

Intermediate Exchange in the IKEv2 Protocol
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Abstract

This document defines a new exchange, called Intermediate Exchange, for the Internet Key Exchange protocol Version 2 (IKEv2). This exchange can be used for transferring large amount of data in the process of IKEv2 Security Association (SA) establishment. Introducing Intermediate Exchange allows re-using existing IKE Fragmentation mechanism, that helps to avoid IP fragmentation of large IKE messages, but cannot be used in the initial IKEv2 exchange.

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1. Introduction

The Internet Key Exchange protocol version 2 (IKEv2) defined in [\[RFC7296\]](#) uses UDP as a transport for its messages. If size of the messages is large enough, IP fragmentation takes place, that may interfere badly with some network devices. The problem is described in more detail in [\[RFC7383\]](#), which also defines an extension to the IKEv2 called IKE Fragmentation. This extension allows IKE messages to be fragmented at IKE level, eliminating possible issues caused by IP fragmentation. However, the IKE Fragmentation cannot be used in the initial IKEv2 exchange (IKE_SA_INIT). This limitation in most cases is not a problem, since the IKE_SA_INIT messages used to be small enough not to cause IP fragmentation.

However, the situation has been changing recently. One example of the need to transfer large amount of data before IKE SA is created is using Quantum Computer resistant key exchange methods in IKEv2. Recent progress in Quantum Computing has brought a concern that classical Diffie-Hellman key exchange methods will become insecure in a relatively near future and should be replaced with Quantum Computer (QC) resistant ones. Currently most of QC-resistant key exchange methods have large public keys. If these keys are exchanged in the IKE_SA_INIT, then most probably IP fragmentation will take place, therefore all the problems caused by it will become inevitable.

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A possible solution to the problem would be to use TCP as a transport for IKEv2, as defined in [\[RFC8229\]](#). However this approach has significant drawbacks and is intended to be a "last resort" when UDP transport is completely blocked by intermediate network devices.

This specification describes a way to transfer large amount of data in IKEv2 using UDP transport. For this purpose the document defines a new exchange for the IKEv2 protocol, called Intermediate Exchange or IKE_INTERMEDIATE. One or more these exchanges may take place right after the IKE_SA_INIT exchange and prior to the IKE_AUTH exchange. The IKE_INTERMEDIATE exchange messages can be fragmented using IKE Fragmentation mechanism, so these exchanges may be used to transfer large amounts of data which don't fit into the IKE_SA_INIT exchange without causing IP fragmentation.

The Intermediate Exchange can be used to transfer large public keys of QC-resistant key exchange methods, but its application is not limited to this use case. This exchange can also be used whenever some data need to be transferred before the IKE_AUTH exchange and for some reason the IKE_SA_INIT exchange is not suited for this purpose. This document defines the IKE_INTERMEDIATE exchange without tying it to any specific use case. It is expected that separate specifications will define for which purposes and how the IKE_INTERMEDIATE exchange is used in the IKEv2.

2. Terminology and Notation

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.

3. Intermediate Exchange Details

3.1. Support for Intermediate Exchange Negotiation

The initiator indicates its support for Intermediate Exchange by including a notification of type INTERMEDIATE_EXCHANGE_SUPPORTED in the IKE_SA_INIT request message. If the responder also supports this exchange, it includes this notification in the response message.

Initiator	Responder
-----	-----
HDR, SAi1, KEi, Ni,	
[N(INTERMEDIATE_EXCHANGE_SUPPORTED)] -->	
	<-- HDR, SAR1, KEr, Nr, [CERTREQ],
	[N(INTERMEDIATE_EXCHANGE_SUPPORTED)]

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The `INTERMEDIATE_EXCHANGE_SUPPORTED` is a Status Type IKEv2 notification. Its Notify Message Type is 16438. Protocol ID and SPI Size are both set to 0. This specification doesn't define any data this notification may contain, so the Notification Data is left empty. However, future enhancements of this specification may override this. Implementations **MUST** ignore the non-empty Notification Data if they don't understand its purpose.

3.2. Using Intermediate Exchange

If both peers indicated their support for the Intermediate Exchange, the initiator may use one or more these exchanges to transfer additional data. Using the `IKE_INTERMEDIATE` exchange is optional, the initiator may find it unnecessary after completing the `IKE_SA_INIT` exchange.

The Intermediate Exchange is denoted as `IKE_INTERMEDIATE`, its Exchange Type is 43.

Initiator	Responder
-----	-----
HDR, ..., SK {...} -->	<-- HDR, ..., SK {...}

The initiator may use several `IKE_INTERMEDIATE` exchanges if necessary. Since initiator's Window Size is initially set to one ([Section 2.3 of \[RFC7296\]](#)), these exchanges **MUST** follow each other and **MUST** all be completed before the `IKE_AUTH` exchange is initiated. The IKE SA **MUST NOT** be considered as established until the `IKE_AUTH` exchange is successfully completed.

The Message IDs for the `IKE_INTERMEDIATE` exchanges **MUST** be chosen according to the standard IKEv2 rule, described in the [Section 2.2. of \[RFC7296\]](#), i.e. it is set to 1 for the first `IKE_INTERMEDIATE` exchange, 2 for the next (if any) and so on. The message ID for the first pair of the `IKE_AUTH` messages is one more than the one that was used in the last `IKE_INTERMEDIATE` exchange.

If the presence of NAT is detected in the `IKE_SA_INIT` exchange via `NAT_DETECTION_SOURCE_IP` and `NAT_DETECTION_DESTINATION_IP` notifications, then the peers **MUST** switch to port 4500 immediately once this exchange is completed, i.e. in the first `IKE_INTERMEDIATE` exchange.

The content of the `IKE_INTERMEDIATE` exchange messages depends on the data being transferred and will be defined by specifications utilizing this exchange. However, since the main motivation for the `IKE_INTERMEDIATE` exchange is to avoid IP fragmentation when large

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amount of data need to be transferred prior to IKE_AUTH, the Encrypted payload MUST be present in the IKE_INTERMEDIATE exchange messages and payloads containing large data MUST be placed inside. This will allow IKE Fragmentation [[RFC7383](#)] to take place, provided it is supported by the peers and negotiated in the initial exchange.

3.3. The IKE_INTERMEDIATE Exchange Protection and Authentication

3.3.1. Protection of the IKE_INTERMEDIATE Messages

The keys SK_e[i/r] and SK_a[i/r] for the Encrypted payload in the IKE_INTERMEDIATE exchanges are computed in a standard fashion, as defined in the [Section 2.14 of \[RFC7296\]](#). Every subsequent IKE_INTERMEDIATE exchange uses the most recently calculated IKE SA keys before this exchange is started. So, the first IKE_INTERMEDIATE exchange always uses SK_e[i/r] and SK_a[i/r] keys that were computed as a result of the IKE_SA_INIT exchange. If the first IKE_INTERMEDIATE exchange performs additional key exchange resulting in the update of SK_e[i/r] and SK_a[i/r], then these updated keys are used for encryption and authentication of the next IKE_INTERMEDIATE exchange, otherwise the current keys are used, and so on.

3.3.2. Authentication of the IKE_INTERMEDIATE Exchanges

The content of the IKE_INTERMEDIATE exchanges must be authenticated in the IKE_AUTH exchange. For this purpose the definition of the blob to be signed (or MAC'ed) from the [Section 2.15 of \[RFC7296\]](#) is modified as follows:

```
InitiatorSignedOctets = RealMsg1 | NonceRData | MACedIDForI [| IntAuth]
ResponderSignedOctets = RealMsg2 | NonceIDData | MACedIDForR [| IntAuth]
```

```
IntAuth = IntAuth_1 | [| IntAuth_2 [| IntAuth_3]] ...
```

```
IntAuth_1 = IntAuth_1_I | IntAuth_1_R
IntAuth_2 = IntAuth_2_I | IntAuth_2_R
IntAuth_3 = IntAuth_3_I | IntAuth_3_R...
```

```
IntAuth_1_I = prf(SK_pi_1, IntAuth_1_I_A [| IntAuth_1_I_P])
IntAuth_2_I = prf(SK_pi_2, IntAuth_2_I_A [| IntAuth_2_I_P])
IntAuth_3_I = prf(SK_pi_3, IntAuth_3_I_A [| IntAuth_3_I_P])
...
```

```
IntAuth_1_R = prf(SK_pr_1, IntAuth_1_R_A [| IntAuth_1_R_P])
IntAuth_2_R = prf(SK_pr_2, IntAuth_2_R_A [| IntAuth_2_R_P])
IntAuth_3_R = prf(SK_pr_3, IntAuth_3_R_A [| IntAuth_3_R_P])
...
```


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IntAuth_1_I/IntAuth_1_R, IntAuth_2_I/IntAuth_2_R, IntAuth_3_I/IntAuth_3_R, etc. represent the results of applying the negotiated prf to the content of the IKE_INTERMEDIATE messages sent by the initiator (IntAuth*_I) and by the responder (IntAuth*_R) in an order of increasing Message IDs (i.e. in an order the IKE_INTERMEDIATE exchanges took place). The prf is applied to the two chunks of data: mandatory IntAuth*__[I/R]_A and optional IntAuth*__[I/R]_P. The IntAuth*__[I/R]_A chunk lasts from the first octet of the IKE Header (not including prepended four octets of zeros, if port 4500 is used) to the last octet of the Encrypted Payload header. The IntAuth*__[I/R]_P chunk is present if the Encrypted payload is not empty. It consists of the not yet encrypted content of the Encrypted payload, excluding Initialization Vector, Padding, Pad Length and Integrity Checksum Data fields (see 3.14 of [\[RFC7296\]](#) for description of the Encrypted payload). In other words, the IntAuth*__[I/R]_P chunk is the inner payloads of the Encrypted payload in plaintext form.

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in Figure 1) is set to the length of `IntAuth_*_[I/R]_P` plus the size of the Payload header (four octets).

The prf calculations MUST be applied to whole messages only, before possible IKE Fragmentation. This ensures that the `IntAuth` will be the same regardless of whether IKE Fragmentation takes place or not. This is important since [\[RFC7383\]](#) allows sending first unfragmented message and then resending it in fragmented form in case of no reply is received. If the message was received in fragmented form, it should be reconstructed before calculating prf as if it were received unfragmented. The `RESERVED` field in the reconstructed Encrypted Payload header MUST be set to the value of the `RESERVED` field in the Encrypted Fragment payload header from the first fragment (that with Fragment Number equal to 1).

Note that it is possible to avoid actual reconstruction of the message by incrementally calculating prf on decrypted (or ready to be encrypted) fragments. However care must be taken to properly replace the content of the Next Header and the Length fields so that the result of computing prf is the same as if it were computed on reconstructed message.

Each calculation of `IntAuth_*_[I/R]` uses its own keys `SK_p[i/r]_*`, which are the most recently updated `SK_p[i/r]` keys available before the corresponded `IKE_INTERMEDIATE` exchange is started. The first `IKE_INTERMEDIATE` exchange always uses `SK_p[i/r]` keys that were computed in the `IKE_SA_INIT` as `SK_p[i/r]_1`. If the first `IKE_INTERMEDIATE` exchange performs additional key exchange resulting in `SK_p[i/r]` update, then this updated `SK_p[i/r]` are used as `SK_p[i/r]_2`, otherwise the original `SK_p[i/r]` are used, and so on. Note, that if keys are updated then for any given `IKE_INTERMEDIATE` exchange the keys `SK_e[i/r]` and `SK_a[i/r]` used for its messages protection (see [Section 3.3.1](#)) and the keys `SK_p[i/r]` for its authentication are always from the same generation.

3.4. Error Handling in the `IKE_INTERMEDIATE` Exchange

Since messages of the `IKE_INTERMEDIATE` exchange are not authenticated until the `IKE_AUTH` exchange successfully completes, possible errors need to be handled with care. There is a trade-off between providing a better diagnostics of the problem and a risk to become a part of DoS attack. See [Section 2.21.1](#) and 2.21.2 of [\[RFC7296\]](#) describe how errors are handled in initial IKEv2 exchanges, these considerations are also applied to the `IKE_INTERMEDIATE` exchange.

4. Interaction with other IKEv2 Extensions

The IKE_INTERMEDIATE exchanges MAY be used during the IKEv2 Session Resumption [[RFC5723](#)] between the IKE_SESSION_RESUME and the IKE_AUTH exchanges. To be able to use it peers MUST negotiate support for intermediate exchange by including INTERMEDIATE_EXCHANGE_SUPPORTED notifications in the IKE_SESSION_RESUME messages. Note, that a flag whether peers supported the IKE_INTERMEDIATE exchange is not stored in the resumption ticket and is determined each time from the IKE_SESSION_RESUME exchange.

5. Security Considerations

The data that is transferred by means of the IKE_INTERMEDIATE exchanges is not authenticated until the subsequent IKE_AUTH exchange is completed. However, if the data is placed inside the Encrypted payload, then it is protected from passive eavesdroppers. In addition the peers can be certain that they receives messages from the party he/she performed the IKE_SA_INIT with if they can successfully verify the Integrity Checksum Data of the Encrypted payload.

The main application for Intermediate Exchange is to transfer large amount of data before IKE SA is set up without causing IP fragmentation. For that reason it is expected that in most cases IKE Fragmentation will be employed in the IKE_INTERMEDIATE exchanges. [Section 5 of \[RFC7383\]](#) contains security considerations for IKE Fragmentation.

Note, that if an attacker was able to break key exchange in real time (e.g. by means of Quantum Computer), then the security of the IKE_INTERMEDIATE exchange would degrade. In particular, such an attacker would be able both to read data contained in the Encrypted payload and to forge it. The forgery would become evident in the IKE_AUTH exchange (provided the attacker cannot break employed authentication mechanism), but the ability to inject forged the IKE_INTERMEDIATE exchange messages with valid ICV would allow the attacker to mount Denial-of-Service attack. Moreover, if in this situation the negotiated prf was not secure against preimage attack with known key, then the attacker could forge the IKE_INTERMEDIATE exchange messages without later being detected in the IKE_AUTH exchange. To do this the attacker should find the same IntAuth_*_[I|R] value for the forged message as for original.

6. IANA Considerations

This document defines a new Exchange Type in the "IKEv2 Exchange Types" registry:

43 IKE_INTERMEDIATE

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

16438 INTERMEDIATE_EXCHANGE_SUPPORTED

7. Acknowledgements

The idea to use an intermediate exchange between IKE_SA_INIT and IKE_AUTH was first suggested by Tero Kivinen. Scott Fluhrer and Daniel Van Geest identified a possible problem with authentication of the IKE_INTERMEDIATE exchange and helped to resolve it. Author is also grateful to Tobias Brunner for raising good points concerning authentication of the IKE_INTERMEDIATE exchange.

8. References

8.1. Normative References

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Author's Address

Valery Smyslov
ELVIS-PLUS
PO Box 81
Moscow (Zelenograd) 124460
RU

Phone: +7 495 276 0211

Email: svan@elvis.ru

