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Network Functions Virtualisation (NFV); Trust; Report on Certificate Management

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Reference

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Foreword

This Group Report (GR) has been produced by ETSI Industry Specification Group (ISG) Network Functions Virtualisation (NFV).

Modal verbs terminology

In the present document "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

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1 Scope

The present document provides guidance to the development community on the use of Public Key Certificates, Attribute Certificates and the supporting infrastructure, including Registration Authorities, and Certificate Authorities. The present document provides this guidance in the context of a number of use cases and references to other publications of ETSI ISG NFV.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] Void.

[i.2] ETSI GS NFV 002: "Network Functions Virtualisation (NFV); Architectural Framework".

[i.3] ETSI GS NFV 003: "Network Functions Virtualisation (NFV); Terminology for Main Concepts in NFV".

[i.4] ETSI GS NFV 004: "Network Functions Virtualisation (NFV); Virtualisation Requirements".

[i.5] ETSI GS NFV-MAN 001: "Network Functions Virtualisation (NFV); Management and Orchestration".

[i.6] Void.

[i.7] Void.

[i.8] ETSI GS NFV-SEC 001: "Network Functions Virtualisation (NFV); NFV Security; Problem Statement".

[i.9] Void.

[i.10] ETSI GS NFV-SEC 009: "Network Functions Virtualisation (NFV); NFV Security; Report on use cases and technical approaches for multi-layer host administration".

[i.11] ETSI GS NFV-SEC 012: "Network Functions Virtualisation (NFV) Release 3; Security; System architecture specification for execution of sensitive NFV components".

[i.12] Void.

[i.13] Recommendation ITU-T X.509: "Information technology - Open Systems Interconnection - The Directory: Public-key and attribute certificate frameworks".

[i.14] IETF RFC 3647: "Internet X.509 Public Key Infrastructure Certificate Policy and Certification Practices Framework".

[i.15] IETF RFC 8446: "The Transport Layer Security (TLS) Protocol Version 1.3".

[i.16] IETF RFC 7030: "Enrollment over Secure Transport".

[i.17] IETF RFC 5280: "Internet X.509 Public Key Infrastructure Certificate and Certificate Revocation List (CRL) Profile".

[i.18] IETF RFC 4210: "Internet X.509 Public Key Infrastructure Certificate Management Protocol (CMP)".

[i.19] ETSI TS 133 310: "Universal Mobile Telecommunications System (UMTS); LTE; Network Domain Security (NDS); Authentication Framework (AF) (3GPP TS 33.310)".

[i.20] IETF RFC 8894: "Simplified Certificate Enrollment Protocol".

[i.21] IETF RFC 8295: "EST (Enrollment over Secure Transport) Extensions".

[i.22] ETSI GS NFV-SEC 021: "Network Functions Virtualisation (NFV) Release 2; Security; VNF Package Security Specification".

[i.23] ETSI GS NFV-SEC 023: "Network Functions Virtualisation (NFV) Release 4; Security; Container Security Specification".

[i.24] ETSI GS NFV-IFA 040: "Network Functions Virtualisation (NFV) Release 4; Management and Orchestration; Requirements for service interfaces and object model for OS container management and orchestration specification".

[i.25] Kubernetes® API v1.21.

NOTE: Available at https://kubernetes.io/docs/reference/generated/kubernetes-api/v1.21/.

3 Definition of terms, symbols and abbreviations

3.1 Terms

For the purposes of the present document, the terms given in ETSI GS NFV 003 [i.3] and the following apply:

attribute certificate: data structure, digitally signed by an Attribute Authority, that binds some attribute values with identification information about its holder

trust chain: data structure, containing a sequence of Certificate Authority certificates where each certificate is signed by the subsequent certificate in the file, ending in a root Certificate Authority certificate

3.2 Symbols

Void.

3.3 Abbreviations

For the purposes of the present document, the abbreviations given in ETSI GS NFV 003 [i.3] and the following apply:

CA	Certificate Authority
CP	Certificate Policy
PKC	Public Key Certificate
PKI	Public Key Infrastructure
RA	Registration Authority
RCA	Root CA

4 Rationale and approach for the use of public key certificates

4.1 Scope

The present document provides a guide to the use of Public Key Infrastructures (PKI) for the purpose of distributing Public Key Certificates (PKC) as applicable to the ETSI ISG NFV for the support of Public Key Cryptography in authenticating, authorizing and encrypting links between objects in NFV.

Each operator should develop Certificate Policy in accordance with their regional and national requirements. The present document assumes that the reader is generally familiar with Digital Signatures, PKIs, and core ETSI NFV specifications. The present document is consistent with the Internet X.509 Certificate Policy and Certification Practices Framework as defined in IETF RFC 3647 [i.14]. The certificate policy defines the structure of PKI.

NOTE: The PKIs described in the present document are privately managed, thus non-private (non-permissioned) PKIs are out of scope of the present document.

4.2 PKI Participants

4.2.0 Introduction

An NFV PKI can be implemented as a multi-tier hierarchy with a Root Certification Authority (RCA) at tier 1. There may be many certificate chains anchored by the RCA. Identified chains can be organized functionally and might include NFVI, VNF, MANO, and Support (such as OSS/BSS). A representative certificate hierarchy is shown in figure 4.2.0-1. The fewer tiers there are in the hierarchy, the smaller attack surface is, at the cost of limiting the number of trust domains.

The end-entity certificate, its private key, and all sub-CA certificates for a given CA chain should be installed on the device (hardware resource or software element, as appropriate). During authentication messaging exchange (using TLS or similar protocol) the end-entity and all sub-CA chain certificates should be sent to the other end point.

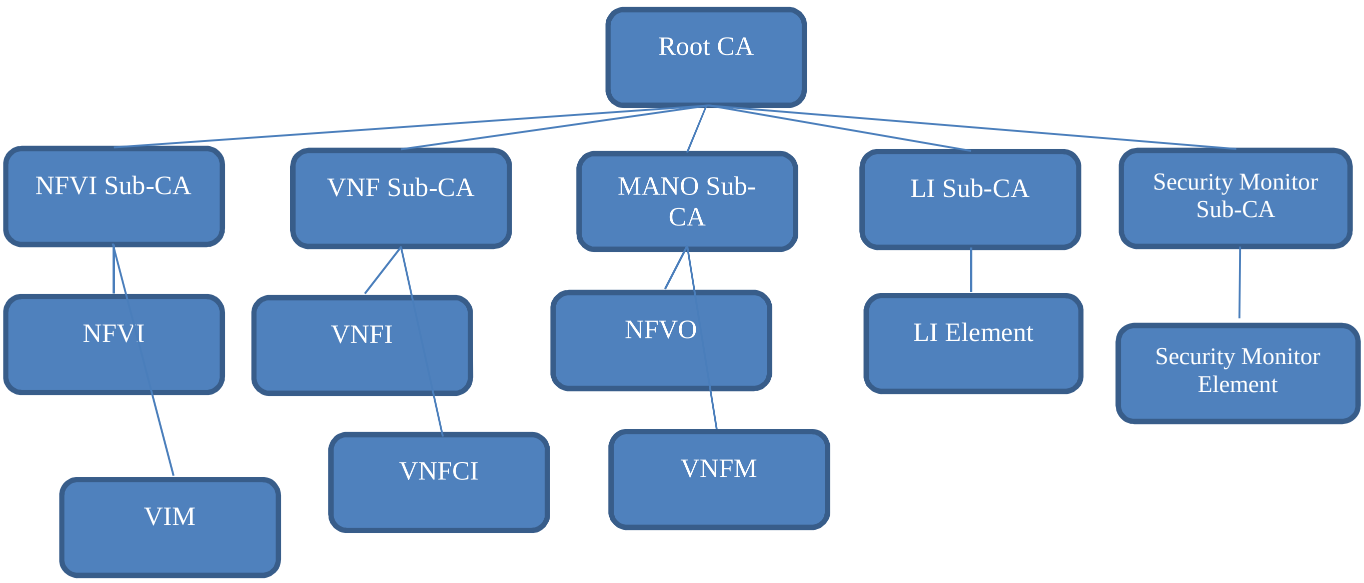

Figure 4.2.0-1: ETSI NFV PKI Certificate Hierarchy

Support of multiple roots is possible and when used it is expected to be specified by the operator. To anchor trust, certificates issued in ecosystems comprised of multiple roots have to be verifiable (chainable) to the corresponding root. This may be accomplished by cross signing certificates or allowing subscribers to honour multiple roots. This may provide ecosystem supply chain benefits at the risk of a substantially increased PKI attack surface. Furthermore, PKI operations of either deploying multiple valid chains or executing cross signing while achieving security over time has proven difficult.

PKI participants can include registration authorities, subscribers, relying parties, and auditors. PKI participants are described below.

4.2.1 Certificate Authorities

The entities called Certificate Authorities (CAs) are the heart of the ETSI NFV PKI. The CA is an aggregate term encompassing the collection of hardware, software, and operating personnel that create, sign, and issue public key certificates to Subscribers or other CAs. The CAs are responsible for:

- Implementing and maintaining a Certificate Policy (CP).
- Issuing compliant certificates.
- Delivery of certificates to Subscribers in accordance with the CP and other documents such as a Subscriber Agreement.
- Revocation of certificates.
- Generation of key pairs, protection, operation, and destruction of CA private keys.
- CA certificate lifecycle management ensure that all aspects of the CA services, operations, and infrastructure related to certificates issued under the CP are in fact compliant to the CP.
- Facilitating as a trusted party the confirmation of the binding between a public key and the identity, and/or other attributes, of the "Subject" of the certificate.

Sub-CAs are operated by designated sub-CA service providers and issue end-entity device certificates to subscribers.

4.2.2 Registration Authorities

Registration authorities (RAs) are entities that enter into an agreement with a CA to collect and verify each Subscriber's identity and information to be entered into the Subscriber's certificates. The RA performs its function in accordance with the CP and will perform front-end functions of confirming the identity of the certificate applicant, approving or denying certificate applications (manual) or requests (dynamic), requesting revocation of certificates, and managing account renewals.

4.2.3 Subscribers

The Subscriber is an organization or process acting on behalf of an organization identified in a Digital Certificate Subscriber Agreement (DCSA). The Subscriber is responsible for completing the certificate application or request. The CA relies on the RA to confirm the identity of the Certificate Applicant and either approves or denies the application or request. If approved, the RA communicates to the CA, and the Subscriber can then request certificates.

Subscribers are expected to comply to both CP requirements and any additional certificate management practices that govern the Subscribers' request for certificates and for handling the corresponding private keys. The Subscriber agrees to be bound by its obligations through execution of the DCSA between the Subscriber and the RA, and any other applicable agreements.

Technically, CAs are also Subscribers of certificates within a PKI, either as a Root CA issuing a self-signed certificate to itself, or as a sub-CA. However, in the present document, Subscriber apply only to the organization requesting device certificates, including those Subscribers who may have arranged to have a sub-CA operated onsite at their facility.

4.2.4 Relying Parties

Relying Parties validate the binding of a public key to a Subscriber's name in a device certificate. The RP is responsible for deciding whether or how to check the validity of a certificate by checking the appropriate certificate status information. The RP can use the certificate to verify the integrity of a digitally signed message, to identify the initiator of a communication, to attest the validity of a device setting or software component, or establish confidential communications with the holder of the certificate. For instance, an NFVi resource can use the device certificate presented by a Support server providing a firmware update and validate the signature of the signed firmware.

4.2.5 Auditors

PKI participants compliance to the CP may be verified by a third party authority.

4.3 Mapping of secure relationships to NFV reference points

The NFV reference architectural framework as defined in ETSI GS NFV 002 [i.2] identifies a number of named reference points and the set of allowed entities that communicate via them. Any of these entities or components may benefit by having a certificate and associated and protected private key to execute cryptographic security functions with other terminating entities.

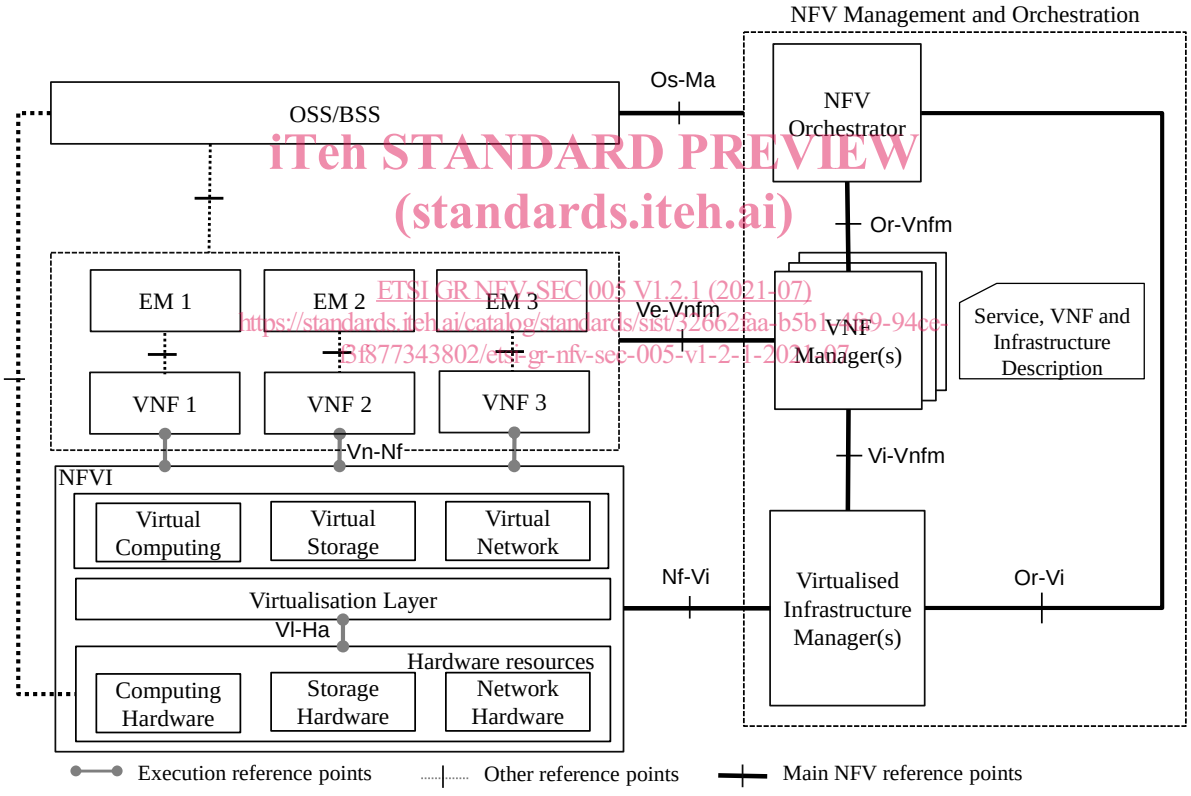

Figure 4.3-1: NFV reference architectural framework

The means by which participants are connected in the PKI is expected to be specified either using online or off-line processes. Furthermore, the Sub-CAs and RAs may exist within the MANO functionality or OSS/BSS environment. Online CA connectivity should be proxied probably via the OSS/BSS. This may facilitate on-line enrolment for certificate issuance in accordance with Enrolment of Secure Transport (EST, IETF RFC 7030 [i.16]) and IETF RFC 8295 [i.21]) or Simplified Certificate Enrollment Protocol (SCEP IETF RFC 8894 [i.20]).

Table 4.3-1: Reference points and Functional Entities they link

Reference point classification	Reference point	PKI applicability	Terminating entities	
Main NFV reference points	**Os-Ma**	**Yes**	**MANO**	**OSS/BSS**
	Ve-Vnfm	Yes	VNF-Manager	EM or VNF
	Nf-Vi	Yes	VIM	NFVI
	Or-Vi	Yes	VIM	NFV Orchestrator
	Vi-Vnfm	Yes	VIM	VNF-Manager
	Or-Vnfm	Yes	VNF-Manager	NFV Orchestrator
Execution refence points	Vi-Ha	NA	Hardware resources	Virtualisation layer
	Vn-Nf	Yes	VNF	NFVI
Other reference points	Not specified	Yes	EM	VNF
	Not specified	Yes	OSS/BSS	EM/VNF
	Not specified	Yes	OSS/BSS	HW resources
NOTE: Vi-Ha is shown here as not applicable simply because it does not appear there is a technical solution (instruction set or other implementation) to allow a VNFI/VNFCI to cryptographically challenge the hardware on which it is being installed. This is a gap as this capability would be useful.				

4.4 Use Cases for the use of certificates in NFV

The benefit to using PKI is the ability to establish security associations between any entity within the domain of the PKI. Security associations are application of security principles to each of the reference points implemented in NFV. The security principles addressable by PKI includes authentication, encryption, and signing. Transport Layer Security (TLS) as specified by IETF RFC 8446 [i.15] provides support for authentication, encryption, and message authentication (signing). File or image signing can also be supported by PKI and may be useful in NFV for distribution of images, packages, and configuration files.

Reference points may be applied between both trusted and untrusted entities. This may apply to multi-tenant or multi-operator environments or to high risk functions within a single-tenant and single-operator environment (such as security monitoring or lawful intercept functions). These use cases and how authentication, encryption, and signing are applied become the primary security association use cases in application of PKI. The criticality of benefit of these capabilities are shown as high, medium, and low in the following tables. The present document is informative, but the intent of the criticality is to indicate the priority of actions: to be mandated (high), to be highly recommended (medium), and to be given careful consideration (low) be done. Also, the use case model here does not imply that PKI and use of PKC are the only way to achieve authentication, encryption, and signing.

Table 4.4-1: PKI trusted use case mapping to NFV reference points

Reference point	Authentication	Encryption	Signing/message authentication
Os-Ma	High	Medium	Low
Ve-Vnfm	High	Medium	Low
Nf-Vi	High	Medium	Low
Or-Vi	Medium	Low	Low
Vi-Vnfm	Medium	Low	Low
Or-Vnfm	Medium	Low	Low
Vi-Ha	NA	NA	NA
Vn-Nf	Medium	NA	NA
EM-VNF (not specified)	High	Medium	Low
OSS/BSS-EM/VNF (not specified)	High	Medium	Low
OSS/BSS-NFVi (not specified)	High	Medium	Low

Table 4.4-2: PKI untrusted use case mapping to NFV reference points

Reference point	Authentication	Encryption	Signing/message authentication
Os-Ma	High	High	Medium
Ve-Vnfm	High	High	Medium
Nf-Vi	High	High	Medium
Or-Vi	High	High	High
Vi-Vnfm	High	High	High
Or-Vnfm	High	High	High
Vi-Ha	NA	NA	NA
Vn-Nf	High	NA	NA
EM-VNF (not specified)	High	Medium	Medium
OSS/BSS-EM/VNF (not specified)	High	Medium	Medium
OSS/BSS-NFVi (not specified)	High	Medium	Medium

While the uses above focus on security associations to support reference points explicitly included on the ETSI NFV reference architecture, any interface connecting to an NFV component can similarly implement authentication, encryption, and signing. Moreover, while authorization in context of role-based or attribute-based access controls are not explicitly treated here, use of PKI credentials rather than traditional user or process identities may provide for greater confidence policy assertions. Moreover, network wide attestation may be similarly possible.

4.5 Considerations for PKC validation

4.5.1 Certificate path building and chain validation

When a PKC is received by an application (e.g. during TLS negotiation), in order for the entity proffering the certificate to be trusted and for the relying party to trust any assertions made in the PKC, the relying party is required to validate the PKC by means of verifying the signature of the certificate with the known public key of the PKC issuer, and verifying the validity of the PKC. Details of steps that should be taken to validate the certificate are outlined in clause 4.5.1.

Any decision to act on the content of a valid PKC is independent of the validity of the PKC, however an invalid PKC should in most circumstances be discarded and any information asserted by the key in the PKC should not be acted on.

A certificate chain (or certificate path) is validated from the end-entity certificate (i.e. the certificate of the entity that the relying party is authenticating or connecting to), through to the root acting as the Trust Anchor of all PKCs in the PKI. The relying party may accept the validity of the end-entity certificate at any stage in the tree, e.g. if any intermediate certificate is considered as "fresh" validation of the chain may be chosen to stop when validation checks reach the first fresh and valid point in the certificate chain.

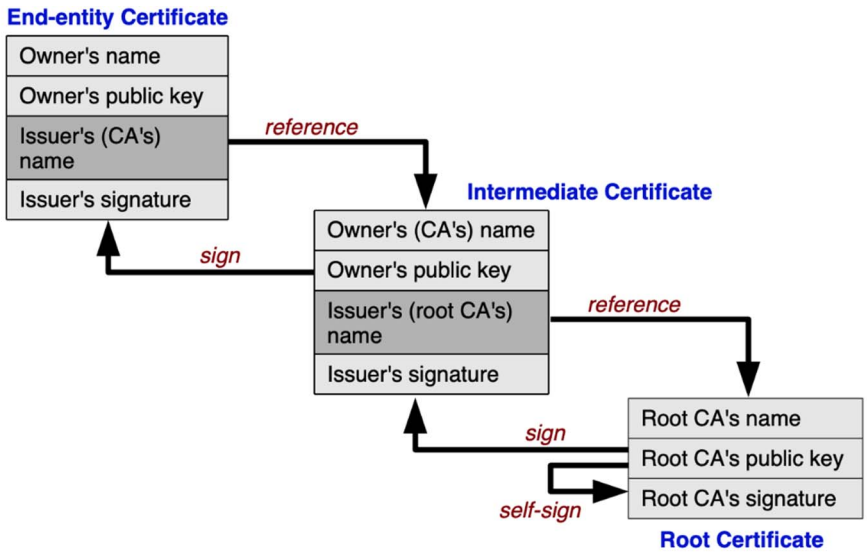

Figure 4.5.1-1: Conventional PKI structure
(from https://upload.wikimedia.org/wikipedia/commons/d/d1/Chain_of_trust.svg)

The following steps provide a guide to implementing certificate path building and validation. At minimum, a relying party needs to make checks consistent with the relying party's Certification Policy which should include the following technical steps (as defined in the Recommendation ITU-T X.509 [i.13]:

a) Check that the signature on the certificate is properly formatted and can be cryptographically verified by using the public key present in the issuer's PKC.

b) Check that the current date and time is within the validity period of the certificate. In particular check that the *notBefore* value is before the time at which the certificate is checked and that the *notAfter* value is after the time at which the certificate is checked.

c) Check that the value of the Issuer field of the certificate matches the value of the Subject field of the issuer's PKC.

d) Check that the *basicConstrains* extension is present in the issuer's PKC and that the value of the CA field is set to *TRUE*. Also, if the *pathLenConstraints* value of the extension is set, check that its value is present and set higher or equal to the current level of the certificate in the chain minus one. For example, in a three-level hierarchy (i.e. End-Entity - level 0, Intermediate CA - level 1, and Root CA - level 2), the value in the Intermediate CA's certificate (if present) should be equal to or greater than 0. For the Root CA's certificate, the value should be greater than or equal to 1. In order to provide flexibility, the *pathLenConstraints* is usually not present in Root CA's certificates.

e) Check for the presence of *authorityKeyIdentifier* extension. If present, and the *keyIdentifier* field is set, check that its value matches the *subjectKeyIdentifier* extension's value in the next certificate in the chain (if present). The values in these extensions are usually calculated by using the Method 1 as described in IETF RFC 5280 [i.17].

f) Check that the *keyUsage* extension in the next certificate in the chain supports certificate signing (i.e. the *keyCertSign* bit is set).

The PKIs may add attribute certificates to the PKC contents. The relying party may be required, in that case, to check for the presence of specific Object Identifiers (OID) in the *certificatePolicies* extension. Relying parties with specific policy requirements (such as subscribers' authentication servers or UE identifiers) should have a list of acceptable policy identifiers that should be used to verify the identifiers present in the certificates. In that case, the relying party should process the extension as follows:

a) Check that the *certificatePolicies* extension is present in the certificate. The value of this extension is a set of *certificatePolicy* values that should be check against the values set in the CP (if present). In particular, for each of the values, the relying party should check that:

   - The required values of the *certPolicyId* field are present. For example, if the CP mandates for a specific value (*1.3.6.1.4.1.XXXX.YYY.ZZZ*) to be present in EE or Sub-CA certificates, the relying party should retrieve the content of the *certPolicyId* field of the *certificatePolicy* and check it against the required value.

   - Although the use of *policyQualifiers* is discouraged as it might introduce interoperability issues, if the *policyQualifiers* field in the *certificatePolicy* extension is set, then the relying party should process the values according to their types as described in IETF RFC 5280 [i.17]. The detailed processing of these values is out of the scope of the present document.

To continue the chain building process, the relying party should repeat the steps above until one trusted certificate is reached.

5 Use cases for the use of certificates in NFV

5.1 VNF certificate use case

5.1.0 Introduction to use cases

VNFs are implemented with one or more VNFCs, which are internal component of a VNF providing a defined sub-set of that VNF's functionality, with the main characteristic that a single instance of this component (i.e. VNFCI) maps 1:1 against a single Virtualisation Container. A VNF instance composed of various VNFCIs could have multiple logical identities, each of which is represented by a certificate, to communicate with different peers. In all of the use cases below, there is a pre-condition that a pre-established relationship exists between the communicating peers and the CA/RA respectively. It is anticipated that multiple CA/RAs will be used for different parts of the NFVI and different Network Services. Some will be private to the infrastructure or tenant and others may use external public CA/RA for example VNF transport connections between Network Operators.

5.1.1 Use case #1: VNF management connection

A VNF instance should be configured and managed by both VNFM and EM, while it needs to be identified in order to be managed and configured. With the precondition that the VNFCI does not have a pre-established relationship with either the VNFM or EM, in order to ensure the security of this management path, a secure connection between a VNFCI and its corresponding VNFM or EM requires a VNFCI to have one or more certificates provisioned to attest its identity to the VNFM or EM to establish a secure connection between them.

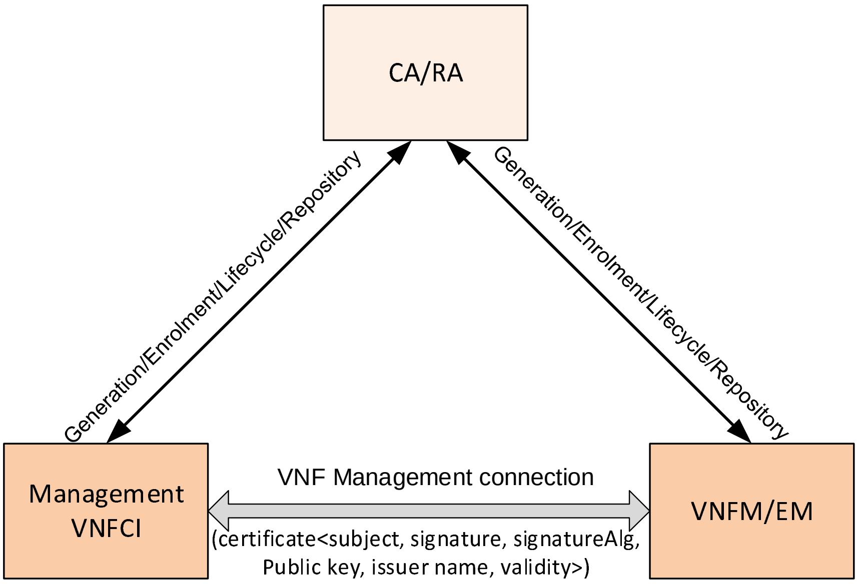

Figure 5.1.1-1: Use case#1 VNFCI management connection

Actors: VNFCI, VNFM/EM, CA/RA.

In this use case, VNFCI and VNFM or EM are validated by CA/RA and get the certificate(s) issued by CA/RA respectively. VNFCI sends its certificate to VNFM or EM, in which the attributes such as <subject, signature, signatureAlg, public key, issuer name, validity, etc.> are included. And VNFM/EM can verify VNFCI's identity via the certificate. And vice versa, VNFCI can validate VNFM/EM's identity in a similar fashion.

5.1.2 Use case #2: VNF transport connection

The VNFCI has the requirement to communicate with other entities, including other VNFCIs, PNFs, etc. With the precondition that the VNFCI does not have a pre-established relationship with either the VNFM or EM, a secure connection (e.g. IPsec) between the VNFCI and the peer or a SeGW requires a VNFCI to have one or more certificates provisioned to attest its identity to the communication peers or SeGWs to establish secure connections between them.

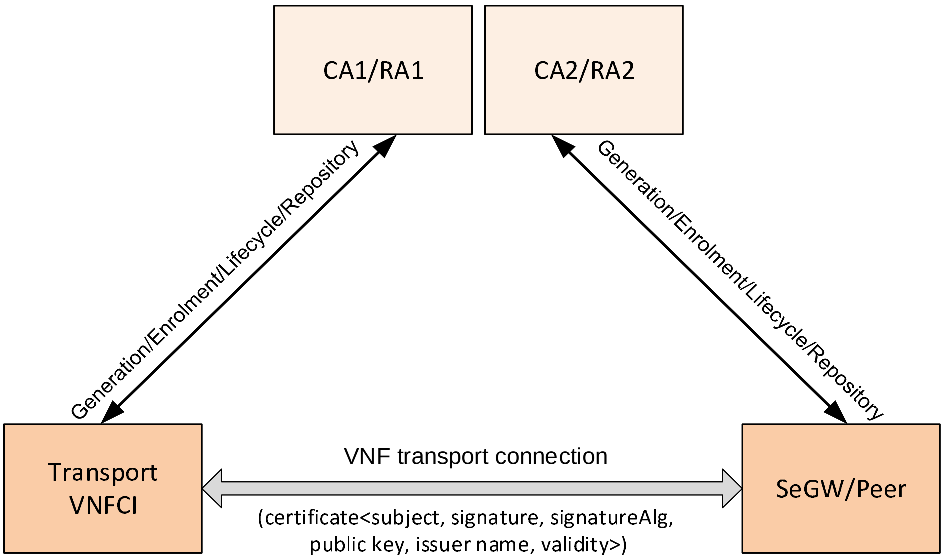

Figure 5.1.2-1: Use case#2 VNFCI transport connection

Actors: VNFCI, CA1/RA1, SeGW/Peer, CA2/RA2.