QUANTUM COMPUTING AND THE FUTURE OF CYBER SECURITY

SIB5100 Information Security and Management

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21501035

Agenda

I. Introduction

II. PQC Algorithms

III. Conclusions

IV. References

V. Q & A

Introduction - Terms and Abbreviations

Kısaltma	Açılımı
PQC	Post-Quantum Cryptography
HSM	Hardware Security Module
KMS	Key Management System
XMSS	Extended Merkle Signature System
LMS	Leighton-Micali Signatures
ML-KEM	Module-Lattice-Based Key-Encapsulation Mechanism Standard
ML-DSA	Module-Lattice-Based Digital Signature Standard
SLH-DSA	Stateless Hash-Based Digital Signature Standard

TABLE I

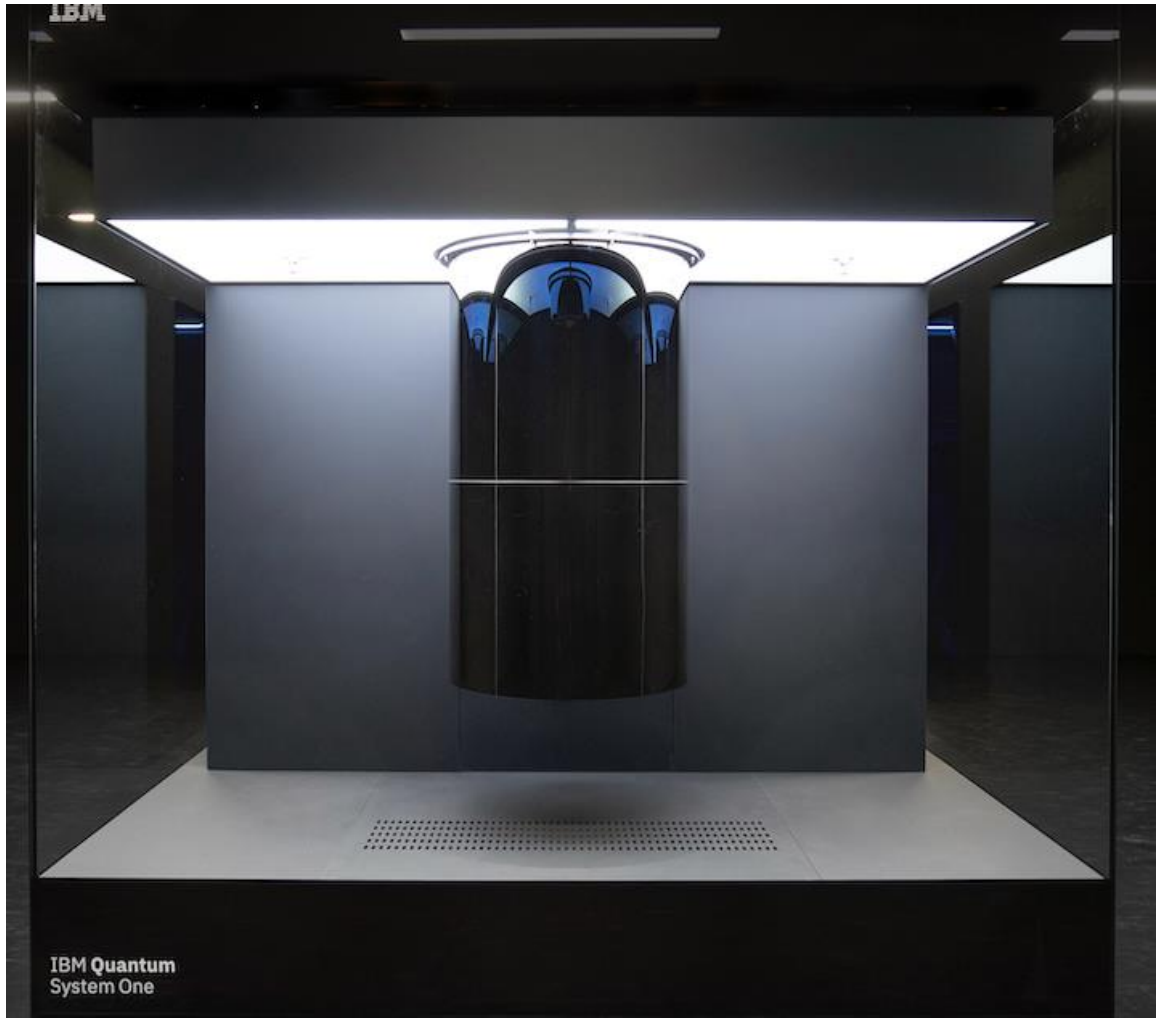
KULLANILAN KISALTMALAR LISTESI

Introduction - Terms and Abbreviations

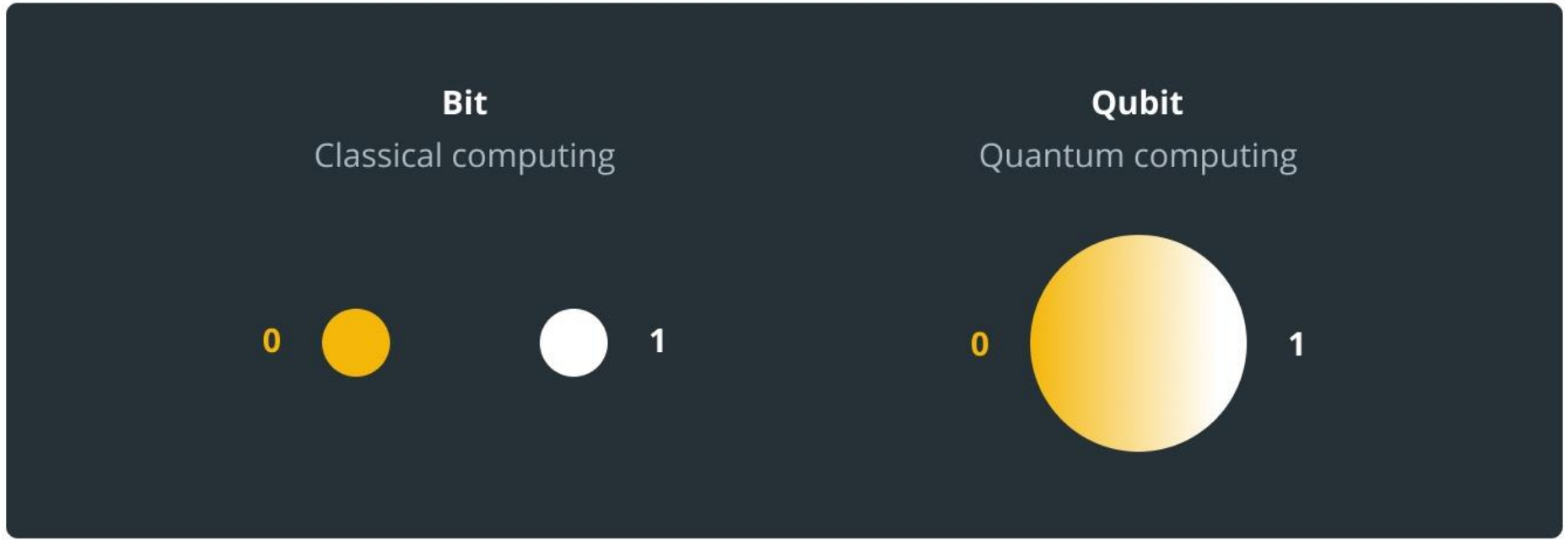
İngilizce Terim	Türkçe Karşılığı
Entangled quantum objects	Dolanık kuantum nesneleri
Quantum bits	Kuantum bitleri
Qubits	Kübitler
Superposition	Üst üste binme
Entanglement	Dolanıklık
Vulnerable Algorithms	Güvenlik Açığı Bulunan Algoritmalar

TABLE II
KULLANILAN TERIMLER LISTESI

Introduction - What is a quantum computer?



Introduction - What is a qubit?



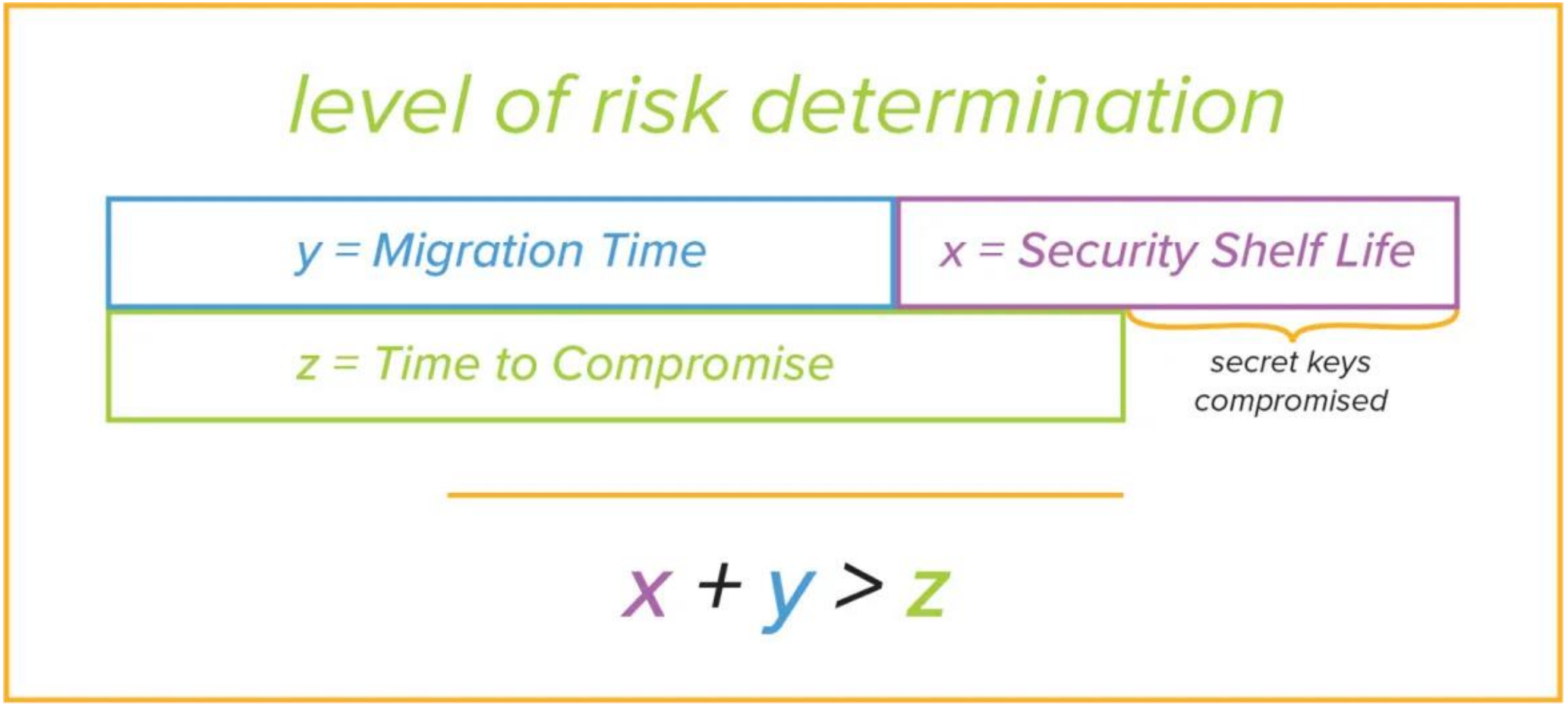
Source: https://cointelegraph.com/learn/articles/post-quantum-threats-to-proof-of-work-cryptocurrencies

Introduction - After quantum computer?

Güvenliği sorgulanacak olan sektörler:

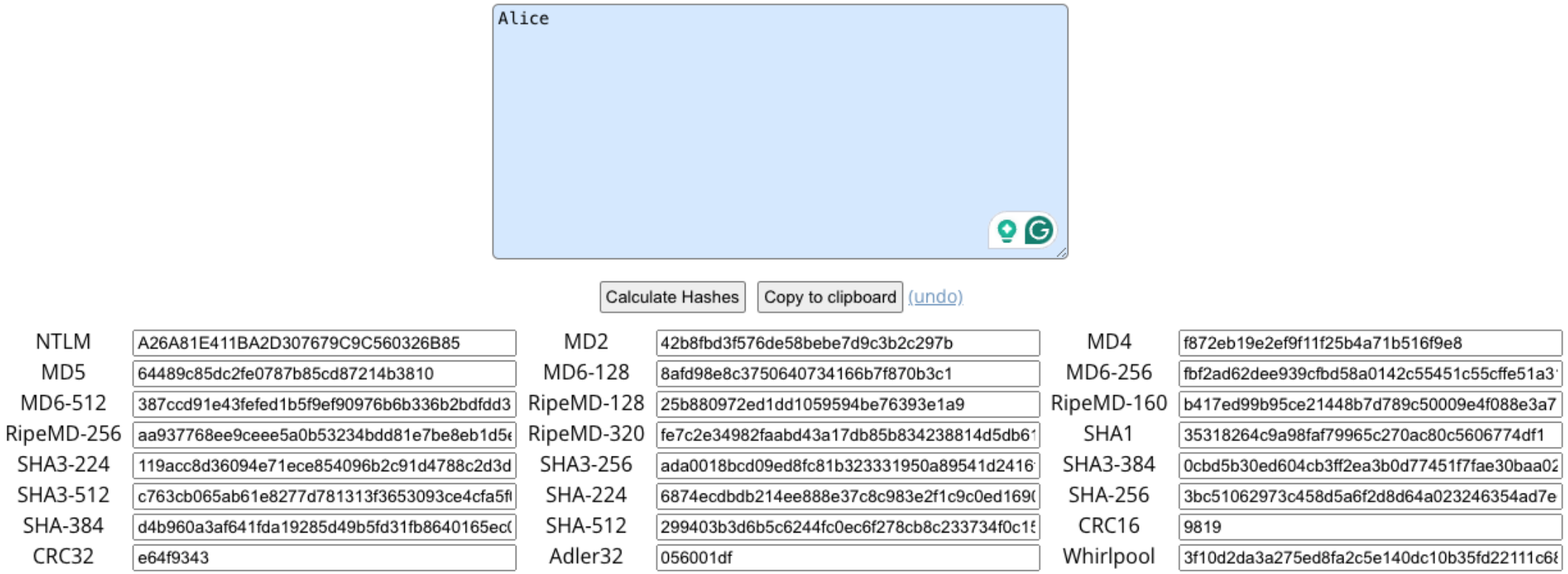
- Crypto Currencies (PoW)
  - Elliptic Curve Digital Signature Algorithm (ECDSA) -> Schor's algorithm
  - Cryptographic hash functions (SHA-256) -> Grover's algorithm
    - Mitigation SHA-256 to SHA-512
- Entire Internet Infrastructure
- Telecommunication
- ….

Introduction - Mosca's Theorem

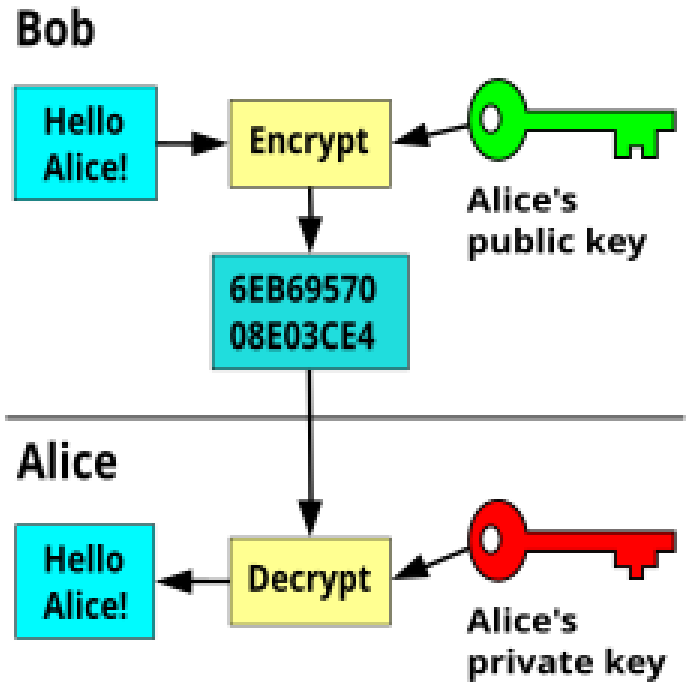


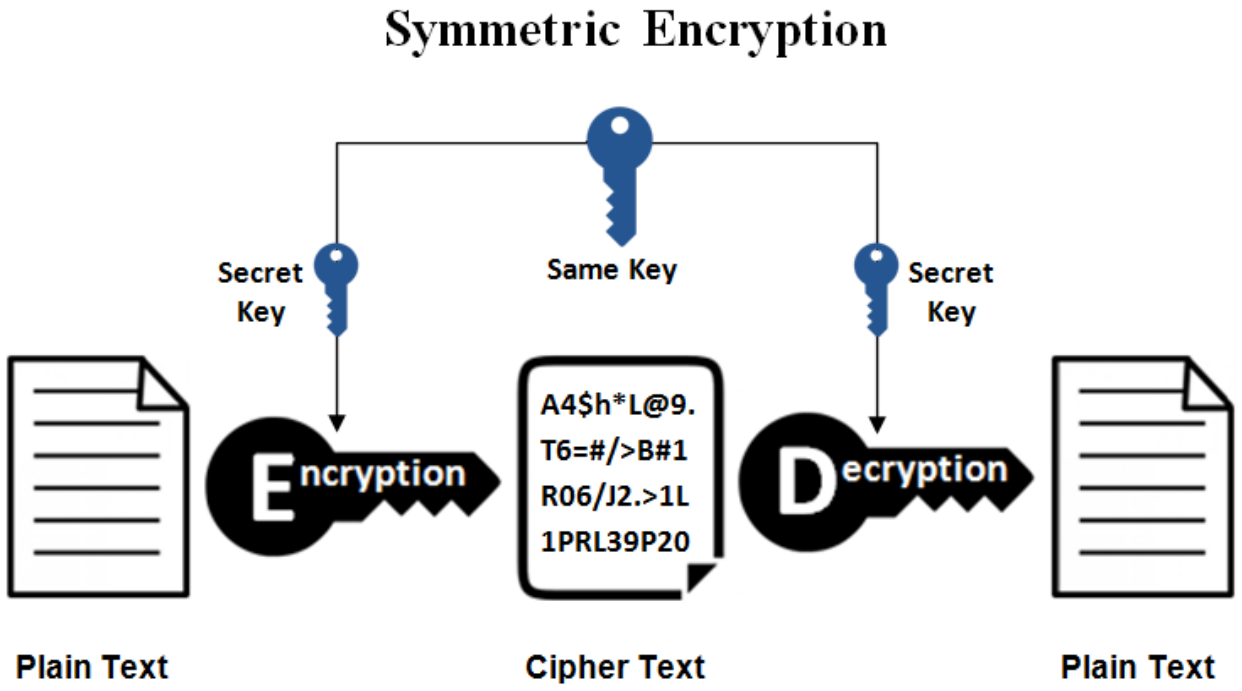
Source: https://www.redhat.com/en/blog/post-quantum-cryptography-introduction

Introduction - What is Cryptography?



Introduction - What is Cryptography?

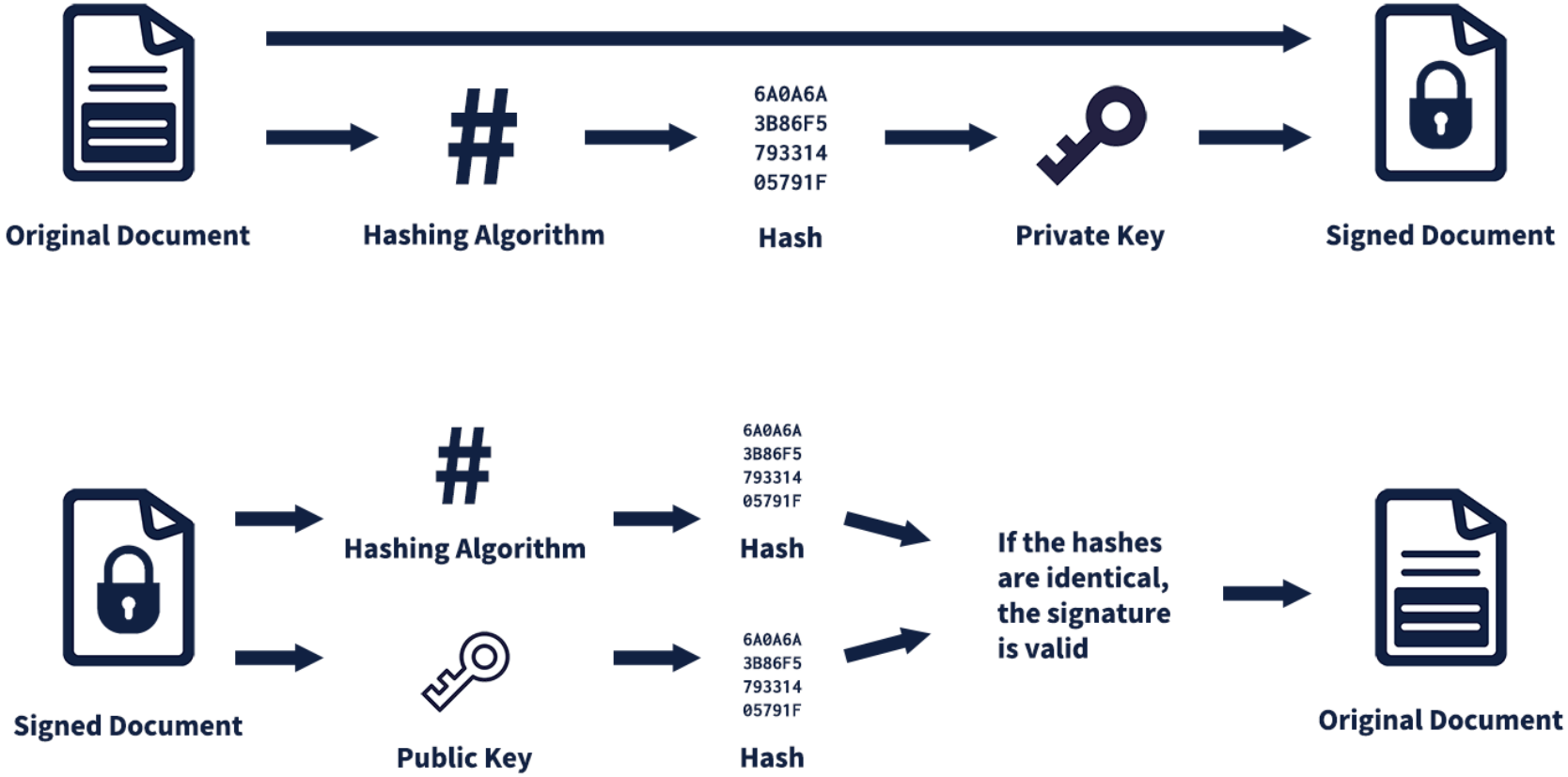




Source: https://upload.wikimedia.org/wikipedia/commons/thumb/f/f9/Public_key_encryption.svg/250px-Public_key_encryption.svg.png

Source: https://www.ssl2buy.com/wp-content/uploads/2015/12/Symmetric-Encryption.png

Introduction - What is Cryptography?



Source: https://techterms.com/img/xl/digital_signature_796.png

Introduction - What is a PQC?

Source: https://www.nist.gov/news-events/news/2024/08/nist-releases-first-3-finalized-post-quantum-encryption-standards

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PQC - Introduction

Aksiyon planı aşağıdakine benzer olmalıdır.

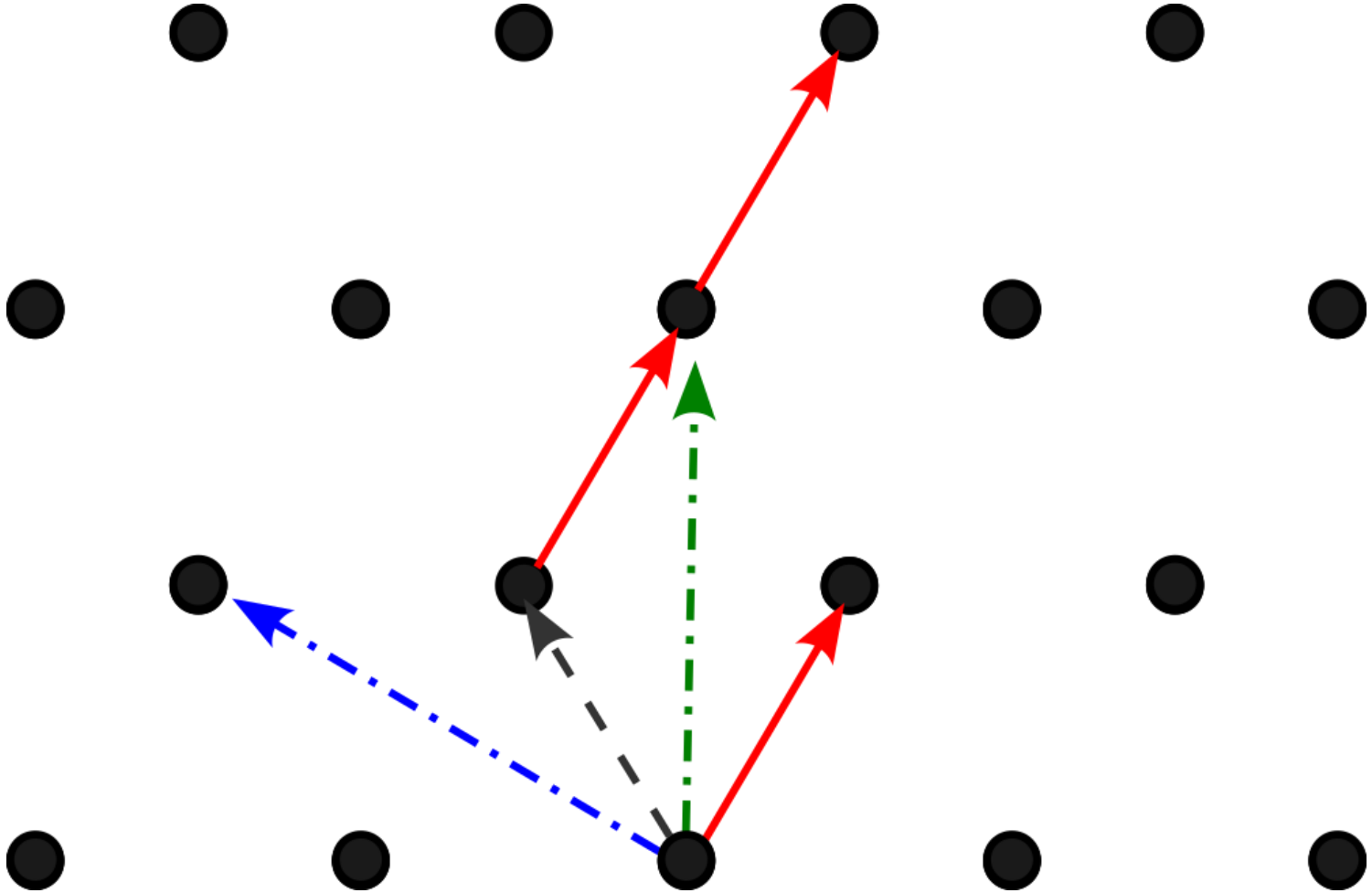
- RSA, DSA, ECC, DH – vulnerable
- TLS, SSH, S/MIME, PGP, IPSEC protocols may be depends on it
- VPNs, Kerberos may be depends on it
- Browsers, encrypted messaging, disk encryption, authentication schemes, … applications may be depends on it

PQC - Hash-based Signatures

Value to sign	Private key	Public key
0	sk0 (randomly generate)	pk0(=HASH(sk0))
1	sk1 (randomly generate)	pk1(=HASH(sk1))
2	sk2 (randomly generate)	pk2(=HASH(sk2))
3	sk3 (randomly generate)	pk3(=HASH(sk3))

Source: https://www.redhat.com/en/blog/post-quantum-cryptography-hash-based-signatures

PQC - Lattice-based Cryptography



PQC - Lattice-based Cryptography

- Klasik encryption yöntemlerinin yerine geçecek.

The other consideration is how you represent the vectors. As with classical cryptography, you can map these vectors into finite fields (either prime fields or binary fields). The main difference between the fields used in lattice operations and those used in Diffie-Helman or Elliptic Curves is one of size. Lattice fields usually fit within the computer's word size, so there is no need to use special big integer arithmetic libraries. The security doesn't come from the size of our vector values, but in the size of the vectors and the number of vectors in our basis.

PQC - Code-based Cryptography

- Ana algoritma lattice-based cryptography
- Bu backup senaryosu
- Just in case
- Harberleşme altyapılarında kullanılan error correction code tabanlı bir yöntem.
  - Hamming Codes
  - Goppa Codes

PQC - Implementation Started

Post-quantum cryptography support

With the PKCS #11 API, you can also perform post-quantum cryptographic operations. Traditional cryptography relies on complicated mathematical problems that are difficult for classical computers to solve. However, with the computing capabilities, quantum computers can solve these problems. Post-quantum cryptography is considered to be resistant to cryptanalytic attacks from quantum computers. It usually uses asymmetric algorithms and has multiple approaches.

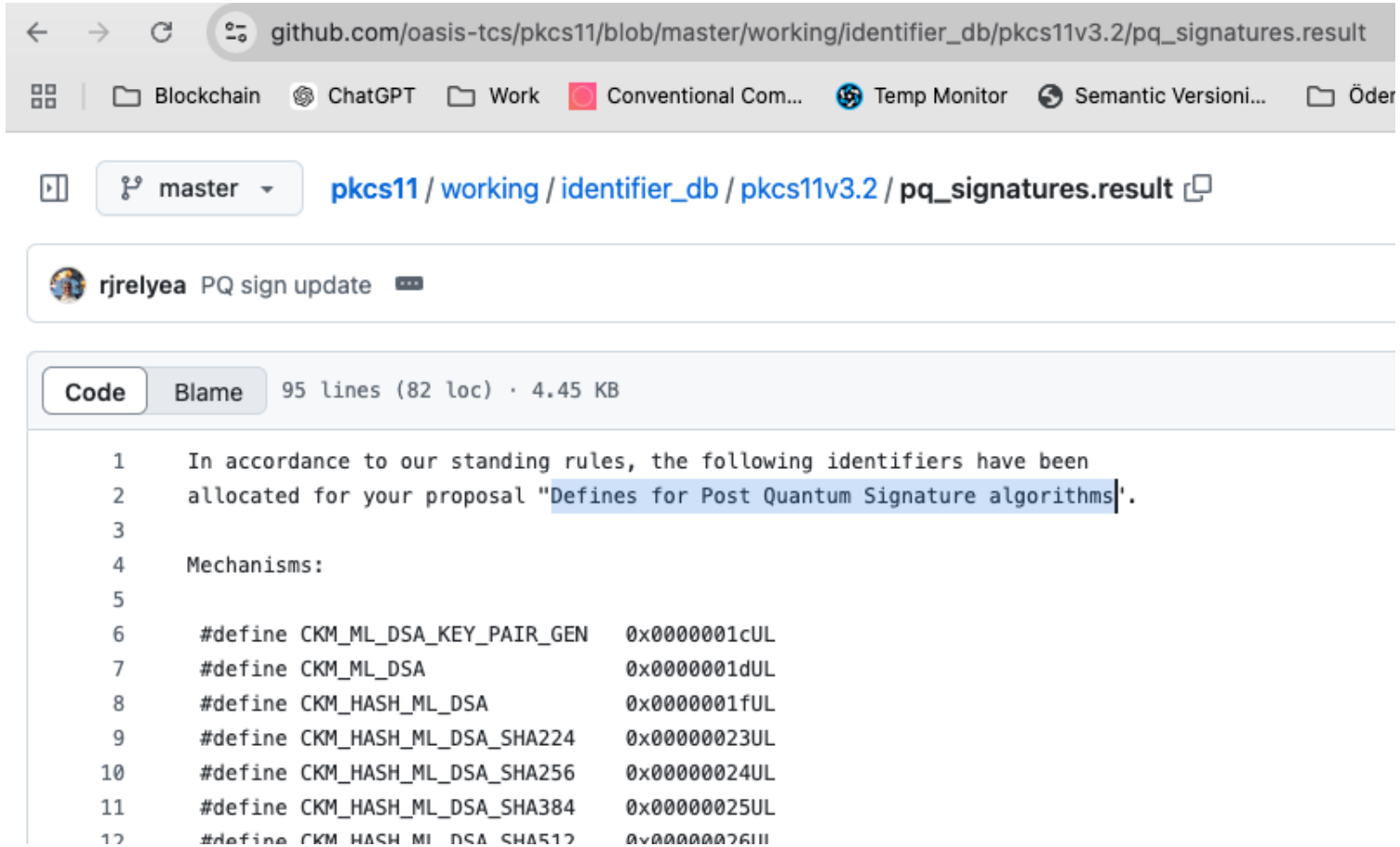
The PKCS #11 API provides the Dilithium algorithm for post-quantum cryptography. It is a lattice-based digital signature scheme and can be used for signature generation and verification. Currently, only the high-security version of round 2 Dilithium is supported and it is not available for `C_SignUpdate` and `C_VerifyUpdate` operations.

Note: The Dilithium algorithm is supported only by the IBM 4769 crypto card, also referred to as Crypto Express 7S (CEX7S). If you create your instances in Virtual Private Cloud (VPC) based regions, where the CEX7S crypto cards are used, you can use the Dilithium algorithm for post-quantum cryptography with the PKCS #11 API. For a list of VPC-based regions, see Regions and locations.

For more information about Dilithium algorithm support in PKCS #11, see PKCS #11 API reference. You can also find Dilithium algorithm code examples in the GitHub sample repository.

Source: https://cloud.ibm.com/docs/hs-crypto?topic=hs-crypto-pkcs11-intro

PQC - Implementation Started



Source: https://github.com/oasis-tcs/pkcs11/blob/master/working/identifier_db/pkcs11v3.2/pq_signatures.result

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Conclusions

While there have been no substantive changes made to the standards since the draft versions, NIST has changed the algorithms' names to specify the versions that appear in the three finalized standards, which are:

- **Federal Information Processing Standard (FIPS) 203** (https://csrc.nist.gov/pubs/fips/203/final), intended as the primary standard for general encryption. Among its advantages are comparatively small encryption keys that two parties can exchange easily, as well as its speed of operation. The standard is based on the CRYSTALS-Kyber algorithm, which has been renamed ML-KEM, short for Module-Lattice-Based Key-Encapsulation Mechanism.
- **FIPS 204** (https://csrc.nist.gov/pubs/fips/204/final), intended as the primary standard for protecting digital signatures. The standard uses the CRYSTALS-Dilithium algorithm, which has been renamed ML-DSA, short for Module-Lattice-Based Digital Signature Algorithm.
- **FIPS 205** (https://csrc.nist.gov/pubs/fips/205/final), also designed for digital signatures. The standard employs the Sphincs+ algorithm, which has been renamed SLH-DSA, short for Stateless Hash-Based Digital Signature Algorithm. The standard is based on a different math approach than ML-DSA, and it is intended as a backup method in case ML-DSA proves vulnerable.

Similarly, when the draft FIPS 206 standard built around FALCON is released, the algorithm will be dubbed FN-DSA, short for FFT (fast-Fourier transform) over NTRU-Lattice-Based Digital Signature Algorithm.

Source: https://www.nist.gov/news-events/news/2024/08/nist-releases-first-3-finalized-post-quantum-encryption-standards

Conclusions

Selected Algorithms:

- FIPS 203 -> ML-KEM -> Module-Lattice-Based Key-Encapsulation Mechanism Standard
- FIPS 204 -> ML-DSA - Module-Lattice-Based Digital Signature Standard
- FIPS 205 -> SLH-DSA - Stateless Hash-Based Digital Signature Standard

Source: https://www.nist.gov/news-events/news/2024/08/nist-releases-first-3-finalized-post-quantum-encryption-standards

Conclusions

- IBM Quantum Computer ve Post Quantum Cryptography üzerine çalışıyor.
- PKCS11 komitesinde bir Red Hat çalışanı, dolaylı olarak IBM var.

Future Works

- FIPS 203, FIPS 204, FIPS 205 , FIPS 206 (draft) incelenebilir.

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[1] An overview of post-quantum threats to proof-of-work cryptocurrencies

[2] Post-quantum cryptography: An introduction

[3] Post-quantum cryptography: Hash-based signatures

[4] Post-quantum cryptography: Lattice-based cryptography

[5] Post-quantum cryptography: Code-based cryptography

[6] NIST Releases First 3 Finalized Post-Quantum Encryption Standards

References

Robert Relyea

Principal Programmer

Relyea has worked in crypto security on the Network Security System code used in Mozilla browsers since 1996. He joined Red Hat in 2006. He is also the co-chair of the OASIS PKCS #11 Technical Committee.

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Q & A

YTÜ YILDIZ TEKNİK ÜNİVERSİTESİ

THANK YOU FOR LISTENING…