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Integrity Protection for Network Service Header (NSH) and Encryption of Sensitive Metadata

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Abstract

This specification adds integrity protection and optional encryption directly to Network Service Headers (NSH) used for Service Function Chaining (SFC).

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Table of Contents

1. Introduction

Many advanced Service Functions (e.g., Performance Enhancement Proxies, NATs, firewalls, etc.) are invoked for the delivery of value-added services, particularly to meet various service objectives such as IP address sharing, avoiding covert channels, detecting and protecting against ever increasing Denial-of-Service (DoS) attacks, network slicing, etc. Because of the proliferation of such advanced SFs together with complex service deployment constraints that demand more agile service delivery procedures, operators need to rationalize their service delivery logics and master their complexity while optimising service activation time cycles. The overall problem space is described in [RFC7498].

[RFC7665] presents an architecture addressing the problematic aspects of existing service deployments, including topological dependence and configuration complexity. It also describes an architecture for the specification, creation, and ongoing maintenance of Service Function Chains (SFC) within a network. That is, how to define an ordered set of SFs and ordering constraints that must be applied to packets/flows

selected as a result of classification. [RFC8300] specifies the SFC encapsulation: Network Service Header (NSH).

NSH data is unauthenticated and unencrypted [RFC8300], forcing a service topology that requires security and privacy to use a transport encapsulation that support such features (e.g., IPsec). The lack of such capability was reported during the development of [RFC8300] and [RFC8459].

This specification fills that void. Concretely, this document adds integrity protection and optional encryption directly to NSH (Section 4). Thus, NSH data does not have to rely on underlying transport encapsulation for security and confidentiality. Note that the payload encapsulated by NSH is not part of the NSH data.

This specification introduces new Variable-Length Context Headers to carry fields necessary for integrity protected and encrypted NSH (Section 6), and is hence only applicable to NSH MD Type 0x02 defined in Section 2.5 of [RFC8300].

2. Terminology

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.

This document makes use of the terms defined in [RFC7665] and [RFC8300].

The document defines the following terms:

- SFC data plane functional element: Refers to SFC-aware Service Function, Service Function Forwarder (SFF), SFC proxy, or classifier as defined in the SFC data plane architecture [RFC7665].

- SFC Control Element: A logical entity that instructs one or more SFC data plane functional elements on how to process NSH packets within an SFC-enabled domain.

- Key Identifier (or Ticket): A key identifier or kerberos like object used to identify and deliver keys to authorized entities.

- NSH imposer: Refers to the SFC data plane element that is entitled to impose NSH with the Context headers defined in this document.

Such element may be a Classifier, an SFC-aware SF, an SFF, or an SFC proxy.

3. Assumptions & Basic Requirements

The NSH format is defined in Section 2 of [RFC8300]; the NSH data can be divided into three parts:

- Base Header: Provides information about the service header and the payload protocol.
- Service Path Header: Provides path identification and location within a service path.
- Context Header: Carries metadata (i.e., context data) along a service path.

NSH allows to share context information (a.k.a., metadata) with upstream SFC-aware data elements on a per SFC/SFP basis. To that aim:

- The control plane is used to instruct the SFC classifier about the set of context information to be supplied in the context of a given chain.
- The control plane is also used to instruct an SFC-aware SF about any metadata it needs to attach to packets for a given SFC. This instruction may occur any time during the validity lifetime of an SFC/SFP. The control plane may indicate, for a given service function chain, an order for consuming a set of contexts supplied in a packet.
- An SFC-aware SF can also be instructed about the behavior it should adopt after consuming a context information that was supplied in the NSH header. For example, the context can be maintained, updated, or stripped.
- An SFC proxy may be instructed about the behavior it should adopt to process the context information that was supplied in the NSH header on behalf of an SFC-unaware SF, e.g., the context can be maintained or stripped.
- The SFC proxy may also be instructed to add some new context information into the NSH header on behalf of an SFC-unaware SF.
- The control plane is assumed to instruct the classifier, SFC-aware SFs, and SFC proxy the set of context headers (privacy-sensitive metadata, typically) that must be encrypted. The control plane

may also indicate the set of SFC data plane element that are entitled to supply a given context header (e.g., in reference to their identifiers as assigned within the SFC-enabled domain).

It is out of the scope of this document to elaborate on how such instructions are conveyed to the appropriate SFC data plane elements, nor to detail the structure used to store the instructions.

In reference to Figure 1,

- Classifiers, SFC-aware SFs, and SFC proxies are entitled to update context header: Only these elements must be able to encrypt and decrypt a supplied context header.

- All SFC data plane elements are entitled to modify the context of the Base and Service Path headers (e.g., SI, TTL). The solution must also provide integrity protection for these two headers.

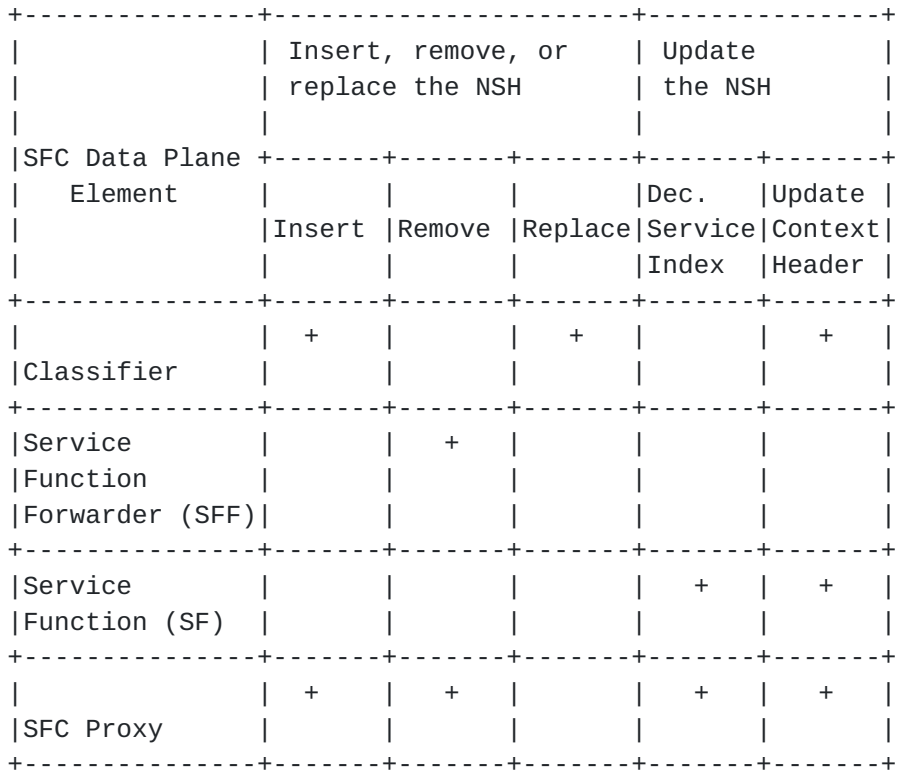


Figure 1: NSH Actions

The solution in the document does not make any assumption about the service chains to be instantiated nor adds constraints to how NSH can be used within a domain. For example, in reference to Figure 2, the solution accommodates deployment schemes such as:

- No metadata is inserted by the classifier: it only proceeds with integrity protection.
- SF1 inserts two metadata M1 and M2 that its encrypts.
- SF2 decrypts M1 and M2, strips M2, and then encrypts M1
- SF3 decrypts M1 and then strips it.

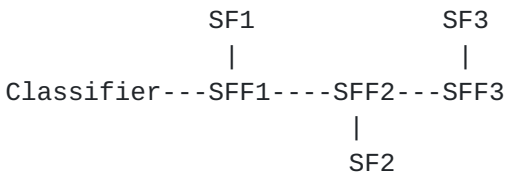


Figure 2: SFC-enabled Domain Example

4. Solution Overview

The Authenticated Encryption with Associated Data (AEAD) algorithm [RFC5116] is used to provide NSH data integrity and to encrypt privacy-sensitive metadata.

The AEAD algorithm to be used by SFC data plane element may be controlled using the control plane or other means. Mandatory to implement AEAD algorithms are listed in Section 5.

AEAD algorithms take as input a single key, a nonce, a plaintext, and "additional data" to be included in the authentication check, as described in Section 2.1 of [RFC5116].

AEAD functions provide a unified encryption and authentication operation which turns plaintext into authenticated ciphertext and back again. When the length of plaintext is zero, the AEAD algorithm acts as a Message Authentication Code (MAC) on the "additional data" input. The length of the AEAD output will generally be larger than the plaintext, but by an amount that varies with the AEAD algorithm.

In order to decrypt and verify, the cipher takes as input the key, nonce, additional data, and the ciphertext. The output is either the plaintext or an error indicating that the decryption failed.

The procedure for establishment of the secret key and AEAD algorithm is outside the scope of this specification. As such, this specification does not mandate support of any given mechanism.

A (non-normative) sample deployment case is provided in Appendix A. Gene

5. Mandatory to Implement AEAD Algorithms

Classifiers, SFC-aware SFs, SFFs, and SFC proxies MUST implement the TLS_AES_128_GCM_SHA256 [GCM] cipher suite and SHOULD implement the TLS_AES_256_GCM_SHA384 [GCM] and TLS_CHACHA20_POLY1305_SHA256 [RFC8439] cipher suites.

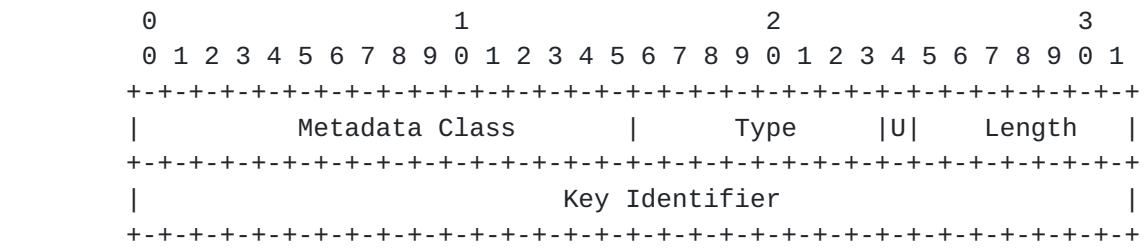
6. New NSH Variable-Length Context Headers

This section specifies the format of new Variable-Langth Context headers that are used for NSH integrity protection and, optionally, metadata encryption.

6.1. Key Identifier Context Header

Key Identifier Context Header is a variable length Key Identifier object used to identify and deliver keys to SFC data plane elements. This is a mandatory TLV that MUST be present if an integrity protected and encrypted NSH solution is desired.

This Context Header is helpful to accommodate deployments relying upon keying material per SFC/SFP. Also, the key needs to be updated after encrypting certain number of NSH data, key identifier helps address the problem of synchronization of keying material.



The description of the fields is as follows:

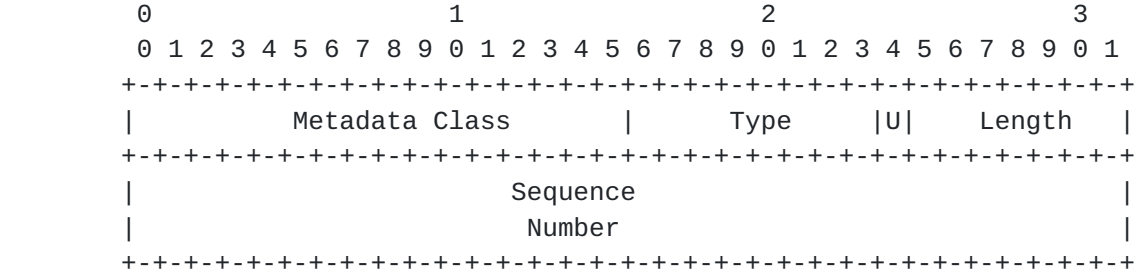
- Metadata Class: MUST be set to 0x0 [RFC8300].
- Type: TBD1 (See Section 9)
- Length: Variable.
- Key Identifier: Carries the key identifier.

6.2. Sequence Number Context Header

Sequence Number Context Header conveys a 64-bit sequence number per key identifier. In this specification, a sequence number needs to be incremented every time NSH is included by the NSH imposer (for a

given SFC/SFP). The sequence number SHOULD NOT be incremented if an existing NSH is being updated.

This is a mandatory TLV that MUST be present if an integrity protected and encrypted NSH solution is desired.

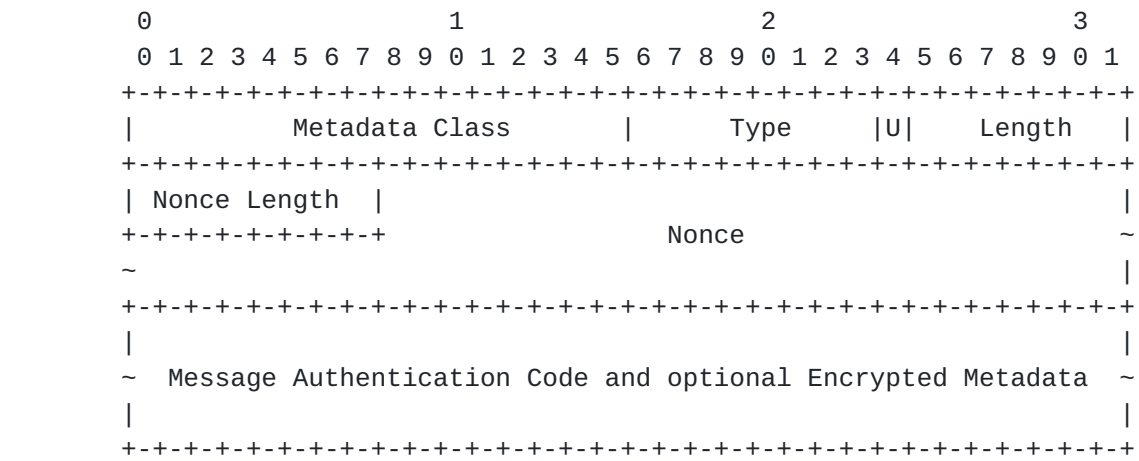


The description of the fields is as follows:

- Metadata Class: MUST be set to 0x0 [RFC8300].
- Type: TBD2 (See Section 9)
- Length: 8 bytes
- Sequence Number: Carries the sequence number.

6.3. MAC and Encrypted Metadata Context Header

MAC and Encrypted Metadata Context Header is a variable-length TLV that carries the Message Authentication Code (MAC) for the entire NSH calculated using K and optionally metadata encrypted K.



The description of the fields is as follows:

- Metadata Class: MUST be set to 0x0 [RFC8300].

- Type: TBD3 (See Section 9)

- Nonce Length: Carries the length of the nonce (Section 4 of [RFC5116]).

- Nonce: Carries the nonce for AEAD algorithms as discussed in Section 3 of [RFC5116]. The associated data (defined in [RFC5116] as A) MUST be the entire NSH data excluding the metadata to be encrypted.

- Message Authentication Code and optional Encrypted Metadata

7. Processing Rules

The following sub-sections describe the processing rules for integrity protected NSH and optionally encrypted metadata.

7.1. Generic Behavior

This document adheres to the recommendations in [RFC8300] for handling the context headers at both ingress and egress SFC boundary nodes. That is, to strip such context headers.

Failures to inject or validate the Context Headers defined in the document SHOULD be logged locally while a notification alarm MAY be sent to an SFC Control Element. The details of sending notification alarms (i.e., the parameters affecting the transmission of the notification alarms depend on the information in the context header such as frequency, thresholds, and content in the alarm SHOULD be configurable by the control plane.

SFC-aware SFs and SFC proxies MAY be instructed to strip some encrypted context headers from the packet or to pass the data to the next SF in the service chain after processing the content of the context headers. If no instruction is provided, the default behavior for intermediary SFC-aware nodes is to maintain such context headers so that the information can be passed to next SFC-aware hops.

An SFC-aware SF or SFC proxy that receive an encrypted metadata, for which it is not allowed to decrypt the data, SHOULD maintain that data when forwarding the packet upstream.

Notes: (1) add more text to handle multiple instances of the TLVs, (2) check which actual SFC element is doing what, ...

7.2. MAC NSH Data Generation

When the length of encrypted metadata is zero, the AEAD algorithm acts as a Message Authentication Code on the input A (defined in [RFC5116]). An NSH imposer inserts a "MAC and Encrypted Metadata" Context Header for integrity protection (Section 6.3). The imposer computes the message integrity for the entire NSH data using K, Nonce, and AEAD algorithm. It inserts the MAC in the "MAC and Encrypted Metadata" Context Header. The length of the MAC is decided by the AEAD algorithm adopted for the particular key identifier.

An entity in the service function path that intends to update NSH MUST do the above to maintain message integrity of the NSH for subsequent validations.

7.3. Encrypted NSH Metadata Generation

An NSH imposer can encrypt all NSH metadata or only a subset of metadata, i.e., encrypted and unencrypted metadata may be carried simultaneously (Figure 3).

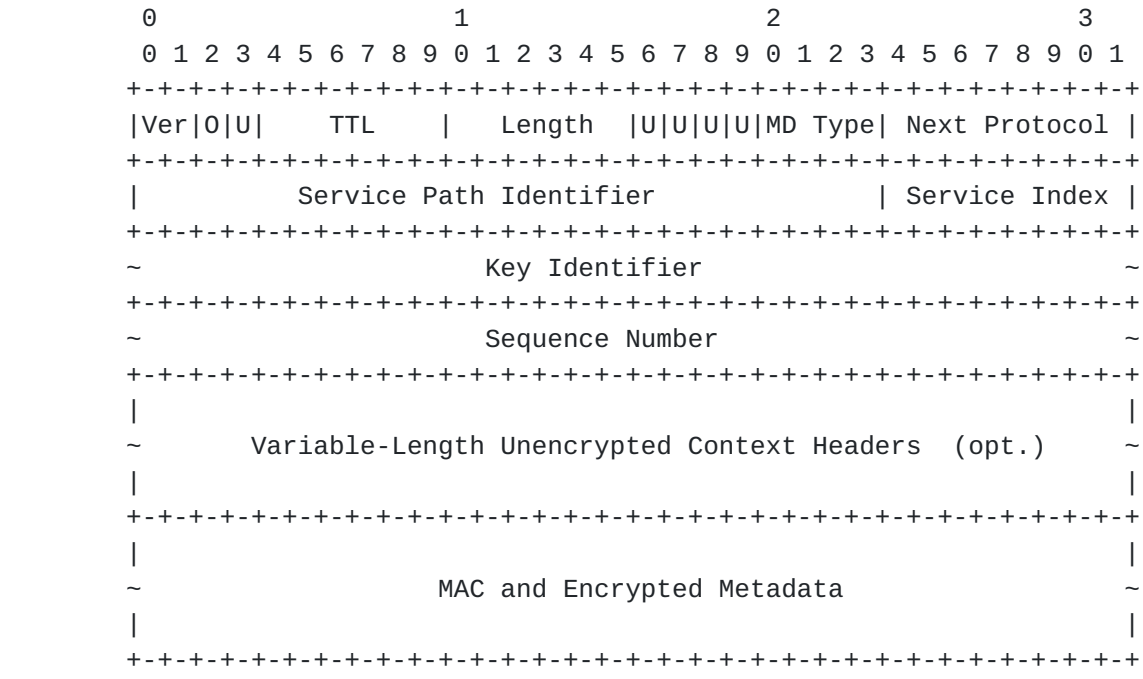


Figure 3: NSH with Encrypted and Unencrypted Metadata

In an SFC-enabled domain where pervasive monitoring [RFC7258] is possible, NSH metadata MUST be encrypted and MUST NOT reveal privacy sensitive metadata to attackers. Privacy specific threats are discussed in Section 5.2 of [RFC6973].

Using K and AEAD algorithm, the NSH imposer encrypts metadata (as set by the control plane Section 3) and inserts the resulting payload in the "MAC and Encrypted Metadata" Context Header (Section 6.3). The entire TLV carrying the privacy-sensitive metadata will be encrypted (that is, including the MD Class, Type, Length, and associated metadata).

An authorized entity in the SFP that intends to update encrypted metadata MUST also do the above.

7.4. Sequence Number Validation for Replay Attack

A Sequence Number is an unsigned 64-bit counter value that increases by one for each NSH created and sent from the NSH imposer, i.e., a per-key identifier packet sequence number. The information is mandatory and MUST always be present.

Processing of the Sequence Number field is at the discretion of the receiver, but all implementations MUST be capable of validating that the Sequence Number that does not duplicate the Sequence Number of any other NSH received during the life of the key identifier.

The NSH imposer's counter is initialized to '0' when a new key identifier is to be used . The sender increments the Sequence Number counter for this key identifier and inserts the 64-bit value into the Sequence Number Context Header (Section 6.2). Thus, the first NSH message (for a given service chain) sent using a given key identifier will contain a Sequence Number of 1. The imposer checks to ensure that the counter has not cycled before inserting the new value in the Sequence Number Context Header. In other words, the sender MUST NOT send a packet on a key identifier if doing so would cause the Sequence Number to rollover.

Sequence Number counters of all participating nodes MUST be reset by establishing a new key identifier prior to the transmission of the 2^64th packet of NSH for a particular key identifier.

7.5. NSH Data Validation

When an SFC data plane element receives an NSH message with encrypted metadata, it MUST first ensure that all mandatory TLVs required for NSH data integrity exist. It MUST discard the message, if mandatory TLVs are absent or if the sequence number is invalid (described in Section 7.4). The node should then proceed with data validation. The SFC data plane element computes the message integrity for the entire NSH data using K and AEAD algorithm for the key identifier being carried in NSH. If the value of the newly generated digest is identical to the one enclosed in NSH, the SFC data plane element is

certain that the header has not been tampered and validation succeeds. Otherwise, the NSH message MUST be discarded.

7.6. Decryption of NSH Metadata

If entitled to consume a supplied encrypted metadata, an SFC-aware SF or SFC proxy decrypts metadata using K and decryption algorithm for the key identifier in NSH. AEAD algorithm has only a single output, either a plaintext or a special symbol FAIL that indicates that the inputs are not authentic (Section 2.2 of [RFC5116]).

There are cryptographic limits on the amount of plaintext which can be safely encrypted under a given set of keys. [AEAD-LIMITS] provides an analysis of these limits under the assumption that the underlying primitive (AES or ChaCha20) has no weaknesses. The NSH imposer SHOULD do a secret key update prior to reaching these limits.

8. Security Considerations

NSH security considerations are discussed in Section 8 of [RFC8300].

The interaction between the SFC-aware data plane elements and a key management system MUST NOT be transmitted in clear since this would completely destroy the security benefits of the integrity protection scheme defined in this document.

NSH data is at risk from four primary attacks:

- A man-in-the-middle attacker modifying NSH data.
- Attacker spoofing NSH data.
- Attacker capturing and replaying NSH data.
- NSH metadata revealing privacy sensitive information to attackers.

In an SFC-enabled domain where the above attacks are possible, NSH data MUST be integrity and replay protected, and privacy-sensitive NSH metadata MUST be encrypted for confidentiality.

No device other than the SFC-aware SFs in the SFC-enabled domain should be able to update the integrity protected NSH data. Similarly, no device other than the SFC-aware SFs and SFC proxies in the SFC-enabled domain be able to decrypt and update the metadata. In other words, if the SFC-aware SFs and SFC proxies in the SFC-enabled domain are considered fully trusted to act on the NSH data, only they can have access to privacy-sensitive NSH metadata and the keying material used to integrity protect NSH and encrypt metadata.

9. IANA Considerations

This document requests IANA to assign the following types from the "NSH IETF-Assigned Optional Variable-Length Metadata Types" (0x0000 IETF Base NSH MD Class) registry available at: https://www.iana.org/assignments/nsh/nsh.xhtml#optional-variable-length-metadata-types.

Value	Description	Reference
TBD1	Key Identifier	[ThisDocument]
TBD2	Sequence Number	[ThisDocument]
TBD3	MAC and Encrypted Metadata	[ThisDocument]

10. Acknowledgements

This document was edited as a follow up to the discussion in IETF#104: https://datatracker.ietf.org/meeting/104/materials/slides-104-sfc-sfc-chair-slides-01 (slide 7).

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11.1. Normative References

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Appendix A. A Deployment Example with KMS

SFC-aware SFs do not share any credentials; instead, they trust a third party, the KMS, with which they have or can establish shared credentials. These pre-established trust relations are used to establish a security association between SFC data plane elements within the context of a given service chain.

The NSH imposer requests a secret key and key identifier from the KMS. The request message also includes identities of the SFC data plane elements (including SFC-aware SFs and SFC proxies) authorized to receive the keying material associated with the key identifier.

Each SFC-aware SF is referenced using an SF identifier that is unique within an SFC-enabled domain. If the request is authorized, then KMS generates the secret key (K), key identifier (kid), and returns them in a response message. The key identifier may be self-contained (key encrypted in the key identifier) or just a handle to some internal data structure within the KMS.

The NSH imposer includes the key identifier in NSH data. The NSH data is protected using K and optionally metadata is encrypted using K. SFC data plane elements in the SFP forward the key identifier to the KMS and request the KMS to retrieve the keying material. If the SFC data plane element is authorized and the key identifier is valid, then the KMS retrieves the secret key and AEAD algorithm associated with the key identifier and conveys them to the SFC data plane element. The other alternative approach is that KMS implicitly pushes the keying material to, particularly, SFC-aware SFs and SFC proxies authorized by the NSH imposer.

If the NSH imposer requests a new key and a new key identifier from KMS, the request message from NSH imposer to KMS also includes identities of the SFC data plane elements (including SFC-aware SFs and SFC proxies) authorized to receive the keying material associated with the new key identifier. For subsequent packets, the new key identifier will be conveyed in the NSH data, NSH data will be integrity protected using the new secret key and optionally NSH metadata is encrypted using the new secret key.

Figure 4 shows an example of an NSH imposer requesting a secret key and key identifier from the KMS. The request message includes identifiers of SF1 and SF2 Service Functions authorized to receive keying material associated with the key identifier. KMS returns the secret key (K) and key identifier in the response message. The NSH imposer includes the key identifier in the NSH data. In this example, SF1 in the SFP forwards the key identifier to the KMS and requests the KMS for keying material associated with the key identifier (In key resolve request message). If SF1 is authorized and the key identifier is valid then KMS retrieves the key and AEAD algorithm associated with the key identifier and conveys them to the SF1 (In Resolve response message). Similarly, SF2 retrieves the keying material associated with the key identifier from KMS.

Note: Update the example with the SFF

The exchange with KMS is not required if the necessary information is pre-provisonned to the authorized SFC-aware SFs and SFC proxies.

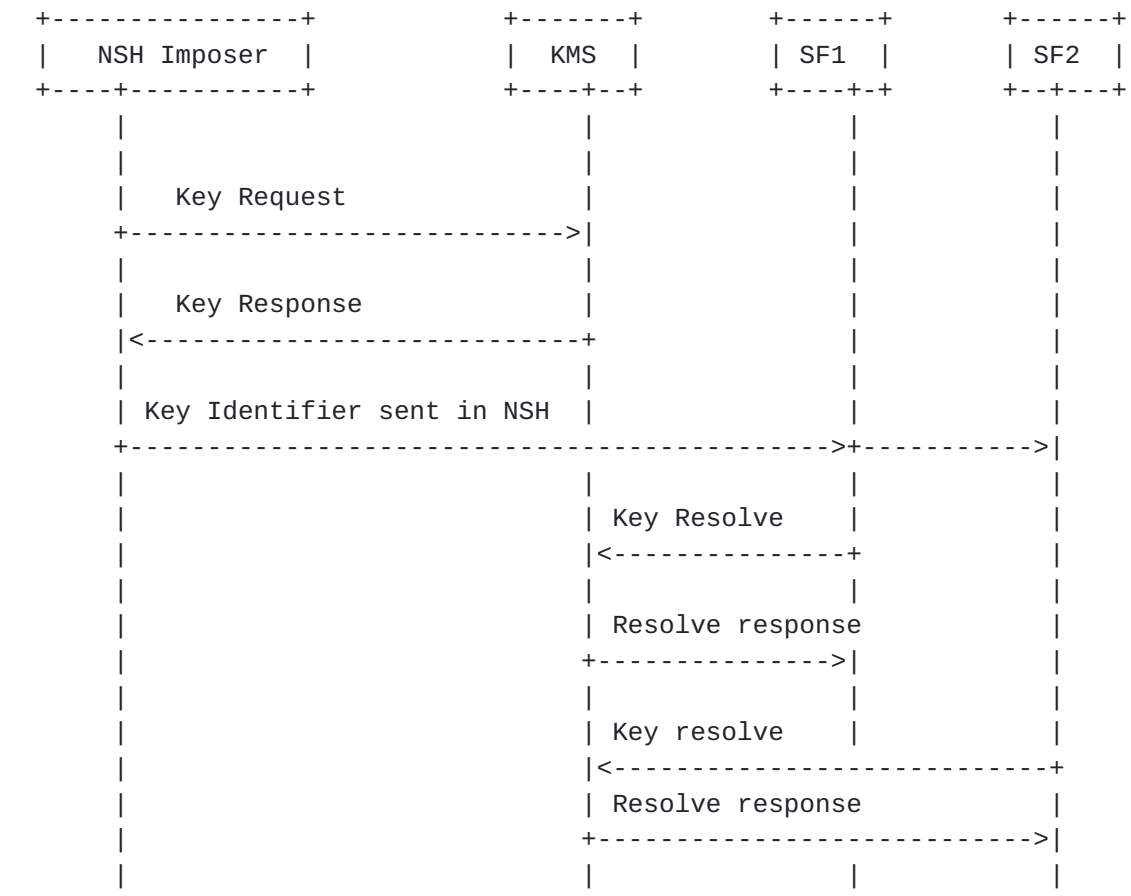

Figure 4: Example of Interactions with KMS

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