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IPsec Key Exchange using a Controller
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Abstract

This document presents a key exchange method allowing devices managed by a controller (e.g., an SDN management station) to create private pair-wise IPsec SAs without IKEv2 or any other direct peer-to-peer session establishment messages. The method can be used when a full mesh of IKEv2 sessions between IPsec devices is not appropriate.

Status of This Memo

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1. Introduction

Network architectures typically have included network devices directly communicating using network control protocols such as routing and signaling protocols. Additionally, secured communications between these network devices are usually accomplished with a key agreement protocol such as IKEv2 [RFC7296], in which the network devices directly authenticate each other and agree upon security policy and keying material to protect communications between themselves. However, controller-based network architectures (sometimes called "Software-Defined Networking") are now being defined [RFC7426] [RFC8192] and implemented. In controller-based network architectures, control protocols --including key exchange

protocols -- are not implemented directly between the network devices. Software-Defined Networks utilize the controller based network design while maximizing the scalability that it provides. The result is a significantly different trust model; rather than apply a peer-to-peer trust model, the network applies a device-to-controller trust model.

The use of IKEv2 in a device-to-controller trust model is not always optimal. Instead, a new key management method is needed for these models. Appendix B describes situations in which Controller IKE may be a better choice than IKEv2.

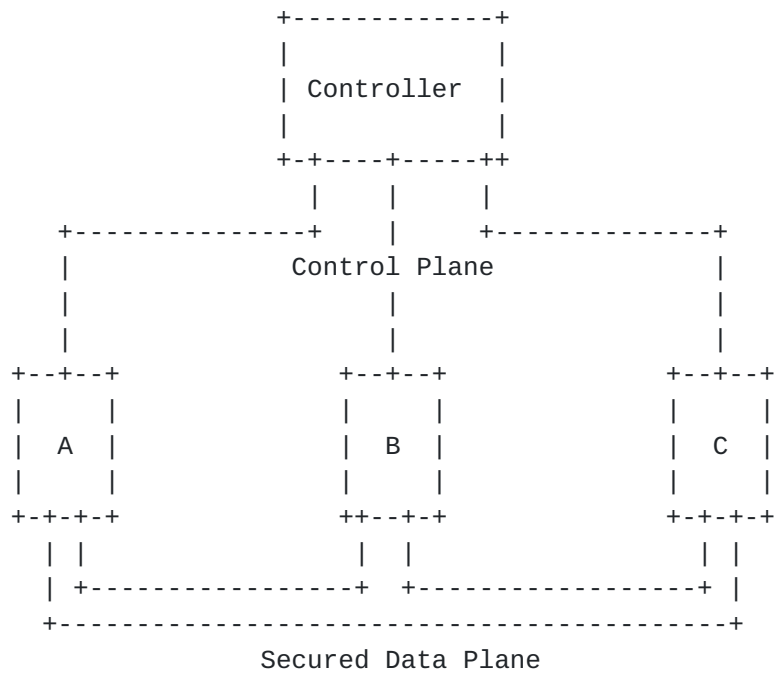


Figure 1: Controller-based Secured Communications

Figure 1 shows an example controller based network design. Three network devices (labeled A, B, and C) setup a protected control plane connection to a Controller. The Controller distributes policy to the network devices, which enables them to securely communicate in the data plane.

When one considers adding a controller to a key exchange method, it is tempting to give it the task of generating and distributing session keys directly to network devices. However, such a design has several security considerations. Because such a controller would have all session keys it could become an active participant or a passive monitor to the secured communications. Also, for scalability reasons one might consider having a controller distribute session keys that are group keys, either a single group key or a set of group

keys that devices use to protect communications between them. This document does not specify the use of group session keys.

Many key exchange methods (such as IKEv2) use a Diffie-Hellman (DH) algorithm to derive keys. When combined with an authentication method, the key exchange method allows two network devices to generate private pair-wise keys with each other. This document presents a key exchange method making use of the device-to-controller trust model, where a controller is used to distribute keying material and policy between network devices, also resulting in the devices generating private pair-wise keys with each other. DH public values are provided to controllers from IPsec devices, where the controller relays the DH public values to authorized peers of that IPsec device as defined by a centralized policy. Network devices then create and install private pair-wise IPsec session keys to be used to secure communications with their peers.

Controller-based key exchange methods can be used to create a Gateway-to-Gateway VPN [RFC7018] in either a Full-Mesh Topology or Dynamic Full-Mesh Topology.

Although IKEv2 is not used in this approach, the key management interfaces between IKEv2 and IPsec defined in RFC 7296 are maintained as much as possible.

1.1. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

2. Overview

In Controller-IKE a controller acts as a trusted third party, which relays policy and keying material between IPsec devices. The controller can be a standalone device, or integrated into a management station. Communications between the controller and the IPsec devices MUST be authenticated, encrypted, and integrity-protected.

All algorithms are selected by the controller or a management station associated with the controller. The combination of a controller and a set of IPsec devices comprises a cooperating group of devices that make up a VPN, where each IPsec device is authorized to communicate with other IPsec devices in the group. Controller policy may allow

an IPsec device to communicate with all other IPsec devices in the group, or may restrict it to a subset of those devices.

DH public values are distributed to the controller from each IPsec device and redistributed from the controller to each authorized peer IPsec device. Each IPsec device creates and maintains a DH pair, which it uses to communicate with other members of the VPN. This distribution of DH public values (and other related values) is intended to be embedded into an existing network device/controller protocol. In particular, Controller-IKE provides a mechanism for secure key management and only key management. It does not provide policy information or configuration as that is assumed to be provided by the controller. One such controller protocol [I-D.ietf-i2nsf-sdn-ipsec-flow-protection] is being developed at this time in the IETF I2NSF working group. Another controller protocol [I-D.sajassi-bess-secure-evpn] is being developed by the IETF BESS working group.

3. Generating Initial IPsec SAs

When an IPsec device begins operation, it generates a DH pair, using an algorithm defined in the IKEv2 Diffie-Hellman Group Transform IDs [IKEV2-IANA]. If the device does not have any active peers it simply distributes its DH public value to the Controller, along with a nonce to be used during SA creation. Whenever a DH pair is created, a new nonce MUST also be created. Whenever DH public values are transmitted, they are transmitted with the corresponding nonce. Whenever a DH private or DH public value is used, it is used along with the corresponding nonce. However, in the diagrams and descriptions below, the nonces are often left out for the sake of clarity.

Upon receiving a peer's DH public value and nonce, the receiver creates IPsec SAs (as described in Section 5.2). For each peer, a pair of IPsec SAs are created by combining the IPsec device's own DH private value with the DH public number received from the Controller.

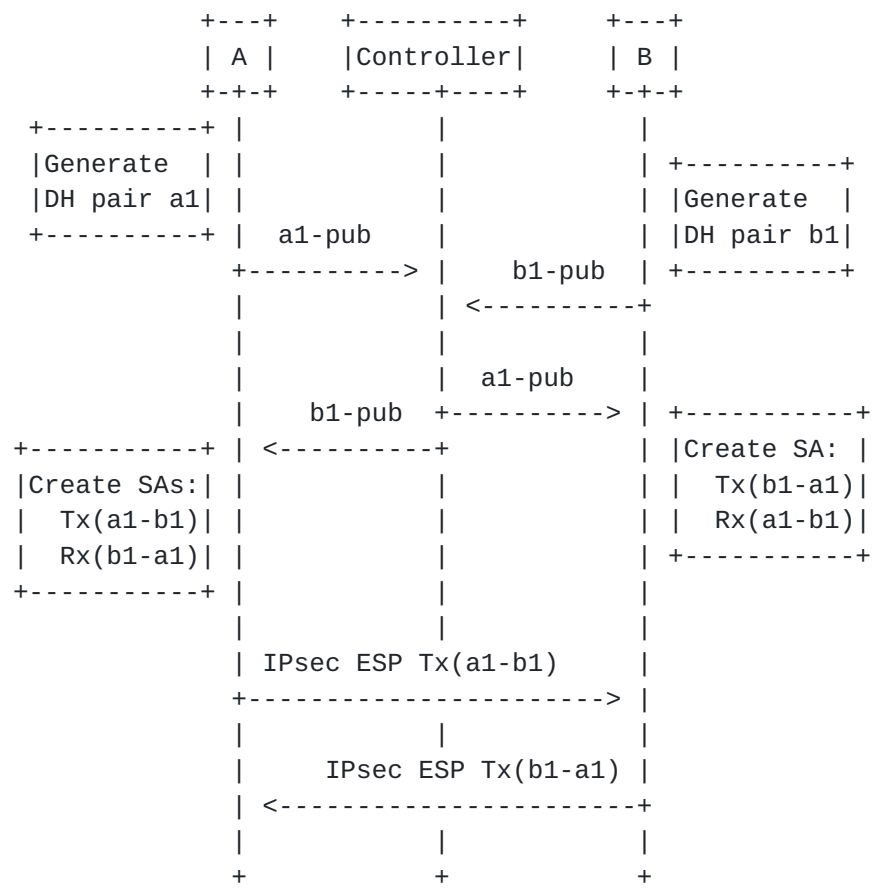


Figure 2: Generation of Initial IPsec SAs between two peers

Figure 2 shows IPsec SA generation between a pair of IPsec devices. Two IPsec devices (A and B shown in Figure 1) join the network. Each creates it's own DH pair (labelled "a1" on A and "b1" on B), and distributes the DH public value (labelled a1-pub and b1-pub) to the Controller. The controller forwards the DH public value to all authorized peers, although for simplicity of exposition the figure only shows the two IPsec devices.

When each device receives the peer's DH public value, a pair of IPsec SAs are generated: one outbound and one inbound. As shown in the figure, A generates an outbound SA labeled Tx(a1-b1), representing that it has been generated using A's DH pair labeled a1 and B's DH pair labeled b1. B generates the same IPsec SA as an inbound SA, which is labeled Rx(a1-b1). Similarly, A generates an inbound IPsec SA labelled Rx(b1-a1), which is the same IPsec SA on B labelled Tx(b1-a1).

This process repeats on both A and B as they discover other IPsec devices with which they are authorized to communicate.

4. Rekey of IPsec SAs

Any IPsec device may initiate a rekey at any time. Common reasons to perform a rekey include a local time or volume based policy, or may be the result of a cipher counter mode Initialization Vector (IV) counter nearing its final value. The rekey process is performed individually for each remote peer. If rekeying is performed with multiple peers simultaneously, then the decision process and rules described in this rekey are performed independently for each peer.

A decision process choosing an outbound IPsec SA is followed when certain events occur, as described in the rules below. The same decision process is followed regardless of whether the device is performing a rekey or responding to a peer's rekey. The decision process is:

1. Determine the outbound SAs with the remote peer's most recently distributed DH public value.

2. Determine which of those outbound SAs are "live". A "live" outbound SA is one built from a DH value from the local peer for which it has observed inbound traffic using any SA based on the same local DH pair. This proves that the remote peer is prepared to receive traffic protected by that DH pair.

3. Choose the "live" outbound SA built from the local peer's most recent DH public value.

A rekey operation follows these four basic rules.

Rule 1 When an IPsec device needs to perform a rekey with a remote peer, it creates a new pair of IPsec SAs by combining the new DH private value with the peer's DH public values. If the remote peer is also in the midst of a rollover and its DH public value has already been received, then this may result in creating two sets of SAs: one pair with the remote peer's old DH public value, and one pair with the remote peer's new DH public value.

Rule 2 When an IPsec device receives a new remote peer's DH public value from the controller it creates and installs a new pair of IPsec SAs by combining the remote peer's new DH public value with its own current local DH private values. If both devices are in the midst of a rollover, this may result in creating two sets of SAs with the remote peer's new DH public value: one with the local old DH private value, and one with the local new DH private value. The outbound SA decision process is performed.

Rule 3 The first IPsec packet received by a rekeying IPsec device on an inbound SA using its new DH pair causes it to perform the outbound SA decision process. It may also shorten the lifetime of IPsec SAs using its own old DH pair that are shared with this peer, as they are no longer in use (other than the inbound SA might receive packets in transit).

Rule 4 The first IPsec packet received from a remote rekeying IPsec device using the remote peer's new DH pair allows the IPsec device to shorten the lifetime of IPsec SAs shared with this peer using unused remote DH pairs.

Two examples follow: a single IPsec device performing a rekey with its peers, and two IPsec devices performing a simultaneous rekey. The same rekey operations described above are exhibited in both cases.

4.1. Single IPsec Device Rekey

When a single IPsec device begins a rekey, it first generates a new DH pair and generates new IPsec SA pairs for each peer with which it is communicating. It does this by combining the new DH private value with each peer's existing DH public value. Only when the new IPsec SAs have been installed and the device is prepared to receive on those new SAs does it then distribute the new DH public value to the Controller, which forwards the new DH public value to its authorized peers. The rekeying IPsec device continues to transmit on the old SAs for each peer until it observes that peer begin to transmit on the new SAs.

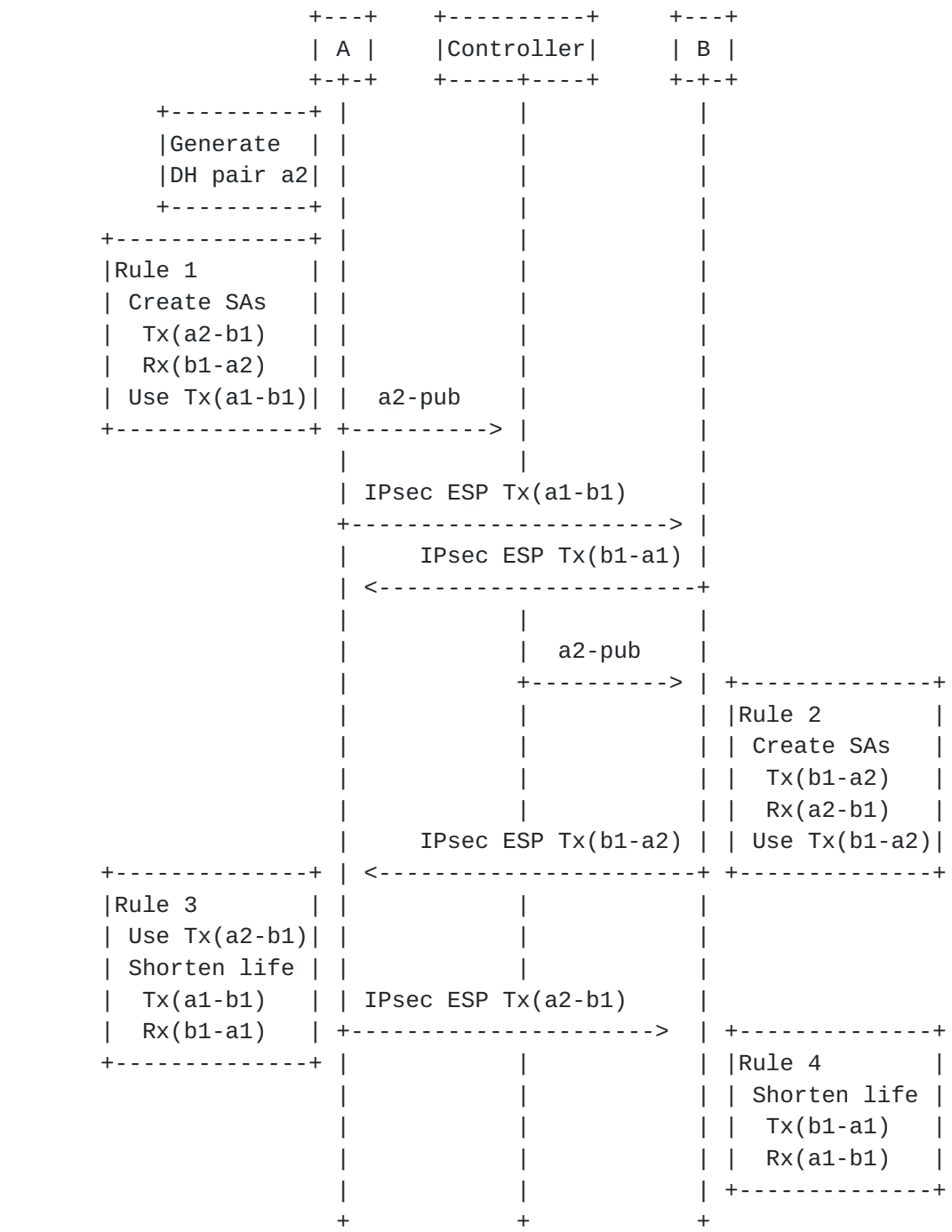


Figure 3: Single IPsec Device Rekey Protocol Flow

In Figure 3, device A is shown as performing a rekey, and it creates a DH pair labelled "a2". The following steps are followed.

1. Rule 1 requires creating new IPsec SAs for each peer. In this example, A creates a new outbound IPsec SA to communicate with B labelled Tx(a2-b1), and a new inbound IPsec SA labelled

Rx(b1-a2). A continues to transmit on Tx(a1-b1) (generated as shown in Figure 2).

2. A distributes the new public value (a2-pub) to the Controller who forwards it to A's authorized peers, which includes B. During this time, both A and B continue to use the initial IPsec SAs setup between them using a1 and b1.

3. When B receives a2 from the controller, B follows Rule 2 by creating Tx(b1-a2), Rx(a2-b1). B also follows the outbound SA decision process, which causes it to change its outbound IPsec SA to A to Tx(b1-a2).

4. When A receives a packet protected by Rx(b1-a2), it follows Rule 3 and performs the outbound SA decision process. This causes it to change its outbound IPsec SA to Use Tx(a2-b1). It also optionally shortens the lifetime of the old IPsec SAs shared with this peer.

5. When B receives a packet protected by Tx(a2-b1), it follows Rule 4, in which it may shorten the lifetime of the old IPsec SAs shared with this peer using DH pairs that are no longer in use.

At the end of the rekey, both A and B retain a single DH pair, and a single set of IPsec SAs between them.

4.2. Simultaneous Rekey of IPsec Devices

When two or more IPsec device simultaneously begin a rekey, they each follow the rekeying method described in the previous section. Every rekeying IPsec device generates a new DH pair and generates new IPsec SA pairs for each peer with which it is communicating by combining their new DH private value with each peer's existing DH public value. When this completes on a particular IPsec device, it distributes the new DH public value to the Controller, which forwards it to its authorized peers. Each continues to transmit on the existing SAs for each peer until it observes that peer transmitting on the new SAs. During a simultaneous rekey up to four pairs of IPsec SAs may be temporarily created, but the four rules ensure that they converge on a single new set of IPsec SAs.

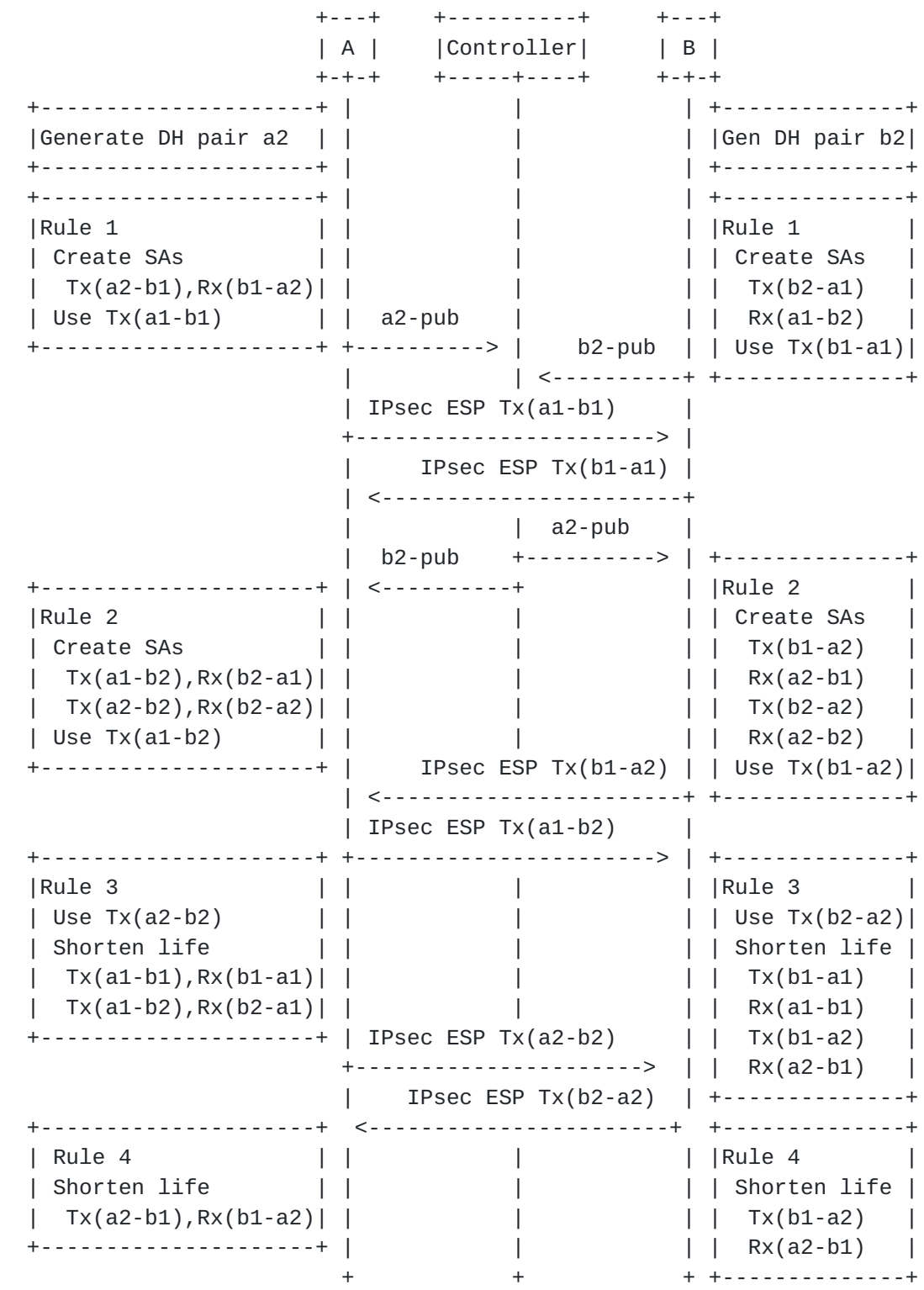


Figure 4: Simultaneous IPsec Device Rekey Protocol Flow

In Figure 4, device A and device B are both shown as performing a rekey. Their initial state corresponds to the final state shown in

Figure 2 (i.e., they are communicating using a single pair of IPsec SAs created from DH pairs "a1" and "b1".

1. A and B follow Rule 1, which includes creating new IPsec SAs for each peer. In this example, A creates a new outbound IPsec SA to communicate with B labelled Tx(a2-b1), and a new inbound IPsec SA labelled Rx(b1-a2). B creates a new outbound IPsec SA to communicate with B labelled Tx(a1-b2), and a new inbound IPsec SA labelled Rx(b2-a1). A and B continue to transmit on IPsec SAs previously created from DH pairs "a1" and "b1".

2. A distributes the new public value (a2-pub) to the Controller who forwards it to A's authorized peers, which includes B. B also distributes the new public value (b2-pub) to the Controller who forwards it to B's authorized peers, which includes A.

3. When A and B receive each other's new peer DH public value from the controller they follows Rule 2. But because now there are four DH values that could be in used between A and B, they must be prepared to use IPsec SAs using each permutation of DH values: a1-b1, a1-b2, a2-b1, a2-b2. Prior to implementing Rule 2, each has already created sets of IPsec SAs matching two of the permutations, so just two more sets must be generated during Rule 2.

   * One pair is created using the IPsec device's old DH pair with the peer's new DH pair. This is necessary, because the peer may transmit on this pair.

   * One pair is created using the IPsec device's new DH pair with the peer's new DH pair. This is the set of IPsec SAs that will be used at the end of the rekey process.

   Each peer begins transmitting on an IPsec SA that combines the remote peer's new DH pair and its own old DH pair, which is the most recent "live" SA on which it can transmit. I.e., A begins transmitting on Tx(a1-b2) and B begins transmitting on Tx(b1-a2).

4. When A receives a packet protected by Rx(b1-a2), it understands that the remote peer has received its new DH public value. A also understands that because of Rule 2 that B must have created IPsec SAs using a2-b2. This allows A to follow Rule 3 and change its outbound IPsec SA to Use Tx(a2-b2). Similarly, when B receives a packet protected by Rx(a1-b2), B recognizes that it can also begin to transmit using Tx(b2-a2). Note that it also possible that A will receive a packet protected by Rx(b2-a2) or B will receive a packet protected by Rx(a2-b2), and then knows it can transmit on an IPsec SA using both of the new DH pairs.

5. Also in Rule 3, Both A and B optionally shorten the lifetime of older IPsec SAs shared with this peer derived from unused DH pairs to be cleaned up. A shortens the lifetime of SAs based on a1. B shortens the lifetime of SAs based on b1.

6. When A and B receive a packet protected by the remote peer's latest DH pair, they shortens the lifetime of SAs based on the remote peer's unused DH pair.

5. IPsec Database Generation

The PAD, SPD, and SAD all need to be setup as defined in the IPsec Security Architecture [RFC4301].

5.1. The Security Policy Database (SPD)

The SPD is implemented using methods outside the scope of this document. The SPD describes the type of traffic that will be protected between IPsec devices and the policy (e.g., ciphers) used to create SAs.

5.2. Security Association Database (SAD)

The SAD is constructed from IPsec policy (e.g., ciphers) obtained (depending on the controller protocol method) either from the controller or distributed by a peer (see Section 6).

Keying Material is generated following the method defined in IKEv2, and depends on SPIs, nonces, and the Diffie-Hellman shared secret.

The following sections describe how the necessary values are determined.

5.2.1. Generating Keying Material for IPsec SAs

5.2.1.1. g^ir

A DH public value is distributed from the peer.

A DH shared secret (g^ir) is computed using the peer's public value, and the device's private value. The DH group to be used must be known by the device. Options include distribution by an SDN controller, or distribution by the peer with the DH public value (see Section 6).

5.2.1.2. Nonces

Nonces are distributed with a DH public value, and are used only with that value. It is RECOMMENDED that nonces are generated as described in Section 2.10 of [RFC7296].

IKEv2 Key derivation specifies an initiator's nonce (Ni) and a responder's nonce (Nr). While neither peer is truly initiating a session), in order to fit the IKE key material models the roles must be assigned. The initiator is chosen as the peer with the larger nonce and the responder is the peer with the smaller. This does mean that the roles can change for each rekey and for each SA within a rekey.

5.2.1.3. SPIs

SPI values that are unique to each generation of keying material need to be determined. While each peer could distribute its own inbound SA value, the SPI value would be used by many peers. Although this is not a problem for an SA lookup (lookup can include the source and destination IP addresses), experience has shown that this is sub-optimal for some hardware SA lookup algorithms. Instead, this specification proposes generating values that are unpredictable and indistinguishable from randomly-generated SPI values.

SPI values are generated using the IKEv2 prf+ function, where nonces are used as the input to the prf. This produces a statistically random SPI value that should be unique. However, with a 32 bit value there is still a very small, but non-zero, chance of SPIs repeating for a given pair of peers. To prevent this and ensure uniqueness in the operational window, we also use the lower 2 bits from each peer's rekey counter.

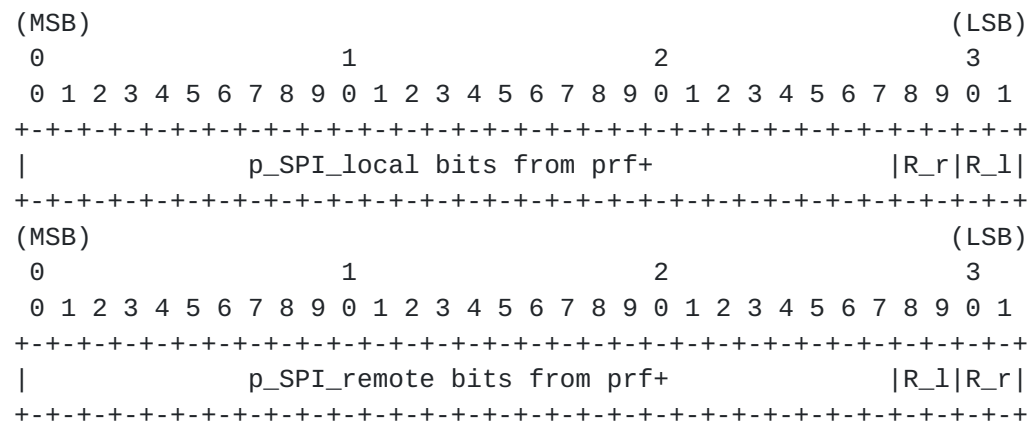
First the SPIs are taken from the prf+ function as 32 bit values and assigned based on which peer is taking the role of initiator and which is taking the role of responder. The p_SPI_i is taken by the device providing Ni, where p_SPI_r is taken by the other device.

```
{p_SPI_i | p_SPI_r } = prf+(Ni | Nr, "SPI generation")
```

Next p_SPI_i and p_SPI_r are mapped from initiator and responder roles to local and remote roles based on the choice of Ni and Nr in 5.2.1.2 and are renamed to p_SPI_local and p_SPI_remote.

Then, 2 2-bit Rotation Numbers (RN) are generated from the 2 least significant bits (LSB) of the 2 rekey counter values (see Section 6). These 4 bits replace the least significant bits of p_SPI_local and p_SPI_remote with the local RN bits taking the least significant

position in p_SPI_local and the remote RN bits taking the least significant position in p_SPI_remote. This shown in the following two diagrams with RN_local shown as R_l and RN_remote shown as R_r.



The reason for changing terminology from initiator/responder to local/remote is because the roles of initiator/responder can change in every rekey. The order of RN_local and RN_remote needs to remain constant. If that order was based on initiator/responder, there's a risk that if the initiator and responder roles changed and the two peers re-keyed on different frequencies, they could end up with identical RN values.

In some circumstances additional values may also need to be added to the prf for peers to ensure that they have implemented the same policy. Appendix A.3.1 includes a discussion of when this might be needed. In these cases, only the prf+ inputs are modified and the Rotation Numbers MUST still be added as above.

Because a device is not choosing its inbound SPI, its SA lookup process needs to be aware that duplicates could occur across different peers. In that case, the inbound SA Lookup SHOULD include a source IP address in addition to the SPI value (see Section 4.1 of [RFC4301]).

5.2.1.4. IPsec key generation

As described in previous sections, a DH public value and a nonce are distributed by peers. These are used to generate IPsec keys following the method defined in the IKEv2. SKEYSEED is generated following Section 2.14 of [RFC7296]:

SKEYSEED = prf(Ni | Nr, g^ir)

KEYMAT can be similarly derived as defined by IKEv2 (Section 2.17 of [RFC7296]), although only SK_d is required to be generated (shown in Section 2.14 of [RFC7296]).

```
SK_d = prf+ (SKEYSEED, Ni | Nr | SPIi | SPIr)

KEYMAT = prf+(SK_d, Ni | Nr)
```

However, with the simplification where only SK_d is generated, it can be observed that the derivation of SK_d could be skipped entirely, and an optimized derivation of KEYMAT could be as follows:

```
KEYMAT = prf+ (SKEYSEED, Ni | Nr | SPIi | SPIr)
```

Note: A single specification for generating KEYMAT will be determined in a future version of this document.

5.3. Peer Authorization Database (PAD)

The PAD identifies authorized peers. PAD entries are either statically configured, or may be dynamically updated by the controller.

The PAD omits authentication data for each peer, because it has delegated authentication and authorization to the controller.

The controller protocol MUST be able to describe an identity that a receiver can match against its local PAD database, to ensure that the peer is an authorized peer.

6. Policy distributed through the Controller

An IPsec device distributes to a controller a DH public value and the associated information and policy needed to create IPsec SAs in a Device Information Message (DIM). The controller then distributes the DIM to all authorized peers of that device. The following data elements MUST be embedded in a DIM message:

- DH public number (used for key computation)
- Nonce (used for key computation and SPI generation)
- Peer identity (used to identify a peer in the PAD)
- An Indication whether this is the initial distributed policy
- A rekey counter, which increases for each unique DIM sent

In cases where a single fixed IPsec policy has been pre-distributed, it is not necessary for the peer to send or receive that policy in a DIM. However, in cases where an IPsec device needs to indicate the policy it is willing to use, the following data elements SHOULD be included in a DIM:

- An IPsec policy or policies
- A lifetime bounding the use of the DH public number. When this DH public number is used to create an IPsec SA, the shortest lifetime is used as an SA lifetime for the pair of generated IPsec SAs. When the lifetime expires, the local version of the DIM and IPsec SAs generated from it MUST be deleted.

Appendix A suggests different ways that this policy may be included in a controller protocol. This document does not define a normative protocol format, because the DIM very likely needs to be integrated into an existing controller protocol rather than be an independent key management protocol. However, the controller protocol MUST provide a strong authentication between the device and the controller, and integrity of the messages MUST be provided. Confidentiality of the messages SHOULD also be provided. It is important that the controller protocol be protected with algorithms that are at least as strong as the algorithms used to protect the IPsec packets.

6.1. IPsec policy negotiation

In many controller based networks, there is a single IPsec policy used by all devices and there is no need to redistribute or select policy details. However, in some circumstances, there may be a need to have multiple policy options. This could happen when a controller changes the policy and wants to smoothly migrate all devices to the new policy. Or it could happen if a network supports devices with different capabilities. In these cases, devices need to be able to choose the correct policy to use for each other device, and must do this without sending additional messages and without sending individual messages to each peer. When a device supports multiple policies, it MUST include those policies within the DIM. This is done by sending multiple distinct policies, in order of preference, where the first policy is the most preferred. The policy to use is selected by taking the receiver's list of policies (i.e., the list advertised by the device that generates Nr), starting with the first policy, compare against the initiator's (device that generates Ni) list, and choosing the first one found in common. The method conforms to the IKEv2 Cryptographic Algorithm Negotiation described in Section 2.7 of [RFC7296]. (However, see additional discussion when IKEv2 payloads are used in Appendix A.3.1).

If there is no match, this indicates a controller configuration error. These devices MUST NOT establish new SAs until a DIM is received that does produce a match.

When a device supports more than one DH group, then a unique DH public number MUST be specified for each in order of preference. The selection of which DH group to use follows the same logic as Policy selection, using the receiver's list order until a match is found in the initiator's list.

7. Security Considerations

This document proposes that a device re-use an ephemeral Diffie-Hellman exponential with multiple peers. There are some known potential vulnerabilities to this approach, which can be mitigated by the device first validating a peer's public value to be a safe public value before combining its own private value with it. The tests which MUST be performed are described in [RFC6989]. See [REUSE] for additional security considerations when reusing ephemeral Diffie-Hellman keys.

A controller acts as a "trusted third party", which asserts that a particular Diffie-Hellman public value is associated with a particular entity. A device receiving the public key is not required to validate the assertion.

A subverted controller can act as a "man-in-the-middle" between a pair of devices. The easiest attack would be for the attacker to adjust the routing for the desired traffic through a compromised gateway and directly observe the cleartext. It is also possible that a subverted controller could provide a device with a Diffie-Hellman public value that actually belongs to a compromised gateway rather than the intended gateway, but doing so does not seem to be necessary. Nonetheless, the attack of a subverted controller can be mitigated by having a device sign its Diffie-Hellman public value (e.g, as a CMS Signed data object), where the receiver validates the digital signature on the object. However, this adds significant processing cost to a rekey and does not fit the controller-based network architecture model.

A subverted IPsec device whose DH pair has been compromised would be vulnerable to all of its IPsec traffic using that DH pair being compromised. Assuming the use of strong DH algorithms (including quantum resistant algorithms as they become available), the compromise would most likely be due to the device itself being compromised. Such a compromised device is also vulnerable to a direct plaintext compromise.

PFS is achieved between rekey periods, as DH pairs are required to be generated independently. However, because a device uses the same long-term key to generate session key with multiple peers, there is no PFS between sessions within the same rekey period. To reduce key exposure outside of a rekey period, when a connection is closed each endpoint MUST forget not only the keys used by the connection but also any information that could be used to recompute those keys. However, the DH private key value and the nonce distributed with it may be forgotten only once the last IPsec SA that uses the private key value is removed from the SAD and there is no chance that a new IPsec SA could be setup that requires the private key value.

If quantum resistance is considered to be an issue, the controller can distribute a PSK, which could be used to create the SK_d in the manner shown in [I-D.ietf-ipsecme-qr-ikev2].

8. IANA Considerations

This memo specifies no IANA actions.

9. Acknowledgements

Graham Bartlett provided many useful comments and suggestions. Rafa Marin-Lopez and Gabriel Lopez-Millan provided valuable reviews and advice regarding SDN use cases.

10. References

10.1. Normative References

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Appendix A. Example Controller protocols

This section contains suggestions of how a Controller protocol might distribute policy for the Controller-based IKE.

A.1. Example: I2NSF

IPsec devices described in this document could be implemented as an Network Security Function (NSF) in the I2NSF Framework [RFC8329]. An I2NSF Controller or NSF Manager could distribute a DIM as a new type of I2NSF Policy Rule. A YANG configuration data model would need to be defined for this. This could be a new "Case 3" defined in [I-D.ietf-i2nsf-sdn-ipsec-flow-protection].

A.2. Example: Network Controller

Site-to-site networks (e.g., an L2VPN or L3VPN) often use a network controller to share networking state between routers. When those routers use IPsec to protect the communications between themselves, this same network controller could distribute DH public number and nonces as well. For example, when a BGP Route Reflector (RR) is used in a network, a new address family (AFI) could distribute the state necessary for a controller-based IPsec key exchange. The BGP session between BGP routers and the Route Reflector (RR) would need to at least be integrity protected from a man in the middle and SHOULD be protected for confidentiality to prevent identity leakage.

The controller protocol MUST provide for adequate synchronization of the state. For example, when IPsec devices are synchronized with a key management protocol it is often necessary for the protocol to indicate when a device has rebooted and thinks that it is contacting peers for the first time. This alerts peers to destroy earlier keying state that they may still believe is current.

One possible method for distributing a DIM within a controller protocol is to use a set of IKEv2 payloads. For example, when a single set of IPsec policy has been distributed to all IPsec devices

by a configuration server then the following minimum required data elements can be distributed using the following IKEv2 payloads.

ID, [N(INITIAL_CONTACT),] KE, Ni

When initiating a rekey, the IPsec device need only distribute its new DH public number due to Rule 1. Existing peers receiving the new DH public number need not be re-told about the previous DH public number. Any new peer that receives and acts upon a "stale" controller message (containing the old DH public number) will still be able to setup IPsec SAs using the old DH public number, and can use them until the new DH public number is received.

A.3. Additional controller protocol considerations

If the controller protocol is more complicated, there are some additional considerations.

A.3.1. Peer-to-peer distribution of IPsec policy

In some cases an IPsec device may have more than one IPsec policy under which it is willing to communicate. This would result in an IPsec device using the decision process described in Section 6.1 to determine which policy to use between itself and that peer. An IKEv2 SA payload could be used to distribute the policies, and the decision process could be used to determine which single set of policy is to be used. Note that the same decision process is followed by both peers. It is important that when an SA payload is used, that each proposal within the SA payload MUST contain at most a single transform for each Transform type (e.g., ENCR and (optionally) ESN for combined mode algorithms, ENCR, INTEG, and (optionally) ESN otherwise). This is due to the absence of a direct peer-to-peer reply message, which would alert the sender of which proposal was chosen.

1. Determine the Responder (as defined in Section 5.2.1.2).

2. Follow the negotiation rules defined in Section 2.7 of IKEv2 [RFC7296] (with the restrictions that more than one transform of each type MUST NOT be present, and no error notifications are returned to the peer). Each peer will independently compare each Proposal in the Responder's SA payload to each Proposal in the Initiator's SA payload and choose the first match.

3. If there is no match, then this is considered a controller error, and the IPsec devices SHOULD report the error to the controller.

Payloads distributed in the controller protocol could be as follows:

ID, [N(INITIAL_CONTACT),] SA, KE, Ni

where the SA payload contains one or more Proposals, each of this includes a transform indicating the Diffie-Hellman group it is willing to use (D-H Transform), and IPsec transforms that it is willing to use (e.g., ENCR, INTEG, and ESN Transforms). The KE payload includes a DH public number matching the D-H Transform.

Because there is no direct peer-to-peer IKE messages, there is a need for peers to reliably know which Proposal in the SA payload was chosen. That is, if they do not reliably follow the same decision process they may end up installing IPsec SAs with incompatible policy. A straightforward method to verify that a peer has chosen the same policy is to include the SA Proposal number (SPN) from the SA payload in the SPI calculation.

{p_SPI_i|p_SPI_r} = prf+(Ni | Nr, "SPI generation" | SPNi | SPNr)

If a device is willing to use more than one DH group, then a single SA payload should be distributed, but the included Proposals may contain different D-H Transforms. A KE payload must be included for each D-H Group that is offered in the SA payload.

ID, [N(INITIAL_CONTACT),] [SA,] KE, [KE,] Ni

A.3.2. Ordering of messages distributed to a controller

A controller protocol may require a method of determining ordering of messages that are distributed, i.e. a Rekey Counter (RC). It is RECOMMENDED that the ordering be defined by a monotonically increasing counter value distributed with the IPsec policy. It is further RECOMMENDED that to ensure ordering after a device reboot that the counter include a "boot count", which increments after each reboot. For example, the counter could be a 64-bit counter where the high order 32 bits are a "boot count", followed by the counter that begins at 1 following the increment of the "boot count".

Appendix B. Choosing whether to use IKEv2 or Controller IKE

The following list describes the circumstances in which Controller IKE may be preferable to IKEv2. Note that Controller IKE does not replace IKEv2, but does provide an alternative for some network architectures where it is more optimal.

Trust Model
: Controller IKE is optimal when a device-to-controller trust model is in use. IKEv2 is a better approach when IPsec devices require a peer-to-peer trust model.

Latency	Controller IKE reduces tunnel session setup latency in a device-to-controller trust model. Once controller communications hace commenced, a session can be initiated with any other IPsec device managed by that controller without requiring additional key management messages. This is optimal when a group of IPsec devices are sensitive to latency.
Load Balancing	In some network architectures a full mesh of IKEv2 sessions can occur without affecting the load of IPsec and IKEv2 processing on any of the communicating IPsec devices, including having protocol state machinery to handle an IPsec peer device that is overloaded and not reliably responding. But when a set of IPsec devices is very large, this can be problematic. Also, when an IPsec device is overloaded there may be re-transmissions of IKEv2 messages, which further complicates protocol state. The simplified control plane of Controller IKE makes load balancing a purely local matter, where the installation of IPsec IPsec SAs takes into consideration only available local resources. And because there are no peer-to-peer key management messages, no re-transmissions occur.
Complexity	Full attribute negotiation is not needed in a controller environment. Controllers enforce the SA policy details, moving complexity away from end nodes. This also reduces the attack surface on the end node.
Network Shape	In some network topologies a persistent bi-directional link does not exist between all peers. Sometimes one direction has significantly reduced capabilities or is even non-existent. This can be either temporary or permanent, and sometimes is a purposefully enforced restriction. Provided that both peers can communicate with the controller, Controller IKE allows for the establishment of SAs and rekeying in these scenarios.

Appendix C. Implementation Considerations

The system architecture of many implementations includes a separation between a data plane "fastpath" and a "control plane". The data plane performs IPsec encapsulation and decapsulation in the simplest and most expedient way possible, where the control plane handles the complexity of network protocols including state machines, timers, network communication, and managing the data plane.

A typical IKEv2 implementation on Linux works this way, with IKEv2 running in user space and IPSec packet processing happening in the kernel. The kernel, or other fast path implementation, provides an interface for the control plane to manage it. This interface includes a way to create SAs, delete SAs, and observe statistics for SAs. Controller IKE is designed to be able to work with these same interfaces. For example a user space implementation of Controller IKE could work with a Linux kernel implementation of the IPSec data plane without needing kernel modifications. SA creation and deletion remains the same. SA creation occurs with Rules 1 and 2. SA deletion happens with Rules 3 and 4. Additionally Rules 3 and 4 need to observe that traffic has arrived on a particular SA. This can be done by observing packet counts on an SA and seeing when they go from zero to any positive number. Due to the asynchronous nature of Controller IKE, Rules 3 and 4 do not require immediate action when the first packets arrive, but instead they can be implemented with relaxed polling.

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