OPEN QUANTUM SAFE

Deployment of PQC

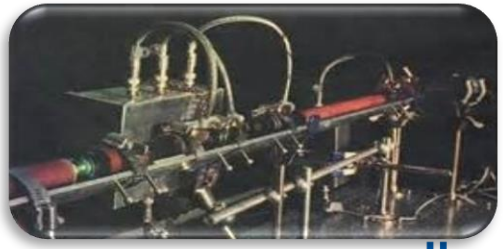
Institut Henri Poincarré

October 7 to 11, 2024

Christian Paquin

Microsoft Research

About me



Université de Montréal

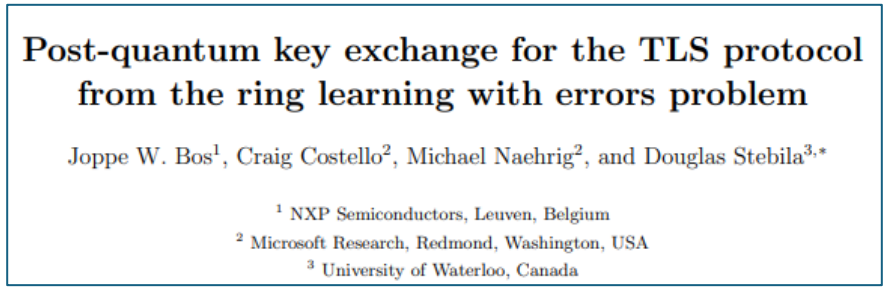
- Studied quantum cryptography 25+ years ago at University of Montreal
- Worked in the industry as a cryptographic engineer
- Now with the *MSR Cryptography* team, working on
  - Post-quantum cryptography
  - Privacy-preserving identity (anonymous credentials, ZK proofs)
  - Content provenance and authenticity (C2PA)
- Links
  - MSR page: https://www.microsoft.com/en-us/research/people/cpaquin/
  - Blog: https://christianpaquin.github.io/

OPEN QUANTUM SAFE

- Development and prototyping of quantum-resistant cryptography
- *liboqs*: C library offering PQC algorithms
- Bindings for C++, C#, go, java, python, rust
- Protocol integration into TLS and CMS (OpenSSL, BoringSSL), SSH (OpenSSH, libssh)
- Application integration into curl, chromium, httpd, nginx, openvpn, quic, wireshark, and more
- Supports pure PQC and hybrid modes
- Now part of the Linux Foundation PQC Alliance

https://openquantumsafe.org

Historical timeline



Post-quantum key exchange for the TLS protocol from the ring learning with errors problem

Joppe W. Bos[1], Craig Costello[2], Michael Naehrig[2], and Douglas Stebila[3,*]

[1] NXP Semiconductors, Leuven, Belgium
[2] Microsoft Research, Redmond, Washington, USA
[3] University of Waterloo, Canada

NIST COMPUTER SECURITY RESOURCE CENTER CSRC

PQC Call for proposals

2015
- BCNF paper (May)

2016
- Initial OQS commit (Aug)
- Windows support (Sept)
- SIDH (Nov)

2017
- NIST Round 1 [69 algs] (Dec)
- Sig API – Picnic (Dec)

2018
- NIST Round 2 [26 algs] (Jan)
- OpenSSL 1.1.1 TLS 1.3 (Apr)
- TLS 1.3 Auth (Jun)
- OQS v0.1.0 (Dec)

2019
- OQS v0.2.0 (Oct)

2020
- NIST Round 3
- OQS v0.3 & v0.4

2021
- OQS v0.5 - v0.7
- OpenSSL 3.0 Provider (Feb)

2022
- 4 selected algs
- NIST Round 4
- OQS v0.7.2

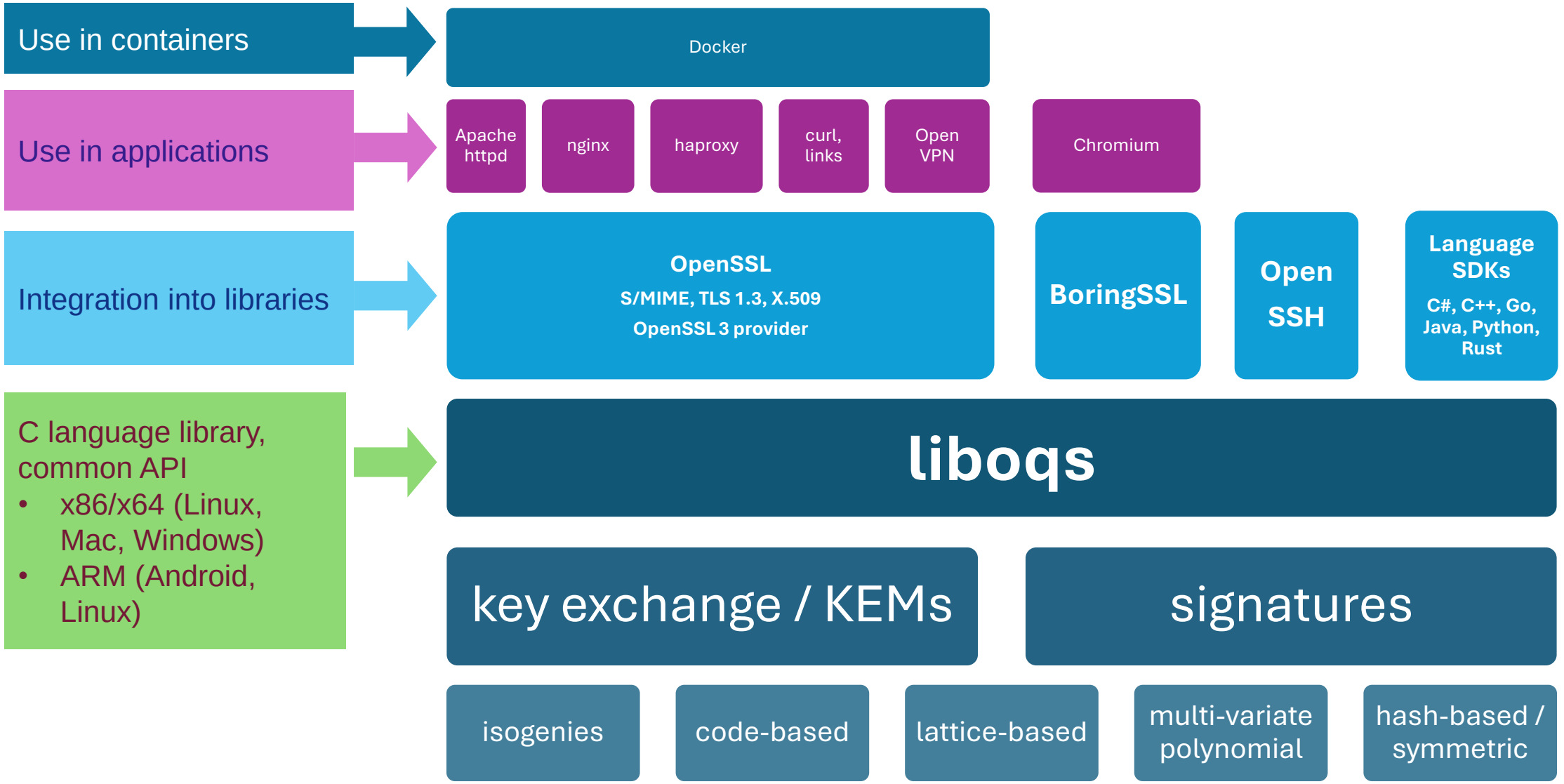
2023
- Signature RFP (Jun)
- Draft standards (Aug)
- OQS v0.8 - v0.9

2024
- Linux Foundation (Jan)
- FIPS Released (Aug)
- OQS v0.10 - v0.11

Post-Quantum Cryptography Alliance
THE LINUX FOUNDATION PROJECTS

- PQCA launched in February 2024
- Projects
  - Open Quantum Safe
    - Support the development and prototyping of quantum-resistant cryptography
  - PQ Code Package
    - High-assurance implementations of standards-track post-quantum cryptography algorithms
- Goal: provide support to make OQS more robust and market ready

OQS Architecture



Latest release: liboqs 0.11.0

- Released Sept 27, 2024
- Updates
  - ML-KEM support
  - Adds MAYO, CROSS signatures from Round 1 Additional Signatures
  - Adds XMSS, LMS (disabled by default)
  - Verified implementations of Kyber-512, -768 from libjade
- Supported algorithms
  - KEM: BIKE, Classic McEliece, FrodoKEM, HQC, Kyber, ML-KEM, NTRU-Prime
  - Sig: CROSS, Dilithium, Falcon, MAYO, ML-DSA (IPD), SPHINCS+, XMSS, LMS

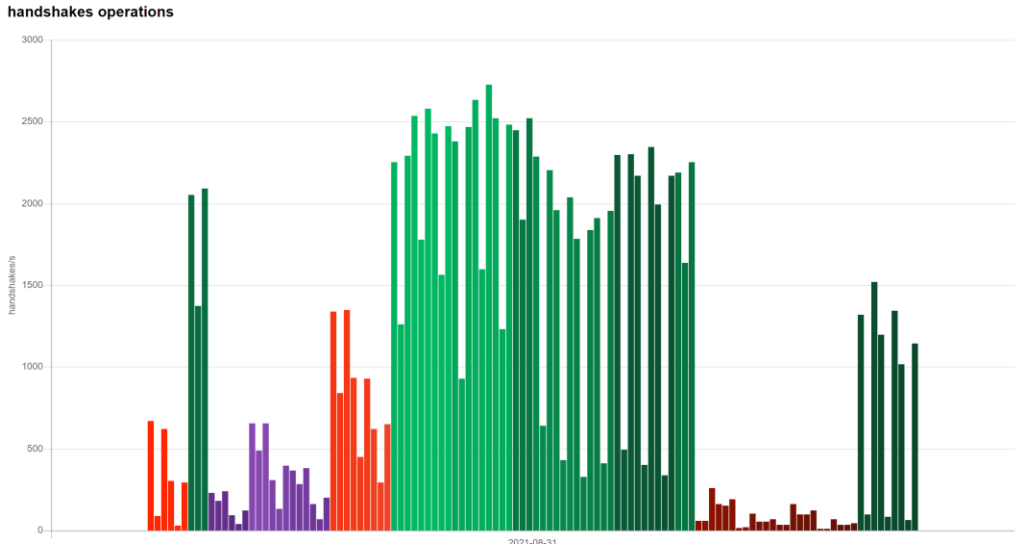
https://github.com/open-quantum-safe/liboqs/releases/tag/0.11.0

TLS

- Specification
  - Hybrid KEM and sig: https://datatracker.ietf.org/doc/draft-ietf-tls-hybrid-design/
  - X.509: https://datatracker.ietf.org/doc/draft-ietf-lamps-dilithium-certificates/
- OpenSSL 3.0 Provider
  - https://github.com/open-quantum-safe/oqs-provider/
  - The recommended way to integrate PQC into OpenSSL 3.0
  - Upcoming integration into OpenSSL announced: https://openssl-library.org/post/2024-09-17-post-quantum/
- Experimental BoringSSL support
  - https://github.com/open-quantum-safe/boringssl
- Interoperability server: https://test.openquantumsafe.org/

TLS Benchmarking

- Core algorithm speed and memory usage
- TLS performance (PQ-only & hybrid)
- Support Intel AVX2 and ARM 64
- https://openquantumsafe.org/benchmarking/



KEM performance

☰ Operations per second per algorithm

Raw Data 2021-08-31

Algorithm	keygen/s	keygen(cycles)	encaps/s	encaps(cycles)	decaps/s	decaps(cycles)
FrodoKEM-1344-AES (x86_64)	588.67	4247027	461.18	5421019	478.51	5223477
FrodoKEM-1344-AES (x86_64-ref)	555.00	4504727	352.55	7090322	358.21	6979490
FrodoKEM-1344-AES (x86_64-noport)	612.13	4083887	481.00	5197275	496.17	5038778
FrodoKEM-1344-SHAKE (x86_64)	207.39	12055505	192.01	13017521	193.08	12949723
FrodoKEM-1344-SHAKE (x86_64-ref)	86.91	28760679	78.46	31867850	72.69	34393744
FrodoKEM-1344-SHAKE (x86_64-noport)	252.25	9910764	240.25	10404343	243.34	10273587
FrodoKEM-640-AES (x86_64)	2184.33	1144361	1503.00	1663334	1653.00	1512282
FrodoKEM-640-AES (x86_64-ref)	1971.67	1267907	1254.67	1992566	1308.33	1910734
FrodoKEM-640-AES (x86_64-noport)	2389.33	1046066	1719.67	1453571	1801.33	1387905
FrodoKEM-640-SHAKE (x86_64)	793.67	3149835	700.67	3567992	717.43	3484136
FrodoKEM-640-SHAKE (x86_64-ref)	350.88	7124020	320.12	7808764	323.45	7728289
FrodoKEM-640-SHAKE (x86_64-noport)	1042.67	2397485	892.00	2802818	863.67	2894581
FrodoKEM-976-AES (x86_64)	1034.32	2416590	781.67	3198448	816.39	3061548
FrodoKEM-976-AES (x86_64-ref)	927.36	2695800	601.13	4158205	639.33	3910549
FrodoKEM-976-AES (x86_64-noport)	1098.97	2274447	841.00	2972547	879.33	2842783
FrodoKEM-976-SHAKE (x86_64)	370.88	6740124	339.44	7364107	315.56	7921259
FrodoKEM-976-SHAKE (x86_64-ref)	155.56	16070978	143.05	17476562	143.90	17369605
FrodoKEM-976-SHAKE (x86_64-noport)	478.51	5223916	430.05	5812636	441.00	5669368

SIG memory consumption

☰ Bytes per algorithm

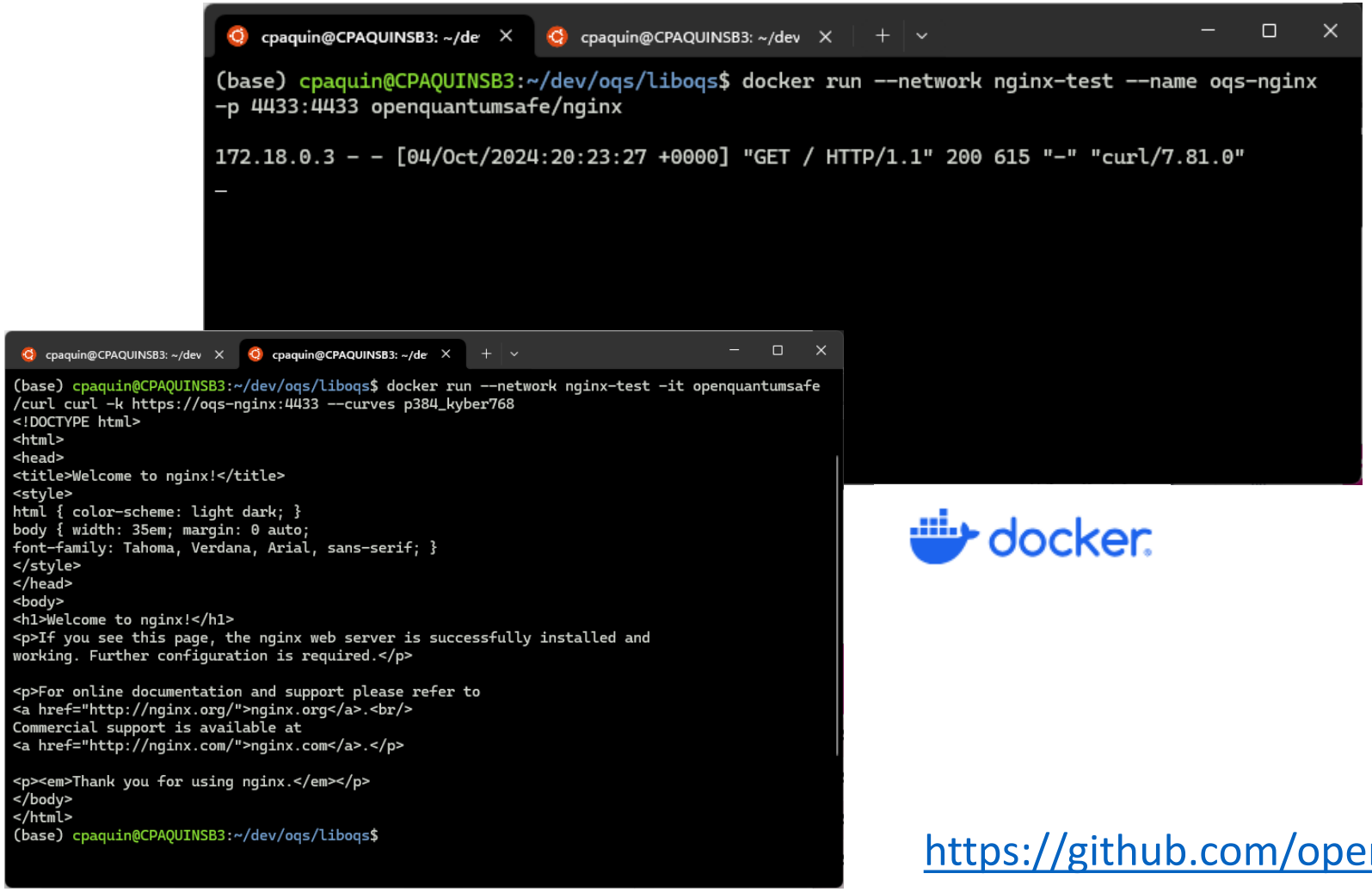
Raw Data 2021-08-31

Algorithm	keygen(maxHeap)	keygen(maxStack)	sign(maxHeap)	sign(maxStack)	verify(maxHeap)	verify(maxStack)
Dilithium2 (x86_64)	12656	20880	11584	49616	11360	21592
Dilithium2 (x86_64-ref)	12656	38952	15400	51360	10752	37120
Dilithium2-AES (x86_64)	12656	17040	15400	44816	10528	14800
Dilithium2-AES (x86_64-ref)	12656	38952	15400	51360	10752	37816
Falcon-512 (x86_64)	10994	19216	11784	40944	11784	2320
Falcon-512 (x86_64-ref)	10994	19200	11784	40944	11784	2304

SSH

- Implements draft-kampanakis-curdle-ssh-pq-ke-04
- OpenSSH: OQS enabled version of OpenSSH v9.7
  - KEM: BIKE, ClassicMcEliece, FrodoKEM, HQC, Kyber, ML-KEM, NTRU-Prime
  - Sig: Dilithium, Falcon, MAYO, ML-DSA, SPHINCS+
- Libssh (inactive)

OQS Demos



Supported

- curl
- Apache httpd
- nginx
- Chromium

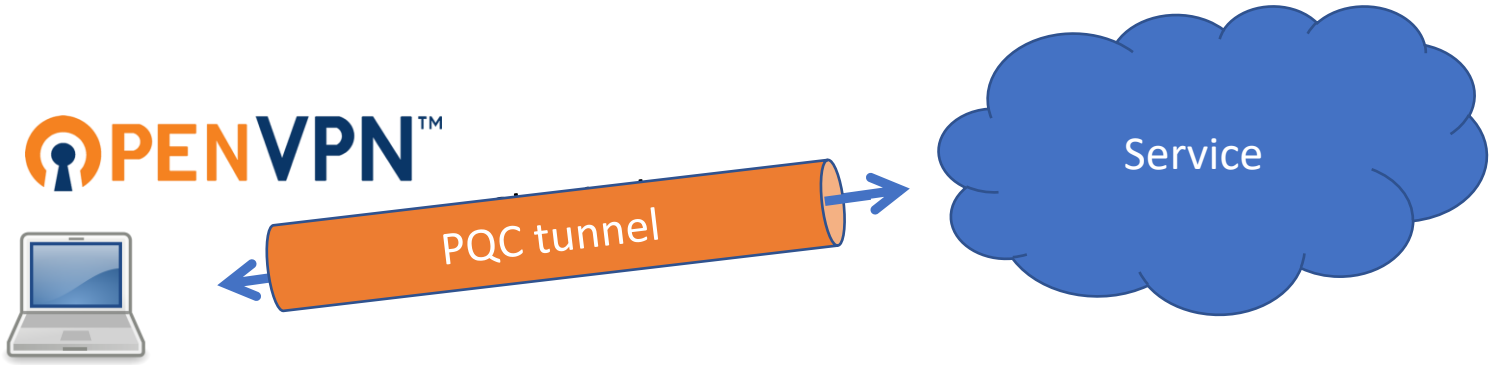
Unsupported

- OpenSSH
- Wireshark
- Epiphany
- OpenVPN
- ngtcp2
- OpenLiteSpeed
- h2load
- HAproxy
- Mosquitto
- Envoy
- Unbound

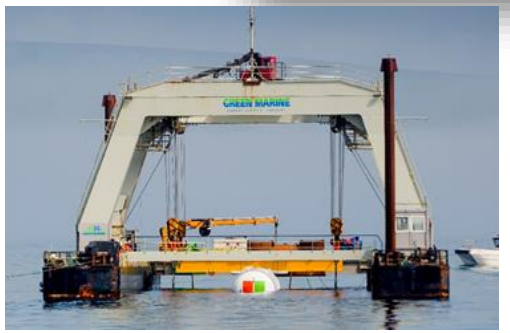
https://github.com/open-quantum-safe/oqs-demos

PQ VPN tunnels

- OpenVPN integration
  - Uses OQS's OpenSSL fork
  - Easy legacy app tunneling
  - https://www.microsoft.com/en-us/research/project/post-quantum-crypto-vpn/



- Project Natick PQC VPN experiment
  - Natick was an underwater datacenter module off the coast of Scotland
  - We ran a PQ VPN from Redmond
    - Used ECDHE-P256 + SIKEp434 hybrid



- https://www.microsoft.com/en-us/research/project/post-quantum-crypto-tunnel-to-the-underwater-datacenter/

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Migration to PQC project

Two workstreams

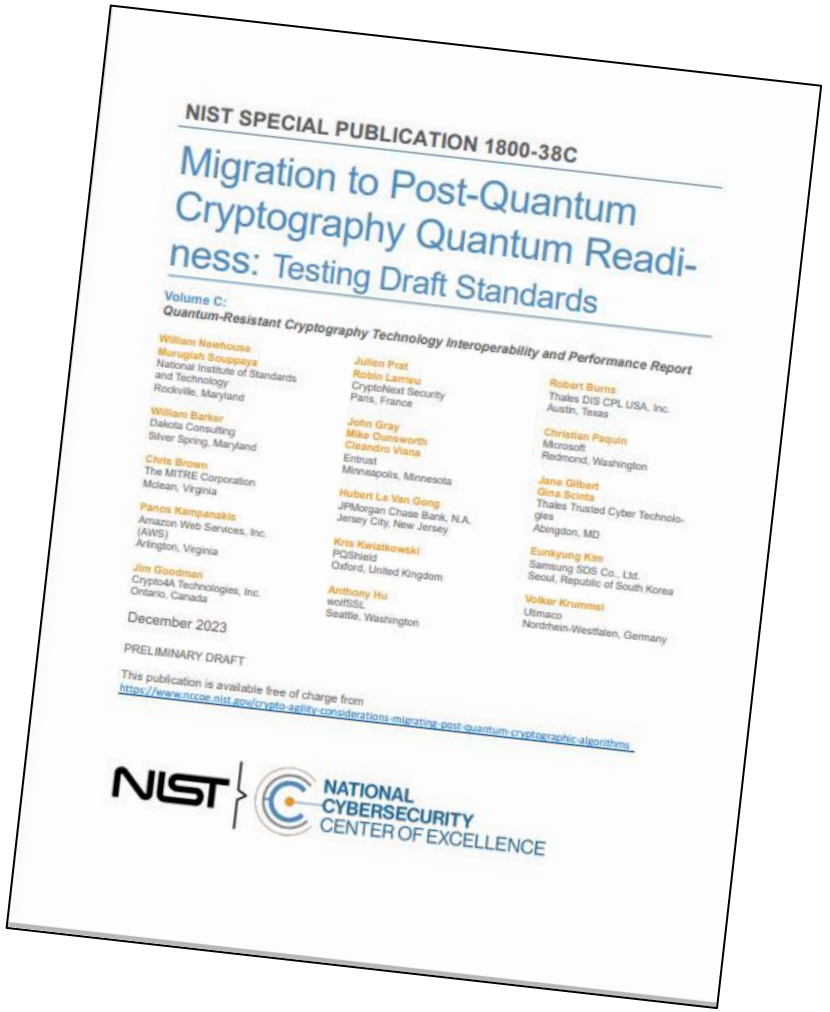
- Vulnerable cryptography detection
- Interoperability and performance

- Amazon Web Services, Inc. (AWS)
- ATIS
- Cisco Systems, Inc.
- Comcast
- Crypto4A Technologies, Inc.
- CryptoNext Security
- Cybersecurity and Infrastructure Security Agency (CISA)
- Data-Warehouse GbmH
- Dell Technologies
- DigiCert
- Entrust
- Gutsy
- HP, Inc.
- HSBC
- IDEMIA Secure Transactions
- IBM
- Information Security Corporation
- InfoSec Global
- ISARA Corporation
- JPMorgan Chase Bank, N.A.
- Keyfactor
- Kudelski IoT
- Microsoft
- National Security Agency (NSA)
- NXP Semiconductors
- Palo Alto Networks
- Post-Quantum
- PQShield
- QuantumXchange
- SafeLogic, Inc.
- Samsung SDS Co., Ltd.
- SandboxAQ
- Santander
- SSH Communications Security Corp
- Thales DIS CPL USA, Inc.
- Thales Trusted Cyber Technologies
- Utimaco
- Verizon
- wolfSSL

https://www.nccoe.nist.gov/crypto-agility-considerations-migrating-post-quantum-cryptographic-algorithms

NCCoE – Interoperability & Performance

- Testing PQC integration in
  - TLS OQS
  - SSH OQS
  - HSM
  - X.509 OQS
  - VPN



NIST SPECIAL PUBLICATION 1800-38C

Migration to Post-Quantum Cryptography Quantum Readiness: Testing Draft Standards

Volume C:
Quantum-Resistant Cryptography Technology Interoperability and Performance Report

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PRELIMINARY DRAFT

This publication is available free of charge from
https://www.nccoe.nist.gov/crypto-agility-considerations-migrating-post-quantum-cryptographic-algorithms

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Get involved

OQS has been at the forefront of PQC standardization, prototyping, and product integration.

The work continues!

https://github.com/open-quantum-safe/

https://discord.gg/qRfMantKwc

cpaquin@microsoft.com