Migrating to quantum-safe crypto to protect against the quantum hacker

CRYPTO + PRIVACY VILLAGE

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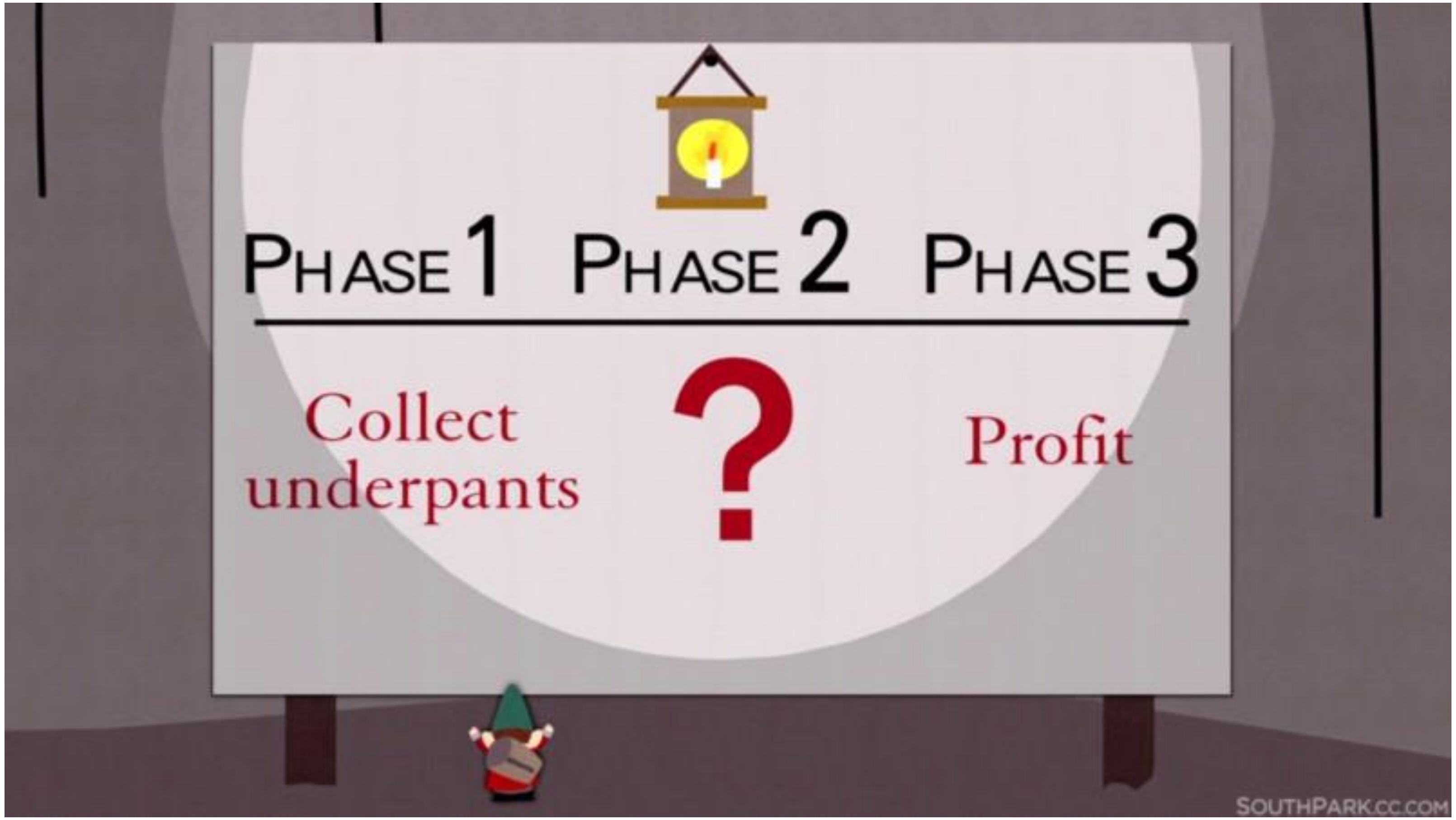
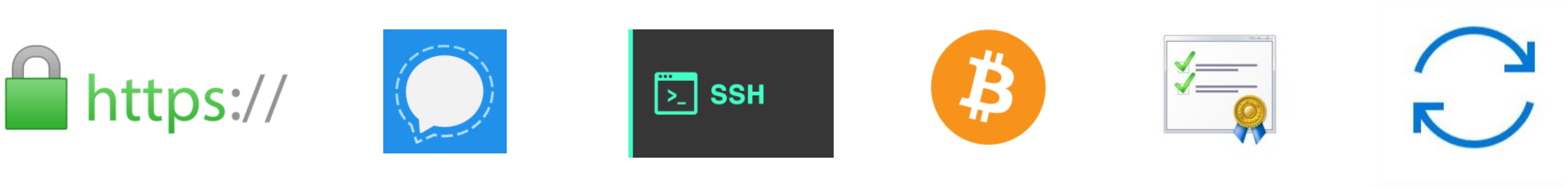
Turns out the underpants business isn’t great



The Quantum Menace

- Quantum computers are bad news for cryptography!
    - Shor (1994) solves the factoring (breaks RSA) and discreet log (breaks DSA, Diffie Hellman, and elliptic curve variants) problems in polynomial time

- Breaks ~~most~~ all the asymmetric crypto in use today



- Could be built within 10-15 years

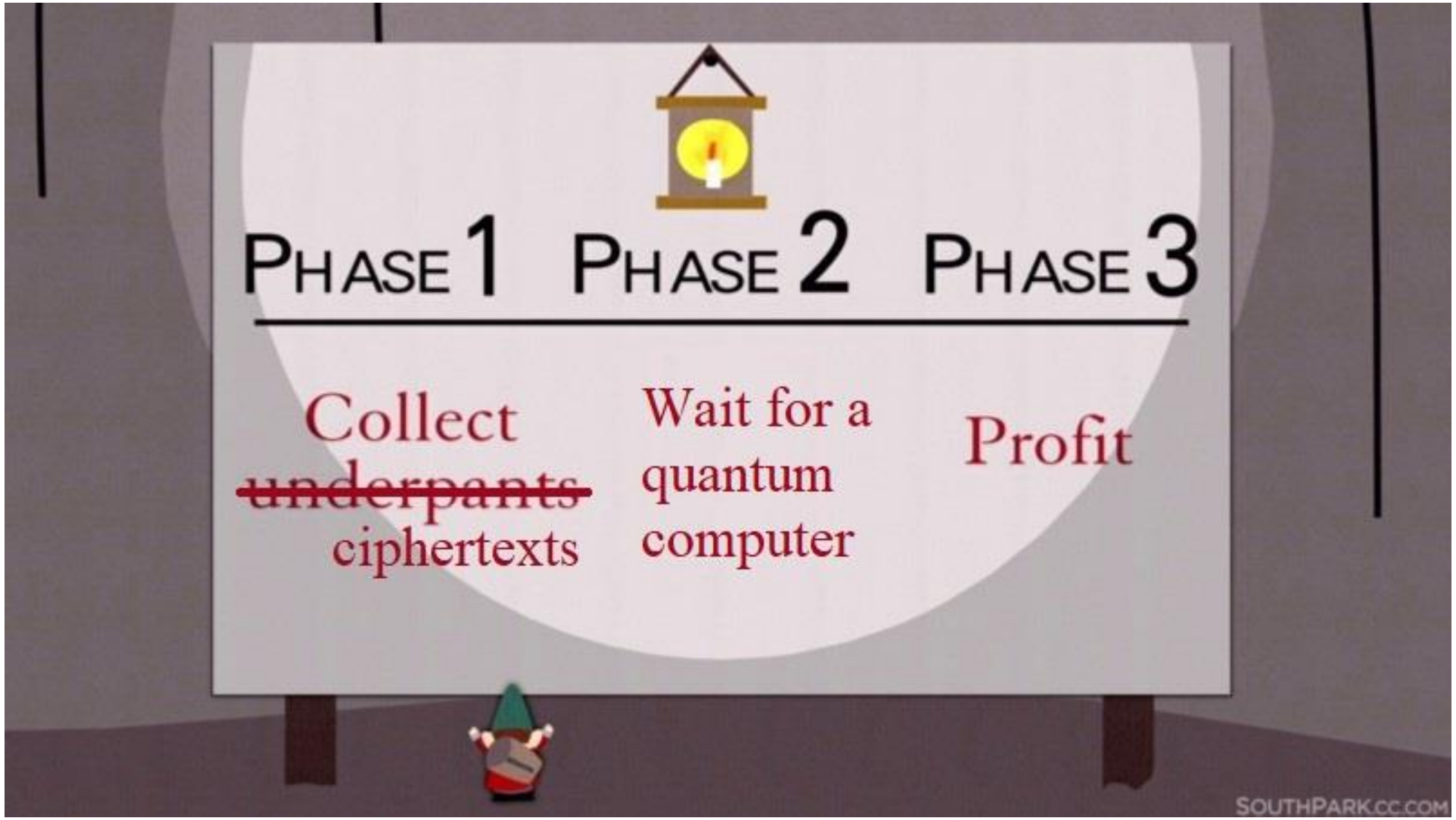
- We need new *quantum-safe* cryptography

Need to migrate to quantum-safe crypto soon

- Capture now, decrypt later
- Updating standards is loooooong
  - TLS, SSH, IKE, PKI, S/MIME, …
- Unknown impact on code base
  - Longer key/message/sig sizes
  - Slower running times
  - Code agility

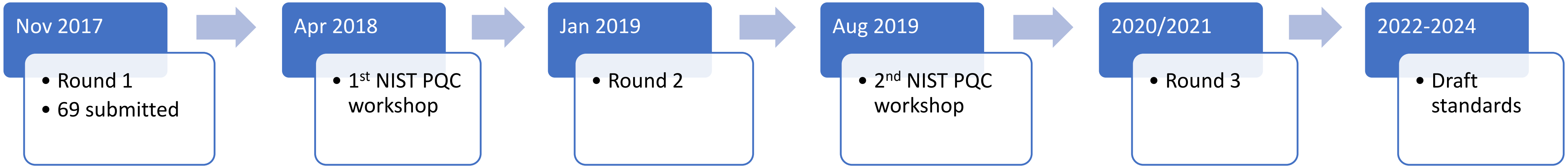
Do your apps protect data that needs to be kept secret for more than 10 years?

Hacker gnomes have a new business model



PHASE 1
PHASE 2
PHASE 3
Collect ~~underpants~~ ciphertexts
Wait for a quantum computer
Profit
SOUTHPARK.CC.COM

NIST competition



Nov 2017
- Round 1
- 69 submitted

Apr 2018
- 1st NIST PQC workshop

Jan 2019
- Round 2

Aug 2019
- 2nd NIST PQC workshop

2020/2021
- Round 3

2022-2024
- Draft standards

Encryption / Key Encapsulation

BIG QUAKE
BIKE
CFPKM
Classic McEliece
Compact LWE
CRYSTALS-KYBER
DAGS
Ding KEX
DME
EMBLEM
R.EMBLEM
FrodoKEM
Giophantus

Guess Again
HILA5
HQC
KCL
KINDI
LAC
LAKE
LEDAkem
LEDApkc
Lepton
LIMA
Lizard
LOCKER

LOTUS
McNie
Mersenne756839
NewHope
NTRUEncrypt
NTRU-HRSS-KEM
NTRU Prime
NTS-KEM
Odd Manhattan
Ouroboros-R
PQ RSA-Enc
QC-MDPC KEM
Ramstake

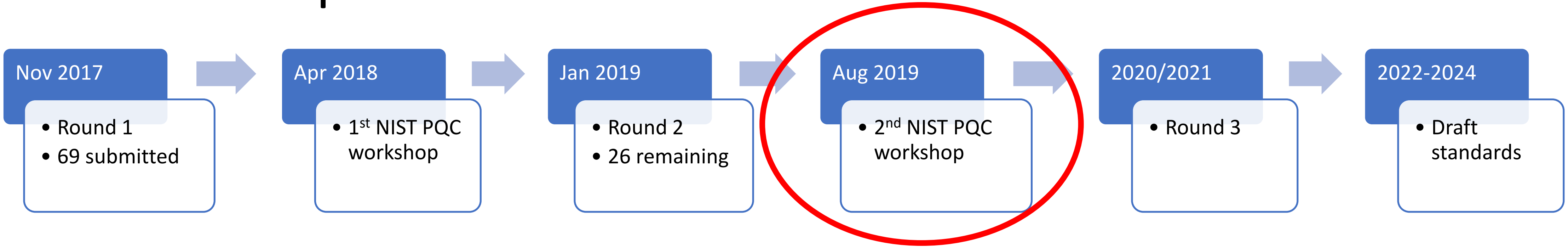
RLCE-KEM
Round2
RQC
SABER
SIKE
Three Bears
Titanium

Signature

CRYSTALS-DILITHIUM
DRS
DualModeMS
FALCON
GeMSS
Gravity-SPHINCS
Gui
HiMQ-3
LUOV
MQDSS

pqNTRUSign
Picnic
PQ RSA-Sig
pqsigRM
qTESLA
RaCoSS
Rainbow
SPHINCS+
WalnutDSA

NIST competition



Nov 2017
- Round 1
- 69 submitted

Apr 2018
- 1st NIST PQC workshop

Jan 2019
- Round 2
- 26 remaining

Aug 2019
- 2nd NIST PQC workshop

2020/2021
- Round 3

2022-2024
- Draft standards

Encryption / Key Encapsulation

BIKE
Classic McEliece
CRYSTALS-KYBER
FrodoKEM

HQC
LAC
LEDAcrypt

NewHope
NTRU
NTRU Prime
NTS-KEM
ROLLO

Round5
RQC
SABER
SIKE
Three Bears

Signature

CRYSTALS-DILITHIUM
FALCON
GeMSS
LUOV
MQDSS

Picnic
qTESLA
Rainbow
SPHINCS+

OPEN QUANTUM SAFE

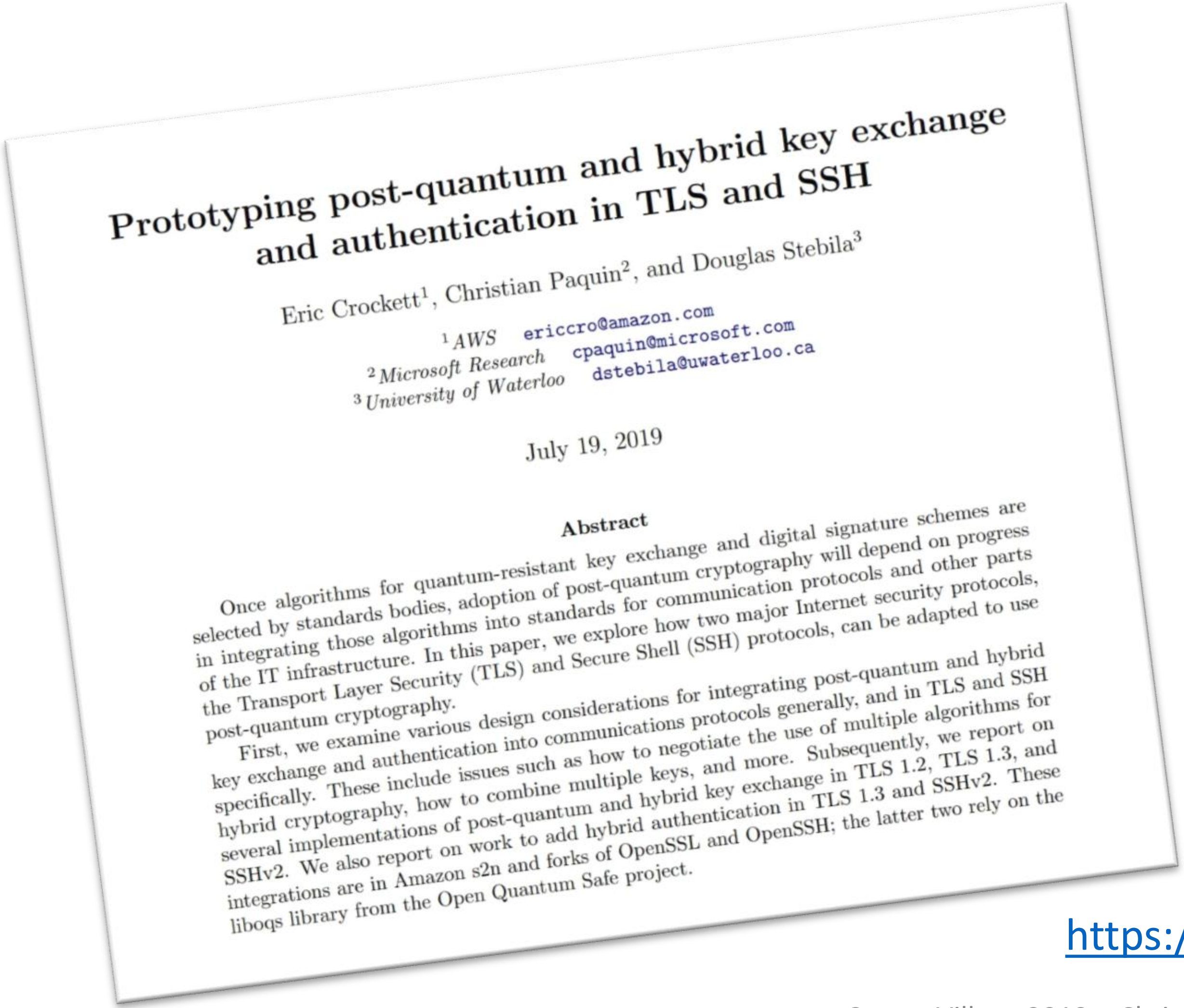
- C library created to simplify integration of PQC into applications
- Contributions from

University of Waterloo · Microsoft · amazon web services™ · Institut Tutte Institute · Royal Holloway University of London

evolutionQ · SRI International · Radboud University · cisco

- Round 2 schemes supported: 9 of 17 KEMs, 6 of 9 signatures
    - v0.2.0 (RC1 released Aug 7th, final on Aug 21st)
- Integrations into OpenSSL, OpenSSH, OpenVPN
    - New: PQC/hybrid KEX/auth in TLS 1.3 and SSH
- C++, C#, and Python wrappers
- https://openquantumsafe.org/

Prototyping PQC paper



Prototyping post-quantum and hybrid key exchange and authentication in TLS and SSH

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Abstract

Once algorithms for quantum-resistant key exchange and digital signature schemes are selected by standards bodies, adoption of post-quantum cryptography will depend on progress in integrating those algorithms into standards for communication protocols and other parts of the IT infrastructure. In this paper, we explore how two major Internet security protocols, the Transport Layer Security (TLS) and Secure Shell (SSH) protocols, can be adapted to use post-quantum cryptography.

First, we examine various design considerations for integrating post-quantum and hybrid key exchange and authentication into communications protocols generally, and in TLS and SSH specifically. These include issues such as how to negotiate the use of multiple algorithms for hybrid cryptography, how to combine multiple keys, and more. Subsequently, we report on several implementations of post-quantum and hybrid key exchange in TLS 1.2, TLS 1.3, and SSHv2. We also report on work to add hybrid authentication in TLS 1.3 and SSHv2. These integrations are in Amazon s2n and forks of OpenSSL and OpenSSH; the latter two rely on the liboqs library from the Open Quantum Safe project.

- Analyze various options to integrate PQC into TLS and SSH
- Focusses on hybrid scenarios
- Lessons learned from OpenSSL, OpenSSH, and s2n integrations

https://eprint.iacr.org/2019/858

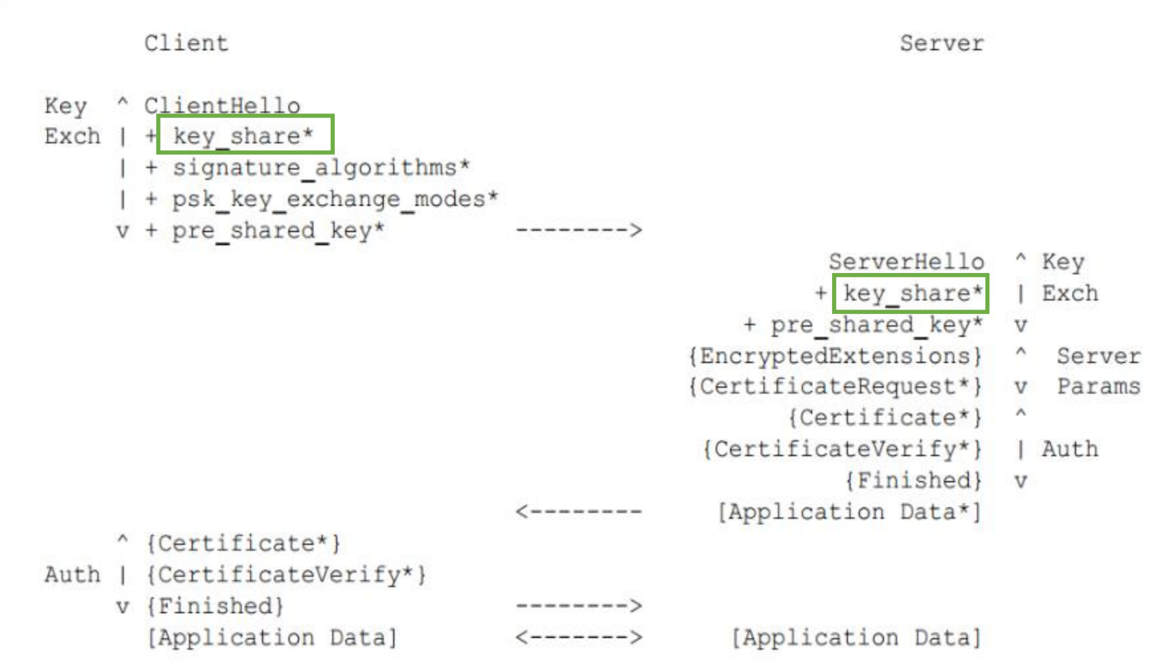
https://openquantumsafe.org/papers/NISTPQC-CroPaqSte19.pdf

Hybrid scenarios

- Early migration should use a hybrid of classical/PQ scheme
  - Security of today + safety net against quantum computer
  - Secure if one of the two is secure
- TLS and SSH negotiate algorithms, but not two at the same time. We need to define either:
  - new combo schemes, e.g. ECDHE-SIKEp503:
    - Easy to implement, backward compatible
  - a new hybrid approach:
    - Flexible negotiation (algs selected separately), need spec/code changes
- Consider backward compatibility, performance, latency, data flow
- Implemented approach: combo schemes and concatenation of keys, ciphertexts, and signatures

AS SEEN IN OQS

TLS case study



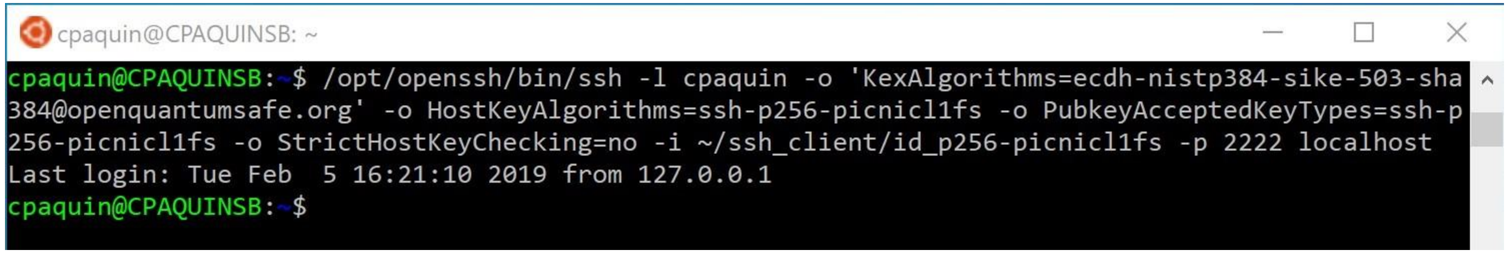
```
       Client                                           Server

Key  ^ ClientHello
Exch | + key_share*
     | + signature_algorithms*
     | + psk_key_exchange_modes*
     v + pre_shared_key*       -------->
                                                  ServerHello  ^ Key
                                                 + key_share*  | Exch
                                            + pre_shared_key*  v
                                        {EncryptedExtensions}  ^  Server
                                        {CertificateRequest*}  v  Params
                                               {Certificate*}  ^
                                         {CertificateVerify*}  | Auth
                                                   {Finished}  v
                               <--------  [Application Data*]
     ^ {Certificate*}
Auth | {CertificateVerify*}
     v {Finished}              -------->
       [Application Data]      <------->  [Application Data]
```

- Added PQ/hybrid KEX & auth
- TLS 1.2 (OpenSSL 1.0.2)
  - Explosion of schemes (specifies KEX, auth, symmetric cipher, hash)
  - Spec message size limit: 2^{24} bytes. OpenSSL limit smaller
  - Tested with OpenSSL tools, apache, OpenVPN
- TLS 1.3 (OpenSSL 1.1.1)
  - PQ algs masquerade as EC curves
  - Concat strategy more secure than 1.2 (KDF hashes transcripts)
  - Spec pub key and sig limit: 2^{16}-1 bytes, cert limit: 2^{24}-1 bytes. OpenSSL limit is smaller
  - Tested with OpenSSL tools, nginx
- https://github.com/open-quantum-safe/openssl

SSH case study

- Added PQ/hybrid KEX & auth to OpenSSH
- Define new algorithms, e.g.: ecdh-nistp384-sike-503-sha384@openquantumsafe.org
- Supports both client and server public key authentication
- Spec message size limit: 2^{32} bytes, large enough for all round 2 candidates, but OpenSSH limit is smaller (2^{18})
- https://github.com/open-quantum-safe/openssh-portable



```
cpaquin@CPAQUINSB:~$ /opt/openssh/bin/ssh -l cpaquin -o 'KexAlgorithms=ecdh-nistp384-sike-503-sha
384@openquantumsafe.org' -o HostKeyAlgorithms=ssh-p256-picnicl1fs -o PubkeyAcceptedKeyTypes=ssh-p
256-picnicl1fs -o StrictHostKeyChecking=no -i ~/ssh_client/id_p256-picnicl1fs -p 2222 localhost
Last login: Tue Feb  5 16:21:10 2019 from 127.0.0.1
cpaquin@CPAQUINSB:~$
```

Key Encapsulation Mechanisms

KEM scheme	OpenSSL 1.0.2 TLS 1.2	OpenSSL 1.1.1 TLS 1.3	OpenSSH 7.9 SSH2
BIKE 1/2/3 L1/3/5 (round 1)	✓	✓	✓
Frodo KEM 640/976 AES/SHAKE	✓	✓	✓
Frodo KEM 1344 AES/SHAKE	☑	☑	✓
Kyber 512/768/1024	✓	✓	✓
LEDAcrypt KEM LT 12/32/52	✓	✓	✓
NewHope 512/1024 CCA	✓	✓	✓
NTRU HPS (2048-509/677)/(4096-821)	✓	✓	✓
NTRU HRSS 701	✓	✓	✓
NTS KEM (12,64)	✗	✗	✗
LightSaber/Saber/FireSaber KEM	✓	✓	✓
SIKE p434/p503/p610/p751	✓	✓	✓

KEM integrations for both PQ and hybrid (with ECDHE)

<u>Legend</u>:

✓ Success

☑ Works with code mods

✗ Doesn't work (large keys)

Signatures

KEM scheme	OpenSSL 1.1.1 TLS 1.3	OpenSSH 7.9 SSH2
Dilithium 2/3/4	✓	✓
MQDSS 31 48/64	☑	✓
Picnic L1 FS/UR	☑	✓
Picnic L3/L5 FS/UR	✗	✓
Picnic2 L1 FS	✓	✓
Picnic2 L3/L5 FS	☑	✓
qTesla I/III-size/III-speed (round 1)	✓	✓
Rainbow Ia Classic	☑	☑
Rainbow Ia Cyclic/Compressed	✓	✓
Rainbow IIIc/Vc Classic/Cyclic/Compressed	☑	✗
SPHINCS+ * 128s *	✓	✓
SPHINCS+ * 128f/192f/192s/256f/256s *	☑	✓

Signature integrations for both PQ and hybrid (with ECDSA)

Legend:

✓ Success

☑ Works with code mods

✗ Doesn't work (large sig)

Demo

SSH2 – OpenSSH 7.9

- KEX: ECDHE P384 + SIKE 503
- Auth: ECDSA P256 + Picnic L1FS
    - Both client and server

What’s next?

For us

- Test all round 2 schemes
- Performance test
- More protocols

For you

- Start planning migration to PQC
- Start using some tools (SSH, OpenVPN)

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