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Postquantum Preshared Keys for IKEv2
draft-fluhrer-qr-ikev2-04

Abstract

The possibility of quantum computers pose a serious challenge to cryptography algorithms widely today. IKEv2 is one example of a cryptosystem that could be broken; someone storing VPN communications today could decrypt them at a later time when a quantum computer is available. It is anticipated that IKEv2 will be extended to support quantum secure key exchange algorithms; however that is not likely to happen in the near term. To address this problem before then, this document describes an extension of IKEv2 to allow it to be resistant to a Quantum Computer, by using preshared keys.

Status of This Memo

This Internet-Draft is submitted in full conformance with the provisions of BCP 78 and BCP 79.

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1. Introduction

It is an open question whether or not it is feasible to build a quantum computer (and if so, when might one be implemented), but if it is, many of the cryptographic algorithms and protocols currently in use would be insecure. A quantum computer would be able to solve DH and ECDH problems, and this would imply that the security of existing IKEv2 systems would be compromised. IKEv1 when used with strong preshared keys is not vulnerable to quantum attacks, because those keys are one of the inputs to the key derivation function. If the preshared key has sufficient entropy and the PRF, encryption and authentication transforms are postquantum secure, then the resulting system is believed to be quantum resistant, that is, believed to be invulnerable to an attacker with a Quantum Computer.

This document describes a way to extend IKEv2 to have a similar property; assuming that the two end systems share a long secret key, then the resulting exchange is quantum resistant. By bringing postquantum security to IKEv2, this note removes the need to use an obsolete version of the Internet Key Exchange in order to achieve that security goal.

The general idea is that we add an additional secret that is shared between the initiator and the responder; this secret is in addition

to the authentication method that is already provided within IKEv2. We stir in this secret into the SK_d value, which is used to generate the key material (KEYMAT) keys and the SKEYSEED for the child SAs; this secret provides quantum resistance to the IPsec SAs (and any child IKE SAs). We also stir in the secret into the SK_pi, SK_pr values; this allows both sides to detect a secret mismatch cleanly.

It was considered important to minimize the changes to IKEv2. The existing mechanisms to do authentication and key exchange remain in place (that is, we continue to do (EC)DH, and potentially a PKI authentication if configured). This does not replace the authentication checks that the protocol does; instead, it is done as a parallel check.

1.1. Changes

Changes in this draft from the previous versions

draft-03

- Modified how we stir the PPK into the IKEv2 secret state
- Modified how the use of PPKs is negotiated

draft-02

- Simplified the protocol by stirring in the preshared key into the child SAs; this avoids the problem of having the responder decide which preshared key to use (as it knows the initiator identity at that point); it does mean that someone with a Quantum Computer can recover the initial IKE negotiation.
- Removed positive endorsements of various algorithms. Retained warnings about algorithms known to be weak against a Quantum Computer

draft-01

- Added explicit guidance as to what IKE and IPsec algorithms are Quantum Resistant

draft-00

- We switched from using vendor ID's to transmit the additional data to notifications
- We added a mandatory cookie exchange to allow the server to communicate to the client before the initial exchange

- We added algorithm agility by having the server tell the client what algorithm to use in the cookie exchange
- We have the server specify the PPK Indicator Input, which allows the server to make a trade-off between the efficiency for the search of the clients PPK, and the anonymity of the client.
- We now use the negotiated PRF (rather than a fixed HMAC-SHA256) to transform the nonces during the KDF

1.2. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

2. Assumptions

We assume that each IKE peer has a list of Postquantum Preshared Keys (PPK) along with their identifiers (PPK_id), and any potential IKE initiator has a selection of which PPK to use with with any specific responder. In addition, the implementation has a configurable flag that determines whether this postquantum preshared key is mandatory. This PPK is independent of the preshared key (if any) that the IKEv2 protocol uses to perform authentication.

3. Exchanges

If the initiator is configured to use a postquantum preshared key with the responder (whether or not the use of the PPK is optional), then it will include a notify payload in the initial exchange as follows:

```

Initiator                               Responder
-----
HDR, SAi1, KEi, Ni, N(PPK_SUPPORT) --->

```

N(PPK_SUPPORT) is a status notification payload with the type [TBA]; it has a protocol ID of 0, and no SPI and no notification data associated with it.

If the initiator needs to resend this initial message with a cookie (because the responder response included a cookie notification), then the resend would include the PPK_SUPPORT notification if the original message did.

When the responder receives this initial exchange with the notify, then it MUST check if has a PPK configured. If it does, it MUST

reply with the IKE initial exchange including a notification in response.

```

Initiator                               Responder
-----
<--- HDR, SAr1, KEr, Nr, [CERTREQ], N(PPK_SUPPORT)

```

If the responder does not have a PPK configured, then it continues with the IKE protocol as normal, not including the notify.

When the initiator receives this reply, it checks whether the responder included the PPK_SUPPORT notify. If the responder did not, then the initiator MUST either proceed with the standard IKE negotiation (without using a PPK), or abort the exchange (for example, because the initiator has the PPK marked as mandatory). If the responder did include the PPK_SUPPORT notify, then it selects a PPK, along with its identifier PPK_id. Then, it computes this modification of the standard IKE key derivation:

```

SKEYSEED = prf(Ni | Nr, gir)
{SK_d' | SK_ai | SK_ar | SK_ei | SK_er | SK_pi' | SK_pr' }
    = prf+ (SKEYSEED, Ni | Nr | SPIi | SPIr }
SK_d = prf(PPK, SK_d')
SK_pi = prf(PPK, SK_pi')
SK_pr = prf(PPK, SK_pr')

```

That is, we use the standard IKE key derivation process except that the three subkeys SK_d, SK_pi, SK_pr are run through the prf again, this time using the PPK as the key.

The initiator then sends the initial encrypted message, including the PPK_id value as follows:

```

Initiator                               Responder
-----
HDR, SK {IDi, [CERT,] [CERTREQ,]
    [IDr,] AUTH, SAi2,
    TSi, TSr, N(PPK_IDENTITY)(PPK_id)} --->

```

N(PPK_IDENTITY) is a status notification payload with the type [TBA]; it has a protocol ID of 0, and no SPI and has a notification data that consists of the identifier PPK_id.

When the responder receives this encrypted exchange, it first computes the values:

```

SKEYSEED = prf(Ni | Nr, g^ir)
{SK_d' | SK_ai | SK_ar | SK_ei | SK_er | SK_pi' | SK_pr' }
= prf+ (SKEYSEED, Ni | Nr | SPIi | SPIr )

```

It then uses the SK_ei value to decrypt the message; and then finds the PPK_id value attached to the notify. It then scans through the payload for the PPK_id attached to the N(PPK_IDENTITY); if it has no such PPK, it fails the negotiation. If it does have a PPK with that identity, it further computes:

```

SK_d = prf(PPK, SK_d')
SK_pi = prf(PPK, SK_pi')
SK_pr = prf(PPK, SK_pr')

```

And computes the exchange (validating the AUTH payload that the initiator included) as standard.

This table summarizes the above logic by the responder

Received PPK_SUPPORT	Have PPK	PPK Mandatory	Action
No	No	*	Standard IKE protocol
No	Yes	No	Standard IKE protocol
No	Yes	Yes	Abort negotiation
Yes	No	*	Standard IKE protocol
Yes	Yes	*	Include PPK_SUPPORT

When the initiator receives the response, then (if it is configured to use a PPK with the responder), then it checks for the presense of the notification. If it receives one, it marks the SA as using the configured PPK to generate SK_d, SK_pi, SK_pr (as shown above); if it does not receive one, it MUST either abort the exchange (if the PPK was configured as mandatory), or it MUST continue without using the PPK (if the PPK was configured as optional).

If the initial exchange had PPK_SUPPORT sent by both the initiator and the responder, and the initiator does not include a PPK_NOTIFY notification, then the responder SHOULD fail the exchange.

With this protocol, the computed SK_d is a function of the PPK, and assuming that the PPK has sufficient entropy (for example, at least 2**256 possible values), then even if an attacker were able to recover the rest of the inputs to the prf function, it would be infeasible to use Grover's algorithm with a Quantum Computer to recover the SK_d value. Similarly, every child SA key is a function of SK_d, hence all the keys for all the child SAs are also quantum resistant (assuming that the PPK was high entropy and secret, and that all the subkeys are sufficiently long). However, this quantum

resistance does not extend to the initial SK_{ei}, SK_{er} keys; an implementation MAY rekey the initial IKE SA immediately after negotiating it; this would reduce the amount of data available to an attacker with a Quantum Computer.

4. PPK ID format

This standard requires that both the initiator and the responder have a secret PPK value, with the responder selecting the PPK based on the PPK_ID that the initiator sends. In this initial standard, both the initiator and the responder are configured with fixed PPK and PPK_ID values, and do the look up based on that. It is anticipated that later standards will extend this technique to allow dynamically changing PPK values. To facilitate such an extension, we specify that the PPK_ID that the initiator sends will have its first octet be the PPK ID Type value, which is encoded as follows:

PPK ID Type	Value
PPK_ID_OPAQUE	0
PPK_ID_FIXED	1
RESERVED TO IANA	2-127
Reserved for private use	128-255

For PPK_ID_OPAQUE, the format of the PPK ID (and the PPK itself) is not specified by this document; it is assumed to be mutually intelligible by both by initiator and the responder. This PPK ID type is intended for those implementations that choose not to disclose the type of PPK to active attackers.

For PPK_ID_FIXED, the format of the PPK ID and the PPK are fixed octet strings; the remaining bytes of the PPK_ID are a configured value. We assume that there is a fixed mapping between PPK_ID and PPK, which is configured locally to both the initiator and the responder. The responder can use to do a look up the passed PPK_id value to determine the corresponding PPK value. Not all implementations are able to configure arbitrary octet strings; to improve the potential interoperability, it is recommended that, in the PPK_ID_FIXED case, both the PPK and the PPK_ID strings be limited to the base64 character set, namely the 64 characters 0-9, A-Z, a-z, + and /.

The PPK ID type values 2-127 are reserved for IANA; values 128-255 are for private use among mutually consenting parties.

5. PPK Distribution

PPK_id's of the type PPK_ID_FIXED (and the corresponding PPKs) are assumed to be configured within the IKE device in an out-of-band fashion. While the method of distribution is a local matter, one suggestion would be to reuse the format within [RFC6030], with the Key Id field being the PPK_ID (without the 0x01 prefix for a PPK_ID_FIXED), and with the PPK being the secret, and the algorithm as PIN ("Algorithm=urn:ietf:params:xml:ns:keyprov:pskc:pin").

6. Upgrade procedure

This algorithm was designed so that someone can introduce PPKs into an existing IKE network without causing network disruption.

In the initial phase of the network upgrade, the network administrator would visit each IKE node, and configure:

- The set of PPKs (and corresponding PPK_id's) that this node would need to know
- For each peer that this node would initiate to, which PPK that we would use
- That the use of PPK is currently optional

With this configuration, the node will continue to operate with nodes that have not yet been upgraded. This is due to the PPK_SUPPORT notify; if the initiator has not been upgraded, it will not send the PPK_SUPPORT notify (and so the responder will know that we will not use a PPK); if the responder has not been upgraded, it will not send the PPK_SUPPORT notify (and so the initiator will know not to use a PPK). And, if both peers have been upgraded, they will both realize it, and in that case, the link will be quantum secure

As an optional second step, after all nodes have been upgraded, then the administrator may then go back through the nodes, and mark the use of PPK as mandatory. This will not affect the strength against a passive attacker; it would mean that an attacker with a Quantum Computer (which is sufficiently fast to be able to break the (EC)DH in real time would not be able to perform a downgrade attack).

7. Security Considerations

Quantum computers are able to perform Grover's algorithm; that effectively halves the size of a symmetric key. Because of this, the user SHOULD ensure that the postquantum preshared key used has at

least 256 bits of entropy, in order to provide a 128 bit security level.

Although this protocol preserves all the security properties of IKE against adversaries with conventional computers, this protocol allows an adversary with a Quantum Computer to decrypt all traffic encrypted with the initial IKE SA. In particular, it allows the adversary to recover the identities of both sides. If there is IKE traffic other than the identities that need to be protected against such an adversary, one suggestion would be to form an initial IKE SA (which is used to exchange identities), perhaps by using the protocol documented in RFC6023. Then, you would immediately create a child IKE SA (which is used to exchange everything else). Because the child IKE SA keys are a function of SK_d , which is a function of the PPK (among other things), traffic protected by that SA is secure against Quantum capable adversaries.

In addition, the policy SHOULD be set to negotiate only quantum-resistant symmetric algorithms; while this RFC doesn't claim to give advise as to what algorithms are secure (as that may change based on future cryptographical results), here is a list of defined IKEv2 and IPsec algorithms that should NOT be used, as they are known not to be Quantum Resistant

Any IKE Encryption algorithm, PRF or Integrity algorithm with key size <256 bits

Any ESP Transform with key size <256 bits

PRF_AES128_XCBC and PRF_AES128_CBC; even though they are defined to be able to use an arbitrary key size, they convert it into a 128 bit key internally

8. References

8.1. Normative References

- [RFC2104] Krawczyk, H., Bellare, M., and R. Canetti, "HMAC: Keyed-Hashing for Message Authentication", RFC 2104, DOI 10.17487/RFC2104, February 1997, <<http://www.rfc-editor.org/info/rfc2104>>.
- [RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <<http://www.rfc-editor.org/info/rfc2119>>.

- [RFC7296] Kaufman, C., Hoffman, P., Nir, Y., Eronen, P., and T. Kivinen, "Internet Key Exchange Protocol Version 2 (IKEv2)", STD 79, RFC 7296, DOI 10.17487/RFC7296, October 2014, <<http://www.rfc-editor.org/info/rfc7296>>.

8.2. Informational References

- [RFC6023] Nir, Y., Tschofenig, H., Deng, H., and R. Singh, "A Childless Initiation of the Internet Key Exchange Version 2 (IKEv2) Security Association (SA)", RFC 6023, DOI 10.17487/RFC6023, October 2010, <<http://www.rfc-editor.org/info/rfc6023>>.
- [RFC6030] Hoyer, P., Pei, M., and S. Machani, "Portable Symmetric Key Container (PSKC)", RFC 6030, DOI 10.17487/RFC6030, October 2010, <<http://www.rfc-editor.org/info/rfc6030>>.
- [SPDP] McGrew, D., "A Secure Peer Discovery Protocol (SPDP)", 2001, <<http://www.mindspring.com/~dmcgrew/spdp.txt>>.

Appendix A. Discussion and Rationale

The idea behind this is that while a Quantum Computer can easily reconstruct the shared secret of an (EC)DH exchange, they cannot as easily recover a secret from a symmetric exchange this makes the SK_d, and hence the IPsec KEYMAT and any child SA's SKEYSEED, depend on both the symmetric PPK, and also the Diffie-Hellman exchange. If we assume that the attacker knows everything except the PPK during the key exchange, and there are 2^n plausible PPK's, then a Quantum Computer (using Grover's algorithm) would take $O(2^{n/2})$ time to recover the PPK. So, even if the (EC)DH can be trivially solved, the attacker still can't recover any key material (except for the SK_ei, SK_er, SK_ai, SK_ar values for the initial IKE exchange) unless they can find the PPK, and that's too difficult if the PPK has enough entropy (for example, 256 bits). Note that we do allow an attacker with a Quantum Computer to rederive the keying material for the initial IKE SA; this was a compromise to allow the responder to select the correct PPK quickly.

Another goal of this protocol is to minimize the number of changes within the IKEv2 protocol, and in particular, within the cryptography of IKEv2. By limiting our changes to notifications, and translating the nonces, it is hoped that this would be implementable, even on systems that perform much of the IKEv2 processing is in hardware.

A third goal was to be friendly to incremental deployment in operational networks, for which we might not want to have a global shared key, and also if we're rolling this out incrementally. This

is why we specifically try to allow the PPK to be dependent on the peer, and why we allow the PPK to be configured as optional.

A fourth goal was to avoid violating any of the security goals of IKEv2.

Appendix B. Acknowledgement

We would like to thank Tero Kivine, Valery Smyslov, Paul Wouters and the rest of the ipsecme working group for their feedback and suggestions for the scheme

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Using Edwards-curve Digital Signature Algorithm (EdDSA) in the Internet
Key Exchange (IKEv2)
draft-ietf-ipsecme-eddsa-04

Abstract

This document describes the use of the Edwards-curve digital signature algorithm in the IKEv2 protocol.

Status of This Memo

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1. Introduction

The Internet Key Exchange protocol [RFC7296] can use arbitrary signature algorithms as described in [RFC7427]. The latter RFC defines the SIGNATURE_HASH_ALGORITHMS notification where each side of the IKE negotiation lists its supported hash algorithms. This assumes that all signature schemes involve a hashing phase followed by a signature phase. This made sense because most signature algorithms either cannot sign messages bigger than their key or truncate messages bigger than their key.

EdDSA ([RFC8032]) defines signature methods that do not require pre-hashing of the message. Unlike other methods, these accept arbitrary-sized messages, so no pre-hashing is required. These methods are called Ed25519 and Ed448, which respectively use the Edwards 25519 and the Edwards 448 ("Goldilocks") curves. Although that document also defines pre-hashed versions of these algorithm, those versions are not recommended for protocols where the entire to-be-signed message is available at once. See section 8.5 or RFC 8032 for that recommendation.

EdDSA defines the binary format of the signatures that should be used in the "Signature Value" field of the Authentication Data Format in section 3. The CURDLE PKIX document ([I.D-curdle-pkix]) defines the object identifiers (OIDs) for these signature methods. For convenience, these OIDs are repeated in Appendix A.

In order to signal within IKE that no hashing needs to be done, we define a new value in the SIGNATURE_HASH_ALGORITHMS notification, one that indicates that no hashing is performed.

1.1. Conventions Used in This Document

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

2. The "Identity" Hash Identifier

This document defines a new value called "Identity" (value is 5) in the hash algorithm registry for use in the SIGNATURE_HASH_ALGORITHMS notification. Inserting this new value into the notification indicates that the receiver supports at least one signature algorithm that accepts arbitrary-sized messages such as Ed25519 and Ed448.

Ed25519 and Ed448 are only defined with the Identity hash, and MUST NOT be sent to a receiver that has not indicated support for the "Identity" hash.

The pre-hashed versions of Ed25519 and Ed448 (Ed25519ph and Ed448ph respectively) MUST NOT be used in IKE.

3. Security Considerations

The new "Identity" value is needed only for signature algorithms that accept an arbitrary-sized input. It MUST NOT be used if none of the supported and configured algorithms have this property. On the other hand there is no good reason to pre-hash the inputs where the signature algorithm has that property. For this reason implementations MUST have the "Identity" value in the SIGNATURE_HASH_ALGORITHMS notification when EdDSA is supported and configured. Implementations SHOULD NOT have other hash algorithms in the notification if all supported and configured signature algorithms have this property.

4. IANA Considerations

IANA has assigned the value 5 for the algorithm with the name "Identity" in the "IKEv2 Hash Algorithms" registry with this draft as reference.

Upon publication of this document IANA is requested to update the entry with this document as reference.

5. Normative References

- [RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <<https://www.rfc-editor.org/info/rfc2119>>.
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- [RFC8032] Josefsson, S. and I. Liusvaara, "Edwards-Curve Digital Signature Algorithm (EdDSA)", RFC 8032, DOI 10.17487/RFC8032, January 2017, <<https://www.rfc-editor.org/info/rfc8032>>.
- [I.D-curdle-pkix]
Josefsson, S. and J. Schaad, "Algorithm Identifiers for Ed25519, Ed25519ph, Ed448, Ed448ph, X25519 and X448 for use in the Internet X.509 Public Key Infrastructure", September 2017, <<https://tools.ietf.org/html/draft-ietf-curdle-pkix-06>>.

Appendix A. ASN.1 Objects

The normative reference for the ASN.1 objects for Ed25519 and Ed448 is in [I.D-curdle-pkix]. They are repeated below for convenience.

A.1. ASN.1 Object for Ed25519

id-Ed25519 OBJECT IDENTIFIER ::= { 1.3.101.112 }

Parameters are absent. Length is 7 bytes.

Binary encoding: 3005 0603 2B65 70

A.2. ASN.1 Object for Ed448

id-Ed448 OBJECT IDENTIFIER ::= { 1.3.101.113 }

Parameters are absent. Length is 7 bytes.

Binary encoding: 3005 0603 2B65 71

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draft-ietf-ipsecme-qr-ikev2-00

Abstract

The possibility of Quantum Computers pose a serious challenge to cryptography algorithms deployed widely today. IKEv2 is one example of a cryptosystem that could be broken; someone storing VPN communications today could decrypt them at a later time when a Quantum Computer is available. It is anticipated that IKEv2 will be extended to support quantum secure key exchange algorithms; however that is not likely to happen in the near term. To address this problem before then, this document describes an extension of IKEv2 to allow it to be resistant to a Quantum Computer, by using preshared keys.

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1. Introduction

It is an open question whether or not it is feasible to build a Quantum Computer (and if so, when one might be implemented), but if it is, many of the cryptographic algorithms and protocols currently in use would be insecure. A Quantum Computer would be able to solve DH and ECDH problems in polynomial time [I-D.hoffman-c2pq], and this would imply that the security of existing IKEv2 [RFC7296] systems would be compromised. IKEv1 [RFC2409], when used with strong preshared keys, is not vulnerable to quantum attacks, because those keys are one of the inputs to the key derivation function. If the preshared key has sufficient entropy and the PRF, encryption and authentication transforms are postquantum secure, then the resulting system is believed to be quantum resistant, that is, invulnerable to an attacker with a Quantum Computer.

This document describes a way to extend IKEv2 to have a similar property; assuming that the two end systems share a long secret key, then the resulting exchange is quantum resistant. By bringing postquantum security to IKEv2, this note removes the need to use an obsolete version of the Internet Key Exchange in order to achieve that security goal.

The general idea is that we add an additional secret that is shared between the initiator and the responder; this secret is in addition to the authentication method that is already provided within IKEv2. We stir this secret into the SK_d value, which is used to generate the key material (KEYMAT) keys and the SKEYSEED for the child SAs; this secret provides quantum resistance to the IPsec SAs (and any child IKE SAs). We also stir the secret into the SK_pi, SK_pr values; this allows both sides to detect a secret mismatch cleanly.

It was considered important to minimize the changes to IKEv2. The existing mechanisms to do authentication and key exchange remain in place (that is, we continue to do (EC)DH, and potentially a PKI authentication if configured). This document does not replace the authentication checks that the protocol does; instead, it is done as a parallel check.

1.1. Changes

Changes in this draft in each version iterations.

draft-ietf-ipsecme-qr-ikev2-00

- o Migrated from draft-fluhrer-qr-ikev2-05 to draft-ietf-ipsecme-qr-ikev2-00 that is a WG item.

draft-fluhrer-qr-ikev2-05

- o Nits and editorial fixes.
- o Made PPK_ID format and PPK Distributions subsection of the PPK section. Also added an Operational Considerations section.
- o Added comment about Child SA rekey in the Security Considerations section.
- o Added NO_PPK_AUTH to solve the cases where a PPK_ID is not configured for a responder.
- o Various text changes and clarifications.

- o Expanded Security Considerations section to describe some security concerns and how they should be addressed.

draft-fluhrer-qr-ikev2-03

- o Modified how we stir the PPK into the IKEv2 secret state.
- o Modified how the use of PPKs is negotiated.

draft-fluhrer-qr-ikev2-02

- o Simplified the protocol by stirring in the preshared key into the child SAs; this avoids the problem of having the responder decide which preshared key to use (as it knows the initiator identity at that point); it does mean that someone with a Quantum Computer can recover the initial IKE negotiation.
- o Removed positive endorsements of various algorithms. Retained warnings about algorithms known to be weak against a Quantum Computer.

draft-fluhrer-qr-ikev2-01

- o Added explicit guidance as to what IKE and IPsec algorithms are quantum resistant.

draft-fluhrer-qr-ikev2-00

- o We switched from using vendor ID's to transmit the additional data to notifications.
- o We added a mandatory cookie exchange to allow the server to communicate to the client before the initial exchange.
- o We added algorithm agility by having the server tell the client what algorithm to use in the cookie exchange.
- o We have the server specify the PPK Indicator Input, which allows the server to make a trade-off between the efficiency for the search of the clients PPK, and the anonymity of the client.
- o We now use the negotiated PRF (rather than a fixed HMAC-SHA256) to transform the nonces during the KDF.

1.2. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

2. Assumptions

We assume that each IKE peer has a list of Postquantum Preshared Keys (PPK) along with their identifiers (PPK_ID), and any potential IKE initiator has a selection of which PPK to use with any specific responder. In addition, implementations have a configurable flag that determines whether this postquantum preshared key is mandatory. This PPK is independent of the preshared key (if any) that the IKEv2 protocol uses to perform authentication. The PPK specific configuration that is assumed on each peer consists of the following tuple:

Peer, PPK, PPK_ID, mandatory_or_not

3. Exchanges

If the initiator is configured to use a postquantum preshared key with the responder (whether or not the use of the PPK is mandatory), then it will include a notification PPK_SUPPORT in the initial exchange as follows:

Initiator	Responder
HDR, SAi1, KEi, Ni, N(PPK_SUPPORT)	---->

N(PPK_SUPPORT) is a status notification payload with the type [TBA]; it has a protocol ID of 0, no SPI and no notification data associated with it.

If the initiator needs to resend this initial message with a cookie (because the responder response included a COOKIE notification), then the resend would include the PPK_SUPPORT notification if the original message did.

If the responder does not support this specification or does not have any PPK configured, then it ignores the received notification and continues with the IKEv2 protocol as normal. Otherwise the responder checks if it has a PPK configured, and if it does, then the responder replies with the IKEv2 initial exchange including a PPK_SUPPORT notification in the response:

Initiator

Responder

```
-----
<--- HDR, SAr1, KEr, Nr, [CERTREQ], N(PPK_SUPPORT)
```

When the initiator receives this reply, it checks whether the responder included the PPK_SUPPORT notification. If the responder did not and the flag `mandatory_or_not` indicates that using PPKs is mandatory for communication with this responder, then the initiator MUST abort the exchange. This situation may happen in case of misconfiguration, when the initiator believes it has a mandatory to use PPK for the responder, while the responder either doesn't support PPKs at all or doesn't have any PPK configured for the initiator. See Section 6 for discussion of the possible impacts of this situation.

If the responder did not include the PPK_SUPPORT notification and using PPKs for this responder is optional, then the initiator continues with the IKEv2 protocol as normal, without using PPKs.

If the responder did include the PPK_SUPPORT notification, then the initiator selects a PPK, along with its identifier PPK_ID. Then, it computes this modification of the standard IKEv2 key derivation:

```
SKEYSEED = prf(Ni | Nr, gir)
{SK_d' | SK_ai | SK_ar | SK_ei | SK_er | SK_pi' | SK_pr' }
  = prf+ (SKEYSEED, Ni | Nr | SPIi | SPIr }
SK_d = prf(PPK, SK_d')
SK_pi = prf(PPK, SK_pi')
SK_pr = prf(PPK, SK_pr')
```

That is, we use the standard IKEv2 key derivation process except that the three subkeys `SK_d`, `SK_pi`, `SK_pr` are run through the `prf` again, this time using the PPK as the key.

The initiator then sends the initial encrypted message, including the PPK_ID value as follows:

Initiator

Responder

```
-----
HDR, SK {IDi, [CERT,] [CERTREQ,]
  [IDr,] AUTH, SAi2,
  TSi, TSr, N(PPK_IDENTITY)(PPK_ID), [N(NO_PPK_AUTH)]} --->
```

PPK_IDENTITY is a status notification with the type [TBA]; it has a protocol ID of 0, no SPI and a notification data that consists of the identifier PPK_ID.

A situation may happen when the responder has some PPKs, but doesn't have a PPK with the PPK_ID received from the initiator. In this case the responder cannot continue with PPK (in particular, it cannot authenticate the initiator), but it could be able to continue with normal IKEv2 protocol if the initiator provided its authentication data computed as in normal IKEv2, without using PPKs. For this purpose, if using PPKs for communication with this responder is optional for the initiator, then the initiator MAY include a notification NO_PPK_AUTH in the above message.

NO_PPK_AUTH is a status notification with the type [TBA]; it has a protocol ID of 0 and no SPI. A notification data consists of the initiator's authentication data computed using SK_pi' (i.e. the data that computed without using PPKs and would normally be placed in the AUTH payload). Authentication Method for computing the authentication data MUST be the same as indicated in the AUTH payload and is not included in the notification. Note that if the initiator decides to include NO_PPK_AUTH notification, then it means that the initiator needs to perform authentication data computation twice that may consume substantial computation power (e.g. if digital signatures are involved).

When the responder receives this encrypted exchange, it first computes the values:

```
SKEYSEED = prf(Ni | Nr, g^ir)
{SK_d' | SK_ai | SK_ar | SK_ei | SK_er | SK_pi' | SK_pr' }
= prf+ (SKEYSEED, Ni | Nr | SPIi | SPIr )
```

It then uses the SK_ei/SK_ai values to decrypt/check the message and then scans through the payloads for the PPK_ID attached to the PPK_IDENTITY notification. If no PPK_IDENTITY notification is found and the peers successfully exchanged PPK_SUPPORT notifications in the initial exchange, then the responder MUST send back AUTHENTICATION_FAILED notification and then fail the negotiation.

If the PPK_IDENTITY notification contains PPK_ID that is not known to the responder or is not configured for use for the identity from IDi payload, then the responder checks whether using PPKs for this initiator is mandatory and whether the initiator included NO_PPK_AUTH notification in the message. If using PPKs is mandatory or no NO_PPK_AUTH notification found, then then the responder MUST send back AUTHENTICATION_FAILED notification and then fail the negotiation. Otherwise (when PPK is optional and the initiator included NO_PPK_AUTH notification) the responder MAY continue regular IKEv2 protocol, except that it uses the data from the NO_PPK_AUTH notification as the authentication data (which usually resides in the AUTH payload), for the purpose of the initiator authentication.

Note, that Authentication Method is still indicated in the AUTH payload.

This table summarizes the above logic by the responder:

Received PPK_SUPPORT	Received NO_PPK_AUTH	Have PPK	PPK Mandatory	Action
No	*	No	*	Standard IKEv2 protocol
No	*	Yes	No	Standard IKEv2 protocol
No	*	Yes	Yes	Abort negotiation
Yes	No	No	*	Abort negotiation
Yes	Yes	No	Yes	Abort negotiation
Yes	Yes	No	No	Standard IKEv2 protocol
Yes	*	Yes	*	Use PPK

If PPK is in use, then the responder extracts corresponding PPK and computes the following values:

```
SK_d = prf(PPK, SK_d')
SK_pi = prf(PPK, SK_pi')
SK_pr = prf(PPK, SK_pr')
```

The responder then continues with the exchange (validating the AUTH payload that the initiator included) as usual and sends back a response, which includes the PPK_IDENTITY notification with no data to indicate that the PPK is used in the exchange:

Initiator	Responder
	<-- HDR, SK {IDr, [CERT,] AUTH, SAr2, TSi, TSr, N(PPK_IDENTITY)}

When the initiator receives the response, then it checks for the presence of the PPK_IDENTITY notification. If it receives one, it marks the SA as using the configured PPK to generate SK_d, SK_pi, SK_pr (as shown above); if it does not receive one, it MUST either fail the IKE SA negotiation sending the AUTHENTICATION_FAILED notification in the Informational exchange (if the PPK was configured as mandatory), or continue without using the PPK (if the PPK was not configured as mandatory and the initiator included the NO_PPK_AUTH notification in the request).

4. Upgrade procedure

This algorithm was designed so that someone can introduce PPKs into an existing IKE network without causing network disruption.

In the initial phase of the network upgrade, the network administrator would visit each IKE node, and configure:

- o The set of PPKs (and corresponding PPK_IDs) that this node would need to know.
- o For each peer that this node would initiate to, which PPK will be used.
- o That the use of PPK is currently not mandatory.

With this configuration, the node will continue to operate with nodes that have not yet been upgraded. This is due to the PPK_SUPPORT notify and the NO_PPK_AUTH notify; if the initiator has not been upgraded, it will not send the PPK_SUPPORT notify (and so the responder will know that we will not use a PPK). If the responder has not been upgraded, it will not send the PPK_SUPPORT notify (and so the initiator will know to not use a PPK). If both peers have been upgraded, but the responder isn't yet configured with the PPK for the initiator, then the responder could do standard IKEv2 protocol if the initiator sent NO_PPK_AUTH notification. If the responder has not been upgraded and properly configured, they will both realize it, and in that case, the link will be quantum secure.

As an optional second step, after all nodes have been upgraded, then the administrator may then go back through the nodes, and mark the use of PPK as mandatory. This will not affect the strength against a passive attacker; it would mean that an attacker with a Quantum Computer (which is sufficiently fast to be able to break the (EC)DH in real time would not be able to perform a downgrade attack).

5. PPK

5.1. PPK_ID format

This standard requires that both the initiator and the responder have a secret PPK value, with the responder selecting the PPK based on the PPK_ID that the initiator sends. In this standard, both the initiator and the responder are configured with fixed PPK and PPK_ID values, and do the look up based on PPK_ID value. It is anticipated that later standards will extend this technique to allow dynamically changing PPK values. To facilitate such an extension, we specify

that the PPK_ID the initiator sends will have its first octet be the PPK_ID Type value. This document defines two values for PPK_ID Type:

- o PPK_ID_OPAQUE (1) - for this type the format of the PPK_ID (and the PPK itself) is not specified by this document; it is assumed to be mutually intelligible by both by initiator and the responder. This PPK_ID type is intended for those implementations that choose not to disclose the type of PPK to active attackers.
- o PPK_ID_FIXED (2) - in this case the format of the PPK_ID and the PPK are fixed octet strings; the remaining bytes of the PPK_ID are a configured value. We assume that there is a fixed mapping between PPK_ID and PPK, which is configured locally to both the initiator and the responder. The responder can use to do a look up the passed PPK_ID value to determine the corresponding PPK value. Not all implementations are able to configure arbitrary octet strings; to improve the potential interoperability, it is recommended that, in the PPK_ID_FIXED case, both the PPK and the PPK_ID strings be limited to the base64 character set, namely the 64 characters 0-9, A-Z, a-z, + and /.

The PPK_ID type value 0 is reserved; values 3-127 are reserved for IANA; values 128-255 are for private use among mutually consenting parties.

5.2. Operational Considerations

The need to maintain several independent sets of security credentials can significantly complicate security administrators job, and can potentially slow down widespread adoption of this solution. It is anticipated, that administrators will try to simplify their job by decreasing the number of credentials they need to maintain. This section describes some of the considerations for PPK management.

5.2.1. PPK Distribution

PPK_IDs of the type PPK_ID_FIXED (and the corresponding PPKs) are assumed to be configured within the IKE device in an out-of-band fashion. While the method of distribution is a local matter and out of scope of this document or IKEv2, [RFC6030] describes a format for symmetric key exchange. That format could be reused with the Key Id field being the PPK_ID (without the PPK_ID Type octet for a PPK_ID_FIXED), the PPK being the secret, and the algorithm ("Algorithm=urn:ietf:params:xml:ns:keyprov:pskc:pin") as PIN.

5.2.2. Group PPK

This document doesn't explicitly require that PPK is unique for each pair of peers. If it is the case, then this solution provides full peer authentication, but it also means that each host must have that many independent PPKs, how many peers it is going to communicate with. As the number of hosts grows this will scale badly.

Even though it is NOT RECOMMENDED, it is possible to use a single PPK for a group of users. Since each peer uses classical public key cryptography in addition to PPK for key exchange and authentication, members of the group can neither impersonate each other nor read other's traffic, unless they use Quantum Computers to break public key operations.

Although it's probably safe to use group PPK in short term, the fact, that the PPK is known to a (potentially large) group of users makes it more susceptible to theft. If an attacker equipped with a Quantum Computer got access to a group PPK, then all the communications inside the group are revealed.

5.2.3. PPK-only Authentication

If Quantum Computers become a reality, classical public key cryptography will provide little security, so administrators may find it attractive not to use it at all for authentication. This will reduce the number of credentials they need to maintain to PPKs only. Combining group PPK and PPK-only authentication is NOT RECOMMENDED, since in this case any member of the group can impersonate any other member even without help of Quantum Computers.

PPK-only authentication can be achieved in IKEv2 if NULL Authentication method [RFC7619] is employed. Without PPK the NULL Authentication method provides no authentication of the peers, however since a PPK is stirred into the SK_pi and the SK_pr, the peers become authenticated if a PPK is in use. Using PPKs MUST be mandatory for the peers if they advertise support for PPK in initial exchange and use NULL Authentication. Additionally, since the peers are authenticated via PPK, the ID Type in the IDi/IDr payloads SHOULD NOT be ID_NULL, despite using NULL Authentication method.

6. Security Considerations

Quantum computers are able to perform Grover's algorithm; that effectively halves the size of a symmetric key. Because of this, the user SHOULD ensure that the postquantum preshared key used has at least 256 bits of entropy, in order to provide a 128-bit security level.

With this protocol, the computed SK_d is a function of the PPK, and assuming that the PPK has sufficient entropy (for example, at least 2^{256} possible values), then even if an attacker was able to recover the rest of the inputs to the prf function, it would be infeasible to use Grover's algorithm with a Quantum Computer to recover the SK_d value. Similarly, every child SA key is a function of SK_d , hence all the keys for all the child SAs are also quantum resistant (assuming that the PPK was high entropy and secret, and that all the subkeys are sufficiently long).

Although this protocol preserves all the security properties of IKEv2 against adversaries with conventional computers, it allows an adversary with a Quantum Computer to decrypt all traffic encrypted with the initial IKE SA. In particular, it allows the adversary to recover the identities of both sides. If there is IKE traffic other than the identities that need to be protected against such an adversary, implementations MAY rekey the initial IKE SA immediately after negotiating it to generate a new SKEYSEED with from the postquantum SK_d . This would reduce the amount of data available to an attacker with a Quantum Computer.

Alternatively, an initial IKE SA (which is used to exchange identities) can take place, perhaps by using the protocol documented in [RFC6023]. After the childless IKE SA is created, implementations would immediately create a new IKE SA (which is used to exchange everything else) by using a rekey mechanism for IKE SAs. Because the rekeyed IKE SA keys are a function of SK_d , which is a function of the PPK (among other things), traffic protected by that IKE SA is secure against Quantum capable adversaries.

If some sensitive information (like keys) is to be transferred over IKE SA, then implementations MUST rekey the initial IKE SA before sending this information to get protection against Quantum Computers.

In addition, the policy SHOULD be set to negotiate only quantum-resistant symmetric algorithms; while this RFC doesn't claim to give advice as to what algorithms are secure (as that may change based on future cryptographical results), below is a list of defined IKEv2 and IPsec algorithms that should NOT be used, as they are known not to be quantum resistant

- o Any IKEv2 Encryption algorithm, PRF or Integrity algorithm with key size less than 256 bits.
- o Any ESP Transform with key size less than 256 bits.

- o PRF_AES128_XCBC and PRF_AES128_CBC; even though they are defined to be able to use an arbitrary key size, they convert it into a 128-bit key internally.

Section 3 requires the initiator to abort the initial exchange if using PPKs is mandatory for it, but the responder didn't include the PPK_SUPPORT notification in the response. In this situation when the initiator aborts negotiation it leaves half-open IKE SA on the responder (because the initial exchange completes successfully from responder's point of view). This half-open SA will eventually expire and be deleted, but if the initiator continues its attempts to create IKE SA with a high enough rate, then the responder may consider it as a Denial-of-Service attack and take some measures (see [RFC8019] for more detail). It is RECOMMENDED that implementations in this situation cache the negative result of negotiation for some time and don't make attempts to create it again for some time, because this is a result of misconfiguration and probably some re-configuration of the peers is needed.

If using PPKs is optional for both peers and they authenticate themselves using digital signatures, then an attacker in between, equipped with a Quantum Computer capable of breaking public key operations in real time, is able to mount downgrade attack by removing PPK_SUPPORT notification from the initial exchange and forging digital signatures in the subsequent exchange. If using PPKs is mandatory for at least one of the peers or PSK is used for authentication, then the attack will be detected and the SA won't be created.

If using PPKs is mandatory for the initiator, then an attacker capable to eavesdrop and to inject packets into the network can prevent creating IKE SA by mounting the following attack. The attacker intercepts the the initial request containing the PPK_SUPPORT notification and injects the forget response containing no PPK_SUPPORT. If the attacker manages to inject this packet before the responder sends a genuine response, then the initiator would abort the exchange. To thwart this kind of attack it is RECOMMENDED, that if using PPKs is mandatory for the initiator and the received response doesn't contain the PPK_SUPPORT notification, then the initiator doesn't abort exchange immediately, but instead waits some time for more responses (possibly retransmitting the request). If all the received responses contain no PPK_SUPPORT, then the exchange is aborted.

7. IANA Considerations

This document defines three new Notify Message Types in the "Notify Message Types - Status Types" registry:

```
<TBA>      PPK_SUPPORT
<TBA>      PPK_IDENTITY
<TBA>      NO_PPK_AUTH
```

This document also creates a new IANA registry for the PPK_ID types. The initial values of this registry are:

PPK_ID Type	Value
-----	-----
Reserved	0
PPK_ID_OPAQUE	1
PPK_ID_FIXED	2
Unassigned	3-127
Reserved for private use	128-255

Changes and additions to this registry are by Expert Review [RFC5226].

8. References

8.1. Normative References

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Appendix A. Discussion and Rationale

The idea behind this document is that while a Quantum Computer can easily reconstruct the shared secret of an (EC)DH exchange, they cannot as easily recover a secret from a symmetric exchange. This makes the SK_d, and hence the IPsec KEYMAT and any child SA's SKEYSEED, depend on both the symmetric PPK, and also the Diffie-Hellman exchange. If we assume that the attacker knows everything except the PPK during the key exchange, and there are 2^n plausible PPKs, then a Quantum Computer (using Grover's algorithm) would take $O(2^{n/2})$ time to recover the PPK. So, even if the (EC)DH can be trivially solved, the attacker still can't recover any key material (except for the SK_ei, SK_er, SK_ai, SK_ar values for the initial IKE exchange) unless they can find the PPK, which is too difficult if the PPK has enough entropy (for example, 256 bits). Note that we do allow an attacker with a Quantum Computer to rederive the keying material for the initial IKE SA; this was a compromise to allow the responder to select the correct PPK quickly.

Another goal of this protocol is to minimize the number of changes within the IKEv2 protocol, and in particular, within the cryptography of IKEv2. By limiting our changes to notifications, and translating

the nonces, it is hoped that this would be implementable, even on systems that perform much of the IKEv2 processing in hardware.

A third goal was to be friendly to incremental deployment in operational networks, for which we might not want to have a global shared key or quantum resistant IKEv2 is rolled out incrementally. This is why we specifically try to allow the PPK to be dependent on the peer, and why we allow the PPK to be configured as optional.

A fourth goal was to avoid violating any of the security goals of IKEv2.

Appendix B. Acknowledgements

We would like to thank Tero Kivinen, Paul Wouters, Graham Bartlett and the rest of the ipsecme Working Group for their feedback and suggestions for the scheme.

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Split DNS Configuration for IKEv2
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Abstract

This document defines two Configuration Payload Attribute Types for the IKEv2 protocol that add support for private DNS domains. These domains should be resolved using DNS servers reachable through an IPsec connection, while leaving all other DNS resolution unchanged. This approach of resolving a subset of domains using non-public DNS servers is referred to as "Split DNS".

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1. Introduction

Split DNS is a common configuration for secure tunnels, such as Virtual Private Networks in which host machines private to an organization can only be resolved using internal DNS resolvers [RFC2775]. In such configurations, it is often desirable to only resolve hosts within a set of private domains using the tunnel, while letting resolutions for public hosts be handled by a device's default DNS configuration.

The Internet Key Exchange protocol version 2 [RFC7296] negotiates configuration parameters using Configuration Payload Attribute Types. This document defines two Configuration Payload Attribute Types that add support for trusted Split DNS domains.

The INTERNAL_DNS_DOMAIN attribute type is used to convey one or more DNS domains that should be resolved only using the provided DNS nameserver IP addresses, causing these requests to use the IPsec connection.

The INTERNAL_DNSSEC_TA attribute type is used to convey DNSSEC trust anchors for those domains.

When only a subset of traffic is routed into a private network using an IPsec SA, these Configuration Payload options can be used to define which private domains should be resolved through the IPsec connection without affecting the client's global DNS resolution.

For the purposes of this document, DNS resolution servers accessible through an IPsec connection will be referred to as "internal DNS servers", and other DNS servers will be referred to as "external DNS servers".

A client using these configuration payloads will be able to request and receive Split DNS configurations using the INTERNAL_DNS_DOMAIN and INTERNAL_DNSSEC_TA configuration attributes. The client device can use the internal DNS server(s) for any DNS queries within the assigned domains. DNS queries for other domains should be send to regular external DNS server.

1.1. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

2. Background

Split DNS is a common configuration for enterprise VPN deployments, in which only one or a few private DNS domains are accessible and resolvable via an IPsec based VPN connection.

Other tunnel-establishment protocols already support the assignment of Split DNS domains. For example, there are proprietary extensions to IKEv1 that allow a server to assign Split DNS domains to a client. However, the IKEv2 standard does not include a method to configure this option. This document defines a standard way to negotiate this option for IKEv2.

3. Protocol Exchange

In order to negotiate which domains are considered internal to an IKEv2 tunnel, initiators indicate support for Split DNS in their CFG_REQUEST payloads, and responders assign internal domains (and DNSSEC trust anchors) in their CFG_REPLY payloads. When Split DNS has been negotiated, the existing DNS server configuration attributes will be interpreted as internal DNS servers that can resolve hostnames within the internal domains.

3.1. Configuration Request

To indicate support for Split DNS, an initiator includes one more `INTERNAL_DNS_DOMAIN` attributes as defined in Section 4 as part of the `CFG_REQUEST` payload. If an `INTERNAL_DNS_DOMAIN` attribute is included in the `CFG_REQUEST`, the initiator SHOULD also include one or more `INTERNAL_IP4_DNS` and `INTERNAL_IP6_DNS` attributes in the `CFG_REQUEST`.

The `INTERNAL_DNS_DOMAIN` attribute sent by the initiator is usually empty but MAY contain a suggested domain name.

The absence of `INTERNAL_DNS_DOMAIN` attributes in the `CFG_REQUEST` payload indicates that the initiator does not support or is unwilling to accept Split DNS configuration.

To indicate support for DNSSEC, an initiator includes one or more `INTERNAL_DNSSEC_TA` attributes as defined in Section 4 as part of the `CFG_REQUEST` payload. If an `INTERNAL_DNSSEC_TA` attribute is included in the `CFG_REQUEST`, the initiator SHOULD also include one or more `INTERNAL_DNS_DOMAIN` attributes in the `CFG_REQUEST`.

An initiator MAY convey its current DNSSEC trust anchors for the domain specified in the `INTERNAL_DNS_DOMAIN` attribute. If it does not wish to convey this information, it MUST use a length of 0.

The absence of `INTERNAL_DNSSEC_TA` attributes in the `CFG_REQUEST` payload indicates that the initiator does not support or is unwilling to accept DNSSEC trust anchor configuration.

3.2. Configuration Reply

Responders MAY send one or more `INTERNAL_DNS_DOMAIN` attributes in their `CFG_REPLY` payload. If an `INTERNAL_DNS_DOMAIN` attribute is included in the `CFG_REPLY`, the responder MUST also include one or both of the `INTERNAL_IP4_DNS` and `INTERNAL_IP6_DNS` attributes in the `CFG_REPLY`. These DNS server configurations are necessary to define which servers should receive queries for hostnames in internal domains. If the `CFG_REQUEST` included an `INTERNAL_DNS_DOMAIN` attribute, but the `CFG_REPLY` does not include an `INTERNAL_DNS_DOMAIN` attribute, the initiator should behave as if Split DNS configurations are not supported by the server.

Each `INTERNAL_DNS_DOMAIN` represents a domain that the DNS servers address listed in `INTERNAL_IP4_DNS` and `INTERNAL_IP6_DNS` can resolve.

If the `CFG_REQUEST` included `INTERNAL_DNS_DOMAIN` attributes with non-zero lengths, the content MAY be ignored or be interpreted as a suggestion by the responder.

For each DNS domain specified in an `INTERNAL_DNS_DOMAIN` attribute, one or more `INTERNAL_DNSSEC_TA` attributes MAY be included by the responder. This attribute lists the corresponding internal DNSSEC trust anchor in the DNS presentation format of a DS record as specified in [RFC4034]. The `INTERNAL_DNSSEC_TA` attribute MUST immediately follow the `INTERNAL_DNS_DOMAIN` attribute that it applies to.

3.3. Mapping DNS Servers to Domains

All DNS servers provided in the `CFG_REPLY` MUST support resolving hostnames within all `INTERNAL_DNS_DOMAIN` domains. In other words, the `INTERNAL_DNS_DOMAIN` attributes in a `CFG_REPLY` payload form a single list of Split DNS domains that applies to the entire list of `INTERNAL_IP4_DNS` and `INTERNAL_IP6_DNS` attributes.

3.4. Example Exchanges

3.4.1. Simple Case

In this example exchange, the initiator requests `INTERNAL_IP4_DNS` and `INTERNAL_DNS_DOMAIN` attributes in the `CFG_REQUEST`, but does not specify any value for either. This indicates that it supports Split DNS, but has no preference for which DNS requests should be routed through the tunnel.

The responder replies with two DNS server addresses, and two internal domains, "example.com" and "city.other.com".

Any subsequent DNS queries from the initiator for domains such as "www.example.com" should use 198.51.100.2 or 198.51.100.4 to resolve.

```
CP(CFG_REQUEST) =
  INTERNAL_IP4_ADDRESS()
  INTERNAL_IP4_DNS()
  INTERNAL_DNS_DOMAIN()

CP(CFG_REPLY) =
  INTERNAL_IP4_ADDRESS(198.51.100.234)
  INTERNAL_IP4_DNS(198.51.100.2)
  INTERNAL_IP4_DNS(198.51.100.4)
  INTERNAL_DNS_DOMAIN(example.com)
  INTERNAL_DNS_DOMAIN(city.other.com)
```

3.4.2. Requesting Domains and DNSSEC trust anchors

In this example exchange, the initiator requests INTERNAL_IP4_DNS, INTERNAL_DNS_DOMAIN and INTERNAL_DNSSEC_TA attributes in the CFG_REQUEST

Any subsequent DNS queries from the initiator for domains such as "www.example.com" or "city.other.com" would be DNSSEC validated using the DNSSEC trust anchor received in the CFG_REPLY

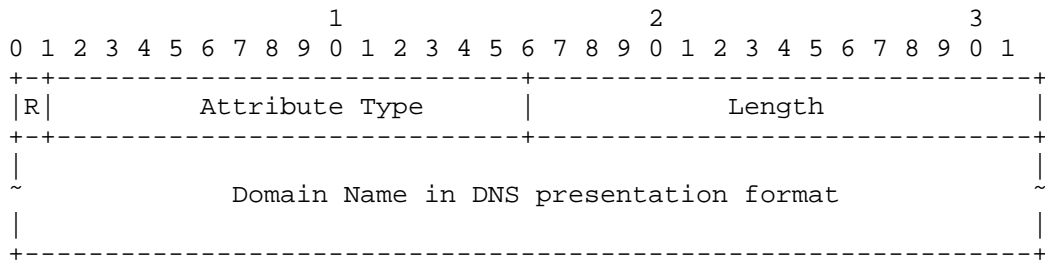
In this example, the initiator has no existing DNSSEC trust anchors would the requested domain. the "example.com" domain has DNSSEC trust anchors that are returned, while the "other.com" domain has no DNSSEC trust anchors

```
CP(CFG_REQUEST) =
INTERNAL_IP4_ADDRESS()
INTERNAL_IP4_DNS()
INTERNAL_DNS_DOMAIN()
INTERNAL_DNSSEC_TA()
```

```
CP(CFG_REPLY) =
INTERNAL_IP4_ADDRESS(198.51.100.234)
INTERNAL_IP4_DNS(198.51.100.2)
INTERNAL_IP4_DNS(198.51.100.4)
INTERNAL_DNS_DOMAIN(example.com)
INTERNAL_DNSSEC_TA(43547,8,1,B6225AB2CC613E0DCA7962BDC2342EA4F1B56083)
INTERNAL_DNSSEC_TA(31406,8,2,F78CF3344F72137235098ECBBD08947C2C90....)
INTERNAL_DNS_DOMAIN(city.other.com)
```

4. Payload Formats

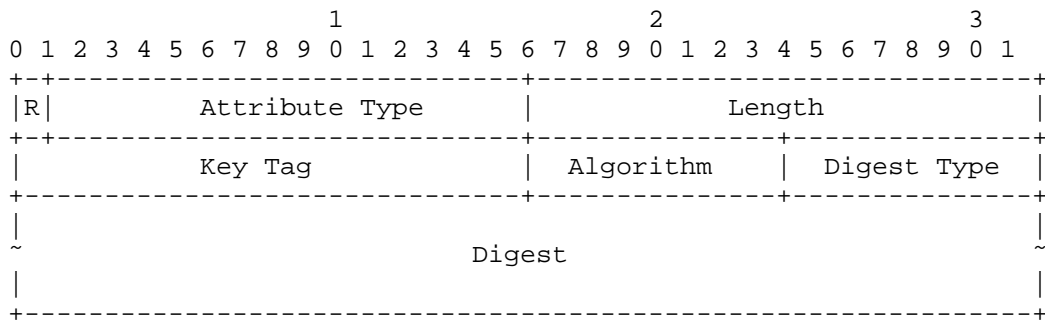
4.1. INTERNAL_DNS_DOMAIN Configuration Attribute Type



- o Reserved (1 bit) - Defined in IKEv2 RFC [RFC7296].
- o Attribute Type (15 bits) 25 - INTERNAL_DNS_DOMAIN.

- o Length (2 octets, unsigned integer) - Length of domain name.
- o Domain Name (0 or more octets) - A Fully Qualified Domain Name used for Split DNS rules, such as example.com, in DNS presentation format and optionally using IDNA [RFC5890] for Internationalized Domain Names. Implementors need to be careful that this value is not null-terminated.

4.2. INTERNAL_DNSSEC_TA Configuration Attribute



- o Reserved (1 bit) - Defined in IKEv2 RFC [RFC7296].
- o Attribute Type (15 bits) [TBD IANA] - INTERNAL_DNSSEC_TA.
- o Length (2 octets, unsigned integer) - Length of DNSSEC Trust Anchor data.
- o Key Tag value (0 or 2 octets, unsigned integer) - Key Tag as specified in [RFC4034] Section 5.1
- o Algorithm (0 or 1 octet) - DNSKEY algorithm value from the IANA DNS Security Algorithm Numbers Registry
- o DS algorithm (0 or 1 octet) - DS algorithm value from the IANA Delegation Signer (DS) Resource Record (RR) Type Digest Algorithms Registry
- o Digest (0 or more octets) - The DNSKEY digest as specified in [RFC4034] Section 5.1 in presentation format.

5. Split DNS Usage Guidelines

If a CFG_REPLY payload contains no INTERNAL_DNS_DOMAIN attributes, the client MAY use the provided INTERNAL_IP4_DNS or INTERNAL_IP6_DNS servers as the default DNS server(s) for all queries.

If a client is configured by local policy to only accept a limited number of INTERNAL_DNS_DOMAIN values, the client MUST ignore any other INTERNAL_DNS_DOMAIN values.

For each INTERNAL_DNS_DOMAIN entry in a CFG_REPLY payload that is not prohibited by local policy, the client MUST use the provided INTERNAL_IP4_DNS or INTERNAL_IP6_DNS DNS servers as the only resolvers for the listed domains and its sub-domains and it MUST NOT attempt to resolve the provided DNS domains using its external DNS servers.

If the initiator host is configured to block DNS answers containing IP addresses from special IP address ranges such as those of [RFC1918], the initiator SHOULD allow the DNS domains listed in the INTERNAL_DNS_DOMAIN attributes to contain those Special IP addresses.

If a CFG_REPLY contains one or more INTERNAL_DNS_DOMAIN attributes and its local policy does not forbid these values, the client MUST configure its DNS resolver to resolve those domains and all their subdomains using only the DNS resolver(s) listed in that CFG_REPLY message. If those resolvers fail, those names MUST NOT be resolved using any other DNS resolvers. Other domain names SHOULD be resolved using some other external DNS resolver(s), configured independently from IKE. Queries for these other domains MAY be sent to the internal DNS resolver(s) listed in that CFG_REPLY message, but have no guarantee of being answered. For example, if the INTERNAL_DNS_DOMAIN attribute specifies "example.com", then "example.com", "www.example.com" and "mail.eng.example.com" MUST be resolved using the internal DNS resolver(s), but "anotherexample.com" and "ample.com" SHOULD NOT be resolved using the internal resolver and SHOULD use the system's external DNS resolver(s).

An initiator SHOULD ignore INTERNAL_DNS_DOMAIN attributes containing domains that are designated Special Use Domain Names in [RFC6761], such as "local", "localhost", "invalid", etc. Although it may explicitly wish to support some Special Use Domain Names.

When an IKE SA is terminated, the DNS forwarding must be unconfigured. The DNS forwarding itself MUST be deleted. All cached data of the INTERNAL_DNS_DOMAIN provided DNS domains MUST be flushed. This includes negative cache entries. Obtained DNSSEC trust anchors MUST be removed from the list of trust anchors. The outstanding DNS request queue MUST be cleared.

INTERNAL_DNS_DOMAIN and INTERNAL_DNSSEC_TA attributes SHOULD only be used on split tunnel configurations where only a subset of traffic is routed into a private remote network using the IPsec connection. If all traffic is routed over the IPsec connection, the existing global

INTERNAL_IP4_DNS and INTERNAL_IP6_DNS can be used without creating specific DNS exemptions.

6. Security Considerations

The use of Split DNS configurations assigned by an IKEv2 responder is predicated on the trust established during IKE SA authentication. However, if IKEv2 is being negotiated with an anonymous or unknown endpoint (such as for Opportunistic Security [RFC7435]), the initiator MUST ignore Split DNS configurations assigned by the responder.

If a host connected to an authenticated IKE peer is connecting to another IKE peer that attempts to claim the same domain via the INTERNAL_DNS_DOMAIN attribute, the IKE connection should only process the DNS information if the two connections are part of the same logical entity. Otherwise, the client should refuse the DNS information and potentially warn the enduser.

INTERNAL_DNSSEC_TA payloads MUST immediately follow an INTERNAL_DNS_DOMAIN payload. As the INTERNAL_DNSSEC_TA format itself does not contain the domain name, it relies on the preceding INTERNAL_DNS_DOMAIN to provide the domain for which it specifies the trust anchor.

If the initiator is using DNSSEC validation for a domain in its public DNS view, and it requests and receives an INTERNAL_DNS_DOMAIN attribute without an INTERNAL_DNSSEC_TA, it will need to reconfigure its DNS resolver to allow for an insecure delegation. It SHOULD NOT accept insecure delegations for domains that are DNSSEC signed in the public DNS view, for which it has not explicitly requested such delegation by specifying the domain specifically using a INTERNAL_DNS_DOMAIN(domain) request.

A domain that is served via INTERNAL_DNS_DOMAIN should pay close attention to their use of indirect reference RRtypes such as CNAME, DNAME, MX or SRV records so that resolving works as intended when all, some or none of the IPsec connections are established.

The content of INTERNAL_DNS_DOMAIN and INTERNAL_DNSSEC_TA may be passed to another (DNS) program for processing. The content MUST be verified and sanitized before passing it to other software. For example, domain names are limited to alphanumeric characters and the minus ("-") and underscore ("_") symbol and if other other characters are present, the entire payload could be ignored and not passed to DNS software, or the malicious characters could be filtered out before passing the payload to DNS software.

7. IANA Considerations

This document defines two new IKEv2 Configuration Payload Attribute Types, which are allocated from the "IKEv2 Configuration Payload Attribute Types" namespace.

Value	Attribute Type	Multi-Valued	Length	Reference
25	INTERNAL_DNS_DOMAIN	YES	0 or more	[this document]
[TBD]	INTERNAL_DNSSEC_TA	YES	0 or more	[this document]

Figure 1

8. References

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Implicit IV for Counter-based Ciphers in IPsec
draft-mglt-ipsecme-implicit-iv-04

Abstract

IPsec ESP sends an initialization vector (IV) or nonce in each packet, adding 8 or 16 octets. Some algorithms such as AES-GCM, AES-CCM, AES-CTR and ChaCha20-Poly1305 require a unique nonce but do not require an unpredictable nonce. When using such algorithms the packet counter value can be used to generate a nonce, saving 8 octets per packet. This document describes how to do this.

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1. Requirements notation

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

2. Introduction

Counter-based AES modes of operation such as AES-CTR ([RFC3686]), AES-CCM ([RFC4309]), and AES-GCM ([RFC4106]) require the specification of a nonce for each ESP packet. The same applies for ChaCha20-Poly1305 ([RFC7634]). Currently this nonce is sent in each ESP packet ([RFC4303]). This practice is designated in this document as "explicit nonce".

In some context, such as IoT, it may be preferable to avoid carrying the extra bytes associated to the IV and instead generate it locally on each peer. The local generation of the nonce is designated in this document as "implicit IV".

The size of this nonce depends on the specific algorithm, but all of the algorithms mentioned above take an 8-octet nonce.

This document defines how to compute the nonce locally when it is implicit. It also specifies how peers agree with the Internet Key Exchange version 2 (IKEv2 - [RFC7296]) on using an implicit IV versus an explicit IV.

This document limits its scope to the algorithms mentioned above. Other algorithms with similar properties may later be defined to use this extension.

This document does not consider AES-CBC ([RFC3602]) as AES-CBC requires the IV to be unpredictable. Deriving it directly from the packet counter as described below is insecure as mentioned in Security Consideration of [RFC3602] and has led to real world chosen plain-text attack such as BEAST [BEAST].

3. Terminology

- o IoT: Internet of Things.
- o IV: Initialization Vector.
- o Nonce: a fixed-size octet string used only once. This is similar to IV, except that in common usage there is no implication of non-predictability.

4. Implicit IV

With the algorithms listed in Section 2, the 8 byte nonce MUST NOT repeat. The binding between a ESP packet and its nonce is provided using the Sequence Number or the Extended Sequence Number. Figure 1 and Figure 2 represent the IV with a regular 4-byte Sequence Number and with an 8-byte Extended Sequence Number respectively.

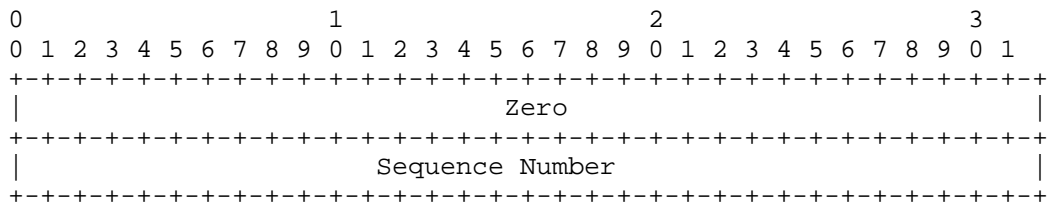


Figure 1: Implicit IV with a 4 byte Sequence Number

- o Sequence Number: the 4 byte Sequence Number carried in the ESP packet.
- o Zero: a 4 byte array with all bits set to zero.

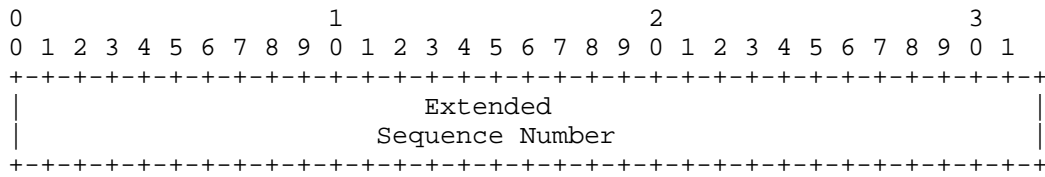


Figure 2: Implicit IV with an 8 byte Extended Sequence Number

- o Extended Sequence Number: the 8 byte Extended Sequence Number of the Security Association. The 4 byte low order bytes are carried in the ESP packet.

5. Initiator Behavior

An initiator supporting this feature SHOULD propose implicit IV for all relevant algorithms. To facilitate backward compatibility with non-supporting peers the initiator SHOULD also include those same algorithms without IIV. This may require extra transforms.

6. Responder Behavior

The rules of SA payload processing ensure that the responder will never send an SA payload containing the IIV indicator to an initiator that does not support IIV.

7. Security Consideration

Nonce generation for these algorithms has not been explicitly defined. It has been left to the implementation as long as certain security requirements are met. This document provides an explicit and normative way to generate IVs. The mechanism described in this document meets the IV security requirements of all relevant algorithms.

As the IV MUST NOT repeat for one SPI when Counter-Mode ciphers are used, Implicit IV as described in this document MUST NOT be used in setups with the chance that the Sequence Number overlaps for one SPI. Multicast as described in [RFC5374], [RFC6407] and [I-D.yeung-g-ikev2] is a prominent example, where many senders share one secret and thus one SPI. Section 3.5 of [RFC6407] explains how repetition MAY BE prevented by using a prefix for each group member, which could be prefixed to the Sequence Number. Otherwise, Implicit IV MUST NOT be used in multicast scenarios.

8. IANA Considerations

AES-CTR, AES-CCM, AES-GCM and ChaCha20-Poly1305 are likely to implement the implicit IV described in this document. This section limits assignment of new code points to the recommended suites provided in [I-D.ietf-ipsecme-rfc4307bis] and [I-D.ietf-ipsecme-rfc7321bis], thus the new Transform Type 1 - Encryption Algorithm Transform IDs are as defined below:

- ENCR_AES-CCM_8_IIV
- ENCR_AES-GCM_16_IIV
- ENCR_CHACHA20-POLY1305_IIV

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