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Internet Key Exchange Protocol Version 2 (IKEv2) Message Fragmentation

Abstract

This document describes a way to avoid IP fragmentation of large Internet Key Exchange Protocol version 2 (IKEv2) messages. This allows IKEv2 messages to traverse network devices that do not allow IP fragments to pass through.

Status of This Memo

This is an Internet Standards Track document.

This document is a product of the Internet Engineering Task Force (IETF). It represents the consensus of the IETF community. It has received public review and has been approved for publication by the Internet Engineering Steering Group (IESG). Further information on Internet Standards is available in Section 2 of RFC 5741.

Information about the current status of this document, any errata, and how to provide feedback on it may be obtained at http://www.rfc-editor.org/info/rfc7383.

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1. Introduction

1.1. Problem Description

The Internet Key Exchange Protocol version 2 (IKEv2), specified in [RFC7296], uses UDP as a transport for its messages. Most IKEv2 messages are relatively small, usually below several hundred bytes. A notable exception is the IKE_AUTH exchange, which requires fairly large messages, up to several KB, especially when certificates are transferred. When the IKE message size exceeds the path MTU, it gets fragmented at the IP level. The problem is that some network devices, specifically some NAT boxes, do not allow IP fragments to pass through. This apparently blocks IKE communication and, therefore, prevents peers from establishing an IPsec Security Association (SA). Section 2 of [RFC7296] discusses the impact of IP fragmentation on IKEv2 and acknowledges this problem.

Widespread deployment of Carrier-Grade NATs (CGNs) introduces new challenges. [RFC6888] describes requirements for CGNs. It states that CGNs must comply with Section 11 of [RFC4787], which requires NATs to support receiving IP fragments (REQ-14). In real life, fulfillment of this requirement creates an additional burden in terms of memory, especially for high-capacity devices used in CGNs. It was found by people deploying IKE that more and more ISPs use equipment that drops IP fragments, thereby violating this requirement.

Security researchers have found, and continue to find, attack vectors that rely on IP fragmentation. For these reasons, and also as articulated in [FRAGDROP], many network operators filter all IPv6 fragments. Also, the default behavior of many currently deployed firewalls is to discard IPv6 fragments.

In one recent study [BLACKHOLES], two researchers utilized a measurement network to measure fragment filtering. They sent packets, fragmented to the minimum MTU of 1280, to 502 IPv6-enabled and reachable probes. They found that during any given trial period, ten percent of the probes did not receive fragmented packets.

Thus, this problem is valid for both IPv4 and IPv6 and may be caused by either deficiency of network devices or operational choice.

1.2. Proposed Solution

The solution to the problem described in this document is to perform fragmentation of large messages by IKEv2 itself and replace them with a series of smaller messages. In this case, the resulting IP datagrams will be small enough so that no fragmentation at the IP level will take place.

The primary goal of this solution is to allow IKEv2 to operate in environments that might block IP fragments. This goal does not assume that IP fragmentation should be avoided completely, but only in those cases when it interferes with IKE operations. However, this solution could be used to avoid IP fragmentation in all situations where fragmentation within IKE is applicable, as recommended in Section 3.2 of [RFC5405]. Avoiding IP fragmentation would be beneficial for IKEv2 in general. The Security Considerations section of [RFC7296] mentions exhaustion of the IP reassembly buffers as one of the possible attacks on the protocol. In [DOSUDPPROT], several aspects of attacks on IKE using IP fragmentation are discussed, and one of the defenses it proposes is to perform fragmentation within IKE, similar to the solution described in this document.

1.3. 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. Protocol Details

2.1. Overview

The idea of the protocol described in this document is to split large IKEv2 messages into a set of smaller ones, called IKE Fragment messages. Fragmentation takes place before the original message is encrypted and authenticated, so that each IKE Fragment message receives individual protection. On the receiving side, IKE Fragment messages are collected, verified, decrypted, and merged together to get the original message before encryption. See Appendix A for details on design rationale.

2.2. Limitations

Since IKE Fragment messages are cryptographically protected, SK_a and SK_e must already be calculated. In general, it means that the original message can be fragmented if and only if it contains an Encrypted payload.

This implies that messages of the IKE_SA_INIT exchange cannot be fragmented. In most cases, this is not a problem because IKE_SA_INIT messages are usually small enough to avoid IP fragmentation. But in some cases (advertising a badly structured long list of algorithms, using large Modular Exponentiation (MODP) groups, etc.), these messages may become fairly large and get fragmented at the IP level. In this case, the solution described in this document will not help.

Among existing IKEv2 extensions, messages of an IKE_SESSION_RESUME exchange, as defined in [RFC5723], cannot be fragmented either. See Section 3 for details.

Another limitation is that the minimum size of an IP datagram bearing an IKE Fragment message is about 100 bytes, depending on the algorithms employed. According to [RFC0791], the minimum IPv4 datagram size that is guaranteed not to be further fragmented is 68 bytes. So, even the smallest IKE Fragment messages could be fragmented at the IP level in some circumstances. But such extremely small Path MTU (PMTU) sizes are very rare in real life.

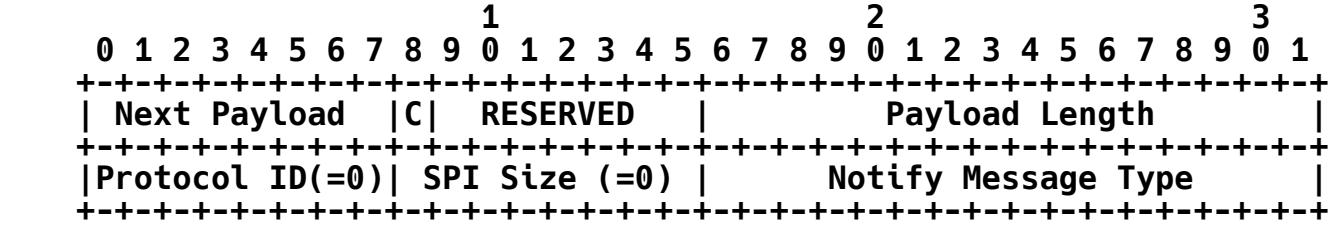
2.3. Negotiation

The initiator indicates its support for IKE fragmentation and willingness to use it by including a Notification payload of type IKEV2_FRAGMENTATION_SUPPORTED in the IKE_SA_INIT request message. If the responder also supports this extension and is willing to use it, it includes this notification in the response message.

```
Initiator                   Responder
-----------                 -----------
HDR, SAi1, KEi, Ni,
   [N(IKEV2_FRAGMENTATION_SUPPORTED)]  -->

                    <--   HDR, SAr1, KEr, Nr, [CERTREQ],
                              [N(IKEV2_FRAGMENTATION_SUPPORTED)]
```

The Notify payload is formatted as follows:



- Protocol ID (1 octet) - MUST be 0.
- SPI Size (1 octet) - MUST be 0, meaning no Security Parameter Index (SPI) is present.
- Notify Message Type (2 octets) - MUST be 16430, the value assigned for the IKEV2_FRAGMENTATION_SUPPORTED notification.

This notification contains no data.

2.4. Using IKE Fragmentation

IKE fragmentation MUST NOT be used unless both peers have indicated their support for it. After that, it is up to the initiator of each exchange to decide whether or not to use it. The responder usually replies in the same form as the request message, but other considerations might override this.

The initiator can employ various policies regarding the use of IKE fragmentation. It might first try to send an unfragmented message and resend it as fragmented only if no complete response is received even after several retransmissions. Alternatively, it might choose

to always send fragmented messages (however, see Section 3), or it might fragment only large messages and messages that are expected to result in large responses.

The following general guidelines apply:

- If either peer has information that a part of the transaction is likely to be fragmented at the IP layer, causing interference with the IKE exchange, that peer SHOULD use IKE fragmentation. This information might be passed from a lower layer, provided by configuration, or derived through heuristics. Examples of heuristics are the lack of a complete response after several retransmissions for the initiator, and receiving repeated retransmissions of the request for the responder.

- If either peer knows that IKE fragmentation has been used in a previous exchange in the context of the current IKE SA, that peer SHOULD continue to use IKE fragmentation for the messages that are larger than the current fragmentation threshold (see Section 2.5.1).

- IKE fragmentation SHOULD NOT be used in cases where IP-layer fragmentation of both the request and response messages is unlikely. For example, there is no point in fragmenting liveness check messages.

- If none of the above apply, the responder SHOULD respond in the same form (fragmented or not) as the request message to which it is responding. Note that the other guidelines might override this because of information or heuristics available to the responder.

In most cases, IKE fragmentation will be used in the IKE_AUTH exchange, especially if certificates are employed.

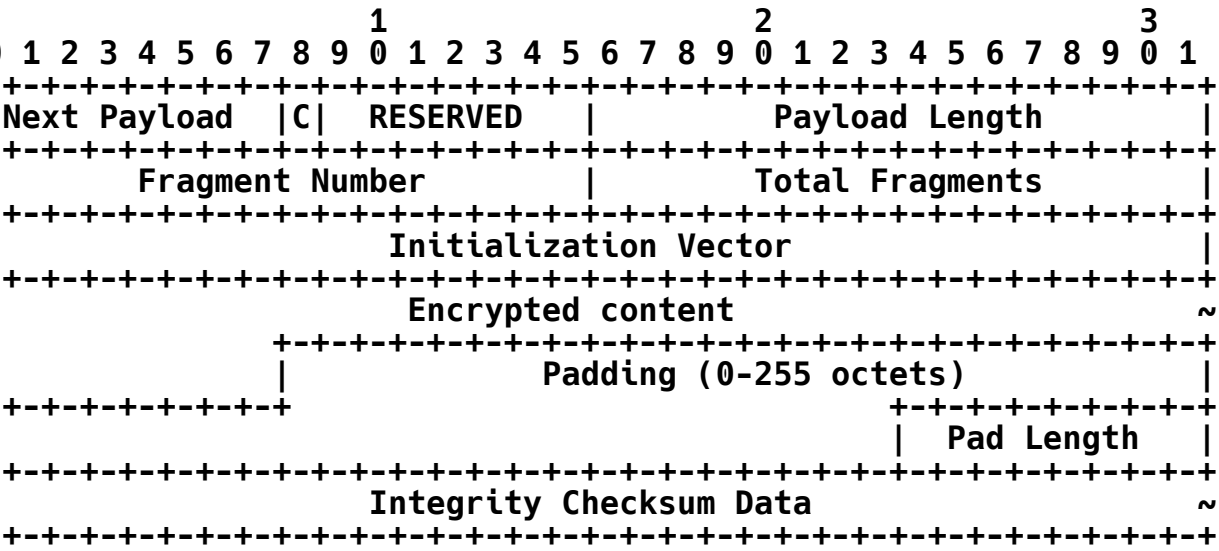
2.5. Fragmenting Message

Only messages that contain an Encrypted payload are subject to IKE fragmentation. For the purpose of construction of IKE Fragment messages, the original (unencrypted) content of the Encrypted payload is split into chunks. The content is treated as a binary blob and is split regardless of the boundaries of inner payloads. Each of the resulting chunks is treated as an original content of the Encrypted Fragment payload and is then encrypted and authenticated. Thus, the Encrypted Fragment payload contains a chunk of the original content of the Encrypted payload in encrypted form. The cryptographic processing of the Encrypted Fragment payload is identical to that

described in Section 3.14 of [RFC7296], as well as documents updating such processing for particular algorithms or modes, such as [RFC5282].

As is the case for the Encrypted payload, the Encrypted Fragment payload, if present in a message, MUST be the last payload in the message.

The Encrypted Fragment payload is denoted SKF{...}, and its payload type is 53. This payload is also called the "Encrypted and Authenticated Fragment" payload.



Encrypted Fragment Payload

- Next Payload (1 octet) - in the very first fragment (with Fragment Number equal to 1), this field MUST be set to the payload type of the first inner payload (the same as for the Encrypted payload). In the rest of the Fragment messages (with Fragment Number greater than 1), this field MUST be set to zero.

- Fragment Number (2 octets, unsigned integer) - current Fragment message number, starting from 1. This field MUST be less than or equal to the next field (Total Fragments). This field MUST NOT be zero.

- Total Fragments (2 octets, unsigned integer) - number of Fragment messages into which the original message was divided. This field MUST NOT be zero. With PMTU discovery, this field plays an additional role. See Section 2.5.2 for details.

The other fields are identical to those specified in Section 3.14 of [RFC7296].

When prepending the IKE header to the IKE Fragment messages, it MUST be taken intact from the original message, except for the Length and Next Payload fields. The Length field is adjusted to reflect the length of the IKE Fragment message being constructed, and the Next Payload field is set to the payload type of the first payload in that message (in most cases, it will be the Encrypted Fragment payload). After prepending the IKE header and all payloads that possibly precede the Encrypted payload in the original message (if any; see Section 2.5.3), the resulting messages are sent to the peer.

Below is an example of fragmenting a message.

```
HDR(MID=n), SK(NextPld=PLD1) {PLD1 ... PLDN}
```

Original Message

```
HDR(MID=n), SKF(NextPld=PLD1, Frag#=1, TotalFrags=m) {...},
HDR(MID=n), SKF(NextPld=0, Frag#=2, TotalFrags=m) {...},
...
HDR(MID=n), SKF(NextPld=0, Frag#=m, TotalFrags=m) {...}
```

IKE Fragment Messages

2.5.1. Selecting Fragment Size

When splitting the content of an Encrypted payload into chunks, the sender SHOULD choose their size so that the resulting IP datagrams will be smaller than some fragmentation threshold. Implementations may calculate the fragmentation threshold using various sources of information.

If the sender has information about the PMTU size, it SHOULD use it. The responder in the exchange may use the maximum size of the received IKE Fragment message IP datagrams as a threshold when constructing a fragmented response. Successful completion of previous exchanges (including those exchanges that cannot employ IKE fragmentation, e.g., IKE_SA_INIT) may be an indication that the fragmentation threshold can be set to the size of the largest message of those messages already sent.

Otherwise, for messages to be sent over IPv6, it is RECOMMENDED that a value of 1280 bytes as a maximum IP datagram size be used ([RFC2460]). For messages to be sent over IPv4, it is RECOMMENDED that a value of 576 bytes as a maximum IP datagram size be used. The

presence of tunnels on the path may reduce these values. Implementations may use other values if they are appropriate in the current environment.

According to [RFC0791], the minimum IPv4 datagram size that is guaranteed not to be further fragmented is 68 bytes, but it is generally impossible to use such a small value for the solution described in this document. Using 576 bytes is a compromise -- the value is large enough for the presented solution and small enough to avoid IP fragmentation in most situations. Several other UDP-based protocols (Syslog, DNS, etc.) use 576 bytes as a safe low limit for IP datagram size.

See Appendix B for correlation between IP datagram size and Encrypted payload content size.

2.5.2. PMTU Discovery

The amount of traffic that the IKE endpoint produces during the lifetime of an IKE SA is fairly modest -- it is usually below 100 KB within a period of several hours. Most of this traffic consists of relatively short messages -- usually below several hundred bytes. In most cases, the only time when IKE endpoints exchange messages of several KB in size is IKE SA establishment, and often each endpoint sends exactly one such message.

For the reasons articulated above, implementing PMTU discovery in IKE is OPTIONAL. It is believed that using the values recommended in Section 2.5.1 as a fragmentation threshold will be sufficient in most cases. Using these values could lead to suboptimal fragmentation, but it is acceptable given the amount of traffic IKE produces. Implementations may support PMTU discovery if there are good reasons to do it (for example, if they are intended to be used in environments where the MTU size might be less than the values listed in Section 2.5.1).

PMTU discovery in IKE follows recommendations given in Section 10.4 of [RFC4821] with some modifications, induced by the distinctive features of IKE listed above. The difference is that the PMTU search is performed downward, while in [RFC4821] it is performed upward. The reason for this change is that IKE usually sends large messages only when the IKE SA is being established, and in many cases there is only one such message. If the probing were performed upward, this message would be fragmented using the smallest allowable threshold, and usually all other messages are small enough to avoid IP fragmentation, so continued probing would be of little value.

It is the initiator of the exchange who performs PMTU discovery. This is done by probing several values of fragmentation threshold. Implementations MUST be prepared to probe in every exchange that utilizes IKE fragmentation to deal with possible changes in path MTU over time. While doing probes, it MUST start from larger values and refragment the original message, using the next smaller value of the threshold if it did not receive a response in a reasonable time after several retransmissions. The exact number of retransmissions and length of timeouts are not covered in this specification because they do not affect interoperability. However, the timeout interval is supposed to be relatively short, so that unsuccessful probes would not delay IKE operations too much. Performing a few retries within several seconds for each probe seems appropriate, but different environments may require different rules. When starting a new probe, the node MUST reset its retransmission timers so that if it employs exponential back-off the timers will start over. After reaching the smallest allowed value for the fragmentation threshold, an implementation MUST continue retransmitting until the exchange either completes or times out using some timeout interval as discussed in Section 2.4 of [RFC7296].

PMTU discovery in IKE is supposed to be coarse-grained, i.e., it is expected that a node will try only a few fragmentation thresholds in order to minimize delays caused by unsuccessful probes. If path MTU information is not yet available, the endpoint may use the link MTU size when it starts probing. In subsequent exchanges, the node should start with the current value of the fragmentation threshold.

If an implementation is capable of receiving ICMP error messages, it can additionally utilize classic PMTU discovery methods, as described in [RFC1191] and [RFC1981]. In particular, if the initiator receives a Packet Too Big error in response to the probe, and it contains a smaller value than the current fragmentation threshold, then the initiator SHOULD stop retransmitting the probe and SHOULD select a new value for the fragmentation threshold that is less than or equal to the value from the ICMP message and meets the requirements listed below.

In the case of PMTU discovery, the Total Fragments field is used to distinguish between different sets of fragments, i.e., the sets that were created by fragmenting the original message using different fragmentation thresholds. Since the sender starts from larger fragments and then makes them smaller, the value in the Total Fragments field increases with each new probe. When selecting the next smaller value for the fragmentation threshold, the sender MUST ensure that the value in the Total Fragments field is really increased. This requirement should not be a problem for the sender, because PMTU discovery in IKE is supposed to be coarse-grained, so

the difference between previous and next fragmentation thresholds should be significant anyway. The need to distinguish between the sets is vital for the receiver, since receiving a valid fragment from a newer set means that it has to start the reassembly process over and not mix fragments from different sets.

2.5.3. Fragmenting Messages Containing Unprotected Payloads

Currently, there are no IKEv2 exchanges that define messages, containing both unprotected payloads and payloads, that are protected by the Encrypted payload. However, IKEv2 does not prohibit such construction. If some future IKEv2 extension defines such a message and it needs to be fragmented, all unprotected payloads MUST be placed in the first fragment (with the Fragment Number field equal to 1), along with the Encrypted Fragment payload, which MUST be present in every IKE Fragment message and be the last payload in it.

Below is an example of a fragmenting message that contains both protected and unprotected payloads.

```
HDR(MID=n), PLD0, SK(NextPld=PLD1) {PLD1 ... PLDN}
```

Original Message

```
HDR(MID=n), PLD0, SKF(NextPld=PLD1, Frag#=1, TotalFrags=m) {...},
HDR(MID=n), SKF(NextPld=0, Frag#=2, TotalFrags=m) {...},
...
HDR(MID=n), SKF(NextPld=0, Frag#=m, TotalFrags=m) {...}
```

IKE Fragment Messages

Note that the size of each IP datagram bearing IKE Fragment messages should not exceed the fragmentation threshold, including the first one, that contains unprotected payloads. This will reduce the size of the Encrypted Fragment payload content in the first IKE Fragment message to accommodate all unprotected payloads. In an extreme case, the Encrypted Fragment payload will contain no data, but it still must be present in the message, because only its presence allows the receiver to determine that the sender has used IKE fragmentation.

2.6. Receiving IKE Fragment Message

The receiver identifies the IKE Fragment message by the presence of an Encrypted Fragment payload in it. In most cases, it will be the first and only payload in the message; however, this may not be true for some hypothetical IKE exchanges (see Section 2.5.3).

Upon receiving the IKE Fragment message, the following actions are performed:

- Check message validity - in particular, check whether the values in the Fragment Number and the Total Fragments fields in the Encrypted Fragment payload are valid. The following tests need to be performed.
  - check that the Fragment Number and the Total Fragments fields contain non-zero values
  - check that the value in the Fragment Number field is less than or equal to the value in the Total Fragments field
  - if reassembling has already started, check that the value in the Total Fragments field is equal to or greater than the Total Fragments field in the fragments that have already been stored in the reassembling queue

  If any of these tests fail, the message MUST be silently discarded.
- Check that this IKE Fragment message is new for the receiver and not a replay. If an IKE Fragment message with the same Message ID, Fragment Number, and Total Fragments fields is already present in the reassembling queue, this message is considered a replay and MUST be silently discarded.
- Verify IKE Fragment message authenticity by checking the Integrity Check Value (ICV) in the Encrypted Fragment payload. If the ICV check fails, the message MUST be silently discarded.
- If reassembling is not finished yet and the Total Fragments field in the received fragment is greater than the Total Fragments field in those fragments that are in the reassembling queue, the receiver MUST discard all received fragments and start the reassembly process over with just the received IKE Fragment message.
- Store the message in the reassembling queue waiting for the rest of the fragments to arrive.

When all IKE Fragment messages (as indicated in the Total Fragments field) are received, the decrypted content of all Encrypted Fragment payloads is merged together to form the content of the original Encrypted payload and, therefore, along with the IKE header and

unprotected payloads (if any), the original message. Then, it is processed as if it was received, verified, and decrypted as a regular IKE message.

If the receiver does not get all IKE fragments needed to reassemble the original message within a timeout interval, it MUST discard all IKE Fragment messages received so far for the exchange. The next actions depend on the role of the receiver in the exchange.

- The initiator acts as described in Section 2.1 of [RFC7296]. It either retransmits the fragmented request message or deems the IKE SA to have failed and deletes it. The number of retransmits and length of timeouts for the initiator are not covered in this specification, since they are assumed to be the same as in a regular IKEv2 exchange and are discussed in Section 2.4 of [RFC7296].

- The responder in this case acts as if no request message was received. It would delete any memory of the incomplete request message and not treat it as an IKE SA failure. It is RECOMMENDED that the reassembling timeout for the responder be equal to the time interval that the implementation waits before completely giving up when acting as the initiator of an exchange. Section 2.4 of [RFC7296] gives recommendations for selecting this interval. Implementations can use a shorter timeout to conserve memory.

2.6.1. Replay Detection and Retransmissions

According to Section 2.2 of [RFC7296], the Message ID is used, in particular, to identify retransmissions of IKE messages. Each request or response message, sent by either side, must have a unique Message ID, or be considered a retransmission otherwise. This logic has already been updated by [RFC6311], which deliberately allows any number of messages with zero Message ID. This document also updates this logic for those situations where IKE fragmentation is in use.

If an incoming message contains an Encrypted Fragment payload, the values of the Fragment Number and Total Fragments fields MUST be used along with the Message ID to detect retransmissions and replays.

If the responder receives a retransmitted fragment of a request when it has already processed that request and has sent back a response, that event MUST only trigger a retransmission of the response message (fragmented or not) if the Fragment Number field in the received fragment is set to 1; otherwise, it MUST be ignored.

3. Interaction with Other IKE Extensions

IKE fragmentation is compatible with most IKE extensions, such as IKE Session Resumption ([RFC5723]), the Quick Crash Detection Method ([RFC6290]), and so on. It neither affects their operation nor is affected by them. It is believed that IKE fragmentation will also be compatible with future IKE extensions, if they follow general principles of formatting, sending, and receiving IKE messages, as described in [RFC7296].

When IKE fragmentation is used with IKE Session Resumption ([RFC5723]), messages of an IKE_SESSION_RESUME exchange cannot be fragmented, since they do not contain an Encrypted payload. These messages may be large due to the ticket size. To avoid IP fragmentation in this situation, it is recommended that smaller tickets be used, e.g., by utilizing a "ticket by reference" approach instead of "ticket by value".

Protocol Support for High Availability of IKEv2/IPsec, described in [RFC6311], requires special care when deciding whether to fragment an IKE message or not. Since it deliberately allows any number of synchronization exchanges to have the same Message ID, namely zero, standard IKEv2 replay detection logic, based on checking the Message ID, is not applicable for such messages, and the receiver has to check message content to detect replays. When implementing IKE fragmentation along with [RFC6311], IKE Message ID Synchronization messages MUST NOT be sent fragmented, to simplify the receiver's task of detecting replays. Fortunately, these messages are small, and there is no point in fragmenting them anyway.

4. Transport Considerations

With IKE fragmentation, if any single IKE Fragment message gets lost, the receiver becomes unable to reassemble the original message. So, in general, using IKE fragmentation implies a higher probability that the message will not be delivered to the peer. Although in most network environments the difference will be insignificant, on some lossy networks it may become noticeable. When using IKE fragmentation, implementations MAY use longer timeouts and do more retransmits than usual before considering the peer dead.

Note that Fragment messages are not individually acknowledged. The response Fragment messages are all sent back together only when all fragments of the request are received, and the original request message is reassembled and successfully processed.

5. Security Considerations

Most of the security considerations for IKE fragmentation are the same as those for the base IKEv2 protocol described in [RFC7296]. This extension introduces the Encrypted Fragment payload to protect the content of an IKE Message Fragment. This allows the receiver to individually check the authenticity of fragments, thus protecting peers from a DoS attack.

The Security Considerations section of [RFC7296] mentions a possible attack on IKE where an attacker could prevent an exchange from completing by exhausting the IP reassembly buffers. The mechanism described in this document allows IKE to avoid IP fragmentation and therefore increases its robustness to DoS attacks.

The following attack is possible with IKE fragmentation. An attacker can initiate an IKE_SA_INIT exchange, complete it, compute SK_a and SK_e, and then send a large but still incomplete set of IKE_AUTH fragments. These fragments will pass the ICV check and will be stored in reassembly buffers, but since the set is incomplete, the reassembling will never succeed and eventually will time out. If the set is large, this attack could potentially exhaust the receiver's memory resources.

To mitigate the impact of this attack, it is RECOMMENDED that the receiver limit the number of fragments it stores in the reassembling queue so that the sum of the sizes of Encrypted Fragment payload contents (after decryption) for fragments that are already placed into the reassembling queue is less than some value that is reasonable for the implementation. If the peer sends so many fragments that the above condition is not met, the receiver can consider this situation to be either an attack or a broken sender implementation. In either case, the receiver SHOULD drop the connection and discard all the received fragments.

This value can be predefined, can be a configurable option, or can be calculated dynamically, depending on the receiver's memory load. Some care should be taken when selecting this value because if it is too small it might prevent a legitimate peer from establishing an IKE SA if the size of messages it sends exceeds this value. It is NOT RECOMMENDED for this value to exceed 64 KB because any IKE message before fragmentation would likely be shorter than that.

If IKE fragments arrive in order, it is possible, but not advised, for the receiver to parse the beginning of the message that is being reassembled and extract the already-available payloads before the reassembly is complete. It can be dangerous to take any action based on the content of these payloads, because the fragments that have not

yet been received might contain payloads that could change the meaning of them (or could even make the whole message invalid), and this can potentially be exploited by an attacker. It is important to address this threat by ensuring that all the fragments are received prior to parsing the reassembled message, as described in Section 2.6.

6. IANA Considerations

This document defines a new payload in the "IKEv2 Payload Types" registry:

53	Encrypted and Authenticated Fragment	SKF

This document also defines a new Notify Message Type in the "IKEv2 Notify Message Types - Status Types" registry:

16430	IKEV2_FRAGMENTATION_SUPPORTED

7. References

7.1. Normative References

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Appendix A. Design Rationale

The simplest approach to IKE fragmentation would have been to fragment a message that is fully formed and ready to be sent. However, if a message got fragmented after being encrypted and authenticated, this could make a simple DoS attack possible. The attacker could infrequently emit forged but valid-looking fragments into the network, and some of these fragments would be fetched by the receiver into the reassembling queue. The receiver would not be able to distinguish forged fragments from valid ones and would only be able to determine that some of the received fragments were forged after the whole message was reassembled and its authenticity check failed.

To prevent this kind of attack and also reduce vulnerability to some other kinds of DoS attacks, it was decided to perform fragmentation before applying cryptographic protection to the message. In this case, each Fragment message becomes individually encrypted and authenticated; this allows the receiver to determine forged fragments and not store them in the reassembling queue.

Appendix B. Correlation between IP Datagram Size and Encrypted Payload Content Size

In the case of IPv4, the content size of the Encrypted Payload is less than the IP datagram size by the sum of the following values:

- IPv4 header size (typically 20 bytes, up to 60 if IP options are present)
- UDP header size (8 bytes)
- non-ESP (Encapsulating Security Payload) marker size (4 bytes if present)
- IKE header size (28 bytes)
- Encrypted payload header size (4 bytes)
- initialization vector (IV) size (variable)
- padding and its size (at least 1 byte)
- ICV size (variable)

The sum may be estimated as 61..105 bytes + IV + ICV + padding.

In the case of IPv6, the content size of the Encrypted Payload is less than the IP datagram size by the sum of the following values:

- IPv6 header size (40 bytes)
- IPv6 extension headers (optional; size varies)
- UDP header size (8 bytes)
- non-ESP marker size (4 bytes if present)
- IKE header size (28 bytes)
- Encrypted payload header size (4 bytes)
- IV size (variable)
- padding and its size (at least 1 byte)
- ICV size (variable)

If no extension header is present, the sum may be estimated as 81..85 bytes + IV + ICV + padding. If extension headers are present, the payload content size is further reduced by the sum of the size of the extension headers. The length of each extension header can be calculated as 8 * (Hdr Ext Len) bytes, except for the fragment header, which is always 8 bytes in length.

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