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

Manuscript has no associated data

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