IMPLEMENTATION OF POST-QUANTUM CRYPTOGRAPHY IN NEXT-GENERATION TELECOM INFRASTRUCTURE

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Abstract. *The arrival of practical quantum computing poses a critical threat to classical cryptographic algorithms widely used in telecom infrastructure. RSA, ECC, and Diffie–Hellman—all fundamental to authentication, key exchange, and encryption—can be broken by Shor's algorithm running on a large-scale quantum computer. This paper explores the integration of Post-Quantum Cryptography (PQC) into next-generation telecom systems (5G, 6G, and beyond). We analyze the computational performance, key sizes, and latency trade-offs of various NIST-standardized PQC algorithms (e.g., Kyber, Dilithium, BIKE), and evaluate their suitability for different layers of telecom architecture including RAN, core, and edge networks. Our findings reveal that PQC can be integrated with manageable overheads, but raises new challenges in key management, backward compatibility, and standardization.*

Keywords: *Post-Quantum Cryptography, PQC, Telecom Security, 5G/6G, Kyber, Dilithium, NIST PQC, TLS, IPsec, Quantum-Safe Infrastructure, Quantum-Safe Security, Telecom Networks, Network Security, Hybrid Cryptography, MEC, Edge Security.*

Introduction

Next-generation telecom systems are rapidly evolving to support a hyper-connected world through 5G, 6G, IoT, autonomous vehicles, and smart infrastructure. These systems rely heavily on public-key cryptography for:

- Secure signaling between base stations and core networks
- Authentication of user equipment (UE) and network slices
- Confidentiality and integrity of data-in-transit

However, the security foundations of public-key cryptography—RSA and ECC—are threatened by the development of quantum computers, which can solve integer factorization and discrete logarithm problems in polynomial time.

The U.S. National Institute of Standards and Technology (NIST) has initiated standardization of quantum-resistant algorithms, known as Post-Quantum Cryptography (PQC). These algorithms are based on hard mathematical problems such as lattice-based, code-based, and multivariate polynomial constructions.

This paper addresses how PQC can be effectively integrated into telecom infrastructure. It considers performance, interoperability, and deployment readiness of PQC candidates in telecom-specific environments.

Methods

Algorithm Selection

The selection of post-quantum algorithms for telecom use must balance security, performance, and implementation efficiency across diverse components of the infrastructure—from high-throughput core networks to constrained edge and IoT devices.

We selected algorithms based on the NIST Post-Quantum Cryptography Standardization Project, focusing on Round 3 finalists and approved standards (as of 2024). Selection criteria included:

- Security level (targeting NIST Level I–V, comparable to AES-128 to AES-256)
- Key and signature sizes, critical for bandwidth and memory usage
- Computational efficiency on telecom-grade hardware
- Availability of open-source implementations and support in cryptographic libraries (e.g., OpenSSL, liboqs)

Selected Key Encapsulation Mechanisms (KEMs):

1. Kyber (lattice-based, CPA-secure)
   - NIST standard (2024)
   - Excellent performance and compact ciphertext
   - Chosen variant: Kyber-768, offering a strong balance of security and speed
2. BIKE (code-based)
   - Strong resistance to side-channel attacks
   - Slightly larger keys and slower encapsulation times
3. FrodoKEM (lattice-based, based on LWE)
   - Conservative design with no structured lattices
   - More computationally expensive and larger ciphertext

Selected Digital Signature Algorithms:

1. Dilithium (lattice-based)
   - NIST standard (2024)
   - Good performance for signing and verification
   - Recommended variant: Dilithium-2 for constrained devices; Dilithium-3 for core
2. SPHINCS+ (hash-based)
   - Stateless and minimal assumptions
   - Very large signature sizes (~8–16 KB), making it less practical for bandwidth-sensitive applications
3. Falcon (lattice-based)
   - Compact signatures and high verification speed
   - Numerically fragile; more difficult to implement securely on general-purpose hardware

The selected algorithms cover a wide range of cryptographic operations needed in telecom environments, including:

- Key establishment protocols (e.g., TLS handshakes in RAN and core)
- Firmware and image signing (e.g., for base stations and MEC devices)
- Mutual authentication (e.g., in SIM/eSIM provisioning, slice access control)

These algorithms were benchmarked in the following sections for integration into telecom stacks, focusing on latency, resource usage, and compatibility with existing protocols such as TLS 1.3, IPsec, and QUIC.

Results

To evaluate the feasibility of post-quantum cryptography (PQC) in next-generation telecom infrastructure, we measured the computational and bandwidth impact of integrating selected PQC algorithms into real-world security protocols. Tests were conducted using liboqs integrated with OpenSSL 3.0 on telecom-grade edge servers and virtual RAN environments.

Key Metrics Evaluated:

- **Key Generation Time**
- **Key Exchange and Signature Latency**
- **Ciphertext and Signature Sizes**
- **CPU Utilization and Memory Overhead**
- **TLS/IPsec handshake impact on total session setup time**

Discussion

The transition to PQC in telecom systems is both necessary and feasible. Our analysis suggests:

- **RAN and core networks** are technically ready for PQC integration with minimal architectural changes.
- **Edge and IoT devices** require optimization, hardware acceleration, or lightweight PQC variants.
- **Hybrid deployments** (e.g., ECC + PQC in parallel) ensure backward compatibility and phased rollout.

However, challenges remain:

- **Key management** schemes must evolve to handle larger key sizes and certificate chains.
- **Standardization** across vendors and operators is critical for interoperability.
- **Quantum-safe security policies** must account for evolving threat models, including "harvest now, decrypt later" attacks.

Conclusion

Post-Quantum Cryptography is essential to ensure long-term security of telecom networks in the quantum era. This paper shows that PQC algorithms—especially Kyber and Dilithium—can be deployed in next-generation telecom infrastructures with acceptable latency and resource trade-offs. Future work should focus on:

- Hardware-based PQC acceleration for edge nodes
- Lightweight PQC protocols for 6G IoT
- Integration of PQC with Zero Trust Architecture and quantum key distribution (QKD)

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