Fully Hybrid TLSv1.3 in WolfSSL on Cortex-M4

Mila Anastasova[1], Reza Azarderakhsh[1,2] *Member*, *IEEE*, and Mehran Mozaffari Kermani [3] *Senior Member*, *IEEE*

[1]CEECS Department and I-SENSE at Florida Atlantic University, Boca Raton, FL, USA
(manastasova2017, razarderakhsh)@fau.edu

[2]PQSecure Technologies, LLC, Boca Raton, FL, USA

[3]CES Department at University of South Florida, Tampa, FL, USA
mehran2@usf.edu

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Content

Motivation behind Hybrid Public Key Infrastructure

ECC offers :

- Efficiency in timing, energy, power consumption, and memory consumption (small key sizes).
- Deployed for key derivation and authentication - ECDH and ECDSA (EdDSA).

Curve448 (and it birationally equivalent Ed448) offers :

- Higher security level (224-bits).
- Addresses security backdoor issues of NIST curves.

Elliptic Curve Cryptography is well-studied and widely deployed. However, large scale quantum computers threatens to break ECDLP in sub-exponential time.

Motivation behind Hybrid Public Key Infrastructure

Lattice-based Post-Quantum Cryptography offers :

- Efficiency in timing, energy, power consumption. Relatively compact key sizes.
- Applicable for many crypto instances (PKE, DSA, Digest, Identification functions, etc.).

CRYSTALS-Kyber and CRYSTALS-Dilithium are :

- Finalist of the NIST PQ Standardization process.
- Addresses security backdoor issues of NIST curves.

Post-Quantum primitives are believed to be robust against quantum adversary. However, they fail to fulfill the security criteria set by the government and industry.

Previous Work

- PQ and Hybrid Signatures in TLSv1.2 and TLSv1.3 :
  - Hybrid Signatures in X.509 presented in [KPDVG18].
  - PQ-only message Signatures in TLSv1.2 are shown in [SKD20b], [SKD20a].
  - PQ-only message and X.509 Signatures in TLSv1.2 are shown in [MS22].
- PQ and Hybrid Key Exchange in TLS and other protocols :
  - Hybrid Key Exchange prototyping and deployment is shown in [CPS19], [CC19].
  - Hybrid Key Exchange in HPKE is presented in [AKM22].
- Library enhancements :
  - OQS and OpenSSL libraries integration of PQ-standalone message and X.509 PKI Signatures [SKD20b].

Our Contributions

Present a Fully Hybrid TLSv1.3 based on Curve448 and Crystals-Kyber1024 and Ed448 and Crystals-Dilithium5 based OpenSSL & wolfSSL cryptographic libraries :

- We enhance OpenSSL to generate X.509 hybrid `Ed448_Dilithium5` keys and certificates in PEM format.
- We implement `Curve448_Kyber1024` hybrid key exchange.
- We upgrade to sign and verify based on hybrid DSS `Ed448_Dilithium5`.
- We deploy processing `Ed448_Dilithium5` hybrid keys and certificates.
- We evaluate our hybrid TLSv1.3 based on `Curve448_Kyber1024` and `Ed448_Dilithium5` on the ARMv7 Cortex-M4 STM32F413 microcontroller.

Curve448 ECDH & Ed448 DSA

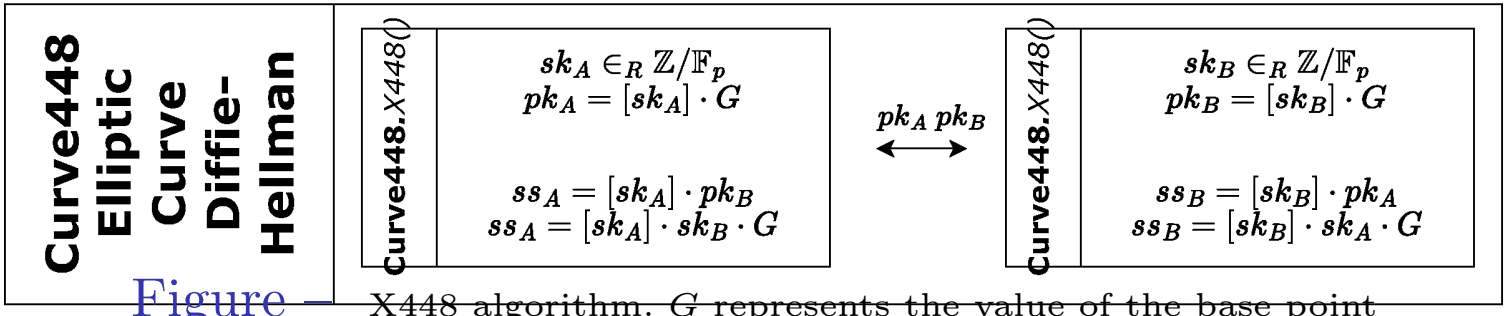

Figure – X448 algorithm. G represents the value of the base point

Figure – Ed448 algorithm [JL17]. H denotes $SHAKE256$. L represents the order of Ed448 curve. G represents the value of the base point

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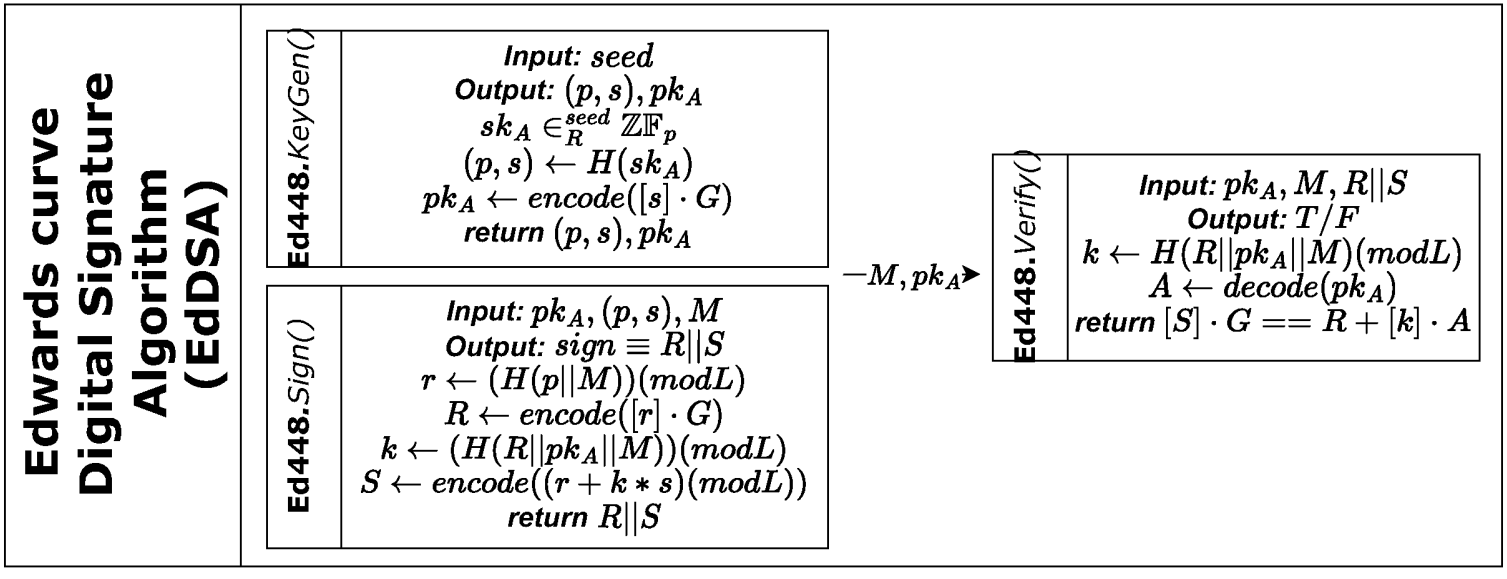

Figure – Ed448 algorithm [JL17]. H denotes $SHAKE256$. L represents the order of Ed448 curve. G represents the value of the base point

Crystals-Kyber & Crystals-Dilithium

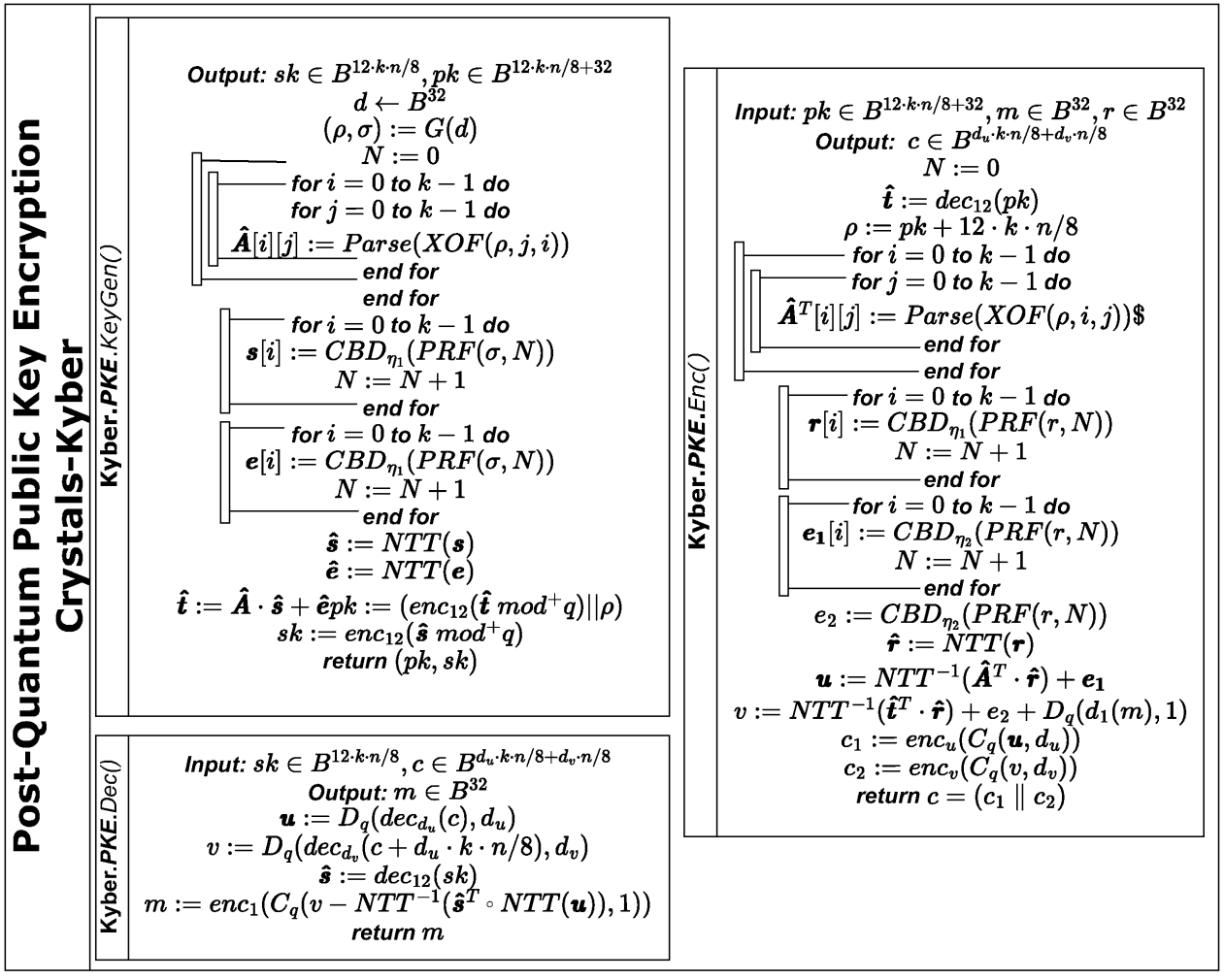

Figure – Crystals-Kyber algorithm [BDK+18]. Each variable represents (the coefficients of) a polynomial, bold text style denotes vector of polynomials, capital letter notation denotes a matrix. *enc* and *dec* represents encode/decode, C and D present Compress/Decompress, respectivel

Crystals-Kyber & Crystals-Dilithium

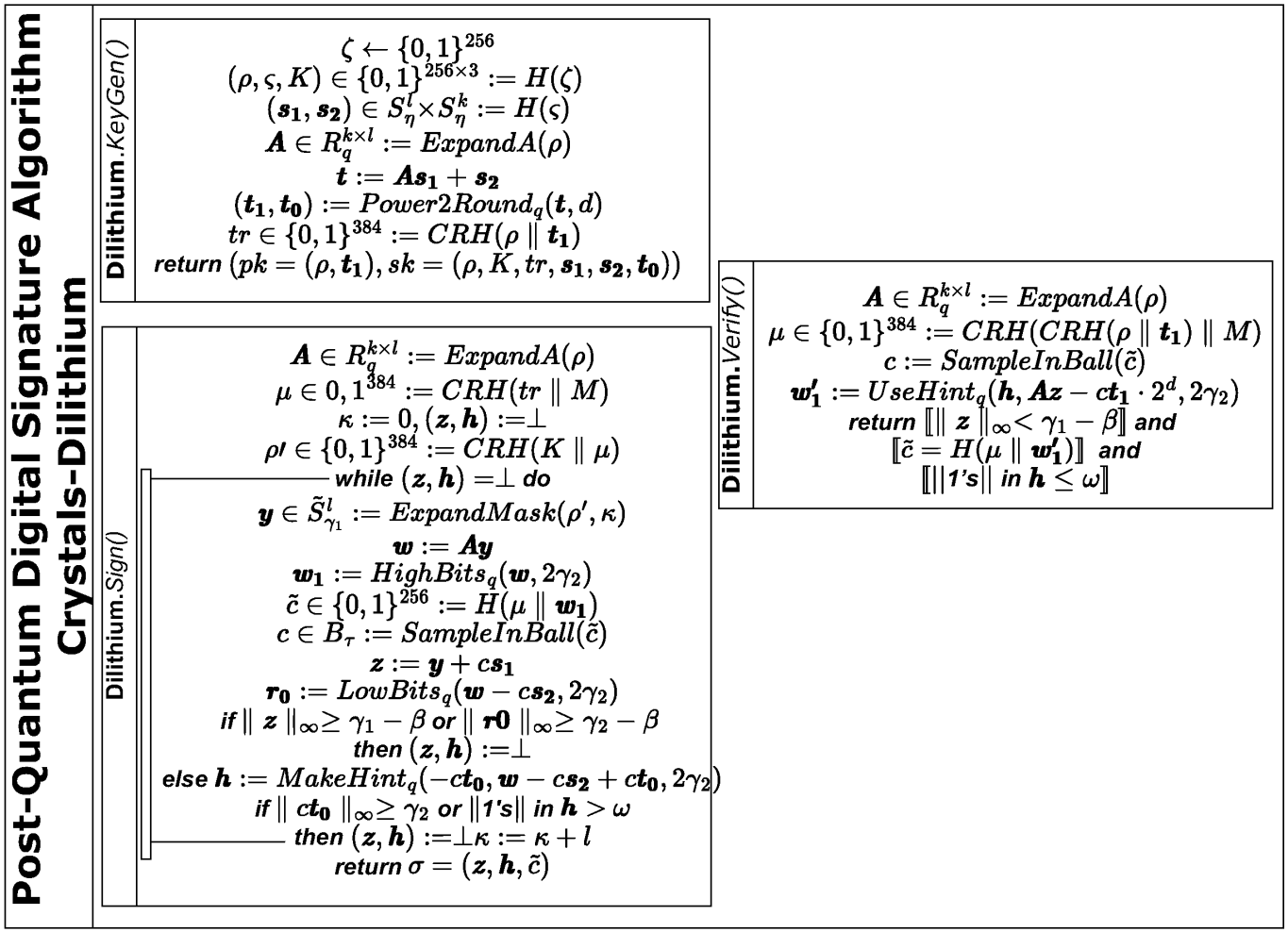

Figure – CRYSTALS-Dilithium algorithm [DKL+18]. Each variable represents a polynomial, bold text style denotes vector of polynomials, capital letter notation denotes a matrix

Crypto Performance on ARM Cortex-M4

Cortex-M4 Features

- 16 32-bit core registers
- *32 32-bit FP registers
- 1 CC per instruction except memory accesses

Implementation strategies

- Use the entire register set.
- Operate on larger operand sets.
- Re-organize the instruction flow for efficient design.

NIST recommended Cortex-M4 WiFi-equipped STM32F413-ZH.

- Features :
  - 1.5MB of flash memory
  - 320KB of RAM
- Tools :
  - STM32CubeIDE
  - wolfSSL library
- Goal :
  - Deploy enhanced Fully Hybrid wolfSSL TLS1.3 protocol to obtain performance.

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Public Key Infrastructure

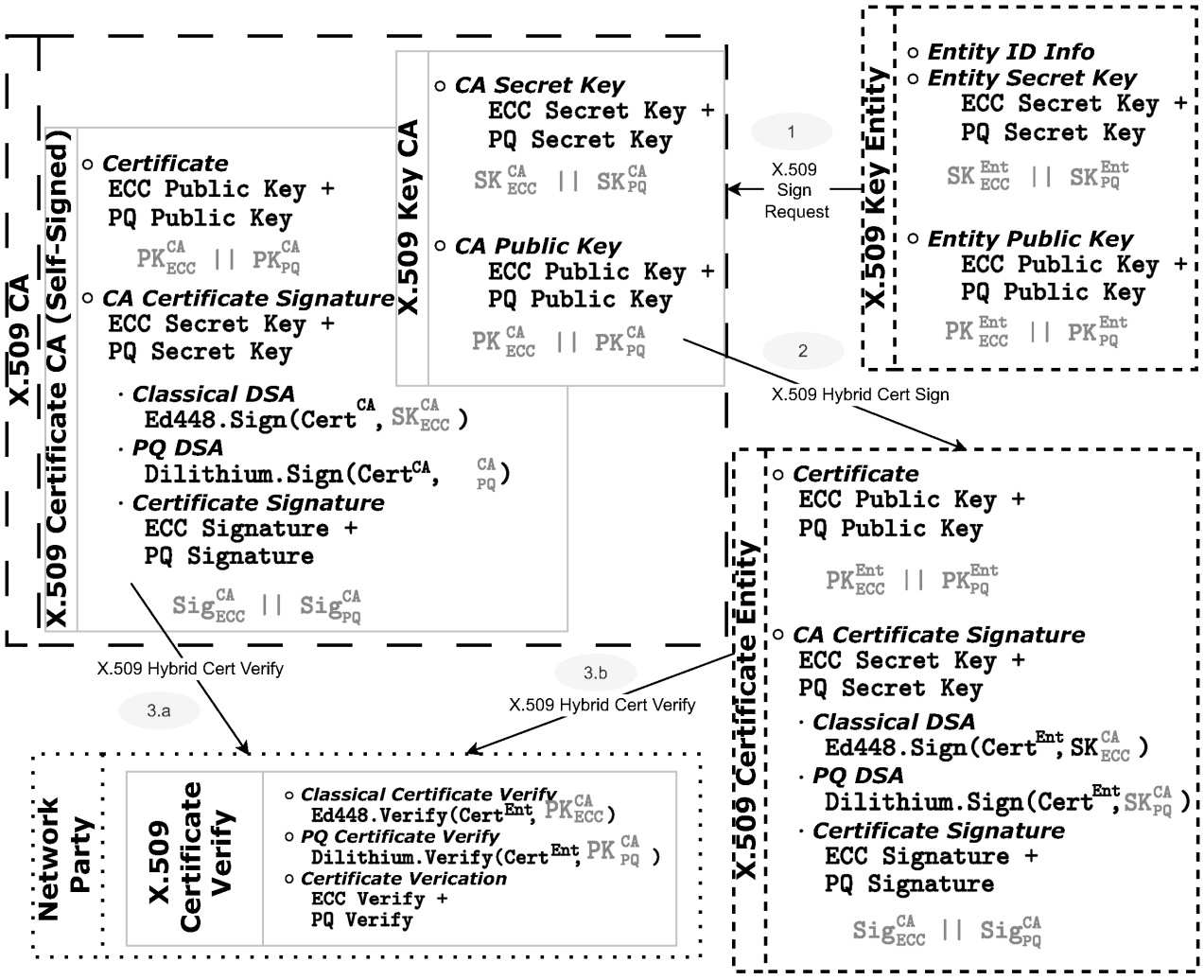

Figure – The Public Key Infrastructure (PKI) built using classical (Ed448) and post-quantum (Dilithium5) Digital Signature Algorithm (DSA) techniques. The gray data refers to the information fields found in the X.509 files. Superscript indicates the owner of the data, while subscript indicates the type of information

Fully Hybrid TLSv1.3

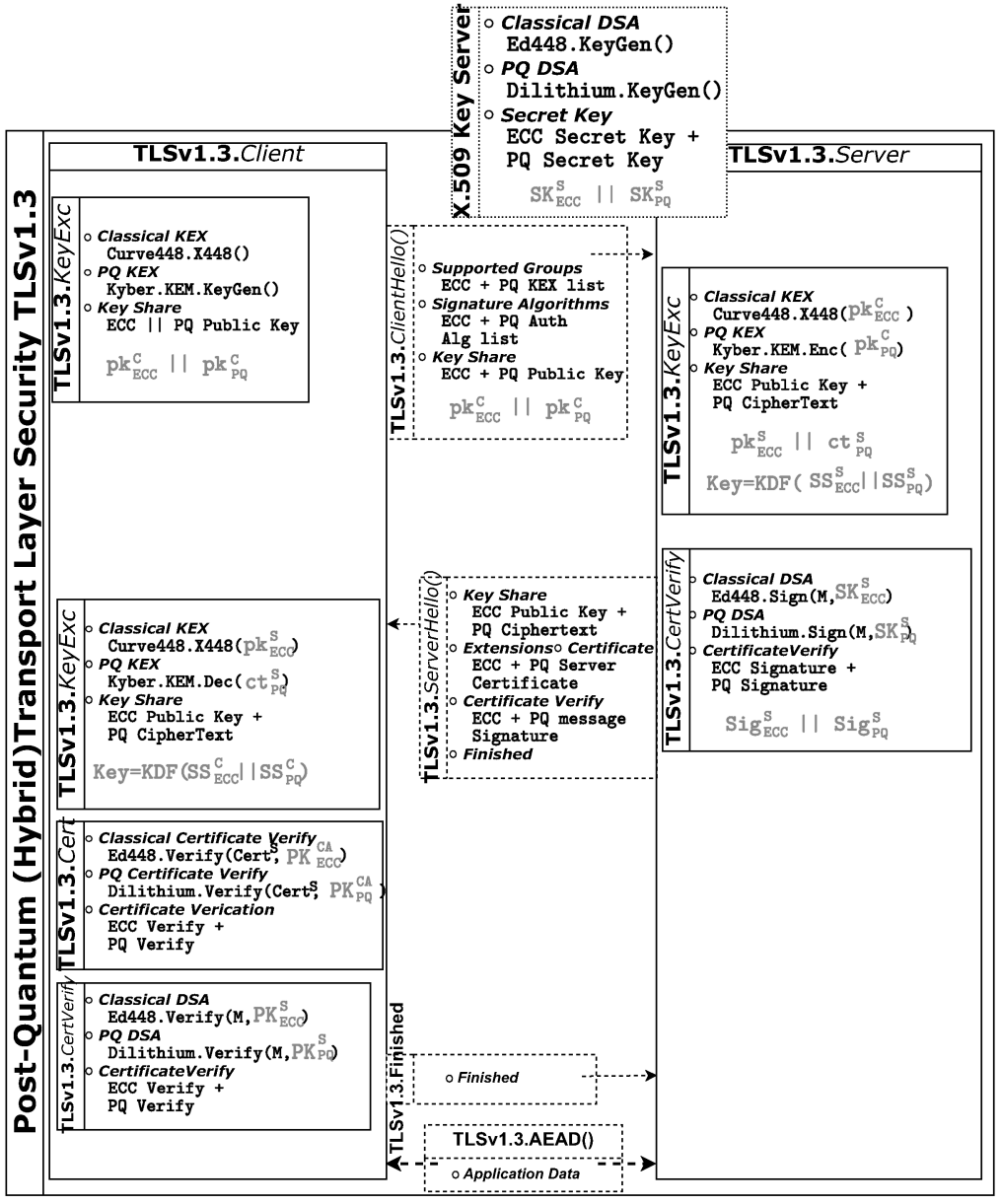

Figure – TLSv1.3 execution flow graphical representation. Gray data refers to the information fields included in X.509 files, where superscript indicates the owner of the data and subscript indicates the type of information. The compute stages are represented by solid box lines, the message flow is represented by discontinuous lines, and the certificate file is represented by scattered box lines

wolfSSL Fully Hybrid TLSv1.3 Performance Evaluation

Work	KEX	Auth	Cert Verify	TLS1.3 handshake	TLS1.3 with AEAD
wolfSSL [wol]	X448	Ed448	Ed448	-	44,358,855
Anastasova et al. [AEKL+23]	X448	Ed448	Ed448	-	46,310,749
This work	X448 & Kyber1024	Ed448 & Dil5	-	97,624,103	106,735,300
	X448 & Kyber1024	Ed448 & Dil5	Ed448 & Dil5	114,017,313	123,139,034

Table – Performance of the entirely hybrid TLSv1.3 handshake and the overall TLSv1.3 protocol when a short 15B message is delivered between communication parties. The values are expressed in terms of clock cycles [CC]

Conclusions & Future Work

- **Conclusions**
  We propose Fully Hybrid TLSv1.3 based on wolfSSL and OpenSSL cryptographic libraries :
  - We generate `Ed448_Dilithium5` hybrid keys and certificates adapting OpenSSL.
  - We deploy high-security `Curve448_Kyber1024` hybrid key exchange in the TLSv1.3 handshake.
  - We deploy `Ed448_Dilithium5` hybrid message signature.
  - We deploy `Ed448_Dilithium5` hybrid certificate verification.
  - We report $\sim\times 2.43$ overhead compared to the classical-only TLSv1.3 based on the same classical primitives when certificate verification is omitted, and $\sim 2.67\times$ overhead when hybrid certificate is transmitted and verified.
- **Future Work**
  - SCA protected Fully Hybrid TLSv1.3.
  - Fully Hybrid TLSv1.3 on higher end ARM platforms.

Thank you for the attention !

If you have any inquiries, please feel free to contact our team :

manastasova2017@fau.edu
razarderakhsh@fau.edu
mehran2@usf.edu

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