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Terminology for Post-Quantum Cryptography (PQC) ~~Traditional~~ Hybrid Schemes

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Abstract

One aspect of the transition to post-quantum algorithms in cryptographic protocols is the development of hybrid schemes that incorporate both post-quantum and ~~traditional~~ conventional asymmetric algorithms.

This document defines terminology for such schemes. It is intended to be used as a reference and, hopefully, ~~to~~ ensure consistency and clarity across different protocols, standards, and organisations.

About This Document

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Status information for this document may be found at https://datatracker.ietf.org/doc/draft-driscoll-pqt-hybrid-terminology/.

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Commenté [BMI1]: To align with https://www.ietf.org/about/groups/iesg/statements/on-inclusive-language/

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1. Introduction

The mathematical problems of integer factorisation and discrete logarithms over finite fields or elliptic curves underpin most of the asymmetric algorithms used for key establishment and digital signatures on the internet. These problems, and hence the algorithms based on them, will be vulnerable to attacks using Shor's Algorithm on a sufficiently large general-purpose quantum computer, known as a Cryptographically Relevant Quantum Computer (CRQC). It is difficult to predict when, or if, such a device will exist. However, it is necessary to anticipate and elaborate ~~defend~~ defense against ~~this possibility~~such vulnerability. Data encrypted today (2022) with an algorithm vulnerable to a quantum computer could be stored for decryption by a future attacker with a CRQC. Signing algorithms that are expected to be in use for many years are also at risk if a CRQC is developed during the operational lifetime of ~~the~~ an algorithm.

Preparing for the potential development of a CRQC requires modifying established (~~standardised~~standardized) protocols to use asymmetric algorithms that are ~~believed~~perceived to be secure against quantum computers as well as today's classical computers. These algorithms are called post-quantum, while algorithms based on integer factorisation, finite-field discrete logarithms or elliptic-curve discrete logarithms are called ~~traditional~~ conventional algorithms.

During the transition from conventional~~traditional~~ to post-quantum algorithms, there may be a ~~desire or a requirement~~need for protocols that use both algorithm types ~~of algorithm~~. Most post-quantum algorithms are less well studied than conventional ~~traditional~~ asymmetric algorithms, so a designer may choose to combine a post-quantum algorithm with a conventional~~traditional~~ algorithm to add protection against an attacker with a CRQC to the security properties provided by the conventional ~~traditional~~ algorithm. A designer may also choose to implement a post-quantum algorithm alongside a conventional ~~traditional~~ algorithm for ease of migration from an

ecosystem where only conventional ~~traditional~~ algorithms are implemented and used,
to one which uses post-quantum algorithms. Examples ~~Work on~~of solutions that
could use both algorithm types ~~of algorithm~~ includes, but not limited to,
[I-D.ietf-ipsecme-ikev2-multiple-ke], [I-D.ietf-tls-hybrid-design],
[I-D.ounsworth-pq-composite-sigs], and
[I-D.becker-guthrie-noncomposite-hybrid-auth].

Schemes that combine
post-quantum and conventional ~~traditional~~ algorithms for key establishment or
digital signatures are often called hybrids. For example~~,~~ :
* NIST
~~define~~ defines hybrid key establishment to be a "scheme that is a combination
of two or more components that are themselves cryptographic key-establishment schemes" [NIST_PQC_FAQ]
* ~~and~~ ETSI ~~define~~ defines hybrid key
exchanges to be "constructions that combine a traditional key exchange...with a post-quantum key exchange...into a single key exchange" [ETSI_TS103774].

The word "hybrid" is also used in
cryptography to describe encryption schemes that combine asymmetric and symmetric algorithms [RFC9180], so using it in the post-quantum
context overloads it and risks misunderstandings. ~~However~~In the meantime, this
terminology is well-established amongst the post-quantum cryptography (PQC)
community. Therefore, ~~so~~ an attempt to move away from its use in for PQC could lead to
multiple definitions for the same concept, resulting in confusion and lack of clarity.

This document provides language for constructions that combine conventional~~traditional~~ and post-quantum algorithms. Specific solutions for
enabling use of multiple asymmetric algorithms in cryptographic schemes may in fact be more general than this, allowing the use of
solely conventional~~traditional~~, or solely post-quantum algorithms. However,
where relevant, we focus on combinations of post-quantum and conventional~~traditional~~ algorithms as these are the motivation for the wider work
in the IETF. ~~It~~ This document is intended as a reference terminology guide for other
documents to add clarity and consistency across different protocols,
standards, and hopefully organisations. Additionally, ~~it~~ this document aims to reduce
misunderstanding about use of the word "hybrid" as well as defining a shared language for different types of post-quantum/ conventional~~traditional~~
hybrid constructions.

In this document, a "cryptographic algorithm" is defined, as in [NIST_SP_800-152], to be a "well-defined computational procedure that

Commenté [BMI2]: I would add a pointer to RFC4949 where an entry is provided for this term:

$ hybrid encryption
(I) An application of cryptography that combines two or more
encryption algorithms, particularly a combination of symmetric and
asymmetric encryption. Examples: digital envelope, MSP, PEM, PGP.
(Compare: superencryption.)

takes variable inputs, often including a cryptographic key, and produces an output". Examples include RSA, ECDH, CRYSTALS-Kyber, and CRYSTALS-Dilithium.

Also, ~~The~~ the expression "cryptographic scheme" ~~is used~~ refers to ~~mean~~ a construction that uses an algorithm or a group of algorithms to achieve a particular cryptographic outcome, e.g., key agreement. A cryptographic scheme may be made up of a number of functions. For example, a Key Encapsulation Mechanism (KEM) is a cryptographic scheme consisting of three functions: Key Generation, Encapsulation, and Decapsulation. A cryptographic protocol incorporates one or more cryptographic schemes. For example, TLS [RFC8446] is a cryptographic protocol which includes ~~schemes~~ mechanisms for key agreement, record layer encryption, and server authentication.

The document uses terms defined in [RFC4949], such as "cryptographic algorithm".

2. Primitives

This section introduces terminology related to cryptographic algorithms, as well as to hybrid constructions for cryptographic schemes.

~~Traditional~~ Conventional Algorithm: An asymmetric cryptographic algorithm based on integer factorisation, finite field discrete logarithms, or elliptic curve discrete logarithms.

Post-Quantum Algorithm: An asymmetric cryptographic algorithm that is believed to be secure against attacks performed using quantum computers as well as classical computers.

Component Algorithm: Each cryptographic algorithm that forms part of a cryptographic scheme.

Single-Algorithm Scheme: A cryptographic scheme with one component algorithm.

A single-algorithm scheme could use either a ~~traditional~~ conventional algorithm or a post-quantum algorithm.

Multi-Algorithm Scheme: A cryptographic scheme with more than one component algorithm.

In a multi-algorithm scheme all component algorithms are of the same type, e.g., all are signature algorithms or all are Public Key Encryption (PKE) algorithms.

Post-Quantum/~~Traditional~~ Conventional (PQ/~~T~~C) Hybrid Scheme: A cryptographic scheme made up of two or more component algorithms where at least

one is a post-quantum algorithm and at least one is a conventional~~traditional~~ algorithm.

PQ/~~T~~C Hybrid Key Encapsulation Mechanism: A Key Encapsulation Mechanism (KEM) made up of two or more component KEM algorithms, where at least one is a post-quantum algorithm and at least one is a conventional ~~traditional~~ algorithm.

PQ/~~T~~C Hybrid Public Key Encryption: A Public Key Encryption (PKE) scheme made up of two or more component PKE algorithms where at least one is a post-quantum algorithm and at least one is a conventional ~~traditional~~ algorithm.

PQ/~~T~~C Hybrid Digital Signature: A digital signature scheme made up of two or more component digital signature algorithms where at least one is a post-quantum algorithm and at least one is a conventional ~~traditional~~ algorithm.

PQ/C~~T~~ hybrid KEMs, PQ/~~T~~C hybrid PKE, and PQ/~~T~~C hybrid digital signatures are all examples of PQ/~~T~~C hybrid schemes.

PQ/~~T~~C Hybrid Combiner: A method that takes two or more component algorithms and combines them to form a PQ/~~T~~C hybrid scheme.

PQ/PQ Hybrid Scheme: A cryptographic scheme made up of two or more component algorithms where all components are post-quantum algorithms.

The definitions for types of PQ/~~T~~C hybrid schemes can adapted to define types of PQ/PQ hybrid schemes in the natural way.

Commenté [BMI3]: That is?

3. Cryptographic Elements

This section introduces terminology related to cryptographic elements and their inclusion in hybrid schemes.

Cryptographic Element: Any data type (private or public) that contains an input or output value for a cryptographic algorithm or for a function making up a cryptographic algorithm.

Types of cryptographic elements include public keys, private keys, plaintexts, ciphertexts, shared secrets, and signature values.

Component Cryptographic Element: A cryptographic element of a component algorithm in a multi-algorithm scheme.

Composite Cryptographic Element: A cryptographic element that incorporates multiple component cryptographic elements of the same type in a multi-algorithm scheme.

For example, a composite cryptographic public key is made up of two component public keys.

Cryptographic Element Combiner: A method that takes two or more component cryptographic elements of the same type and combines them to form a composite cryptographic element.

A cryptographic element combiner could be concatenation, such as where two component public keys are concatenated to form a composite public key as in [I-D.ietf-tls-hybrid-design], or something more involved such as the dualPRF defined in [BINDEL].

4. Protocols

This section introduces terminology related to the use of post-quantum and conventional ~~traditional~~ algorithms together in protocols.

PQ/~~T~~C Hybrid Protocol: A protocol that uses two or more component algorithms providing the same cryptographic functionality, where at least one is a post-quantum algorithm and at least one is a conventional ~~traditional~~ algorithm.

For example, a PQ/~~T~~C hybrid protocol providing confidentiality could use a PQ/~~T~~C hybrid KEM such as in [I-D.ietf-tls-hybrid-design], or it could combine the output of a post-quantum KEM and a traditional KEM at the protocol level, such as in [I-D.ietf-ipsecme-ikev2-multiple-ke]. Similarly, a PQ/~~T~~C hybrid protocol providing authentication could use a PQ/~~T~~C hybrid digital signature scheme, or it could include both post-quantum and conventional ~~traditional~~ single-algorithm digital signature schemes.

Composite PQ/~~T~~C Hybrid Protocol: A protocol that incorporates one or more PQ/~~T~~C hybrid schemes in such a way that the protocol fields and message flow are the same as those in a version of the protocol that uses single-algorithm schemes.

In a composite PQ/~~T~~C hybrid protocol, changes are primarily made to the formats of the cryptographic elements, while the protocol fields and message flow remain largely unchanged. In implementations most changes are likely to be made to the cryptographic libraries, with minimal changes to the protocol libraries.

Non-composite PQ/~~T~~C Hybrid Protocol: A protocol that incorporates multiple single-algorithm schemes of the same type, where at least one uses a post-quantum algorithm and at least one uses a conventional ~~traditional~~ algorithm, in such a way that the formats of the component cryptographic elements are the same as when they are used as part of single-algorithm schemes.

In a non-composite PQ/~~T~~C hybrid protocol, changes are primarily made to the protocol fields, the message flow, or both, while changes to cryptographic elements are minimised. In implementations, most changes are likely to be made to the protocol libraries, with minimal changes to the cryptographic libraries.

NOTE: A PQ/~~T~~C hybrid protocol could be neither entirely composite nor entirely non-composite. For example, in a protocol that offers both confidentiality and authentication, the key establishment could be done in a composite manner while the authentication is done in a non-

composite manner.

5. Functionality

This section describes properties that may be desired from or achieved by a PQ/T hybrid scheme or PQ/~~T~~C hybrid protocol.

PQ/~~T~~C Hybrid Confidentiality: The property that confidentiality is achieved by a PQ/C~~T~~ hybrid scheme or PQ/T hybrid protocol as long as at least one component encryption algorithm remains secure.

PQ/T Hybrid Authentication: The property that authentication is achieved by a PQ/T hybrid scheme or a PQ/T hybrid protocol as long as at least one component authentication algorithm remains secure.

EDNOTE 1: It may be useful to distinguish between source authentication (i.e., authentication of the sender of a particular message) and identity authentication (i.e., authentication of the identity of the sender).

The security properties of a PQ/T hybrid scheme or protocol depend on the security of its component algorithms, the choice of PQ/T hybrid combiner and the capability of an attacker. Changes to the security of a component algorithm can impact the security properties of a PQ/T hybrid scheme providing hybrid confidentiality or hybrid authentication. For example, if a post-quantum component algorithm is broken, the PQ/T hybrid scheme is likely to continue to achieve confidentiality against a classical attacker, but will be vulnerable to a quantum attacker.

Note that PQ/T hybrid protocols that offer both confidentiality and authentication do not necessarily offer both PQ/T hybrid confidentiality and PQ/T hybrid authentication. For example, [I-D.ietf-tls-hybrid-design] provides PQ/T hybrid confidentiality but does not address authentication. Therefore, if the design in [I-D.ietf-tls-hybrid-design] is used with X.509 certificates as defined in [RFC5280] only authentication with a single algorithm is achieved.

PQ/T Hybrid Interoperability: The property that a PQ/T hybrid scheme or PQ/T hybrid protocol can be completed successfully provided that both parties support at least one component algorithm.

For example, a PQ/T hybrid digital signature might achieve hybrid interoperability if the signature can be verified by either verifying the traditional or the post-quantum component, such as in the OR modes described in [I-D.ounsworth-pq-composite-sigs].

In the case of a PQ/T hybrid protocol which aims to achieve both authentication and confidentiality then at least one component algorithm for each type of scheme must be supported by both parties.

It is not possible for a PQ/T hybrid scheme to achieve both PQ/T hybrid interoperability and PQ/T hybrid confidentiality. For PQ/T hybrid interoperability the scheme needs to work with any one of the component algorithms, while to achieve PQ/T hybrid

confidentiality all component algorithms need to be used. However, it is possible for a PQ/T hybrid protocol to achieve PQ/T hybrid interoperability and PQ/T hybrid confidentiality by building in downgrade protection at the protocol level. For example in [I-D.ietf-tls-hybrid-design] the client uses the TLS supported groups extension to advertise support for a PQ/T hybrid scheme and the server can select this group if it supports the scheme. This is protected using TLS's existing downgrade protection, so achieves PQ/T hybrid confidentiality, but the connection can still be made if either the client or server does not support the scheme, so PQ/T hybrid interoperability is achieved.

The same is true for PQ/T hybrid interoperability and PQ/T hybrid authentication. It is not possible to achieve both with a PQ/T hybrid scheme, but it is possible with a PQ/T hybrid protocol that has appropriate downgrade protection.

EDNOTE 2: Other properties may be desired from a PQ/T Hybrid scheme e.g. backwards compatibility, crypt agility. Should these be defined here?

6. Certificates

This section introduces terminology related to the use of certificates in hybrid schemes.

PQ/T Hybrid Certificate: A digital certificate that contains public keys for two or more component algorithms where at least one is a conventional ~~traditional~~ algorithm, and at least one is a post-quantum algorithm.

A PQ/T hybrid certificate could be used to facilitate a PQ/T hybrid authentication protocol. However, a PQ/T hybrid authentication protocol does not need to use a PQ/T hybrid certificate; separate certificates could be used for individual component algorithms.

The component public keys in a PQ/T hybrid certificate could be included as a composite public key or as individual component public keys.

The use of a PQ/T hybrid certificate does not necessarily achieve hybrid authentication of the identity of the sender; this is determined by properties of the chain of trust. For example, an end-entity certificate that contains a composite public key as defined in [I-D.ounsworth-pq-composite-keys] but which is signed using a single-algorithm digital signature scheme could be used to provide hybrid authentication of the source of a message, but would not achieve hybrid authentication of the identity of the sender.

TODO 1: Terminology for certificate chains and PKI.

TODO 2: Terminology for algorithm specification.

7. Security Considerations

This document defines security-relevant terminology to be used in documents specifying PQ/T hybrid protocols and schemes. However, the document itself does not have a security impact on ~~internet~~Internet protocols. The security considerations for each PQ/T hybrid protocol are specific to that protocol and should be discussed in the relevant specification documents.

8. IANA Considerations

This document has no IANA actions.

9. Informative References

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