Challenges in Transitioning to Post quantum Cryptography

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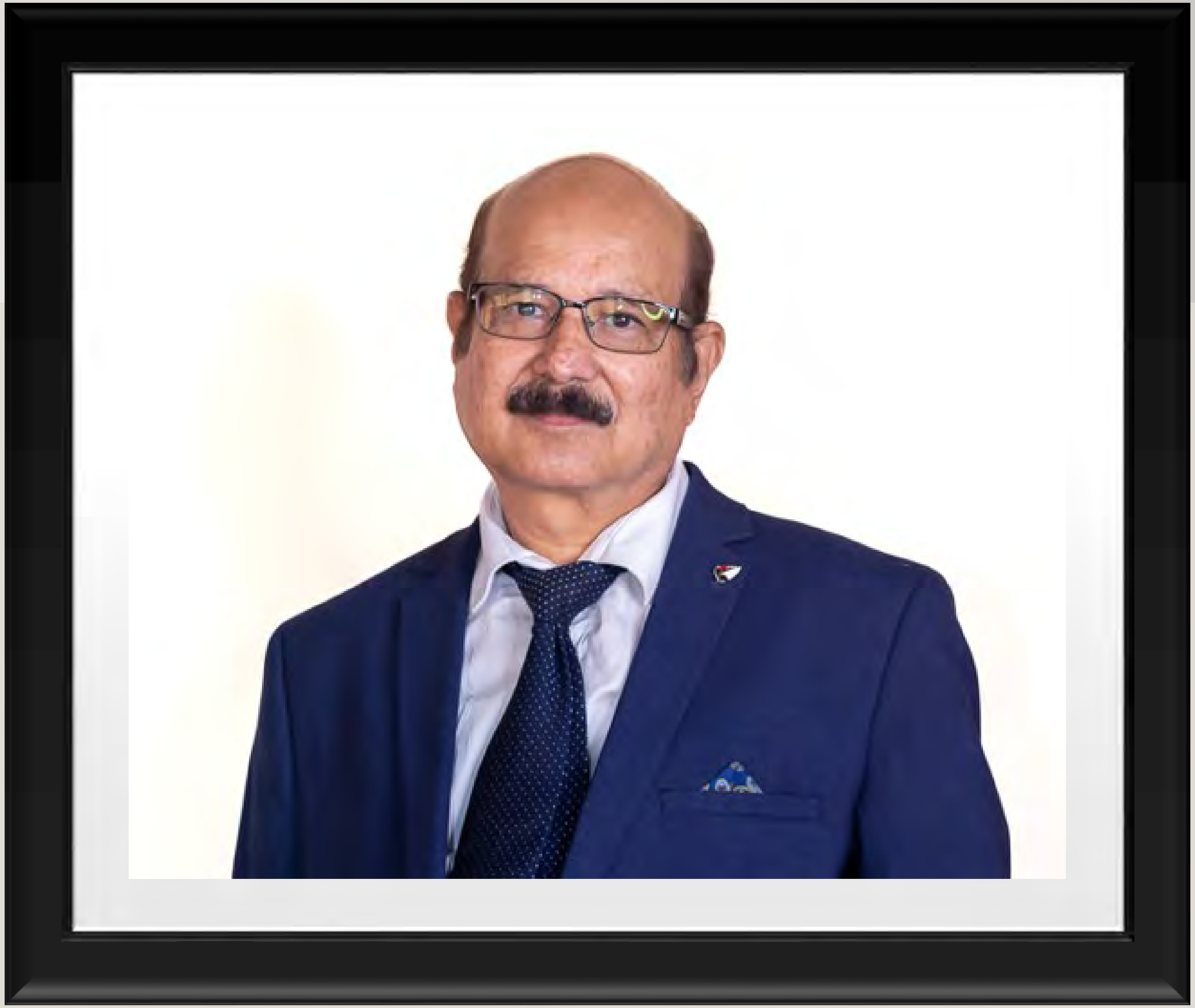
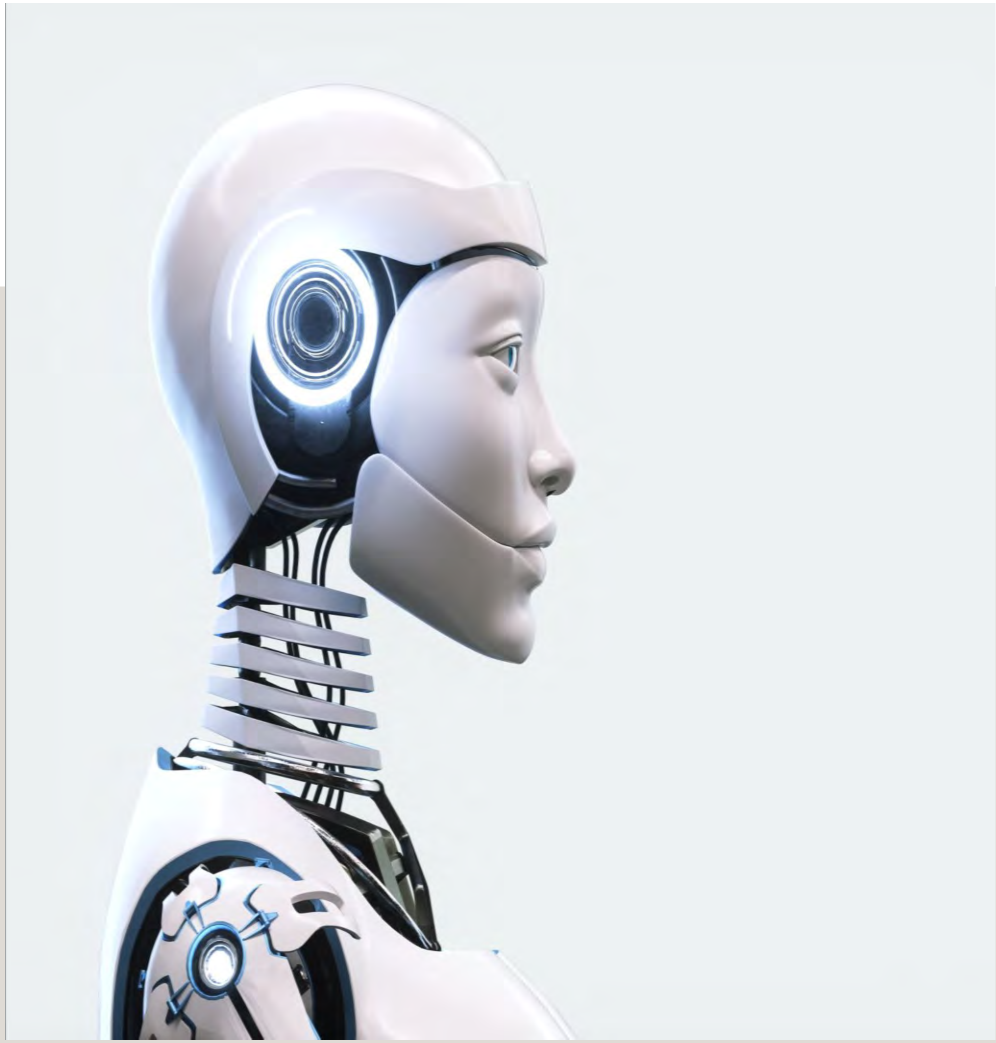
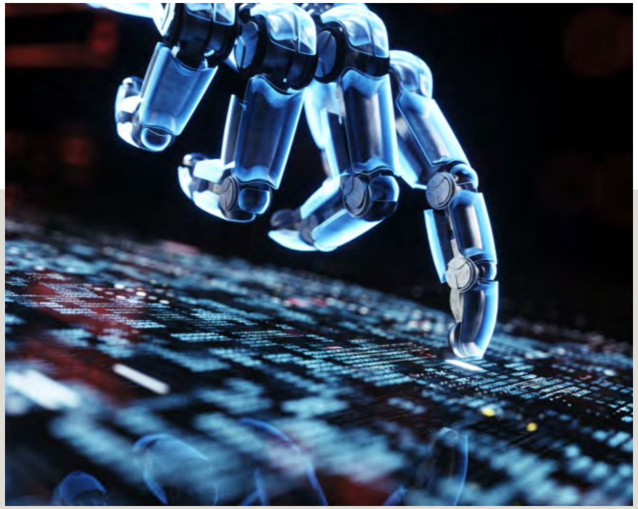




Educational Background

D.Sc. Information Technology, Towson University, December 2011.
M.B.A. UB/Towson University, December 2008.
M.Sc. Physics, South Gujarat University, India, May 1990.
B.Sc. Physics, South Gujarat University, India, May 1986.

Professional Experience

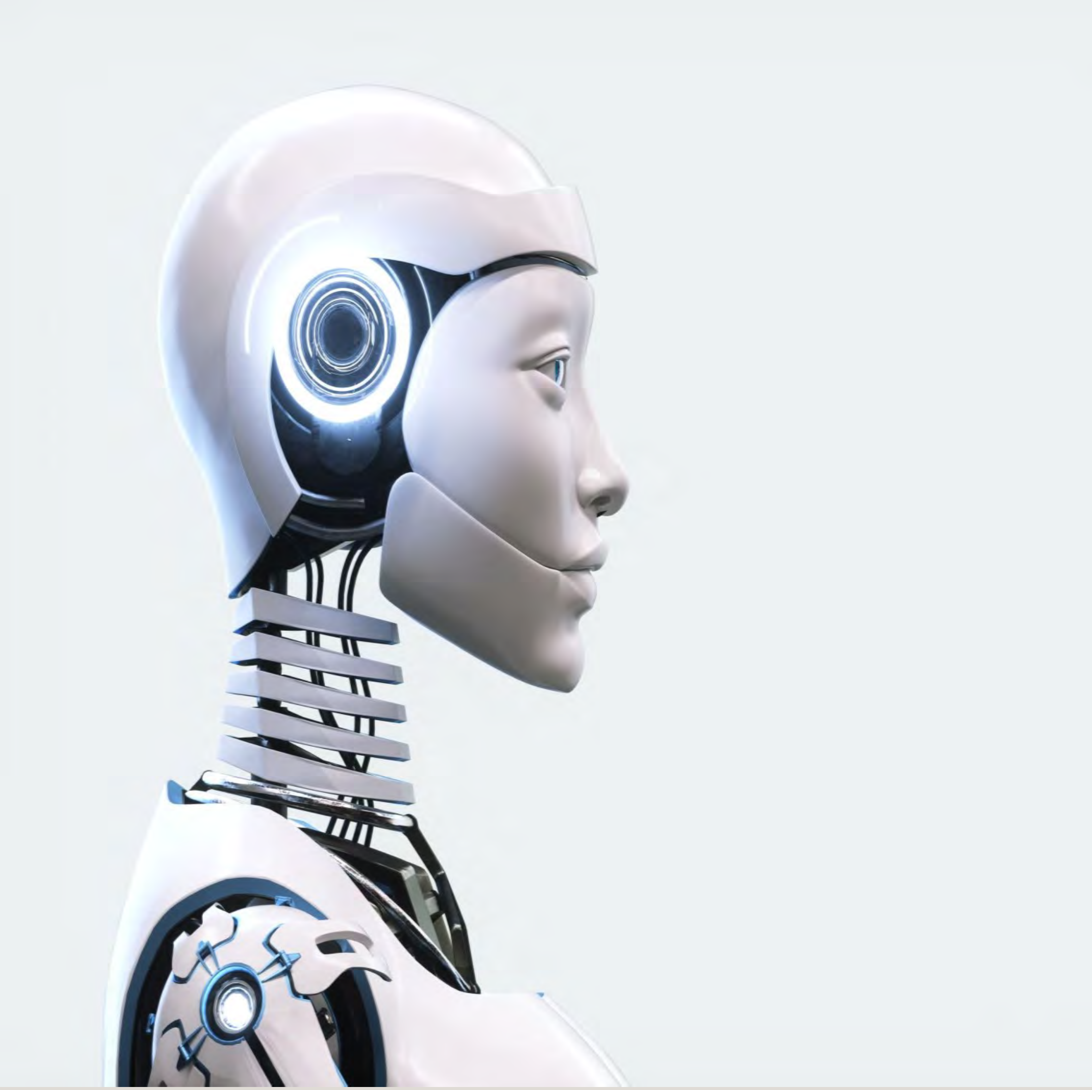


Industries : (Health Care / Pharmaceuticals) CEO/Chairman

IT/Cybersecurity, Quantum Computing CEO/ President

Academia: Assistant Professor / Associate Professor / Full Professor

Administrative: Program Co-Ordinator, Program Director, Department Chair



Scholarly Works

US Patents

Bharat S Rawal, Selvi, S. Sharmila, **Methods and systems for secure sharing of data between user devices using a Proxy Re-Encryption Key (PRE**)." U.S. Patent Application 16/688,642 filed September 3, 2020. Granted 2022

Bharat S Rawal, Dhananjay Singh." **Methods and systems for providing reward-based verified recommendations.** Published & Granted

U.S. Patent 11,386,444, issued July 12, 2022.

Books

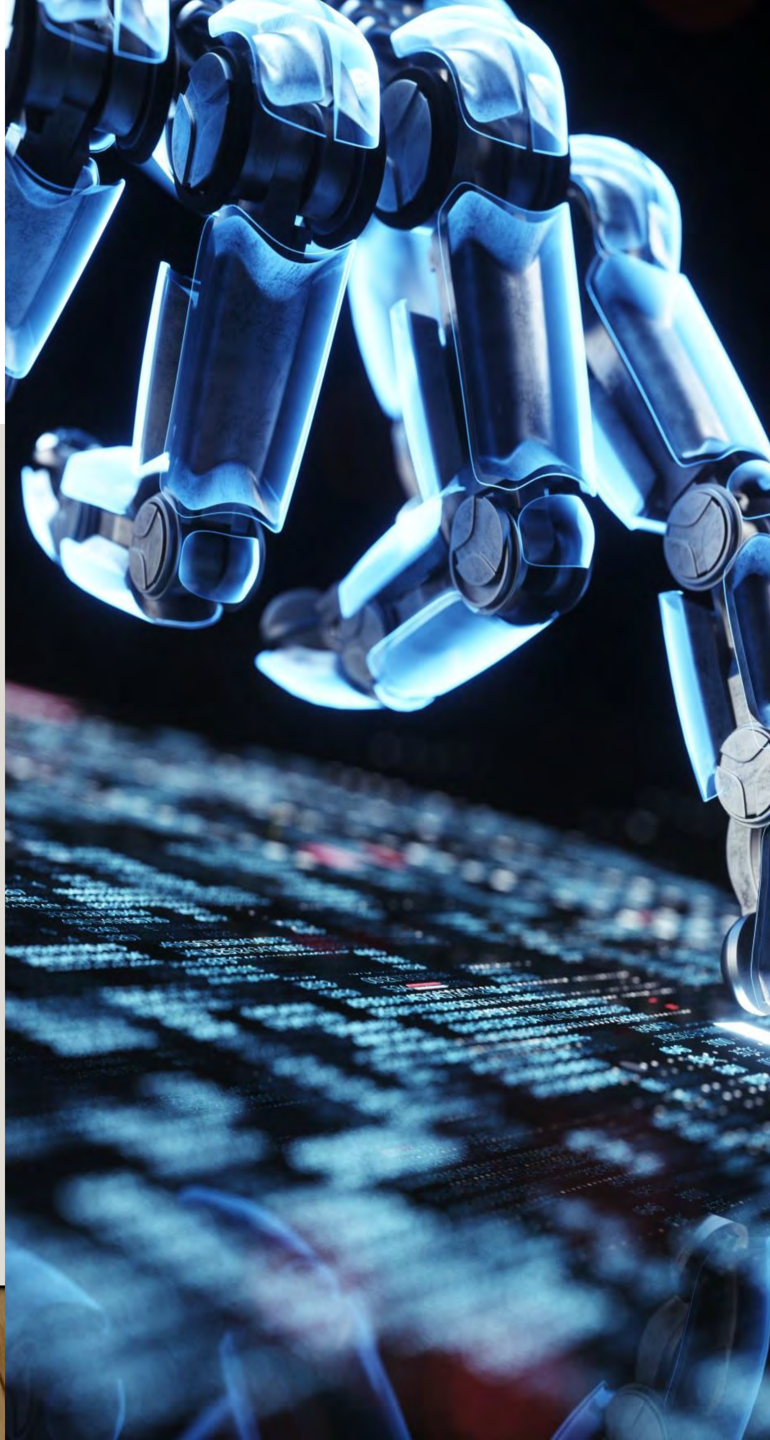
- Rawal, Bharat S., Gunasekaran Manogaran, and M. Poongodi. "Implementing and Leveraging Blockchain Programming." (2022).
  Authorship: First Author

- Rawal, Bharat S., Gunasekaran Manogaran, and Alexender Peter. "Cybersecurity and Identity Access Management." (2022).
- Authorship: First Author

- IET Book “Intelligent Multimedia Technologies for Financial Risk Management: Trends, Tools" - In press (2023).
- Authorship: Co-Author

- Springer’s Book “Artificial Intelligence in IoT and Cyborgization" (2023).
- Authorship: Co-Author

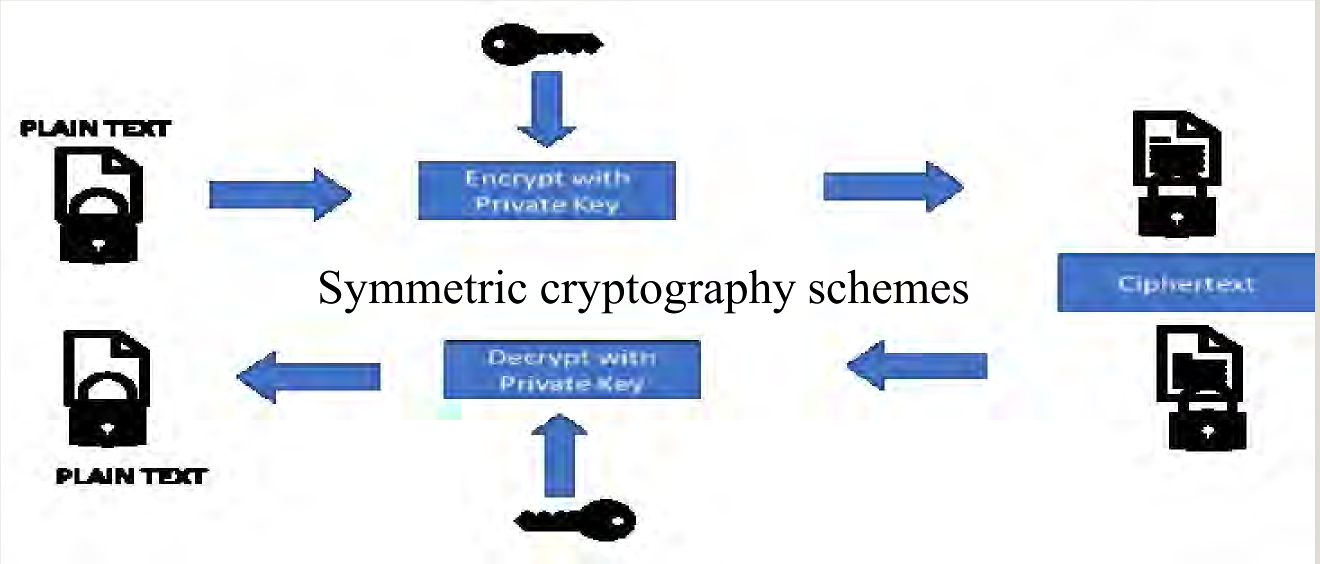
- Introduction to Quantum Computing Springer Book (2024) In Press
- Authorship: Co-Author



CRYPTOGRAPHY

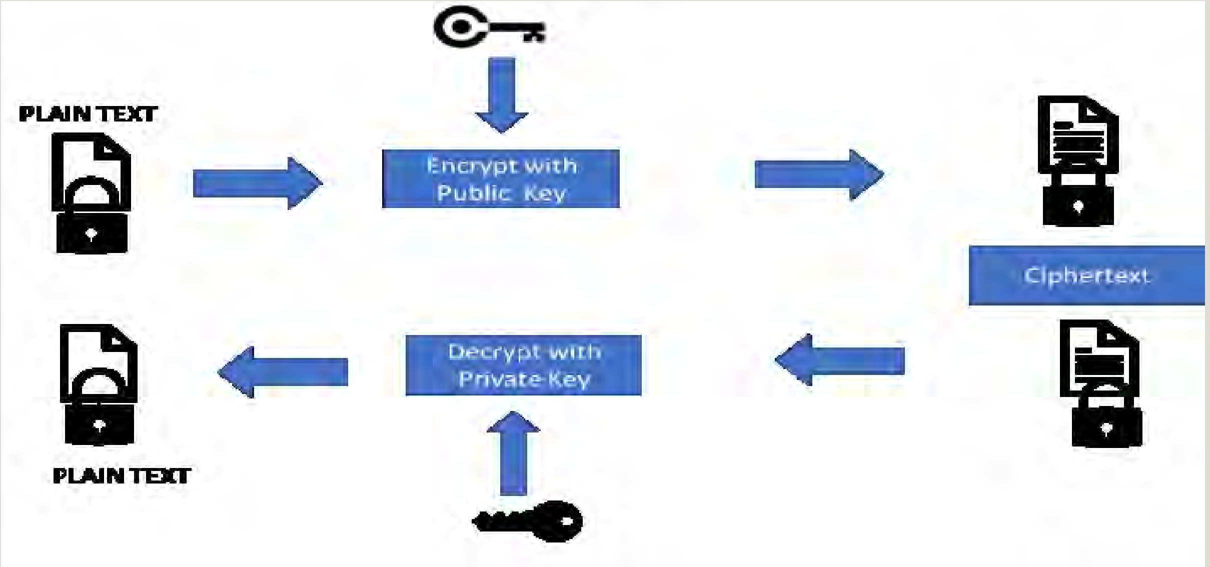
Cryptography is the practice and study of techniques for secure communication in the presence of adversarial behavior. It involves constructing and analyzing protocols that prevent third parties or the public from reading private messages.

SYMMETRIC CRYPTOGRAPHY SCHEMES



Symmetric cryptography schemes

ASYMMETRIC CRYPTOGRAPHY SCHEMES



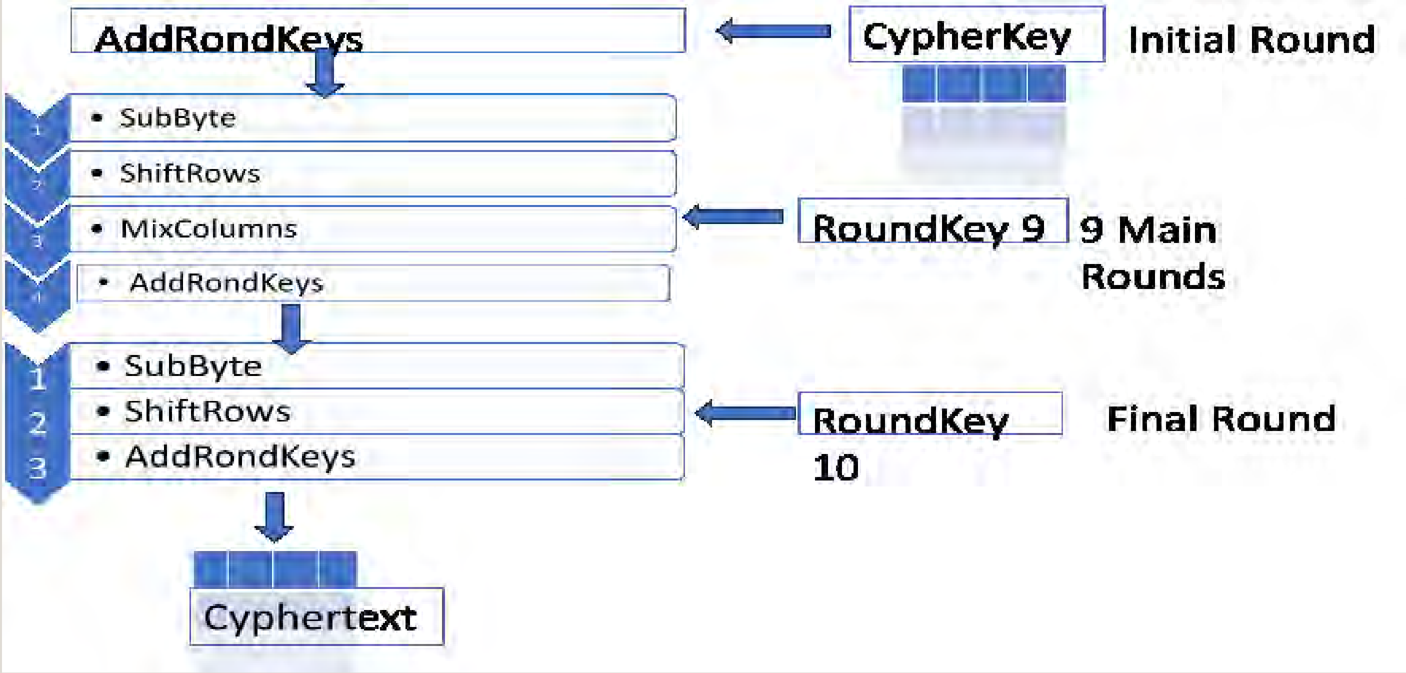
TYPES OF CRYPTOGRAPHY

- Hash-based Cryptography
- Code-based Cryptography
- Lattice-based Cryptography
- Elliptic Curve Cryptography (ECC)
- Homomorphic Encryption

WIDELY USED CRYPTOGRAPHY

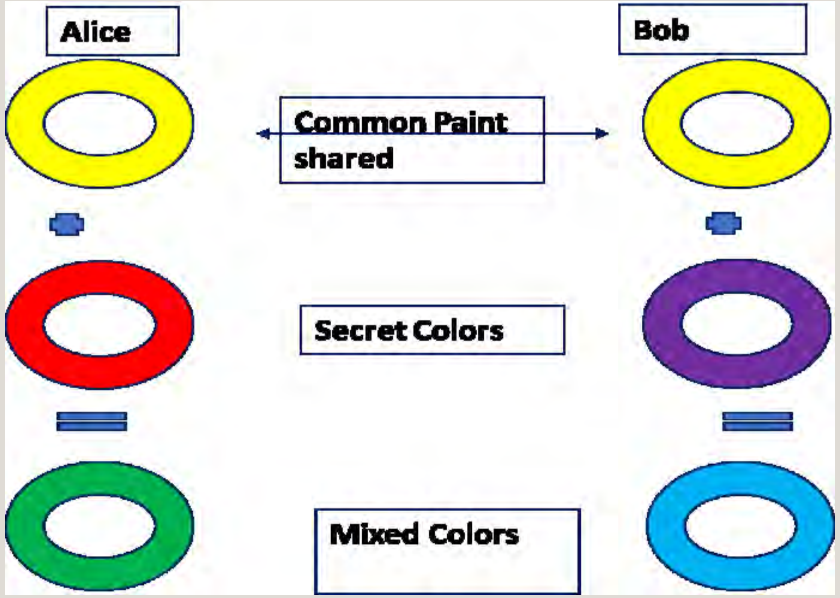
- Advanced Encryption Standard (AES): Known for its security and efficiency, AES comes in three key sizes: AES-128, AES-192, and AES-2561.
- Triple Data Encryption Algorithm (TDEA/Triple DES): DES is used three times in a row with distinct keys in symmetric encryption1.
- Blowfish: A symmetric block cipher that operates on 64-bit blocks.
- Twofish: Another symmetric block cipher designed as a successor to Blowfish.
- ChaCha20: A stream cipher known for its speed and security.
- RC4: A widely used stream cipher, although it has some vulnerabilities.
- Serpent: A symmetric block cipher with a 128-bit block size.
- Camellia: A symmetric block cipher developed jointly by Japan and NTT.
- IDEA (International Data Encryption Algorithm): A block cipher used in some legacy systems.

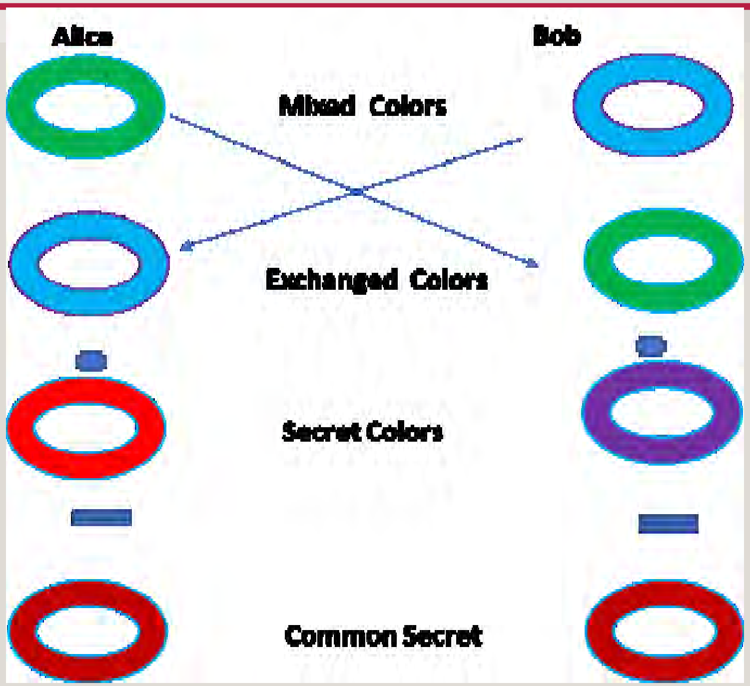
SYMMETRIC CRYPTOGRAPHY SCHEMES AES



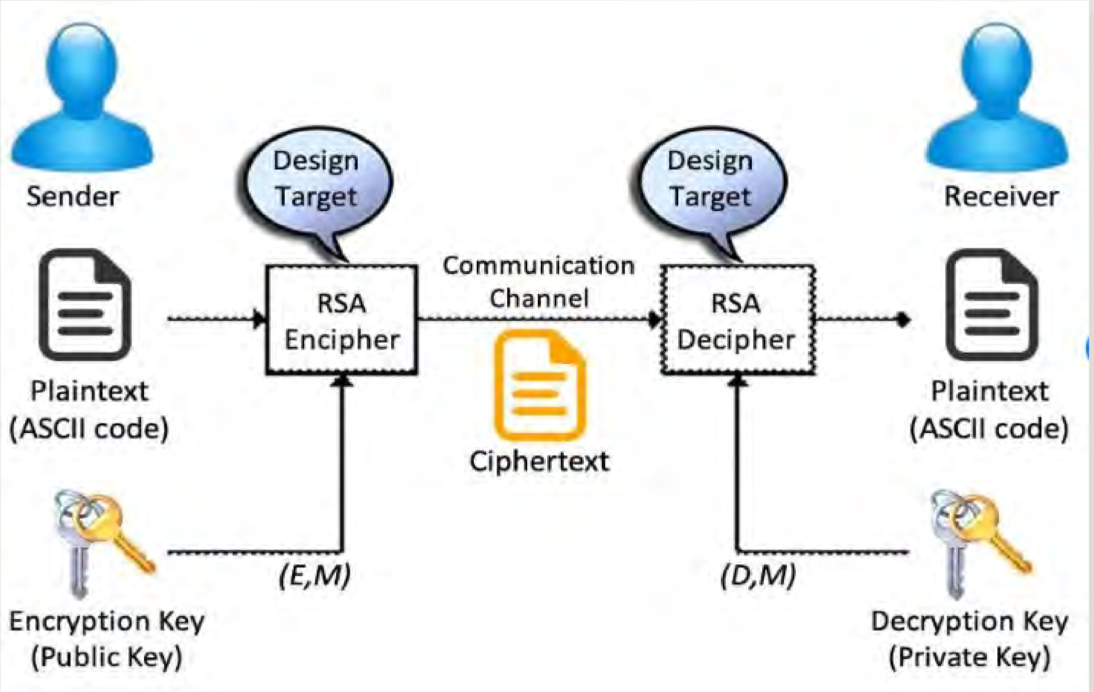
ASYMMETRIC CRYPTOGRAPHY SCHEMES

Diffie Helman Key Exchange





ASYMMETRIC CRYPTOGRAPHY SCHEMES
RIVEST–SHAMIR–ADLEMAN (RSA)



RSA algorithm structure

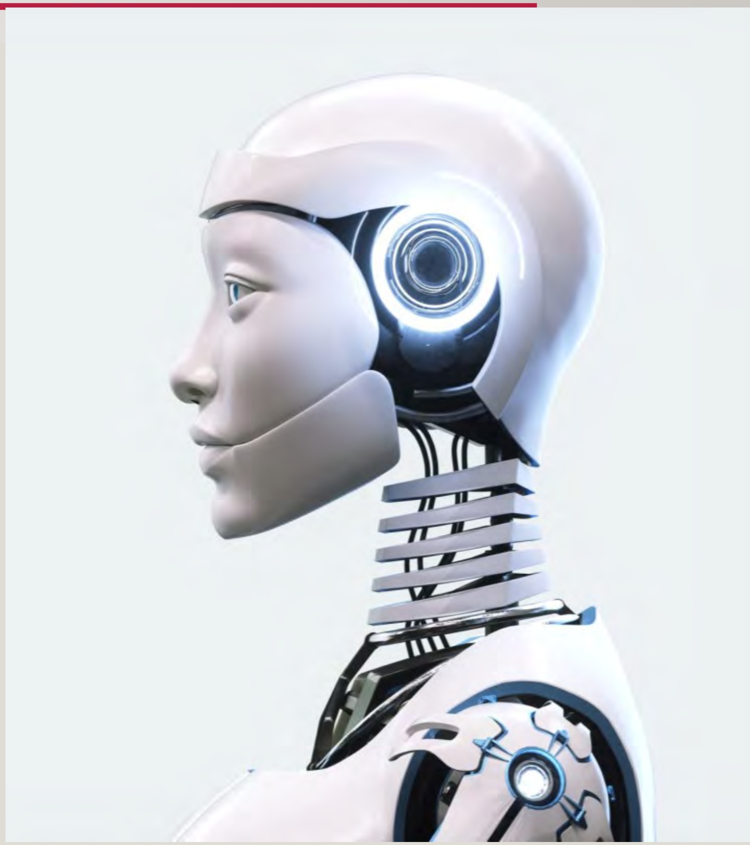
POST QUANTUM CRYPTOGRAPHY NOW

Shor's algorithms can break the following cryptosystems.
RSA
Diffie- Hellman key -exchange
Elliptical Curve Cryptosystem
Buchmann-William's Key exchange
Algebraic Homomorphic
When are we expecting the availability of large quantum computers? 10, 15, or 20 years, depending on the speed of technological advancements.
Why do we have to act now?

1) Development and standardization take time.
2) Improvement also takes time.
3) Take time to build confidence in PQC.
4) It takes time to improve the usability of PQC.
5) Last year 2022 NIST announces the list of PQC.

POST QUANTUM CRYPTOGRAPHY

Recently NIST has selected four cryptosystems: CRYSTALS-Kyber, Dilithium, FALCON, and SPHINCS+. CRYSTALS-Kyber is for use in general encryption. It offers several benefits including two parties can exchange relatively modest encryption keys and maintain the required speed of operation. It is faster among cross-platforms, and it is designed for efficient constant time implementation, same optimized routines across all parameters sets.



CRYSTALS-KYBER

CRYSTALS-Kyber uses a set of parameters to define the security level and efficiency of the scheme. The parameters include the dimension of the underlying lattice, the number of rounds for the encryption algorithm, and the number of bits used for public keys, secret keys, and ciphertexts. The specific values of these parameters can be chosen based on the desired security level.

Crystal-Kyber = [A; Public Key] [s; secrete key] + [e: (α, β, θ) small error terms]
= [t; public key]
$V = t\alpha, + \beta + m$
$U = A\alpha + \theta$
$D = V - sU$

FALCON

The snapshot of the Falcon cryptosystem is reproduced here under.
Falcon work over the cyclotomic ring R = Z q[x]/ (x^n + 1).
Keygen (): Generate matrices A, B with coefficients in R such that.
--> BA = 0
--> B has small coefficients
pk ←A
sk ← B

Sign (m, sk) (Performed using FFT)
Compute c such that cA = H(m)
v ← "a vector in the lattice Λ(B), close to c"
s ← c − v
The signature sig is s = (s1, s2)

Verify (m, pk sig)
Accept if:
s is short
sA = H(m)
The main design goal is compactness: to minimize |pk| + |sig

CRYSTALS-Dilithium

The signature scheme is reproduced here

Gen

$A \leftarrow Rq(k \times l)$

$(s1, s2) \leftarrow Sl\eta \times Sk\,\eta$

$t := As1 + s2$

return $(pk = (A, t), sk = (A, t, s1, s2))$

Sign (**sk**, **M**)

$z := \perp$

While $z = \perp$ do

$y \leftarrow S\,l\,\gamma1 - 1$

$w1 := \text{HighBits}(Ay, 2\gamma2)$

$c \in B60 := H(M \parallel w1)$

$z := y + cs1$

if $\|z\|\infty \geq \gamma1 - \beta$ or $\|\text{LowBits}(Ay - cs2, 2\gamma2)\|\infty \geq \gamma2 - \beta$, then $z := \perp$

return $\sigma = (z, c)$

Verify $(pk, M, \sigma = (z, c))$

$w'1 := \text{HighBits}(Az - ct, 2\gamma2)$

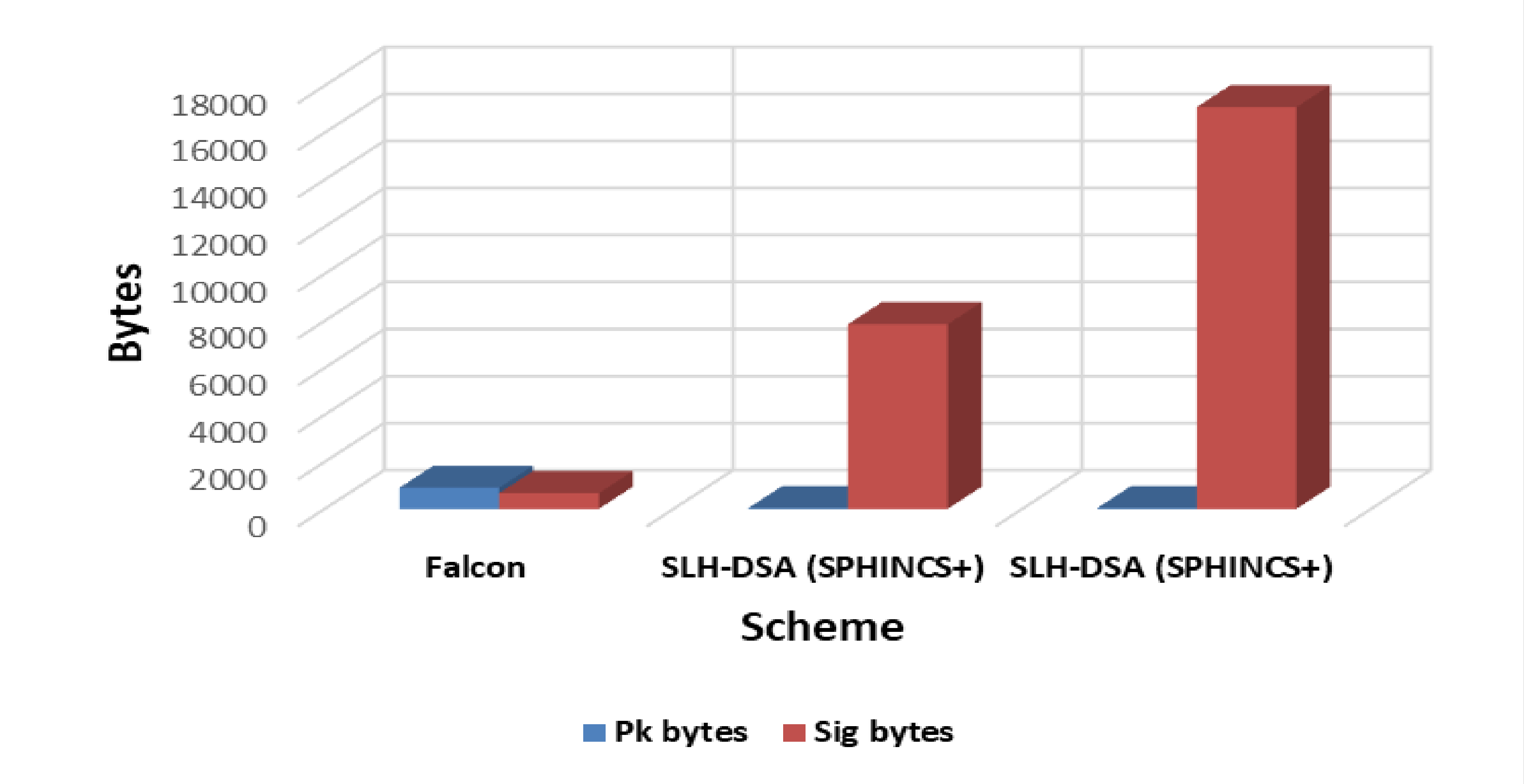
if return $[\ \|z\|\infty < \gamma1 - \beta]$ and $[c = H(M \parallel w'1)]$

SPHINCS+

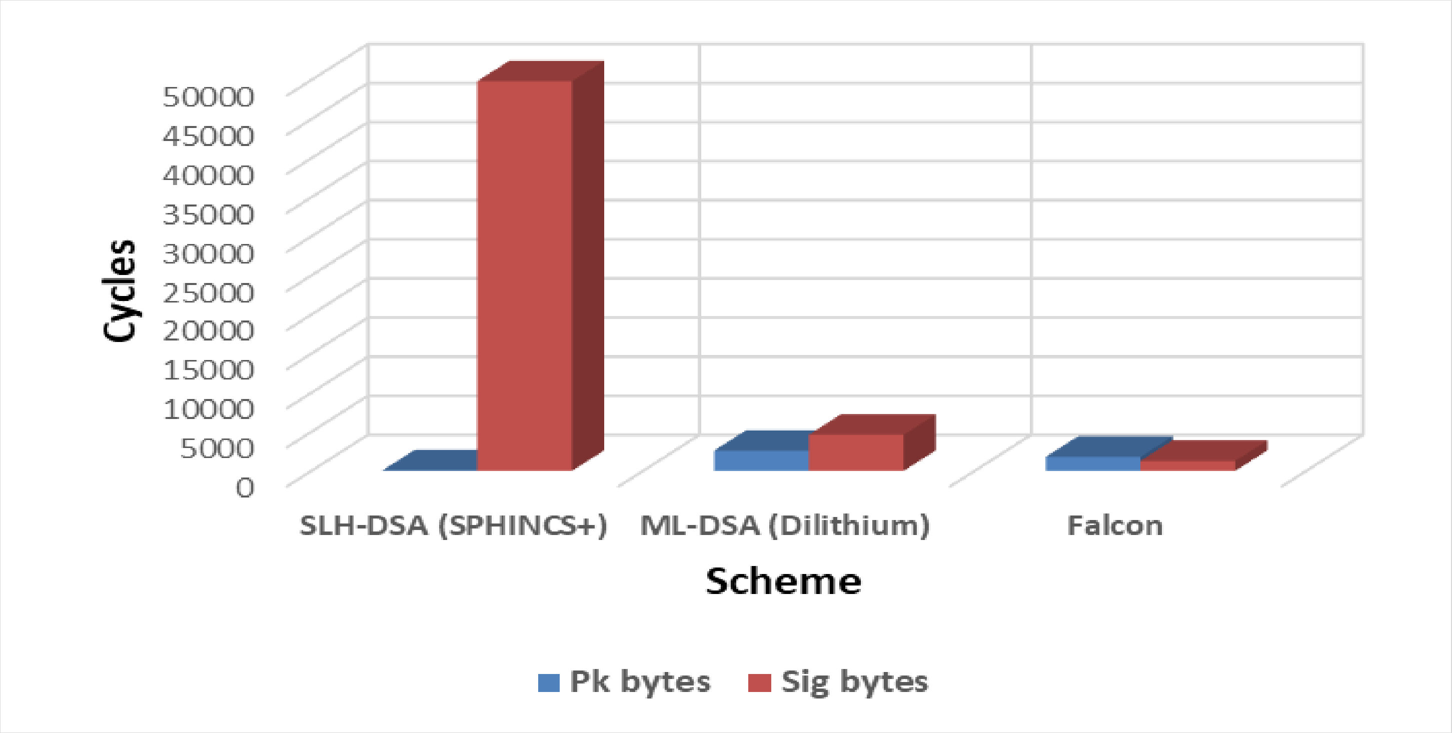
SPHINCS+ cryptography which utilizes FTS schemes [24]. This method uses a so-called hyper tree to authenticate a large number of key pairs with few-time signatures. Signature schemes known as "few-time signatures' enable a key pair to generate a limited quantity of signatures. For every new communication, a pseudo-random FTS key pair is chosen to sign it. The FTS signature and the authentication data for that FTS key pair make up the signature. A hyper tree signature, or a signature using a certification tree of a Merkle tree signature, represents the authentication information.

PQC

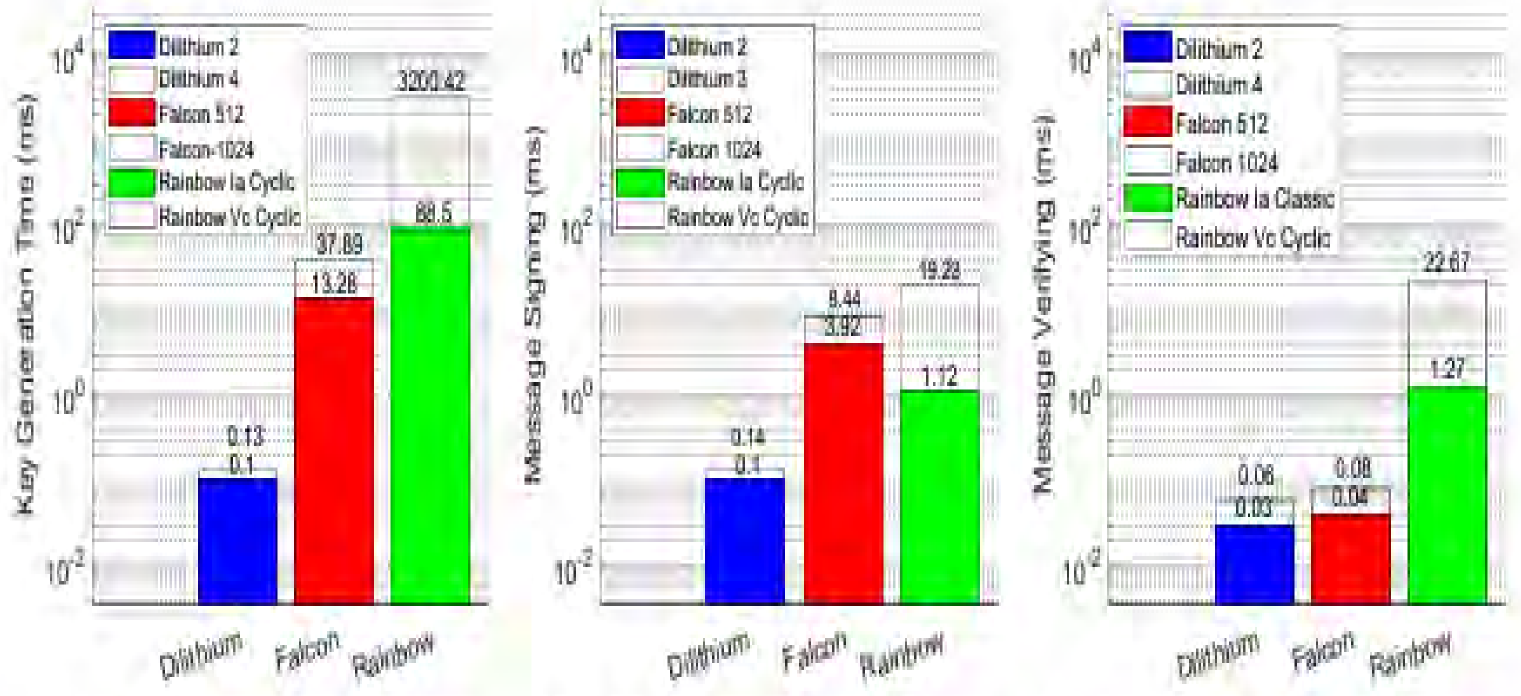
The comparison of key size with Falcon for security level 1.



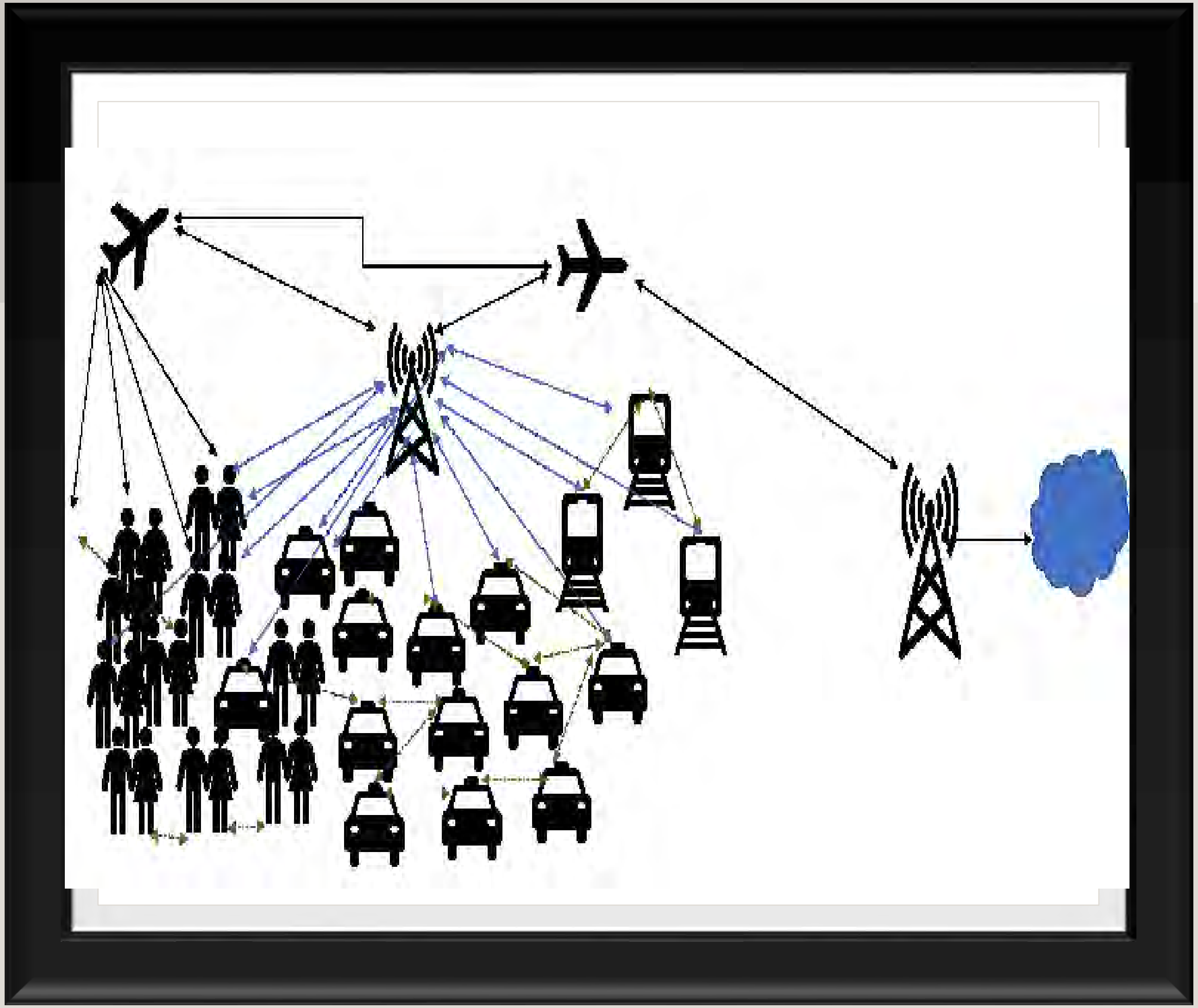
Comparisons the public key sizes and signature bytes of Falcon and SPHINICS+ and Dilithium at NIST security level 5.

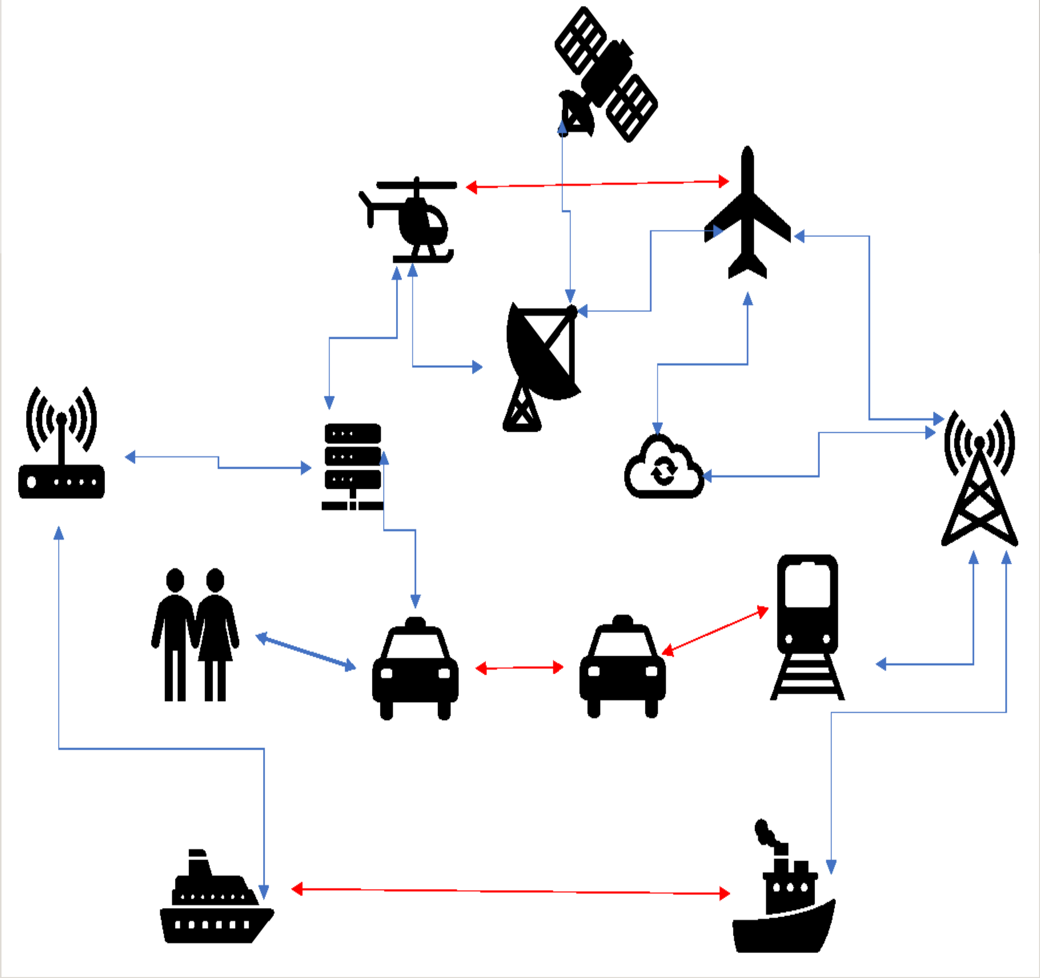


The fastest (colored bar) and slowest (outlined bar) signature candidates from each family cross the three signature phases, with a message length of 100 Bytes



(a) Key generation time (b) Message signing time (c) Message verifying time





No-Sum Sequence

We reproduce a quick overview of the NS sequence here [45,46]. If any element cannot be represented as a sum of any subset in a given set, this sequence can be termed an NS sequence. Each of its elements cannot equate to the sum of any combinations of the other non-repeated elements in the sequence where any element is a positive number. The NS sequence reproduced here could be mathematically represented as given in the equation under [37].

No-Sum Sequence

1	3
2	4
3	5
4	6
5	16
6	17
7	49
8	50
9	148
10	149
11	445
12	446
13	1336
14	1337
15	4009
16	4010
17	12028
18	12029
19	36085
20	36086

PQC Share

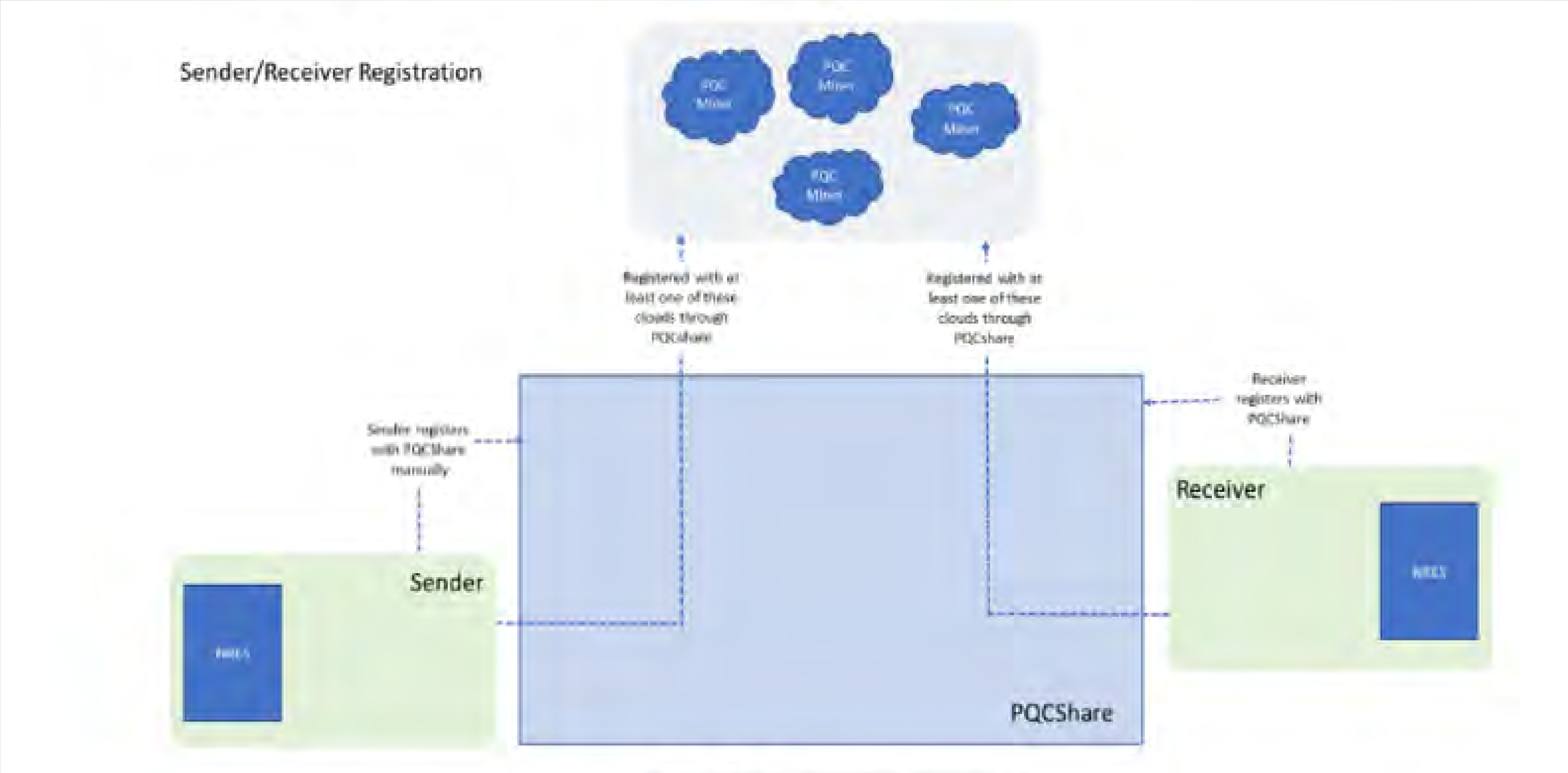


FIG. 24 Registration process

It is too early to draw a conclusion since we are in the preliminary stages of exploration and standardization, but we observed in PQC that great security comes with an increase in key length, which could delay the handshake process and has an impact on the performance the system. Also, we expect the hardware to scale in performance and hard speed. We can see several solutions exist to overcome the large key sizes, software, and hard hardware faults, and malfunctions due to the complex implementation of PQC.

We proposed other cryptographic primitives to make the most popular cryptosystems quantum safe. We suggest adding additional security for smaller lattice based PQC systems so that our current network system can handle them without significant delays. Also, we explore the technique for verifying the source of the QKD transmission solving NS sequence puzzle at both ends.

Questions ????

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