

Network Working Group
Request for Comments: 4359
Category: Standards Track

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January 2006

The Use of RSA/SHA-1 Signatures within
Encapsulating Security Payload (ESP) and Authentication Header (AH)

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Abstract

This memo describes the use of the RSA digital signature algorithm as an authentication algorithm within the revised IP Encapsulating Security Payload (ESP) as described in RFC 4303 and the revised IP Authentication Header (AH) as described in RFC 4302. The use of a digital signature algorithm, such as RSA, provides data origin authentication in applications when a secret key method (e.g., HMAC) does not provide this property. One example is the use of ESP and AH to authenticate the sender of an IP multicast packet.

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1. Introduction

Encapsulating Security Payload (ESP) [ESP] and Authentication Header (AH) [AH] headers can be used to protect both unicast traffic and group (e.g., IPv4 and IPv6 multicast) traffic. When unicast traffic is protected between a pair of entities, HMAC transforms (such as [HMAC-SHA]) are sufficient to prove data origin authentication. An HMAC is sufficient protection in that scenario because only the two entities involved in the communication have access to the key, and proof-of-possession of the key in the HMAC construct authenticates the sender. However, when ESP and AH authenticate group traffic, this property no longer holds because all group members share the single HMAC key. In the group case, the identity of the sender is not uniquely established, since any of the key holders has the ability to form the HMAC transform. Although the HMAC transform establishes a group-level security property, data origin authentication is not achieved.

Some group applications require true data origin authentication, where one group member cannot successfully impersonate another group member. The use of asymmetric digital signature algorithms, such as RSA, can provide true data origin authentication.

With asymmetric algorithms, the sender generates a pair of keys, one of which is never shared (called the "private key") and one of which is distributed to other group members (called the "public key").

When the private key is used to sign the output of a cryptographic hash algorithm, the result is called a "digital signature". A receiver of the digital signature uses the public key, the signature value, and an independently computed hash to determine whether or not the claimed origin of the packet is correct.

This memo describes how RSA digital signatures can be applied as an ESP and AH authentication mechanism to provide data origin authentication.

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. Algorithm and Mode

The RSA Public Key Algorithm [RSA] is a widely deployed public key algorithm commonly used for digital signatures. Compared to other public key algorithms, signature verification is relatively efficient. This property is useful for groups where receivers may have limited processing capabilities. The RSA algorithm is commonly supported in hardware.

Two digital signature encoding methods are supported in [RSA]. RSASSA-PKCS1-v1_5 MUST be supported by a conforming implementation. RSASSA-PSS is generally believed to be more secure, but at the time of this writing is not ubiquitous. RSASSA-PSS SHOULD be used whenever it is available. SHA-1 [SHA] MUST be used as the signature hash algorithm used by the RSA digital signature algorithm.

When specified for ESP, the Integrity Check Value (ICV) is equal in size to the RSA modulus, unless the RSA modulus is not a multiple of 8 bits. In this case, the ICV MUST be prepended with between 1 and 7 bits set to zero such that the ICV is a multiple of 8 bits. This specification matches the output S [RSA, Section 8.1.1] (RSASSA-PSS) and [RSA, Section 8.2.1] (RSASSA-PKCS1-v1_5) when the RSA modulus is not a multiple of 8 bits. No implicit ESP ICV Padding bits are necessary.

When specified for AH, the ICV is equal in size of the RSA modulus, unless the RSA modulus is not a multiple of 32 bits (IPv4) or 64 bits (IPv6) [AH, Section 2.6]. In this case, explicit ICV Padding bits are necessary to create a suitably sized ICV [AH, Section 3.3.3.2.1].

The distribution mechanism of the RSA public key and its replacement interval are a group policy matter. The use of an ephemeral key pair with a lifetime of the ESP or AH Security Association (SA) is RECOMMENDED. This recommended policy reduces the exposure of the RSA

private key to the lifetime of the data being signed by the private key. Also, this obviates the need to revoke or transmit the validity period of the key pair.

Digital signature generation is performed as described in [RSA, Section 8.1.1] (RSASSA-PSS) and [RSA, Section 8.2.1] (RSASSA-PKCS1-v1_5). The authenticated portion of the AH or ESP packet ([AH, Section 3.3.3], [ESP, Section 3.3.2]) is used as the message M, which is passed to the signature generation function. The signer's RSA private key is passed as K. Summarizing, the signature generation process computes a SHA-1 hash of the authenticated packet bytes, signs the SHA-1 hash using the private key, and encodes the result with the specified RSA encoding type. This process results in a value S, which is known as the ICV in AH and ESP.

Digital signature verification is performed as described in [RSA, Section 8.1.2] (RSASSA-PSS) and [RSA, Section 8.2.2] (RSASSA-PKCS1-v1_5). Upon receipt, the ICV is passed to the verification function as S. The authenticated portion of the AH or ESP packet is used as the message M, and the RSA public key is passed as (n, e). In summary, the verification function computes a SHA-1 hash of the authenticated packet bytes, decrypts the SHA-1 hash in the ICV, and validates that the appropriate encoding was applied and was correct. The two SHA-1 hashes are compared, and if they are identical the validation is successful.

2.1. Key Size Discussion

The choice of RSA modulus size must be made carefully. If too small of a modulus size is chosen, an attacker may be able to reconstruct the private key used to sign packets before the key is no longer used by the sender to sign packets. This order of events may result in the data origin authentication property being compromised. However, choosing a modulus size larger than necessary will result in an unnecessarily high cost of CPU cycles for the sender and all receivers of the packet.

A conforming implementation MUST support a modulus size of 1024 bits.

Recent guidance [TWIRL, RSA-TR] on key sizes makes estimates as to the amount of effort an attacker would need to expend in order to reconstruct an RSA private key. Table 1 summarizes the maximum length of time that selected modulus sizes should be used. Note that these recommendations are based on factors such as the cost of processing and memory, as well as cryptographic analysis methods, which were current at the time these documents were published. As those factors change, choices of key lifetimes should take them into account.

Number of Modulus Bits	Recommended Maximum Lifetime
-----	-----
768	1 week
1024	1 year

Table 1. RSA Key Use Lifetime Recommendations

3. Performance

The RSA asymmetric key algorithm is very costly in terms of processing time compared to the HMAC algorithms. However, processing cost is decreasing over time. Faster general-purpose processors are being deployed, faster software implementations are being developed, and hardware acceleration support for the algorithm is becoming more prevalent.

Care should be taken that RSA signatures are not used for applications when potential receivers are known to lack sufficient processing power to verify the signature. It is also important to use this scheme judiciously when any receiver may be battery powered.

The RSA asymmetric key algorithm is best suited to protect network traffic for which:

- o The sender has a substantial amount of processing power, and
- o The network traffic is small enough that adding a relatively large authentication tag (in the range of 62 to 256 bytes) does not cause packet fragmentation.

RSA key pair generation and signing are substantially more expensive operations than signature verification, but these are isolated to the sender.

The size of the RSA modulus affects the processing required to create and verify RSA digital signatures. Care should be taken to determine the size of modulus needed for the application. Smaller modulus sizes may be chosen as long as the network traffic protected by the private key flows for less time than it is estimated that an attacker would take to discover the private key. This lifetime is considerably smaller than most public key applications that store the signed data for a period of time. But since the digital signature is used only for sender verification purposes, a modulus that is considered weak in another context may be satisfactory.

The size of the RSA public exponent can affect the processing required to verify RSA digital signatures. Low-exponent RSA signatures may result in a lower verification processing cost. At the time of this writing, no attacks are known against low-exponent RSA signatures that would allow an attacker to create a valid signature using the RSAES-OAEP scheme.

The addition of a digital signature as an authentication tag adds a significant number of bytes to the packet. This increases the likelihood that the packet encapsulated in ESP or AH may be fragmented.

4. Interaction with the ESP Cipher Mechanism

The RSA signature algorithm cannot be used with an ESP Combined Mode algorithm that includes an explicit ICV. The Combined Mode algorithm will add the ESP ICV field, which does not allow use of a separate authentication algorithm to add the ESP ICV field. One example of such an algorithm is the ESP Galois/Counter Mode algorithm [AES-GCM].

5. Key Management Considerations

Key management mechanisms negotiating the use of RSA signatures MUST include the length of the RSA modulus during policy negotiation using the Authentication Key Length SA Attribute. This gives a device the opportunity to decline use of the algorithm. This is especially important for devices with constrained processors that might not be able to verify signatures using larger key sizes.

Key management mechanisms negotiating the use of RSA signatures also MUST include the encoding method during policy negotiation using the Signature Encoding Algorithm SA Attribute.

A receiver must have the RSA public key in order to verify integrity of the packet. When used with a group key management system (e.g., RFC 3547 [GDOI]), the public key SHOULD be sent as part of the key download policy. If the group has multiple senders, the public key of each sender SHOULD be sent as part of the key download policy.

Use of this transform to obtain data origin authentication for pairwise SAs is NOT RECOMMENDED. In the case of pairwise SAs (such as negotiated by the Internet Key Exchange [IKEV2]), data origin authentication can be achieved with an HMAC transform. Because the performance impact of an RSA signature is typically greater than an HMAC, the value of using this transform for a pairwise connection is limited.

6. Security Considerations

This document provides a method of authentication for ESP and AH using digital signatures. This feature provides the following protections:

- o Message modification integrity. The digital signature allows the receiver of the message to verify that it was exactly the same as when the sender signed it.
- o Host authentication. The asymmetric nature of the RSA public key algorithm allows the sender to be uniquely verified, even when the message is sent to a group.

Non-repudiation is not claimed as a property of this transform. At times, the property of non-repudiation may be applied to digital signatures on application-level objects (e.g., electronic mail). However, this document describes a means of authenticating network-level objects (i.e., IP packets), which are ephemeral and not directly correlated to any application. Non-repudiation is not applicable to network-level objects (i.e., IP packets).

A number of attacks are suggested by [RFC3552]. The following sections describe the risks those attacks present when RSA signatures are used for ESP and AH packet authentication.

SHA-1 has been scheduled to be phased out in 2010, due to the steady advances in technology by which an adversary can double its computing power in roughly eighteen months. Recent attacks on SHA-1 underscore the importance of replacing SHA-1, but have not motivated replacing it before that date [SHA-COMMENTS]. The use of this transform after that date SHOULD be preceded by an analysis as to its continued suitability.

6.1. Eavesdropping

This document does not address confidentiality. That function, if desired, must be addressed by an ESP cipher that is used with the RSA signatures authentication method. The RSA signature itself does not need to be protected from an eavesdropper.

6.2. Replay

This document does not address replay attacks. That function, if desired, is addressed through use of ESP and AH sequence numbers as defined in [ESP] and [AH].

6.3. Message Insertion

This document directly addresses message insertion attacks. Inserted messages will fail authentication and be dropped by the receiver.

6.4. Deletion

This document does not address deletion attacks. It is concerned only with validating the legitimacy of messages that are not deleted.

6.5. Modification

This document directly addresses message modification attacks. Modified messages will fail authentication and be dropped by the receiver.

6.6. Man in the Middle

As long as a receiver is given the sender RSA public key in a trusted manner (e.g., by a key management protocol), it will be able to verify that the digital signature is correct. A man in the middle will not be able to spoof the actual sender unless it acquires the RSA private key through some means.

The RSA modulus size must be chosen carefully to ensure that the time a man in the middle needs to determine the RSA private key through cryptanalysis is longer than the amount of time that packets are signed with that private key.

6.7. Denial of Service

According to IPsec processing rules, a receiver of an ESP and AH packet begins by looking up the Security Association in the SA database. If one is found, the ESP or AH sequence number in the packet is verified. No further processing will be applied to packets with an invalid sequence number.

An attacker that sends an ESP or AH packet matching a valid SA on the system and also having a valid sequence number will cause the receiver to perform the ESP or AH authentication step. Because the process of verifying an RSA digital signature consumes relatively large amounts of processing, many such packets could lead to a denial of service (DoS) attack on the receiver.

If the message was sent to an IPv4 or IPv6 multicast group, all group members that received the packet would be under attack simultaneously.

This attack can be mitigated against most attackers by encapsulating ESP or AH using an RSA signature for authentication within ESP or AH using an HMAC transform for authentication. In this case, the HMAC transform would be validated first, and as long as the attacker does not possess the HMAC key no digital signatures would be evaluated on the attacker packets. However, if the attacker does possess the HMAC key (e.g., the attacker is a legitimate member of the group using the SA), then the DoS attack cannot be mitigated.

7. IANA Considerations

An assigned number is required in the "IPSec Authentication Algorithm" name space in the Internet Security Association and Key Management Protocol (ISAKMP) registry [ISAKMP-REG]. The mnemonic should be "SIG-RSA".

An assigned number is also required in the "IPSEC AH Transform Identifiers" name space in the ISAKMP registry. Its mnemonic should be "AH_RSA".

A new "IPSEC Security Association Attribute" is required in the ISAKMP registry to pass the RSA modulus size. The attribute class should be called "Authentication Key Length", and it should be a Variable type.

A second "IPSEC Security Association Attribute" is required in the ISAKMP registry to pass the RSA signature encoding type. The attribute class should be called "Signature Encoding Algorithm", and it should be a Basic type. The following rules apply to define the values of the attribute:

Name	Value
----	-----
Reserved	0
RSASSA-PKCS1-v1_5	1
RSASSA-PSS	2

Values 3-61439 are reserved to IANA. New values MUST be added due to a Standards Action as defined in [RFC2434]. Values 61440-65535 are for private use and may be allocated by implementations for their own purposes.

8. Acknowledgements

Scott Fluhrer and David McGrew provided advice regarding applicable key sizes. Scott Fluhrer also provided advice regarding key lifetimes. Ian Jackson, Steve Kent, and Ran Canetti provided many helpful comments. Sam Hartman, Russ Housley, and Lakshminth Dondeti provided valuable guidance in the development of this document.

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Acknowledgement

Funding for the RFC Editor function is provided by the IETF Administrative Support Activity (IASA).

